DOGGER BANK D WIND FARM

Preliminary Environmental Information Report

Volume 2
Appendix 12.6 Information and Modelling Methods for Disturbance to Marine Mammals

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Glossary

Term	Definition
Array Area	The area within which the wind turbines, inter-array cables and Offshore Platform(s) will be located.
Design	All of the decisions that shape a development throughout its design and pre-construction, construction / commissioning, operation and, where relevant, decommissioning phases.
Effect	An effect is the consequence of an impact when considered in combination with the receptor's sensitivity / value / importance, defined in terms of significance.
Environmental Impact Assessment (EIA)	A process by which certain planned projects must be assessed before a formal decision to proceed can be made. It involves the collection and consideration of environmental information and includes the publication of an Environmental Statement.
Environmental Statement (ES)	A document reporting the findings of the EIA which describes the measures proposed to mitigate any likely significant effects.
Impact	A change resulting from an activity associated with the Project, defined in terms of magnitude.
Inter-Array Cables	Cables which link the Wind Turbines to the Offshore Platform(s).
Mitigation	Any action or process designed to avoid, prevent, reduce or, if possible, offset potentially significant adverse effects of a development. All mitigation measures adopted by the Project are provided in the Commitments Register.
Offshore Export Cables	Cables which bring electricity from the Offshore Platform(s) to the transition joint bay at landfall.
Offshore Platform(s)	Fixed structures located within the DBD Array Area that contain electrical equipment to aggregate and, where required, convert the power from the wind turbines, into a more suitable voltage for transmission through the export cables to the Onshore Converter Station. Such structures could include (but are not limited to): Offshore Converter Station(s) and an Offshore Switching Station.
Study Areas	A geographical area and / or temporal limit defined for each EIA topic to identify sensitive receptors and assess the relevant likely significant effects.
The Project	Dogger Bank D Offshore Wind Farm Project, also referred to as DBD in this PEIR.

Term	Definition
Wind Turbines	Power generating devices located within the DBD Array Area that convert kinetic energy from wind into electricity.

12.6 Information and Modelling Methods for Disturbance to Marine Mammals

12.6.1 Introduction

1. This appendix to the Dogger Bank D Offshore Wind Farm (hereafter 'the Project' or 'DBD') Preliminary Environmental Information Report (PEIR) supports **Volume 1, Chapter 12 Marine Mammals and Underwater Noise**.

2. The disturbance effects of the Project have been addressed in **Volume 1, Chapter 12 Marine Mammals and Underwater Noise**. The purpose of this appendix is to provide further information on disturbance caused by underwater noise which has been referred to throughout in **Volume 1, Chapter 12 Marine Mammals and Underwater Noise**. The offshore elements of the Project will include wind turbines, inter-array cables, offshore export cables and the offshore platforms. A full description of the Project is provided in **Volume 1, Chapter 4 Project Description**.

3. **Section 12.6.2** and **12.6.4** set out the methodologies used for the interim Population Consequences of Disturbance (iPCoD) and the dose-response curve (DRC) approach. **Section 12.7.1.2** of **Volume 1, Chapter 12 Marine Mammals and Underwater Noise** details the findings for the disturbance assessment.

4. In addition to these two disturbance modelling approaches, extensive literature reviews in **Section 12.6.3** discuss empirical data of behavioural responses of marine mammals to pile driving and aid to support the assessment set out in **Section 12.7.1.2** of **Volume 1, Chapter 12 Marine Mammals and Underwater Noise**.

5. Two case-studies from German offshore wind farms (OWFs) have been summarised in **Section 12.6.5** to provide information on the effectiveness of Acoustic Deterrent Devices (ADDs), and observed disturbances using noise abatement when piling, supporting **Section 12.7.1.2.2.3** of **Volume 1, Chapter 12 Marine Mammals and Underwater Noise.**

6. **Section 12.6.6** details how disturbance through underwater noise from vessel activities may affect marine mammals. Assessment of this potential and the increased risk of vessel collision is set out in **Sections 12.7.1.4** and **12.7.1.7** of **Volume 1, Chapter 12 Marine Mammals and Underwater Noise.**

12.6.2 Population Modelling

7. This Section supports **Volume 1, Chapter 12 Marine Mammals and Underwater Noise**, **Section 12.7.1.2.2.5** that presents the Project-alone iPCoD results, and **Section 12.8.3.1.2.3** in which long-term modelling results for the cumulative disturbance of the Project with other plans and projects were presented.

12.6.2.1 Introduction

8. In **Volume 1, Chapter 12 Marine Mammals and Underwater Noise**, the results for disturbance from piling (**Section 12.7.1.2**) conclude that elevations in sub-sea noise due to installation activities could potentially lead to the behavioural disturbance of a large number of individuals of the key species identified within the marine mammal Study Area.

9. Population modelling has therefore been conducted for harbour porpoise *Phocoena phocoena*, bottlenose dolphin *Tursiops truncates*, minke whale *Balaenoptera acutorostrata*, grey seal *Halichoerus grypus* and harbour seal *Phoca vitulina*. The iPCoD framework (Harwood *et al.* 2014, King *et al.* 2015, Harwood and King 2017) has been used to predict the potential medium- and long-term population consequences of the predicted amount of disturbance resulting from the piling at the Project.

10. iPCoD uses a stage-structured model of population dynamics with nine age classes and one stage class (adults 10 years and older). The model is used to run a number of simulations of future population trajectory with and without the predicted level of impact to allow an understanding of the potential future population-level consequences of predicted behavioural responses and auditory injury.

12.6.2.2 Methodology

12.6.2.2.1 Piling Parameters

11. The amount of piling required would be dependent on the foundations selected and the final piling schedule. The worst-case scenario for the Project (maximum number of monopiles with the highest strike rate) has been taken forward for modelling in iPCoD.

12. The number of marine mammals that are at potential risk of Permanent Threshold Shift (PTS) is taken from a pile event involving the sequential installation of two monopiles in a 24 hour period, using cumulative sound exposure level (SEL_{cum}) for the worst-case location at the DBD Array Area (where largest impact range or area has been modelled see **Appendix 12.3 Underwater Noise Modelling Report**).

13. At this stage, uncertainty exists around the exact piling schedule that would be used for construction of the Project. The maximum offshore construction period is currently set to be five years, although the period during which piling is likely to occur would be much shorter (**Table 12.6-1**).

14. It is also important to note that there is uncertainty around the size of the turbine diameter and the subsequent number of turbines required. For example, if the maximum diameter monopiles are chosen for the final Project design, then the maximum number of turbines would be significantly less than 113. Therefore, the modelling encompasses a precautionary worst-case, by assuming 113 monopiles of 18m diameter (in addition to the monopiles required for the platforms).

Table 12.6-1 Piling Parameters Used as Inputs to the iPCoD Model

Parameters	Value
Number of monopiles (wind turbines & offshore platform)	113 + 12 = 125
Number of piling days	125
Piling schedule	5 years

12.6.2.2.2 Model Inputs

15. The iPCoD model was set up using the programme R v4.3.1 (R Core Team 2023) with RStudio as the user interface. To enable the iPCoD model to be run, the following data were provided:

- Demographic parameters for each key species;
- User specified input parameters:
  - Vulnerable subpopulations; and
  - Residual days of disturbance.
- Number of animals predicted to experience PTS and / or disturbance during piling; and
- Estimated piling schedule during the proposed construction programme.

12.6.2.2.3 Demographic Parameters

16. Demographic parameters for the key species assessed in the population model are presented in **Table 12.6-2**. In the case of harbour seal, evidence for demographic parameters for the English populations is lacking (Sinclair *et al.* 2020).

17. The combined counts for harbour seal in the south-east (SE) Management Unit (MU) in 2019 (3,081) was 27.6% lower than the 2012 to 2018 mean count. Additional surveys in 2020 and 2021 confirmed the decrease (Special Committee of Seals (SCOS) 2021). Given that the SE England MU appears to be decreasing in recent years, the worst-case demographic parameters for the similarly decreasing population on the Scottish east coast have been utilised in the modelling as well as the numbers for the SE England harbour seal population.

18. The iPCoD model does not include parameters for common dolphin or white-beaked dolphin, so population modelling could not be carried out for these two species.

Table 12.6-2 Demographic Parameters Recommended for Each Species for the Relevant Management Unit (MU) (Extracted from Table 3 in Sinclair et al. 2020)

Species	MU	Age calf / pup becomes independent	Age of first birth	Calf / Pup Survival	Juvenile Survival	Adult Survival	Fertility	Growth Rate
		age1	age2	Surv [1]	Surv [7]	Surv [13]		
Harbour porpoise	338,918	1	5	0.6	0.85	0.925*	0.479	1.000
Bottlenose dolphin	2,022	2	9	0.86	0.94	0.94	0.25	1.000
Minke whale	20,118	1	9	0.72	0.77	0.96	0.9	1.000
Grey seal	56,505	1	5	0.222	0.94	0.94	0.84	1.01
Harbour seal (stable population)**	4,992	1	4	0.55	0.61	0.9451	0.88	1.000

Species	MU	Age calf / pup becomes independent	Age of first birth	Calf / Pup Survival	Juvenile Survival	Adult Survival	Fertility	Growth Rate
		age1	age2	Surv [1]	Surv [7]	Surv [13]		
Harbour seal (declining population)***	4,992	1	4	0.5	0.5	0.7701	0.88	0.8200

*assuming high adult survival in the North Sea
**based on the parameters on the Northern Ireland MU
***based on the parameters for Scottish East Coast

12.6.2.2.4 Reference Population

19. **Table 12.6-3** provides the reference populations used in the iPCoD modelling.

