Pentland floating offshore wind farm

Volume 3: Appendix A.11.1

Underwater Noise Impact Assessment

PENTLAND FLOATING OFFSHORE WIND FARM

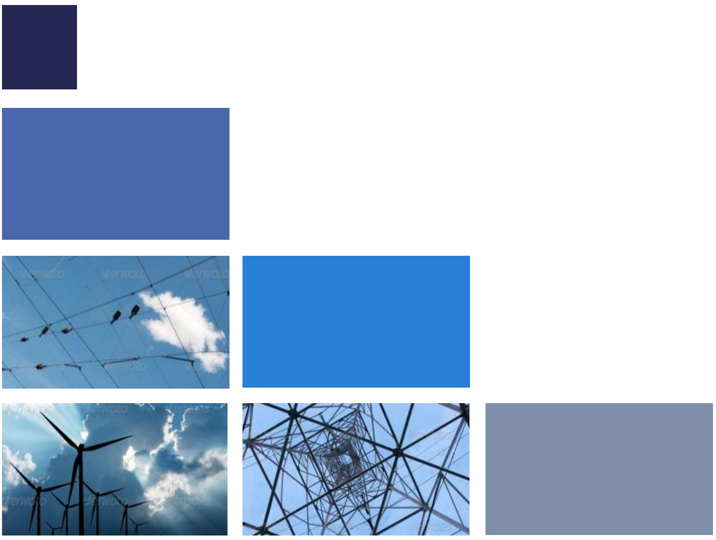
OFFSHORE EIAR (VOLUME 3): TECHNICAL APPENDICES

APPENDIX 11.1: UNDERWATER NOISE IMPACT ASSESSMENT

Document Title:	Pentland Floating Offshore Wind Farm Offshore EIAR
Document no.	GBPNTD-ENV-SMR-RP-00001
Project:	Pentland Floating Offshore Wind Farm
Originator Company	SMRU Consulting
Revision	01
Originator	Racheal Sinclair / Alex Brown
Date	25.07.2022

Revision History:

Revision	Date	Status	Originator	Reviewed	Approved
01	25.07.2022	Final	RS/AB	TW	PM



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Pentland Floating Offshore Wind Farm: Underwater Noise Impact Assessment

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Report Code:	SMRUC-XOD-2022-002
Date:	Friday, 22 July 2022

THIS REPORT IS TO BE CITED AS: SINCLAIR, RR; STEVENS, A; KLEMENTISOVA, K & BROWN, A. (2022). PENTLAND FLOATING OFFSHORE WIND FARM: UNDERWATER NOISE IMPACT ASSESSMENT. REPORT NUMBER SMRUC-XOD-2022-002, PROVIDED TO XODUS, JULY 2022 (UNPUBLISHED).

Document Control

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Rev.	Date.	Reason for Issue.	Prep.	Reviewed
1	April 2022	First Draft	SMRUC	JLS (Xodus)
2	May 2022	Second draft	SMRUC	MM (Xodus)
3	June 2022	Third draft	SMRUC	MM (Xodus)
4	June 2022	Fourth draft	SMRUC	HWL
5	July 2022	Fifth draft	SMRUC	MM (Xodus)
6	July 2022	Final draft for issue	SMRUC	MM (Xodus)

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1 Introduction

1.1 The Project

Highland Wind Limited (HWL) is proposing to demonstrate a floating offshore wind farm, named the Pentland Floating Offshore Wind Farm (PFOWF), referred to as 'the Offshore Development' within this Report. Through installation and operation of the PFOWF, HWL aims to test and demonstrate a solution for floating offshore wind in Scotland. The proposed wind farm is located approximately 7.5 km off the coast of Dounreay, Caithness at the same location as the Dounreay Trì Floating Demonstrator Project which was granted key consents and a Marine Licence in 2017. The proposed offshore area where the wind turbine generators (WTGs) will be installed (the PFOWF Array Area) is a reduction of the area consented under the Dounreay Trì Marine Licence.

The Project will consist of an offshore array of up to seven floating WTGs. The floating WTGs will be connected by subsea inter-array cables and up to two offshore export cables will transfer the energy generated, to the landfall on the Dounreay coast.

The PFOWF Array Area and the Offshore Export Cable Corridor (ECC) have been further refined following consultation to increase the set back of the Array Area from the Dounreay coast and to decrease its overall size, thereby reducing the horizontal spread of the WTGs and minimising potential visual impacts on land-based receptors.

Additionally, the maximum number of WTGs to be deployed has been decreased from ten to seven, further reducing potential visual impacts and impacts on other receptors. The original Dounreay Trì Project consented boundary along with the refined PFOWF Array Area and Offshore ECC are shown in Figure 1.1.

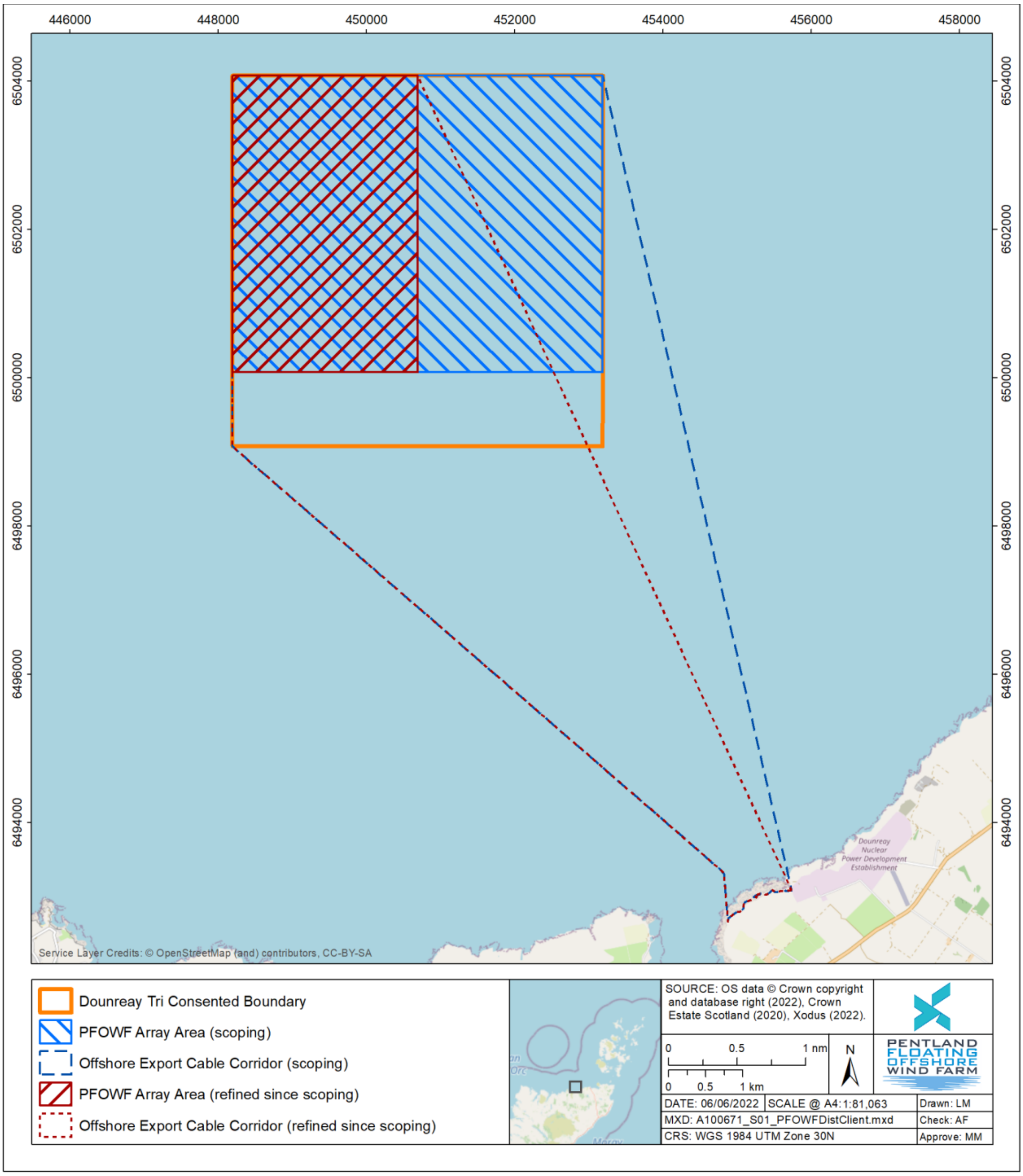


Figure 1.1 Location of PFOWF Offshore Development

1.2 Purpose of this document

HWL are currently progressing the Environmental Impact Assessment (EIA) and Habitats Regulations Appraisal (HRA) for the Offshore Development. This document provides the quantitative underwater noise impact assessment for the Offshore Development to support the EIA. This document draws upon outputs of the underwater noise modelling conducted by Subacoustech and presented in the associated report (Midforth *et al.* 2022).

Underwater noise impacts to marine mammal receptors are assessed for the following activities:

- Impact piling (also described within this report as pile driving);

- Geophysical and Unexploded Ordinance (UXO) surveys[1];
- UXO Clearance; and
- Other construction activities.

Additionally, an assessment of cumulative effects is presented to assess the predicted impacts of the Offshore Development cumulatively with other offshore developments in the relevant marine mammal management units.

This technical report should be read in conjunction with:

- Marine Mammals and other Megafauna, Chapter 11 in the Pentland Floating Offshore Wind Farm Offshore EIA Report (Vol 3); and
- Pentland Floating Offshore Wind Farm (PFOWF): Underwater noise modelling, Subacoustech Environmental Report No. P296R0108 (Midforth *et al.* 2022) – Appendix 11.1 in the Pentland Floating Offshore Wind Farm Offshore EIA Report (Vol 3).

1.3 Marine mammal baseline

The marine mammal baseline characterisation is presented in Pentland Floating Offshore Windfarm Offshore EIA Report (Vol 3), Chapter 11. The baseline characterisation details the occurrence of marine mammal species present in the PFOWF study area for marine mammals, compiled through a combination of a literature reviews and data obtained from site-specific surveys (HiDef 2015, 2016, 2021). The conclusion of the baseline characterisation is a set of recommended density estimates and Management Units (MUs) for each species to be used in this quantitative noise impact assessment (Table 1.1).

Table 1.1 Marine mammal MUs and density estimates.

Species	MU	MU Size	MU Ref	Density ($\#/km^2$)	Density Ref
Harbour porpoise[2]	North Sea	346,601	IAMMWG (2021)	0.1520	SCANS III Block S (Hammond *et al.* 2021)
	West Scotland	28,936	IAMMWG (2021)		
Bottlenose dolphin[3]	Coastal East Scotland (CES)	224[4]	Arso Civil *et al.* (2021)	0.0037	SCANS III Block S

[1] A geophysical survey employing a magnetometer will be undertaken in summer 2022 or 2023 to identify any UXO that may need to be avoided by minor re-routeing of the cables, or minor modifications of the anchor positions. Multibeam echo sounder (MBES) and side scan sonar (SSS) may also be required. Based on an initial desk-based UXO assessment undertaken by Ordtek (Ordtek, 2021) it is assumed that it will be possible to avoid any UXO encountered during the survey. Should any further mitigation be required, such as clearance or detonation, this would be subject to separate assessment and applications.

[2] The Offshore Development is located on the border of two harbour porpoise MUs and impacts are predicted to extend into each of these

[3] The Offshore Development is located on the border of four bottlenose dolphin MUs and impacts are predicted to extend into each of these

[4] 5-year weighted mean of annual estimates

Species	MU	MU Size	MU Ref	Density (#/km^2)	Density Ref
	Coastal West Scotland and the Hebrides (CWSH)	45	IAMMWG (2021)		(Hammond *et al.* 2021)
	Oceanic Waters (OW)	70,249	IAMMWG (2021)		
	Greater North Sea (GNS)	2,022	IAMMWG (2021)		
White-beaked dolphin	Celtic and Greater North Seas (CGNS)	43,951	IAMMWG (2021)	0.08	Site-specific surveys 2015-2016 (HiDef 2016)
Risso's dolphin	Celtic and Greater North Seas (CGNS)	12,262	IAMMWG (2021)	0.0135	SCANS III Block K[5] (Hammond *et al.* 2021)
Common dolphin	Celtic and Greater North Seas (CGNS)	102,656	IAMMWG (2021)	0.012	Site-specific surveys 2020-2021 (HiDef 2021)
Minke whale	Celtic and Greater North Seas (CGNS)	20,118	IAMMWG (2021)	0.0095	SCANS III Block S (Hammond *et al.* 2021)
Harbour seal	North Coast & Orkney (NCO)	Count: 1,405 Scaled[6]: 1,951	SCOS (2021)	Grid cell specific	Habitat Preference Map (Carter *et al.* 2020)
Grey seal	North Coast & Orkney (NCO)	Count: 8,599 Scaled[7]: 35,979	SCOS (2021)	Grid cell specific	Habitat Preference Map (Carter *et al.* 2020)

[5] No Risso's dolphin density estimate is available for SCANS III Block S, so the adjacent Block K value is used instead

[6] Assumes that 72% of the total harbour seal population is hauled-out during the August surveys (Lonergan *et al.* 2013). To account for the portion of the population at sea then: 1405/72*100 = 1,951

[7] Assumes that 23.9% of the total grey seal population is hauled-out during the August surveys (Russell *et al.* 2016a). To account for the portion of the population at sea then: 8599/23.9*100 = 35,979

2 Methods

2.1 Assessment of Injury

Exposure to loud sounds can lead to a reduction in hearing sensitivity, which can be measured as a shift in the threshold at which acoustic sounds are audible. These auditory threshold shifts are generally restricted to particular frequencies which are species-specific. A hearing threshold shift can result from physiological changes to the auditory system and may be temporary (TTS) or permanent (PTS) in nature. The PTS-onset thresholds used in this assessment are those presented in Southall *et al.* (2019). The method used to calculate PTS-onset impact ranges for both 'instantaneous' PTS (SPL_{peak}), and 'cumulative' (SEL_{cum}, over 24 hours) sounds are detailed in Offshore EIAR (Volume 3): Technical Appendix 11.1: Underwater Noise Modelling (Midforth *et al.* 2022).

It is worth noting that, although measuring the same potential effect of introduced underwater noise (i.e. PTS), the values given by the SPL_{peak} criteria and SEL_{cum} criteria are describing separate physical processes. The SPL_{peak} measures the instantaneous noise level at the loudest part of installation, when the maximum blow energy is being used, whereas the SEL_{cum} measures the total sound received over the entire piling operation, including during the soft start ramp up period. These metrics are used to identify the distance from a noise source that a fleeing receptor would have to be at, or beyond to avoid receiving sound levels which surpass its hearing threshold. In some cases, this can result in a situation where the impact range from the single strike SPL_{peak} criterion is calculated to have greater impact ranges than the multiple strike SEL_{cum} criteria.

2.2 Assessment of Disturbance

The methods used in undertaking the modelling and assessing the disturbance effects of underwater noise during geophysical and UXO surveys, UXO clearance, pile driving, and other construction activities are detailed in the below sections.

2.2.1 Pile-driven anchors

The assessment of disturbance from pile-driven anchors was based on the current best practice methodology (Southall *et al.* 2019, Tyack and Thomas 2019, Southall *et al.* 2021), making use of the best available scientific evidence (Graham *et al.* 2019, Whyte *et al.* 2020, Benhemma-Le Gall *et al.* 2021). This incorporates the application of a species-specific dose-response approach, rather than a fixed behavioural acoustic threshold approach. Noise contours at 5 dB intervals were generated by noise modelling and were overlain on species density surfaces to predict the number of animals potentially disturbed. This allowed for the quantification of the number of animals that will potentially respond.

Compared with a fixed distance (i.e. the Effective Deterrence Range, EDR) or a fixed noise threshold approach, the application of a dose-response curve allows for more realistic assumptions about animal response as it varies with exposure (or dose), and it is supported by a growing number of studies (Southall *et al.* 2019, Tyack and Thomas 2019, Southall *et al.* 2021). A dose-response curve is used to quantify the probability of a response from an animal to a dose of a certain stimulus or stressor (Dunlop *et al.* 2017) and is based on the assumption that not all animals in an impact zone will respond. The dose can either be determined using the distance from the sound source or the received weighted or unweighted sound level at the receiver (Sinclair *et al.* 2021).

Using a species specific dose response approach, rather than a fixed behavioural threshold, to assess disturbance is currently considered to be the best practice methodology and the latest guidance provided in Southall *et al.* (2019) is that *"Apparent patterns in response as a function of received noise level (sound pressure level) highlighted a number of potential errors in using all-or-nothing* *"thresholds" to predict whether animals will respond. Tyack and Thomas (2019) subsequently and substantially expanded upon these observations. The clearly evident variability in response is likely attributable to a host of contextual factors, which emphasizes the importance of estimating not only a dose-response function but also characterizing response variability at any dosage"*.

2.2.1.1 Cetacean disturbance: harbour porpoise dose-response function

To estimate the number of cetaceans predicted to experience behavioural disturbance as a result of pile driving, this impact assessment uses the porpoise dose-response function presented in Graham *et al.* (2017a) (Figure 2.1).

The Graham *et al.* (2017a) dose-response function was developed using data on harbour porpoise collected during the first six weeks of piling during Phase 1 of the Beatrice Offshore Wind Farm monitoring program. Changes in porpoise occurrence (detection positive hours per day) were estimated using 47 click detectors (continuous porpoise detectors, CPODs[8]) placed around the wind farm site during piling and compared with baseline data from 12 sites outside of the wind farm area prior to the commencement of operations, to characterise this variation in occurrence. Porpoise were considered to have exhibited a behavioural response to piling when the proportional decrease in occurrence was greater than 0.5. The probability that porpoise occurrence did or did not show a response to piling was modelled along with the estimated received single -pulse sound exposure levels (Graham *et al.* 2017a).

Since the initial development of the dose-response function in 2017, additional data from the remaining pile driving events at Beatrice Offshore Windfarm have been processed and are presented in Graham *et al.* (2019). The passive acoustic monitoring showed a 50% probability of porpoise response (a significant reduction in detection relative to baseline) within 7.4 km at the first location piled, with decreasing response levels over the construction period to a 50% probability of response within 1.3 km by the final piling location (Figure 2.2) (Graham *et al.* 2019). Therefore, using the dose-response function derived from the initial piling events for all piling events in the impact assessment is precautionary, as evidence shows that porpoise response is likely to diminish over the construction period.

[8] CPODs monitor the presence and activity of toothed cetaceans by the detection within the CPOD app of the trains of echo-location clicks that they make. See https://www.chelonia.co.uk/index.html

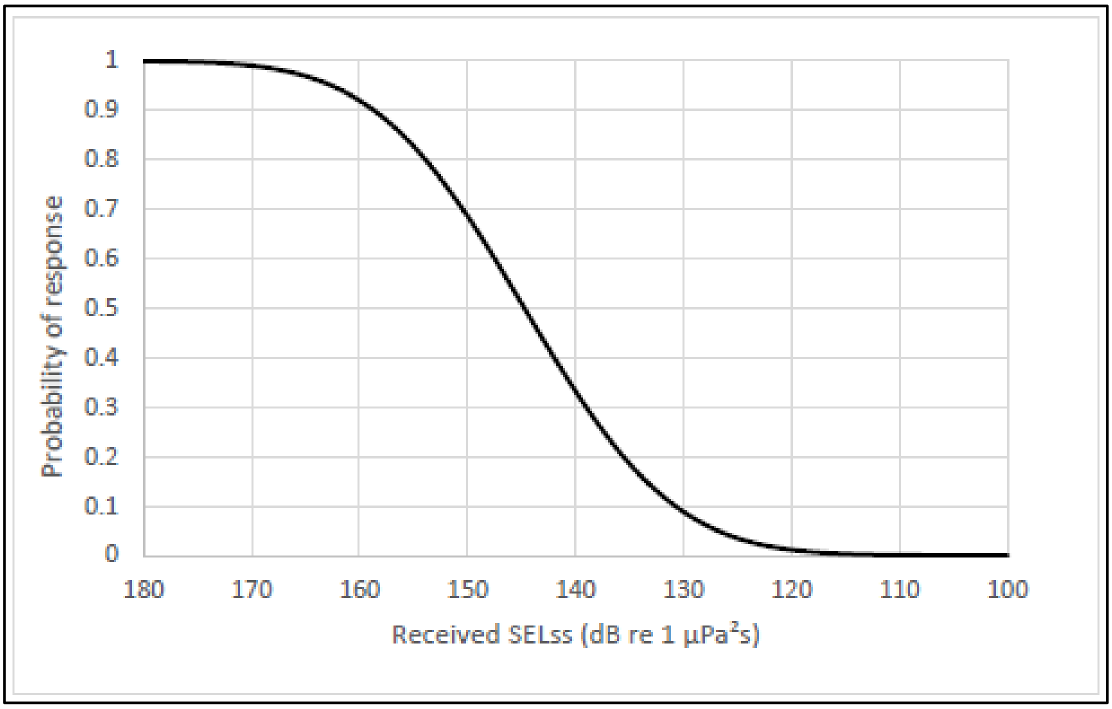


Figure 2.1 Relationship between the proportion of animals responding and the received single strike SEL (SELss), based on passive acoustic monitoring results obtained during Phase 1 of the Beatrice Offshore Wind Farm monitoring program (Graham *et al.* 2017a).

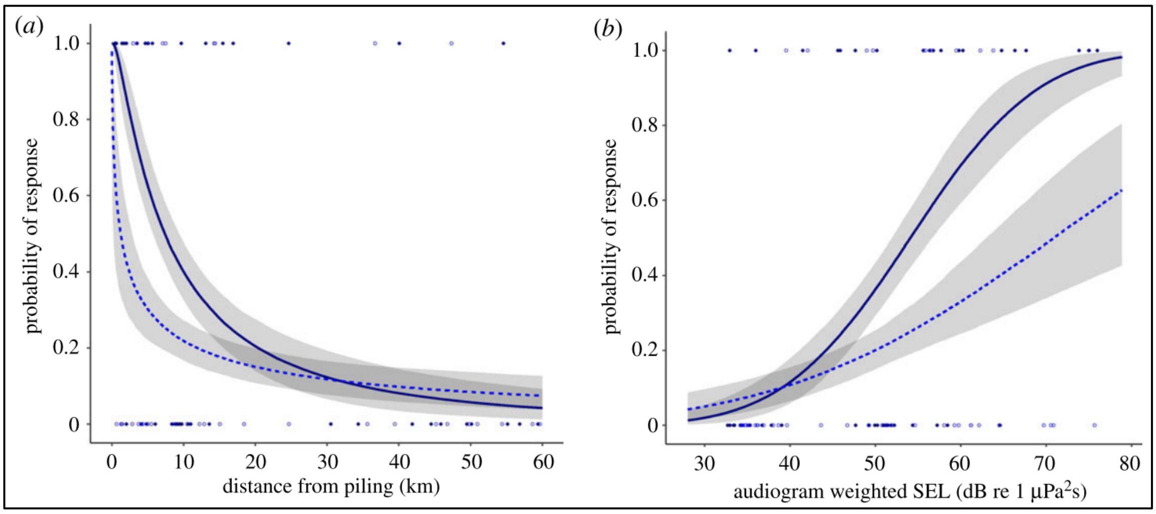


Figure 2.2 The probability of a harbour porpoise response (24 h) in relation to the partial contribution of (a) distance from piling and (b) audiogram-weighted received single-pulse SEL for the first location piled (solid navy line) and the final location piled (dashed blue line). Obtained from Graham *et al.* (2019) - refer to publication for additional explanation of the figure.

In the absence of species-specific data on bottlenose dolphins, Risso's dolphins or minke whales, this dose -response curve has been adopted for all cetaceans. This is likely to be highly over precautionary as porpoise are considered to be particularly responsive to anthropogenic disturbance compared to other odontocetes (e.g., Ketten 2000, Lucke *et al.* 2009, Brandt *et al.* 2013, Thompson *et al.* 2013, Tougaard *et al.* 2013, Brandt *et al.* 2018, Sarnocinska *et al.* 2019, Thompson *et al.* 2020, Benhemma-Le Gall *et al.* 2021). Lucke *et al.* (2009) aimed to provide the first reliable information for the harbour porpoise for impulsive sound exposure as the threshold shift for the harbour porpoise differs from other odontocetes. The study concluded that harbour porpoise exhibit a relatively high temporary threshold shift (TTS) growth factor and have a slow recovery rate which, in combination, make them more vulnerable than mid-frequency cetaceans. Further recent TTS experiments and field studies also support that harbour porpoise (and finless porpoise) are more sensitive to sound than initially anticipated from extrapolation of bottlenose dolphin results. Their behavioural reactions to noise also suggest that the noise response thresholds and TTS both critically depend on stimulus frequency (Tougaard *et al.* 2015).

A study conducted by Moray Offshore Renewables Limited (2012) reviewing both responses of harbour porpoise and bottlenose dolphins to received sound level was not significant, but this was likely due to the small sample size. The best-fit relationships were indicative of a higher level responses by harbour porpoises than bottlenose dolphins at similar noise levels, with moderate changes in behaviour predicted to occur at approximately 50-60 dB re 1 µPa lower in harbour porpoises (Moray Offshore Renewables Limited 2012).

There is no disturbance threshold (effective disturbance range or dose-response curve) for any other cetacean species included in this assessment. Therefore, in the absence of an alternative, the assessment for all cetacean species has used the harbour porpoise derived dose-response curve. This is considered to be highly precautionary and, as such, the number of animals predicted to experience behavioural disturbance is considered to be an over-estimate and should be interpreted with caution and due consideration of species-specific baseline knowledge.

2.2.1.2 Pinniped disturbance: harbour seal dose-response curve

For both harbour and grey seals, the dose-response function adopted was based on data presented in Whyte *et al.* (2020) study on harbour seals (Figure 2.3).

The Whyte *et al.* (2020) study updates the initial dose-response information presented in Russell *et al.* (2016c) and Russell and Hastie (2017), where the percentage change in harbour seal density was predicted at the Lincs Offshore Wind Farm. The original study used telemetry data from 25 harbour seals tagged in the Wash between 2003 and 2006, in addition to a further 24 harbour seals tagged in 2012, to estimate levels of seal usage in the area, in order to assess how seal usage changed in relation to the pile driving activities at the Lincs Offshore Wind Farm in 2011-2012.

In the Whyte *et al.* (2020) dose-response function it has been assumed that all seals are displaced at sound exposure levels above 180 dB re 1 µPa^{2}s. This is a conservative assumption since there were no data presented in the study for harbour seal responses at this level. It is also important to note that the percentage decrease in response in the categories 170≤175 and 175≤180 dB re 1 µPa^{2}s is slightly anomalous (higher response at a lower sound exposure level) due to the small number of spatial cells included in the analysis for these categories (n= 2 and 3 respectively).

Given the large confidence intervals (CIs) on the data, this assessment presents the mean number of seals predicted to be disturbed alongside the 95% CIs, for context.

There are no corresponding data for grey seals and, as such, the harbour seal function is applied to the grey seal disturbance assessment. This is considered to be an appropriate proxy for grey seals, since both species are categorised within the same functional hearing group. However, it is likely that this over-estimates the grey seal response, since grey seals are considered to be less sensitive to behavioural disturbance than harbour seals and could tolerate more days of disturbance before there is likely to be an effect on vital rates (Booth *et al.* 2019). Recent studies of tagged grey seals have shown that there is vast individual variation is responses to pile driving, with some animals not showing any evidence of a behavioural response (Aarts *et al.* 2018). Likewise, if the impacted area is considered to be a high quality foraging patch, it is likely that some grey seals may show no behavioural response at all, given their motivation to remain in the area for foraging (Hastie *et al.* 2021). Therefore, the adoption of the harbour seal dose-response function for grey seals is considered to be precautionary as it will likely over-estimate the potential for effects on grey seals.

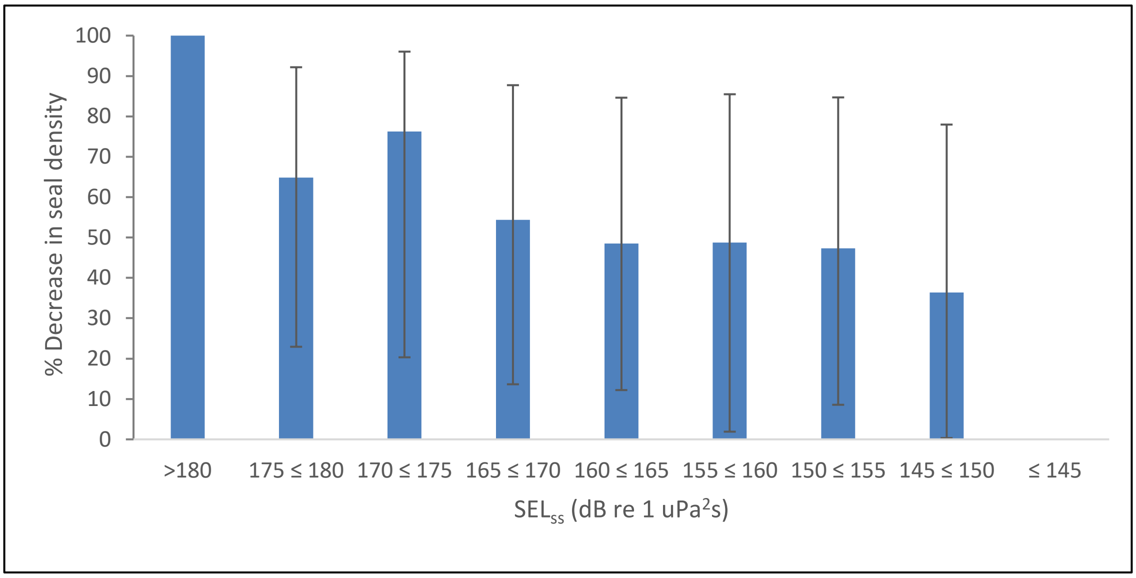


Figure 2.3 Predicted decrease in seal density as a function of estimated sound exposure level, error bars show 95% Confidence Interval (Whyte *et al.* 2020).

2.2.2 UXO Clearance

While there are empirically-derived dose-response relationships for pile driving; these are not directly applicable to the assessment of UXO detonation due to the very different nature of the sound emission. While both sound sources (piling and explosives) are categorised as "impulsive" sound sources, they differ drastically in the number of pulses and the overall duration of the noise emission, both of which will ultimately drive the behavioural response. While one UXO-detonation is anticipated to result in a one-off startle-response or aversive behaviour, the series of pulses emitted during pile driving will more or less continuously drive animals out of the impacted area, giving rise to a measurable and quantifiable dose-response relationship. For UXO clearance, there are no dose-response functions available that describe the magnitude and transient nature of the behavioural effects of UXO detonation on marine mammals.

2.2.2.1 Low-order clearance

There is no guidance available on which thresholds should be used to assess disturbance from low-order UXO clearance. Current risk assessments conducted to support UXO Marine Licence Applications that include deflagration as the preferred method, assume an EDR of 5 km (e.g., Sofia Offshore Wind Farm[9]). As a consequence, due to the absence of formal guidance, this approach has been adopted here for the assessment of disturbance from low-order detonation of UXOs at the Offshore Development.

[9] Sofia Offshore Wind Farm UXO Clearance Marine License Application (GoBe 2021) MLA/2020/00489

2.2.2.2 High-order clearance

Since there is no dose-response function available that appropriately reflects the behavioural disturbance from UXO detonation, other behavioural disturbance thresholds have been considered instead.

There is guidance available on the EDR that should be applied to assess the significance of noise disturbance against Conservation Objectives of harbour porpoise Special Areas of Conservation (SACs) in England, Wales & Northern Ireland (JNCC 2020). This guidance advises that an effective deterrence range of 26 km around the source location is used to determine the impact area from high-order UXO detonation with respect to disturbance of harbour porpoise in SACs. However, the guidance itself acknowledges that this EDR is based on the EDR recommended for pile driving of monopiles (without noise abatement measures), since there is no equivalent data for explosives.

"The 26 km EDR is also to be used for the high order detonation of unexploded ordnance (UXOs) despite there being no empirical evidence of harbour porpoise avoidance." (JNCC 2020)

The guidance also acknowledges that the disturbance resulting from a single explosive detonation would likely not cause the more wide-spread prolonged displacement that has been observed in response to pile driving activities:

"...a one-off explosion would probably only elicit a startle response and would not cause widespread and prolonged displacement..." (JNCC 2020)

While SMRU Consulting acknowledges that Marine Scotland and NatureScot have not signed up to the JNCC (2020) guidance, SMRU Consulting proposes to present the 26 km EDR in this underwater noise assessment for context and for comparison to the alternative fixed noise threshold described below.

Some recent assessments of UXO clearance activities have used the TTS-onset threshold to indicate the level at which a 'fleeing' response may be expected to occur in marine mammals (e.g., Seagreen and Neart na Goithe). This is a result of discussion in Southall *et al.* (2007) which states that in the absence of empirical data on responses, the use of the TTS-onset threshold may be appropriate for single pulses (like UXO detonation).

"Even strong behavioral responses to single pulses, other than those that may secondarily result in injury or death (e.g., stampeding), are expected to dissipate rapidly enough as to have limited long-term consequence. Consequently, upon exposure to a single pulse, the onset of significant behavioral disturbance is proposed to occur at the lowest level of noise exposure that has a measurable transient effect on hearing (i.e., TTS-onset). We recognize that this is not a behavioral effect per se, but we use this auditory effect as a de facto behavioral threshold until better measures are identified. Lesser exposures to a single pulse are not expected to cause significant disturbance, whereas any compromise, even temporarily, to hearing functions has the potential to affect vital rates through altered behavior." (Southall et al. 2007).

"Due to the transient nature of a single pulse, the most severe behavioral reactions will usually be temporary responses, such as startle, rather than prolonged effects, such as modified habitat utilization. A transient behavioral response to a single pulse is unlikely to result in demonstrable effects on individual growth, survival, or reproduction. Consequently, for the unique condition of a single pulse, an auditory effect is used as a de facto disturbance criterion. It is assumed that significant behavioral disturbance might occur if noise exposure is sufficient to have a measurable transient effect on hearing (i.e., TTS-onset). Although TTS is not a behavioral effect per se, this approach is used because any compromise, even temporarily, to hearing functions has the potential to affect vital rates by interfering with essential communication and/or detection capabilities. This approach is expected to be

precautionary because TTS at onset levels is unlikely to last a full diel cycle or to have serious biological consequences during the time TTS persists." (Southall et al. 2007).

