LLŶR FLOATING OFFSHORE WIND PROJECT

Llŷr 1 Floating Offshore Wind Farm

Environmental Statement

Volume 6: Appendix 21C – Marine Mammal Underwater Noise Assessment

August 2024

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Approval for Issue

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Acronyms and abbreviations

Acronym or Abbreviation	Definition	Acronym or Abbreviation	Definition
%	Percentage	MMMP	Marine Mammal Mitigation Plan
CV	Coefficient of Variation	MU	management Unit
CR	Cable route	n/km^2	Number of individuals per square kilometre
dB	Decibel	NEQ	Net Explosive Quantity
dB re 1µPa	Decibel referenced to 1microPascal	NMFS	National Marine Fisheries Service
dB re 1µPa@1m	Decibel referenced to 1microPascal at 1m	NRW	Natural Resources Wales
dB re $1µPa^2$	Decibel referenced to 1microPascal squared	NRW (A)	Natural Resources Wales (Advisory)
dB re $1µPa^2.s$	Decibel referenced to 1microPascal squared per second	PCW	Phocid carnivores in water
D / R	Dose response	PTS	Permanent threshold shift
EDR	Effective Deterrence Range	PW	Phocid pinnipeds underwater
EIA	Environmental Impact Assessment	RIAA	Report to Inform Appropriate Assessment
EPS	European Protected Species	rms	Root mean square
ES	Environmental Statement	SAC	Special Area of Conservation
FLOW	Floating Offshore Wind Farm	SBP	Sub bottom profiling
HF	High frequency (cetacean)	SEL	Sound exposure level
HiDef	HiDef Aerial Surveying Ltd	SELcum	Cumulative SEL
HRA	Habitat Regulations Assessment	SELss	Single strike SEL
Hz	Hertz (cycles per second)	SPL	Sound pressure level
JNCC	Joint Nature Conservation Committee	SPLcum	Cumulative SPL
kg	kilogram	SPLpeak	The maximum SPL
kHz	Kilo Hertz	SSS	Side scan sonar
kJ	Kilo Joules	TTS	Temporary threshold shift
km	Kilometre	UK	United Kingdom
km^2	Square kilometre	USBL	Ultra-short baseline
LF	Low frequency (cetacean)	UXO	Unexploded ordnance
m/s	metres per second	VHF	Very high frequency (cetacean)
MBES	Multibeam Echosounder	WTG	Wind turbine generator
MF	Mid frequency (cetacean)		

Glossary of project terms

Term	Definition
The Applicant	The developer of the Project, Llŷr Floating Wind Limited
Array	All wind turbine generators, inter array cables, mooring lines, floating sub-structures and supporting subsea infrastructure within the Array Area, as defined, when considered collectively, excluding the offshore export cable(s).
Array Area	The area within which the wind turbine generators, inter array cables, mooring lines, floating sub-structures and supporting subsea infrastructure will be located
Floventis Energy	The company developing the proposed Project, a joint venture between Cierco Ltd and SBM Offshore Ltd
Landfall	The location where the offshore export cable(s) from the Array Area, as defined, are brought onshore and connected to the onshore export cables (as defined) via the transition joint bays (TJB).
Llŷr 1	The proposed Project, for which the Applicant is applying for Section 36 and Marine Licence consents. Including all offshore and onshore infrastructure and activities, and all project phases.
Marine Licence	A licence required under the Marine and Coastal Access Act 2009 for marine works which is administered by Natural Resources Wales (NRW) Marine Licensing Team (MLT) on behalf of the Welsh Ministers.
Offshore Development Area	The footprint of the offshore infrastructure and associated temporary works, comprised of the Array Area and the Offshore Export Cable Corridor, as defined, that forms the offshore boundary for the S36 Consent and Marine Licence application
Offshore Export Cable	The cable(s) that transmit electricity produced by the WTGs to landfall.
Offshore Export Cable Corridor (OfECC)	The area within which the offshore export cable circuit(s) will be located, from the Array Area to the Landfall.
Onshore Development Area	The footprint of the onshore infrastructure and associated temporary works, comprised of the Onshore Export Cable Corridor and the Onshore Substation, as defined, and including new access routes and visibility splays, that forms the onshore boundary for the planning application.
Onshore Export Cable(s)	The cable(s) that transmit electricity from the landfall to the onshore substation
Onshore Export Cable Corridor (OnECC)	The area within which the onshore export cable circuit(s) will be located.
proposed Project	All aspects of the Llŷr 1 development (i.e. the onshore and offshore components).
Onshore Substation	Located within the Onshore Development Area, converts high voltage generated electricity into low voltage electricity that can be used for the grid and domestic consumption.
Section 36 consent	Consent to construct and operate an offshore generating station, under Section 36 (S.36) of the Electricity Act 1989. This includes deemed planning permission for onshore works.

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21C – MARINE MAMMAL UNDERWATER NOISE ASSESSMENT

21.1 Scope of Report

1. This **Appendix 21C**, prepared by HiDef Aerial Surveying Ltd. ('HiDef'), presents the results of the underwater noise assessment for marine mammals. It is based on the noise modelling report the '*Underwater Noise Impact Study for Llŷr Floating Offshore Wind Farm, Celtic Sea, Wales'* (**Appendix 21B: Marine Mammals Underwater Noise Modelling: Marine Mammals Underwater Noise Modelling**).
2. The results from **Appendix 21B: Marine Mammals Underwater Noise Modelling** inform potential impact ranges related to pre-construction, construction and operational noise generating activities. Then using marine mammal density estimated from **Appendix 21A: Marine Mammal and Megafauna Baseline,** the potential numbers of animals at risk of auditory injury and disturbance are presented.
3. Key activities included in the noise modelling and noise assessment are:
    - Pre-construction geophysical surveys;
    - Unexploded ordnance clearance;
    - Impact piling;
    - Activities involved in installing the export cable;
    - General vessel activity; and
    - Underwater noise generated during turbine operation.
4. Key marine mammals assessed are harbour porpoise, common dolphin, bottlenose dolphin, minke whale and grey seal (**Appendix 21A: Marine Mammal and Megafauna Baseline**).
5. This **Appendix 21C** summarises the assessment's results and presents a discussion on the precaution inherent in the assessment.
6. These results are then taken forward to the **Environmental Statement (ES) Volume 3, Chapter 21: Marine Mammals** and **Volume 6, Chapter 8E: HRA RIAA** (Habitats Regulation Assessment; Report to Inform Appropriate Assessment) for the assessment of significance in terms of Environmental Impact Assessment (EIA) Regulations and HRA.

21.2 Introduction

7. Llŷr Floating Wind Limited (hereafter the Applicant) is proposing to develop the Llŷr 1 Floating Offshore Wind Farm (hereafter referred to as the 'proposed Project'), located approximately 35 km off the coast of Pembrokeshire in the Celtic Sea.
8. The proposed Project is a test and demonstration wind farm development, comprising up to ten wind turbine generators (WTGs). The proposed Project will make landfall at Freshwater West before connecting into Pembroke Dock power station and the national grid network.
9. The Applicant is seeking a Section 36 consent and Marine Licence for Llŷr 1, and this chapter forms part of the ES which is submitted in support of those consent applications.
10. This report provides an assessment of potential impacts on marine mammal species from underwater noise sources during pre-construction, construction, and operational related activities at the proposed Project.
11. This assessment should be read in conjunction with the following linked and supporting chapters:
    - **Volume 1, Chapter 04: Description of the Proposed Project**;

- **Volume 6, Appendix 4A: Outline Construction Environmental Management Plan** for the Marine Mammal Mitigation Plan (MMMP);
- **Volume 6, Appendix 21A: Marine Mammal and Megafauna Baseline**;
- **Volume 6, Appendix 21B: Marine Mammals Underwater Noise Modelling** (the underwater noise modelling report prepared by Award Environmental Consultants Ltd);
- **Volume 6, Appendix 21C: Annex A – Impact Assessment Maps**; and
- **Volume 6, Appendix 21C: Annex B - Common Dolphin Impact Assessment Comparison Using Site-Specific Density**.

12. Activities that generate noise levels with the potential to result in auditory injury and / or disturbance considered in this report are:

- Pre- installation geophysical surveys;
- Unexploded ordnance clearance;
- Impact piling;
- Drilling;
- Other construction activities including – dredging, cable laying, jetting, rock placement;
- Vessel activity; and
- Turbine operational noise.

13. This report sets out the background related to how underwater noise can impact marine mammals, relative to their hearing abilities and details the impact criteria used in this assessment. Impact criteria include auditory impairment and disturbance / displacement. It is standard practice to use auditory impairment to represent injury for marine mammals in the United Kingdom (UK) (JNCC, 2010).

14. The following sections consider the identified activities in turn. The background and context of these activities are discussed. The methods of assessment are presented in terms of impact thresholds used and assumptions made. The results are detailed for each activity. The precaution associated with the assessment methods and the uncertainties involved with the prediction of underwater noise impacts are discussed.

15. This report presents the results of the noise assessment. The significance, context, and conclusions of these results under EIA and HRA legislation are presented in the **Chapter 21: Marine Mammals** and **Appendix 8E: HRA RIAA**.

21.3 Background

21.3.1. How Underwater Noise May Affect Marine Mammals

16. The underwater acoustic environment is of key importance for marine mammals. For many species the ability to 'hear' is their primary sense. Sound is used by marine mammals for key life purposes e.g. communication, foraging, navigation, and predator prey interactions (e.g. Tougaard *et al.,* 2015).

17. Anthropogenic noise input into the marine environment can have a range of impacts on marine mammals. Any resulting deleterious effect depends on a variety of parameters including the acoustic characteristics of the noise, the environmental conditions in the region, and the activity of the marine mammal at that time (e.g. travelling or foraging). If anthropogenic noise is sufficiently loud it can result in injury to marine mammal hearing and in extreme cases can result in physical injury / mortality (e.g. Robinson *et al.,* 2022). Lower levels of noise can result in animals being disturbed and or displaced from the locality, which has the potential to impact their health and fitness, for example, if this change in behaviour affects the individuals' ability to feed or care for their young. Anthropogenic noise that is not

at a level such that a behavioural response is observed, can still result in masking important acoustic signals (i.e. communication, foraging, predator avoidance) also with the potential to impact the individuals' health and fitness (NRC, 2003).

18. Anthropogenic noise consists of a range of frequency content, and volume levels. Acoustic characteristics of any anthropogenic noise source must therefore be considered in relation to marine mammals hearing ability and sensitivity. Marine mammal hearing ability is classified into functional hearing groups (**Table 21C-1**) (NMFS, 2018; Southall *et al.,* 2019). Any noise source emitting sound within these frequencies has the potential to impact marine mammals.

Table 21C-1. Marine mammal hearing groups (NMFS, 2018)

Functional hearing group	Example species	Generalised Hearing Range	Range of best hearing
Low Frequency cetaceans (LF)	Minke whale	7 Hz to 35 kHz	200 Hz to 19 kHz
Mid- frequency cetaceans (MF)	Bottlenose dolphin; Common dolphin	150 Hz to 160 kHz	8.8 kHz to 110 kHz
High-frequency cetaceans (HF)	Harbour porpoise	275 Hz to 160 kHz	12 kHz top 140 kHz
Phocid pinnipeds (PW) underwater	Harbour seal; Grey seal	50 Hz to 86 kHz	1.9 kHz to 140 kHz

19. This report uses the thresholds and nomenclature as detailed in Southall *et al.* (2019). There are slight differences in nomenclature to be aware of between Southall *et al.* (2019) and NMFS (2018) and these are detailed in **Table 21C-2**. However, in terms of assessment the groups and impact criteria are equivalent.

Table 21C-2. Marine mammal functional hearing group nomenclature (NMFS, 2018; Southall et al., 2019)

	NMFS (2018)	Southall *et al.* (2019)
Functional hearing group	Low Frequency cetaceans (LF)	Low-frequency cetaceans (LF)
	Mid- frequency cetaceans (MF)	High-frequency cetaceans (HF)
	High-frequency cetaceans (HF)	Very high-frequency cetaceans (VHF)
	Phocid pinnipeds (PW) underwater	Phocid carnivores in water (PCW)

21.3.2. *Auditory Impairment (Injury)*

20. When exposed to loud sound, marine mammal hearing can become permanently damaged. Permanent Threshold Shift (PTS) as defined in Southall *et al.,* (2007) is the minimum exposure for the onset of permanent hearing loss. It is important to note that PTS occurrence does not mean that the individual is deaf (Booth *et al.,* 2018), but that the magnitude and frequency band within which this occurs affects the degree of impact to biological fitness. Southall *et al.,* (2019) updated these criteria from their original 2007 recommendations (**Table 21C-3**).

21. PTS-onset is assessed under dual exposure criteria: the instantaneous and accumulated (cumulative) risks from impulsive and non-impulsive sound sources. Impulsive sound sources are characterised by a relatively rapid rise time to maximum amplitude (e.g. impact piling, explosions). Non-impulsive sounds lack this sharp rise time and so do not present the same level of injurious risk in comparison to impulsive sounds, hence lower threshold criteria (e.g. vessels, drilling, operational wind turbines). PTS-onset is considered for this assessment in terms of 'instantaneous' PTS-onset (SPL_{peak}) and 'cumulative' PTS-onset (SEL_{cum}), the latter relating to the accumulation of noise over time to a level that could cause hearing damage.

Table 21C-3. PTS-onset thresholds for marine mammals (Southall et al., 2019)

Functional hearing group	Impulsive noise Instantaneous PTS-onset (SPL_{peak} dB re 1 µPa unweighted) PTS	Impulsive noise Cumulative PTS-onset (SEL_{cum} dB re 1 µPa^2.s weighted) PTS	Non-impulsive noise Cumulative PTS-onset (SEL_{cum} dB re 1 µPa^2.s weighted) PTS
LF cetaceans	219	183	199
HF cetaceans	230	185	198
VHF cetaceans	202	155	173
PCW pinnipeds	218	185	201

22. Instantaneous PTS-onset (SPL_{peak}) is unweighted, meaning the full range of frequency content is included because the injury mechanism associated with a high sudden noise, is not frequency dependant.
23. The SEL_{cum} criterion can be weighted or unweighted. Usually because animals do not hear equally well at all frequencies, auditory weighting curves are used (Southall *et al.,* 2019) as filters to de-emphasise noise at the frequencies animals hear less well (**Figure 21C-1**) and are therefore useful when assessing the impact of noise over time. Weighted criteria were used in this assessment.
24. The cumulative PTS-onset is a metric representing noise accumulated during the length of time the noise source is present in the environment, up to a maximum of 24 hours. This noise-dose accumulation can be modelled in two ways: 1) using a static animal approach, where the individual is assumed to remain at the same location throughout the defined time-period, or 2) a fleeing animal approach, where it is assumed, the individual is swimming away at a consistent reference speed.
25. **Table 21C-4** details the flee speeds used in the underwater noise modelling. Both model approaches were presented in **Appendix 21B: Marine Mammals Underwater Noise Modelling**).

