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EIAR Volume 7: Planning Stage Plans
Appendix 4: Marine Megafauna Mitigation Plan (MMMP)

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Dublin Array Offshore Wind Farm

Environmental Impact Assessment Report

Volume 7, Appendix 4: Marine Megafauna Mitigation Plan (MMMP)

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Glossary

Term	Definition
Permanent Threshold Shift (PTS)	Permanent threshold shift (or PTS) is a permanent increase in the threshold of hearing (minimum intensity needed to hear a sound) at a specific frequency above a previously established reference level.
Sound Exposure Level (SEL)	The decibel level of the time integral (summation) of the squared pressure over the duration of a sound event; units of dB re 1 µPa2/s.
Sound Pressure Level (SPL)	A means of characterising the amplitude of a sound. There are several ways sound pressure can be measured. The most common of these are the root-mean-square (RMS) pressure, the peak pressure and the peak-to-peak pressure.
Temporary Threshold Shift (TTS)	Temporary threshold shift (or TTS) is a temporary increase in the threshold of hearing (minimum intensity needed to hear a sound) at a specific frequency above a previously established reference level.
Passive Acoustic Monitoring (PAM)	Used to measure, monitor and determine the sources of sound in underwater environments. This is a versatile, non-invasive and cost effective method to detect, classify and track marine mammals over large areas for long periods.
Noise abatement	A primary mitigation methodology used to reduce the noise emissions at source.
Marine Mammal Observer (MMO)	A marine mammal observer (MMO) is a professional in environmental consulting who specialises in whales and dolphins and is responsible for spotting and identifying animals through visual or passive acoustic means.
Mitigation Zone	The zone which is required to remain clear of marine mammals for a specified time-frame, prior to a noisy activity taking place.
PTS-Onset Distance	The distance from the sound source at which the received level decreases to below the level of PTS-onset for a specific marine mammal hearing group.

Acronyms

Term	Definition
3D UHRS	Deep 3D Ultra-High Resolution Seismic
ADD	Acoustic Deterrent Device
ADO	Alternative Design Option

Term	Definition
BEIS	Department for Business, Energy and Industrial Strategy
dB	Decibels
ECC	Export Cable Corridor
EIAR	Environmental Impact Assessment Report
IWDG	Irish Whale & Dolphin Group
JNCC	Joint Nature Conservation Committee
g	Grams
kg	Kilograms
kJ	Kilojoules
km	Kilometres
LAT	Lowest Astronomical Tide
m	Metres
MAG	Magnetometer
MAP	Maritime Area Planning
MP	Monopile
MARA	Maritime Area Regulatory Authority
MBES	Multi-Beam Echo Sounder
MDO	Maximum Design Option
MMMP	Marine Megafauna Mitigation Plan
MMO	Marine Mammal Observers
NPWS	National Parks & Wildlife Service
O&M	Operations and Maintenance
OCC	Onshore Compensation Compound
OES	Onshore Electrical System
OSP	Offshore Substation Platform
OWF	Offshore Wind Farm
PAM	Passive Acoustic Monitoring
PP	Pin-Pile
PDA	Planning and Development Act
PEMP	Project Environmental Management Plan
PTS	Permanent Threshold Shift
RMS	Root Mean Squared
ROV	Remotely Operated Vehicle

Term	Definition
SBI	Shallow 3D Sub-Bottom Imaging System
SBP	Sub Bottom Profiler
SEL	Sound Exposure Level
SPL	Sound Pressure Level
SSS	Side Scan Sonar
TJB	Transition Joint Bay
TTS	Temporary Threshold Shift
USBL	Ultra-short Baseline
UXO	Unexploded Ordnance
WTG	Wind Turbine Generator
VHF	Very High Frequency
HF	High Frequency
LW	Low Frequency
PCW	Phocid in Water

1 Introduction

1.1 Overview

1.1.1 Dublin Array Offshore Wind Farm is a proposed offshore wind farm (OWF) on the Kish and Bray Banks. The Kish and Bray Banks are located approximately 10 kilometres (km) off the east coast of Ireland, immediately south of Dublin city off the coast of counties Dublin and Wicklow. The wind farm will be located within an area of approximately 59 km^2, in water depths ranging from 2 metres (m) to 50 m lowest astronomical tide (LAT).

1.1.2 The Applicant is applying for permission for all components of the Dublin Array OWF under Section 291 of the Planning and Development Act 2000, as amended (PDA) (as inserted by the Maritime Area Planning (MAP) Act 2021). The proposed development is comprised of the following components as described in Volume 2, Chapter 6: Project Description of the Environmental Impact Assessment Report (EIAR):

- The offshore wind farm infrastructure, which comprises turbine foundations, subsea inter array electricity cables, an offshore substation platform and offshore electricity export cables;
- The landfall and Transition Joint Bay (TJB) which describes the point at which the offshore export cables are brought onshore;
- The Operations and Maintenance (O&M) base; and
- The Onshore Electrical System (OES) which comprises underground electricity transmission cables; an onshore substation (referred to in the EIAR as an onshore compensation compound [OCC]); and underground electricity cable circuits connecting the OCC to an existing Eirgrid substation.

1.2 Purpose of the MMMP

1.2.1 This Marine Megafauna Mitigation Plan (MMMP) serves as the primary mitigation tool for protected marine megafauna species; including marine mammals, basking sharks and sea turtles, and supports the consent application for the proposed Dublin Array Offshore Wind Farm project. The MMMP should be read alongside the Environmental Vessel Management Plan (EVMP), which outlines avoidance and preventative measures to mitigate potential vessel-related impacts.

1.2.2 The purpose of this MMMP is to provide a strategy for the project, to ensure appropriate controls are in place to manage environmental risks associated with the construction of the Dublin Array offshore infrastructure as assessed in the EIAR.

1.2.3 The MMMP may be modified as required should new and updated guidance be issued, or conditions be posed as part of the consent process, by the relevant regulatory authorities. Furthermore, the specifics of the mitigation measures and how they will be applied will be dependent on factors determined by future engineering decisions within the project design flexibility. If updates to the MMMP are required, the updated MMMP will be submitted to the relevant Regulatory Authority for approval, prior to the start of construction.

1.2.4 The MMMP has the following primary objectives:

- To outline the mitigation measures in place during geophysical surveys for mitigating and minimising acoustic impacts;
- To outline the mitigation measures in place during pile driving activities for mitigating and minimising acoustic impacts; and
- To outline the mitigation measures place during unexploded ordnance (UXO) clearance activities for mitigating and minimising acoustic impacts.

Legislation and regulation

1.2.5 Marine megafauna in Ireland comprise groups of species that are protected under different pieces of legislation.

1.2.6 The Wildlife Act (1976) (and subsequent amendments 2000, 2005, 2010 and 2012) provides specific protection to (most relevant) all marine mammals species, all marine turtles, and basking shark. Under the Act it is an offence to disturb, harm, kill, or otherwise wilfully interfere with or destroy the breeding place of a protected species and if activity is likely to cause any of the above, measures must be taken to prevent it.

1.2.7 Article 12 of the Habitats Directive further requires that Member States take the requisite measures to establish a system of strict protection for Annex IV listed species in their natural range, prohibiting (i) all forms of deliberate capture or killing of specimens of these species in the wild; (ii) deliberate disturbance of these species, particularly during the period of breeding, rearing, hibernation and migration; (iii) deliberate destruction or taking of eggs from the wild; (iv) deterioration or destruction of breeding sites or resting places. Annex IV species includes all cetaceans and marine turtles.

1.3 Approach to measures in the MMMP

1.3.1 The mitigation approach is based on the Department of Arts, Heritage and the Gaeltacht[1] (DAHG) (2014) guidance document. However, it is considered that the DAHG (2014) guidance does not fully reflect the latest industry standards, best practice, and most up-to-date scientific knowledge. It is understood that the guidance is in the process of being updated, however an updated version was not available at the time of writing this iteration of the MMMP. Where the Applicant is aware of more up-to-date industry standards, best practice and scientific knowledge regarding mitigation for OWF, it has compared these to the DAHG (2014) and proposed an approach that, where possible, builds on the principles of the DAHG (2014) guidance document and enhances the protection of marine megafauna whilst maintaining the overall feasibility of the proposed development.

1.3.2 This MMMP takes account of the following guidance:

- DAHG (2014): Guidance to Manage the Risk to Marine Mammals from Man-made Sound Sources in Irish Waters;
- Irish Whale and Dolphin Group (IWDG) (2020): IWDG policy on offshore windfarm development;
- Joint Nature Conservation Committee (JNCC) (2017): JNCC guidelines for minimising the risk of injury to marine mammals from geophysical surveys;
- JNCC (2010a): JNCC guidelines for minimising the risk of injury to marine mammals from using explosives;
- JNCC (2010b): Statutory nature conservation agency protocol for minimising the risk of injury to marine mammals from piling noise;
- JNCC (2023a): Draft guidelines for minimising the risk of injury to marine mammals from unexploded ordnance clearance in the marine environment; and
- JNCC (2023b): JNCC guidance for the use of Passive Acoustic Monitoring in UK waters for minimising the risk of injury to marine mammals from offshore activities.

1.3.3 The MMMP may be updated prior to construction for a range of purposes including the publication of new and updated guidance.

[1] The Department of Arts, Heritage and the Gaeltacht (DAHG) was renamed the Department of Housing, Local Government and Heritage with effect from September 2020.

1.4 Implementation of the MMMP

1.4.1 Key to the implementation of this MMMP is the delegation of responsibility, as relevant, to the specific contractor's scope of works, and relevant appointed person(s), who will regularly liaise with and update the Applicant on all environmental issues relating to the project during the construction phase. As part of the appointment of a contractor and agreement of contracts, the Applicant will determine the lines of communication for environmental compliance with the relevant stakeholders.

1.4.2 The appointed contractor will be responsible for developing final construction methods and installation procedures for the Dublin Array offshore infrastructure. Contractors and their subcontractors will ensure that all relevant environmental and maritime legislation is complied with, that all necessary licences and permissions are obtained, that all Project Design Features and Avoidance and Preventative Measures are applied and that good working practices are adhered to, to minimise risks to the environment.

1.4.3 Contractors will be responsible for implementing the MMMP through contractual agreements with the Applicant. Contractors will also be required to complete their own Project Environmental Management Plans (PEMPs) that are specific to their works and that are compliant with the MMMP. Requirements of the MMMP will be communicated to contractors (and their subcontractors) as required, to discharge the relevant consent conditions and to communicate project requirements and standards to facilitate incorporation into contractor PEMPs.

1.4.4 All project personnel are required to ensure compliance with the requirements of this MMMP (and subsequent revisions thereof) and are responsible for ensuring that their actions constitute good environmental practice. All personnel are also encouraged to provide feedback and suggestions for improvements to ensure effective environmental management of all construction activities.

2 Summary of relevant species

2.1.1 Volume 3, Chapter 5: Marine Mammal Ecology (hereafter referred to as the Marine Mammals chapter) of the EIAR characterised the following marine mammals as common in the Irish Sea: harbour porpoise (*Phocoena phocoena*), bottlenose dolphin (*Tursiops truncatus*), common dolphin (*Delphinus delphis*), minke whale (*Balaenoptera acutorostrata*), grey seal (*Halichoerus grypus*) and harbour seal (*Phoca vitulina*).

2.1.2 Volume 3: Chapter 4: Fish and Shellfish Ecology (hereafter referred to as the Fish and Shellfish chapter) of the EIAR recognise that basking shark and some species of turtle occur in the Irish Sea. Basking shark (*Cetorhinus maximus*) are known to migrate through the Irish Sea, with records of basking sharks across the western Irish Sea, including the study area (e.g., Dolton *et al.*, 2020; IWDG, 2023). In addition, five species of marine turtles have been recorded in Irish waters including leatherback turtle (*Dermochelys coriacea*), loggerhead turtle (*Caretta caretta*) and Kemp's Ridley turtle (*Lepidochelys kempii*) (King and Berrow, 2009), with records of leatherback turtles along the east coast of Ireland including the study area (Doyle, 2007; King and Berrow, 2009; Penrose *et al.*, 2022). Rare vagrant species of turtle to southern Irish waters include hawksbill turtle (*Eretmochelys imbricata*) and green turtle (*Chelonia mydas*) (King and Berrow, 2009).

2.1.3 The primary purpose of the MMMP is to mitigate and minimise acoustic impacts in protected marine megafauna, including marine mammal species, basking shark and sea turtle. Although the measures are primarily designed for marine mammals, they will also offer a precautionary approach to protection for other species that are less acoustically sensitive than marine mammals such as basking shark and sea turtles, in the absence of species-specific guidance. For ease the MMMP refers to mitigation for marine mammals only hereafter.

3 Noise and Vibration Impacts

3.1 Overview

3.1.1 Construction of OWFs involves multiple activities that can have direct and indirect impacts on marine mammals.

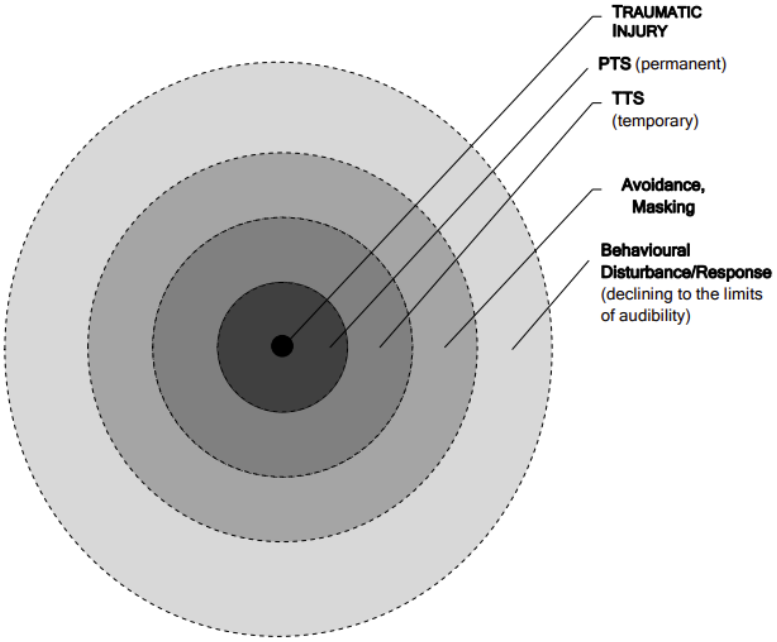
3.1.2 As assessed in the Marine Mammals chapter, the primary impacts to marine mammals will be as a result of underwater noise produced during the construction phase.

