EIA Report Volume 3, Appendix 8.1: Underwater Noise Modelling Assessment

MarramWind Offshore Wind Farm

December 2025

MarramWind

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Contents

Appendix A. Additional Modelling Results

1. Introduction

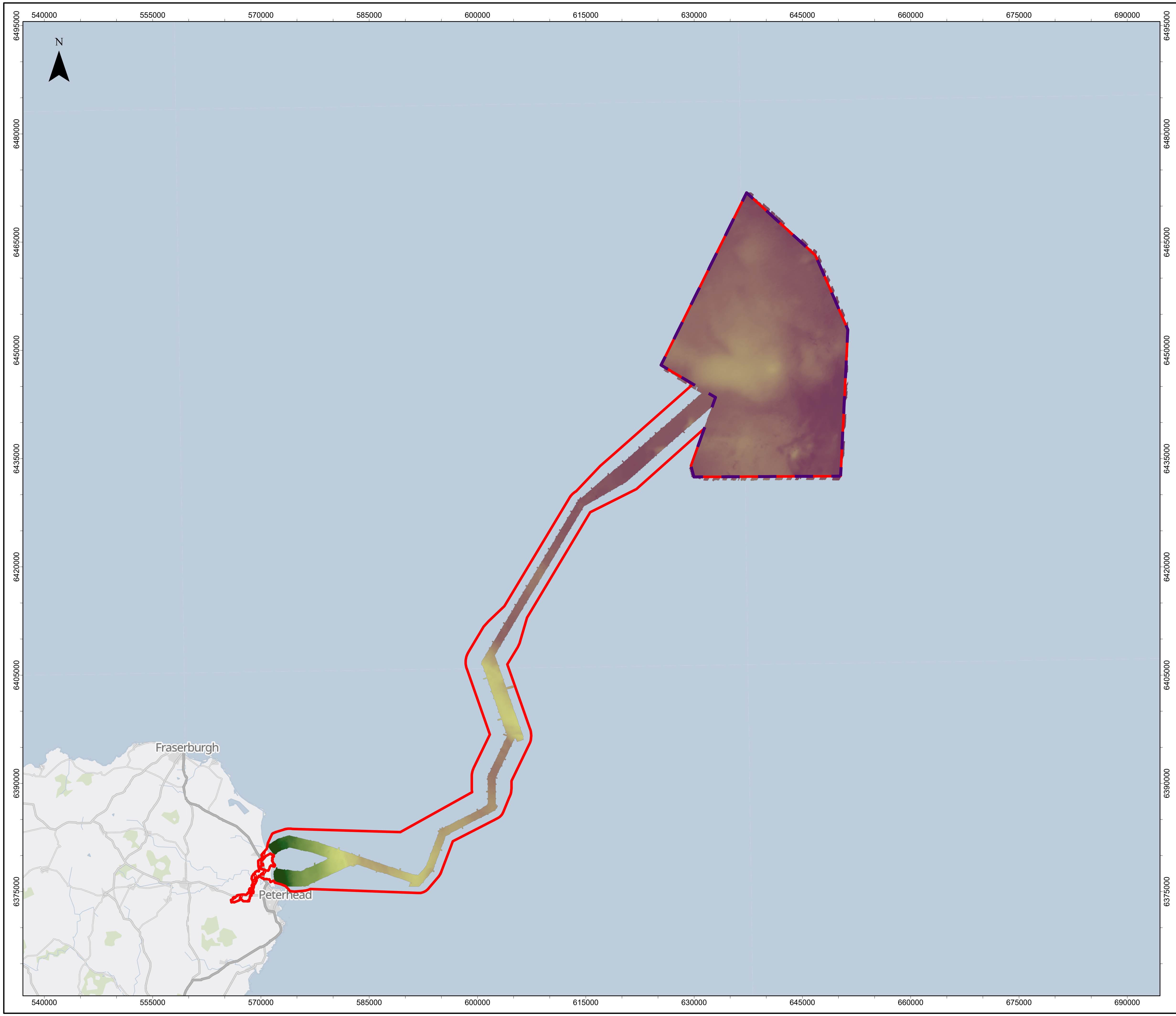
1.1.1.1 MarramWind Offshore Wind Farm (hereafter, referred to as ‘the Project’) is a proposed floating offshore wind farm in the Scottish North Sea. As part of the Environmental Impact Assessment (EIA) process, the Project has undertaken detailed modelling and analysis in relation to underwater noise and its effect on marine mammals and fish during the construction and operation of the Project.

1.1.1.2 The Option Agreement Area (OAA) covers a sea surface area of 684 kilometre (km^2) and is situated approximately 75km off the northeast coast of Scotland in water depths averaging 111 metres (m), which is shown in **Figure 1**. The Project has a proposed capacity of up to 3 gigawatts (GW).

1.1.1.3 This Report presents a detailed assessment of the potential underwater noise during the construction and operation of the Project and includes the following:

- Background information covering the units for measuring and assessing underwater noise, and a review of the underwater noise metrics and criteria used to assess the possible environmental effects in marine receptors (**Section 2**).
- Discussion of the approach, input parameters and assumptions for the detailed impact piling modelling undertaken (**Section 3**).
- Presentation and interpretation of the detailed subsea noise modelling for impact piling with regards to its effect on marine mammals and fish (**Section 4**).
- Modelling of the other noise sources expected around the construction and operation of the Project, including drag embedment anchors, suction anchors, cable laying, drilling, ground preparations, vessel noise, operational WTG noise, and UXO clearance (**Section 5**).
- Summary and conclusions (**Section 6**).

1.1.1.4 Further modelling results covering non-pulse thresholds for impact piling (see **Section 2.3.3**) are presented in **Appendix A**.



Red Line Boundary

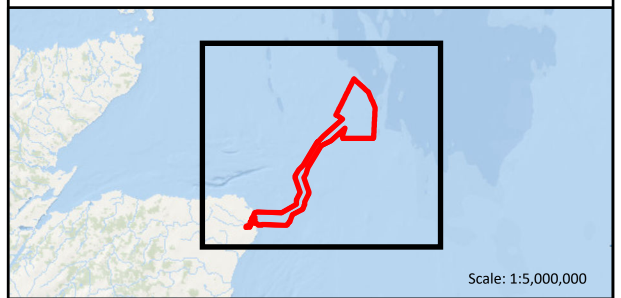
Option Agreement Area

Bathymetry (m)

-2

-133.507

0 10 20 Kilometres



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MarramWind Offshore Wind Farm

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Figure 1 Overview map showing the OAA, its location in the North Sea and the surrounding bathymetry

Environmental Impact Assessment Report

Appendix 8.1

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2. Background to Underwater Noise Metrics

2.1 Underwater noise

2.1.1.1 Sound travels much faster in water (approximately 1,500m/s) than in air (340m/s). Since water is a relatively incompressible, dense medium, the pressure associated with underwater sound tends to be much higher than in air. It should be noted that presentation of underwater noise levels is different to airborne noise levels, as a different scale is used between in water and in air measurements. Therefore, noise measurements in air are not directly comparable to noise measurements underwater.

2.1.2 Units of measurement

2.1.2.1 Sound measurements underwater are usually expressed using the Decibel (dB) scale, which is a logarithmic measure of sound. A logarithmic scale is used, as this better reflects how sound is perceived. For example, equal increments of sound levels do not have an equal increase in the perceived sound. Instead, each doubling of sound level will cause a roughly equal increase of loudness. Any quantity expressed in this dB scale is termed a 'level'. For example, if the unit is sound pressure, it will be termed a 'sound pressure level' on the dB scale.

2.1.2.2 The fundamental definition of the dB scale is given by:

$$Level = 10 \times \log_{10}\left(\frac{Q}{Q_{ref}}\right)$$

where Q is the quantity being expressed on the scale, and Q_{ref} is the reference quantity.

2.1.2.3 The dB scale represents a ratio. It is therefore used with a reference unit, which expresses the base from which the ratio is expressed. The reference quantity is conventionally smaller than the smallest value to be expressed on the scale so that any level quoted is positive. For example, a reference quantity of 20µPa is used for sound in air since that is the lower threshold of human hearing.

2.1.2.4 When used with sound pressure, the pressure value is squared. So that variations in the units agree, the sound pressure must be specified as units of root mean square (RMS) pressure squared. This is equivalent to expressing the sound as:

$$Sound\ pressure\ level\ (L_p) = 20 \times \log_{10}\left(\frac{P_{RMS}}{P_{ref}}\right)$$

2.1.2.5 For underwater sound a unit of 1µPa is typically used as the reference unit (P_{ref}); a Pascal (Pa) is equal to the pressure exerted by one Newton over one square metre, one micropascal (µPa) equals one millionth of this.

2.1.3 Sound pressure level (L_p or SPL)

2.1.3.1 The sound pressure level (SPL or L_p) is normally used to characterise noise of a continuous nature, such as drilling, boring, or background sea and river noise levels. To calculate the SPL, the variation in sound pressure is measured over a specific period to determine the RMS level of the time-varying sound. The SPL ($L_{p,RMS}$) can therefore be considered a measure of the average unweighted level of sound over the measurement period.

2.1.3.2 Where SPL is used to characterise transient pressure waves, such as that from impact piling, seismic airgun or underwater blasting, it is critical that the period over which the RMS level is calculated is quoted e.g., $L_{p,125ms}$. For instance, in the case of a pile strike lasting a tenth of a second, the mean taken over a tenth of a second will be ten times higher than the mean averaged over one second. Often, transient sounds such as these are quantified using “peak” SPLs ($L_{p,pk}$) or Sound Exposure Levels (SEL, L_E).

2.1.3.3 Unless otherwise defined, all L_p noise levels in this Report are referenced to 1 μPa.

2.1.4 Peak sound pressure level ($L_{p,pk}$ or SPL_{peak})

2.1.4.1 The SPL_{peak}, or $L_{p,pk}$, is often used to characterise transient sound from impulsive sources, such as percussive impact piling. $L_{p,pk}$ is calculated using the maximum variation of the pressure from positive to zero within the wave. This represents the maximum change in positive pressure (differential pressure from positive to zero) as the transient pressure wave propagates.

2.1.5 Sound exposure level ($L_{E,p,t}$ or SEL_{cum})

2.1.5.1 When considering the noise from transient sources, the issue of the duration of the pressure wave is often addressed by measuring the total acoustic energy (energy flux density) of the wave. This form of analysis was used by Bebb and Wright (1953, 1954a, 1954b and 1955), and later by Rawlins (1987), to explain the apparent discrepancies in the biological effect of short- and long-range blast waves on human divers. More recently, this form of analysis has been used to develop criteria for assessing injury ranges for fish and marine mammals from various noise sources (Popper *et al.,* 2014 and Southall *et al.,* 2019).

2.1.5.2 The SEL ($L_{E,p}$) sums the acoustic energy over a measurement period (t), and effectively takes account of both the SPL of the sound and the duration it is present in the acoustic environment. Sound exposure (SE) is defined by the equation:

$$SE = \int_0^T p^2(t)dt$$

where p is the acoustic pressure in Pa, T is the total duration of sound in seconds, and t is time in seconds. The SE is a measurement of acoustic energy and has units of Pascal squared seconds (Pa^2s).

2.1.5.3 To express the SE on a logarithmic scale, by means of a dB, it must be compared with a reference acoustic energy (${p^2}_{ref}$) and a reference time (T_{ref}). The $L_{E,p,t}$ is then defined by:

$$L_{E,p} = 10 \times \log_{10}\left(\frac{\int_0^T p^2(t)dt}{{P^2}_{ref}T_{ref}}\right)$$

2.1.5.4 By using a common reference pressure (p_{ref}) of 1 μPa for assessments of underwater noise, the $L_{E,p}$ and L_p can be compared using the expression:

$$L_{E,p} = L_p + 10 \times \log_{10} T$$

where L_p is a measure of the average level of broadband noise and the $L_{E,p}$ sums the cumulative broadband noise energy.

2.1.5.5 This means that, for continuous sounds of less than (i.e., fractions of) one second, the $L_{E,p,1s}$ will be lower than the L_p. For periods greater than one second, the $L_{E,p}$ will be numerically greater than the L_p (i.e., for a continuous sound of 10 seconds duration, the $L_{E,p,10s}$ will be

10dB higher than the L_p; for a sound of 100 seconds duration the $L_{E,p,100s}$ will be 20dB higher than the L_p, and so on).

2.1.5.6 Where a single impulse noise such as the soundwave from a pile strike is considered in isolation, this can be represented by a “single strike” $L_{E,p}$ or SEL_{ss}. A cumulative $L_{E,p,t}$, or SEL_{cum}, accounts for the exposure from multiple impulses or pile strikes over time, where the number of impulses replaces the T in the equation above, leading to:

$$L_{E.p.t} = L_E + 10 \times \log_{10} X$$

where L_E is the sound exposure level of one impulse and X is the total number of impulses or strikes. Unless otherwise defined, all L_E noise levels in this Report are references to 1 μPa^2s.

2.2 Properties of sound

2.2.1.1 Sound can be categorised loosely into two types: impulsive sound and non-impulsive sound. Non-impulsive noise can be defined as a steady-state noise which does not necessarily have a long duration (e.g., vibropiling, drilling). Impulsive noise can be defined as a sound with a high peak sound pressure, short duration, fast rise-time and a broad frequency content at the source (e.g., seismic airguns, explosives, impact piling).

2.2.1.2 These differences are important to consider regarding the potential for auditory injury, as impulsive noise is more injurious than non-impulsive noise.

2.2.1.3 Due to the differences between impulsive and non-impulsive noise sources, different metrics are appropriate for describing these different sound sources. For example:

- impulsive noises: use SPL_{peak} ($L_{p,pk}$) and cumulative SEL ($L_{E,p,t}$); and
- non-impulsive noises: use cumulative SEL ($L_{E,p,t}$)

2.2.1.4 Objective categorisation of a noise as impulsive or non-impulsive can sometimes be challenging. This is particularly the case if a sound is travelling over long distances. For example, if an impulsive sound propagates through an environment, the energy within the sound wave will scatter and dissipate, and it becomes less impulsive with distance from the noise source. This is important to consider regarding auditory injury and impact range calculations, as noise will become less injurious if it becomes less impulsive.

2.2.1.5 Research to define the range-dependent transition from impulsive and non-impulsive noise (see Martin *et al.*, 2020) has been a significant field of study. Although the situation is complex, Hastie *et al.* (2019) concluded that an impulsive sound can be considered effectively non-impulsive 3.5km from the source on some metrics.

2.2.1.6 However, the recent study by Matei *et al.* (2024) concludes that there is still insufficient evidence to clearly define a transition point suitable for an assessment such as this, although it is reasonable to presume there is a fully impulsive region close to the source, a fully non-impulsive region at some greater distance, and a transition region in between. The paper makes it clear that there is a substantial reduction in impulsiveness within the first 5km. Due to the uncertainty in identifying a transition point, no presumption of a change in impulsiveness has been made in this Report, although the sound should be considered not fully impulsive where PTS ranges are calculated above 5km. Results in respect of both impulsive and non-impulsive criteria (see also **Section 2.3.3** in respect of marine mammals) have been presented for piling noise sources.

2.2.2 Particle motion

2.2.2.1 The movement of the particles that make up a medium is an important component of sound. Particle motion is present wherever there is sound, and it describes the back-and-forth movement of particles in water, which in the context of underwater noise, are caused by a sound wave passing through the water column. This back-and-forth movement means that, unlike sound pressure at a single point, particle motion always contains directional information (Hawkins and Popper, 2017). Regarding quantifying particle motion, it is usually defined in reference to the velocity of the particle (often a peak particle velocity (PPV)), but sometimes the related acceleration or displacement of the particle is used.

2.2.2.2 It has been identified by several researchers that most fish species, (e.g., Popper and Hawkins, 2019; Nedelec *et al*., 2016; Radford *et al.,* 2012), as well as marine invertebrates (see Solé *et al*., 2023) are sensitive to particle motion rather than sound pressure. However, sound pressure metrics are still preferred and more widely used than particle motion due to a lack of supporting data in relation to particle motion (Popper and Hawkins, 2018). There continue to be calls for additional research on the levels of and effects on marine receptors with respect to particle motion.

2.3 Analysis of environmental effects

2.3.1.1 Over the last 20 years it has become increasingly evident that noise from human activities in and around underwater environments can have an impact on the marine species in the area. The extent to which intense underwater sound might cause adverse impacts in species is dependent upon the incident sound level, source frequency, duration of exposure, and/or repetition rate of an impulsive sound (see, for example, Hastings and Popper, 2005). As a result, scientific interest in the hearing abilities of aquatic species has increased. Studies are primarily based on evidence from high level sources of underwater noise such as seismic airguns, impact piling and blasting as these sources are likely to have the greatest immediate environmental impact and therefore the clearest observable effects, although interest in chronic noise exposure is increasing.

2.3.1.2 The impacts of underwater sound on marine species can be broadly summarised as follows:

- physical traumatic injury and fatality;
- auditory injury (either permanent or temporary); and
- disturbance and behavioural responses.

2.3.1.3 The following sections discuss the underwater noise criteria used in this study with respect to species of marine mammals and fish that may be present around the Project.

2.3.2 Assessment criteria

2.3.2.1 The main metrics and criteria that have been used in this study to aid assessment of environmental effects come from two key papers covering underwater noise and its effects:

- Southall *et al*. (2019) marine mammal exposure criteria.
- Popper *et al*. (2014) sound exposure guidelines for fishes and sea turtles.

2.3.2.2 At the time of writing these include the most up-to-date and authoritative criteria for assessing environmental effects for use in impact assessments. Although it is noted that other papers have been published recently with new guidance (e.g., National Marine Fisheries Service (NMFS), 2024), these have not yet been formally accepted by the Scottish regulators.

2.3.3 Marine mammals

2.3.3.1 The Southall *et al*. (2019) paper is currently the most used and recognised reference for marine mammal hearing thresholds for noise exposure. It provides identical thresholds to those from the NMFS (2018) guidance for marine mammals. It should be noted that, despite the identical thresholds, the marine mammal hearing groups are described slightly differently in the Southall *et al.* (2019) paper compared to the NMFS (2018) guidance. Therefore, care should be taken if comparing results using the Southall *et al*. (2019) to NMFS (2018) criteria.

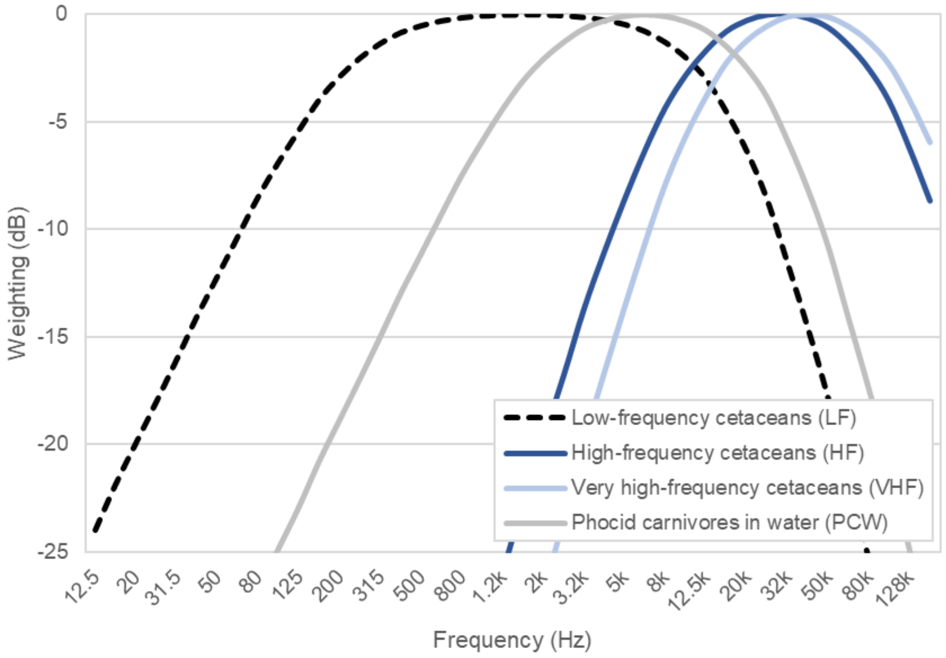
2.3.3.2 The Southall *et al*. (2019) guidance categorises marine mammals into groups of similar species and applies filters to the unweighted noise to approximate the hearing sensitivities of the receptor in question. The hearing groups given by Southall *et al*. (2019) are summarised in **Table 2.1** and **Plate 2.1** Further groups for sirenians and other marine carnivores in water (e.g., sealions, walrus) are given, but these have not been included in this study as those species are not commonly found in the North Sea.

2.3.3.3 It should be noted that despite Southall *et al*. (2019) referring to SPL_{peak} and cumulative SEL as SEL_{cum}, this notation has since been updated (ISO 18405:2017) and will be referred to as $L_{p,pk}$ and $L_{E,p,t}$ respectively in the rest of this Report.

Table 2.1 Marine mammal hearing groups (from Southall *et al*., 2019)

Hearing group	Generalised hearing range	Example species
Low-frequency cetaceans (LF)	7Hz to 35kHz	Baleen whales (including minke whale).
High-frequency cetaceans (HF)	150Hz to 160kHz	Dolphins, toothed whales, beaked whales, bottlenose whales (including bottlenose dolphin).
Very high-frequency cetaceans (VHF)	275Hz to 160kHz	True porpoises (including harbour porpoise).
Phocid carnivores in water (PCW)	50Hz to 86kHz	True seals (including harbour seals).

Plate 2.1 Auditory weighting functions for low-frequency cetaceans (LF), high-frequency cetaceans (HF), very high-frequency cetaceans (VHF), and phocid carnivores in water (PCW) (from Southall *et al.*, 2019)



2.3.3.4 Southall *et al*. (2019) considers the nature of the sound in the context of whether it is an impulsive or non-impulsive noise source (see **Section 2.2** for details).

2.3.3.5 Although the use of impact ranges derived using the impulsive criteria are recommended for all but clearly defined non-impulsive sources, it should be recognised that where calculated ranges are beyond 5km (see **Section 2.2**), the sound is expected to be beyond the fully impulsive region and the real impact range is likely to be somewhere between ranges based on the impulsive and non-impulsive impact criteria. Therefore, if the modelled impact range of an impulsive noise has been predicted to be greater than 5km, the non-impulsive impact range should also be considered. Both impulsive and non-impulsive criteria have been presented in this study.

2.3.3.6 **Table 2.2** and **Table 2.3** present the impulsive and non-impulsive criteria set out by Southall *et al*. (2019) for permanent threshold shift (PTS) and temporary threshold shift (TTS) in marine mammals used in this study.

Table 2.2 Unweighted $L_{p,pk}$ criteria for PTS and TTS in marine mammals (Southall *et al.*, 2019)

Southall *et al.* (2019)	$L_{p,pk}$ (dB re 1 µPa)	
	Impulsive	
	PTS	TTS
Low-frequency cetaceans (LF)	219	213
High frequency-cetaceans (HF)	230	224

Southall *et al.* (2019)	$L_{p,pk}$ (dB re 1 µPa)	
	Impulsive	
	PTS	TTS
Very high-frequency cetaceans (VHF)	202	196
Phocid carnivores in water (PCW)	218	212

Table 2.3 Weighted $L_{E,p,24h,wtd}$ criteria for PTS and TTS in marine mammals (Southall *et al.*, 2019)

Southall *et al.* (2019)	$L_{E,p,24h,wtd}$ (dB re 1 µPa^{2}s)			
	Impulsive		Non-impulsive	
	PTS	TTS	PTS	TTS
Low-frequency cetaceans (LF)	183	168	199	179
High frequency-cetaceans (HF)	185	170	198	178
Very high-frequency cetaceans (VHF)	155	140	173	153
Phocid carnivores in water (PCW)	185	170	201	181

2.3.3.7 Where $L_{E,p,t}$ thresholds are required for marine mammals, a fleeing animal model has been used. This assumes that a receptor, when exposed to high noise levels, will swim away from the noise source. For this study, the following flee speeds have been used for marine mammals:

- 2.1m/s for low-frequency cetaceans (LF) (Scottish Natural Heritage; SNH, 2016);
- 1.52m/s for high-frequency cetaceans (HF) (Bailey and Thompson, 2006);
- 1.4m/s for very high-frequency cetaceans (VHF) (SNH, 2016); and
- 1.8m/s for phocid carnivores in water (PCW) (SNH, 2016).

2.3.3.8 These are considered worst-case assumptions as marine mammals are expected to be able to swim much faster under stress conditions (Kastelein *et al.* 2018), especially at the start of any noisy process when the receptor will be closest.

2.3.3.9 The fleeing animal model and the assumptions related to it are discussed in more detail in **Section 3.4**.

2.3.4 Fish

2.3.4.1 The Popper *et al*. (2014) guidelines are recognised as a suitable reference for underwater noise impacts on marine fauna (aside from marine mammals) in UK waters. Popper *et al*. (2014) provides a summary of research and guidelines for fish (and other marine fauna) exposure to sound and uses categories for fish that are representative of the species present in the region surrounding the Project.

2.3.4.2 The Popper *et al*. (2014) guidelines present criteria dependent on the type of noise source, species of marine fauna and their hearing capabilities, and impact type. Noise sources considered in the guidance include explosions, pile driving, seismic airguns, sonar, and shipping and continuous noise. For this study, criteria for pile driving, explosions, and shipping and continuous noise have been used.

2.3.4.3 For each sound source, the marine fauna is categorised into groups of fish, sea turtles, and eggs and larvae. Due to their diversity and quantity, fish are categorised further into three groups depending on their hearing capabilities, which can be indicated by whether they possess a swim bladder or not, and whether the swim bladder is involved in hearing.

2.3.4.4 Popper *et al*. (2014) provides separate criteria, depending on the species and the noise source, for various impacts associated with noise exposure. These are mortality and potential mortal injury, impairment (split into recoverable injury, TTS, and masking), and behavioural effects.

2.3.4.5 Depending on the noise source, quantitative criteria are given in appropriate metrics ($L_{p,pk}$, $L_{E,p,24h}$, etc.), which can then be used as thresholds for the onsets of listed impacts. Where insufficient data are available, Popper *et al.* (2014) also gives a description of relative risk. This summarises the effect of the noise as having either a high, moderate or low relative risk of an effect on an individual near (tens of meters), intermediate (hundreds of meters) or far (thousands of meters) from the source.

2.3.4.6 Where $L_{E,p,t}$ thresholds are required for fish, both a stationary and a fleeing animal model has been used. This is due to the diversity of species considered under this criterion, and as a result, both models encompass the diversity of responses to noise.

2.3.4.7 Most species described by Popper *et al.* (2014) are likely to be able to move away from a sound that is loud enough to cause harm (Dahl *et al*., 2015; Popper *et al*., 2014). For those species that can swim away, a speed of 1.5m/s (based on Hirata, 1999) is considered a conservative speed at which to base a fleeing animal model. However, considering the diversity of species described by Popper *et al*. (2014), whether an animal flees or remains stationary in response to a loud noise will differ between species. It is recognised that there is limited evidence for fish fleeing from high level noise sources in the wild. Those species that are most likely to remain stationary are thought more likely to be benthic species or species without a swim bladder, due to their reduced hearing capabilities making these species the least sensitive to noise (e.g., Goertner *et al*., 1994; Goertner *et al*., 1978; Stephenson *et al*., 2010; Halvorsen *et al*., 2012).

2.3.4.8 Hubert *et al*. (2024) noted that pelagic fish did not clearly flee on exposure to sound, albeit tested at sound pressure levels far lower than piling noise, and did not rule out the possibility that a flee response could occur at higher levels. Despite this, including only a stationary animal model as a worst-case scenario is likely to greatly overestimate the potential risk to fish species. A combined approach is recommended, which considers impact ranges from both fleeing and stationary receptors. Impact ranges from both stationary and fleeing receptors are therefore included in this Report.

2.3.4.9 The thresholds and relative risk descriptions from the Popper *et al*. (2014) criteria used in this study are reproduced in **Table 2.4** to **Table 2.6**, covering pile driving, explosions (for UXO clearance), and shipping and continuous noise sources. Similar to the Southall *et al*. (2019) criteria in **Section 2.3.3**, the Popper *et al*. (2014) criteria use the SPL_{peak}, SPL_{RMS} and SEL_{cum} notation, and as noted previously this Report will use respectively the $L_{p,pk}$, L_p, and $L_{E,p,t}$ notation from ISO 18405:2017 from hereafter for consistency.

2.3.4.10 Note that many of the criteria in **Table 2.4** to **Table 2.6** use a 'greater than' symbol to denote a threshold. This is where limited data are available but there is a recognition that the species group under consideration is less sensitive than the data on which the criteria are based. Especially for any species in the 'no swim bladder' and 'swim bladder not involved in hearing' categories, impact ranges are likely to be somewhat over precautionary.

Table 2.4 Recommended guidelines for pile driving according to Popper *et al.* (2014) for species of fish, sea turtles, and eggs and larvae (N = near-field; I = intermediate-field, F = far-field)

Popper *et al.* (2014) criteria for pile driving					
Receptor	**Mortality and potential mortal injury**	**Impairment**			**Behaviour**
		Recoverable injury	**TTS**	**Masking**	
Fish: no swim bladder	> 219dB $L_{E,p,24h}$ > 213dB $L_{p,pk}$	> 216dB $L_{E,p,24h}$ > 213dB $L_{p,pk}$	>> 186dB $L_{E,p,24h}$	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder not involved in hearing	210dB $L_{E,p,24h}$ > 207dB $L_{p,pk}$	203dB $L_{E,p,24h}$ > 207dB $L_{p,pk}$	> 186dB $L_{E,p,24h}$	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder involved in hearing	207dB $L_{E,p,24h}$ > 207dB $L_{p,pk}$	203dB $L_{E,p,24h}$ > 207dB $L_{p,pk}$	186dB $L_{E,p,24h}$	(N) High (I) High (F) Moderate	(N) High (I) High (F) Moderate
Sea turtles	> 210dB $L_{E,p,24h}$ > 207dB $L_{p,pk}$	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) High (I) Moderate (F) Low
Eggs and larvae	> 210dB $L_{E,p,24h}$ > 207dB $L_{p,pk}$	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low

Table 2.5 Recommended guidelines for explosions according to Popper *et al.* (2014) for species of fish, sea turtles, and eggs and larvae (N = near-field; I = intermediate-field, F = far-field)

Popper *et al.* (2014) criteria for explosions					
Receptor	**Mortality and potential mortal injury**	**Impairment**			**Behaviour**
		Recoverable injury	**TTS**	**Masking**	
Fish: no swim bladder	229 – 234dB $L_{p,pk}$	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	N/A	(N) High (I) Moderate (F) Low

Popper *et al.* (2014) criteria for explosions					
Receptor	**Mortality and potential mortal injury**	**Impairment**			**Behaviour**
		Recoverable injury	**TTS**	**Masking**	
Fish: swim bladder not involved in hearing	229 – 234dB $L_{p,pk}$	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	N/A	(N) High (I) Low (F) Low
Fish: swim bladder involved in hearing	229 – 234dB $L_{p,pk}$	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	N/A	(N) High (I) Low (F) Low
Sea turtles	229 – 234dB $L_{p,pk}$	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	N/A	(N) High (I) Low (F) Low
Eggs and larvae	> 13 mm/s peak velocity	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	N/A	(N) High (I) Low (F) Low

Table 2.6 Recommended guidelines for shipping and continuous sounds according to Popper *et al.* (2014) for species of fish, sea turtles, and eggs and larvae (N = near-field; I = intermediate-field, F = far-field)

Popper *et al.* (2014) criteria for shipping and continuous sounds					
Receptor	**Mortality and potential mortal injury**	**Impairment**			**Behaviour**
		Recoverable injury	**TTS**	**Masking**	
Fish: no swim bladder	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: swim bladder not involved in hearing	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: swim bladder involved in hearing	(N) Low (I) Low (F) Low	170dB $L_{p,48h}$	158dB $L_{p,12h}$	(N) High (I) High (F) High	(N) High (I) Moderate (F) Low
Sea turtles	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) High (I) Moderate (F) Low
Eggs and larvae	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) Moderate (I) Moderate (F) Low

2.3.4.11 It is important to note that despite the emerging evidence that fish are sensitive to particle motion (see **Section 2.2.2**), the Popper *et al*. (2014) guidance defines noise impacts in terms of sound pressure or sound pressure-associated functions (i.e., $L_{E,p,t}$).

