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Glossary

Term	Definition
Decibel (dB)	A customary scale commonly used (in various ways) for reporting levels of sound. A difference of 10 dB corresponds to a factor of 10 in sound power. The actual sound measurement is compared to a fixed reference level and the "decibel" value is defined to be $10\log_{10}(actual/reference)$ where $(actual/reference)$ is a power ratio. Because sound power is usually proportional to sound pressure squared, the decibel value for sound pressure is $20\log_{10}(actual\ pressure/reference\ pressure)$. The standard reference for underwater sound is 1 micropascal (μPa). The dB symbol is followed by a second symbol identifying the specific reference value (e.g. re 1 μPa).
Peak pressure	The highest pressure above or below ambient that is associated with a sound wave.
Peak-to-peak pressure	The sum of the highest positive and negative pressures that are associated with a sound wave.
Permanent Threshold Shift (PTS)	Onset ofA a permanent total or partial loss of hearing caused by acoustic trauma. PTS results in irreversible damage to the sensory hair cells of the air, and thus a permanent reduction of hearing acuity
Sound Exposure Level (SEL)	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.
Sound Exposure Level, single strike (SEL_{ss})	Calculation of the sound exposure level representative of a single noise impulse, typically a pile strike.
Sound Exposure Level, cumulative (SEL_{cum})	Single value for the collected, combined total of sound exposure over a specified time or multiple instances of a noise source.
Sound Pressure Level (SPL)	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})	The highest (zero-peak) positive or negative sound pressure, in decibels.
Temporary Threshold Shift (TTS)	Onset of Ttemporary reduction of hearing acuity because of exposure to sound over time. Exposure to high levels of sound over relatively short time periods could cause the same amount of TTS as exposure to lower levels of sound over longer time periods. The mechanisms underlying TTS are not well

	understood, but there may be some temporary damage to the sensory cells. The duration of TTS varies depending on the nature of the stimulus.
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 "weighting envelope" in the frequency domain, typically to make an unweighted level relevant to a particular species. Examples of this are the dB(A), where the overall sound level has been adjusted to account for the hearing ability of humans in air, or the filters used by Southall *et al*. (2019) for marine mammals.

1 Introduction

The Rampion 2 offshore wind farm is a proposed extension to the existing Rampion wind farm located off the coast of Sussex. As part of the Environmental Impact Assessment (EIA) process, Subacoustech Environmental Ltd. have undertaken detailed underwater noise modelling and analysis in relation to marine mammals and fish at the proposed wind farm site.

The Rampion 2 development is situated 13 km from the Sussex coast at its closest point and surrounds the south, and west sides of the existing Rampion site and has a proposed capacity of up to 1,200 MW. The location of the wind farm is shown in Figure 1-1.

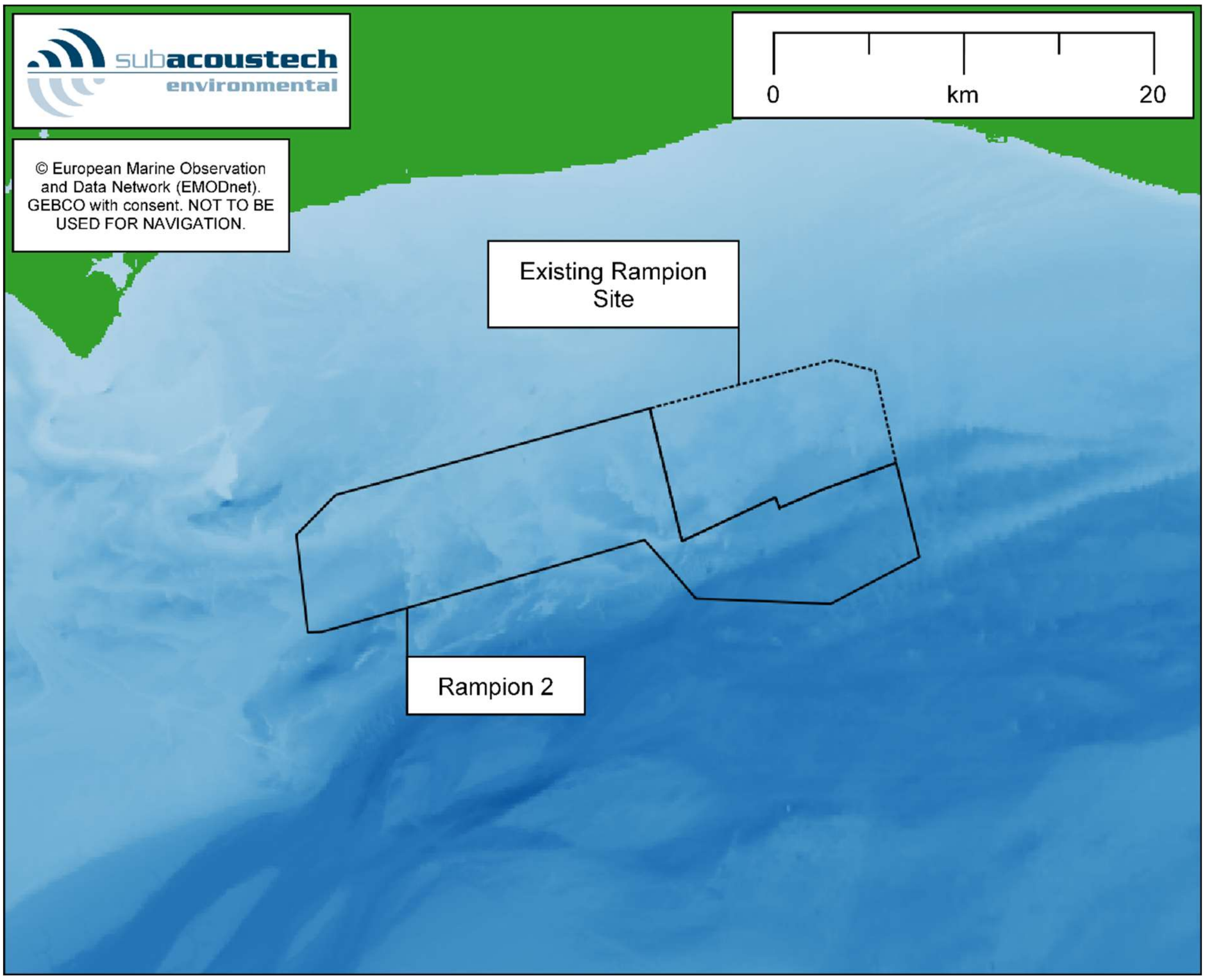


Figure 1-1 Overview map showing the Rampion 2 site boundary (solid line) as well as the existing Rampion offshore wind farm (dotted line)

This report presents a detailed assessment of the potential underwater noise during the construction and operation of Rampion 2 and its effects, and covers the following:

- A review of background information on 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 noise modelling undertaken (Section 3);
- Presentation and interpretation of the detailed subsea noise modelling for impact piling with regards to the effects in marine mammals and fish using various metrics and criteria (Section 4);
- Noise modelling of the other noise sources expected around construction and operation of the wind farm including cable laying, rock placement, dredging, trenching, vessel activity, operational WTG noise and UXO detonation (Section 5); and
- Summary and conclusions (Section 6).

Further modelling of the non-impulsive criteria for impact piling are provided in Appendix A of this report.

2 Background to underwater noise metrics

2.1 Underwater noise

Sound travels much faster in water (approximately 1,500 ms^{-1}) than in air (340 ms^{-1}). Since water is a relatively incompressible, dense medium, the pressure associated with underwater sound tends to be much higher than in air. As an example, background noise levels in the sea of 130 dB re 1 µPa for UK coastal waters are not uncommon (Nedwell *et al*. 2003; Nedwell *et al.* 2007).

It should be noted that stated underwater noise levels should not be confused with noise levels in air, which use a different scale.

2.1.1 Units of measurement

Sound measurements underwater are usually expressed using the decibel (dB) scale, which is a logarithmic measure of sound. A logarithmic scale is used because, rather than equal increments of sound having an equal increase in effect, typically each doubling of sound level will cause a roughly equal increase of "loudness."

Any quantity expressed in this scale is termed a "level." If the unit is sound pressure, expressed on the dB scale, it will be termed a "sound pressure level."

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.

The dB scale represents a ratio, for instance an increase of 6 dB can be interpreted as "twice as much as…" (although this is a simplistic description). 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 20 µPa is used for sound in air since that is the lower threshold of human hearing.

A refinement is that the scale, when used with sound pressure, is applied to the pressure squared rather than just the pressure. If this were not the case, when the acoustic power level of a source rose by 10 dB the sound pressure would rise by 20 dB. 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:

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

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

Unless otherwise defined, all noise levels in this report are referenced to 1 µPa.

2.1.1.1 Sound pressure level (SPL)

The sound pressure level (SPL) is normally used to characterise noise and vibration of a continuous nature, such as drilling, boring, continuous wave sonar, 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 can therefore be considered a measure of the average unweighted level of sound over the measurement period.

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. 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 or sound exposure levels (SELs).

2.1.1.2 Peak sound pressure level (SPL_{peak})

Peak SPLs are often used to characterise transient sound from impulsive sources, such as percussive impact piling. SPL_{peak} 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.

A further variation of this is the peak-to-peak SPL ($SPL_{peak\text{-}to\text{-}peak}$) where the maximum variation of the pressure from positive to negative is considered. Where the wave is symmetrically distributed in positive and negative pressure, the peak-to-peak pressure will be twice the peak level, or 6 dB higher (see section 2.1.1).

2.1.1.3 Sound exposure level (SEL)

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, 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).

The SEL sums the acoustic energy over a measurement period, 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 Pascals, T is the total duration of the sound in seconds, and t is the time in seconds. The SE is a measurement of acoustic energy and has units of Pascal squared seconds (Pa^2s).

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

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

By selecting a common reference pressure (p_{ref}) of 1 μPa for assessments of underwater noise, the SEL and SPL can be compared using the expression:

$$SEL = SPL + 10 \times \log_{10} T$$

where the SPL is a measure of the average level of broadband noise and the SEL sums the cumulative broadband noise energy.

This means that, for continuous sounds of less than one second, the SEL will be lower than the SPL. For periods greater than one second, the SEL will be numerically greater than the SPL (i.e. for a continuous sound of 10 seconds duration, the SEL will be 10 dB higher than the SPL; for a sound of 100 seconds duration the SEL will be 20 dB higher than the SPL, and so on).

2.2 Analysis of environmental effects

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 blasting or impact piling, 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.

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.

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 at the Rampion 2 wind farm site.

2.2.1 Criteria to be used

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 noise exposure criteria;
- Popper *et al*. (2014) sound exposure guidelines for fishes; and
- Hawkins *et al*. (2014) observed responses in fish.

At the time of writing these are used as the most up to date and authoritative criteria for assessing environmental effects for use in impact assessments.

2.2.1.1 Marine mammals

The Southall *et al*. (2019) paper is effectively an update of the previous Southall *et al.* (2007) paper and provides identical thresholds to those from the National Marine Fisheries Service (NMFS) (2018) guidance for marine mammals.

The Southall *et al*. (2019) guidance groups marine mammals into categories of similar species and applies filters to the unweighted noise to approximate the hearing sensitivities of the receptor. The hearing groups given in Southall *et al*. (2019) are summarised in Table 2-1 and Figure 2-1. Further groups for sirenians and other marine carnivores in water are also given, but these have not been used for this study as those species are not commonly found in the North Sea.

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

Table 2-1 Marine mammal hearing groups (from Southall et al., 2019)

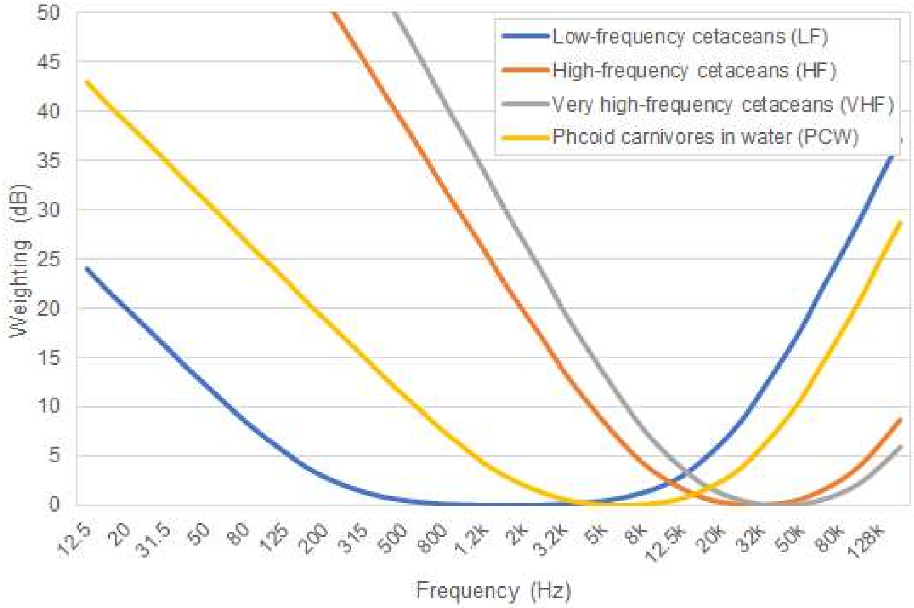


Figure 2-1 Auditory weighting functions for low-frequency cetaceans (LF), high-frequency cetaceans (HF), very high-frequency cetaceans (VHF), and phocid carnivores in water (PCW) (from Southall et al., 2019)

Southall *et al*. (2019) also gives individual criteria based on whether the noise source is considered impulsive or non-impulsive. Southall *et al*. categorises impulsive noises as having high peak sound pressure, short duration, fast rise-time and broad frequency content at source, and non-impulsive sources as steady-state noise. Explosives, impact piling and seismic airguns are considered impulsive noise sources and sonars, vibro-piling, drilling and other low-level continuous noises are considered non-impulsive. A non-impulsive noise does not necessarily have to have a long duration.

Southall *et al*. (2019) presents single strike, unweighted peak criteria (SPL_{peak}) and cumulative (i.e. more than a single sound impulse) weighted sound exposure criteria (SEL_{cum}) for both permanent threshold shift (PTS), where unrecoverable hearing damage may occur, and temporary threshold shift (TTS), where a temporary reduction in hearing sensitivity may occur in individual receptors.

As sound pulses propagate through the environment and dissipate, they also lose their most injurious characteristics (e.g. rapid pulse rise time and high peak sound pressure) and become more like a “non-pulse” at greater distances; Southall *et al*. (2019) briefly discusses this. Active research is currently underway into the identification of the distance at which the pulse can be considered effectively non-impulsive, and Hastie *et al*. (2019) have analysed a series of impulsive data to investigate this. Although the situation is complex, the paper reported that most of the signals crossed their threshold for rapid rise time and high peak sound pressure characteristics associated with impulsive noise at around 3.5 km from the source. However, research by Martin *et al*. (2020) casts doubt on these findings, showing that noise in this category should be considered impulsive as long as it is above effective quiet. To provide as much detail as possible, both impulsive and non-impulsive criteria from Southall *et al.* (2019) have been included in this study, with the non-impulsive criteria presented in Appendix A.

Table 2-2 and Table 2-3 present the Southall *et al*. (2019) criteria for the onset of PTS and TTS risk for each of the key marine mammal hearing groups considering impulsive and non-impulsive sources.

Southall *et al.* (2019)	**Unweighted SPL_{peak} (dB re 1 µPa)**	
	Impulsive	
	PTS	**TTS**
Low-frequency cetaceans (LF)	219	213
High-frequency cetaceans (HF)	230	224
Very high-frequency cetaceans (VHF)	202	196
Phocid carnivores in water (PCW)	218	212

Table 2-2 Single strike SPL_{peak} criteria for PTS and TTS in marine mammals (Southall et al., 2019)

Southall *et al.* (2019)	Weighted SEL_{cum} (dB re 1 µPa²s)			
	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

Table 2-3 Impulsive and non-impulsive SEL_{cum} criteria for PTS and TTS in marine mammals (Southall et al., 2019)

Where SEL_{cum} are required, a fleeing animal model has been used for marine mammals. This assumes that a receptor, when exposed to high noise levels, will swim away from the noise source. For this, a constant fleeing speed of 3.25 ms^{-1} has been assumed for the low-frequency cetaceans (LF) group (Blix and Folkow, 1995), based on data for minke whale, and for other receptors, a constant rate of 1.5 ms^{-1} has been assumed for fleeing, which is a cruising speed for a harbour porpoise (Otani *et al*., 2000). These are considered worst case assumptions as marine mammals are expected to be able to swim much faster under stress conditions. The fleeing animal model and the assumptions related to it are discussed in more detail in section 3.2.3.

It is worth noting that, with regards to the criteria from NMFS (2018), although numerically identical to Southall *et al.* (2019), the guidance applies different names to the marine mammal groups and weightings. For example, what Southall *et al*. (2019) calls high-frequency cetaceans (HF), NMFS (2018) calls mid-frequency cetaceans (MF), and what Southall *et al*. (2019) calls very high-frequency cetaceans (VHF), NMFS (2018) refers to as high-frequency cetaceans (HF). As such, care should be taken when comparing results using the Southall *et al*. (2019) and NMFS (2018) criteria, especially as the “HF” groupings and criteria describe different species depending on which study is being used.

2.2.1.2 Fish

The large number of, and variation in, fish species leads to a greater challenge in production of a generic noise criterion, or range of criteria, for the assessment of noise impacts. Whereas previous studies applied broad criteria based on limited studies of fish that are not present in UK waters (e.g. McCauley *et al*., 2000), or measurement data not intended to be used as criteria (Hawkins *et al*., 2014), the publication of Popper *et al*. (2014) provides an authoritative summary of the latest research and guidelines for fish exposure to sound and uses categories for fish that are representative of the species present in UK waters. However, in the absence of reliable criteria for disturbance in fish, the observed levels presented in Hawkins *et al*. (2014) have been included as part of this study.

The Popper *et al*. (2014) study groups species of fish by whether they possess a swim bladder, and whether it is involved in its hearing; a group for fish eggs and larvae is also included. The guidance also gives specific criteria (as both unweighted SPL_{peak} and unweighted SEL_{cum} values) for a variety of noise sources.

For this study, criteria for impact piling, continuous noise sources, and explosions have been considered; these are summarised in Table 2-4 to Table 2-6.

Type of animal	Mortality and potential mortal injury	Impairment	
		Recoverable injury	TTS
Fish: no swim bladder	> 219 dB SEL_{cum} > 213 dB peak	> 216 dB SEL_{cum} > 213 dB peak	>> 186 dB SEL_{cum}
Fish: swim bladder is not involved in hearing	210 dB SEL_{cum} > 207 dB peak	203 dB SEL_{cum} > 207 dB peak	> 186 dB SEL_{cum}
Fish: swim bladder involving in hearing	207 dB SEL_{cum} > 207 dB peak	203 dB SEL_{cum} > 207 dB peak	186 dB SEL_{cum}
Sea turtles	> 210 dB SEL_{cum} > 207 dB peak	See Table 2-7	See Table 2-7
Eggs and larvae	> 210 dB SEL_{cum} > 207 dB peak	See Table 2-7	See Table 2-7

Table 2-4 Criteria for mortality and potential mortal injury, recoverable injury and TTS in species of fish from impact piling noise (Popper et al., 2014)

Type of animal	Impairment	
	Recoverable injury	TTS
Fish: swim bladder involved in hearing	170 dB RMS for 48 hrs	158 dB RMS For 12 hrs

Table 2-5 Criteria for recoverable injury and TTS in species of fish from continuous noise sources (Popper et al., 2014)

Type of animal	Mortality and potential mortal injury
Fish: no swim bladder	229 – 234 dB peak
Fish: swim bladder is not involved in hearing	229 – 234 dB peak
Fish: swim bladder involving in hearing	229 – 234 dB peak
Sea turtles	229 – 234 dB peak
Eggs and larvae	> 13 mm s^{-1} peak velocity

Table 2-6 Criteria for potential mortal injury in species of fish from explosions (Popper et al., 2014)

Where insufficient data are available, Popper *et al*. (2014) also gives qualitative criteria that summarise the effect of the noise as having either a high, moderate or low effect on an individual in either the near-field (tens of metres), intermediate-field (hundreds of metres), or far-field (thousands of metres). These qualitative effects are reproduced in Table 2-7 to Table 2-9.

