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IMMINGHAM EASTERN RO-RO TERMINAL

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Associated British Ports

Immingham Eastern Ro-Ro Terminal

Environmental Statement:
Appendix 9.2: Underwater Noise Assessment

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1 Introduction

1.1.1 This report presents an assessment of the potential effects of underwater noise and vibration from the proposed Immingham Eastern Ro-Ro Terminal (IERRT) on marine fauna. The assessment has been undertaken to support the Environmental Statement (ES) that has been prepared for the proposed development. In particular, the assessment has informed the outcomes of the nature conservation and marine ecology assessment (Chapter 9 of the ES), which in turn has informed the Habitats Regulations Assessment (HRA) (Application Document Reference number 9.6) and the Water Framework Direct (WFD) Compliance assessment which is included in Appendix 8.1 to the Environmental Statement (ES) and submitted with the Development Consent Order (DCO) application. A detailed description of the proposed development and construction methodology on which this assessment is based on is included in Chapters 2 and 3 of the ES.

1.1.2 This report has been structured as follows:

- **Section 1: Introduction** provides a brief introduction to the project and need for this assessment;
- **Section 2: Principles of Underwater Acoustics** presents the basic principles which are fundamental to undertaking robust underwater noise assessments;
- **Section 4: Underwater Noise Propagation** reviews the key factors influencing the propagation of underwater noise and presents the preferred underwater noise propagation model that has been applied in this underwater noise assessment;
- **Section 5: Ambient Noise** presents the baseline acoustic conditions of the study area;
- **Section 6: Noise Characteristics of Proposed Development Activities** presents the specific acoustic characteristics of the proposed construction and operational activities;
- **Section 7: Hearing Sensitivity and Responses of Marine Fauna** reviews the hearing sensitivity of marine fauna that occur in the study area and the latest available published criteria that have been applied to determine the scale of potential physiological and behavioural effects;
- **Section 8: Noise Propagation Modelling Outputs** presents the outputs of the underwater noise modelling;
- **Section 9: Potential Effects** reviews the potential effects on local marine fauna; and
- **Section 10: Summary and Conclusions** presents and overview of the outcome of the underwater noise assessment and conclusions.

2 Consultation

2.1.1 Consultation as to whether there are likely to be any underwater noise and vibration effects as a result of the construction and operation of the IERRT project has been undertaken with the Marine Management Organisation (MMO), Cefas (as advisors to the MMO) and the Environment Agency. The outcomes of the formal scoping process, as well as any feedback received in response to the publication of the PEIR, have also been taken into account to inform the assessment.

2.1.2 The outcome of the consultation that has been undertaken to date, along with how it has influenced the nature conservation and marine ecology assessment, is presented in Table 1.

Table 1. Summary of consultation to date

Consultee	Reference, Date	Summary of Response	How comments have been addressed in this chapter
Planning Inspectorate (PINS) MMO	Scoping Opinion, October 2021 Table ID 4.3.11 Appendix 2 MMO response	The ES should either include an assessment of effects of noise and vibration associated with the additional vessel movements in and out of the port (i.e., during operation) or a justification as to why significant effects are unlikely, supported by evidence of agreement to this approach from Natural England and the MMO.	Potential disturbance to coastal waterbirds resulting from noise and visual stimuli in operation (including vessel movements) has been considered in the assessment in the ES (Section 9.8). Operational underwater noise effects have been scoped out with a rationale provided in the ES (Section 9.8).
PINS MMO	Scoping Opinion, October 2021 Table ID 4.3.12 Appendix 2 MMO response	The MMO agree that a simple modelling approach in this instance is appropriate (though there are some limitations). The ES should provide full details of the underwater noise modelling used and a justification as to why the approach is considered to be robust.	Noted.
Environment Agency	Environment Agency response dated 23 February 2022	Due to a current lack of specialist resource in respect of the noise impacts from percussive piling on migratory fish, we are currently deferring to the Marine Management Organisation and its specialist advisers in respect of this topic.	Noted.

Consultee	Reference, Date	Summary of Response	How comments have been addressed in this chapter
MMO	MMO response dated 23 February 2022	Primary impacts associated with underwater noise during the construction phase have been considered. Given the location and proposed activities, the MMO, in consultation with Cefas, consider that potential displacement and acoustic barriers to migration are likely to be the main potential impacts of concern.	Noted.
MMO	MMO response dated 23 February 2022	The assessment refers to noise exposure criteria from Popper *et al.* (2014) for fish species in terms of mortality and injury. For behaviour, the assessment uses thresholds derived from Hawkins *et al.* (2014). These thresholds can be considered to be a conservative indicator for the risk of behavioural responses and potential displacement. Furthermore, these thresholds are based on the single strike sound exposure level, and the peak-to-peak sound pressure level.	Noted.
MMO	MMO response dated 23 February 2022	It is not entirely appropriate to convert the peak-to-peak threshold to a zero-to-peak threshold as has been done, although we do appreciate that like-for-like metrics with the source level are trying to be compared.	The peak-to-peak threshold provided by Hawkins *et al.* (2014) have been converted to a zero-to-peak threshold using a metric conversion that is provided by NOAA Fisheries in their spreadsheet tool and user manual (NOAA, 2021). This allows like-for-like metrics to be compared which is essential for a robust assessment.

Consultee	Reference, Date	Summary of Response	How comments have been addressed in this chapter
MMO	MMO response dated 23 February 2022	The noise assessment consists of a mismatch of models and tools and is somewhat confusing. In addition to the simple spreading model and source model, the assessment uses a calculator developed by the National Marine Fisheries Service (NMFS) (2021) to calculate the ranges at which the instantaneous peak and cumulative sound exposure level (SEL) thresholds for impact pile driving are reached.	The noise assessment consists of the following three tools: the logarithmic spreading model to predict unweighted received levels and effects of dredging/vessel movements on fish, the NMFS pile driving calculator to determine the potential impacts of piling on fish (NMFS, 2021) and the NOAA spreadsheet tool to determine the potential impacts of piling and dredging/vessel movements on marine mammals (NOAA, 2021). We also use an Environment Agency model to estimate the source level of the tubular piles being driven by an impact hammer.
MMO	MMO response dated 23 February 2022	The MMO, in consultation with Cefas, are not familiar with this calculator or its workings, but it appears that the thresholds for fish in the calculator are derived from the Fisheries Hydroacoustic Working Group (FHWG) (2008) and cannot be changed. Therefore, without taking a more detailed look at the calculator, it is not clear how the ranges in Table 6 of this Appendix have been derived, which are based on the Popper *et al.* criteria.	The existing thresholds within the NMFS pile driving calculator have been modified and replaced with the Popper *et al.* (2014) thresholds by copying the relevant cells from the pile driving calculator worksheet into a new Excel spreadsheet.
MMO	MMO response dated 23 February 2022	Source level is a modelling concept, and source level estimates are, in general, highly contextual to the propagation model they are used with. This is especially the case for peak	The source levels for project activities are based on published zero-peak sound pressure level (SPL), sound exposure level (SEL) and/or root mean

Consultee	Reference, Date	Summary of Response	How comments have been addressed in this chapter
		pressure source levels, due to the empirical nature of methods which might be used for the calculation of peak pressure propagation loss. Such empirical methods can produce reasonable predictions after suitable validation or calibration. However, an *ad hoc* assemble of disparate tools and source level estimates as shown in this assessment offers less confidence in the accuracy of the predictions. A more defensible approach, but still based on simple models could start from assessing the received levels in the sound exposure level (SEL) metric (single strike SEL), where, arguably, there is better understanding of both source levels and propagation loss (and where appropriately conservative estimates could be derived from peer-reviewed literature), and then these received levels could be translated to the peak-pressure metric (for example, Lippert *et al*., 2015).	square (RMS) measurements taken in the field and back-calculating to 1 m using the simple logarithmic spreading model. Following feedback from the MMO and Cefas advisors, the unweighted received levels in the SEL metric associated with the proposed development activities have been modelled and then translated to the peak SPL metric using equation (1) in Lippert *et al*. (2015). Further details are provided in Section 4 of this report.
MMO	MMO response dated 23 February 2022	The source levels that have been input into the NMFS calculator for impact piling do not appear to be correct (i.e., 232 dB SPLpeak, 207 dB SEL, and 217 dB root mean square (RMS) sound pressure). It is not clear why the rms source level is 10 dB higher than the SEL source level. Additionally, the rms metric is not appropriate for assessing impulsive sources such as impact piling.	RMS SL was not used to predict the distance at which fish response criteria are reached during impact piling and has been removed from the list of input values included in Table 6 of this report to avoid confusion. The basis of the peak SPL SL and SEL SL input values is explained in the right-hand column of Table 6 of this report.

Consultee	Reference, Date	Summary of Response	How comments have been addressed in this chapter
MMO	MMO response dated 23 February 2022	The NOAA calculator has also been used for calculating vibro-piling impact ranges. The input values are provided in Table 7 of this Appendix. The peak source level has been stated as 198 dB, while the SEL and RMS source levels are 183 dB. These values are different to the source level values provided earlier. Additionally, please note that vibro-piling is not impulsive, so the rms metric is more appropriate in this instance.	The NMFS piling calculator allows you to specify the distance from the source at which the acoustic values were measured. The values quoted in Table 7, Appendix 9.2 of the PEIR were, therefore, the near-source measurements taken at 10 m from the source and the assumption that more than one piling rig with vibro hammers will be used concurrently. The SL values quoted in Section 5.2, Appendix 9.2 of the PEIR have been back-calculated to 1 m using the simple logarithmic spreading model (equation 1). The input values specified in this appendix have been amended so they only quote SL values at 1 m to avoid any confusion.
MMO	MMO response dated 23 February 2022	Paragraph 8.1.22 states "*The range at which the Hawkins et al. (2014) quantitative instantaneous peak SPL behavioural threshold is reached is within around 52 m from dredging…*". However, the rms source level for dredging cannot be compared with the (arbitrary) SPLpeak Hawkins *et al*. (2014) threshold as they are different metrics.	This paragraph has now been removed from this report as it is not appropriate to compare different metrics.
MMO	MMO response dated 23 February 2022	It has been stated that piling will be undertaken for 20 weeks, however it is not clear exactly when the piling and dredging works will be taking place, and whether the	The exact timing and programme for the piling and dredging have not been confirmed at this stage and, therefore, the assessment has been undertaken

Consultee	Reference, Date	Summary of Response	How comments have been addressed in this chapter
		works will overlap with sensitive periods for migratory fish species. There is a likelihood that noise from construction activities will create a temporary acoustic barrier in the river during construction operations which may cause behavioural changes in migrating and spawning fish during their upstream or downstream migrations. Therefore, more information should be provided on sensitive seasons of fish species known to migrate through the area where the works are proposed in relation to the proposed dates for piling and dredging works.	on the basis that the works could take place at any time of year as a worst case. Further details of the sensitive seasons for fish species that migrate through the Humber Estuary is provided in Section 9.6 of the Nature Conservation and Marine Ecology chapter (Chapter 9) of the ES.
MMO	MMO response dated 23 February 2022	The MMO, in consultation with Cefas, cannot agree with the significant levels of the assessment presented in relation to underwater noise impacts on fish receptors from both dredging and dredge and disposal works, and piling works.	Noted.
MMO	MMO response dated 23 February 2022	The MMO, in consultation with Cefas, are not confident with the appropriateness of the assumption that fish swim passively with tidal flows as a worst-case scenario. For instance, exposure times would be different (i.e., higher) for migratory fish species swimming against tidal flow in their up or downstream migration or for those waiting in 'refuge areas' so that they do not expend energy to wait for the right tidal flow to migrate up or downstream. Therefore, assuming that fish swim passively	Noted and agreed. As explained above, it is not possible to confirm the exact timing and programme for the piling and dredging at this stage and the assessment has, therefore, been undertaken on the basis that the works could be undertaken at any time of year. Piling restrictions to avoid sensitive periods for migratory fish have been discussed with the MMO and Cefas and are set out in Section 9.9 of

Consultee	Reference, Date	Summary of Response	How comments have been addressed in this chapter
		is too simplistic and not an accurate representation of the worst-case scenario as it would be worse if fish swim actively against the tidal flow on their way to spawning and nursery grounds which may lead to moving towards the source of noise, and this is very time dependent. Consequently, the level of impacts from underwater noise on migratory fish would be determined by the exact timing when the works are undertaken. Therefore, it is recommended that an estimate of the timing and duration of the proposed works (i.e., months) is provided to identify possible seasonal constraints in relation to any overlap with the spawning and migratory periods for those sensitive and protected species.	the Nature Conservation and Marine Ecology chapter (Chapter 9) of the ES and Section 10 of this report. Piling restrictions for fish have also been incorporated into the DCO (within the deemed marine licence).
MMO	MMO response dated 23 February 2022	The overall impacts will depend on the final timing and duration (i.e., specific months) of the piling, dredging and disposal works in relation to the sensitive seasons for fish in the vicinity of the works. Therefore, a detailed description of the sensitive seasons of fish species known to migrate through the area where the works are proposed in relation to the proposed dates for piling and dredging works should be provided.	As noted above, the exact timing and programme for the piling and dredging have not been confirmed at this stage and, therefore, the assessment has been undertaken on the basis that the works could take place at any time of year as a worst case. Further details of the sensitive seasons for fish species that migrate through the Humber Estuary is provided in Section 9.6 of the Nature Conservation and Marine Ecology chapter (Chapter 9) of the ES.