2.3.4.12 It has been suggested that the criteria set out by Popper *et al.* (2014) could have been derived from unmeasured particle motion, as well as sound pressure. Whilst this may be true, sound pressure remains the preferred metric in the criteria due to a lack of data surrounding particle motion (Popper and Hawkins, 2018), particularly in regarding the ability to predict the consequences of the particle motion of a noise source, and the sensitivity of fish to a specific particle motion value. Therefore, as stated by Popper and Hawkins (2019): "*since there is an immediate need for updated criteria and guidelines on potential effects of anthropogenic sound on fishes, we recommend, as do our colleagues in Sweden (Andersson et al., 2017), that the criteria proposed by Popper et al. (2014) should be used*."

2.3.5 Marine invertebrates

2.3.5.1 A review by Solé *et al.* (2023) highlights the increasing evidence that some types of anthropogenic noise can negatively impact a variety of marine invertebrate taxa. These impacts include changes in behaviour, physiology, and rate of mortality, as well as physical impairment, at the individual, population, or ecosystem level. Much of the damage from exposure to noise comes from vibration of the invertebrate body (André *et al.,* 2016) caused by the passage of sound.

2.3.5.2 Comparatively, the studies described by Solé *et al.* (2023) show a general inconsistency in the way noise impacts have been quantified for marine invertebrates. For example, Hubert *et al*. (2021) notes behavioural changes in blue mussels to 150 and 300Hz tones, whereas Spiga *et al.* (2016) describes behavioural changes in the same species at $L_{E,p}$ (single pulse) 153.47dBre1µPa. These inconsistencies make it difficult to generate accurate thresholds for the onset of any impact for species. A notable exception is the cephalopods group, in which several studies, mainly by Solé *et al.* (2013, 2018, 2019) and André *et al.* (2011) show a consistent threshold for auditory damage on various species of cephalopod at 157dB re 1 µPa. While further research is needed even on this group to ensure accurate thresholds which are satisfactory to regulators, the current state of research on cephalopods sets a goal for the research required for other marine invertebrate groups, if they are to be used usefully as impact thresholds.

2.3.5.3 The meta-analysis conducted by Solé *et al.* (2023) also reveals inconsistencies in the responses of taxonomically near species of marine invertebrates to the effect of anthropogenic noise. For example, Fields *et al.* (2019) demonstrates low mortality of zooplankton during seismic airguns, whereas for the same noise source, McCauley *et al.* (2017) showed mass mortality of krill larvae. The effect of noise on one species may not necessarily be applicable on another species despite being taxonomically near, which again makes it difficult to generate a generalised impact threshold that can confidently be applied to different taxonomic groups of marine invertebrates.

2.3.5.4 In its current state, research on the effects of anthropogenic noise on marine invertebrates is emerging, but more slowly than for marine mammals and fish. At this time, this research is in too early a stage to be used to accurately generate impact thresholds which would be satisfactory to regulators. The data available could potentially be referenced for some species but with caution, as there are still considerable gaps in the knowledge that would enable reliable conclusions for the impact of noise for most species.

3. Modelling Methodology

3.1.1.1 To estimate the underwater noise levels likely to arise during the construction and operation of the Project, predictive modelling has been undertaken. The methods described in this section, and used within this Report, meet the requirements set by the National Physical Laboratory (NPL) Good Practice Guide 133 for underwater noise measurement (Robinson *et al*., 2014).

3.1.1.2 Of those considered, the noise source of most importance is impact piling of driven piles for offshore substation and reactive power compensation platform (RCP) foundations, and for driven pile anchors, due to the potential noise levels and duration it will be present (Bailey *et al*., 2014). As such, the noise related to impact piling activity is the primary focus of this study.

3.1.1.3 The modelling of impact piling has been undertaken using the INSPIRE underwater noise model, which has been widely used for wind farm assessments around the UK. The INSPIRE model (currently version 5.3) is a semi-empirical underwater noise propagation model based around a combination of numerical modelling, a combined geometric energy flow/hysteresis loss method, and actual measured data. It is designed to calculate the propagation of noise in acoustically shallow (i.e., generally around 100m or less), mixed water, typical of the conditions around the UK and well suited for use in the North Sea.

3.1.1.4 It is worth identifying that the conditions at the Project are slightly deeper than this in some locations, and there is limited data available for impact piling in these conditions. INSPIRE is designed to extrapolate to parameters beyond which empirical data is available: for example, the size of piles and hammer energies modelled at offshore wind farm projects in previous assessments have routinely been considerably greater than for which data is available, with ultimately good results – however, a particular limitation in respect of relatively deep water at the Project should be noted.

3.1.1.5 INSPIRE provides estimates of unweighted $L_{p,pk}$, $L_{E,p,ss}$ and $L_{E,p,t}$ noise levels, as well as other weighted noise metrics. Calculations are made along 180 equally spaced transects (one every two degrees). For each modelling run a criterion level can be specified allowing a contour to be drawn, within which a given effect may occur. These results can then be plotted over digital bathymetry data so that impact ranges can be clearly visualised as necessary. INSPIRE also produces these results as GIS shapefiles.

3.1.1.6 INSPIRE considers a wide array of input parameters, including variations in bathymetry and source frequency to ensure accurate results are produced specific to the location and nature of the piling operation. It should also be noted that the results should be considered conservative as maximum design parameters and worst-case assumptions have been selected for:

- piling hammer blow energies;
- soft start, hammer energy ramp up, and strike rate;
- total duration of piling; and
- receptor swim speeds.

3.1.1.7 Simpler modelling approaches have been used for noise sources other than impact piling; these are covered in **Section 5**.

3.2 Modelling confidence

3.2.1.1 The INSPIRE model is semi-empirical, and as such a validation process is inherently built into the development process. Whenever a new set of good, reliable, impact piling measurement data is gathered through offshore surveys, either by Subacoustech or a third party, it is compared against the outputted levels from INSPIRE and, if necessary, the model can be adjusted. Currently over 100 separate impact piling noise datasets primarily from the North and Irish Seas have been used as part of the development for the latest version of INSPIRE, and in each case, an average, or slightly conservative, fit to the data is used. This means that for a given parameter set, some measured data points will be louder than the predicted level. Designing the model to over-predict for all parameters would ultimately lead to an over-precautionary and unrealistic model.

3.2.1.2 INSPIRE is designed to predict trends in the effect of increasing parameters beyond empirical data, and uses the data combined with standard acoustic theory to predict the effect of greater blow energies, larger piles and deeper water on the noise levels produced and propagated in the water.

3.2.1.3 The largest pile diameter included in the analysis for development of INSPIRE v5.3 was 9.5m in diameter, and the highest blow energy included was 3,000kJ. The model has been validated by comparing the noise levels outputted from the model with measurements and modelling undertaken by third parties, for example in Thompson *et al*. (2013) and Thompson *et al.* (2025, in prep.). In Thompson *et al.* (2025), piles up to 10m in diameter and blow energies up to 4400 kJ were modelled in blind testing against measured data, and a good agreement was found.

3.2.1.4 The version of INSPIRE used at the Project (v5.3) is the product of reanalysing all the impact piling noise in Subacoustech Environmental's measurement database and any other data available and cross-referencing it with blow energy data from piling logs. This gives a database of single strike noise levels referenced to a specific blow energy at a specific range and environmental conditions, primarily water depth.

3.2.1.5 Previous iterations of the INSPIRE model have endeavoured to give a worst-case estimate of underwater noise levels produced by various permutations of impact piling parameters. There is always some natural variability with underwater noise measurements, even when considering measurements of pile strikes under the same conditions (i.e., at the same blow energy, taken at the same range). For example, there can be variations in noise level of up to five or even 10dB, as seen in Bailey *et al*. (2010) and the data shown in **Plate 3.1** and **Plate 3.3**. When modelling using the upper bounds of this range, in combination with other worst-case parameter selections, conservatism can be compounded to create excessively overcautious predictions, especially when calculating $L_{E,p,t}$. With this in mind, the current version of INSPIRE attempts to calculate closer to the average fit of the measured noise levels at all ranges, and the use of worst-case parameters maintains a degree of precaution in the estimation.

3.2.1.6 **Plate 3.1** and **Plate 3.3** present a small selection of the measured impact piling noise data plotted against outputs from INSPIRE. The plots show data points from measured data (in blue) plotted alongside modelled data (in orange) using INSPIRE v5.3, matching the pile size, blow energy and position of the measured data. These show the fit to the data, with the INSPIRE data points placed, more or less, in the middle of the measured noise levels at each range (as also shown in **Plate 3.2** and **Plate 3.4**). When combined with the worst-case assumptions in parameter selection, modelled results will remain precautionary. The greatest deviations from the model tend to be at the greatest distances (>10km), where INSPIRE appears over-precautionary in many cases, but due to the lower relative levels the influence on the overall $L_{E,p,t}$ exposure will be small.

3.2.1.7 Statistical analysis has been conducted of the fits between measured data and modelled data to show the confidence present in INSPIRE modelling using v5.3. **Plate 3.2** and **Plate 3.4** show the distribution of the predicted against measured data for a slightly conservative fit with unweighted $L_{p,pk}$ (R^2 = 0.79) and unweighted $L_{E,p,ss}$ (R^2 = 0.82).

Plate 3.1 Comparison between example measured $L_{p,pk}$ impact piling data (blue) and modelled data using INSPIRE version 5.3 (orange)[1]

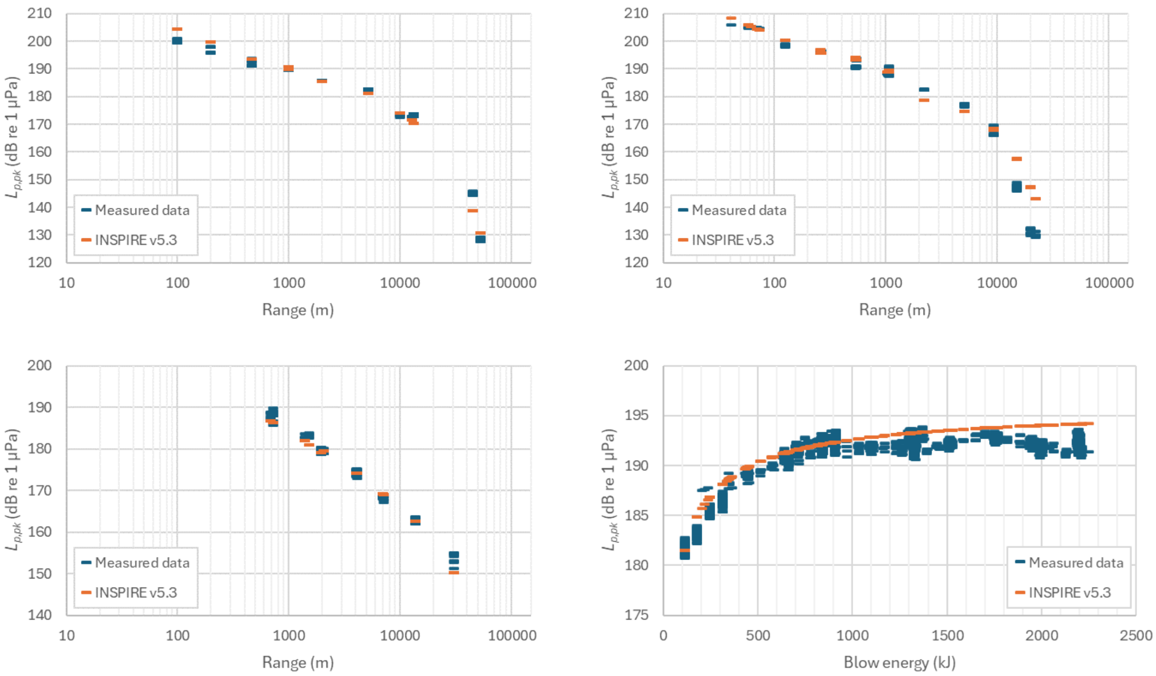
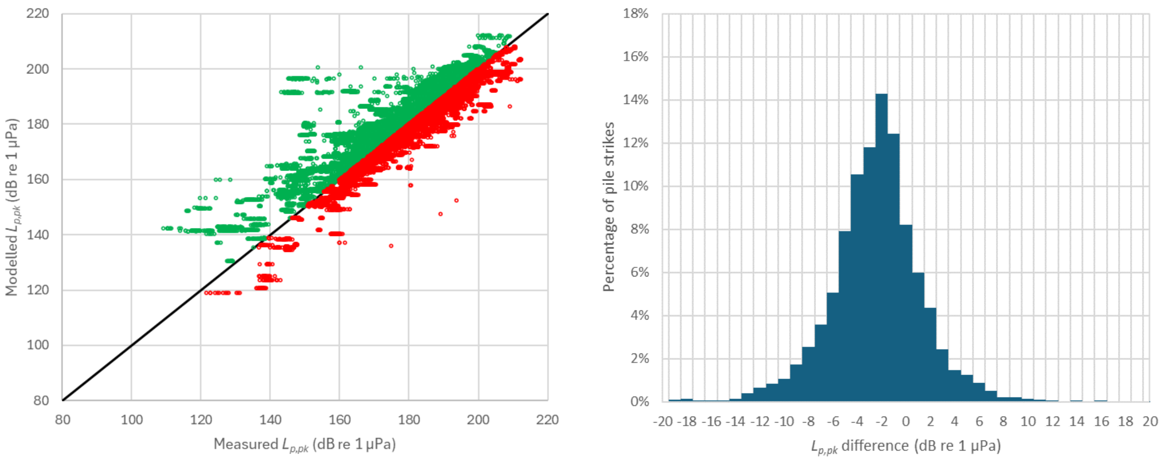


Plate 3.2 Distribution of measured impact piling data against modelled levels using INSPIRE v5.3 for unweighted $L_{p,pk}$ (R2 = 0.79)



[1] Top Left: 6.0m pile, 890kJ max hammer energy, Irish Sea, 2010; Top Right: 5.2m pile, 1,700kJ max hammer energy, Lincolnshire Coast, 2011; Bottom Left: 1.8m pile, 300kJ max hammer energy, North Sea, 2011; Bottom Right: 8.9m pile, 1.5km range, 2,250kJ max hammer energy, North Sea, 2024.

Plate 3.3 Comparison between example measured $L_{E,p,ss}$ impact piling data (blue) and modelled data using INSPIRE version 5.3 (orange)

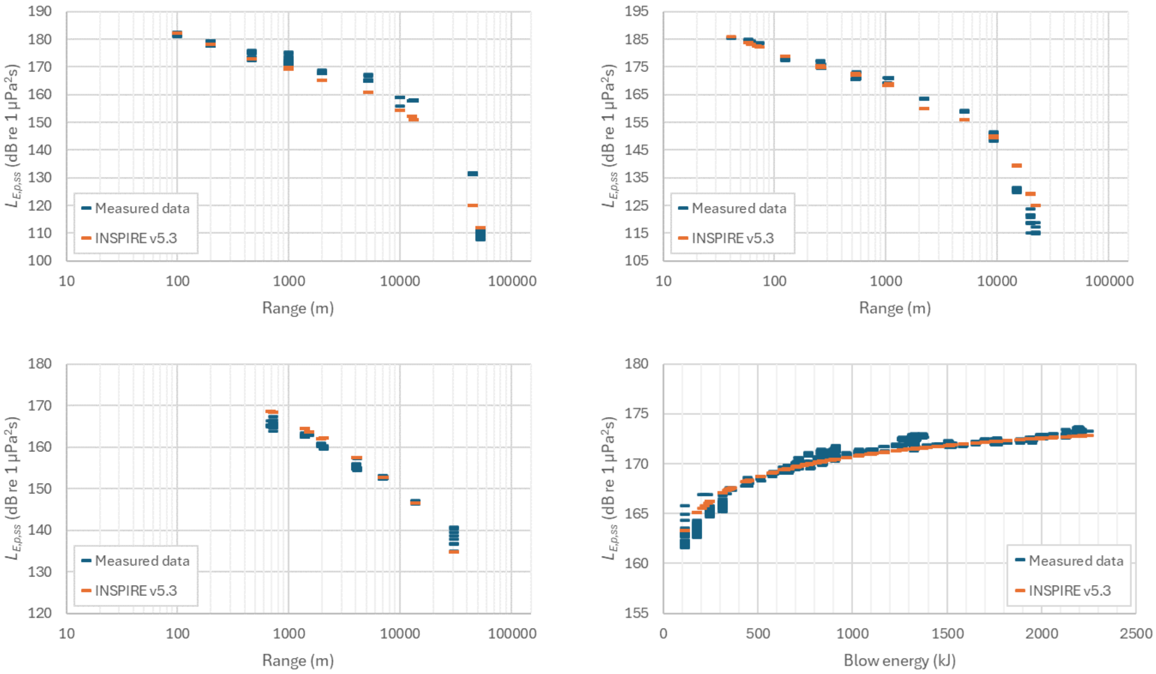
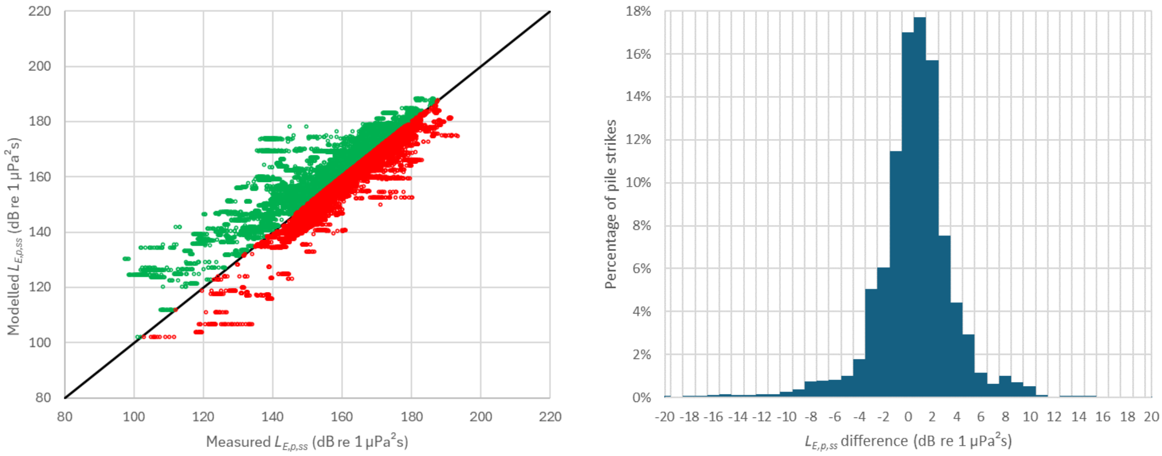


Plate 3.4 Distribution of measured impact piling data against modelled levels using INSPIRE v5.3 for unweighted $L_{E,p,ss}$ (R2 = 0.82)



3.2.1.8 Additional validation has been undertaken using data presented by von Pein *et al.* (2022), which studied trends in noise level with changes in piling parameters using data primarily acquired in the North Sea and Baltic Sea. The data showed a strong correlation with blow energy, and a lower correlation with pile diameter, which Subacoustech agrees with, although the calculated correlation based on that data appears to overestimate its trend. **Plate 3.5** and **Plate 3.6** are adapted from von Pein *et al.* (2022), replicating their results and overlaying with measured data from Subacoustech (selecting samples taken at the reference distance) and results at equivalent datapoints using INSPIRE v5.3.

3.2.1.9 This shows a very good agreement with Subacoustech's data (relating to blow energy). It should be noted that the upper and lower bounds for a correlation of noise level with pile diameter, based on the von Pein *et al.* (2022) data alone, could easily be close to horizontal; there is also no control for blow energy, which is not constant. With the inclusion of Subacoustech's data, there is little correlation at greater pile diameters, and it can be seen that the variations at a single pile diameter are largely controlled by changes in blow energy.

Plate 3.5 Data relating blow energy to noise level ($L_{E,p,ss}$) adapted from von Pein (2022) (green) overlaid with Subacoustech measured data (blue) and INSPIRE v5.3 predictions (orange). Scaling law bounds from von Pein (2022)

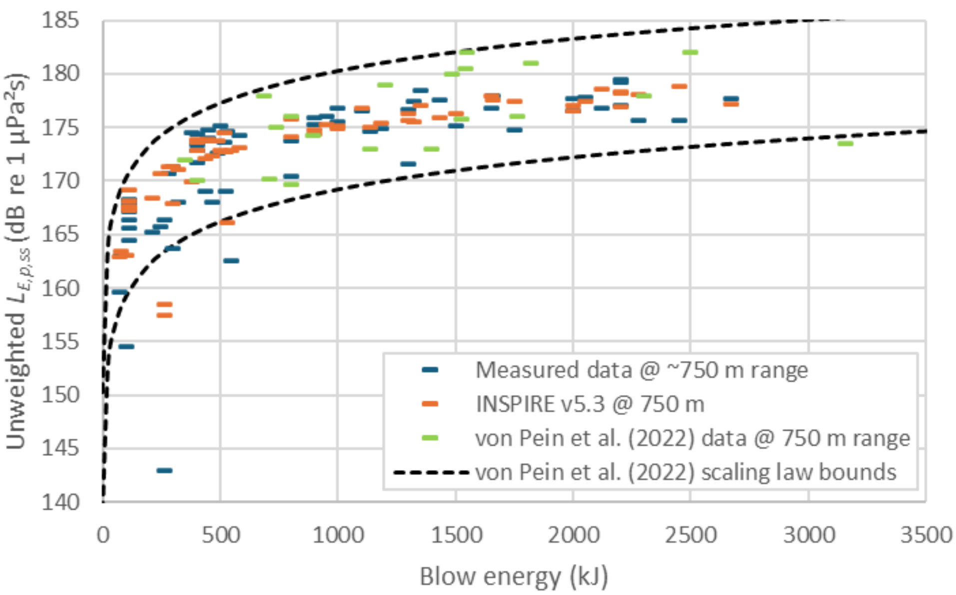
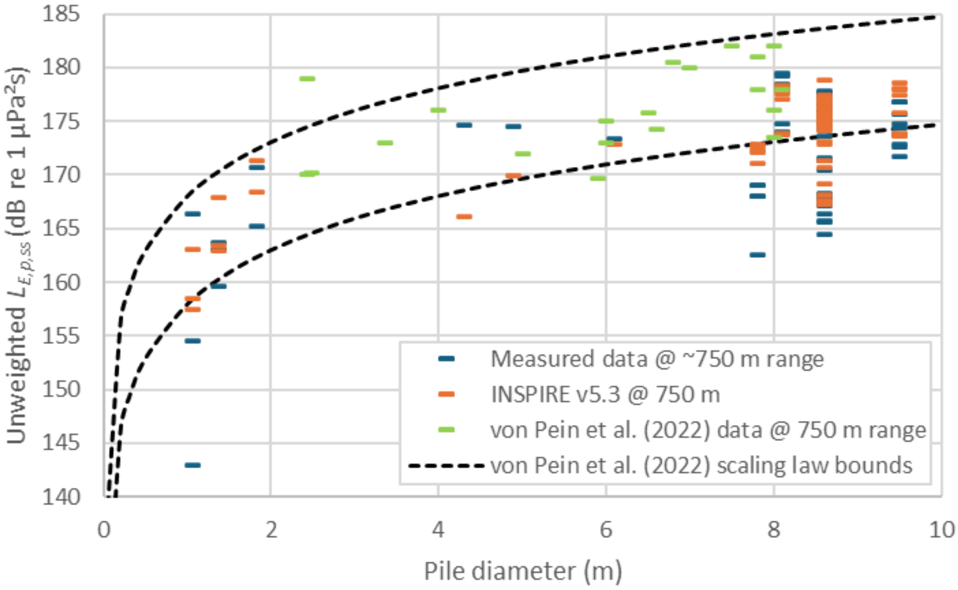


Plate 3.6 Data relating pile diameter to noise level ($L_{E,p,ss}$) adapted from von Pein (2022) (green) overlaid with Subacoustech measured data (blue) and INSPIRE v5.3 predictions (orange). Scaling law bounds from von Pein (2022)



3.3 Modelling parameters

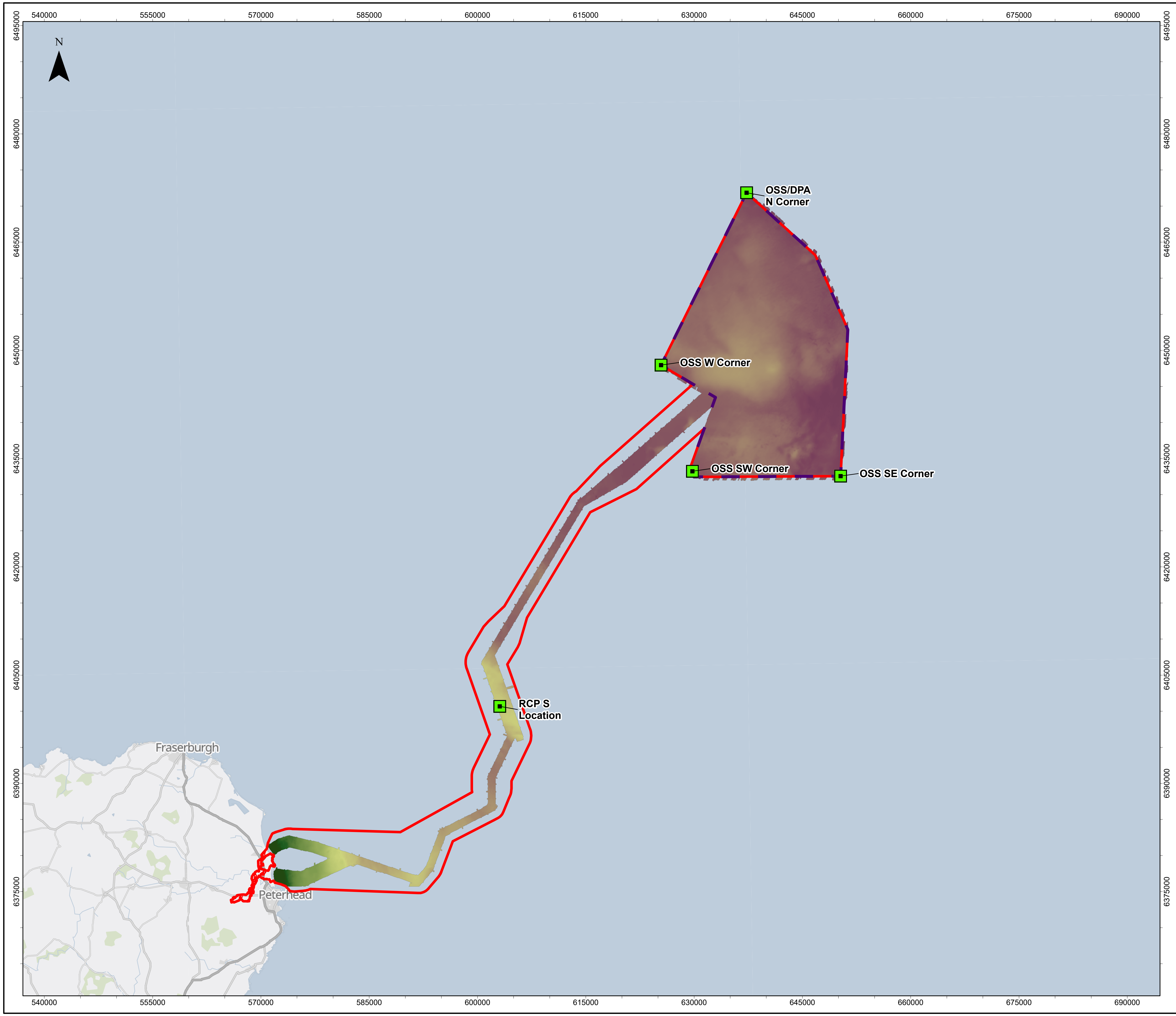
3.3.1 Modelling locations

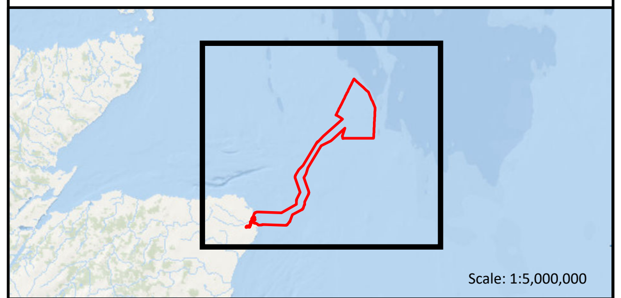
3.3.1.1 Modelling for driven pile installation has been undertaken at six representative locations covering the Project OAA and cable route, giving a spread of water depths, distances to shore and bathymetry stretching into deeper water. Four offshore substation locations have been selected at the corners of the OAA along with two RCP locations along the cable corridor. Driven pile anchors have been considered at the deepest, and therefore worst-case, offshore substation location at the north corner.

3.3.1.2 These locations are summarised in **Table 3.1** and illustrated in **Figure 2**.

Table 3.1 Summary of the underwater noise modelling locations used for this study (WGS 84) (OSS = offshore substation and DPA = drive pile anchor)

Modelling locations	Latitude	Longitude	Water depth
OSS SE corner	58.0093°N	0.4564°W	116 m
OSS SW corner	58.0218°N	0.8031°W	109 m
OSS / DPA N corner	58.3659°N	0.6534°W	117 m
OSS W corner	58.1551°N	0.8687°W	103 m
RCP S location	57.7363°N	1.2687°W	74 m
RCP N location	57.9679°N	1.0886°W	111 m





	dd/mm/yyyy	--	--	--	--
2	19/09/2025	PB	LT	LG	NC
1	15/07/2025	PB	LT	LG	NC
REV	REV DATE	GIS CREATOR	GIS REVIEWER	TECHNICAL CHECKER	TECHNICAL APPROVER

WSP DRAWING NUMBER 808368-WEIS-IA-E5-FG-U8-57754

MarramWind DRAWING NUMBER MAR-GEN-ENV-MAP-WSP-000173

DATUM	ETRS 89	PROJECTION	UTM Zone 30N
SCALE	1:500,000	PAGE SIZE	A3

PROJECT TITLE

MarramWind Offshore Wind Farm

DRAWING TITLE

Figure 2 Approximate positions of the modelling locations for the Project

Environmental Impact Assessment Report
Appendix 8.1

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MarramWind

3.3.2 Discounted reactive compensation platform North

3.3.2.1 Early in the Project's design evolution process, the southerly and northerly RCP locations (RCP S and RCP N respectively) described above were selected at locations along the offshore export cable corridor for the purposes of underwater noise modelling. These were in locations of relatively shallow and deeper water respectively. As the Project's design evolution progressed, the RCP N location was discounted as it was considered to be in an inappropriate location between the onshore and offshore substation locations (i.e. not close enough to the mid-point between the two substations) for the electrical engineering requirements of the Project's transmission.

3.3.2.2 The underwater noise modelling outputs were already produced by this time so the full findings, including those for RCP N are presented in this Appendix. The wider technical aspect chapter that make reference to this Appendix (most notably **Volume 1, Chapter 10: Benthic, Epibenthic and Intertidal Ecology**; **Chapter 11: Marine Mammals**; and **Chapter 13: Fish Ecology**) do not consider the underwater noise modelling output for RCP N.

3.3.2.3 It has not been deemed necessary to model an additional or replacement RCP location because the driven pile installation techniques (and therefore the maximum design parameters) used for the RCPs and offshore substations are the same, so the underwater noise modelling outputs for the RCPs and offshore substations can be directly compared. The underwater noise modelling has considered noise propagation in relatively shallow water (via the southerly RCP location) and relatively deep water (via the offshore substations). The outputs are therefore considered to remain representative of the variable water depths, distances to shore and bathymetry across the Offshore Red Line Boundary where driven piles may be installed.