Type of animal	**Impairment**			**Behaviour**
	Recoverable injury	**TTS**	**Masking**	
Fish: no swim bladder	See Table 2-4	See Table 2-4	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder is not involved in hearing	See Table 2-4	See Table 2-4	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder involving in hearing	See Table 2-4	See Table 2-4	(N) High (I) High (F) Moderate	(N) High (I) High (F) Moderate
Sea turtles	(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	(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 2-7 Summary of the qualitative effects on species of fish from impact piling noise (Popper et al., 2014) (N = Near-field; I = Intermediate-field; F = Far-field)

Type of animal	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 is 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 involving in hearing	(N) Low (I) Low (F) Low	See Table 2-5	See Table 2-5	(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

Table 2-8 Summary of the qualitative effects on fish from continuous noise from Popper et al. (2014) (N = Near-field; I = Intermediate-field; F = Far-field)

Type of animal	Impairment			Behaviour
	Recoverable injury	TTS	Masking	
Fish: no swim bladder	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	N/A	(N) High (I) Moderate (F) Low
Fish: swim bladder is not involved in hearing	(N) High (I) High (F) Low	(N) High (I) Moderate (F) Low	N/A	(N) High (I) High (F) Low
Fish: swim bladder involving in hearing	(N) High (I) High (F) Low	(N) High (I) High (F) Low	N/A	(N) High (I) High (F) Low
Sea turtles	(N) High (I) High (F) Low	(N) High (I) High (F) Low	N/A	(N) High (I) High (F) Low
Eggs and larvae	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	N/A	(N) High (I) Low (F) Low

Table 2-9 Summary of the qualitative effects on species of fish from explosions (Popper et al., 2014) (N = Near-field; I = Intermediate-field; F = Far-field)

Both fleeing animal and stationary animal models have been used to cover the SEL_{cum} criteria for fish. It is recognised that there is limited evidence for fish fleeing from high level noise sources in the wild, and it would reasonably be expected that the reaction would differ between species. Most species are likely to move away from a sound that is loud enough to cause harm (Dahl *et al*., 2015; Popper *et al*., 2014), some may seek protection in the sediment and others may dive deeper in the water column. For those species that flee, the speed chosen for this study of 1.5 ms^{-1} is relatively slow in relation to data from Hirata (1999) and thus is considered somewhat conservative.

Although it is feasible that some species will not flee, those that are likely to remain are thought more likely to be benthic species or species without a swim bladder; these are the least sensitive species. For example, from Popper *et al*. (2014): “There is evidence (e.g. Goertner *et al*., 1994; Stephenson *et al*., 2010; Halvorsen *et al*., 2012) that little or no damage occurs to fishes without a swim bladder except at very short ranges from an in-water explosive event. Goertner (1978) showed that the range from an explosive event over which damage may occur to a non-swim bladder fish is in the order of 100 times less than that for swim bladder fish.”

Stationary animal modelling has been included in this study, based on research from Hawkins *et al*. (2014) and other modelling for similar EIA projects, and as a worst case the stationary modelling results for fish should be considered in the first instance. However, basing the modelling on a stationary (zero flee speed) receptor is likely to greatly overestimate the potential risk to fish species, assuming that an individual would remain in the high noise level region of the water column, especially when considering the precautionary nature of the parameters already built into the cumulative exposure calculations.

In the absence of reliable numeric criteria for disturbance in fish, observed levels from Hawkins *et al*. (2014) have been used for this study, although the authors of the paper themselves urge caution with the use of the values as criteria. The study was conducted under conditions, which are unlikely to be equivalent to those around at this wind farm.

The report gives unweighted SPL_{peak}, $SPL_{peak\text{-}to\text{-}peak}$, and SEL_{ss} levels where a 50% response level was recorded in sprat and mackerel for an impulsive noise source, simulating pile driving. These levels are summarised in Table 2-10.

Noise metric	Observed noise level for 50% response
Unweighted SPL_{peak}	173 dB re 1 µPa
	168 dB re 1 µPa
Unweighted $SPL_{peak\text{-}to\text{-}peak}$	163 dB re 1 µPa
Unweighted SEL_{ss}	142 dB re 1 µPa^{2}s
	135 dB re 1 µPa^{2}s

Table 2-10 Levels for a 50 % response was observed in fish from Hawkins et al. (2014)

2.2.1.3 Particle motion

The criteria defined in the above section all define the noise impacts on fishes in terms of sound pressure or sound pressure-associated functions (i.e., SEL). It has been identified by researchers (e.g., Popper and Hawkins (2019), Nedelec *et al*. (2016), Radford *et al.* (2012)) that species of fish, as well as invertebrates, actually detect particle motion rather than pressure. Particle motion describes the back-and-forth movement of a tiny theoretical 'element' of water, substrate or other media as a sound wave passes, rather than the pressure caused by the action of the force created by this movement. Particle motion 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. Note that species in the "Fish: swim bladder involved in hearing" category, the most sensitive species, are sensitive to sound pressure.

Popper and Hawkins (2018) state that in derivation of the sound pressure-based criteria in Popper *et al.* (2014) it may be the unmeasured particle motion detected by the fish, to which the fish were responding: there is a relationship between particle motion and sound pressure in a medium. This relationship is very difficult to define where the sound field is complex, such as close to the noise source or where there are multiple reflections of the sound wave in shallow water. Even these terms “shallow” and “close” do not have simple definitions.

The primary reason for the continuing use of sound pressure as the criteria, despite particle motion appearing to be the physical measure to which the fish react or sense, is a lack of data (Popper and Hawkins, 2018) both in respect of predictions of the particle motion level as a consequence of a noise source such as piling, and a lack of knowledge of the sensitivity of a fish, or a wider category of fish, to a particle motion value. There continue to be calls for additional research on the levels of and effects with respect to levels of particle motion. Until sufficient data are available to enable revised thresholds based on the particle motion metric, Popper *et al.* (2014) continues to be the best source of criteria in respect to fish impacts (Andersson *et al.,* 2016, Popper *et al.,* 2019).

2.2.1.4 Impact of underwater noise on humans

The impact of excessive levels of noise in air is well known to cause deafness and legislation is in place to control the effects of noise as a pollutant and as a hazard in the case of occupational noise exposure. The effects of waterborne noise have not been widely investigated, with most research and analysis having been conducted for the military sector. However, where there has been a great deal of attention given to exposure of noise to humans in air then the possibility of waterborne noise exposure should be taken into consideration. In the case of impact piling for the installation of offshore wind turbines which are in the vicinity of popular diving sites or are situated close to the coast, the potential risk of adverse effects exists.

The effects of exposure of humans to underwater impulsive sound depends on the level of exposure, and may be divided into three categories – primary, or life threatening physical injury, including death and severe physical injury; secondary, or non-life threatening physical injury, and in particular auditory damage; and tertiary injury, due to behavioural effects.

Physical injury and mortality

Much of the available information on underwater effects on humans concerns blast injuries and was carried out during the 1940s and 1950s. Bebb and Wright (1951 to 1955) conducted experiments using animals and volunteer divers which demonstrated that severe symptoms of blast occurred for blast waves with peak pressures of about 246 dB re 1 µPa and above. These results suggested underwater blast waves with a level of 246 dB re 1 µPa peak pressure or above could prove lethal to unprotected divers. Further existing information on the effects of underwater blasts arise from accidental exposure to blast summarized by Cudahy and Parvin (2001), however in these instances no record of the pressure wave parameters is available.

Measurements of underwater bolt guns have been undertaken previously. Underwater bolt guns contain an explosive propellant and which exposes the operator to significant levels of blast pressures. Sterba (1987a) investigated the potential for hearing damage due to a Ramset Stud Gun. The impulse resulting from firing the gun was measured to be 10.76 psi-ms (74.19 Pa-s). Two of the five divers operating the gun reported tinnitus which resolved within one hour. Measurements undertaken in July 1993 recorded the noise exposure experienced by divers when using a Cox's Bolt Gun and a Tornado Stud Gun (Nedwell *et al*., 1993). Measurements were taken at the diver's ear and a peak pressure of 350,000 Pa, with a corresponding impulse of 500 Pa-s were recorded for the Cox's Bolt Gun. The divers described the experience as "unpleasant" leading to the guns being fired at arm's length.

Auditory injury

Exposure to underwater sounds that are not high enough to cause physical injury could still potentially cause auditory damage. This could occur as a result of a single traumatic exposure to a high level of noise. Also, and more commonly, is the effect of cumulative exposure of noise over a longer period in the same manner as airborne noise. Such exposure may result in TTS, and if continued at a high enough level could lead to significant hearing loss in the long term.

Criteria for assessing human audiological injury to exposure of underwater sound

Existing criteria are defined in the Control of Noise at Work Regulations (2021) and are utilised to judge the hazard from airborne noise exposure. It has been determined that where exposure to a sound level equivalent of 85 dB(A) re 20 µPa (111 dB re 1 µPa) for an eight hour period is exceeded, a significant risk of long term hearing loss exists; for each halving of the duration of exposure an increase in level of 3 dB is permitted. Peaks in excess of 130 dB re 20 µPa (166 dB re 1 µPa) are also hazardous and can cause traumatic injury, in which permanent damage can be caused by a single exposure.

A significant experimental programme reported by Nedwell (1998) indicates that the ear is inefficient in perceiving sound in water due to water's high acoustical impedance and the consequent mismatch of acoustical impedance. The degree of reduction in efficiency is frequency dependent.

Measurements of underwater hearing threshold were made in a water tank. The subject was submerged in the experimental facility with their sternal notch at mid water depth, breathing from a diving valve from a cylinder of air placed within the tank, but away from the diver. Measurements of hearing threshold in air and in water were taken at all of the audiometric test frequencies: measurements were made of the hearing threshold of pure tones at 1/3-octave centre frequencies from 20 Hz to 20 kHz.

Figure 2-2 illustrates the results. Whereas human hearing in air is most sensitive at about 2 kHz, in water the results indicate it is most sensitive at about 800 Hz. Underwater hearing is inefficient at low frequencies, but increases in sensitivity at about 40 dB per decade (12 dB per doubling of frequency) in the range from 20 Hz to about 600 Hz. There is a broad and fairly flat threshold of underwater hearing at about 48 dB re 1 µPa from about 600 Hz to 1.2 kHz. At higher frequencies the sensitivity generally decreases at about 40 dB per octave. It may be seen that at all frequencies the sensitivity of underwater hearing is significantly lower than in air. The difference is smallest at the lowest frequencies measured, of the order of 20 dB, and increases to about 70 dB at 4 kHz.

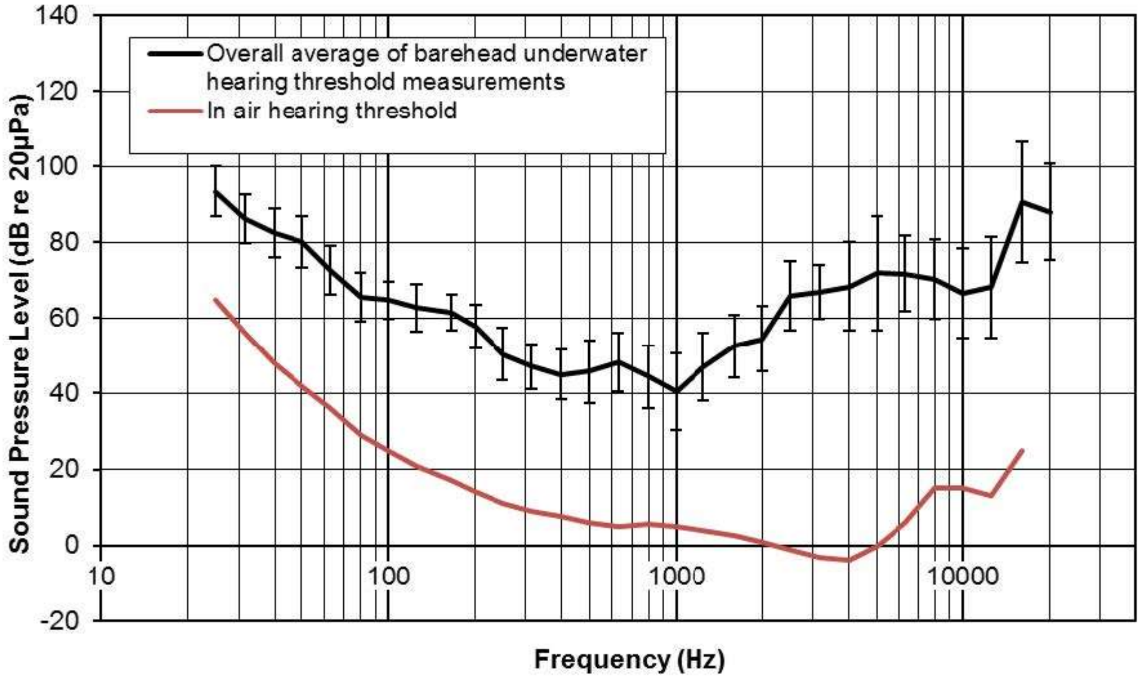


Figure 2-2 Results of underwater hearing threshold measurements (Nedwell, 1998)

The implication of this result is that a significant degree of protection from the effects on hearing of underwater impulsive sound is conferred by the inefficiency of the hearing process, and this effect can be used to modify the criteria indicated above for application to divers. The corrected level is termed the dB(UW) level, and a level of 85 dB(UW) for an eight hour period could indicate a risk of hearing loss. However, if the time of exposure is reduced to 15 minutes a level of 100 dB(UW) is permitted. Peaks in excess of 130 dB(UW) are assumed to be capable of causing permanent traumatic auditory injury. It should be noted that the link between the airborne noise exposure criteria as noted in the Control of Noise at Work Regulations 2021 and the dB(UW) is only at a preliminary stage, and further study in this area is required before confident assertions with respect to underwater noise impacts on humans can be made.

Startle

A further effect that divers could experience from exposure to underwater noise is significant behavioural effects that could lead to injury. This could occur in the case of diver who is subjected to a sudden exposure of sound resulting in the diver being startled. Adverse effects to a diver may include a reaction of panic and rapid surfacing leading to a risk of decompression injury or death, or the spitting out his diving valve heightening the attendant risk of drowning.

There are no existing guidelines as to acceptable levels of noise in respect of startle. However, a level of 90 dB(A) in air is judged to be "loud" 90 dB(UW) re 20 µPa for divers in the water is equivalent to 90 dB(A) re 20 µPa for people normally in air. This criterion is similar in level to 145 dB SEL/SPL_{RMS} re 1µPa, which Parvin *et al.* (2001) suggests as guidance to avoid an aversion response. In order to establish a relevant noise level to elicit a 'startle' response, it is considered that 110 dB(UW) may be appropriate (this is mid-way between the 'loud' 90 dB(UW) and 130 dB(UW), which is likely to be injurious). This level has therefore been taken as representative of a level where a recreational diver might react strongly or panic and suddenly surface from depth, potentially dangerously. This therefore appears to represent a suitable criterion. On this basis, and until better information is available, a level of 110 dB(UW) has adopted as the criterion for a level of noise above which strong aversive reaction or avoidance may occur.

3 Modelling methodology

To estimate the underwater noise levels likely to arise during the construction and operation of Rampion 2, predictive noise modelling has been undertaken. The methods described in this section, and utilised within this report, meet the requirements set by the NPL Good Practice Guide 133 for underwater noise measurement (Robinson *et al*., 2014).

The modelling of impact piling has been undertaken using the INSPIRE underwater noise model. The INSPIRE model (currently version 5.1) is a semi-empirical underwater noise propagation model based around a combination of numerical modelling and actual measured data. It is designed to calculate the propagation of noise in shallow, mixed water, typical of the conditions around the UK and very well suited to the region around Rampion 2. The model has been tuned for accuracy using over 80 datasets of underwater noise propagation from monitoring around offshore piling activities.

The model provides estimates of unweighted SPL_{peak}, SEL_{ss}, and SEL_{cum} noise levels, as well as various other weighted noise metrics. Calculations are made along 180 equally spaced radial 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 contours as GIS shapefiles.

INSPIRE considers a wide array of input parameters, including variations in bathymetry and source frequency content 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, ramp up profile, and strike rate;
- Total duration of piling; and
- Receptor swim speeds.

A simple modelling approach has been used for noise sources other than piling that may be present during the lifecycle of Rampion 2; these are discussed in section 5.

3.1 Modelling confidence

Previous iterations of the INSPIRE model have endeavoured to give a conservative estimate of underwater noise levels from impact piling. There is always some natural variability with underwater noise measurements, even when considering measurements of pile strikes at the same blow energy taken at the same range. For example, there can be variations in noise level of up to 5 or even 10 dB, as seen in Bailey *et al*. (2010) and the data shown in . When modelling using the upper bounds of this range, along with other worst case parameter selections, conservatism can be compounded and create overcautious predictions, especially when calculating SEL_{cum}. With this in mind, the current version of the INSPIRE model attempts to calculate an average fit to the measured noise levels at all ranges.

The current version of INSPIRE (version 5.1) is the product of re-analysing all the impact piling noise measurements in Subacoustech Environmental's measurement database and cross-referencing it with blow energy data from piling logs, giving a database of single strike noise levels referenced to a specific blow energy at a specific range. This analysis showed that the previous versions of INSPIRE could overestimate the change in noise level with higher blow energies and underestimate levels at lower blow energies, which in some cases led to overestimations in predicted levels.

As INSPIRE is semi-empirical, 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 it is compared against the outputted levels from INSPIRE and, if necessary, the model can be adjusted accordingly. Currently over 80 separate impact piling noise datasets from all around the UK have been used as part of the development for the latest version of INSPIRE, and in each case, an average fit is used.

In addition, INSPIRE is also validated by comparing the noise levels outputted from the model with measurements and modelling undertaken by third parties.

Figure 3-1 and Figure 3-2 presents a small selection of measured impact piling noise data plotted against outputs from INSPIRE for SPL_{peak} and SEL_{ss}. The plots show data points from measured data (in blue) plotted alongside modelled data (in orange) using INSPIRE version 5.1, matching the pile size, blow energy and range from the measured data. These show the average fit to the data, with the INSPIRE model data points sitting, more or less, in the middle of the measured noise levels at each range.

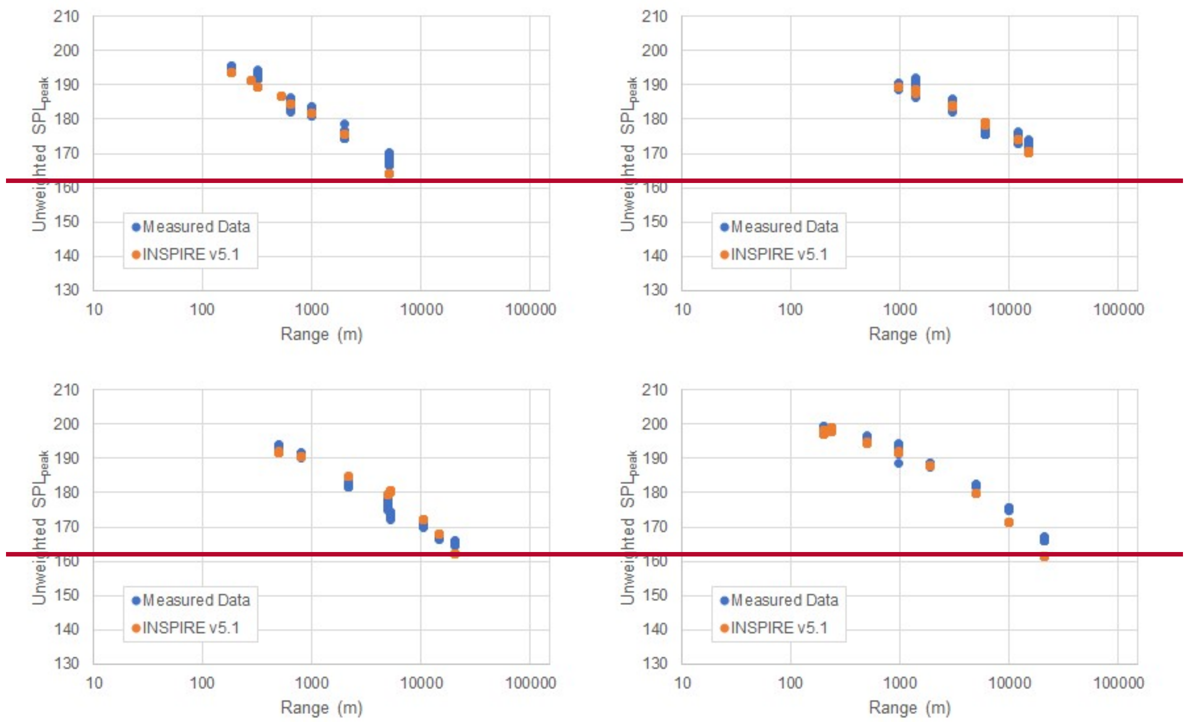
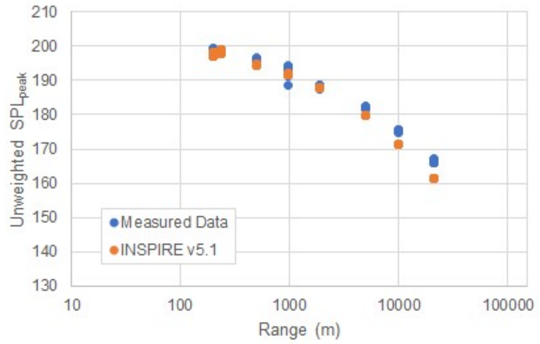


Figure 3-1 Comparison between example measured impact piling data (blue points) and modelled data using INSPIRE version 5.1 (orange points)

Top Left: 1.8 m pile, Irish Sea, 2010; Top Right: 9.5 m pile, North Sea, 2020; Bottom Left: 6.1 m pile, Southern North Sea, 2009; Bottom Right: 6 m pile, Southern North



Sea, 2009.