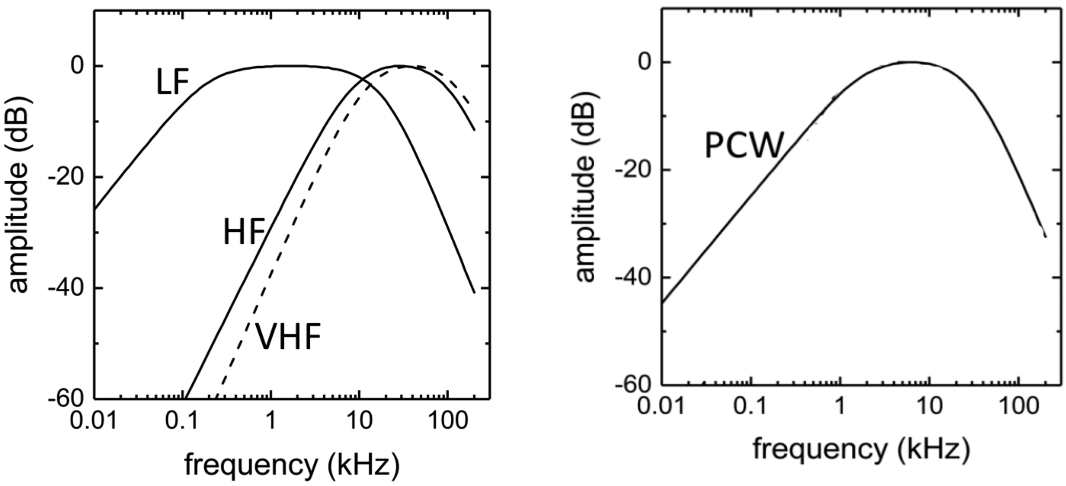


Figure 21C-1. Derived auditory weighting curves for the functional hearing groups (LF, HF, VHF and PCW) (Southall et al., 2019)

Table 21C-4. Fleeing model with representative swim speeds per marine mammal species of interest

Functional hearing group	Modelled swim speeds (m/s)	Reference
LF cetacean	2.3	Boisseau *et al*., 2021
HF cetacean	1.52	Bailey *et al*., 2010
VHF cetacean	1.5	Otani *et al*., 2001
PCW pinniped	1.8	Thompson, 2015

21.3.3. Disturbance / Displacement

26. There is no single threshold that can be applied to assess the impact ranges within which an animal may be disturbed / displaced. Theoretically the range within which behavioural responses may be observed is larger than PTS and Temporary Threshold Shift (TTS) ranges, but less than where the noise levels fall to background environmental levels. Individual response to noise in the environment is inherently variable and is highly context specific (Southall *et al.,* 2007). Any observed behavioural response to noise is often related to several factors, including age of the individual (e.g. natural hearing loss), the individuals' experience through prior exposure to similar noise, and the current activity at that time (e.g. foraging or travelling). Minor or temporary responses may just be an indication that the sound is audible, but without resulting in any lasting biological consequences. Disturbance impact criteria are varied in the academic literature; therefore, the criteria are typically chosen to best reflect the effects of greatest concern from the noise source type, such as effects are thought to negatively impact reproduction or survival.

27. This assessment has used a range of disturbance thresholds as recommended in Natural Resources Wales (NRW) guidance relevant for each of the noise activities assessed for the proposed Project (NRW, 2023) (**Table 21C-5**).

Table 21C-5. Summary of disturbance thresholds used in quantitative assessment

Disturbance threshold	Activity
NMFS (2005) - Level B 120 dB re 1µPa (rms)	Other construction activities Vessel activity Turbine operational noise
NMFS (2005) - Level B 160 dB re 1µPa (rms)	Pre-installation geophysical surveys Impact piling
JNCC (2020a) – Effective Deterrent Range (EDR) 5 km	Pre-installation geophysical surveys
Southall *et al.* (2019) – TTS	Unexploded Ordnance Clearance
NRW (2023) Fixed - 143 dB re $1\mu Pa^2.s$	Impact piling (harbour porpoise)
Graham *et al.* (2017) Whyte *et al.* (2020) Dose response curves	Impact piling (all marine mammals)

21.3.4. Marine Mammal Density Estimates and Reference Populations

28. Marine mammal density estimates, and reference populations taken forward for quantitative assessment are presented in **Table 21C-6** as discussed with NRW Advisory (A) and Joint Nature Conservation Committee (JNCC) (**Section 21.3**: Stakeholder Engagement in **Chapter 21: Marine Mammals**). In line with advice, the assessment of potential impacts for common dolphin using the site-specific digital video aerial survey absolute average density (Llŷr marine megafauna survey area) is presented in **Appendix 21C: Annex B** for comparative purposes. See the **Appendix 21A: Marine Mammal and Megafauna Baseline** for detail on the choice of density estimates and reference populations.

Table 21C-6. Summary of the density estimates and refence populations taken forward to quantitative assessment

Species	Reference population (abundance)	Density (n/km^2) relevant to the Project	Density source
Grey seal	OSPAR III Region (62,358; SCOS, 2021; Carter *et al.*, 2022)	Grid cell specific (Carter *et al.*, 2022)	At-sea densities (Carter *et al.*, 2022)
Harbour porpoise	Celtic and Irish Sea (62,517; IAMMWG, 2022)	0.137 (95% CI 0.02 – 0.54; Llŷr marine megafauna survey area)	Site-specific digital video aerial survey (absolute model-based overall average)
Common dolphin	Celtic and Greater North Seas (102,656; IAMMWG, 2022)	0.841 (0.264 Coefficient of Variation, CV)	SCANS-IV survey block CS-C (absolute design-based estimates; Gilles *et al.*, 2023)
Bottlenose dolphin	Offshore Channel and SW England (10,947; IAMMWG, 2022)	0.4195 (0.406 CV)	SCANS-IV survey block CS-C (absolute design-based estimates; Gilles *et al.*, 2023
Minke whale	Celtic and Greater North Seas (20,118; IAMMWG, 2022)	0.011 (0.755 CV)	SCANS-III survey block D (absolute design-based estimates; Hammond *et al.*, 2021)

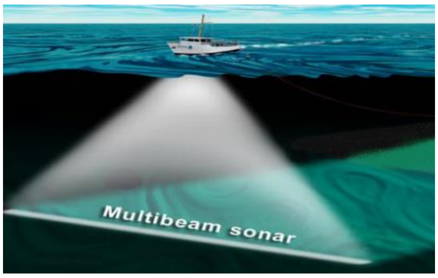
21.4 Pre-Construction

21.4.1. Geophysical Surveys

General Background

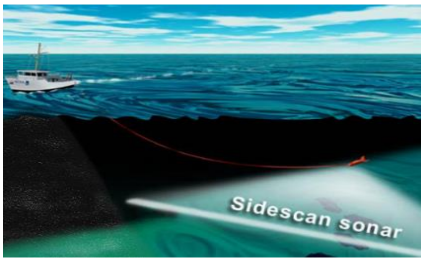
29. It is not yet known what geophysical or geotechnical surveys will be required for the proposed Project. Therefore, information in **Figure 21C-2** provides a high-level description of the noise emitting equipment types that have been included in the noise modelling study (**Appendix 21B: Marine Mammals Underwater Noise Modelling**) that could be used in a typical pre-construction survey. Geotechnical surveys, such as seabed sampling and coring systems, or cone penetration testing etc., and other equipment such as magnetometers are not included for assessment in this Appendix as they are not considered to be noise generating acoustic systems.

30. Geophysical surveys use sound to map the seabed characteristics prior to construction to inform installation requirements. These surveys will be used to inspect proposed anchor and mooring locations for the floating platforms and WTGs, and to confirm cable routeing requirements for export cables. They are also used post-construction to survey the built infrastructure.



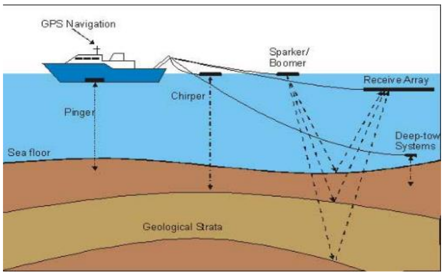
Crocker and Fratantonio (2016)

Multibeam Echosounder (MBES) is a seafloor imaging system, that uses a transducer array mounted on the ship's hull. It surveys a large swath of area, the width of which is determined by the water depth. Multibeam measures the reflectivity (backscatter) to assess depth and seafloor characteristics.



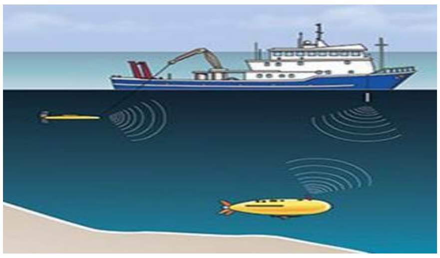
Crocker and Fratantonio (2016)

Side Scan Sonar (SSS) is a sea floor imaging technique that provides information on a strip of seabed, perpendicular to the SSS device. Typically mounted on a tow body operated at depth. SSS sends a fan shaped beam of sound towards the seafloor, using two transducers, one either side of the tow body and measures the intensity of the acoustic reflection. It does not assess the depth.



https://www.ga.gov.au/__data/assets/image/0009/61479/Subbottom_profile_Fig1_large.jpg

Sub bottom profiling (SBP) is a broad term for a range of acoustic sources designed to obtain information of the characteristics of the sediment layers below the seabed. Varied acoustic characteristics enable different equipment to penetrate the surface to several hundred meters, whereas others will survey the top few meters. The choice of equipment depends on the need or aim for the survey data.



https://crewing.odessa.ua/wp-content/uploads/2018/10/dp7.jpg

Ultra-short Baseline (USBL) is a method of underwater acoustic positioning. This consists of a transceiver and a transponder. The transceiver is usually on a pole under the vessel and the transponder is on the seafloor or on an ROV (or towfish). The acoustic signal emitted and received determines range and angle to the transponder.

Figure 21C-2. General description of the geophysical equipment considered in the underwater noise assessment

31. The equipment used to characterise the sea floor utilise a variety of sound sources and thus, a variety of acoustic characteristics. Directivity of the signal is an important consideration in that a highly directed signal towards the seafloor reduces the amount of horizontal transmission of noise. MBES and SSS systems scan a swath of the seabed as they move along track. The directivity of the signal therefore tends to be narrower across track than along track. Across track this can be in the order of approximately 2° and along track can be up to 50° (Hartley Anderson Ltd, 2020). SBP is a broad term, and so the characteristics ultimately used depends on the type of SBP. Types include, sparker, boomer, pinger chirp and parametric. All SPB types except parametric, have relatively broad sound transmissions (up to approx. 75°) whereas parametric SBP can be highly focused at < 5° (Hartley Anderson Ltd, 2020). USBL acoustic signal tends to be broader than the other equipment types detailed here.

Assessment Methods

32. This assessment has been based on acoustic characteristics sourced from the available literature (**Table 21C-7**; Appendix 21B: Marine Mammals Underwater Noise Modelling[1]).

Table 21C-7. Example equipment that may be used for pre-construction surveys detailing typical frequency content and sound pressure levels used in the underwater noise modelling

Equipment	Operating frequency (kHz)	Estimated source sound Pressure Level (dB re 1µPa)	Sound source data reference
Swathe or multi-beam echo sounder (MBES)	170 – 450	221 SPL_{peak}	Genesis (2011) and equipment specification sheet[2]
Side scan sonar (SSS) (e.g. EdgeTech 4200 Series)	300 – 600	226 SPL_{peak}	Genesis (2011) and equipment specification sheet [3]
Sub-bottom profiling (SBP) (e.g. Innomar SES-2000)	0.5 – 12	238 SPL_{peak}	Equipment specification sheets[4]
Ultra-short Baseline (USBL) (e.g. Kongsberg HiPAP 502)	21 – 31	207 SPL_{peak}	Equipment specification sheet[5]

33. The acoustic characteristics for the range of geophysical equipment has been considered in the context of marine mammal auditory sensitivities (**Table 21C-8**).

34. Assessment of injury used Southall *et al.,* (2019) PTS-onset thresholds for cumulative noise (SEL_{cum}) (**Appendix 21B: Marine Mammals Underwater Noise Modelling**) using the static receptor model.

35. Disturbance has been assessed using the JNCC (2020a) EDR for geophysical surveys of 5km for comparison. EDRs assume a fixed distance which equates to an average temporary habitat loss due to sound exposure for individual animals (JNCC, 2020a).

36. Directivity was incorporated into **Appendix 21B: Marine Mammals Underwater Noise Modelling** using a range of beam width degrees depending on the frequency content of the signal. A 500 Hz signal was modelled with a ± 30° beam pointing downwards, and at 12 kHz the focus is much narrower at ± 10° (P.Ward *pers comm.)*.

[1] As presented in the stakeholder meeting (NRW / JNCC) in May 2023
[2] 443809ad_em2040c_mk2_data_sheet_slim_pu.pdf (kongsberg.com)
[3] 4200 Brochure 081815.pdf (edgetech.com)
[4] Innomar "smart" SBP
[5] https://www.kongsberg.com/maritime/products/Acoustic-Positioning-Communication/acoustic-

Table 21C-8. Comparison of the typical acoustic characteristics from the example equipment and the overlap with marine mammal functional hearing groups

Equipment	Operating frequency (kHz)	Sound Pressure Level (dB re 1µPa)	Marine Mammal functional hearing group (P – PTS / D – Disturbance)			
			LF	HF	VHF	PCW
MBES	170 – 450	221 SPL_{peak}	Above all hearing ranges			
SSS	300 – 600	226 SPL_{peak}	Above all hearing ranges			
SBP	0.5 – 12	238 SPL_{peak}	P / D	P / D	P / D	P / D
USBL	21 – 31	207 SPL_{peak}	D	D	D	D

Results

Auditory Injury (PTS)

38. Although indicative source levels for MBES and SSS exceed the unweighted SPL_{peak} threshold (**Table 21C-3**), the frequency content for these two equipment types is above the hearing ranges for all functional hearing groups. Further, high frequency sound is rapidly attenuated in the shallow (<200m) environment, and the sound produced by MBES and SSS is highly directional, both of which reduces horizontal transmission. Therefore, there is minimal PTS-onset risk from these two systems (JNCC, 2010).

39. Noise modelling (**Appendix 21B: Marine Mammals Underwater Noise Modelling**) indicates the risk of auditory injury for marine mammals from the SBP is within 82m for the LF functional hearing group (minke whale), and less than 10m for all other groups. Likewise, for the USBL, the predicted injury range is 100m for LF cetaceans, and less than 10m for all other groups. This was assessed as non-impulsive noise over a maximum exposure of 24 hours.

40. These results are consistent with BEIS (2020) in their review of consented offshore wind farms in the Southern North Sea harbour porpoise Special Area of Conservation (SAC). In this review they conducted noise modelling for a representative SBP (source level 267 dB SPL_{peak}) and predicted a maximum PTS-onset range for harbour porpoises of ~23m.

41. Geophysical surveys are a moving acoustic source, and marine mammals are highly mobile. It is therefore highly unlikely that any individual will be within these ranges for any extended period. Although PTS-onset is theoretically possible, it is unlikely particularly when these ranges are fully mitigable using standard JNCC guidance (JNCC, 2017).

42. In all cases, the PTS-onset risk is minimal.

Disturbance

43. As indicated in **Table 21C-8** there is no potential for disturbance from the MBES or SSS. There is however a risk of disturbance from the SBP and the USBL for all functional hearing groups.

44. JNCC (2010) European Protected Species (EPS) Guidance concludes that the use of SBP "Could, in a few cases, cause localised short-term impacts on behaviour such as avoidance. However, it is unlikely that this would be considered as disturbance in the terms of the EPS Regulations." It is therefore likely that any disturbance resulting from the operation of the SBP will be spatially localised and temporary in nature.

45. The risk of disturbance from USBL, is generally likely to be less than for the SBP based on a comparison of the acoustic characteristics (**Table 21C-8**). However, there is potential for disturbance due to the frequency content of the example equipment for all functional hearing groups.

Assessment of Disturbance at Any One Time (Static Source)

46. Using the precautionary Effective Deterrent Range (EDR) (JNCC, 2020a) of 5km is precautionary because this does not consider directionality, nor frequency content and therefore applies to both the SBP and USBL.

47. The use of the 5km EDR suggests that at any one time an area of 78.5km^2 may be ensonified to the level that a disturbance response may be observed.

48. For all species, the impact at population level is minimal (**Table 21C-9**) with the highest estimate being 0.30% of the reference population equating to 33 individual bottlenose dolphins at risk of disturbance.

Table 21C-9. Number of animals predicted to be disturbed by geophysical surveys at any one time.