3.3.3 Impact piling parameters

3.3.3.1 Two impact piling scenarios have been considered in this study, both involving 3m diameter piles installed with a maximum blow energy of 3,500kJ. The offshore substation and RCP driven piles measure 95m in length and the driven pile anchors measure 30m in length, with all the other parameters for the piling scenarios (blow energies, strike rates) being the same.

3.3.3.2 For $L_{E,p,t}$ criteria, the soft start and blow energies, along with the total duration of piling and strike rate, must be considered; this is summarised for the modelled scenarios in **Table 3.2**.

3.3.3.3 In a 24-hour period, it is expected that a maximum of two piles can be sequentially installed from the same piling vessel. This has been taken into consideration for the modelling. Where multiple sequential piles are modelled, no break has been assumed between each one as a worst-case scenario.

3.3.3.4 Due to the deep water and the length of anchor piles being used, the impact piling will take place subsea, with the hammer submerged. The modelling has assumed a length of 95m for the offshore substation and RCP piles and 30m for the driven pile anchors. Both piles will be installed to a depth so that 0.5m of the pile sits proud of the seabed once complete. The reduction in the radiating area of the pile has been considered when calculating the noise levels.

Table 3.2 Summary of the soft start and ramp up used for the impact piling modelling.

Impact piling	9% (320kJ)	14% (490kJ)	18% (630kJ)	38% (1330kJ)	62% (2170kJ)	76% (2660kJ)	81% (2835kJ)	100% (3500kJ)
No. of strikes	180	180	180	150	180	150	2331	150
Duration (minutes)	30	6	6	5	6	5	~78	5
Strike rate (bl/min)	6	30	30	30	30	30	30	30
3,501 strikes over 2 hours 20minutes 42 seconds per pile. 7,002 strikes over 4 hours 41 minutes 24 seconds for two sequentially installed piles.								

3.3.4 Apparent source levels

3.3.4.1 Noise modelling requires knowledge of a source level, which is the theoretical noise level at one metre from the noise source. It is worth noting that the 'source level' technically does not exist in the context of many shallow water (<100m) noise sources (Heaney *et al*., 2020). The noise level at one metre from the pile will be highly complex and vary up and down the water column by the pile, which is a long, extended noise source, rather than being one simple noise level. In practice, for underwater noise modelling such as this, it is effectively an 'apparent source level' that is used, essentially a value that can be used to produce correct noise levels at range (for a specific model), as required in impact assessments.

3.3.4.2 The INSPIRE model requires an apparent source level, which is estimated based on the pile diameter and the blow energy imparted on the pile by the hammer. This is adjusted depending on the water depth at the modelling location to allow for the length of the pile (and effective surface area) in contact with the water, which can affect the amount of noise that is transmitted from the pile into its surroundings. The unweighted, single strike $L_{p,pk}$ and $L_{E,p,ss}$ apparent source levels estimated for this study are provided in **Table 3.3**. These figures are presented in accordance with requests commonly made by regulatory authorities, although as indicated above, they are not necessarily compatible with any other model or predicted apparent source level. Due to the piling largely taking place subsea, the apparent source levels for the offshore substation and RCP driven pile locations are the same.

Table 3.3 Summary of the maximum unweighted source levels used for modelling (OSS = offshore substation and DPA = driven pile anchor)

Source levels	Modelling location	$L_{p,pk}$ @ 1m	$L_{E,p,ss}$ @ 1m
Offshore substation / RCP driven piles (3m diameter / 95m length / 3,500kJ hammer energy)	OSS SE corner	244.3dB re 1 µPa	217.0dB re 1 µPa²s
	OSS SW corner	244.3dB re 1 µPa	217.0dB re 1 µPa²s
	OSS N corner	244.3dB re 1 µPa	217.0dB re 1 µPa²s
	OSS W corner	244.3dB re 1 µPa	217.0dB re 1 µPa²s

Source levels	Modelling location	$L_{p,pk}$ @ 1m	$L_{E,p,ss}$ @ 1m
	RCP S location	244.3dB re 1 µPa	217.0dB re 1 µPa²s
	RCP N location	244.3dB re 1 µPa	217.0dB re 1 µPa²s
Driven pile anchors (3m diameter / 30m length / 3,500kJ hammer energy)	DPA N corner	243.1dB re 1 µPa	216.5dB re 1 µPa²s

3.3.5 Predicted noise levels at 750m from the noise source

3.3.5.1 In addition to the apparent source levels given in the previous section, it is useful to look at the potential noise levels at a range of 750m from the noise source, which is a common feature of underwater noise studies for where the primary consideration is impact piling.

3.3.5.2 These levels have the added advantage of being comparable with other modelling or measurements (as a valid measurement can be taken at this range), where the source level (or apparent source level) may not. A summary of the modelled, unweighted levels at a range of 750m is given in **Table 3.4**, considering the transect with the greatest noise transmission at each location while piling at the maximum hammer blow energy. Due to the subsea piling and the similar water depths at, and surrounding, the modelling locations, the differences between the offshore substation and RCP driven pile results are minimal.

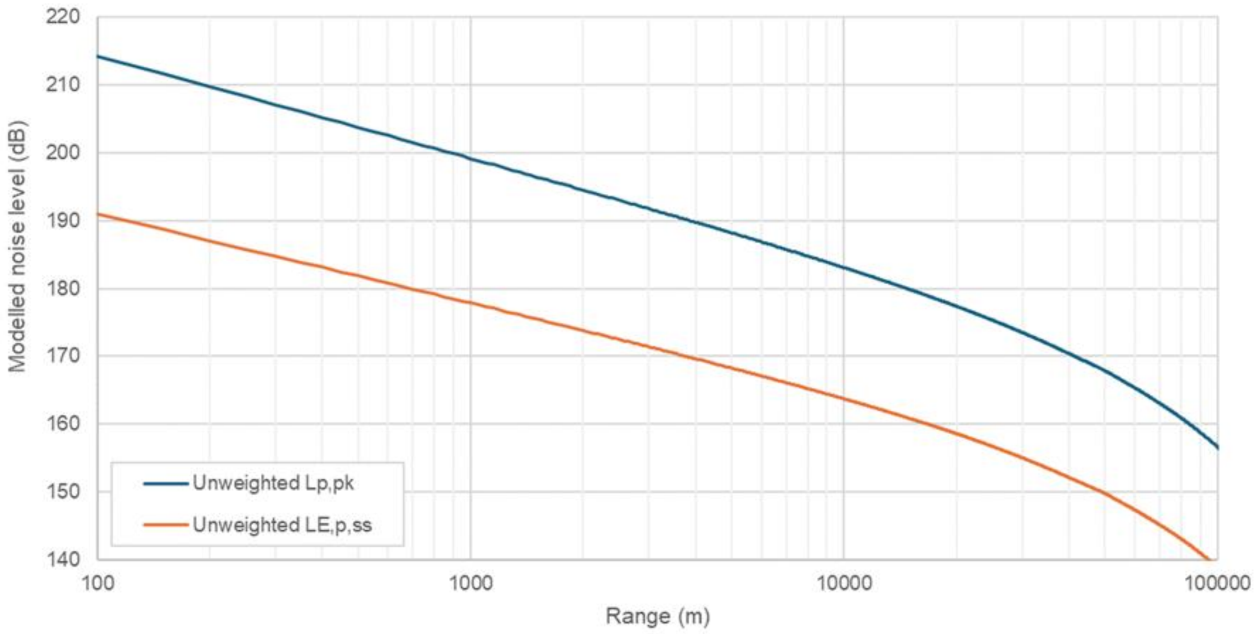
Table 3.4 Summary of the maximum predicted $L_{p,pk}$ and $L_{E,p,ss}$ (single strike) noise levels at a range of 750m from the noise source when considering the maximum hammer blow energy

Predicted levels at 750m range	Modelling location	$L_{p,pk}$ @ 750m	$L_{E,p,ss}$ @ 750m
Offshore substation / RCP driven piles (3m diameter / 95m length / 3,500kJ hammer energy)	OSS SE corner	201.1dB re 1 µPa	179.5dB re 1 µPa²s
	OSS SW corner	201.1dB re 1 µPa	179.5dB re 1 µPa²s
	OSS N corner	201.1dB re 1 µPa	179.5dB re 1 µPa²s
	OSS W corner	201.1dB re 1 µPa	179.5dB re 1 µPa²s
	RCP S location	200.9dB re 1 µPa	179.4dB re 1 µPa²s
	RCP N location	201.1dB re 1 µPa	179.5dB re 1 µPa²s
Driven pile anchors (3m diameter / 30m length / 3,500kJ hammer energy)	DPA N corner	199.8dB re 1 µPa	179.0dB re 1 µPa²s

3.3.6 Predicted noise levels against range

3.3.6.1 **Plate 3.7** has been provided in order to show the noise transmission, which can be used as a basis to compare and validate the levels against future noise monitoring. This plot presents the predicted unweighted $L_{p,pk}$ and $L_{E,p,ss}$ noise levels against range over the longest calculated transect to the northwest (332°), from the N corner modelling location, during installation of offshore substation driven piles using the maximum blow energy (3,500kJ). It should not be assumed necessarily comparable to any other transect or blow energy, although it is expected to present a worst-case scenario.

Plate 3.7 Modelled unweighted $L_{p,pk}$ and $L_{E,p,ss}$ noise levels with range for the maximum offshore substation driven pile blow energy from the N corner along a north-westerly transect



3.3.7 Environmental conditions

3.3.7.1 With the inclusion of measured noise propagation data for similar offshore piling operations in UK waters, the INSPIRE model intrinsically accounts for various environmental conditions. This includes the differences that can occur with the temperature and salinity of the water throughout the day or year, as well as the sediment type in and around the site. Data from the British Geological Survey (BGS) show that the seabed in and around the Project is generally made up of sand over a bedrock of sandstone.

3.3.7.2 Digital bathymetry from the European Marine Observation and Data Network (EMODnet) has been used for this modelling, with mean tidal depth assumed throughout.

3.4 $L_{E,p,t}$ and fleeing receptors

3.4.1.1 Expanding on the information in **Section 2.3** regarding $L_{E,p,t}$ and fleeing animal assumptions used for modelling, this section sets out to explain the methodology behind calculating these results to aid with interpretation.

3.4.1.2 When an $L_{E,p,t}$ impact range is presented for a fleeing animal, this range can be considered a starting position (at the commencement of piling) for the fleeing receptor. For example, if a receptor began to flee in a straight line from the noise source, starting at the position (distance from a pile) denoted by a modelled PTS contour, the receptor would receive exactly the noise exposure as per the PTS onset criterion under consideration.

3.4.1.3 When considering a stationary receptor (i.e., one that stays at the same position throughout piling, with no flee response), calculating the $L_{E,p,t}$ is straightforward: all the noise levels produced and received at a single point along a transect are aggregated to calculate the $L_{E,p,t}$. If this calculated level is greater than the threshold being modelled, the model steps away from the noise source and the noise levels from that new location are aggregated to calculate a new $L_{E,p,t}$. This continues outward until the threshold is met.

3.4.1.4 For a fleeing animal, the receptor's distance from the noise source while moving away also needs to be considered. To model this, a nominal starting point close to the source is chosen and the received noise level for each noise event (e.g., pile strike) is noted; the receptor moves away from the source at a defined speed throughout the piling event. For example, if a noise (i.e., a pulse from a pile strike) occurs every six seconds, and an animal is fleeing at a rate of 1.5m/s, it is 9m further from the source after each noise pulse, resulting in a slightly reduced noise level each time. These values are then aggregated into an $L_{E,p,t}$ value over the entire operation. The faster an animal is fleeing, the greater the distance travelled between noise pulses. The impact range outputted by the model for this situation is the distance the receptor must be at the start of the operation to exactly meet the exposure threshold.

3.4.1.5 As an example, the graphs **Plate 3.8** and **Plate 3.9** show the difference in the received $L_{E,p,t}$ from a stationary receptor and a fleeing receptor travelling at a constant speed of 1.5 m/s, using the offshore substation driven pile installation scenario at the N corner modelling location for a single pile installation.

3.4.1.6 The received single strike $L_{E,p,ss}$ from the stationary receptor, as illustrated in **Plate 3.8**, shows the noise level gradually increasing as the blow energy increases throughout the piling operation, and reducing slightly at the end of the piling operation as the radiating area reduces as the pile is installed. These step changes are also visible for the fleeing receptor, but as the receptor is further from the noise source by the time the levels increase, the total received exposure reduces, resulting in progressively lower received noise levels. As an example, for the first 30minutes of piling, where the blow energy for the monopile is 320kJ (9% of maximum energy), fleeing at a rate of 1.5m/s, a receptor has the potential to move 2.7km from the noise source. After the full installation of 2 hours, 20minutes, the receptor has the potential to be over 12km from the noise source.

3.4.1.7 **Plate 3.9** shows the effect that these different received levels have when calculating the $L_{E,p,t}$, clearly showing the difference in the cumulative levels between a receptor remaining still, as opposed to fleeing. To use an extreme example, starting at a range of 1m, the first strike results in a received level of 210.9dB re 1 μPa^{2}s. If the receptor were to remain stationary at a point 1m from the pile throughout the piling operation, it would receive a cumulative noise exposure of 251.7dB re 1 μPa^{2}s, whereas when fleeing at 1.5m/s over the same scenario, a cumulative received exposure of just 211.7dB re 1 μPa^{2}s would be received.

3.4.1.8 To summarise, if the receptor were to start fleeing in a straight line from the noise source starting at a range closer than the modelled value, it would receive a noise exposure in excess of the criterion, and if the receptor were to start fleeing from a range further than the modelled value, it would receive a noise exposure below the criterion. This is illustrated in **Plate 3.7**.

Plate 3.8 Received single strike noise levels ($L_{E,p,ss}$) for receptors during offshore substation driven pile installation at the N corner modelling location, assuming both a stationary and fleeing receptor starting at a location 1 m from the noise source

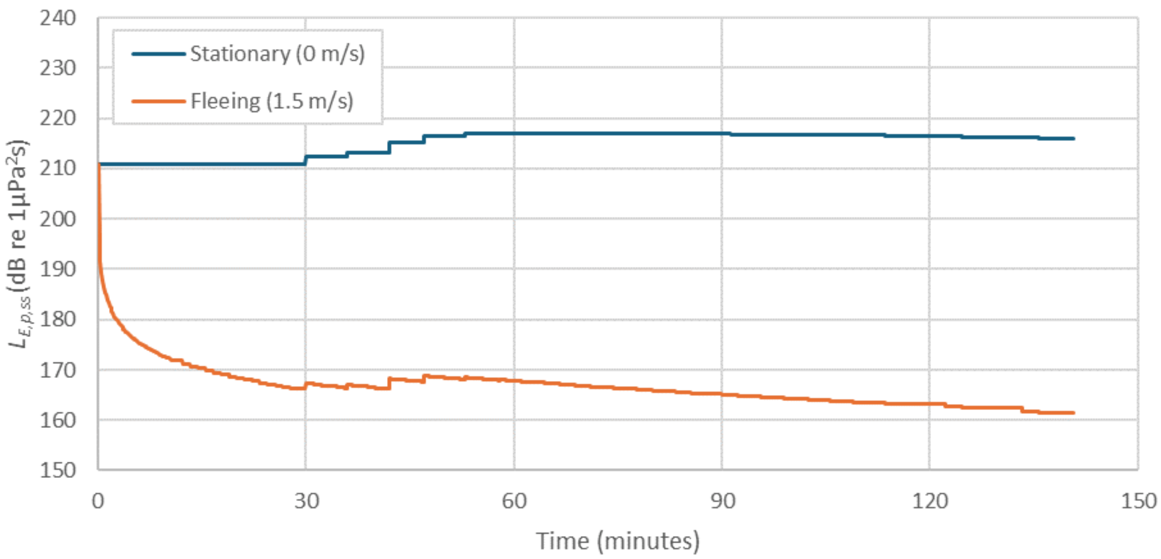
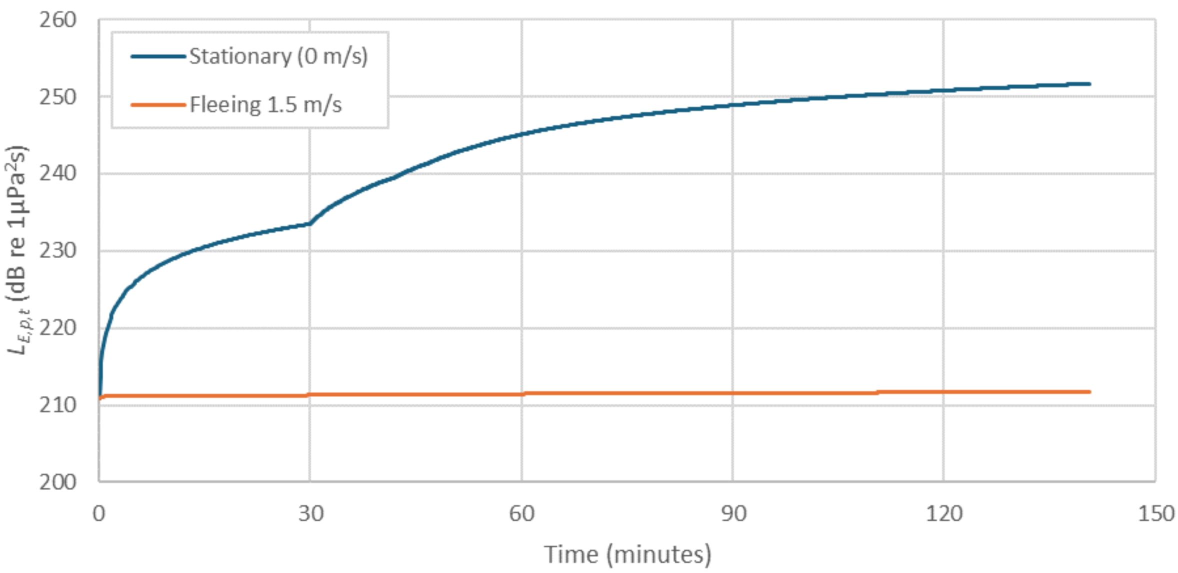
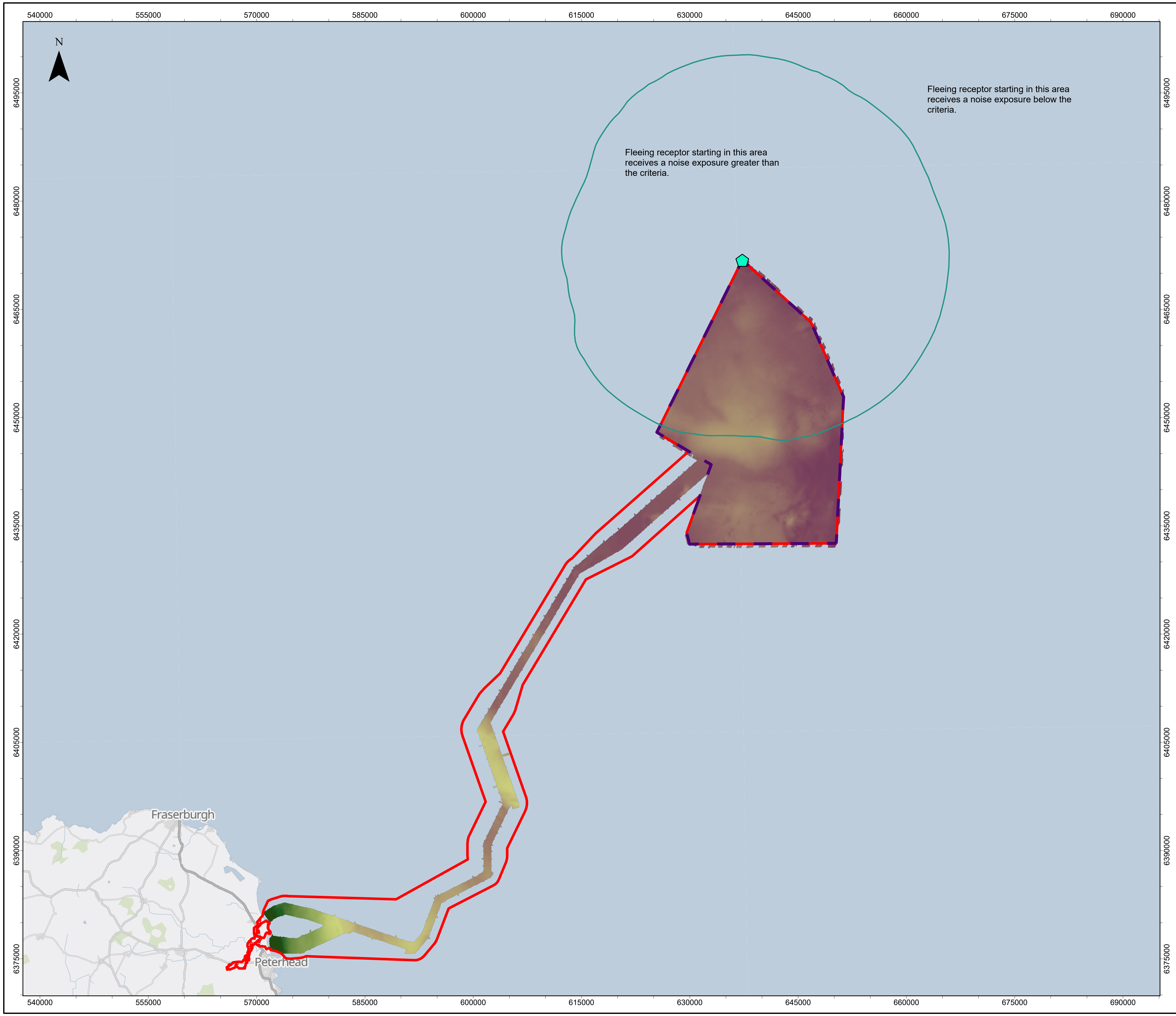


Plate 3.9 Cumulative received noise level ($L_{E,p,t}$) for receptors during offshore substation pile installation at the N corner modelling location, assuming both a stationary and fleeing receptor starting at a location 1 m from the noise source



3.4.1.9 Some modelling approaches include the effects of Acoustic Deterrent Devices (ADDs) that cause receptors to flee from the immediate area around the pile before activity commences. Subacoustech Environmental's approach does not include this, however the efficacy of using an ADD can still be inferred from the results. For example, if a receptor were to flee for 20minutes from an ADD at a rate of 1.5m/s, it would travel 1.8km before piling begins. If a calculated cumulative $L_{E,p,t}$ impact range was below 1.8km, it can be assumed that the ADD will be effective in eliminating the risk of exceedance of the threshold. The noise from an ADD is of a much lower level than impact piling, and as such its overall effect on the total $L_{E,p,t}$ exposure would be minimal (see **Figure 3**).



Red Line Boundary

Option Agreement Area

Marram DPA N x2 Unwtd 186dB SELcum (Flee 1,5)

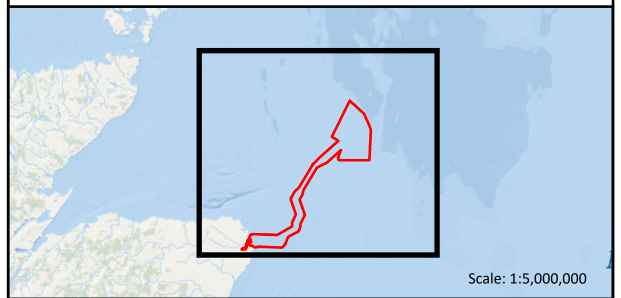
North corner modelling location

Bathymetry (m)

-2

-133.507

0 10 20 Kilometres



	dd/mm/yyyy	--	--	--	--
2	19/09/2025	PB	LT	LG	NC
1	14/08/2025	PB	LT	LG	NC
REV	REV DATE	GIS CREATOR	GIS REVIEWER	TECHNICAL CHECKER	TECHNICAL APPROVER

WSP DRAWING NUMBER 808368-WEIS-IA-E5-FG-U8-13572

MarramWind DRAWING NUMBER MAR-GEN-ENV-MAP-WSP-000176

DATUM	ETRS 89	PROJECTION	UTM Zone 30N
SCALE	1:500,000	PAGE SIZE	A3

PROJECT TITLE

MarramWind Offshore Wind Farm

DRAWING TITLE

Figure 3 Example plot showing a fleeing animal LE,p,t criteria contour and the areas where the cumulative noise exposure will exceed a given impact criterion

Environmental Impact Assessment Report

Appendix 8.1

NOT TO BE USED FOR NAVIGATION

wsp

MarramWind

3.4.2 The effects of input parameters on $L_{E,p,t}$ and fleeing receptors

3.4.2.1 As discussed earlier, parameters such as bathymetry, hammer blow energies, piling ramp up, strike rate and duration all influence predicted noise levels and exposures. When considering $L_{E,p,t}$ and a fleeing animal model, some of these parameters can have a greater influence on the predicted noise levels than others.

3.4.2.2 Parameters such as hammer blow energy can have a clear effect on the impact ranges, with higher energies resulting in high apparent source noise levels and therefore larger impact ranges. When considering cumulative noise levels, these higher levels are compounded, sometimes thousands of times, due to the number of pile strikes. With this in mind, the ramp up from lower to higher blow energies requires careful consideration for fleeing receptors, as levels while the receptor is closer to the noise source will have a greater effect on the overall cumulative exposure level.

3.4.2.3 Linked to the effect of the ramp up is the strike rate, as the more pile strikes that occur while the receptor is close to the noise source, the greater the exposure and the greater effect it will have to the $L_{E,p,t}$. The faster the strike rate, the shorter the distance the receptor can flee between each pile strike, which leads to a greater exposure overall.

3.4.2.4 In general, the greatest contribution to the received exposure is found when a receptor is close to the noise source. If high blow energies or a fast strike rate are implemented at or close to the start of piling activities, it will tend to make impact ranges worse.

3.4.2.5 Another factor that can cause big differences in calculated impact ranges is the bathymetry, as deeper water results in a slower attenuation of noise (i.e., levels remain higher over greater distances). However, it is not feasible to limit piling activity in or near to deep water at the Project.

4. Modelling Results

4.1.1.1 This section presents the modelled impact ranges from impact piling to install piled foundations for jacket structures and turbine moorings at the Project following the parameters detailed in **Section 3.3**. These results cover the Southall *et al*. (2019) marine mammal criteria (**Section 2.3.3**), and the Popper *et al*. (2014) fish criteria (**Section 2.3.4**).

4.1.1.2 To aid navigation, **Table 4.1** gives a list of the results tables presented in **Section 4.2**. The largest modelled ranges from impact piling at the Project are predicted at the offshore substation N corner modelling location due to the deep water at, and surrounding, that location. However, due to the similar water depths and subsea piling, most of the calculated impact ranges are similar. Modelling covering concurrent piling at multiple locations is presented in **Section 4.3**.

4.1.1.3 Throughout this Report any predicted ranges smaller than 50m and areas less than 0.01km^2 for single strike criteria, and ranges smaller than 100m and areas less than 0.1km^2 for cumulative criteria, have not been presented in detail. At ranges this close to the noise source, the modelling processes are unable to model to a sufficient level of accuracy due to complex acoustic effects present near the source. These ranges are given as “less than” this limit (e.g., <100m).

4.1.1.4 The modelling results for the Southall *et al*. (2019) non-impulsive marine mammal criteria are presented in **Appendix A**.

Table 4.1 Summary of the single location impact piling modelling results presented in Section 4.2

Table (page)	Parameters	Criteria		
Table 4.2	Offshore substation driven piles SE corner (**Section 4.2.1**).	Southall *et al.* (2019).	Unweighted $L_{p,pk}$ (Impulsive)	
Table 4.3			Weighted $L_{E,p,24h,wtd}$ (Impulsive)	Single pile
Table 4.4				Two sequential piles
Table 4.5		Popper *et al*. (2014).	Unweighted $L_{p,pk}$ (Pile driving)	
Table 4.6			Unweighted $L_{E,p,24h}$ (Pile driving)	Single pile
Table 4.7				Two sequential piles
Table 4.8	Offshore substation driven piles SW corner (**Section 4.2.2**).	Southall *et al.* (2019).	Unweighted $L_{p,pk}$ (Impulsive)	
Table 4.9			Weighted $L_{E,p,24h,wtd}$ (Impulsive)	Single pile
Table 4.10				Two sequential piles
Table 4.11		Popper *et al*. (2014).	Unweighted $L_{p,pk}$ (Pile driving)	
Table 4.12			Unweighted $L_{E,p,24h}$ (Pile driving)	Single pile
Table 4.13				Two sequential piles
Table 4.14			Unweighted $L_{p,pk}$ (Impulsive)	

Table (page)	Parameters	Criteria		
Table 4.15	Offshore substation driven piles N corner (**Section 4.2.3**).	Southall *et al.* (2019).	Weighted $L_{E,p,24h,wtd}$ (Impulsive)	Single pile
Table 4.16				Two sequential piles
Table 4.17		Popper *et al.* (2014).	Unweighted $L_{p,pk}$ (Pile driving)	
Table 4.18			Unweighted $L_{E,p,24h}$ (Pile driving)	Single pile
Table 4.19				Two sequential piles
Table 4.20	Offshore substation driven piles W corner (**Section 4.2.4**).	Southall *et al.* (2019).	Unweighted $L_{p,pk}$ (Impulsive)	
Table 4.21			Weighted $L_{E,p,24h,wtd}$ (Impulsive)	Single pile
Table 4.22				Two sequential piles
Table 4.23		Popper *et al.* (2014).	Unweighted $L_{p,pk}$ (Pile driving)	
Table 4.24			Unweighted $L_{E,p,24h}$ (Pile driving)	Single pile
Table 4.25				Two sequential piles
Table 4.26	RCP driven piles S location (**Section 4.2.5**).	Southall *et al.* (2019).	Unweighted $L_{p,pk}$ (Impulsive)	
Table 4.27			Weighted $L_{E,p,24h,wtd}$ (Impulsive)	Single pile
Table 4.28				Two sequential piles
Table 4.29		Popper *et al.* (2014).	Unweighted $L_{p,pk}$ (Pile driving)	
Table 4.30			Unweighted $L_{E,p,24h}$ (Pile driving)	Single pile
Table 4.31				Two sequential piles
Table 4.32	RCP driven piles N location (**Section 4.2.6**).	Southall *et al.* (2019).	Unweighted $L_{p,pk}$ (Impulsive)	
Table 4.33			Weighted $L_{E,p,24h,wtd}$ (Impulsive)	Single pile
Table 4.34				Two sequential piles
Table 4.35		Popper *et al.* (2014).	Unweighted $L_{p,pk}$ (Pile driving)	
Table 4.36			Unweighted $L_{E,p,24h}$ (Pile driving)	Single pile
Table 4.37				Two sequential piles
Table 4.38	Driven pile anchors N corner (**Section 4.2.7**).	Southall *et al.* (2019).	Unweighted $L_{p,pk}$ (Impulsive)	
Table 4.39			Weighted $L_{E,p,24h,wtd}$ (Impulsive)	Single pile
Table 4.40				Two sequential piles
Table 4.41		Popper *et al.* (2014).	Unweighted $L_{p,pk}$ (Pile driving)	
Table 4.42			Unweighted $L_{E,p,24h}$ (Pile driving)	Single pile
Table 4.43				Two sequential piles

4.1.1.5 **Table 4.2** to **Table 4.43** present the impact piling modelling results at the Project, covering offshore substation and RCP foundations, and driven pile anchors. For these scenarios, the largest marine mammal impact ranges are predicted for the LF cetaceans using the impulsive $L_{E,p,24h,wtd}$ criteria at the N corner for offshore substation driven piles with maximum PTS ranges of 25km. For fish, the largest recoverable injury ranges (203dB $L_{E,p,24h}$) are predicted out to 4.9km for a stationary receptor. These ranges reduce to less than 100m when a fleeing receptor is assumed.