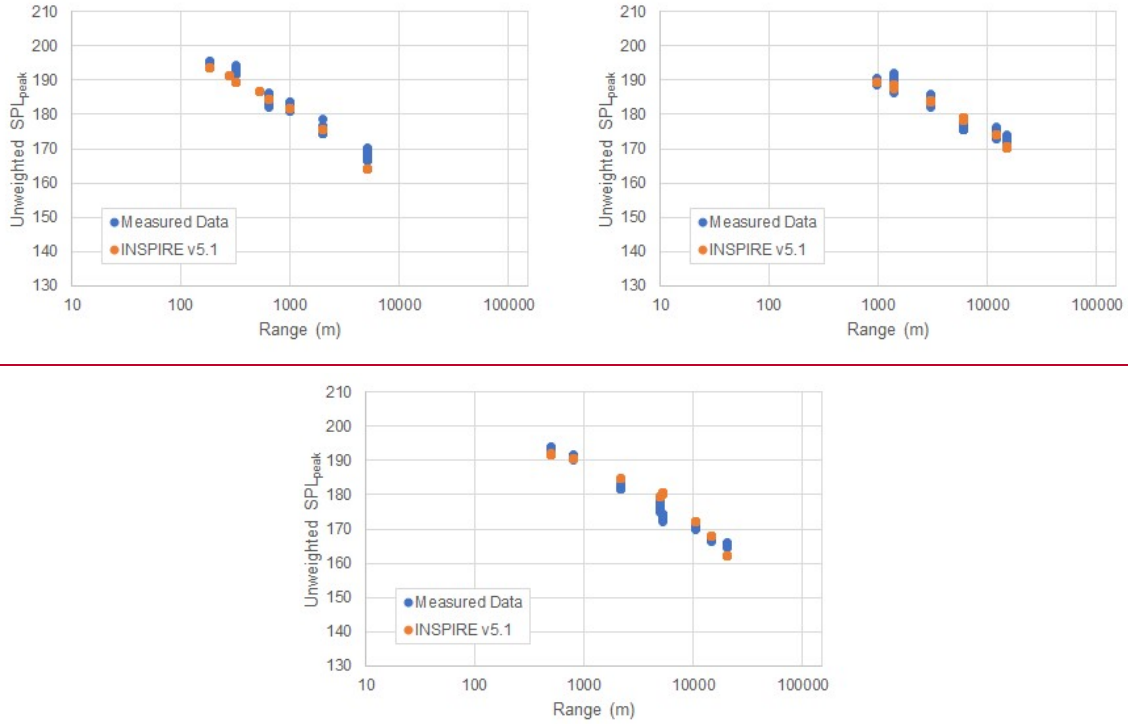


Figure 3-1 Comparison between example unweighted SPL_{peak} measured data (blue points) and modelled data using INSPIRE version 5.1 (orange points) (Top Left: 6.0 m pile, maximum blow energy: 1000 kJ, North Sea, 2009; Top Right: 1.8 m pile, maximum blow energy: 260 kJ, Irish Sea, 2010; Bottom Left: 9.5 m pile, maximum blow energy: 1600 kJ, North Sea, 2020; Bottom Right: 6.1 m pile, maximum blow energy: 1100 kJ, North Sea, 2009)

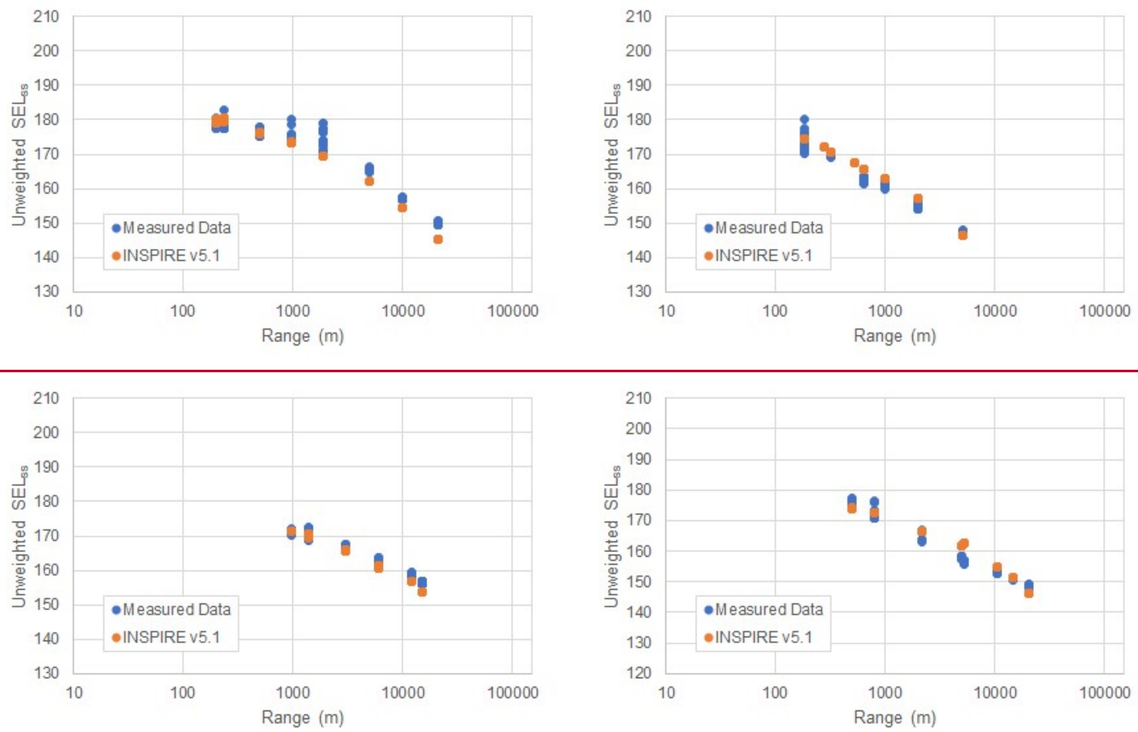


Figure 3-2 Comparison between example unweighted SEL$_{ss}$ measured data (blue points) and modelled data using INSPIRE version 5.1 (orange points) (Top Left: 6.0 m pile, maximum blow energy: 1000 kJ, North Sea, 2009; Top Right: 1.8 m pile, maximum blow energy: 260 kJ, Irish Sea, 2010; Bottom Left: 9.5 m pile, maximum blow energy: 1600 kJ, North Sea, 2020; Bottom Right: 6.1 m pile, maximum blow energy: 1100 kJ, North Sea, 2009)

3.2 Modelling parameters

3.2.1 Modelling locations

Modelling has been undertaken at four representative locations, covering the extents and various water depths at the Rampion 2 site. These locations are at the North West (NW), South (S), East (E), and West (W) of the site boundary. Cumulative effects have been considered with piling at the E and W locations.

These locations are summarised in Table 3-1 and illustrated in Figure 3-3.

Modelling locations	North West (NW)	South (S)	East (E)	West (W)
Latitude	50.6659° N	50.5926° N	50.6412° N	50.6333° N
Longitude	0.4924° W	0.2365° W	0.1796° W	0.6250° W
Water depth (mean tide)	17.4 m	53.4 m	43.8 m	26.4 m

Table 3-1 Summary of the underwater noise modelling locations at the Rampion site

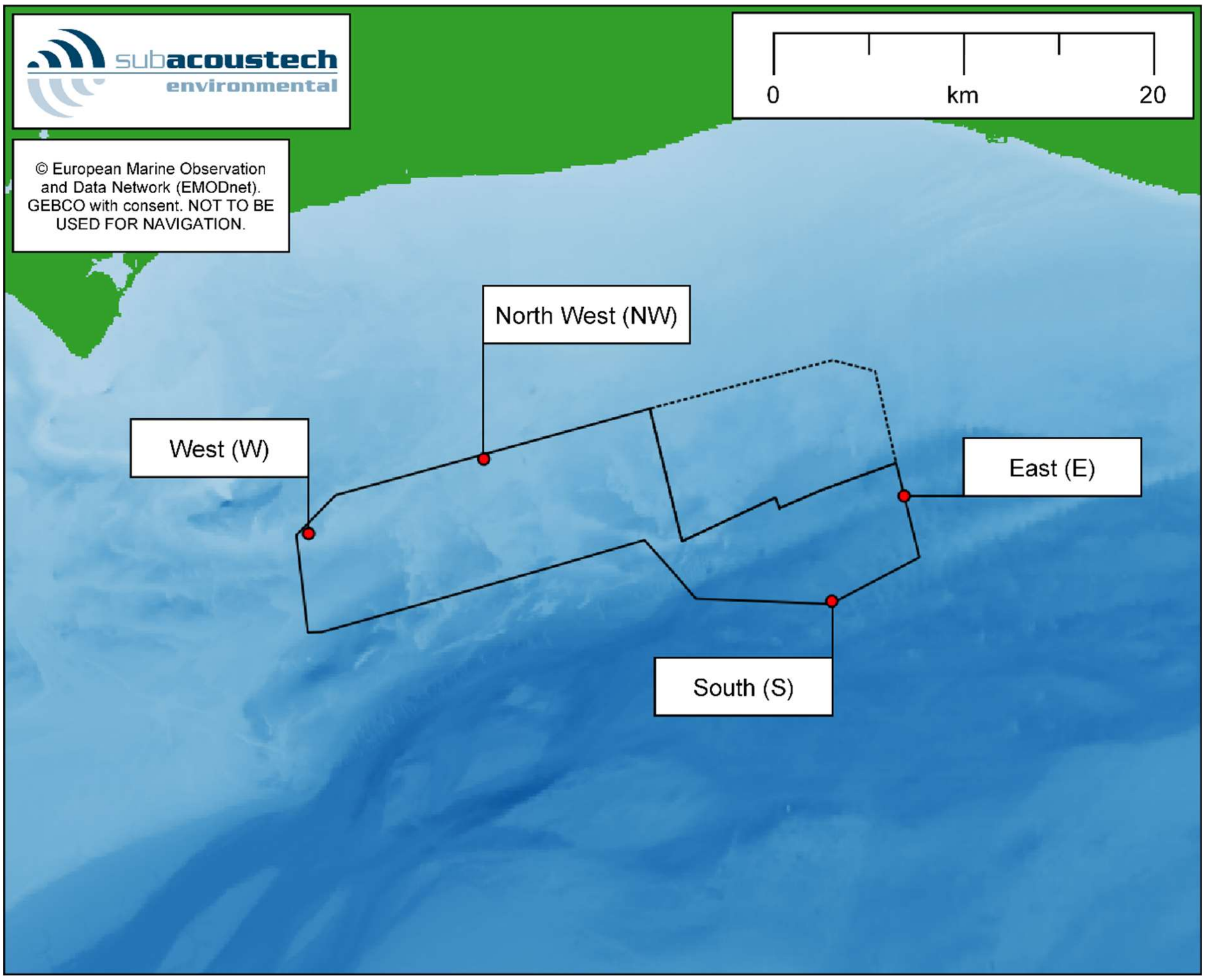


Figure 3-3 Approximate positions of the modelling locations at the Rampion 2 site

3.2.2 Impact piling parameters

Several piling scenarios have been modelled including monopile and jacket pile foundations for wind turbine generators (WTGs), covering both worst-case and most likely installation scenarios. The worst-case scenarios consider the maximum possible piling durations and blow energies at the end of ramp up, which may prove to be highly unrealistic due to hammer capacity or pile fatigue, or other on-site practicalities. The most likely scenarios use more realistic blow energies and durations, which have been chosen based on what has been seen at other wind farm installations. The modelled scenarios include:

- Worst-case monopile foundations – up to 13.5 m in diameter, installed using a maximum blow energy of 4,400 kJ;
- Most likely monopile foundations – up to 13.5 m in diameter, installed using a maximum blow energy of 4,000 kJ;
- Worst-case jacket foundations – up to 4.5 m in diameter, installed using a maximum blow energy of 2,500 kJ; and

- Most likely jacket foundations – up to 4.5 m in diameter, installed using a maximum blow energy of 2,000 kJ.

For SEL_{cum}, the soft start and ramp up of blow energies along with the total duration and strike rate must also be considered; these vary for the worst-case and most likely scenarios; these are summarised in Table 3-2 to Table 3-5. The main difference between the worst-case and most likely scenarios are that the most likely scenario uses lower blow energies and has a shorter period at full energy; the soft start and ramp up periods are the same for all scenarios.

The modelled scenarios contain a total of 8,776 pile strikes over 4 hours 30 minutes for the worst-case scenarios and 5,451 strikes over 2 hours 55 minutes for the most likely scenarios.

In a 24-hour period it is expected that either a maximum of 2 monopile foundations or 4 jacket foundations can be installed. This is included as part of the modelling assuming that the foundations are installed consecutively. This increases the overall upper limit of piling durations in a 24-hour period for monopile foundations to 9 hours and 5 hours 50 minutes for worst-case and most likely scenarios, respectively. For jacket foundations this is 18 hours and 11 hours 40 minutes for worst-case and most likely scenarios, respectively.

Scenarios covering both a single pile installation and multiple sequential piles installed in a day have been included in this study.

Worst-case monopile foundations	**880 kJ**	**1,760 kJ**	**2,640 kJ**	**3,520 kJ**	**4,400 kJ**
Number of strikes	75	75	113	113	8,400
Duration	7.5 mins	7.5 mins	7.5 mins	7.5 mins	240 mins
Strike rate	10 strikes per minute (1 strike every 6s)		15 strikes per minute (1 strike every 4s)		35 strikes per minute

Table 3-2 Summary of the worst-case ramp up scenario used for calculating SEL_{cum} for monopile foundations

Most likely monopile foundations	**800 kJ**	**1,600 kJ**	**2,400 kJ**	**3,200 kJ**	**4,000 kJ**
Number of strikes	75	75	113	113	5,075
Duration	7.5 mins	7.5 mins	7.5 mins	7.5 mins	145 mins
Strike rate	10 strikes per minute (1 strike every 6s)		15 strikes per minute (1 strike every 4s)		35 strikes per minute

Table 3-3 Summary of the most likely ramp up scenario used for calculating SEL_{cum} for monopile foundations

Worst-case jacket foundations	**500 kJ**	**1,000 kJ**	**1,500 kJ**	**2,000 kJ**	**2,500 kJ**
Number of strikes	75	75	113	113	8,400
Duration	7.5 mins	7.5 mins	7.5 mins	7.5 mins	240 mins
Strike rate	10 strikes per minute (1 strike every 6s)		15 strikes per minute (1 strike every 4s)		35 strikes per minute

Table 3-4 Summary of the worst-case ramp up scenario used for calculating SEL_{cum} for jacket foundations

Most likely jacket foundations	400 kJ	800 kJ	1,200 kJ	1,600 kJ	2,000 kJ
Number of strikes	75	75	113	113	5,075
Duration	7.5 mins	7.5 mins	7.5 mins	7.5 mins	145 mins
Strike rate	10 strikes per minute (1 strike every 6s)		15 strikes per minute (1 strike every 4s)		35 strikes per minute

Table 3-5 Summary of the most likely ramp up scenario used for calculating SEL_{cum} for jacket foundations

In addition, there is a possibility that piling may occur simultaneously at two separate locations, for this simultaneous piling for the worst case parameters has been modelled at the E and W locations covering the largest spread of source locations.

3.2.2.1 Source levels

Noise modelling requires knowledge of the source level, which is the theoretical noise level at one metre from the noise source. The INSPIRE model assumes that the noise source – the hammer striking the pile – acts as an effective single point, as it will appear at a distance. The source level 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 pile 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 SPL_{peak} and SEL_{ss} source levels estimated for this study are provided in Table 3-6 and Table 3-7.

SPL_{peak} source levels (dB re 1 µPa @ 1 m)	Location	Monopile foundations	Jacket foundations
Worst-case Monopile: 1~~2~~3.5 m / 4,400 kJ Jacket: 3 m / 2,500 kJ	NW	242.6	241.2
	S	242.6	241.4
	E	242.6	241.3
	W	242.6	241.3
Most likely Monopile: 13.5~~2~~ m / 4,000 kJ Jacket: 3 m / 2,000 kJ	NW	242.4	240.6
	S	242.4	240.8
	E	242.4	240.7
	W	242.4	240.7

Table 3-6 Summary of the unweighted SPL_{peak} source levels used for modelling

SEL_{ss} source levels (dB re 1 µPa^{2}s @ 1 m)	Location	Monopile foundations	Jacket foundations
Worst-case Monopile: 1~~2~~3.5 m / 4,400 kJ Jacket: 3 m / 2,500 kJ	NW	223.7	221.9
	S	223.7	222.2
	E	223.7	222.2
	W	223.7	222.0
Most likely Monopile: 1~~2~~3.5 m / 4,000 kJ Jacket: 3 m / 2,000 kJ	NW	223.5	221.3
	S	223.5	221.5
	E	223.5	221.5
	W	223.5	221.4

Table 3-7 Summary of the unweighted SEL_{ss} source levels used for modelling

3.2.2.2 Environmental conditions

With the inclusion of measured 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, as well as the sediment type surrounding the site. Data from the British Geological Survey show that the seabed surrounding the Rampion 2 site is generally made up of various combinations of gravel and sand.

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

3.2.3 Cumulative SELs and fleeing receptors

Expanding on the information in section 2.2.1 regarding SEL_{cum} and the fleeing animal model used for modelling, it is important to understand the meaning of the results presented in the following sections.

When an SEL_{cum} impact range is presented for a fleeing animal, this range can essentially be considered a starting position (at commencement of piling) for the fleeing animal receptor. For example, if a receptor starting at the position denoted on a PTS contour began to flee, in a straight line away from the noise source, the receptor would receive exactly the noise exposure as per the PTS criterion under consideration.

To help explain this, it is helpful to examine how the multiple pulse SEL_{cum} ranges are calculated. As explained in section 2.1.1.3, the SEL_{cum} is a measure of the total received noise over the whole piling operation; in the case of the Southall *et al*. (2019) and Popper *et al*. (2014) criteria this covers any piling in a 24-hour period.

When considering a stationary receptor, i.e., one that stays at the same position throughout piling, calculating the SEL_{cum} is relatively straightforward: all the noise levels received at a single point along the transect are aggregated to calculate the SEL_{cum}. 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 the new SEL_{cum}. This continues outward until the threshold is crossed.

For a fleeing animal, the receptor's distance from the noise source while moving away needs to be considered. To model this, a starting point close to the source is chosen, and then the received noise level for each pile strike while the receptor is fleeing is noted. For example, if a pile strike occurs every 6 seconds and an animal is fleeing at a rate of 1.5 ms^{-1}, it is 9 m further from the source after each subsequent pile strike, resulting in a slightly reduced received noise level with each strike. These values are then aggregated into an SEL_{cum} over the entire piling period. The faster an animal is fleeing the greater distance travelled between each pile strike. The impact range outputted by the model for this situation is the distance the receptor must be at the start of piling to exactly meet the exposure threshold.

The graphs in Figure 3-4 and Figure 3-5 show the difference in the SELs received by a stationary receptor and a fleeing receptor travelling at a constant speed of 1.5 ms^{-1}, using the worst case monopile foundation parameters (Table 3-2). This was carried out at the E location for a single monopile installation using the worst-case parameters as an example.

The received SEL_{ss} from the stationary receptor, as illustrated in Figure 3-4 shows the noise level gradually increasing as the blow energy increases throughout the piling operation. These step changes are also visible for the fleeing receptor, but as the receptor is further from the source by the time the levels increase, the total received exposure is reduced, resulting in progressively lower received noise levels. For example, after the first 7.5 minutes where the blow energy is 880 kJ, the fleeing receptor will have already moved 650 m away. After the full piling duration of 4.5 hours, the receptor will be over 24 km from the pile.

Figure 3-5 shows the effect these different received levels have when calculating the SEL_{cum}. It clearly shows the difference in cumulative effect of the receptor remaining still as opposed to fleeing. To use an extreme example, starting at a range of 1 m, the first strike results in a received level of 218.6 dB re 1 μPa²s. If the receptor were to remain stationary throughout the 4.5 hours of piling it would receive a cumulative received level of 263.0 dB re 1 μPa²s, whereas fleeing at 1.5 ms⁻¹ over the same piling scenario would result in a cumulative received level of just 222.9 dB re 1 μPa²s.