Table 12.6-3 Reference Population Uses in the iPCoD Modelling

Species	Management unit/s relevant for the Project	Population	Source
Harbour porpoise	North Sea (NS) Assessment Unit	338,918	Gilles *et al.* (2024)
Bottlenose dolphin	Greater North Sea (GNS) MU	2,022	Inter-Agency Marine Mammal Working Group (IAMMWG) 2023
Minke whale	Celtic and Greater North Sea (CGNS) MU	20,118	
Grey Seal	North-east (NE) & SE England MU	56,505	Special Committee of Seals (SCOS), 2022
Harbour Seal	NE & SE England MU	4,992	SCOS, 2022

12.6.2.2.5 Residual Days Disturbance

20. Empirical evidence from constructed wind farms (e.g. Graham *et al.* 2019; Brandt *et al.* 2011) suggests that the detection of animals returns to baseline levels in the hours following a disturbance from piling and therefore, for the most part, it can be assumed that the disturbance occurs only on the day (24 hours) that piling takes place (at least in the case of harbour porpoise which was the focus of these studies). However, the number of residual days of disturbance has been conservatively set to one, meaning the model assumes that disturbance occurs on the day of piling and persists for a period of 24 hours after piling ceases.

12.6.2.2.6 Vulnerable Sub-Populations

21. For the purposes of the modelling, it was assumed that the entire population of interest was potentially vulnerable to pile driving disturbance and PTS.

12.6.2.2.7 Number of Animals Experiencing PTS or Disturbance

22. The number of animals predicted to experience PTS and / or disturbance during piling was based on the density values provided as part of the baseline assessment in **Volume 1, Chapter 12 Marine Mammals and Underwater Noise** for harbour porpoise. In the case of disturbance, the estimated number of harbour porpoise, bottlenose dolphin and harbour seal was derived through the DRC assessment, and for minke whale and grey seal it was based on known disturbance ranges (Russel *et al.* 2016; Richardson *et al.* 1986).

23. **Table 12.6-4** presents the number of individuals that could potentially be disturbed due to piling at DBD alone, without any mitigation.

Table 12.6-4 Estimated Number of Marine Mammals to have PTS or to be Disturbed During Each Piling Event

Species	Number of animals affected during each piling event	
	PTS	Disturbance
Harbour porpoise	118	5,015
Bottlenose dolphin	0.0001	67
Minke whale	4	44
Grey seal	0.13	185
Harbour seal	0.00002	0.03

24. For cumulative effects assessments (CEA), the number of animals predicted to experience PTS and / or disturbance during piling was based on the density values that were published in the respective PEIR or Environmental Statement (ES) chapters for the projects screened into the CEA (see **Appendix 12.5 Cumulative Assessment Screening** for details).

25. **Table 12.6-5** presents the number of individuals that could potentially be affected by PTS or be disturbed from piling at the OWF projects screened into the CEA. The number of animals predicted to experience PTS and / or disturbance during piling was based on the values the Project has based their cumulative assessment on, taken from the relevant PEIRs or ESs.

Table 12.6-5 Estimated Number of Marine Mammals to have PTS or to be Disturbed During Each Piling Event (and % of Reference Population) at Other Plans and Projects

Project	Harbour porpoise		Bottlenose dolphin		Minke whale		Grey seal		Harbour seal	
	PTS	Disturbance	PTS	Disturbance	PTS	Disturbance	PTS	Disturbance	PTS	Disturbance
Dogger Bank South (East)[1]	144	4,295.5	0.004	0.14	5.6	28.3	1.1	3,124.2	0.01	8.1
Dogger Bank South (West)	132	5,097.7	0.004	0.1	9.4	56.5	1.2	2,378.7	0.005	7.0
Caledonia	*Until the publication of the offshore ES chapters, this project will not be included in the population modelling but will be assessed quantitatively in Section 12.8.3.1 in* ***Volume 1, Chapter 12 Marine Mammals and Underwater Noise.***									
Sheringham Shoal Extension[2]	27	1,886	0.003	0.009	0.92	7.2	0.63	1,769.1	0.22	511
Dudgeon Extension[2]*	148	1,886	0.003	0.012	1.5	11	1.09	1,531.5	0.11	149
Five Estuaries[3]	340	6,583	-	-	-	-	1	102	1	1
Nordsee Cluster B - N-3.5	*There is no ES or PEIR available in the public domain for this German project. Additionally, searches for "Umweltverträglichkeitsprüfung" (the German term for Environmental Impact Assessment (EIA)) have not yielded any results.*									

[1] RWE (2024)
[2] Equinor (2022)
[3] Five Estuaries OWF Limited (2024)

Project	Harbour porpoise		Bottlenose dolphin		Minke whale		Grey seal		Harbour seal	
	PTS	Disturbance	PTS	Disturbance	PTS	Disturbance	PTS	Disturbance	PTS	Disturbance
Nordsee Cluster B - N-3.6	*These projects will therefore not be included in the population modelling but will be assessed quantitatively in Section 12.8.3.1 in **Volume 1, Chapter 12 Marine Mammals and Underwater Noise**.*									
North Falls[4]	74	6,832	-	-	2	25	0.007	138	0.00005	7
Outer Dowsing[5] - Array	39	2,012	1	66	1	15	1	342	1	21
Outer Dowsing - ORCP	4	601	1	17	1	4	1	214	1	154
Rampion 2 [6]**	26	752	1	126	1	8	0	0	0	0
West of Orkney [7]	93	1,349	1	-	22	90	-[8]	-	-[8]	-

*disturbance is based on species specific SCANS- III block densities
**PTS is based on 2 monopiles at 4,400kJ hammer energy

[4] SSE & RWE (2024)
[5] Outer Dowsing Offshore Wind (2024)
[6] Rampion 2 Wind Farm (2023)
[7] Offshore Wind Power Limited (2023)
[8] Outside of grey seal and harbour seal study areas

12.6.2.2.8 Piling Schedule

26. The piling schedule was developed assuming the worst-case of 125 monopiles to be installed individually (i.e. turbines and platforms). The schedule assumes that these days would take place on randomly allocated days within a five-year offshore construction window.

12.6.2.2.9 Assumptions and Limitations

27. The iPCoD framework (version 5.2) (Harwood *et al.* 2014, King *et al.* 2015) has been used to predict the potential medium- and long-term population consequences of the predicted amount of disturbance resulting from the piling at the Project.

28. Insufficient empirical evidence regarding how alterations in behaviour and hearing sensitivity may affect the ability of individual marine mammals to survive and reproduce. Therefore, in the absence of empirical data, the iPCoD framework uses the results of an expert elicitation process described in Donovan *et al.* (2016) to predict the effects of disturbance and PTS on survival and reproductive rates. The process generates a set of statistical distributions for these effects and then simulations are conducted using values randomly selected from these distributions that represent the opinions of a 'virtual' expert. This process is repeated many hundreds of times to capture the uncertainty among experts. While the iPCoD model is subject to many assumptions and uncertainties relating to the link between impacts and vital rates, the model presents the best available scientific expert opinion at the time of assessment.

29. In the latest update of the iPCoD model there was no elicitation for minke whale (PTS or disturbance), or bottlenose dolphins (disturbance) and the results presented in **Volume 1, Chapter 12 Marine Mammals and Underwater Noise** were highly conservative and represented an overestimate of any potential population level effects. There were several precautions built into the iPCoD model that meant that the results were highly precautionary and would over-estimate the true population level effects. These included, but were not limited to, the following three factors:

- The fact that the model assumed a minke whale would not forage for 24 hours after being disturbed;
- The lack of density dependence in the model (meaning the population would not respond to any reduction in population size);
- The level of environmental and demographic stochasticity in the model.

30. The following sections explore the background to each of these factors to illustrate the level of conservatism in this modelling and provide critical context for the evaluation of these results.

12.6.2.2.10 Duration of Disturbance

31. The iPCoD model for minke whale and bottlenose dolphin disturbance was last updated following the expert elicitation in 2013 (Harwood *et al.* 2014). When this expert elicitation was conducted, the experts provided responses on the assumption that a disturbed individual would not forage for 24 hours. However, the most recent expert elicitation in 2018 highlighted that this was an unrealistic assumption for harbour porpoises (generally considered to be more responsive than minke whales and bottlenose dolphin) and was amended to assume that disturbance resulted in six hours of non-foraging time (Booth *et al.* 2019).

32. Minke whales and bottlenose dolphins were not included in the updated expert elicitation for disturbance, and, thus, the iPCoD model still assumes 24 hours of non-foraging time for minke whales and bottlenose dolphin. Given the current understanding of marine mammal reactions to pile driving, this scenario appears unrealistic. A recent study estimated energetic costs associated with disturbance from sonar, where it was assumed that one hour of feeding cessation was classified as a mild response, two hours of feeding cessation was classified as a strong response and eight hours of feeding cessation was classified as an extreme response (Czapanskiy *et al.* 2021).