Consultee	Reference, Date	Summary of Response	How comments have been addressed in this chapter
MMO and Cefas	Pre-application meeting, 7 April 2022.	The meeting provided an update of the IERRT and focused on discussing comments received from the MMO and Cefas on the PEIR with respect to the acoustic modelling used to inform the underwater noise assessment on fish and potential effects on migratory fish species.	The underwater noise assessment, including the acoustic modelling, has been updated taking on board consultee comments from this meeting.
MMO and Cefas	MMO/Cefas response to pre-application meeting minutes (MMO Cefas meeting note underwater noise 07 Apr 2022), 5 May 2022	1. The minutes, including the summary of responses provided in Table 1 of this document, are an accurate account of what was discussed at the meeting.	Noted.
		2. Cefas welcome the additional clarifications provided by the Applicant, and it appears as though various updates/clarifications have been made to the underwater noise assessment (although an updated report has not been reviewed by Cefas). The original comments/reservations provided by Cefas were more for the Applicant to note for future assessments, as the conclusions of the assessment were reasonable, and the applicant was proposing a number of mitigation measures.	Noted.
		3. The only additional comment is a further reflection on the response from the Applicant (in Table 1), regarding the Lippert *et al.* (2015) approach: "*The empirical approach suggested by Lippert et al. (2015) requires a large number of input parameters which are not currently possible to define, such as mass of*	Following this advice, the unweighted received levels in the SEL metric associated with the proposed development activities have now been modelled and then translated to the peak SPL metric using equation (1) in

Consultee	Reference, Date	Summary of Response	How comments have been addressed in this chapter
		the ram weight and pile impedance". The idea is to use SEL modelling (i.e., source, propagation) in the first instance, and then translate this into SPL_{peak} with Lippert, which is relatively straightforward. See equation (1) in Lippert *et al.* (2015) where A and B are empirical constants, with approximate values A=1.4 and B=40. The extension of this equation, namely eq. (4), can indeed improve the predictions, but the differences are likely to be small and have to be seen in the context of modelling/predicting the SEL in the first place.	Lippert *et al*. (2015). Further details are provided in Section 4 of this report.
MMO and Cefas	ABPmer technical note, 21 April 2022 MMO/Cefas response to technical note, 18 May 2022 ABPmer technical note, 13 June 2022 MMO/Cefas response to technical note, 20 September 2022	A technical note on the proposed mitigation measures for migratory fish was prepared by ABPmer and issued to the MMO on 21 April 2022. Further comments and advice from the MMO and Cefas were received on 18 May 2022, and these have been taken into consideration in the environmental assessment. A second technical note on the proposed piling restrictions for migratory fish was prepared by ABPmer and issued to the MMO on 13 June 2022. The key information included within the technical note has been incorporated into the ES assessment. Further comments and advice from the MMO and Cefas were received on 20 September 2022.	The approach to the proposed mitigation measures relating to piling and underwater noise, set out in Section 10 of this report and Section 9.9 of the Nature Conservation and Marine Ecology chapter (Chapter 9) of the ES, has been developed in consultation with the MMO and Cefas.

Consultee	Reference, Date	Summary of Response	How comments have been addressed in this chapter
	Pre-application meeting, 3 October 2022 (including pre-meeting briefing note, 30 September 2022, post-meeting note, 8 November 2022)	A meeting was held with the MMO and Cefas to discuss the evidence and piling restrictions (pre- and post-meeting notes were also issued).	
MMO and Cefas	MMO/Cefas letter, 1 December 2022	Inclusion of appropriate temporal restrictions for both percussive piling and vibro-piling should be addressed.	Section 10 of this report and Section 9.9 of Chapter 9 of the ES details the seasonal restrictions on the duration of percussive piling activity that are proposed as mitigation for the IERRT project. The effects of vibro-piling on migratory fish are not considered to be significant and do not need to be mitigated. This is further explained in this assessment.
		Clear justification should be provided for the proposed night time piling restriction dates together with an explanation of why piling restrictions should only be applied at night and only to percussive piling in respect of each relevant fish species.	Section 10 of this report and Section 9.9 of Chapter 9 of the ES sets out the justification for the proposed night time piling restriction dates. Seasonal piling restrictions on the duration of percussive piling activity between specified dates are also proposed as mitigation for the IERRT (which are not just applied at night). The effects of vibro-piling on migratory fish are not considered to be significant and do not need to be mitigated. This is further explained in this assessment.

		Explanation required of why the timing of the proposed piling restrictions outlined do not correlate with the timing of those used for Able Marine Energy Park (AMEP), which are referenced as an example of best practice in the estuary.	The proposed restrictions (set out in Section 10 of this report and Section 9.9 of Chapter 9 of the ES) take account of the fact that the underwater noise levels associated with the piling for IERRT (and effects on migratory fish) are less than for the AMEP development. This is in particular due to the following: - The maximum pile diameter of the piles required for IERRT is anticipated to be 1.422 m whereas for AMEP the maximum pile diameter size is 2.54 m and therefore the levels of noise generated at the source of piling will be significantly less for IERRT compared to AMEP; - The piling required for AMEP will result in an acoustic barrier across the entire width of the estuary whereas a partial acoustic barrier is predicted for IERRT given the smaller size of the piles, as well as the fact that IERRT is located downstream and in a slightly wider part of the estuary; - The duration of the piling works is approximately 24 or 37 weeks for IERRT compared to a minimum 2-year construction programme for AMEP; and

Consultee	Reference, Date	Summary of Response	How comments have been addressed in this chapter
			- The marine piling required for the AMEP involves construction of a continuous pile wall. This requires less time between each pile being driven for set up/mobilisation of the piling rig. The piling required for the IERRT project will involve a significant amount of time to set up between each pile being driven, meaning the piling rate per day will be lower than AMEP.
		Assessment of the effects of noise and vibration from piling operations (including any additional piling from recent changes in project design) to be included in the nature conservation and marine ecology chapter.	An assessment of the effects of underwater noise and vibration from piling operations (including effects from recent project design changes) is provided in this report.

3 Principals of Underwater Acoustics

3.1 Introduction

3.1.1 Underwater sound is generated by the movement or vibration of any immersed object in water. Sound can be detected: (a) as pressure fluctuations in the medium above and below the local hydrostatic pressure (sound pressure); and (b) by the back-and-forth motion of the medium, referred to as particle motion (ISO, 2017).

3.2 Sound pressure

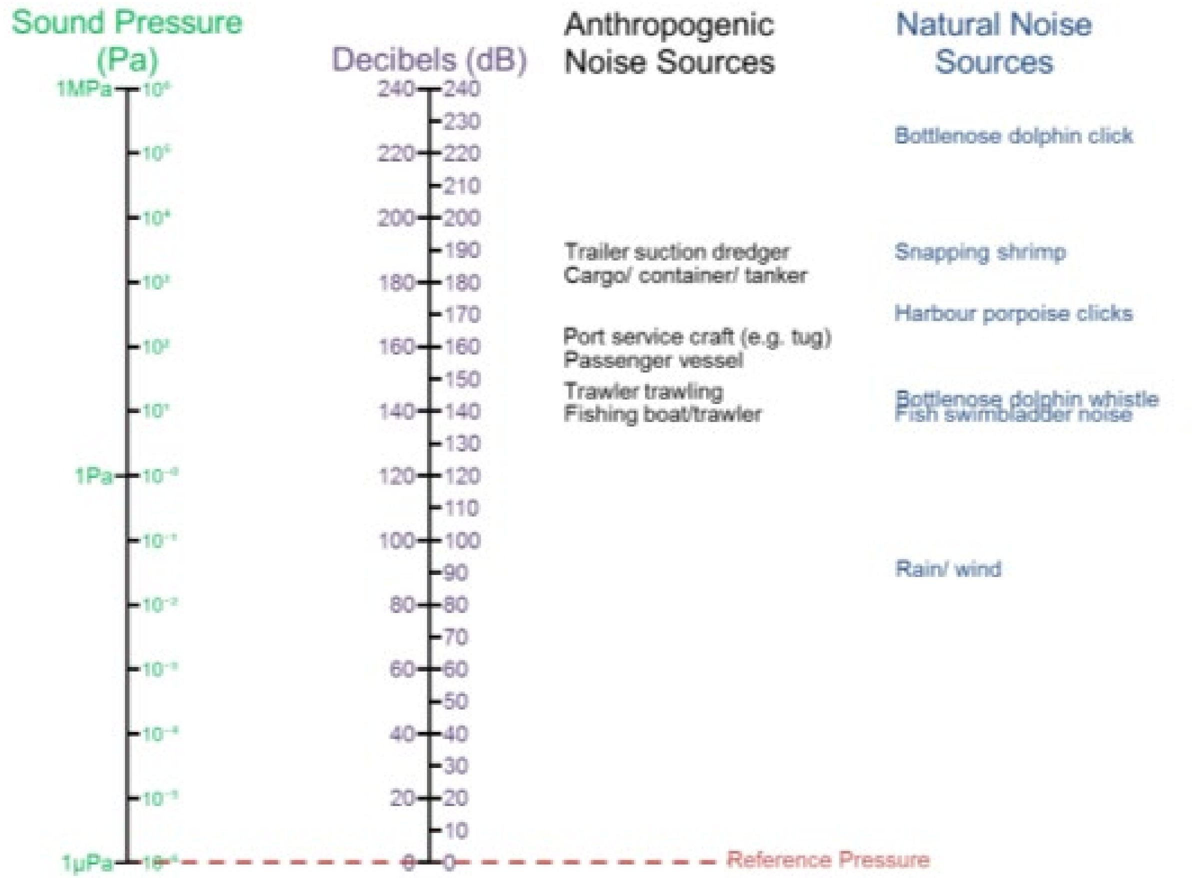
3.2.1 Sound pressure acts in all directions and is a scalar quantity that can be described in terms of its magnitude and its temporal and frequency characteristics. An important property of sound or 'noise' is its loudness. A loud noise usually has a larger pressure variation and a weak one has a smaller pressure variation.

3.2.2 Pressure and pressure variations are expressed in Pascal, abbreviated as Pa, which is defined as Newton per square metre (N/m^2). It is not appropriate to express sound or noise in terms of Pa because it would involve dealing with numbers from as small as 0.000001 to as big as 2,000,000. The use of a logarithmic scale, of which the most commonly used is the decibel (dB) scale, compresses the range so that it can be easily described. Figure 1 shows how sounds can be expressed both linearly in Pa and logarithmically in dB.

3.2.3 Confusion arises because sound levels given in dB in water are not the same as sound levels given in dB in air. There are two reasons for this:

- **Reference intensities.** The reference intensities used to compute sound levels in dB are different in water and air. Scientists arbitrarily agreed to use as the reference intensity for underwater sound, the intensity of a sound wave with a pressure of 1 microPascal (µPa). However, in the case of sound in air, scientists selected to use 20 µPa as a reference intensity as it is consistent with the minimum threshold of young human adults in their range of best hearing (1,000 -3,000 Hz); and
- **Densities and sound speeds.** The intensity of a sound wave depends not only on the pressure of the wave, but also on the density and sound speed of the medium through which the sound is travelling. Sounds in water and sounds in air that have the same pressures have very different intensities because the density of water is much greater than the density of air and because the speed of sound in water is much greater than the speed of sound in air. For the same pressure, higher density and higher sound speed both give a lower intensity.

3.2.4 The dB levels for sound in water and in air are, therefore, not directly comparable.



Source: MMO, 2015

Figure 1. The sound pressure (Pa) and decibel (dB) scale

3.3 Particle motion

3.3.1 Particle motion is an oscillation back and forth in a particular direction; it is a vector quantity that can only be fully described by specifying both the magnitude and direction of the motion, as well as its magnitude, temporal, and frequency characteristics. The particle motion component of underwater sound comprises both the velocity (m/s) and the acceleration (m/s²) of molecules in the sound wave.

3.3.2 Particle motion was previously considered impossible to record (Wysocki and Ladich, 2005). However, two approaches have been used in research to estimate particle acceleration (Radford *et al*., 2012): 1) accelerometers and 2) the recording of pressure differences between two hydrophones. This was followed closely by the development of a particle motion sensor (Sigray and Andersson, 2011), which has been validated in field studies near an offshore wind farm in the western part of the Baltic Sea.

3.3.3 Detection of particle motion requires different types of sensors than those utilized by a conventional hydrophone (Hawkins and Popper, 2017). Such sensors must specify the particle motion in terms of the particle displacement, or its time derivatives (particle velocity or particle acceleration) in three dimensions.

3.4 Underwater noise metrics

3.4.1 There are a number of different metrics that may be used as measures of sound pressure (NPL, 2014). The key metrics that are used to characterise noise are as follows:

- **Peak sound pressure (or zero-peak sound pressure).** The maximum sound pressure during a stated time interval. A peak sound pressure may arise from a positive or negative sound pressure, and the unit is Pa. This quantity is typically useful as a metric for a pulsed waveform, though it may also be used to describe a periodic waveform;
- **Peak-peak sound pressure.** The sum of the peak compressional pressure and the peak rarefactional pressure during a stated time interval. This quantity is typically most useful as a metric for a pulsed waveform, though it may also be used to describe a periodic waveform. Peak-peak sound pressure is expressed in Pa;
- **Root mean square (RMS) sound pressure.** The square root of the mean square pressure, where the mean square pressure is the time integral of squared sound pressure over a specified time interval divided by the duration of the time interval. The RMS sound pressure is expressed in Pa;
- **Sound exposure level (SEL).** The integral of the square of the sound pressure over a stated time interval or event (such as an acoustic pulse). Sound exposure is expressed in units of $Pa^2 \cdot s$. The quantity is sometimes taken as a proxy for the energy content of the sound wave. Note that SEL is a useful measure of the exposure of a receptor to a sound field, and a frequency weighting is commonly applied; and
- **Frequency weighting.** Frequency-dependent normalised factor(s) by which spectral components are multiplied, resulting in the modification of the amplitude of some components. Frequency weightings are normalised factors and have no units or dimensions but are sometimes expressed as relative factors in decibels (with no reference value). The main motivation for applying a frequency weighting is to account for the frequency-dependent sensitivity of a receptor.

3.4.2 The type of pressure measurement used is an important consideration when comparing noise levels and criteria and the type of pressure measurement should be stated when quoting noise levels.

4 Underwater Noise Propagation

4.1.1 The process of noise travelling through a medium is referred to as noise propagation. The factors that influence the propagation of noise in the marine environment and contribute to propagation (or transmission) loss[1] broadly include the following (NPL, 2014):

- The reduction (or attenuation) of sound away from the source due to geometrical spreading;
- Absorption of the sound by the seawater and the seabed;
- The interaction with the sea-surface (reflection and scattering);
- The interaction with (and transmission through) the seabed;
- The refraction of the sound due to the sound speed gradient;
- The bathymetry (water depth) between source and receiver positions; and
- Source and receiver depth.

4.1.2 The propagation of underwater noise is a very complex process and, therefore, predicting the received sound pressure levels at distance from a source is extremely difficult. Use is generally made of theoretical models or empirical models based on field measurements.