Therefore, an estimation of the extent of behavioural disturbance can be based on the sound levels at which the onset of TTS is predicted to occur from impulsive sounds. Marine Scotland and NatureScot currently accept that TTS-onset as a proxy for disturbance from UXO detonation is the most appropriate threshold to use given the lack of empirical data. TTS-onset thresholds are taken as those proposed for different functional hearing groups by Southall *et al.* (2019) (Table 2.1). While the TTS-onset thresholds can be used as a proxy for disturbance, the resulting impact assessment should detail the limitations to this approach, including the fact that it may over-estimate the potential for an ecologically significant effect, as acknowledged by Southall *et al.* (2007), and that impulsive noise becomes non-impulsive at large distances from the sound source due to propagation effects (Southall *et al.* 2007, Hastie *et al.* 2019, Martin *et al.* 2020). The sound level at which an animal is at risk of TTS from less impulsive or non-impulsive sound will be above those indicated by the TTS-onset thresholds for impulsive sound.

Table 2.1 TTS-onset thresholds for impulsive noise as proposed by Southall *et al*. (2019), with relevance for species in UK waters.

Hearing group	TTS-onset: weighted SEL (dB re 1 µPa²s)	TTS-onset: unweighted SPL_{0-p} (dB re 1 µPa)
Low frequency (minke whale)	168	213
High frequency (dolphin species)	170	224
Very high frequency (harbour porpoise)	140	196
Phocids in water (seals)	170	212

In the absence of agreed thresholds to assess the potential for behaviour disturbance in marine mammals from UXO detonations, the impact assessment for high-order UXO clearance presents results for each of the following behavioural disturbance thresholds:

- 26 km EDR
- TTS-onset thresholds

2.2.3 Geophysical and UXO surveys

The Ordtek (2021) Risk Assessment Report concluded that the density of UXOs and, thus, the likelihood of their encounter, is likely to be 'low-medium' across the PFOWF Offshore Site (the area encompassing the PFOWF Array Area and Offshore Export Cable Corridor (ECC), as defined below, to Mean High Water Springs (MHWS)). Dedicated surveys will be undertaken to confirm the presence of any such items within the area of development.

There is currently no guidance on the thresholds to be used to assess disturbance of marine mammals from geophysical surveys. Therefore, the Offshore EIA provides a qualitative assessment for these impacts. The assessment is based on the limited evidence that is available in the existing literature for that impact pathway and species combination, where available.

2.2.4 Other construction activities

There is currently no guidance on the thresholds to be used to assess disturbance of marine mammals from other construction related activities such as drilling, dredging or vessel activity. Therefore, the impact assessment for the Offshore Development provides a qualitative assessment for these impacts. The assessment is based on the limited evidence that is available in the existing literature for that impact pathway and species combination, where available.

2.3 Impact assessment

The assessment methodology provided for marine mammal and megafauna receptors has developed to reflect the sensitivities and conservation needs of highly mobile species. Definitions of impact magnitude and significance have been adapted from the *Guidelines for ecological impact assessment in the UK and Ireland: terrestrial, freshwater and coastal* (CIEEM 2019) with those receptors in mind.

2.3.1 Sensitivity

The sensitivities of marine mammal receptors have been defined by their potential vulnerability to an impact from the proposed development, how an impact is expected to affect vital rates and their ability to recover from such impact. The definitions of terms relating to the sensitivity of marine mammals are detailed in Table 2.2.

Table 2.2 Receptor Sensitivity and Value Assessment Criteria

Sensitivity	Description
Very High	No ability to adapt behaviour so that individual vital rates (survival and reproduction) are highly likely to be significantly affected. No tolerance – effect will cause a significant change in individual vital rates (survival and reproduction). No ability for the animal to recover from any impact on vital rates (reproduction and survival rates).
High	Very limited ability to adapt behaviour so that individual vital rates (survival and reproduction) are likely to be significantly affected. Very limited tolerance – effect is likely to cause a significant change in individual vital rates (survival and reproduction). Very limited ability for the animal to recover from any impact on vital rates (reproduction and survival rates).
Moderate	Limited ability to adapt behaviour so that individual vital rates (survival and reproduction) may be significantly affected. Limited tolerance – effect may cause a significant change in individual vital rates (survival and reproduction). Limited ability for the animal to recover from any impact on vital rates (reproduction and survival rates).
Low	Ability to adapt behaviour so that individual vital rates (survival and reproduction) may be affected, but not at a significant level. Some tolerance – no significant change in individual vital rates (survival and reproduction). Ability for the animal to recover from any impact on vital rates (reproduction and survival rates).
Negligible	Receptor is able to adapt behaviour so that individual vital rates (survival and reproduction) are not affected. Receptor is able to tolerate the effect without any impact on individual vital rates (survival and reproduction). Receptor is able to return to previous behavioural states/activities once the impact has ceased.

2.3.2 Receptor value

For the purpose of impact assessment, receptors can be assigned a value or importance based on a pre-defined judgement that considers conservation status, level of legal protection and/or guidance or policy. Value definitions applicable to marine mammals, birds or fish are presented in Table 2.3. By these definitions, all marine mammal receptors considered in this assessment are considered of 'high' conservation value due to their inclusion in Annex IV of the EU Habitats Directive as a European Protected Species (EPS) and / or as qualifying interests of UK and European Protected Sites (SACs). Therefore, receptor value has not been used to differentiate effect outcomes in this assessment.

Table 2.3 Value of receptor

Sensitivity	Description
Very High	Receptor of very high importance or rarity (e.g., species that are globally threatened, such as those listed on the OSPAR list of Threatened and Declining Species or the International Union for Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species ('Red List') including those listed as *endangered* or *critically endangered*) and/or a significant proportion of the international population (> 1%) is found within the Project site.
High	Receptor of high importance or rarity (e.g., species that are globally threatened, such those listened on the OSPAR list of Threatened and Declining Species or species listed as *near-threatened* or *vulnerable* on the IUCN Red List; species listed on Annex IV of the EU Habitats Directive as a European Protected Species (EPS)) and/or species which are a qualifying interest of a SAC and a significant proportion of the national population (> 1%) is found within the Project site.
Moderate	Receptor is of moderate importance or rarity (e.g., species that are considered *least concern* on the IUCN Red List; listed as a breeding species on Schedule 1 of the Wildlife and Countryside Act 1981, form a cited interest of a Site of Special Scientific Interest (SSSI), and/or are listed in the UK BAP) and/or a significant proportion of the regional population (> 1%) is found within the Project site.
Low	Any other species of conservation interest.
Negligible	Receptor of very low importance, such as those which are generally abundant around the UK with no specific value or conservation concern.

2.3.3 Magnitude

The magnitude of impacts are defined by their outcomes and durations. Table 2.4 provides an overview of the range of impact magnitudes referred to within this assessment. The impact magnitude has been assessed as either high, moderate, low, negligible or no change.

Table 2.4 Definitions of Impact Magnitude

Magnitude	Description
High	Total loss of, or major alteration to conservation status or integrity of a receptor with situation likely to be irreversible, even in the long term. Fundamental alteration to the character and composition of any proposed or designated sites.
Moderate	Clear effect on the conservation status or integrity of the receptor in the short to medium term (i.e. 6-15 years), although this is likely to be reversible in the long-term (i.e. 15 years or more) through replacement.
Low	Minor shift away from baseline conditions. Effects will be detectable but unlikely to be of a scale or duration to have a significant effect on the conservation status or integrity of the receptor in the short term (i.e. 1-5 years). Overall baseline character of site will not be substantially altered.
Negligible	Very slight change from the baseline conditions. Changes barely detectable, approximating to the 'no change' situation. Any effects likely to be reversible within 12 months and not affect the conservation status or integrity of the receptor.
No change	Impact is highly localised and short term with full rapid recovery expected result in very slight or imperceptible changes to baseline conditions or receptor population.

2.3.4 Significance of effects

The significance of effects is a product of the receptor sensitivity/value and the magnitude of the impact on it, moderated by professional judgment. The effect significance for this marine mammal assessment has been assessed as either major, moderate, minor or negligible using the matrix in Table 2.5. In terms of EIA, only effects which are 'moderate' or 'major' are considered significant, while effects which are 'minor' or 'negligible' constitute a non-significant effect.

Table 2.5 Significance of effects matrix for marine mammal assessment

Sensitivity of Receptor	Magnitude of Impact				
	No Change	Negligible	Low	Moderate	High
Negligible	Negligible	Negligible	Negligible	Negligible	Minor
Low	Negligible	Negligible	Minor	Minor	Moderate
Moderate	Negligible	Minor	Minor	Moderate	Major
High	Negligible	Minor	Moderate	Major	Major
Very High	Negligible	Minor	Major	Major	Major

2.3.5 Species-specific relationships with injury from pile driving activities

2.3.5.1 Expert elicitation

The ecological consequences of PTS for marine mammals are uncertain. At a Department for Business, Energy & Industrial Strategy (BEIS) funded expert elicitation workshop held at the University of St Andrews (March 2018), experts in marine mammal hearing discussed the nature, extent and potential consequence of PTS to UK marine mammal species (Booth and Heinis 2018). This workshop outlined and collated the best and most recent empirical data available on the effects of PTS on marine mammals. A number of general points came out in discussions as part of the elicitation. These included that PTS did not mean animals were deaf, that the limitations of the ambient noise environment should be considered and that the magnitude and frequency band in which PTS occurs are critical to assessing the effect on vital rates.

Southall *et al.* (2007) defined the onset of TTS as "*being a temporary elevation of a hearing threshold by 6 dB"* (in which the reference pressure for the dB is 1µPa). Although 6 dB of TTS is a somewhat arbitrary definition of onset, it has been adopted largely because 6 dB is a measurable quantity that is typically outside the variability of repeated thresholds measurements. The onset of PTS was defined as a non-recoverable elevation of the hearing threshold of 6 dB, for similar reasons. Based upon TTS growth rates obtained from the scientific literature, it has been assumed that the onset of PTS occurs after TTS has grown to 40 dB. The growth rate of TTS is dependent on the frequency of exposure, but is nevertheless assumed to occur as a function of an exposure that results in 40 dB of TTS (i.e., 40 dB of TTS is assumed to equate to 6 dB of PTS).

For piling noise, most energy is between ~30- 500 Hz, with a peak usually between 100- 300 Hz and energy extending above 2 kHz (Kastelein *et al.* 2015, Kastelein *et al.* 2016). Studies have shown that exposure to impulsive pile driving noise induces TTS in a relatively narrow frequency band in harbour porpoise and harbour seals (reviewed in Finneran 2015), with statistically significant TTS occurring at 4 and 8 and centred at 4 kHz (Kastelein *et al.* 2016). Therefore, during the expert elicitation, the experts agreed that any threshold shifts as a result of pile driving would manifest themselves in the 2-10 kHz range (Kastelein *et al.* 2017) and that a PTS 'notch' of 6-18 dB in a narrow frequency band in the 2-10 kHz region is unlikely to significantly affect the fitness of individuals (ability to survive and reproduce). The expert elicitation concluded that:

- the effects of a 6 dB PTS in the 2-10 kHz band was unlikely to have a large effect on survival or fertility of the species of interest.
- for all species experts indicated that the most likely predicted effect on survival or fertility as a result of 6 dB PTS was likely to be very small (i.e., <5% reduction in survival or fertility).
- the defined PTS was likely to have a slightly larger effect on calves/pups and juveniles than on mature females' survival or fertility.

2.3.5.1.1 Harbour porpoise

For harbour porpoise, the predicted decline in vital rates from the impact of a 6 dB PTS in the 2-10 kHz band for different percentiles of the elicited probability distribution are provided in Table 2.6. The data provided in Table 2.6 should be interpreted as:

- Experts estimated that the median decline in an individual mature female harbour porpoise's survival was 0.01% (due to a 6 dB PTS (a notch a few kHz wide and 6 dB high) occurring somewhere in the hearing between 2-10 kHz).
- Experts estimated that the median decline in an individual mature female harbour porpoise's fertility was 0.09% (due to a 6 dB PTS (a notch a few kHz wide and 6 dB high) occurring somewhere in the hearing between 2-10 kHz).
- Experts estimated that the median decline in an individual harbour porpoise juvenile or dependent calf survival was 0.18% (due to a 6 dB PTS (a notch a few kHz wide and 6 dB high) occurring somewhere in the hearing between 2-10 kHz).

Table 2.6 Predicted decline in harbour porpoise vital rates for different percentiles of the elicited probability distribution

	Percentiles of the elicited probability distribution								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Adult survival	0	0	0	0.01	0.01	0.03	0.05	0.1	0.23
Fertility	0	0	0.02	0.05	0.09	0.16	0.3	0.7	1.35
Calf/Juvenile survival	0	0	0.02	0.09	0.18	0.31	0.49	0.8	1.46

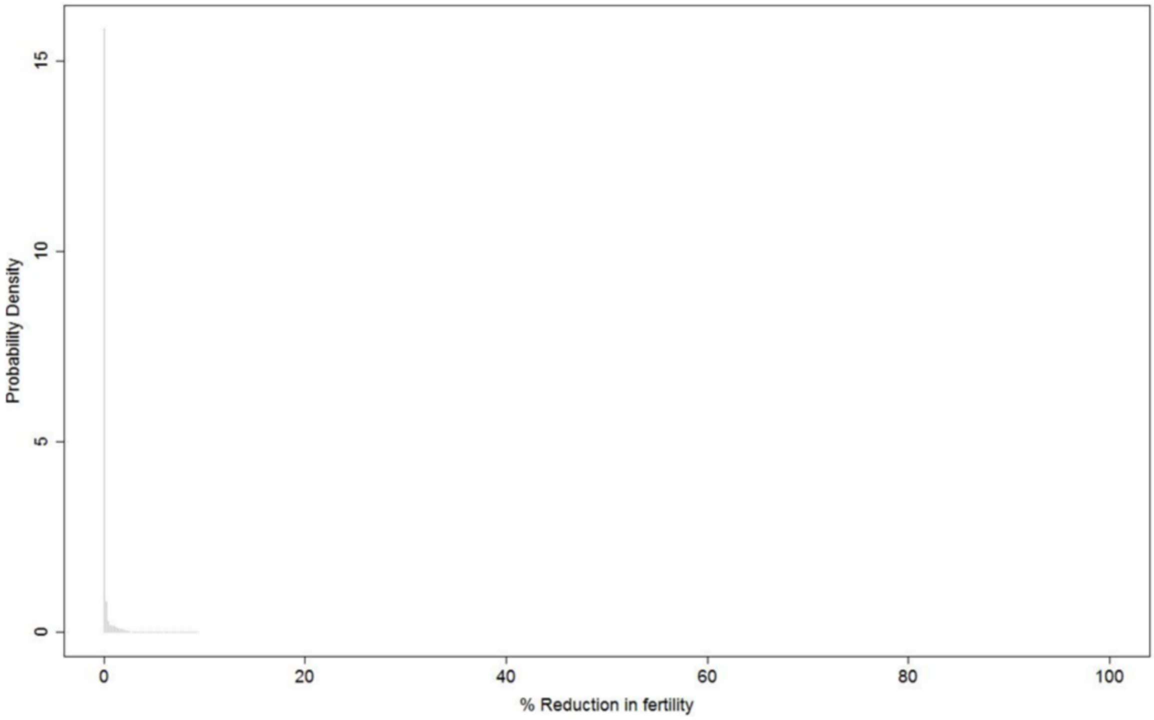


Figure 2.4 Probability distribution showing the consensus distribution for the effects on fertility of a mature female harbour porpoise as a consequence of a maximum 6 dB of PTS within a 2-10 kHz band

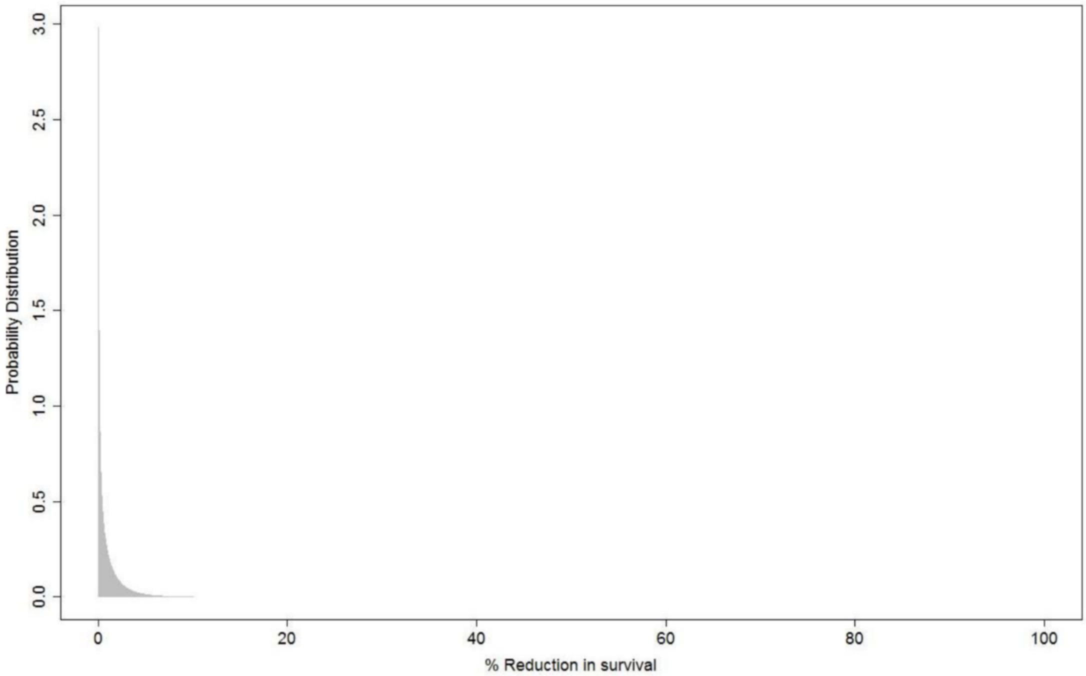


Figure 2.5 Probability distribution showing the consensus distribution for the effects on survival of a mature female harbour porpoise as a consequence of a maximum 6 dB of PTS within a 2-10 kHz band

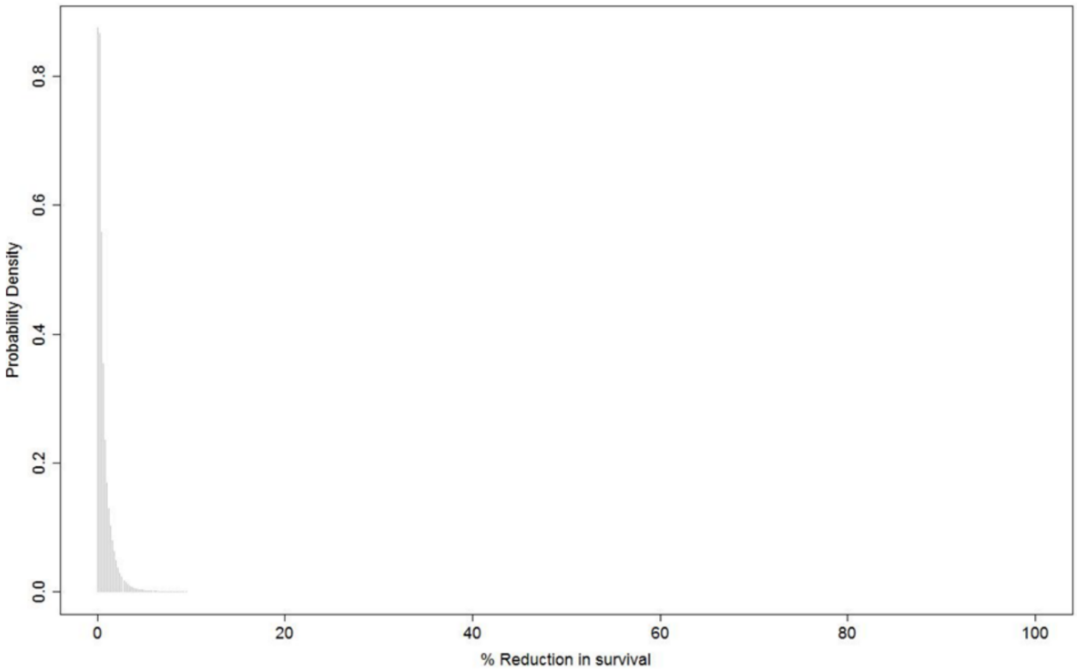


Figure 2.6 Probability distribution showing the consensus distribution for the effects on survival of juvenile or dependent calf harbour porpoise as a consequence of a maximum 6 dB of PTS within a 2-10 kHz band

2.3.5.1.2 Bottlenose dolphin

The predicted decline in bottlenose dolphin vital rates from the impact of a 6 dB PTS in the 2-10 kHz band for different percentiles of the elicited probability distribution are provided in Table 2.7. The data provided in Table 2.7 should be interpreted as:

- Experts estimated that the median decline in an individual mature female bottlenose dolphin's survival was 1.6% (due to a 6 dB PTS (a notch a few kHz wide and 6 dB high) occurring somewhere in the hearing between 2-10 kHz).
- Experts estimated that the median decline in an individual mature female bottlenose dolphin's fertility was 0.43% (due to a 6 dB PTS (a notch a few kHz wide and 6 dB high) occurring somewhere in the hearing between 2-10 kHz).
- Experts estimated that the median decline in an individual bottlenose dolphin juvenile survival was 1.32% (due to a 6 dB PTS (a notch a few kHz wide and 6 dB high) occurring somewhere in the hearing between 2-10 kHz).
- Experts estimated that the median decline in an individual bottlenose dolphin dependent calf survival was 2.96% (due to a 6 dB PTS (a notch a few kHz wide and 6 dB high) occurring somewhere in the hearing between 2-10 kHz).

Table 2.7 Predicted decline in bottlenose dolphin vital rates for different percentiles of the elicited probability distribution

	Percentiles of the elicited probability distribution								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Adult survival	0	0.18	0.57	1.04	1.6	2.34	3.39	5.18	10.99
Fertility	0	0.04	0.13	0.26	0.43	0.85	1.66	3.49	6.22
Juvenile survival	0.01	0.11	0.35	0.75	1.32	2.14	3.3	5.19	11.24
Calf survival	0	0.29	0.93	1.77	2.96	4.96	7.81	10.69	14.79

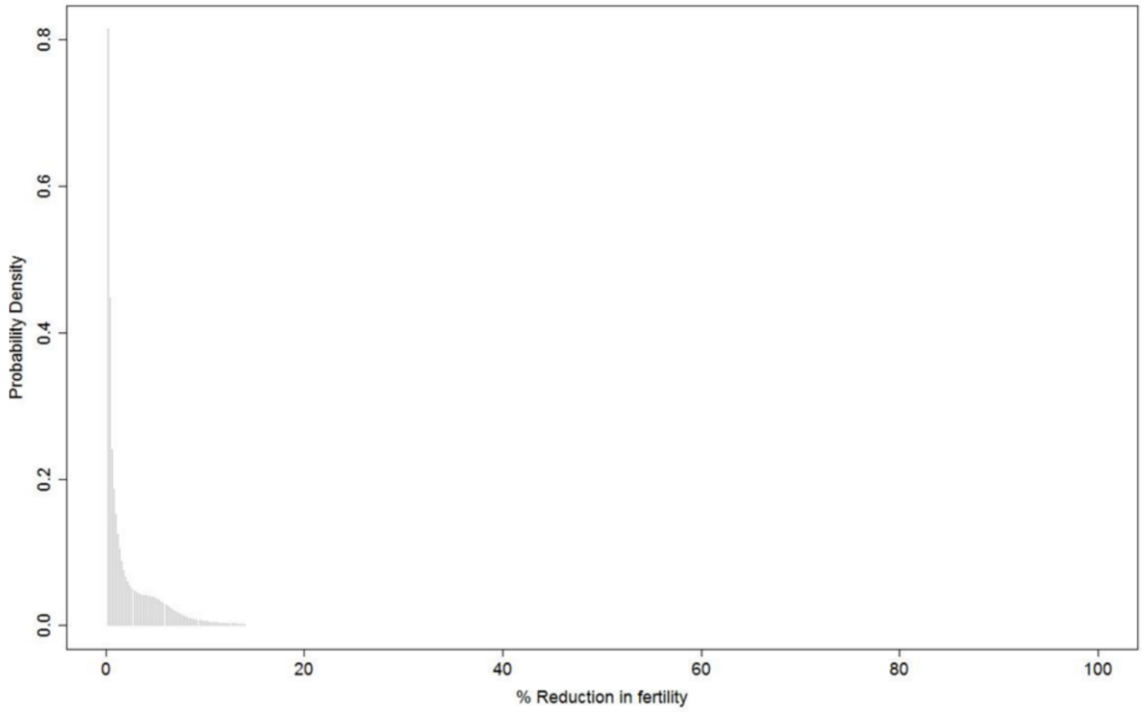


Figure 2.7 Probability distribution showing the consensus distribution for the effects on fertility of mature female bottlenose dolphin as a consequence of a maximum 6 dB of PTS within a 2-10 kHz band

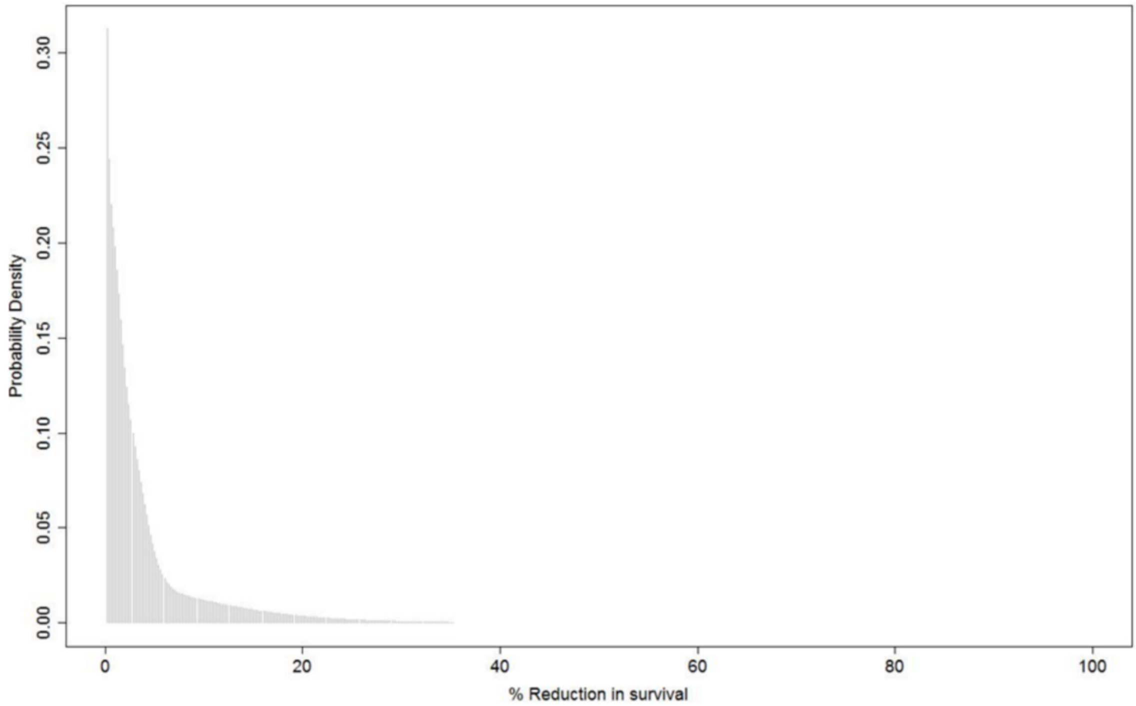


Figure 2.8 Probability distribution showing the consensus distribution for the effects on survival of mature female bottlenose dolphin as a consequence of a maximum 6 dB of PTS within a 2-10 kHz band

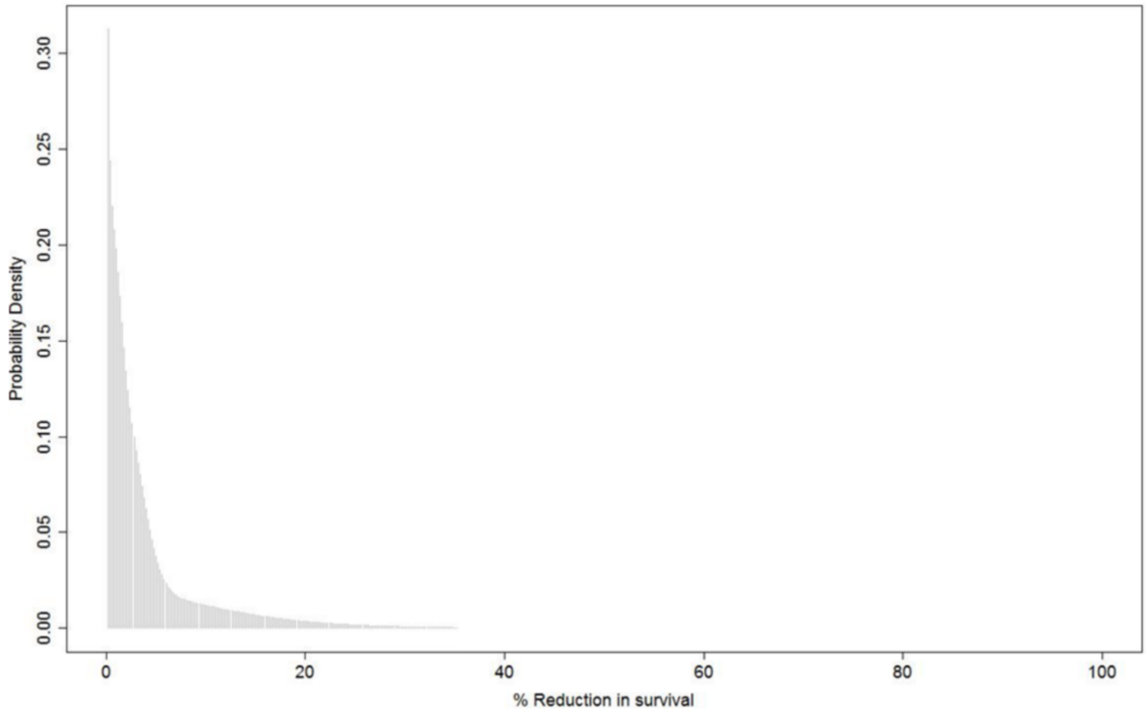


Figure 2.9 Probability distribution showing the consensus distribution for the effects on survival of juvenile or dependent calf bottlenose dolphin as a consequence of a maximum 6 dB of PTS within a 2-10 kHz band

2.3.5.1.3 Harbour and grey seals

The predicted decline in harbour and grey seals vital rates from the impact of a 6 dB PTS in the 2-10 kHz band for different percentiles of the elicited probability distribution are provided in Table 2.8. The data provided in Table 2.8 should be interpreted as:

- Experts estimated that the median decline in an individual mature female seal's survival was 0.39% (due to a 6 dB PTS (a notch a few kHz wide and 6 dB high) occurring somewhere in the hearing between 2-10 kHz).
- Experts estimated that the median decline in an individual mature female seal's fertility was 0.27% (due to a 6 dB PTS (a notch a few kHz wide and 6 dB high) occurring somewhere in the hearing between 2-10 kHz).
- Experts estimated that the median decline in an individual seal pup/juvenile survival was 0.52% (due to a 6 dB PTS (a notch a few kHz wide and 6 dB high) occurring somewhere in the hearing between 2-10 kHz).