33. The presumption of a 24-hour feeding cessation for minke whale and bottlenose dolphin surpasses what is typically deemed an extreme response. Hence, it is regarded as unrealistic and likely to inflate the actual disturbance levels anticipated from the Project. For this reason, the current version of iPCoD is not deemed appropriate for minke whale and bottlenose dolphin.

34. Despite these limitations and uncertainties, this assessment has been carried out according to best practice, using the best available scientific information, and the latest expert elicitation results from Sinclair *et al.* (2020). The information provided is therefore considered to be sufficient to carry out an adequate assessment for harbour porpoise, bottlenose dolphin, minke whale, grey seal, and harbour seal.

12.6.2.2.11 Lack of Density Dependence

35. Another potential limitation of the iPCoD model is that no form of density dependence has been incorporated due to the uncertainties as to how this may occur. Density dependence is described as 'the process whereby demographic rates change in response to changes in population density, resulting in an increase in the population growth rate when density decreases, and a decrease in that growth rate when density increases' (Harwood *et al.* 2014).

36. The iPCoD scenario run for bottlenose dolphin assumes no density dependence since there is insufficient data to parameterise this relationship. Essentially, this means that there is no ability for the modelled impacted population to increase in size and return to carrying capacity following disturbance.

37. At a recent expert elicitation on bottlenose dolphins, conducted for the purpose of modelling population impacts of the Deepwater Horizon oil spill (Schwacke *et al.* 2022), experts agreed that there would likely be a concave density dependence on fertility, which means that, in reality, it would be expected that the impacted population would recover to carrying capacity (which is assumed to be equal to the size of un-impacted population – i.e. it is assumed the un-impacted population is at carrying capacity) rather than continuing at a stable trajectory that is smaller than that of the un-impacted population.

38. The limitations for assuming a simple linear ratio between the maximum net productivity level and carrying capacity have been highlighted by Taylor and Master (1993) as simple models demonstrate that density dependence is likely to involve several biological parameters which themselves have biological limits (e.g. fecundity and survival). For United Kingdom (UK) populations of harbour porpoise (and other marine mammal species) however, there is no published evidence for density dependence and therefore, density dependence assumptions are not currently included within the iPCoD protocol.

12.6.2.2.12 Environmental and Demographic Stochasticity

39. The iPCoD model attempts to model some of the sources of uncertainty inherent in the calculation of the potential effects of disturbance on marine mammal population. This includes demographic stochasticity and environmental variation. Environmental variation is defined as ‘the variation in demographic rates among years as a result of changes in environmental conditions’ (Harwood *et al.* 2014). Demographic stochasticity is defined as ‘variation among individuals in their realised vital rates as a result of random processes’ (Harwood *et al.* 2014).

40. The iPCoD protocol describes this in further detail: ‘Demographic stochasticity is caused by the fact that, even if survival and fertility rates are constant, the number of animals in a population that die and give birth will vary from year to year because of chance events. Demographic stochasticity has its greatest effect on the dynamics of relatively small populations, and we have incorporated it in models for all situations where the estimated population within an MU is less than 3,000 individuals. One consequence of demographic stochasticity is that two otherwise identical populations that experience exactly the same sequence of environmental conditions will follow slightly different trajectories over time. As a result, it is possible for a ‘lucky’ population that experiences disturbance effects to increase, whereas an identical undisturbed but ‘unlucky’ population may decrease’ (Harwood *et al.* 2014).

41. This is clearly evidenced in the outputs of iPCoD where the un-impacted (baseline) population size varies greatly between iterations, not as a result of disturbance but simply as a result on environmental and demographic stochasticity. In the example provided on **Figure 12.6-1**, after 25 years of simulation, the un-impacted population size varies between 176 (lower 2.5%) and 418 (upper 97.5%). Thus, the change in population size resulting from the impact of disturbance is significantly smaller than that driven by the environmental and demographic stochasticity in the model.

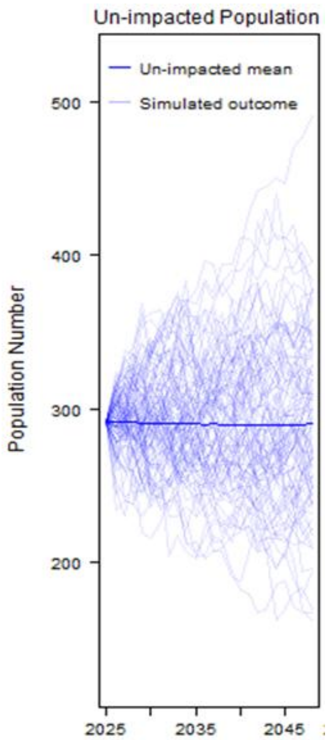

Figure 12.6-1 Simulated Un-impacted (Baseline) Population Size over the 25 Years Modelled

42. Despite these limitations and uncertainties, this assessment has been carried out according to best practice, using the best available scientific information, and the latest expert elicitation results from Booth and Heinis (2018). The information provided is therefore considered to be sufficient to carry out an adequate assessment for harbour porpoise, bottlenose dolphin, minke whale, grey and harbour seal.

12.6.2.3 Summary

43. All of the precautions built into the iPCoD model mean that the results were considered to be highly precautionary. Despite the discussed limitations and uncertainties, this assessment has been carried out according to best practice, using the best available scientific information, and the latest expert elicitation results from Booth and Heinis (2018). The information provided was therefore considered to be sufficient to carry out an adequate assessment for bottlenose dolphin, harbour porpoise, harbour seal and grey seal. Results have also been presented for minke whale, noting the caveat above regarding no update to the expert elicitation for minke whale.

12.6.2.4 Presentation of Results

44. The iPCoD modelling results presented in **Sections 12.7.1.2.2.5** and **12.8.3.1.2.2** of **Volume 1, Chapter 12 Marine Mammals and Underwater Noise** considered the median of the ratio of impacted: un-impacted population sizes for the relevant marine mammal populations as the key metric to determine effect significance using the iPCoD method. This is due to the fact that the median of the ratio of impacted: un-impacted population sizes is considered more statistically robust to the effects of extreme outliers than the mean value, particularly with lower sample sizes (Sinclair *et al.* 2019).

45. In addition, this metric is considered least sensitive to misspecification of demographic parameters, therefore enabling more robust assessment of offshore renewable effects (Jital *et al.* 2017; Sinclair *et al.* 2019). Evaluations of the sensitivity of outputs to misspecification of demographic parameters have demonstrated that the ratio output metric of the counterfactual of population size (the median of the ratio of the impacted to un-impacted population size across all simulated matched replicate pairs) is a robust metric, and is therefore recommended for population viability type analyses that compare modelled populations with counterfactual populations in the context of offshore wind Environmental Impact Assessments (EIA) (Jital *et al.* 2017; Sinclair *et al.* 2019). The approach taken in the PEIR is therefore in line with the guidance set out by the iPCoD developers (Sinclair *et al.* 2019) and others (Jitlal *et al.* 2017).

46. This rationale, developed by the authors of the iPCoD code, has resulted in the median of the ratio of impacted:un-impacted population sizes being used and accepted for other recent OWF EIAs, such as Moray West (Moray West OWF (West) Limited, 2018), Seagreen Alpha and Bravo Wind farms (Seagreen Wind Energy Limited, 2018), the Sheringham and Dudgeon Extension OWF Projects (Equinor, 2022), North Falls (SSE & RWE, 2024) and the Dogger Bank South (DBS) projects (RWE, 2024) which all presented the median of the ratio of impacted to un-impacted population size.

47. It is important to note that iPCoD runs 1,000 permutations of a population growth projection for impacted and unimpacted populations. This results in 1,000 impacted: un-impacted population pairs for each time-point in the modelling period (often 25 years). Calculating the ratio between each pair and then taking the median of all ratios results in the "median of the ratio of impacted: unimpacted population sizes", which is expressed in percentage terms in the iPCoD results tables: Table 11.38 to Table 11.44 for Project-alone assessment and Tables 11.86 to 11.92 for cumulative disturbance of **Volume 1, Chapter 12 Marine Mammals and Underwater Noise**. Crucially, this is not the same process as taking the median of the 1,000 impacted populations at a given time point, the median of the un-impacted population, and then comparing their ratio. In short, one method results in the median of all modelled population differences, the other method results in the difference between the medians of all modelled impacted and unimpacted populations. Therefore, it is not possible to use the average (mean or median) population values presented within the iPCoD tables to calculate the median of the ratio of impacted: un-impacted population sizes, which is also presented in the same tables and is the primary metric for assessing effect significance.

48. It is important to note that it should not be expected that calculating the percentage difference between the mean impacted and un-impacted population sizes at a given timepoint (presented in the result tables) will result in the same value as the mean ratio of impacted: un-impacted population sizes presented in the same tables.

49. The presentation of the results in **Volume 1, Volume 1, Chapter 12 Marine Mammals and Underwater Noise,** will therefore be presented using the following timepoints:

- **2029**: the start of piling at DBD;
- **2030**: marks the end of the second year, since piling first commenced;
- **2033**: marks the end of the five-year construction window over which piling could occur;
- **2034**: marks the end of a six-year period (based on the former Favourable Conservation Status reporting period); and
- **2054**: marks the end of 25 years of modelling, since piling first commenced.