4.1.3 In accordance with good practice guidance (NPL, 2014), and in agreement with the MMO and Cefas as their advisor on issues relating to underwater noise, a simple logarithmic spreading model has been used to predict the propagation of sound pressure from the sources of construction and operational noise associated with the proposed development (MMO, 2021). This model is represented by a logarithmic equation and incorporates factors for noise attenuation and absorption losses. The advantage of this model is that it is simple to use and quick to provide first order calculations of the received (unweighted) levels with distance from the source due to geometric spreading.

$$L(R) = SL - N\,log_{10}(R) - \alpha R$$

Equation 1 Simple logarithmic spreading model

L(R) is the received level at distance R from a source;

R is the distance in metres from the source to the receiver;

SL is the Source Level (i.e., the level of sound generated by the source);

N is a factor for attenuation due to geometric spreading; and

α is a factor for the absorption of sound in water and boundaries (i.e., the sediment or water surface) in dB m^{-1}.

[1] The reduction in signal as sound propagates from source to receiver.

4.1.4 The Environment Agency has compiled observed data representing factors for attenuation (N coefficient) and absorption (α coefficient) which were presented at the Institute of Fisheries Management (IFM) Conference on 23 May 2013. These observed data were collected from the following construction projects undertaken in shallow water estuarine and coastal locations:

- Russian River New Bridge in Geyserville, California (Illinworth and Rodkin, 2007);
- San Rafael Sea Wall in San Francisco Bay, California (Illinworth and Rodkin, 2007);
- Scroby Sands Offshore Wind Farm located off the coast of Great Yarmouth (Nedwell *et al*., 2007a);
- North Hoyle Offshore Wind Farm in Liverpool Bay (Nedwell *et al*., 2007a);
- Kentish Flats Offshore Wind Farm located off the coast of Kent (Nedwell *et* al., 2007a);
- Burbo Bank Offshore Wind Farm in Liverpool Bay (Nedwell *et al*., 2007a);
- Barrow Offshore Wind Farm located south west of Walney Island (Nedwell *et al*., 2007a); and
- Belvedere Energy-from-Waste Plant on Thames Estuary (measurements collected by Subacoustech Ltd on behalf of the Environment Agency and Costain).

4.1.5 These provide a mean N coefficient of 17.91 (Standard Deviation (SD) 3.05) and α coefficient of 0.00523 dB m^{-1} (SD 0.00377 dB m^{-1}) based on 11 and 9 observations respectively. The Environment Agency has recommended the application of these model input values in underwater noise assessments undertaken in shallow water environments (e.g., URS Scott Wilson, 2011; ABPmer, 2015). These values are, therefore, considered to be appropriate to use for the underwater noise assessment in support of the proposed development.

4.1.6 On advice from the MMO and Cefas, the received levels associated with the proposed development activities have been modelled in the SEL metric and then translated to the peak SPL metric using equation (1) in Lippert *et al*. (2015):

$$SPL_{peak} = A\ SEL + B$$

Equation 2 Relationship between peak SPL and SEL

A is an empirical constant estimated from measurements with an approximate value of 1.4; and

B is an empirical constant estimated from measurements with an approximate value of – 40.

4.1.7 It is important to recognise that there are a number of limitations associated with the use of simple logarithmic spreading models (NPL, 2014). Such models do not account for changes in bathymetry, and therefore are not able to predict the changes in sound propagation caused by sand banks and complex changes in water depths. In addition, they do not explicitly include frequency dependence, and so cannot predict the increased transmission loss at high frequencies due to increased sound absorption. Farcas *et al*. (2016) also demonstrated how use of these simple models in complex environments typical of coastal and inland waters can underestimate noise levels close to the source and substantially overestimate noise levels further from the source. In other words, they can underestimate the risk of injury or disturbance to marine fauna close to the source whilst giving the impression that a larger area would be affected.

4.1.8 Although this equation generally represents a simplistic model of propagation loss, its use is an established approach in EIAs that has been widely accepted by UK regulators for recent port and waterfront developments.

4.1.9 In terms of fish, the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) in the United States recommends the use of the practical spreading model to developers and has incorporated this model in its pile driving calculation spreadsheet to assess the potential impacts of pile driving on fish (NMFS, 2021). This calculator has, therefore, been used to calculate the range at which the peak SPL and cumulative SEL thresholds for pile driving (Popper *et al*., 2014) are reached. Further details of the assumptions and input values that have been applied are provided in Section 9.1 of this report.

4.1.10 In terms of marine mammals, NOAA (2021) has developed a user spreadsheet tool for assessing the potential effects of different types of noise activities on marine mammals which is based on the simple logarithmic spreading model. This spreadsheet tool has been used to predict the range at which the relevant weighted cumulative SEL and instantaneous peak SPL acoustic thresholds (NOAA, 2018) for the onset of temporary threshold shift (TTS) and permanent threshold shift (PTS) are reached during the proposed piling, dredging and vessel activity. Further details, including the input values that have been used are presented in Section 9.2 of this report.

4.1.11 The proposed development takes place in very shallow water and, therefore, the propagation of noise will be limited. Shallow water acts as a high pass filter that only allows signals to pass with a frequency higher than a certain cut-off frequency and attenuates signals with frequencies lower than this cut-off frequency. The cut-off frequency gets higher as the water gets shallower (Harland *et al*., 2005). In this way, the propagation of low frequency underwater noise such as piling will be reduced in very shallow water locations compared to in the deep oceanic waters. At high frequencies (>10 kHz), increasing absorption also prevents high frequency sound propagating over great distances in shallow water.

4.1.12 Overall, therefore, a simple logarithmic spreading model is considered proportionate and appropriate to use for this underwater noise assessment. The MMO, and Cefas as their advisor, agree that a simple modelling approach in this instance is appropriate (MMO, 2021).

5 Ambient Noise

5.1 Introduction

5.1.1 Ambient sound is an important consideration in underwater noise assessments as it allows the noise levels caused by a project to be assessed in the context of existing background levels of sound. This section reviews the characteristics of key sources of ambient sound in the study area and considers how these might propagate and vary in space and time.

5.2 Definition

5.2.1 Ambient sound is commonly defined as background acoustic sound without distinguishable sources (e.g., Wenz, 1962; Urick, 1983). This definition, however, has the problem of how to identify distinguishable sources, and how to eliminate them from the measurements.

5.2.2 Measurements to characterise the ambient sound in a specific location (i.e., incorporating both natural and anthropogenic sources) are becoming more common as interest grows in the trends in anthropogenic noise in the ocean, for example in response to the Marine Strategy Framework Directive (MSFD) and UK Marine Strategy (Defra, 2019). The EU MSFD Technical Sub-Group (TSG) on Noise defined ambient sound as follows:

> *"All sound except that resulting from the deployment, operation or recovery of the recording equipment and its associated platform, where 'all sound' includes both natural and anthropogenic sounds" (Dekeling et al., 2014, p 20).*

5.2.3 Measurements that characterise the ambient sound at specific locations and include noise from identifiable sources together with non-identifiable sources, are also sometimes referred to as the local 'soundscape' (NPL, 2014).

5.3 Sources of ambient sound

5.3.1 Ambient sound covers the whole acoustic spectrum from below 1 Hz to well over 100 kHz (Harland *et al*., 2005). At the lower frequencies shipping noise dominates, while at the higher frequencies noise from waves and precipitation dominates.

5.3.2 Natural sources of ambient sound comprise both physical processes and biological activity. Physical processes that are relevant to the study area include wind- and wave-driven turbulence, precipitation, and sediment transport processes (Malme *et al*., 1989; Harland *et al*., 2005). Biological activity includes echo locating marine mammals and fish communication (Battele, 2004; Harland *et al*., 2005). These sources of ambient sound vary on a diurnal cycle, a tidal cycle and/or an annual cycle.

5.3.3 A range of anthropogenic noise sources contribute to ambient sound. These can be of short duration and impulsive (e.g., seismic surveys, piling, explosions) or long lasting and continuous (e.g., dredging, shipping, trawling, sonar, drilling, small craft, and energy installations) (Dekeling *et al*., 2014). Impulsive sounds may, however, be repeated at intervals (duty cycle) and such repetition may become 'smeared' with distance and reverberation and become indistinguishable from continuous noise. The key anthropogenic sources contributing to ambient sound in the study area are reviewed below.

Vessel traffic

5.3.4 Shipping noise is the dominant contributor to ambient sound in shallow water areas close to shipping lanes and in deeper waters. At longer ranges the sounds of individual ships merge into a background continuum (Harland *et al*., 2005). Shipping noise will vary on a diurnal cycle (e.g., ferry and coastal traffic) and an annual cycle (seasonal activity). The source levels (SLs) associated with large ships such as super tankers and container ships are in the range 180 to 190 dB re 1µPa m (MMO, 2015). For smaller shipping vessels and boats the range is 150 to 180 dB re 1µPa m (UKMMAS, 2010; CEDA, 2011). Although the exact characteristics depend on vessel type, size and operational mode, the strongest energy occurs below 1,000 Hz.

5.3.5 Small motorised craft (e.g., outboard powered inflatables, speed boats and work boats) produce relatively low levels of noise (75 to 159 dB re 1µPa m), and the output characteristics are highly dependent on speed and other operational characteristics (Richardson *et al*., 1995). Many of these sources have greater sound energy in higher frequency bands (i.e., above 1,000 Hz) than large ships. Sail powered craft are generally very quiet with the only sound coming from flow noise, wave slap and rigging noise.

5.3.6 Vessel traffic in the study area originates from commercial and recreational vessels travelling to and from the Port of Immingham. Further details of the movement of different types of vessels are provided in the Commercial and Recreational Navigation chapter (Chapter 10) of the ES.

Dredging

5.3.7 Dredging activities emit moderate levels of broadband noise (around 150 to 188 dB re 1µPa m), mainly at lower frequencies (less than 500 Hz) (Thomsen *et al*., 2009; Jones and Marten, 2016). Maintenance dredging is carried out in the main navigation channel and berths at the Port of Immingham. The amount of dredging and volume of material removed varies depending on the surveyed levels of the channel and the requirements of the Port. Further details of existing maintenance dredging activities in the study area are included in the physical processes chapter (Chapter 7) of the ES.

5.4 Frequency dependence of sound propagation

5.4.1 Shallow and very shallow water[2], such as that at the study area, acts as a high pass filter that only allows signals to pass with a frequency higher than a certain cut-off frequency and attenuates signals with frequencies lower than this cut-off frequency. The cut-off frequency gets higher as the water gets shallower (Harland *et al*., 2005). In this way, distant shipping makes a reduced contribution to ambient sound in very shallow coastal waters and low frequency sound originates from local sources rather than the great distances found in the deep oceanic waters. At high frequencies (>10 kHz), increasing absorption also prevents high frequency sound propagating over great distances in shallow water so the ambient sound at the study area is dominated by local sound sources.

5.5 Spatiotemporal variation

5.5.1 Ambient sound levels can show significant variation over space and time (NPL, 2014). The observed temporal and spatial variation in ambient sound level can be tens of decibels (in other words, the amplitude can vary by orders of magnitude). This variation can be in the short-term of minutes and hours, or a medium-term such as a diurnal variation (day to night), variation with tidal flows, or a longer-term seasonal variation. The sound level can also depend on location, an example of one cause of this being proximity to a shipping lane, another being proximity to a biological source such as snapping shrimp.

5.6 Measured levels of ambient sound

5.6.1 A series of pre-construction and during construction underwater noise monitoring was undertaken in the Humber Estuary at Green Port Hull (GPH) from 17 to 22 October 2014 inclusive, in line with ABP' commitments included in the GPH Environmental Management and Monitoring Plan (EMMP). The purpose of this monitoring was to provide better certainty for the prediction of impacts for future developments (ABPmer, 2017).

5.6.2 RMS SPLs showed a repeating pattern of peaks and troughs, ranging from 107 to 154 dB re 1 μPa. Flow speed and broadband SPL were shown to be significantly positively correlated, which suggests that noise levels in the estuary are primarily dependent on tidal flow speed, with levels increasing with higher flow speeds (ABPmer, 2017).

2 The definition of shallow water is somewhat arbitrary. For this underwater noise assessment, shallow water is defined as the depths found on the UK continental shelf i.e., 20 to 200 metres. Very shallow water has depths less than 20 metres.

6 Noise Characteristics of Proposed Development Activities

6.1 Introduction

6.1.1 During the construction and operation of the proposed development there are a number of activities that are expected to generate underwater noise levels which may affect marine fauna. This section reviews the underwater noise characteristics of these activities and the associated noise levels that have been applied in the assessment. The worst-case potential scenario is considered in order to define the project envelope.

6.2 Piling

6.2.1 The proposed development will involve the installation of approximately 214 steel tubular piles, which are estimated to be a maximum of 1,422 mm diameter in size. The piling for the finger piers will be from a crane barge or jack up utilising a crawler crane, a vibratory hammer (PVE 38M or equivalent as required) and percussive piling hammer (such as BSP CG300). The piles will be transported to the jetty area by flat top barges and lifted with the barge mounted crane into a piling gate supported on the edge of the barge. The piling gate supports the pile during the pile driving process to ensure it maintains position. The vibro hammer will then be placed onto the top of the pile using the crane and the pile will be vibrated through the softer ground layers. Once the pile has refused and can no longer be advanced through the ground the vibro hammer will be removed and placed on the barge using the crane. The percussive hammer will then be lifted by the crane onto the top of the pile. This percussive hammer will strike the pile head, incrementally advancing the pile into the harder ground levels until final pile toe level is achieved.

6.2.2 The approach jetty will be built in the same way as above where there is sufficient water depth to enable barge access. Where barge access cannot be achieved due to shallow water depths, a land-based crane positioned on completed sections of the jetty will be used. The piling equipment and process will be the same as described above. Piling works will be undertaken simultaneously on two fronts (i.e., the land and water based approached described above) using up to four piling rigs and may result in cumulative piling noise.

6.2.3 Every pile will involve a different duration of installation based on the specific ground conditions that the pile is being driven through. The assessment is, therefore, based on the likely maximum timeframes that are estimated to be required. Each tubular pile is anticipated to require approximately 5 minutes of vibro piling and approximately 45 minutes of impact piling. The likely maximum impact piling scenario is for 4 tubular piles to be installed each day using up to four piling rigs across both fronts. The maximum impact pile driving scenario will involve approximately 20 minutes of vibro piling and 180 minutes of impact piling per day in a 12-hour shift. In reality, less than 4 piles are likely to be driven per day and, therefore, the assessment is considered to represent a worst case.