Table 2.8 Predicted decline in harbour and grey seal vital rates for different percentiles of the elicited probability distribution

	Percentiles of the elicited probability distribution								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Adult survival	0.02	0.1	0.18	0.27	0.39	0.55	0.78	1.14	1.89
Fertility	0.01	0.02	0.05	0.14	0.27	0.48	0.88	1.48	4.34
Calf survival	0	0.04	0.15	0.32	0.52	0.8	1.21	1.88	3

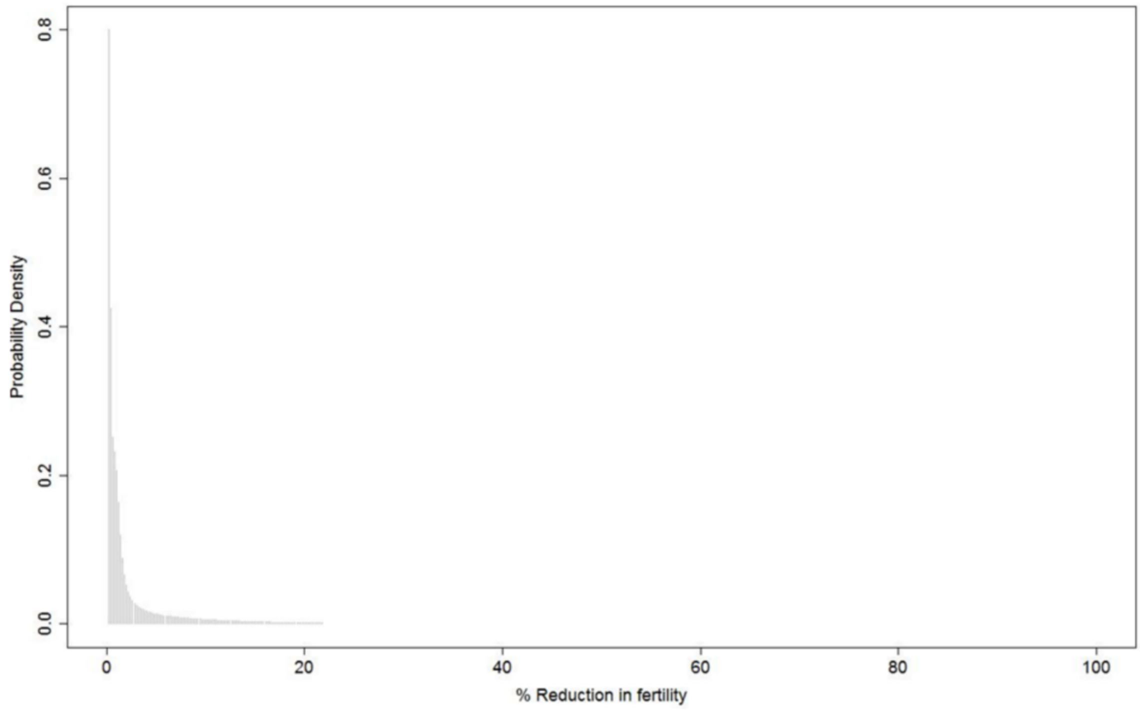


Figure 2.10 Probability distribution showing the consensus distribution for the effects on fertility of a mature female (harbour or grey) seal as a consequence of a maximum 6 dB of PTS within a 2-10 kHz band

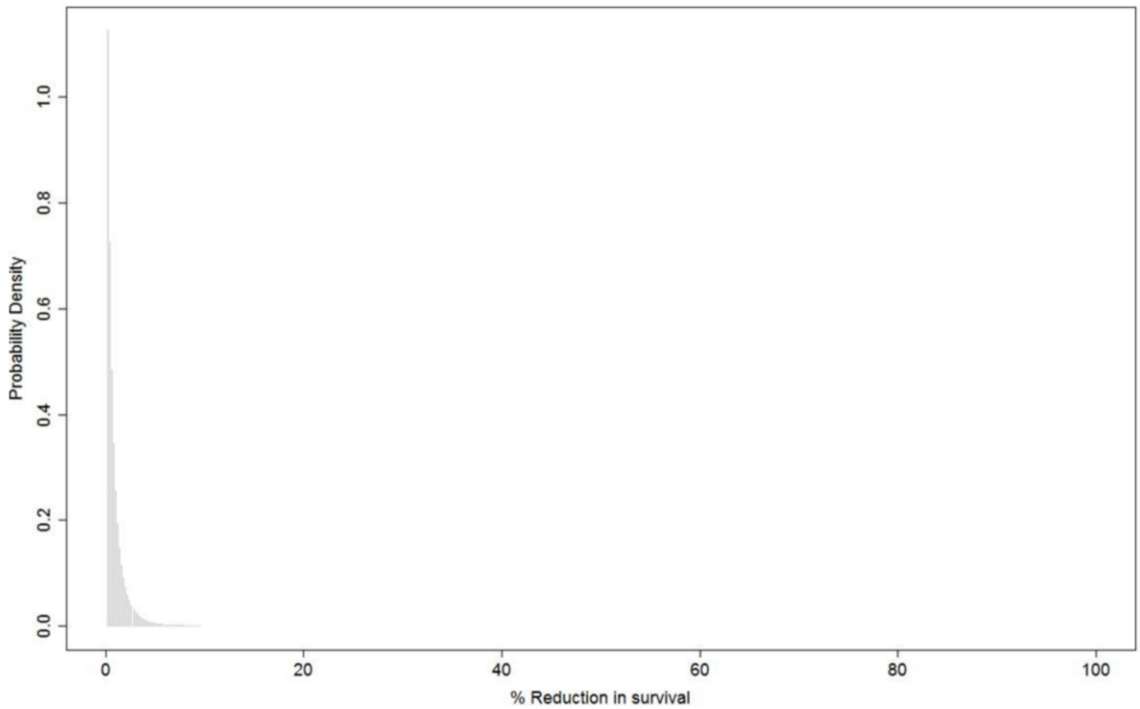


Figure 2.11 Probability distribution showing the consensus distribution for the effects on survival of a mature female (harbour or grey) seal as a consequence of a maximum 6 dB of PTS within a 2-10 kHz band

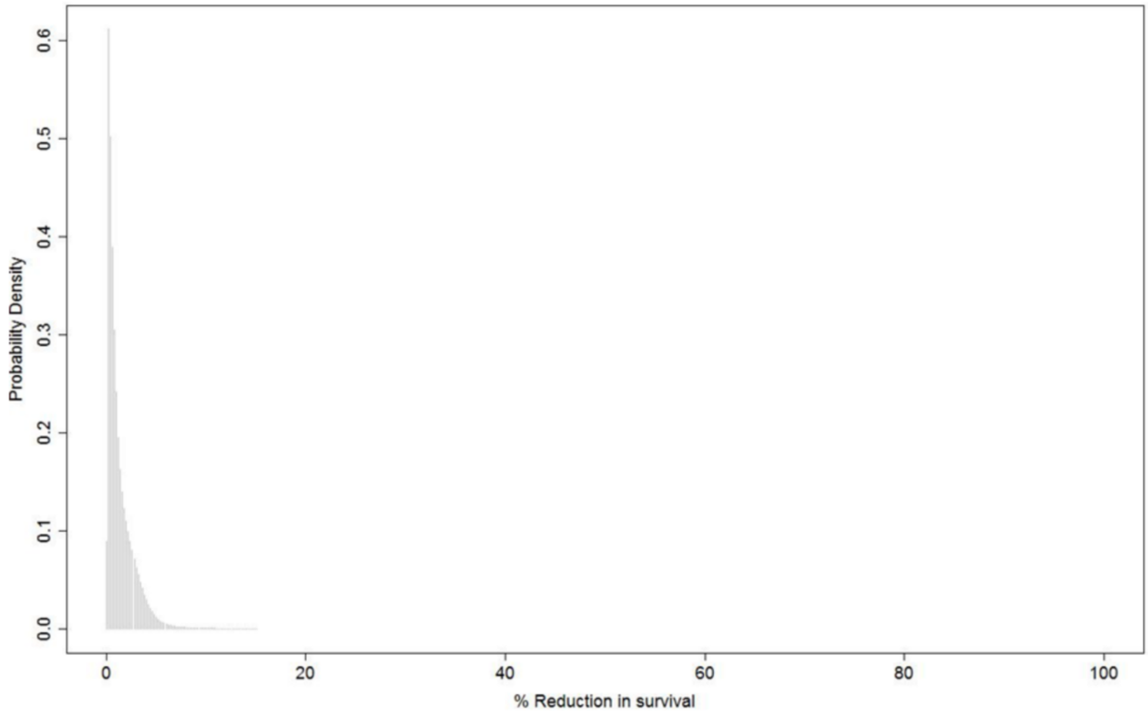


Figure 2.12 Probability distribution showing the consensus distribution for the effects on survival of juvenile or dependent pup (harbour or grey) seal as a consequence of a maximum 6 dB of PTS within a 2-10 kHz band

2.3.5.2 Other PTS-onset information

The low frequency noise produced during piling may be more likely to overlap with the hearing range of low frequency cetacean species such as minke whales. For minke whales, Tubelli *et al.* (2012) estimated the most sensitive hearing range (the region with thresholds within 40 dB of best sensitivity) to extend from 30 to 100 Hz up to 7.5 to 25 kHz, depending on the specific model used. Therefore a 2-10 kHz notch of 6 dB will only affect a small region of minke whale hearing. In addition, minke whale communication signals have been demonstrated to be below 2 kHz (Edds-Walton 2000, Mellinger *et al.* 2000, Gedamke *et al.* 2001, Risch *et al.* 2013, Risch *et al.* 2014). Like other mysticete whales, minke whales are also thought to be capable of hearing sounds through their skull bones (Cranford and Krysl 2015).

Data collected during wind farm construction have demonstrated that porpoise detections around the pile driving site decline several hours prior to the start of pile driving, and it is assumed that this is due to the increase in other construction related activities and vessel presence in advance of the actual pile driving (Brandt *et al.* 2018, Graham *et al.* 2019, Benhemma-Le Gall *et al.* 2020). Therefore, the presence of construction related vessels prior to the start of piling can act as a local scale deterrent for harbour porpoise and therefore reduce the risk of auditory injury. Assumptions that harbour porpoise are present in the vicinity of the pile driving at the start of the soft start are therefore likely to be overly conservative.

Seals are less dependent on hearing for foraging than cetaceans, but rely on sound for communication and predator avoidance (Deecke *et al.* 2002). Seals have very well developed tactile sensory systems that are used for foraging (Dehnhardt *et al.* 2001) and Hastie *et al.* (2015) reported that, based on calculations of SEL of tagged seals during the Lincs Offshore Wind Farm construction, at least half of the tagged seals would have received a dose of sound greater than published thresholds for PTS. A recent update of this analysis using the revised Southall *et al.* (2019) thresholds and weighting reduced this proportion to 25% of the seals (Russell and Hastie 2017). Based on the extent of the offshore wind farm construction in the Wash over the last ten years and the degree of overlap with the foraging ranges of harbour seals in the region (Russell *et al.* 2016b), it would not be unreasonable to suggest that a large number of individuals of the Wash population may have experienced levels of sound with the potential to cause hearing loss.

The Wash harbour seal population has been increasing over this period which may provide an indication that either: a) seals are not developing PTS despite predictions of exposure that would indicate that they should; or b) that the survival and fitness of individual seals are not affected by PTS. Point a) would indicate that methods for predicting PTS are perhaps unreliable and/or over precautionary, and b) would suggest a lack of sensitivity to the effects of PTS.

2.3.5.3 Conclusion: sensitivity to PTS from piling

In conclusion, given the results of the expert elicitation, which combined our best knowledge on the effects of PTS-onset on marine mammals, the sensitivity of all marine mammal species to PTS-onset resulting from pile driving noise is considered to be **Low**, whereby individual vital rates (survival and reproduction) may be affected, but not at a significant level. In the absence of specific information for white-beaked dolphins, Risso's dolphins, common dolphins and minke whales, these species have also been assumed to have a Low sensitivity to PTS-onset resulting from pile driving noise (Table 2.9).

Table 2.9 Species specific sensitivity to PTS from pile driving

Species	Sensitivity to PTS from piling
Harbour porpoise	Low
Bottlenose dolphin	Low
White-beaked dolphin	Low
Risso's dolphin	Low
Common dolphin	Low
Minke whale	Low
Harbour seal	Low
Grey seal	Low

2.3.6 Species-specific relationships for injury from other activities

The current knowledge on the sensitivity of marine mammals to low frequency broadband pulsed noise (piling and airguns) has been summarised in (Booth and Heinis 2018) and presented above. By contrast, there is little information available on the sensitivity of marine mammals to injury (PTS) from other noise sources such as UXO clearance or dredging.

2.3.6.1 UXO

Clearance of UXO through detonation is considered to be one of the loudest sources of underwater noise, and as an impulsive sound, it has the potential to cause injury and disturbance in marine mammals. The size of the charge weight will impact the sound levels produced by a detonation, which depends on the energy required for the controlled explosion. Depending on the detonation, SELs can be above 223.5 dB re 1 $\mu Pa^2 s$ at the source. The sound produced by these controlled explosions is low frequency with the main energy centred around 1 kHz (von Benda-Beckmann *et al.* 2015). For most marine mammal species considered here, the hearing sensitivity below 1 kHz is relatively poor and thus it is expected that a PTS at this frequency would result in little effect on vital rates. Therefore, the sensitivity of marine mammals to PTS from UXO clearance is assessed as **Low**.

2.3.6.2 Dredging

Dredging is described as a continuous broadband sound source, with the main energy below 1 kHz (however, the frequency and sound pressure level can vary considerably depending on the equipment, activity, and environmental characteristics) (Todd et al., 2015). The source level of dredging has been described to vary between SPL 172-190 dB re 1 µPa at 1 meter with a frequency range of 45 Hz to 7 kHz (Evans 1990, Thompson *et al*. 2009, Verboom 2014). It is expected that the underwater noise generated by dredging will be below the PTS-onset threshold (Todd *et al*., 2015) and thus the risk of injury is unlikely, though disturbance may occur. For most marine mammal species considered here, the hearing sensitivity below 1 kHz is relatively poor and thus it is expected that a PTS at this frequency would result in little effect on vital rates. Therefore, the sensitivity of marine mammals to PTS from dredging is assessed as **Low**.

2.3.6.3 Trenching

Underwater noise generation during cable trenching is highly variable and dependent on the physical properties of the seabed that is being cut. At the North Hoyle OWF, trenching activities had a peak energy between 100 Hz – 1 kHz and in general the sound levels were generally only 10-15 dB above background levels (Nedwell *et al.* 2003). For most marine mammal species considered here, the hearing sensitivity below 1 kHz is relatively poor and thus it is expected that a PTS at these low frequency ranges would result in little effect on vital rates. Therefore, the sensitivity of marine mammals to PTS from trenching is assessed as **Low**.

2.3.6.4 Vessels

OSPAR (2009) summarise general characteristics of commercial vessel noise. Vessel noise is continuous, and is dominated by sounds from propellers, thrusters and various rotating machinery (e.g., power generation, pumps). In general, support and supply vessels (50-100 m) are expected to have broadband source levels in the range 165-180 dB re 1µPa, with the majority of energy below 1 kHz (OSPAR 2009). Large commercial vessels (>100 m) produce relatively loud and predominately low frequency sounds, with the strongest energy concentrated below several hundred Hz. For most marine mammal species considered here, the hearing sensitivity below 1 kHz is relatively poor and thus it is expected that a PTS at these low frequency ranges would result in little effect son vital rates. Therefore, the sensitivity of marine mammals to PTS from vessels is assessed as **Low**.

2.3.6.5 Cable laying

Underwater noise generated during cable installation is generally considered to have a low potential for effects on marine mammals due to the non-impulsive nature of the noise generated and that any generated noise is likely to be dominated by the vessel from which installation is taking place (Genesis 2011). As detailed above, the sensitivity of marine mammals to PTS from vessel noise is assessed as **Low**.

2.3.6.6 Drilling

The continuous sound produced by drilling has been likened to that produced by dredging activity; low frequency noise caused by rotating machinery (Greene 1987). Recordings of drilling at the North Hoyle offshore windfarm suggest that the sound produced has a fundamental frequency at 125 Hz (Nedwell *et al.* 2003). For most marine mammal species considered here, the hearing sensitivity below 1 kHz is relatively poor and thus it is expected that a PTS at these low frequency ranges would result in little effect on vital rates. Therefore, the sensitivity of marine mammals to PTS from drilling is assessed as **Low**.

2.3.6.7 Conclusion: sensitivity to PTS from other construction activities

The MMO (2015) provide information on the acoustic properties of anthropogenic continuous noise sources; this includes noise sources such as dredging, drilling and shipping. For all three activities, the main energy is listed as being <1 kHz. For most marine mammal species considered here, the hearing sensitivity below 1 kHz is relatively poor and thus it is expected that a PTS at these low frequency ranges would result in little effect on vital rates. Therefore, the sensitivity of marine mammals to PTS from these low frequency, continuous noise sources is assessed as **Low**.

The sensitivity of marine mammals to PTS from other construction related activities is therefore considered to be **Low**, whereby individual vital rates (survival and reproduction) may be affected, but not at a significant level (Table 2.10).

Table 2.10 Species specific sensitivity to PTS from other construction activities

Species	Sensitivity to PTS from other construction activities
Harbour porpoise	Low
Bottlenose dolphin	Low
White-beaked dolphin	Low
Risso's dolphin	Low
Common dolphin	Low
Minke whale	Low
Harbour seal	Low
Grey seal	Low

2.3.7 Species-specific relationships with disturbance from pile driving activities

2.3.7.1 Harbour porpoise sensitivity to pile driving disturbance

Previous studies have shown that harbour porpoises are displaced from the vicinity of piling events. For example, studies at wind farms in the German North Sea have recorded large declines in porpoise detections close to the piling (>90% decline at noise levels above 170 dB) with decreasing effect with increasing distance from the pile (25% decline at noise levels between 145 and 150 dB) (Brandt *et al.* 2016). The detection rates revealed that porpoise were only displaced from the piling area in the short term (1 to 3 days) (Brandt *et al.* 2011, Dähne *et al.* 2013, Brandt *et al.* 2016, Brandt *et al.* 2018). Harbour porpoise are small cetaceans which makes them vulnerable to heat loss and requires them to maintain a high metabolic rate with little energy remaining for fat storage (e.g., Rojano-Doñate *et al.* 2018). This makes them vulnerable to starvation if they are unable to obtain sufficient levels of prey intake.

Studies using Digital Acoustic Recording Tags (DTAGs) have shown that porpoise tagged after capture in pound nets foraged on small prey nearly continuously during both the day and the night on their release (Wisniewska *et al.* 2016). However, Hoekendijk *et al.* (2018) point out that this could be an extreme short term response to capture in nets, and may not reflect natural harbour porpoise behaviour. Nevertheless, if the foraging efficiency of harbour porpoise is disturbed or if they are displaced from a high-quality foraging ground, and are unable to find suitable alternative feeding grounds, they could potentially be at risk of changes to their overall fitness if they are not able to compensate and obtain sufficient food intake in order to meet their metabolic demands.

The results from Wisniewska *et al.* (2016) could also suggest that porpoises have an ability to respond to short term reductions in food intake, implying a resilience to disturbance. As Hoekendijk *et al.* (2018) argue, this could help explain why porpoises are such an abundant and successful species. It is important to note that the studies providing evidence for the responsiveness of harbour porpoises to piling noise have not provided any evidence for subsequent individual consequences. In this way, responsiveness to disturbance cannot reliably be equated to sensitivity to disturbance and porpoises may well be able to compensate by moving quickly to alternative areas to feed, while at the same time increasing their feeding rates.

Monitoring of harbour porpoise activity at the Beatrice Offshore Wind Farm during pile driving activity has indicated that porpoises were displaced from the immediate vicinity of the pile driving activity, with a 50% probability of response occurring at approximately 7 km (Graham *et al.* 2019). This monitoring also indicated that the response diminished over the construction period, so that eight months into the construction phase, the range at which there was a 50% probability of response was only 1.3 km. In addition, the study indicated that porpoise activity recovered between pile driving events.

A study of tagged harbour porpoises has shown large variability between individual responses to an airgun stimulus (van Beest *et al.* 2018). Of the five porpoises tagged and exposed to airgun pulses at ranges of 420-690 m (SEL 135-147 dB re 1 $\mu Pa^2 s$), one individual showed rapid and directed movements away from the source. Two individuals displayed shorter and shallower dives immediately after exposure and the remaining two animals did not show any quantifiable response. Therefore, there is expected to be a high level of variability in responses from individual harbour porpoises exposed to low frequency broadband pulsed noise (including both airguns and impact piling).

At a BEIS-funded expert elicitation workshop held in Amsterdam in June 2018, experts in marine mammal physiology, behaviour and energetics discussed the nature, extent and potential consequences of disturbance to harbour porpoise from exposure to low frequency broadband pulsed noise (e.g., impact piling, airgun pulses) (Booth *et al.* 2019). Experts were asked to estimate the potential consequences of a six-hour period of zero energy intake, assuming that disturbance from a pile driving event resulted in missed foraging opportunities for this duration. A Dynamic Energy Budget model for harbour porpoise (based on the DEB model in Hin *et al.* (2019)) was used to aid discussions regarding the potential effects of missed foraging opportunities on survival and reproduction. The model described the way in which the life history processes (growth, reproduction and survival) of a female and her calf depend on the way in which assimilated energy is allocated between different processes and was used during the elicitation to model the effects of energy intake and reserves following simulated disturbance.

The experts agreed that first year calf survival (post-weaning) and fertility were the most likely vital rates to be affected by disturbance, but that juvenile and adult survival were unlikely to be significantly affected as these life-stages were considered to be more robust. Experts agreed that the final third of the year was the most critical for harbour porpoises as they reach the end of the current lactation period and the start of new pregnancies, therefore it was thought that significant effects on fertility would only occur when animals received repeated exposure throughout the whole year. Experts agreed it would likely take high levels of repeated disturbance to an individual before there was any effect on that individual's fertility (Figure 2.13 left), and that it was very unlikely an animal would terminate a pregnancy early. The experts agreed that calf survival could be reduced by only a few days of repeated disturbance to a mother/calf pair during early lactation (Figure 2.13 right); however, it is highly unlikely that the same mother-calf pair would repeatedly return to the area in order to receive these levels of repeated disturbance.

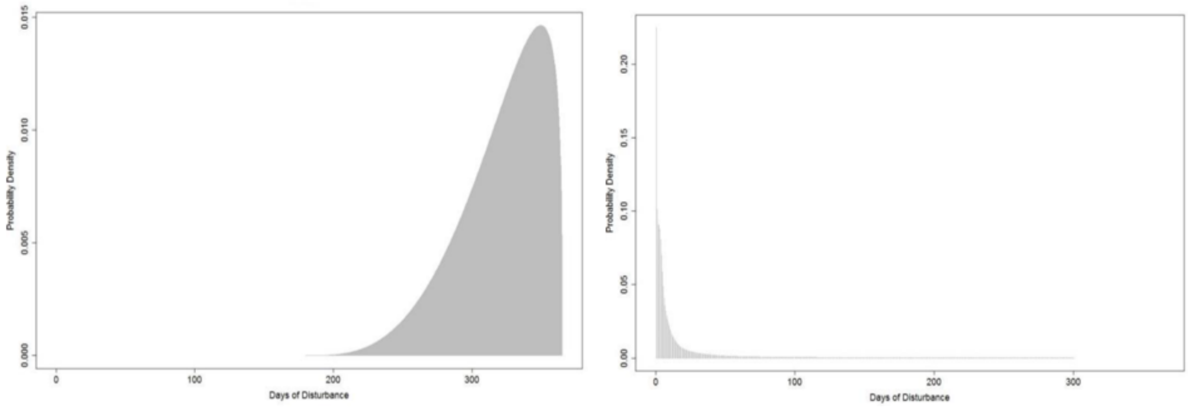


Figure 2.13: Probability distributions showing the consensus of the expert elicitation for harbour porpoise disturbance from piling (Booth *et al.* 2019)**. Left: the number of days of disturbance (i.e., days on which an animal does not feed for six hours) a pregnant female could 'tolerate' before it has any effect on fertility. Right: the number of days of disturbance (of six hours zero energy intake) a mother/calf pair could 'tolerate' before it has any effect on survival.**

A recent study by Benhemma-Le Gall *et al.* (2021) provided two key findings in relation to harbour porpoise response to pile driving. Porpoise were not completely displaced from the piling site: detections of clicks (echolocation) and buzzing (associated with prey capture) in the short-range (2 km) did not cease in response to pile driving, and porpoise appeared to compensate: detections of both clicks (echolocation) and buzzing (associated with prey capture) increased above baseline levels with increasing distance from the pile, which suggests that those porpoise that are displaced from the near-field, compensate by increasing foraging activities beyond the impact range (Figure 2.14). Therefore, porpoise that experience displacement are expected to be able to compensate for the lost foraging opportunities and increased energy expenditure of fleeing.

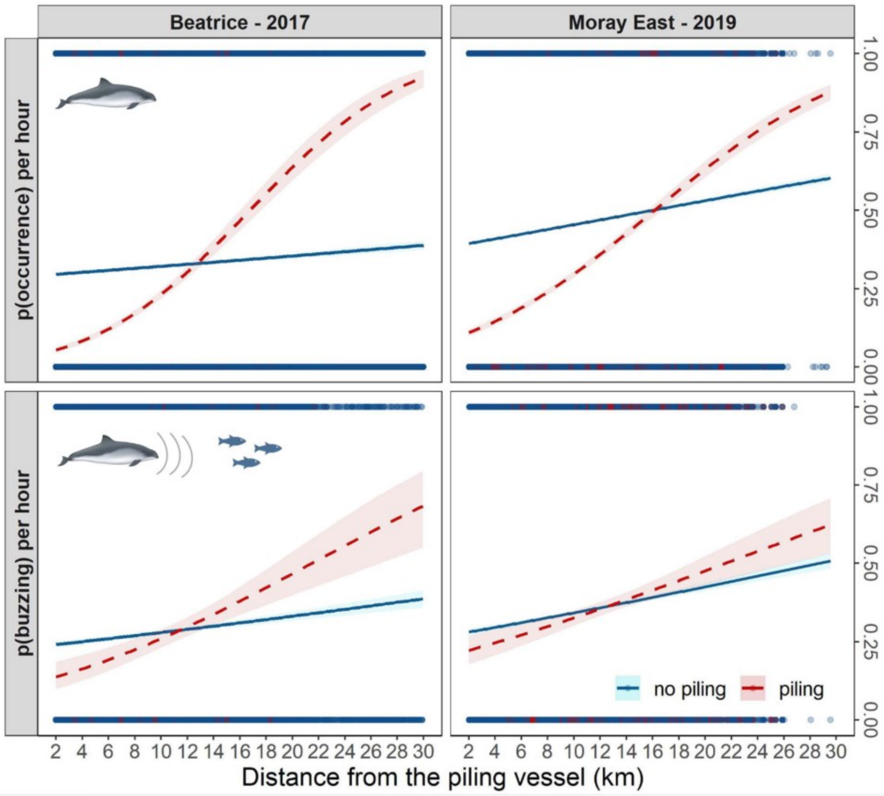


Figure 2.14 The probability of harbour porpoise occurrence and buzzing activity per hour during (dashed red line) and out with (blue line) impact piling hours, in relation to distance from the impact piling vessel at Beatrice (left) and Moray East (right). Obtained from Benhemma-Le Gall *et al.* (2021)

Due to observed responsiveness to piling, their income breeder life history, and the low numbers of days of disturbance expected to affect calf survival, harbour porpoises have been assessed here as having a **low** sensitivity to disturbance and resulting displacement from foraging grounds.

2.3.7.2 Bottlenose dolphin sensitivity to pile driving disturbance

Bottlenose dolphins have been shown to be displaced from an area as a result of the noise produced by offshore construction activities; for example, avoidance behaviour in bottlenose dolphins has been shown in relation to dredging activities (Pirotta *et al.* 2013). In a recent study on bottlenose dolphins in the Moray Firth (in relation to the construction of the Nigg Energy Park in the Cromarty Firth), small effects of pile driving on dolphin presence have been observed, however, dolphins were not excluded from the vicinity of the piling activities (Graham *et al.* 2017b). In this study the median peak-to-peak source levels recorded during impact piling were estimated to be 240 dB re 1µPa (range 8 dB) with a single pulse source level of 198 dB re 1 µPa^{2}s. The pile driving resulted in a slight reduction of the presence, detection positive hours and the encounter duration for dolphins within the Cromarty Firth, however, this response was only significant for the encounter durations. Encounter durations decreased within the Cromarty Firth (though only by a few minutes) and increased outside of the Cromarty Firth on days of piling activity. These data highlight a small spatial and temporal scale disturbance to bottlenose dolphins as a result of impact piling activities.

According to the opinions of the experts involved in the expert elicitation for the interim Population Consequences of Disturbance (iPCoD) framework, which forms our best available knowledge on the topic, disturbance would be most likely to affect bottlenose dolphin calf survival, where: “Experts felt that disturbance could affect calf survival if it exceeded 30-50 days, because it could result in mothers becoming separated from their calves and this could affect the amount of milk transferred from the mother to her calf" (Harwood *et al.* 2014a).

There is the potential for behavioural disturbance and displacement to result in disruption in foraging and resting activities and an increase in travel and energetic costs. However, it has been previously shown that bottlenose dolphins have the ability to compensate for behavioural responses as a result of increased commercial vessel activity (New *et al.* 2013). Therefore, while there remains the potential for disturbance and displacement to affect individual behaviour and therefore vital rates and population level changes, bottlenose dolphins do have some capability to adapt their behaviour and tolerate certain levels of temporary disturbance. Therefore, since bottlenose dolphins are expected to be able to adapt their behaviour, with the impact most likely to result in potential changes in calf survival (but not expected to affect adult survival or future reproductive rates) bottlenose dolphins are considered to have a **Low** sensitivity to behavioural disturbance from piling.

2.3.7.3 White-beaked dolphin sensitivity to pile driving disturbance

There is a single study detailing white beaked dolphin responses to playbacks of amplitude-modulated tones and synthetic pulse-bursts; responses were observed in 90 out of 123 exposures and received levels varied between 153 and 161 dB re 1 µPa for pulse-burst signals (Rasmussen et al. 2016). Due to the limited information on the effects of disturbance on white-beaked dolphins, bottlenose dolphins can be used as a proxy since both species are categorised as high-frequency cetaceans. Therefore, white-beaked dolphins are also considered to have a **Low** sensitivity to behavioural disturbance from piling.

2.3.7.4 Risso's dolphin sensitivity to pile driving disturbance

In the absence of any species-specific data, given that they are both grouped as high-frequency cetaceans, and are therefore likely to have similar hearing abilities, Risso's dolphins are also considered to have a **Low** sensitivity to behavioural disturbance from piling.

2.3.7.5 Common dolphin sensitivity to pile driving disturbance

The hearing range of common dolphins is currently estimated from their sound production, and has been labelled medium-high frequency, spanning between 150 Hz to 160 kHz (Finneran 2016, Houser *et al.* 2017). There are few studies investigating the effects of pile driving on common dolphins, which could relate to their occupation of deeper waters, contrasting with the shallower habitat in which offshore construction frequently occurs.

However, an analysis of pile driving activity in Broadhaven Bay, Ireland, found construction activity to be associated with a reduction in the presence of minke whales and harbour porpoise, but not with common dolphins (Culloch *et al.* 2016). Conversely, increased vessel presence during the construction period was associated with a decrease of common dolphins in the surrounding area. While there is little information on the effects of pile driving on common dolphins, there are a few studies documenting the effects of seismic activity. Although the noise produced by airguns differs in its duration and cumulative acoustic energy levels, it may be similar in its frequency range to the low-frequency noise produced by pile driving. In general, there is contrasting evidence for the response of common dolphins to seismic surveys. While some research indicates no change in the occurrence or sighting density of common dolphins when exposed to seismic activity (Stone *et al.* 2017, Kavanagh *et al.* 2019), Goold (1996) found a reduction in common dolphin presence within 1 km of ongoing seismic surveys near Pembrokeshire.

The sparse information available for the effects of construction, seismic activity and vessel noise on common dolphins makes it difficult to assess the risk for this species. While there is some evidence of disturbance of animals by seismic activity, and reduced presence in increasingly noisy habitat, this species may adjust its whistle characteristics to account for masking, suggesting some flexibility or tolerance.

Given that they are grouped as high-frequency cetaceans alongside bottlenose dolphins, and are therefore likely to have similar hearing abilities, common dolphins are also considered to have a **Low** sensitivity to behavioural disturbance from piling.

2.3.7.6 Minke whale sensitivity to pile driving disturbance

There is little information available on the behavioural responses of minke whales to underwater noise. Minke whales have been shown to change their diving patterns and behavioural state in response to disturbance from whale watching vessels; and it was suggested that a reduction in foraging activity at feeding grounds could result in reduced reproductive success in this capital breeding species (Christiansen *et al.* 2013). There is only one study showing minke whale reactions to sonar signals (Sivle *et al.* 2015) with severity scores above 4 for a received SPL of 146 dB re 1 µPa (score 7) and a received SPL of 158 dB re 1 µPa (score 8). There is a study detailing minke whale responses to the Lofitech device which has a source level of 204 dB re 1 µPa @1m, which showed minke whales within 500 m and 1,000 m of the source exhibiting a behavioural response. The estimated received level at 1,000 m was 136.1 dB re 1 µPa (McGarry *et al.* 2017).

Since minke whales are known to forage in UK waters in the summer months, there is the potential for displacement to affect reproductive rates. However, due to their large size and capacity for energy storage, it is expected that minke whales will be able to tolerate temporary displacement from foraging areas much better than harbour porpoise and individuals are expected to be able to recover from any impact on vital rates. Therefore, minke whales have been assessed as having a **Low** sensitivity to disturbance from pile driving.

2.3.7.7 Harbour seal sensitivity to pile driving disturbance

A study of tagged harbour seals in the Wash has shown that they are displaced from the vicinity of piles during impact piling activities. Russell *et al.* (2016b) showed that seal abundance was significantly reduced within an area with a radius of 25 km from a pile during piling activities, with a 19 to 83% decline in abundance during impact piling compared to during breaks in piling. The duration of the displacement was only in the short-term as seals returned to non-piling distributions within two hours after the end of a piling event. Unlike harbour porpoise, both harbour and grey seals store energy in a thick layer of blubber, which means that they are more tolerant of periods of fasting when hauled out and resting between foraging trips, and when hauled out during the breeding and moulting periods. Therefore, they are unlikely to be particularly sensitive to short-term displacement from foraging grounds during periods of active piling.

At the expert elicitation workshop in Amsterdam in 2018 (Booth *et al.* 2019), experts agreed the most likely potential consequences of a six hour period of zero energy intake, assuming that disturbance (from exposure to low frequency broadband pulsed noise (e.g., impact piling, airgun pulses) resulted in missed foraging opportunities. In general, it was agreed that harbour seals were considered to have a reasonable ability to compensate for lost foraging opportunities due to their generalist diet, mobility, life history and adequate fat stores. The survival of 'weaned of the year' animals and fertility were determined to be the most sensitive life history parameters to disturbance (i.e., leading to reduced energy intake). Juvenile harbour seals are typically considered to be coastal foragers (Booth et al. 2019) and so less likely to be exposed to disturbances and similarly pups were thought to be unlikely to be exposed to disturbance due to their proximity to land. Unlike for harbour porpoise, there was no DEB model available to simulate the effects of disturbance on seal energy intake and reserves, therefore, the opinions of the experts were less certain. Experts considered that the location of the disturbance would influence the effect of the disturbance, with a greater effect if animals were disturbed at a foraging ground as opposed to when animals were transiting through an area. It was thought that for an animal in bad condition, moderate levels of repeated disturbance might be sufficient to reduce fertility (Figure 2.15 left), however there was a large amount of uncertainty in this estimate. The 'weaned of the year' were considered to be most vulnerable following the post-weaning fast, and that during this time, experts felt it might take ~60 days of repeated disturbance before there was expected to be any effect on the probability of survival (Figure 2.15 right), however again, there was a lot of uncertainty surrounding this estimate. Similar to above, it is considered unlikely that individual harbour seals would repeatedly return to a site where they had been previously displaced from in order to experience this number of days of repeated disturbance.

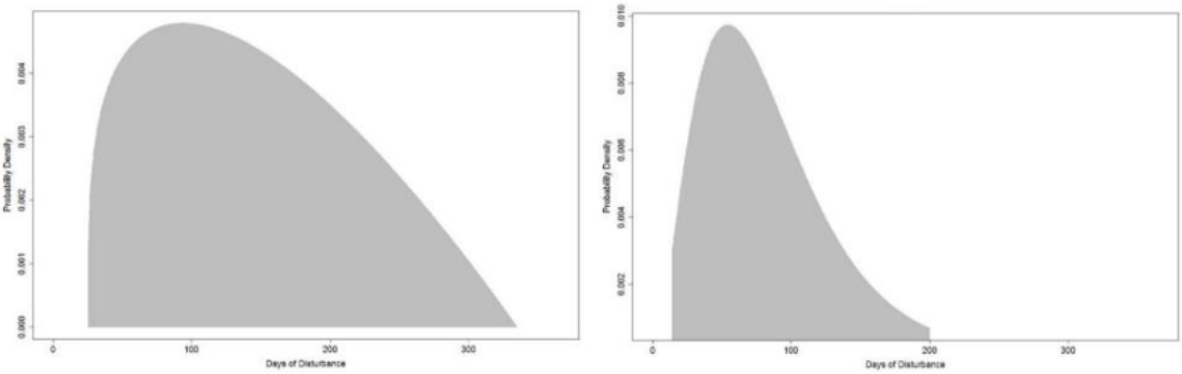


Figure 2.15 Probability distributions showing the consensus of the expert elicitation for harbour seal disturbance from piling. X-axis = days of disturbance; y-axis = probability density. Left: the number of days of disturbance (i.e. days on which an animal does not feed for six hours) a pregnant female could 'tolerate' before it has any effect on fertility. Right: the number of days of disturbance (of six hours zero energy intake) a 'weaned of the year' harbour seal could 'tolerate' before it has any effect on survival. Figures obtained from Booth *et al.* (2019).

Due to observed responsiveness to piling, harbour seals have been assessed as having **moderate** sensitivity to disturbance and resulting displacement from foraging grounds during impact piling events.