3.1.3 Sound waves can propagate in various manners depending on the nature of the sound, the position of the sound source in relation to the water column, bathymetry, and seawater properties. As sound travels through water, it experiences sound attenuation (where sound waves lose amplitude and intensity due to energy loss through a medium). This phenomenon affects high frequency sounds to a greater degree than lower frequencies. Therefore, the risk of an acoustic impact is reduced with increasing distance from the source.

3.1.4 A range of impacts may be experienced by marine mammals from construction activities that produce noise, which can simplistically be described as depending on their presence within the relevant zone of impact (Figure 1). Exposure to loud sounds, which can arise when a receptor is close to the noise source, can lead to a reduction in hearing sensitivity (a shift in hearing threshold). This threshold shift results from physical injury to the auditory system and may be temporary (Temporary Threshold Shift (TTS)) or permanent (Permanent Threshold Shift (PTS)). Disturbance effects, which can include avoidance, masking, and displacement, may occur over a larger zone of impact.

3.1.5 PTS occurs when the hearing sensitivity is reduced after noise exposure, with no hearing recovery in the impacted frequencies. PTS can occur instantaneously or cumulatively (i.e. exposed to the sound source over an extended period). The level of injury depends on the duration, frequency and intensity of the sound source and received level. Whilst PTS is considered a permanent effect, the most likely response of an animal exposed to noise levels that could induce PTS is to flee the ensonified area. TTS is commonly viewed as the "onset of a fleeing response" and used as an indicator of disturbance rather than an injurious effect. A disturbance response can occur below the area of TTS, however; it may occur in the area over which the noise is audible. Whilst mitigations measures are aimed at reducing PTS, the project has committed to at-source noise mitigation measures (i.e., noise abatement systems [NAS]) which inherently provides mitigation against TTS and disturbance during pile driving.

Appendix 2 - Schematic diagram showing hypothetical zones of impact around a high energy underwater sound source (at centre) and listing the potential effects upon a receiving animal, assuming spherical spreading. PTS = Permanent Threshold Shift; TTS = Temporary Threshold Shift. (*after* NRC[2]).



Note:

It should be remembered that this is a somewhat simplistic model, that factors such as local propagation and individual hearing ability can influence the actual effect elicited and that hypothetical zones of impact may merge with or overlap one another.

Figure 1 Schematic diagram showing hypothetical zones of impact around a high energy underwater sound source (at centre) and listing the potential effects upon a receiving animal, assuming spherical spreading. PTS = Permanent Threshold Shift; TTS = Temporary Threshold Shift. (after NRC) (taken from DAHG, 2014)

3.1.6 The impacts of underwater noise on marine mammals, as assessed in the Marine Mammal chapter, are:

- Auditory injury, which is defined as PTS[2]; and
- Behavioural responses (e.g. displacement, disturbance).

3.1.7 There are uncertainties relating to the underwater noise modelling and impact assessment undertaken for the purposes of the EIAR. The current methods for prediction of underwater noise impacts are based on the received sound levels. With regards to PTS-onset, it is expected that only a proportion of animals within PTS-onset ranges will actually experience PTS. With regards to this approach for behavioural responses, it is likely that factors other than noise levels alone will also influence the probability of response and the strength of response. However, at present, it is impossible to adequately take these factors into account in a predictive sense.

[2] For justification for not including TTS as an auditory injury, please see the relevant section.

Approach to TTS

3.1.8 TTS is, by definition, temporary, and the duration of effect at the threshold for TTS onset is likely to be short and therefore unlikely to cause any major consequences for an animal. An impact range which encompasses such a large variation in the predicted effect on individuals is extremely difficult to interpret in terms of the potential consequences for individuals. It is important to bear in mind that the quantification of the spatial extent over which any impact is predicted to occur in the environmental assessment process, is done so in order to inform an assessment of the potential magnitude and significance of an impact.

3.1.9 The TTS thresholds are not intended to indicate a level of impact of concern per se but are used to enable the prediction of where PTS might occur. Therefore, they have not been used for the basis of any assessment of impact significance for marine mammals in the Marine Mammals chapter. Furthermore, it is considered that TTS would not constitute an injury under the Regulations. This is the approach taken in other regions such as the UK (JNCC, 2010b). As such, the impact of TTS is not considered further in this MMMP.

3.1.10 Whilst TTS is not explicitly considered further, it is noted that some of the measures in this MMMP may also provide benefit in reducing the zone of impact and therefore number of animals that experience TTS, specifically the use of at-source noise abatement.

3.2 Relevant information from EIAR assessment

3.2.1 The EIAR Marine Mammals chapter assessed the risk of underwater noise impacts from the following activities:

- Geophysical surveys;
- Impact pile driving;
- UXO clearance; and
- Other construction activity.

3.2.2 The mitigation applied to the other construction activity comprised the use of the EVMP, which is detailed in a separate document. It is considered that the impact from other construction activity is being mitigated through other means (i.e. the EVMP), and this MMMP need not apply to other construction activity.

Project Design Parameters

3.2.3 The precautionary impact ranges for marine mammals established in the EIAR and presented below are based on the underwater noise modelling for the most sensitive species, the parameters for which are based on the project design parameters for the offshore infrastructure. The project design parameters informing the assessment of potential impacts on marine mammals as a result of underwater noise during pile-driving, geophysical site investigation surveys and UXO clearance is presented in Table 12 of the Marine Mammal Chapter which outlines the Maximum Design Option (MDO) and Alternative Design Option (ADO) assessed.

Auditory injury or PTS

3.2.4 The assessment of auditory injury or PTS has been undertaken using noise exposure criteria, for activities during construction.

3.2.5 Noise exposure criteria are typically represented by dual exposure metrics, including the frequency-weighted cumulative sound exposure level (SEL_{cum}; expressed in decibels (dB) re. 1 μPa^2-s or μPa^2s; where both the received level and duration of exposure are accounted for) and the unweighted zero to peak sound pressure level (SPL_{peak}; expressed in dB re. 1 µPa in water (ISO 18405, 2017; Juretzek *et al*., 2021)). The ranges relating to SPL_{peak} indicate the distance from the sound source to which an animal can experience instantaneous injury.

3.2.6 If an individual is within the impact ranges of SPL_{peak}, they risk immediate onset of a PTS in hearing. Marine mammals typically flee when exposed to loud noises within their hearing ranges. This means that the received level decreases as they increase the distance from the source. SEL_{cum} distances are typically greater than SPL_{peak} as the former criteria considers an accumulation of sound exposure across a period of 24-hours.

3.2.7 Noise modelling has been undertaken by Subacoustech Environmental to assess the potential impacts on marine mammals as a result of pile driving and UXO clearance within the array area (Volume 4, Appendix 4.3.5-7: Underwater Noise Assessment; Table 1 and Table 2). Impact ranges for marine mammals were calculated using the Southall *et al*. (2019) impulsive criteria.

3.2.8 All presented noise modelling results for piling incorporate a 10 dB reduction in source level to account for noise attenuation. While it is expected that construction will occur with mitigation measures in place, the specific measures have not yet been confirmed. Therefore, a flat, broadband 10 dB reduction has been used as a conservative estimate, based on data from Verfuss *et al.* (2019), in order to reflect the typical effectiveness of most potential mitigation measures. The evidence for this reduction is provided in Annex A to this MMMP (Annex A: Noise Abatement and Mitigation Systems – A Targeted Literature Review).

3.2.9 The Applicant has committed to deploying a bubble curtain for high order clearance of UXOs. It is recognised, however, that the noise produced by the detonation of explosives is affected by several different elements and therefore a precautionary approach has been taken whereby the underwater noise propagation estimates do not include the addition of a bubble curtain.

Table 1 Predicted impact ranges for auditory injury (PTS-onset) from pile driving

Species	Threshold	Metric	NE MP	SE MP	NE PP	SE PP
Harbour porpoise (VHF)	Instantaneous PTS (SPL_{peak})	Area (km^2)	0.07	0.04	0.06	0.04
		Max Range (m)	150	120	140	110
	Cumulative PTS (SEL_{cum})	Area (km^2)	<0.1	<0.1	<0.1	<0.1
		Max Range (m)	<150	<100	<100	<100
Bottlenose & common	Instantaneous PTS (SPL_{peak})	Area (km^2)	<0.01	<0.01	<0.01	<0.01
		Max Range (m)	<50	<50	<50	<50

Species	Threshold	Metric	NE MP	SE MP	NE PP	SE PP
dolphin (HF)	Cumulative PTS (SEL_{cum})	Area (km^2)	<0.1	<0.1	<0.1	<0.1
		Max Range (m)	<100	<100	<100	<100
Minke whale (LF)	Instantaneous PTS (SPL_{peak})	Area (km^2)	<0.01	<0.01	<0.01	<0.01
		Max Range (m)	<50	<50	<50	<50
	Cumulative PTS (SEL_{cum})	Area (km^2)	<0.1	<0.1	<0.1	<0.1
		Max Range (m)	<100	<100	<100	<100
Harbour & grey seal (PCW)	Instantaneous PTS (SPL_{peak})	Area (km^2)	<0.01	<0.01	<0.01	<0.01
		Max Range (m)	<50	<50	<50	<50
	Cumulative PTS (SEL_{cum})	Area (km^2)	<0.1	<0.1	<0.1	<0.1
		Max Range (m)	<100	<100	<100	<100

*MP = Monopile
*PP = Pin-pile
*NE = North East
*SE = South East
*VHF = Very High Frequency
*HF = High Frequency
*LF = Low Frequency
*PCW = Phocid in Water

Table 2 Summary of the source level and unmitigated impact ranges (km) for various UXO charge sizes using the impulsive criteria from Southall et al. (2019) (without bubble curtain)

Charge weight	Source level	VHF	HF	LF	PCW
Weighted SEL PTS-onset impact ranges (km)					
Low order (0.25 kg)	215.2	0.08	<0.05	0.23	<0.05
25 kg + donor	228.0	0.57	<0.05	2.20	<0.05
55 kg + donor	230.1	0.74	<0.05	3.20	<0.05
120 kg + donor	232.3	0.95	<0.05	4.70	0.07
240 kg + donor	234.2	1.10	<0.05	6.50	0.10
525 kg + donor	236.4	1.40	0.05	9.50	0.13
Unweighted SPL_{peak} PTS-onset impact ranges (km)					
Low order (0.25 kg)	269.8	0.99	0.06	0.17	0.19
25 kg + donor	284.9	4.60	0.26	0.81	0.90
55 kg + donor	287.5	6.00	0.34	1.00	1.10
120 kg + donor	290.0	7.70	0.45	1.30	1.50
240 kg + donor	292.3	9.80	0.56	1.70	1.90
525 kg	294.8	13.00	0.73	2.20	2.50

3.2.10 The published literature was used in the assessment of the risk of auditory injury as a result of geophysical surveys. This approach also used the noise exposure criteria, and existing impact modelling for geophysical equipment. The impact of auditory injury from geophysical surveys are summarised in Table 3.

Table 3 Predicted auditory injury (PTS) impact ranges for geophysical survey equipment.

Equipment	PTS range
Magnetometer (MAG)	Passive sound systems therefore there is no risk of auditory injury to marine mammals.
Multi-beam Echo Sounder (MBES) & Side Scan Sonar (SSS)	Both systems are outside the hearing range of cetaceans (Southall et al., 2019). A recent comprehensive assessment of the characteristics of acoustic survey sources proposed that MBES and SSS should be considered *de minimis* in terms of being unlikely to result in auditory injury to marine mammals (Ruppel *et al.*, 2022).
Ultra-short Baseline (USBL)	Transmission loss from geometric spreading and frequency-dependent absorption will be such that SPLs within the main beam of the USBL can be expected to drop to below 200dB re 1 µPa and below the PTS thresholds within a few metres of the source.
Sub-bottom Imaging (SBI)	The source levels of SBI equipment are below the PTS-onset thresholds for harbour porpoise, minke whale, dolphins and seals.
Sub-bottom Profiler (SBP) & 3D Ultra High	Results for SBPs have indicated that PTS-onset for porpoise is likely to arise between 17 – 23 m from the use of this equipment at source levels of 267 dB re 1 µPa (SPL_{peak}) (Department for Business Energy & Industrial Strategy (BEIS), 2020). Noise modelling have previously indicated PTS-onset in minke whales

Equipment	PTS range
Resolution Seismic (UHRS) Profiling	within 5 m of the source when SBP pingers operate with a sound source of 220 dB re 1 µPa (SPL_{peak}) (Shell, 2017), and ~10 m for seals (BEIS, 2019).

3.2.11 Of the equipment listed in Table 3, only certain geophysical equipment, namely sub-bottom profilers (SBPs), ultra-high resolution seismic (UHRS) and ultra-short baseline (USBL), operate within the auditory bandwidth for marine mammals and therefore have the potential to cause acoustic impacts. The EIAR Marine Mammal chapter determined that any injury from geophysical surveys is anticipated to be limited to the immediate vicinity (<25 m) of the equipment and/or vessel, for all marine mammal hearing groups and so species.

Behavioural disturbance

3.2.12 The assessment of behavioural disturbance in the EIAR encompassed the area of possible auditory masking and avoidance (i.e. displacement effect).

3.2.13 To estimate the number of porpoise predicted to experience behavioural disturbance as a result of pile driving, the impact assessment as outlined in the Marine Mammals chapter used the porpoise dose-response function presented in Graham *et al.* (2017) (Figure 2). Graham *et al.* (2017) dose-response function which was developed using data on harbour porpoise collected during the first six weeks of impact piling during Phase 1 of the Beatrice Offshore Wind Farm (Moray Firth, Scotland) monitoring program. Changes in porpoise occurrence (detection positive hours per day) were estimated using 47 CPODs[3] placed around the wind farm site during piling and compared with baseline data from 12 sites outside of the wind farm area prior to the commencement of operations, to characterise this variation in occurrence. Porpoise were considered to have exhibited a behavioural response to piling when the proportional decrease in occurrence was greater than 0.5 (i.e., 50%). The probability that porpoise occurrence did or did not show a response to piling was modelled along with the received single-pulse sound exposure levels piling source levels based on the received noise levels (Graham *et al.*, 2017).