4.1.1.6 Differences between single pile and sequential installed piles results are relatively small for fleeing receptors. This is due to the range at which the receptors have reached by the time the second piling operation begins, at these ranges the additional noise exposure is much less than it was for the first pile.

4.2 Single location modelling

4.2.1 Offshore substation southeast corner

Table 4.2 Summary of the unweighted $L_{p,pk}$ impact ranges for marine mammals using the Southall *et al*. (2019) impulsive criteria covering the offshore substation driven pile installation at the southeast corner modelling location

Southall *et al*. (2019) Unweighted $L_{p,pk}$		Offshore substation driven piles			
		Area	**Maximum range**	**Minimum range**	**Mean range**
PTS (Impulsive)	LF (219dB)	0.01km^2	50m	< 50m	50m
	HF (230dB)	< 0.01km^2	< 50m	< 50m	< 50m
	VHF (202dB)	1.3km^2	660m	650m	660m
	PCW (218dB)	0.01km^2	60m	60m	60m
TTS (Impulsive)	LF (213dB)	0.05km^2	120m	120m	120m
	HF (224dB)	< 0.01km^2	< 50m	< 50m	< 50m
	VHF (196dB)	8.1km^2	1.6km	1.6km	1.6km
	PCW (212dB)	0.06km^2	140m	140m	140m

Table 4.3 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria covering the offshore substation driven pile installation modelling for a single pile at the southeast corner modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		**Offshore substation driven piles (single pile)**			
		Area	**Maximum range**	**Minimum range**	**Mean range**
PTS (Impulsive)	LF (183dB)	1,100km²	20km	17km	19km
	HF (185dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (155dB)	17km²	2.4km	2.2km	2.3km
	PCW (185dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Impulsive)	LF (168dB)	18,000km²	91km	66km	77km
	HF (170dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (140dB)	4,100km²	39km	33km	36km
	PCW (170dB)	1,200km²	21km	18km	19km

Table 4.4 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria covering the offshore substation driven pile installation modelling for two sequentially installed piles at the southeast corner modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		**Offshore substation driven piles (two sequentially installed piles)**			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183dB)	1,500km²	24km	20km	22km
	HF (185dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (155dB)	32km²	3.3km	3.0km	3.2km
	PCW (185dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Impulsive)	LF (168dB)	22,000km²	101km	68km	83km
	HF (170dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (140dB)	5,800km²	48km	39km	43km
	PCW (170dB)	1,800km²	27km	21km	24km

Table 4.5 Summary of the unweighted $L_{p,pk}$ impact ranges for fish using the Popper *et al.* (2014) pile driving criteria covering the offshore substation driven pile installation at the southeast corner modelling location

Popper *et al.* (2014) Unweighted $L_{p,pk}$		Offshore substation driven piles			
		Area	**Maximum range**	**Minimum range**	**Mean range**
Pile driving	213dB	0.05km^2	120m	120m	120m
	207dB	0.29km^2	310m	310m	310m

Table 4.6 Summary of the unweighted $L_{E,p,24h}$ impact ranges for fish using the Popper *et al.* (2014) pile driving criteria covering the offshore substation driven pile installation modelling for a single pile at the southeast corner modelling location

Popper *et al.* (2014) Unweighted $L_{E,p,24h}$		Offshore substation driven piles (single pile)			
		Area	**Maximum range**	**Minimum range**	**Mean range**
Pile driving (Fleeing 1.5 m/s)	219dB	< 0.1km^2	< 100m	< 100m	< 100m
	216dB	< 0.1km^2	< 100m	< 100m	< 100m
	210dB	< 0.1km^2	< 100m	< 100m	< 100m
	207dB	< 0.1km^2	< 100m	< 100m	< 100m
	203dB	< 0.1km^2	< 100m	< 100m	< 100m
	186dB	1,700km^2	25km	21km	23km
Pile driving (Stationary 0.0m/s)	219dB	0.14km^2	230m	200m	210m
	216dB	0.36km^2	350m	330m	340m
	210dB	2.8km^2	950m	930m	940m
	207dB	7.6km^2	1.6km	1.6km	1.6km
	203dB	28km^2	3.1km	3.0km	3.0km
	186dB	3,000km^2	32km	29km	31km

Table 4.7 Summary of the unweighted $L_{E,p,24h}$ impact ranges for fish using the Popper *et al.* (2014) pile driving criteria covering the offshore substation driven pile installation modelling for two sequentially installed piles at the southeast corner modelling location

Popper *et al.* (2014) Unweighted $L_{E,p,24h}$		**Offshore substation driven piles (two sequentially installed piles)**			
		Area	Maximum range	Minimum range	Mean range
Pile driving (Fleeing 1.5 m/s)	219dB	< 0.1km^2	< 100m	< 100m	< 100m
	216dB	< 0.1km^2	< 100m	< 100m	< 100m
	210dB	< 0.1km^2	< 100m	< 100m	< 100m
	207dB	< 0.1km^2	< 100m	< 100m	< 100m
	203dB	< 0.1km^2	< 100m	< 100m	< 100m
	186dB	2,600km^2	31km	26km	29km
Pile driving (Stationary 0.0m/s)	219dB	0.36km^2	350m	330m	340m
	216dB	0.99km^2	580m	550m	560m
	210dB	7.6km^2	1.6km	1.6km	1.6km
	207dB	21km^2	2.6km	2.6km	2.6km
	203dB	75km^2	4.9km	4.9km	4.9km
	186dB	5,300km^2	44km	38km	41km

4.2.2 Offshore substation southwest corner

Table 4.8 Summary of the unweighted $L_{p,pk}$ impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria covering the offshore substation driven pile installation at the southwest corner modelling location

Southall *et al.* (2019) Unweighted $L_{p,pk}$		Offshore substation driven piles			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219dB)	0.01km²	50m	< 50m	50m
	HF (230dB)	< 0.01km²	< 50m	< 50m	< 50m
	VHF (202dB)	1.3km²	650m	650m	650m
	PCW (218dB)	0.01km²	60m	60m	60m
TTS (Impulsive)	LF (213dB)	0.05km²	120m	120m	120m
	HF (224dB)	< 0.01km²	< 50m	< 50m	< 50m
	VHF (196dB)	8.1km²	1.6km	1.6km	1.6km
	PCW (212dB)	0.06km²	140m	140m	140m

Table 4.9 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria covering the offshore substation driven pile installation modelling for a single pile at the southwest corner modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		Offshore substation driven piles (single pile)			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183dB)	1,000km²	19km	17km	18km
	HF (185dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (155dB)	16km²	2.3km	2.2km	2.3km
	PCW (185dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Impulsive)	LF (168dB)	17,000km²	86km	61km	73km
	HF (170dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (140dB)	3,900km²	37km	33km	35km
	PCW (170dB)	1,100km²	19km	18km	19km

Table 4.10 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al*. (2019) impulsive criteria covering the offshore substation driven pile installation modelling for two sequentially installed piles at the southwest corner modelling location

Southall *et al*. (2019) Weighted $L_{E,p,24h,wtd}$		Offshore substation driven piles (two sequentially installed piles)			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183dB)	1,400km^2	22km	20km	21km
	HF (185dB)	< 0.1km^2	< 100m	< 100m	< 100m
	VHF (155dB)	30km^2	3.2km	3.0km	3.1km
	PCW (185dB)	< 0.1km^2	< 100m	< 100m	< 100m
TTS (Impulsive)	LF (168dB)	20,000km^2	97km	61km	80km
	HF (170dB)	< 0.1km^2	< 100m	< 100m	< 100m
	VHF (140dB)	5,300km^2	44km	37km	41km
	PCW (170dB)	1,700km^2	24km	22km	23km

Table 4.11 Summary of the unweighted $L_{p,pk}$ impact ranges for fish using the Popper *et al.* (2014) pile driving criteria covering the offshore substation driven pile installation at the southwest corner modelling location

Popper *et al*. (2014) Unweighted $L_{p,pk}$		Offshore substation driven piles			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213dB	0.05km^2	120m	120m	120m
	207dB	0.29km^2	310m	310m	310m

Table 4.12 Summary of the unweighted $L_{E,p,24h}$ impact ranges for fish using the Popper *et al.* (2014) pile driving criteria covering the offshore substation driven pile installation modelling for a single pile at the southwest corner modelling location

Popper *et al*. (2014) Unweighted $L_{E,p,24h}$		Offshore substation driven piles (single pile)			
		Area	Maximum range	Minimum range	Mean range
Pile driving (Fleeing 1.5 m/s)	219dB	< 0.1km^2	< 100m	< 100m	< 100m
	216dB	< 0.1km^2	< 100m	< 100m	< 100m
	210dB	< 0.1km^2	< 100m	< 100m	< 100m

Popper *et al.* (2014) Unweighted $L_{E,p,24h}$		**Offshore substation driven piles (single pile)**			
		Area	**Maximum range**	**Minimum range**	**Mean range**
	207dB	< 0.1km^2	< 100m	< 100m	< 100m
	203dB	< 0.1km^2	< 100m	< 100m	< 100m
	186dB	1,600km^2	23km	22km	23km
Pile driving (Stationary 0.0m/s)	219dB	0.14km^2	230m	200m	210m
	216dB	0.36km^2	350m	330m	340m
	210dB	2.8km^2	950m	930m	940m
	207dB	7.4km^2	1.6km	1.5km	1.5km
	203dB	28km^2	3.0km	3.0km	3.0km
	186dB	2,900km^2	31km	29km	30km

Table 4.13 Summary of the unweighted $L_{E,p,24h}$ impact ranges for fish using the Popper *et al.* (2014) pile driving criteria covering the offshore substation driven pile installation modelling for two sequentially installed piles at the southwest corner modelling location

Popper *et al.* (2014) Unweighted $L_{E,p,24h}$		**Offshore substation driven piles (two sequentially installed piles)**			
		Area	**Maximum range**	**Minimum range**	**Mean range**
Pile driving (Fleeing 1.5 m/s)	219dB	< 0.1km^2	< 100m	< 100m	< 100m
	216dB	< 0.1km^2	< 100m	< 100m	< 100m
	210dB	< 0.1km^2	< 100m	< 100m	< 100m
	207dB	< 0.1km^2	< 100m	< 100m	< 100m
	203dB	< 0.1km^2	< 100m	< 100m	< 100m
	186dB	2,400km^2	29km	26km	28km
Pile driving (Stationary 0.0m/s)	219dB	0.36km^2	350m	330m	340m
	216dB	0.99km^2	580m	550m	560m
	210dB	7.6km^2	1.6km	1.6km	1.6km
	207dB	21km^2	2.6km	2.6km	2.6km
	203dB	74km^2	4.9km	4.9km	4.9km
	186dB	5,000km^2	42km	38km	40km

4.2.3 Offshore substation north corner

Table 4.14 Summary of the unweighted $L_{p,pk}$ impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria covering the offshore substation driven pile installation at the north corner modelling location

Southall *et al.* (2019) Unweighted $L_{p,pk}$		Offshore substation driven piles			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219dB)	0.01km²	50m	< 50m	50m
	HF (230dB)	< 0.01km²	< 50m	< 50m	< 50m
	VHF (202dB)	1.3km²	660m	650m	660m
	PCW (218dB)	0.01km²	60m	60m	60m
TTS (Impulsive)	LF (213dB)	0.05km²	120m	120m	120m
	HF (224dB)	< 0.01km²	< 50m	< 50m	< 50m
	VHF (196dB)	8.1km²	1.6km	1.6km	1.6km
	PCW (212dB)	0.06km²	140m	140m	140m

Table 4.15 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria covering the offshore substation driven pile installation modelling for a single pile at the north corner modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		Offshore substation driven piles (single pile)			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183dB)	1,100km²	20km	18km	19km
	HF (185dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (155dB)	17km²	2.4km	2.3km	2.4km
	PCW (185dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Impulsive)	LF (168dB)	20,000km²	91km	68km	80km
	HF (170dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (140dB)	4,300km²	40km	34km	37km
	PCW (170dB)	1,300km²	21km	18km	20km

Table 4.16 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria covering the offshore substation driven pile installation modelling for two sequentially installed piles at the north corner modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		Offshore substation driven piles (two sequentially installed piles)			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183dB)	1,600km^2	25km	20km	23km
	HF (185dB)	< 0.1km^2	< 100m	< 100m	< 100m
	VHF (155dB)	33km^2	3.4km	3.1km	3.3km
	PCW (185dB)	< 0.1km^2	< 100m	< 100m	< 100m
TTS (Impulsive)	LF (168dB)	24,000km^2	101km	71km	87km
	HF (170dB)	< 0.1km^2	< 100m	< 100m	< 100m
	VHF (140dB)	6,100km^2	48km	39km	44km
	PCW (170dB)	1,900km^2	27km	22km	25km

Table 4.17 Summary of the unweighted $L_{p,pk}$ impact ranges for fish using the Popper *et al.* (2014) pile driving criteria covering the offshore substation driven pile installation at the north corner modelling location

Popper *et al.* (2014) Unweighted $L_{p,pk}$		Offshore substation driven piles			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213dB	0.05km^2	120m	120m	120m
	207dB	0.29km^2	310m	310m	310m

Table 4.18 Summary of the unweighted $L_{E,p,24h}$ impact ranges for fish using the Popper *et al.* (2014) pile driving criteria covering the offshore substation driven pile installation modelling for a single pile at the north corner modelling location

Popper *et al.* (2014) Unweighted $L_{E,p,24h}$		Offshore substation driven piles (single pile)			
		Area	Maximum range	Minimum range	Mean range
Pile driving (Fleeing 1.5m/s)	219dB	< 0.1km^2	< 100m	< 100m	< 100m
	216dB	< 0.1km^2	< 100m	< 100m	< 100m
	210dB	< 0.1km^2	< 100m	< 100m	< 100m

Popper *et al.* (2014) Unweighted $L_{E,p,24h}$		Offshore substation driven piles (single pile)			
		Area	**Maximum range**	**Minimum range**	**Mean range**
	207dB	< 0.1km^2	< 100m	< 100m	< 100m
	203dB	< 0.1km^2	< 100m	< 100m	< 100m
	186dB	1,800km^2	25km	22km	24km
Pile driving (Stationary 0.0m/s)	219dB	0.14km^2	230m	200m	210m
	216dB	0.36km^2	350m	330m	340m
	210dB	2.8km^2	950m	930m	940m
	207dB	7.6km^2	1.6km	1.6km	1.6km
	203dB	29km^2	3.1km	3.0km	3.0km
	186dB	3,100km^2	33km	30km	31km

Table 4.19 Summary of the unweighted $L_{E,p,24h}$ impact ranges for fish using the Popper *et al.* (2014) pile driving criteria covering the offshore substation driven pile installation modelling for two sequentially installed piles at the north corner modelling location

Popper *et al.* (2014) Unweighted $L_{E,p,24h}$		Offshore substation driven piles (two sequentially installed piles)			
		Area	**Maximum range**	**Minimum range**	**Mean range**
Pile driving (Fleeing 1.5m/s)	219dB	< 0.1km^2	< 100m	< 100m	< 100m
	216dB	< 0.1km^2	< 100m	< 100m	< 100m
	210dB	< 0.1km^2	< 100m	< 100m	< 100m
	207dB	< 0.1km^2	< 100m	< 100m	< 100m
	203dB	< 0.1km^2	< 100m	< 100m	< 100m
	186dB	2,700km^2	32km	27km	29km
Pile driving (Stationary 0.0m/s)	219dB	0.36km^2	350m	330m	340m
	216dB	0.99km^2	580m	550m	560m
	210dB	7.6km^2	1.6km	1.6km	1.6km
	207dB	21km^2	2.6km	2.6km	2.6km
	203dB	75km^2	4.9km	4.9km	4.9km
	186dB	5,500km^2	44km	39km	42km

4.2.4 Offshore substation west corner

Table 4.20 Summary of the unweighted $L_{p,pk}$ impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria covering the offshore substation driven pile installation at the west corner modelling location

Southall *et al.* (2019) Unweighted $L_{p,pk}$		Offshore substation driven piles			
		Area	**Maximum range**	**Minimum range**	**Mean range**
PTS (Impulsive)	LF (219dB)	0.01km²	50m	< 50m	50m
	HF (230dB)	< 0.01km²	< 50m	< 50m	< 50m
	VHF (202dB)	1.3km²	650m	650m	650m
	PCW (218dB)	0.01km²	60m	60m	60m
TTS (Impulsive)	LF (213dB)	0.05km²	120m	120m	120m
	HF (224dB)	< 0.01km²	< 50m	< 50m	< 50m
	VHF (196dB)	8.0km²	1.6km	1.6km	1.6km
	PCW (212dB)	0.06km²	140m	140m	140m

Table 4.21 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria covering the offshore substation driven pile installation modelling for a single pile at the west corner modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		Offshore substation driven piles (single pile)			
		Area	**Maximum range**	**Minimum range**	**Mean range**
PTS (Impulsive)	LF (183dB)	1,000km²	19km	17km	18km
	HF (185dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (155dB)	16km²	2.3km	2.1km	2.2km
	PCW (185dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Impulsive)	LF (168dB)	18,000km²	84km	63km	75km
	HF (170dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (140dB)	3,900km²	37km	33km	35km
	PCW (170dB)	1,100km²	20km	18km	19km

Table 4.22 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria covering the offshore substation driven pile installation modelling for two sequentially installed piles at the west corner modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		Offshore substation driven piles (two sequentially installed piles)			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183dB)	1,400km²	22km	20km	21km
	HF (185dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (155dB)	29km²	3.2km	2.9km	3.1km
	PCW (185dB)	<0.1km²	< 100m	< 100m	< 100m
TTS (Impulsive)	LF (168dB)	21,000km²	95km	63km	81km
	HF (170dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (140dB)	5,400km²	44km	38km	42km
	PCW (170dB)	1,700km²	24km	22km	23km

Table 4.23 Summary of the unweighted $L_{p,pk}$ impact ranges for fish using the Popper *et al.* (2014) pile driving criteria covering the offshore substation driven pile installation at the west corner modelling location

Popper *et al.* (2014) Unweighted $L_{p,pk}$		Offshore substation driven piles			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213dB	0.05km²	120m	120m	120m
	207dB	0.29km²	310m	310m	310m

Table 4.24 Summary of the unweighted $L_{E,p,24h}$ impact ranges for fish using the Popper *et al.* (2014) pile driving criteria covering the offshore substation driven pile installation modelling for a single pile at the west corner modelling location

Popper *et al.* (2014) Unweighted $L_{E,p,24h}$		Offshore substation driven piles (single pile)			
		Area	Maximum range	Minimum range	Mean range
Pile driving (Fleeing 1.5 m/s)	219dB	< 0.1km²	< 100m	< 100m	< 100m
	216dB	< 0.1km²	< 100m	< 100m	< 100m
	210dB	< 0.1km²	< 100m	< 100m	< 100m

Popper *et al.* (2014) Unweighted $L_{E,p,24h}$		Offshore substation driven piles (single pile)			
		Area	Maximum range	Minimum range	Mean range
	207dB	< 0.1km²	< 100m	< 100m	< 100m
	203dB	< 0.1km²	< 100m	< 100m	< 100m
	186dB	1,600km²	23km	22km	23km
Pile driving (Stationary 0.0m/s)	219dB	0.14km²	230m	200m	210m
	216dB	0.36km²	350m	330m	340m
	210dB	2.8km²	950m	930m	940m
	207dB	7.4km²	1.6km	1.5km	1.5km
	203dB	28km²	3.0km	3.0km	3.0km
	186dB	2,900km²	31km	29km	30km

Table 4.25 Summary of the unweighted $L_{E,p,24h}$ impact ranges for fish using the Popper *et al.* (2014) pile driving criteria covering the offshore substation driven pile installation modelling for two sequentially installed piles at the west corner modelling location

Popper *et al.* (2014) Unweighted $L_{E,p,24h}$		Offshore substation driven piles (two sequentially installed piles)			
		Area	Maximum range	Minimum range	Mean range
Pile driving (Fleeing 1.5 m/s)	219dB	< 0.1km²	< 100m	< 100m	< 100m
	216dB	< 0.1km²	< 100m	< 100m	< 100m
	210dB	< 0.1km²	< 100m	< 100m	< 100m
	207dB	< 0.1km²	< 100m	< 100m	< 100m
	203dB	< 0.1km²	< 100m	< 100m	< 100m
	186dB	2,400km²	29kmkm	26km	28km
Pile driving (Stationary 0.0m/s)	219dB	0.36km²	350m	330m	340m
	216dB	0.99km²	580m	550m	560m
	210dB	7.4km²	1.6km	1.5km	1.5km
	207dB	20km²	2.6km	2.5km	2.5km
	203dB	74km²	4.9km	4.8km	4.9km
	186dB	5,000km²	42km	38km	40km

4.2.5 Reactive compensation platform south location

Table 4.26 Summary of the unweighted $L_{p,pk}$ impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria covering the RCP driven pile installation at the south RCP modelling location

Southall *et al.* (2019) Unweighted $L_{p,pk}$		RCP driven piles			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219dB)	0.01km²	< 50m	< 50m	< 50m
	HF (230dB)	< 0.01km²	< 50m	< 50m	< 50m
	VHF (202dB)	1.3km²	640m	630m	640m
	PCW (218dB)	0.01km²	60m	60m	60m
TTS (Impulsive)	LF (213dB)	0.05km²	120m	120m	120m
	HF (224dB)	< 0.01km²	< 50m	< 50m	< 50m
	VHF (196dB)	7.5km²	1.6km	1.5km	1.5km
	PCW (212dB)	0.06km²	140m	140m	140m

Table 4.27 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria covering the RCP driven pile installation modelling for a single pile at the south RCP modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		RCP driven piles (single pile)			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183dB)	810km²	17km	14km	16km
	HF (185dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (155dB)	12km²	2.1km	1.8km	2.0km
	PCW (185dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Impulsive)	LF (168dB)	12,000km²	75km	29km	61km
	HF (170dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (140dB)	3,200km²	35km	26km	32km
	PCW (170dB)	900km²	18km	15km	17km

Table 4.28 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria covering the RCP driven pile installation modelling for two sequentially installed piles at the south RCP modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		RCP driven piles (two sequentially installed piles)			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183dB)	1,100km^2	21km	15km	18km
	HF (185dB)	< 0.1km^2	< 100m	< 100m	< 100m
	VHF (155dB)	220km^2	2.8km	2.4km	2.7km
	PCW (185dB)	< 0.1km^2	< 100m	< 100m	< 100m
TTS (Impulsive)	LF (168dB)	14,000km^2	84km	29km	66km
	HF (170dB)	< 0.1km^2	< 100m	< 100m	< 100m
	VHF (140dB)	4,200km^2	41km	26km	36km
	PCW (170dB)	1,300km^2	23km	17km	20km

Table 4.29 Summary of the unweighted $L_{p,pk}$ impact ranges for fish using the Popper *et al.* (2014) pile driving criteria covering the RCP driven pile installation at the south RCP modelling location

Popper *et al.* (2014) Unweighted $L_{p,pk}$		RCP driven piles			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213dB	0.05km^2	120m	120m	120m
	207dB	0.28km^2	300m	300m	300m

Table 4.30 Summary of the unweighted $L_{E,p,24h}$ impact ranges for fish using the Popper *et al.* (2014) pile driving criteria covering the RCP driven pile installation modelling for a single pile at the south RCP modelling location

Popper *et al.* (2014) Unweighted $L_{E,p,24h}$		RCP driven piles (single pile)			
		Area	Maximum range	Minimum range	Mean range
Pile driving (Fleeing 1.5 m/s)	219dB	< 0.1km^2	< 100m	< 100m	< 100m
	216dB	< 0.1km^2	< 100m	< 100m	< 100m
	210dB	< 0.1km^2	< 100m	< 100m	< 100m

Popper *et al.* (2014) Unweighted $L_{E,p,24h}$		**RCP driven piles (single pile)**			
		Area	**Maximum range**	**Minimum range**	**Mean range**
	207dB	< 0.1km²	< 100m	< 100m	< 100m
	203dB	< 0.1km²	< 100m	< 100m	< 100m
	186dB	1,300km²	22km	18km	20km
Pile driving (Stationary 0.0m/s)	219dB	0.14km²	230m	200m	210m
	216dB	0.36km²	350m	330m	340m
	210dB	2.6km²	930m	900m	910m
	207dB	7.2km²	1.5km	1.5km	1.5km
	203dB	26km²	3.0km	2.9km	2.9km
	186dB	2,500km²	30km	26km	28km

Table 4.31 Summary of the unweighted $L_{E,p,24h}$ impact ranges for fish using the Popper *et al*. (2014) pile driving criteria covering the RCP driven pile installation modelling for two sequentially installed piles at the south RCP modelling location

Popper *et al.* (2014) Unweighted $L_{E,p,24h}$		**RCP driven piles (two sequentially installed piles)**			
		Area	**Maximum range**	**Minimum range**	**Mean range**
Pile driving (Fleeing 1.5 m/s)	219dB	< 0.1km²	< 100m	< 100m	< 100m
	216dB	< 0.1km²	< 100m	< 100m	< 100m
	210dB	< 0.1km²	< 100m	< 100m	< 100m
	207dB	< 0.1km²	< 100m	< 100m	< 100m
	203dB	< 0.1km²	< 100m	< 100m	< 100m
	186dB	1,800km²	27km	20km	24km
Pile driving (Stationary 0.0m/s)	219dB	0.36km²	350m	330m	340m
	216dB	0.99km²	580m	550m	560m
	210dB	7.2km²	1.5km	1.5km	1.5km
	207dB	19km²	2.5km	2.5km	2.5km
	203dB	68km²	4.8km	4.6km	4.7km
	186dB	4,200km²	40km	33km	37km

4.2.6 Reactive compensation platform north location

Table 4.32 Summary of the unweighted $L_{p,pk}$ impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria covering the RCP driven pile installation at the north RCP modelling location

Southall *et al.* (2019) Unweighted $L_{p,pk}$		**RCP driven piles**			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219dB)	0.01km^2	50m	< 50m	50m
	HF (230dB)	< 0.01km^2	< 50m	< 50m	< 50m
	VHF (202dB)	1.3km^2	650m	650m	650m
	PCW (218dB)	0.01km^2	60m	60m	60m
TTS (Impulsive)	LF (213dB)	0.05km^2	120m	120m	120m
	HF (224dB)	< 0.01km^2	< 50m	< 50m	< 50m
	VHF (196dB)	8.1km^2	1.6km	1.6km	1.6km
	PCW (212dB)	0.06km^2	140m	140m	140m

Table 4.33 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria covering the RCP driven pile installation modelling for a single pile at the north RCP modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		**RCP driven piles (single pile)**			
		Area	**Maximum range**	**Minimum range**	**Mean range**
PTS (Impulsive)	LF (183dB)	970km^2	19km	16km	18km
	HF (185dB)	< 0.1km^2	< 100m	< 100m	< 100m
	VHF (155dB)	16km^2	2.3km	2.2km	2.3km
	PCW (185dB)	< 0.1km^2	< 100m	< 100m	< 100m
TTS (Impulsive)	LF (168dB)	15,000km^2	82km	48km	70km
	HF (170dB)	< 0.1km^2	< 100m	< 100m	< 100m
	VHF (140dB)	3,700km^2	36km	30km	34km
	PCW (170dB)	1,100km^2	19km	17km	19km

Table 4.34 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria covering the RCP driven pile installation modelling for two sequentially installed piles at the north RCP modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		RCP driven piles (two sequentially installed piles)			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183dB)	1,300km²	22km	18km	20km
	HF (185dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (155dB)	30km²	3.2km	2.9km	3.1km
	PCW (185dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Impulsive)	LF (168dB)	18,000km²	93km	48km	75km
	HF (170dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (140dB)	5,000km²	43km	34km	40km
	PCW (170dB)	1,600km²	24km	20km	22km

Table 4.35 Summary of the unweighted $L_{p,pk}$ impact ranges for fish using the Popper *et al.* (2014) pile driving criteria covering the RCP driven pile installation at the north RCP modelling location

Popper *et al.* (2014) Unweighted $L_{p,pk}$		RCP driven piles			
		Area	**Maximum range**	**Minimum range**	**Mean range**
Pile driving	213dB	0.05km²	120m	120m	120m
	207dB	0.29km²	310m	310m	310m

Table 4.36 Summary of the unweighted $L_{E,p,24h}$ impact ranges for fish using the Popper *et al.* (2014) pile driving criteria covering the RCP driven pile installation modelling for a single pile at the north RCP modelling location

Popper *et al.* (2014) Unweighted $L_{E,p,24h}$		RCP driven piles (single pile)			
		Area	**Maximum range**	**Minimum range**	**Mean range**
Pile driving (Fleeing 1.5 m/s)	219dB	< 0.1km²	< 100m	< 100m	< 100m
	216dB	< 0.1km²	< 100m	< 100m	< 100m
	210dB	< 0.1km²	< 100m	< 100m	< 100m

Popper *et al.* (2014) Unweighted $L_{E,p,24h}$		**RCP driven piles (single pile)**			
		Area	**Maximum range**	**Minimum range**	**Mean range**
	207dB	< 0.1km²	< 100m	< 100m	< 100m
	203dB	< 0.1km²	< 100m	< 100m	< 100m
	186dB	1,500km²	23km	20km	22km
Pile driving (Stationary 0.0m/s)	219dB	0.14km²	230m	200m	210m
	216dB	0.36km²	350m	330m	340m
	210dB	2.8km²	950m	930m	940m
	207dB	7.4km²	1.6km	1.5km	1.5km
	203dB	28km²	3.0km	3.0km	3.0km
	186dB	2,800km²	31km	28km	30km

Table 4.37 Summary of the unweighted $L_{E,p,24h}$ impact ranges for fish using the Popper *et al.* (2014) pile driving criteria covering the RCP driven pile installation modelling for two sequentially installed piles at the north RCP modelling location

Popper *et al.* (2014) Unweighted $L_{E,p,24h}$		**RCP driven piles (two sequentially installed piles)**			
		Area	**Maximum range**	**Minimum range**	**Mean range**
Pile driving (Fleeing 1.5 m/s)	219dB	< 0.1km²	< 100m	< 100m	< 100m
	216dB	< 0.1km²	< 100m	< 100m	< 100m
	210dB	< 0.1km²	< 100m	< 100m	< 100m
	207dB	< 0.1km²	< 100m	< 100m	< 100m
	203dB	< 0.1km²	< 100m	< 100m	< 100m
	186dB	2,200km²	28km	23km	27km
Pile driving (Stationary 0.0m/s)	219dB	0.36km²	350m	330m	340m
	216dB	0.99km²	580m	550m	560m
	210dB	7.6km²	1.6km	1.6km	1.6km
	207dB	21km²	2.6km	2.6km	2.6km
	203dB	75km²	4.9km	4.9km	4.9km
	186dB	4,800km²	41km	35km	39km

4.2.7 Driven pile anchor north corner

Table 4.38 Summary of the unweighted $L_{p,pk}$ impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria covering driven pile anchor installation at the north corner modelling location

Southall *et al.* (2019) Unweighted $L_{p,pk}$		Driven pile anchors			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219dB)	< 0.01km²	< 50m	< 50m	< 50m
	HF (230dB)	< 0.01km²	< 50m	< 50m	< 50m
	VHF (202dB)	0.91km²	540m	540m	540m
	PCW (218dB)	< 0.01km²	< 50m	< 50m	< 50m
TTS (Impulsive)	LF (213dB)	0.03km²	100m	100m	100m
	HF (224dB)	< 0.01km²	< 50m	< 50m	< 50m
	VHF (196dB)	5.6km²	1.3km	1.3km	1.3km
	PCW (212dB)	0.04km²	120m	120m	120m