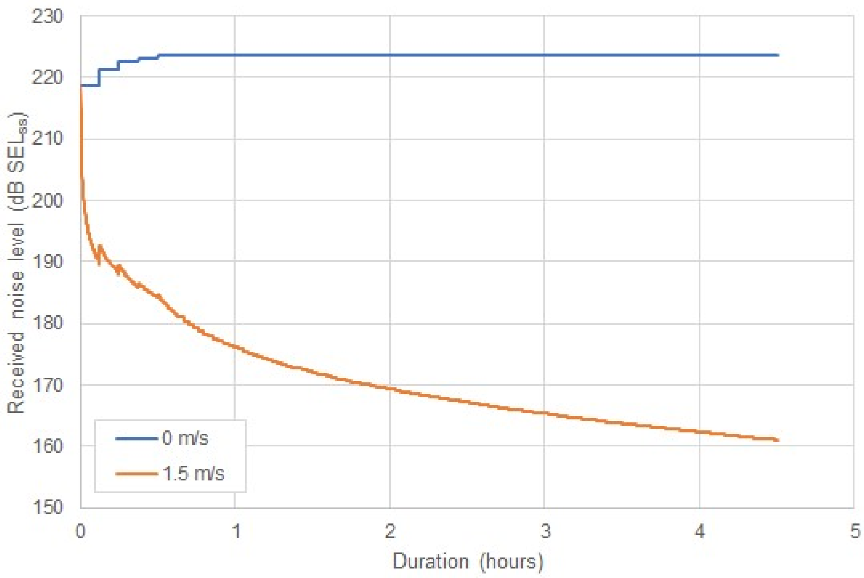


Figure 3-4 Received single-string noise levels (SEL_{ss}) for receptors during the worst case monopile piling parameters at the E location, assuming both a stationary and a fleeing receptor starting at a location 1 m from the noise source

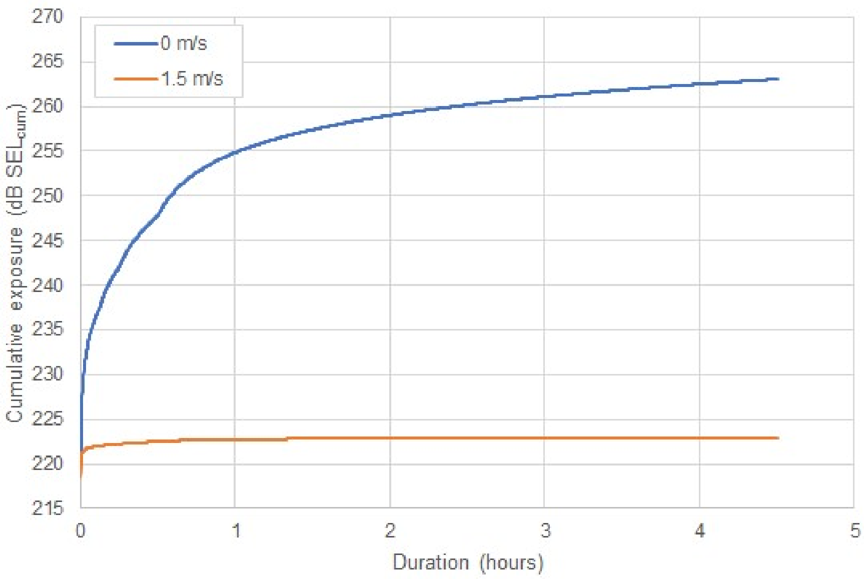


Figure 3-5 Cumulative received noise levels (SEL_{cum}) for receptors during the worst case monopile piling parameters at the E location, assuming both a stationary and fleeing receptor starting at a location 1 m from the noise source

The outputted SEL_{cum} values, and ranges presented in section 4, represent the position from where a receptor must begin fleeing at the start of piling in order to exactly receive the noise exposure criterion at the end of the modelled piling event. 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 criteria, and if the receptor were to start fleeing from a range further than the modelled value it would receive a noise exposure below the criteria. This is illustrated in Figure 3-6.

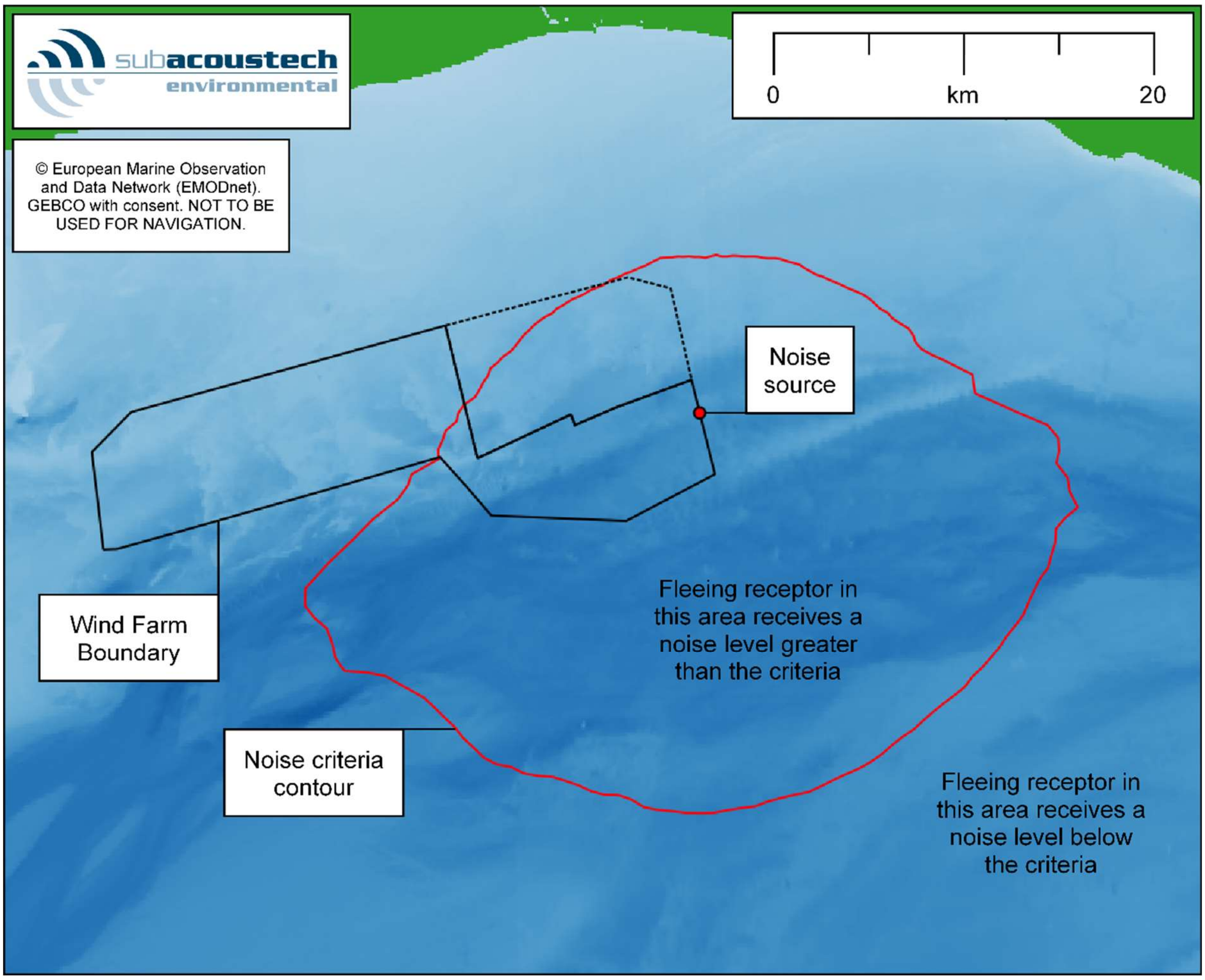


Figure 3-6 Example plot showing a fleeing animal SEL_{cum} criteria contour and the areas where the cumulative received noise level will exceed the impact criteria

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's modelling approach does not include this, but the effects of using an ADD can still be inferred from the results. For example, if a receptor were to flee for 20 minutes from an ADD at a rate 1.5 ms^{-1}, it would travel 1.8 km before piling begins. If a cumulative SEL impact range from INSPIRE was calculated to be below 1.8 km, it can safely be assumed that the ADD will be effective in eliminating the risk of injury on the receptor. The noise from an ADD is of a much lower level than impact piling, and as such, the overall effect on the SEL_{cum} exposure on a receptor would be negligible.

3.2.3.1 The effects of input parameters on cumulative SELs and fleeing receptors

As discussed in section 3.2.2, parameters such as water depth, hammer blow energies, piling ramp up, strike rate and duration all have an effect on predicted noise levels. When considering SEL_{cum} and a fleeing animal model, some of these parameters can have a greater influence than others.

Parameters like hammer blow energy can have a clear effect on impact ranges, with higher energies resulting in higher 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 low blow energies to higher ones requires careful consideration for fleeing animals, as the levels while the receptors are relatively close to the noise source will have a greater effect on the overall cumulative exposure level. Figure 3-7 summarises the hammer blow energy ramp up for the four modelled cumulative scenarios, showing how the monopile scenarios reach a higher blow energy over a greater total duration, as well as the effect of multiple consecutive piling operations.

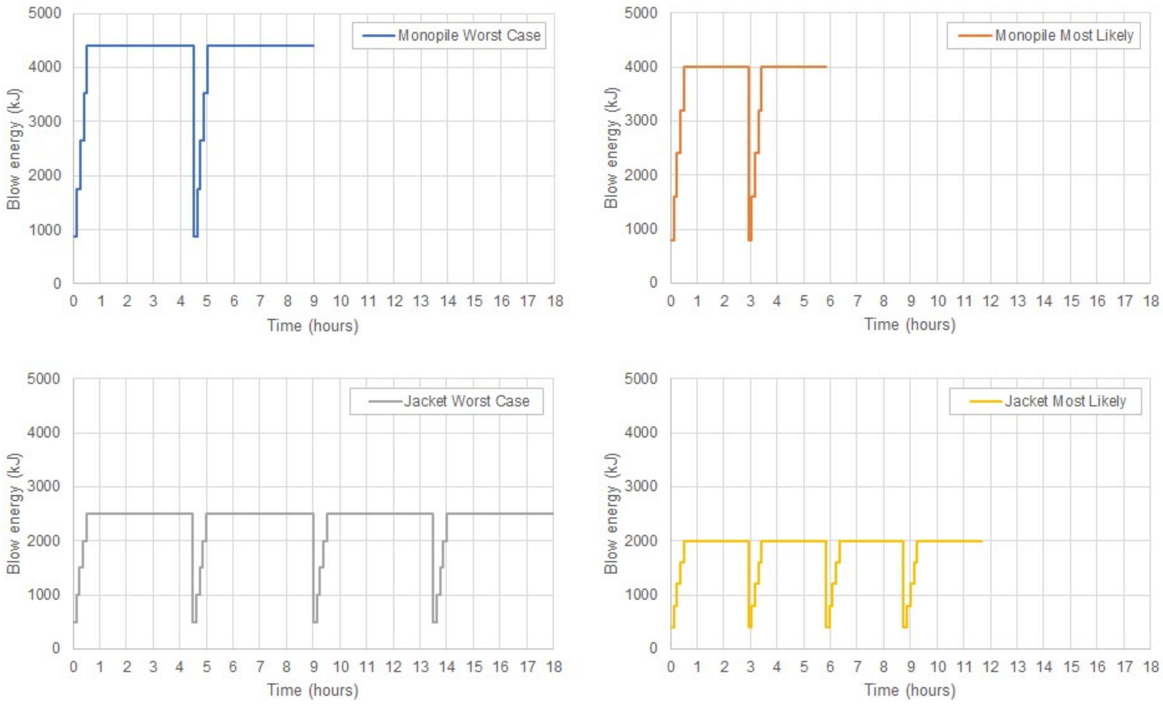


Figure 3-7 Graphical representation of the blow energy for the three modelled ramp up scenarios

Linked to the effect of the ramp up is the strike rate, as the more strikes that occur while the receptor is close to the noise source, the greater the exposure and the greater effect it will have on the SEL_{cum}. The faster the strike rate, the shorter the distance the receptor can flee between each pile strike, which leads to greater exposure. Figure 3-8 shows the strike rate against time for the monopile and jacket foundation modelled scenarios. All the scenarios considered for Rampion 2 utilise the same strike rates for the various stages of the installation, with longer periods at full energy for the worst-case parameters.

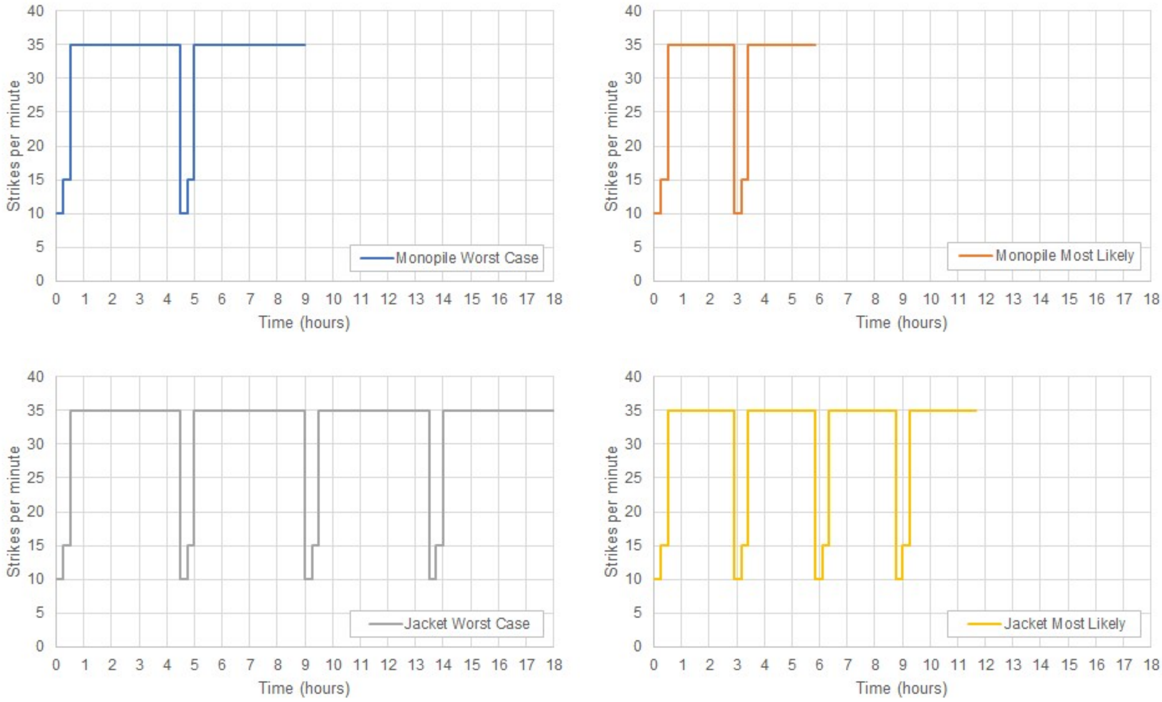


Figure 3-8 Graphical representation of the strike rate for the three modelled ramp up scenarios

4 Modelling results

The following sections present the modelled impact ranges for the parameters detailed in section 3 and the criteria outlined in section 2.2.1, split into the Southall *et al*. (2019) marine mammal criteria (section 4.1) and the Popper *et al*. (2014) fish criteria (section 0), with subsections covering the worst-case and most likely monopile and jacket foundations. To aid navigation Table 4-1 contains a list of all the impact range tables in this section. Noise from simultaneous piling at multiple locations is considered in section 4.3.

Further modelling has also been completed for non-impulsive noise criteria, these are presented in Appendix A.

For the results presented in this section, predicted ranges smaller than 50 m and areas less than 0.01 km^2 for single strike criteria, and ranges smaller than 100 m and areas less than 0.1 km^2 for cumulative criteria, have not been presented. This close to the noise source, the modelling processes are unable to model to a sufficient level of accuracy due to acoustic effects near the pile.

The largest ranges are predicted for the worst-case scenarios at the deeper S and E locations, with smaller ranges predicted for the shallower NW and W locations and the most likely scenarios where lower blow energies are utilised.

Table (page)	Parameters	Criteria	
Table 4-2 (p39)	Worst-case monopile foundations	Southall *et al*. (2019)	Unweighted SPL_{peak}
Table 4-3 (p41)			Weighted SEL_{cum} – single pile
Table 4-4 (p42)			Weighted SEL_{cum} – 2 sequential piles
Table 4-5 (p43)	Most likely monopile foundations		Unweighted SPL_{peak}
Table 4-6 (p44)			Weighted SEL_{cum} – single pile
Table 4-7 (p45)			Weighted SEL_{cum} – 2 sequential piles
Table 4-8 (p46)	Worst-case jacket foundations		Unweighted SPL_{peak}
Table 4-9 (p47)			Weighted SEL_{cum} – single pile
Table 4-10 (p48)			Weighted SEL_{cum} – 4 sequential piles
Table 4-11 (p49)	Most likely jacket foundations		Unweighted SPL_{peak}
Table 4-12 (p50)			Weighted SEL_{cum} – single pile

Table 4-13 (p51)			Weighted SEL_{cum} – 4 sequential piles
Table 4-14 (p53)	Worst-case monopile foundations	Popper *et al.* (2014)	Unweighted SPL_{peak}
Table 4-15 (p55)			Unweighted SEL_{cum} – single pile
Table 4-16 (p57)			Unweighted SEL_{cum} – 2 sequential piles
Table 4-17 (p57)	Most likely monopile foundations		Unweighted SPL_{peak}
Table 4-18 (p59)			Unweighted SEL_{cum} – single pile
Table 4-19 (p61)			Unweighted SEL_{cum} – 2 sequential piles
Table 4-20 (p61)	Worst-case jacket foundations		Unweighted SPL_{peak}
Table 4-21 (p63)			Unweighted SEL_{cum} – single pile
Table 4-22 (p65)			Unweighted SEL_{cum} – 4 sequential piles
Table 4-23 (p65)	Most likely jacket foundations		Unweighted SPL_{peak}
Table 4-24 (p67)			Unweighted SEL_{cum} – single pile
Table 4-25 (p69)			Unweighted SEL_{cum} – 4 sequential piles
Table 4-26 (p70)	Worst-case monopile foundations	Hawkins *et al.* (2014)	Unweighted SPL_{peak} Unweighted $SPL_{peak\text{-}to\text{-}peak}$ Unweighted SEL_{ss}
Table 4-27 (p71)	Most likely monopile foundations		
Table 4-28 (p72)	Worst-case jacket foundations		
Table 4-29 (p74)	Most likely jacket foundations		

Table 4-1 Summary of the results tables presented in this section

4.1 Marine mammal criteria

Table 4-2 to Table 4-13 present the modelling results in terms of the Southall *et al.* (2019) marine mammal criteria covering the worst-case and most likely monopile and jacket foundation parameters.

The largest marine mammal impact ranges are predicted for worst-case monopile foundations at the S location followed by the E location, due in part to the water depths at, and surrounding, those locations. Maximum PTS injury ranges are predicted in fleeing LF cetaceans with ranges of up to 15 km and for fleeing VHF cetaceans of up to 7.4 km, both at the S location for worst-case monopile foundations. Smaller ranges are predicted at the NW and W location due to the shallower water depths and proximity to the coastline.

When comparing the impact ranges for a single pile installation and multiple sequential pile installations, the overall increases are negligible, as by the time the subsequent piles are installed, the fleeing receptor is at such a distance from the source that the additional exposure is minimal. The largest increases seen for these scenarios are only a few hundred metres.

Further Southall *et al*. (2019) criteria covering non-impulsive in marine mammals are presented in Appendix A.