2.3.7.8 Grey seal sensitivity to pile driving disturbance

There are still limited data on grey seal behavioural responses to pile driving. The key dataset on this topic is presented in Aarts *et al.* (2018) where 20 grey seals were tagged in the Wadden Sea to record their responses to pile driving at two offshore wind farms: Luchterduinen in 2014 and Gemini in 2015. The grey seals showed varying responses to the pile driving, including no response, altered surfacing and diving behaviour, and changes in swimming direction. The most common reaction was a decline in descent speed and a reduction in bottom time, which suggests a change in behaviour from foraging to horizontal movement. The distances at which seals responded varied significantly; in one instance a grey seal showed responses at 45 km from the pile location, while other grey seals showed no response when within 12 km. Differences in responses could be attributed to differences in hearing sensitivity between individuals, differences in sound transmission with environmental conditions or the behaviour and motivation for the seal to be in the area. The telemetry data also showed that seals returned to the pile driving area after pile driving ceased. While this evidence base is from studies of grey seals tagged in the Wadden Sea, it is expected that grey seals in the Irish Sea would respond in a similar way, and therefore the data are considered to be applicable.

The expert elicitation workshop in Amsterdam in 2018 (Booth *et al.* 2019) concluded that grey seals were considered to have a reasonable ability to compensate for lost foraging opportunities due to their generalist diet, mobility, life history and adequate fat stores and that the survival of 'weaned of the year' animals and fertility were determined to be the most sensitive parameters to disturbance (i.e., reduced energy intake). However, in general, experts agreed that grey seals would be much more robust than harbour seals to the effects of disturbance due to their larger energy stores and more generalist and adaptable foraging strategies. It was agreed that grey seals would require moderate-high levels of repeated disturbance before there was any effect on fertility rates to reduce fertility (Figure 2.16 left). The 'weaned of the year' were considered to be most vulnerable following the post-weaning fast, and that during this time it might take ~60 days of repeated disturbance before there was expected to be any effect on weaned-of-the-year survival (Figure 2.16 right), however, there was a lot of uncertainty surrounding this estimate.

Grey seals are capital breeders and store energy in a thick layer of blubber, which means that, in combination with their large body size, they are tolerant of periods of fasting as part of their normal life history. Grey seals are also highly adaptable to a changing environment and are capable of adjusting their metabolic rate and foraging tactics, to compensate for different periods of energy demand and supply (Beck *et al.* 2003, Sparling *et al.* 2006). Grey seals are also very wide ranging and are capable of moving large distances between different haul out and foraging regions (Russell *et al.* 2013). Therefore, they are unlikely to be particularly sensitive to displacement from foraging grounds during periods of active piling.

Hastie *et al.* (2021) found that grey seal avoidance rates in response to impact piling sounds were dependent on the quality of the prey patch, with grey seals continuing to forage at high density prey patches when exposed to pile driving sounds, but showing reduced foraging success at low density prey patches when exposed to pile driving sounds. Additionally, the seals showed an initial aversive response to the impact piling playbacks (lower proportion of dives spent foraging) but this diminished during each trial. Therefore, the likelihood of grey seal response is expected to be linked to the quality of the prey patch.

Due to observed responsiveness to piling, and their life-history characteristics, grey seals have been assessed as having **Negligible** sensitivity to disturbance and resulting displacement from foraging grounds during impact piling events.

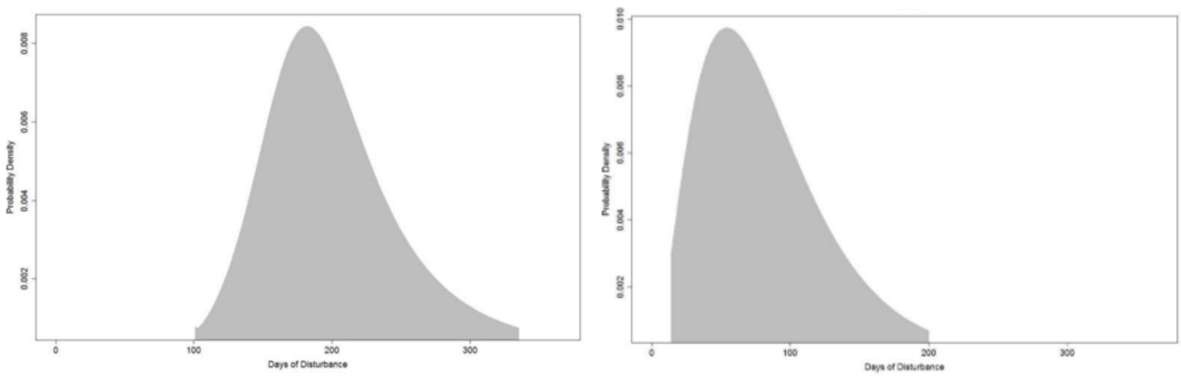


Figure 2.16 Probability distributions showing the consensus of the expert elicitation for grey seal disturbance from piling (Booth *et al*. 2019). X-axis = days of disturbance; y-axis = probability density. Left: the number of days of disturbance (i.e. days on which an animal does not feed for six hours) a pregnant female could 'tolerate' before it has any effect on fertility. Right: the number of days of disturbance (of six hours zero energy intake) a 'weaned of the year' grey seal could 'tolerate' before it has any effect on survival.

2.3.7.9 Conclusion: sensitivity to pile driving disturbance

In conclusion, all cetacean species included in this impact assessment have been assessed as having a **Low** sensitivity to disturbance from pile driving, grey seals as having a **Negligible** sensitivity and harbour seals as having a **Moderate** sensitivity (Table 2.9), whereby individual vital rates (survival and reproduction) may be affected, but not at a significant level.

Table 2.11 Species-specific sensitivity to disturbance from pile driving

Species	Sensitivity to disturbance from pile driving
Harbour porpoise	Low
Bottlenose dolphin	Low
White-beaked dolphin	Low
Risso's dolphin	Low
Common dolphin	Low
Minke whale	Low
Harbour seal	Moderate
Grey seal	Negligible

2.3.8 Species-specific relationships with disturbance from other activities

2.3.8.1 Vessels

2.3.8.1.1 Harbour porpoise

Given their high-frequency hearing range, it has been suggested that porpoise are more likely to be sensitive to vessels that produce medium to high frequency noise components (Hermannsen *et al.* 2014). However, harbour porpoise are known to avoid vessels and behavioural responses have been shown in porpoise exposed to vessel noise that contains low levels of high-frequency components (Dyndo *et al.* 2015). Thomsen *et al.* (2006) estimated that porpoise will respond to both small (~2 kHz) and large (~0.25 kHz) vessels at approximately 400 m. Wisniewska *et al.* (2018) presented data that suggested that porpoises may respond to very close-range vessel passes with an interruption in foraging. However, observed responses were short lived, porpoises were observed to resume foraging ten minutes after a very close-range vessel encounter, and tagged porpoises remained in areas where shipping levels were high. Overall, despite animals remaining in heavily trafficked areas, the incidence of responses to vessels was low, indicating little fitness cost to exposure to vessel noise and any local scale responses taken to avoid vessels. It is likely that porpoise may become habituated where vessel movements are regular and predictable, whereas, they may be expected to show more of a local behavioural response to novel vessel activities related to construction activities.

Data collected during windfarm construction have demonstrated that porpoise detections around the pile driving site decline several hours prior to the start of pile driving, and it is assumed that this is 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). Therefore, because the dose-response relationships relating displacement to piling are based on data collected over periods including such vessel activity, these local responses to novel activity such as pile driving vessels have effectively already been included in the assessment of underwater noise related to pile driving above.

Land-based surveys in Swansea Bay, Wales, found a significant correlation between porpoise sightings and the number of vessels present, with 26% of the interactions considered to be negative (moving away or prolonged dives), occurring within distances of up to 1 km between the animal and the vessel.

The type of vessel was relevant, as smaller motorised boats (jet-ski, speed boat, small fishing vessels), were associated with more negative behaviours than larger ships (Oakley *et al.* 2017).

Heinänen and Skov (2015) suggested that harbour porpoise density was significantly lower in areas with vessel transit rates of greater than 20,000 ships/year (80 per day). Vessel traffic in the PFOWF area will be significantly below this figure. Therefore, harbour porpoise are assessed as having a **Low** sensitivity to disturbance from vessels.

2.3.8.1.2 Dolphin sensitivity to vessels

Bottlenose dolphin: Pirotta *et al.* (2015) found that transit of vessels in the Moray Firth resulted in a reduction (by almost half) of the likelihood of recording bottlenose dolphin prey capture buzzes. They also suggest that vessel presence, not just vessel noise, resulted in disturbance. There is however likely to be rapid recovery from disturbance from vessel presence and vessel noise, as they recorded little pre-emptive disturbance or recovery time following disturbance. There is evidence of bottlenose dolphin habituation to boat traffic, particularly in relation to larger vessel types (Sini *et al.* 2005). Lusseau *et al.* (2011) undertook a modelling study which predicted that increased vessel movements associated with offshore wind development in the Moray Firth did not have a negative effect on the local population of bottlenose dolphin. They hypothesise that this was because most of the vessels were commercial ones, which have more predictable patterns of movement than the recreational vessels and are thus less likely to disrupt the feeding behaviour of dolphins than recreational or tourist activity. Therefore, bottlenose dolphins have been assumed as having a **Low** sensitivity to disturbance from vessels.

Common dolphin: Relatively few studies investigate or document the effects of marine construction on common dolphins, but there is some evidence of the effects of vessel traffic and boat noise on common dolphins. While the direct impacts of vessel noise on common dolphins are rather under-researched, the presence of vessel activity has been found to alter their behavioural states and has been linked to disturbance. In New Zealand, Markov chain models were used to assess the impacts of tourism on the behaviour of common dolphins. Foraging and resting bouts were significantly disrupted by boat interactions, with less time spent in these states. In addition, post-disturbance activity indicated a shift from foraging states to milling and socialising and returns to foraging took significantly longer (Stockin *et al.* 2008, Meissner *et al.* 2015). While the aforementioned studies relate to short term effects, a long-term study of common dolphins in the waters around Ischia Island, Italy, found declines that could have resulted from a combination of habitat degradation and disturbance from increasing traffic. There is therefore the potential for vessel activity to result in changes to behaviour, however, it is expected that the types of vessels associated with OWF developments are less impactful than vessels such as tourism vessels, which specifically target marine mammals. It is likely that the sensitivity of common dolphins is similar to that of bottlenose dolphins, and as such, common dolphins have been assumed as having a **Low** sensitivity to disturbance from vessels.

Risso's dolphin: In the absence of any species-specific data, given that all dolphin species are grouped as high-frequency cetaceans, and are therefore likely to have similar hearing abilities, Risso's dolphins are also considered to have a **Low** sensitivity to behavioural disturbance from vessels.

2.3.8.1.3 Minke whale sensitivity to vessels

There is limited information available on the responses of minke whales to vessels. Whale watching vessels that specifically target minke whales have been shown to cause behavioural responses in minke whales and repeated exposure can result in a decrease in foraging activity (Christiansen *et al.* 2013). However, these are vessels which specifically target and follow minke whales, so it is unknown whether minke whales respond to more general ship traffic. A conservative approach is assumed that considers vessel disturbance could result in temporary displacement of minke whales from the immediate area, however, there is no evidence that the PFOWF Offshore Site is an important foraging habitat for minke whales, and given their generalist and varied diet, it is not expected that any temporary displacement resulting from vessel activity in relation to PFOWF will lead to any significant effect on individual energy budgets and subsequently fitness. The sensitivity of minke whales to vessel disturbance is therefore assessed as **Low**.

2.3.8.1.4 Seal sensitivity to vessels

Jones *et al.* (2017) presents an analysis of the predicted co-occurrence of ships and seals at sea which demonstrates that UK wide there is a large degree of predicted co-occurrence, particularly within 50 km of the coast, close to seal haul-outs. There is no evidence relating decreasing seal populations with high levels of co-occurrence between ships and animals. In fact, in areas where seal populations are showing high levels of growth (e.g. southeast England) ship co-occurrences are highest (Jones *et al.* 2017). Thomsen *et al.* (2006) estimated that both harbour and grey seals will respond to both small (~2 kHz) and large (~0.25 kHz) vessels at approximately 400 m. The sensitivity of seals to disturbance from vessels at sea is therefore assessed as **Negligible**.

2.3.8.2 Dredging

Information regarding the sensitivity of marine mammals to other construction activities is currently limited. Available studies focus primarily on disturbance from dredging, and confirmed behavioural responses have been observed in cetaceans. Pirotta *et al.* (2013) noted that bottlenose dolphin presence in foraging areas of Aberdeen harbour decreased as dredging intensity increased. Due to the consistently high presence of shipping activity all year round, the dolphins were considered to be habituated to high levels of vessel disturbance and, therefore, in this particular instance, Pirotta *et al.* (2013) concluded that the avoidance behaviour was a direct result of dredging activity. However, this distinction in the source of the disturbance reaction cannot always be determined. For example, Anderwald *et al.* (2013) observed minke whales off the coast of Ireland in an area of high vessel traffic during the installation of a gas pipeline where dredging activity occurred. The data suggested that the avoidance response observed was likely attributed to the vessel presence rather than the dredging and construction activities themselves.

As the disturbance effects from other construction activities are closely associated with the disturbance from vessel presence required for the activity, it is difficult to determine the sensitivity specifically to disturbance from other construction activities in isolation (Todd *et al.* 2015). Therefore, it is anticipated that the sensitivity of each species will be similar to that discussed in the previous sections regarding sensitivity to vessel disturbance and should be considered as **Low** for all cetacean species, and **Negligible** for grey and harbour seals.

2.3.8.3 UXO

It is noted in the JNCC et al. (2020) guidance that *"...a one-off explosion would probably only elicit a startle response and would not cause widespread and prolonged displacement..."*. Therefore, it is not expected that disturbance from a single high-order UXO detonation would result in any significant effects, and that disturbance from a single noise event would not be sufficient to result in any changes to the vital rates of individuals. Therefore, the sensitivity of marine mammals for disturbance from UXO clearance is expected to be **Low**.

2.3.8.4 Conclusion: sensitivity to disturbance from other activities

In conclusion, all marine mammal species included in this impact assessment have been assessed as having either a **Negligible** or a **Low** sensitivity to disturbance from other construction activities (Table 2.12).

Table 2.12 Species-specific sensitivity to disturbance from other activities

Species	Sensitivity to disturbance		
	Vessels	UXO	Other construction activity
Harbour porpoise	Low	Low	Low
Bottlenose dolphin	Low	Low	Low
White-beaked dolphin	Low	Low	Low
Risso’s dolphin	Low	Low	Low
Common dolphin	Low	Low	Low
Minke whale	Low	Low	Low
Harbour seal	Negligible	Low	Negligible
Grey seal	Negligible	Low	Negligible

2.4 Population modelling

The (iPCoD framework (Harwood *et al.* 2014b, King *et al.* 2015) was used to predict the potential population consequences of the predicted amount of PTS and disturbance resulting from the piling. 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.

Simulations were run comparing projections of the baseline population (i.e., under current conditions, assuming current estimates of demographic parameters persist into the future) with a series of paired ‘impact’ scenarios with identical demographic parameters, incorporating a range of estimates for disturbance. Each simulation was repeated 1,000 times and each simulation draws parameter values from a distribution describing the uncertainty in the parameters. This creates 1,000 matched pairs of population trajectories, differing only with respect to the effect of the disturbance and the distributions of the two trajectories can be compared to demonstrate the magnitude of the long-term effect of the predicted impact on the population, as well as demonstrating the uncertainty in predictions.

Population modelling for impacts solely from the Offshore Development was only conducted if the proportion of the MU predicted to be impacted by piling was >1%. Any impact to <1% of the MU from piling is assumed to result in no change to the population size or trajectory.

3 Uncertainties and Limitations

There are uncertainties relating to the underwater noise modelling and impact assessment. Broadly, these relate to predicting exposure of animals to underwater noise, predicting the response of animals to underwater noise and predicting potential population consequences of disturbance from underwater noise. Further detail of such uncertainty is set out below.

3.1 Exposure to noise

There are uncertainties relating to the ability to predict the exposure of animals to underwater noise, as well as in predicting the response to that exposure. These uncertainties relate to a number of factors: the ability to predict the level of noise that animals are exposed to, particularly over long periods of time; the ability to predict the numbers of animals affected, and the ability to predict the individual and ultimately population consequences of exposure to noise. These are explored in further detail in the paragraphs below.

The propagation of underwater noise is relatively well understood and modelled using standard methods. However, there are uncertainties regarding the amount of noise actually produced by each pulse at source and how the pulse characteristics change with range from the source. There are also uncertainties regarding the position of receptors in relation to received levels of noise, particularly over time, and understanding how the position of receptors in the water column may affect received level. Noise monitoring is not always carried out at distances relevant to the ranges predicted for effects on marine mammals, so effects at greater distances remain un-validated in terms of actual received levels. The extent to which ambient noise and other anthropogenic sources of noise may mask signals from the offshore wind farm construction are not specifically addressed. The dose-response curves for porpoise include behavioural responses at noise levels down to 120 dB SEL_{ss} which may be indistinguishable from ambient noise at the ranges these levels are predicted.

3.2 Cumulative PTS

The cumulative sound exposure level (SEL_{cum}), is energy-based and is a measure of the accumulated sound energy an animal is exposed to over an exposure period. An animal is considered to be at risk of experiencing "cumulative PTS" if the SEL_{cum} exceeds the energy-based threshold. The calculation of SEL_{cum} is undertaken with frequency-weighted sound levels, using species group-specific weighing functions to reflect the hearing sensitivity of each functional hearing group. To assess the risk of cumulative PTS, it is necessary to make assumptions on how animals may respond to noise exposure, since any displacement of the animal relative to the noise source will affect the sound levels received. For this assessment, it was assumed that animals would flee from the pile foundation at the onset of piling. A fleeing animal model was therefore used to determine the cumulative PTS impact ranges, to determine the minimum distance to the pile site at which an animal can start to flee, without the risk of experiencing cumulative PTS.

There is much more uncertainty associated with the prediction of the cumulative PTS impact ranges than with those for the instantaneous PTS. One reason is that the sound levels an animal receives, and which are cumulated over a whole piling sequence are difficult to predict over such long periods of time, as a result of uncertainties about the animal's (responsive) movement in terms of its changing distance to the sound source and the related speed, and its position in the water column.

Another reason is that the prediction of the onset of PTS (which is assumed to be at the SEL_{cum} threshold values provided by Southall et al. 2019) is determined with the assumptions that:

a) the amount of sound energy an animal is exposed to within 24 hours will have the same effect on its auditory system, regardless of whether it is received all at once (i.e., with a single bout of sound) or in several smaller doses spread over a longer period (called the equal-energy hypothesis); and,

b) the sound keeps its impulsive character, regardless of the distance to the sound source.

In practice:

a) there is a recovery of a threshold shift caused by the sound energy if the dose is applied in several smaller doses (e.g., between pulses during pile driving or in piling breaks) leading to an onset of PTS at a higher energy level than assumed with the given SEL_{cum} threshold; and,

b) pulsed sound loses its impulsive characteristics while propagating away from the sound source, resulting in a slower shift of an animal's hearing threshold than would be predicted for an impulsive sound.

Both assumptions therefore lead to a conservative determination of the impact ranges and are discussed in further detail in the sections below.

Modelling the SEL_{cum} impact ranges of PTS with a 'fleeing animal' model, as is typical in noise impact assessments, are subject to both above-mentioned uncertainties and the result is a highly precautionary prediction of impact ranges. As a result of these and the uncertainties on animal movement, model parameters, such as swim speed, are generally highly conservative and, when considered across multiple parameters, this precaution is compounded therefore the resulting predictions are very precautionary and very unlikely to be realised.

3.2.1 Equal energy hypothesis

The equal-energy hypothesis assumes that "exposures of equal energy are assumed to produce equal amounts of noise-induced threshold shift, regardless of how the energy is distributed over time". However, a continuous and an intermittent noise exposure of the same SEL will produce different levels of TTS (Ward 1997). Ward (1997) highlights that the same is true for impulsive noise, giving the example of simulated gunfires of the same SEL_{cum} exposed to human, where 30 impulses with an SPL_{peak} of 150 dB re 1 m Pa result in a TTS of 20 dB, while 300 impulses of a respectively lower SPL_{peak} did not result in any TTS.

Finneran (2015) showed that several marine mammal studies have demonstrated that the temporal pattern of the exposure does in fact affect the resulting threshold shift (e.g., Kastak *et al.* 2005, Mooney *et al.* 2009, Finneran *et al.* 2010, Kastelein *et al.* 2013). Intermittent noise allows for some recovery of the threshold shift in between exposures, and therefore recovery can occur in the gaps between individual pile strikes and in the breaks in piling activity, resulting in a lower overall threshold shift, compared to continuous exposure at the same SEL. Kastelein *et al.* (2013) showed that, for seals, the threshold shifts observed did not follow the assumptions made in the guidance regarding the equal-energy hypothesis; instead, the threshold shifts observed were more similar to the hypothesis presented in Henderson *et al.* (1991) that hearing loss induced due to noise does not solely depend upon the total amount of energy, but on the interaction of several factors such as the level and duration of the exposure, the rate of repetition, and the susceptibility of the animal. Therefore, the equal-energy hypothesis assumption behind the SEL_{cum} threshold is not valid, and as such, models will overestimate the level of threshold shift experienced from intermittent noise exposures.

One more detailed example to give is the study of Kastelein *et al.* (2014), where a harbour porpoise was exposed to a series of 1-2 kHz sonar down-sweep pulses of 1 second duration of various combinations, with regard to received sound pressure level, exposure duration and duty cycle (% of time with sound during a broadcast) to quantify the related threshold shift. The porpoise experienced a 6 to 8 dB lower TTS when exposed to sound with a duty cycle of 25% compared to a continuous sound (Figure 3.1). A 1 sec silent period in-between pulses resulted in a 3 to 5 dB lower TTS compared to a continuous sound (Figure 3.1).

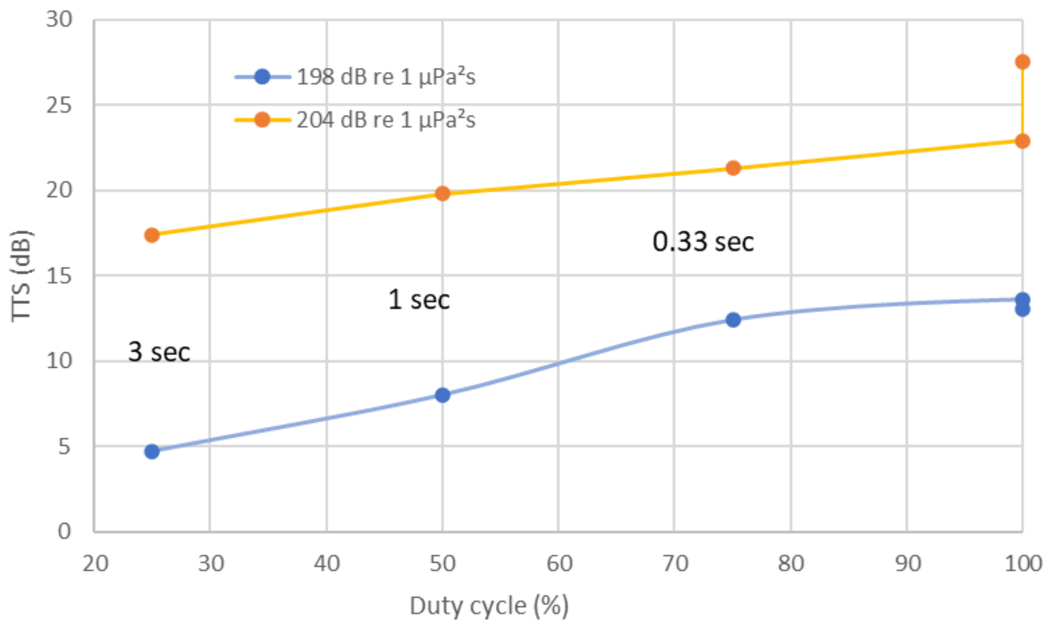


Figure 3.1: Temporary threshold shift (TTS) elicited in a harbour porpoise by a series of 1-2 kHz sonar down-sweeps of 1 second duration with varying duty cycle and a constant SEL_{cum} of 198 and 204 dB re1 µPa²s, respectively. Also labelled is the corresponding 'silent period' in-between pulses. Data from Kastelein *et al.* (2014).

Kastelein et al. (2015) showed that the 40 dB hearing threshold shift (the PTS-onset threshold) for harbour porpoise, is expected to be reached at different SEL_{cum} levels depending on the duty cycle: for a 100% duty cycle, the 40 dB hearing threshold shift is predicted to be reached at a SEL_{cum} of 196 dB re 1 µPa²s, but for a 10% duty cycle, the 40 dB hearing threshold shift is predicted to be reached at a SEL_{cum} of 206 dB re 1 µPa²s (thus resulting in a 10 dB re 1 µPa²s difference in the threshold).

Pile strikes are relatively short signals; the signal duration of monopile pile strikes may range between 0.1 sec (De Jong and Ainslie 2008) and approximately 0.3 sec (Dähne *et al.* 2017) measured at a distance of 3.3 to 3.6 km. Duration will however increase with increasing distance from the pile site.

For the pile driving at PFOWF, the soft start and ramp-up is 16 blows per minute for the cautious worst-case scenario. Assuming a signal duration of around 0.5 sec for a pile strike, the soft start ramp-up will be a 13.3% duty cycle (0.5 sec pulse followed by 3.25 sec silence). In the study of Kastelein *et al.* (2014), a silent period of 3 sec corresponds to a duty cycle of 25%. The reduction in TTS at a duty cycle of 25% is 5.5-8.3 dB. Assuming similar effects to the hearing system of marine mammals in the Pentland Firth, the PTS-onset threshold would be expected to be around 2.4 dB higher than that proposed by Southall et al. (2019) and used in the current assessment, as reasoned in the following section.

Southall *et al*. (2009) calculates the PTS-onset thresholds based on the assumption that a TTS of 40 dB will lead to PTS, and that an animal's hearing threshold will shift by 2.3 dB per dB SEL received from an impulsive sound. This means, if the same SEL elicits a ≥5.5 dB lower TTS at 25% duty cycle compared to 100% duty cycle, to elicit the same TTS as a sound of 100% duty cycle, a ≥2.4 dB (≥5.5 dB / 2.3) higher SEL is needed with a 25% duty cycle than with a 100% duty cycle. The threshold at which PTS-onset is likely is therefore at least 2.4 dB higher than the PTS-onset threshold proposed by

Southall *et al*. (2019). If a 2 or 3 dB increase in the PTS-threshold is assumed, then this can make a significant difference to the maximum predicted impact range for cumulative PTS (Table 3.1).

While more research needs to be conducted to understand the exact magnitude of this effect in relation to pile driving sound, this study proves a significant reduction in the risk of PTS even through short silent periods for TTS recovery as found in pile driving.

Table 3.1 Difference in predicted cumulative PTS impact ranges if recovery between pulses is accounted for and the PTS-onset threshold is increased by 2 or 3 dB.

Threshold		Max impact range (km)	Reduction in impact range (km)
Minke whale			
PTS	183 SEL_{cum}	26.85	-
PTS + 2 dB	185 SEL_{cum}	21.49	5.36
PTS + 3 dB	186 SEL_{cum}	18.98	7.87
Harbour porpoise			
PTS	155 SEL_{cum}	8.64	-
PTS + 2 dB	157 SEL_{cum}	5.84	2.8
PTS + 3 dB	158 SEL_{cum}	4.65	3.99

3.2.2 Impulsive characteristics

Southall *et al.* (2019) acknowledges that as a result of propagation effects, the sound signal of certain sound sources (e.g., impact piling) loses its impulsive characteristics and could potentially be characterised as non-impulsive beyond a certain distance. The changes in noise characteristics with distance generally result in exposures becoming less physiologically damaging with increasing distance as sharp transient peaks become less prominent (Southall *et al.* 2007). The Southall *et al.* (2019) updated criteria proposed that, while keeping the same source categories, the exposure criteria for impulsive and non-impulsive sound should be applied based on the signal features likely to be perceived by the animal rather than those emitted by the source. Methods to estimate the distance at which the transition from impulsive to non-impulsive noise are currently being developed (Southall *et al.* 2019).

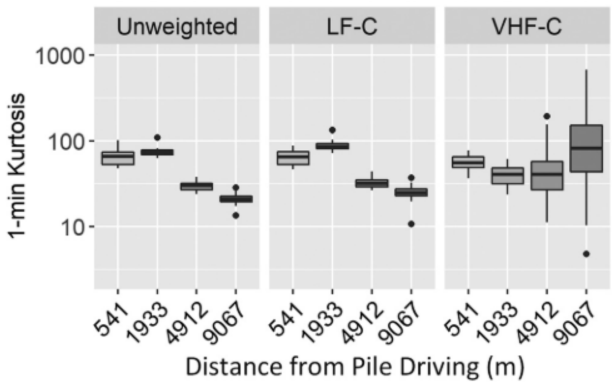
Using the criteria of signal duration, rise time, crest factor and peak pressure divided by signal duration, Hastie *et al.* (2019) estimated the transition from impulsive to non-impulsive characteristics of impact piling noise during the installation of offshore wind turbine foundations at the Wash and in the Moray Firth. Hastie *et al.* (2019) showed that the noise signal experienced a high degree of change in its impulsive characteristics with increasing distance. Southall *et al.* (2019) state that mammalian hearing is most readily damaged by transient sounds with rapid rise-time, high peak pressures, and sustained duration relative to rise-time. Therefore, of the four criteria used by Hastie *et al.* (2019), the rise-time and peak pressure may be the most appropriate indicators to determine the impulsive/non-impulsive transition. Based on this data it is expected that the probability of a signal being defined as “impulsive” (using the criteria of rise time being less than 25 ms) reduces to only 20% between ~2 and 5 km from the source. Predicted PTS impact ranges based on the impulsive noise thresholds may therefore be overestimates in cases where the impact ranges lie beyond this. Any animal present beyond that distance when piling starts will only be exposed to non-impulsive noise, and therefore impact ranges should be based on the non-impulsive thresholds.

It is acknowledged that the Hastie *et al.* (2019) study is an initial investigation into this topic, and that further data are required in order to set limits to the range at which impulsive criteria for PTS are applied.

Since the Hastie *et al.* (2019) study, Martin *et al.* (2020) investigated the sound emission of different sound sources to test techniques for distinguishing between the sound being impulsive or non-impulsive. For impulsive sound sources, they included impact pile driving of four 4-legged jacket foundation installed at around 20 m water depth (at the Block Island Wind Farm in the USA). For the impact piling sound they recorded sound at four distances between ~500 m and 9 km, recording the sound of 24 piling events. To investigate the impulsiveness of the sound, they used three different parameters and suggested the use of kurtosis[10] to further investigate the impulsiveness of sound, with studies on chinchilla hearing showing a positive correlation between the magnitude of PTS and the kurtosis value, with an increase in PTS for a kurtosis value from 3 up to 40 (Hamernik *et al.* 2007). Therefore, Martin *et al.* (2020) argued that:

- Kurtosis of 0-3 = continuous sinusoidal signal (non-impulsive);
- Kurtosis of 3-40 = transition from non-impulsive to impulsive sound; and
- Kurtosis of 40 = fully impulsive.

For the evaluation of their data, Martin *et al.* (2020) used unweighted as well as LF-Cetacean (C) and VHF-C weighted sound, based on the species-specific weighting curves in Southall *et al.* (2019) to investigate the impulsiveness of sound. Their results for pile driving are shown in Figure 3.2. For the unweighted and LF-C weighted sound, the kurtosis value was >40 within 2 km from the piling site. Beyond 2 km, the kurtosis value decreased with increasing distance. For the VHF-C weighted sound, kurtosis factor is more inconclusive with the median value >40 for the 500 m and 9 km measuring stations, and at 40 for the stations in-between. However, the variability of the kurtosis value for the VHF-C weighted sound increased with distance.



	Median value (1-min kurtosis)		
Distance (km)	Unweighted	LF-C	VHF-C
0.541	65	65	60
1.933	70	85	40
4.912	30	30	40
9.067	20	25	80

Figure 3.2: The range of kurtosis weighted by LF-C and VHF-C Southall *et al*. (2019) auditory frequency weighting functions for 30 min of impact pile driving data measured in 25 m of water at the Block Island Wind Farm. Boxplots show the median value (horizontal lines), interquartile range (boxes) and outlier values (dots). Boxplots reproduced from Martin *et al*. (2017); adjacent table shows approximate median values extracted from the boxplot.

From these data, Martin *et al.* (2020) conclude that the change to non-impulsiveness *"is not relevant for assessing hearing injury because sounds retain impulsive character when SPLs are above EQT*

[10] Kurtosis is a measure of the asymmetry of a probability distribution of a real-valued variable.

[effective quiet threshold[11]]" (i.e., the sounds they recorded retain their impulsive character while being at sound levels that can contribute to auditory injury). However, we contest this conclusion and note that Figure 3.2 clearly shows (for unweighted and LF-C weighted sound) that piling sound loses its impulsiveness with increasing distance from the piling site - the kurtosis value decreases with increasing distance and therefore the sound loses its harmful impulsive characteristics.

There are some points that need to be considered before adopting kurtosis as an impulsiveness measure, with the recommended threshold value of 40. Firstly, this value was experimentally obtained for chinchillas that were exposed to noise for a 5-day period under controlled conditions. Caution may need to be taken to directly adopt this threshold-value (and the related dose-response of increasing PTS with increasing kurtosis between 3 and 40) to marine mammals in the wild, especially given that the PTS guidance considers time periods of up to 24 hours. Secondly, kurtosis is recommended to be computed over at least 30 seconds, which means that it is not a specific measure that can be used for single blows of a piling sequence. Instead, kurtosis has been recommended to evaluate steady-state noise in order to include the risk from embedded impulsive noise (Goley *et al.* 2011). Metrics used by Hastie *et al.* (2019) computed for each pile strike (e.g., rise-time) may be more suitable to be included in piling impact assessments, as, for each single pile strike, the sound exposure levels received by an animal are considered. It is currently unknown which metric is the most useful and how they correlate with the magnitude of auditory injury in (marine) mammals.

Southall (2021) points out that *"at present there are no properly designed, comparative studies evaluating TTS for any marine mammal species with various noise types, using a range of impulsive metrics to determine either the best metric or to define an explicit threshold with which to delineate impulsiveness".* He proposes that the presence of high-frequency noise energy could be used as a proxy for impulsiveness, as all currently used metrics have in common that a high frequency spectral content result in high values for those metrics. His suggestion is an interim approach: *"the range at which noise from an impulsive source lacks discernable energy (relative to ambient noise at the same location) at frequencies ≥ 10 kHz could be used to distinguish when the relevant hearing effect criteria transitions from impulsive to nonimpulsive".* Southall (2021), however, notes that *"it should be recognized that the use of impulsive exposure criteria for receivers at greater ranges (tens of kilometers) is almost certainly an overly precautionary interpretation of existing criteria".*

Considering that an increasing proportion of the sound emitted during a piling sequence will become less impulsive (and thereby less harmful) while propagating away from the sound source, and this effect starts at ranges below 5 km in all above mentioned examples, the cumulative PTS-onset threshold for animals starting to flee at 5 km should be higher than the Southall (2021) threshold adopted for this assessment (i.e., the risk of experiencing PTS becomes lower), and any impact range estimated beyond this distance should be considered as an unrealistic over-estimate, especially when they result in very large distances.