Species	Density (n/km^2)	Area impacted (km^2)	Number impacted	% MU reference population
Grey seal	Grid cell specific (Carter *et al*., 2022)	78.5	<1	0.001
Harbour porpoise	0.137	78.5	11	0.017
Common dolphin	0.841	78.5	66	0.064
Bottlenose dolphin	0.4195	78.5	33	0.301
Minke whale	0.011	78.5	<1	0.004

49. The significance, context, and conclusions of these results under EIA and HRA legislation are presented in the **Chapter 21: Marine Mammals** and **Appendix 8E: HRA RIAA.**

21.4.2. Unexploded Ordnance (UXO)

General Background

50. There is potential for UXO to be found within the development area and / or the cable corridor[6]. The seabed around the UK is littered with ordnance left after past military conflicts, but also from military firing ranges and offshore disposal. Detection of potential UXO targets is one aim of the pre-construction surveys. Smaller developments such as the proposed Project are likely to be able to microsite around identified targets; however, this is not always practical and therefore clearance may be needed on health and safety grounds.

51. Historically, clearance has been undertaken using High-order methods. High-order is a technique where a donor charge is placed adjacent to the UXO to initiate a controlled explosion of the entire explosive content. This method has the potential to affect a large area with the high noise levels that result having the potential to cause auditory injury, or even physical injury, to marine mammals. More recently, new less noisy alternatives to high-order are becoming available for commercial use. Techniques such as low-order deflagration, or water jet disruption.

52. Deflagration is a low-order method which uses a donor shape charge to inject a high velocity plasma stream into the UXO, thereby rapidly burning out the explosive content. This method has been tested both in controlled test facilities (Robinson *et al.,* 2020) and in the marine

[6] Ordtek | UXO Specialists | Mine Map: Offshore UXO Contamination

environment as part of the Offshore Energy SEA funded projects programme[7]. The research is ongoing, and the results of the in-situ testing are not available at date of writing (January 2024).

53. The controlled environment study (Robinson *et al.,* 2020; Cheong *et al.,* 2020) has shown that the noise levels from the deflagration method are significantly reduced from a high-order detonation for the equivalent target, by more the 20 dB (**Figure 21C-3**).

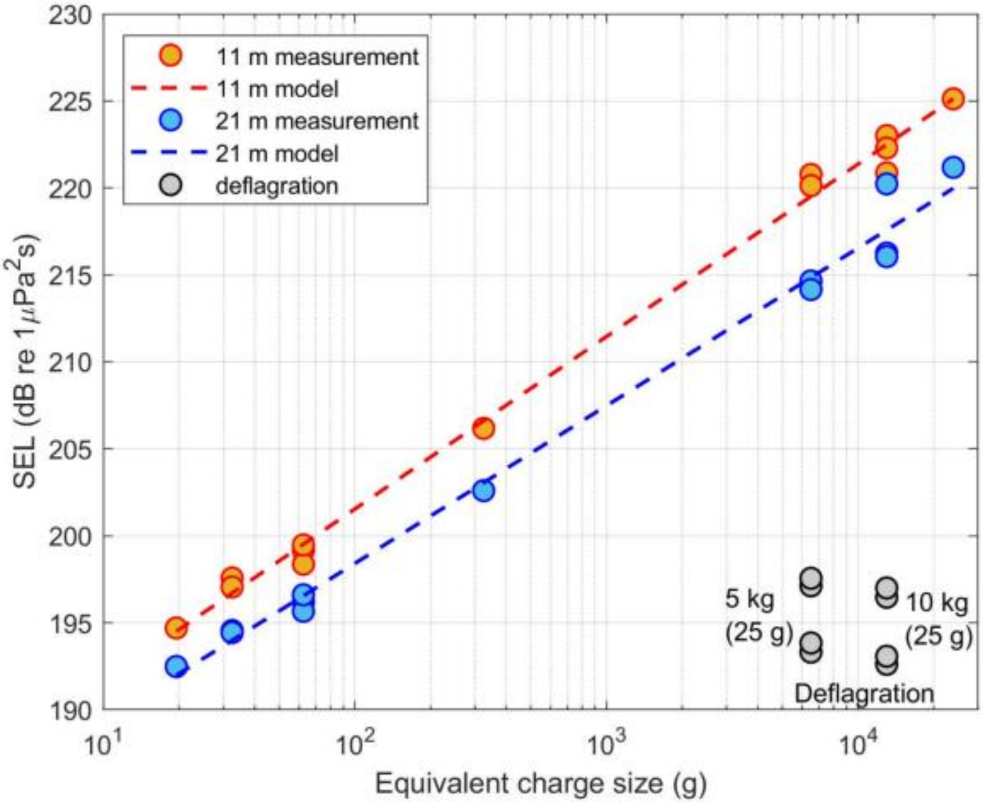


Figure 21C-3. The SEL at nominal distances of 11 m and 21 m plotted against charge size for all detonations. The low-order deflagration data appear in the bottom left of the plot, with the size of the main charge and shaped charge indicated (Cheong et al., 2020)

54. Water jet disruption is another technique used in offshore wind developments, sometimes referred to as ‘low yield’. Described in the supporting information for the Seagreen Marine Licence application (Xodus, 2021) as high-pressure water jets that target the main explosive filling of the UXO, resulting in the rupture of the UXO casing and disintegration of the primary energetic component, without combustion of the explosive material.

55. Information on noise levels emitted by the low noise alternative techniques, is becoming available in the literature and through the BEIS Offshore Energy SEA Research (OESESA) programme[8]. The policy paper issued by the UK Government on behalf of all devolved jurisdictions “*Marine Environment: unexploded ordnance clearance joint interim position statement*” (BEIS, 2022) is further guidance. This states that low noise alternatives to high-order clearance should be prioritised when developing protocols to clear UXOs. Additionally, it states the assessment of clearance should adhere to environmental precautionary principles and assess the risk and impact of detonation of the device plus the donor charge at full potential, i.e. a high-order detonation. Therefore, although it is expected that if any UXO

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[7] https://www.gov.uk/guidance/offshore-energy-strategic-environmental-assessment-sea-an-overview-of-the-sea-process#offshore-energy-sea-research-programme

[8] OESEA research related papers (publishing.service.gov.uk)

clearance is required, this will be undertaken using low-order clearance methods, the potential impact associated with high-order detonation is also provided to ensure a precautionary assessment.

Assessment Methods

56. There is little information at the time of writing as to the presence, number, or type of UXOs that may be present in the proposed Project Array Area Therefore, this assessment has modelled the impact using the same range of charge weights used in the Erebus floating offshore wind (FLOW) underwater noise impact study (Barham *et al.,* 2021; **Table 21C-10**). The use of Erebus FLOW information is considered appropriate for use due to the close geographical location of Erebus to the proposed Project Array Area, and because these were informed on site surveys. Modelling of UXO clearance has been undertaken using the suite of equations as detailed in **Section 5.3** in **Appendix 21B: Marine Mammals Underwater Noise Modelling.** It should be noted that these equations are based on an explosive source in midwater column, whereas UXOs are located on the seafloor, partially or fully buried, and therefore this modelling methodology is likely to be precautionary, as it does not account for any sound attenuation from the seabed substrate.

Table 21C-10. Acoustic source levels in unweighted SPL_{peak} and SEL_{ss} as a function of charge weight for low-order and high-order detonations (Appendix 21B: Marine Mammals Underwater Noise Modelling)

Detonation type	Charge weight [kg]	SPLpeak [dB re 1 mPa at 1 m]	SELss [dB re 1 mPa².s]
Low-order	0.1	266.7	212.6
	0.25	269.9	215.2
	0.5	272.1	217.1
	2	276.7	220.9
High-order	25	284.9	227.9
	55	287.5	230.1
	120	290.1	232.3
	240	292.3	234.2
	525	294.9	236.4
	794	296.2	237.5

57. The range within which there is a risk of PTS-onset has been modelled using Southall *et al.* (2019) SPL_{peak} thresholds. The range within which there could be a behavioral reaction has been modelled using the TTS given in Southall *et al.* (2019). Although TTS is not a disturbance metric (as it represents a temporary reduction in hearing ability) the use of the TTS-onset threshold is considered appropriate for UXO clearance disturbance assessment, because noise resulting from a UXO clearance event is short lived in the environment, in the order of seconds (Robinson *et al.,* 2022). Southall *et al.* (2007) define an explosion as a single pulse and they state: -

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

58. To quantify the impact of noise relating to auditory injury (PTS-onset) and disturbance (TTS-onset), the area around the noise source was determined using the thresholds as defined in Southall *et al.* (2019). Based on agreed density estimates (**Table 21C-6**; **Section 21.3.4**) for each species, the number of animals within impact ranges were calculated together with an estimate of the proportion of the reference population at risk of impact.

Results

Auditory Injury (PTS)

59. PTS-onset ranges for the high-order scenario are detailed in **Table 21C-11** and **Table 21C-12**. The worst-case range based on SPL_{peak} threshold was 19.25 km for VHF (harbour porpoise) for the highest charge weight modelled (794kg) and 10.75km for LF (minke whale) based on SEL_{ss} threshold.

60. PTS-onset ranges for the low-order scenario are detailed in **Table 21C-13** and **Table 21C-14**. The worst-case range based on SPL_{peak} threshold was 2.6km for VHF (harbour porpoise) for the highest charge weight modelled (2kg) and 579m for LF (minke whale) based on SELss threshold (see **Appendix 21C: Annex A**, **Section 21.2** for impact contour maps).

61. The number of animals at risk of PTS-onset for the high-order scenario was estimated using the predicted ranges of PTS-onset for all species groups (**Table 21C-15** and **Table 21C-16**). The worst-case number of individuals impacted based on the charge weight of 794kg (Net Explosive Quantity, NEQ) was 160 harbour porpoises relating to 0.255% of the reference population, based on the SPL_{peak} threshold, and four minke whale, relating to 0.02% of the reference population based on the SEL_{ss} threshold.

62. The number of animals at risk of PTS-onset for the low-order scenario was estimated using the predicted ranges of PTS-onset for all species groups (**Table 21C-17** and **Table 21C-18**). The worst-case number of individuals impacted based on the charge weight of 2kg (NEQ) was three harbour porpoises relating to a negligible percentage (less than 0.02%) of the reference population, based on the SPL_{peak} threshold.

Table 21C-11. High-order detonation - summary of PTS-onset ranges (m) based on impulsive SPL_{peak} thresholds given by Southall et al. (2019) (Appendix 21B: Marine Mammals Underwater Noise Modelling)

Functional Hearing Group	25 kg (NEQ)	55 kg (NEQ)	120 kg (NEQ)	240 kg (NEQ)	525 kg (NEQ)	794 kg (NEQ)
LF	951	1,237	1,600	2,000	2,600	3,000
HF	289	376	487	614	797	915
VHF	6,100	7,900	10,250	13,000	16,750	19,250
PCW	1,061	1,375	1,780	2,250	2,900	3,350

Table 21C-12. High-order detonation – summary of PTS-onset ranges (m) based on SEL_{ss} weighted thresholds given by Southall et al. (2019) (Appendix 21B: Marine Mammals Underwater Noise Modelling)

Functional Hearing Group	25 kg (NEQ)	55 kg (NEQ)	120 kg (NEQ)	240 kg (NEQ)	525 kg (NEQ)	794 kg (NEQ)
LF	2,000	2,900	4,300	6,000	8,900	10,750
HF	<10	<10	<10	<10	<10	11
VHF	55	82	120	169	248	304
PCW	330	486	713	1,003	1,470	1,800

Table 21C-13. Low-order detonation - summary of PTS-onset ranges (m) based on impulsive SPL_{peak} thresholds given by Southall et al. (2019) (Appendix 21B: Marine Mammals Underwater Noise Modelling)

Functional Hearing Group	0.1 kg (NEQ)	0.25 kg (NEQ)	0.5 kg (NEQ)	2.0 kg (NEQ)
LF	151	205	258	410
HF	45	62	78	124
VHF	972	1,315	1,660	2,600
PCW	168	228	288	457

Table 21C-14. Low-order detonation – summary of PTS-onset ranges (m) based on SEL_{ss} weighted thresholds given by Southall et al. (2019) (Appendix 21B: Marine Mammals Underwater Noise Modelling)

Functional Hearing Group	0.1 kg (NEQ)	0.25 kg (NEQ)	0.5 kg (NEQ)	2.0 kg (NEQ)
LF	133	209	293	579
HF	<10	<10	<10	<10
VHF	3	5	8	16
PCW	22	34	48	95

Table 21C-15. High-order detonation – summary of number of individuals within PTS-onset area (km^2) based on impulsive SPL_{peak} thresholds given by Southall et al. (2019)

Species	Density (n/km^2)	Area impacted (km^2)	Number impacted	% MU reference population
Grey seal	Grid cell specific (Carter *et al.*, 2022)	35.26	<1	0.000
Harbour porpoise	0.137	1,164	160	0.255
Common dolphin	0.841	2.63	2	0.000
Bottlenose dolphin	0.4195	2.63	1	0.000
Minke whale	0.011	28.27	<1	0.000

Table 21C-16. High-order detonation – summary of number of individuals within PTS-onset area (km²) based on impulsive on SEL_{ss} weighted thresholds given by Southall et al. (2019). Negligible means less than 0.02% of MU reference population

Species	Density (n/km²)	Area impacted (km²)	Number impacted	% MU reference population
Grey seal	Grid cell specific (Carter *et al.*, 2022)	10.18	<1	0.000
Harbour porpoise	0.137	0.29	<1	0.000
Common dolphin	0.841	0	0	0.000
Bottlenose dolphin	0.4195	0	0	0.000
Minke whale	0.011	363.05	4	0.020

Table 21C-17. Low-order detonation – summary of number of individuals within PTS-onset area (km²) based on impulsive SPL_{peak} thresholds given by Southall et al. (2019).

Species	Density (n/km²)	Area impacted (km²)	Number impacted	% MU reference population
Grey seal	Grid cell specific (Carter *et al.*, 2022)	0.66	<1	0.000
Harbour porpoise	0.137	21.24	3	0.005
Common dolphin	0.841	0.05	<1	0.000
Bottlenose dolphin	0.4195	0.05	<1	0.000
Minke whale	0.011	0.53	<1	0.000

Table 21C-18. Low-order detonation – summary of number of individuals within PTS-onset area (km²) based on impulsive on SEL_{ss} weighted thresholds given by Southall et al. (2019).

Species	Density (n/km²)	Area impacted (km²)	Number impacted	% MU reference population
Grey seal	Grid cell specific (Carter *et al.*, 2022)	0.03	<1	0.000
Harbour porpoise	0.137	0	0	0
Common dolphin	0.841	0	0	0
Bottlenose dolphin	0.4195	0	0	0
Minke whale	0.011	1.05	<1	0.000

Disturbance

63. TTS-onset threshold was used to predict the range within which a behavioural response may be observed. The worst-case range in the high-order scenario, based on SPL_{peak} threshold was 37.5km for VHF (harbour porpoise) for the highest charge weight modelled (794kg) and 155km for LF (minke whale) based on SEL_{ss} threshold (see **Table 21C-19** and **Table 21C-20**) for full range of TTS-onset ranges).

64. TTS-onset ranges for the low-order scenario are detailed in **Table 21C-21** and **Table 21C-22**. The worst-case range based on SPL_{peak} threshold was 5.1km for VHF (harbour porpoise) for

the highest charge weight modelled (2kg) and 8.2km for LF (minke whale) based on SEL_{ss} threshold. (see **Appendix 21C: Annex A**, **Section 21.3** for impact contour maps).

65. The number of animals at risk of TTS-onset as the proxy for disturbance, for the high-order scenario was estimated using the predicted ranges of TTS-onset for all species groups (**Table 21C-23** and **Table 21C-24**). The worst-case number of individuals impacted based on the charge weight of 794kg (NEQ) was 605 harbour porpoises based on the SPL_{peak} threshold, relating to 0.96% of the reference population, and 614 minke whales, based on the SEL_{ss} threshold, relating to 3.05% of the reference population.