Table 4.39 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria covering driven pile anchor installation modelling for a single pile at the north corner modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		Driven pile anchors (single pile)			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183dB)	930km²	18km	16km	17km
	HF (185dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (155dB)	17km²	2.4km	2.2km	2.3km
	PCW (185dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Impulsive)	LF (168dB)	18,000km²	87km	66km	77km
	HF (170dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (140dB)	4,300km²	39km	34km	37km
	PCW (170dB)	1,200km²	21km	18km	20km

Table 4.40 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria covering driven pile anchor installation modelling for two sequentially installed piles at the north corner modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		Driven pile anchors (two sequentially installed piles)			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183dB)	1,300km^2	22km	19km	21km
	HF (185dB)	< 0.1km^2	< 100m	< 100m	< 100m
	VHF (155dB)	32km^2	3.4km	3.0km	3.2km
	PCW (185dB)	< 0.1km^2	< 100m	< 100m	< 100m
TTS (Impulsive)	LF (168dB)	22,000km^2	97km	69km	84km
	HF (170dB)	< 0.1km^2	< 100m	< 100m	< 100m
	VHF (140dB)	6,100km^2	48km	39km	44km
	PCW (170dB)	1,900km^2	27km	22km	25km

Table 4.41 Summary of the unweighted $L_{p,pk}$ impact ranges for fish using the Popper *et al.* (2014) pile driving criteria covering driven pile anchor installation at the north corner modelling location

Popper *et al.* (2014) Unweighted $L_{p,pk}$		Driven pile anchors			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213dB	0.03km^2	100m	100m	100m
	207dB	0.20km^2	250m	250m	250m

Table 4.42 Summary of the unweighted $L_{E,p,24h}$ impact ranges for fish using the Popper *et al.* (2014) pile driving criteria covering driven pile anchor installation modelling for a single pile at the north corner modelling location

Popper *et al.* (2014) Unweighted $L_{E,p,24h}$		Driven pile anchors (single pile)			
		Area	Maximum range	Minimum range	Mean range
Pile driving (Fleeing 1.5 m/s)	219dB	< 0.1km^2	< 100m	< 100m	< 100m
	216dB	< 0.1km^2	< 100m	< 100m	< 100m
	210dB	< 0.1km^2	< 100m	< 100m	< 100m

Popper *et al.* (2014) Unweighted $L_{E,p,24h}$		**Driven pile anchors (single pile)**			
		Area	**Maximum range**	**Minimum range**	**Mean range**
	207dB	< 0.1km²	< 100m	< 100m	< 100m
	203dB	< 0.1km²	< 100m	< 100m	< 100m
	186dB	1,500km²	23km	20km	22km
Pile driving (Stationary 0.0m/s)	219dB	0.11km²	200m	180m	190m
	216dB	0.31km²	330m	300m	310m
	210dB	2.1km²	830m	800m	810m
	207dB	5.8km²	1.4km	1.4km	1.4km
	203dB	22km²	2.7km	2.6km	2.6km
	186dB	2,600km²	30km	27km	29km

Table 4.43 Summary of the unweighted $L_{E,p,24h}$ impact ranges for fish using the Popper *et al.* (2014) pile driving criteria covering driven pile anchor installation modelling for two sequentially installed piles at the north corner modelling location

Popper *et al.* (2014) Unweighted $L_{E,p,24h}$		**Driven pile anchors (two sequentially installed piles)**			
		Area	**Maximum range**	**Minimum range**	**Mean range**
Pile driving (Fleeing 1.5 m/s)	219dB	< 0.1km²	< 100m	< 100m	< 100m
	216dB	< 0.1km²	< 100m	< 100m	< 100m
	210dB	< 0.1km²	< 100m	< 100m	< 100m
	207dB	< 0.1km²	< 100m	< 100m	< 100m
	203dB	< 0.1km²	< 100m	< 100m	< 100m
	186dB	2,200km²	29km	24km	27km
Pile driving (Stationary 0.0m/s)	219dB	0.31km²	330m	300m	310m
	216dB	0.74km²	500m	480m	490m
	210dB	5.8km²	1.4km	1.4km	1.4km
	207dB	16km²	2.3km	2.2km	2.2km
	203dB	58km²	4.4km	4.3km	4.3km
	186dB	4,800km²	41km	36km	39km

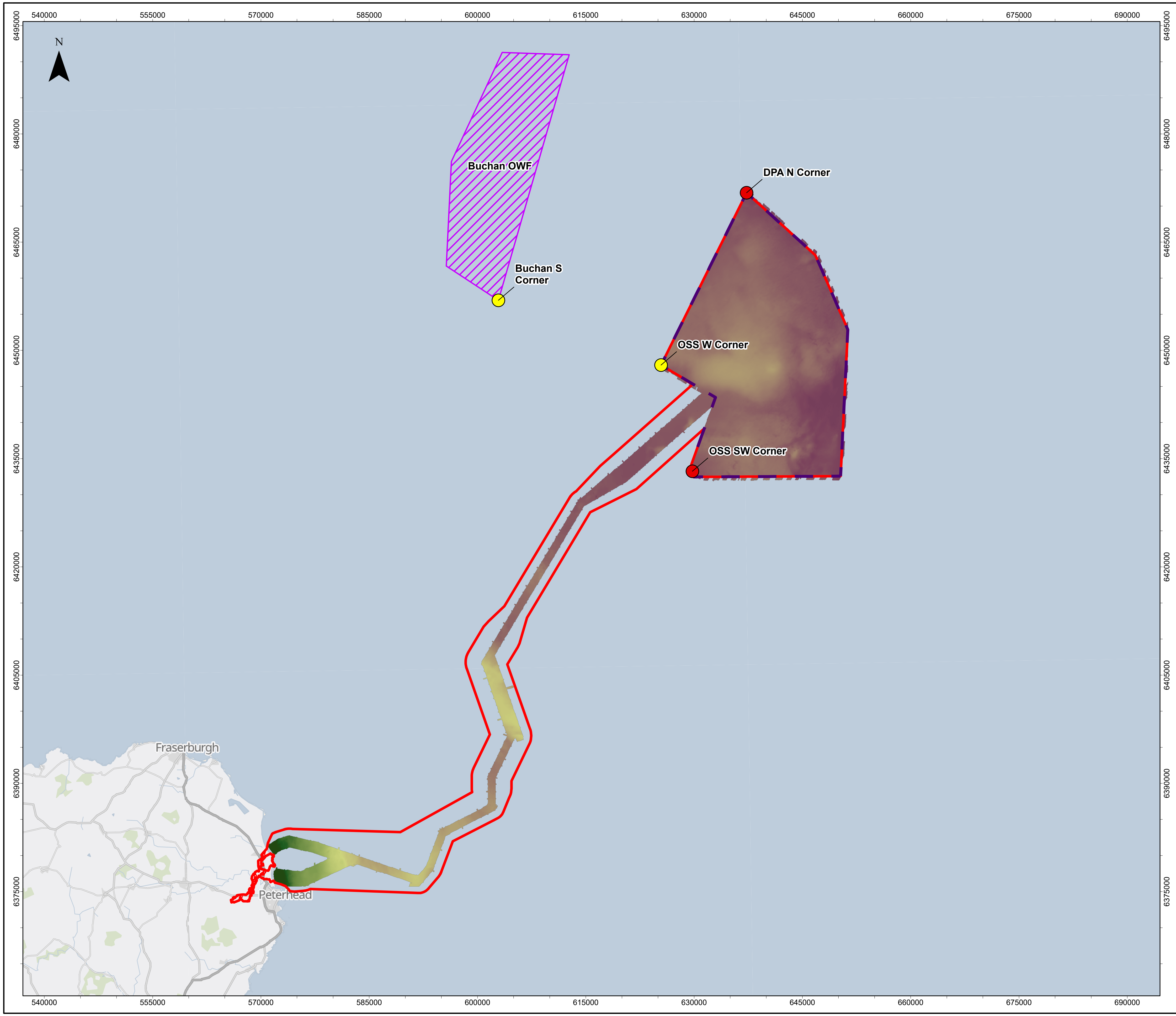
4.3 Multiple location modelling

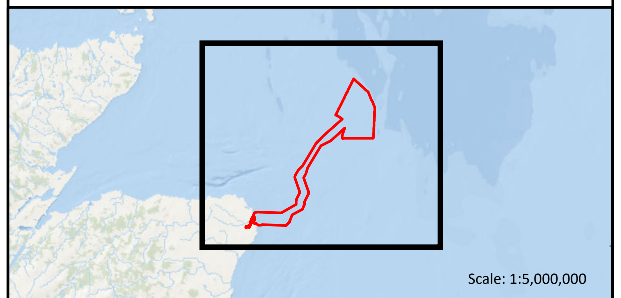
4.3.1.1 Modelling has been carried out to investigate the potential impacts of multiple piling vessels installing foundations simultaneously at separated locations. Two scenarios have been considered, each considering two sequentially installed piles:

- Simultaneous installation of offshore substation driven piles at the SW corner of the OAA, and driven pile anchors at the N corner of the OAA.
- Simultaneous installation of offshore substation driven piles at the W corner of the OAA and a location at the southern corner of the nearby Buchan OWF. The parameters assumed for the Buchan location are the same as those for the Project offshore substation scenarios.

4.3.1.2 The locations used for these scenarios are shown in **Figure 4**.

4.3.1.3 When considering $L_{E,p,t}$ modelling, piling from multiple sources can increase impact ranges significantly as, in this case, it introduces noise from two times the number of pile strikes to the water. Unlike the single location sequential piling investigated in **Section 4.2**, fleeing receptors can be closer to a source for a higher number of the pile strikes, taking into account the other piling locations, which results in higher cumulative noise exposures. **Figure 5** shows the TTS contour for fish from Popper *et al*. (2014) (186dB $L_{E,p,24h}$) for a fleeing receptor as an example. The red contours show the impact from each location modelled individually (as presented in **Section 4**), and the blue contour shows the increase in the predicted impacts when multiple sources are active simultaneously, resulting in a contour encircling all the red contours.





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MarramWind DRAWING NUMBER MAR-GEN-ENV-MAP-WSP-000180

DATUM	ETRS 89	PROJECTION	UTM Zone 30N
SCALE	1:500,000	PAGE SIZE	A3

PROJECT TITLE
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Figure 4 Approximate positions of the modelling locations used for concurrent modelling at the Project and Buchan

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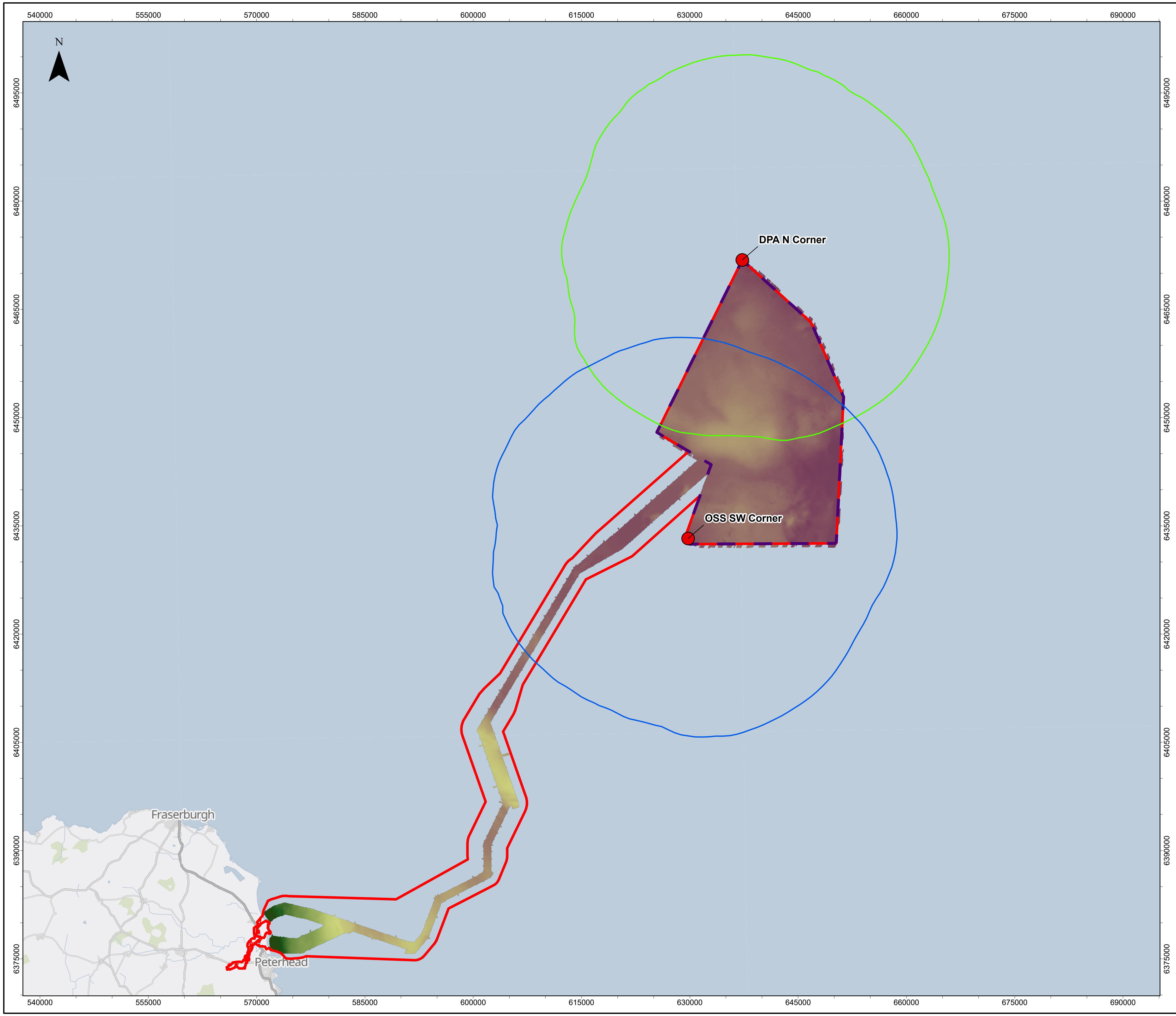

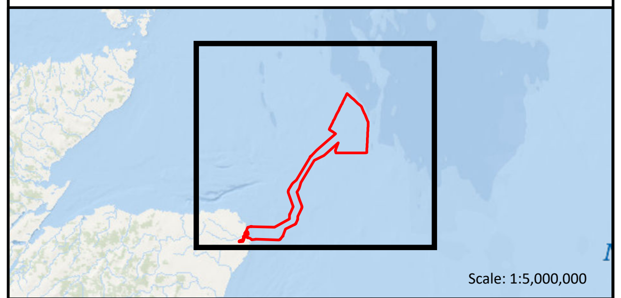

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DATUM	ETRS 89	PROJECTION	UTM Zone 30N
SCALE	1:500,000	PAGE SIZE	A3

PROJECT TITLE

MarramWind Offshore Wind Farm

DRAWING TITLE

Figure 5 Example contour plot showing the interaction between two noise sources occurring simultaneously (TTS in fish, 186 dB LE,p,24h, fleeing animal)

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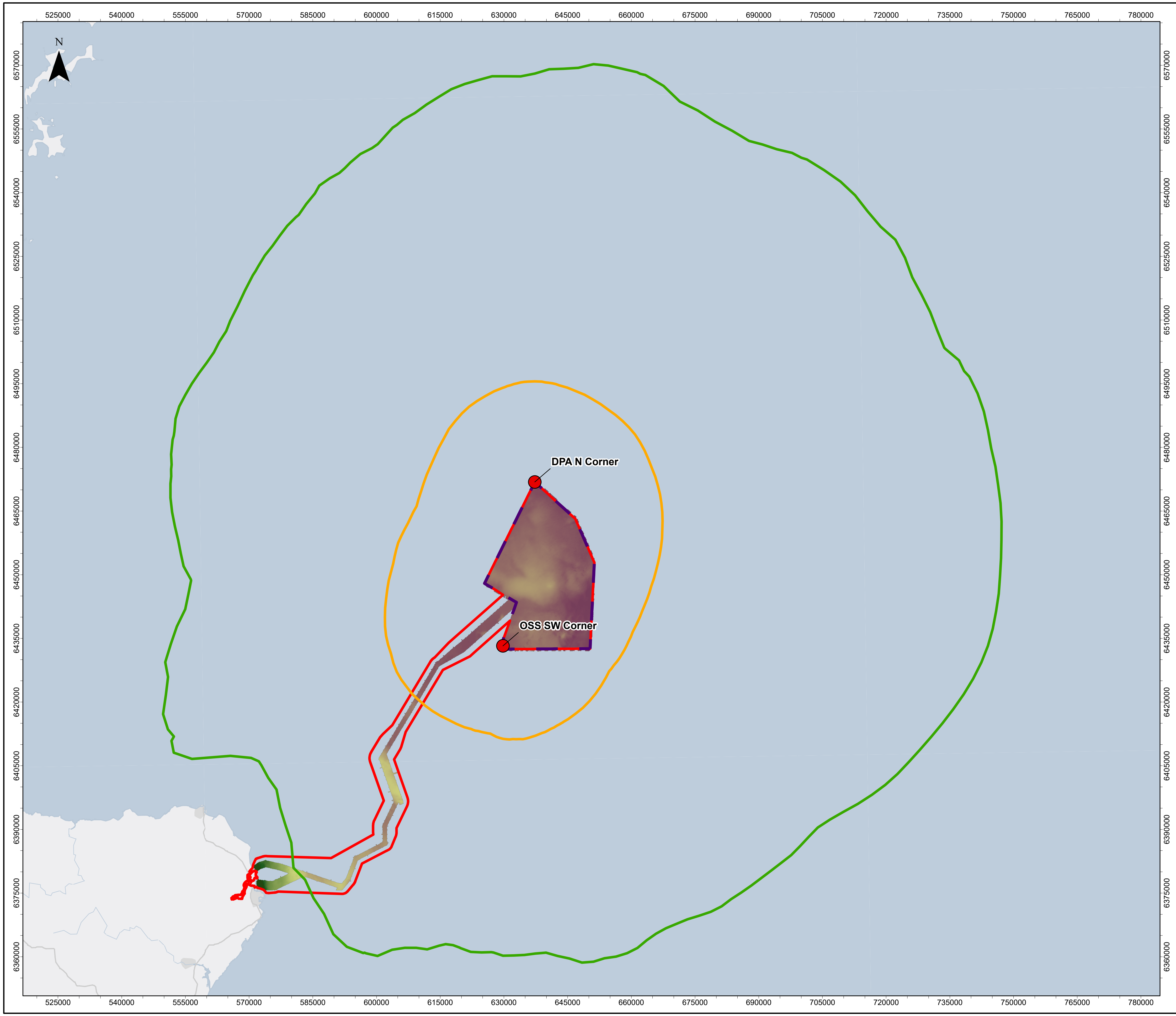
4.3.1.4 The modelled scenario was chosen to provide the greatest geographical spread of noise sources that would lead to the greatest impact range contours. In a modelling scenario where piles are installed close to each other, there would be an expansion of the single location contour in all directions, but by less overall than the spread seen in **Figure 4**.

4.3.1.5 For the results in the following section only impact areas rather than linear ranges are provided as results; impact ranges have not been presented due to there being multiple starting points for receptors (a linear impact range, such as those discussed in **Section 3.4**, requires a single start point, which is not possible with multiple pile locations). Fields denoted with a dash “-” show where there is no in-combination effect when piling occurs at the two locations simultaneously. This is generally where the ranges are small enough that the distant sites do not produce an influencing additional exposure, such as with the typically small HF cetacean-weighted impact ranges.

4.3.1.6 Specific circumstances would lead to the combined range being less than the two separated ranges combined: this is commonly where the modelling locations are close, or individual ranges are very large. In other cases, the combined ranges may be greater than the two separated ranges in summation: this is often where the individual ranges are large but there is little overlap between them when not in combination.

4.3.2 The Project locations

4.3.2.1 **Figure 6** to **Figure 8** show the in-combination impacts of the Project.



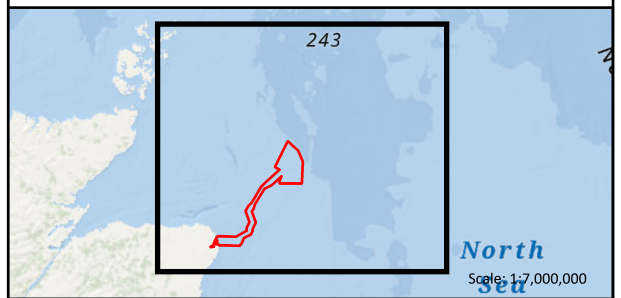
Red Line Boundary
Option Agreement Area
Concurrent modelling locations
Marram OSS SW x2 + Marram DPA N x2 LF 183dB SELcum (Flee 2,1)
Marram OSS SW x2 + Marram DPA N x2 LF 168dB SELcum (Flee 2,1)

Bathymetry (m)

-2

-133.507

0 10 20 30 40 Kilometres



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PROJECT TITLE

MarramWind Offshore Wind Farm

DRAWING TITLE

Figure 6 Contour plots showing the in-combination impacts of concurrent installation of OSS foundations at the SW corner and DPAs at the N corner of the Project for LF cetaceans and HF cetaceans using the impulsive Southall et al. (2019) criteria assuming fleeing animals

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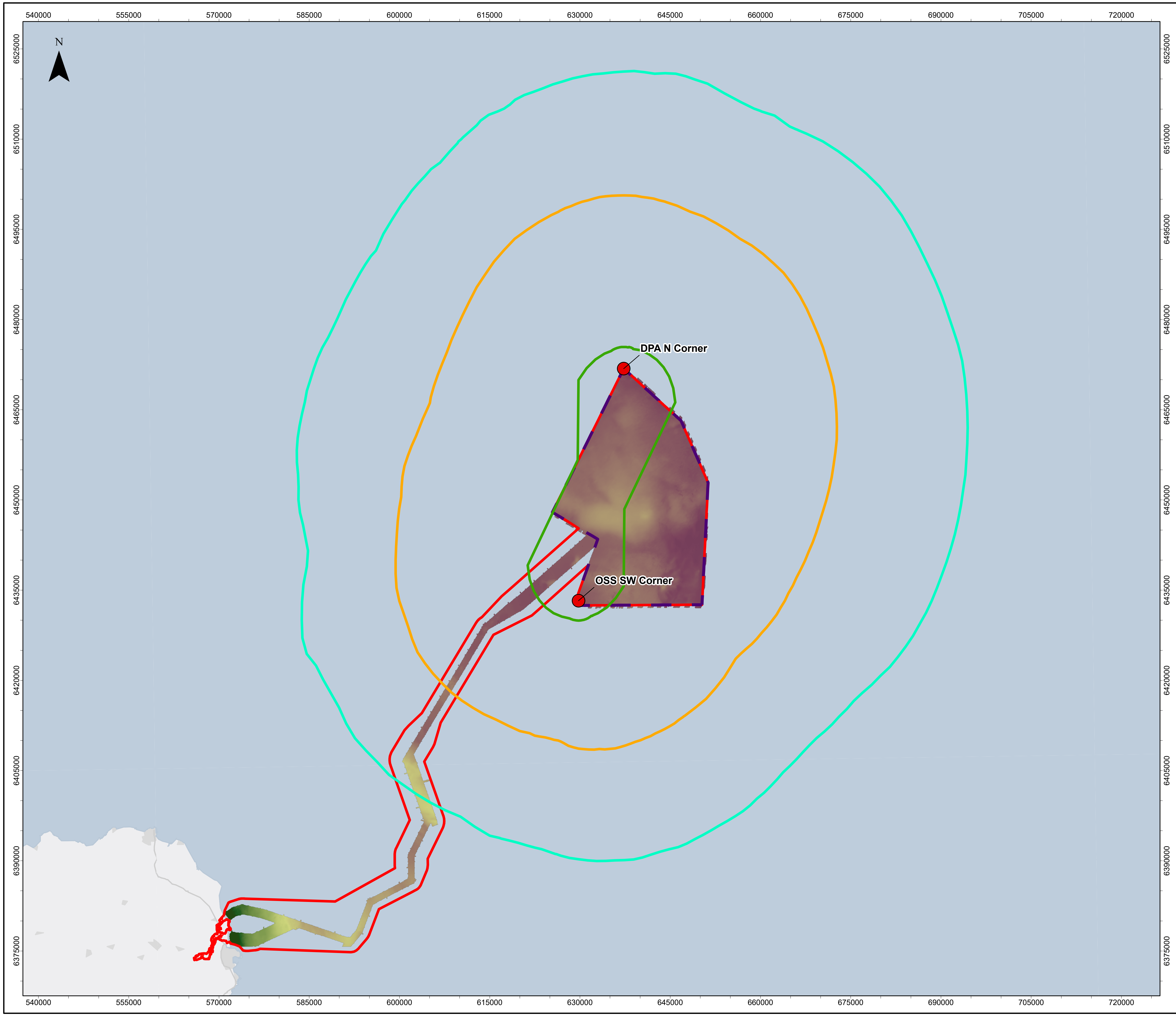


Red Line Boundary

Option Agreement Area

Marram OSS SW x2 + Marram DPA N x2 VHF 155dB SELcum (Flee 1,4)

Marram OSS SW x2 + Marram DPA N x2 PCW 170dB SELcum (Flee 1,8)

Marram OSS SW x2 + Marram DPA N x2 VHF 140dB SELcum (Flee 1,4)

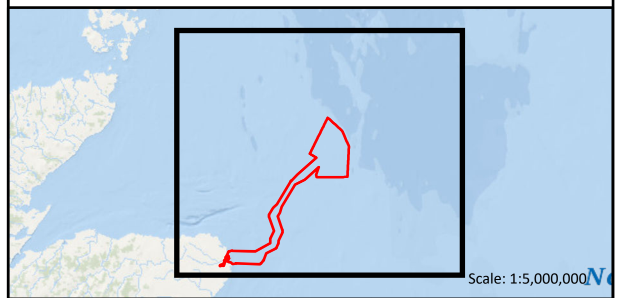
Concurrent modelling locations

Bathymetry (m)

-2

-133.507

0 10 20 30 Kilometres



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MarramWind DRAWING NUMBER MAR-GEN-ENV-MAP-WSP-000189

DATUM ETRS 89 | PROJECTION UTM Zone 30N

SCALE 1:600,000 | PAGE SIZE A3

PROJECT TITLE

MarramWind Offshore Wind Farm

DRAWING TITLE

Figure 7 Contour plots showing the in-combination impacts of concurrent installation of OSS foundations at the SW corner and DPAs at the N corner of the Project for VHF cetaceans and PCW pinnipeds using the impulsive Southall et al. (2019) criteria assuming fleeing animals

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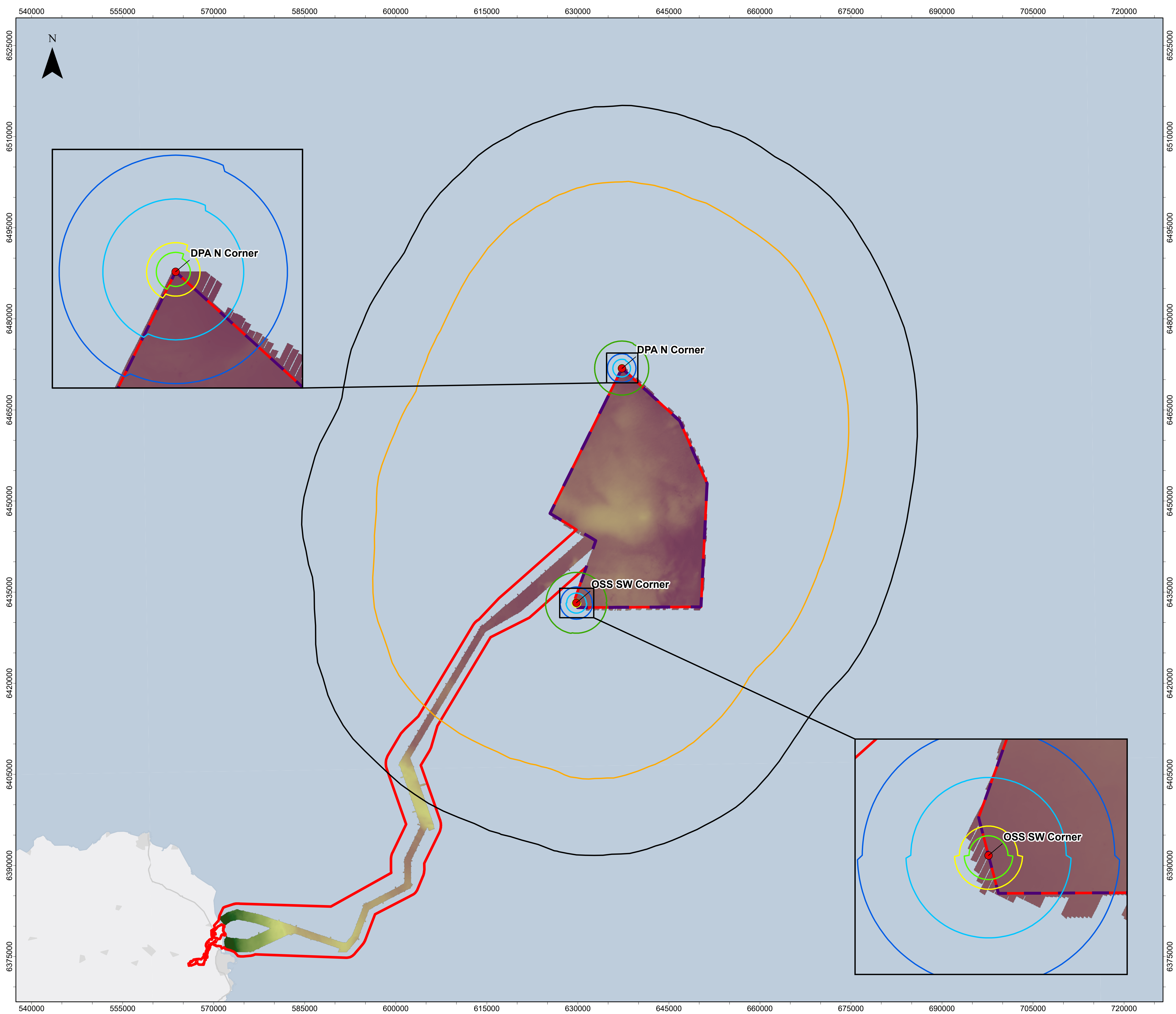


Red Line Boundary

Option Agreement Area

Marram OSS SW x2 + Marram DPA N x2 Unwtd 186dB SELcum (Flee 1,5)

Marram OSS SW x2 + Marram DPA N x2 Unwtd 186dB SELcum (St 0,0)

Marram OSS SW x2 + Marram DPA N x2 Unwtd 203dB SELcum (St 0,0)

Marram OSS SW x2 + Marram DPA N x2 Unwtd 207dB SELcum (St 0,0)

Marram OSS SW x2 + Marram DPA N x2 Unwtd 210dB SELcum (St 0,0)

Marram OSS SW x2 + Marram DPA N x2 Unwtd 216dB SELcum (St 0,0)

Marram OSS SW x2 + Marram DPA N x2 Unwtd 219dB SELcum (St 0,0)

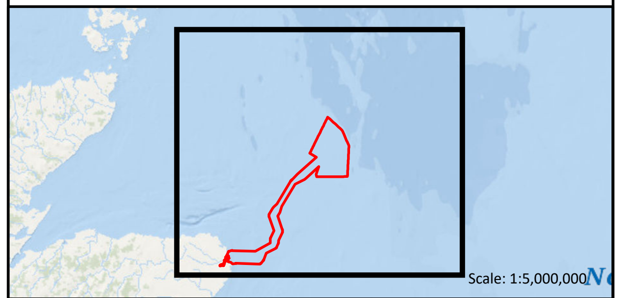
Concurrent modelling locations

Bathymetry (m)