12.6.3 Review of potential disturbance from underwater noise during piling

50. Since there were no agreed thresholds or criteria for the behavioural response and disturbance of marine mammals at the time of writing, therefore it was not possible to conduct underwater noise modelling to predict impact ranges.

51. Instead, a review of most recent available information on the potential disturbance of marine mammals during piling has been conducted to get a better understanding of the potential effects and inform the assessment set out in **Section 12.7.1.2** in **Volume 1, Chapter 12 Marine Mammals and Underwater Noise**.

52. The Joint Nature Conservation Committee (JNCC) *et al.* (2010) guidance proposed that "*any action that is likely to increase the risk of long-term decline of the population(s) of (a) species could be regarded as disturbance under the Regulations.*"

53. This guidance indicated that a score of five or more on the Southall *et al.* (2007) behavioural response severity scale could be significant (see **Table 12.6-6**). The more severe the response on the scale, the less time animals will likely tolerate the disturbance before it causes significant negative effects on their life functions, which would then constitute a disturbance.

Table 12.6-6 Southall et al. (2007) Severity Scale for Ranking Observed Behavioural Responses of Free-Ranging Marine Mammals

Response score	Corresponding behaviours in free-ranging subjects
0	*No observable response.*
1	*Brief orientation response (investigation / visual orientation).*
2	*Moderate or multiple orientation behaviours* *Brief or minor cessation / modification of vocal behaviour* *Brief or minor change in respiration rates*
3	*Prolonged orientation behaviour* *Individual alert behaviour* *Minor changes in locomotion speed, direction, and / or dive profile but no avoidance of sound source* *Moderate change in respiration rate* *Minor cessation or modification of vocal behaviour*

4	*Moderate changes in locomotion speed, direction, and / or dive profile but no avoidance of sound source* *Brief, minor shift in group distribution* *Moderate cessation or modification of vocal behaviour*
5	*Extensive or prolonged changes in locomotion speed, direction, and / or dive profile but no avoidance of sound source* *Moderate shift in group distribution* *Change in inter-animal distance and / or group size (aggregation or separation)* *Prolonged cessation or modification of vocal behaviour*
6	*Minor or moderate individual and / or group avoidance of sound source* *Brief or minor separation of females and dependent offspring* *Aggressive behaviour related to sound exposure (e.g. tail / flipper slapping, fluke display, jaw clapping / gnashing teeth, abrupt directed movement, bubble clouds)* *Extended cessation or modification of vocal behaviour* *Visible startle response* *Brief cessation of reproductive behaviour*
7	*Extensive or prolonged aggressive behaviour* *Moderate separation of females and dependent offspring* *Clear anti-predator response* *Severe and / or sustained avoidance of sound source* *Moderate cessation of reproductive behaviour*
8	*Obvious aversion and / or progressive sensitisation* *Prolonged or significant separation of females and dependent offspring with disruption of acoustic reunion mechanisms* *Long-term avoidance of area* *Prolonged cessation of reproductive behaviour*
9	*Outright panic, flight, stampede, attack of conspecifics, or stranding events* *Avoidance behaviour related to predator detection*

54. It should be noted that a behavioural response does not mean that the individuals will avoid the area. In addition, the maximum predicted ranges for behavioural response have been based on the maximum hammer energy at the worst-case location for noise propagation. In reality, the duration of any piling at maximum energy would be less (if this energy is reached at all) and noise propagation would vary considerably with location (i.e. be less than the worst-case).

12.6.3.1 Behavioural Response of Harbour Porpoise to Piling

55. A study of harbour porpoise at Horns Rev II (Brandt *et al.* 2011) found that at the closest distances to pile driving (2.5km), porpoise activity was reduced between one and two days after the pile driving activity (with 100% avoidance). However, the duration of this effect decreased significantly with distance, such that at distances of 10.1 to 17.8km, avoidance occurred in 32 to 49% of the population, and at 21.2km, harbour porpoise abundance reduced by just 2%. This suggests that it is unrealistic to assume all individuals would be displaced. In reality, not all individuals would move out of the area. To take this into account within the marine mammal assessments, it was assumed that 75% or 50% of harbour porpoise may show a behavioural response. This approach was consistent with the response at distances of 10.1 to 17.8km indicated by the Brandt *et al.* (2011) study (**Figure 12.6-2**), at which approximately 50% of individuals present could respond at the maximum predicted level as suggested by the DRC in Thompson *et al.* (2013).

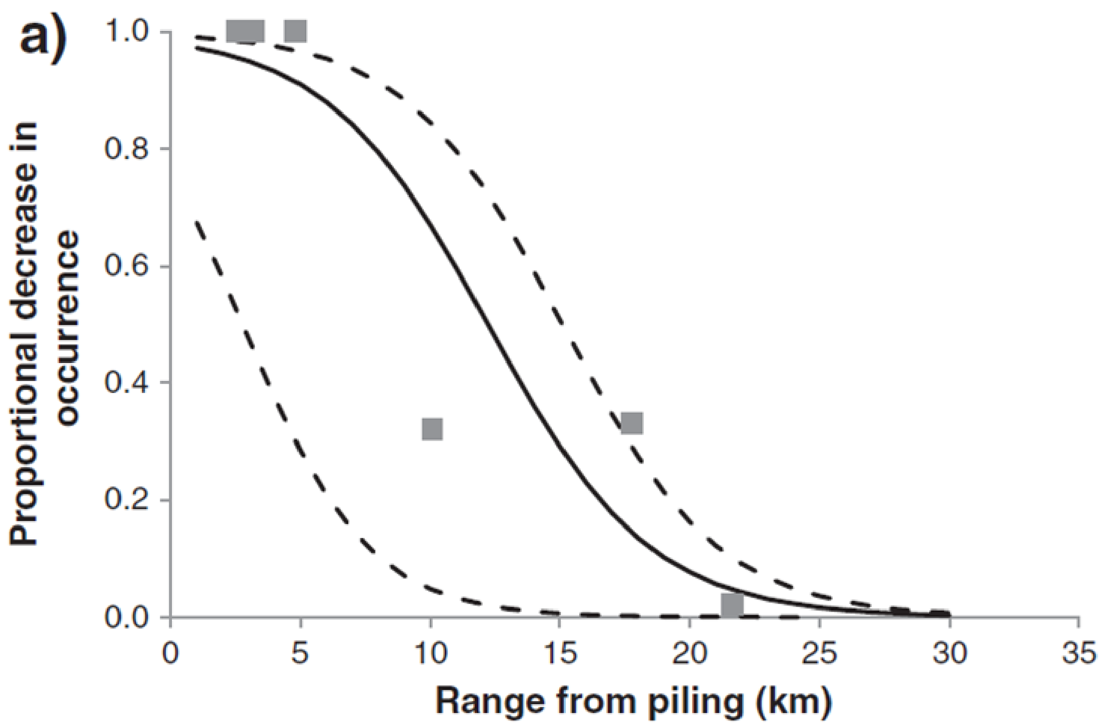

Figure 12.6-2 Predicted Harbour Porpoise Dose-Response Curve Based on the Monitoring of Piling Activity at Horns Rev II (Based on Data from Brandt et al. 2011, as Presented in Thompson et al. (2013))

56. During the construction of the Beatrice OWF and Moray East OWF in Scotland, cetacean porpoise detectors (CPODs) were deployed to monitor harbour porpoise presence (Benhemma-Le Gall *et al.* 2021). In addition, the broadband noise levels and vessel Automatic Identification System (AIS) data were recorded and monitored. The study aimed to assess the response of harbour porpoise to changes in the baseline noise level due to impact piling and increased vessel activity. At Beatrice OWF, piling involved 2.2m jacket pin piles. The findings demonstrated an 8-17% decline in porpoise presence during impact piling and other construction activities compared to baseline levels (Benhemma-Le Gall *et al.* 2021).

57. An increase in broadband noise levels due to piling led to a significant reduction in porpoise presence. When piling was not occurring, porpoise detections decreased by 17% as the noise levels increased (from 102dB re 1 µPa (sound pressure level (SPL)) to 159dB re 1 µPa (SPL)) (**Figure 12.6-3**; Benhemma-Le Gall *et al.* 2021). During piling, porpoise detections decreased by 9% as noise levels increased (from 102dB to 159dB). A similar reduction in buzz vocalisations, which are associated with the foraging behaviours, was also observed. When piling was not taking place, buzz vocalisations decreased by 41.5% as the noise levels increased (from 104dB re 1 µPa (SPL) to 155dB re 1 µPa (SPL)). During piling, porpoise detections decreased by 61.8% as noise levels increased (from 104dB to 155dB re 1 µPa (SPL)) (Benhemma-Le Gall *et al.* 2021).

58. During piling at Moray East OWF, harbour porpoise buzz vocalisations increased by 4.2% compared to the baseline levels. At this point, foundations at Beatrice OWF were constructed, and the introduction of hard substrates were likely to have improved the fine-scale habitat for key harbour porpoise prey species, with the potential for increasing prey resources (Benhemma-Le Gall *et al.* 2021).