3.2.14 As there is no disturbance threshold for any other cetacean species in the EIAR, in the complete absence of an alternative, the assessment for all cetacean species has used the porpoise dose-response function. This is considered highly precautionary and as such the number of animals predicted to experience behavioural disturbance is considered to be an over-estimate and should be interpreted with a large degree of caution.

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

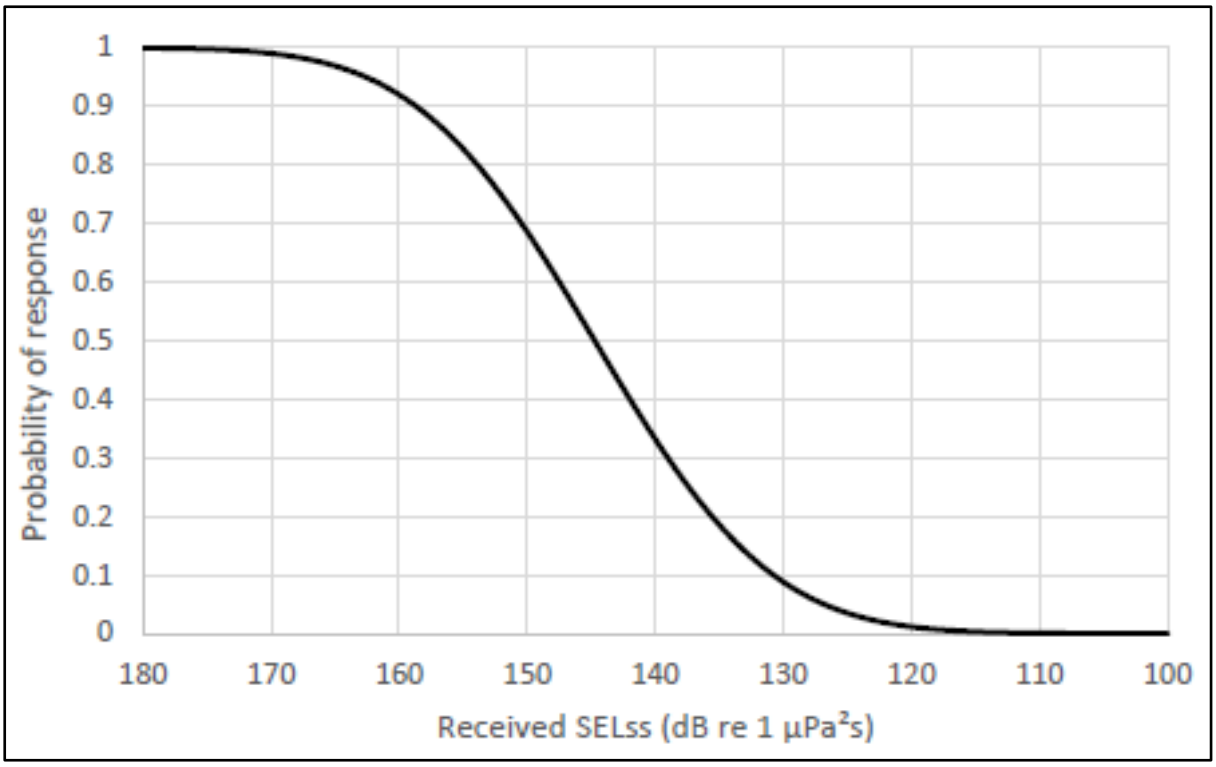


Figure 2 Relationship between the proportion of porpoise responding and the received single strike SEL (SEL_{ss}) (Graham *et al.*, 2017).

3.2.15 For seals, the dose-response function adopted was based on the data presented in Whyte *et al.* (2020). The Whyte *et al.* (2020) study updates the initial dose-response information presented in Russell *et al.* (2016) and Russell and Hastie (2017), where the percentage change in harbour seal density was predicted at the Lincs offshore wind farm. The original study used telemetry data from 25 harbour seals tagged in the Wash (located in Norfolk, England) between 2003 and 2006, in addition to a further 24 harbour seals tagged in 2012, to estimate levels of seal usage in the area in order to assess how seal usage changed in relation to the pile driving activities at the Lincs Offshore wind farm in 2011-2012. In the Whyte *et al.* (2020) dose-response function it has been assumed that all seals are displaced at sound exposure levels above 180 dB re 1µPa^{2}s. This is a conservative assumption since there were no data presented in the study for harbour seal responses at this level.

3.2.16 There are no corresponding data for grey seals and, as such, the harbour seal dose-response function is applied to the grey seal disturbance assessment. This is considered to be an appropriate proxy for grey seals, since both species are categorised within the same functional hearing group (Southall *et al.*, 2019).

3.2.17 Level B harassment threshold has also been presented as an alternative disturbance threshold for dolphins and minke whales. The Level B harassment threshold predicts that Level B harassment will occur when an animal is exposed to received levels above 160 dB re 1 µPa (rms) for non-explosive impulsive (e.g., seismic airguns, impact pile driving) or intermittent (e.g. scientific, non-tactical sonar) sound sources.

3.2.18 For UXO clearance, there are no dose-response functions available that describe the magnitude and transient nature of the behavioural impact of UXO detonation on marine mammals. Since there is no dose-response function available that has been demonstrated to reflect the behavioural disturbance from UXO detonation, other behavioural disturbance thresholds have been considered instead. This includes a 26 km EDR for high order UXO clearance and 5 km EDR for low order clearance.

3.2.19 For geophysical surveys, as with the auditory injury assessment, the evaluation of behavioural disturbance risk in the EIAR Marine Mammal chapter was informed by published literature, noise exposure criteria, and existing impact modelling for geophysical equipment. The EIAR determined that potential disturbance from geophysical surveys is anticipated to be spatially limited, with any behavioural response expected to be temporary. Disturbance distances are predicted to be 2.5-5 km. Noise transmission is highly directional and aimed directly at the seabed, resulting in minimal horizontally propagation of noise which reduces the impacts for all marine mammal hearing groups and species.

3.3 Types of mitigation measures

3.3.1 It is considered that risk minimisation measures (e.g. those outlined in DAHG, 2014) regarding acoustic impacts to marine megafauna are focussed on:

- Reducing the overall duration of the impact;
- Reducing the sound levels emitted (through the use of lower impact methods or noise reduction methods); and,
- Reducing the likelihood of animals being present in the immediate vicinity of the high-level sound source (through the use of a “ramp-up” or “soft-start”, and the use of marine mammal observers (MMOs)).

3.3.2 A number of alternatives in relation to the reduction of potential impacts on marine mammal species have been considered during the project development. Alternatives are identified at many levels and stages during the evolution of a project, from project concepts and site locations, through site layouts, technologies or operational plans, and on to mitigation and any monitoring measures.

3.3.3 The construction of the proposed development will be undertaken over a period no longer than is necessary. In this way, the duration of the impacts during the construction phase will be as low as possible.

3.3.4 A range of methods for construction have been considered, with those selected being able to achieve the activity and proposed development objectives whilst not leading to residual significant adverse effects on marine mammals.

3.3.5 The scope of this MMMP is the measures that fall into the category of Other Avoidance and Preventative Measures in place during offshore construction.

3.3.6 These measures can broadly be considered as aimed at reducing the sound levels emitted (through the use of lower impact methods or noise reduction methods), and reducing the likelihood of animals being present in the immediate vicinity of the high level sound source.

3.3.7 It is considered that these measures will reduce the likelihood of auditory injury and disturbance impacts in protected marine megafauna. Specifically, it is considered that measures aimed at reducing the sound levels emitted will reduce both the risk of injury and disturbance in marine mammals. Whereas measures aimed at reducing the likelihood of animals being present in the immediate vicinity, will primarily reduce the risk of injury or PTS-onset.

4 Piling MMMP

4.1 Introduction

4.1.1 This section of the MMMP details the proposed marine mammal mitigation and monitoring procedures during piling activities. The objective of the Piling MMMP is to minimise the risk of acoustic impacts to marine mammals as a result of noise generated by piling activities.

4.1.2 For underwater noise from impact piling, the MDO presented is based on the maximum spatial extent of noise propagation generated by largest pile diameter and blow energy imparted on the pile and the longest duration of piling. In line with the modelling, the piling scenario with the largest noise impact ranges represents the maximum design scenario (see Table 4). The maximum number of piled foundations would represent the temporal maximum design scenario for disturbance from impact piling. The maximum predicted impact range for underwater noise for piled foundations would represent the spatial maximum design scenario for disturbance.

4.2 Piling parameters

4.2.1 A wide range of foundation options are available for the offshore infrastructure. The final foundation options will be chosen based on the selected Wind Turbine Generators (WTGs) and Offshore Substation Platform (OSP) taking account of key factors such as seabed conditions, water depth, wind, wave and current regime and economic factors. The foundation types which have been short-listed include:

- Steel Monopole; and
- Multileg:
  - Driven or drill-piled multileg;
  - Suction bucket multileg.

4.2.2 Table 4 summarises the foundation parameters as outlined in full within the Project Description Chapter.

Table 4 OSP and wind turbine generators foundation parameter summary

Parameter	OSP	Option A WTG	Option B WTG	Option C WTG
Maximum number of foundations required	1	50	45	39
Maximum number of monopiles	1	50	45	39
Maximum number of multi-leg pin-piled jackets	12	200	180	156

4.2.3 There will not be any concurrent piling (2 vessels piling at the same time). It has been assumed that one monopile is installed in a 24-hour period, and that up to four pin-piles can be installed at one location in a 24-hour period.

4.2.4 The maximum hammer energy proposed for monopiles is 6,372 kilojoules (kJ). The maximum hammer energy proposed for jacket pin piles is 4,695 kJ.

4.3 Mitigation measures

Mitigation Zone

4.3.1 The approach to defining the size of the Mitigation Zone is to apply the larger distance from either a) the maximum potential instantaneous PTS onset impact range or b) the guidance from DAHG (2014).

4.3.2 Based on the modelling undertaken for the EIAR, the maximum potential instantaneous PTS onset impact range is 150 m. It is highlighted that the Applicant will update the noise modelling, if required, prior to construction once the final project design option(s) is consented. Nevertheless, at present, the DAHG (2014[4]) guidance recommends a Mitigation Zone of 1,000 m for piling, which is greater than the largest instantaneous PTS-onset impact range for the proposed development. Therefore, following a precautionary approach, the Applicant will use a 1,000 m Mitigation Zone.

Pre-start monitoring

4.3.3 The purpose of pre-start monitoring is to ensure the Mitigation Zone[5] is free of marine mammals prior to the commencement of piling operations.

4.3.4 The use of MMOs for pre-start monitoring has been a common form of observational monitoring in the USA and UK since the 1980/90s, with the practice first introduced in Irish Guidelines in 2007 (Department of the Environment, Heritage and Local Government (DEHLG), 2007), and is now seen as an industry standard practice.

4.3.5 Under the DAHG (2014) guidance, MMOs are the primary or only monitoring approach acceptable to monitor the mitigation zone, for risk management purposes. Whilst the Applicant will undertake this approach during daylight hours, a deviation from this approach is proposed for piling during limited visibility such as at night time (see following sections).

[4] At the time of publication updates to this guidance are still pending.
[5] A Mitigation Zone (also referred to as a Monitoring Zone, e.g. by DAHG [2014]) is an area that is required to remain clear of marine mammals for a specified time-frame, prior to a noisy activity taking place.

4.3.7 DAHG (2014) recommends the following approach to MMOs be adopted, which the Applicant will implement through this MMMP:

- The MMO(s) should be qualified and experienced. DAHG (2014) states that a qualified and experienced MMO is defined as *"a visual observer who has undergone formal marine mammal observation and distance estimation training (JNCC MMO training course or equivalent) and also has a minimum of 6 weeks full-time marine mammal survey experience at sea over a 3-year period in European waters*";
- The MMO should have an unobstructed view of the Mitigation Zone;
- The MMO should be ideally located near the centre of the Mitigation Zone (i.e., adjacent to the sound source);
- Pre-start monitoring of the Mitigation Zone should be conducted for **at least 30 minutes** before piling commences;
- Piling is not to commence until at least 30 minutes have elapsed with no marine mammals detected within the Mitigation Zone by the MMO;
- Once piling has commenced, there is no requirement to cease piling if a marine mammal occurs within the Mitigation Zone; however the MMO should continue monitoring the Mitigation Zone during the ramp-up/ soft-start procedure; and
- If for any reason there is a break in piling for a period longer than 10 minutes, then pre-start monitoring must be undertaken again, followed by the subsequent ramp-up procedure.

Pre-piling PAM

4.3.8 Passive acoustic monitoring (PAM) is the use of acoustic sensors to detect vocalising marine mammals. Since the mid-2000s, PAM has been used as a monitoring tool in the marine development industry. Initially, PAM was not sufficiently developed to be regarded as the primary or sole monitoring approach for risk management purposes. This is because the method in its early state of development was not capable of reliably detecting all marine mammal species in many practical field situations (e.g. aboard a moving motorised vessel) and it also relied on vocalising individuals occurring within the detection/range capability of the equipment. The guidance from DAHG (2014) highlights these limitations of PAM, which were identified during the early stage of development.

4.3.9 However, more recently PAM has become a part of the industry standard for undertaking monitoring for marine mammals. Specifically, it has been used to undertake monitoring for marine mammal presence in the mitigation zone during periods of limited visibility including night time. This has had the consequent benefit of reducing delays in the construction and/or operations of offshore industries.

4.3.10 The acceptance and recommendation of PAM is provided by JNCC (2023b), who state that "PAM is considered a viable monitoring method for vocalizing species during periods when effective visual monitoring is not possible." Furthermore, whilst not part of the regulatory guidelines in Ireland, IWDG (2020) recommends that PAM is used in standard mitigation protocols to "*allow detection of cetaceans in poor visibility during the hours of darkness and for detecting animals underwater where source levels are often highest*".