66. The number of animals at risk of TTS-onset for the low-order scenario was estimated using the predicted ranges of TTS-onset for all species groups (**Table 21C-25** and **Table 21C-26**). The worst-case number of individuals impacted based on the charge weight of 2kg (NEQ) was 11 harbour porpoises which relates to a negligible percentage of the reference population (based on the SPL_{peak} threshold) and three minke whales, relating to 0.011 percentage of the reference population (based on the SEL_{ss} threshold).

Table 21C-19. High-order detonation - summary of TTS-onset ranges (m) based on impulsive SPL_{peak} thresholds given by Southall et al. (2019) (Appendix 21B: Marine Mammals Underwater Noise Modelling)

Functional Hearing Group	25 kg (NEQ)	55 kg (NEQ)	120 kg (NEQ)	240 kg (NEQ)	525 kg (NEQ)	794 kg (NEQ)
LF	1,830	2,350	3,050	3,850	5,000	5,700
HF	552	719	932	1,174	1,520	1,750
VHF	11,750	15,250	20,000	25,000	32,500	37,500
PCW	2,000	2,650	3,400	4,300	5,600	6,400

Table 21C-20. High-order detonation – summary of TTS-onset ranges (m) based on SEL_{ss} weighted thresholds given by Southall et al. (2019) (Appendix 21B: Marine Mammals Underwater Noise Modelling)

Functional Hearing Group	25 kg (NEQ)	55 kg (NEQ)	120 kg (NEQ)	240 kg (NEQ)	525 kg (NEQ)	794 kg (NEQ)
LF	28,250	41,500	61,000	86,000	126,000	155,000
HF	28	42	62	87	128	156
VHF	792	1,166	1,710	2,400	3,500	4,300
PCW	4,650	6,00	10,000	14,000	20,750	25,500

Table 21C-21. Low-order detonation - summary of TTS-onset ranges (m) based on impulsive SPL_{peak} thresholds given by Southall et al. (2019) (Appendix 21B: Marine Mammals Underwater Noise Modelling)

Functional Hearing Group	0.1 kg (NEQ)	0.25 kg (NEQ)	0.5 kg (NEQ)	2.0 kg (NEQ)
LF	290	394	497	789
HF	87	119	150	238
VHF	1,880	2,550	3,200	5,100
PCW	324	440	554	880

Table 21C-22. Low-order detonation – summary of TTS-onset ranges (m) based on SEL_{ss} weighted thresholds given by Southall et al. (2019) (Appendix 21B: Marine Mammals Underwater Noise Modelling)

Functional Hearing Group	0.1 kg (NEQ)	0.25 kg (NEQ)	0.5 kg (NEQ)	2.0 kg (NEQ)
LF	1,890	2,950	4,150	8,200
HF	1	3	4	8
VHF	52	82	116	229
PCW	312	490	689	1,360

Table 21C-23. High-order detonation – summary of number of individuals within TTS-onset area (km²) based on impulsive SPL_{peak} thresholds given by Southall et al. (2019).

Species	Density (n/km²)	Area impacted (km²)	Number impacted	% MU reference population
Grey seal	Grid cell specific (Carter *et al.*, 2022)	128.68	2	0.002
Harbour porpoise	0.137	4417	605	0.968
Common dolphin	0.841	9.62	8	0.008
Bottlenose dolphin	0.4195	9.62	4	0.037
Minke whale	0.011	102.07	1	0.006

Table 21C-24. High-order detonation – summary of number of individuals within TTS-onset area (km²) based on impulsive on SEL_{ss} weighted thresholds given by Southall et al. (2019).

Species	Density (n/km²)	Area impacted (km²)	Number impacted	% MU reference population
Grey seal	Grid cell specific (Carter *et al.*, 2022)	2,042.82	17	0.028
Harbour porpoise	0.137	58.09	8	0.013
Common dolphin	0.841	0.08	<1	0.000
Bottlenose dolphin	0.4195	0.08	<1	0.000
Minke whale	0.011	55,836.87	614	3.053

Table 21C-25. Low-order detonation – summary of number of individuals within TTS-onset area (km²) based on impulsive SPL_{peak} thresholds given by Southall et al. (2019).

Species	Density (n/km²)	Area impacted (km²)	Number impacted	% MU reference population
Grey seal	Grid cell specific (Carter *et al.*, 2022)	2.43	<1	0.000
Harbour porpoise	0.137	81.71	11	0.018
Common dolphin	0.841	0.18	<1	0.000
Bottlenose dolphin	0.4195	0.18	<1	0.001
Minke whale	0.011	1.96	<1	0.000

Table 21C-26. Low-order detonation – summary of number of individuals within TTS-onset area (km²) based on impulsive SEL_{ss} weighted thresholds given by Southall et al. (2019).

Species	Density (n/km²)	Area impacted (km²)	Number impacted	% MU reference population
Grey seal	Grid cell specific (Carter *et al.*, 2022)	5.81	<1	0.000
Harbour porpoise	0.137	0.16	<1	0.000
Common dolphin	0.841	0	0	0
Bottlenose dolphin	0.4195	0	0	0
Minke whale	0.011	211	3	0.011

67. The significance, context, and conclusions of these results under EIA and HRA legislation are presented in the **Chapter 21** and **Appendix 8E.**

21.5 Construction

21.5.1. Piling

General Background

68. Impact piling is a method of driving foundation piles into the seabed. The technique involves a 'hammer', a large weight or ram being dropped or driven onto the top of the pile, resulting in the pile being forced into the seabed. Impact piling is an impulsive noise source and can represent a significant source of noise into the marine environment (e.g. JNCC, 2010; Graham *et al.,* 2017; Bellmann *et al.,* 2020), with the potential to injure and disturb marine mammals (Thompson *et al.,* 2020).

69. The noise levels from impact piling can be variable, depending on several parameters which can all make a difference to the levels of noise in the environment (e.g. pile diameter, hammer energy, bathymetry, seabed composition). Conventional assumption is that the larger the pile diameter, the greater the hammer energy is needed to install, and that increasing hammer energies results in increasing noise levels (Thompson *et al.,* 2020). Contrary to this convention (which is based on monopiles) it has been found that noise levels underwater reduce as piling progresses for pin piles, even as the hammer energy increases (Thompson *et al.,* 2020; Verfuss *et al*., 2023). This pattern of noise is likely to be because the length of pile remaining in the water column reduces as the pile is embedded in the sediment. If impact piling is selected as the installation method the examples from pin piling will be a more relevant comparison than monopile foundations, as the proposed project is a floating offshore wind project (e.g. Thompson *et al.,* 2020).

Assessment Methods

70. Published literature were reviewed to determine the noise levels appropriate for the proposed Project (see **Appendix 21B: Marine Mammals Underwater Noise Modelling**). These data were combined and a trendline fitted to estimate the likely source noise level to be generated during piling with a 3m diameter pile (**Table 21C-27**). The modelling presented in **Appendix 21B: Marine Mammals Underwater Noise Modelling**: Marine Mammals Underwater Noise Modelling used a standard approach and combined two common propagation models, 'Bellhop' based on ray theory, and 'RAM' based on parabolic equation. Neither model can completely represent the range of frequencies a pile driving event emits,

but instead can be used in combination, which is currently a standard modelling approach (Farcas *et al*., 2016).

Table 21C-27. Estimated source level used for the noise modelling of impact piling at the proposed Project Array Area (Appendix 21B: Marine Mammals Underwater Noise Modelling)

Pile diameter	SPL_{peak}	SEL_{ss}
3m	235 dB re 1 µPa @ 1 m	218 dB re 1 µPa^2.s @ 1 m

71. Should piling prove to be the installation choice for the proposed Project, the anchors will be held in place with pin piles. The underwater noise profile is therefore likely to follow a similar decreasing noise pattern as has been observed (Thompson *et al.,* 2020; Verfuss *et al*., 2023). However, no reduction in noise levels has been reflected within the modelling approach used, instead it has been assumed that the noise emission is consistent with the hammer energy over the piling duration and therefore the results are likely to overestimate the accumulated levels of impact.

72. Piling parameters used to assess auditory injury and disturbance in terms of piling time per pin pile, the strike rates, and the and the soft-start protocol were all taken from the noise study carried out for the Erebus FLOW EIA The model used a generic protocol, i.e. an initial source level of 13 dB lower that the maximum level, increasing in discrete steps of approximately 3.5 dB every 5 minutes to the maximum level after a 20-minute period See **Appendix 21B: Marine Mammals Underwater Noise Modelling** for full details of the modelling conducted for impact pile assessment.

73. The noise propagation modelling assumed: –

- Maximum pile diameter 3m;
- Minimum hammer energy 50 kj and maximum hammer energy 800 kj;
- Piling in one location at a time, no concurrent piling events; and
- ~ 4 hours to drive one pile to the design depth.

74. One location was chosen for use as the representative piling location (see **Appendix 21C: Annex A**, **Section 21.1**). This location is to the east of the updated Array Area boundary. However, this one location was deemed sufficient for modelling purposes because the environmental conditions, including water depth, are similar throughout the wider region Propagation modelling was then radiated out from this point location using 36 radial transects. Impact ranges were modelled for the oceanographic conditions found in February and in August, as these represent the largest differences in the sound speed profile in the area and therefore should cover the full range of potential noise levels. Radiated noise travels further in colder water temperatures than in warmer temperatures, due to the density of the water with temperature (**Appendix 21B: Marine Mammals Underwater Noise Modelling**).

Auditory Injury (PTS)

75. To quantify the impact of noise levels leading to auditory injury (PTS-onset) the impact area around the noise source was determined using the thresholds as defined in Southall *et al.* (2019). Then, based on the agreed density estimates for each species (**Table 21C-6**), the number of animals at risk within PTS-onset impact ranges were calculated, and presented together with an estimate of the proportion of the reference population at risk of impact.

76. Instantaneous PTS-onset was calculated using SPL_{peak} thresholds. Accumulated PTS-onset (SEL_{cum}) was calculated for two scenarios:

- A static animal scenario was modelled over a range of time periods (single strike, 0.5 hrs, 1 hr, 2 hrs, 3 hrs, and 4 hrs). The impact ranges calculated represent the area within which an animal, if it stayed in the same location, would accrue enough noise dose to reach PTS-onset; and
- A fleeing animal scenario was modelled, which assumes that the animal would be swimming away from the noise during the piling activity and used agreed flee speeds (**Table 21C-4**) to estimate the spatial / temporal accumulation of noise. This enables assessment of a 'safe start' distance. If within this range at the commencement of piling, an individual will accrue PTS-onset even if swimming away throughout the piling sequence. If an animal's starting position is outside this range, it will not accrue enough noise to reach PTS-onset.

77. As mentioned in **Section 21.3.3**, a single threshold against which disturbance can be assessed does not exist. Therefore, a range of approaches has been presented to assess the disturbance risk from pin piling and these are described in the following sections.

Disturbance - Fixed Noise Threshold

78. Fixed noise thresholds assume that all animals exposed to a certain level of sound are disturbed to a level that may impact life history features (ability to forage, reduced fitness, displacement from key habitat, mother / calf separation). Two assessments using fixed noise thresholds are presented.

- The fixed noise threshold of NMFS level B 160 dB re 1 mPa (rms) disturbance threshold was used for all species (NMFS, 2023) for assessment under EIA regulations (**Chapter 21: Marine Mammals**).
- For the harbour porpoise HRA assessment, a fixed noise threshold of 143 dB re 1µPa SEL_{ss} unweighted (Tougaard, 2021 in NRW 2023) was used to conduct an area-based assessment. This is used to determine the spatial extent of a SAC that may experience significant disturbance. This was applied to the harbour porpoise assessment in line with NRW (2023) and JNCC (2020a) guidance (**Appendix 8E: HRA RIAA**). JNCC (2020a) guidance states that an adverse effect on site integrity should be assessed for harbour porpoise SACs using the spatial and temporal thresholds of:
    - 20% of the relevant area of the site in any given day; or
    - An average of 10% of the relevant area of the site over a season.

79. Noise modelling was conducted using radial transects (**Appendix 21B: Marine Mammals Underwater Noise Modelling**) therefore a minimum and maximum range of impact distances are presented to reflect the variability in the transmission of sound along these transects. The maximum impact ranges predicted in February and August were taken forward for the assessment of the spatial overlap with West Wales Marine / Gorllewin Cymru Forol SAC and the Bristol Channel Approaches / Dynesfeydd Môr Hafren SAC (**Appendix 8E: HRA RIAA**). As noted above, the impact ranges were modelled from one location, however, in order to represent the worst-case spatial overlap with the harbour porpoise SACs, the nominal piling location was positioned within the array site to a location that resulted in the greatest overlap with the SACs. The proportion of the spatial overlap was then determined relative to the total SAC area.

Disturbance - Dose Response Curves

80. Dose response (D / R) curves build on fixed thresholds but reflect a more realistic scenario, in that not all animals respond to noise levels at the same level in the same way. D / R curves apply the probability of a response to represent the proportion of animals that experience a behavioural response relative to the noise level received (Sinclair *et al*., 2023).

81. For cetacean species, the D / R curves as presented in Graham *et al.* (2017a) are applied (**Figure 21C-4**). These reflect the data collected on harbour porpoise responses during pin piling at Beatrice Offshore Windfarm and have become the standard approach for the assessment of noise disturbance (Sinclair *et al.,* 2023). The D / R curve was built using changes in harbour porpoise occurrence, using acoustic detections captured by an array of CPODs[9] placed around the wind farm site. The resulting D / R curve indicates the proportion of animals predicted to exhibit a behavioural response.

82. Since 2017, additional data from the monitoring of pile driving events in the Moray Firth have been analysed (Graham *et al.,* 2019) which highlight that harbour porpoise responses to pin piling reduces during the construction period. This observed reduction in response means the use of the probability of response from the 2017 initial piling events provides a precautionary assessment.

83. Cetacean D / R curves for piling only exist for harbour porpoise. However, harbour porpoise is considered to be one of the most sensitive marine mammal species to acoustic disturbance (Tougaard *et al.,* 2015), therefore the application of the same D / R curves to all other cetaceans adds further precaution.

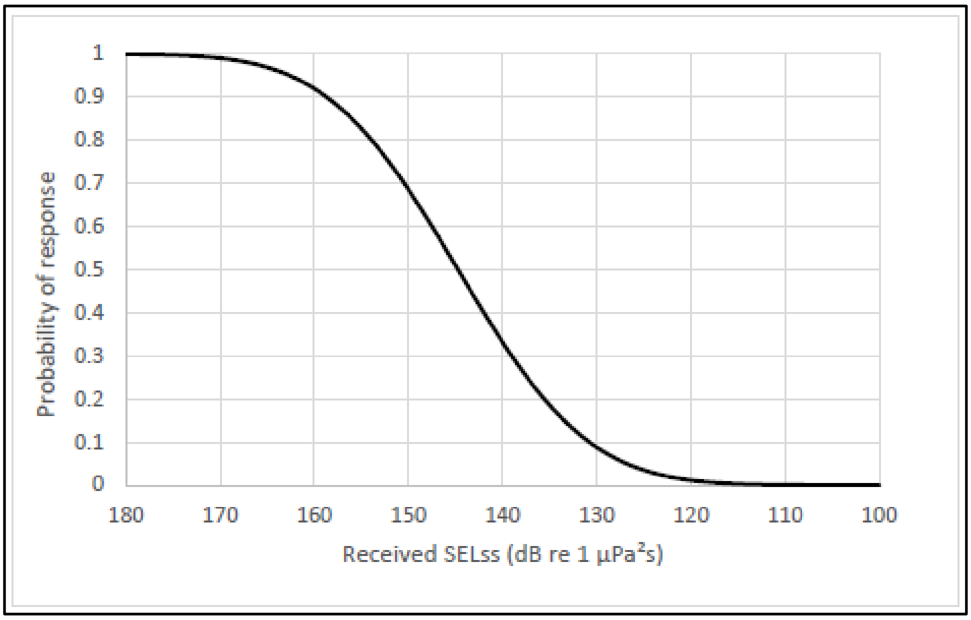

Figure 21C-4. Dose response curve showing the probability of harbour porpoise response to received levels (SEL_{ss} single strike) from Graham et al. (2017)

84. Whyte *et al.* (2020) presented data based on harbour seals tagged in the Wash and looked at how their at-sea usage changed in relation to pile driving activities. These data have been used to generate a seal dose response function (**Figure 21C-5**). There are no equivalent data for grey seals; however, both seal species are categorised within the same functional hearing

[9] CPODs are acoustic detectors that log the echolocation clicks generated by harbour porpoise. See https://www.chelonia.co.uk/index.html

group and therefore this is considered to be an appropriate approach. Furthermore, research suggests it is likely that grey seals are less responsive than harbour seals and so using the harbour seal D / R function is likely to be conservative (Booth *et al.,* 2019).