6.2.4 The marine piling works will be undertaken seven days per week.

Impact piling

6.2.5 The highest peak underwater noise levels generated during the proposed marine works will arise from impact piling. Impact piling involves a large weight or 'ram' being dropped or driven onto the top of the pile, driving it into the seabed. Noise is created in air by the hammer, as a direct result of the impact of the hammer with the pile. Some of this airborne noise is transmitted into the water. Of more significance to the underwater noise, however, is the direct radiation of noise from the surface of the pile into the water as a consequence of the compressional, flexural, or other complex structural waves that travel down the pile following the impact of the hammer on its head. As water is of similar density to steel and, in addition, due to its high sound speed, waves in the submerged section of the pile couple sound efficiently into the surrounding water. These waterborne waves will radiate outwards, usually providing the greatest contribution to the underwater noise.

6.2.6 At the end of the pile, force is exerted on the substrate not only by the force transmitted from the hammer by the pile, but also by the structural waves travelling down the pile which induce lateral waves in the seabed. These may travel as both compressional waves, in a similar manner to the sound in the water, or as a seismic wave, where the displacement travels as Rayleigh waves (Brekhovskikh, 1960). The waves can travel outwards through the seabed or by reflection from deeper sediments. As they propagate, sound will tend to 'leak' upwards into the water, contributing to the waterborne soundwaves. Since the speed of sound is generally greater in consolidated sediments than in water, these waves usually arrive first as a precursor to the waterborne wave. Generally, the level of the seismic wave is typically 10 to 20 dB below the waterborne arrival, and hence it is the latter that dominates the noise.

6.2.7 Impulsive sources such as pile driving should have SLs expressed for a single pulse as either SEL with units of dB re 1 μPa^2 s, or as a peak-peak or zero-peak SPL, with units of dB re 1 μPa (Farcas *et al*., 2016). Impact piling is impulsive in character with multiple pulses occurring at blow rates in the order of 30 to 60 impacts per minute. Typical SLs range from peak SPL of 190 to 245 dB re 1 μPa (DPTI, 2012). Most of the sound energy usually occurs at lower frequencies between 100 Hz and 1 kHz. Factors that influence the SL include the size, shape, length and material of the pile, the weight and drop height of the hammer, and the seabed material and depth.

6.2.8 The SL for the impact driving of tubular piles as part of the proposed development is assumed based on the loudest near-source (10 m from the source) sound pressure measurements (SEL, peak SPL and RMS) for the percussive piling installation of the nearest-sized 1.52 m Cast-in-Steel-Shell (CISS) steel pipe piles in a shallow water environment (Illinworth & Rodkin, 2007; ICF Jones & Stokes and Illingworth and Rodkin, 2009; Rodkin and Pommerenck, 2014). Back-calculating the sound pressure measurements to 1 m using the simple logarithmic spreading model (equation 1) provides an estimated SL of 203 dB re 1 µPa^2 s (SEL metric), 228 dB re 1 µPa m (peak SPL metric) and 213 dB re 1 µPa m (RMS metric).

6.2.9 Piling will be undertaken simultaneously using piling rigs. Adding two identical sources (i.e., doubling the signal) will increase the received level by 3 dB. In other words, the unweighted peak SL of concurrent impact piling by more than one piling rig is assumed to be 206 dB re 1 µPa^2 s (SEL metric), 231 dB re 1 µPa m (peak SPL metric) and 216 dB re 1 µPa m (RMS metric).

Vibro piling

6.2.10 Vibratory hammers use oscillatory hammers that vibrate the pile, causing the sediment surrounding the pile to liquefy and allow pile penetration (ICF Jones & Stokes and Illingworth & Rodkin, 2009). Peak SPLs for vibratory hammers can exceed 180 dB; however, the sound from these hammers rises relatively slowly. The vibratory hammer produces sound energy that is spread out over time and is generally 10 to 20 dB lower than impact pile driving. Although peak sound levels can be substantially less than those produced by impact hammers, the total energy imparted can be comparable to impact driving because the vibratory hammer operates continuously and requires more time to install the pile.

6.2.11 The SL for the vibratory driving of tubular piles as part of the proposed development is assumed based on the loudest near-source (10 m from the source) sound pressure measurements (SEL, peak SPL and RMS) for the vibratory piling installation of the nearest-sized 1.83 m steel pipe piles in a shallow water environment (Illinworth & Rodkin, 2007; ICF Jones & Stokes and Illingworth and Rodkin, 2009; Rodkin and Pommerenck, 2014). Back-calculating the sound pressure measurements to 1 m using the simple logarithmic spreading model (equation 1) provides an estimated SL of 198 dB re 1 µPa^2 s (SEL metric), 213 dB re 1 µPa m (peak SPL metric) and 198 dB re 1 µPa m (RMS metric).

6.2.12 Piling will be undertaken simultaneously using piling rigs. Adding two identical sources (i.e., doubling the signal) will increase the received level by 3 dB. In other words, the unweighted peak SL of concurrent vibro piling by more than one piling rig is assumed to be 201 dB re 1 µPa^2 s (SEL metric), 216 dB re 1 µPa m (peak SPL metric) and 201 dB re 1 µPa m (RMS metric).

6.3 Dredging

6.3.1 The dredging requirements for the proposed development will involve the use of a backhoe dredger (e.g., Mannu Pekka or similar) and trailing suction hopper dredger (TSHD) (e.g., Cork Sand and Long Sand or similar). The backhoe dredging will involve the excavated material being loaded directly to attendant split barges for disposal. TSHD is the method that is predominantly used for existing maintenance dredge activities within the Port of Immingham and its approaches and will continue to be used in the future. Dredge operations will be continuous (24/7).

6.3.2 Dredging involves a variety of sound generating activities which can be broadly divided into sediment excavation, transport, and placement of the dredged material at the disposal site (CEDA, 2011; WODA, 2013; Jones and Marten, 2016). For most dredging activities, the main source of sound relates to the vessel engine noise. Dredging activities produce broadband and continuous sound[3], mainly at lower frequencies of less than 500 Hz and moderate RMS SLs from around 150 to 188 dB re 1 µPa m (Thomsen *et al*., 2009; CEDA, 2011; Robinson *et al*., 2011; WODA, 2013; MMO, 2015; Jones and Marten, 2016).

6.3.3 Backhoe dredgers generate RMS SLs in the range of 154 to 179 dB re 1 µPa m (Reine *et al*., 2012; Nedwell *et al*., 2008). Measurements of underwater sound from backhoe dredging operations indicate that the highest levels of underwater sound occur when the excavator is in contact with the seabed. This type of dredging is generally considered to be quieter compared to other types of dredging, with recorded sound levels just above the background sound at approximately 1 km from the source (CEDA, 2011).

6.3.4 SLs of TSHDs are variable but generally range from 160 to above 180 dB re 1 µPa m for large TSHDs (Robinson *et al*., 2011). The most intense sound emissions from the TSHDs are in the low frequencies, up to and including 1,000 Hz in most cases (Robinson *et al*., 2011; De Jong *et al*., 2010). Differences in sound levels are mainly a result of the difference in size between the dredging vessels observed rather than the materials dredged. High frequency components of the broadband sound are generated by sand and gravel movement through the suction pipes, the movement of the draghead on the seabed, splashing from the spillways, cavitation, and use of positioning thrusters. Also, gravelly sand extraction resulted in higher levels of this sound than sandy gravel when comparing the same dredging vessel (Robinson *et al*., 2011).

6.3.5 Overall, the dredgers involved in the proposed development during construction and operation are anticipated to generate a worst-case unweighted RMS SL of up to 188 dB re 1 µPa m.

6.4 Vessel movements

6.4.1 Vessels involved during the construction of the proposed development will primarily be the crane barge(s), flat top barge(s), tugs, safety boat/crew transfer vessel, backhoe dredger with associated attendant split barges and TSHD. During operation, the new facility is designed to service the embarkation and disembarkation of principally commercial cargo carried either by accompanied trailer (where the Heavy Goods Vehicle (HGV) tractor unit and driver travel on the vessel with the trailer) or unaccompanied trailers

[3] Continuous sound is defined here as a sound wave with a continuous waveform, as opposed to transient/pulsed sounds such as pile driving that start and end in a relatively short amount of time.

which are delivered to the embarkation port and then collected at the port of disembarkation by different HGV tractor units and drivers. A TSHD will be involved in any future maintenance dredging requirements for the berths (Section 6.3).

6.4.2 The dredgers and barges are anticipated to generate SLs of up to 188 dB re 1 μPa m (UKMMAS, 2010; CEDA, 2011). The ro-ro vessels involved during the operation of the new facility will produce RMS SLs in the region of 178 to 184 dB re 1μPa m (McKenna *et al*., 2012; MMO, 2015).

6.4.3 Overall, the vessels movements involved in the construction and operation of the proposed development are anticipated to generate worst case unweighted RMS SLs of up to 188 dB re 1 μPa m. Continuous (24/7) noise generation from vessel activities has been assumed and as such, provides a precautionary assessment.

7 Hearing Sensitivity and Responses of Marine Fauna

7.1 Introduction

7.1.1 The impact of underwater noise upon wildlife is primarily dependent on the sensitivity of the species likely to be affected. The following sections describe the hearing sensitivity of marine fauna that occur in the study area and the latest available published criteria that have been applied in the underwater noise assessment to determine the scale of potential physiological and behavioural effects.

7.2 Benthic invertebrates

7.2.1 Benthic invertebrates lack a gas-filled bladder and are, therefore, unable to detect the pressure changes associated with sound waves (Carrol *et al*., 2017). All cephalopods as well as some bivalves, echinoderms, and crustaceans, however, have a sac-like structure called a statocyst which includes a mineralised mass (statolith) and associated sensory hairs. Statocysts develop during the larval stage and may allow an organism to detect the particle motion associated with soundwaves in water to orient itself (Carrol *et al*., 2017). In addition to statocysts, cephalopods have epidermal hair cells which help them to detect particle motion in their immediate vicinity, comparable to lateral lines in fish. Similarly, decapods have sensory setae on their body, including on their antennae which may be used to detect low-frequency vibrations. Whole body vibrations due to particle motion have been detected in cuttlefish and scallops, although species names and details of associated behavioural responses are not specified (Carrol *et al*., 2017).

7.2.2 Scientific understanding of the potential effects of underwater noise on invertebrates is relatively underdeveloped (Hawkins *et al*., 2015). There is limited research to suggest that exposure to near-field low-frequency sound may cause anatomical damage (Carrol *et al*., 2017). Anecdotal evidence indicates there was pronounced statocyst and organ damage in seven stranded giant squid after nearby seismic surveys (Guerra *et al*., 2004). Day *et al.* (2016) found airgun exposure caused damaged statocysts in rock lobsters up to a year later. No such effects, however, were detected in other studies (Christian *et al.*, 2003; Lee-Dadswell, 2009). The disparate results between studies seem to be due to differences in SELs and duration, in some cases due to tank interference, although taxa-specific differences in physical vulnerability to acoustic stress cannot be discounted (Carrol *et al.*, 2017).

7.2.3 There is increasing evidence to suggest that benthic invertebrates respond to particle motion[4] (Roberts *et al*., 2016). For example, blue mussels *Mytilus*

[4] Particle motion is a back and forth motion of the medium in a particular direction; it is a vector quantity that can only be fully described by specifying both the magnitude and direction of the motion, as well as its magnitude, temporal, and frequency characteristics.

edulis vary valve gape, oxygen demand and clearance rates (Spiga *et al*., 2016; Roberts *et al*., 2016) and hermit crabs *Paganus bernhardus* shift their shell and at very high amplitudes, leave their shell, examine it, and then return (Roberts *et al*., 2016). The vibration levels at which these responses were observed generally correspond to levels measured near anthropogenic operations such as pile driving and up to 300 m from explosives testing (blasting) (Roberts *et al*., 2016). A range of behavioural effects have also been recorded in decapod crustaceans, including a change in locomotion activity, reduction in antipredator behaviour and change in foraging habits (Tidau and Briffa, 2016). Population level and mortality effects, however, are considered unlikely. Effects on benthic invertebrates are, therefore, not considered further in the assessment.

7.3 Fish

7.3.1 In comparison to marine mammals, fish are more sensitive to noise at lower frequencies and generally have a reduced range of hearing than marine mammals (i.e., their hearing ability spans a restricted range of frequencies).

7.3.2 There is a wide diversity in hearing structures in fish which leads to different auditory capabilities across species (Webb *et al*., 2008). All fish can sense the particle motion component of an acoustic field via the inner ear as a result of whole-body accelerations (Radford *et al*., 2012), and noise detection (‘hearing’) becomes more specialised with the addition of further hearing structures. Particle motion is especially important for locating sound sources through directional hearing (Popper *et al*., 2014; Hawkins *et al*., 2015; Nedelec *et al*., 2016). Although many fish are also likely to detect sound pressure[5], particle motion is considered equally or potentially more important (Hawkins and Popper, 2017).

7.3.3 From the few studies of hearing capabilities in fishes that have been conducted, it is evident that there are potentially substantial differences in auditory capabilities from one fish species to another (Hawkins and Popper, 2017). Since it is not feasible to determine hearing sensitivity for all fish species, one approach to understand hearing has been to distinguish fish groups on the basis of differences in their anatomy and what is known about hearing in other species with comparable anatomy (Popper *et al*., 2014).

7.3.4 The Nature Conservation and Marine Ecology chapter (Chapter 9) of the ES provides a detailed review of the fish receptors that occur in the study area. Categories proposed by Popper *et al.* (2014) for each of the key fish species are included in Table 2.

5 Pressure fluctuations in the medium above and below the local hydrostatic pressure; it acts in all directions and is a scalar quantity that can be described in terms of its magnitude and its temporal and frequency characteristics.

Table 2. Categorisation of key fish species in the study area according to Popper *et al*. (2014) criteria

Swim Bladder or Air Cavities Aid Hearing	Swim Bladder Does Not Aid Hearing	No Swim Bladder
Allis shad (*Alosa alosa*)	Atlantic cod (*Gadus morhua*)	Dab (*Limanda limanda*)
Herring (*Clupea harengus*)	European eel (*Anguilla anguilla*)	Dover sole (*Solea solea*)
Sprat (*Spratus spratus*)	Atlantic salmon (*Salmo salar*)	European plaice (*Pleuronectes platessa*),
Twaite shad (*Alosa fallax*)	European seabass (*Dicentrarchus labrax*)	Flounder (*Platichthys flesus*)
	European smelt (*Osmerus eperlanus*)	River lamprey (*Lampetra fluviatilis*)
	Sea trout (*Salmo trutta*)	Sea lamprey (*Petronmyzon marinus*)
	Whiting (*Merlangius merlangus*)	

7.3.5 The first category comprises fish that have special structures mechanically linking the swim bladder to the ear. These fish are sensitive primarily to sound pressure, although they also detect particle motion (Hawkins and Popper, 2017). They have a wider frequency range, extending to several kHz and generally show higher sensitivity to sound pressure than fishes in the other categories.