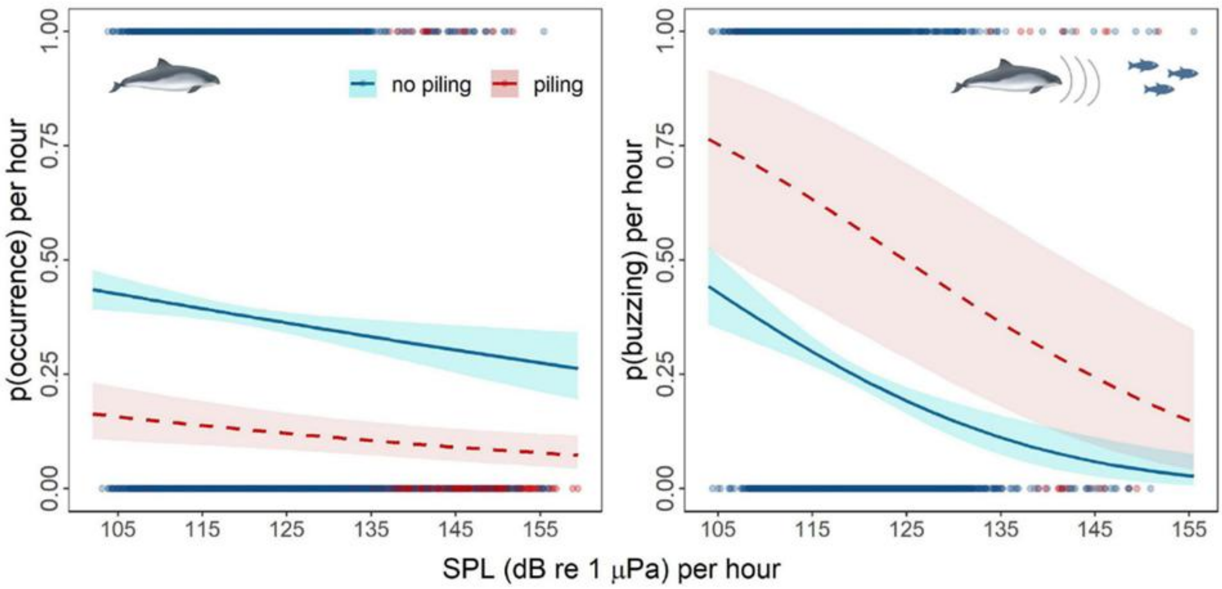

Figure 12.6-3 [Left] The Probability of Harbour Porpoise Presence in Relation to the SPL (Red = During Piling, Blue = Outside of Piling Time, and [Right] the Probability of Buzzing Activity per Hour in Relation to the SPL (Red = During Piling, Blue = Outside of Piling) [Source: Benhemma-Le Gall et al. 2021]

59. A more recent study demonstrated that harbour porpoise started to leave the area in the two days leading up to a piling event, when pre-piling installation activities and vessel presence increased (Benhemma-Le Gall *et al.* 2023). The study found a 33% decline in acoustic click detections during the 48-hours prior to piling, which provided evidence that porpoises were displaced for a longer time period than just the piling event itself.

60. Findings from the PrePARED[9] research by Benhemma-Le Gall *et al.* (2024) indicated that following the installation of XXL monopiles (up to 10m diameter), harbour porpoise detections (using CPODs) were at comparable levels 24-hours after piling to those recorded three days prior to piling. Furthermore, a deterrence radius of less than 10km was identified, suggesting that the overly cautious and potentially outdated EDR of 26km (JNCC *et al.* 2020) should be reduced.

[9] PrePARED (Predators and Prey Around Renewable Energy Development) is a research project, funded by the Offshore Wind Evidence & Change programme and Crown Estate Scotland (https://owecprepared.org/)

12.6.3.2 Behavioural Response of Dolphins to Piling

61. There is limited information on the behavioural response of any dolphin species to piling.

62. In the Southall *et al.* (2007) paper, a review of data available for mid-frequency cetaceans (including species such as sperm whale *Physeter macrocephalus* and beluga whale *Delphinapterus leucas*) indicated that a significant response was observed at a SPL of 120dB to 130dB re 1μPa (root mean square (rms)). However, the majority of individuals did not display a significant behavioural response until exposed to a level of 170dB to 180dB re 1μPa (rms). Some mid-frequency species showed no behavioural response even at these higher levels. It should be noted that few of the reviewed studies were based on dolphin species.

63. Graham *et al.* (2017a) studied the responses of bottlenose dolphins to both impact and vibration pile driving noise during harbour construction works in northeast Scotland. The study used passive acoustic monitoring (PAM) devices to record cetacean activity and noise recorders to measure and predict received noise levels. The local abundance and occurrence patterns of bottlenose dolphins were compared with a five-year baseline. The median peak-to-peak source level for impact piling was estimated at 240dB re 1μPa (single-pulse SEL_{ss} (sound exposure Level) 198dB re 1μPa^2s), and the rms source level for vibration piling was 192dB re 1μPa (Graham *et al.* 2017a).

64. The study found that bottlenose dolphin was not excluded from areas near impact piling or vibration piling sites. However, some minor effects were observed, with bottlenose dolphin spending less time near construction activities during both types of piling (Graham *et al.* 2017a). Dolphins generally exhibited a weak behavioural response to impact piling, reducing their time around the construction activity during piling (Graham *et al.* 2017a). Fine-scale behavioural responses to piling were observed at predicted received single-pulse SEL values between 104 and 136.2dB re 1μPa^2s for impact piling (Graham *et al.* 2017a).

65. During the Beatrice OWF piling campaign in 2017, dolphin detections decreased by 50% in the Impact Areas (at least 53km from the piling site) and by 14% in the Reference Area (at least 80km from the piling site), compared to baseline years (Fernandez-Betelu *et al.* 2021). In 2019, during impact piling at the Moray East OWF no significant difference in dolphin detections was found between the Study Areas (Impact Area at least 45km from the piling site; Reference Area at least 78km from the piling site) compared to baseline years (Fernandez-Betelu *et al.* 2021).The southern coast of the Moray Firth was the closest area to the offshore activities within this bottlenose dolphin population's range, with piling at Beatrice occurring 50–70km from the studied population, and at Moray East 40–70km from the population. Analyses showed that dolphins continued to use the southern coast of the Moray Firth during the seismic survey and impact pile-driving, indicating that the species was not significantly affected at this distance of 40-70km (Fernandez-Betelu *et al.* 2021). While displacement distances were available for other marine mammal species (such as harbour porpoises), no such studies were conducted for bottlenose dolphins. However, as dolphins are generally less sensitive to underwater noise than harbour porpoises, shorter displacement ranges would be expected (Fernandez-Betelu *et al.* 2021).

66. While displacement distances were available for other marine mammal species (such as harbour porpoise), no such studies were conducted for bottlenose dolphins. However, since dolphins are generally less sensitive to underwater noise than harbour porpoises, shorter displacement ranges would be expected (Fernandez-Betelu *et al.* 2021).

67. Pile-driving noise can potentially be perceived by dolphins from a minimum of 10km up to 40km away, interfering with their communication, echolocation, and breeding. Depending on the type of communication, clicks can be masked up to 6km, while whistles can be masked up to 40km away.

68. Although there was limited evidence regarding the disturbance ranges of dolphin species due to impact piling, the information presented suggests that dolphin presence may decrease due to piling works. However, there was no indication of a significant disturbance response, with individuals remaining near the piling activities. Based on the literature provided, their sensitivity would be less than that of harbour porpoise (low).

12.6.3.3 Behavioural response of Minke Whale to Piling

69. There is limited information on the behavioural response of minke whale to piling. Southall *et al.* (2007) recommended that the most appropriate way to assess the disturbance effect of a noise source on marine mammals is through empirical studies. The same paper presented a severity scale for observed behavioural responses, and subsequent JNCC guidance indicated that a score of five or more on this scale could be significant (see **Table 12.6-6**). A score of five relates to extensive changes in swim speed and direction, or dive pattern, without avoidance of the noise source, or a moderate shift in distributions, a change in group size, aggregations and separation distances, and a prolonged cessation in vocal behaviours. The higher the behavioural response score, the more likely the associated noise source would result in a significant disturbance effect.

70. Southall *et al.* (2007) included a summary of observed behavioural responses to noise sources, though most studies included were based on the responses to seismic surveys. These studies provided relevant information on whale species' behavioural responses.

71. Whale species have been observed to exhibit behavioural responses at a received level of 150dB to 160dB re 1μPa (rms) (Malme *et al.* 1983, 1984; Richardson *et al.* 1986; Ljungblad *et al.* 1988; Todd *et al.* 1996; McCauley *et al.* 1998), with behavioural changes including:

- Visible startle responses;
- Extended cessation or modification of vocal behaviour;
- Brief cessation of reproductive behaviour; and
- Brief and minor separation of females and dependent offspring.

72. During migration periods, bowhead whales *Balaena mysticetus* exhibited avoidance behaviours at distances of more than 20km from seismic sources (Koski and Johnson, 1987; Richardson *et al.* 1999). However, during foraging periods, bowhead whales did not respond beyond 6km from the source (Richardson *et al.* 1986; Miller *et al.* 2005). Richardson *et al.* (1986) concluded that avoidance and behavioural responses were observed once noise levels exceeded 160dB re 1μPa due to a single airgun.