-2

-133.507

0 10 20 30 Kilometres



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DATUM	ETRS 89	PROJECTION	UTM Zone 30N
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PROJECT TITLE
MarramWind Offshore Wind Farm

DRAWING TITLE
Figure 8 Contour plots showing the in-combination impacts of concurrent installation of OSS foundations at the SW corner and DPAs at the N corner of the Project for fish using the pile driving Popper et al. (2014) criteria assuming both fleeing and stationary animals

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Appendix 8.1

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wsp MarramWind

Table 4.44 Summary of the impact areas for the installation of offshore substation foundations at the southwest corner and driven pile anchors at the N corner of the Project for marine mammals using the impulsive Southall *et al.* (2019) $L_{E,p,24h,wtd}$ criteria assuming a fleeing animal

Offshore substation driven pile / driven pile anchor foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		SW corner (offshore substation)	N corner (driven pile anchor)	In-combination area
PTS (Impulsive)	LF (183dB)	1,400km²	1,300km²	4,100km²
	HF (185dB)	< 0.1km²	< 0.1km²	-
	VHF (155dB)	30km²	32km²	590km²
	PCW (185dB)	< 0.1km²	< 0.1km²	-
TTS (Impulsive)	LF (168dB)	20,000km²	22,000km²	31,000km²
	HF (170dB)	< 0.1km²	< 0.1km²	-
	VHF (140dB)	5,300km²	6,100km²	11,000km²
	PCW (170dB)	1,700km²	1,900km²	5,100km²

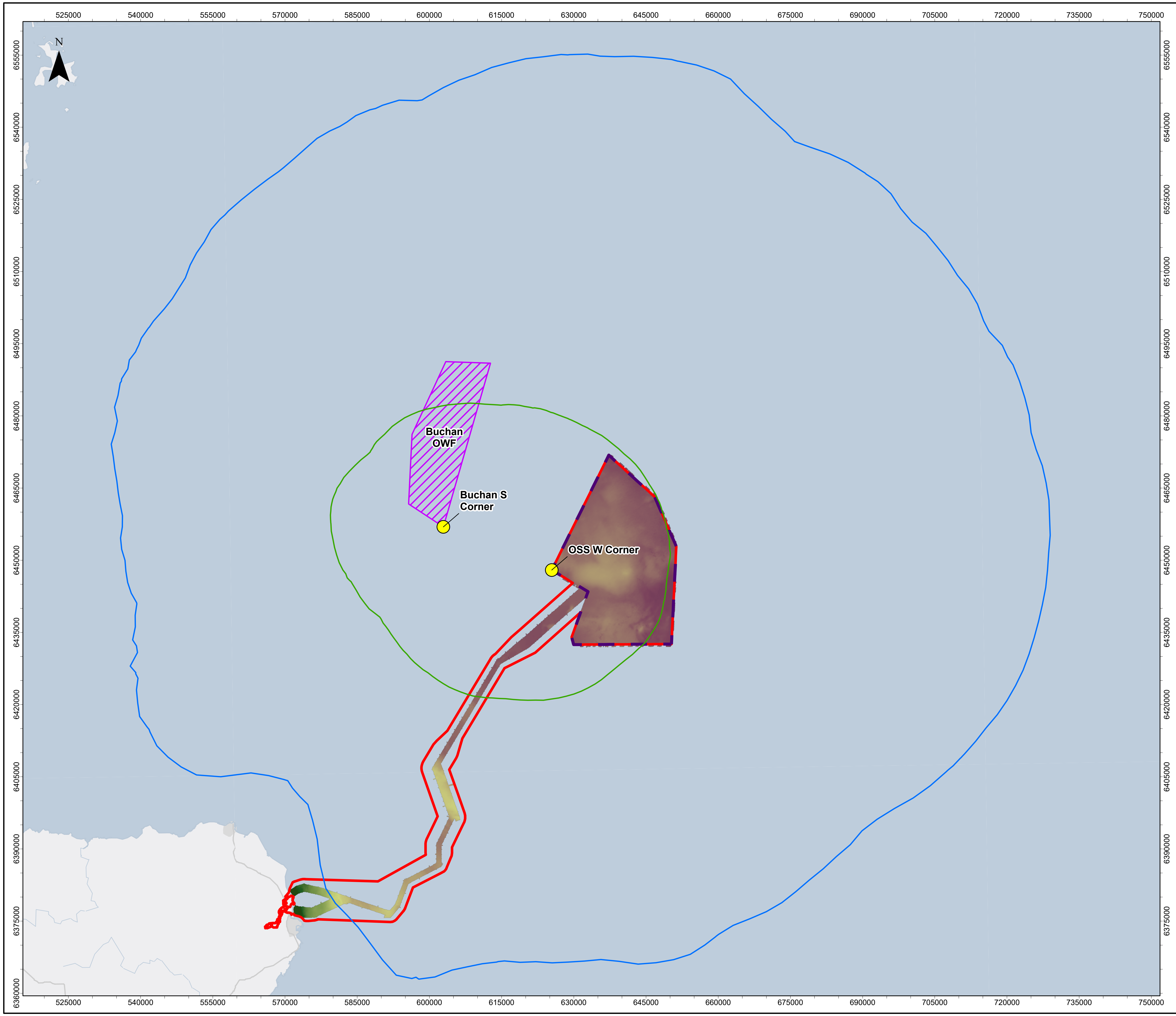
Table 4.45 Summary of the impact areas for the installation of offshore substation foundations at the southwest corner and driven pile anchors at the N corner of the Project for fish using the pile driving Popper *et al.* (2019) $L_{E,p,24h}$ criteria assuming both fleeing and stationary animals

Offshore substation driven pile / driven pile anchor foundations (Popper *et al.*, 2014) $L_{E,p,24h}$		SW corner (offshore substation)	N corner (driven pile anchor)	In-combination area
Fleeing (1.5 m/s)	219dB	< 0.1km²	< 0.1km²	-
	216dB	< 0.1km²	< 0.1km²	-
	210dB	< 0.1km²	< 0.1km²	-
	207dB	< 0.1km²	< 0.1km²	-
	203dB	< 0.1km²	< 0.1km²	-
	186dB	2,400km²	2,200km²	5,800km²
Stationary (0.0m/s)	219dB	0.36km²	0.31km²	1.0km²
	216dB	0.99km²	0.74km²	2.3km²
	210dB	7.6km²	5.8km²	15km²
	207dB	21km²	16km²	39km²
	203dB	74km²	58km²	140km²

Offshore substation driven pile / driven pile anchor foundations (Popper *et al.*, 2014) $L_{E,p,24h}$		**SW corner (offshore substation)**	**N corner (driven pile anchor)**	**In-combination area**
	186dB	5,000km^2	4,800km^2	9,600km^2

4.3.3 The Project and Buchan locations

4.3.3.1 **Figure 9** to **Figure 11** show the in-combination impacts of the Project with Buchan Offshore Wind Farm.



Red Line Boundary

Option Agreement Area

Buchan array area

Marram OSS W x2 + Buchan S x2 LF 168dB SELcum (Flee 2,1)

Marram OSS W x2 + Buchan S x2 LF 183dB SELcum (Flee 2,1)

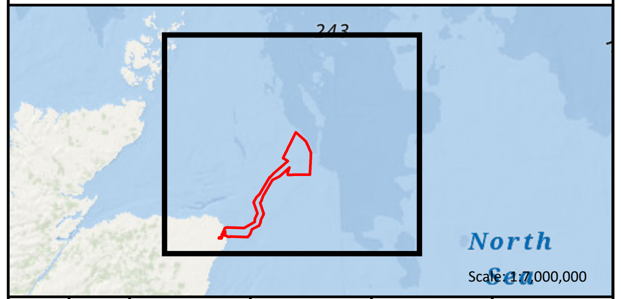
MarramWind+Buchan concurrent modelling locations

Bathymetry (m)

-2

-133.507

0 10 20 30 40 Kilometres



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PROJECT TITLE

MarramWind Offshore Wind Farm

DRAWING TITLE

Figure 9 Contour plots showing the in-combination impacts of concurrent installation of OSS foundations at the W corner of the Project and the S corner of Buchan for LF cetaceans and HF cetaceans using the impulsive Southall et al.(2019) criteria assuming fleeing animals

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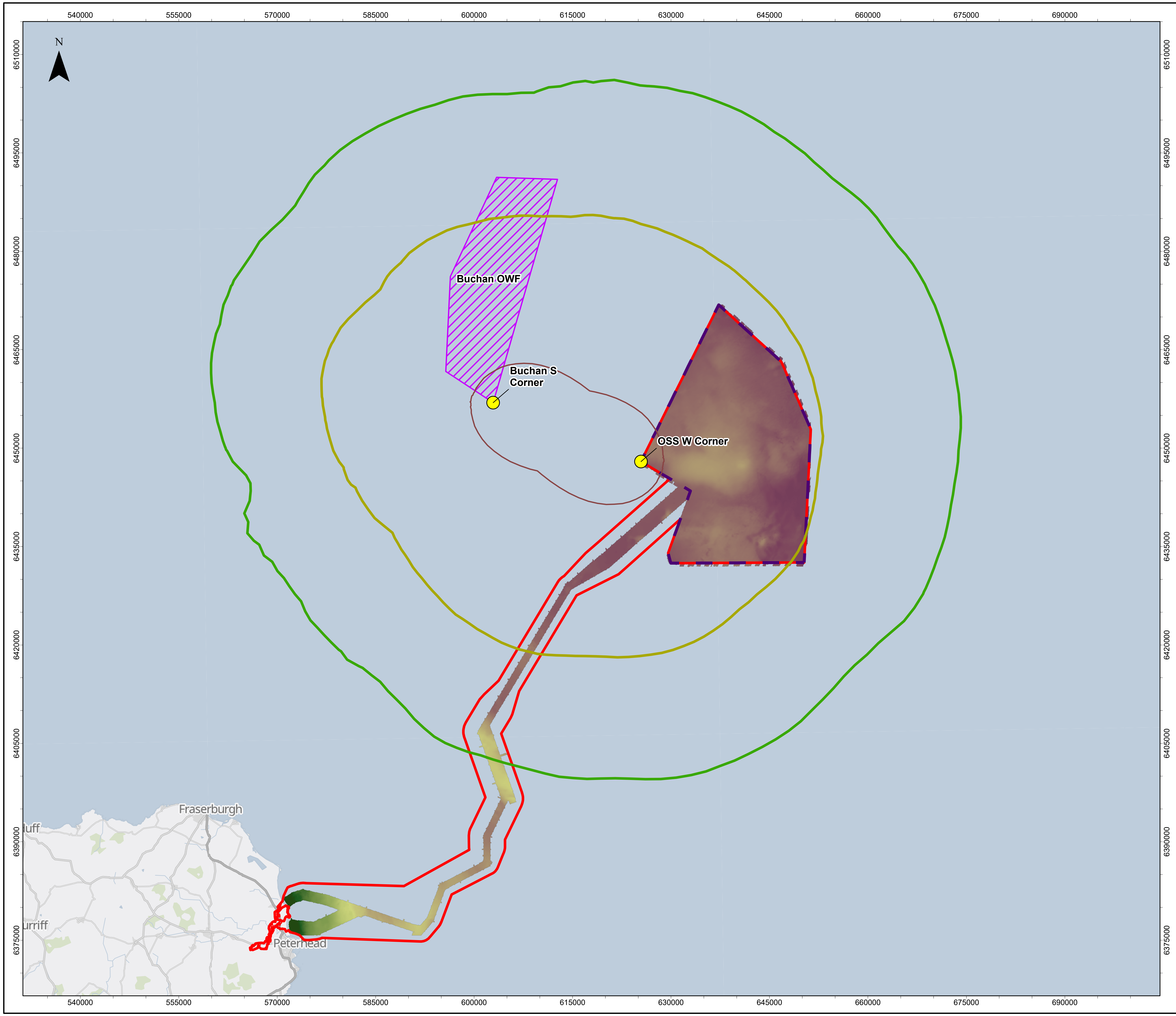


Red Line Boundary

Option Agreement Area

Buchan array area

Marram OSS W x2 + Buchan S x2 VHF 155dB SELcum (Flee 1,4)

Marram OSS W x2 + Buchan S x2 PCW 170dB SELcum (Flee 1,8)

Marram OSS W x2 + Buchan S x2 VHF 140dB SELcum (Flee 1,4)

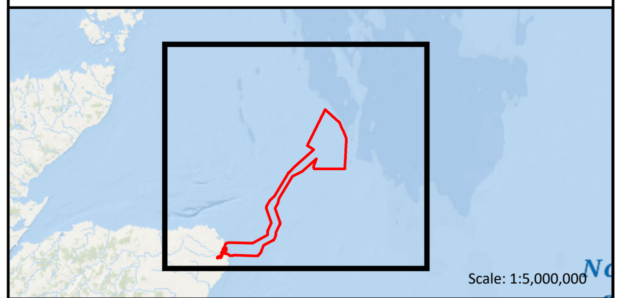
MarramWind+Buchan concurrent modelling locations

Bathymetry (m)

-2

-133.507

0 10 20 Kilometres



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PROJECT TITLE

MarramWind Offshore Wind Farm

DRAWING TITLE

Figure 10 Contour plots showing the in-combination impacts of concurrent installation of OSS foundations at the W corner of the Project and the S corner of Buchan for VHF cetaceans and PCW pinnipeds using the impulsive Southall et al. (2019) criteria assuming fleeing animals

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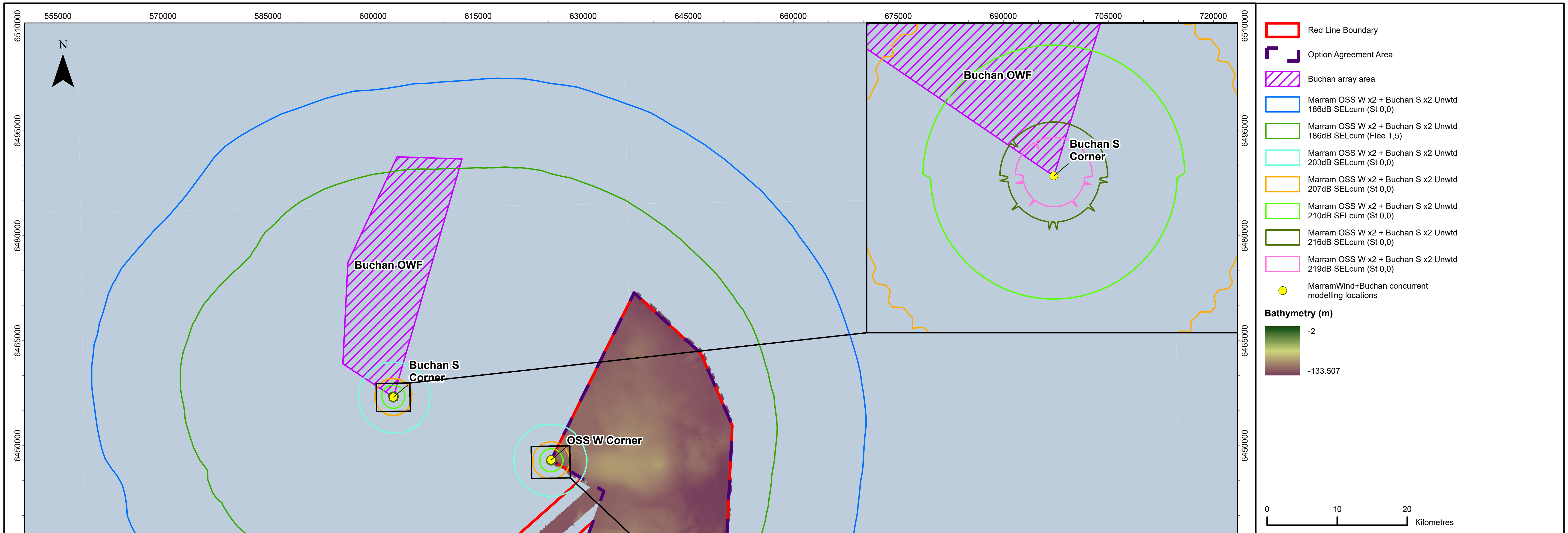
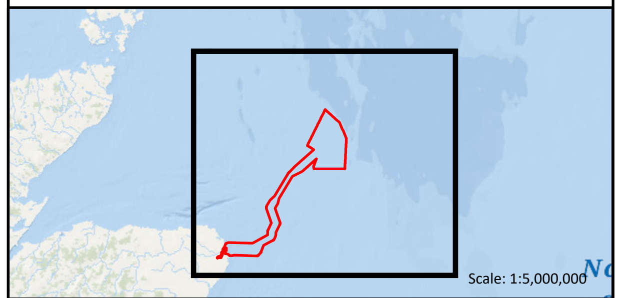
wsp MarramWind





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MarramWind Offshore Wind Farm

DRAWING TITLE

Figure 11 Contour plots showing the in-combination impacts of concurrent installation of OSS foundations at the W corner of the Project and the S corner of Buchan for fish using the pile driving Popper et al. (2014) criteria assuming both fleeing and stationary animals

Environmental Impact Assessment Report
Appendix 8.1

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Table 4.46 Summary of the impact areas for the installation of offshore substation foundations at the west corner of the Project and the south corner of Buchan for marine mammals using the impulsive Southall *et al.* (2019) $L_{E,p,24h,wtd}$ criteria assuming a fleeing animal

Offshore substation driven pile foundations (Southall *et al.*, 2019) $L_{E,p,24h,wtd}$		West corner (offshore substation)	Buchan S (offshore substation)	In-combination area
PTS (Impulsive)	LF (183dB)	1,400km²	1,300km²	3,400km²
	HF (185dB)	< 0.1km²	< 0.1km²	-
	VHF (155dB)	29km²	26km²	420km²
	PCW (185dB)	< 0.1km²	< 0.1km²	-
TTS (Impulsive)	LF (168dB)	21,000km²	19,000km²	28,000km²
	HF (170dB)	< 0.1km²	< 0.1km²	-
	VHF (140dB)	5,400km²	5,000km²	9,300km²
	PCW (170dB)	1,700km²	1,500km²	4,000km²

Table 4.47 Summary of the impact areas for the installation of offshore substation foundations at the W corner of the Project and the S corner of Buchan for fish using the pile driving Popper et al. (2019) $L_{E,p,24h}$ criteria assuming both fleeing and stationary animals

Offshore substation driven pile foundations (Popper *et al.*, 2014) $L_{E,p,24h}$		W corner (OSS)	Buchan S (OSS)	In-combination area
Fleeing (1.5 m/s)	219dB	< 0.1km²	< 0.1km²	-
	216dB	< 0.1km²	< 0.1km²	-
	210dB	< 0.1km²	< 0.1km²	-
	207dB	< 0.1km²	< 0.1km²	-
	203dB	< 0.1km²	< 0.1km²	-
	186dB	2,400km²	2,200km²	5,000km²
Stationary (0.0m/s)	219dB	0.36km²	0.36km²	1.3km²
	216dB	0.99km²	0.99km²	2.7km²
	210dB	7.4km²	7.4km²	17km²
	207dB	20km²	20km²	44km²
	203dB	74km²	71km²	170km²

Offshore substation driven pile foundations (Popper *et al.*, 2014) $L_{E,p,24h}$		**W corner (OSS)**	**Buchan S (OSS)**	**In-combination area**
	186dB	5,000km^2	4,700km^2	8,700km^2

5. Other Noise Sources

5.1.1.1 Although impact piling is expected to produce the biggest impacts from noise during offshore construction and development (Bailey *et al*., 2014), several other anthropogenic sources of noise may be present. Each of these has been considered, and relevant biological noise criteria presented, in this Section.

5.1.1.2 **Table 5.1** provides a summary of the various noise producing sources, aside from impact piling, that are expected to be present during the construction and operation of the Project.

Table 5.1 Summary of the possible noise making activities at the Project other than impact piling

Activity	Description
Cable laying	Noise from the cable laying vessel and other associated noise during the offshore cable installation.
Drag embedment anchors	An alternative mooring method for fixing WTGs to the seabed.
Dredging	Dredging may be required on site for seabed preparation work for certain foundation options, as well as for the export cable, array cables and interconnector cable installation. Both backhoe and suction dredging have been included.
Drilling	There is the potential for drilling to take place for works nearshore and at landfall.
Rock placement	May be required on site for installation of offshore cables (cable crossings and cable protection) and scour protection around foundation structures.
Suction pile installation	An alternative method for fixing the WTG foundations to the seabed. Underwater suction pumps are the primary source of noise.
Trenching	Plough trenching may be required during installation of the offshore cables.
Vessel noise	Jack-up barges for piling substructure and WTG installation. Other large and medium sized vessels to carry out other construction tasks and anchor handling. Other small vessels for crew transport and maintenance on site.
Operational WTGs	Noise transmitted through the water from operational WTGs. The project design envelope has made predictions for turbine parameters which could be available for the Project and has allowed for power outputs of between 14 and 25 MW.
UXO clearance	There is a possibility that unexploded ordnance (UXO) may exist within the Project boundaries, which would need to be cleared before construction can begin.

5.1.1.3 The majority of these activities are covered in **Section 5.2,** with operational WTG noise; mooring line noise; and UXO clearance assessed in **Sections 5.3** to **5.5**, respectively.

5.1.1.4 The NPL Good Practice Guide 133 for underwater noise measurements (Robinson *et al*., 2014) indicates that, under certain circumstances, a simple modelling approach may be considered appropriate. Such an approach has been used for these noise sources, which are variously either quiet compared to impact piling (e.g., drilling), or where detailed modelling would imply unjustified accuracy (e.g., for small charges such as those used in low-order detonations). The high-level overview of modelling that has been presented here is considered sufficient and there would be little benefit in using a more detailed modelling approach at this stage due to their relatively low impacts. The limitations of this approach are noted, including the lack of frequency and bathymetric dependence.

5.2 Noise making activities

5.2.1.1 For the purposes of identifying the greatest effects from noise, approximate subsea noise levels have been predicted using a simple modelling approach based on measurement data from Subacoustech Environmental's own underwater noise measurement database scaled to relevant parameters for the Project and to the specific noise sources to be used. The calculation of underwater noise transmission loss for these non-impulsive sources is based on empirical analysis of the noise measurements taken along transects around these sources by Subacoustech Environmental. The predictions use the following principle fitted to the measured data, where R is the range from the source, N is the transmission loss coefficient, and α is the absorption loss coefficient:

$$Received\ level = Source\ level\ (SL) - N \log_{10} R - \alpha R$$

5.2.1.2 Predicted source levels and propagation calculations for the construction activities are presented in **Table 5.2** along with a summary of the number of datasets used in each case. As previously, all criteria use the same assumptions as presented in **Section 2.3**, and ranges smaller than 50m (single pulse) and 100m (cumulative) have not been presented. It should be reiterated that this modelling approach does not take bathymetry or any other environmental conditions into account, and as such can be applied to any location at, or surrounding, the Project.

Table 5.2 Summary of the estimated unweighted source levels and transmission losses for the different considered noise sources

Source	Estimated L_p source level	Transmission loss parameters	Comments
Cable laying	171dB re 1 µPa @ 1 m	N: 13, α: 0 (no absorption)	Based on 11 datasets from a pipe laying vessel measuring 300m in length; this is considered a worst-case noise source for cable laying operations.
Drag embedment anchors	171dB re 1 µPa @ 1 m	N: 19, α: 0.0009	Based on two datasets of excavator scraping noise, which is a worst-case equivalence to the noise, as the drag embedment anchors should be embedded in deep mud.
Dredging (backhoe)	165dB re 1 µPa @ 1 m	N: 19, α: 0.0009	Based on three datasets from backhoe dredgers.
Dredging (suction)	186dB re 1 µPa @ 1 m	N: 19, α: 0.0009	Based on five datasets from suction and cutter suction dredgers.
Drilling	169dB re 1 µPa @ 1 m	N: 16, α: 0.0006	Based on six datasets from various drilling operations covering ground investigations and pile installation. A 200 kW drill has been assumed for modelling.

Source	Estimated L_p source level	Transmission loss parameters	Comments
Rock placement	172dB re 1 µP @ 1 m	N: 12, α: 0.0005	Based on four datasets from rock placement vessel *Rollingstone*.
Suction caisson installation	192dB re 1 µPa @ 1 m	N: 19, α: 0.0009	Based on a review by Koschinski and Lüdemann (2019), which states the noise from suction pumps at Borkum Riffgrund 2 could not be measured above background levels. Therefore, this estimated source level is highly precautionary.
Trenching	172dB re 1 µPa @ 1 m	N: 13, α: 0.0004	Based on three datasets of measurements from trenching vessels more than 100m in length.
Vessel noise (large)	168dB re 1 µPa @ 1 m	N: 12, α: 0.0021	Based on five datasets of large vessels including container ships, Floating Production Storage and Offloading vessels (FPSOs) and other vessels more than 100m in length. Vessel speed assumed as 10 kn.
Vessel noise (medium)	161dB re 1 µPa @ 1 m	N: 12, α: 0.0021	Based on three datasets of moderate sized vessels less than 100m in length. Vessel speed assumed as 10 kn.

5.2.1.3 All values of N and α are empirically derived and will be linked to the size and shape of the machinery, the transect on which the measurements were taken and the local environment at the time.

5.2.1.4 For $L_{E,p,t}$ calculations in this Section, the duration the noise is present also needs to be considered, with all sources assumed to operate constantly for 24 hours to give a worst-case assessment of the noise. Due to the low noise level of the sources, both fleeing and stationary animals have been included for all $L_{E,p,t}$ criteria.

5.2.1.5 To account for the weightings required for modelling using the Southall *et al*. (2019) criteria (see **Section 2.3.3**), reductions have been applied to the source levels of the various noise sources. **Plate 5.1** shows the representative noise measurements used to calculate these reductions, which have been adjusted based on the source levels given in **Table 5.2.** Details of the reductions in source level for each of the marine mammal weightings are given in **Table 5.3**.

Plate 5.1 Summary of the 1/3rd octave frequency bands to which Southall *et al.* (2019) weightings have been applied

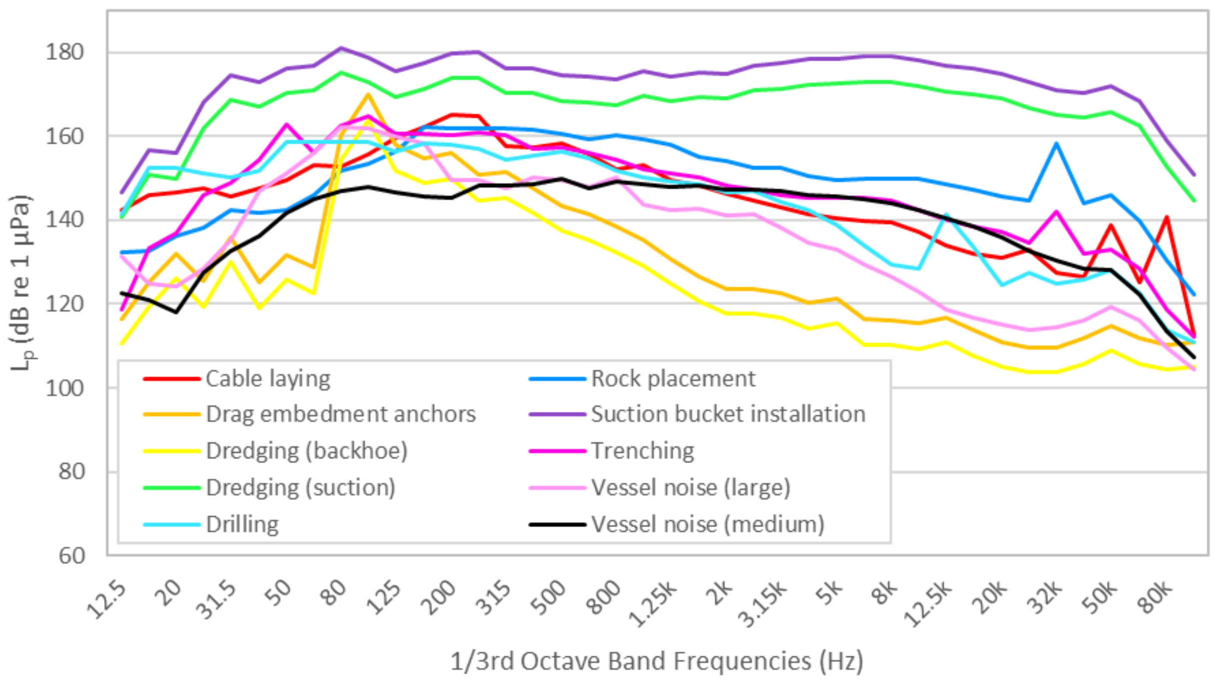

Table 5.3 Reductions in source level for the different construction noise sources considered when the Southall *et al.* (2019) weightings are applied

Source	**Reduction in L_p source level from the unweighted level (Southall *et al.*, 2019)**			
	LF	**HF**	**VHF**	**PCW**
Cable laying	3.6dB re 1 µPa	22.9dB re 1 µPa	23.9dB re 1 µPa	13.2dB re 1 µPa
Drag embedment anchors	6.3dB re 1 µPa	46.7dB re 1 µPa	48.7dB re 1 µPa	23.1dB re 1 µPa
Dredging (backhoe)	6.3dB re 1 µPa	46.7dB re 1 µPa	48.7dB re 1 µPa	23.1dB re 1 µPa
Dredging (suction)	2.5dB re 1 µPa	7.9dB re 1 µPa	9.6dB re 1 µPa	4.2dB re 1 µPa
Drilling	4.0dB re 1 µPa	25.8dB re 1 µPa	48.7dB re 1 µPa	13.2dB re 1 µPa
Rock placement	1.6dB re 1 µPa	11.9dB re 1 µPa	12.5dB re 1 µPa	8.2dB re 1 µPa
Suction caisson installation	2.5dB re 1 µPa	7.9dB re 1 µPa	9.6dB re 1 µPa	4.2dB re 1 µPa
Trenching	4.1dB re 1 µPa	23.0dB re 1 µPa	25.0dB re 1 µPa	13.7dB re 1 µPa
Vessel noise	5.5dB re 1 µPa	34.4dB re 1 µPa	38.6dB re 1 µPa	17.4dB re 1 µPa

5.2.1.6 The modelled impact ranges for these sources are presented in **Table 5.4** to **Table 5.6**. Given the modelled impact ranges, almost all marine mammals would have to be closer than 100m from the noise sources at the start of the activity to acquire the necessary exposure to induce PTS as per Southall *et al*. (2019), with the possible exception of suction dredging, rock placement and suction caisson installation for stationary receptors. The exposure calculations assume the same receptor fleeing speeds as the impact piling modelling in **Section 2.3.3**. These ranges only represent a range where the receptor reaches the 'onset' stage, which is the minimum exposure that could potentially lead to the start of an effect and may only be marginal. In most hearing groups the noise levels are low enough that this only represents a minimal risk.

5.2.1.7 For fish, there is a minimal risk of any injury or TTS with reference to the L_p guidance for continuous noise sources in Popper *et al*. (2014).

5.2.1.8 All sources presented here produce much quieter levels than the results presented for impact piling in **Section 4**.