4.3.11 It is acknowledged that PAM is not without limitation, however the selection of an appropriate PAM system can provide robust and effective monitoring to achieve the highest likelihood of detecting marine mammals for the purposes of mitigation. The Applicant is cognisant of this and would select the most appropriate PAM system for the scenario.

4.3.12 Specifically, the Applicant would commit to a PAM system that can detect the full range of cetacean vocalisations. In the development area, the key cetacean species of concern are harbour porpoise, bottlenose dolphin, common dolphin and minke whale. These species are representative of the full range of cetacean frequency hearing groups, meaning that their vocalisations occur across a wide frequency range. Hence a PAM system would be chosen that could detect the full frequency range of cetacean vocalisations. It is acknowledged that seal species are not known to vocalise regularly and therefore PAM would not reliably detect these species.

4.3.13 The Applicant would also commit to deploying the PAM system from a static vessel where possible. This would enhance the likelihood of detecting low frequency cetacean vocalisations, which can otherwise be masked to an extent by towing vessel noise.

4.3.14 Where possible, a PAM system that allows for distance determination would be used. This would allow for the PAM Operator to confidently state whether the animals are within or outside the Mitigation Zone. However, if this is not possible, a general rule set would be agreed. For example, it could be assumed that all detections are within the Mitigation Zone regardless of species, depending on the distance of the hydrophones to the acoustic source.

4.3.15 It is highlighted that the PAM system should be able to detect all harbour porpoise within the PTS-onset range (of 150 m), as PAM is known to be effective at detecting harbour porpoise at distance of up to 300 m. Other species can be detected at even greater distances from the PAM system, hence other species will also be detected if they are present within the PTS-onset range.

4.3.16 As it is acknowledged that PAM is not 100% effective at detecting all marine mammal species in the area, the proposed use of PAM during periods of poor visibility is proposed to be complemented by the use of an Acoustic Deterrent Device (ADD) also during periods of poor visibility only. More information on the proposed use of ADDs is provided in Section 4.4.

PAM procedure

4.3.17 PAM is proposed be used as the primary monitoring tool to support mitigation during periods of poor visibility (including nighttime), when an MMO cannot visually observe. Specifically, PAM will be used to monitor the extent of the Mitigation Zone prior to piling start up during poor periods of visibility, or during a break greater than 10 minutes. If the PAM is unavailable during this period, the operations would need to wait until daylight.

4.3.18 The PAM would be used in the same way as visual observations prior to the start of piling activity. Specifically, that a PAM operative would acoustically monitoring for a minimum of 30 minutes prior to piling commencing, and if a marine mammal is detected, piling should not commence until 30 minutes after the last acoustic detection within the Mitigation Zone. This procedure follows the DAHG (2014) guidance for visual observations, which is also used in the JNCC (2023b) guidance specifically for PAM.

4.3.19 The PAM operator will follow the same data forms and communications procedure as the MMO.

4.3.20 Given the proposed project will require piling during periods of limited visibility and in the hours of darkness, it is proposed that pre-piling PAM will be implemented.

4.3.21 DAHG (2014) states that PAM "*may be recommended or required as part of the licence/consent conditions in order to optimise marine mammal detection around the site of a plan or project*". Therefore, the final approach to the PAM procedure for monitoring and mitigation for the proposed development will be reviewed following the issuing of licence/consent and associated conditions.

4.4 Acoustic Deterrent Devices

4.4.1 Acoustic Deterrent Devices (ADDs) are underwater units which emit randomised bursts of audio signals across a range of frequencies. The signals are intended to discourage marine mammals from entering, or encourage marine mammals to leave, an area in which human activities with the potential to cause injury are about to begin.

4.4.2 The DAHG (2014) guidance mentions ADDs briefly as an example of an anthropogenic noise source, however the guidance does not address the use of ADDs specifically.

4.4.3 Guidance in other jurisdictions recommend or, in some cases, require the use of ADDs. JNCC (2010b) considers that ADDs should be considered as a form of mitigation during piling operations, when used in concert with MMOs/PAM Operators.

4.4.4 Evidence available suggests that ADDs can effectively deter a wide range of marine mammals from the immediate vicinity. For example, harbour porpoises show a 50% probability of a significant behavioural response in the 3 hours following a 15-minute ADD exposure, with effects observed up to 21.7 km (Thompson *et al*., 2020). The ORJIP review (Sparling *et al*., 2015) indicates that ADDs can be effective for grey and harbour seals at ranges of approximately 1,000 m. Minke whales have also demonstrated notable deterrent responses, including increased swim speeds and directed movement away from the ADD up to 4 km away (McGarry *et al*., 2017).

4.4.5 It is proposed to use ADDs as an additional mitigation tool prior to the start of piling activities during periods of limited visibility and in the hours of darkness. An ADD will be deployed in close proximity to the pile to be installed, outside of any NAS surrounding the pile.

4.4.6 The ADD will not be activated until the PAM pre-piling procedure has been completed and no marine mammals have been detected for at least 30 minutes in the Mitigation Zone. The PAM will be continued through the activation of the ADD until the commencement of piling.

4.4.7 Following completion of the pre-piling procedure by the PAM Operator, the ADD will be activated for 15 minutes immediately preceding the commencement of piling operations. This will act as a lower form of soft start (Section 4.6) and allow time for any non-vocalising animals remaining in the area, which could not be detected by the PAM Operator, to leave the area.

4.4.8 The ADD will be deactivated at the beginning of piling operations.

4.5 Noise Abatement

4.5.1 The Applicant commits to the implementation of at-source mitigation methods to minimise the underwater noise impacts. Therefore, all underwater noise modelling for piling have assumed mitigation methods applied to reduce the at-source underwater noise levels by 10 dB.

4.5.2 The use and effectiveness of each at-source noise abatement method is subject to environmental conditions such as water depth, current speed, wave height and wind speed. These are described further in Verfuss *et al.* (2019). These system specific environmental limitations need to be taken into consideration when considering which at-source noise abatement method may be suitable for use during construction of the proposed development.

4.5.3 A literature review of the available NAS and Noise Mitigation Systems (NMS) is included in Annex A of this MMMP. The document provides a targeted literature review of current noise abatement and mitigation systems that could be used to reduce noise emission and propagation from the installation of foundation designs options considered for the proposed development. The NAS and NMS options addressed therein are:

- Bubble Curtains;
- Isolating Casing;
- Hydrosound damper (HSD);
- Pile Cushioning;
- Cofferdams;
- Screens;
- BLUE Piling Technology; and
- Vibro-hammer.

4.5.4 Annex A provides evidence that a 10 dB reduction in impact piling noise is appropriate and achievable via any of the commercially available and commonly used NMS and NAS. The main points of uncertainty regarding the effectiveness and suitability of NAS for the proposed development include the combination of very shallow water depth and high tidal current velocity at the Dublin Array site (peak speeds of 1.9 m/s during spring tides and 1.1 m/s during neap tides), alongside modern improvements in design and installation methods.

4.5.5 The existing evidence base shows that a reduction in broadband single-strike sound exposure and peak levels of at least 10 dB should be achievable via any of the commercially available and commonly used NMS and NAS. It is also important to note that this conclusion is based on the implementation of a single NMS or NAS (*e.g.* a single bubble curtain). Evidence shows that NMS and NAS performance are best when multiple methods are used together, which results in the potential for a higher dB reduction. Therefore, the Dublin Array OWF could use a combination of available technology where possible, such as combining pile cushions, HSD and bubble curtains in suitable water depths. Where current is a concern, NMS methods such as pile cushions, AdBm's NMS, PULSE, or BLUE piling technology would be suitable. NAS technology independent of current include isolation casings, HSD and cofferdams. HSDs in principle are not limited to pile diameter or water depth which makes the technology a desirable choice depending on cost and availability. Site specific information on the geology based on future geotechnical investigation will be useful to more accurately model noise propagation based on the foundation design/pile diameter/length which would be fundamental in choosing an appropriate NAS.

4.6 Soft-Start procedure

4.6.1 Following the pre-piling procedures (as identified above, MMO/PAM pre-piling search), a soft-start procedure for piling will commence. A typical impact piling sequence will begin with a soft start[6] period, where both the hammer energy and blow rate are less than used during the main piling stage. Hammer energy will commence at a low percentage of the rated hammer energy and then ramp up gradually over the duration of the soft start to full operational energy and blow rate.

4.6.2 The soft start and ramp up period are standard engineering practices which are necessary during the early stages of installation to maintain pile orientation and stability. These processes also result in the gradual introduction of noise into the marine environment, encouraging both fish and marine mammal species that are sensitive to sound to move away from the noise source.

4.6.3 This will comprise a maximum scenario of 5 minutes slow strike rate of one blow every 30 seconds up to 671 kJ (10.5% and 14% of the maximum hammer energies modelled for monopiles and pin piles, respectively), followed by 30 minutes of 20 blows per minute, also up to 671 kJ. Together, this comprises a soft start that is 35 minutes in duration. This is within the DAHG (2014) guidance which advises a soft start period of 20-40 minutes.

4.6.4 Once the proposed soft start is complete, the hammer energy will increase over time as a ramp up to the required hammer energy required to reach penetration depth. The specified ramp up used for the purposes of underwater noise modelling is based on a conservative assessment and is not reflective of the actual change in energy for all piles; however, it can be interpreted as an upper limit on the allowable energy at any time during the piling event.

[6] Soft start is a mitigation technique used during piling operations where the piling hammer energy is gradually increased from a low level to full power over a set period. This method reduces the initial noise and vibration impacts on marine life

4.7 Breaks in piling procedure

4.7.1 Standard DAHG (2014) guidance for breaks in piling activity (high output pile driving) will be followed should they occur. If there is a break in piling operations for a period of greater than 10 minutes, then a pre-piling search and soft-start procedure will be repeated prior to piling recommencing, if it is possible to do so. If a search of the Mitigation Zone has been continued during piling, the MMO/PAM operator will be able to confirm the presence or absence of marine mammals and it may be possible to commence the soft-start immediately. If there has been no search during piling, then a pre-piling search will need to be undertaken prior to soft-start commencing.

4.7.2 Where possible (i.e. if vessel remains on site), the MMO/PAM operator should maintain monitoring throughout any break in piling activities to ensure that no marine mammals are present within the Mitigation Zone.

4.8 Communications

4.8.1 The MMO, PAM operator and ADD operator (the mitigation personnel) will be appointed either directly or indirectly by the Applicant. A communications protocol will be developed between the mitigation personnel and the construction manager and/or appropriate crew members. The below section details the personnel, organisations, and responsibilities for the MMMP:

- The Applicant's Environmental Manager:
  - Overall responsibility for compliance with all environmental monitoring, mitigation and reporting requirements on the proposed development. Will ensure that the mitigation personnel, nominated Client Representative for construction activities and installation personnel have received all relevant information, and will consult with them before making decisions affecting the MMMP.
- Mitigation personnel (to be confirmed):
  - Responsible for advising on, monitoring and recording compliance with this MMMP. Liaises with the nominated Client Representative for construction activities, and Offshore Construction Contractor as appropriate. The mitigation personnel are responsible for the PAM equipment (verification and calibration prior to use) and ADD in accordance with the MMMP, co-ordination of deployment, maintenance, operation, and recording/reporting.
- Nominated Client Representative for construction activities (the Applicant):
  - Takes offshore responsibility that the requirements of this MMMP are met, responsible for ensuring adequate communication and liaison between mitigation personnel and installation personnel as required. The Client Representative (and/or mitigation personnel) has the responsibility to delay piling activities if necessary to do so.
- Offshore Construction Contractor (to be confirmed):
  - Responsible for informing mitigation personnel about scheduled piling activity and communication as per protocol. Responsible for providing pile driving records to mitigation personnel and Client Representative;
  - The communications protocol and flow charts will include but not be limited to procedures:
  - *To notify the MMO/PAM operator to begin 30-minute pre-search prior to soft-start commencing;*
  - *For the mitigation personnel to give the nominated Offshore Construction Contractor the green light for construction activities;*

- *The nominated Client Representative or Offshore Construction Contractor to notify the mitigation personnel that there has been a delay in the onset of the soft-start;*
- *For the MMO/PAM operator to notify nominated Offshore Construction Contractor or Client Representative for construction activities that a marine mammal has been detected within the mitigation zone and that the soft-start will need to be delayed;*
- *The client* to notify MARA that the piling operations have been successfully completed.

4.9 Reporting

4.9.1 A record of piling operations, MMO/PAM monitoring effort, ADD durations, and sightings will be maintained during piling. These reports include:

- An outline of the marine mammal monitoring methodology and procedures employed;
- A record of all piling operations detailing dates, soft-start duration, piling duration, hammer energy during soft-start and full-power, and any operational issues. Also included will be the ADD timings and durations;
- A record of monitoring effort including the duration of the MMO/PAM operator's search, environmental conditions, a description of any marine mammal sightings, passive acoustic recordings and any actions taken. A record of any incidental sightings will also be made during the pre-piling search or operations;
- Details of any problems encountered during the piling process including any instances of non-compliance with the marine licence; and
- Any recommendations for amendment of the protocol.

4.9.2 Reports will be collated and provided to the relevant Regulatory Authority for information once the works are complete, alongside a summary report of the numbers of marine mammals recorded (visually or acoustically) and any mitigation actions required during construction. The report will also discuss the protocols followed, and put forward any recommendations based on project experience, that could benefit future OWF construction projects.

5 Geophysical Survey MMMP

5.1 Introduction

5.1.1 This section of the MMMP details the proposed marine mammal mitigation and monitoring procedures during pre-construction geophysical surveys. The objective of the Geophysical Survey MMMP is to minimise the risk of acoustic impacts to marine mammals as a result of noise generated by geophysical survey activities.

5.2 Survey Equipment

5.2.1 A series of pre-construction surveys will be undertaken in the array area and along the Export Cable Corridor (ECC). The purpose of these surveys will be to further characterise the seabed conditions and morphology, determine soil design parameters and identify any potential obstructions or hazards to the construction works as well as furthering understanding of baseline metocean conditions. These surveys will also confirm the feasibility of the installation techniques.