For the purpose of presenting a precautionary assessment, the quantitative impact assessment for PFOWF is based on fully impulsive thresholds, but the potential for overestimation should be noted.

[11] From Martin *et al.* (2020): The proposed effective quiet threshold (EQT) is the 1-min auditory frequency weighted SPL that accumulates to this 1-min SEL, which numerically is 18 dB below the 1-min SEL [because $10 \cdot \log_{10}$(1 min/1 s) dB¼17.7 dB]. Thus, the proposed level for effective quiet is equivalently a 1-min SPL that is 50 dB below the numeric value of the auditory frequency-weighted Southall et al. (2019) daily SEL TTS threshold for non-impulsive sources.

3.2.3 Animal depth

Empirical data on SEL_{ss} levels recorded during piling construction at the Lincs offshore wind farm have been compared to estimates obtained using the Aquarius pile driving model[12] (Whyte *et al.* 2020). This has demonstrated that measured recordings of SEL_{ss} levels made at 1 m depth were all lower than the model predicted single-strike sound exposure levels for the shallowest depth bin (2.5 m). In contrast, measurements made at 9 m depth were much closer to the model predicted single-strike sound exposure levels. This highlights the limitations of modelling exposure using depth averaged sound levels, as the acoustic model can overpredict exposure at the surface. This is important to note since animals may conduct shorter and shallower dives when fleeing (e.g. van Beest *et al.* 2018).

3.2.4 Conclusion

Given the above, SMRU Consulting considers that the calculated SEL_{cum} PTS-onset impact ranges are highly precautionary and that the true extent of effects (impact ranges and numbers of animals experiencing PTS) will likely be considerably less than that assessed here.

3.3 Proportion experiencing PTS

It is also important to note that only 18-19% of animals are predicted to experience PTS at the PTS-onset threshold level. This was the approach adopted by Donovan *et al.* (2017) to develop their dose response curve implemented into the SAFESIMM (Statistical Algorithms For Estimating the Sonar Influence on Marine Megafauna) model, based on the data presented in Finneran *et al.* (2005). Therefore, where PTS-onset ranges are provided, it is not expected that all individuals within that range will experience PTS. Therefore, the number of animals predicted to be within PTS-onset ranges are precautionary.

3.4 Density

There are uncertainties relating to the ability to predict the responses of animals to underwater noise and the number of animals potentially exposed to levels of noise that may cause an impact is uncertain. Given the high spatial and temporal variation in marine mammal abundance and distribution in any particular area of the sea, it is difficult to predict how many animals may be present within the range of noise impacts. All methods for determining at sea abundance and distribution suffer from a range of biases and uncertainties.

3.5 Predicting response

In addition, there are limited empirical data available to inform predictions of the extent to which animals may experience auditory damage or display responses to noise. The current methods for prediction of behavioural responses are based on received sound levels, but it is likely that factors other than noise levels alone will also influence the probability of response and the strength of response (e.g., previous experience, behavioural and physiological context, proximity to activities, characteristics of the sound other than level, such as duty cycle and pulse characteristics). However, at present, it is impossible to adequately take these factors into account in a predictive sense. This assessment makes use of the monitoring work that has been carried out during the construction of

[12] From more information on the Aquarius model see: de Jong, C., Binnerts, B., Prior, M., Colin, M., Ainslie, M., Mulder, I., and Hartstra, I. (2019). "Wozep – WP2: update of the Aquarius models for marine pile driving sound predictions," TNO Rep. (2018), number R11671, The Hague, Netherlands, p. 94. Retrieved from https://www.noordzeeloket.nl/publish/pages/160801/update_aquarius_models_pile_driving_sound_predeictions_tno_2019.pdf

the Beatrice Offshore Wind Farm and therefore uses the most recent and site-specific information on disturbance to harbour porpoise as a result of pile driving noise.

There is also a lack of information on how observed effects (e.g., short-term displacement around impact piling activities) manifest themselves in terms of effects on individual fitness, and ultimately population dynamics (see the section above on marine mammal sensitivity to disturbance and the recent expert elicitation conducted for harbour porpoise and both seal species) in order to attempt to quantify the amount of disturbance required before vital rates are impacted.

3.6 Duration of effect

The duration of disturbance is another uncertainty. Studies at Horns Rev 2 demonstrated that porpoises returned to the area between 1 and 3 days (Brandt *et al.* 2011) and monitoring at the Dan Tysk Wind Farm as part of the Disturbance Effects on the Harbour Porpoise Population in the North Sea (DEPONS) project found return times of around 12 hours (van Beest *et al.* 2015). Two studies at Alpha Ventus demonstrated, using aerial surveys, that the return of porpoises was about 18 hours after piling (Dähne *et al.* 2013). A recent study of porpoise response at the Gemini wind farm in the Netherlands, also part of the DEPONS project, found that local population densities recovered between two and six hours after piling (Nabe-Nielsen *et al.* 2018). An analysis of data collected at the first seven offshore wind farms in Germany has shown that harbour porpoise detections were reduced between one and two days after piling (Brandt *et al.* 2018). Analysis of data from monitoring of marine mammal activity during piling of jacket pile foundations at Beatrice Offshore Wind Farm (Graham *et al.* 2017a, Graham *et al.* 2019) provides evidence that harbour porpoise were displaced during pile driving but return after cessation of piling, with a reduced extent of disturbance over the duration of the construction period. This suggests that the assumptions adopted in the current assessment are precautionary as animals are predicted to remain disturbed at the same level for the entire duration of the pile driving phase of construction.

3.7 PTS-onset

There are no empirical data on the threshold for auditory injury in the form of PTS-onset for marine mammals, as to test this would be inhumane. Therefore, PTS-onset thresholds are estimated based on extrapolating from TTS-onset thresholds. For pulsed noise, such as piling, NOAA have set the onset of TTS at the lowest level that exceeds natural recorded variation in hearing sensitivity (6 dB), and assumes that PTS occurs from exposures resulting in 40 dB or more of TTS measured approximately four minutes after exposure (NMFS 2018b).

3.8 Population Modelling

There is a lack of empirical data on the way in which changes 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 conducted according to the protocol described in Donovan *et al.* (2016) to predict the effects of disturbance and PTS on survival and reproductive rate. 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 100s of times to capture the uncertainty among experts.

There are several precautions built into the iPCoD model and this specific scenario that mean that the results are considered to be highly precautionary and likely over-estimate the true population level effects. These include:

- The fact that the model assumes a dolphin will not forage for 24 hours after being disturbed,

- The lack of density dependence in the model (meaning the population will not respond to any reduction in population size), and
- The level of environmental and demographic stochasticity in the model.

3.8.1 Duration of disturbance

The iPCoD model for bottlenose dolphin disturbance was last updated following the expert elicitation in 2013 (Harwood *et al.* 2014a). 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 bottlenose dolphins), and was amended to assume that disturbance resulted in 6 hours of non-foraging time (Booth *et al.* 2019). Unfortunately, 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 bottlenose dolphins. This is unrealistic considering what we now know about marine mammal behavioural responses to pile driving. A recent study estimated energetic costs associated with disturbance from sonar, where it was assumed that 1 hour of feeding cessation was classified as a mild response, 2 hours of feeding cessation was classified as a strong response and 8 hours of feeding cessation was classified as an extreme response (Czapanskiy *et al.* 2021). Assuming 24 hours of feeding cessation for bottlenose dolphins in the iPCoD model is significantly beyond that which is considered to be an extreme response, and is therefore considered to be unrealistic and will over-estimate the true disturbance levels expected from the Offshore Development.

3.8.2 Lack of density dependence

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.* 2014a). The iPCoD scenario run for bottlenose dolphins assumes no density dependence, since there is insufficient data to parameterise this relationship. Essentially, what this means is that there is no ability for the modelled impacted population to increase in size back up to carrying capacity following disturbance. 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.* 2021), 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.

3.8.3 Environmental and demographic stochasticity

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.* 2014a). Demographic stochasticity is defined as *"variation among individuals in their realised vital rates as a result of random processes"* (Harwood *et al.* 2014a).

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 3000 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.* 2014a).

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 in Figure 3.3, 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.

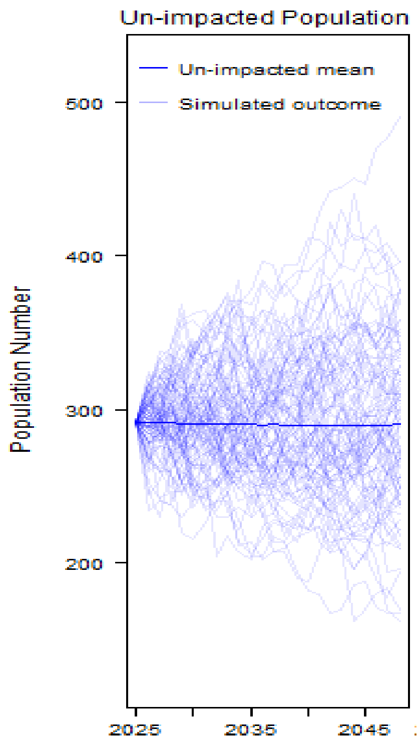


Figure 3.3 Simulated un-impacted (baseline) population size over the 25 years modelled

3.8.4 Summary

All of the precautions built into the iPCoD model mean that the results are considered to be highly precautionary. Despite these limitations and uncertainties, this assessment has been carried out according to best practice and using the best available scientific information. The information provided is therefore considered to be sufficient to carry out an adequate assessment.

4 Impact assessment: Geophysical & UXO surveys

4.1 Overview

In summer 2021, site-specific geophysical and geotechnical surveys were conducted to inform detailed design and array layout for the development. It is not currently anticipated that any further geophysical survey will be required prior to the installation of the subsea infrastructure. However, if during the detailed survey design, it is determined that additional data is required to better inform the design, an application for a site survey and a European Protected Species (EPS) licence will be submitted prior to undertaking any further geophysical surveys.

During summer 2022 or 2023, an unexploded ordnance (UXO) survey will be undertaken. This will enable any UXOs present in the survey area to be identified, as their presence may result in the need for minor re-routing of cables or the modification of anchor positions. This survey will require the use of a magnetometer, and likely also multibeam echo sounder (MBES) and side scan sonar (SSS).

Further geotechnical surveys (borehole drilling) will be required to obtain additional seabed information and will be scheduled during 2022 or 2023.

In 2025 and 2026, pre-installation surveys will be undertaken to visually inspect the mooring locations and cable routes using remotely operated vehicles (ROVs), to confirm the exact routing required and determine if any seabed preparation is required. These surveys are anticipated to take two to three days to complete across the site (excluding weather delays). Operations will likely be conducted between April and October, due to the typically more favourable weather conditions for offshore operations in the Offshore Site during this time, to minimise weather delays. The use of MBES may be required for these surveys and will be confirmed during the detailed design.

All survey equipment will utilise ultra-short baseline (USBL) positioning equipment to ensure precise subsea locations. This may include a high precision acoustic positioning (HiPAP) system.

4.1.1 Survey equipment

The proposed survey equipment is detailed in Table 4.1 and further described below in relation to their sound source, which in all cases is electromagnetically generated. The final specifications will depend on the selected survey contractors, but sound frequency characteristics and source pressure level parameters are given for typical equipment expected to be used.

Table 4.1 Characteristics of sound emitting geophysical survey equipment

Equipment	Description	Planned operational frequency (kHz)	Estimated source sound pressure level (dB re 1 µPa @ 1m)	Beam Width
MBES	Dual head, hull or ROV mounted system	200 – 400	218 (peak), 213 (rms)	Along track: ≤ 1.5°
SSS	Tow fish or ROV mounted system	300 & 900	210 (peak), 242 (rms)	Across track: 140° (± 70°)
USBL	Hull mounted (very dependent on unit selected)	20 – 35	194 (peak), 188 (rms)	1.8 – 2.6°
Magnetometer	Towed, often piggybacked towed from SSS Passive system (no noise emitted)			Across track: ~ 100° (± ~50°)

MBES: MBES is used to acquire detailed seabed topography and water depth by emitting a fan shaped swath of acoustic energy (sound waves) along a survey transect. The sound waves are reflected from the seabed to enable high resolution seafloor mapping. The MBES can be either hull mounted or ROV mounted.

SSS: SSS utilises conical or fan shaped pulses of sounds directed at the seafloor to provide information on the surface of the seabed through analysis of reflected sound.

USBL system: A USBL system is used to obtain accurate equipment positioning during sampling activities. This system consists of a transceiver mounted under the vessel, and a transponder on deployed equipment. The transceiver transmits an acoustic pulse which is detected by the transponder, followed by a reply of an acoustic pulse from the transponder. This pulse is detected by the transceiver and the time from transmission of the initial pulse is measured by the USBL system and converted into a range.

Magnetometer: A magnetometer is used to measure the variation in the earth's total magnetic field to detect and map ferromagnetic objects on or near the sea floor along the survey's vessel tracks. Often, two magnetometers are mounted in a gradiometer format to measure the magnetic gradient between the two sensors. The magnetometer is a passive system and, therefore, does not emit any noise.

4.1.2 Marine mammal hearing groups

An essential step in assessing the potential for effects on relevant species is a consideration of their auditory sensitivities. Marine mammal hearing groups and auditory injury criteria from Southall *et al*. (2019), and corresponding species of relevance to this assessment, are summarised in Table 4.2. There are no audiogram data available for low-frequency cetaceans; therefore, predictions are based on the hearing anatomy for each species and considerations of the frequency range of vocalisations.

Table 4.2 Marine mammal hearing groups, estimated hearing range and sensitivity and injury criteria and corresponding species relevant to this assessment (Southall *et al.*, 2019)

Hearing Group	Species	Estimated hearing range	Estimated region of greatest sensitivity†	Estimated peak sensitivity
Low-frequency (LF) cetaceans	Minke whale	7 Hz –35 kHz	200 Hz –19 kHz	-
High-frequency (HF) cetaceans	Bottlenose dolphin White-beaked dolphin Risso's dolphin Common dolphin	150 Hz –160 kHz	8.8 –110 kHz	58 kHz
Very high-frequency (VHF) cetacean	Harbour porpoise	275 Hz –160 kHz	12 –140 kHz	105 kHz
Phocid carnivores in water (PCW)	Harbour seal Grey seal	50 Hz –86 kHz	1.9 –30 kHz	13 kHz

†Region of greatest sensitivity represents low-frequency(F1) and high-frequency(F2) inflection points, while peak sensitivity is the frequency at which the lowest threshold was measured (T0) (Southall et al., 2019).

4.2 Screening for potential effects

Prior to an evaluation in relation to each item of equipment, the overlap between survey equipment operating characteristics and marine mammal functional hearing capability is considered in Table 4.3. Where there is no overlap between hearing capability and functional hearing, there is no potential for disturbance effects to occur; however, the potential for injury will still need to be considered if animals could be exposed to sound pressure of sufficient magnitude to cause hearing damage or other harm.

Table 4.3 Comparison of noise emitting survey equipment operating characteristics and overlap with marine mammal hearing capabilities

Equipment	Estimated source pressure level	Expected Sound Frequency	Functional hearing group			
			LF	HF	VHF	PCW
MBES	218 (peak), 213dB rms	200 - 400 kHz	Above all hearing ranges			
SSS	210 (peak), 242dB rms	300 kHz & 900 kHz	Above all hearing ranges			
USBL	194 (peak), 188 (rms)	20 – 35 kHz	No	Yes	Yes	Yes

4.3 Potential for injury

While the indicative source levels for MBES and SSS exceed the unweighted injury threshold for harbour porpoise and seals, peak energy is far above that of greatest hearing sensitivity and the frequency of the source is sufficiently high that sound pressure levels would be rapidly attenuated to below thresholds for PTS-onset for porpoise within a few metres of the source. JNCC (2017) do not advise that mitigation to avoid injury from use of MBES is necessary in shallow (< 200 m) waters where the MBES used are of high frequencies (as they are planned to be here). EPS Guidance (JNCC *et al.* 2010) for use of SSS states that *"this type of survey is of a short-term nature and results in a negligible risk of an injury or disturbance offence (under the Regulations)."* An equivalent conclusion was reached by DECC (2011). Therefore, the risk of injury from MBES and SSS is concluded to be of **Negligible** magnitude.

The source levels of USBL equipment are below the PTS-onset thresholds for all marine mammal species and therefore it is concluded that there would be **no risk of PTS-onset** to any marine mammals from the use of USBL equipment.

4.4 Disturbance from USBL

As indicated in Table 4.3, there is no potential for disturbance effects to occur through use of MBES or SSS, as the sound levels emitted are above 200 kHz and therefore above the hearing frequency range of the marine mammals likely to be present in the region.

As indicated in Table 4.3, disturbance effects to minke whales (low frequency cetaceans) through use of USBL are highly unlikely, as the sound levels emitted are above 20 kHz and therefore above the hearing frequency range of minke whales. However, the expected sound frequency for the USBL falls within the function hearing range for all other relevant species and, therefore, has the potential to result in disturbance effects. Based on the disturbance criteria used by the NMFS in the US (NMFS 2018a), assessment indicates that a marine mammal would experience disturbance in close proximity (<6 m) to the source. Therefore, for a disturbance effect to occur, the animals would have to be in very close proximity to the USBL. Should the short-term operations result in a response by an animal, this would not be likely to impair the ability of an animal to survive or reproduce, or result in any effects to the local populations or distribution. Any response will likely be temporary; for example, evidence from Thompson *et al.* (2013) suggests that short-term disturbance caused by a commercial two-dimensional seismic survey (a much louder noise source than USBL) does not lead to long-term displacement of harbour porpoises.

It has been very conservatively assumed that over the course of the survey all marine mammals in the Offshore Development area plus a 500 m buffer (to account for survey line turns and propagation of noise levels which may result in disturbance effects) could potentially be disturbed at some point. This results in an area of disturbance totalling 50.2 km^2. This calculation provides the following, very precautionary, estimate of the number of animals that might potentially be disturbed over the duration of the survey:

- For bottlenose dolphin, the density was predicted to be 0.0037 animals/km^2, leading to an estimate of <1 individual potentially experiencing disturbance.
- For harbour porpoise, the density was predicted to be 0.1520 animals/km^2, leading to an estimate of 10 porpoise potentially experiencing disturbance.
- For minke whale, the density was predicted to be 0.0095 animals/km^2, leading to an estimate of <1 minke whale potentially experiencing disturbance.
- For white-beaked dolphin, the density was predicted to be 0.08 animals/km^2, leading to an estimate of 4 dolphins potentially experiencing disturbance.
- For Risso’s dolphin, the density was predicted to be 0.0135 animals/km^2, leading to an estimate of <1 Risso’s dolphin potentially experiencing disturbance.
- For common dolphin, the density was predicted to be 0.012 animals/km^2, leading to an estimate of 1 common dolphin potentially experiencing disturbance.
- For harbour seals, the grid cell specific density estimates resulted in an estimate of <1 harbour seal potentially experiencing disturbance.
- For grey seals, the grid cell specific density estimates resulted in an estimate of 28 grey seals potentially experiencing disturbance.

For all species, the number of animals predicted to experience disturbance from geophysical surveys represents <0.1% of the relevant MU.

This approach is very precautionary as it overestimates the area over which disturbance may occur as well as the number and distribution of animals likely to be exposed. The likelihood of local-scale avoidance of moving vessels by marine mammals will reduce the likelihood and magnitude of exposure to the USBL noise source.

For any marine mammal present any disturbance would be short-term and temporary because of both the directionality of the sound and the limited duration of the surveys. Similarly, underwater noise from USBL operation is not expected to add significantly in a cumulative manner to noise from other activities in the region. Disturbance effects to marine mammals are therefore expected to be restricted to isolated, temporary and short-lived effects upon low numbers of animals and, overall, to be **Negligible** in magnitude.

Table 4.4 Sensitivity, impact magnitude and resulting effect significance for geophysical and UXO surveys

Species	Impact	Magnitude	Sensitivity	Significance of effect
Harbour porpoise	PTS-onset	Negligible	Low	Negligible
	Disturbance	Negligible	Low	Negligible
Bottlenose dolphin	PTS-onset	Negligible	Low	Negligible
	Disturbance	Negligible	Low	Negligible
White-beaked dolphin	PTS-onset	Negligible	Low	Negligible
	Disturbance	Negligible	Low	Negligible
Risso’s dolphin	PTS-onset	Negligible	Low	Negligible
	Disturbance	Negligible	Low	Negligible
Common dolphin	PTS-onset	Negligible	Low	Negligible
	Disturbance	Negligible	Low	Negligible
Minke whale	PTS-onset	Negligible	Low	Negligible
	Disturbance	Negligible	Low	Negligible
Harbour seal	PTS-onset	Negligible	Low	Negligible
	Disturbance	Negligible	Low	Negligible
Grey seal	PTS-onset	Negligible	Low	Negligible
	Disturbance	Negligible	Low	Negligible

4.5 Conclusion

The sensitivity of all species to PTS-onset from geophysical and UXO survey has been assessed as **Low**. Overall, the risk of PTS-onset to all species of marine mammal from Geophysical and UXO surveys (using MBES, SSS and USBL) is concluded to be of **Negligible** magnitude, noting that the characteristics of USBL are such that there is no risk of PTS-onset. Therefore, effects of this activity are considered to be of **Negligible** significance, which is **Not Significant** in EIA terms (Table 4.4).

Potential disturbance impacts to marine mammals resulting from the planned survey activities are expected to be restricted to the use of USBL, and result in isolated, temporary and short-lived effects upon low numbers of animals and, overall, to be **Negligible** in magnitude. The sensitivity of all species to disturbance from USBL has been assessed as **Low**. Therefore, effects of this activity are considered to be of **Negligible** significance, which is **Not Significant** in EIA terms (Table 4.4).

4.6 Mitigation measures

JNCC (2017) guidelines for minimising the risk of injury to marine mammals from geophysical survey outline measures for reducing the risk of injury to negligible levels. As the risk of injury from the planned geophysical and UXO survey activities has been assessed as negligible in the absence of any mitigation, it is proposed that no mitigation is required. It is considered that this aligns with Marine Scotland guidance on the mitigation of EPS, which states that “Mitigation measures should be put in place whenever there is concern that an activity is likely to cause an offence, and should be proportionate to the risk of injury or disturbance" (Marine Scotland 2020). It is noted that JNCC (2017) do not advise that mitigation is required for MBES surveys in shallow waters as the high frequencies typically used fall outside the hearing frequencies of cetaceans and the sounds produced are likely to attenuate more quickly than deeper water applications, a situation which applies to the planned geophysical and UXO surveys for MBES and SSS.

Survey operations, particularly during periods of vessel transit, will adhere to the Scottish Marine Wildlife Watching Code (SNH 2017) in order to minimise the risk of disturbance to marine mammals from the vessel presence.

5 Impact Assessment: UXO clearance

5.1 Overview

Based on an initial desk-based UXO assessment undertaken by Ordtek (2021), it is assumed that it will be possible to avoid any UXO encountered during the survey. Should any further mitigation be required, such as clearance or detonation, this would be subject to separate assessment and licence applications. Although the requirement for detonation is considered extremely unlikely, an impact assessment has been carried out as a precaution, with the aim of understanding the potential effects of such events, should they be required in future. Two options are considered in this impact assessment: high-order detonation (where a donor charge triggers the UXO to detonate to its full potential) and low-order clearance (specifically deflagration, where a specialist donor charge is used to induce a subsonic combustion of the explosive material in the UXO, thus preventing an explosive detonation). It is expected that if any UXO clearance is required, that it would be undertaken using low-order clearance, however, the potential effect associated with a high-order detonation is provided here to ensure a precautionary assessment through use of the worst-case scenario.

5.2 Injury

Full details of the underwater noise modelling and the resulting injury (PTS-onset) impact areas and ranges are detailed in Volume 3, Appendix 11.1: Underwater Noise Modelling (Midforth *et al.* 2022). The source level of each UXO charge weight was calculated in accordance with Soloway and Dahl (2014), Arons (1954) and Barett (1996), using conservative calculation parameters that result in the upper estimate of the source level for each charge size. This is therefore considered to be an indication of the potential maximum noise output from each charge size and, as such, likely results in an overestimate of PTS-onset impact ranges, especially for larger charge sizes (Table 5.1). Under the worst-case high order UXO detonation scenario (525 kg + donor) using SPL_{peak}, <1 animal is expected to experience PTS-onset for all LF and HF cetaceans assessed and harbour seals. The number of animals predicted to experience PTS-onset is greatest for harbour porpoise (81) and is also higher for grey seals (12). Using SEL_{cum}, the number of HF cetaceans and harbour seals predicted to experience injury remains unchanged (<1), predictions are reduced to 1 for harbour porpoise, reduced to 6 for grey seals and increased to 3 for minke whale.

The predicted extent of PTS-onset impacts is of local spatial extent and to low numbers of animals (in absolute terms and/or relative to the relevant MU); however, since PTS is a permanent change in the hearing threshold, effects not recoverable. As part of any future consent for UXO removal the Project will be required to implement a UXO specific marine mammal monitoring plan (MMMP) to ensure that the risk of PTS is reduced to negligible. The exact mitigation measures contained with the UXO MMMP are yet to be determined and will be agreed with Marine Scotland. However, multiple measures are available and have been implemented elsewhere for UXO clearance. These include the use of acoustic deterrent devices (ADDs) and scarer charges to displace animals to beyond the PTS-onset impact range, or noise abatement techniques where appropriate.

The sensitivity of marine mammals to PTS-onset from UXO clearance has been assessed as **Low** and, considering the embedded mitigation measures, the magnitude of this impact is considered to be **Negligible**. Therefore, effects of this activity are assessed as of **Negligible** significance, which is **Not Significant** in EIA terms.

Table 5.1 Number of animals predicted to experience injury (PTS-onset) from high-order UXO detonation (in the absence of any mitigation measures)

Species	Parameter	0.5 kg	25 kg + donor	55 kg + donor	120 kg + donor	240 kg + donor	525 kg + donor
SPL_{peak} (Southall *et al*. 2019)							
LF	Range (km)	0.22	0.82	1.0	1.3	1.7	2.2
	Area (km^2)	0.2	2.1	3.1	5.3	9.1	15.2
	# MW	<1	<1	<1	<1	<1	<1
HF	Range (km)	0.07	0.26	0.34	0.45	0.56	0.73
	Area (km^2)	0.0	0.2	0.4	0.6	1.0	1.7
	# BND	<1	<1	<1	<1	<1	<1
	# WBD	<1	<1	<1	<1	<1	<1
	# RD	<1	<1	<1	<1	<1	<1
	# CD	<1	<1	<1	<1	<1	<1
VHF	Range (km)	1.2	4.6	6.0	7.8	9.8	13.0
	Area (km^2)	4.5	66.5	113.1	191.1	301.7	530.9
	# HP	<1	10	17	29	46	81
PCW	Range (km)	0.24	0.91	1.1	1.5	1.9	2.5
	Area (km^2)	0.2	2.6	3.8	7.1	11.3	19.6
	# HS	<1	<1	<1	<1	<1	<1
	# GS	<1	2	2	5	7	12
SEL_{cum} (Southall *et al.* 2019)							
LF	Range (km)	0.32	2.2	3.2	4.7	6.5	9.5
	Area (km^2)	0.3	15.2	32.2	69.4	132.7	283.5
	# MW	<1	<1	<1	1	1	3
HF	Range (km)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	Area (km^2)	0.0	0.0	0.0	0.0	0.0	0.0
	# BND	<1	<1	<1	<1	<1	<1
	# WBD	<1	<1	<1	<1	<1	<1
	# RD	<1	<1	<1	<1	<1	<1
	# CD	<1	<1	<1	<1	<1	<1
VHF	Range (km)	0.11	0.57	0.74	0.95	1.1	1.4
	Area (km^2)	0.0	1.0	1.7	2.8	3.8	6.2
	# HP	<1	<1	<1	<1	1	1
PCW	Range (km)	0.06	0.39	0.57	0.83	1.1	1.6
	Area (km^2)	0.0	0.5	1.0	2.2	3.8	8.0
	# HS	<1	<1	<1	<1	<1	<1
	# GS	<1	1	1	2	2	6

Notes: MW = minke whale; HP = harbour porpoise; BND = bottlenose dolphin; WBD = white-beaked dolphin; RD = Risso's dolphin; CD = common dolphin; HS = harbour seal; GS = grey seal.

5.3 Disturbance

In the absence of agreed thresholds to assess the potential for behavioural disturbance in marine mammals from UXO detonations, this assessment presents results for each of the following behavioural disturbance thresholds:

- 26 km EDR for high-order detonations

- 5 km EDR for low-order detonations
- TTS-onset thresholds

The disturbance effects of UXO clearance are predicted to be of local spatial extent, short-term duration and intermittent and extremely infrequent (if it occurs at all). As part of any future consent for UXO removal HWL will be required to implement a specific MMMP during UXO operations to minimise the risk of injury to marine mammals, the provisions of which will be agreed with Marine Scotland. However, multiple measures are available and have been implemented elsewhere for UXO clearance. These include the use of ADDs and scarer charges to displace animals to beyond the PTS impact range, or noise abatement techniques where appropriate.

5.3.1 26 km EDR – high-order

It has been advised by JNCC that an effective deterrence range of 26 km around the source location is used to determine the impact area from UXO clearance with respect to disturbance of harbour porpoise in SACs (JNCC 2020). In the absence of agreed metrics for other species and given a lack of empirical data on the likelihood of response to explosives, this 26 km radius (area of 2,124 km^2) has been applied for all species. The resulting number of animals, proportion of the reference population and impact magnitude is detailed in Table 5.2. This is quantified by calculating the numbers of animals likely to be within the effective deterrence range by multiplying the area of the impact footprint by the appropriate density estimate.

There are concerns regarding the assessment of disturbance from UXOs. The guidance itself acknowledges that the 26 km EDR is based on the EDR recommended for pile driving of monopiles, since there is no equivalent data for explosives. The guidance also acknowledges that the disturbance resulting from a single explosive detonation would likely not cause the more widespread displacement that may last up to several days following the activity that has been observed in response to pile driving activities.

Additionally, the 26 km EDR was advised for harbour porpoise only. There is no evidence that a 26 km EDR is suitable for any other species of marine mammal. Thus the 26 km EDR has been used here for illustrative purposes only for other marine mammal species, and should be viewed with caution as there is no evidence to support this impact range.

It is predicted that high-order UXO clearance will have the greatest percentage impact on the grey seal MU, disturbing 4.43% of the MU, followed by 2.44% for bottlenose dolphin and 2.67% for harbour seal (Table 5.2). Given the higher percentage of the relevant MUs predicted to experience disturbance, these species are assessed as a **Low** magnitude, where effects may be detectable but unlikely to be of a scale or duration to have a significant effect on the conservation status or integrity of the receptor in the short term (1-5 years).

The percentage of the MU predicted to be disturbed was much lower for all other species assessed (<0.25%) and, therefore, harbour porpoise, white-beaked dolphin, minke whale and Risso’s dolphin are assessed as a **Negligible** magnitude, where changes are barely detectable, approximating to the ‘no change’ situation. Any effects are likely to be reversible within 12 months and will not affect the conservation status or integrity of the receptor.

All marine mammals are assessed as having a **Low** sensitivity to disturbance from UXO clearance. The magnitude of this impact pathway, using a 26 km EDR, has been assessed as **Negligible** (harbour porpoise, white-beaked dolphin, Risso’s dolphin, common dolphin and minke whale) or **Low** (bottlenose dolphin, harbour seal and grey seal). Therefore, effects from this activity are concluded to be of **Negligible** or **Minor** significance, both of which are **Not Significant** in EIA terms.

Table 5.2 Number of animals predicted to experience behavioural disturbance from high-order UXO detonation assuming a 26 km EDR

Species	MU	Density (#/km²)	Area (km²)	# Animals	% MU	Magnitude	Sens.	Effect Sign.
Harbour porpoise	346,601 (NS)	0.1520	995	151	0.04%	Negligible	Low	Negligible
	28,936 (WS)	0.1520	485	74	0.25%	Negligible	Low	Negligible
Bottlenose dolphin	224	0.0037	1,478	5	2.44%	Low	Low	Minor
White-beaked dolphin	43,951	0.08	1,478	118	0.27%	Negligible	Low	Negligible
Risso's dolphin	12,262	0.0135	1,478	20	0.16%	Negligible	Low	Negligible
Common dolphin	102,656	0.012	1,478	18	0.02%	Negligible	Low	Negligible
Minke whale	20,118	0.0095	1,478	14	0.07%	Negligible	Low	Negligible
Harbour seal	1,951	Grid cell specific	1,478	52	2.67%	Low	Low	Minor
Grey seal	35,979	Grid cell specific	1,478	1,594	4.43%	Low	Low	Minor

5.3.2 5 km EDR – low-order

It is important to note that while high-order detonation represents the very worst -case scenario for UXO clearance, it is highly likely that low-order clearance methods (deflagration) will be used instead. Recent risk assessments conducted to support UXO Marine Licence applications in the southern North Sea have proposed, with support from JNCC and Natural England, an assumed EDR of 5 km for low-order deflagration (e.g., Sofia offshore wind farm). Due to the absence of formal guidance, this approach has been adopted here for the assessment of disturbance from low-order detonation of UXOs at the Offshore Site. It is noted that empirical data on open water noise levels and animal responses to low-order deflagration are required to validate the proposed 5 km EDR, but that evidence from tests in a flooded quarry support the proportionally lower noise levels expected from this technique relative to high-order detonation (Robinson *et al.* 2020).

Given the low number of animals and percentage of each MU predicted to experience disturbance (Table 5.3), all species have been assessed as **Negligible** magnitude, where changes are barely detectable, approximating to the 'no change' situation. Any effects are likely to be reversible within 12 months and will not affect the conservation status or integrity of the receptor.

All marine mammals are assessed as having a **Low** sensitivity to disturbance from UXO clearance and the magnitude of impact from low-order UXO clearance using a 5 km EDR is assessed as **Negligible** for all species. Therefore, effects from this activity are concluded to be of **Negligible** significance for all species assessed, which is **Not Significant** in EIA terms.