4.1.1 Worst-case monopile foundations

Southall *et al.* (2019) Unweighted SPL_{peak}		Worst-case monopile foundation							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	< 0.01 km^2	< 50 m	< 50 m	< 50 m	0.02 km^2	90 m	90 m	90 m
	HF Cetacean	< 0.01 km^2	< 50 m	< 50 m	< 50 m	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	VHF Cetacean	0.57 km^2	430 m	420 m	430 m	2.8 km^2	970 m	930 m	950 m
	PCW Pinniped	< 0.01 km^2	< 50 m	< 50 m	< 50 m	0.03 km^2	100 m	100 m	100 m
S	LF Cetacean	0.01 km^2	< 50 m	< 50 m	< 50 m	0.05 km^2	120 m	120 m	120 m
	HF Cetacean	< 0.01 km^2	< 50 m	< 50 m	< 50 m	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	VHF Cetacean	1.4 km^2	680 m	680 m	680 m	8.7 km^2	1.7 km	1.7 km	1.7 km
	PCW Pinniped	0.01 km^2	60 m	60 m	60 m	0.06 km^2	140 m	140 m	140 m
E	LF Cetacean	0.01 km^2	< 50 m	< 50 m	< 50 m	0.04 km^2	120 m	120 m	120 m
	HF Cetacean	< 0.01 km^2	< 50 m	< 50 m	< 50 m	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	VHF Cetacean	1.4 km^2	660 m	660 m	660 m	8.1 km^2	1.6 km	1.6 km	1.6 km
	PCW Pinniped	0.01 km^2	50 m	50 m	50 m	0.06 km^2	140 m	140 m	140 m
W	LF Cetacean	0.01 km^2	< 50 m	< 50 m	< 50 m	0.03 km^2	110 m	110 m	110 m
	HF Cetacean	< 0.01 km^2	< 50 m	< 50 m	< 50 m	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	VHF Cetacean	0.91 km^2	550 m	520 m	540 m	4.6 km^2	1.3 km	1.2 km	1.2 km
	PCW Pinniped	0.01 km^2	< 50 m	< 50 m	< 50 m	0.05 km^2	120 m	120 m	120 m

Table 4-2 Summary of the impact ranges from the worst-case monopile foundation modelling at Rampion 2 using the Southall et al. (2019) unweighted SPL_{peak} criteria for marine mammals

Southall *et al.* (2019) Weighted SEL_{cum} (impulsive)		Worst-case monopile foundation – single pile							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	8.6 km^2	3.2 km	500 m	1.4 km	730 km^2	26 km	4.6 km	13 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	6.8 km^2	2.2 km	800 m	1.4 km	530 km^2	21 km	5.6 km	12 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	35 km^2	5.2 km	1.7 km	3.1 km
S	LF Cetacean	380 km^2	15 km	5.9 km	11 km	2700 km^2	46 km	14 km	28 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	120 km^2	7.3 km	4.5 km	6.0 km	1800 km^2	33 km	14 km	23 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	450 km^2	15 km	7.8 km	12 km
E	LF Cetacean	280 km^2	14 km	4.0 km	8.6 km	2300 km^2	44 km	11 km	25 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	85 km^2	6.7 km	3.3 km	5.0 km	1500 km^2	32 km	11 km	21 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	350 km^2	14 km	6.0 km	10 km
W	LF Cetacean	43 km^2	7.2 km	950 m	3.2 km	1100 km^2	31 km	4.5 km	16 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	19 km^2	3.8 km^2	1.4 km	2.4 km	700 km^2	24 km	4.4 km	14 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	90 km^2	8.7 km	2.2 km	5.0 km

Table 4-3 Summary of the impact ranges from the worst-case monopile foundation modelling at Rampion 2 for a single pile using the Southall et al. (2019) weighted SEL_{cum} impulsive criteria for marine mammals

Southall *et al.* (2019) Weighted SEL_{cum} (impulsive)		Worst-case monopile foundation – 2 sequentially installed piles							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	8.6 km^2	3.2 km	500 m	1.4 km	730 km^2	26 km	4.6 km	13 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	6.9 km^2	2.2 km	800 m	1.4 km	550 km^2	21 km	5.6 km	12 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	36 km^2	5.3 km	1.7 km	3.2 km
S	LF Cetacean	380 km^2	15 km	5.9 km	11 km	2700 km^2	46 km	14 km	28 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	120 km^2	7.4 km^2	4.5 km	6.1 km	1800 km^2	34 km	14 km	23 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	470 km^2	16 km	7.8 km	12 km
E	LF Cetacean	280 km^2	14 km	4.0 km	8.7 km	2300 km^2	44 km	11 km	25 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	87 km^2	6.9 km	3.3 km	5.1 km	1500 km^2	33 km	11 km	21 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	360 km^2	15 km	6.0 km	10 km
W	LF Cetacean	43 km^2	7.2 km	950 m	3.2 km	1100 km^2	31 km	4.5 km	16 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	20 km^2	3.8 km	1.4 km	2.4 km	720 km^2	24 km	4.4 km	14 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	92 km^2	8.9 km	2.2 km	5.1 km

Table 4-4 Summary of the impact ranges from the worst-case monopile foundation modelling at Rampion 2 for two sequentially installed piles using the Southall et al. (2019) weighted SEL_{cum} impulsive criteria for marine mammals

4.1.2 Most likely monopile foundations

Southall *et al.* (2019) Unweighted SPL_{peak}		Most likely monopile foundation							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	0.02 km²	90 m	90 m	90 m
	HF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF Cetacean	0.54 km²	420 m	410 m	420 m	2.7 km²	950 m	910 m	930 m
	PCW Pinniped	0.01 km²	< 50 m	< 50 m	< 50 m	0.03 km²	100 m	100 m	100 m
S	LF Cetacean	0.01 km²	< 50 m	< 50 m	< 50 m	0.04 km²	120 m	120 m	120 m
	HF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF Cetacean	1.4 km²	670 m	660 m	660 m	8.4 km²	1.6 km	1.6 km	1.6 km
	PCW Pinniped	0.01 km²	50 m	50 m	50 m	0.06 km²	140 m	140 m	140 m
E	LF Cetacean	0.01 km²	< 50 m	< 50 m	< 50 m	0.04 km²	120 m	120 m	120 m
	HF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF Cetacean	1.3 km²	650 m	640 m	650 m	7.7 km²	1.6 km	1.6 km	1.6 km
	PCW Pinniped	0.01 km²	50 m	50 m	50 m	0.06 km²	140 m	130 m	140 m
W	LF Cetacean	0.01 km²	< 50 m	< 50 m	< 50 m	0.03 km²	100 m	100 m	100 m
	HF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF Cetacean	0.87 km²	540 m	510 m	530 m	4.4 km²	1.3 km	1.1 km	1.2 km
	PCW Pinniped	0.01 km²	< 50 m	< 50 m	< 50 m	0.04 km²	120 m	120 m	120 m

Table 4-5 Summary of the impact ranges from the most likely monopile foundation modelling at Rampion 2 using the Southall et al. (2019) unweighted SPL_{peak} criteria for marine mammals

Southall *et al.* (2019) Weighted SEL_{cum} (impulsive)		Most likely monopile foundation – single pile							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	7.3 km²	3.0 km	450 m	1.3 km	710 km²	25 km	4.5 km	13 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	5.7 km²	2.0 km	750 m	1.3 km	480 km²	19 km	5.5 km	11 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	30 km²	4.7 km	1.6 km	3.0 km
S	LF Cetacean	360 km²	15 km	5.8 km	10 km	2700 km²	45 km	14 km	27 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	100 km²	6.6 km	4.4 km	5.6 km	1700 km²	31 km	14 km	22 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	410 km²	14 km	7.8 km	11 km
E	LF Cetacean	260 km²	14 km	3.9 km	8.4 km	2300 km²	43 km	11 km	24 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	73 km²	6.1 km	3.2 km	4.7 km	1400 km²	30 km	11 km	20 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	310 km²	13 km	5.9 km	9.6 km
W	LF Cetacean	39 km²	6.9 km	850 m	3.0 km	1000 km²	31 km	4.4 km	1.6 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	17 km²	3.4 km	1.3 km	2.2 km	640 km²	23 km	4.4 km	13 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	79 km²	8.0 km	2.1 km	4.8 km

Table 4-6 Summary of the impact ranges from the most likely monopile foundation modelling at Rampion 2 for a single pile using the Southall et al. (2019) weighted SEL_{cum} impulsive criteria for marine mammals

Southall *et al.* (2019) Weighted SEL_{cum} (impulsive)		Most likely monopile foundation – 2 sequentially installed piles							
		PTS				**TTS**			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	7.4 km²	3.0 km	450 m	1.3 km	710 km²	26 km	4.5 km	13 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	6.0 km²	2.1 km	750 m	1.3 km	510 km²	20 km	5.5 km	12 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	33 km²	5.0 km	1.6 km	3.1 km
S	LF Cetacean	360 km²	15 km	5.8 km	10 km	2700 km²	45 km	14 km	28 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	110 km²	6.9 km	4.4 km	5.8 km	1700 km²	33 km	14 km	23 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	440 km²	15 km	7.8 km	12 km
E	LF Cetacean	260 km²	14 km	3.9 km	8.4 km	2300 km²	44 km	11 km	24 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	78 km²	6.5 km	3.2 km	4.9 km	1500 km²	32 km	11 km	20 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	340 km²	14 km	5.9 km	9.9 km
W	LF Cetacean	39 km²	7.0 km	850 m	3.0 km	1000 km²	31 km	4.4 km	16 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	17 km²	3.4 km	1.3 km	2.2 km	650 km²	23 km	4.4 km	13 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	86 km²	8.5 km	2.1 km	4.9 km

Table 4-7 Summary of the impact ranges from the most likely monopile foundation modelling at Rampion 2 for two sequentially installed piles using the Southall et al. (2019) weighted SEL_{cum} impulsive criteria for marine mammals

4.1.3 Worst-case jacket foundations

Southall *et al.* (2019) Unweighted SPL_{peak}		Worst-case jacket foundation							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	0.02 km²	70 m	70 m	70 m
	HF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF Cetacean	0.38 km²	360 m	350 m	350 m	2.0 km²	810 m	780 m	790 m
	PCW Pinniped	< 0.01 km²	< 50 m	< 50 m	< 50 m	0.02 km²	80 m	80 m	80 m
S	LF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	0.03 km²	100 m	100 m	100 m
	HF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF Cetacean	0.99 km²	560 m	560 m	560 m	6.1 km²	1.4 km	1.4 km	1.4 km
	PCW Pinniped	< 0.01 km²	< 50 m	< 50 m	< 50 m	0.04 km²	120 m	120 m	120 m
E	LF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	0.03 km²	100 m	100 m	100 m
	HF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF Cetacean	0.93 km²	550 m	540 m	550 m	5.6 km²	1.4 km	1.3 km	1.3 km
	PCW Pinniped	0.01 km²	< 50 m	< 50 m	< 50 m	0.04 km²	110 m	110 m	110 m
W	LF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	0.02 km²	90 m	90 m	90 m
	HF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF Cetacean	0.63 km²	460 m	430 m	450 m	3.3 km²	1.1 km	980 m	1.0 km
	PCW Pinniped	< 0.01 km²	< 50 m	< 50 m	< 50 m	0.03 km²	100 m	100 m	100 m

Table 4-8 Summary of the impact ranges from the worst-case jacket foundation modelling at Rampion 2 using the Southall et al. (2019) unweighted SPL_{peak} criteria for marine mammals

Southall *et al.* (2019) Weighted SEL_{cum} (impulsive)		Worst-case jacket foundation – single pile							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	2.2 km²	1.7 km	200 m	670 m	580 km²	23 km	3.9 km	12 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	2.7 km²	1.4 km	450 m	870 m	430 km²	18 km	5.1 km	11 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	25 km²	4.5 km	1.4 km	2.7 km
S	LF Cetacean	280 km²	13 km	5.0 km	8.9 km	2400 km²	43 km	13 km	26 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	75 km²	5.8 km	3.7 km	4.8 km	1500 km²	30 km	13 km	21 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	400 km²	14 km	7.4 km	11 km
E	LF Cetacean	190 km²	12 km	3.1 km	7.2 km	2000 km²	41 km	10 km	23 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	53 km²	5.3 km	2.6 km	4.0 km	1300 km²	29 km	11 km	19 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	300 km²	13 km	5.6 km	9.3 km
W	LF Cetacean	21 km²	5.3 km	450 m	2.1 km	880 km²	29 km	3.9 km	14 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	9.8 km²	2.7 km	950 m	1.7 km	580 km²	22 km	4.1 km	12 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	72 km²	7.8 km	2.0 km	4.5 km

Table 4-9 Summary of the impact ranges from the worst-case jacket foundation modelling at Rampion 2 for a single pile using the Southall et al. (2019) weighted SEL_{cum} impulsive criteria for marine mammals

Southall *et al.* (2019) Weighted SEL_{cum} (impulsive)		Worst-case jacket foundation – 4 sequentially installed piles							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	2.2 km^2	1.7 km	200 m	670 m	580 km^2	23 km	3.9 km	12 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	2.8 km^2	1.5 km	450 m	880 m	440 km^2	19 km	5.1 km	11 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	26 km^2	4.6 km	1.4 km	2.7 km
S	LF Cetacean	280 km^2	13 km	5.0 km	9.0 km	2400 km^2	43 km	13 km	26 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	77 km^2	5.9 km	3.7 km	4.9 km	1600 km^2	31 km	13 km	22 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	410 km^2	15 km	7.4 km	11 km
E	LF Cetacean	190 km^2	12 km	3.1 km	7.2 km	2000 km^2	41 km	10 km	23 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	54 km^2	5.4 km	2.6 km	4.0 km	1300 km^2	30 km	11 km	19 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	310 km^2	14 km	5.6 km	9.5 km
W	LF Cetacean	21 km^2	5.3 km	450 m	2.1 km	880 km^2	28 km	3.9 km	14 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	10 km^2	2.8 km	950 m	1.7 km	600 km^2	22 km	4.1 km	13 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	75 km^2	8.0 km	2.0 km	4.6 km

Table 4-10 Summary of the impact ranges from the worst-case jacket foundation modelling at Rampion 2 for four sequentially installed piles using the Southall et al. (2019) weighted SEL_{cum} impulsive criteria for marine mammals

4.1.4 Most likely jacket foundations

Southall *et al.* (2019) Unweighted SPL_{peak}		Most likely jacket foundation							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	0.01 km²	70 m	70 m	70 m
	HF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF Cetacean	0.33 km²	330 m	320 m	320 m	1.7 km²	750 m	720 m	740 m
	PCW Pinniped	< 0.01 km²	< 50 m	< 50 m	< 50 m	0.02 km²	80 m	80 m	80 m
S	LF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	0.03 km²	90 m	90 m	90 m
	HF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF Cetacean	0.82 km²	510 m	510 m	510 m	5.1 km²	1.3 km	1.3 km	1.3 km
	PCW Pinniped	< 0.01 km²	< 50 m	< 50 m	< 50 m	0.03 km²	110 m	110 m	110 m
E	LF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	0.02 km²	90 m	80 m	90 m
	HF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF Cetacean	0.77 km²	500 m	500 m	500 m	4.7 km²	1.2 km	1.2 km	1.2 km
	PCW Pinniped	< 0.01 km²	< 50 m	< 50 m	< 50 m	0.03 km²	100 m	100 m	100 m
W	LF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	0.02 km²	80 m	70 m	80 m
	HF Cetacean	< 0.01 km²	< 50 m	< 50 m	< 50 m	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF Cetacean	0.53 km²	420 m	400 m	410 m	2.8 km²	990 m	910 m	950 m
	PCW Pinniped	< 0.01 km²	< 50 m	< 50 m	< 50 m	0.03 km²	90 m	90 m	90 m

Table 4-11 Summary of the impact ranges from the most likely jacket foundation modelling at Rampion 2 using the Southall et al. (2019) unweighted SPL_{peak} criteria for marine mammals

Southall *et al.* (2019) Weighted SEL_{cum} (impulsive)		Worst-case jacket foundation – single pile							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	0.9 km^2	1.2 km	150 m	440 m	520 km^2	22 km	3.6 km	11 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	1.4 km^2	1.0 km	300 m	620 m	360 km^2	17 km	4.9 km	9.8 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	20 km^2	3.8 km	1.3 km	2.4 km
S	LF Cetacean	230 km^2	12 km	4.5 km	8.2 km	2300 km^2	41 km	13 km	25 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	53 km^2	4.7 km	3.3 km	4.1 km	1400 km^2	28 km	13 km	20 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	340 km^2	13 km	7.1 km	10 km
E	LF Cetacean	160 km^2	11 km	2.8 km	6.5 km	1900 km^2	39 km	9.9 km	22 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	36 km^2	4.3 km	2.3 km	3.3 km	1100 km^2	27 km	10 km	18 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	250 km^2	12 km	5.3 km	8.6 km
W	LF Cetacean	14 km^2	4.5 km	300 m	1.7 km	790 km^2	27 km	3.6 km	14 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	6.1 km^2	2.1 km	800 m	1.4 km	490 km^2	20 km	3.9 km	12 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	58 km^2	6.8 km	1.9 km	4.1 km

Table 4-12 Summary of the impact ranges from the most likely jacket foundation modelling at Rampion 2 for a single pile using the Southall et al. (2019) weighted SEL_{cum} impulsive criteria for marine mammals

Southall *et al.* (2019) Weighted SEL_{cum} (impulsive)		Worst-case jacket foundation – 4 sequentially installed piles							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	1.0 km²	1.2 km	150 m	440 m	520 km²	22 km	3.6 km	11 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	1.5 km²	1.1 km	300 m	640 m	380 km²	17 km	4.9 km	10 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	22 km²	4.1 km	1.3 km	2.5 km
S	LF Cetacean	230 km²	12 km	4.5 km	8.2 km	2300 km²	41 km	13 km	25 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	57 km²	5.0 km	3.3 km	4.2 km	1400 km²	29 km	13 km	21 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	370 km²	14 km	7.1 km	10 km
E	LF Cetacean	160 km²	11 km	2.8 km	6.5 km	1900 km²	40 km	9.9 km	22 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	40 km²	4.6 km	2.3 km	3.5 km	1200 km²	28 km	10 km	18 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	280 km²	13 km	5.3 km	9.0 km
W	LF Cetacean	14 km²	4.5 km	300 m	1.7 km	800 km²	27 km	3.6 km	14 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	6.5 km²	2.2 km	800 m	1.4 km	530 km²	21 km	3.9 km	12 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	64 km²	7.4 km	1.9 km	4.3 km

Table 4-13 Summary of the impact ranges from the most likely jacket foundation modelling at Rampion 2 for four sequentially installed piles using the Southall et al. (2019) weighted SEL_{cum} impulsive criteria for marine mammals

4.2 Fish criteria

Table 4-14 to Table 4-25 present the impact ranges for the fish criteria for pile driving from Popper *et al*. (2014) covering the worst-case and most likely monopile and jacket foundation parameters as described in section 3.

The worst-case recoverable injury ranges (203 dB SEL_{cum} threshold) in species of fish are 450 m for the worst case monopile, assuming the fish can flee, but up to 13 km for the worst-case jacket foundation if they remain stationary throughout the entire piling operation; both of these ranges are for the S location.

Maximum TTS ranges (186 dB SEL_{cum} threshold) are predicted of up to 25 km for the worst-case monopile foundations at the S location when assuming a fleeing animal model. The maximum predicted ranges increase to 41 km for the worst-case monopile foundations and 44 km for the worst-case jacket foundations when considering a stationary animal, with the increase in ranges for the jacket foundations caused by the increased piling duration.

Table 4-26 to Table 4-29 give the predicted ranges for the observed levels given in Hawkins *et al*. (2014) for a 50% response in fish from impulsive noise. These show that a disturbance response may occur in fish out to a maximum of 67 km from the source using the most precautionary of thresholds.

When comparing the impact ranges for a single pile installation and sequential pile installations, the overall increases are negligible when considering a fleeing animal, as by the time the subsequent piles are installed, the fleeing receptor is at such a distance that the additional exposure is minimal. When considering a stationary animal, the ranges are significantly increase as the receptor is essentially receiving either double or quadruple the number of pile strikes from monopile and jacket pile foundations respectively.