5.2.2 Geophysical surveys are non-intrusive and will utilise towed equipment such as sidescan sonar, sub-bottom profiler, ultra-short baseline, multibeam echosounder and magnetometry equipment to gather detailed information on the bathymetry, seabed sediments, geology, and anthropogenic features (e.g., existing seabed infrastructure, UXO) that exist across the offshore development area. Remotely Operated Vehicles (ROV) may also be used for further identification of findings from the geophysical surveys, however ROVs are passive and, therefore, do not emit any noise and are therefore scoped out of assessment herein. Details on each of the geophysical survey equipment are outlined below:

- Multi-Beam Echo Sounder (MBES): MBES is used to acquire detailed seabed topography and water depth by emitting a fan shaped swath of acoustic energy (sound waves) along a survey transect. The sound waves are reflected from the seabed to enable high resolution seafloor mapping. The MBES can be either hull- or ROV-mounted.
- Side Scan Sonar (SSS): SSS utilises conical or fan-shaped pulses of sounds directed at the seafloor to provide information on the surface of the seabed through analysis of reflected sound.
- Ultra-short baseline (USBL): A USBL system is used to obtain accurate equipment positioning during sampling activities. This system consists of a transceiver mounted under the vessel and a transponder on deployed equipment. The transceiver transmits an acoustic pulse which is detected by the transponder, followed by a reply of an acoustic pulse from the transponder. Range and bearing information allow an accurate estimate of the location of the deployed equipment.

- Sub Bottom Profiler (SBP): The SBP is a type of geophysical survey tool that uses low frequency or high frequency sounds (pings) to identify acoustic impedance of the sub-surface geology and to identify transitions from one stratigraphic sequence to another. Sound sources that produce lower frequency pulses can penetrate through and be reflected by subsurface sediments (low-resolution data), whilst higher frequency pulses achieve higher resolution images but do not penetrate the subsurface sediments.

- Deep 3D Ultra-High Resolution Seismic (3D UHRS) - sparker: A small seismic source containing a cluster of electrodes. These systems discharge high voltage impulses which heat the surrounding water within which the device is located through the use of electrode tips. The generation of heat and subsequently, steam, results in the emission of an acoustic impulse (Hartley Anderson Ltd, 2020). Sparkers fall under the category of SBPs, however they use a seismic source. While sparkers are less directional than other SBPs, the acoustic energy they emit is still focussed towards the sea floor.

- Shallow 3D Sub-Bottom Imaging System (SBI): provides a real-time 3D view of the sub-seabed via multiple 5 m wide data swaths that penetrate the seabed up to 8 m. The SBI uses a frequency modulated signal to identify buried objects, anomalies, geohazards, and stratigraphy to a 10 cm resolution. SBIs are typically deployed on an ROV or towfish, close to the seabed, and operate at a much lower source level than sub-bottom profilers.

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

5.2.3 DAHG (2014) guidance mitigation measures apply to:

- all seismic surveys (including the testing and full operational use of airguns, water guns, sparkers, boomers and vertical seismic profiling [VSP] or checkshot systems) in inshore and offshore Irish waters;

- all multibeam, single beam, side-scan sonar and sub-bottom profiler (e.g., pinger or chirp system) surveys within bays, inlets or estuaries and within 1,500m of the entrance of enclosed bays/inlets/estuaries;

- or as advised by the relevant Regulatory Authority.

5.2.4 Most of the geophysical equipment proposed to be used for the proposed development falls within the categories outlined in the DAHG (2014) guidance, namely MBES, SSS and SBP surveys. However, since the proposed development is not located within bays, inlets or estuaries, nor within 1,500 m of the entrance to enclosed bays, inlets or estuaries, there is no requirement to mitigate for these equipment types.

5.2.5 USBL, SBI and MAG are not explicitly listed within the DAHG (2014) guidance. MAGs are a passive system and so do not require mitigation. USBL, although an active sound source, operates at frequencies and source levels with a very limited range (Table 3), making mitigation unnecessary. As an SBI is a type of SBP, it will be considered in the same way as an SBP for mitigation purposes i.e. mitigation is not required due to the proposed development location.

5.2.6 The mitigation measures detailed below are therefore only applied in the event of undertaking geophysical surveys using 3D UHRS (sparker)

5.3 Mitigation measures

Mitigation Zone

5.3.1 According to DAHG (2014), the appropriate Mitigation Zone for geophysical acoustic surveys is dependent on the specification/type of equipment being used. DAHG (2014) recommend that a 1,000 m Mitigation Zone is appropriate for seismic surveys, which is interpreted to include surveys that use a sparker.

5.3.2 It is highlighted that a 1,000 m Mitigation Zone is much larger than predicted impact ranges for auditory injury (see Section 3.2), therefore it is suitably precautionary to reduce the risk of this acoustic impact.

Pre-start monitoring

5.3.3 The purpose of a pre-start MMO search is to ensure the Mitigation Zone is free of marine mammals prior to the commencement of piling operations. The use of MMOs has been a common form of observational monitoring in the USA and UK since the 1980/90s and is now seen as an industry standard practice.

5.3.4 DAHG (2014) advises that the pre-start monitoring of the Mitigation Zone should be at least 30 minutes for geophysical acoustic surveys (including seismic surveys using sparkers) in waters <200 m (relevant to the proposed development).

5.3.5 The start of the acoustic geophysical equipment will be delayed if marine mammals are detected within the Mitigation Zone during the pre-start monitoring. The start of the source will be delayed for at least 30 minutes following the last sighting within the Mitigation Zone. This will allow the animals time to move away from the acoustic source prior to activation and therefore reduce the risk of acoustic impacts.

5.4 Soft-Start Procedure

5.4.1 Survey equipment with a source SPL above 170 dB re 1µPa shall commence from a lower energy start-up. In the case of a sparker, this means to start with the lowest electrical discharge possible. Following this, the output can allowed to increase gradually up to the necessary maximum output over a period of 40 minutes.

5.4.2 After the ramp-up commences, there is no requirement to halt activities even if visibility worsens or if marine mammals enter the Mitigation Zone.

5.5 Line Changes

5.5.1 The procedure for line changes is relevant to seismic surveys i.e. those using sparkers for the purpose of this proposed development.

5.5.2 For line changes taking longer than 40 minutes, the source will be stopped, then a pre-start search of 30 minutes followed by a soft-start will be required to resume operations.

5.5.3 For line changes less than 40 minutes, the activity can continue as normal i.e. no reduced acoustic output.

5.6 Breaks in Operations

5.6.1 For any breaks in operation of the equipment of between 5 and 10 minutes, the mitigation personnel will undertake dedicated monitoring to check no marine mammals are present within the Mitigation Zone prior to the source restarting. If no marine mammal is sighted in the Mitigation Zone, operations can commence at with the source at full power. If a marine mammal is sighted within the mitigation zone during a break in operation, the equipment will recommence operations with a complete soft start, once the mitigation zone has been clear for 30 minutes from the last sighting (i.e. the standard pre-start monitoring).

5.6.2 For any breaks in seismic survey (i.e. sparker) operations of more than 10 minutes, the equipment will only recommence following a full 30 minutes of dedicated pre-start monitoring and a soft start. If the mitigation personnel has been monitoring prior to and throughout the break, this time contributes to the pre-start monitoring time.

5.6.3 Should marine mammals be sighted within the mitigation zone during breaks in geophysical survey activity, the start of the equipment will be delayed for at least 30 minutes from the last sighting within the mitigation zone.

5.7 Communications

5.7.1 A pre-survey kick-off meeting is recommended to confirm the marine mammal mitigation requirements and further meetings on board the vessel, between the vessel surveyors and engineers, and the mitigation personnel, to agree on mitigation procedures as set out in the MMMP and consent. All communications are to follow the agreed protocol.

5.8 Reporting

5.8.1 The mitigation personnel will compile data throughout the survey into three main data sheets: 1) Cover Page, 2) Operations, 3) Effort, and 4) Sightings, in line with Appendix 6 of the DAHG guidance (2014). This will be accompanied by an Operations Report, which will cover the contents outlined in Appendix 6.

6 UXO MMMP

6.1 Introduction

6.1.1 This section of the MMMP details the proposed marine mammal mitigation and monitoring procedures during UXO clearance activities. The objective of the UXO MMMP is to minimise the risk of acoustic impacts to marine mammals as a result of noise generated by UXO clearance activities.

6.1.2 The MMMP presented here can be considered a proposed list of measures and procedures, which can be modified in accordance with advice received from the regulator and their specialist UXO advisors as appropriate prior to UXO clearance activities commencing. Specifically, once UXO identification surveys are complete, further details of the anticipated number, location and type of UXO that may require clearance will be known. The DAHG (2014) guidance does not specifically cover UXO; however, it does provide guidance on blasting. The DAHG (2014) guidance on blasting has been used to inform this UXO MMMP, alongside other guidance specific to the use of explosives (e.g. JNCC guidelines for minimising the risk of injury to marine mammals from using explosives [JNCC, 2010a]).

6.2 UXO parameters

6.2.1 If UXO are found, a risk assessment will be undertaken and items of UXO will either be avoided, removed or detonated *in situ*.

6.2.2 Recent advancements in the available methods for UXO clearance mean that high-order detonation, where an attempt is made to fully detonate the contents of the UXO, may be avoided. The methods of UXO clearance considered include:

- Avoidance through micro-siting of infrastructure (e.g. cable routing);
- Relocation of UXO to a safe area;
- In situ detonation of UXO – low order; and
- In situ detonation of UXO – high order (considered as a last resort only).

6.2.3 Low order is the preferred clearance method and will be attempted on all suitable UXO that require clearance, resulting in less potential for acoustic impacts.

6.2.4 The low order technique uses a user filled shaped-charge to create a plasma-jet, which causes a build-up of pressure within the UXO target, leading to a burst of the UXO casing, disrupting the contents by introducing heat to ignite the explosive fill to rapidly burn. As a result, the contents of the UXO are neutralised without detonation.

6.2.5 It is acknowledged that avoidance, relocation or low order methodologies may not be possible for some UXO and, therefore, as a worst-case scenario, high order detonation may be required. As such, high order detonation, where an attempt is made to fully detonate the contents of the UXO, represents the highest potential for impacts to marine mammals, as assessed in the Marine Mammals EIAR chapter (Volume 3, Chapter 5). High order detonation will be used in the following scenarios, and only as a last resort:

- When the low order method has been unsuccessful;
- When it is deemed unsafe to attempt a low order detonation; or
- In circumstances when expert opinion advises that high order disposal is preferred.

6.2.6 A high order detonation is achieved by placing a donor charge adjacent to the UXO target. The preferred method of deployment is by ROV. The detonation produces a high-speed shockwave which sets off the main charge within the UXO target, in effect destroying the UXO target.

6.2.7 For high order clearance, a bubble curtain will be deployed (see section 3.2 for further detail). Where a bubble curtain is required, works will wait until conditions are favourable for the deployment of the abatement system, prior to the clearance activity proceeding.

6.3 Mitigation measures

Mitigation Zone

6.3.1 As advised by DAHG (2014), the appropriate Mitigation Zone for blasting (and so inferred to be applicable to UXO clearance) is a 1,000 m radius around the sound source. It is noted that a 1,000 m distance is also advised by JNCC (2010a) for explosive use. Therefore, the Applicant proposes to implement a 1,000m Mitigation Zone for all UXO clearance.

6.3.2 It is noted that a distance modification can be agreed with the Regulatory Authority under the DAHG (2014) guidance, as long as information specific to the location and/or plan/project is available to inform the mitigation process.

Pre-start monitoring

6.3.3 The Applicant has committed to not undertaking UXO clearance during periods of poor visibility (including nighttime). This is on the basis of health and safety. Therefore, UXO clearance will only be undertaken during daylight and good visibility conditions. This is in accordance with DAHG (2014) guidance.

6.3.4 During all pre-start monitoring periods, the MMO will undertake visual observations within the 1,000 m Mitigation Zone around the UXO location from a suitable elevated platform that allows 360 degree visual observations.

6.3.5 DAHG (2014) advise that the pre-start monitoring of the Mitigation Zone should be at least 30 minutes before the sound-producing activity is due to commence. However, it is noted that JNCC (2010a) recommend that a more precautionary pre-start monitoring duration of 60 minutes is undertaken for explosive use. The Applicant therefore proposes to undertake UXO clearance pre-start monitoring for a period of at least 60 minutes. This is more precautionary and, whilst it is in keeping with DAHG (2014) guidance of at least 30 minutes, it goes beyond the DAHG guidance to offer increased protection to marine mammals from acoustic impacts.

6.3.6 Using the principles of DAHG (2014), UXO detonation should not occur until at least 60 minutes have elapsed with no marine mammal detections in the mitigation zone.

Soft-start charges

6.3.7 Clearance of UXO has the potential to cause acoustic impacts over large distances. To illustrate, high order clearance of the largest expected UXO size may lead to injury of animals up to 13,000 m away. Disturbance may occur up to 26 km away from high order clearance. Therefore, it is important to introduce measures that reduce the risk of such acoustic impacts occurring.

6.3.8 The Applicant proposes to use soft-start charges to reduce the risk of injury in marine mammals from high order clearance. While the effectiveness of soft-start charges for displacement of marine mammals is currently unknown, it is assumed that a series of small detonations of increasing size will induce avoidance behaviour and provide additional time for animals to move away from the clearance location, prior to the main detonation. This should reduce the risk of animals being within the injury range.

6.3.9 For high-order clearance of UXOs, additional mitigation in the form of soft-start detonations should be undertaken. Depending on the size of the UXO, it is proposed to use between 2-4 soft-start charges between 50- 200 g each, spaced at 5-minute intervals. For all species, the maximum predicted impact range for PTS from the soft-start charges is <1,000 m therefore, these detonations do not themselves pose a risk of injury as there should be no marine mammals within 1,000 m following the pre-start monitoring.