Table 5.4 Summary of the impact ranges for the different noise sources related to the construction and operation of the Project using the non-impulsive criteria from Southall *et al.* (2019) for marine mammals assuming a fleeing receptor

Southall *et al.* (2019) $L_{E,p,24h,wtd}$ (Fleeing)	**PTS (Non-impulsive)**				**TTS (Non-impulsive)**			
	LF (199dB)	**HF (198dB)**	**VHF (173dB)**	**PCW (201dB)**	**LF (179dB)**	**HF (178dB)**	**VHF (153dB)**	**PCW (181dB)**
Cable laying	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m
Drag embedment anchors	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m
Dredging (backhoe)	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m
Dredging (suction)	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m	250m	< 100m
Drilling	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m
Rock placement	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m	1.2km	< 100m
Suction caisson installation	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m	780m	< 100m
Trenching	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m
Vessel noise (large)	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m
Vessel noise (medium)	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m	< 100m

Table 5.5: Summary of the impact ranges for the different noise sources related to the construction and operation of the Project using the non-impulsive criteria from Southall *et al.* (2019) for marine mammals assuming a stationary receptor

Southall *et al.* (2019) $L_{E,p,24h,wtd}$ (Stationary)	**PTS (Non-impulsive)**				**TTS (Non-impulsive)**			
	LF (199dB)	**HF (198dB)**	**VHF (173dB)**	**PCW (201dB)**	**LF (179dB)**	**HF (178dB)**	**VHF (153dB)**	**PCW (181dB)**
Cable laying	<100m	<100m	<100m	<100m	810m	<100m	2.3km	110m
Drag embedment anchors	<100m	<100m	<100m	<100m	<100m	<100m	<100m	<100m
Dredging (backhoe)	<100m	<100m	<100m	<100m	<100m	<100m	<100m	<100m
Dredging (suction)	<100m	<100m	570m	<100m	640m	390m	4.3km	420m
Drilling	<100m	<100m	<100m	<100m	<100m	<100m	<100m	<100m
Rock placement	<100m	<100m	900m	<100m	2.1km	410m	13km	460m
Suction caisson installation	130m	<100m	1.1km	<100m	1.3km	770m	6.8km	830m
Trenching	<100m	<100m	<100m	<100m	830m	<100m	1.9km	120m
Vessel noise (large)	<100m	<100m	<100m	<100m	480m	<100m	140m	<100m
Vessel noise (medium)	<100m	<100m	<100m	<100m	<100m	<100m	<100m	<100m

5.2.1.9 It should be noted that ranges for stationary animals are theoretical only and are expected to be over-conservative as the assumption is for the receptor to remain stationary in respect to the noise source for the entire assessment period (24 hours), when in a number of these instances, the noise source moves.

5.2.1.10 **Table 5.6** assumes a stationary animal, although the duration of exposure is as per the specific criteria.

Table 5.6 Summary of the impact ranges for the different noise sources related to the construction and operation of the Project using the continuous noise criteria from Popper *et al.* (2014) for fish (swim bladder involved in hearing)

Popper *et al*. (2014) L_p	Recoverable injury 170dB re 1 µPa (48 hours)	TTS 158dB re 1 µPa (12 hours)
Cable laying	< 50m	< 50m
Drag embedment anchors	< 50m	< 50m
Dredging (backhoe)	< 50m	< 50m
Dredging (suction)	< 50m	< 50m
Drilling	< 50m	< 50m
Rock placement	< 50m	< 50m
Suction caisson installation	< 50m	60m
Trenching	< 50m	< 50m
Vessel noise (large)	< 50m	< 50m
Vessel noise (medium)	< 50m	< 50m

5.3 Operational wind turbine generator noise

5.3.1.1 The noise source for most operational WTGs is the radiating area of the foundation in the water. For a fixed-bottom monopile foundation, this is the surface area of the cylindrical pile in the water column. Other fixed foundations such as jacket or tripod foundations, or floating designs, are more complex. The complexities of the acoustics in large structures such as these make it difficult to predict their effect on the noise output (Tougaard *et al*., 2020). The radiating area source for a floating WTG is limited to the weighted and buoyant section that rests beneath the sea surface, a significantly smaller area than for a fixed WTG foundation. With a much smaller submerged radiating area, the noise is expected to be lower, with a reasonable assumption of equivalent sound generation within the WTG and transmission through the tower (Risch *et al*., 2023).

5.3.1.2 Little empirical data exists for the operational noise produced by floating WTGs. For example, Bellmann *et al.* (2023), Tougaard *et al*. (2020) and the study by Stöber and Thomsen (2021) did not consider any floating designs. Measurements taken by Jasco Applied Science (Martin *et al*., 2011) of the Hywind demonstrator, west of Stavanger, Norway, showed broadband noise levels of the order of 120dB re 1 µPa (L_p) over an approximate 10-week period in June to August 2011, at a range of 150m from the WTG. However, much of this was found to be influenced by ambient noise from existing shipping sources and none of the components of noise relating to WTG operation appeared to exceed 110dB re 1 µPa (L_p) at the monitoring location. It is worth noting that this is dominated by noise at low frequency (< 100 Hz), which is below the auditory sensitivity for most marine mammals, and they differ minimally from background noise over the long term at all measured frequencies up to 16 kHz (1/3rd octave band). It is therefore likely that even if the noise measurement at the position near the WTG was influenced by operational WTG noise, ambient noise levels will typically reach this level naturally; the WTG in this study was 2.3 MW (82.4 m rotor diameter). While some other monitoring data for floating wind farm projects do exist (Molinero, 2020; Risch *et al.*, 2023), comparing potential noise levels to worst-case examples such as those from Hywind are considered best practice for this study as they are the largest available.

5.3.1.3 Using the Tougaard *et al*. (2020) calculator for fixed foundations, uplifts of between 11dB and 14dB would need to be applied to the data from a 2.3 MW floating WTG to the sizes proposed for the Project (14 and 25 MW). This would suggest levels of between 131 and 134dB re 1 μPa (L_p) at 150m for the floating turbines at the Project.

5.3.1.4 Using this extrapolated level and the Popper *et al*. (2014) criteria for continuous noise, the TTS threshold of 158dB (L_p) would require an individual to be closer than 20m for 12 hours continuously. For a source near the surface in water depths of the order of 110m, this would be very low risk. As studies have shown that fish populations have increased in the vicinity of OWFs (Stenberg *et al*., 2015), there appears to be minimal risk to fish from operational WTGs from the standpoint of underwater noise or any other potential stressor.

5.3.1.5 To compare this to the relevant marine mammal impact thresholds in Southall *et al*. (2019), at a range of 100m from the floating WTG for an hour, a receptor would receive an unweighted 174dB ($L_{E,p,1h}$) considering the larger WTG size. With weighting considered, this is still well below potentially injurious or TTS thresholds for any Southall *et al*. (2019) criteria. Therefore, for noise from operational floating WTGs, TTS risk is small. Importantly this also assumes a stationary animal model with an individual remaining within 100m from a WTG for much more than a 1-hour period. This is a highly unlikely scenario. When the animal is able to move, the risk of direct harm from the noise is minimal.

5.4 Mooring line noise

5.4.1.1 As well as relatively low noise levels from the operational machinery in a variety of conditions (see the previous **Section 5.3**), measurements taken by Jasco (2011) for Statoil at Hywind Demonstrator in Norway identified what appeared to be a “snapping” noise. A subsequent more detailed study at Hywind Scotland (Burns *et al.*, 2022) showed lower levels of somewhat different (and less impulsive) noises, but transients identified were associated with strain and friction in the mooring system, and they became increasingly frequent with increasing wave height. It is understood that the mooring lines at Hywind Scotland Pilot Park are designed to be permanently in tension such that no line should ever go into slack, even in extreme conditions, partly to avoid the risk of entanglement of marine mammals (Statoil, 2015). As the mooring lines appear to be the source of the noise, this may be caused by the specific circumstances at the Hywind project: that is, the specific type of mooring, depth of water, length of mooring lines in use, current and current fluctuations. The findings at Hywind were isolated, and it does not necessarily follow that this will occur at the Project but does not rule out the potential for it either. Further evidence is required to investigate whether other floating WTG moorings are shown to create similar transient noises.

5.4.1.2 As the source of noise is unclear and Burns *et al.* (2022) showed it to be somewhat variable, its distance from the monitor cannot be ascertained and thus a prediction of the noise closer to the source is not possible for estimation of PTS in terms of $L_{p,pk}$. Analysis of the Hywind data by Xodus (2015) for the Hywind Scotland Project predicted a potential $L_{E,p,24h}$ of up to 157dB re 1 μPa^{2}s caused by snapping chains from six WTGs; the equivalent for ten would be approximately 160dB re 1 μPa^{2}s. This prediction makes a series of worst-case assumptions (e.g., all WTGs producing the maximum number of snaps in a day, equivalent noise levels from multiple locations affecting a receptor to the same degree) and this level is below any PTS or injury criteria to marine mammals or fish. Also as noted, the subsequent study by Burns *et al.* (2022) did not identify the snapping noise so this is likely to be moot.

5.4.1.3 There are no reliable noise thresholds that would be recommended to identify disturbance for rare/intermittent impulses of this type. As any transients occurred at an average rate of less than one per hour, disturbance leading to avoidance behaviour is considered unlikely.

5.5 Unexploded ordnance clearance

5.5.1.1 It is possible that UXO devices with a range of charge weights (or quantity of contained explosive) are present within the Project's OAA. These would need to be cleared before any construction can begin. When modelling potential noise from UXO clearance, a variety of explosive types need to be considered, with the potential that many have been subject to degradation and burying over time. Two otherwise identical explosive devices are likely to produce different blasts in the case where one has spent an extended period on the seabed or sits in a different topographical situation. A selection of explosive sizes has been considered based on what might be present, and in each case, it has been assumed that the maximum explosive charge in each device is present and either detonates with the clearance (high-order) or a clearance method such as deflagration (low-order) can be used. It is expected that a low-order technique will be the primary method of UXO clearance, with high-order clearance only to occur in exceptional circumstances.

5.5.2 Estimation of underwater noise levels

High-order clearance

5.5.2.1 The noise produced by the detonation of explosives is affected by several different elements, only one of which can easily be factored into a calculation: the charge weight. In this case the charge weight is based on the equivalent weight of TNT. Many other elements relating to its situation (e.g., its design, composition, age, position, orientation, whether it is covered by sediment) and exactly how they will affect the sound produced by detonation are usually unknown and cannot be directly considered in this type of assessment. This leads to a high degree of uncertainty in the estimation of the source noise level. A worst-case estimation has therefore been used for calculations, assuming the UXO to be detonated is not buried, degraded or subject to any other significant attenuation from its 'as-new' condition. A 'high-order' clearance technique, using an external 'donor charge' initiator to detonate the explosive material in the UXO, theoretically produces a blast wave equivalent to full detonation of the device.

5.5.2.2 The consequence of this is that the noise levels produced, particularly by the larger explosives under consideration, are likely to be over-estimated as some degree of attenuation (i.e. from topography, burying, degradation, orientation) would be expected.

5.5.2.3 It should be noted that a high-order clearance technique would be a last resort, after the use of a less intrusive and quieter technique such as low-order clearance.

5.5.2.4 The maximum equivalent charge weight for the potential UXO devices that could be present within the Project's OAA has been estimated as 907 kg. This has been modelled alongside a range of smaller devices, at charge weights of 25, 55, 120, 240, 525, 698, and 750 kg, which have been chosen to give a good spread of potential devices that have been identified at other sites in the North Sea. In each case, an additional donor weight of 0.5 kg has been included to initiate detonation.

5.5.2.5 Estimation of the source noise level for each charge weight has been carried out in accordance with the methodology of Soloway and Dahl (2014), which follows Arons (1954) and the Marine Technical Directorate Ltd. (MTD) (1996).

Low-order clearance

5.5.2.6 Other techniques are expected to be the first choice for UXO clearance, to reduce the consequences of noise caused by detonation of the main charge of the UXO. Deflagration is such an alternative technique, intended to result in a 'low-order' burn of the explosive material in a UXO, which destroys, but does not detonate, the internal explosive.

5.5.2.7 Where the technique proceeds as intended, it is still not without noise impact. The process requires an initial shaped explosive donor charge, typically less than 250 g, to breach the casing and ignite the internal high explosive (HE) material without full detonation. The shaped charge and burn will both produce noise, although it will be significantly less than the high-order detonation of the much larger UXO. It may not destroy all the HE, which would necessitate further deflagration events or collection of the remnants. The deflagration may produce an unintentional high-order event.

5.5.2.8 For calculation of the scenario of total destruction of the HE material using deflagration, it is anticipated that the initial shaped charge is the greatest source of noise (Cheong *et al.*, 2020). The shaped charge is treated as a bulk charge with noise explosive quantity determined according to the size of UXO on which it is placed. A prediction of this impact is based on a charge weight of 250 g. The worst-case scenario would of course be a high-order detonation with maximum pressures from complete detonation of the UXO, and this has been calculated separately for comparison.

5.5.3 Estimation of underwater noise propagation

5.5.3.1 For this assessment, the attenuation of the noise from UXO detonation has been accounted for in calculations using geometric spreading and a sound absorption coefficient, primarily using the methodologies cited in Soloway and Dahl (2014), which establishes a trend based on measured data in open water. These are, for $L_{p,pk}$:

$$L_{p,pk} = 52.4 \times 10^6 \left(\frac{R}{W^{1/3}}\right)^{-1.13}$$

and for $L_{E,p}$:

$$L_{E,p} = 6.14 \times \log_{10}\left(W^{1/3}\left(\frac{R}{W^{1/3}}\right)^{-2.12}\right) + 219$$

where W is the equivalent charge weight for TNT in kg and R is the range from the source.

5.5.3.2 These equations give a relatively simple calculation which can be used to give an indication of the range of effect. The equation does not consider variable bathymetry or seabed type, and thus calculation results will be the same regardless of where it is used. An attenuation correction can be added to the Soloway and Dahl (2014) equations for the absorption over long ranges (i.e., of the order of thousands of metres), based on measurements of high intensity noise propagation taken in the North Sea and Irish Sea. This uses standard frequency-based absorption coefficients for the seawater conditions expected in the region.

5.5.3.3 Despite this attenuation correction, the resulting noise levels still need to be considered carefully. For example, $L_{p,pk}$ noise levels over larger distances are difficult to predict accurately (von Benda-Beckmann *et al*., 2015). Soloway and Dahl (2014) only verify results from the equation above for small charges at ranges of less than 1km, although the results are similar to the measurements presented by von Benda-Beckmann *et al*. (2015). At longer ranges, greater confidence is expected with the $L_{E,p}$ calculations. It should be noted that Ocean Winds (2024) indicates that, based on measurements of noise from deflagration in the Moray Firth, these calculations are likely to produce a higher, and therefore precautionary, prediction of noise levels than are seen in practice.

5.5.3.4 A further limitation in the Soloway and Dahl (2014) equations are that variations in noise levels at different depths are not considered. Where animals are swimming near the surface, the acoustics can cause the noise level, and hence the exposure, to be lower (MTD, 1996). The risk to animals near the surface may therefore be lower than indicated by the impact ranges and therefore the results presented can be considered conservative in respect of the impact at different depths.

5.5.3.5 Additionally, an impulsive wave tends to be smoothed (i.e., the pulse becomes longer) over distance (Cudahy and Parvin, 2001), meaning the injurious potential of a wave at greater range can be even lower than just a reduction in the absolute noise level. An assessment in respect of SEL is considered preferential at long range as it considers the overall energy, and the degree of smoothing of the peak with increasing distance is less critical.

5.5.3.6 The selection of assessment criteria must also be considered in light of this. As discussed in **Section 2.2**, the smoothing of the pulse at range means that a pulse may be considered non-impulsive at distance, suggesting that, at greater ranges, it may be more appropriate to use the non-impulsive criteria. This consideration may begin at 3.5km (Hastie *et al*., 2019) to 5km (Matei *et al*., 2023), although as blast noise is inherently more impulsive than piling, the transition from full impulsivity may occur further from the UXO source location.

5.5.3.7 A summary of the unweighted UXO clearance source levels, calculated using the equations above, are given in **Table 5.7**.

Table 5.7 Summary of the $L_{p,pk}$ and $L_{E,p}$ source levels used for UXO clearance modelling

Charge weight	$L_{p,pk}$ source level	$L_{E,p}$ source level
Low order (0.25 kg)	269.8dB re 1 μPa @ 1 m	215.2dB re 1 μPa²s @ 1 m
25 kg (+ donor)	284.9dB re 1 μPa @ 1 m	228.0dB re 1 μPa²s @ 1 m
55 kg (+ donor)	287.5dB re 1 μPa @ 1 m	230.1dB re 1 μPa²s @ 1 m
120 kg (+ donor)	290.0dB re 1 μPa @ 1 m	232.3dB re 1 μPa²s @ 1 m
240 kg (+ donor)	292.3dB re 1 μPa @ 1 m	234.2dB re 1 μPa²s @ 1 m
525 kg (+ donor)	294.8dB re 1 μPa @ 1 m	236.4dB re 1 μPa²s @ 1 m
698 kg (+ donor)	295.7dB re 1 μPa @ 1 m	237.1dB re 1 μPa²s @ 1 m
750 kg (+ donor)	296.0dB re 1 μPa @ 1 m	237.3dB re 1 μPa²s @ 1 m
907 kg (+ donor)	296.6dB re 1 μPa @ 1 m	237.9dB re 1 μPa²s @ 1 m

5.5.4 Impact ranges

5.5.4.1 **Table 5.8** to **Table 5.11** present the impact ranges for UXO detonation, considering various charge weights and impact criteria. It should be noted that Popper *et al*. (2014) gives specific impact criteria for explosions (**Table 2.5**). A UXO detonation source is defined as a single pulse, as such the $L_{E,p}$ criteria from Southall *et al*. (2019) have been given as single pulse values in the following tables and fleeing animal assumptions do not apply. As with the previous sections, ranges smaller than 50m have not been presented.

5.5.4.2 Although the impact ranges in **Table 5.8** to **Table 5.11** are large, the duration the noise is present must also be considered. For the detonation of a UXO, each explosion is a single noise event, compared to the multiple pulse nature and longer durations of impact piling.

Table 5.8 Summary of the PTS and TTS impact ranges for UXO detonation using the impulsive $L_{p,pk}$ noise criteria from Southall *et al.* (2019) for marine mammals

Southall *et al.* (2019) $L_{p,pk}$	**PTS (impulsive)**				**TTS (impulsive)**			
	LF 219dB	HF 230dB	VHF 202dB	PCW 218dB	LF 213dB	HF 224dB	VHF 196dB	PCW 212dB
Low-order (0.25 kg)	170m	60m	990m	190m	320m	100m	1.8km	360m
25 kg (+ donor)	820m	260m	4.6km	910m	1.5km	490m	8.5km	1.6km
55 kg (+ donor)	1.0km	340m	6.0km	1.1km	1.9km	640m	11km	2.1km
120 kg (+ donor)	1.3km	450m	7.8km	1.5km	2.5km	830m	14km	2.8km
240 kg (+ donor)	1.7km	560m	9.8km	1.9km	3.2km	1.0km	18km	3.5km
525 kg (+ donor)	2.2km	730m	12km	2.5km	4.1km	1.3km	23km	4.6km
698 kg (+ donor)	2.4km	810m	13km	2.7km	4.5km	1.4km	25km	5.0km
750 kg (+ donor)	2.5km	830m	14km	2.8km	4.6km	1.5km	26km	5.1km
907 kg (+ donor)	2.7km	880m	15km	3.0km	4.9km	1.6km	28km	5.5km

Table 5.9 Summary of the PTS and TTS impact ranges for UXO detonation using the impulsive $L_{E,p}$ (single pulse) noise criteria from Southall *et al.* (2019) for marine mammals

Southall *et al.* (2019) $L_{E,p}$ (single pulse)	**PTS (impulsive)**				**TTS (impulsive)**			
	LF 183dB	**HF 185dB**	**VHF 155dB**	**PCW 185dB**	**LF 168dB**	**HF 170dB**	**VHF 140dB**	**PCW 170dB**
Low-order (0.25 kg)	230m	< 50m	80m	< 50m	3.2km	< 50m	750m	570m
25 kg (+ donor)	2.2km	< 50m	570m	390m	29km	150m	2.4km	5.2km
55 kg (+ donor)	3.2km	< 50m	740m	570m	41km	210m	2.8km	7.5km
120 kg (+ donor)	4.7km	< 50m	950m	830m	57km	300m	3.2km	10km
240 kg (+ donor)	6.5km	< 50m	1.1km	1.1km	76km	390m	3.5km	14km
525 kg (+ donor)	9.5km	50m	1.4km	1.6km	100km	530m	4.0km	19km
698 kg (+ donor)	10km	60m	1.5km	1.9km	110km	590m	4.1km	22km
750 kg (+ donor)	11km	60m	1.5km	2.0km	110km	600m	4.2km	22km

Southall *et al.* (2019) $L_{E,p}$ (single pulse)	PTS (impulsive)				TTS (impulsive)			
	LF 183dB	HF 185dB	VHF 155dB	PCW 185dB	LF 168dB	HF 170dB	VHF 140dB	PCW 170dB
907 kg (+ donor)	12km	70m	1.6km	2.2km	120km	650m	4.3km	24km

Table 5.10 Summary of the PTS and TTS impact ranges for UXO detonation using the non-impulsive $L_{E,p}$ (single pulse) noise criteria from Southall *et al.* (2019) for marine mammals

Southall *et al.* (2019) $L_{E,p}$ (single pulse)	PTS (non-impulsive)				TTS (non-impulsive)			
	LF 199dB	HF 198dB	VHF 173dB	PCW 201dB	LF 179dB	HF 178dB	VHF 153dB	PCW 181dB
Low-order (0.25 kg)	< 50m	< 50m	< 50m	< 50m	460m	< 50m	110m	80m
25 kg (+ donor)	130m	< 50m	< 50m	< 50m	4.4km	< 50m	730m	790m
55 kg (+ donor)	190m	< 50m	< 50m	< 50m	6.4km	60m	940m	1.1km
120 kg (+ donor)	280m	< 50m	70m	< 50m	9.4km	80m	1.1km	1.6km
240 kg (+ donor)	390m	< 50m	100m	70m	13km	110m	1.4km	2.3km
525 kg (+ donor)	570m	< 50m	130m	100m	18km	160m	1.7km	3.3km
698 kg (+ donor)	660m	< 50m	150m	110m	21km	180m	1.8km	3.8km
750 kg (+ donor)	680m	< 50m	160m	120m	22km	190m	1.8km	4.0km
907 kg (+ donor)	750m	< 50m	170m	130m	24km	200m	1.9km	4.3km

Table 5.11 Summary of the impact ranges for UXO detonation using the explosions $L_{p,pk}$ noise criteria from Popper *et al.* (2014) for species of fish

Popper *et al.* (2014) $L_{p,pk}$	Mortality and potential mortal injury	
	234dB	229dB
Low-order (0.25 kg)	< 50m	60m
25 kg (+ donor)	170m	290m
55 kg (+ donor)	230m	380m
120 kg (+ donor)	300m	490m
240 kg (+ donor)	370m	620m
525 kg (+ donor)	490m	810m

Popper *et al*. (2014) $L_{p,pk}$	**Mortality and potential mortal injury**	
	234dB	**229dB**
698 kg (+ donor)	530m	890m
750 kg (+ donor)	550m	910m
907 kg (+ donor)	580m	970m

5.5.5 Summary

5.5.5.1 The maximum PTS ranges calculated for the largest high-order UXO clearance is 15km for the VHF cetacean category when considering the $L_{p,pk}$ criteria. For $L_{E,p}$ criteria, the largest PTS range is calculated for LF cetaceans with a predicted impact range of 12km using the impulsive noise criteria. As explained earlier, this assumes no degradation of the UXO and no smoothing of the pulse over distance, which is very precautionary. Although an assumption of non-pulse could underestimate the potential impact (Martin *et al*., 2020) (the equivalent range based on LF cetacean non-pulse criteria is 750m), it is likely that the long-range smoothing of the pulse peak would reduce its potential harm and the maximum 'impulsive' range for all species is precautionary.

5.5.5.2 A low-order clearance would produce a maximum impact range of 990m for VHF cetaceans, with all other species groups lower than this. A low-order methodology is expected to be used for UXO clearance, with high-order being a last resort.

6. Summary and Conclusions

6.1.1.1 The level of underwater noise from the installation of jacket structures and turbine moorings using impact piling during construction has been estimated using the INSPIRE semi-empirical underwater noise model. This approach considers a wide variety of input parameters including bathymetry, hammer blow energy, strike rate, and the flee speed of the receptor.

6.1.1.2 Six modelling locations were chosen to give spatial variation across the Project as well as accounting for changes in water depth. Both piling scenarios considered 3 m diameter piles installed with maximum blow energies of 3,500 kJ.

6.1.1.3 The modelling results were analysed in terms of relevant noise metrics and criteria to assess the effects of impact piling noise on marine mammals (Southall *et al*., 2019) and fish (Popper *et al*., 2014), which have been used to inform biological assessments.

6.1.1.4 For marine mammals, maximum PTS ranges ($L_{E,p,24h,wtd}$) were predicted for LF cetaceans with ranges of up to 25km predicted at the N corner for offshore substation driven pile installation. For fish, the largest recoverable injury ranges (203dB $L_{E,p,24h}$) were predicted to be 4.9km for a stationary receptor, reducing to less than 100m when a fleeing receptor was considered.

6.1.1.5 Noise sources other than piling have been considered using a high-level, simple modelling approach, including the potential installation of drag embedment anchors, suction anchors, cable laying, drilling, ground preparations, vessel noise and operational WTG noise. The risk of any potentially injurious effects to fish or marine mammals from these sources are expected to be minimal as the noise emissions from these are close to, or below, the appropriate injury criteria, even when very close to the source of the noise.

6.1.1.6 Potential noise from UXO clearance has also been considered at the Project. There is a risk of PTS up to 990m for VHF cetaceans, with use of the expected low-order UXO clearance technique. In the event that a high-order detonation does occur, the maximum PTS range is up to 15km from the largest UXO device considered (907 kg + donor charge), using the unweighted $L_{p,pk}$ criteria for VHF cetaceans. However, this is likely to be highly precautionary as the impact range is based on a worst-case criterion and calculation methodology that does not account for any smoothing of the pulse over long ranges, which would reduce the pulse peak and other characteristics of the sound that cause injury.

6.1.1.7 The outputs of this modelling have been used to inform assessments of the impacts of underwater noise on marine mammals and fish at the Project in their respective reports.

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8. Glossary of Terms, Abbreviations And Units

8.1 Abbreviations

Acronym	Definition
ADD	Acoustic Deterrent Device
BGS	British Geological Survey
DPA	Driven Pile Anchor
EMODnet	European Marine Observation and Data Network
FPSO	Floating Production Storage and Offloading
GIS	Geographic Information System
HE	High Explosive
HF	High-Frequency Cetaceans
INSPIRE	Impulsive Noise Sound Propagation and Impact Range Estimator
ISO	International Organisation for Standardisation
LF	Low-Frequency Cetaceans
MTD	Marine Technical Directorate
NMFS	National Marine Fisheries Service
NPL	National Physical Laboratory
OAA	Option Agreement Area
OSS	Offshore Substation
OWF	Offshore Wind Farm
PCW	Phocid Carnivores in Water
PPV	Peak Particle Velocity
PTS	Permanent Threshold Shift
RCP	Reactive Power Compensation Platform
RMS	Root Mean Square
SE	Sound Exposure
SEL ($L_{E,p}$)	Sound Exposure Level

Acronym	Definition
SEL_{cum} ($L_{E,p,t}$)	Cumulative Sound Exposure Level
SEL_{ss} ($L_{E,p,ss}$)	Single Strike Sound Exposure Level
SNH	Scottish Natural Heritage (NatureScot)
SPL	Sound Pressure Level
SPL_{peak} ($L_{p\text{-}pk}$)	Peak Sound Pressure Level
SPL_{RMS} (L_p)	Root Mean Square Sound Pressure Level
TNT	Trinitrotoluene (explosive)
TTS	Temporary Threshold Shift
UK	United Kingdom of Great Britain and Northern Ireland
UXO	Unexploded Ordnance
VHF	Very High-Frequency Cetaceans
WTG	Wind Turbine Generator

8.2 Glossary of terms

Term	Definition
Decibel	A customary scale commonly used (in various ways) for reporting levels of sound. The dB represents a ratio/comparison of a sound measurement (e.g., sound pressure) over a fixed reference level. The dB symbol is followed by a reference value (e.g., re 1 μPa).
Peak pressure	The highest pressure above or below ambient that is associated with a sound wave.
Permanent Threshold Shift	Noise threshold that represents the onset level of a permanent impairment in hearing caused by acoustic trauma. PTS results in irreversible damage to the sensory hair cells of the ear, and thus a permanent reduction of hearing acuity.
Root Mean Square	The square root of the arithmetic average of a set of squared instantaneous values. Used for presentation of an average sound pressure level.
Sound Exposure Level (SEL or $L_{E,p}$)	The constant sound level acting for one second, which has the same amount of acoustic energy, as indicated by the square of the sound pressure, as the original sound. It is the time-integrated, sound-pressure-squared level. SEL is typically used to compare transient sound events having different time durations, pressure levels, and temporal characteristics.

Term	Definition
Sound Exposure Level, cumulative (SEL_{cum} or $L_{E,p,t}$)	Single value for the collected, combined total of sound exposure over a specified time or multiple instances of a noise source.
Sound Exposure Level, single strike (SEL_{ss} or $L_{E,p,ss}$)	Calculation of the sound exposure level representative of a single noise impulse, typically a pile strike.
Sound Pressure Level (SPL or L_p)	The sound pressure level is an expression of sound pressure using the decibel (dB) scale; the standard frequency pressures of which are 1 μPa for water and 20 μPa for air.
Sound Pressure Level Peak (SPL_{peak} or $L_{p,pk}$)	The highest (zero-peak) positive or negative sound pressure, in decibels.
Temporary Threshold Shift	Onset threshold level for a temporary reduction of hearing acuity caused by exposure to sound over time.
Unweighted sound level	Sound levels which are “raw” or have not been adjusted in any way, for example to account for the hearing ability of a species.
Weighted sound level	A sound level which has been adjusted with respect to a “auditory weighting function” or “weighting envelope” in the frequency domain, typically to make an unweighted level relevant to a particular species.

8.3 Units

Unit	Definition
bl/min	Blows per minute (frequency/strike rate)
dB	Decibel (sound pressure)
GW	Gigawatt (power)
Hz	Hertz (frequency)
kg	Kilogram (mass)
kHz	Kilohertz (frequency)
kJ	Kilojoule (energy)
km	Kilometre (distance)
km^2	Square kilometres (area)
kn	Knot (speed)
kW	Kilowatt (power)
m	Metre (distance)
mm/s	Millimetres per second (particle velocity)

Unit	Definition
m/s	Metres per second (speed)
MW	Megawatt (power)
Pa	Pascal (pressure)
Pa^2s	Pascal squared seconds (acoustic energy)
μPa	Micropascal (pressure)
$μPa^2s$	Micropascal squared seconds (acoustic energy)
s	Seconds (time)

Appendix A
Additional Modelling Results

Following the impulsive Southall *et al*. (2019) modelled impact ranges presented in **Section 4**, the modelling results for the non-impulsive criteria are presented in the following sections. The predicted ranges here fall well below those presented in the main report for the impulsive criteria.