4.2.1 Worst-case monopile foundations

Popper *et al.* (2014) Unweighted SPL_{peak}		Worst-case monopile foundation			
		Area	Max	Min	Mean
NW	213 dB	0.02 km^2	90 m	90 m	90 m
	207 dB	0.14 km^2	210 m	210 m	210 m
S	213 dB	0.05 km^2	120 m	120 m	120 m
	207 dB	0.30 km^2	310 m	310 m	310 m
E	213 dB	0.04 km^2	120 m	120 m	120 m
	207 dB	0.29 km^2	310 m	300 m	300 m
W	213 dB	0.03 km^2	110 m	110 m	110 m
	207 dB	0.21 km^2	260 m	260 m	260 m

Table 4-14 Summary of the impact ranges from worst-case monopile foundation modelling at Rampion 2 using the Popper et al. (2014) unweighted SPL_{peak} pile driving criteria for pile driving

Popper *et al.* (2014) Unweighted SELcum		Worst-case monopile foundation – single pile							
		Fleeing animal (1.5 ms^{-1})				Stationary animal			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	1.0 km^2	600 m	550 m	580 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	2.3 km^2	900 m	800 m	860 m
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	9.9 km^2	1.9 km	1.7 km	1.8 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	19 km^2	2.7 km	2.3 km	2.5 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	43 km^2	4.1 km	3.3 km	3.7 km
	186 dB	130 km^2	10 km	2.9 km	5.9 km	680 km^2	21 km	9.1 km	14 km
S	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	2.7 km^2	950 m	900 m	930 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	6.4 km^2	1.5 km	1.4 km	1.4 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	36 km^2	3.5 km	3.3 km	3.4 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	79 km^2	5.2 km	4.9 km	5.0 km
	203 dB	0.3 km^2	400 m	150 m	270 m	200 km^2	8.4 km	7.6 km	8.0 km
	186 dB	980 km^2	24 km	11 km	17 km	2400 km^2	35 km	18 km	27 km
E	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	2.6 km^2	950 m	850 m	910 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	6.1 km^2	1.5 km	1.4 km	1.4 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	32 km^2	3.3 km	3.1 km	3.2 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	68 km^2	4.9 km	4.4 km	4.7 km
	203 dB	< 0.1 km^2	250 m	< 100 m	150 m	160 km^2	8.0 km	6.4 km	7.2 km
	186 dB	780 km^2	23 km	8.2 km	15 km	2000 km^2	34 km	16 km	24 km
W	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	1.7 km^2	750 m	700 m	730 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	3.6 km^2	1.2 km	1.1 km	1.1 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	16 km^2	2.4 km	2.2 km	2.3 km

	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	33 km^2	3.4 km	3.0 km	3.3 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	76 km^2	5.3 km	4.3 km	4.9 km
	186 dB	250 km^2	15 km	2.9 km	8.2 km	940 km^2	26 km	7.7 km	17 km

Table 4-15 Summary of the impact ranges from worst-case monopile foundation modelling at Rampion 2 for a single pile using the Popper et al. (2014) unweighted SEL_{cum} pile driving criteria for fish assuming both a fleeing and a stationary animal model

Popper *et al.* (2014) Unweighted SELcum		Worst-case monopile foundation – 2 sequentially installed piles							
		Fleeing animal (1.5 ms^{-1})				Stationary animal			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	2.3 km^2	900 m	800 m	860 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	4.9 km^2	1.3 km	1.2 km	1.2 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	19 km^2	2.7 km	2.3 km	2.5 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	36 km^2	3.7 km	3.1 km	3.4 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	77 km^2	5.6 km	4.3 km	4.9 km
	186 dB	130 km^2	11 km	2.9 km	5.9 km	980 km^2	26 km	10 km	17 km
S	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	6.5 km^2	1.5 km	1.4 km	1.4 km
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	15 km^2	2.3 km	2.2 km	2.2 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	79 km^2	5.2 km	4.9 km	5.0 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	160 km^2	7.4 km	6.8 km	7.2 km
	203 dB	0.3 km^2	450 m	150 m	290 m	370 km^2	12 km	9.6 km	11 km
	186 dB	1000 km^2	25 km	11 km	17 km	3100 km^2	41 km	20 km	30 km
E	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	6.1 km^2	1.5 km	1.4 m	1.4 km
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	14 km^2	2.2 km	2.1 km	2.1 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	68 km^2	4.9 km	4.4 km	4.7 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	130 km^2	7.1 km	5.9 km	6.5 km
	203 dB	0.1 km^2	300 m	< 100 m	160 m	300 km^2	11 km	8.1 km	9.7 km
	186 dB	800 km^2	23 km	8.2 km	15 km	2600 km^2	40 km	17 km	28 km
W	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	3.6 km^2	1.2 km	1.1 km	1.1 km
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	7.9 km^2	1.7 km	1.5 km	1.6 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	33 km^2	3.4 km	3.0 km	3.3 km

	207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m	63 km²	4.8 km	3.9 km	4.5 km
	203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m	130 km²	7.5 km	5.2 km	6.4 km
	186 dB	260 km²	15 km	2.9 km	8.3 km	1300 km²	30 km	8.6 km	19 km

Table 4-16 Summary of the impact ranges from worst-case monopile foundation modelling at Rampion 2 for two sequentially installed piles using the Popper et al. (2014) unweighted SEL_{cum} pile driving criteria for fish assuming both a fleeing and a stationary animal model

4.2.2 Most likely monopile foundations

Popper *et al.* (2014) Unweighted SPL_{peak}		Most likely monopile foundation			
		Area	Max	Min	Mean
NW	213 dB	0.02 km²	90 m	90 m	90 m
	207 dB	0.13 km²	210 m	200 m	210 m
S	213 dB	0.04 km²	120 m	120 m	120 m
	207 dB	0.29 km²	300 m	300 m	300 m
E	213 dB	0.04 km²	120 m	120 m	120 m
	207 dB	0.28 km²	300 m	300 m	300 m
W	213 dB	0.03 km²	100 m	100 m	100 m
	207 dB	0.20 km²	260 m	250 m	260 m

Table 4-17 Summary of the impact ranges from most likely monopile foundation modelling at Rampion 2 using the Popper et al. (2014) unweighted SPL_{peak} pile driving criteria for pile driving

Popper *et al.* (2014) Unweighted SEL_{cum}		Most likely monopile foundation – single pile							
		Fleeing animal (1.5 ms^{-1})				Stationary animal			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	0.6 km^2	450 m	400 m	430 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	1.2 km^2	650 m	600 m	630 m
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	5.7 km^2	1.4 km	1.3 km	1.3 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	11 km^2	2.1 km	1.8 km	1.9 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	27 km^2	3.2 km	2.7 km	2.9 km
	186 dB	110 km^2	9.4 km	2.8 km	5.5 km	490 km^2	17 km	8.3 km	12 km
S	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	1.4 km^2	700 m	650 m	680 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	3.3 km^2	1.1 km	1.0 km	1.0 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	19 km^2	2.5 km	2.4 km	2.4 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	43 km^2	3.8 km	3.6 km	3.7 km
	203 dB	0.1 km^2	250 m	< 100 m	180 m	120 km^2	6.3 km	5.9 km	6.1 km
	186 dB	900 km^2	22 km	10 km	16 km	1900 km^2	30 km	17 km	24 km
E	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	1.2 km^2	650 m	600 m	630 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	3.0 km^2	1.0 km	950 m	980 m
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	17 km^2	2.4 km	2.3 km	2.3 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	38 km^2	3.6 km	3.4 km	3.5 km
	203 dB	< 0.1 km^2	150 m	< 100 m	100 m	100 km^2	6.0 km	5.2 km	5.6 km
	186 dB	710 km^2	21 km	8.1 km	14 km	1600 km^2	29 km	15 km	22 km
W	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	0.9 km^2	550 m	500 m	530 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	2.0 km^2	850 m	750 m	800 m
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	9.2 km^2	1.8 km	1.7 km	1.7 km

	207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m	19 km²	2.6 km	2.4 km	2.5 km
	203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m	48 km²	4.2 km	3.5 km	3.9 km
	186 dB	220 km²	14 km	2.8 km	7.8 km	710 km²	22 km	7.0 km	15 km

Table 4-18 Summary of the impact ranges from most likely monopile foundation modelling at Rampion 2 for a single pile using the Popper et al. (2014) unweighted SEL_{cum} pile driving criteria for fish assuming both a fleeing and a stationary animal model

Popper *et al.* (2014) Unweighted SELcum		Most likely monopile foundation – 2 sequentially installed piles							
		Fleeing animal (1.5 ms^{-1})				Stationary animal			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	1.2 km^2	650 m	600 m	630 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	2.7 km^2	950 m	850 m	930 m
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	11 km^2	2.1 km	1.8 km	1.9 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	22 km^2	2.9 km	2.5 km	2.7 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	49 km^2	4.4 km	3.5 km	4.0 km
	186 dB	120 km^2	10 km	2.8 km	5.7 km	740 km^2	22 km	9.3 km	15 km
S	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	3.3 km^2	1.1 km	1.0 km	1.0 km
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	7.8 km^2	1.7 km	1.6 km	1.6 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	43 km^2	3.8 km	3.6 km	3.7 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	92 km^2	5.6 km	5.3 km	5.4 km
	203 dB	0.2 km^2	300 m	< 100 m	210 m	230 km^2	9.0 km	8.0 km	8.6 km
	186 dB	950 km^2	24 km	10 km	17 km	2500 km^2	36 km	19 km	28 km
E	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	3.0 km^2	1.0 km	950 m	980 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	7.3 km^2	1.6 km	1.5 km	1.5 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	38 km^2	3.6 km	3.4 km	3.5 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	80 km^2	5.3 km	4.7 km	5.0 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	190 km^2	8.6 km	6.8 km	7.7 km
	186 dB	760 km^2	22 km	8.1 km	15 km	2100 km^2	35 km	16 km	25 km
W	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	2.0 km^2	850 m	750 m	810 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	4.3 km^2	1.3 km	1.1 km	1.2 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	19 km^2	2.6 km	2.4 km	2.5 km

	207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m	39 km²	3.7 km	3.2 km	3.5 km
	203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m	87 km²	5.8 km	4.5 km	5.3 km
	186 dB	240 km²	15 km	2.8 km	8.0 km	1000 km²	27 km	7.9 km	17 km

Table 4-19 Summary of the impact ranges from most likely monopile foundation modelling at Rampion 2 for two sequentially installed piles using the Popper et al. (2014) unweighted SEL_{cum} pile driving criteria for fish assuming both a fleeing and a stationary animal model

4.2.3 Worst-case jacket foundations

Popper *et al.* (2014) Unweighted SPL_{peak}		**Worst-case jacket foundation**			
		Area	Max	Min	Mean
NW	213 dB	0.02 km²	70 m	70 m	70 m
	207 dB	0.09 km²	170 m	170 m	170 m
S	213 dB	0.03 km²	100 m	100 m	100 m
	207 dB	0.20 km²	260 m	260 m	260 m
E	213 dB	0.03 km²	100 m	100 m	100 m
	207 dB	0.20 km²	250 m	250 m	250 m
W	213 dB	0.02 km²	90 m	90 m	90 m
	207 dB	0.14 km²	220 m	210 m	220 m

Table 4-20 Summary of the impact ranges from worst-case jacket foundation modelling at Rampion 2 using the Popper et al. (2014) unweighted SPL_{peak} pile driving criteria for pile driving

Popper *et al.* (2014) Unweighted SEL_{cum}		Worst-case jacket foundation – single pile							
		Fleeing animal (1.5 ms^{-1})				Stationary animal			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	0.7 km^2	500 m	450 m	480 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	1.4 km^2	700 m	650 m	680 m
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	6.5 km^2	1.5 km	1.4 km	1.4 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	13 km^2	2.2 km	1.9 km	2.0 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	31 km^2	3.4 km	2.9 km	3.1 km
	186 dB	75 km^2	7.9 km	2.5 km	4.5 km	530 km^2	18 km	8.5 km	13 km
S	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	1.6 km^2	750 m	700 m	730 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	4.3 km^2	1.2 km	1.2 km	1.2 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	24 km^2	2.8 km	2.7 km	2.8 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	54 km^2	4.3 km	4.1 km	4.1 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	140 km^2	7.0 km	6.5 km	6.8 km
	186 dB	780 km^2	21 km	9.6 km	15 km	2000 km^2	32 km	18 km	25 km
E	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	1.6 km^2	750 m	700 m	730 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	4.0 km^2	1.2 km	1.1 km	1.1 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	22 km^2	2.7 km	2.6 km	2.6 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	47 km^2	4.0 km	3.7 km	3.9 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	120 km^2	6.7 km	5.6 km	6.2 km
	186 dB	610 km^2	20 km	7.4 km	13 km	1700 km^2	31 km	15 km	23 km
W	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	1.1 km^2	600 m	550 m	580 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	2.4 km^2	900 m	850 m	870 m
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	11 km^2	2.0 km	1.8 km	1.9 km

	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	23 km^2	2.9 km	2.5 km	2.7 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	56 km^2	4.5 km	3.7 km	4.2 km
	186 dB	170 km^2	13 km	2.5 km	6.9 km	780 km^2	23 km	7.3 km	15 km

Table 4-21 Summary of the impact ranges from worst-case jacket foundation modelling at Rampion 2 for a single pile using the Popper et al. (2014) unweighted SEL_{cum} pile driving criteria for fish assuming both a fleeing and a stationary animal model

Popper *et al.* (2014) Unweighted SEL_{cum}		**Worst-case jacket foundation – 4 sequentially installed piles**							
		Fleeing animal (1.5 ms^{-1})				**Stationary animal**			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	3.2 km^2	1.1 km	950 m	1.0 km
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	6.5 km^2	1.5 km	1.4 km	1.4 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	25 km^2	3.1 km	2.6 km	2.8 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	46 km^2	4.2 km	3.4 km	3.8 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	96 km^2	6.4 km	4.7 km	5.5 km
	186 dB	77 km^2	8.1 km	2.2 km	4.6 km	1100 km^2	28 km	10 km	18 km
S	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	10 km^2	1.9 km	1.8 km	1.8 km
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	24 km^2	2.8 km	2.7 km	2.8 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	110 km^2	6.2 km	5.9 km	6.0 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	220 km^2	8.9 km	8.0 km	8.5 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	480 km^2	14 km	11 km	12 km
	186 dB	800 km^2	22 km	9.6 km	15 km	3400 km^2	44 km	21 km	32 km
E	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	9.3 km^2	1.8 km	1.7 km	1.7 km
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	22 km^2	2.7 km	2.6 km	2.6 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	96 km^2	5.9 km	5.1 km	5.5 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	180 km^2	8.4 km	6.7 km	7.6 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	390 km^2	13 km	9.0 km	11 km
	186 dB	630 km^2	20 km	7.4 km	13 km	3000 km^2	43 km	18 km	29 km
W	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	5.3 km^2	1.4 km	1.3 km	1.3 km
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	11 km^2	2.0 km	1.8 km	1.9 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	45 km^2	4.1 km	3.4 km	3.8 km

	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	82 km^2	5.6 km	4.4 km	5.1 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	160 km^2	8.6 km	5.3 km	7.2 km
	186 dB	180 km^2	13 km	2.5 km	7.0 km	1500 km^2	33 km	9.0 km	21 km

Table 4-22 Summary of the impact ranges from worst-case jacket foundation modelling at Rampion 2 for four sequentially installed piles using the Popper et al. (2014) unweighted SEL_{cum} pile driving criteria for fish assuming both a fleeing and a stationary animal model

4.2.4 Most likely jacket foundations

Popper *et al.* (2014) Unweighted SPL_{peak}		**Most likely jacket foundation**			
		Area	Max	Min	Mean
NW	213 dB	0.01 km^2	70 m	70 m	70 m
	207 dB	0.08 km^2	160 m	160 m	160 m
S	213 dB	0.03 km^2	90 m	90 m	90 m
	207 dB	0.17 km^2	230 m	230 m	230 m
E	213 dB	0.02 km^2	90 m	80 m	90 m
	207 dB	0.16 km^2	230 m	230 m	230 m
W	213 dB	0.02 km^2	80 m	80 m	80 m
	207 dB	0.12 km^2	200 m	200 m	200 m

Table 4-23 Summary of the impact ranges from most likely jacket foundation modelling at Rampion 2 using the Popper et al. (2014) unweighted SPL_{peak} pile driving criteria for pile driving

Popper *et al.* (2014) Unweighted SEL_{cum}		Most likely jacket foundation – single pile							
		Fleeing animal (1.5 ms^{-1})				Stationary animal			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	0.3 km^2	350 m	300 m	330 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	0.7 km^2	500 m	450 m	480 m
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	3.2 km^2	1.1 km	950 m	1.1 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	6.8 km^2	1.6 km	1.4 km	1.5 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	17 km^2	2.5 km	2.2 km	2.3 km
	186 dB	54 km^2	6.5 km	2.0 km	3.9 km	360 km^2	14 km	7.6 km	10 km
S	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	0.7 km^2	500 m	450 m	480 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	1.9 km^2	800 m	750 m	780 m
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	11 km^2	1.9 km	1.8 km	1.9 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	25 km^2	2.9 km	2.8 km	2.8 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	73 km^2	5.0 km	4.7 km	4.8 km
	186 dB	650 km^2	19 km	9.2 km	14 km	1500 km^2	27 km	16 km	22 km
E	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	0.7 km^2	500 m	450 m	480 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	1.6 km^2	750 m	700 m	730 m
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	9.8 km^2	1.8 km	1.8 km	1.8 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	23 km^2	2.8 km	2.7 km	2.7 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	63 km^2	4.7 km	4.2 km	4.5 km
	186 dB	500 km^2	17 km	7.0 km	12 km	1200 km^2	25 km	14 km	19 km
W	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	0.5 km^2	450 m	400 m	420 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	1.2 km^2	650 m	600 m	610 m
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	5.4 km^2	1.4 km	1.3 km	1.3 km

	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	12 km^2	2.0 km	1.9 km	1.9 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	30 km^2	3.3 km	2.9 km	3.1 km
	186 dB	140 km^2	11 km	2.3 km	6.1 km	550 km^2	19 km	6.2 km	13 km

Table 4-24 Summary of the impact ranges from most likely jacket foundation modelling at Rampion 2 for a single pile using the Popper et al. (2014) unweighted SEL_{cum} pile driving criteria for fish assuming both a fleeing and a stationary animal model

Popper *et al.* (2014) Unweighted SELcum		Most likely jacket foundation – 4 sequentially installed piles							
		Fleeing animal (1.5 ms^{-1})				Stationary animal			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	1.6 km^2	750 m	650 m	700 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	3.2 km^2	1.1 km	950 m	1.0 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	14 km^2	2.2 km	2.0 km	2.1 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	26 km^2	3.1 km	2.7 km	2.9 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	57 km^2	4.8 km	3.8 km	4.3 km
	186 dB	60 km^2	7.0 km	2.0 km	4.0 km	810 km^2	23 km	9.6 km	15 km
S	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	4.5 km^2	1.3 km	1.2 km	1.2 km
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	11 km^2	1.9 km	1.8 km	1.9 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	57 km^2	4.4 km	4.2 km	4.3 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	120 km^2	6.4 km	6.0 km	6.2 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	290 km^2	10 km	8.8 km	9.6 km
	186 dB	700 km^2	20 km	9.2 km	15 km	2700 km^2	38 km	19 km	28 km
E	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	4.2 km^2	1.2 km	1.1 km	1.2 km
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	9.8 km^2	1.8 km	1.8 km	1.8 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	50 km^2	4.2 km	3.8 km	4.0 km
	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	100 km^2	6.1 km	5.2 km	5.7 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	230 km^2	9.6 km	7.4 km	8.6 km
	186 dB	540 km^2	19 km	7.0 km	12 km	2300 km^2	37 km	16 km	26 km
W	219 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	2.6 km^2	950 m	850 m	910 m
	216 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	5.5 km^2	1.4 km	1.3 km	1.3 km
	210 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	24 km^2	2.9 km	2.6 km	2.8 km

	207 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	47 km^2	4.1 km	3.5 km	3.9 km
	203 dB	< 0.1 km^2	< 100 m	< 100 m	< 100 m	100 km^2	6.4 km	4.8 km	5.7 km
	186 dB	150 km^2	12 km	2.3 km	6.4 km	1100 km^2	28 km	8.2 km	18 km

Table 4-25 Summary of the impact ranges from most likely jacket foundation modelling at Rampion 2 for four sequentially installed piles using the Popper et al. (2014) unweighted SEL_{cum} pile driving criteria for fish assuming both a fleeing and a stationary animal model

4.2.5 Hawkins et al. (2014) levels

Hawkins *et al.* (2014)		Worst-case monopile foundation			
		Area	Max	Min	Mean
NW	173 dB (SPL_{peak})	230 km^2	11 km	6.6 km	8.5 km
	168 dB (SPL_{peak})	460 km^2	17 km	8.0 km	12 km
	163 dB ($SPL_{peak-to-peak}$)	1500 km^2	33 km	11 km	20 km
	142 dB (SEL_{ss})	1500 km^2	33 km	11 km	20 km
	135 dB (SEL_{ss})	2800 km^2	47 km	13 km	27 km
S	173 dB (SPL_{peak})	1000 km^2	21 km	14 km	18 km
	168 dB (SPL_{peak})	1800 km^2	30 km	17 km	23 km
	163 dB ($SPL_{peak-to-peak}$)	4100 km^2	50 km	21 km	35 km
	142 dB (SEL_{ss})	4200 km^2	50 km	21 km	35 km
	135 dB (SEL_{ss})	6500 km^2	67 km	23 km	43 km
E	173 dB (SPL_{peak})	840 km^2	20 km	12 km	16 km
	168 dB (SPL_{peak})	1500 km^2	28 km	14 km	21 km
	163 dB ($SPL_{peak-to-peak}$)	3500 km^2	48 km	18 km	32 km
	142 dB (SEL_{ss})	3600 km^2	48 km	18 km	32 km
	135 dB (SEL_{ss})	5600 km^2	65 km	19 km	39 km
W	173 dB (SPL_{peak})	360 km^2	15 km	5.7 km	11 km
	168 dB (SPL_{peak})	660 km^2	21 km	6.4 km	14 km
	163 dB ($SPL_{peak-to-peak}$)	1900 km^2	37 km	9.5 km	23 km
	142 dB (SEL_{ss})	1900 km^2	37 km	9.8 km	23 km
	135 dB (SEL_{ss})	3500 km^2	51 km	12 km	30 km

Table 4-26 Summary of the impact ranges from worst-case monopile foundation modelling at Rampion 2 using the Hawkins et al. (2014) levels for 50% response in fish