7.3.6 The second category comprises fish with a swim bladder where the organ does not appear to play a role in hearing. Some of the fish in this category are considered to be more sensitive to particle motion than sound pressure (see below) and show sensitivity to only a narrow band of frequencies, namely the salmonids (Salmonidae) (Hawkins and Popper, 2016). This second category also comprises fishes with swim bladders that are close, but not intimately connected, to the ear, such as codfishes (Gadidae) and eels (Anguillidae). These fish are sensitive to both particle motion and sound pressure, and show a more extended frequency range, extending up to about 500 Hz (Popper and Coombs, 1982; Popper and Fay, 2011; Hawkins and Popper, 2017).

7.3.7 The third category comprises fish which lack swim bladders that are sensitive only to sound particle motion and show sensitivity to only a narrow band of frequencies (e.g., flatfishes, sharks, skates, and rays). Particle motion rather than sound pressure is considered to be potentially more important to fish without swim bladders. Acoustic particle motion in the water and seabed, for example, has been shown to induce behavioural reactions in sole (Mueller-Blenkle *et al*., 2010). However, there is no published literature on the levels of particle motion generated during construction activities (e.g., pile-driving) and the distance at which they can be detected. This may be due to the fact that there are far fewer devices (and less skill in their use) for detection and analysis of particle motion compared to hydrophone devices for detection of sound pressure (Martin *et al*., 2016). Direct measurements of particle motion have also been hampered by the lack of guidance on data analysis methods.

7.3.8 Particle velocity can be calculated indirectly from sound pressure measurements using relatively simple models (MacGillivray *et al*., 2004). However, such estimates of sound particle velocity are only valid in environments that are distant from reflecting boundaries and other acoustic discontinuities. These conditions are rarely met in the shelf-sea and shallow-water habitats that most aquatic organisms inhabit and that are applicable to the study area (Nedelec *et al*., 2016).

7.3.9 Steps that are required to improve knowledge of the effects of particle motion on marine fauna have recently been set out (Popper and Hawkins, 2018). However, at present there continues to be a lack of particle motion measurement standards, lack of easy to use and reasonably priced instrumentation to measure particle motion, and lack of sound exposure criteria for particle motion. As such, the scope for considering particle motion in underwater noise assessments is currently limited (Faulkner *et al*., 2018). The underwater noise assessment has, therefore, been based on the latest available evidence and focused on the effects of sound pressure.

7.3.10 The extent to which intense underwater sound might cause an adverse environmental impact in a particular fish species is dependent upon the level of sound pressure or particle motion, its frequency, duration and/or repetition (Hastings and Popper, 2005). The range of potential effects from intense sound sources, such as pile driving, includes immediate death, permanent or temporary tissue damage and hearing loss, behavioural changes, and masking effects. Tissue damage can result in eventual death or may make the fish less fit until healing occurs, resulting in lower survival rates. Hearing loss can also lower fitness until hearing recovers. Behavioural changes can potentially result in animals avoiding migratory routes or leaving feeding or reproduction grounds with potential population level consequences. Biologically important sounds can also be masked where the received levels are marginally above existing background levels (Hawkins and Myrberg Jr, 1983). The ability to detect and localise the source of a sound is of considerable biological importance to many fish species and is often used to assess the suitability of a potential mate or during territorial displays and during predator prey interactions.

7.3.11 The published noise exposure criteria for fish that have been used in this underwater noise assessment are presented in Table 3.

Table 3. Fish response criteria applied in this assessment

Fish Hearing Category*	Piling		Dredging and Vessel Movements			Piling
	Mortality and Potential Mortal Injury*	Recoverable Injury*	Mortality and Potential Mortal Injury*	Recoverable Injury*	TTS*	Behaviour**
Swim bladder involved in hearing (primarily pressure detection)	207 dB SEL_{cum} >207 dB peak	203 dB SEL_{cum} >207 dB peak	(N) Low (I) Low (F) Low	170 dB RMS for 48 h	158 dB RMS for 12 h	> 157 dB peak
Swim bladder is not involved in hearing (particle motion detection)	210 dB SEL_{cum} >207 dB peak	203 dB SEL_{cum} >207 dB peak	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	> 157 dB peak
No swim bladder (particle motion detection)	>219 dB SEL_{cum} >213 dB peak	>216 dB SEL_{cum} >213 dB peak	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	> 157 dB peak
Eggs and larvae	210 dB SEL_{cum} >207 dB peak	(N) Moderate (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	> 157 dB peak

* Popper *et al.* (2014).
** Hawkins *et al.* (2014).
Peak and RMS SPL is in dB re 1 µPa and cumulative SEL (SEL_{cum}) is in dB re 1 µPa^{2}s.
All criteria are presented as sound pressure even for fish without swim bladders since no data for particle motion exist.
Relative risk (high, moderate, low) is given for animals at three distances from the source defined in relative terms as near (N), intermediate (I), and far (F).

7.3.12 The Popper *et al.* (2014) quantitative instantaneous peak SPL and cumulative SEL criteria for different marine activities involved in the proposed development (i.e., piling, dredging and vessel movements) have been used to determine the mortality/potential mortal injury and recoverable injury for all the fish hearing categories representing the key fish species that occur in the study area (Table 2). These guidelines are based on an understanding that fish will respond to sounds and their hearing sensitivity.

7.3.13 While the Popper *et al.* (2014) noise exposure criteria provide thresholds for auditory impairment, there are many data gaps that preclude the setting of specific noise exposure criteria for behavioural responses in fish (Popper *et al*., 2014; Hawkins and Popper, 2017; Faulkner *et al*., 2018). The onset of behavioural responses is much more difficult to quantify as reactions are likely to be strongly influenced by behavioural or ecological context and the effect of a particular response is often unclear and may not necessarily scale with received sound level (Hawkins and Popper, 2014; Hawkins *et al*., 2015; Faulkner *et al*., 2018). In other words, behaviour may be more strongly related to the particular circumstances of the animal, the activities in which it is engaged, and the context in which it is exposed to sounds (Ellison *et al*., 2012; Pena *et al*., 2013). For example, a startle or reflex response to the onset of a noise source does not necessarily lead to displacement from the ensonified area.

7.3.14 This uncertainty is further compounded by the limitations of observing fish behavioural responses in a natural context. Few studies have conducted behavioural field experiments with wild fish and laboratory experiments may not give a realistic measure of how fish will respond in their natural environment (Hastings and Popper, 2005; Kastelein *et al*., 2008; Popper and Hastings, 2009). As a consequence, only hearing data based on behavioural experiments is acceptable for assessing the ability of fish to detect sound (Sisneros *et al*., 2016).

7.3.15 Recent studies have considered approaches to quantify the risk of behavioural responses, for example through dual criteria based on dose-response curves for proximity to the sound source and received sound level (Dunlop *et al*., 2017). An empirical behavioural threshold could also be adopted using *in situ* observed responses of fish to similar sound sources (Faulkner *et al*., 2018). A study observing the responses of caged fish to nearby air gun operations found that initial increases in swimming behaviour may occur at a level of 156 dB re 1 µPa RMS (McCauley *et al*., 2000). At levels of around 161-168 dB re 1 µPa RMS active avoidance of the air gun source would be expected to occur (Pearson *et al*., 1992; McCauley *et al*., 2000). These responses may, however, differ from those of unconfined fish.

7.3.16 More recent work has been undertaken by Hawkins *et al.* (2014) reporting behavioural responses of schools of wild sprat and mackerel to playbacks of pile driving. At a single-pulse peak-to-peak SPL of 163 dB re 1 µPa (equivalent to peak SPL of 157 dB re 1 µPa using the metric conversion provided by NOAA Fisheries in their spreadsheet tool and associated user manual; NOAA, 2021), schools of sprat and mackerel were observed to disperse or change depth on 50% of presentations. In the absence of similar data for other species, this threshold has been applied for all fish species (Table 3 of this report).

7.3.17 Auditory and non-auditory injuries in fish have not been observed or documented to occur in association with dredging (Thomsen *et al*., 2009). The literature suggests that dredging noise is unlikely to cause direct mortality or instantaneous injury. However, the (predominantly) low-frequency sounds produced by dredging overlap with the hearing range of many fish species, which may pose a risk in TTS, auditory masking, and behavioural effects (McQueen *et al*., 2019), as well increased stress-related cortisol levels in fish species (Wenger *et al*., 2017). A TTS involves a temporary reduction of hearing capability caused by exposure to underwater noise. An intense short exposure can produce the same scale of TTS as a long-term, repeated exposure to lower sound levels. The significance of the TTS varies among species depending on their dependence on sound as a sensory cue for ecologically relevant functions. Furthermore, it is important to note that the biological significance of such responses is largely unknown.

7.3.18 Potential behavioural effects in the past have also been inferred by comparing the received sound level with the auditory threshold of marine fauna. Richardson *et al*. (1995) and Thomsen *et al*. (2006), for example, have used received levels of noise in comparison with the corresponding hearing thresholds of marine fauna in order to estimate the range of audibility and zones of influence from underwater sound sources. This form of analysis has been taken a stage further by Nedwell *et al*. (2007b), where the underwater noise is compared with receptor hearing threshold across the entire receptor auditory bandwidth in the same manner that the dB(A) is used to assess noise sources in air for humans. These include behavioural thresholds, where received sound levels around 90 dB above hearing threshold (dB_{ht}) are considered to cause a strong behavioural avoidance, levels around 75 dB_{ht} a moderate behavioural response and levels around 50 dB_{ht} a minor response.

7.3.19 The dB_{ht} criteria have previously been applied in a number of EIAs for offshore renewable energy development applications and the Environment Agency has in the past recommended it to be used in impact assessments in coastal/estuarine environments (e.g., ABPmer, 2015; URS Scott Wilson, 2011). However, it is worth noting that the dB_{ht} criteria have not been validated by experimental study and have not been published in an independent peer-reviewed paper. The dB_{ht} approach does not take into account potential for sound sensitivity to changes with that of the life stage of the organism, time of year, animal motivation, or other factors that might affect hearing and behavioural responses to sound (Hawkins and Popper, 2017). Furthermore, the dB_{ht} criteria are based on measures of inner ear responses and should rather be based on behavioural threshold determinations (Popper *et al*., 2014; Hawkins and Popper, 2017). The use of dB_{ht} criteria is, therefore, not advisable and has not been applied to this assessment (Hawkins and Popper, 2017).

7.4 Marine mammals

7.4.1 Marine mammals are particularly sensitive to underwater noise at higher frequencies and generally have a wider range of hearing than other marine fauna, namely fish (i.e., their hearing ability spans a larger range of frequencies). The hearing sensitivity and frequency range of marine mammals varies between different species and is dependent on their physiology.

7.4.2 The impacts of underwater noise on marine mammals can broadly be split into lethal and physical injury, auditory injury, and behavioural response. The possibility exists for lethality and physical damage to occur at very high exposure levels, such as those typically close to underwater explosive operations or offshore impact piling operations. A PTS is permanent hearing damage caused by very intensive noise or by prolonged exposure to noise. As explained above, a TTS involves a temporary reduction of hearing capability caused by exposure to underwater noise. Both PTS and TTS are considered to be auditory/physiological injuries.

7.4.3 At lower SPLs, it is more likely that behavioural responses to underwater sound will be observed. These reactions may include the animals leaving the area for a period of time, or a brief startle reaction. Masking effects may also occur at lower levels of noise. Masking is the interference with the detection of biologically relevant communication signals such as echolocation clicks or social signals. Masking has been shown in acoustic signals used for communication among marine mammals (see Clark *et al.,* 2009). Masking may in some cases hinder echolocation of prey or detection of predators. If the signal-to-noise ratio prevents detection of subtle or even prominent pieces of information, inappropriate or ineffective responses may be shown by the receiving organism.

7.4.4 NOAA (2018) provides technical guidance for assessing the effects of underwater anthropogenic (human-made) sound on the hearing of marine mammal species. Specifically, the received levels, or acoustic thresholds, at which individual marine mammals are predicted to experience changes in their hearing sensitivity (either temporary or permanent) for acute, incidental exposure to underwater anthropogenic sound sources are provided. These thresholds update and replace the previously proposed criteria in Southall *et al.* (2007) for preventing auditory/physiological injuries in marine mammals. Further recommendations have recently been published regarding marine mammal noise exposure by Southall *et al.* (2019) which complement the NOAA (2018) thresholds and also look at a wider range of marine mammals species, as well as the hearing sensitivity of amphibious mammals (e.g., seals, sea otters) to airborne noise.

7.4.5 The NOAA (2018) and Southall *et al.* (2019) thresholds are categorised according to marine mammal hearing groups. The Nature Conservation and Marine Ecology chapter (Chapter 9) of the ES provides a detailed review of the marine mammal receptors that occur in the study area. The key marine mammal species comprise harbour porpoise, common seal, and grey seal.

According to NOAA (2018), harbour porpoise is categorised as a high-frequency (HF) cetacean and common and grey seals are categorised as pinniped phocids in water (PW) (earless seals or 'true seals').

7.4.6 NOAA (2018) and Southall *et al.* (2019) provide weighted cumulative SEL acoustic thresholds for non-impulsive sources (e.g., vibro piling) and unweighted peak SPL and weighted cumulative SEL acoustic thresholds for impulsive sources (e.g., impact piling) which are categorised according to marine mammal hearing groups. The relevant acoustic thresholds for the onset of TTS and PTS due to non-impulsive and impulsive sound sources for the relevant marine mammal groups are presented in Table 4.

Table 4. Marine mammal response criteria applied in this assessment

Marine Mammal Hearing Group	Impulsive (Impact Piling)		Non-Impulsive (Vibro Piling, Dredging and Vessel Movements)	
	TTS	PTS	TTS	PTS
High-frequency (HF) cetaceans (harbour porpoise)	140 dB SEL_{cum} 196 dB peak	155 dB SEL_{cum} 202 dB peak	153 dB SEL_{cum}	173 dB SEL_{cum}
Phocid pinnipeds in water (PW) (true seals)	170 dB SEL_{cum} 212 dB peak	185 dB SEL_{cum} 218 dB peak	181 dB SEL_{cum}	201 dB SEL_{cum}
Peak SPL has a reference value of 1 µPa and weighted cumulative SEL has a reference value of 1 μPa^2s.				