73. In a study on migrating bowhead whales, most individuals avoided a seismic survey source at distances of up to 20km (using airgun arrays of up to 16 guns, with a total volume of 560 to 1,500 cu. in.), with significantly reduced presence between 20 and 30km from the source, where estimated received noise levels were 120 to 130dB re 1μPa (rms) (Richardson *et al.* 1999).

74. During foraging periods, bowhead whales did not respond beyond 6km from the source (Richardson *et al.* 1986; Miller *et al.* 2005). Observations of behavioural changes in baleen whale species have shown avoidance reactions up to 10km for a seismic survey, with a noise source level of 143dB re 1μPa (peak to peak) (Macdonald *et al.* 1995).

75. Dose-response functions for avoidance responses of grey whales *Eschrichtius robustus* to both continuous and impulsive noises were developed for vessel noise and seismic air guns by Malme (1984). For continuous noise sources, avoidance of minke whale started at a received level of 110-119dB re 1μPa (L_{peak}, rms), with more than 80% of individuals responding at 130dB re 1 μPa (L_{peak}, rms), and 50% at 120dB re 1 μPa (L_{peak}, rms).

76. Higher noise levels were required for an avoidance response due to the impulsive noise source (seismic airguns), with 10% of migrating grey whales responding at 164dB re 1 μPa (L_{peak}, rms), 50% at 170dB re 1μPa (L_{peak}, rms), and 90% at 180dB re 1μPa (L_{peak}, rms) (Malme, 1984 cited in Tyack and Thomas, 2019). A secondary study (Malme *et al.* 1988) using 100 cu. in. air guns (with a source level of 226dB re 1μPa) for foraging grey whales found a response level (where individuals would cease foraging activities) of 50% at 173dB re 1μPa (L_{peak}, rms), and 10% at 163dB re 1μPa (L_{peak}, rms).

77. There is limited information on the potential disturbance ranges of minke whales to piling, but some studies provide observed disturbances of baleen whale species to seismic surveys. Baleen whale species have been observed to respond up to 20km during migration, with disturbances observed up to 30km from a seismic source. One study found that baleen whales were more sensitive to continuous sources than impulsive sources. Typically, baleen whales have been reported to avoid and respond at impulsive noise levels of 150-160dB re 1μPa (rms) (Malme *et al.* 1983, 1984; Richardson *et al.* 1986; Ljungblad *et al.* 1988; Todd *et al.* 1996; McCauley *et al.* 1998), with 50% of individuals responding at 170dB to 173dB re 1μPa (L_{peak}, rms) (Malme *et al.* 1984; Malme *et al.* 1988).

78. The studies summarised above suggest that baleen whale species (including minke whale) may be similarly sensitive to disturbance from underwater noise as harbour porpoise, and therefore a medium sensitivity is appropriate.

12.6.3.4 Behavioural Response of Seals to Piling

79. The Southall *et al.* (2007) paper presented limited data on seal species. Although these species are not found in UK waters, one study included ringed seals *Pusa hispida*, bearded seals *Erignathus barbatus*, and spotted seals *Phoca largha* (Harris *et al.* 2001). This study found that a significant response began at received noise levels of 160 to 170dB re 1µPa (rms), although many individuals showed no response at noise levels up to 180dB re 1µPa (rms). Only at much higher SPLs (190 to 200dB re 1µPa (rms)) did a significant number of seals exhibit a disturbance response.

80. Tagged harbour seals in the Wash showed that seals were not excluded from the vicinity of the Lincs OWF during the overall construction phase. However, there was clear evidence of avoidance during pile driving, with significantly reduced seal activity up to 25km from piling sites (Russell *et al.* 2016). Within two hours after piling ceased, seal distribution returned to pre-piling levels (Russell *et al.* 2016).

12.6.4 Dose-response Curves

81. This section in the appendix supports **Section 12.7.1.2.2.2** of **Volume 1, Chapter 12 Marine Mammals and Underwater Noise** which presents the number of individuals that could be affected from piling disturbance.

82. The dose-response methodology has been adopted in this assessment for species with appropriate dose-response experiments published in scientific literature, specifically for harbour porpoise, harbour seal and grey seal (per current best practice guidance in Southall *et al.* 2021).

83. Due to differences in audiograms and behaviour, it is not appropriate to extrapolate the findings of Graham *et al.* (2017b) to other cetacean species, but in the absence of other accepted disturbance methods the dose-response approach has also been applied to dolphin species, as a very precautionary measure to assess the animals disturbed by piling at the Project.

84. The assessment was based on SEL_{ss} for the worst-case scenario of a monopile struck with a maximum hammer energy of 8,000kJ. To estimate the number of animals disturbed by piling, SEL_{ss} contours at 5dB increments (generated by the noise modelling, see **Appendix 12.3 Underwater Noise Modelling Report**) were overlain on the relevant species density surfaces, to quantify the number of animals receiving each SEL_{ss}, and, subsequently, the number of animals likely to be disturbed, based on the corresponding dose-response curve.

85. As per current best practice guidance (Southall *et al.* 2021), a behavioural disturbance dose-response analysis has been carried out for those species for which appropriate dose-response evidence existed within the scientific literature.

86. The dose-response relationship for harbour porpoise was developed by Graham *et al.* (2017b) using data collected during Phase 1 of piling at the Beatrice OWF. This relationship is displayed on **Figure 12.6-4**. Subsequent studies revealed that the responses of harbour porpoises to piling noise diminished over the construction period (Graham *et al.* 2019). Therefore, applying the dose-response relationship from an initial piling event to all piling events in the PEIR marine mammal assessment is considered conservative.

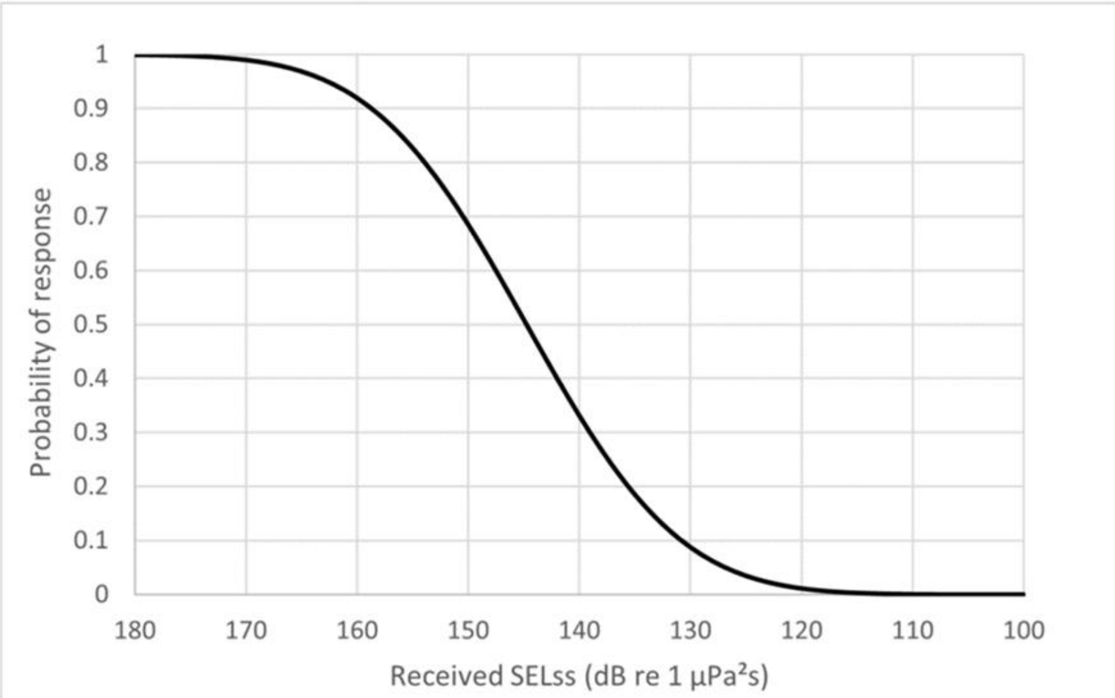

Figure 12.6-4 Dose-Response Relationship Developed by Graham et all. (2017b) Used for Harbour Porpoise in the Assessment

87. For both harbour seal and grey seal, a dose-response relationship, derived from harbour seal telemetry data collected during several months of piling at the Lincs OWF, has been used (Whyte *et al.* 2020). Whyte *et al.* (2020) tested the effects of pile driving noise (characterised as SEL_{SS} (dB re 1 µPa s)) on harbour seal disturbance in 5dB increments between 115dB to 180dB SEL_{SS} (dB re 1 µPa s). From this data, a dose-response curve was derived and applied to SEL contours from 120dB to 200dB SEL re 1 µPa s.

88. As shown on **Figure 12.6-5**, the highest SEL from single strike (SEL_{SS}) considered in the Whyte *et al.* (2020) study was 180 dB re 1μPa²s. The PEIR marine mammal assessment has therefore conservatively assumed that at SEL_{SS} > 180dB re 1μPa²s, all seals would be disturbed. The dose-response curve for harbour seal has been used for grey seals, as both species have similar hearing audiograms.