Hawkins *et al.* (2014)		Most likely monopile foundation			
		Area	Max	Min	Mean
NW	173 dB (SPL_{peak})	230 km^2	11 km	6.5 km	8.4 km
	168 dB (SPL_{peak})	450 km^2	16 km	8.0 km	12 km
	163 dB ($SPL_{peak\text{-}to\text{-}peak}$)	1500 km^2	33 km	11 km	20 km
	142 dB (SEL_{ss})	1500 km^2	32 km	11 km	20 km
	135 dB (SEL_{ss})	2700 km^2	46 km	13 km	27 km
S	173 dB (SPL_{peak})	1000 km^2	21 km	14 km	18 km
	168 dB (SPL_{peak})	1700 km^2	29 km	17 km	23 km
	163 dB ($SPL_{peak\text{-}to\text{-}peak}$)	4000 km^2	49 km	21 km	35 km
	142 dB (SEL_{ss})	4100 km^2	49 km	21 km	35 km
	135 dB (SEL_{ss})	6400 km^2	66 km	23 km	43 km
E	173 dB (SPL_{peak})	830 km^2	20 km	12 km	16 km
	168 dB (SPL_{peak})	1400 km^2	28 km	14 km	21 km
	163 dB ($SPL_{peak\text{-}to\text{-}peak}$)	3500 km^2	48 km	18 km	31 km
	142 dB (SEL_{ss})	3500 km^2	48 km	18 km	32 km
	135 dB (SEL_{ss})	5600 km^2	65 km	19 km	39 km
W	173 dB (SPL_{peak})	350 km^2	14 km	5.7 km	10 km
	168 dB (SPL_{peak})	650 km^2	21 km	6.4 km	14 km
	163 dB ($SPL_{peak\text{-}to\text{-}peak}$)	1900 km^2	37 km	9.4 km	23 km
	142 dB (SEL_{ss})	1900 km^2	37 km	9.8 km	23 km
	135 dB (SEL_{ss})	3400 km^2	50 km	12 km	30 km

Table 4-27 Summary of the impact ranges from most likely monopile foundation modelling at Rampion 2 using the Hawkins et al. (2014) levels for 50% response in fish

Hawkins *et al.* (2014)		Worst-case jacket foundation			
		Area	Max	Min	Mean
NW	173 dB (SPL_{peak})	190 km²	9.4 km	6.1 km	7.7 km
	168 dB (SPL_{peak})	380 km²	15 km	7.6 km	11 km
	163 dB ($SPL_{peak-to-peak}$)	1300 km²	31 km	11 km	19 km
	142 dB (SEL_{ss})	1200 km²	30 km	11 km	19 km
	135 dB (SEL_{ss})	2400 km²	43 km	13 km	25 km
S	173 dB (SPL_{peak})	890 km²	20 km	13 km	17 km
	168 dB (SPL_{peak})	1600 km²	27 km	16 km	22 km
	163 dB ($SPL_{peak-to-peak}$)	3700 km²	47 km	21 km	33 km
	142 dB (SEL_{ss})	3700 km²	46 km	21 km	33 km
	135 dB (SEL_{ss})	5900 km²	63 km	23 km	42 km
E	173 dB (SPL_{peak})	720 km²	19 km	11 km	15 km
	168 dB (SPL_{peak})	1300 km²	26 km	14 km	20 km
	163 dB ($SPL_{peak-to-peak}$)	3200 km²	46 km	18 km	30 km
	142 dB (SEL_{ss})	3200 km²	45 km	18 km	30 km
	135 dB (SEL_{ss})	5100 km²	61 km	19 km	38 km
W	173 dB (SPL_{peak})	300 km²	13 km	5.6 km	9.7 km
	168 dB (SPL_{peak})	570 km²	20 km	6.1 km	13 km
	163 dB ($SPL_{peak-to-peak}$)	1700 km²	35 km	9.1 km	22 km
	142 dB (SEL_{ss})	1700 km²	34 km	9.3 km	22 km
	135 dB (SEL_{ss})	3100 km²	48 km	11 km	29 km

Table 4-28 Summary of the impact ranges from worst-case jacket foundation modelling at Rampion 2 using the Hawkins et al. (2014) levels for 50% response in fish

Hawkins *et al.* (2014)		Most likely jacket foundation			
		Area	Max	Min	Mean
NW	173 dB (SPL_{peak})	170 km²	9.0 km	5.9 km	7.4 km
	168 dB (SPL_{peak})	350 km²	14 km	7.4 km	10 km
	163 dB ($SPL_{peak\text{-}to\text{-}peak}$)	1200 km²	29 km	10 km	19 km
	142 dB (SEL_{ss})	1200 km²	28 km	10 km	18 km
	135 dB (SEL_{ss})	2300 km²	41 km	12 km	25 km
S	173 dB (SPL_{peak})	830 km²	19 km	13 km	16 km
	168 dB (SPL_{peak})	1500 km²	26 km	16 km	21 km
	163 dB ($SPL_{peak\text{-}to\text{-}peak}$)	3600 km²	46 km	21 km	33 km
	142 dB (SEL_{ss})	3500 km²	45 km	21 km	33 km
	135 dB (SEL_{ss})	5700 km²	62 km	23 km	41 km
E	173 dB (SPL_{peak})	670 km²	18 km	11 km	14 km
	168 dB (SPL_{peak})	1200 km²	25 km	13 km	19 km
	163 dB ($SPL_{peak\text{-}to\text{-}peak}$)	3100 km²	45 km	18 km	30 km
	142 dB (SEL_{ss})	3000 km²	44 km	18 km	30 km
	135 dB (SEL_{ss})	4900 km²	60 km	19 km	37 km
W	173 dB (SPL_{peak})	280 km²	12 km	5.5 km	9.3 km
	168 dB (SPL_{peak})	530 km²	19 km	6.0 km	13 km
	163 dB ($SPL_{peak\text{-}to\text{-}peak}$)	1600 km²	34 km	8.9 km	21 km
	142 dB (SEL_{ss})	1600 km²	33 km	9.1 km	21 km
	135 dB (SEL_{ss})	2900 km²	46 km	11 km	28 km

Table 4-29 Summary of the impact ranges from most likely jacket foundation modelling at Rampion 2 using the Hawkins et al. (2014) levels for 50% response in fish

4.3 Multiple location piling

Additional modelling has been carried out to investigate the potential impacts of two piling installations occurring simultaneously at separated foundation locations for the SEL_{cum} critiera. Using the worst-case monopile and jacket scenarios from the previous sections, modelling has been carried out for simultaneous piling at both the E and W modelling locations, representing a worst-case spatial spread of locations. The worst case includes two monopiles or four pin piles installed sequentially at each location. All modelling in this section assumes that the two piling operations start at the same time.

When considering SEL_{cum} modelling, piling from multiple sources has the ability to increase impact ranges and areas significantly as, in this case, it introduces double the number of pile strikes to the water. Unlike sequential piling, the fleeing receptor can be closer to a source for more of the pile strikes resulting in a higher overall received level. Figure 4-1 shows the TTS contour for fish from Popper *et al*. (2014) (186 dB SEL_{cum}) as an example, given as unweighted SEL_{cum} for a fleeing receptor. The blue contours show the impact from each modelling location individually, and the red contour shows the increase in impact when both sources occur simultaneously, resulting in a contour encircling the previous two.

The modelling scenario of the E and W locations was chosen to provide the greatest geographical spread of impact range contours. In a modelling scenario where two piles are installed immediately adjacent to one another, there would be an expansion of the single location contour in all directions, but less than the East-West spread extent seen in Figure 4-1. It is understood that for operational and safety reasons the course or route of piling rigs would be designed to ensure that they would not be positioned near to each other at any time during piling, so the immediately adjacent scenario should not occur. Thus the ‘separated’ scenario here represents a worst case.

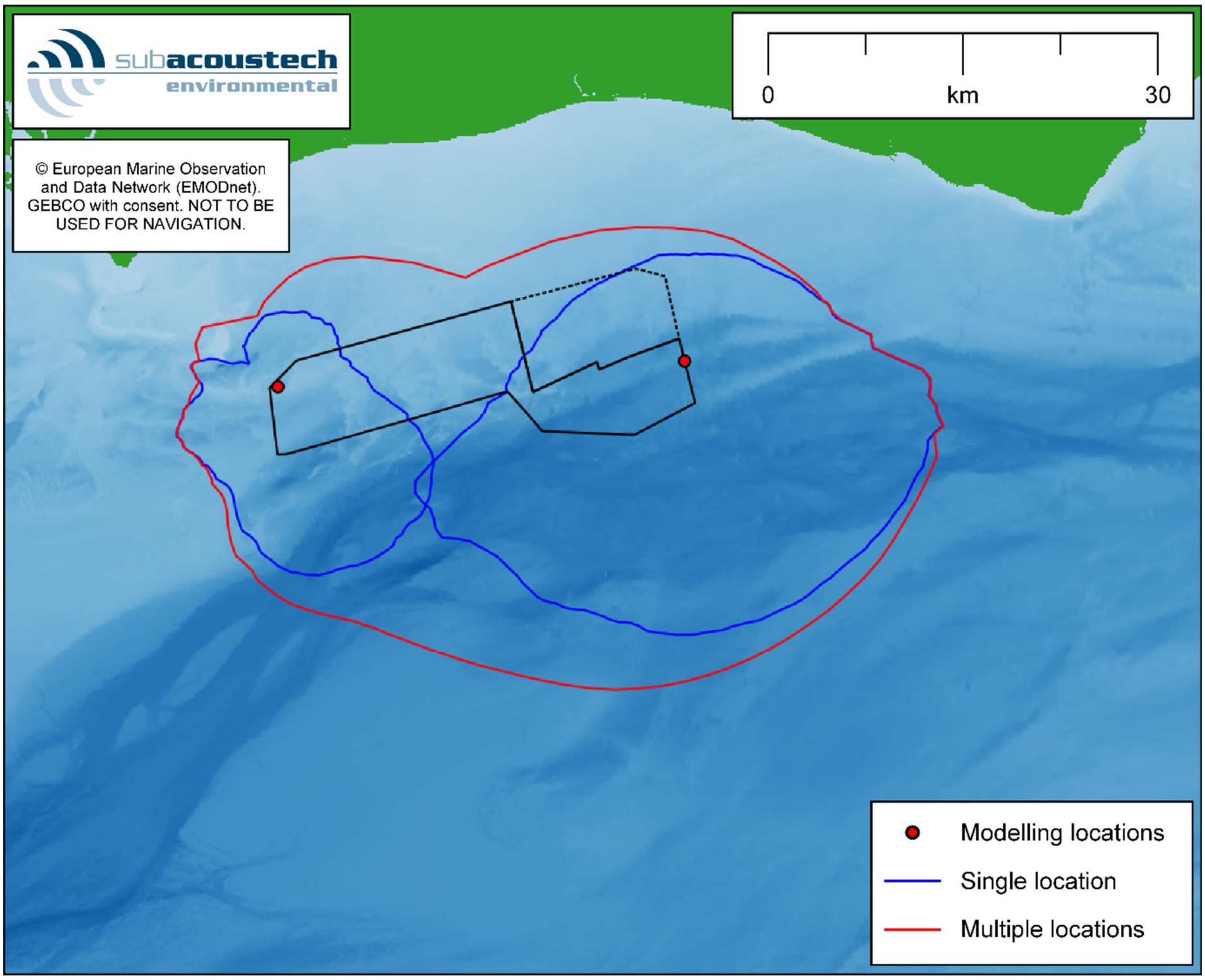


Figure 4-1 Contour plots showing the interaction between two noise sources when occurring simultaneously, contours for fish, TTS, 186 dB SEL_{cum}

Sections 4.3.1 and 4.3.2 present contour plots for the multiple location piling scenarios alongside tables showing the increase in overall area. Impact ranges have not been presented in this section as there are two starting points for receptors. Fields denoted with a dash "-" show where there is no in-combination effect when the two piles are installed simultaneously, generally where the individual ranges are small enough that the distant site does not produce an influencing additional exposure. Contours that are too small to be seen clearly at the scale of the figures have not been included.

The non-impulsive criteria from Southall *et al*. (2019) are presented in Appendix A.

4.3.1 Marine mammal criteria

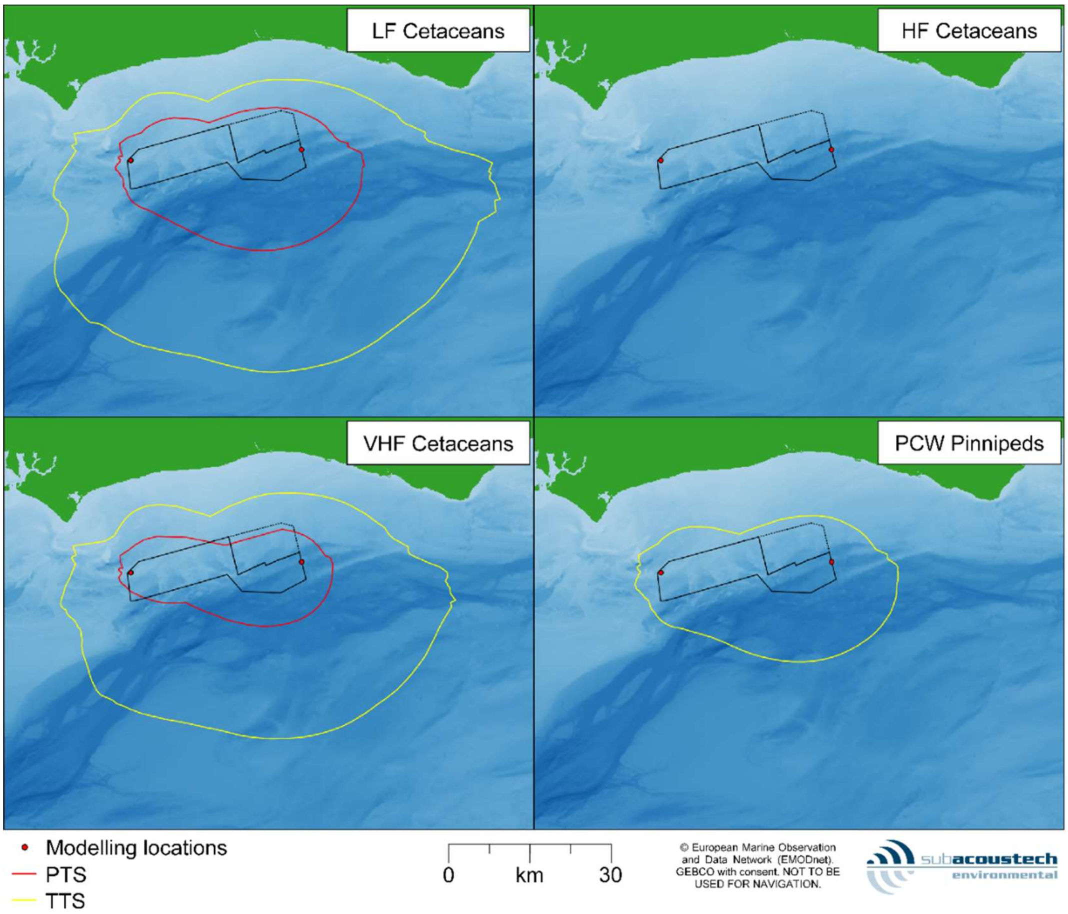


Figure 4-2 Contour plots showing the in-combination impacts of simultaneous installation of worst-case monopile foundations (based on a single pile) at the E and W modelling locations for marine mammals using the Southall et al. (2019) impulsive criteria, assuming a fleeing receptor

Worst-case monopile foundation Southall *et al*. (2019) Weighted SEL_{cum}		**Single monopile**		
		E area	**W area**	**In-combination area**
PTS	LF (183 dB)	280 km^2	43 km^2	890 km^2
	HF (185 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (155 dB)	85 km^2	19 km^2	510 km^2
	PCW (185 dB)	< 0.1 km^2	< 0.1 km^2	-
TTS	LF (168 dB)	2300 km^2	1100 km^2	3300 km^2
	HF (170 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (140 dB)	1500 km^2	700 km^2	2400 km^2
	PCW (170 dB)	350 km^2	89 km^2	970 km^2

Table 4-30 Summary of the impact areas for the installation of a single monopile foundation using the worst-case monopile parameters at the E and W modelling locations for marine mammals using the impulsive Southall et al. (2019) SEL_{cum} criteria assuming a fleeing receptor

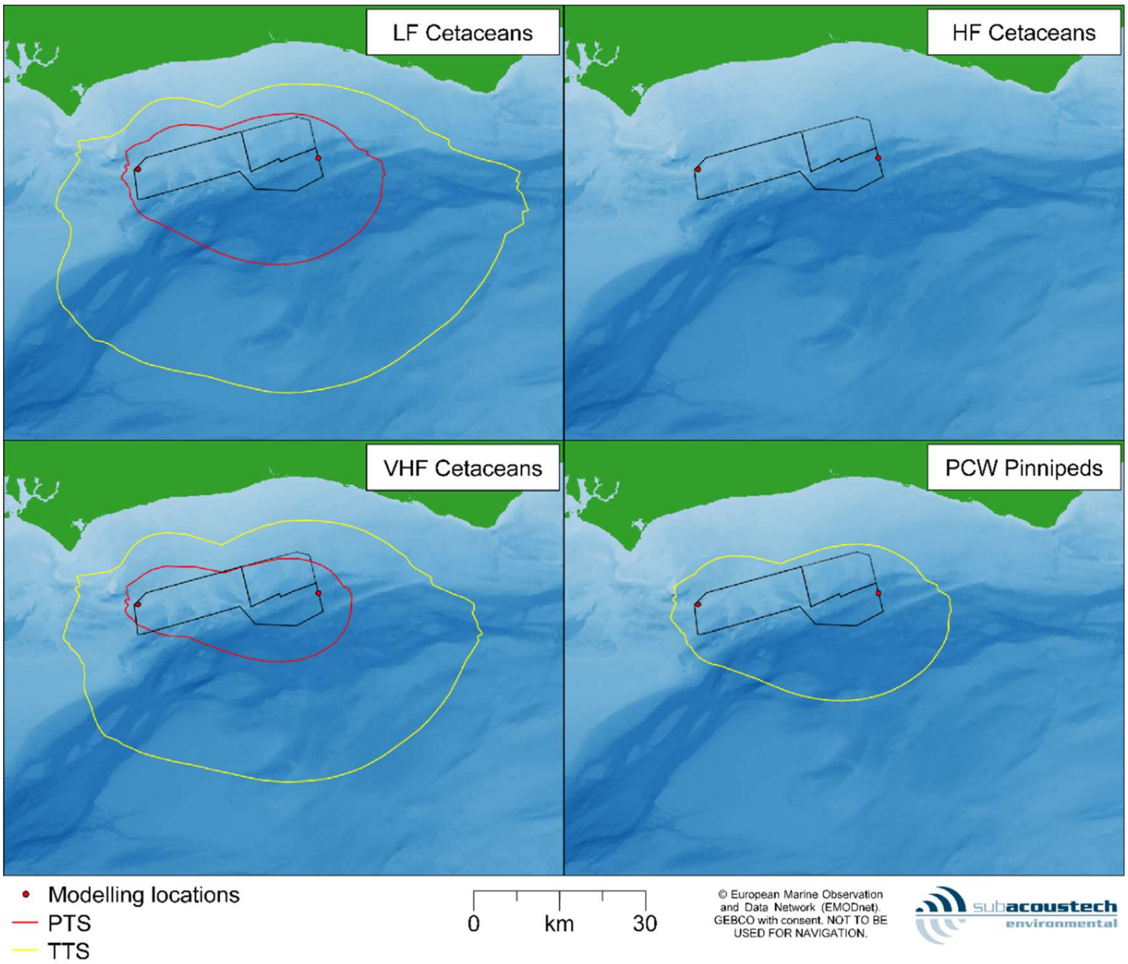


Figure 4-3 Contour plots showing the in-combination impacts of simultaneous installation of worst-case monopile foundations (based on 2 piles installed sequentially) at the E and W modelling locations for marine mammals using the Southall et al. (2019) impulsive criteria, assuming a fleeing receptor

Worst-case monopile foundation Southall *et al*. (2019) Weighted SEL_{cum}		**2 sequentially installed monopiles**		
		E area	**W area**	**In-combination area**
PTS	LF (183 dB)	280 km^2	43 km^2	890 km^2
	HF (185 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (155 dB)	87 km^2	20 km^2	530 km^2
	PCW (185 dB)	< 0.1 km^2	< 0.1 km^2	-
TTS	LF (168 dB)	2300 km^2	1100 km^2	3300 km^2
	HF (170 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (140 dB)	1500 km^2	720 km^2	2500 km^2
	PCW (170 dB)	360 km^2	92 km^2	1000 km^2

Table 4-31 Summary of the impact areas for the sequential installation of two monopile foundations using the worst-case monopile parameters at each of the E and W modelling locations for marine mammals using the impulsive Southall et al. (2019) SEL_{cum} criteria assuming a fleeing receptor