6.3.10 Scare charges are not proposed to be used for low order clearance. The noise produced during low order clearance of UXOs scales with the size of the donor charge only, rather than the size of the UXO. The size of the donor charge for low order clearance is anticipated to be up to 0.25 kilograms (kg). As a result, the auditory impact ranges are significantly smaller. To illustrate, the PTS range is predicted to be <1,000 m, which is fully encompassed by the size of the Mitigation Zone, therefore there should not be any animals within the PTS-onset range for low order clearance. Similarly, the area of disturbance from low order is predicted to be notably smaller than that for high order. Therefore, it is considered that the use of explosive soft-start charges would add to the overall disturbance of marine mammals whilst providing limited benefit to reducing the risk of injury.

Bubble curtain

6.3.11 In order to reduce the propagation of noise through the water column and so the acoustic impact ranges, a bubble curtain will be deployed for high order clearance. The use of bubble curtains have previously been employed during UXO detonation (Merchant and Robinson, 2019, Croci *et al.*, 2014, Schmidtke, 2010, Schmidtke, 2012, Cheong *et al.*, 2023). It is noted that the IWDG (2020) recommend that where UXO removal is not possible, ordnance should be detonated with the use of *"noise abatement to reduce noise impact".* Noise abatement includes the use of bubble curtains.

6.3.12 The use of bubble curtains to mitigate high-order clearance of UXO have proved successful and there is increasing information on the effectiveness of bubble curtains to reduce this underwater noise source. For example, Croci *et al.* (2014) presented the results of a study whereby the transmission of a shock wave (one which simulated a shock wave produced by high-order UXO detonation) propagating through a bubble curtain was investigated. In this study, the attenuation by the use of a bubble curtain was ~ 48 dB (in terms of peak pressure) (Croci *et al*., 2014). Another experimental set-up by Cheong *et al.* (2023) investigated the effectiveness of small bubble curtains around UXO by conducting controlled experimental trials in a quarry facility. Three charge sizes of known quantities were used, of 45 grams (g), 250 g and 465 g. In this study, the results demonstrate that bubble curtains can achieve a reduction in peak sound pressure level of between 13 dB and 17 dB, and in SEL of between 7 dB and 8 dB (Cheong *et al.*, 2023).

6.3.13 Whilst the application of a bubble curtain has not been considered in the underwater noise modelling to determine impact (specifically PTS-onset) ranges presented in Table 2, it is expected that a reduction in the sound pressure level will reduce the acoustic impact ranges. To add to this, it is highlighted that in the UK, it is assumed that high order clearance with a bubble curtain will disturb harbour porpoises up to 15 km away, rather than 26 km away for high order with no bubble curtain.

Post-detonation search

6.3.14 Whilst not explicitly stated in DAHG (2014), it is recommended for the MMO on the vessel to undertake a post-detonation search of the mitigation zone for at least 15 minutes after the final detonation, to look for evidence of acoustic impacts to marine life, including any fish kills. Any other unusual observations will be noted in the post-activity report. This follows best practice from JNCC (2010a).

6.4 Reporting

6.4.1 A detailed record of UXO clearance operations, mitigation procedures and marine mammal sightings will be prepared and submitted in compliance with consent conditions and will include completion and submission of standardised forms in line with the DAHG (2014) guidance.

6.4.2 Reporting will include a record of:

- All confirmed UXO identified, including estimated size, type, location and water depth;

- The approach taken for each confirmed UXO, including the dates, times, disposal method attempted, size, type and number of donor charge(s) used;
- Vessel presence, location and activity during UXO clearance operations;
- The outcome of each UXO disposal, including evidence of high-order detonation, any clearing charges required and method of debris and residue recovery;
- The mitigation procedures followed for each UXO disposal, including details of visual observations, and size and timing of soft-start charges where required;
- All marine mammal sightings and completed marine mammal recording forms; and
- Any problems encountered and instances of non-compliance with the UXO MMMP and variations from agreed procedures.

6.4.3 Reports will be collated and provided to the relevant Regulatory Authority for information once the works are complete, alongside a summary report of the numbers of marine mammals recorded and any mitigation actions required during UXO clearance. The report will also discuss the protocols followed, and put forward any recommendations based on project experience, that could benefit future OWF construction projects.

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Dublin Array Offshore Wind Farm

Environmental Impact Assessment Report

Volume 7, Appendix 4: Marine Megafauna Mitigation Plan (MMMP)

Annex A: Noise Abatement and Mitigation Systems – A Targeted Literature Review

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Acronyms

Term	Definition
BBC	Big Bubble Curtain
BOEM	Bureau of Ocean Energy Management
BSH	Bundesamt für Seeschifffahrt und Hydrographie
dB	Decibel
HSD	HydroSound Damper
Hz	Hertz
JNCC	Joint Nature Conservation Committee
kJ	Kilojoules
Leq	Equivalent Continuous Sound Level
µPa	Micro Pascal
MSFD	Marine Strategy Framework Directive
NAS	Noise Abatement Systems
NMS	Noise Mitigation System
OWF	Offshore Windfarm(s)
PTS	Permanent Threshold Shift
SEL	Sound Exposure Level
SNCB	Statutory Nature Conservation Bodies
SPL	Sound Pressure Level
TTS	Temporary Threshold Shift
UK	United Kingdom
WTG	Wind Turbine Generators

1 Introduction

1.1.1 This report provides a targeted literature review of current noise abatement and mitigation systems that could be used to reduce noise emission and propagation from the installation of foundation design options considered as part of Dublin Array Offshore Wind Farm (hereafter 'Dublin Array'). The Applicant is committing to the use of noise abatement methodology that can provide at least a 10 decibel (dB) reduction in impact piling noise level while installing the foundations for the wind turbine generators (WTG). As the decibel scale is logarithmic, a 10 dB reduction represents a tenfold reduction in impact piling noise.

1.1.2 This document provides evidence that this 10 dB reduction in impact piling noise is appropriate and achievable. The main factors influencing the choice of NAS for Dublin Array include the combination of very shallow water depth and high tidal current velocity at the Dublin Array site (peak speeds of 1.9 m/s during spring tides and 1.1 m/s during neap tides), alongside modern improvements in design and installation methods. Note this does not include any engineering review of the site-specific parameters or health and safety feasibility.

1.1.3 Impact pile-driving (piling) is currently the most common approach for installing foundations for OWFs and other structures, such as substations, piers and harbours (Koschinski and Lüdemann 2013; 2020; Weilgart, 2023). Alternative installation methods such as gravity-based foundations (Esteban *et al.,* 2019), suction buckets (Feld, 2001; Guo *et al.,* 2022) or vibratory pile driving (Matuschek and Betke, 2009; Tsouvalas, 2020) are either still under development or only applicable to specific site conditions. The sound generated from pile-driving is strongly dependent on pile diameter, water depth, substrate structure and hammer impact energy (Dähne *et al.,* 2017). Single pile strikes are termed pulse (or impulsive) sounds where the acoustic characteristics include a rapid rise time to maximum pressure followed by a sharp decrease to a minimum pressure, where it then continues as a diminishing, oscillating pressure wave (Amaral *et al.,* 2020). Some monopile installations may take several hours and up to 5,000 strikes to drive one pile into the seafloor. The associated noise produced during this installation duration can create impacts such as disturbance and/or displacement responses for marine mammals and can potentially cause instantaneous and cumulative auditory injuries.

1.2 Noise Exposure Criteria

1.2.1 Noise exposure criteria are used to aid assessment of the environmental impacts of underwater noise and are typically represented by dual exposure metrics including the frequency-weighted sound exposure level (SEL; expressed in decibels (dB) re. μPa^2–s or μPa^2s) and the unweighted peak sound pressure level (SPL; expressed in units relative to 1 µPa in water; ISO 18405, 2017; Juretzek *et al.,* 2021). A hydraulic hammer with an energy of 1000 kJ results in sound pressure levels around 237 dB re 1 µPa at 1 m with a predominant frequency bandwidth between 100–1000 hertz (Hz; Heldebrand, 2009; Rako-Gospić and Picciulin, 2019). Current hydraulic hammers for monopile installation have a standard energy up to 5,500 kJ (IQIP, 2023a) and it is estimated that future hammer energies could range up to 7,500 kJ within the next 5–10 years to shorten the time required for installation and to adapt to the increases in pile diameter and installation depth (Bruns, 2014).

1.2.2 These higher hammer energies will increase noise emissions further into the marine environment and may require noise mitigation and abatement systems to reduce the associated impacts. Noise mitigation systems (NMS) are designed to reduce noise emissions into the marine environment through the installation method (*e.g.* integrated Monopile Installer, PULSE® and BLUE piling® technology) and are examples of primary noise mitigation (Weilgart *et al*., 2023). Noise abatement systems (NAS) aim to reduce noise emissions present in the water column by reducing the sound propagation from anthropogenic activities (*e.g.* hydro-sound dampers or bubble curtains) and are classed as secondary noise mitigation (Dähne *et al.,* 2017; Weilgart *et al*., 2023). Currently, there is no guidance published by regulators on the use of NMS or NAS in Irish waters. In the UK, where the offshore wind industry is more mature, use of NMS or NAS is typically at the discretion of the relevant regulator (who are informed by statutory nature conservation bodies (SNCBs) and scientific advisers) to determine whether NMS or NAS should be a condition on a marine licence. There are discussions underway regarding revision to UK policy for potentially introducing thresholds for noise in the marine environment.

1.3 Impacts of Underwater Noise

1.3.1 Underwater noise frequencies emitted during pile-driving overlap with various marine mammal species' hearing and vocalising ranges which can lead to direct and indirect impacts (Duarte *et al.,* 2021). Effects of these sounds have the potential to influence and/or cause masking of biologically important sounds, effect behavioural responses, and/or have physiological impacts (Southall *et al.,* 2007; Popper *et al.,* 2014; Erbe *et al.,* 2016). Physiological impacts can result in either a temporary threshold shift (TTS) or permanent threshold shift (PTS) in marine mammal hearing. TTS is where an individual experiences an increase in hearing thresholds before they return to a pre-exposure baseline (Tougaard, 2021). Auditory injury in marine mammals occurs at PTS onset, where hearing is negatively impacted and cannot recover (Tougaard, 2021).

1.3.2 Table 1 presents TTS and PTS onset thresholds for marine mammals based on criteria for designated hearing groups (Southall *et al.,* 2019).

Table 1 PTS and TTS onset thresholds for marine mammals in different hearing groups exposed to impulsive noise (Source: Southall *et al*. 2019).

Hearing Group[1]	PTS Threshold		TTS Threshold	
	Peak SPL (dB re 1 µPa)	SEL (weighted, dB re 1 µPa^{2}s)	Peak SPL (dB re 1 µPa)	SEL (weighted, dB re 1 µPa^{2}s)
Low-frequency (LF) cetaceans (Baleen whales)	219	183	213	168
High-frequency (HF) cetaceans (Toothed whales other than true porpoises)	230	185	224	170
Very high-frequency (VHF) cetaceans (True porpoises)	202	155	196	140
Phocid pinnipeds in water (PCW) (True seals)	218	185	212	170

1.3.3 An example of a noise assessment of a 44 m long x 1.8 m diameter pin pile installation with a maximum hammer energy of 510 kJ in water depths ca. 42 m is included in Bailey et al. (2010). It was estimated that threshold for TTS onset would have been exceeded within 10 m of the pile driving operations for cetaceans (whales, dolphins, and porpoise) and within 40 m for pinnipeds (seals). The peak broadband levels estimated to cause PTS onset would occur within 5 m for cetaceans and 20 m for pinnipeds. Ranges for TTS and PTS onset are dependent on the location, environment, installation method and size of piles. All projects undergoing the application process where underwater noise has the potential to impact marine mammals should carry out underwater noise modelling to inform the consenting and mitigation process.

1.4 Noise Exposure Limits

1.4.1 Several countries have implemented, or are in the process of implementing, frameworks for regulating noise exposure from pile-driving to protect marine mammals. The International Organization for Standardization (ISO 18406, 2017; last reviewed and confirmed up to date in 2022) published a standard for measuring underwater sound from percussive piling (*e.g.* monopile, jackets, tripods, *etc.*), except vibro-piling or sheet piling, within water depths ranging between 4–100 m. Guidance for underwater noise measurement during OWF installation have been published in Germany (BSH, 2011), the Netherlands (De Jong *et al.,* 2011), America (BOEM, 2021) and the UK (NPL, 2021). Guidance for minimising the risk of injury to marine mammals from offshore activities have been published in the UK (JNCC, 2010), Ireland (NPWS, 2014), Denmark (Danish Energy Agency, 2022) and America (BOEM, 2019).

[1] Hearing group outlines species and species groups that may be recorded in Irish waters.

1.4.2 Germany's regulation authority, Bundesamt für Seeschifffahrt und Hydrographie (BSH), was the first to establish a legal dB limit of 160 dB re 1 µPa^{2}s SEL (190 dB re 1 µPa peak-to-peak) which must be complied with at a distance of 750 m from the pile installation location (Koschinski and Lüdemann, 2013; BSH, 2013). Since 2013, licences for pile driving are only granted if the anticipated generated piling noise is below this legal limit (Merchant and Robinson, 2020). These limitations have been adopted in marine licences for some projects in other jurisdictions, such as Taiwan, where potential OWF installations are a concern for the critically endangered Taiwanese white dolphin (*Sousa chinensis taiwanensis;* Liu *et al.,* 2018). Merchant (2019) reviewed the German approach and concluded that it is the most effective noise management model currently available.

1.4.3 Within the European Marine Strategy Framework Directive (MSFD), underwater noise is addressed as a priority for implementation where it considers that 'good environmental status (GES) is achieved when introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment' (European Commission, 2017). To implement this, Belgium adopted an 'interim' criterion for impulsive noise of a 'maximum zero to peak noise level (Lz-p) of 185 dB re 1 µPa at 750 m from the source' (Anonymous, 2012 as cited in Rumes *et al.,* 2016); however, noise mitigation is only implemented if this noise threshold is exceeded and not all OWF developments monitor noise during installation, but rather inspect it *ad hoc*. Belgium also has seasonal piling restrictions where there is no piling from 1st January to 30th April to protect sensitive life-history periods for key species such as harbour porpoise and seals (Rumes *et al.,* 2016; Verfuss *et al.* 2016).