Table 5.3 Number of animals predicted to experience behavioural disturbance from low-order UXO detonation assuming a 5 km EDR

Species	MU	Density (#/km²)	Area (km²)	# Animals	% MU	Magnitude	Sens.	Effect Sign.
Harbour porpoise	346,601	0.152	79	12	< 0.01%	Negligible	Low	Negligible
Bottlenose dolphin	224	0.0037	79	< 1	0.13%	Negligible	Low	Negligible
White-beaked dolphin	43,951	0.08	79	6	0.01%	Negligible	Low	Negligible
Risso's dolphin	12,262	0.0135	79	1	0.01%	Negligible	Low	Negligible
Common dolphin	102,656	0.012	79	1	< 0.01%	Negligible	Low	Negligible
Minke whale	20,118	0.0095	79	1	< 0.01%	Negligible	Low	Negligible
Harbour seal	1,951	Grid cell specific	79	<1	0.05%	Negligible	Low	Negligible
Grey seal	35,979	Grid cell specific	79	49	0.14%	Negligible	Low	Negligible

5.3.3 TTS-onset

An estimation of the extent of behavioural disturbance can be based on the sound levels at which the onset of TTS is predicted to occur from impulsive sounds. As stated by Southall et al. (2007): *"Although TTS is not a behavioral effect per se, this approach is used because any compromise, even temporarily, to hearing functions has the potential to affect vital rates by interfering with essential communication and/or detection capabilities. This approach is expected to be precautionary because TTS at onset levels is unlikely to last a full diel cycle or to have serious biological consequences during the time TTS persists".* Therefore, using TTS-onset as a proxy for disturbance for a single pulse sound source is expected to over-estimate the true behavioural response.

Full details of the underwater noise modelling and the resulting TTS-onset impact areas and ranges are detailed in Volume 3, Appendix 11.1: Underwater Noise Modelling (Midforth *et al.* 2022).

As expected, the TTS-onset impact area increases with the size of the charge used (Table 5.4). The greatest TTS-onset impact area was predicted to occur for VHF cetaceans at 1,193 km² for a 525 kg + donor charge. This also resulted in the greatest number of animals exposed to TTS-onset, with 181 harbour porpoises (127 in North Sea MU; 54 in West Scotland MU). Whilst this is the greatest number of animals, it should be noted that this equates to 0.04% of the North Sea MU and 0.19% of the West Scotland MU. For LF cetaceans the greatest TTS-onset impact area was 52.8 km², and for HF cetaceans it was 5.3 km². For all high-order UXOs for both LF and HF cetaceans it is anticipated that <1 animal within these impact areas would experience TTS-onset.

For phocids (in water), the greatest TTS-onset impact area was estimated at 66.5 km². This resulted in predicted TTS-onset to <1 harbour seal and 40 grey seals, corresponding to < 0.01% and 0.11% of the relevant MUs, respectively.

TTS-onset is predicted to be of local spatial extent, short term duration and intermittent. Given the low number of animals and percentage of each MU predicted to experience disturbance (Table 5.4), all species have been assessed as **Negligible** magnitude, where changes are barely detectable, approximating to the 'no change' situation. Any effects are likely to be reversible within 12 months and will not affect the conservation status or integrity of the receptor.

All marine mammals are assessed as having a **Low** sensitivity to disturbance from UXO clearance and the magnitude of impact from high-order or low-order UXO clearance, using TTS as a proxy for a disturbance threshold, is assessed as **Negligible** for all species. Therefore, effects from this activity are concluded to be of **Negligible** significance for all species assessed, which is **Not Significant** in EIA terms.

Table 5.4 Number of animals predicted to experience TTS-onset from high-order UXO detonation

Species		0.5 kg	25 kg + donor	55 kg + donor	120 kg + donor	240 kg + donor	525 kg + donor
LF	Range (km)	0.41	1.5	1.9	2.5	3.2	4.1
	Area (km^2)	0.5	7.1	11.3	19.6	32.2	52.8
	# MW	<1	<1	<1	<1	<1	1
	Magnitude	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
HF	Range (km)	0.13	0.49	0.64	0.83	1.0	1.3
	Area (km^2)	0.1	0.8	1.3	2.2	3.1	5.3
	# BND	<1	<1	<1	<1	<1	<1
	# WBD	<1	<1	<1	<1	<1	<1
	# RD	<1	<1	<1	<1	<1	<1
	# CD	<1	<1	<1	<1	<1	<1
	Magnitude	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
VHF	Range (km)	2.3	8.5	11	14	18	23
	Area (km^2)	16.6	227.0	380.1	615.8	1017.9	1,193
	# HP	3	35	58	94	155	181
	Magnitude	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
PCW	Range (km)	0.45	1.6	2.1	2.8	3.5	4.6
	Area (km^2)	0.6	8.0	13.9	24.6	38.5	66.5
	# HS	<1	<1	<1	<1	<1	<1
	# GS	<1	5	9	15	23	40
	Magnitude	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible

Notes: MW = minke whale; HP = harbour porpoise; BND = bottlenose dolphin; WBD = white-beaked dolphin; RD = Risso's dolphin; CD = common dolphin; HS = harbour seal; GS = grey seal.

5.4 Conclusion

UXO Clearance is not anticipated to be required for the Offshore Development, and is not part of the current consent application which this assessment supports. However, for the purpose of providing a comprehensive assessment of potential worst-case impacts associated with project activities, an initial assessment of noise-related effects of UXO clearance has been undertaken.

The sensitivity of marine mammals to PTS-onset from UXO clearance has been assessed as **Low** and, considering the embedded mitigation measures, the magnitude of this impact is considered to be **Negligible**. Therefore, effects from this activity are assessed as of **Negligible** significance, which is **Not Significant** in EIA terms.

All marine mammals are assessed as having a **Low** sensitivity to disturbance from UXO clearance. The magnitude of this impact pathway, using the most precautionary assessment approach of a 26 km EDR, has been assessed as **Negligible** (harbour porpoise, white-beaked dolphin, Risso's dolphin, common dolphin and minke whale) or **Low** (bottlenose dolphin, harbour seal and grey seal).

Therefore, effects from this activity are concluded to be of **Negligible** or **Minor** significance, both of which are **Not Significant** in EIA terms.

5.5 Mitigation measures

Mitigation measures for UXO clearance will be developed in a subsequent consent application for this activity, should UXO clearance be required. In principle, such activities will be conducted in line with the current requirements of the JNCC (2017) guidelines and any EPS Licence issued by Marine Scotland. Marine Scotland guidance on the mitigation of EPS states that ‘Mitigation measures should be put in place whenever there is concern that an activity is likely to cause an offence, and should be proportionate to the risk of injury or disturbance’ (Marine Scotland 2014). A UXO clearance-specific MMMP will be implemented, detailing measures necessary to ensure that the risk of injury PTS reduced to negligible levels, and that the risk of disturbance is reduced as far as possible (embedded mitigation).

6 Impact Assessment: Impact piling

6.1 Overview

If driven (impact) piles are selected as the anchor solution to be used for the Offshore Development, piling is anticipated to take place over a four to seven month period, likely over summer to avoid the potential for weather downtime. This period includes contingency to mitigate the potential risk of weather delays and/or additional unforeseen circumstances. A single, cautious worst-case piling scenario has been used to undertake the assessments for injury and disturbance, to represent the maximum possible pile size, piling durations, and blow energies which may be used. This includes:

- Piles of 5 m diameter, 20 m length installed with a maximum hammer energy of up to 2,500 kJ
- Up to a maximum of three large piles could be installed in one day, however, one pile per day is considered as a cautious worst case in terms of disturbance

Detailed anticipated project design parameters for the installation of 7 WTGs are presented in Table 6.1. Should impact piling of anchor piles be required, it is highly likely that the actual piling parameters will be such that lesser impacts will occur; for example, the use of smaller diameter piles, lower hammer energy, and a shorter total duration of active piling. Therefore, the following assessment presented for impact piling can be considered highly precautionary.

Table 6.1 Project design parameters relevant to underwater noise impacts, representing a cautious worst-case piling scenario used in the assessment of potential effects on marine mammals

Pile driving	
# WTGs	7
Substructure types	Semi-submersible or Tension leg platform
# piles required per WTG	Max = 9
# piles total	Max = 63
Hammer energy	Max = 2,500 kJ (5 m diameter pile)
Duration to pile 1 pile	Max = 8 hours, Average = 4 hours
# Piles installed in 24 hours	Min = 1, Max = 3
Total number of days when piling may occur over construction period	63 days (1 pile per day x maximum number of piles (63))
No of concurrent piling events	None

Table 6.2 provides further details of parameters (e.g. worst-case soft start procedure) used to inform the prediction of PTS-onset using SEL_{cum} criteria. While the installation of three piles in a day might appear to represent a worst case in terms of SEL_{cum} impact ranges, the energy received by a receptor accumulates relatively quickly, from a limited number of higher amplitude hammer strikes while relatively close to the source, such that SEL_{cum} PTS-onset thresholds would not be any larger for >8 hours of piling (i.e. a single pile) considering the anticipated fleeing movement.

Estimates of impact ranges for instantaneous PTS-onset (based on SPL_{peak} criteria) are based on maximum hammer energy.

Table 6.2 Piling parameters used to assess PTS-onset (SEL_{cum})

	5%	10%	20%	40%	100%	TOTAL
Hammer Energy (kJ)	125	250	500	1000	2500	-
No. of strikes	80	80	80	80	14,592	**14,912**
Blow rate (bpm)	16	16	16	16	32	**-**
Duration (mins)	5	5	5	5	456	**476 min (7.9 hrs)**

6.2 Injury

Full details of the underwater noise modelling and the resulting injury (PTS-onset) impact areas and ranges are detailed in Volume 3, Appendix 11.1: Underwater Noise Modelling (Midforth *et al.* 2022).

Table 6.3 presents the injury (PTS-onset) impact area, impact range and number of individuals of each functional hearing group predicted to experience PTS-onset for the worst-case scenario for piling activities. The instantaneous PTS-onset impact ranges are low for all groups, with a maximum range of 0.65 km for harbour porpoise (VHF cetaceans) and equating to <1 animal for all groups. This impact is of **Negligible** magnitude.

For the onset of cumulative PTS, the maximum predicted impact extent is for minke whale (LF cetaceans) where the PTS-onset impact range is 27 km which equates to 10 minke whales and 0.047% of the MU. The cumulative PTS-onset impact range for harbour porpoise is 8.7 km and equates to < 0.01% of the MU. For all other species the cumulative PTS-onset impact range was <0.1 km equating to <1 animal.

As stated in section 3.2, the modelled ranges for cumulative PTS-onset are highly precautionary and should be regarded as over-estimates. Despite this, the number of animals predicted to experience PTS-onset per piling day is low and the probability of the PTS causing a change in vital rates is expected to be very low (Booth and Heinis 2018). Therefore, it is not expected that a sufficient number of animals would experience a change in vital rates; and that any change is expected to be barely detectable and will not affect conservation status or integrity of the receptor. Given the low numbers of animals affected, and that HWL will commit to a Piling MMMP (which will ensure PTS is reduced to a negligible level), this impact is of **Negligible** magnitude.

Table 6.3 PTS-onset predictions for impact piling

Hearing group	Threshold	Species	Area (km^2)	Max range (km)	# animals	% MU
Instantaneous PTS (SPL_{peak})						
LF	219	Minke whale	<0.01	0.2	<1	0.000
HF	230	Bottlenose dolphin White-beaked dolphin Risso's dolphin Common dolphin	0.02	0.1	<1	0.000
VHF	202	Harbour porpoise	1.22	0.65	<1	0.000
PCW	218	Harbour seal Grey seal	0.16	0.25	<1	0.000
Cumulative PTS (SEL_{cum})						
LF	183	Minke whale	1000	27	10	0.047
HF	185	Bottlenose dolphin White-beaked dolphin Risso's dolphin Common dolphin	<0.1	<0.1	<1	0.000
VHF	155	Harbour porpoise	150	8.7	23	0.006[1]
PCW	185	Harbour seal Grey seal	<0.1	<0.1	<1	0.000

[1] *The entire impact area lies within the North Sea MU for harbour porpoise.*

The predicted extent of PTS-onset is of local spatial extent and to low numbers of animals (in absolute terms and/or relative to the relevant MU); however, since PTS is a permanent change in the hearing threshold, it is not recoverable. HWL has committed to a Piling MMMP to ensure that the risk of PTS is reduced to negligible. The exact mitigation measures contained with the Piling MMMP are yet to be determined and will be agreed with Marine Scotland post-consent. However, multiple measures are available and have been implemented elsewhere for piling, such as the use of MMOs, PAM and ADDs to ensure that the mitigation zone is free of animals. The magnitude of this impact is therefore considered to be **Negligible**.

All species of marine mammal have been assessed as having a **Low** sensitivity to PTS-onset from impact piling, and the magnitude of this impact, considering embedded mitigation, is considered to be **Negligible** for all species assessed. Therefore, the predicted effects of PTS-onset for this activity are considered to be of **Negligible** significance, which is **Not Significant** in EIA terms.

6.3 Disturbance

Table 6.4 presents the number of each species and percentage of the MU predicted to be impacted during the worst-case impact piling scenario.

Table 6.4 Disturbance predictions for impact piling

Species	Density (animals/km^2)	MU	# impacted	% MU
Harbour porpoise*	0.152	NS	323	0.09
		WS	318	1.10
		NS + WS	641	0.17
Bottlenose dolphin*	0.0037	CES	6	2.57
		CWSH	4	7.88
		OW	4	0.1
		GNS	2	0.11
White-beaked dolphin	0.08	CGNS	337	0.77
Risso's dolphin	0.0135	CGNS	57	0.46
Common dolphin	0.012	CGNS	8	0.01
Minke whale	0.0095	CGNS	40	0.20
Harbour seal	Grid cell specific	NC&O	116 (10 – 225)	5.93 (0.53 – 11.52)
Grey seal	Grid cell specific	NC&O	1,890 (203 – 3,377)	5.03 (0.57 – 9.39)

* The impact contours from impact piling at the PFOWF Array Area are predicted to extend across two harbour porpoise and four bottlenose dolphin MUs; therefore, the predicted disturbance levels have been presented for each MU separately.

6.3.1 Harbour porpoise, white beaked dolphin, Risso's dolphin, common dolphin and minke whale

White-beaked dolphin, Risso's dolphin, common dolphin and minke whale are predicted to experience disturbance to ≤ 0.77% of their respective MUs. For harbour porpoise, the disturbance impact area extends across two MUs: disturbance is predicted to occur to 0.09% of the North Sea MU and 1.10% of the West Scotland MU. While the proportion of the West Scotland MU predicted to be disturbed is higher than those of other species, this value is considered to be highly conservative given the continuous habitat, distribution and exchange of individuals between the two MUs. It is noted that combining piling impacts across the two MUs for harbour porpoise results in a predicted 0.17% of the combined MU disturbed.

Given the low number of animals and percentage of each MU predicted to experience disturbance, alongside the limited number of total piling days (max 63 days), impacts to all the aforementioned species have been assessed as **Negligible** magnitude, where changes are expected to be barely detectable and are likely to be reversible within 12 months and will not affect the conservation status or integrity of the receptor.

6.3.2 Bottlenose dolphins

Using the harbour porpoise dose-response curve for pile driving, the impact contours from impact piling at the PFOWF Array Area are predicted to extend across four bottlenose dolphin MUs: Coastal East Scotland, Coastal West Scotland and the Hebrides (CWSH), Oceanic Waters and Greater North Sea (Figure 6.1). Therefore, the predicted disturbance levels have been presented for each MU separately in Table 6.4 and Table 6.5. The highest levels of response are expected within the CES and CWSH; however, these estimates are highly precautionary for the following reasons:

- Bottlenose dolphins are expected to be less sensitive to underwater noise than harbour porpoise; and
- There is a lack of evidence of bottlenose dolphin habitat use along the north coast of Scotland (including the Highlands and Islands).

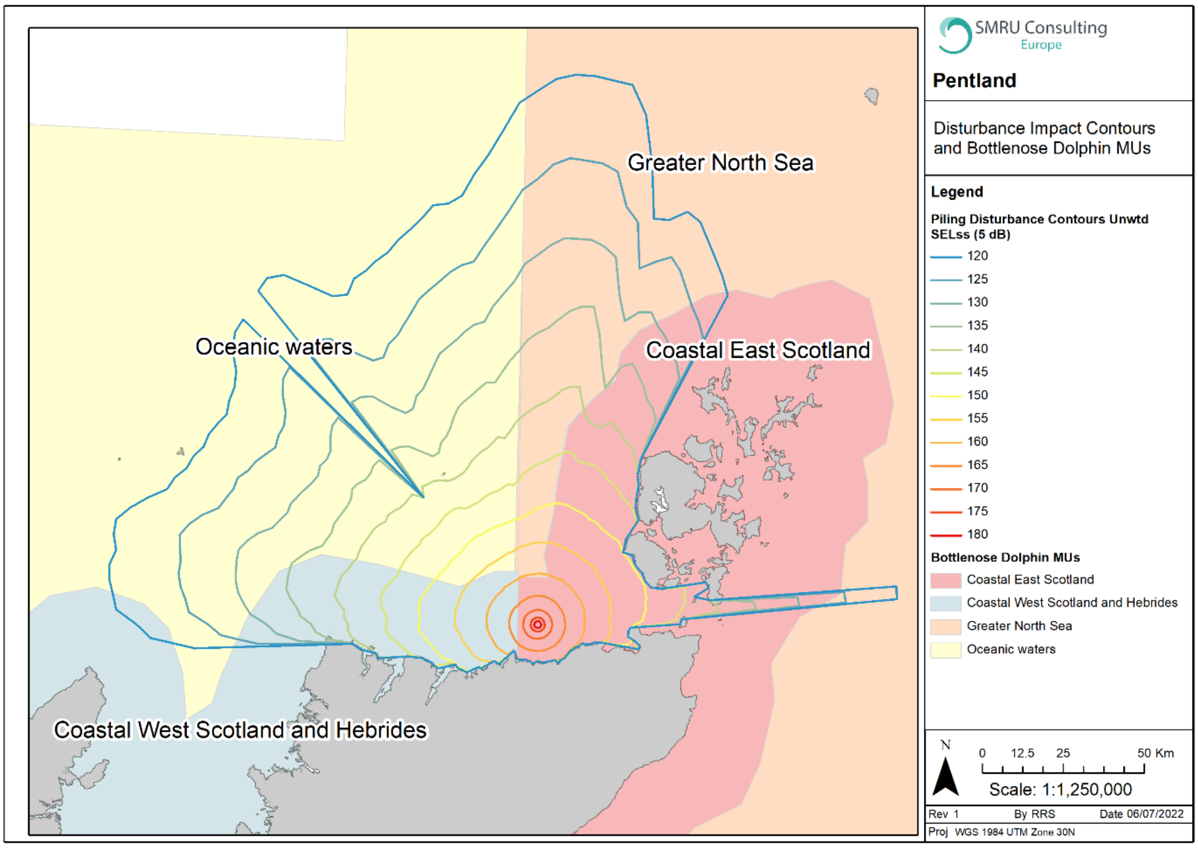


Figure 6.1 Worst-case piling disturbance impact contours and the bottlenose dolphin MUs.

The harbour porpoise dose-response curve has been used as a proxy for bottlenose dolphin response in the absence of similar empirical data. However, this makes the assumption that the same disturbance relationship is observed in bottlenose dolphins. It is anticipated that this approach will be overly precautionary as evidence suggests that bottlenose dolphins are less sensitive to disturbance compared to harbour porpoise. A literature review of recent (post Southall *et al.* (2007)) behavioural responses by harbour porpoises and bottlenose dolphins to noise was conducted by Moray Offshore Renewables Limited (2012). Several studies have reported a moderate to high level of behavioural response at a wide range of received SPLs (100 and 180 dB re 1µPa) (Lucke *et al.* 2009, Tougaard *et al.* 2009, Brandt *et al.* 2011). Conversely, a study by Niu *et al.* (2012) reported moderate level responses to non-pulsed noise by bottlenose dolphins at received SPLs of 140 dB re 1µPa. Another high frequency cetacean, Risso's dolphin, reported no behavioural response at received SPLs of 135 dB re 1µPa (Southall *et al.* 2010). Whilst both species showed a high degree of variability in responses and a general positive trend with higher responses at higher received levels, moderate level responses were observed above 80 dB re 1µPa in harbour porpoise and above 140 dB re 1µPa in bottlenose dolphins (Moray Offshore Renewables Limited 2012), indicating that moderate level responses by bottlenose dolphins will be exhibited at a higher received SPL and, therefore, they are likely to show a lesser response to disturbance. Furthermore, the relatively dynamic social structure of bottlenose dolphins (Connor *et al.* 2001) and the fact that they have no significant predation threats and do not appear to face excessive competition for food with other marine mammal species, have potentially resulted in a higher tolerance to perceived threats or disturbances in their environment, which may make them less sensitive to disturbance.

Sightings of bottlenose dolphins in the CWSH MU are primarily located in and around the Sound of Barra and throughout the Inner Hebrides, with most sightings around Mull, the Small Isles and Skye (Hebridean Whale and Dolphin Trust 2018). While there have been sightings of bottlenose dolphins along the north coast of mainland Scotland, Orkney and the Shetlands, the number of animals using the north coast appears to be low (Cheney *et al.* 2013), and much of these rely on publicly reported sightings where species identification may be unreliable, given the known presence of other dolphin species in the area (Risso's dolphin and white-beaked dolphin) (Reid *et al.* 2003). Bottlenose dolphins within the coastal east Scotland MU are typically found in shallower depths (<20 m depth contour) (Quick *et al.* 2014) and, therefore, most of the those animals potentially disturbed by pile driving are anticipated to be the offshore ecotype and not part of the Moray Firth SAC population. In addition, no bottlenose dolphins were sighted during the 13 aerial surveys of the Dounreay Trì project area (+ 2 km buffer), surveyed by HiDef between January and December 2015. It is therefore expected that bottlenose dolphin presence along the north coast of mainland Scotland, Orkney and Shetland is rare and thus in reality disturbance to any bottlenose dolphin in this area is unlikely.

To assess whether this (highly precautionary) predicted level of disturbance would be sufficient to cause a population level effect, the iPCoD model[13] (version 5.2) was run. Models were run for the two coastal bottlenose dolphin MUs separately. The demographic parameters used were those for the coastal east Scotland MU (Sinclair *et al.* 2020). Two piling schedules were created: 'even spread' - with 63 piling days spread evenly across an indicative four-month piling window (April-July); and, 'consecutive' - with 63 consecutive piling days centred on May-June.

The results of the modelling showed that there was an extremely small or no predicted effect on most combinations of piling scenarios, MUs and time periods (Table 6.5). Predicted impacts were slightly greater for the CWSH MU, and for the consecutive piling schedule. While the models for the CWSH MU suggest a slight decline at 1 year and 12-year simulations, these are considered to be highly unlikely scenarios given that baseline data indicate a very low probability of bottlenose dolphin presence in the impact area, particularly those associated with the CWSH MU.

Therefore, disturbance to bottlenose dolphins from impact-piling is assessed as of **Negligible** magnitude for the CES MU, as there is only a slight change from baseline that will have no effect on the conservation status or integrity of the receptor. The impact of this activity is assessed as of **Low** magnitude for the CWSH MU, as there will be a detectable, minor shift away from baseline conditions that is unlikely to have a significant effect on the conservation status or integrity of the receptor in the short term (i.e. 1-5 years). It is noted that the assessment for the CWSH MU is highly precautionary in terms of the expected number of animals disturbed (in terms of occurrence in area, dose-response function, piling parameters) and that the 'consecutive' piling schedule is also highly unlikely to be realised.

[13] http://www.smruconsulting.com/products-tools/pcod/ipcod/

Table 6.5 Bottlenose dolphin population modelling results

Time period	Parameter	Coastal East Scotland MU (224 animals; 6 impacted per day)		Coastal West Scotland and Hebrides MU (45 animals 4 impacted per day)	
	Piling schedule:	even spread	consecutive	even spread	consecutive
After 1 year	Un-impacted population mean	232	232	48	48
	Impacted population mean	232	232	47	47
	Impacted population as % of un-impacted	100.00	100.00	97.92	97.92
After 6 years	Un-impacted population mean	278	279	57	57
	Impacted population mean	278	278	57	57
	Impacted population as % of un-impacted	100.00	99.64	100.00	100.00
After 12 years	Un-impacted population mean	346	344	71	71
	Impacted population mean	346	343	70	71
	Impacted population as % of un-impacted	100.00	99.71	98.59	100.00

6.3.3 Harbour seals

Harbour seal disturbance due to impact piling is predicted to be 5.93% of the MU (CI: 0.53- 11.52) per piling day, equating to 116 animals (CI: 10-225) (Figure 6.2).

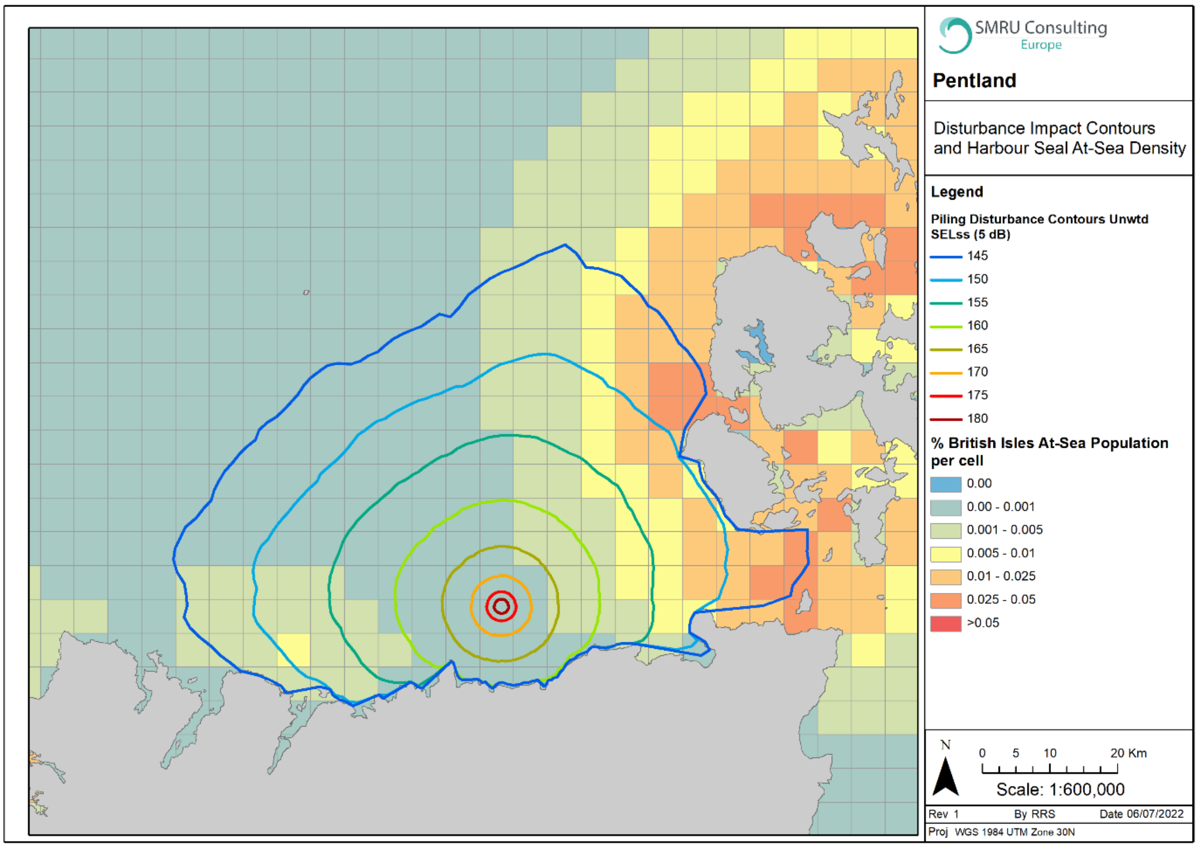


Figure 6.2 Impact piling disturbance impact contours and the harbour seal density surface.

To assess whether the predicted level of disturbance would be sufficient to cause a population level effect, the iPCoD model was run, using the demographic parameters for the North Coast and Orkney MU (Sinclair *et al.* 2020). As for bottlenose dolphins, 'even spread' and 'consecutive' piling schedules were run, each including a maximum of 63 days of piling disturbance.

The results of the modelling showed that there was no predicted effect on the harbour seal population as a result of the piling activity for the Offshore Development, for either piling schedule (Table 6.6). It should be noted that while the results in Table 6.6 may appear alarming given the sharp population decline, this is because the North Coast and Orkney MU has been in decline since the mid-1990s (SCOS 2021), and thus, even in the absence of disturbance from the Offshore Development, the population is projected to greatly decline over the simulation period (assuming the current rate of decline continues). There is no influence of disturbance from the Offshore Development impacting the rate of this decline; the impacted population is expected to remain the same as the unimpacted population. This is therefore assessed as of **Negligible** magnitude.

Table 6.6 Harbour seal population modelling results

Time period	Parameter	North Coast and Orkney MU (1,951 animals; 116 impacted per day)	
	Piling schedule:	even spread	consecutive
After 1 year	Un-impacted population mean	1,744	1,748
	Impacted population mean	1,744	1,748
	Impacted population as % of un-impacted	100%	100%
After 6 years	Un-impacted population mean	1,006	1,017
	Impacted population mean	1,006	1,017
	Impacted population as % of un-impacted	100%	100%
After 12 years	Un-impacted population mean	519	524
	Impacted population mean	519	524
	Impacted population as % of un-impacted	100%	100%

6.3.4 Grey seals

Grey seal disturbance due to impact piling is predicted to be 5.03% (CI: 0.57- 9.39) of the MU per piling day, equating to 1,890 animals (CI: 203- 3,377) (Figure 6.3).

To assess whether the predicted level of disturbance would be sufficient to cause a population level effect on grey seals, the iPCoD model was run, using the demographic parameters for the North Coast and Orkney MU (Sinclair *et al.* 2020). As for bottlenose dolphins and harbour seal, ‘even spread’ and ‘consecutive’ piling schedules were run, each including a maximum of 63 days of piling disturbance.

The results of the modelling showed that there was no predicted effect on the grey seal population as a result of the piling activity for the Offshore Development (Table 6.7). The impacted population is expected to remain the same as the unimpacted population. This is therefore assessed as a **Negligible** magnitude.

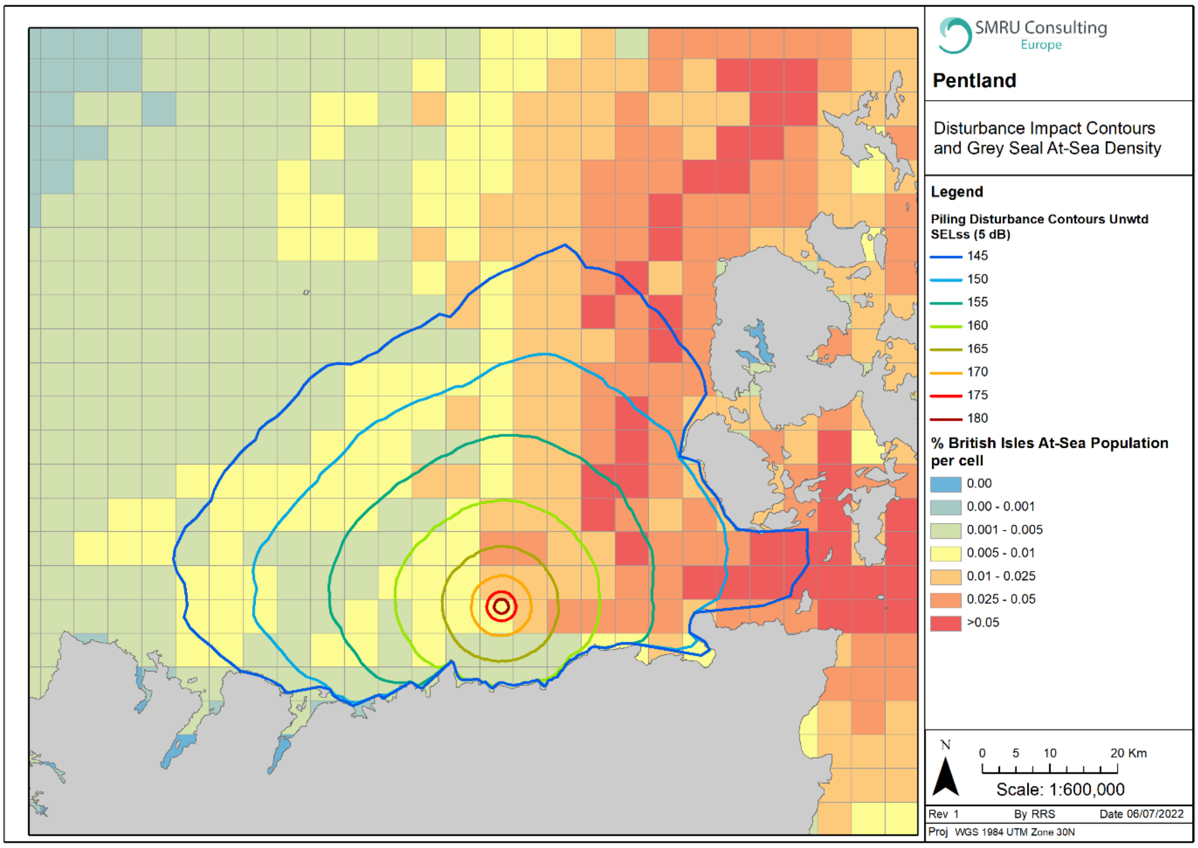


Figure 6.3 Impact piling disturbance impact contours and the grey seal density surface

Table 6.7 Grey seal population modelling results

Time period	Parameter	North Coast and Orkney MU (35,979 animals; 1,890 impacted per day)	
	Piling schedule:	even spread	consecutive
After 1 year	Un-impacted population mean	36,241	36,227
	Impacted population mean	36,241	36,227
	Impacted population as % of un-impacted	100.00	100.00
After 6 years	Un-impacted population mean	37,293	37,393
	Impacted population mean	37,293	37,393
	Impacted population as % of un-impacted	100.00	100.00
After 12 years	Un-impacted population mean	38,776	38,823
	Impacted population mean	38,776	38,823
	Impacted population as % of un-impacted	100.00	100.00

6.4 Conclusion

All species of marine mammal are assessed as having a **Low** sensitivity to PTS-onset from impact piling noise. Considering embedded mitigation measures, including development and implementation of a piling MMMP, the effects of PTS-onset from a cautious worst-case piling scenario is assessed as **Negligible** magnitude for all species. Therefore, for all species, this impact pathway is assessed as of **Negligible** significance, which is **Not Significant** in EIA terms (Table 6.8).

Harbour seals were assessed as being of **Moderate** sensitivity to disturbance from impact piling noise, with grey seals assessed as of **Negligible** sensitivity, and all relevant cetacean species as of **Low** sensitivity. Considering a cautious worst-case piling scenario, disturbance from piling has been assessed as of **Low** magnitude for bottlenose dolphin for the Coastal West Scotland and Hebrides MU, and of **Negligible** magnitude for bottlenose dolphin for the Coastal East Scotland MU and all other marine mammal species. Therefore, this effect is assessed as of **Negligible** or **Minor** significance, which is **Not Significant** in EIA terms (Table 6.8).