Single location modelling

Offshore substation southeast corner

Table A.1: Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) non-impulsive criteria covering the offshore substation driven pile installation modelling for a single pile at the southeast corner modelling location

Southall *et al*. (2019) Weighted $L_{E,p,24h,wtd}$		Offshore substation driven piles (single pile)			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199dB)	< 0.1km²	< 100m	< 100m	< 100m
	HF (198dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (173dB)	< 0.1km²	< 100m	< 100m	< 100m
	PCW (201dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Non-impulsive)	LF (179dB)	3,100km²	34km	28km	31km
	HF (178dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (153dB)	68km²	4.8km	4.4km	4.7km
	PCW (181dB)	< 0.1km²	< 100m	< 100m	< 100m

Table A.2 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al*. (2019) non-impulsive criteria covering the offshore substation driven pile installation modelling for two sequentially installed piles at the southeast corner modelling location

Southall et al. (2019) Weighted LE,p,24h,wtd		Offshore substation driven piles (two sequentially installed piles)			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199dB)	< 0.1km2	< 100m	< 100m	< 100m
	HF (198dB)	< 0.1km2	< 100m	< 100m	< 100m
	VHF (173dB)	< 0.1km2	< 100m	< 100m	< 100m
	PCW (201dB)	< 0.1km2	< 100m	< 100m	< 100m
TTS (Non-impulsive)	LF (179dB)	4,100km2	41km	32km	36km
	HF (178dB)	< 0.1km2	< 100m	< 100m	< 100m
	VHF (153dB)	110km2	6.3km	5.6km	6.0km
	PCW (181dB)	< 0.1km2	< 100m	< 100m	< 100m

Offshore substation southwest corner

Table A.3 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) non-impulsive criteria covering the offshore substation driven pile installation modelling for a single pile at the southwest corner modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		Offshore substation driven piles (single pile)			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199dB)	< 0.1km^2	< 100m	< 100m	< 100m
	HF (198dB)	< 0.1km^2	< 100m	< 100m	< 100m
	VHF (173dB)	< 0.1km^2	< 100m	< 100m	< 100m
	PCW (201dB)	< 0.1km^2	< 100m	< 100m	< 100m
TTS (Non-impulsive)	LF (179dB)	2,800km^2	32km	28km	30km
	HF (178dB)	< 0.1km^2	< 100m	< 100m	< 100m
	VHF (153dB)	65km^2	4.7km	4.5km	4.6km
	PCW (181dB)	< 0.1km^2	< 100m	< 100m	< 100m

Table A.4 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) non-impulsive criteria covering the offshore substation driven pile installation modelling for two sequentially installed piles at the southwest corner modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		Offshore substation driven piles (two sequentially installed piles)			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199dB)	< 0.1km^2	< 100m	< 100m	< 100m
	HF (198dB)	< 0.1km^2	< 100m	< 100m	< 100m
	VHF (173dB)	< 0.1km^2	< 100m	< 100m	< 100m
	PCW (201dB)	< 0.1km^2	< 100m	< 100m	< 100m
TTS (Non-impulsive)	LF (179dB)	3,700km^2	37km	31km	35km
	HF (178dB)	< 0.1km^2	< 100m	< 100m	< 100m
	VHF (153dB)	110km^2	6.1km	5.7km	5.9km
	PCW (181dB)	< 0.1km^2	< 100m	< 100m	< 100m

Offshore substation north corner

Table A.5 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) non-impulsive criteria covering the offshore substation driven pile installation modelling for a single pile at the north corner modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		Offshore substation driven piles (single pile)			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199dB)	< 0.1km^2	< 100m	< 100m	< 100m
	HF (198dB)	< 0.1km^2	< 100m	< 100m	< 100m
	VHF (173dB)	< 0.1km^2	< 100m	< 100m	< 100m
	PCW (201dB)	< 0.1km^2	< 100m	< 100m	< 100m
TTS (Non-impulsive)	LF (179dB)	3,200km^2	35km	29km	32km
	HF (178dB)	< 0.1km^2	< 100m	< 100m	< 100m
	VHF (153dB)	70km^2	4.9km	4.6km	4.7km
	PCW (181dB)	< 0.1km^2	< 100m	< 100m	< 100m

Table A.6 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al*. (2019) non-impulsive criteria covering the offshore substation driven pile installation modelling for two sequentially installed piles at the north corner modelling location

Southall *et al*. (2019) Weighted $L_{E,p,24h,wtd}$		Offshore substation driven piles (two sequentially installed piles)			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199dB)	< 0.1km²	< 100m	< 100m	< 100m
	HF (198dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (173dB)	< 0.1km²	< 100m	< 100m	< 100m
	PCW (201dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Non-impulsive)	LF (179dB)	4,400km²	41km	33km	37km
	HF (178dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (153dB)	120km²	6.4km	5.8km	6.2km
	PCW (181dB)	< 0.1km²	< 100m	< 100m	< 100m

Offshore substation west corner

Table A.7 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) non-impulsive criteria covering the offshore substation driven pile installation modelling for a single pile at the west corner modelling location

Southall *et al*. (2019) Weighted $L_{E,p,24h,wtd}$		Offshore substation driven piles (single pile)			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199dB)	< 0.1km²	< 100m	< 100m	< 100m
	HF (198dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (173dB)	< 0.1km²	< 100m	< 100m	< 100m
	PCW (201dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Non-impulsive)	LF (179dB)	2,900km²	32km	28km	30km
	HF (178dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (153dB)	64km²	4.6km	4.3km	4.5km
	PCW (181dB)	< 0.1km²	< 100m	< 100m	< 100m

Table A.8 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) non-impulsive criteria covering the offshore substation driven pile installation modelling for two sequentially installed piles at the west corner modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		Offshore substation driven piles (two sequentially installed piles)			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199dB)	< 0.1km^2	< 100m	< 100m	< 100m
	HF (198dB)	< 0.1km^2	< 100m	< 100m	< 100m
	VHF (173dB)	< 0.1km^2	< 100m	< 100m	< 100m
	PCW (201dB)	< 0.1km^2	< 100m	< 100m	< 100m
TTS (Non-impulsive)	LF (179dB)	3,800km^2	37km	32km	35km
	HF (178dB)	< 0.1km^2	< 100m	< 100m	< 100m
	VHF (153dB)	110km^2	6.0km	5.5km	5.8km
	PCW (181dB)	< 0.1km^2	< 100m	< 100m	< 100m

Reactive compensation platform south location

Table A.9 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) non-impulsive criteria covering the RCP driven pile installation modelling for a single pile at the south RCP modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		RCP driven piles (single pile)			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199dB)	< 0.1km^2	< 100m	< 100m	< 100m
	HF (198dB)	< 0.1km^2	< 100m	< 100m	< 100m
	VHF (173dB)	< 0.1km^2	< 100m	< 100m	< 100m
	PCW (201dB)	< 0.1km^2	< 100m	< 100m	< 100m
TTS (Non-impulsive)	LF (179dB)	2,200km^2	30km	22km	27km
	HF (178dB)	< 0.1km^2	< 100m	< 100m	< 100m
	VHF (153dB)	53km^2	4.3km	3.8km	4.1km
	PCW (181dB)	< 0.1km^2	< 100m	< 100m	< 100m

Table A.10 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) non-impulsive criteria covering the RCP driven pile installation modelling for two sequentially installed piles at the south RCP modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		RCP driven piles (two sequentially installed piles)			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199dB)	< 0.1km²	< 100m	< 100m	< 100m
	HF (198dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (173dB)	< 0.1km²	< 100m	< 100m	< 100m
	PCW (201dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Non-impulsive)	LF (179dB)	2,800km²	34km	22km	30km
	HF (178dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (153dB)	86km²	5.5km	4.9km	5.2km
	PCW (181dB)	< 0.1km²	< 100m	< 100m	< 100m

Reactive compensation north location

Table A.11 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) non-impulsive criteria covering the RCP driven pile installation modelling for a single pile at the north RCP modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		RCP driven piles (single pile)			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199dB)	< 0.1km²	< 100m	< 100m	< 100m
	HF (198dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (173dB)	< 0.1km²	< 100m	< 100m	< 100m
	PCW (201dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Non-impulsive)	LF (179dB)	2,700km²	31km	25km	29km
	HF (178dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (153dB)	65km²	4.7km	4.4km	4.6km
	PCW (181dB)	< 0.1km²	< 100m	< 100m	< 100m

Table A.12 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) non-impulsive criteria covering the RCP driven pile installation modelling for two sequentially installed piles at the north RCP modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		RCP driven piles (two sequentially installed piles)			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199dB)	< 0.1km²	< 100m	< 100m	< 100m
	HF (198dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (173dB)	< 0.1km²	< 100m	< 100m	< 100m
	PCW (201dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Non-impulsive)	LF (179dB)	3,400km²	36km	28km	33km
	HF (178dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (153dB)	110km²	6.1km	5.6km	5.9km
	PCW (181dB)	< 0.1km²	< 100m	< 100m	< 100m

Driven pile anchor north corner

Table A.13 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) non-impulsive criteria covering driven pile anchor installation modelling for a single pile at the north corner modelling location

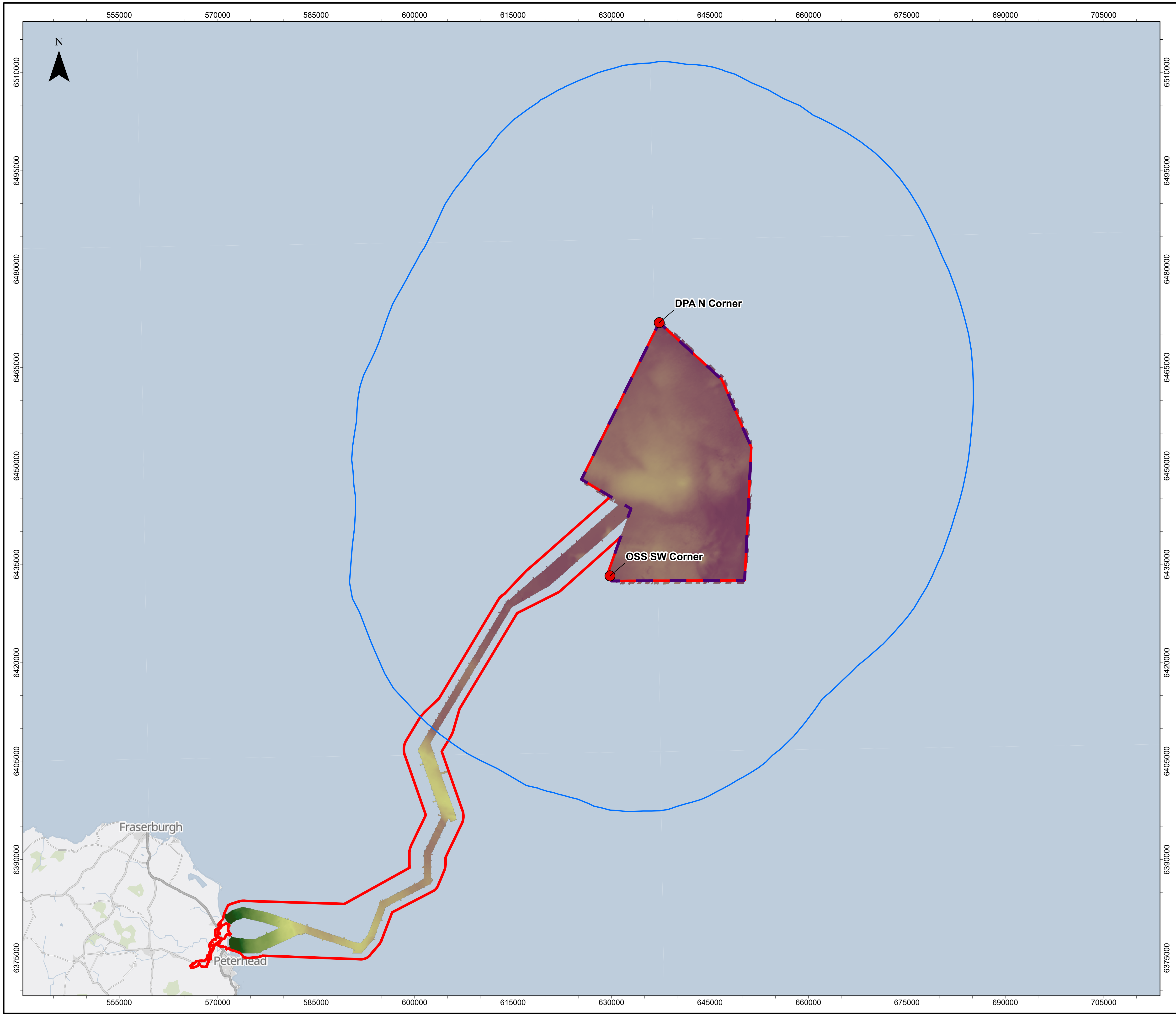
Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		Driven pile anchors (single pile)			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199dB)	< 0.1km²	< 100m	< 100m	< 100m
	HF (198dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (173dB)	< 0.1km²	< 100m	< 100m	< 100m
	PCW (201dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Non-impulsive)	LF (179dB)	2,800km²	32km	27km	30km
	HF (178dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (153dB)	69km²	4.8km	4.5km	4.7km
	PCW (181dB)	< 0.1km²	< 100m	< 100m	< 100m

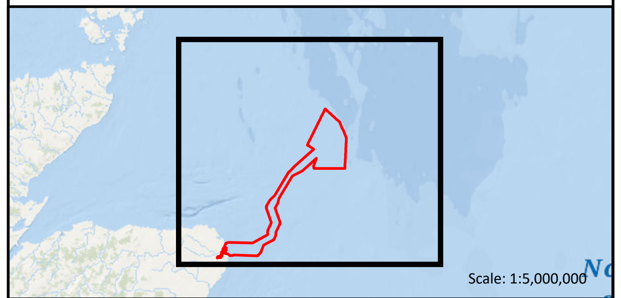
Table A.14 Summary of the weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the Southall *et al.* (2019) non-impulsive criteria covering driven pile anchor installation modelling for two sequentially installed piles at the north corner modelling location

Southall *et al.* (2019) Weighted $L_{E,p,24h,wtd}$		Driven pile anchors (two sequentially installed piles)			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199dB)	< 0.1km²	< 100m	< 100m	< 100m
	HF (198dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (173dB)	< 0.1km²	< 100m	< 100m	< 100m
	PCW (201dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Non-impulsive)	LF (179dB)	3,800km²	38km	30km	35km
	HF (178dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (153dB)	120km²	6.4km	5.8km	6.1km
	PCW (181dB)	< 0.1km²	< 100m	< 100m	< 100m

Multiple location modelling

The Project locations





REV	REV DATE	GIS CREATOR	GIS REVIEWER	TECHNICAL CHECKER	TECHNICAL APPROVER
	dd/mm/yyyy	--	--	--	--
2	19/09/2025	PB	LT	LG	NC
1	23/07/2025	PB	LT	LG	NC

WSP DRAWING NUMBER 808368-WEIS-IA-E5-FG-U8-3989

MarramWind DRAWING NUMBER MAR-GEN-ENV-MAP-WSP-000196

DATUM	ETRS 89	PROJECTION	UTM Zone 30N
SCALE	1:550,000	PAGE SIZE	A3

PROJECT TITLE

MarramWind Offshore Wind Farm

DRAWING TITLE

Figure A.1 Contour plots showing the in-combination impacts of concurrent installation of OSS foundations at the SW corner and DPAs at the N corner of the Project for LF cetaceans and HF cetaceans using the non-impulsive Southall et al. (2019) criteria assuming fleeing animals

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Appendix 8.1

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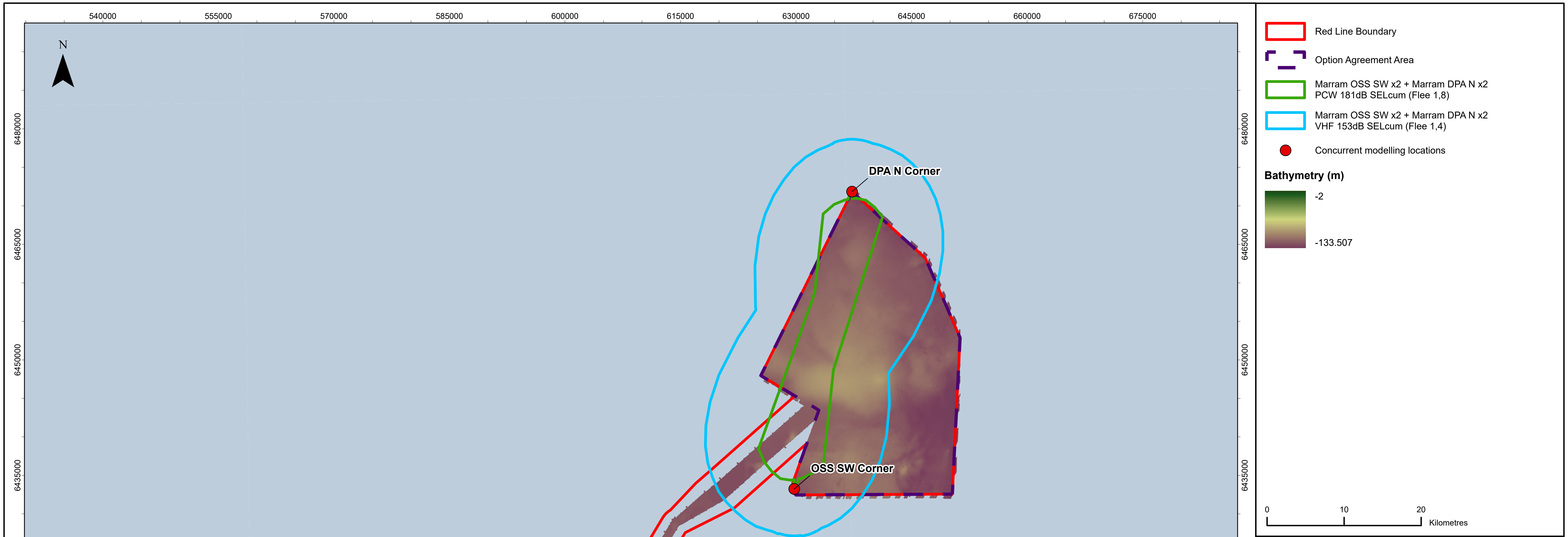
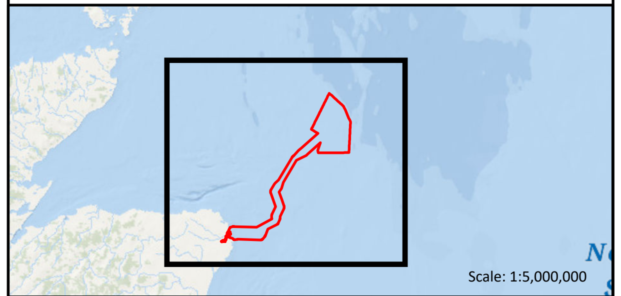
wsp

MarramWind





REV	REV DATE	GIS CREATOR	GIS REVIEWER	TECHNICAL CHECKER	TECHNICAL APPROVER
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WSP DRAWING NUMBER	808368-WEIS-IA-E5-FG-U8-27052		
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DATUM	ETRS 89	PROJECTION	UTM Zone 30N
SCALE	1:500,000	PAGE SIZE	A3

PROJECT TITLE

MarramWind Offshore Wind Farm

DRAWING TITLE

Figure A.2 Contour plots showing the in-combination impacts of concurrent installation of OSS foundations at the SW corner and DPAs at the N corner of the Project for VHF cetaceans and PCW pinnipeds using the non-impulsive Southall et al. (2019) criteria assuming fleeing animals

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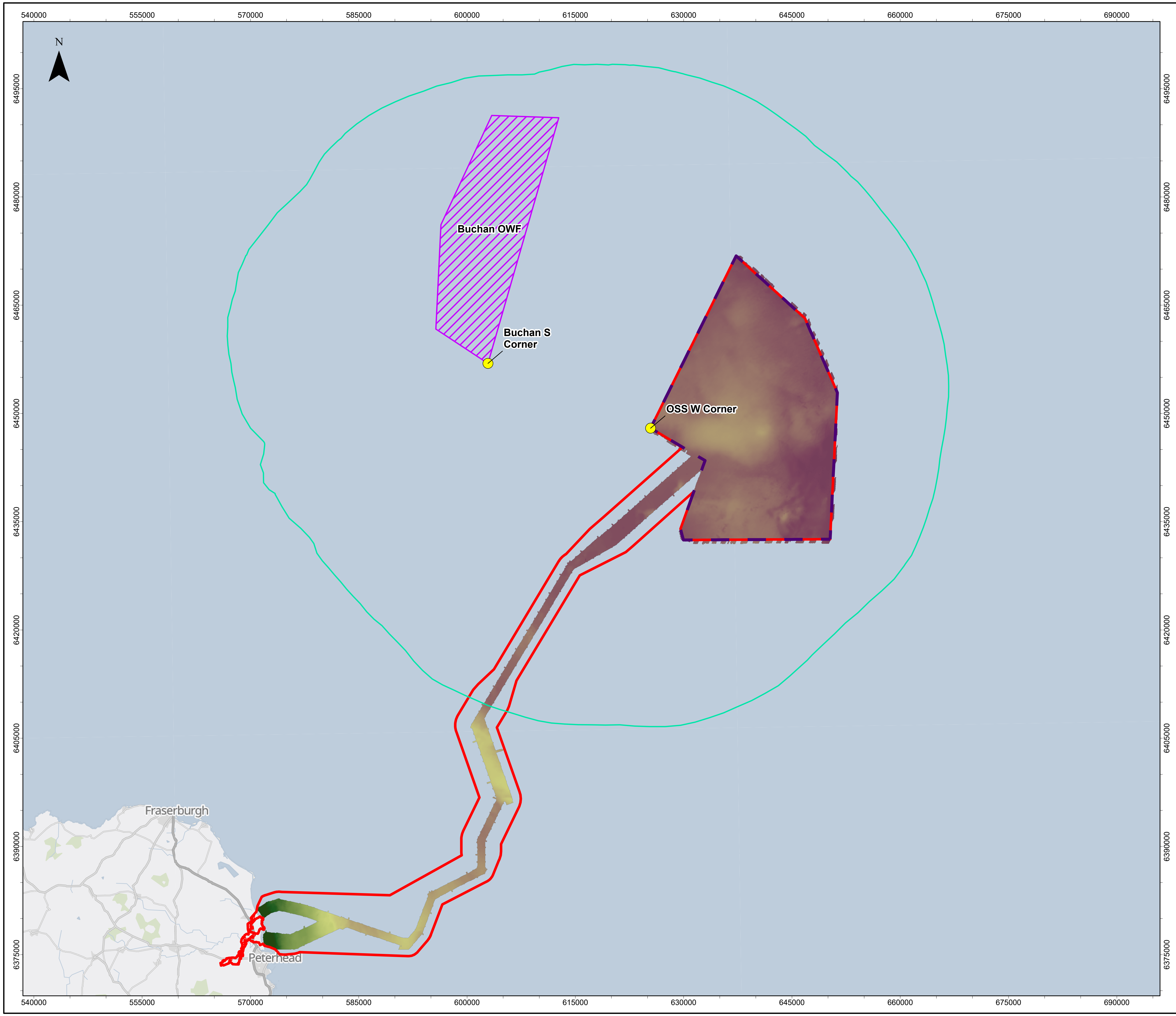
Appendix 8.1

NOT TO BE USED FOR NAVIGATION

Table A.15 Summary of the impact areas for the installation of offshore substation foundations at the southwest corner and driven pile anchors at the north corner of the Project for marine mammals using the non-impulsive Southall *et al.* (2019) $L_{E,p,24h,wtd}$ criteria assuming a fleeing animal

Offshore substation driven pile / driven pile anchor foundations (Southall *et al*., 2019) $L_{E,p,24h,wtd}$		Southwest corner (offshore substation)	North corner (driven pile anchor)	In-combination area
PTS (Non-impulsive)	LF (199dB)	< 0.1km^2	< 0.1km^2	-
	HF (198dB)	< 0.1km^2	< 0.1km^2	-
	VHF (173dB)	< 0.1km^2	< 0.1km^2	-
	PCW (201dB)	< 0.1km^2	< 0.1km^2	-
TTS (Non-impulsive)	LF (179dB)	3,700km^2	3,800km^2	8,300km^2
	HF (178dB)	< 0.1km^2	< 0.1km^2	-
	VHF (153dB)	110km^2	120km^2	1,100km^2
	PCW (181dB)	< 0.1km^2	< 0.1km^2	240km^2

The Project and Buchan locations



Red Line Boundary

Option Agreement Area

Buchan array area

Marram OSS W x2 + Buchan S x2 LF
179dB SELcum (Flee 2,1)

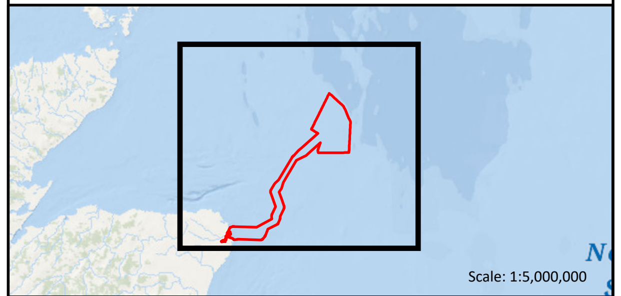
MarramWind+Buchan concurrent
modelling locations

Bathymetry (m)

-2

-133.507

0 10 20 Kilometres



	dd/mm/yyyy	--	--	--	--
2	19/09/2025	PB	LT	LG	NC
1	23/07/2025	PB	LT	LG	NC
REV	REV DATE	GIS CREATOR	GIS REVIEWER	TECHNICAL CHECKER	TECHNICAL APPROVER

WSP DRAWING NUMBER	808368-WEIS-IA-E5-FG-U8-64794
MarramWind DRAWING NUMBER	MAR-GEN-ENV-MAP-WSP-000200

DATUM	ETRS 89	PROJECTION	UTM Zone 30N
SCALE	1:500,000	PAGE SIZE	A3

PROJECT TITLE

MarramWind Offshore Wind Farm

DRAWING TITLE

Figure A.3 Contour plots showing the in-combination impacts of concurrent installation of OSS foundations at the W corner of the Project and the S corner of Buchan for LF cetaceans and HF cetaceans using the non-impulsive Southall et al. (2019) criteria assuming fleeing animals

Environmental Impact Assessment Report

Appendix 8.1

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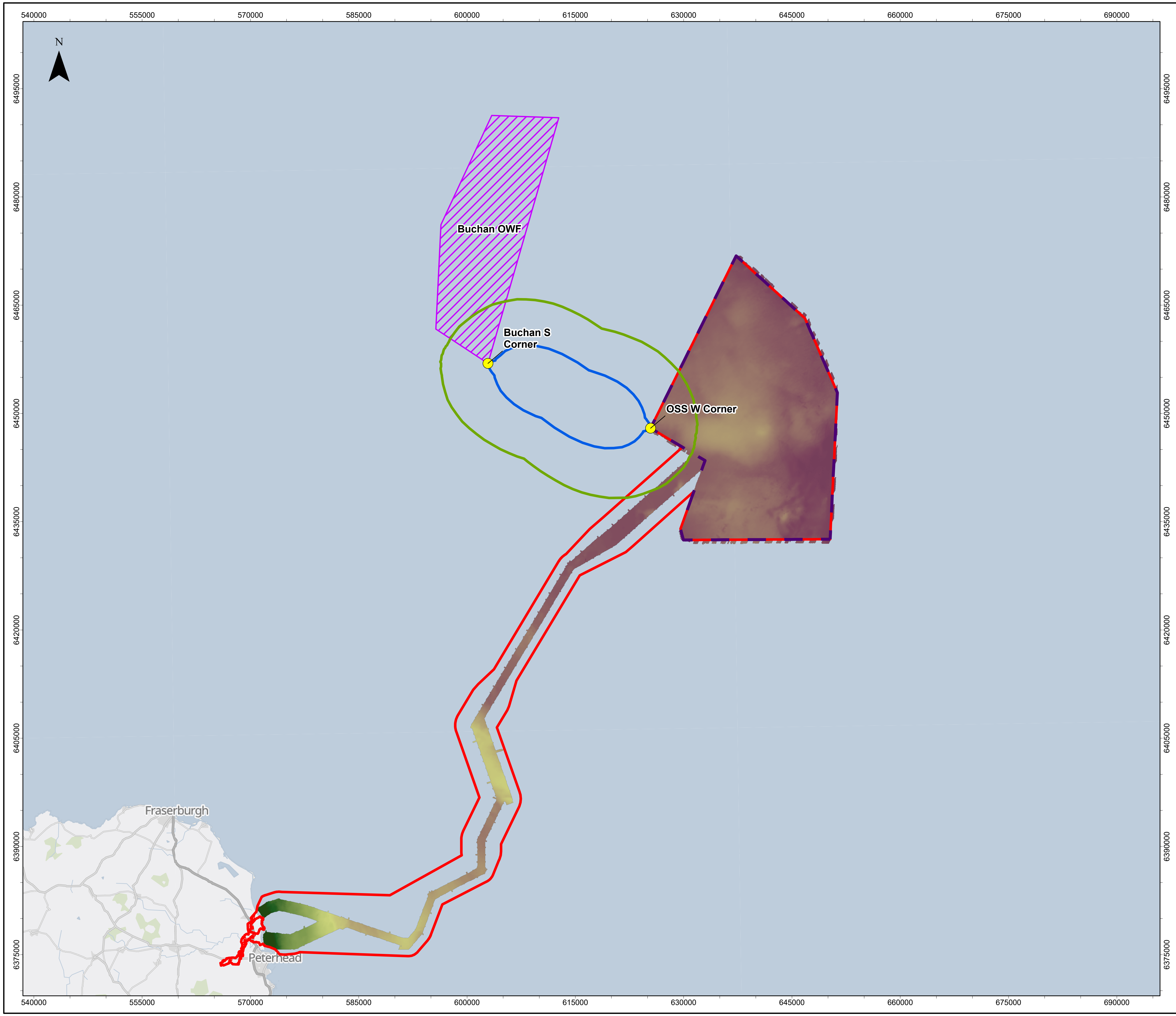
wsp

MarramWind



Red Line Boundary

Option Agreement Area

Buchan array area

Marram OSS W x2 + Buchan S x2 PCW 181dB SELcum (Flee 1,8)

Marram OSS W x2 + Buchan S x2 VHF 153dB SELcum (Flee 1,4)

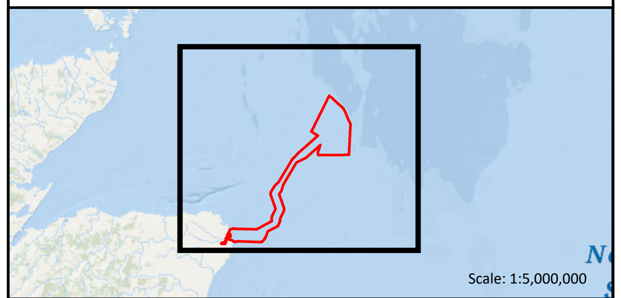
MarramWind+Buchan concurrent modelling locations

Bathymetry (m)

-2

-133.507

0 10 20 Kilometres



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2	19/09/2025	PB	LT	LG	NC
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REV	REV DATE	GIS CREATOR	GIS REVIEWER	TECHNICAL CHECKER	TECHNICAL APPROVER

WSP DRAWING NUMBER 808368-WEIS-IA-E5-FG-U8-75708

MarramWind DRAWING NUMBER MAR-GEN-ENV-MAP-WSP-000202

DATUM	ETRS 89	PROJECTION	UTM Zone 30N
SCALE	1:500,000	PAGE SIZE	A3

PROJECT TITLE
MarramWind Offshore Wind Farm

DRAWING TITLE
Figure A.4 Contour plots showing the in-combination impacts of concurrent installation of OSS foundations at the at the W corner of the Project and the S corner of Buchan for VHF cetaceans and PCW pinnipeds using the non-impulsive Southall et al. (2019) criteria assuming fleeing animals
Environmental Impact Assessment Report
Appendix 8.1

NOT TO BE USED FOR NAVIGATION

wsp MarramWind

Table A 16: Summary of the impact areas for the installation of offshore substation foundations at the west corner of the Project and the south corner of Buchan for marine mammals using the non-impulsive Southall *et al.* (2019) $L_{E,p,24h,wtd}$ criteria assuming a fleeing animal

Offshore substation driven pile foundations (Southall *et al*., 2019) $L_{E,p,24h,wtd}$		West corner (offshore substation)	Buchan south (offshore substation)	In-combination area
PTS (Non-impulsive)	LF (199dB)	< 0.1km²	< 0.1km²	-
	HF (198dB)	< 0.1km²	< 0.1km²	-
	VHF (173dB)	< 0.1km²	< 0.1km²	-
	PCW (201dB)	< 0.1km²	< 0.1km²	-
TTS (Non-impulsive)	LF (179dB)	3,800km²	3,400km²	7,100km²
	HF (178dB)	< 0.1km²	< 0.1km²	-
	VHF (153dB)	110km²	96km²	690km²
	PCW (181dB)	< 0.1km²	< 0.1km²	190km²

MarramWind