1.4.4 The Netherlands mitigates piling and geophysical survey activities on a case-by-case basis (Anonymous, 2012b as cited in Rumes *et al.,* 2016). An example presented in Rumes *et al*. (2016) showed that a noise restriction was set at Borssele OWF at 160-172 dB re µPa²s 750 m from the source. Continuous noise monitoring was undertaken and a seasonal piling restriction was in place between 1st January and 31st May to protect sensitive life-history periods for key species such as harbour porpoise and seals (Rumes *et al.,* 2016; Verfuss *et al.* 2016).

1.4.5 The Danish Energy Agency have published guidelines (2022) for managing underwater noise during the installation of impact or vibratory driven piles. These guidelines include a required prognosis scenario section which asks the developer to consider noise reduction methodologies during a planned construction case. The developer may choose to use NAS or not, but must show that the planned activity complies with the relevant PTS thresholds highlighted in their guidance. Thresholds are species specific to cover six species of marine mammal common to Danish waters and were derived from Southall *et al.* (2019) and reviewed in Tougaard (2021). The guidance refers to three reviews (Koschinski *et al.,* 2020; Merchant and Robinson, 2020; Bellmann *et al.*, 2020) of available NMS and NAS technologies that were accessible at the time of writing the guidance (Danish Energy Agency, 2022). The guidance notes that acoustic measurements must be taken during pile driving and must remain within the approved prognosis to avoid non-compliances.

1.4.6 In Ireland, the National Parks and Wildlife Service (NPWS) published guidance to manage the risk anthropogenic sound-sources pose to marine mammals in Irish waters (NPWS, 2014). This guidance presents a staged process towards managing risk but does not enforce any process nor state explicit decibel limits to restrict noise impacts. In section 4, the guidance details various management options for regulatory authorities to consider while approving any marine licences. The following point references use of NAS as a risk minimisation measure:

> "**A6.4.** *Incorporate the use of fully enclosing or confined bubble curtains, encircling absorptive barriers (e.g., isolation casings, cofferdams) or other demonstrably effective noise reduction methods at the immediate works site, in order to reduce underwater sound propagation from on-site operations. Studies have shown that such methods can provide a significant reduction in sound input to the wider aquatic environment in the order of 10-30 dB."*

1.4.7 No decibel-specific limits currently exist in the UK, although noise may be one factor considered within the UK marine licensing system (Convention on Biological Diversity, 2016). England's regulatory authority (Marine Management Organisation) has recently stated during a NAS workshop in March 2024 that there will be a requirement to use NAS for piling activities which require a European Protected Species (EPS) Licence, but they have not yet released documentation regarding this recent change (as of September 2024), although it is expected imminently. It is important to recognise the objective of including NAS in EPS licensing has been to satisfy the conditions required to grant a licence, notably on consideration of satisfactory alternatives, rather than a predefined noise limit or reduction.

1.4.8 Most remaining countries developing OWFs approach restrictions by making NAS a requirement rather than explicitly providing a decibel limit (Convention on Biological Diversity, 2016). Therefore, restrictions and rules vary considerably by jurisdiction, and in most cases will be appraised in terms of environmental impact on a case-by-case basis.

1.4.9 Explicit decibel restrictions may become part of guidance issued in other jurisdictions in the future, with many European countries at least mentioning NAS in official documents concerning noise and piling efforts. Thus, current piling operations and plans for future operations must be mindful that a legal requirement for NAS to reduce the impacts of underwater noise may emerge in the future, if not already implemented as for some jurisdictions, as discussed above.

1.4.10 The following section will set out the evidence base for impact piling noise reductions for several NMS and NAS. The evidence base will demonstrate that the 10 dB reduction in impact piling noise at Dublin Array is appropriate and achievable.

2 Literature Review

2.1.1 Noise levels associated with impact pile-driving varies depending on the type of pile (e.g. pin or monopile), impact hammer energies and environmental conditions (Dähne *et al.,* 2017). For example, pile driving a 4 m diameter monopile can generate noise with SPLs between 192-261 dB re 1µPa @1m and SELs between 210-215 dB re 1µPa^{2}s (Hildebrand, 2005; Nedwell and Howell, 2004; OSPAR, 2009; as cited in NPWS, 2014). Figure 1 presents measured zero-to-peak Sound Pressure Levels (Lp, pk) and broadband Sound Exposure Levels (L_E resp. SEL_{05}) at various diameter monopile installations. No noise abatement systems were used during these measured activities. SEL_{05} resp. L_{05}: exceedance level of the single blow analysis of the SEL, which was exceeded in 5% of all single strikes over the considered time interval Source: Bellmann *et al.* (2020).The figure highlights the range in zero to peak SPL (dB re 1 µPa) and broadband SEL (dB re 1 µPa^{2}s) measurements at 750 m from monopile installations of various pile diameters when NAS is not implemented. The SEL ranges from approximately 143 – 181 dB re 1 µPa^{2}s at 750 m from the source, with SPL ranging from approximately 168 – 204 dB re 1 µPa (Bellmann *et al.,* 2020).

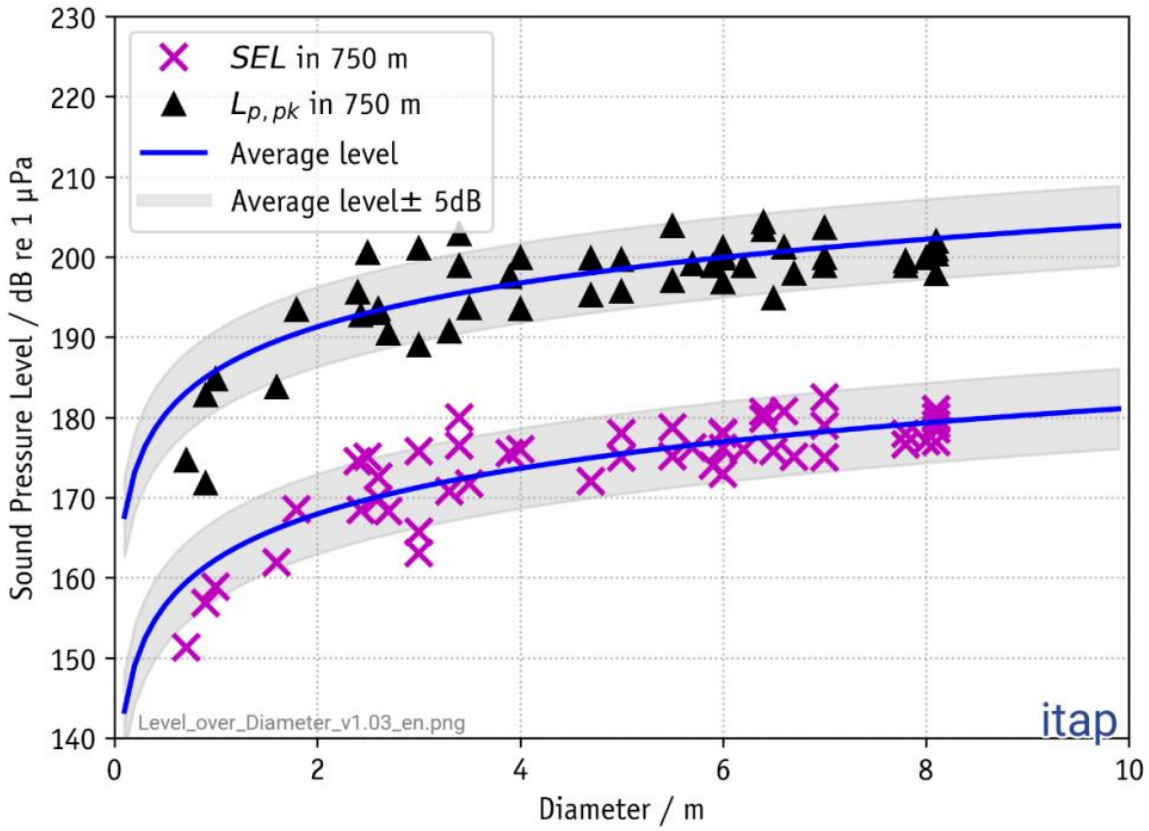

Figure 1 Measured zero-to-peak Sound Pressure Levels (Lp, pk) and broadband Sound Exposure Levels (L_E resp. SEL_{05})

2.1.2 During OWF construction, NAS for monopile installation (i.e. pile driving) has typically consisted of bubble curtains, isolation casings and/or hydro sound dampers (HSD; Weilgart, 2023), whereas installation of jacket foundations has only used bubble curtains, except for one HSD-prototype test (Verfuss *et al.,* 2019) which has not been commercialised at the time of this review. These systems are considered by German authorities, the country with the strictest noise reduction legislation, as state-of-the-art systems for water depths up to 40 m (Koschinski and Lüdemann, 2020; Verfuss *et al.,* 2019). All three systems provide a sound barrier around the piling location and can be used in conjunction with one another. The following sections provide more information on these three systems and their effectiveness, as well as pile cushioning, cofferdam, screen and vibro-hammer systems.

2.2 Big Bubble Curtains

2.2.1 Big Bubble Curtains (BBCs) are the most commonly used NAS approach for OWF foundations (Convention on Biological Diversity, 2016; Department of Arts Heritage and the Gaeltacht, 2014; Koschinski and Lüdemann, 2013; Koschinski and Lüdemann, 2020). The technology includes a flexible hose system, which lies on the seabed surrounding the noise source, and is connected to a support vessel equipped with compressors designed to press air into the hose system (Bellmann, 2014). The compressed air escapes from nozzle openings in the hose and in turn creates a continuous flow of bubbles across the water column. Noise propagating through the water is reduced by being scattered, reflected, and absorbed by the air barrier (Koschinski and Lüdemann, 2020; Zhu *et al.*, 2023). BBCs are independent from foundation design and installation vessel but requires a separate vessel which adds additional non-impulsive noise (*e.g.* vessel engine and compressors) into the marine environment. Another benefit of BBCs far-field NAS ability includes an effective method of mitigating noise that re-enters the water column at distances up to 150–160 m from the pile driving ("ground-coupling effect"; Weilgart, 2023).

2.2.2 BBC systems can be designed to have either a single (BBC) or double (DBBC) row of hoses spaced at least the water depth apart from each other on the seabed. Noise reduction depends on the air supply (volume and pressure), nozzle hose configuration and length, water depth, subsea soil conditions and current direction and speed (Weilgart, 2023). The BBC installation process can be adapted to any construction activity, with an appropriate water depth and current to limit bubble dispersal (Merchant and Robinson, 2020). Acoustic monitoring conducted by Nehls *et al.* (2016) showed that pile driving for OWF foundations insulated by a BBC reduced noise levels between 9–13 dB (Table 2). Results from these data conclude that use of NAS reduced spatial and temporal disturbance effects for harbour porpoise (*Phocoena phocoena*) by up to 90%. However, at greater depths (> 40 m) implementation of bubble curtains becomes increasingly difficult due to the dispersion of bubbles in the water column. Additionally, locations with strong currents (>0.75 m/s) or sub-optimal configurations contribute to a decrease in noise reduction (Bellmann *et al.,* 2020). A large body of evidence indicates that use of even a single bubble curtain can reduce noise by at least 10 dB (see Table 2) in both shallow and deeper water. In addition, bubble curtains are a proven solution for both monopiles and jacket foundations in suitable environmental conditions (*i.e.* appropriate water depth and current).

Table 2 Achieved noise reduction for the sound exposure level (dB re 1 µPa²s) using single or double big bubble curtains during monopile installations across various water depths. Source: BSH (n.d.).

System configuration	ΔSEL reduction [dB re 1 µPa²s] (min. ≤ average ≤ max.)
Single Big Bubble Curtain – BBC (> 0.3 m^3/(min*m), water depth < 25 m)	11 ≤ 14 ≤ 15
Double Big Bubble Curtain – DBBC (> 0.3 m^3/(min*m), water depth < 25 m)	14 ≤ 17 ≤ 18
Single Big Bubble Curtain – BBC (> 0.3 m^3/(min*m), water depth ~ 40 m)	7 ≤ 9 ≤ 11
Double Big Bubble Curtain – DBBC (> 0.3 m^3/(min*m), water depth ~ 40 m)	8 ≤ 11 ≤ 13
Double Big Bubble Curtain – DBBC (> 0.4 m^3/(min*m), water depth ~ 40 m)	12 ≤ 15 ≤ 18
Double Big Bubble Curtain – DBBC (> 0.5 m^3/(min*m), water depth > 40 m)	~ 15 – 16

2.3 Little Bubble Curtain

2.3.1 The Little Bubble Curtain (LBC) is an alternative bubble curtain design to the BBC and is a form of NAS. To date, it has been tested during the construction of two OWFs in Germany, but is currently unavailable commercially (Koschinski and Lüdemann, 2020). One of the key differences between LBCs and BBCs is the deployment and design of the technology. Whilst BBCs are flexible hoses laid on the seabed by a support vessel which surrounds the pile installation vessel during piling (Bellmann, 2014), LBCs are purposefully designed to enclose the pile itself (Koschinski and Lüdemann, 2013). LBCs can be attached to a jacket foundation structure before it is placed in the water (Grießmann *et al*., 2010) or can be transported out to the piling location and added to the pile *in situ* (Koschinski and Lüdemann, 2013). The effectiveness of LBCs is dependent on tidal speed and direction (Bellmann, 2020). As the bubbles are being produced close to the pile, strong tides can push the bubbles away from one side of the pile, effectively mitigating underwater noise in one direction only (Rolfes *et al*., 2012). When an LBC was deployed during strong tides at the Alpha Ventus OWF in Germany, the maximum noise reduction was 15 dB SEL (Table 3) in the direction of tidal flow whilst against the tidal flow the noise reduction was recorded as a maximum of 5 dB SEL (Rolfes *et al*., 2012). A noise reduction of 10 dB is therefore likely to be achievable in areas with low tidal or current speeds.