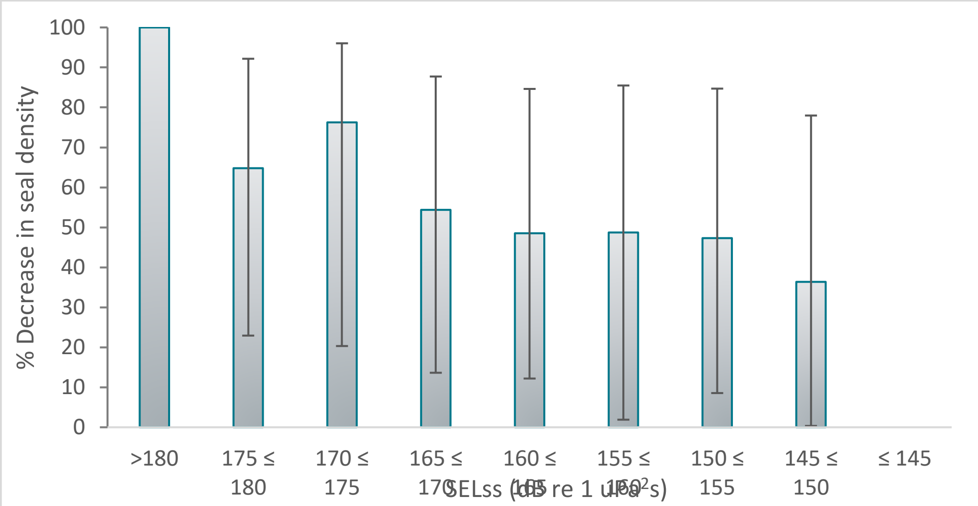

Figure 21C-5. Percentage decrease in seal density as a function of received levels (SEL_{ss} single strike) from Whyte et al. (2020)

Results

Auditory Injury (PTS)

85. **Table 21C-28** provides the summary of the maximum impact ranges for instantaneous PTS-onset and cumulative PTS-onset for both the static receptor and the fleeing model (see **Appendix 21C: Annex A** Sections 21.4 and 21.5 for impact contour maps).

86. **Table 21C-29** provides the summary of the area impacted based on the ranges from **Table 21C-28**, the number of animals potentially affected and the proportion of the reference population at risk of PTS-onset. The worst-case estimate is predicted from the static cumulative scenario, of 15 harbour porpoise and 30 minke whale. It is unlikely that these animals will remain stationary for the four-hour scenario whilst the pin piles are being installed. In all other cases the predictions are that less than one individual is at risk, with the exception of minke whale which predicts one minke whale at risk in the fleeing model scenario.

Table 21C-28. Summary of maximum PTS-onset ranges for impact piling of a 3 m pin pile (Appendix 21B: Marine Mammals Underwater Noise Modelling)

Functional hearing group	Instantaneous PTS-onset (SPL_{peak}) in (m)	Cumulative PTS-onset (SEL_{cum}) in (m) Static Receptor model	Cumulative PTS-onset (SEL_{cum}) in (m) Fleeing Receptor model
LF	<10	29,557	5,500
HF	<10	168	100
VHF	39	5,849	100
PCW	<10	3,310	60

Table 21C-29. Summary of area impact and numbers of individuals at risk of instantaneous or accumulated PTS-onset.

Species	Metric	Density (n/km^2)	Area impacted (km^2)	Number impacted	% MU reference population
Grey seal	SPL_{peak}	Grid cell specific (Carter *et al.*, 2022)	0	0	0
	Static – SEL_{cum}		34.42	<1	0
	Flee - SEL_{cum}		0.01	<1	0.001
Harbour porpoise	SPL_{peak}	0.137	0.0478	<1	0.000
	Static - SEL_{cum}		107.48	15	0.000
	Flee - SEL_{cum}		0.03	<1	0.024
Common dolphin	SPL_{peak}	0.841	0	0	0.000
	Static - SEL_{cum}		0.09	<1	0
	Flee - SEL_{cum}		0.03	<1	0.000
Bottlenose dolphin	SPL_{peak}	0.4195	0	0	0.000
	Static - SEL_{cum}		0.09	<1	0
	Flee - SEL_{cum}		0.03	<1	0.000
Minke whale	SPL_{peak}	0.011	0	0	0.000
	Static - SEL_{cum}		2744.55	30	0
	Flee - SEL_{cum}		95.03	1	0.150

Disturbance

Fixed Threshold Assessment

87. Modelling the impact using the NMFS Level B 160 dB re 1 mPa (rms), estimated impact ranges from 6,449m to 9,271m for all species. This reflects the minimum impact range (summer) and maximum range (winter). The number of individuals at risk of disturbance are detailed in **Table 21C-30**. The largest number predicted is 227 common dolphins, reflecting 0.22% of the reference population. In all but the winter scenario for bottlenose dolphins, the percentage of the reference population affected is less than 1%. The percentage of the MU populations of bottlenose dolphins at risk of disturbance is 1.03% for the worst-case scenario of winter noise propagation.

Table 21C-30. Summary of the number of individuals potentially at risk of disturbance using the NMFS Level B fixed threshold criteria.

Species	Density (n/km^2)	Area impacted (km^2)		Number impacted	% MU reference population
Grey seal	Grid cell specific (Carter *et al.*, 2022)	Min	130.66	2	0.002
		Max	270.02	3	0.005
Harbour porpoise	0.137	Min	130.66	18	0.029
		Max	270.02	37	0.059
Common dolphin	0.841	Min	130.66	110	0.107
		Max	270.02	227	0.221
Bottlenose dolphin	0.4195	Min	130.66	5	0.501
		Max	270.02	113	1.035
Minke whale	0.011	Min	130.66	2	0.007
		Max	270.02	3	0.015

88. Fixed noise thresholds were modelled as recommended in NRW (2023) for the harbour porpoise HRA assessment. The range (in meters) within which individuals present may be at risk of disturbance was from 20,047m to 39,279m using the 143 dB re 1 mPa^2.s unweighted fixed threshold (see **Appendix 21C: Annex A, Section 21.7** for the impact contour map).

89. The estimated impact ranges using the alternative fixed threshold of 103 dB re 1 mPa^2.s weighted ranged from 13,177m to 19,728m. The total number of individuals at risk of disturbance are detailed in **Table 21C-31**.

90. The area impacted has been calculated by deducting the area of land within the radius. The maximum number predicted to experience noise at levels that may result in disturbance, based on the 143 dB re 1 mPa^2.s unweighted fixed threshold, is 649 individuals. This represents 1.04% of the reference population. To note, this is not the number of animals disturbed within the SAC overlap, but the predicted number throughout the area impacted based on this fixed threshold.

Table 21C-31. Summary of number of animals at risk of disturbance using the fixed SELss thresholds for harbour porpoise

Species	Density (n/km^2)	Fixed threshold (dB re 1 mPa^2.s unweighted / weighted)	Area impacted (km^2)	Number impacted	% MU reference population
Harbour porpoise	0.137	143	1,326.31	182	0.29
			4,739.89	649	1.04
		103	545.49	75	0.12
			1,222.69	168	0.26

91. The results relating to the harbour porpoise HRA assessment are not discussed further in this report, instead taken through to the **Appendix 8E: HRA RIAA**, where the significance in HRA terms is presented.

<u>Dose Response Assessment (D / R)</u>

92. The predicted number of individuals at risk of disturbance using the D / R methodology for both cetaceans and seals is presented in **Table 21C-32**. See **Section 21.6** in **Appendix 21C: Annex A** for the unweighted SEL_{ss} contour maps for impact piling at the proposed Project Array Area. The noise modelling report (**Appendix 21B: Marine Mammals Underwater Noise Modelling)** modelled the scenario in February and in August to capture the full range of noise propagation conditions. As noted above, noise tends to travel further in the colder conditions in February. The results presented here are based on the February model, and so represent the worst-case scenario, and thus likely to overestimate the impacts as piling for the proposed Project is likely to be conducted in the summer months.

Table 21C-32. Summary of the worst-case (February) number of animals at risk of disturbance using Dose-response curves (Graham et al. (2017) for all cetaceans and Whyte et al. (2020) for the grey seal)

Species	Density (n/km^2)	Total area impacted (km^2)	Number impacted (CI)	% MU reference population
Grey seal	Grid cell specific (Carter *et al.*, 2022)	42,142	848 (6-2185)	1.360
Harbour porpoise	0.137	42,142	1202	1.922
Common dolphin	0.841	42,142	7379	7.188
Bottlenose dolphin	0.419	933	35	0.320
Minke whale	0.011	42,142	97	0.480

93. Research based on noise monitoring data from the Moray Firth has indicated that harbour porpoises do not completely leave an area whilst offshore wind construction is occurring (Benhemma-Le-Gall *et al.,* 2021), as harbour porpoise regularly continued to use the site throughout the three-year construction period and Beatrice Wind Farm (Beatrice 2017; 2.4m diameter pin pile – Moray East 2019; 2.5m diameter pin pile). Graham *et al., (*2017) found that neither harbour porpoise nor bottlenose dolphin were completely displaced by impact piling (piling source level 240 dB re 1 µPa @ 1 m $SPL_{peak-peak}$) from the region.

94. There are several studies that have reported the duration of effect following piling activity for harbour porpoise and return times range from two to six hours after piling (Nabe-Nielsen *et al.,*2018) to between one to three days (Brandt *et al.,* 2011). Return time is likely to depend on the biological value of the area to the animal, any habituation to the noise (Graham *et al.,* 2019) and the noise characteristics themselves. It is therefore likely that any disturbance that occurs from pin piling from the proposed Project will be temporary. The assessment based on the assumption that all animals will remain disturbed at the same level throughout is precautionary.

95. The significance, context, and conclusions of these results under EIA and HRA legislation are presented in the **Chapter 21: Marine Mammals** and **Appendix 8E: HRA RIAA.**

21.5.2. Other Construction Activities

General Background

96. Other construction activities considered in this assessment include drilling, dredging, cable laying, jetting, and rock placement activities (**Appendix 21B: Marine Mammals Underwater Noise Modelling**). Drilling may be required to secure the foundations instead, or in combination with pin piling, while dredging, trenching, jetting and rock placement activities may be required for the inter-array and export cable installation.

97. The noise generated by drilling is predominantly from the rotating drill bit cutting into the seabed, the level of which will depend on the substrate itself. The noise generated tends to be broadband (**Appendix 21B: Marine Mammals Underwater Noise Modelling**: Marine Mammals Underwater Noise Modelling) and at levels below auditory injury thresholds.

98. There are a few different types of dredgers (cutter suction, trailing-suction, hopper, grab and backhoe dredgers – see Todd *et al.* (2015)), and the type of dredger used for the proposed Project will depend on the seabed characteristics. Dredging noise tends to be broadband, and at levels considered unlikely to cause auditory injury for marine mammals as they are below PTS-onset thresholds (Todd *et al.,* 2015). The noise recorded whist dredging is occurring has been thought to be related to the vessel itself (**Appendix 21B: Marine Mammals Underwater Noise Modelling**; Todd *et al.,* 2015).

99. Jetting is a technique used to cut a trench for a cable, whereby a high-powered water jet is used to displace sediment ready for cable laying.

100. Rock placement is used where necessary to protect the cable in-situ.

101. It is not currently known whether all these other construction activities will be employed at this project, but they have been considered here to cover a representative range of additional construction activities.

102. Few studies have specifically investigated the impact of dredging, trenching or rock dumping on marine animals. However, like dredging, the noise emitted from these other activities are thought to be broadband, with most energy below 1 kHz (Todd *et al.,* 2015; Culloch *et al.,* 2016).

Assessment Methods

103. Vessel activity and other activities associated with cable laying have been modelled using source levels and frequency spectra obtained from the literature (see **Appendix 21B: Marine Mammals Underwater Noise Modelling** and **Table 21C-33** for details). The risk of auditory injury has been assessed using the SEL_{cum} (24-hour exposure) (Southall *et al.,* 2019). This represents a worst-case, as it assumes that construction activity sources are operating 24 hours a day. The risk of disturbance has been assessed using the fixed threshold NMFS level B disturbance threshold for continuous noise (NRW, 2023).

Table 21C-33. Acoustic source levels used for the assessment of 'other construction' installation activities, including cable laying, trenching, dredging and rock placement (reproduced from Appendix 21B: Marine Mammals Underwater Noise Modelling)

Noise activity	Acoustic source level [SPL_{peak} dB re 1 µPa]
Cable-laying	197
Jet trenching	181
Backhoe dredging	165
Suction dredging	186
Rock placement	172

104. In contrast to the impact piling assessment, noise modelling used two locations for these activities, the Array Area (WTG), and the cable route (CR; offshore export cable corridor) (**Figure 21C-6**).