Table 6.8 Impact magnitude, sensitivity and resulting impact significance for impact pile-driving activities

Species	Impact	Magnitude	Sensitivity	Effect Significance
Harbour porpoise	PTS-onset	Negligible	Low	Negligible
	Disturbance	Negligible	Low	Negligible
Bottlenose dolphin	PTS-onset	Negligible	Low	Negligible
	Disturbance (CES)	Negligible	Low	Negligible
	Disturbance (CWSH)	Low	Low	Minor
White-beaked dolphin	PTS-onset	Negligible	Low	Negligible
	Disturbance	Negligible	Low	Negligible
Risso's dolphin	PTS-onset	Negligible	Low	Negligible
	Disturbance	Negligible	Low	Negligible
Common dolphin	PTS-onset	Negligible	Low	Negligible
	Disturbance	Negligible	Low	Negligible
Minke whale	PTS-onset	Negligible	Low	Negligible
	Disturbance	Negligible	Low	Negligible
Harbour seal	PTS-onset	Negligible	Low	Negligible
	Disturbance	Negligible	Moderate	Minor
Grey seal	PTS-onset	Negligible	Low	Negligible
	Disturbance	Negligible	Negligible	Negligible

6.5 Mitigation measures

A piling-specific MMMP will be implemented to ensure that the risk of injury PTS is negligible, and that the risk of disturbance is reduced as far as possible (embedded mitigation). The MMMP will include measures in line with the *Statutory nature conservation agency protocol for minimising the risk of injury to marine mammals from piling noise* (JNCC 2010) and will consider Marine Scotland (2020) guidance on The protection of Marine European Protected Species from injury and disturbance for Scottish inshore waters.

No additional mitigation measures are required to minimise the effects of PTS or disturbance from pile-driving noise.

7 Impact assessment: Other construction activities

7.1 Overview

A simple assessment of the noise impacts from non-piling noise is presented in Volume 3, Appendix 11.1: Underwater Noise Modelling (Midforth *et al.* 2022) for the following construction activities:

- Cable laying: Noise from the cable laying vessel and any other associated noise during the offshore cable installation.
- Dredging: Dredging may be required on site for seabed preparation work for certain foundation options. Suction dredging has been assumed as a worst-case.
- Trenching: Plough trenching may be required during offshore cable installation.
- Rock placement: Included as an example of protection for offshore cables (cable crossings and cable protection) and scour protection around anchors.
- Vessel noise: Large and medium-sized vessels for WTG and other infrastructure transport and installation (including anchor pile installation), other construction tasks and anchor handling. Other small vessels for crew transport and maintenance on site.

Subacoustech have provided approximate underwater noise levels associated with the various construction activities, based on their own underwater noise measurement database (Table 7.1). In their modelling for cumulative PTS, they assumed the worst-case scenario that all other construction activity sources were operating 24 hours a day.

Table 7.1 Summary of the estimated unweighted source levels and transmission losses for the different construction noise sources considered

Source	Estimated unweighted source level	Approximate transmission loss	Comments
Cable laying	171 dB re 1 µPa @ 1 m (RMS)	$13\log10R$ (no absorption)	Based on 11 datasets from a cable laying vessel measuring 300 m in length; this is considered a worst-case noise source for cable laying operations
Suction dredging	186 dB re 1 µPa @ 1 m (RMS)	$19\log10R - 0.0009R$	Based on five datasets from suction and cutter suction dredgers
Trenching	172 dB re 1 µPa @ 1 m (RMS)	$13\log10R - 0.0004R$	Based on three datasets of measurements from trenching vessels more than 100 m in length
Rock placement	172 dB re 1 µPa @ 1 m (RMS)	$12\log10R - 0.0005R$	Based on four datasets from rock placement vessel ‘Rollingstone’
Vessel noise (large)	168 dB re 1 µPa @ 1 m (RMS)	$12\log10R - 0.0021R$	Based on five datasets of large vessels including container ships, FPSOs and other vessels more than 100 m in length. Vessel speed assumed as 10 knots
Vessel noise (medium)	161 dB re 1 µPa @ 1 m (RMS)	$12\log10R - 0.0021R$	Based on three datasets of moderate sized vessels less than 100 m in length. Vessel speed assumed as 10 knots

7.2 Injury

Using the non-impulsive weighted SEL_{cum} PTS-onset injury thresholds from Southall *et al*. (2019) resulted in estimated PTS impact ranges of <100 m for all marine mammal species for each non-piling construction activity (Table 7.2). These values mean that animals would have to stay within these very small ranges for 24 hours before they experienced injury, which is an extremely unlikely scenario as it is far more likely that any marine mammal within the injury zone would move away from the vicinity of the vessel and the construction activity. The magnitude of impact of non-piling construction noise is therefore assessed to be **Negligible**.

Table 7.2 Summary of the injury impact ranges for the different construction noise sources using the non-impulsive criteria from Southall *et al*. (2019) for marine mammals

PTS-onset Threshold (weighted SEL_{cum})		Cable laying	Suction dredging	Trenching	Rock Placement	Vessels (large)	Vessels (medium)
LF	199	<100 m	<100 m	<100 m	<100 m	<100 m	<100 m
HF	198	<100 m	<100 m	<100 m	<100 m	<100 m	<100 m
VHF	173	<100 m	<100 m	<100 m	<100 m	<100 m	<100 m
PCW	201	<100 m	<100 m	<100 m	<100 m	<100 m	<100 m

7.3 Disturbance

There is little evidence on the effects of disturbance of marine mammals from offshore construction activities (e.g., rock placement, cable laying, trenching, etc.). The available evidence (see bullet points below) suggests that any potential displacement will be on a local scale (i.e., within 5 km) and limited to the duration of the activities, and therefore unlikely to significantly affect marine mammal vital rates. The following sections provide a brief summary of a literature search conducted to determine the effect of disturbance from other construction activities on marine mammals

7.3.1 Dredging

- **Harbour porpoise**: Dredging at a source level of 184 dB re 1 µPa at 1 m would result in avoidance up to 5 km from the dredging site (Verboom 2014). Conversely, (Diederichs *et al.* 2010) found much more localised impacts; using Passive Acoustic Monitoring there was short term avoidance (~3 hours) at distances of up to 600 m from the dredging vessel, but no significant long-term effects. Modelling potential impacts of dredging using a case study of the Maasvlatke port expansion (assuming maximum source levels of 192 dB re 1 µPa) predicted a disturbance range of 400 m, while a more conservative approach predicted avoidance of harbour porpoise up to 5 km (McQueen *et al.* 2020).
- **Bottlenose dolphin**: Increased dredging activity at Aberdeen Harbour was associated with a reduction in bottlenose dolphin presence and, during the initial dredge operations, bottlenose dolphins were absent for five weeks (Pirotta *et al.* 2013).
- **White-beaked dolphin**: There is currently no information available on the impacts of dredging for white beaked dolphins. Currently their hearing range has only been investigated at frequencies above 16 kHz (Nachtigall *et al.* 2008) which is above the typical range for dredging. Localised, temporary avoidance of dredging activities is assumed.
- **Risso's dolphin**: There is currently no information available on the effects of dredging for Risso's dolphins. Localised, temporary avoidance of dredging activities is assumed.
- **Common dolphin**: In northwest Ireland, construction related activity (including dredging) did not result in any evidence of a negative effect on common dolphins (Culloch *et al*. 2016).
- **Minke whale**: In northwest Ireland, construction related activity (including dredging) has been linked to reduced minke whale presence (Culloch *et al.* 2016).
- **Grey and harbour seal**: Based on the generic threshold of behavioural avoidance of pinnipeds (140 dB re 1 µPa SPL) (Southall *et al.* 2007), acoustic modelling of dredging demonstrated that

disturbance could be caused to individuals between 400 m to 5 km from site (McQueen *et al.* 2020).

7.3.2 Other activities (inc. rock placing, trenching, construction vessel activity)

For other noise sources such as rock placing and trenching, there is no information available in the literature on marine mammal responses. The Moray East impact assessment assessed the potential for disturbance to marine mammals from various construction activities, including cable laying, rock placing, trenching and vessels. The assessment used two fixed noise thresholds to assess this impact:

- 90 dB_{ht}(*Species*): defined by Nedwell *et al.* (2005) as a strong avoidance reaction by virtually all individuals. This is described as an "instinctive reaction" where animals will avoid the noise; and
- 75 dB_{ht}(*Species*): defined by Nedwell *et al.* (2005) as mild behavioural avoidance.

The Moray East assessment concluded that there were only limited disturbance impact ranges from these activities, with impact ranges for cable laying up to 220 m, for rock placement up to 550 m, for trenching up to 640 m, and for vessel noise up to 200 m (Table 7.3).

The Neart na Gaoithe offshore windfarm Environmental Statement[14] states that based on a study of underwater noise at the North Hoyle offshore wind farm during cable laying activities, the SPL at 160 m was below the 75 dB_{ht}(*Species*) threshold and thus the effects of disturbance were predicted to be highly localised.

While there is a lack of data on the responses of marine mammals to other construction noise (such as dredging, trenching, cable laying etc.), previous modelling suggests that any potential displacement will be on a local scale (i.e., max 5 km) and limited to the duration of the activities, and therefore unlikely to significantly affect marine mammal vital rates. Therefore, the impact is assessed as **Low** magnitude for all marine mammal species.

Table 7.3 Predicted impact ranges (m) for disturbance from various construction activities – data obtained from the Moray East ES[15]

	Minke whale		Dolphins		Porpoise		Seals	
	90 dB_{ht}	75 dB_{ht}	90 dB_{ht}	75 dB_{ht}	90 dB_{ht}	75 dB_{ht}	90 dB_{ht}	75 dB_{ht}
Cable laying	18 m	180 m	9 m	75 m	29 m	220 m	2 m	29 m
Rock placing	70 m	390 m	31 m	170 m	99 m	550 m	17 m	99 m
Trenching	59 m	390 m	81 m	350 m	140 m	640 m	12 m	87 m
Vessel noise	6 m	130 m	12 m	110 m	22 m	200 m	<1 m	11 m

Vessel noise levels from construction vessels will result in an increase in non-impulsive, continuous sound in the vicinity of the Offshore Development, typically in the range of 10- 100 Hz (although higher frequencies may also be produced) (Sinclair *et al.* 2021) with an estimated source level of 161-168 SEL_{cum} dB re 1 µPa@1m (RMS) for medium and large construction vessels, travelling at a speed of 10 knots (Volume 3, Appendix 11.1: Underwater Noise Modelling (Midforth *et al.* 2022)).

[14] Neart na Gaoithe Offshore Wind Farm Environmental Statement. Chapter 13 Marine Mammals

[15] Moray Offshore Renewables Ltd. Environmental Statement. Technical Appendix 7.3 A – Marine Mammals Environmental Impact Assessment (2012).

During the construction of the Beatrice and Moray East offshore windfarms within the Moray Firth, harbour porpoise occurrence decreased with increasing vessel presence, with the magnitude of decrease depending on the distance to the vessel (Benhemma-Le Gall *et al.* 2021). For example, the probability of harbour porpoise occurrence at a mean vessel distance of 2 km decreased by up to 95% from a probability of occurrence of 0.37 when no vessels were present to 0.2 for the highest vessel intensity of 9.8 min per km^2 (the sum of residence times for all vessels present in that hour per kilometre squared). At a mean vessel distance of 3 km, the probability decreased by up to 57% to 0.16 for the highest vessel intensity. No apparent response was observed at 4 km. It is expected that other cetacean species may be displaced to a similar extent.

It is anticipated there will be a maximum of 10 vessels on site simultaneously during the construction period. There are very few studies that indicate a critical level of activity in relation to risk of collisions, but an analysis presented in Heinänen and Skov (2015) suggested that harbour porpoise density was significantly lower in areas with vessel transit rates of greater than 80 per day (within a 5 km^2 area). Even considering the existing levels of vessel traffic in the area, the addition of construction traffic for the Offshore Development will still be well below this figure.

The commitment to the adoption of best practice vessel-handing protocols (e.g., following the Codes of Conduct provided by the WiSe (Wildlife-Safe) Scheme, Scottish Marine Wildlife Watching Code or Guide to Best Practice for Watching Marine Wildlife) during construction will minimise the potential for any effects.

Therefore, the impact of noise from vessel activity is expected to be of **Low** magnitude. As stated previously, the sensitivity of all cetacean species to disturbance from vessel noise is expected to be **Low** and is expected to be **Negligible** for both seal species.

7.4 Conclusion

PTS-onset effects from other construction activities has been assessed as **Negligible** magnitude for all marine mammal species, and the sensitivity of all species to PTS from other construction noise has been assessed as **Low**. Therefore, the significance of effect of PTS-onset from other construction noise is concluded to be of **Negligible** significance, which is **Not Significant** in EIA terms (Table 7.4).

Disturbance from other construction activities has been assessed as **Low** magnitude for all marine mammal species, and the sensitivity of cetacean species to disturbance from other construction noise has been assessed as **Negligible** (seals) to **Low** (cetaceans). Therefore, the effect of disturbance from other construction noise is concluded to be of **Negligible** to **Minor** significance, both of which are **Not Significant** in EIA terms (Table 7.4).

Table 7.4 Impact magnitude, sensitivity and resulting effect significance for other construction activities

Species	Impact	Magnitude	Sensitivity	Effect Significance
Harbour porpoise	PTS-onset	Negligible	Low	Negligible
	Disturbance	Low	Low	Minor
Bottlenose dolphin	PTS-onset	Negligible	Low	Negligible
	Disturbance	Low	Low	Minor
White-beaked dolphin	PTS-onset	Negligible	Low	Negligible
	Disturbance	Low	Low	Minor
Risso's dolphin	PTS-onset	Negligible	Low	Negligible
	Disturbance	Low	Low	Minor
Common dolphin	PTS-onset	Negligible	Low	Negligible
	Disturbance	Low	Low	Minor
Minke whale	PTS-onset	Negligible	Low	Negligible
	Disturbance	Low	Low	Minor
Harbour seal	PTS-onset	Negligible	Low	Negligible
	Disturbance	Low	Negligible	Negligible
Grey seal	PTS-onset	Negligible	Low	Negligible
	Disturbance	Low	Negligible	Negligible

7.5 Mitigation measures

The commitment to the adoption of best practice vessel-handing protocols (e.g., following the Codes of Conduct provided by the WiSe Scheme, Scottish Marine Wildlife Watching Code or Guide to Best Practice for Watching Marine Wildlife) during construction will help to minimise the potential for any underwater noise-related injury or disturbance from other construction activities (embedded mitigation).

No additional mitigation measures are required to minimise the effects of PTS or disturbance from other construction activities. Nonetheless, these activities will give prior consideration of Marine Scotland (2020) guidance on The protection of Marine European Protected Species from injury and disturbance for Scottish inshore waters, and, if required, additional proportional mitigation measures may be developed through EPS licencing and other post-consent processes.

8 Impact assessment: Operational phase

8.1 Overview

During the operational phase of the Offshore Development, there is the potential for underwater noise to be generated by the sudden re-tension in a mooring line following a period of slackness resulting from large amplitude and/or high frequency surface motions (Liu 1973). Whilst mooring lines are designed to be permanently in tension and, therefore, should not go slack even in extreme conditions (partly to avoid the risk of marine mammal entanglement) (Statoil 2015), there is limited evidence that mooring lines associated with floating offshore windfarm (FOWFs) have the potential to produce transient impulsive 'pinging' or 'snapping' noises during the operational phase of the development. Hereafter, this is referred to as mooring line 'pinging'.

The presence of pinging sounds was identified at the Hywind Demonstrator Project in Norway (Martin *et al.* 2011). However, due to the relatively small number of floating WTGs currently installed and operational, and the variability in their configuration, the availability of underwater noise-related data for operational noise is limited and there is a knowledge gap regarding the dynamic movement of the cables that link the floating WTGs (Rentschler *et al.* 2019)

8.2 Injury

Data is available for the Hywind Demonstrator Project for a single WTG where noise measurements were taken in water depths of 200 m at 91 m off the seabed (approximately mid-depth) at 150 m from the installation (Martin *et al.* 2011). During the two-month monitoring period, up to 23 pinging sounds were identified per day. Of these, less than 10 pinging sounds per day exceeding an SPL_{peak} of 160 dB re 1 µPa were identified on most days. As the precise source of the noise could not be determined, the exact distance from the monitoring location cannot be ascertained and, therefore, a prediction of the noise closer to the source is not possible for estimation of PTS in terms of SPL_{peak}. The pinging sounds were broadband, with tones between 260-740 Hz consistent with a 'ringing' rope under tension.

Subsequent analysis undertaken for the Hywind Scotland Pilot Park by Xodus Group Ltd (2015) predicted a potential cumulative SEL (unweighted) of up to 156 dB re 1 µPa^2s over 24 hours at 150 m from the WTG resulting from mooring line pinging. This value is below the onset criteria for injury to marine mammals and, therefore, means that, should any pinging noise occur, it will not result in injury. Therefore, should mooring line pinging occur at the Offshore Development, there is considered to be **no risk of injury** to marine mammals.

8.3 Disturbance

There are currently no reliable disturbance thresholds that would be recommended for the kind of intermittent/rare impulses that would be generated from mooring line pinging. Statoil (2015) used the 140 dB re 1 µPa (rms) criterion for mild behavioural disturbance marine mammals for impulsive sounds in the Hywind Scotland Pilot Park Environmental Statement and found that this would be exceeded up to approximately 250 m from each WTG and that a strong behavioural disturbance would be experienced within approximately 30 m of each WTG. As this assessment used impulsive noise thresholds, it likely represents an overestimate of the potential behavioural disturbance. Therefore, as mooring line pinging has been determined to occur at an average rate of less than once per hour, disturbance resulting in avoidance behaviour is considered to be unlikely and, therefore of **Negligible** magnitude.

8.4 Conclusion

It is not known whether mooring line pinging noise will occur at the Offshore Development, as currently only one set of data from the Hywind Demonstrator Project is available for analysis. Furthermore, the mooring arrangement and equipment used will differ for the Offshore Development, resulting in further uncertainty as to whether mooring line pinging noise will occur. Sudden re-tensioning of mooring lines is undesirable from a project design perspective, and will be sought to be eliminated or minimised during the design phase for engineering considerations.

There is expected to be **No risk** of injury from mooring line pinging as the noise levels are expected to be below the thresholds which cause PTS-onset, which is carried through as **No risk** in terms of effect significance.

The sensitivity of all marine mammals to disturbance from mooring line pinging noise is assessed as **Low** (while there is no information on responses of marine mammals to mooring line pinging noise, it is expected to be the same or less than that of impact piling). The risk of behavioural disturbance from mooring line pinging is considered to be of **Negligible** magnitude. Therefore, this effect is concluded to be of **Negligible** significance and **Not Significant** in EIA terms (Table 8.1).

Table 8.1 Impact magnitude, sensitivity and resulting effect significance for mooring line pinging noise

Species	Impact	Magnitude[1]	Sensitivity	Effect Significance[1]
Harbour porpoise	PTS-onset	No risk	Low	No risk
	Disturbance	Negligible	Low	Negligible
Bottlenose dolphin	PTS-onset	No risk	Low	No risk
	Disturbance	Negligible	Low	Negligible
White-beaked dolphin	PTS-onset	No risk	Low	No risk
	Disturbance	Negligible	Low	Negligible
Risso’s dolphin	PTS-onset	No risk	Low	No risk
	Disturbance	Negligible	Low	Negligible
Common dolphin	PTS-onset	No risk	Low	No risk
	Disturbance	Negligible	Low	Negligible
Minke whale	PTS-onset	No risk	Low	No risk
	Disturbance	Negligible	Low	Negligible
Harbour seal	PTS-onset	No risk	Low	No risk
	Disturbance	Negligible	Low	Negligible
Grey seal	PTS-onset	No risk	Low	No risk
	Disturbance	Negligible	Low	Negligible

[1] While it is noted that ‘no risk’ is not an assessment term featured in impact magnitude and significance criteria presented in Sections 2.3.3 and 2.3.4, it is considered more appropriate than ‘no change’ here due to the potential mooring line pinging noise levels being below which the onset of PTS is predicted to occur (see Section 8.2).

8.5 Mitigation measures

No additional mitigation measures are required to minimise the effects of PTS or disturbance from mooring line pinging noise.

9 Cumulative effects assessment

Cumulative effects can be defined as effects upon a single receptor from the Offshore Development when considered alongside other proposed and reasonably foreseeable projects and developments. This includes all projects that result in a comparative effect that is not intrinsically considered as part of the existing environment and is not limited to offshore wind projects. A staged process has identified a number of reasonably foreseeable projects and developments which may act cumulatively with the Offshore Development.

9.1 Approach to identifying relevant projects

The cumulative effects assessment (CEA) methodology is described in Volume 2, Chapter 6: EIA Methodology and Volume 3, Appendix 6.1: Cumulative Assessment Approach. A long list of projects, plans and activities was produced, based on Zones of Influence for each receptor along with the potential for different project types and phases to act cumulatively with the Offshore Development. For marine mammals, the spatial scale for including projects relates to those occurring within the relevant Management Unit for each relevant species. The long list of projects was reviewed to determine the potential for cumulative effect, taking into consideration potential impact pathways and / or the potential for physical or temporal overlap of impacts from other development activities and those of the Offshore Development. This considers additional information gathered for each development within the project long list, beyond the information used to identify the projects to be screened into the long list. For instance, where cumulative impacts are only expected to arise during the construction phase, only those projects with overlapping construction periods with the Offshore Development were screened into the short list. In these instances, projects were screened into the short list if construction occurred in 2025 or 2026. It is noted that horizontal directional drilling (HDD) is anticipated to commence in 2024; however, activities associated with HDD works will take place predominantly onshore with the export cable exit point 400 m to 700 m offshore within the near-shore environment. There are not anticipated to be any effects from HDD on marine mammals and therefore HDD works are not considered further in this assessment.

If there was low confidence in the data gathered for other developments screened into the project long list (e.g., no information was available on construction timelines or limited project details), the project was screened out of the short list as a meaningful cumulative assessment cannot be carried out. However, if other developments were considered to be reasonably foreseeable, for example, offshore wind projects which have recently been awarded an Option Agreement from Crown Estate Scotland in the ScotWind seabed leasing round, these projects were also considered qualitatively.

The long list of projects was screened to remove all projects that have:

- no data available;
- no timeline available; or
- no temporal overlap.

The cumulative project short list was submitted to Marine Scotland and consultees for comment, and, following updates, provides the list of projects to be considered in the marine mammal CEA; this short list is included in Offshore EIA (Volume 3) Appendix 6.1. An illustration of the projects considered in this cumulative effects assessment for marine mammals is provided in Figure 9.1.

9.2 Screening Noise Impacts

Certain noise impacts assessed for the Offshore Development alone are not considered in the marine mammal CEA due to:

- a) the highly localised nature of the impacts,
- b) management and mitigation measures in place for the Offshore Development and on other projects will reduce the risk occurring, and
- c) where the potential significance of the effect from the Offshore Development alone has been assessed as negligible significance.

The noise impacts excluded from the marine mammal CEA for these reasons are:

- Auditory injury (PTS): where PTS may result from activities such as pile driving and UXO clearance, suitable mitigation will be put in place to reduce injury risk to marine mammals to negligible levels (as a requirement of European Protected Species legislation);
- Disturbance from vessels: highly localised and negligible significance. In addition, it is expected that all offshore projects will employ a vessel management plan or follow best practice guidance to reduce the potential for disturbance effects;
- Barrier effects/ operational noise: highly localised and negligible significance.

Therefore, the only impact associated with the Offshore Development that is considered in the marine mammal CEA is the potential for disturbance from underwater noise during construction activities.

Other projects with impact pathways considered to have the potential to act cumulatively with the Offshore Development include construction phases of offshore wind farms and other marine renewable developments (wave and tidal), coastal developments (involving piling of port infrastructure), cable and pipeline installation (involving dredging/trenching), seismic survey (generating noise through the use of airguns), along with carbon capture and storage (noise associated with e.g., construction of infrastructure (inc. piling), geophysical survey, pipeline installation) and oil and gas decommissioning (noise from removal of infrastructure, rock placement).

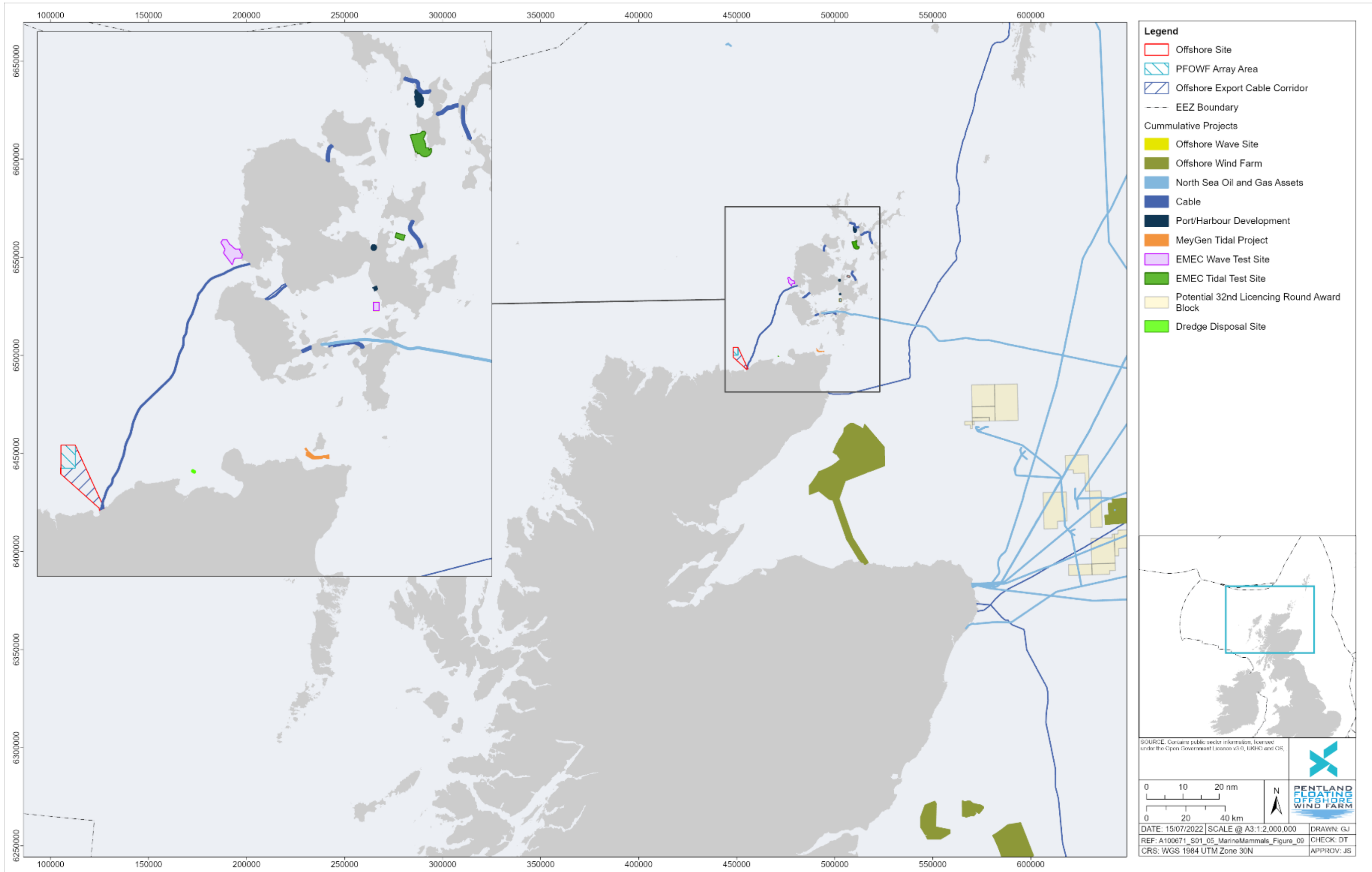


Figure 9.1 Illustration of projects considered in the cumulative effects assessment for marine mammals

9.3 Disturbance from underwater noise

9.3.1 Offshore wind farms

Different OWF EIAs have assessed disturbance using a variety of thresholds and methods, including effective deterrence ranges, fixed noise thresholds and dose-response curves. This means that the predicted number of animals disturbed is not comparable between projects. However, since the consents for these Projects are based on the numbers presented in the EIAs, they have been presented here as the most relevant indication of the number of animals that may be impacted by each OWF Project. For all OWF projects screened into this CEA, the worst-case disturbance ranges for impact piling presented in the respective EIAs are included in the assessment.

For those Projects where data may be unavailable (for example, Project EIAs undertaken in other countries or Projects that haven't yet released Preliminary Environmental Information Report (PEIR) or EIA Reports) the assessment of disturbance follows the advice provided in JNCC (2020) where unabated impact pile-driving of a monopile and clearance of a UXO is predicted to have an effective deterrence range (EDR) of 26 km for harbour porpoise. In the absence of recommended EDRs for other species, this has been applied to all marine mammals. For floating OWF projects, an EDR of 15 km has been assumed for the worst-case scenario that pin piles may be required to anchor mooring lines. EDRs are combined with the estimated density of animals from the SCANS-III survey block relevant to each development.

9.3.2 Other marine renewables developments

While several operational wave and tidal developments were screened into the short list (see Offshore EIA (Volume 3) Appendix 6.1) for potential cumulative impacts to marine mammals from risk of collision and entanglement due to overlap in operational timelines, none were identified as having sufficient information available to identify potentially overlapping construction timelines with PFOWF, and associated potential for cumulative noise impacts.

It is noted that the MeyGen tidal project has currently four 1.5 MW turbines deployed, as well as a subsea hub for the existing turbines which was installed in 2020. In 2017, Meygen Limited were granted permission to deploy a further four turbines (Phase 1b); however, no construction activity for this phase has taken place to date, and there is very limited publicly available information on their construction timelines for this phase. The project has restrictions on the consent for phased development (under the deploy and monitor approach) and cannot proceed to subsequent phases without application and further consultation. On 7th July 2022, Meygen Limited was successful in the Contracts for Difference (CfD) Allocation Round 4, for Phase 1c (28MW). Whilst the results announcement from the Department for Business, Energy and Industrial Strategy indicates that MeyGen aim to install this phase in 2026/27, a new separate application will need to be made to Marine Scotland for this phase under their phased consent condition. As the CfD announcement was made less than one month prior to submission of the application for the Offshore Development (i.e. beyond the 6 month cut-off agreed with MS-LOT), and there is no further information available on MeyGen's plans or construction timelines for any of these works, this project has not been considered in the assessment of cumulative noise effects for PFOWF.

9.3.3 Seismic surveys

The potential number of seismic surveys that could be undertaken is unknown. Therefore, it has been assumed that four seismic surveys are conducted within the North Sea at any one time (to account for concurrent surveys in the northern and southern North Sea in both UK waters and those of neighbouring North Sea nations). It has been assumed that the EDR for seismic surveys is 12 km as per the advice provided in JNCC (2020). It is considered that this approach is sufficiently precautionary (i.e., it is unlikely that this number of seismic surveys will be occurring concurrently with the Offshore Development construction) to also account for any behavioural disturbance resulting from high-resolution geophysical site surveys (HRGS) within relevant regions (e.g., to support wind farm development). While the potential for behavioural disturbance from HRGS is poorly understood, it is acknowledged to be of a considerably lower magnitude than that of seismic surveys (e.g., precautionary 5 km EDR suggested in JNCC *et al*. 2020). The estimated disturbed area is combined with the estimated density of animals from the SCANS-III survey block relevant to each development.

It is acknowledged that seismic surveys are a moving sound source and not a point source. Therefore, the approach presented in BEIS (2020) has been adopted here which assumes that a seismic survey vessel travelling at 4.5 knots (8.3 km/h) could, in theory, survey a total of 199 km of survey line in a single 24 hour period and therefore impact an area of 5,228 km^2/day (Figure 9.2). The estimated disturbed area is combined with an average density of animals from the SCANS-III survey block relevant to each development.

The BEIS (2020) report states that this is *"an unrealistic worst-case scenario as it is very unlikely that a survey would be undertaken along a single transect line of 199 km in a single day […]. Shorter survey lines will require the vessel to undertake line turns each lasting approximately three hours, during which time the airguns will be switched off, thus reducing the length of line surveyed in a day"*. It is also worth highlighting that large scale airgun seismic surveys in the North Sea do not occur often. As stated in BEIS (2020), the majority of oil and gas seismic surveys that occurred within the Southern North Sea SAC between 2008 and 2015 lasted less than 30 days. Therefore, while this scenario is presented in this CEA, it is illustrative only and represents an unrealistic worst-case scenario.

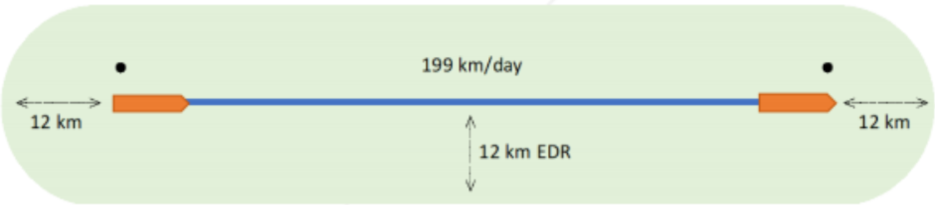


Figure 9.2 Maximum worst-case theoretical area of impact over a single day from a seismic survey travelling at 4.5 knots using 12 km EDR (BEIS 2020)

9.3.4 Cables and pipelines

The primary impact pathway for cables and pipelines is underwater noise produced by pre-laying activities such as dredging and cable/pipe laying activities including vessel noise. There were four cable and pipeline projects screened into this cumulative impact assessment: Scotland England Green Link 1, Scotland England Green Link 2, NorthConnect and the Celtic Interconnector. The risk assessment conducted for the Celtic Interconnector states that neither the geotechnical equipment nor the vessel noise is expected to elicit a behavioural response in marine mammals (Intertek 2014); therefore, this project was not included further in this CEA. The marine mammal ecological impact assessment conducted for the NorthConnect project determined that the maximum predicted disturbance range for all marine mammals would be 464 m for the sub-bottom profiler, with smaller impact ranges for vessel noise and cable burial works (NorthConnect KS 2018); therefore a maximum EDR of 500 m was assumed here. The Scotland England Green Link project Scoping Report identified underwater noise as a potential impact on marine mammals from pre-sweeping dredging and cable installation, though an impact range has not yet been presented (AECOM UK Limited 2021). To be precautionary, a 5 km EDR has been assumed here (see Table 7.3 for context).

9.3.5 Carbon capture and storage

The only carbon capture and storage project screened into the assessment is Acorn, however, this project is pre-consent and no information on construction methods or potential impacts are available. As such, it was not possible to include this project in the quantitative CEA.