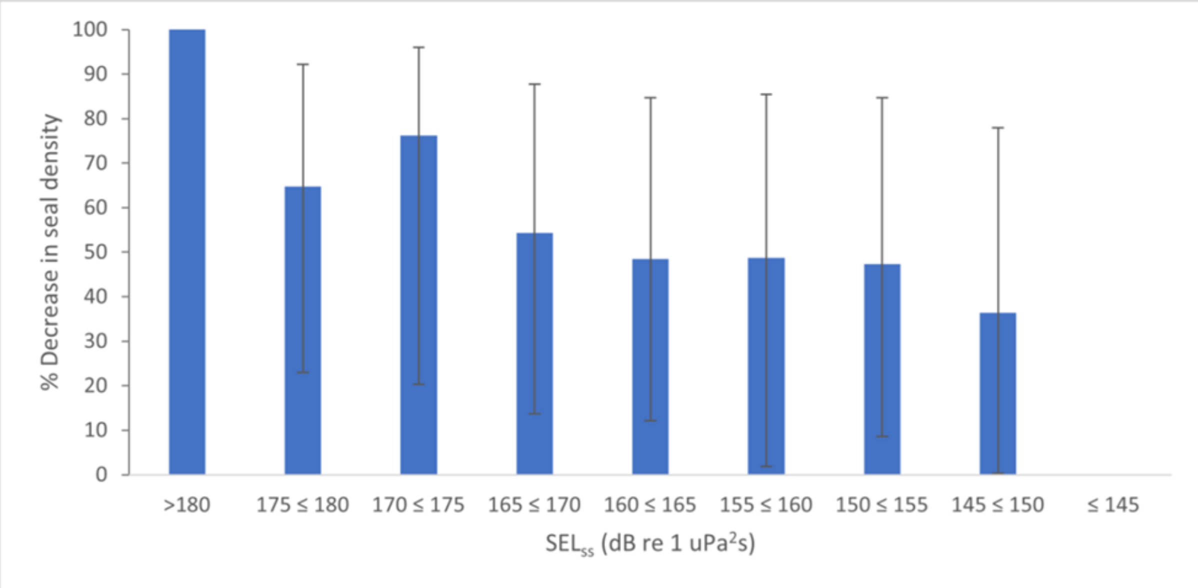

Figure 12.6-5 Dose-Response Behavioural Disturbance Data for Harbour Seal Derived from The Data Collected and Analysed by Whyte et al. (2020). This Data Has Been Used for Harbour and Grey Seals in the Assessment.

12.6.4.1 Methodology

89. To estimate the number of animals disturbed by piling, SEL_{SS} contours at 5dB increments (generated by the noise modelling – see **Figure 12.6-1**) were overlain on the relevant species density surfaces, to quantify the number of animals receiving each SEL_{SS}, and, subsequently, the number of animals likely to be disturbed, based on the corresponding DRC (for dolphin species, the harbour porpoise DRC was used).

90. For harbour porpoise and bottlenose dolphin, the underlying densities used for the DRC were those of the Small Cetaceans in the European Atlantic and North Sea (SCANS) IV blocks surrounding the Project (NS-C, NS-D, NS-G, NS-H). While for harbour porpoise, each block had an assigned density (Gilles *et al.* 2023), block NS-D and NS-G had no densities for bottlenose dolphins. Instead, thereof, block density for NS-H (0.0014 animal/km²) was assigned to block NS-G, and block density for NS-C (0.0419 animal/km²) was assigned to block NS-D.

91. For common dolphin and white-beaked dolphin, the underlying density data was sourced from Waggitt *et al.* (2019), which covered a sufficiently large area to apply this data (see **Section 12.5.6** in **Volume 1, Chapter 12 Marine Mammals and Underwater Noise** for more information on caveats for using this data on a small spatial scale). The August dataset generated the highest densities compared to other months.

92. For grey seal and harbour seal, the underlying data was sourced from Carter *et al.* (2022), with species-specific correction factors applied (see **Appendix 12.2 Marine Mammals Technical Report** and SCOS-BP 21/02 in SCOS, 2021).

12.6.4.2 Assumptions and Limitations

93. There was a lack of empirical data on bottlenose dolphin, minke whale or grey seal responses to pile driving to derive species-specific DRCs for these species. For grey seal, the harbour seal DRC has been used as a reasonable proxy since both species were of the same hearing group. For the remaining species, all dolphins and minke whale, the harbour porpoise DRC was used although there were uncertainties regarding the use of this proxy since the species have all been classified as being in different hearing groups, and thus in reality their response to the same sound source was unlikely to be the same.

94. The use of the dose-response relationship for harbour seal from Whyte *et al.* (2020) in conjunction with the modelling results presented here was conservative. The exact drivers behind the dose-response relationship were unknown and likely to be influenced by a combination of distance from the sound source and the received level. Yet, the DRC presented in Whyte *et al.* (2020) was based upon received level only. Responses of animals were not only elicited by the received level but also by other factors, such as signal shape. The shape of a signal with the same SEL from the same sound source differs depending on distance. Piling noise has been noted to lose its impulsive character with distance (Southall *et al.* 2007, Hastie *et al.* 2019, Southall *et al.* 2019; **Figure 12.6-6**), and therefore animals were expected to react less strongly to piling noise with the same received levels when exposed at larger distances. Such an effect has been quantified for blue whales with regard to military sonar, where a received level of 170dB SEL from cumulative exposure (SEL_{CUM}) at 1km resulted in a probability response of >0.5 at severity score 4-6 whereas the same received level of 170dB SEL_{CUM} at 5km resulted in a probability of response of <0.1 at severity score 4-6 (Southall *et al.* 2019). This is important to note, since the original dataset in Whyte *et al.* (2020) showed that "*predicted seal density significantly decreased within 25km or above SEL_{SS} 145dB re 1µPa^{2}s*".

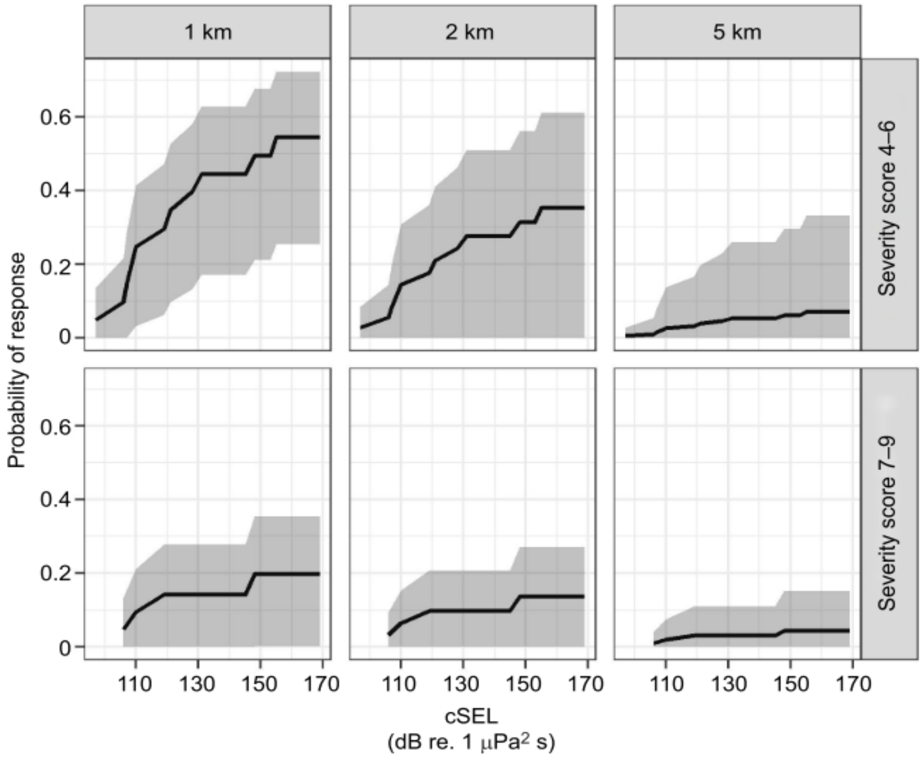

Figure 12.6-6 Behavioural Response Probability for Blue Whales Exposed to Military Sonar as a Function of Received Level and Distance from the Sound Source. Severity Score 4-6 Denotes 'Moderate Severity' and 7-9 Denotes 'High Severity'. Image Taken from Southall et al. (2019)

95. In addition to these issues, it should be recognised that estimates of received noise levels were likely to be extremely conservative given they have been based on the maximum hammer energy. In practice, pile driving at other UK OWFs has often been completed using much lower than the predicted hammer energies as shown for other OWFs (Dudgeon OWF Limited, 2016).

12.6.5 Case-Studies

96. This appendix section supports **Section 12.7.1.2.2.3** of **Volume 1, Chapter 12 Marine Mammals and Underwater Noise** which provides an assessment of ADD activation duration and the resulting potential disturbance to marine mammals.