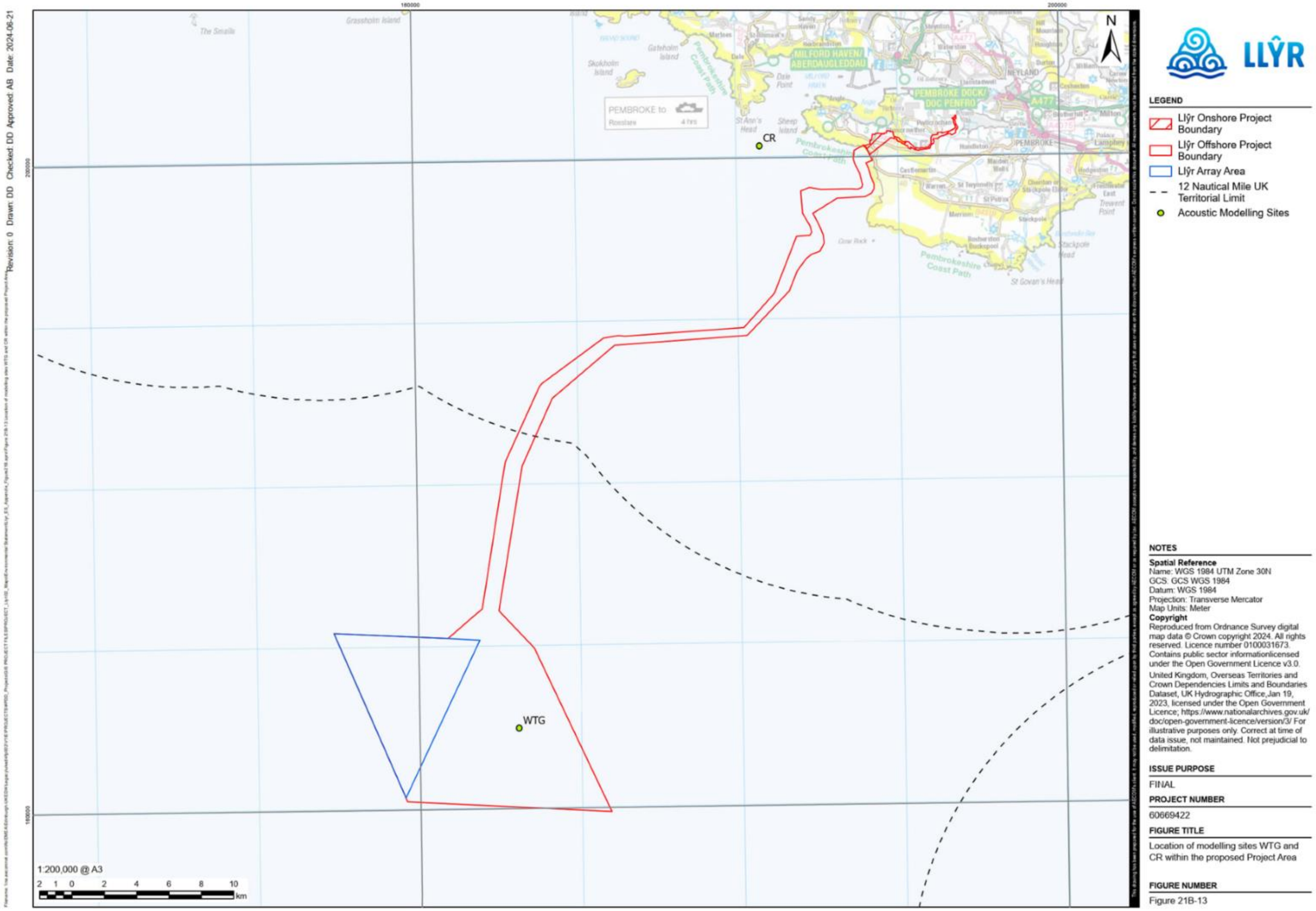

Figure 21C-6. Location of modelling sites WTG and CR within the Llŷr proposed Project area (reproduced from Appendix 21B: Marine Mammals Underwater Noise Modelling)

Results

105. All 'other construction' activities assessed generate much lower levels of noise in comparison to pile driving.

Auditory Injury (PTS)

106. Not all activities generated noise at levels that breached PTS-onset thresholds, nor for all species functional hearing groups. **Table 21C-34** details the PTS-onset ranges predicted using the static model and presents the operational period and functional hearing group where the PTS-onset threshold was breached. Where the thresholds were not breached results are not shown. The maximum range predicted was for the cable laying activity at 421m, VHF functional hearing group. This means a harbour porpoise would need to remain within 421m of the cable laying activity for 24 hours to accumulate enough noise-dose to breach PTS-onset.

107. **Table 21C-35** shows that in the fleeing model scenario, that there is no risk of PTS-onset for any marine mammal functional hearing groups, provided the individual was located at least 35m from the activity location at the commencement of the activity. Drilling returned the worst-case of 35m for the VHF cetacean functional hearing group (harbour porpoise).

108. Therefore, the risk of any animal sustaining auditory injury from these 'other construction' activities is extremely low.

Table 21C-34. Summary of maximum PTS-onset ranges for drilling, cable laying, jetting, backhoe and suction dredging, and rock placement – static receptor model (Appendix 21B: Marine Mammals Underwater Noise Modelling) WTG Array Area; CR cable route

Activity	Functional hearing group	Activity location	Operational period (hr)	Max range (m)
Drilling	VHF	WTG	8	50
			12	50
			24	93
Cable laying	LF	WTG	4	50
			8	100
			12	123
			24	200
		CR	2	41
			4	100
			8	133
			12	177
			24	328
	VHF	WTG	1	50
			2	50
			4	100
			8	163
			12	221
			24	327
		CR	1	50
			2	88
			4	149
			8	221
			12	286
			24	421

Activity	Functional hearing group	Activity location	Operational period (hr)	Max range (m)
Jetting	LF	WTG	24	41
		CR	24	47
	VHF	WTG	4	50
			8	50
			12	88
			24	140
		CR	4	50
			8	88
			12	123
			24	177
Backhoe dredging	No impacts from either WTG or CR			
Suction dredging	LF	WTG	12	41
			24	50
		CR	8	39
			12	50
			24	101
	VHF	WTG	2	39
			4	50
			8	82
			12	100
			24	163
		CR	2	41
			4	50
			8	101
			12	133
			24	219
Rock placement	VHF	WTG	24	44

Table 21C-35. Summary of maximum 'safe start' range based on SEL_{cum} for drilling, cable laying, jetting, backhoe and suction dredging, and rock placement – fleeing receptor model (Appendix 21B: Marine Mammals Underwater Noise Modelling) WTG Array Area; CR cable route

Activity	Functional hearing group	Activity location	Maximum 'safe start' range (m)
Drilling	LF	CR	31
	VHF	WTG	**35**
		CR	10
Cable laying	LF	WTG & CR	31
	VHF	WTG & CR	10
Jetting	VHF	WTG & CR	18
Backhoe dredging	No impact in either WTG or CR		
Suction dredging	VHF	WTG & CR	16

Activity	Functional hearing group	Activity location	Maximum 'safe start' range (m)
Rock placement	No impact in either WTG or CR		

Disturbance (Level B – 120 dB re 1 µPa rms)

109. The maximum impact range for disturbance using the fixed NMFS Level B threshold for continuous noise (120 dB re 1 µPa rms) was 21.9km for cable laying activity based on the CR modelling location (**Table 21C-36**). This results in the worst-case estimate of 1,010 common dolphin at risk of disturbance from this activity, which is 0.99% of the reference population (**Table 21C-37**).

110. For seals, the densities used to estimate the number of seals at risk is variable because it is based on the density surface maps in Carter *et al.* (2022), and therefore comparison was made between the CR and the WTG modelling scenarios. Land was removed from the area assessed, and the highest number of seals disturbed was found to be from the CR location.

Table 21C-36. Summary of maximum impact ranges (m) at which the received levels fell below disturbance threshold (120 dB re 1 µPa rms) for all marine mammals

Activity	WTG	CR
Drilling	1,106	N/A
Cable laying	19,558	21,854
Jetting	4,002	5,451
Backhoe dredging	286	550
Suction dredging	9,845	10,704
Rock placement	901	1,501

Table 21C-37. Summary of the minimum and maximum estimates of the number of animals potentially at risk of disturbance worst-case from cable laying, and the 'best' estimate from backhoe dredging.

Species	Density (n/km^2)	Total area impacted (km^2)	Number impacted	% MU reference population
Grey seal	Grid cell specific (Carter *et al.*, 2022	853.87	91	0.146
		0.26	<1	0.000
Harbour porpoise	0.137	1,201.71	165	0.263
		0.26	<1	0.000
Common dolphin	0.841	1,201.71	1011	0.984
		0.26	<1	0.000
Bottlenose dolphin	0.4195	1,201.71	504	4.605
		0.26	<1	0.000
Minke whale	0.011	1,201.71	13	0.066
		0.26	<1	0.000

111. It is worth noting here that the Level B threshold of 120 dB re 1 µPa (rms) is very close to the level of background noise that typically exists in the marine environment without acoustic input from 'other construction activities' (**Appendix 21B: Marine Mammals Underwater Noise Modelling**). Therefore, it is likely that assessment using the Level B threshold for continuous noise is assessing audibility rather than potential behavioural disturbance.

112. The significance, context, and conclusions of these results under EIA and HRA legislation are presented in the **Chapter 21: Marine Mammals** and **Appendix 8E: HRA RIAA.**

21.5.3. Disturbance from Vessels

General Background

113. Disturbance from vessels may be due to the noise levels emitted, or the presence of vessels, or more likely, a combination of both. Disturbance resulting in a behavioural response tends to be context specific and depends much on the individual's prior exposure to vessel activity, the motivation to remain in the area (e.g. if valuable foraging area, protection of young), and the individual's own hearing ability.

114. Vessel disturbance is considered relative to noise radiated, and noise levels from vessels are varied and depend on parameters such as vessel size and speed (Richardson *et al.,* 1995). Vessel activity in general is likely to raise the existing noise levels in the area, and potential impacts from this, aside from displacement, could be a loss of communication space (Erbe *et al.,* 2016) and a loss of foraging opportunities (Williams *et al.,* 2021).

115. Benhemma-Le Gall *et al.* (2021) monitored harbour porpoise occurrence during offshore wind farm construction in the Moray Firth, Scotland, and found that there was a decrease in harbour porpoise acoustic detections within 12km of piling activity, but also up to 4km from general construction vessel activity suggesting there is a short-term behavioural response associated with vessel and construction noise.

Assessment Methods

116. Noise levels and frequency content of example vessel noise were obtained from a literature review (**Table 21C-38**). Large vessel refers to a typical project support vessel of 100m in length, and medium vessel relates to a typical support vessel of 50m in length. The risk of auditory injury has been assessed using the SEL_{cum} (24-hour exposure) (Southall *et al.,* 2019) using both the static receptor model and the fleeing receptor model. The risk of disturbance has been assessed using the fixed threshold NMFS level B disturbance threshold for continuous noise (NRW, 2023). **Appendix 21B: Marine Mammals Underwater Noise Modelling** presented estimates from models both in the cable route (offshore export cable corridor; CR) and in the Array Area (WTG). In this report, we present the worst-case estimate resulting from either modelling location.

Table 21C-38. Acoustic source levels used in the underwater noise modelling of impact (Appendix 21B: Marine Mammals Underwater Noise Modelling)

Vessel size category	Acoustic source level [SPL_{peak} dB re 1 µPa]
Project vessel (large)	180
Project vessel (medium)	170

Results

Auditory Injury (PTS)

117. PTS-onset risk was assessed using the stationary receptor model over the maximum exposure of 24 hours (**Table 21C-39**). It is worth highlighting that this scenario is extremely unlikely as both the vessel and the marine mammal will be moving. The worst-case prediction is that a VHF cetacean (harbour porpoise) would have to remain within 164m of a large vessel for 24 hours to experience PTS-onset.

118. The results from the fleeing receptor model indicated that the safe start range was negligible for all functional hearing groups except for the VHF cetacean (harbour porpoise) where this was 12m for the large vessel scenario (**Appendix 21B: Marine Mammals Underwater Noise Modelling**).

Table 21C-39. Summary of the maximum distance (m) for vessel activity, within which PTS-onset may occur. Stationary animals exposed to continuous noise for 24 hours (Appendix 21B: Marine Mammals Underwater Noise Modelling)

Vessel size category	LF Cetacean	HF Cetacean	VHF Cetacean	PCW
Project vessel (large)	41	<10	164	<10
Project vessel (medium)	<10	<10	<10	<10

Disturbance (Level B – 120 dB re 1 µPa rms)

119. The maximum disturbance range predicted using the NMFS Level B fixed disturbance threshold was 4.5km (**Table 21C-40**). This is consistent with the research published by Benhemma-Le Gall *et al.* (2021) for harbour porpoise in the Moray Firth. Using this impact range, estimates of numbers of animals at risk of disturbance are low, with the largest number being 54 common dolphins (**Table 21C-42**).

Table 21C-40. Summary of the maximum impact ranges for disturbance from vessel activity, using the fixed threshold of 120 dB re 1µPa (rms) Level B harassment threshold

Vessel size category	Impact range (m)
Project vessel (large)	4,503
Project vessel (medium)	1,100

Table 21C-41. Summary of the number of animals potentially at risk of disturbance using the fixed threshold of 120 dB re 1µPa (rms) Level B harassment threshold for both the project vessel (large) and project vessel (medium) impact ranges (Table 21C-40).

Species	Density (n/km^2)	Total area impacted (km^2)	Number impacted	% MU reference population
Grey seal	Grid cell specific (Carter *et al.*, 2022)	63.7	<1	0.001
		3.8	<1	0.000
Harbour porpoise	0.137	63.7	9	0.014
		3.8	<1	0.001
Common dolphin	0.841	63.7	54	0.052
		3.8	3	0.003
Bottlenose dolphin	0.4195	63.7	27	0.244
		3.8	2	0.015
Minke whale	0.011	63.7	<1	0.003
		3.8	<1	0.000

120. The significance, context, and conclusions of these results under EIA and HRA legislation are presented in the **Chapter 21: Marine Mammals** and **Appendix 8E: HRA RIAA.**

21.6 Operation

21.6.1. Operational Turbine Noise

General Background

Underwater Noise from Operational Turbines

121. Noise emitted from the mechanical components of the WTG, such as the gearbox and generator can travel through the WTG tower to the floating foundation, and propagate to the surrounding water, creating a low frequency continuous underwater noise source (Nedwell *et al*., 2003; Tougaard *et al.*, 2020). Underwater noise from fixed-foundation turbines has been characterised in several studies (e.g. Tougaard *et al*., 2020); however, there is limited data about how this occurs in floating turbines, and it is considered likely to be dependent on the design of the turbines and their foundations.

122. Tougaard *et al*. (2020) published a study of underwater noise data from 17 operational fixed-foundation WTGs from 0.2 MW to 6.15 MW power output. They determined that the measured sound levels from the wind turbines was most significantly influenced by the distance from the turbines, with smaller effects from wind speed and turbine size. These data were used to establish a formula for the estimation of broadband noise levels based on these parameters. Based on estimated sound levels from this formula, underwater noise propagation modelling was conducted by Subacoustech for Erebus FLOW (Barham and Mason, 2021) and Pentland FLOW (Midforth *et al*., 2022). For both developments, the assessment concluded that, for all marine mammal functional hearing groups, an animal would have to remain within less than 100 m of the turbines for more than 1-hour before there was any potential for injury or disturbance. This is considered highly unlikely given the highly mobile nature of these species.

123. In fixed-foundation turbines, operational noise can radiate into the water throughout the monopile. For floating turbines, the radiating area is limited to the floating substructures which are just below the water surface, meaning that the underwater noise generated from floating turbines may be less than in fixed-foundation equivalents. However, there is also potential that floating turbine designs which use a buoyancy chamber may act as a resonating chamber which may change the sound characteristics of underwater noise produced from the mechanical components.

124. A study of underwater noise produced at Hywind FLOW (Burns *et al*., 2022) recorded dominant noise from the turbines at low frequencies (<100 Hz). A further noise between approximately 350 and 460 Hz was also detected, which is thought to be associated with the Hywind turbines although the precise source of the noise could not be identified.

125. Risch *et al.* (2023) reported source levels from Kincardine and Hywind Scotland of between 144.8 dB re 1 µPa.m and 145.8 dB re 1 µPa.m for the frequency range 25 Hz to 20 kHz, with most of the operational noise concentrated below 200 Hz.

126. Whilst most species are thought to be capable of hearing the operational noise output from floating turbines, it is also thought that in many instances the radiating noise will be hidden within background noise levels. With most of the frequency content concentrated below 200Hz, it is likely to be of lower impact to all marine mammals, except perhaps the Low functional hearing group (Southall *et al.,* 2019) which includes minke whales.

Underwater Noise Associated with Mooring Lines and Cables

127. During higher wind speeds there is potential for transient underwater noise to be generated by the mooring lines and cables which connect the floating turbine to the pin-pile foundations (Risch *et al.,* 2023; Burns *et al.,* 2022).

128. Given that it is a relatively new technology and there are few operational turbines, there is limited knowledge and evidence regarding the underwater noise generated from FLOW, and the dynamic movement and associated noise resulting from mooring lines and cables (Rentschler *et al*., 2019). Therefore, this assessment can only consider very limited existing evidence and empirical data, which may not be indicative of the underwater noise at the proposed Project.

129. 'Snapping' sounds, associated with the re-tensioning of mooring lines, were identified at the Norwegian Hywind Demonstrator floating offshore wind Project, over a 10-week monitoring period in summer 2011 (Martin *et al*., 2011). Underwater noise levels were sampled 150m from the Hywind array area, at 200m depth, from approximately mid-water column (91m from the seabed). Between 0 and 23 intermittent 'snaps' (which exceeded 160 dB SPL_{peak}) were recorded per day per turbine at the Hywind site.