7.4.7 Peak SPL acoustic thresholds for impulsive sound sources provide an estimate of the instantaneous worst-case potential effects on marine mammals. Cumulative SEL is calculated from the energy in a representative single pile strike and the number of strikes over a 24-hour period. This measure assumes that all strikes have the same received single strike SEL value, which is rarely the case since the animal (or source) is likely to be moving relative to each other. It also assumes that the animal is stationary within the zone of potential effect for a 24-hour period which is highly unlikely. Furthermore, it does not take potential physiological or physical recovery from any effects of a single signal exposure into account. As such, this averaging metric has the potential to result in false conclusions on the effects of sound exposure and needs to be treated with more caution as noted by Hawkins and Popper (2017).

7.4.8 There are no equivalent SPL behavioural response criteria that would represent the sources of underwater noise associated with the proposed development. Behavioural reactions to acoustic exposure are less predictable and difficult to quantify than effects of noise exposure on hearing or physiology as reactions are highly variable and context specific (Southall *et al*., 2007).

7.4.9 Field studies have demonstrated behavioural responses of harbour porpoises to anthropogenic noise (Cefas, 2020). A number of studies have shown avoidance of pile driving activities during offshore wind farm construction (Brandt *et al*., 2011; Carstensen *et al*., 2006; Dähne *et al*., 2013), with the range of measurable responses extending to at least 21 km in some cases (Tougaard *et al*., 2009). Seismic surveys have also elicited avoidance behaviour in harbour porpoises, albeit short-term (Thompson *et al*., 2013), and monitoring of echolocation activity suggests possible negative effects on foraging activity in the vicinity of seismic operations (Pirotta *et al*., 2014). There is a scarcity of studies quantifying behavioural impacts from dredging (Thomsen *et al*., 2011). An investigation by Diederichs *et al.* (2011) showed that harbour porpoises temporarily avoided an area of sand extraction off the Island of Sylt in Germany. Diederichs *et al*. (2011) found that, when the dredging vessel was closer than 600 m to the porpoise detector location, it took three times longer before a porpoise was again recorded in the area than during times without sand extraction. However, after the dredging vessel left the area, the clicks resumed to the baseline rate that was present before the dredging vessel had entered the area.

7.4.10 Few studies have documented responses of seals to underwater noise in the field (Cefas, 2020). Tracking studies found reactions of the grey seals to pile driving during the construction of windfarms were diverse (Aarts *et al*., 2017). These included altered surfacing or diving behaviour, and changes in swim direction including swimming away from the source, heading into shore or travelling perpendicular to the incoming sound, or coming to a halt. Also, in some cases no apparent changes in their diving behaviour or movement was observed. Of the different behavioural changes observed a decline in descent speed occurred most frequent, which suggests a transition from foraging (diving to the bottom) to more horizontal movement. These changes in behaviour were on average larger and occurred more frequent at smaller distances from the pile driving events, and such changes were statistically significantly different at least up to 36 km. In addition to changes in dive behaviour, also changes in movement were recorded. There was evidence that on average grey seals within 33 km were more likely to swim away from the pile driving. In some cases, seals exposed to pile-driving at close range, returned to the same area on subsequent trips. This suggests that some seals had an incentive to go to these areas, which was stronger than the potential deterring effect of the pile-driving.

7.4.11 A telemetry study found no overall significant displacement of common seal during construction of a wind farm in The Wash, south-east England (Russell *et al*., 2016). However, during piling, seal usage (abundance) was significantly reduced up to 25 km from the piling activity; within 25 km of the centre of the wind farm, there was a 19 to 83% (95% confidence intervals) decrease in usage compared to during breaks in piling, equating to a mean estimated displacement of 440 individuals. This amounts to significant displacement starting from predicted received levels of between 166 and 178 dB re 1 µPa (peak-peak). Displacement was limited to piling activity; within 2 hours of cessation of pile driving, seals were distributed as per the non-piling scenario.

7.4.12 Koschinski *et al*. (2003) conducted a playback experiment on harbour seals in which the recorded sound of an operational wind turbine was projected via a loudspeaker, resulting in modest displacement of seals from the source (median distance was 284 vs 239 m during control trials). Two further studies of ringed seals (*Phoca hispida*), which are closely related to both harbour and grey seals, have observed behaviour in response to anthropogenic noise: Harris *et al*., (2001) reported animals swimming away and avoidance within ~150 m of a seismic survey, while Moulton *et al*., (2003) found no discernible difference in seal densities in response to construction and drilling for an oil pipeline.

7.4.13 A number of field observations of harbour porpoise and pinnipeds to multiple pulse sounds have been made and are reviewed by Southall *et al.* (2007). The results of these studies are considered too variable and context-specific to allow single disturbance criteria for broad categories of taxa and of sounds to be developed. Another way to evaluate the responses of marine mammals and the likelihood of behavioural responses is by comparing the received sound level against species specific hearing threshold levels. Further information on the dB_{ht} metric and its limitations is provided in Section 7.3 and is, therefore, not repeated here.

7.4.14 Masking effects may also occur at lower levels of noise. Masking is the interference with the detection of biologically relevant communication signals such as echolocation clicks or social signals. Masking has been shown in acoustic signals used for communication among marine mammals. Masking may in some cases hinder echolocation of prey or detection of predators. If the signal-to-noise ratio prevents detection of subtle or even prominent pieces of information, inappropriate or ineffective responses may be shown by the receiving organism.

8 Noise Propagation Modelling Outputs

8.1.1 The simple logarithmic spreading model (equation 1) described in Section 4 was applied to the worst case (highest) unweighted SLs associated with the proposed development activities (i.e., impact piling with two rigs, vibro piling with two rigs, dredging and vessel movements) to determine the unweighted received levels with range. These received levels represent unweighted metrics as recommended in NPL (2014). Table 5 shows the results of this analysis at various distances from the sources of noise associated with the proposed development.

Table 5. Maximum predicted unweighted received levels during proposed development activities

Range (m)	Impact Piling (SEL in dB 1 μPa²·s)	Vibro Piling (SEL in dB 1 μPa²·s)	Dredging and Vessel Movements (RMS in dB re 1 μPa)
1	206	201	188
10	188	183	170
100	170	165	152
200	164	159	146
500	155	150	137
1,000	147	142	129
2,300*	134	129	116
3,400**	125	120	107
5,000	114	109	96
10,000	82	77	64

* Approximate distance from the most seaward point of the proposed development and opposite shore at low water.
** Approximate distance from the most seaward point of the proposed development and opposite shore at high water.

8.1.2 The SEL received levels of underwater noise generated during impact piling for the proposed development are predicted to reduce to around 147 dB 1 μPa²·s within 1 km of the source of piling which is equivalent to peak SPL of 166 dB re 1 μPa using equation 2 (Section 4) and comparable to the SL generated by a tug and barge (MMO, 2015). The peak levels of underwater noise that reach the opposite shore of the estuary are predicted to range from approximately 125 to 134 dB 1 μPa² s (equivalent to 135 to 147 dB re 1 μPa) depending on the tidal state. These levels are comparable to the SLs generated by recreational boats (MMO, 2015).

8.1.3 The SEL received levels of underwater noise generated during vibro piling are predicted to reduce to around 142 dB 1 μPa²·s within 1 km of the source of piling which is equivalent to peak SPL of 159 dB re 1 μPa and comparable to the SL generated by a passenger vessel or a recreational boat (MMO, 2015).

8.1.4 The levels of underwater noise generated by dredging and vessel movements are predicted to reach existing background levels previously measured in the Humber Estuary (Section 5.6) within around 100 m from the source. It should be noted that the proposed development is located at the Port of Immingham which already experiences intermittent elevated levels of underwater noise of a similar scale to that which is predicted outside of the immediate vicinity of the piling. This is due to the large range of vessels that already operate in this area, including tugs and barges, cargo vessels and oil tankers, as well as ongoing maintenance dredging.

9 Potential Effects

9.1 Fish

Impact piling

9.1.1 The calculator developed by NMFS (2021) as a tool for assessing the potential effects to fish exposed to elevated levels of underwater sound produced during pile driving has been used to calculate the range at which the instantaneous peak and cumulative SEL thresholds for impact pile driving (Popper *et al*., 2014) are reached. The model input values and associated assumptions for impact piling are included in Table 6.

Table 6. NMFS piling calculator input values for impact piling

Model Inputs	Value	Assumptions
Number of strikes per pile	675	Maximum value provided for existing field data in the NMFS pile driving calculator (NMFS, 2021) and, therefore, considered a reasonable worst case.
Number of piles per day	4	The maximum impact piling scenario is for the marine works to comprise up to 4 tubular piles to be installed each day (see Section 6.2 of this report).
Peak SPL SL	231	Loudest near-source (10 m from the source) sound pressure measurements for the percussive piling installation of 1.52 m CISS steel pipe piles in a shallow water environment (Illinworth & Rodkin, 2007; ICF Jones & Stokes and Illingworth and Rodkin, 2009; Rodkin and Pommerenck, 2014) back-calculated to 1 m and the assumption that more than one piling rig with impact hammers will be used concurrently (see Section 6.2 of this report).
SEL SL	206	As above.
Distance from source (m)	1	The sound levels that were measured for the percussive piling installation of 1.52 m CISS steel pipe piles in a shallow water environment (Illinworth & Rodkin, 2007; ICF Jones & Stokes and Illingworth and Rodkin, 2009; Rodkin and Pommerenck, 2014) have been back-calculated to 1 m from the source (see Section 6.2 of this report).
Noise reduction due to abatement (dB)	NA	Not applicable.
Transmission loss coefficient	17.91	Derived from 11 observations of transmission loss coefficient collected from a number of construction projects undertaken in shallow water estuarine and coastal locations (see Section 4 of this report).

9.1.2 The distances at which potential mortality/injury and behavioural effects in fish are predicted to occur during impact piling activities associated with the construction of the proposed development are included in Table 7.

Table 7. Approximate distances (metres) fish response criteria are reached during concurrent impact piling

Fish Hearing Category	Mortality/ Potential Mortal Injury		Recoverable Injury		Behaviour
	Peak	SEL_{cum}	Peak	SEL_{cum}	Peak
Swim bladder involved in hearing (primarily pressure detection)	22	72	22	121	1,554
Swim bladder is not involved in hearing (particle motion detection)	22	49	22	121	1,554
No swim bladder (particle motion detection)	10	15	10	23	1,554
Eggs and larvae	22	49	(N) Moderate (I) Low (F) Low		1,554

9.1.3 Given the mobility of fish, any individuals that might be present within the localised areas associated with potential mortality/injury during pile driving activities would be expected to easily move away and avoid harm.

9.1.4 Behavioural reactions are anticipated to occur across 67% width of the Humber Estuary at low water and 46% of the estuary width at high water, therefore, potentially creating a partial temporary barrier to fish movements. The scale of the behavioural response is partly dependent on the hearing sensitivity of the species. Fish with a swim bladder involved in hearing (e.g., herring) may exhibit a moderate behavioural reaction within distance in which a behavioural response is predicted (e.g., a sudden change in swimming direction, speed, or depth). Fish with a swim bladder that is not involved in hearing (e.g., European eel) are likely to display a milder behavioural reaction. Fish without a swim bladder (e.g., river lamprey) are anticipated to only show very subtle changes in behaviour in this zone.

9.1.5 The scale of the behavioural effect is also dependent on the size of fish (which affects maximum swimming speed). Smaller fish, juveniles and fish larvae swim at slower speeds and are likely to move passively with the prevailing current. Larger fish are more likely to actively swim and, therefore, may be able to move out of the behavioural effects zone in less time, although it is recognised that the movement of fish is very complex and not possible to define with a high degree of certainty.

9.1.6 The effects of piling noise on fish also need to be considered in terms of the duration of exposure. Piling noise will take place over a period of approximately 24 weeks. However, piling will not take place continuously as there will be periods of downtime, pile positioning and set up.

9.1.7 The construction of the IERRT project may be completed in a single stage, or it may be sequenced such that the construction of the southernmost pier takes place at the same time as operation of the northernmost pier (see Chapter 3 of the ES). In the case of a sequenced construction, the overall duration of piling will be extended to 37 weeks. However, there will be no change in the overall peak levels of underwater noise generated by the construction of all three berths at once versus a sequenced construction (i.e., the magnitude of change). Therefore, the underwater noise assessment is considered the worst case and will not be altered by a sequenced construction period.

9.1.8 The marine piling works will be undertaken Monday to Sunday. The maximum impact piling scenario is for 4 tubular piles to be installed each day from either front (i.e., the land and water), involving approximately 180 minutes of impact piling per day in a 12-hour shift. There will, therefore, be significant periods over a 24-hour period when fish will not be disturbed by any impact piling noise. The actual proportion of impact piling is estimated to be at worst around 13% (based on 180 minutes of impact piling each working day) over any given construction week. In other words, any fish that remain within the predicted behavioural effects zone at the time of percussive piling will be exposed a maximum of up to 13% of the time.

9.1.9 It is also important to consider the noise from piling against existing background or ambient noise conditions (Section 5 of this report). The area in which the construction will take place already experiences regular vessel operations and ongoing maintenance dredging, and, therefore, fish are likely to be habituated to a certain level of anthropogenic background noise.

Vibro piling

9.1.10 The calculator developed by NMFS (2021) has been used to calculate the range at which the instantaneous peak and cumulative SEL thresholds for vibro driving (Popper *et al*., 2014) are reached. The model input values and associated assumptions for vibro piling are included in Table 8.

9.1.11 The distances at which potential mortality/injury and behavioural effects in fish are predicted to occur during vibro piling activities associated with the construction of the proposed development are included in Table 9.

9.1.12 Given the mobility of fish, any individuals that might be present within the localised areas associated with potential mortality/injury during pile driving activities would be expected to easily move away and avoid harm.

9.1.13 Behavioural reactions are anticipated to occur across 48% of the width of the Humber Estuary at low water and 33% of the estuary width at high water. The scale of the behavioural response is partly dependent on the hearing sensitivity of the species. Fish with a swim bladder involved in hearing (e.g., herring) may exhibit a moderate behavioural reaction within distance in which a behavioural response is predicted (e.g., a sudden change in swimming direction, speed, or depth). Fish with a swim bladder that is not involved in hearing (e.g., European eel) are likely to display a milder behavioural reaction. Fish without a swim bladder (e.g., river lamprey) are anticipated to only show very subtle changes in behaviour in this zone.