12.6.5.1 Beatrice OWF

97. The study at Beatrice OWF (Graham *et al.* 2019) found that at the start of the piling campaign, there was a 50% chance of a harbour porpoise responding to piling activity within 7.4km during the 24 hours following piling. This response distance reduced to 4.0km by the middle of the campaign and to 1.3km by the end. The response to audiogram-weighted SEL noise levels also decreased over time, with a 50% response at 54.1dB re 1μPa^{2}s initially, increasing to 60.0dB re 1μPa^{2}s mid-campaign, and to 70.9dB re 1μPa^{2}s by the end. Similarly, the response to unweighted SEL noise levels reduced, with a 50% response at 144.3dB re 1μPa^{2}s initially, increasing to 150.0dB re 1μPa^{2}s mid-campaign, and to 160.4dB re 1μPa^{2}s by the end.

98. The study (Graham *et al.* 2019) compared harbour porpoise presence with and without ADDs and assessed the impact of vessel activity within 1km of the piling site. A significant short-term difference (less than 12 hours post-piling) was observed with ADD use, but no long-term difference. The 50% response distance was up to 5.3km with ADDs and up to 0.7km without. However, only two locations used ADDs, so the sample size was small.

99. Overall, the study showed that harbour porpoise response to piling activities decreased over time, indicating habituation. ADDs reduced porpoise presence short-term, and higher vessel activity increased the likelihood of a response. The response was best explained by distance from the piling site and received noise levels, considering hearing sensitivity.

12.6.5.2 Gescha 2

100. The Gescha 2 study (Rose *et al.* 2019) analysed the impact from the construction of 11 OWFs in Germany on harbour porpoise in the German North Sea and adjacent Dutch waters from 2014 to 2016. It also included data from the Gescha 1 study, which examined the impact of eight German OWFs from 2009 to 2013. The study used CPODs and digital aerial surveys to monitor harbour porpoise presence and abundance, and measured noise levels at 750m and 1,500m from the piling source. Most piling activities in this study used noise abatement systems to reduce disturbance impacts on harbour porpoise.

101. The Gescha 2 study found that noise levels during piling were mostly below the 160dB limit at 750m, as mandated by the German Federal Maritime and Hydrographic Agency. These levels were 9dB lower than those recorded in the Gescha 1 study, thanks to advancements in noise abatement methods. Noise levels with abatement were 15dB lower than unmitigated piling. Despite expectations, the improved noise abatement did not lead to a reduction in disturbance impacts on harbour porpoise.

102. The Gescha 2 study found that the disturbance impact range for harbour porpoise due to piling was 17km (Standard Deviation (SD) 15-19km), with a disturbance duration of 28 to 48 hours, according to CPOD data. Aerial data showed an impact range of 11.4 to 19.5km (at least 12 hours after piling). These results were similar to the Gescha 1 study, which had a disturbance range of 15km (SD 14-16km) and a duration of 25 to 30 hours, despite higher noise levels.

103. CPOD data indicated no correlation between received noise levels below 165dB at 750m and the disturbance range, suggesting porpoises maintained a certain distance from noisy activities regardless of noise levels above a threshold. The study only recorded noise up to 20kHz, potentially missing higher frequency noise.

104. A reduction in harbour porpoise presence was observed for all OWFs (for both the Gescha 1 and 2 studies) up to 24 hours prior to any noisy activity, likely due to increased vessel activity at the pile location. Displacement during pile driving was greater than before piling. In Gescha 2, detection rates decreased within 15km of the piling location three hours before piling, with no difference observed at 25km.

12.6.6 Review of Potential Disturbance from Vessel Activity

105. This part of the appendix supports **Sections 12.7.1.4** and **12.7.1.7** of **Volume 1, Chapter 12 Marine Mammals and Underwater Noise** which provide an assessment of the potential for disturbance from construction and the elevated risk of vessel collision with marine mammals.

106. Noise levels reported by Malme *et al.* (1989) and Richardson *et al.* (1995) for transiting large surface vessels indicate that physiological damage to auditory sensitive marine mammals would be unlikely. The potential risk of PTS in marine mammals as a result of vessel noise is highly unlikely, as the sound levels would be well below the threshold for PTS (Southall *et al.* 2019). In general, vessels generate noise in the low frequency range between 10-100 hertz (Hz) (Erbe *et al.* 2019).

107. Vessel noise has been shown to affect the behaviour of marine mammals, where changes in vocalisation and behavioural state have been observed, in addition to displacement of animals from areas where ships were present.

108. The disturbance impact of displacement has been seen across a variety of marine mammal species. In a large-scale study of harbour porpoise density in UK waters, including the North Sea MU and the Irish Sea MU, increased vessel activity was associated with lower porpoise densities. However, in NW Scottish waters, shipping had little effect on the density of individuals (Heinänen and Skov, 2015). A similar trend was seen with a study of Indo-Pacific bottlenose dolphins, when analysing habitat occupancy along the coast of Western Australia, dolphin density was negatively affected by vessels at one site but had no significant impact at the other (Marley *et al.* 2017a). Displacement was also seen with harbour porpoise detections around a pile driving site, where detections declined several hours prior to the start of pile driving. The decline was assumed to be due to the increase in other construction related activities and vessel presence in advance of the actual pile driving (Brandt *et al.* 2018; Benhemma-Le Gall *et al.* 2021).

109. However, for harbour seals a recent UK telemetry study showed there was no evidence of reduced seal presence as a result of vessel traffic. This was despite distributional overlaps (overlaps were most frequently found within 50km of the coast) between seal and vessel presence and high cumulative sound levels (Jones *et al.* 2017). Another study of grey seal pup tracks in the Celtic Sea and adult grey seals in the English Channel found that no animals were exposed to cumulative shipping noise that exceeded thresholds for temporary threshold shifts (TTS) (using the Southall *et al.* 2019 thresholds) (Trigg *et al.* 2020). A study of grey seal pupping beaches around Ramsey Island in Pembrokeshire found that disturbance occurred when vessels were closer than 150m to seal locations (Strong and Morris, 2010). Reduced presence of common dolphins was seen with the construction of a pipeline in NW Ireland due to vessel presence, however patterns suggested disturbance impacts were only short term (Culloch *et al.* 2016).

110. As well as the potential to have displacement effects, vessel activity has also been shown to elicit other potential behavioural changes. One study between 2012 - 2016 tagged seven harbour porpoises in a region of high shipping density in the inner Danish waters and Belt seas. The tagging of individuals provided data on responses to stressors in the marine environment. High noise levels coincided with erratic behaviour including 'vigorous fluking', bottom diving, interrupted foraging, and the cessation of vocalisations. Four out of six of the animals that were exposed to noise levels above 96dB re 1μPa (16kHz third octave levels) produced significantly fewer buzzes at high volumes of vessel noise. In one case, the proximity of a single vessel resulted in a 15 minute cessation in foraging (Wisniewska *et al.* 2018). Studies for bottlenose dolphin have indicated vessel presence has the potential to increase swimming speeds and reduce the time spent for foraging, resting and socialising (Marley *et al.* 2017b; Piwetz, 2019). Behavioural changes associated with disturbance have also been seen in common dolphins, due to the presence of vessels. Foraging and resting activity was significantly disrupted by vessel activity and returns to foraging activity took significantly longer than returns to other states (Stockin *et al.* 2008; Meissner *et al.* 2015). Behavioural changes have also been seen in minke whale with vessel interactions including a decrease in foraging activity, increase in swim speeds and energy expenditure (Christiansen *et al.* 2014).

111. Evidence suggests marine mammal species respond to vessel presence in a variety of ways, but all have the potential to be disturbed either through displacement, behavioural changes or both. Responses depended on a range of environmental factors but also the type and size of vessels. Some of the studies mentioned above based findings on fast moving vessels and vessels seeking close proximity to species, such as fast ferries and whale watching vessels (Wisniewska *et al.* 2018; Christiansen *et al.* 2014). Therefore, less of a disturbance effect is likely for the proposed construction vessels which would be slow moving or stationary.

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List of Acronyms

Acronym	Definition
ADD	Acoustic Deterrent Devices
AIS	Automatic Identification System
CGNS	Celtic and Greater North Seas
CPOD	Cetacean Porpoise Detector
DBD	Dogger Bank D Offshore Wind Farm
DBS	Dogger Bank South Offshore Wind Farm
DRC	Dose-Response Curve
EDR	Effective Deterrence Radius
EIA	Environmental Impact Assessment
ES	Environmental Statement
FCS	Favorable Conservation Status
GNS	Greater North Sea
Hz	hertz
IAMMWG	Inter-Agency Marine Mammal Working Group
iPCoD	interim Population Consequences of Disturbance
JNCC	Joint Nature Conservation Committee
MU	Management Unit
NE	North-east
NS	North Sea
OWF	Offshore wind farm
PAM	Passive Acoustic Monitoring
PEIR	Preliminary Environmental Information Report
PINS	Planning Inspectorate
PrePARED	Predators and Prey Around Renewable Energy Development

Acronym	Definition
PTS	Permanent Threshold Shift
RMS	Root Mean Square
SCANS	Small Cetaceans in the European Atlantic and North Sea
SCOS	Special Committee on Seals
SD	Standard Deviation
SE	South-east
SEL	Sound Exposure Level
SELss	Single Strike Sound Exposure Level
SELcum	Cumulative Sound Exposure Level
SELpeak	Peak Level
SPL	Sound Pressure Level
TTS	Temporary Threshold Shifts
UK	United Kingdom

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