130. Analysis of the transient sounds in Scotland (Risch *et al.,* 2023) found that although individual events within the recorded signal, did reach kurtosis values that could indicate impulsiveness, the overall recorded signal mean kurtosis levels indicate that the noise is not classified as fully impulsive, therefore they conclude that assessment should be made using non-impulsive impact criteria.

131. In the analysis of the data conducted for the Hywind Scotland Pilot Park (Burns *et al.,* 2022) a potential cumulative SEL of up to 156 dB re 1 μPa^2sec over 24 hours was predicted from six turbines, which is below the onset criteria for injury to marine mammals (Southall *et al*., 2019). This study concluded that, based on analysis of the underwater noise recorded at the Hywind Demonstrator Project, any behavioural disturbance for marine mammals would be highly localised to the array up to approximately 250m from each turbine. Additionally, given the low frequency and intermittent nature of the noise, it is unlikely that disturbance leading to any avoidance behaviour would occur.

132. Although limited, the existing evidence suggests that underwater noise generated from mooring lines will not be sufficient to illicit a significant disturbance response in marine mammals. However, the potential for snapping noise may relate to the mooring configuration choice. Catenary mooring configurations allows for some movement in the chains and ropes and therefore potential for snapping due to re-tensioning. There is a lower potential for this noise source for a taut mooring system configuration (Benjamins *et al.,* 2014).

Assessment Methods

133. Estimated underwater noise source levels from the Erebus ES (Barham and Mason, 2021), and recorded operational noise at Hywind FLOW have been used to inform the specific underwater noise propagation modelling for the Project (**Appendix 21B: Marine Mammals Underwater Noise Modelling**). Broadband noise Source Levels varied at Hywind FLOW from 158.9 dB re 1μPa^2m^2 to 172.0 dB re 1μPa^2m^2 (**Appendix 21B: Marine Mammals Underwater Noise Modelling**; Burns *et al.,* 2020). Underwater noise propagation modelling was undertaken using an acoustic source level based on the 75th percentile for a 20-knot wind, 167.2 dB re 1μPa^2m^2 from Hywind FLOW (**Table 21C-42**). This was selected as Burns *et al.,* (2020) found that the 75th percentile sound level modelled for 24 hours best matched the recorded daily sound level.

134. Only broadband data were taken forward to assessment, although intermittent snapping or clicking noise has been observed in some instances, there was no frequency spectrum data available to enable inclusion into the modelling.

Table 21C-42. Estimated source level used for the noise modelling of turbine operational noise at the proposed Project Array Area

Activity	SPL_{peak}	SPL_{rms}
Turbine operation	167.2 dB re 1 µPa @ 1 m	161 dB re 1 µPa @ 1 m

Results

Auditory Injury (PTS)

135. Modelling has indicated that there is negligible risk to any marine mammal functional hearing group of accruing PTS-onset. The predicted impact range is less than 10m for all species groups, the minimum model resolution (**Appendix 21B: Marine Mammals Underwater Noise Modelling**), indicating that any individual would need to be within 10m for 24 hours to affect hearing from operational noise.

Disturbance (Level B – 120 dB re 1 µPa rms)

136. The predicted range of impact using the NMFS Level B threshold for continuous noise is a maximum of 588m for all marine mammal functional hearing groups (**Appendix 21B: Marine Mammals Underwater Noise Modelling**). The potential for disturbance from operational noise is therefore highly localised.

137. The significance, context, and conclusions of these results under EIA and HRA legislation are presented in the **Chapter 21** and **Appendix 8E.**

21.7 Precaution in the Assessment

138. Underwater noise assessments are subject to several assumptions and uncertainties. The assessment is based on the best available information and consistent with currently accepted industry standards. It is worth setting out the uncertainties as this highlights the level of over-precaution within the modelling predictions.

139. The modelling of underwater noise propagation as a scientific discipline has been established for decades (Farcas *et al.,* 2016) and the modelling algorithms used are acoustically well understood. However, the outputs from these models are reliant on the input data used. Usually, measured data specific to the proposed location required are not available at the environmental impact assessment stage, and reliance therefore is made of information gathered from the literature for similar noise sources.

140. Noise modelling starts with an estimation of the source level of the activity. The source level does not exist in reality; therefore, an estimation of the noise is made either by using a mathematical source model, or by using in-field measurements back-calculated to the source (at 1m). There are several mathematical equations used to model the source and input parameters of the equations relate to physical properties of the source (e.g. for pile driving – the diameter of the pile and the hammer energy). When representative source levels are used from the literature, these invariably have been measured in-situ, on a transect in a particular set of environmental conditions and therefore, because noise propagation is dependent on these environmental conditions, the resulting source level estimation is technically only valid for use in that same location. Often there is no choice but to use proxy source levels in circumstances as close as possible to the situation being modelled (**Appendix 21B: Marine Mammals Underwater Noise Modelling**).

141. Impact piling is modelled as a point source, i.e. all sound energy originates from a point within the water column. However, impact piling is not a point source, but instead a line source, which is more complex modelling methodology than for a point source (Farcas *et al.,* 2016). Although the line source methodology is more realistic, the use of a point source, at the time of writing, is the accepted method used in offshore wind impact assessments.

142. The estimation of the UXO source level is based on equations developed by Soloway and Dahl (2014). These equations reflect measurements taken from detonations located within the water column, and therefore do not account for any attenuation by the seabed. This means subsequent propagation modelling will likely overestimate the noise in the environment at distance. Currently, there are no suitable models available that represent a UXO clearance event on the seabed, and therefore the source level used is likely to be an overestimate.

143. If the source level used is an under or overestimate, it will in turn mean the impact radii predicted are also under or over estimated. Therefore, it is common practice to take the precautionary approach in choice of source level used, even if that may be an overestimate (**Appendix 21B: Marine Mammals Underwater Noise Modelling**).

144. Usually, noise modelling outputs present depth averaged noise levels along the modelled transect. It can be seen from **Figures 21B-1 to 21B-6** in **Appendix 21B: Marine Mammals Underwater Noise Modelling** that the noise levels at any one vertical position can vary, and typically noise levels are quieter at the surface. This has relevance when considering the noise dose accrued by individuals that are fleeing from the area. Generally, low swim speeds and deep dives are associated with foraging behaviour, but faster swim speeds and linear movements are associated with traveling behaviour (van Beest *et al.,* 2018). It is likely that in a fleeing scenario any individual will therefore be exposed to a lower noise dose than predicted.

145. Impact ranges are estimated by applying impact acoustic thresholds to the modelled noise levels in the environment to determine the range within which there is a risk. Auditory injury thresholds (PTS-onset) are applied using Southall *et al.,* (2019) thresholds (consistent with NMFS, 2018 guidance). There are inherent uncertainties and data limitations in the setting of such thresholds. These thresholds are based on a limited number of species, and a limited number of sound sources, therefore information has by necessity been extrapolated (NMFS, 2018) and so functional hearing groups are used. The Southall *et al.* (2019) PTS-onset thresholds are accepted as industry standard.

146. Notwithstanding the uncertainties with the PTS-onset thresholds, instantaneous PTS-onset is far less uncertain than cumulative PTS-onset. Sound Exposure Level (SEL) is a proxy for the energy content of the sound (NPL, 2014), and cumulative SEL is the total sound exposure determined for an extended period or sequence of pulses / events. This assumes therefore that a louder short duration sound may be equal in effect to a lower longer, or intermittent noise over a longer duration. This is termed the equal energy hypothesis. This may not be the case, as it does not reflect recovery between pulses (NMFS, 2018). The assumption of equal energy hypothesis may therefore overestimate the risk; however, there is no alternative methodology currently.

147. Typically, it is assumed that all animals within the PTS-onset threshold will experience hearing loss. The numbers presented in this report are presented under that assumption. However, this is not necessarily the case, as the threshold is PTS-onset, which means that animals can start to experience hearing loss at the threshold. This was the approach taken by Donovan *et al.* (2017) in their paper "A *simulation approach to assessing environmental risk of sound exposure to marine mammals*". They introduced a term 'probability of effect' and suggested

that the number of individuals that would experience PTS at PTS-onset was in the range of 8 to 19 percent.

148. In the fleeing model, assumptions need to be made in relation to the individual animal's fleeing response. Usually, it is assumed individuals swim directly away at a constant speed, and the speeds chosen are conservative and this adds a further layer of precaution into the modelling exercise.

149. Alternatively, in the static animal model, it is assumed that an animal remains in the same location throughout the noise exposure which is biologically unrealistic.

150. Cumulative PTS-onset is assessed for impact piling using the impulsive noise impact threshold. Impulsive noise is considered a greater risk for mammal hearing because short sharp sounds create a greater risk of causing direct mechanical fatigue to the inner ear in comparison to non-impulsive sounds. Impact piling is impulsive at source, but for injury to occur it is also assumed that it is impulsive at the individual animal location regardless of the distance. However, it is well understood that impulsive noise characteristics transition to non-impulsive as the noise propagates away from source (Hastie *et al.,* 2019). Therefore, in assessing impact ranges in tens of km in terms of impulsive noise is a precautionary approach driven by uncertainties (Southall, 2021).

151. The received noise level at which disturbance occurs is varied, and reported levels in association with observed behavioural reactions can sometimes be conflicting. Any behavioural response is context specific and therefore difficult to predict. A range of fixed and D / R approaches have been used in this assessment, but it is worth highlighting that threshold levels of 120 dB re 1µPa (rms) and the lowest 5 dB D / R contour are close to environmental background noise levels. Therefore, estimated impacts using these levels may overestimate the disturbance impact. The correlation of disturbance to a loss of biological fitness is not well understood, therefore these thresholds represent the risk of disturbance, rather than the prediction of deleterious effects.

152. In conclusion, it is likely that all precautions highlighted here compound resulting in a highly precautionary assessment.

21.8 Conclusions

153. This report has provided an assessment of the potential impacts to marine mammal species from underwater noise sources during pre-construction and construction and operational related activities at the Llŷr 1 proposed Project in the Celtic Sea, Wales. The assessment builds on the Underwater Noise Impact Study prepared by Award Environmental Consultants Ltd (**Appendix 21B: Marine Mammals Underwater Noise Modelling**), and the results from this assessment are used in the **Chapter 21: Marine Mammals** and **Appendix 8E: HRA RIAA** where context and significance conclusions are presented.

154. Auditory injury (PTS-onset) was assessed under dual exposure criteria (Southall *et al.,* 2019) recommended for the assessment of the instantaneous and accumulated (cumulative) risk of hearing damage, from impulsive and non-impulsive sound sources. Static and fleeing animal approaches were modelled for the assessment of accumulated PTS-onset.

155. This assessment has used varied disturbance thresholds relevant for each of the noise activities and follow Natural Resources Wales guidance (NRW, 2023) because there is no single threshold that can be applied for disturbance / displacement impacts.

156. Results of modelling undertaken indicate that there is minimal risk of auditory injury from the operation of the geophysical equipment reviewed in this assessment. Worst-case injury ranges based on the static cumulative model are between 82-100m, if the individual remains

at this range for 24 hours. Therefore, although there is a theoretical auditory injury risk, this can be fully mitigated using standard JNCC mitigation measures (see Marine Mammal Mitigation Plan in **Volume 6, Appendix 4A: Outline Construction Environmental Management Plan**).

157. There is no information at the time of writing as to the presence, number, or type of UXOs that may be present. in the proposed Project area. Therefore, this assessment has modelled the impact using the same range of charge weights as considered for the Erebus application (Barham and Mason, 2021).

158. High-order clearance models highlight a significant risk of injury and disturbance for marine mammals. Predicted impacts from the low-order scenarios are significantly reduced from high-order estimates. Although the number of animals estimated to experience PTS-onset were not at levels that would be deemed significant at the population level, there is a welfare risk to individuals impacted. All cetaceans are EPS, therefore, should UXO clearance be required, this activity will require further assessment under EPS legislation once more information is known.

159. The impact from the pin piling activity was modelled based on acoustic characteristics obtained from the published literature which were appropriate for a 3m diameter pile.

160. The risk of instantaneous injury from impact piling is minimal for all functional hearing group species (although not zero). The results presented in this report indicate that the numbers of individuals at risk of auditory injury are negligible relative to reference populations.

161. Disturbance impacts were estimated using two fixed noise thresholds, and a dose response curve approach. Disturbance assessed under the Level B NMFS threshold were negligible in terms of proportion of the reference population. Disturbance estimates using the dose response curve, indicated that there was >1% of the reference population potentially at risk of disturbance for harbour porpoise, common dolphin and minke whale. The significance of this is assessed in **Chapter 21: Marine Mammals**.

162. The potential spatial extent of behavioural disturbance within harbour porpoise SACs, from the piling activity was assessed using the fixed noise threshold of 143 dB re 1µPa SEL_{ss} unweighted (Tougaard, 2021 in NRW 2023). Spatial area overlap is presented in this report. Results are taken through to the **Appendix 8E: HRA RIAA** for assessment of impacts under HRA.

163. Other construction activities (including drilling, dredging, cable laying jetting and rock placement activities) and general vessel activity were assessed for both auditory injury (cumulative PTS-onset; static and fleeing model approach) and disturbance using NMFS 120 dB re 1 µPa (rms) threshold.

164. Results presented in this report indicate that the risk of auditory injury are minimal from other construction activities and vessel activity. Worst-case disturbance impact ranges estimated were for the cable laying activity at 21.9km, and at 4.5km from vessel activity. It is worth reiterating that the Level B threshold of 120 dB re 1 µPa (rms) is close to the level of noise that exists in the environment without acoustic input from the other construction activities or vessel noise (**Appendix 21B: Marine Mammals Underwater Noise Modelling**). Therefore, it is probable that assessment using the Level B threshold for continuous noise is assessing ranges of audibility as well as the potential for disturbance.

165. The impact from continuous underwater noise generated by the operating turbines was assessed using current understanding on operational turbine noise. Modelling has indicated that there is negligible risk to any marine mammal functional hearing group of accruing PTS-

onset, and the maximum potential range within which there is a disturbance risk, is within 600m for all marine mammals.

166. The non-zero numbers of animals predicted for both UXO clearance and impact piling activities, will mean that potential mitigation methods to negate this risk as far as possible will be needed. This is considered in the draft outline marine mammals mitigation plan (MMMP) (**Volume 6, Appendix 4A: Outline Construction Environmental Management Plan**). All cetaceans are EPS and therefore consideration of EPS licensing will be required.

21.9 References

Bailey, H., Senior, B., Simmons, D., Rusin, J., Picken, G. and Thompson, P.M., 2010. Assessing Underwater Noise Levels during Pile-Driving at an Offshore Windfarm and Its Potential Effects on Marine Mammals. Marine Pollution Bulletin 60 (6), pp.888-897.

Barham, R. and Mason, T., 2021. "Erebus Offshore Wind: Underwater noise assessment", Subacoustech Environmental Report No. P282R0106, 7 October 2021.

BEIS, 2020. Review of Consented Offshore Wind Farms in the Southern North Sea Harbour Porpoise SAC. September 2020. [Online]. Available at: Review of Consented Offshore Wind Farms in the Southern North Sea Harbour Porpoise SAC (publishing.service.gov.uk) [Accessed: 20 November 2023].

BEIS, 2022. Policy paper. Marine environment: unexploded ordnance clearance joint interim position statement. [Online]. Available at: https://www.gov.uk/government/publications/marine-environment-unexploded-ordnance-clearance-joint-interim-position-statement/marine-environment-unexploded-ordnance-clearance-joint-interim-position-statement [Accessed: 01 June 2023].

Bellmann, M.A., Brinkmann, J., May, A., Wendt, T., Gerlach, S. and Remmers, P., 2020. Underwater noise during the impulse pile-driving procedure: Influencing factors on pile-driving noise and technical possibilities to comply with noise mitigation values. Federal Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie (BSH)), Order No. 10036866. Edited by the itap GmbH.