Table 8. NMFS piling calculator input values for vibro piling

Model Inputs	Value	Assumptions
Number of strikes per pile	675	Maximum value provided for existing field data in the NMFS pile driving calculator (NMFS, 2021) and, therefore, considered a reasonable worst case.
Number of piles per day	4	The maximum vibro piling scenario is for the marine works to comprise up to 4 tubular piles to be installed each day (see Section 6.2 of this report).
Peak SPL SL	216	Loudest near-source (10 m from the source) sound pressure measurements for the vibratory piling installation of 1.83 m steel pipe piles in a shallow water environment (Illinworth & Rodkin, 2007; ICF Jones & Stokes and Illingworth and Rodkin, 2009; Rodkin and Pommerenck, 2014) back-calculated to 1 m and the assumption that more than one piling rig with vibro hammers will be used concurrently (see Section 6.2 of this report).
SEL SL	201	As above.
RMS SL	201	As above.
Distance from source (m)	1	The sound levels that were measured for the vibratory piling installation of 1.83 m steel pipe piles in a shallow water environment (Illinworth & Rodkin, 2007; ICF Jones & Stokes and Illingworth and Rodkin, 2009; Rodkin and Pommerenck, 2014) have been back-calculated to 1 m from the source (see Section 6.2 of this report).
Noise reduction due to abatement (dB)	NA	Not applicable.
Transmission loss coefficient	17.91	Derived from 11 observations of transmission loss coefficient collected from a number of construction projects undertaken in shallow water estuarine and coastal locations (see Section 4 of this report).

9.1.14 The scale of the behavioural effect is also dependent on the size of fish (which affects maximum swimming speed). Smaller fish, juveniles and fish larvae swim at slower speeds and are likely to move passively with the prevailing current. Larger fish are more likely to actively swim and, therefore, may be able to move out of the behavioural effects zone in less time.

Table 9. Approximate distances (metres) fish response criteria are reached during concurrent vibro piling

Fish Hearing Category	Mortality/ Potential Mortal Injury		Recoverable Injury		Behaviour
	Peak	SEL_{cum}	Peak	SEL_{cum}	Peak
Swim bladder involved in hearing (primarily pressure detection)	3	38	3	64	1,105
Swim bladder is not involved in hearing (particle motion detection)	3	26	3	64	1,105
No swim bladder (particle motion detection)	1	8	1	12	1,105
Eggs and larvae	3	26	(N) Moderate (I) Low (F) Low		1,105

9.1.15 The effects of piling noise on fish also need to be considered in terms of the duration of exposure. Piling noise will take place over a period of approximately 24 weeks. However, piling will not take place continuously as there will be periods of downtime, pile positioning and set up.

9.1.16 The construction of the IERRT project may be completed in a single stage, or it may be sequenced such that the construction of the southernmost pier takes place at the same time as operation of the northernmost pier (see Chapter 3 of the ES). In the case of a sequenced construction, the overall duration of piling will be extended to 37 weeks. However, there will be no change in the overall peak levels of underwater noise generated by the construction of all three berths at once versus a sequenced construction (i.e., the magnitude of change). Therefore, the underwater noise assessment is considered the worst case and will not be altered by a sequenced construction period.

9.1.17 The marine piling works will be undertaken Monday to Sunday. The maximum vibro piling scenario is for 4 tubular piles to be installed each day from either front (i.e., the land and water), involving around 20 minutes of vibro piling per day in a 12-hour shift. There will, therefore, be significant periods over a 24-hour period when fish will not be disturbed by any vibro driving noise. The actual proportion of vibro piling is estimated to be at worst around 1% (based on an estimated 20 minutes of vibro piling each working day) over any given construction week. In other words, any fish that remain within the predicted behavioural effects zone at the time of vibro piling will be exposed a maximum of up to 1% of the time.

9.1.18 It is also important to consider the noise from piling against existing background or ambient noise conditions (Section 5 of this report). The area in which the construction will take place already experiences regular vessel operations and ongoing maintenance dredging, and, therefore, fish are likely to be habituated to a certain level of anthropogenic background noise.

Dredging and vessel movements

9.1.19 The relative risk and distances at which potential mortality/injury and behavioural effects in fish are predicted to occur as a result of the dredging and vessel movements associated with the construction and operation of the proposed development are included in Table 10.

9.1.20 The worst-case SL generated by dredging and vessels is below the Popper *et al.* (2014) quantitative instantaneous peak SPL and cumulative SEL thresholds for pile driving, which indicates that there is no risk of mortality, potential mortal injury or recoverable injury in all categories of fish even at the very source of the dredger or vessel noise. This appears to correlate with the Popper *et al.* (2014) recommended qualitative guidelines for continuous noise sources which consider that the risk of mortality and potential mortal injury in all fish is low in the near, intermediate and far-field (Table 10). According to Popper *et al*. (2014), the risk of recoverable injury is also considered low for fish with no swim bladder and fish with a swim bladder that is not involved in hearing. There is a greater risk of recoverable injury in fish where the swim bladder is involved in hearing (e.g., herring) whereby a cumulative noise exposure threshold is recommended (170 dB rms for 48 h). The distance at which recoverable injury is predicted in these fish as a result of the dredging and vessel movements is 10 m (Table 10).

9.1.21 Popper *et al*. (2014) advise that there is a moderate risk of TTS occurring in the nearfield (i.e., tens of metres from the source) in fish with no swim bladder and fish with a swim bladder that is not involved in hearing and a low risk in the intermediate and far-field. There is a greater risk of TTS in fish where the swim bladder is involved in hearing (e.g., herring) whereby a cumulative noise exposure threshold is recommended (158 dB rms for 12 h). The distance at which TTS is predicted in these fish as a result of the dredging and vessel movements is 46 m (Table 10).

9.1.22 Popper *et al.* (2014) guidelines suggest that there is considered to be a high risk of potential behavioural responses occurring in the nearfield (i.e., tens of metres from the source) for fish species with a swim bladder involved in hearing and a moderate risk in other fish species (Table 10). At intermediate distances (i.e., hundreds of metres from the source) there is considered to be a moderate risk of potential behavioural responses in all fish and in the far field (i.e., thousands of metres from the source) there is considered to be a low risk of a response in all fish.

9.1.23 Overall, there is considered to be a low risk of any injury in fish as a result of the underwater noise generated by dredging and vessel movements. The level of exposure will depend on the position of the fish with respect to the source, the propagation conditions, and the individual’s behaviour over time. However, it is unlikely that a fish would remain in the vicinity of a dredger for extended periods. Behavioural responses are anticipated to be spatially negligible in scale and fish will be able to move away and avoid the source of the noise as required. Furthermore, the period of dredging will be short term (approximately 80 days (11 weeks) in total).

Table 10. Relative risk and distances (metres) fish response criteria are reached during dredging and vessel movements

Fish Hearing Category	Mortality/ Potential Mortal Injury/ Recoverable Injury	Recoverable injury	TTS	Behaviour
Swim bladder involved in hearing (primarily pressure detection)	(N) Low (I) Low (F) Low	10	46	(N) High (I) Moderate (F) Low
Swim bladder is not involved in hearing (particle motion detection)	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Moderate (F) Low
No swim bladder (particle motion detection)	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Moderate (F) Low
Eggs and larvae	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Moderate (F) Low
Distances are in metres (m). Relative risk (high, moderate, low) is given for animals at three distances from the source defined in relative terms as near (N), intermediate (I), and far (F).				

9.2 Marine mammals

Impact piling

9.2.1 NOAA's user spreadsheet tool (NOAA, 2021) has been used to predict the range at which the weighted cumulative SEL and instantaneous peak SPL acoustic thresholds (NOAA, 2018) for the onset of PTS and TTS are reached during the proposed impact piling activity.

9.2.2 In accordance with the guidance provided in NOAA's user manual and the instructions included within the user spreadsheet, 'Tab E.1: Impact pile driving (stationary source: impulsive, intermittent)' and 'E1.2: Method to calculate peak and SEL_{cum} using rms SPL source level' was selected as the most appropriate method to apply for the percussive piling activity. The model input values, and associated assumptions are included in Table 11.

Table 11. NOAA user spreadsheet tool input values for 'Tab E.1: Impact pile driving (stationary source: impulsive, intermittent)'

Model Inputs	Value	Assumptions
Weighting factor adjustment (kHz)	2	Default value for impact pile driving hammers provided in the NOAA instructions (NOAA, 2021).
Lp,0-pk specified at "x" meters (dB re 1 µPa)	231	Loudest near-source (10 m from the source) sound pressure measurements for the percussive piling installation of 1.52 m CISS steel pipe piles in a shallow water environment (Illinworth & Rodkin, 2007; ICF Jones & Stokes and Illingworth and Rodkin, 2009; Rodkin and Pommerenck, 2014) back-calculated to 1 m and the assumption that more than one piling rig with impact hammers will be used concurrently (see Section 6.2 of this report).
Sound Pressure Level (L_{rms}), specified at "x" metres (dB re 1 µPa)	216	Loudest near-source (10 m from the source) sound pressure measurements for the percussive piling installation of 1.52 m CISS steel pipe piles in a shallow water environment (Illinworth & Rodkin, 2007; ICF Jones & Stokes and Illingworth and Rodkin, 2009; Rodkin and Pommerenck, 2014) back-calculated to 1 m and the assumption that more than one piling rig with impact hammers will be used concurrently (see Section 6.2 of this report).
Number of piles per day	4	The maximum impact piling scenario is for the marine works to comprise up to 4 tubular piles to be installed each day (see Section 6.2 of this report).
Strike (pulse) duration (seconds)	0.1	Default value provided in the NOAA instructions (NOAA, 2021).

Model Inputs	Value	Assumptions
Number of strikes per pile	675	Maximum value provided for existing field data in the NMFS pile driving calculator (NMFS, 2021) and, therefore, considered a reasonable worst case.
Transmission loss coefficient	17.91	Derived from 11 observations of transmission loss coefficient collected from a number of construction projects undertaken in shallow water estuarine and coastal locations (see Section 4 of this report).
Distance of sound pressure level measurement (m)	1	The sound levels that were measured for the percussive piling installation of 1.52 m CISS steel pipe piles in a shallow water environment (Illinworth & Rodkin, 2007; ICF Jones & Stokes and Illingworth and Rodkin, 2009; Rodkin and Pommerenck, 2014) have been back-calculated to 1 m from the source (see Section 6.2 of this report).

9.2.3 The distances at which PTS and TTS in marine mammals are predicted to occur during impact piling activities associated with the construction of the proposed development are included in Table 12.

Table 12. Approximate distances (metres) marine mammal response criteria are reached during impact piling

Marine Mammal Hearing Group	PTS		TTS	
	SEL_{cum}	Peak	SEL_{cum}	Peak
Harbour porpoise	1,833	42	12,611	90
Common seal and grey seal	938	5	6,452	12

9.2.4 There is predicted to be a risk of instantaneous PTS and TTS in harbour porpoise within 42 m and 90 m respectively from the source of the percussive piling noise. The risk of instantaneous PTS and TTS in seals is within 5 m and 12 m respectively.

9.2.5 If the propagation of underwater noise from impact piling were unconstrained by any boundaries, the maximum theoretical distance at which the predicted cumulative SEL weighted levels of underwater noise during impact piling is within the limits of PTS and TTS in harbour porpoise is 1.8 km and 12.6 km respectively. The maximum distance for PTS and TTS in seals is 0.9 km and 6.5 km respectively.

9.2.6 Assuming a lower worst case swimming speed of 1.5 m/s for all marine mammal species (including both adults and juveniles), the maximum time that would take harbour porpoise to leave the centre of the cumulative SEL weighted PTS and TTS injury zones during impact piling is estimated to be 20 minutes and 2.3 hours respectively. This is less than 10% of the time that would be required for an injury to occur and, therefore, assuming harbour porpoise evade the injury effects zone, they are not considered to be at risk of any permanent or temporary injury during impact piling. The maximum time that would take seals to leave the PTS and TTS zones is estimated to be 10 minutes and 1.2 hours respectively. This is less than 5% of the time that would be required for an injury to occur and, therefore, assuming seals evade the injury effects zone, they are not considered to be at risk of any permanent or temporary injury during impact piling.

9.2.7 Impact piling is predicted to cause instantaneous injury effects within close proximity to the activity and strong behavioural responses over a wider area although this will be constrained to within the outer section of the Humber Estuary between Hull and Cleethorpes.

9.2.8 The results indicate that if any marine mammals present in the Humber Estuary were to remain stationary within the cumulative SEL distances from the source of piling over a 24-hour period, it could result in temporary and/or permanent hearing injury. However, it is considered highly unlikely that any individual marine mammal will stay within this ‘injury zone’ during the piling operations.

9.2.9 Any marine mammals present are likely to evade the area. Behavioural responses could include movement away from a sound source, aggressive behaviour related to noise exposure (e.g., tail/flipper slapping, fluke display, abrupt directed movement), visible startle response and brief cessation of reproductive behaviour (Southall *et al*., 2007). Mild to moderate behavioural responses of any individuals within these zones could include movement away from a sound source and/or visible startle response (Southall *et al*., 2007).

9.2.10 The effects of piling noise on marine mammals also need to be considered in terms of the duration of exposure. Piling noise will take place over a period of approximately 24 weeks. However, piling will not take place continuously as there will be periods of downtime, pile positioning and set up.

9.2.11 The construction of the IERRT project may be completed in a single stage, or it may be sequenced such that the construction of the southernmost pier takes place at the same time as operation of the northernmost pier (see Chapter 3 of the ES). In the case of a sequenced construction, the overall duration of piling will be extended to 37 weeks. However, there will be no change in the overall peak levels of underwater noise generated by the construction of all three berths at once versus a sequenced construction (i.e., the magnitude of change). Therefore, the underwater noise assessment is considered the worst case and will not be altered by a sequenced construction period.

9.2.12 The marine piling works will be undertaken Monday to Sunday. The maximum impact piling scenario is for 4 tubular piles to be installed each day from either front (i.e., the land and water), involving approximately 180 minutes of impact piling per day in a 12-hour shift. There will, therefore, be significant periods over a 24-hour period when fish will not be disturbed by any impact piling noise. The actual proportion of impact piling is estimated to be at worst around 13% (based on 180 minutes of impact piling each working day) over any given construction week. In other words, any fish that remain within the predicted behavioural effects zone at the time of percussive piling will be exposed a maximum of up to 13% of the time.