9.3.6 Coastal developments

Where available, the worst-case disturbance ranges presented in EIAs for coastal developments are included in the assessment. This includes the Faray slipway extension and landing jetty in Orkney, where the EIAR for this project identified potential disturbance impacts to marine mammals as a result of piling between May and June, and predicted an area of disturbance of 7.99 km^2 for all marine mammals species (corresponding to the modelled extent of the SPL_{rms} 160 dB re 1 µPa noise contour) and estimated the number of animals disturbed based on SCANS-III density estimates for cetaceans and site-specific surveys for seals (ITPEnergised 2021). It should be noted that the number of animals estimated to be disturbed presented for this project are considered to be highly precautionary due to the likelihood of bubble curtains being deployed around sheet piling to mitigate the potential for PTS, and therefore reducing the extent of disturbance.

Two additional coastal development projects were screened into the CEA: Hatston Pier Proposed Extension and Scapa Deep Water Quay, both part of the Orkney Harbours Masterplan. At this time, scoping reports provide the only available environmental assessment information for these two projects. No quantitative assessment is provided of impacts to marine mammals, but both projects note the potential for impact piling (tubular (i.e. pin) or sheet piles) and the potential for impacts on marine mammals. Therefore, a 15 km EDR, to account for pin-piling, is applied to each project's location, trimmed to exclude land masses and waters in the acoustic shadow from land masses. The resulting assumed impact areas were 57 km^2 (Hatston) and 165 km^2 (Scapa).

9.3.7 Oil and gas decommissioning

There were several oil and gas decommissioning projects that were initially screened into the CEA for marine mammals. The majority of these have publicly available Decommissioning Plans and upon review of these Plans, many had scoped out impacts from underwater noise. The remaining Plans all stated that underwater noise would be limited to cutting operations, trenching and vessel noise (no explosive decommissioning was included), with many of the Plans stating that a Simultaneous Operations (SIMOPS) Plan for vessel activity would be put in place to minimise noise related impacts. Therefore, it is expected that any residual effects of underwater noise from these oil and gas decommissioning activities would be negligible. As such, they were not included quantitatively in the CEA for marine mammals.

9.4 Precaution in the assessment

It should be noted that there are significant levels of precaution / conservatism within this CEA, resulting in the estimated effects being highly precautionary. The main areas of precaution / conservatism in the assessment include:

- The approach of summing across concurrent activities assumes that there is no spatial overlap in the impact footprints between individual activities, which is highly conservative considering the close proximity of many of the OWF projects;
- The inclusion of projects with a high degree of uncertainty; for example, those lacking consent, an EIAR, PEIR, and/or Scoping Report. In such instances, worst-case scenarios are assumed in the absence of other information;

- The exact timing of pile driving for each development is unknown, therefore it has been assumed that these activities could occur at any point throughout the construction window. This has resulted in piling activities occurring over multiple consecutive years with associated estimated disturbance levels far greater than would occur in reality;
- The timelines presented in PEIR and EIAR chapters are worst-case scenarios and the true period of piling activity will likely be shorter;
- The assumption that all OWF developments will install pile-driven monopile foundations. The project envelope for most of these developments includes options for pin-piles or monopiles, alongside options for non-piled foundations. As a worst-case assumption monopiles have been assumed; however, a portion of these projects may instead use jacket foundations with pin-piles, which will have a much lower recommended effective deterrence range (15 km instead of 26 km, equating to a 66% smaller area) (JNCC 2020), and will therefore disturb far fewer animals;
- In the absence of project-specific assessments of the number of disturbed animals, the application of EDRs based on those recommended for harbour porpoise; these can be considered to be precautionary for other species of marine mammal, which have not been reported to respond as strongly to relevant underwater noise as porpoise; and,
- The assumption that the extent of the disturbance effects remains constant throughout the construction of each wind farm. Passive acoustic monitoring during pin piling at the Beatrice wind farm in the Moray Firth showed a 50% probability of porpoise response (a significant reduction in detection relative to baseline) within 7.4 km at the first location piled, with decreasing response levels over the construction period, to a 50% probability of response within 1.3 km by the final piling location (Graham *et al.* 2019).

9.5 Results

9.5.1 Harbour porpoise

All projects in the North Sea and West Scotland MUs considered in the CEA for harbour porpoise are shown in Table 9.1. All of these fall within the North Sea MU, and so only impacts to the North Sea MU are assessed in this CEA.

The worst-case scenario assumes that in 2025, disturbance to the harbour porpoise MU is caused by the Offshore Development together with 11 other offshore wind farm construction activities, three cable/pipeline projects, three coastal developments and four seismic surveys (Table 9.1). It is highly unlikely that all of these projects, would conduct unmitigated construction activities at the same time. For example, the Hornsea, Norfolk, East Anglia, Dogger Bank and DEP/SEP projects will all be required to implement a Site Integrity Plan (SIP) in order to ensure that the potential for disturbance from underwater noise within the Southern North Sea (SNS) SAC does not exceed the limits of 20% of the area over a day, or 10% of the area on average over a season. The purpose of the SIP is to manage the uncertainty presented by future construction scenarios cumulatively with respect to underwater noise within the Southern North Sea (SNS) SAC, to provide mitigation measures if required, and to provide certainty that adherence to the threshold values are not exceeded. Therefore, to avoid the thresholds being exceeded, mitigation measure(s) would be required across the various OWFs. Thus, the requirement for a SIP to ensure compliance with the SNS SAC conservation objectives will ensure that considerably fewer harbour porpoise will be disturbed than the worst-case unmitigated numbers presented in this CEA.

Even in the extremely unlikely scenario that all projects construct in 2025 as planned, and that they construct without mitigation, the overall impact represents 6.0% of the MU disturbed per activity day (when seismic surveys are excluded) or 9.2% (when seismic surveys are included). The majority of this combined impact is predicted to come from the four seismic surveys, pile driving at the Hornsea Projects, Dudgeon & Sheringham Shoal Extensions, the Norfolk Projects, the Dogger Bank Projects and the East Anglia Projects, with these wind projects being subject to implementation of a SIP to manage disturbance to the SNS SAC. It should be noted that the proportion of the overall predicted disturbance effects that are attributable to the Offshore Development is minimal (2% or 1% depending on whether seismic surveys are included), and represents a maximum of 63 days of piling disturbance. Thus, the inclusion of the Offshore Development makes a negligible difference to the CEA result.

The upcoming ScotWind OWFs have not been included quantitatively here as there is no information available yet upon which to base an assessment. However, it is expected that these projects will construct well after the Offshore Development and therefore there is expected to be no overlap in construction activities.

Even in the extremely unlikely scenario that all projects construct in 2025 as planned, and that they construct without mitigation, the overall cumulative impact of disturbance to harbour porpoise is assessed as being of **Low** magnitude since it relates to temporary displacement effects to a wide-ranging species across a large, open habitat, such that the combined impacts would not be expected to result in an effect on the conservation status or integrity of the species. This assessment of a **Low** magnitude, combined with a **Low** sensitivity to construction noise disturbance for harbour porpoise, results in a conclusion of **Minor** effect significance, which is considered to be **Not Significant** in EIA terms.

Table 9.1 Number of harbour porpoise predicted to be disturbed each day in the CEA

Project	2022	2023	2024	2025	2026	2027	2028
PFOWF (this project)				**323**	**323**		
Wind farms							
Rampion 2			551	551	551	551	
Hornsea Four					6417	6417	
Norfolk Vanguard	2676	2676	2676	2676			
Norfolk Boreas				2251	2251	2251	2251
East Anglia ONE North				1289	1289	1289	
East Anglia Two					1551	1551	1551
East Anglia Three			1889	1889			
Thor (Danish waters)				588	588		
Green Volt			284	284	284		
Blyth Offshore Demo 2				423			
Dogger Bank C			1920				
Sofia		2035	2035	2035	2035		
Hornsea Three		4999	4999	4999			
Dudgeon & Sheringham Shoal Extensions			3483	3483	3483		
Cables							
Scotland England Green Link 1		47	47	47	47		
Scotland England Green Link 2			47	47	47	47	47
NorthConnect	0	0	0	0	0		
Coastal developments							
Faray slipway				4	4		
Hatston Pier Extension			9	9	9	9	
Scapa Deep Water Quay			25	25	25	25	
Seismic surveys							
Seismic survey 1*	2719	2719	2719	2719	2719	2719	2719
Seismic survey 2	2719	2719	2719	2719	2719	2719	2719
Seismic survey 3	2719	2719	2719	2719	2719	2719	2719
Seismic survey 4	2719	2719	2719	2719	2719	2719	2719
Totals (excluding seismic survey)							
Total porpoise	2676	9757	17965	20921	18902	12140	3849
% MU	0.8%	2.8%	5.2%	6.0%	5.5%	3.5%	1.1%
% of the total attributable to the Offshore Development	0%	0%	0%	2%	2%	0%	0%
Totals (including seismic survey)							
Total porpoise	13552	20633	28841	31797	29778	23061	14725
% MU	3.9%	6.0%	8.3%	9.2%	8.6%	6.6%	4.2%
% of the total attributable to the Offshore Development	0%	0%	0%	1%	1%	0%	0%

* To assess the impact from seismic surveys, an average density across the entire MU was assumed (0.52 porpoise/km^2)

9.5.2 Bottlenose dolphin

No projects were identified in the cumulative short list within the bottlenose dolphin Coastal West Scotland and Hebrides MU; therefore, the CEA presented here is limited to those projects that are within (or adjacent to) the Coastal East Scotland MU. Considering that the population is considered to be largely restricted to shallow, near-shore waters, no disturbance is considered from seismic survey activity. Similarly, as the Green Volt wind farm project is located > 70 km offshore, the only noise impact pathway considered here for the bottlenose dolphin CES MU is other construction activities associated with export cable installation, with landfall planned in the Peterhead area on the Aberdeenshire coast. This is addressed by applying a precautionary EDR of 5 km, as has been suggested by some authors for harbour porpoise responses to dredging activity (Verboom, 2014; McQueen *et al.*, 2020).

The upcoming ScotWind OWFs have not been included quantitatively here as there is no information available yet upon which to base an assessment. However, it is expected that these projects will construct well after the Offshore Development and therefore there is expected to be no overlap in activities. Given the more offshore locations of the ScotWind projects, it is also expected that there would be very limited potential for effects on the coastal bottlenose dolphin population.

The worst-case scenario assumes that in 2025 and 2026, disturbance to the bottlenose dolphin CES MU is caused by the Offshore Development together with one other offshore wind farm construction activity, three cable/pipeline projects and three coastal developments, with a total of 14 dolphins (6.3% of the CES MU) predicted to be disturbed per activity day. Piling associated with the Offshore Development accounts for the greatest contribution to these totals (6 dolphins per activity day) (Table 9.2).

To assess whether this (highly precautionary) predicted level of disturbance would be sufficient to cause a population level effect, the iPCoD model[16] (version 5.2) was run. The demographic parameters used were those for the coastal east Scotland MU (Sinclair *et al.* 2020). A single schedule was run: 'consecutive' - with disturbance assumed to 14 animals on 63 consecutive days centred on May-June. This scenario is considered worst-case as it resulted in the greatest predicted impacts for the project alone (see Section 6.3.2).

The results of the modelling showed that there was an extremely small predicted impact, with impacted populations predicted to be 99.1%, 99.3% and 99.7% of unimpacted populations at 1, 6 and 12 years after the disturbance, respectively. This is not considered to represent a significant effect on the conservation status or integrity of the population.

Bottlenose dolphins have been assessed as of **Low** sensitivity to construction noise disturbance, and the cumulative effect of disturbance has been assessed as **Low** magnitude**.** Therefore, this effect is assessed as **Minor** significance, which is considered to be **Not Significant** in EIA terms.

Table 9.2 Number of bottlenose dolphins predicted to be disturbed each day in the CEA

Project	2022	2023	2024	2025	2026	2027	2028
PFOWF (this project)				**6**	**6**		
Wind farms							
Green Volt			2	2	2		
Cables							
Scotland England Green Link 1		2	2	2	2		
Scotland England Green Link 2			2	2	2	2	2
NorthConnect			<1	<1	<1	<1	<1
Coastal developments							
Faray slipway				0	0		
Hatston Pier Extension			<1	<1	<1	<1	
Scapa Deep Water Quay			1	1	1	1	
Totals*							
Total dolphins	0	2	6	14	14	4	0
% MU	0%	0.9%	3.6%	6.3%	6.3%	1.8%	0.9%
% of the total attributable to the Offshore Development	n/a	0%	0%	43%	43%	0%	0%

*Note: * <1 dolphin at Hatston and <1 at NorthConnect projects combined are considered as 1 dolphin in the totals*

[16] http://www.smruconsulting.com/products-tools/pcod/ipcod/

9.5.3 White-beaked dolphin

While a large number of projects were screened into the marine mammal CEA for the white-beaked dolphin Celtic and Greater North Sea MU, most projects concluded that white-beaked dolphins were not common enough at the site to be screened into the project specific impact assessment. As a result, there is little impact to the white-beaked dolphin MU predicted in this CEA, as indicated by multiple zeros in cells in Table 9.3. The worst-case scenario assumes that in 2025, disturbance to the white-beaked dolphin MU is caused by the Offshore Development together with four other offshore wind farm construction activities, two cable/pipeline projects, three coastal developments and four seismic surveys (Table 9.3). Assuming these projects all construct at the same time, this results in disturbance to 1,174 white-beaked dolphins (2.7% MU) per day.

White-beaked dolphins have been assessed as of **Low** sensitivity to construction noise disturbance, and the cumulative impact of disturbance has been assessed as **Low** magnitude**.** Therefore, this effect is assessed as **Minor** significance, which is considered to be **Not Significant** in EIA terms.

Table 9.3 Number of white-beaked dolphins predicted to be disturbed each day in the CEA

Project	2022	2023	2024	2025	2026	2027	2028
PFOWF (this project)				**337**	**337**		
Wind farms							
Rampion 2			0	0	0	0	
Erebus					0		
Hornsea Four					85	85	
Norfolk Vanguard	0	0	0	0			
Norfolk Boreas				0	0	0	0
East Anglia ONE North				0	0	0	
East Anglia Two					0	0	0
East Anglia Three			0	0			
Awel y Môr							0
Codling Wind Park			0	0	0		
Dublin Array				0	0		
North Irish Sea Array Offshore Wind Farm				0	0	0	
Thor				0	0		
Green Volt			26	26	26		
Blyth Offshore Demonstrator – Phase 2				172			
Dogger Bank C			3				
Sofia		3	3	3	3		
Hornsea Three		5	5	5			
Dudgeon & Sheringham Shoal Extensions			0	0	0		
Stora Middelground					0		
Cables							
Scotland England Green Link 1		19	19	19	19		
Scotland England Green Link 2			19	19	19	19	19
NorthConnect	0	0	0	0	0		
Coastal developments							
Faray slipway extension and landing jetty				1	1		
Hatston Pier Extension			1	1	1	1	
Scapa Deep Water Quay			3	3	3	3	
Seismic surveys							
Seismic survey 1*	147	147	147	147	147	147	147
Seismic survey 2	147	147	147	147	147	147	147
Seismic survey 3	147	147	147	147	147	147	147
Seismic survey 4	147	147	147	147	147	147	147
Totals							
Total dolphins	588	615	663	1,174	1,083	692	607
% MU	1.3%	1.4%	1.5%	2.7%	2.5%	1.6%	1.4%
% of the total attributable to the Offshore Development	0%	0%	0%	28.7%	31.1%	0%	0%
* To assess the impact from seismic surveys, an average density across the entire MU was assumed (0.028 dolphins/km^2).							

9.5.4 Risso's dolphin

While a large number of projects were screened into the marine mammal CEA for the Risso's dolphin Celtic and Greater North Sea MU, most projects concluded that Risso's dolphins were not common enough at the site to be screened into the project specific impact assessment. As a result, there is little impact to the Risso's dolphin MU predicted in this CEA, as indicated by multiple zeros in cells in Table 9.4. The worst-case scenario assumes that in 2025-2026, disturbance to the Risso's dolphin MU is caused by the Offshore Development together with three other offshore wind farm construction activities and four seismic surveys (Table 9.4). Assuming these projects all construct at the same time, this results in disturbance to 242 Risso's dolphins (2.0% MU) per day.

Risso's dolphins have been assessed as of **Low** sensitivity to construction noise disturbance. Even in the extremely unlikely scenario presented in this CEA, the overall impact of cumulative noise disturbance to Risso's dolphins is assessed as being of **Low** magnitude since it is not expected that the combined impacts would result in an effect on the conservation status or integrity of the species. Therefore, this effect is assessed as of **Minor** significance, which is considered to be **Not Significant** in EIA terms.

Table 9.4 Number of Risso's dolphins predicted to be disturbed each day in the CEA

Development	2022	2023	2024	2025	2026	2027	2028
PFOWF (this project)				**57**	**57**		
Wind farms							
Rampion 2			0	0	0	0	
Erebus					0		
Hornsea Four					0	0	
Norfolk Vanguard	0	0	0	0			
Norfolk Boreas				0	0	0	0
East Anglia ONE North				0	0	0	
East Anglia Two					0	0	0
East Anglia Three			0	0			
Awel y Môr							69
Codling Wind Park			7	7	7		
Dublin Array				7	7		
North Irish Sea Array Offshore Wind Farm				7	7	7	
Thor				0	0		
Green Volt			0	0	0		
Blyth Offshore Demonstrator – Phase 2				0			
Dogger Bank C			0				
Sofia		0	0	0	0		
Hornsea Three		0	0	0			
Dudgeon & Sheringham Shoal Extensions			0	0	0		
Stora Middelground					0		
Cables							
Scotland England Green Link 1		0	0	0	0		
Scotland England Green Link 2			0	0	0	0	0
NorthConnect	0	0	0	0	0		
Coastal developments							
Faray slipway extension and landing jetty				0	0		
Hatston Pier Extension			0	0	0	0	
Scapa Deep Water Quay			0	0	0	0	
Seismic surveys							
Seismic survey 1*	41	41	41	41	41	41	41
Seismic survey 2	41	41	41	41	41	41	41
Seismic survey 3	41	41	41	41	41	41	41
Seismic survey 4	41	41	41	41	41	41	41
Totals							
Total dolphins	164	164	171	242	242	171	233
% MU	1.3%	1.3%	1.4%	2.0%	2.0%	1.4%	1.9%
% of the total attributable to the Offshore Development	0%	0%	0%	23.6%	23.6%	0%	0%

* To assess the impact from seismic surveys, an average density across the entire MU was assumed (0.0078 dolphins/km^2).

9.5.5 Common dolphin

While a large number of projects were screened into the marine mammal CEA for the common dolphin Celtic and Greater North Sea MU, most projects, including all North Sea wind farm projects, concluded that common dolphins were not common enough at the site to be screened into the project specific impact assessment. As a result, there is little impact to the common dolphin MU predicted in this CEA, as indicated by multiple zeros in cells in Table 9.5. The worst-case scenario assumes that in 2026, disturbance to the common dolphin MU is caused by the Offshore Development, together with two other offshore wind farm construction activities (Rampion 2 and Erebus), one coastal development and four seismic surveys. Assuming these projects all construct at the same time, this results in disturbance to 2,150 common dolphins (2.1% MU) per day.

Common dolphins have been assessed as of **Low** sensitivity to construction noise disturbance. Even in the extremely unlikely scenario presented in this CEA, the overall impact of cumulative noise disturbance to common dolphins is assessed as being of **Low** magnitude since it is not expected that the combined impacts would result in an effect on the conservation status or integrity of the species. Therefore, this effect is assessed as of **Minor** significance, which is considered to be **Not Significant** in EIA terms.

Table 9.5 Number of common dolphins predicted to be disturbed each day in the CEA

Development	2022	2023	2024	2025	2026	2027	2028
PFOWF (this project)				**8**	**8**		
Wind farms							
Rampion 2			508	508	508	508	
Erebus					265		
Hornsea Four					0	0	
Norfolk Vanguard	0	0	0	0			
Norfolk Boreas				0	0	0	0
East Anglia ONE North				0	0	0	
East Anglia Two					0	0	0
East Anglia Three			0	0			
Awel y Môr							0
Codling Wind Park			0	0	0		
Dublin Array				0	0		
North Irish Sea Array Offshore Wind Farm				0	0	0	
Thor				0	0		
Green Volt			0	0	0		
Blyth Offshore Demonstrator – Phase 2				0			
Dogger Bank C			0				
Sofia		0	0	0	0		
Hornsea Three		0	0	0			
Dudgeon & Sheringham Shoal Extensions			0	0	0		
Stora Middelground					0		
Cables							
Scotland England Green Link 1		0	0	0	0		
Scotland England Green Link 2			0	0	0	0	0
NorthConnect	0	0	0	0	0		
Coastal developments							
Faray slipway extension and landing jetty				1	1		
Hatston Pier Extension			0	0	0	0	
Scapa Deep Water Quay			0	0	0	0	
Seismic surveys							
Seismic survey 1*	342	342	342	342	342	342	342
Seismic survey 2	342	342	342	342	342	342	342
Seismic survey 3	342	342	342	342	342	342	342
Seismic survey 4	342	342	342	342	342	342	342
Totals							
Total dolphins	1,368	1,368	1,876	1,885	2,150	1,876	1,368
% MU	1.3%	1.3%	1.8%	1.8%	2.1%	1.8%	1.3%
% of the total attributable to the Offshore Development	0%	0%	0%	0.4%	0.4%	0%	0%
* To assess the impact from seismic surveys, an average density across the entire MU was assumed (0.065 dolphins/km^2).							

9.5.6 Minke whale

The worst-case scenario assumes that in 2026, disturbance to the minke whale MU is caused by the Offshore Development together with eight other offshore wind farm construction activities, two cable/pipeline projects, three coastal developments and four seismic surveys (Table 9.6). Assuming these projects all construct at the same time, this results in disturbance to 770 minke whales (3.8% MU) per day.

Minke whales have been assessed as of **Low** sensitivity to construction noise disturbance. Even in the extremely unlikely scenario presented in this CEA, the overall impact of cumulative noise disturbance to minke whales is assessed as being of **Low** magnitude since it is not expected that the combined impacts would result in an effect on the conservation status or integrity of the species. Therefore, this effect is assessed as of **Minor** significance, which is considered to be **Not Significant** in EIA terms.

Table 9.6 Number of minke whale predicted to be disturbed each day in the CEA

Project	2022	2023	2024	2025	2026	2027	2028
PFOWF (this project)				40	40		
Wind farms							
Rampion 2			5	5	5	5	
Erebus					55		
Hornsea Four					46	46	
Norfolk Vanguard	0	0	0	0			
Norfolk Boreas				0	0	0	0
East Anglia ONE North				0	0	0	
East Anglia Two					0	0	0
East Anglia Three			0	0			
Awel y Môr							38
Codling Wind Park			96	96	96		
Dublin Array				96	96		
North Irish Sea Array Offshore Wind Farm				96	96	96	
Thor				0	0		
Green Volt			22	22	22		
Blyth Offshore Demonstrator – Phase 2				27			
Dogger Bank C			34				
Sofia		36	36	36	36		
Hornsea Three		38	38	38			
Dudgeon & Sheringham Shoal Extensions			0	0	0		
Stora Middelground					0		
Cables							
Scotland England Green Link 1		3	3	3	3		
Scotland England Green Link 2			3	3	3	3	3
NorthConnect	0	0	0	0	0		
Coastal developments							
Faray slipway extension and landing jetty				1	1		
Hatston Pier Extension			1	1	1	1	
Scapa Deep Water Quay			2	2	2	2	
Seismic surveys							
Seismic survey 1*	67	67	67	67	67	67	67
Seismic survey 2	67	67	67	67	67	67	67
Seismic survey 3	67	67	67	67	67	67	67
Seismic survey 4	67	67	67	67	67	67	67
Totals							
Total dolphins	268	345	508	734	770	421	309
% MU	1.3%	1.4%	2.5%	3.6%	3.8%	2.1%	1.5%
% of the total attributable to the Offshore Development	0%	0%	0%	5%	5%	0%	0%
* To assess the impact from seismic surveys, an average density across the entire MU was assumed (0.013 dolphins/km^2).							

9.5.7 Harbour and grey seals

The worst-case scenario assumes that in 2025-2026, disturbance to harbour and grey seal of the North Coast and Orkney MU is caused by the Offshore Development together with three other coastal developments. Assuming these projects construct at the same time, this results in disturbance to 162 harbour seals (8.3% MU) and 2,698 grey seals (7.5% MU) per day (Table 9.7).

Table 9.7 Number of harbour and grey seals predicted to be disturbed each day in the CEA

Project	2022	2023	2024	2025	2026	2027	2028
Harbour seals							
PFOWF (this project)				**116**	**116**		
Coastal developments							
Faray slipway extension and landing jetty				2	2		
Hatston Pier Extension			7	7	7	7	
Scapa Deep Water Quay			37	37	37	37	
Total number of harbour seals	0	0	44	162	162	44	0
% MU	0.0%	0.0%	2.3%	8.3%	8.3%	2.3%	0.0%
% of the total attributable to the Offshore Development	na	na	0%	71.6%	71.6%	0%	na
Grey seals							
PFOWF (this project)				**1,890**	**1,980**		
Coastal developments							
Faray slipway extension & landing jetty				277	277		
Hatston Pier Extension			78	78	78	78	
Scapa Deep Water Quay			453	453	453	453	
Total number of grey seals	0	0	531	2,698	2,698	0	0
% MU	0%	0%	1.5%	7.5%	7.5%	1.5%	0%
% of the total attributable to the Offshore Development	na	na	0%	70.1%	70.1%	0%	na

To assess whether the predicted level of disturbance would be sufficient to cause a population level effect on grey seals, the iPCoD model was run, using the demographic parameters for the North Coast and Orkney MU (Sinclair *et al.* 2020). Two schedules of disturbance were considered:

- 'even spread' - 63 days of overlapping activity, with 63 days of piling impact from the Offshore Development, Hatston and Scapa projects evenly spread across a four-month piling window, 21 days of which also included piling impacts from Faray slipway; and,
- 'consecutive' - 63 consecutive days of overlapping activity from the Offshore Development, Hatston and Scapa projects, 21 of which also included piling impacts from Faray slipway.

The results of the modelling showed that there was no predicted impact on the harbour or grey seal population as a result of the cumulative disturbance activity for either schedule (Table 9.8). The impacted populations are expected to remain the same as the unimpacted populations. This is therefore assessed as a **Negligible** magnitude.

Harbour and grey seals have been assessed as of **Moderate** and **Negligible** sensitivity to construction noise disturbance, respectively. Even in the extremely unlikely scenario presented in this CEA, the overall impact of cumulative noise disturbance to both harbour and grey seal is assessed as being of **Negligible** magnitude as assessment results predict that changes will be barely detectable, approximating to the 'no change' situation, and will not affect the conservation status or integrity of the receptor. Therefore, this effect is assessed as of **Minor** significance for harbour seals, and **Negligible** significance for grey seals, both of which are considered to be **Not Significant** in EIA terms.

Table 9.8 Harbour and grey seal cumulative impact population modelling results

Time period	Parameter	Harbour seals (1,951 animals in MU; up to 162 impacted per day)		Grey seals (35,979 animals in MU; up to 2,698 impacted per day)	
	Piling schedule:	even spread	consecutive	even spread	consecutive
After 1 year	Un-impacted population mean	1,746	1,744	36,174	36,347
	Impacted population mean	1,746	1,744	36,174	36,347
	Impacted population as % of un-impacted	100.00	100.00	100.00	100.00
After 6 years	Un-impacted population mean	1,002	1,003	37,416	37,414
	Impacted population mean	1,002	1,003	37,416	37,414
	Impacted population as % of un-impacted	100.00	100.00	100.00	100.00
After 12 years	Un-impacted population mean	518	519	38,776	38,797
	Impacted population mean	518	519	38,776	38,797
	Impacted population as % of un-impacted	100.00	100.00	100.00	100.00

10 Summary

No significant effects, either from injury or disturbance, were predicted for any marine mammal species from the introduction of underwater noise associated with the Offshore Development proposed activities during the pre-construction, construction or operational phases. Likewise, no significant effects were predicted for any marine mammal species in the CEA for introduced underwater noise from the proposed activities.

The following tables summarise the results of the impact assessment.

10.1 Injury and disturbance effects from geophysical and UXO surveys

The impact assessment has found no significant effects from injury or disturbance from geophysical and UXO surveys.

Table 10.1 Significance of injury effects from geophysical and UXO surveys

Species	Mitigation	Sensitivity	Magnitude	Effect Significance
Harbour porpoise	None required.	Low	Negligible	Negligible
Bottlenose dolphin		Low	Negligible	Negligible
White-beaked dolphin		Low	Negligible	Negligible
Minke whale		Low	Negligible	Negligible
Risso's dolphin		Low	Negligible	Negligible
Harbour seal		Low	Negligible	Negligible
Grey seal		Low	Negligible	Negligible

Table 10.2 Significance of disturbance effects from geophysical and UXO surveys

Species	Mitigation	Sensitivity	Magnitude	Effect Significance
Harbour porpoise	Adherence to the Scottish Marine Wildlife Watching Code (SNH 2017)	Low	Negligible	Negligible
Bottlenose dolphin		Low	Negligible	Negligible
White-beaked dolphin		Low	Negligible	Negligible
Minke whale		Low	Negligible	Negligible
Risso's dolphin		Low	Negligible	Negligible
Harbour seal		Low	Negligible	Negligible
Grey seal		Low	Negligible	Negligible

10.2 Injury and disturbance effects from UXO clearance

The impact assessment has found no significant effects from injury or disturbance from UXO clearance.

Table 10.3 Significance of injuryeffects from UXO clearance

Species	Mitigation	Sensitivity	Magnitude	Effect Significance
Harbour porpoise	UXO MMMP	Low	Negligible	Negligible
Bottlenose dolphin		Low	Negligible	Negligible
White-beaked dolphin		Low	Negligible	Negligible
Minke whale		Low	Negligible	Negligible
Risso's dolphin		Low	Negligible	Negligible
Harbour seal		Low	Negligible	Negligible
Grey seal		Low	Negligible	Negligible

Table 10.4 Significance of disturbance effects from UXO clearance

Species	Mitigation	Sensitivity	Magnitude		Effect Significance	
			High-order	Low-order	High-order	Low-order
Harbour porpoise	UXO MMMP	Low	Negligible	Negligible	Negligible	Negligible
Bottlenose dolphin		Low	Low	Negligible	Minor	Negligible
White-beaked dolphin		Low	Negligible	Negligible	Negligible	Negligible
Minke whale		Low	Negligible	Negligible	Negligible	Negligible
Risso's dolphin		Low	Negligible	Negligible	Negligible	Negligible
Harbour seal		Low	Low	Negligible	Minor	Negligible
Grey seal		Low	Low	Negligible	Minor	Negligible

10.3 Injury and disturbance effects from pile driving

The impact assessment has found no significant effects from injury or disturbance from pile driving.

Table 10.5 Significance of injury effects from pile driving

Species	Mitigation	Sensitivity	Magnitude	Effect Significance
Harbour porpoise	Piling MMMP	Low	Negligible	Negligible
Bottlenose dolphin		Low	Negligible	Negligible
White-beaked dolphin		Low	Negligible	Negligible
Minke whale		Low	Negligible	Negligible
Risso's dolphin		Low	Negligible	Negligible
Harbour seal		Low	Negligible	Negligible
Grey seal		Low	Negligible	Negligible

Table 10.6 Significance of disturbance effect from pile driving

Species	Mitigation	Sensitivity	Magnitude	Effect Significance
Harbour porpoise - NS MU	Piling MMMP	Low	Negligible	Negligible
Harbour porpoise - WS MU		Low	Negligible	Negligible
Bottlenose dolphin - CES MU		Low	Negligible	Negligible
Bottlenose dolphin - CWSH MU		Low	Low	Minor
White-beaked dolphin		Low	Negligible	Negligible
Minke whale		Low	Negligible	Negligible
Risso's dolphin		Low	Negligible	Negligible
Harbour seal		Moderate	Negligible	Minor
Grey seal		Negligible	Negligible	Negligible

10.4 Injury and disturbance effects from other construction activities

The impact assessment has found no significant effects from injury or disturbance from other construction activities (dredging, trenching, cable laying, vessels etc.).

Table 10.7 Significance of injury impacts from other construction activities

Species	Mitigation	Sensitivity	Magnitude	Effect Significance
Harbour porpoise	Best practice vessel-handing protocols.	Low	Negligible	Negligible
Bottlenose dolphin		Low	Negligible	Negligible
White-beaked dolphin		Low	Negligible	Negligible
Minke whale		Low	Negligible	Negligible
Risso's dolphin		Low	Negligible	Negligible
Harbour seal		Low	Negligible	Negligible
Grey seal		Low	Negligible	Negligible

Table 10.8 Significance of disturbance effects from other construction activities

Species	Mitigation	Sensitivity	Magnitude	Effects Significance
Harbour porpoise	Best practice vessel-handing protocols	Low	Low	Minor
Bottlenose dolphin		Low	Low	Minor
White-beaked dolphin		Low	Low	Minor
Minke whale		Low	Low	Minor
Risso's dolphin		Low	Low	Minor
Harbour seal		Negligible	Low	Negligible
Grey seal		Negligible	Low	Negligible

10.5 Injury and disturbance effects from operations and maintenance activities

The impact assessment has found no significant effects from injury or disturbance from mooring line pinging.

Table 10.9 Significance of injury effects from mooring line pinging

Species	Mitigation	Sensitivity	Magnitude[1]	Effects Significance[1]
Harbour porpoise	None	Low	No risk	No risk
Bottlenose dolphin		Low	No risk	No risk
White-beaked dolphin		Low	No risk	No risk
Minke whale		Low	No risk	No risk
Risso's dolphin		Low	No risk	No risk
Harbour seal		Low	No risk	No risk
Grey seal		Low	No risk	No risk

[1] While it is noted that 'no risk' is not an assessment term featured in impact magnitude and significance criteria presented in Sections 2.3.3 and 2.3.4, it is considered more appropriate than 'no change' here due to the potential mooring line pinging noise levels being below which the onset of PTS is predicted to occur (see Section 8.2).

Table 10.10 Significance of disturbance effects from mooring line pinging

Species	Mitigation	Sensitivity	Magnitude	Effects Significance
Harbour porpoise	None	Low	Negligible	Negligible
Bottlenose dolphin		Low	Negligible	Negligible
White-beaked dolphin		Low	Negligible	Negligible
Minke whale		Low	Negligible	Negligible
Risso's dolphin		Low	Negligible	Negligible
Harbour seal		Low	Negligible	Negligible
Grey seal		Low	Negligible	Negligible

10.6 Cumulative disturbance effects from underwater noise

The impact assessment has found no potential significant effects from disturbance from the CEA for underwater noise.

Table 10.11 Significance of cumulative disturbance effects from underwater noise

Species	Sensitivity	Magnitude	Effects Significance
Harbour porpoise	Low	Low	Minor
Bottlenose dolphin	Low	Low	Minor
White-beaked dolphin	Low	Low	Minor
Minke whale	Low	Low	Minor
Risso's dolphin	Low	Low	Minor
Harbour seal	Moderate	Negligible	Minor
Grey seal	Negligible	Low	Negligible

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