2.4 Isolation Casing

2.4.1 An isolation casing is a form of NAS with a shell-in-shell system around the pile in which a shielding effect of the casing reduces the radiated noise. The most used approach is the IHC Integrated Monopile Installer which includes a noise mitigation screen and provides several additional built-in features which aid in decoupling radiated noise from the water column close to pile. The IHC system is a double-walled steel pipe with an air gap in between, with an additional bubble curtain used in the centre around the pile (Weilgart *et al.,* 2023). The noise mitigation screen is also insensitive to currents (Bellmann *et al.,* 2020). By combining several principles of noise reduction in various layers around the pile, isolation casings, such as the IHC Integrated Monopile Installer, are capable of a high noise reduction comparable to or exceeding that of a bubble curtain (Koschinski and Lüdemann, 2020). Whilst there is less evidence for isolation casings, data collected indicates that a noise reduction of at least 10 dB (Table 3) is achievable (Koschinski and Lüdemann, 2020). Current isolation casings are designed and used during installation of monopiles up to a diameter of 8.8 m only, not for other foundation types (IQIP, 2023b; Le Monde International, 2023).

2.5 Hydrosound Damper

2.5.1 The Hydrosound Damper (HSD) is a lightweight, cost effective (no compressors required), reusable NAS that has no impact on installation times but does require customisation for each project. Noise reduction by HSD is largely independent of water depth and currents however, for deeper water (> 40 m), the practicability and efficiency of this systems remains to be proven (Koschinski and Lüdemann, 2020; Verfuss *et al.,* 2019). Of the three proven and most frequently used noise mitigation systems the HSD has the smallest evidence base and has not been used on jacket foundations. Nonetheless, the existing evidence does indicate that at least a 10 dB reduction (Table 3) could be expected (Koschinski and Lüdemann, 2020; Verfuss *et al.,* 2019).

2.6 Pile Cushioning

2.6.1 Pile cushioning is a NMS used to dampen high-frequency impact force and reduces the peak of the sound pressure (Deng *et al.*, 2016) while reducing the driving force as the pulse duration is prolonged. This is achieved by adding a layer(s) of cushioning material between the hammer and pile (Koschinski and Lüdemann, 2020). There are a number of companies developing pile cushioning systems to limit the impact of noise and reduce the material fatigue of the pile as a consequence of pile driving. Examples include the Menck Noise Reduction Unit (MNRU; developed by Menck) and piling under limited stress equivalent (PULSE; developed by IHC IQIP). Pile cushioning has been shown to reduce noise emissions by 3–6 dB SEL and 9 - 12 dB SPL at the source (Table 3) (Merchant and Robinson, 2020).

2.7 Cofferdams

2.7.1 Dewatered cofferdams are a NAS that involve a steel tube that surrounds a pile from the seabed to the water surface which creates an air gap between the pile and the water (Bellmann, 2014; Koschinski and Lüdemann, 2020). This gap effectively reduces the sound energy transfer into the marine environment when the cofferdam is sealed at the bottom and dewatered by pumps (Thomsen, 2012 as cited in Koschinski and Lüdemann, 2020). This NAS has been used for jacket installations of offshore platforms within depths ≤40 m (*e.g.* BorWin beta and DolWin alpha converter platforms and HelWin alpha cable access tower and piles; Wijk, 2013 as cited in Koschinski and Lüdemann, 2020). Full scale prototype monopiles (pile diameter of 5.9 m) have also been trialled using this NMS at Anholt OWF (McKenzie Maxon, 2012; Thomsen, 2012), but installation was not successful using this method due to seal failure with the seabed. Although existing evidence proposes a high noise reduction potential of cofferdams (up to 23 dB SEL (Table 3); McKenzie Maxon, 2012 as cited in Koschinski and Lüdemann, 2020), the measurements at Anholt only showed a reduction up to 13 dB SEL due to a compromise in the seal allowing some sea water to enter (McKenzie Maxon, 2012 as cited in Koschinski and Lüdemann, 2020). Cofferdams are not a typical NAS in OWF construction.

2.8 Screens

2.8.1 IHC Noise Mitigation Screen is a NMS that has recently been assessed as the most effective near-pile mitigation system (Weilgart, 2023). This technology features a pipe-in-pipe system that reduces SEL up to 17 dB (Table 3) (BSH, n.d.). This technology is independent of current and can be used in any water depth in principle; however, to date, this system has only been used in water depths of 40 m (Weilgart, 2023). It is recommended to be used with a DBBC which can further reduce SELs up to 22 dB in shallow water depths (*ca.* 40 m; Weilgart, 2023).

2.8.2 The company AdBm developed a customisable noise mitigation screen which was first deployed commercially in 2019 (Verfuss *et al.* 2019). Limited studies have focussed on the system's acoustic performance (Weilgart, 2023), but noise reports for Borsselle 2 OWF which used the AdBm NMS and DBBC within 32 m water depth measured a max SEL of 157 dB at a distance of 752 m from the pile (Van Oord, 2020). Degraer *et al.* (2019) report on the AdBm system reducing zero to peak SPL by 3 – 6 dB re 1 µPa at a distance of 750 m from five pile driving events (7.2-7.8 m diameter piles driven using a 3,500 Kj hydraulic hammer in 26 – 47 m water depth) (Table 3). On their website, AdBm suggest that their system should be used with a DBBC to increase the NMS's performance as hammer energies and pile sizes continue to increase (AdBm technologies, 2020).

2.9 BLUE Piling Technology

2.9.1 BLUE Piling Technology is a NMS consisting of an impact hammer with lower noise emissions than a conventional impact hammer. The technology consists of a steel housing that is filled with water. The water is then accelerated upwards by the release of a small amount of gas, which applies force to the pile and lifts some of the water in the housing. The lifted water then falls down, providing a secondary force to the pile. The cycle is repeated until the pile is installed to the required depth (Rumes *et al*., 2016). This technology significantly reduces underwater noise when compared to an impact hammer, by reducing vibrations on the pile wall and prolonging the pulse duration (Bellmann *et al.,* 2020). A prototype was successfully tested on a full-scale monopile in offshore conditions, with the manufacturer predicting a reduction in noise levels of at least 20 dB SEL (Table 3) (IQIP, 2021).

2.10 Vibro-hammer

2.10.1 Vibratory hammer technology is a NMS and one of the optimum methods available for installing monopiles over 6 m diameter within 80 m water depths (Gerwick, 2007; Wybren, 2011 as cited in University of Strathclyde, 2015; Weilgart, 2023). The noise generated by this activity is non-impulsive and peaks at low frequencies (< 40 Hz; Koschinski and Lüdemann, 2020). The OWF Nordsee Ost (located in the German sector of the North Sea) used a combination of vibropilling and impact pile driving to install 196 pin piles of the 48 jacket foundations for wind turbines and one substation in water depths up to 25 m (Offshore Energy, 2014). Pin piles were vibropiled to 1/3 of the final penetration depth before using an impact pile driving method to final depth (Koschinski *et al.,* 2020). Noise emissions from vibropiling are in the order of 10–20 dB (Table 3) lower than mitigated impacts of pile driving at identical situations (Gerke and Bellmann, 2012; Kringelum, 2013; as cited in Koschinski *et al.,* 2020); however, vibropiling emits a continuous noise compared to the impulsive characteristic of impact pile driving which makes direct comparisons difficult (Koschinski *et al.,* 2020).

2.11 Summary of NMS/NAS

2.11.1 Table 3 provides a summary of various NAS and NMS technologies, their compatibility to different operational contexts, and their typical ranges of noise reduction. This table also distinguishes between primary (NMS) and secondary (NAS) noise mitigation measures. Primary noise mitigation counteracts the generation of noise directly at the source whereas, secondary noise mitigation reduces the radiation of noise by placing sound barriers at a distance from the pile (Dähne *et al.,* 2017; Weilgart *et al*., 2023).

Table 3 Summary of available NAS and NMS methods and performance parameters.

Method / System	Noise Reduction Principle	Can be used in combination with:	Noise Reduction	Development Status
Little Bubble Curtains[a]	Reflection, scattering and absorption (frequency dependent)	Single, double, triple application; isolation casing; Hydro Sound Dampers; reduced blow energy; prolonging pulse duration	11–15 dB SEL	Experimented in the German test field, but not further developed for commercial use.
Big Bubble Curtains[a]	Reflection, scattering and absorption (frequency dependent)	Single, double, triple application; isolation casing; Hydro Sound Dampers; reduced blow energy; prolonging pulse duration	Single: 11 – 15 dB SEL (depth[2]: 25 m), Double: 14 – 18 dB SEL (depth: 25 m)	State of the art (up to ~45 m water depth, ~ 8 m pile diameter).
Isolation Casings[a]	Shielding, reflection	Additional built-in features; double bubble curtain; reduced blow energy; prolonging pulse duration	13 – 17 dB SEL (depth: < 45 m)	State of the art (up to ~ 45 m water depth, ~ 8 m pile diameter)
Hydro Sound Dampers[a]	Encapsulated resonator system. Scattering and absorption by resonators, reflection, dissipation and material damping (frequency tuning possible)	Double Bubble curtain; reduced blow energy; prolonging pulse duration; pile cushioning	up to 12 dB SEL (depth: 40–60 m)	State of the art (in principle unlimited by water depth, ~ 8 – 13 m pile diameter)
Pile cushions[b]	Dampens high-frequency noise and wave amplitudes, prolongation of the pulse duration	All secondary noise mitigation measures	3–6 dB SEL 9–12 dB SPL	Proven modular add-on that can be used with hydrohammers. Also proven to reduce installation fatigue and lessen installation time.

[2] Where depth is included with a noise reduction value, this is the water depth the device was tested within.

Method / System	Noise Reduction Principle	Can be used in combination with:	Noise Reduction	Development Status
Dewatered Cofferdams[a]	Decoupling noise from the water column	Double Bubble curtain; Hydro Sound Dampers; reduced blow energy; prolonging pulse duration	13 – 23 dB SEL (depth: < 20 m)	Monopile full scale prototype tested offshore in 2011 and 2012, state of the art in substations
IHC Noise Mitigation Screen[b]	Pipe-in-pipe system	Double Bubble Curtain	Up to 17 dB SEL	Proven in water depths up to 40m, has been used on hundreds of monopiles.
AdBm NMS[b]	Encapsulated resonator screen system. Broadband frequency attenuation	Completely customisable in design	Up to 3 – 6 dB SPL at targeted frequency (depth: < 47 m)	Full scale model successfully tested by Van Oord in 2019. Van Oord plan to continue to use this technology in future wind farms (in principle not constrained by water depth).
BLUE Piling Technology[b]	Prolongation of the pulse duration	All secondary noise mitigation measures	20–24 dB SEL (depth: 22.4 m)	Full scale prototype successfully tested under offshore conditions, improvements on technology currently being studied and implemented.
Vibro-hammer[b]	Alternative piling method using low frequency oscillations	All secondary noise mitigation measures	10 – 20 dB SEL, 30 s (depth: < 25 m)	Proven technology in combination with impact piling. Exclusive vibropiling: Offshore pilot wind turbine with monopile successfully installed in Dutch waters.
Suction Bucket Jacket[b]	Alternative low-noise foundation	All secondary noise mitigation measures	N / A	Proven technology with 32 turbines successfully installed since 2014. Further development may be needed due to currently limited experience.

Key: a: Secondary Mitigation Measure/Noise Abatement System; b: Primary Mitigation Measure/Noise Mitigation System. SEL is measured in dB re 1 μPa^2s and SPL in dB re 1 µPa.

Method / System	Noise Reduction Principle	Can be used in combination with:	Noise Reduction	Development Status
Additional note- performance is non verified by author, based on literature cited only. **Sources:** Bubble Curtains: Koschinski 2011, Koschinski and Lüdemann 2020, Merchant and Robinson, 2020, Bohne *et al.,* 2019, Tsouvalas *et al.,* 2016. Isolation Casings: Verfuss *et al.,* 2019, O'Kelly and Arshad, 2016, Koschinski and Lüdemann, 2015. Hydro Sound Dampers: Bellmann *et al.,* 2020, Elmer, 2018, Elmer and Savery, 2014. Pile cushioning: Merchant and Robinson, 2020. Dewatered Cofferdams: Koschinski and Lüdemann, 2020, Kim *et al.,* 2019, O'Kelly and Arshad, 2016. AdBm NMS: Bellmann *et al.,* 2020, Degraer *et al.,* 2019, Elzinga *et al.,* 2019, Rumes *et al.,* 2016. BLUE Piling Technology: Merchant, 2019, Rumes *et al.,* 2016, Koschinski and Lüdemann, 2015. Vibratory Hammer: Tsouvalas, 2020, Foglia *et al.,* 2016. Suction Bucket Jacket: Bellmann *et al.,* 2020, Wang *et al.,* 2018; Lüdeke, 2017.				

3 Conclusion

3.1.1 In summary, there are many different NMS and NAS technologies available for commercial use that are proven to reduce propagation of underwater noise into the wider marine environment, and some technologies that are in their prototype/testing phase of development. The main factors to consider when determining an appropriate NAS strategy are water depth and oceanographic features (*e.g.* current speed), size of the pile and whether jacket foundations would be used.

3.1.2 The existing evidence base shows that a reduction in broadband single-strike sound exposure and peak levels of at least 10 dB should be achievable via any of the commercially available and commonly used NMS and NAS. This noise reduction commitment is appropriate as it provides suitable conservatism to noise reduction estimates whilst also presenting a realistic case. It is also important to note that this conclusion is based on the implementation of a single NMS or NAS (*e.g.* a single bubble curtain). Evidence shows that NMS and NAS performance are best when multiple methods are used together, which results in the potential for a higher dB reduction. Therefore, Dublin Array could use a combination of available technology where possible, such as combining pile cushions, HSD and bubble curtains in suitable water depths. Where current is a concern for Dublin Array, NMS methods such as pile cushions, AbDms NMS, PULSE, or BLUE piling technology would be suitable. NAS technology independent of current include isolation casings, HSD and cofferdams. HSDs in principle are not limited to pile diameter or water depth which makes the technology a desirable choice depending on cost and availability. Site specific information on the geology based on future geotechnical investigation will be useful to more accurately model noise propagation based on the foundation design/pile diameter/length which would be fundamental in choosing an appropriate NAS.

3.1.3 Consideration for alternative foundation types and installation methods such as vibropiling should be given as an alternative for monopile pile driving. Where evidence suggests that vibropiling can be used in deeper waters and may have lesser impacts on marine mammals (*e.g.* no risk of instantaneous injury from the propagating sound).

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