9.2.13 It is also important to consider the noise from piling against existing background or ambient noise conditions (Section 5 of this report). The area in which the construction will take place already experiences regular vessel operations and ongoing maintenance dredging, and, therefore, marine mammals are likely to be habituated to a certain level of anthropogenic background noise.

Vibro piling

9.2.14 NOAA's user spreadsheet tool (NOAA, 2021) has been used to predict the range at which the weighted cumulative SEL acoustic thresholds (NOAA, 2018) for the onset of PTS and TTS are reached during the proposed vibro piling activity.

9.2.15 In accordance with the guidance provided in NOAA's user manual and the instructions included within the user spreadsheet, 'Tab A.1: Vibratory pile driving (stationary source: non-impulsive, continuous)' was selected as the most appropriate method to apply for the vibro piling activity. The model input values and associated assumptions are included in Table 13.

Table 13. NOAA user spreadsheet tool input values for 'Tab A.1: Vibratory pile driving (stationary source: non-impulsive, continuous)'

Model Inputs	Value	Assumptions
Weighting factor adjustment (kHz)	2.5	Default value for vibratory pile driving hammers provided in the NOAA instructions (NOAA, 2021).
Sound Pressure Level (L_{rms}), specified at "x" metres (dB re 1 µPa)	201	Loudest near-source (10 m from the source) sound pressure measurements for the vibratory piling installation of 1.83 m steel pipe piles in a shallow water environment (Illinworth & Rodkin, 2007; ICF Jones & Stokes and Illingworth and Rodkin, 2009; Rodkin and Pommerenck, 2014) and the assumption that more than one piling rig with vibro hammers will be used concurrently (see Section 6.2 of this report).
Number of piles within 24 hr period	4	The maximum vibro piling scenario is for the marine works to comprise up to 4 tubular piles to be installed each day (see Section 6.2 of this report).
Duration to drive a single pile (minutes)	5	Each tubular pile will require 5 minutes of vibro piling (see Section 6.2 of this report).

Model Inputs	Value	Assumptions
Transmission loss coefficient	17.91	Derived from 11 observations of transmission loss coefficient collected from a number of construction projects undertaken in shallow water estuarine and coastal locations (see Section 4 of this report).
Distance of sound pressure level measurement (m)	1	The sound levels that were measured for the vibratory piling installation of 1.83 m steel pipe piles in a shallow water environment (Illinworth & Rodkin, 2007; ICF Jones & Stokes and Illingworth and Rodkin, 2009; Rodkin and Pommerenck, 2014) have been back-calculated to 1 m from the source (see Section 6.2 of this report).

9.2.16 The distances at which PTS and TTS in marine mammals are predicted to occur during vibro piling activities associated with the construction of the proposed development are included in Table 14.

Table 14. Approximate distances (metres) marine mammal response criteria are reached during vibro piling

Marine Mammal Hearing Group	PTS	TTS
High-frequency (HF) cetaceans (porpoises, river dolphins)	94	1,223
Phocid pinniped (PW) (true seals)	44	581

9.2.17 If the propagation of underwater noise from vibro piling were unconstrained by any boundaries, the maximum theoretical distance at which the predicted cumulative SEL weighted levels of underwater noise during vibro piling is within the limits of PTS and TTS in harbour porpoise is 94 m and 1.2 km respectively. The maximum distance for PTS and TTS in seals is 44 m and 581 m respectively.

9.2.18 Assuming a lower worst case swimming speed of 1.5 m/s for all marine mammal species (including both adults and juveniles), the maximum time that would take harbour porpoise to leave the centre of the cumulative SEL weighted PTS and TTS injury zones during vibro piling is estimated to be 1 minute and 14 minutes respectively. This is less than 1% of the time that would be required for an injury to occur and, therefore, assuming harbour porpoise evade the injury effects zone, they are not considered to be at risk of any permanent or temporary injury during vibro piling. The maximum time that would take seals to leave the PTS and TTS zones is estimated to be 29 seconds and 6 minutes respectively. This is less than 0.4% of the time that would be required for an injury to occur and, therefore, assuming seals evade the injury effects zone, they are not considered to be at risk of any permanent or temporary injury during vibro piling.

9.2.19 The results indicate that if any marine mammals present in the estuary were to remain stationary within the cumulative SEL distances from the source of piling over a 24-hour period, it could result in temporary and/or permanent hearing injury. However, it is considered highly unlikely that any individual marine mammal will stay within this 'injury zone' during the piling operations.

9.2.20 Any marine mammals are likely to evade the area. Behavioural responses could include movement away from a sound source, aggressive behaviour related to noise exposure (e.g., tail/flipper slapping, fluke display, abrupt directed movement), visible startle response and brief cessation of reproductive behaviour (Southall *et al*., 2007). Mild to moderate behavioural responses of any individuals within these zones could include movement away from a sound source and/or visible startle response (Southall *et al*., 2007).

9.2.21 The effects of piling noise on marine mammals also need to be considered in terms of the duration of exposure. Piling noise will take place over a period of approximately 24 weeks. However, piling will not take place continuously as there will be periods of downtime, pile positioning and set up.

9.2.22 The construction of the IERRT project may be completed in a single stage, or it may be sequenced such that the construction of the southernmost pier takes place at the same time as operation of the northernmost pier (see Chapter 3 of the ES). In the case of a sequenced construction, the overall duration of piling will be extended to 37 weeks. However, there will be no change in the overall peak levels of underwater noise generated by the construction of all three berths at once versus a sequenced construction (i.e., the magnitude of change). Therefore, the underwater noise assessment is considered the worst case and will not be altered by a sequenced construction period.

9.2.23 The marine piling works will be undertaken Monday to Sunday. The maximum vibro piling scenario is for 4 tubular piles to be installed each day from either front (i.e., the land and water), involving around 20 minutes of vibro piling per day in a 12-hour shift. There will, therefore, be significant periods over a 24-hour period when marine mammals will not be disturbed by any vibro driving noise. The actual proportion of vibro piling is estimated to be at worst around 1% (based on an estimated 20 minutes of vibro piling each working day) over any given construction week. In other words, any marine mammals that remain within the predicted behavioural effects zone at the time of vibro piling will be exposed a maximum of up to 1% of the time.

9.2.24 It is also important to consider the noise from piling against existing background or ambient noise conditions. The area in which the construction will take place already experiences regular vessel operations, and, therefore, marine mammals are likely to be habituated to a certain level of anthropogenic background noise disturbance.

Dredging and vessel movements

9.2.25 NOAA's user spreadsheet tool (NOAA, 2021) has been used to predict the range at which the weighted cumulative SEL acoustic thresholds (NOAA, 2018) for PTS and TTS are reached during the proposed dredging and vessel movements associated with the construction and operation of the proposed development.

9.2.26 In accordance with the guidance provided in NOAA's user manual and the instructions included within the user spreadsheet, 'Tab C: Mobile source, non-impulsive, continuous ('safe distance' methodology)' was selected as the most appropriate method to apply for the dredging and vessel activity. The model input values, and associated assumptions are included in Table 15.

Table 15. NOAA user spreadsheet tool input values for 'Tab C: Mobile source, non-impulsive, continuous ('safe distance' methodology)'

Model Inputs	Value	Assumptions
Weighting factor adjustment (kHz)	2.5	The maximum recommended default value provided in the user spreadsheet (NOAA, 2021) that leads to the greatest predicted ranges for PTS and TTS and is, therefore, considered a worst case.
Source Level (L_{rms})	188	The maximum estimated RMS SL for all forms of dredging and vessels that will be involved in construction and operation of the proposed development (see Section 6.3 and Section 6.4 of this report).
Source velocity (m/s)	1	Value is based on the minimum sailing speed of a dredging vessel as it removes material from the seabed. A lower source velocity value predicts greater ranges at which PTS and TTS are reached and, therefore, the lowest reasonable source velocity associated with the dredging and vessel activity has been applied as a worst case.

9.2.27 The distances at which PTS and TTS in marine mammals are predicted to occur during dredging and vessel movements associated with the construction and operation of the proposed development are included in Table 16.

Table 16. Approximate distances (metres) marine mammal response criteria are reached during dredging and vessel movements

Marine Mammal Hearing Group	PTS	TTS
High-frequency (HF) cetacean (harbour porpoise)	<1	44
Phocid pinniped (PW) (grey seal and common seal)	<1	12

9.2.28 There is predicted to be no risk of PTS in harbour porpoise and the risk of TTS is limited to within less than 44 m from the dredging or vessel activity (Table 16). There is predicted to be no risk of PTS in seals and the risk of TTS is limited to within 12 m from the source.

9.2.29 Overall, there is not considered to be any risk of injury or significant disturbance to marine mammals from the proposed dredging and vessel activities that are proposed for the project at the Port of Immingham even if the dredging and vessel movements were to take place continuously 24/7.

10 Summary and Conclusions

10.1.1 This report presents the underwater noise modelling that has been undertaken to determine the potential impacts of underwater noise on key marine receptors as a result of the construction and operation of the IERRT project.

10.1.2 In accordance with available guidance (NPL, 2014; Farcas *et al*., 2016; Faulkner *et al*., 2018), and as agreed by the MMO and Cefas, a simple logarithmic spreading model has been selected to predict the propagation of sound pressure from the key sources of underwater noise, taking account of its limitations and constraints. The predicted levels of underwater noise have been compared against peer-reviewed noise exposure criteria to determine the potential risk of impact on marine fauna (Hawkins *et al*., 2014; Popper *et al.*, 2014; NOAA, 2018; Southall *et al*., 2019).

10.1.3 A number of mitigation measures are proposed to reduce or minimise potential adverse effects during construction:

- **Soft start**: The gradual increase of piling power, incrementally, until full operational power is achieved will be used as part of the piling methodology. This will give fish and marine mammals the opportunity to move away from the area before the onset of full impact strikes. The duration of the soft start is proposed to be 20 minutes in line with the JNCC piling protocol (JNCC, 2010);
- **Vibro piling**: Vibro piling is proposed to be used where possible (which produces lower peak source noise levels than percussive piling) ;
- **Seasonal piling restrictions**: During percussive piling the following further restrictions are proposed:
  - No percussive piling is to take place within the waterbody between 1 April and 31 May inclusive in any calendar year. This will minimise the potential impact on the greatest number of different migratory fish in the Humber Estuary, in accordance with the periods identified in the marine ecology assessment (Chapter 9 of the ES). This restriction does not apply to percussive piling that can be undertaken outside the waterbody at periods of low water[6].
  - The duration of percussive piling is to be restricted within the waterbody from 1 June to 30 June and 1 August to 31 October inclusive in any year to minimise the impacts on fish migrating through Humber Estuary during this period. The maximum amount of percussive piling permitted within any 4-week period must not exceed 140 hours where a single piling rig is in operation or a total of 196

[6] The force generated by piling outside the waterbody will be exerted on the ground at that location. The sound waves can travel outwards through the seabed or be reflected from deeper sediments. As these waves propagate, sound will also 'leak' upwards contributing to the airborne sound wave. The underwater noise from piling outside the waterbody will, therefore, be considerably reduced (and negligible in scale) as a result of absorption of the sound by the ground and air, the interaction with the ground surface (reflection and scattering), and the interaction with and transmission through the ground.

hours where two or more rigs are in operation. The measurement of time during each work-block described above must begin at the start of each timeframe, roll throughout it, then cease at the end, where measurement will begin again at the start of the next timeframe, such process to be repeated until the end of piling works. This restriction does not apply to percussive piling that can be undertaken outside the waterbody at periods of low water. This approach has been developed in consultation with the MMO and Cefas;

- **Night time working restriction**: The upstream migration of river lamprey takes place almost exclusively at night (Environment Agency, 2013). There is also an increase in glass eel migratory activity during the night time (Harrison *et al*., 2014). No percussive piling is to take place within the waterbody between 1 March to 31 March, 1 June to 30 June and 1 August to 31 October inclusive after sunset and before sunrise on any day. Percussive piling operations that have already been initiated will, however, be completed where an immediate cessation of the activity would form an unsafe working practice. This restriction does not apply to percussive piling that can be undertaken outside the waterbody at periods of low water which will limit the potential effects of underwater piling noise on the nocturnal movements of river lamprey and glass eels; and
- **Marine Mammal Observer**: In addition, in order to further reduce the significance of the impact to marine mammals the JNCC 'Statutory nature conservation agency protocol for minimising the risk of injury to marine mammals during piling' (JNCC, 2010) will be followed during percussive piling.

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12 Abbreviations/Acronyms

ABP	Associated British Ports
CEDA	Centre for Environmental Data Analysis
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CISS	Cast-in-Steel-Shell
dB	Decibel
DCO	Development Consent Order
Defra	Department for Environment, Food and Rural Affairs
DPTI	Department for Infrastructure and Transport
EMMP	Environmental Management and Monitoring Plan
ES	Environmental Statement
EU	European Union
FHWG	Fisheries Hydroacoustic Working Group
GPH	Green Port Hull
HF	High Frequency
HGV	Heavy Goods Vehicle
HRA	Habitats Regulations Assessment
ID	Identity
IERRT	Immingham Eastern Ro-Ro Terminal
IFM	Institute of Fisheries Management
ISO	International Organization for Standardization
JNCC	Joint Nature Conservation Committee
Lrms	RMS Sound Pressure Level
MMO	Marine Management Organisation
MSFD	Marine Strategy Framework Directive
NA	Not applicable.
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPL	National Physical Laboratory
Pa	Pascal
PEIR	Preliminary Environmental Information Report
PINS	Planning Inspectorate
PTS	Permanent Threshold Shift
PW	Pinniped Phocids in Water
RMS	Root Mean Square
SD	Standard Deviation
SEL	Sound Exposure Level
SELcum	Cumulative Sound Exposure Level
SL	Source Level
SPL	Sound Pressure Level
SPLpeak	Peak (Maximum) Sound Pressure Level
TSG	Technical Sub-Group
TSHD	Trailing Suction Hopper Dredger
TTS	Temporary Threshold Shift
UK	United Kingdom
UKMMAS	UK Marine Monitoring Assessment Strategy

WFD	Water Framework Directive
WODA	World Organisation of Dredging Associations
μPa	microPascal

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

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