Benhemma-Le Gall, A., Graham, I.M., Merchant, N.D. and Thompson, P.M., 2021. Broad-Scale Responses of Harbor Porpoises to Pile-Driving and Vessel Activities During Offshore Windfarm Construction. Front. Mar. Sci. 8, 664724.

van Beest, F.M., Teilmann, J., Dietz, R., Galatius, A., Mikkelsen, L., Stalder, D., Sveegaard, S. and Nabe-Nielsen, J,. 2018. Environmental drivers if harbour porpoise fine-scale movements. Marine Biology, 165, 95.

Benjamins, S., Harnois, V., Smith, H.C.M., Johanning, L., Greenhill, L., Carter, C. and Wilson, B., 2014. Understanding the potential for marine megafauna entanglement risk from renewable marine energy developments. Scottish Natural Heritage Commissioned Report No. 791.

Boisseau, O., McGarry, T., Stephenson, S., Compton, R., Cucknell, A. C., Ryan, C., McLanaghan, R. and Moscrop, A., 2021. Minke whales Balaenoptera acutorostrata avoid a 15 kHz acoustic deterrent device (ADD). Marine Ecology Progress Series, 667, pp.191-206.

Booth, C.G. and Heinis, F., 2019. Updating the Interim PCoD Model: Workshop Report - New transfer functions for the effects of disturbance on vital rates in marine mammal species. Report Code SMRUC-BEI-2018-011, submitted to the Department for Business, Energy and Industrial Strategy (BEIS), February 2019 (unpublished).

Brandt, M.J., Diederichs, A., Betke, K. and Nehls, G., 2011. Responses of harbour porpoises to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea. Marine Ecology Progress Series, 421, pp.205-216.

Burns, R.D.J., S.B. Martin, M.A. Wood, C.C. Wilson, C.E. Lumsden, and F. Pace., 2022. Hywind Scotland Floating Offshore Wind Farm: Sound Source Characterisation of Operational Floating Turbines. Document 02521, Version 3.0 FINAL. Technical report by JASCO Applied Sciences for Equinor Energy AS.

Carter, M.I., Boehme, L., Cronin, M.A., Duck, C.D., Grecian, W.J., Hastie, G.D., Jessopp, M., Matthiopoulos, J., McConnell, B.J., Miller, D.L. and Morris, C.D., 2022. Sympatric seals, satellite tracking and protected areas: habitat-based distribution estimates for conservation and management. Frontiers in Marine Science, 9, 875869.

Cheong, S-H., Wang L., Lepper, P. and Robinson, S., 2020. Characterisation of Acoustic Fields Generated by UXO Removal - Phase 2 (Offshore Energy SEA Sub-Contract OESEA-19-107), NPL Report AC 19.

Crocker, S.E. and Fratantonio, F.D., 2016. Characteristics of sounds emitted during high resolution marine geophysical surveys. NUWC-NPT Technical Report 12, 203.

Culloch, R.M., Anderwald, P., Brandecker, A., Haberlin, D., McGovern, B., Pinfield, R., Visser, F., Jessopp, M. and Cronin, M., 2016. Effect of construction-related activities and vessel traffic on marine mammals. Marine Ecology Progress Series, 549.

Donovan, C.R., Harris, C.M., Milazzo, L., Harwood, J., Marshall, L., and Williams, R., 2017. A simulation approach to assessing environmental risk of sound exposure to marine mammals. Ecology and Evolution, 7(7), pp.2101-2111.

Erbe C., Reichnuth C., Cunningham K., Lucke K. and Dooling R., 2016. Communication masking in marine mammals: A review and research strategy. Marine Pollution Bulletin, 103(1-2), pp.15-38.

Farcas, A., Thompson, P.M. and Merchant, N.D., 2016. Underwater noise modelling for environmental impact assessment. Environmental Impact Assessment Review 57, pp.114-122.

Genesis, 2011. Review and Assessment of Underwater Sound Produced from Oil and Gas Sound Activities and Potential Reporting Requirements under the Marine Strategy Framework Directive. Document J71656-Final Report-G2. [Online]. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/851545/Review_and_Assessment_of_underwater_sound_produced_from_oil_and_gas_sound_activities.pdf [Accessed: 05 June 2023].

Gilles, A., Authier, M., Ramirez-Martinez, N.C., Araújo, H., Blanchard, A., Carlström, J., Eira, C., Dorémus, G, Fernández-Maldonado, C., Geelhoed, S.C.V., Kyhn, L., Laran, S., Nachtsheim, D., Panigada, S, Pigeault, R, Sequeira, M., Sveegaard, S., Taylor, N.L., Owen, K., Saavedra, C., Vázquez-Bonales, J.A., Unger, B., Hammond, P.S., 2023. Estimates of cetacean abundance in European Atlantic waters in summer 2022 from the SCANS-IV aerial and shipboard surveys. Final report published 29 September 2023. 64 pp.

Graham, I.M., Farcas, A., Merchant, N.D. and Thompson, P., 2017a. Beatrice Offshore Wind Farm: An interim estimate of the probability of porpoise displacement at different unweighted single-pulse sound exposure levels. Prepared by the University of Aberdeen for Beatrice Offshore Windfarm Ltd

Graham, I.M., Pirotta, E., Merchant, N.D., Farcas, A., Barton, T.R., Cheney, B., Hastie, G.D. and Thompson, P., 2017. Responses of bottlenose dolphins and harbor porpoises to impact and vibration piling noise during harbor construction. Ecosphere, 8(5).

Graham, I.M., Merchant, N.D., Farcas, A., Barton, T.R.C., Cheney, B., Bono, S. and Thompson, P.M., 2019. Harbour porpoise responses to pile-driving diminish over time. Royal Society Open Science 6, 190335.

Hammond P.S., Lacey C., Gilles A., Viquerat S., Borjesson P., Herr H., Macleod K., Ridous V., Santos M.B., Scheidat M., Teilmann J., Vingada J. and Oien N., 2021. Estimates of cetacean abundance in European Atlantic waters in Summer 2016 from the SCANS-III aerial and shipboard surveys. [Online]. Available at: https://synergy.st-andrews.ac.uk/scans3/files/2017/05/SCANS-III-design-based-estimates-2017-05-12-final-revised.pdf [Accessed: 20 July 2023].

Hartley Anderson Limited, 2020. Underwater acoustic surveys: review of source characteristics, impacts on marine species, current regulatory framework and recommendations for potential management options. NRW Evidence Report No: 448, 136pp.

Hastie, G., Merchant, N.D., Gotz, T., Russel D.J.F., Thompson, P. and Janik, V., 2019. Effects of impulsive noise on marine mammals: investigating range-dependant risk. Ecological Applications 29(5), e01906.

IAMMWG, 2022. Updated abundance estimates for cetacean Management Units in UK waters (Revised 2022). JNCC Report No. 680, JNCC Peterborough, ISSN 0963-8091.

JNCC. 2010. The protection marine European Protected Species from injury and disturbance, Guidance for the marine area in England and Wales and the UK offshore marine area. Joint Nature Conservation Committee, Natural England and Countryside Council for Wales [Online]. Available at: https://assets.publishing.service.gov.uk/media/5dea1d35e5274a06dee23a34/Draft_Guidance_on_the_Protection_of_Marine_European_Protected_Species_from_Injurt_and_Disturbance.pdf [Accessed: 14 July 2023].

JNCC, 2020a. Guidance for assessing the significance of noise disturbance against the Conservation Objectives of Harbour porpoise SACs. [Online]. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/889842/SACNoiseGuidanceJune2020.pdf [Accessed: 17 July 2023].

JNCC, 2020b. Statutory nature conservation agency protocol for minimising the risk of injury to marine mammals from piling noise. [Online]. Available at: https://hub.jncc.gov.uk/assets/31662b6a-19ed-4918-9fab-8fbcff752046 [Accessed: 05 June 2023].

JNCC, 2017. JNCC guidelines for minimising the risk of injury to marine mammals from geophysical surveys. [Online]. Available at: https://hub.jncc.gov.uk/assets/e2a46de5-43d4-43f0-b296-c62134397ce4 [Accessed: 14 July 2023].

Martin, B., MacDonnell, J., Vallarta, J., Lumsden, E. and Burns, R., 2011. HYWIND Acoustic Measurement Report: Ambient Levels and HYWIND Signature. Technical report for Statoil by JASCO Applied Sciences. [Online]. Available at: https://static1.squarespace.com/static/52aa2773e4b0f29916f46675/t/5fda3a9324291a0a8b1d0a25/1608 137377245/Equinor-Hywind-Acoustic-Measurement-Report-JASCO-00229-December-2011.pdf [Accessed: 05 June 2023].

Midforth F., Barham R. and Mason, T., 2022. Pentland Floating Offshore Wind Farm (PFOWF) underwater noise modelling. Vol 3 Appendix A.10.1. [Online]. Available at: https://marine.gov.scot/sites/default/files/appendix_10.1._underwater_noise_modelling2_redacted.pdf [Accessed: 19 July 2023].

Nabe-Nielsen, J., van Beest, F., Grimm, V., Sibly, R., Teilmann, J. and Thompson, P.M., 2018. Predicting the impacts of anthropogenic disturbances on marine populations. Conservation Letters, e12563.

Nedwell, J.R., Langworthy, J. and Howell, D., 2003. Assessment of subsea noise and vibration from offshore wind turbines and its impact on marine wildlife. Initial measurements of underwater noise during construction of offshore wind farms, and comparison with background noise. Subacoustech Report Ref. 544R0423.

NMFS, 2005. National Marine Fisheries Service (NMFS). 2005. Scoping Report for NMFS EIS for the National Acoustic Guidelines on Marine Mammals. National Marine Fisheries Service.

NMFS, 2023. Summary of Marine Mammal Protection Act Acoustic Thresholds. [Online]. Available at: https://www.fisheries.noaa.gov/s3/2023-02/ESA%20all%20species%20threshold%20summary_508_OPR1.pdf [Accessed: 13 July 2023].

NMFS, 2018. National Marine Fisheries Service. 2018. Revisions to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OPR-59, 167 p.

NRC, 2003. Ocean noise and marine mammals. National Research Council. The National Academies Press. USA.

NRW, 2023. NRW's Position on Assessing Behavioural Disturbance of Harbour Porpoise (Phocoena phocoena) from underwater noise. [Online]. Available at:

https://naturalresourceswales.gov.uk/guidance-and-advice/business-sectors/marine/marine-mammals-assessing-the-effects-of-hearing-injury-from-underwater-noise-for-environmental-assessments/?lang=en [Accessed: 13 July 2023].

Otani, S.N., Kato, Y. and Akito, A.K., 2001. Oxygen consumption and swim speed of the harbour porpoise Phocoena. Fisheries Science, 67(5), pp.894-898.

Rentschler, M.U.T., Adam, F, and Chainho, P., 2019. Design optimization of dynamic inter-array cable systems for floating offshore wind turbines. Renewable and sustainable Energy Reviews, 111, pp.622-635.

Richardson, W.J., Green, J.C.R., Malme C.I., Thomson, D.H., 1995. Marine mammals and Noise. Academic Press. An imprint of Elsevier. USA.

Risch, D., Favill, G., Marmo, B., vanGeel, N., Benjamins, S., Thompson, P., Wittich, A. and Wilson, B., 2023. Characterisation of underwater operational noise of two types of floating offshore wind turbines technical report for Supergen. [Online]. Available at: https://supergen-ore.net/uploads/resources/Fortune_Report_Final.pdf [Accessed: 19 April 2023].

Robinson, S.P., Wang, L., Cheong, S.H., Lepper, P.A., Hartley, J.P., Thompson, P.M., Edwards, E., and Bellmann, M., 2022. Acoustic characterisation of unexploded ordnance disposal in the North Sea using high-order detonations. Marine Pollution Bulletin, 184, 114178.

SCOS, 2021. Scientific Advice on matters Related to the Management of Seal Populations: 2021. Natural Environment Research Council – Special Committee on Seals. [Online]. Available at: http://www.smru.st-andrews.ac.uk/files/2022/08/SCOS-2021.pdf [Accessed: 19 April 2023].

Robinson, S.P., Wang, L., Cheong, S.H., Lepper, P.A., Marubini, F. and Hartley, J.P., 2020. Underwater acoustic characterisation of unexploded ordnance disposal using deflagration. Marine Pollution Bulletin 160, 1116456.

Sinclair, R.R.; Kazer, S.; Ryder, M.; New, P. and Verfuss, U.K., 2023. Review and recommendations on assessment of noise disturbance for marine mammals. NRW Evidence Report No. 529, 141.

Soloway, A.G. and Dahl, P.H., 2014. Peak sound pressure and sound exposure level from underwater explosions in shallow water. The Journal of the Acoustical Society of America, 136(3).

Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene, C.R.J., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W.J., Thomas, J.A. and Tyack. P.L., 2007. Marine mammal noise exposure criteria: initial scientific recommendations. Aquatic Mammals 33, pp.411-414.

Southall, B., Finneran, J.J., Reichmuth, C., Nachtigall, P.E., Ketten, D.R., Bowles, A.E., Ellison, W.T., Nowacek, D. and Tyack, P., 2019. Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. Aquatic Mammals 45, pp.125-232.

Southall, B., 2021. Evolutions in Marine Mammal Noise Exposure Criteria. Acoustics Today, 17(2).

Thompson, D., 2015. Parameters for collision risk models. Report by Sea Mammal Research Unit, University of St Andrews, for Scottish Natural Heritage. [Online]. Available at: https://www.nature.scot/doc/assessing-collision-risk-between-underwater-turbines-and-marine-wildlife [Accessed: 05 June 2023].

Todd, V.L.G., Todd, I.B., Gardiner, J.C., Morrin, E.C.N., MacPherson, N.A., DiMarzio, N.A. and Thomsen, F., 2015. A review of impacts of marine dredging activities on marine mammals. ICES Journal of Marine Science 72(2), pp.328-340.

Tougaard, J., 2021. Thresholds for behavioural responses to noise in marine mammals. Background note to revision of guidelines from the Danish Energy Agency.

Tougaard, J., Wright A.J., and Madsen P.T., 2015. Cetacean noise criteria revisited in the light of proposed exposure limits for harbour porpoises. Marine Pollution Bulletin, 90(1-2), pp.196-208.

Tougaard, J., Hermannsen, L. and Madsen, P.T., 2020. How loud is the underwater noise from operating offshore wind turbines?. The Journal of the Acoustical Society of America, 148(5), pp.2885-2893.

Verfuss, U.K., Remmers, P., Ryder, M., Palmer, K., Wood, J.D., and Bellmann, M.A., 2023. Reducing uncertainty in underwater noise assessments (ReCon). Report to Offshore Renewables Joint Industry Programme (ORJIP) for Offshore wind. The Carbon Trust. [Online]. Available at: www.carbontrust.com/our-work-and-impact/guides-reports-and-tools/reducing-uncertainty-in-underwater-noise-assessments-for-offshore-wind-recon [Accessed: 21 November 2023].

Whyte, K., Russell, D., Sparling, C., Binnerts, B. and Hastie, G., 2020. Estimating the effects of pile driving sounds on seals: Pitfalls and possibilities. The Effects of Noise on Aquatic Life, 14, pp.3948-3958.

Williams, R., Ashe, E., Yruretagoyena, L., Mastick, N., Siple, M., Wood, J., Joy, R., Langrock, R., Mew,s S. and Finne, E., 2021. Reducing vessel noise increases foraging in endangered killer whales. Marine Pollution Bulletin, 173(A), 112976.

Xodus, 2021. Seagreen Alpha and Bravo Site UXO, boulder and debris clearance – Marine Licence Application. Supporting Environmental Information. LF000009-CST-OF-LIC-REP-0005. Available at: https://marine.gov.scot/sites/default/files/a4_report_with_paragraph_numbering_redacted_1.pdf [Accessed: 05 June 2023].