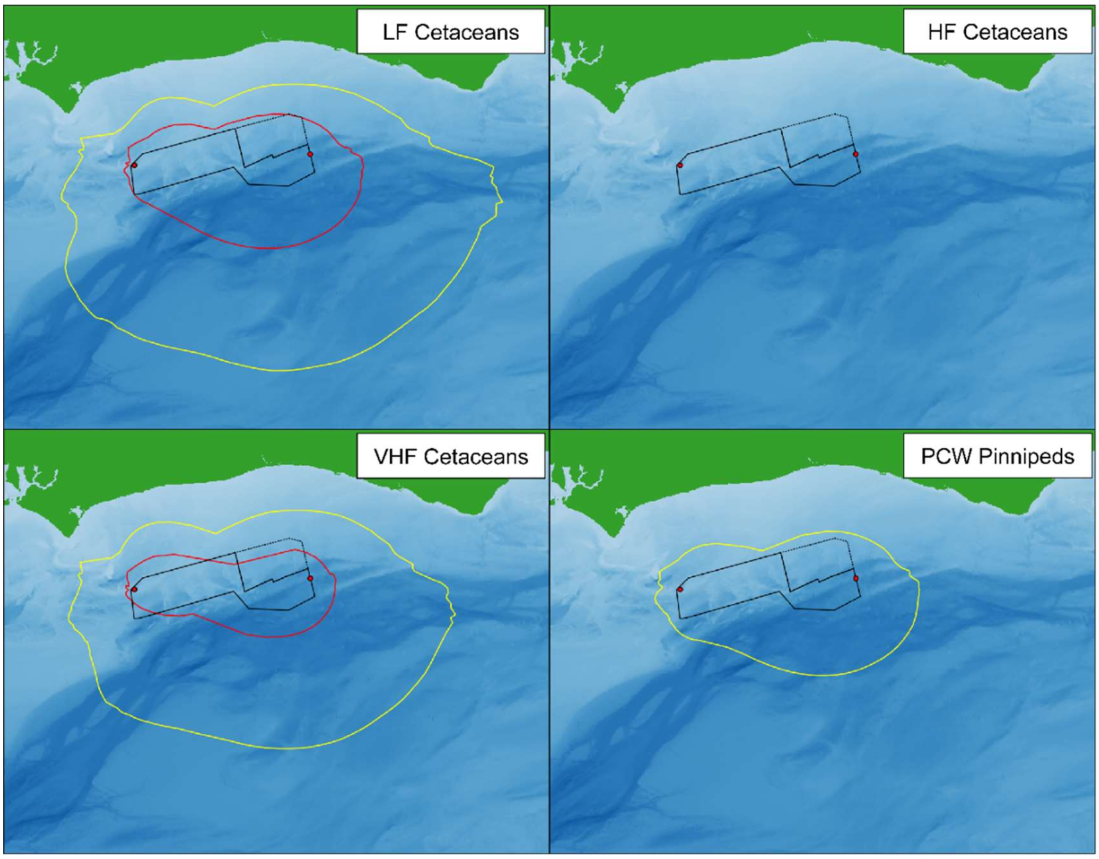


Figure 4-4 Contour plots showing the in-combination impacts of simultaneous installation of worst-case jacket foundations (based on a single pile) at the E and W modelling locations for marine mammals using the Southall et al. (2019) impulsive criteria, assuming a fleeing receptor

Worst-case jacket pile foundation Southall *et al*. (2019) Weighted SELcum		**Single jacket pile**		
		E area	**W area**	**In-combination area**
PTS	LF (183 dB)	190 km²	21 km²	760 km²
	HF (185 dB)	< 0.1 km²	< 0.1 km²	-
	VHF (155 dB)	53 km²	9.8 km²	420 km²
	PCW (185 dB)	< 0.1 km²	< 0.1 km²	-
TTS	LF (168 dB)	2000 km²	880 km²	3000 km²
	HF (170 dB)	< 0.1 km²	< 0.1 km²	-
	VHF (140 dB)	1300 km²	580 km²	2200 km²
	PCW (170 dB)	300 km²	72 km²	900 km²

Table 4-32 Summary of the impact areas for the installation of a single monopile jacket pile foundation using the worst-case monopile jacket pile parameters at the E and W modelling locations for marine mammals using the impulsive Southall et al. (2019) SEL_{cum} criteria assuming a fleeing receptor

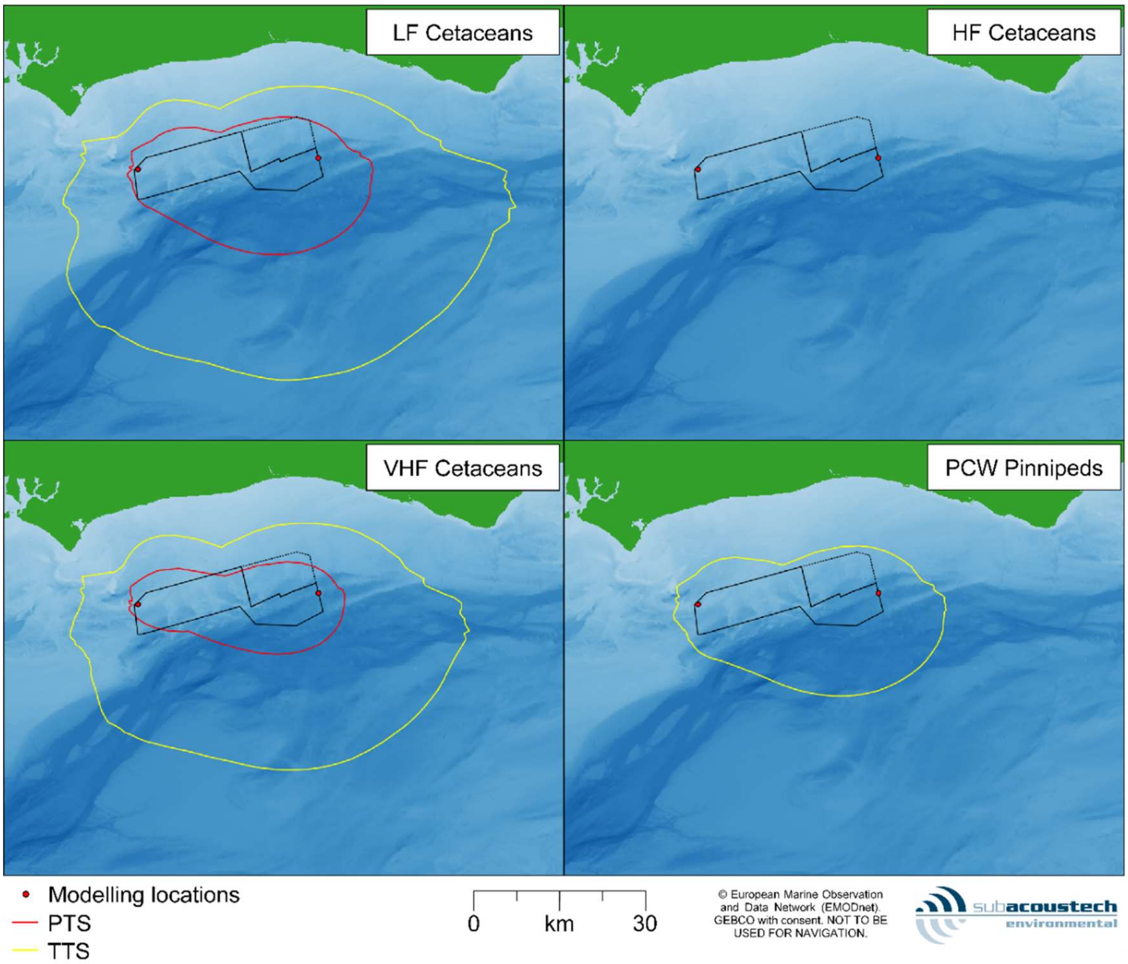


Figure 4-5 Contour plots showing the in-combination impacts of simultaneous installation of worst-case ~~monopile~~ jacket pile foundations (based on ~~2~~ 4 piles installed sequentially) at the E and W modelling locations for marine mammals using the Southall et al. (2019) impulsive criteria, assuming a fleeing receptor

Worst-case jacket pile foundation Southall *et al*. (2019) Weighted SEL_{cum}		**4 sequentially installed jacket piles**		
		E area	**W area**	**In-combination area**
PTS	LF (183 dB)	190 km^2	21 km^2	760 km^2
	HF (185 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (155 dB)	54 km^2	10 km^2	450 km^2
	PCW (185 dB)	< 0.1 km^2	< 0.1 km^2	-
TTS	LF (168 dB)	2000 km^2	880 km^2	3000 km^2
	HF (170 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (140 dB)	1300 km^2	600 km^2	2200 km^2
	PCW (170 dB)	310 km^2	75 km^2	930 km^2

Table 4-33 Summary of the impact areas for the sequential installation of four jacket~~monopile~~ foundations using the worst-case ~~monopile~~ jacket pile parameters at each of the E and W modelling locations for marine mammals using the impulsive Southall et al. (2019) SEL_{cum} criteria assuming a fleeing receptor

4.3.2 *Fish criteria*

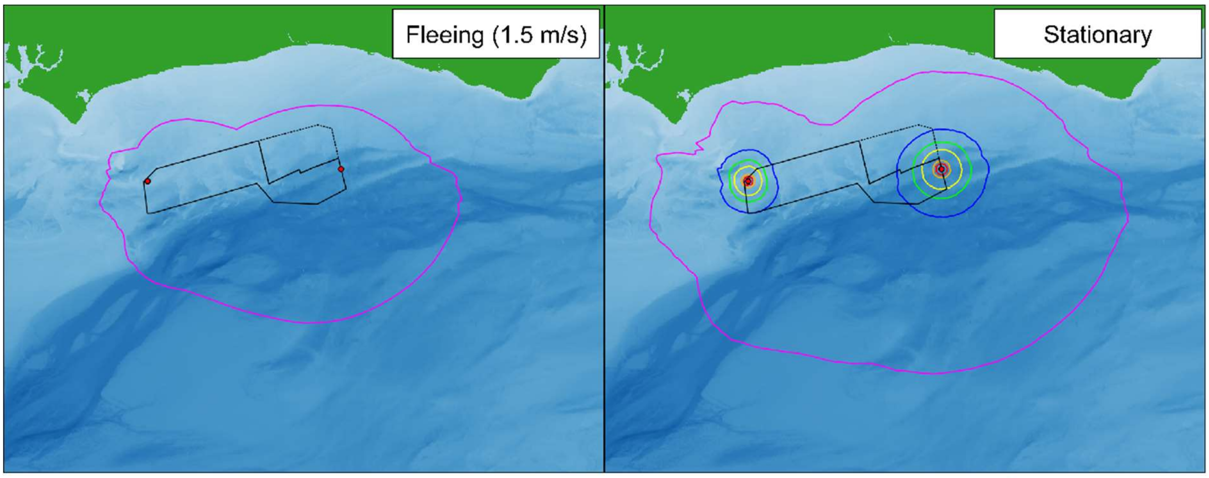


Figure 4-6 Contour plots showing the in-combination impacts of simultaneous installation of worst-case monopile foundations (based on a single pile) at the E and W modelling locations for fish using the Popper et al. (2014) impact piling criteria, assuming fleeing and stationary receptors

Worst-case monopile foundation Popper *et al.* (2014) Unweighted SEL_{cum}		**Single monopile**		
		E area	**W area**	**In-combination area**
Fleeing (1.5 m/s)	219 dB	< 0.1 km^2	< 0.1 km^2	-
	216 dB	< 0.1 km^2	< 0.1 km^2	-
	210 dB	< 0.1 km^2	< 0.1 km^2	-
	207 dB	< 0.1 km^2	< 0.1 km^2	-
	203 dB	< 0.1 km^2	< 0.1 km^2	-
	186 dB	780 km^2	250 km^2	1500 km^2
Stationary	219 dB	2.6 km^2	1.7 km^2	4.2 km^2
	216 dB	6.1 km^2	3.6 km^2	9.9 km^2
	210 dB	32 km^2	16 km^2	49 km^2
	207 dB	68 km^2	33 km^2	100 km^2
	203 dB	160 km^2	76 km^2	240 km^2
	186 dB	2000 km^2	940 km^2	2800 km^2

Table 4-34 Summary of the impact areas for the installation of a single monopile foundation using the worst-case monopile parameters at the E and W modelling locations for fish using the Popper et al. (2014) SEL_{cum} impact piling criteria assuming both a fleeing and stationary receptor

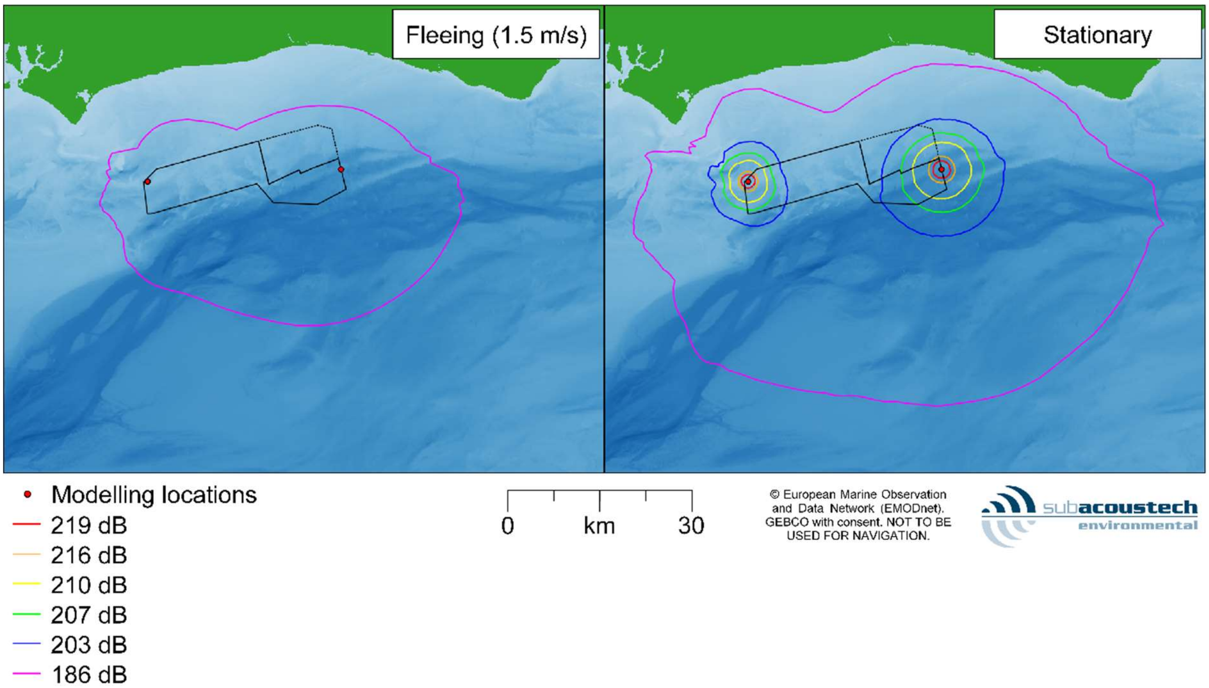


Figure 4-7 Contour plots showing the in-combination impacts of simultaneous installation of worst-case monopile foundations (based on 2 piles installed sequentially) at the E and W modelling locations for fish using the Popper et al. (2014) impact piling criteria, assuming fleeing and stationary receptors

Worst-case monopile foundation Popper *et al*. (2014) Unweighted SEL_{cum}		**2 sequentially installed monopiles**		
		E area	**W area**	**In-combination area**
Fleeing (1.5 m/s)	219 dB	< 0.1 km^2	< 0.1 km^2	-
	216 dB	< 0.1 km^2	< 0.1 km^2	-
	210 dB	< 0.1 km^2	< 0.1 km^2	-
	207 dB	< 0.1 km^2	< 0.1 km^2	-
	203 dB	0.1 km^2	< 0.1 km^2	-
	186 dB	800 km^2	260 km^2	1600 km^2
Stationary	219 dB	6.1 km^2	3.6 km^2	9.9 km^2
	216 dB	14 km^2	7.9 km^2	22 km^2
	210 dB	68 km^2	33 km^2	100 km^2
	207 dB	130 km^2	63 km^2	200 km^2
	203 dB	300 km^2	130 km^2	430 km^2
	186 dB	2600 km^2	1300 km^2	3500 km^2

Table 4-35 Summary of the impact areas for the sequential installation of two monopile foundations using the worst-case monopile parameters at each of the E and W modelling locations for fish using the Popper et al. (2014) SEL_{cum} impact piling assuming both a fleeing and stationary receptor

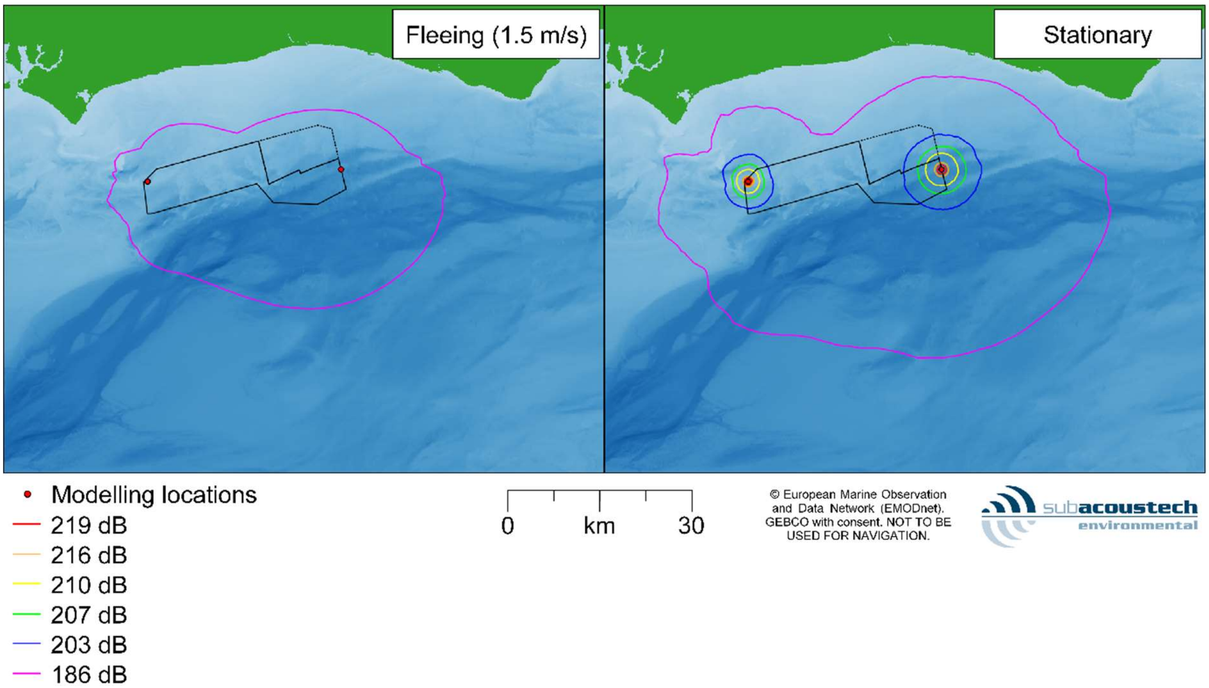


Figure 4-8 Contour plots showing the in-combination impacts of simultaneous installation of worst-case jacket foundations (based on a single pile) at the E and W modelling locations for fish using the Popper et al. (2014) impact piling criteria, assuming fleeing and stationary receptors

Worst-case jacket pile foundation Popper *et al.* (2014) Unweighted SEL_{cum}		**Single jacket pile**		
		E area	**W area**	**In-combination area**
Fleeing (1.5 m/s)	219 dB	< 0.1 km^2	< 0.1 km^2	-
	216 dB	< 0.1 km^2	< 0.1 km^2	-
	210 dB	< 0.1 km^2	< 0.1 km^2	-
	207 dB	< 0.1 km^2	< 0.1 km^2	-
	203 dB	< 0.1 km^2	< 0.1 km^2	-
	186 dB	610 km^2	170 km^2	1300 km^2
Stationary	219 dB	1.6 km^2	1.1 km^2	2.7 km^2
	216 dB	4.0 km^2	2.4 km^2	6.3 km^2
	210 dB	22 km^2	11 km^2	33 km^2
	207 dB	47 km^2	23 km^2	70 km^2
	203 dB	120 km^2	56 km^2	180 km^2
	186 dB	1700 km^2	780 km^2	2500 km^2

Table 4-36 Summary of the impact areas for the installation of a single jacket~~monopile~~ foundation using the worst-case jacket ~~monopile~~foundation parameters at the E and W modelling locations for fish using the Popper et al. (2014) SEL_{cum} impact piling criteria assuming both a fleeing and stationary receptor

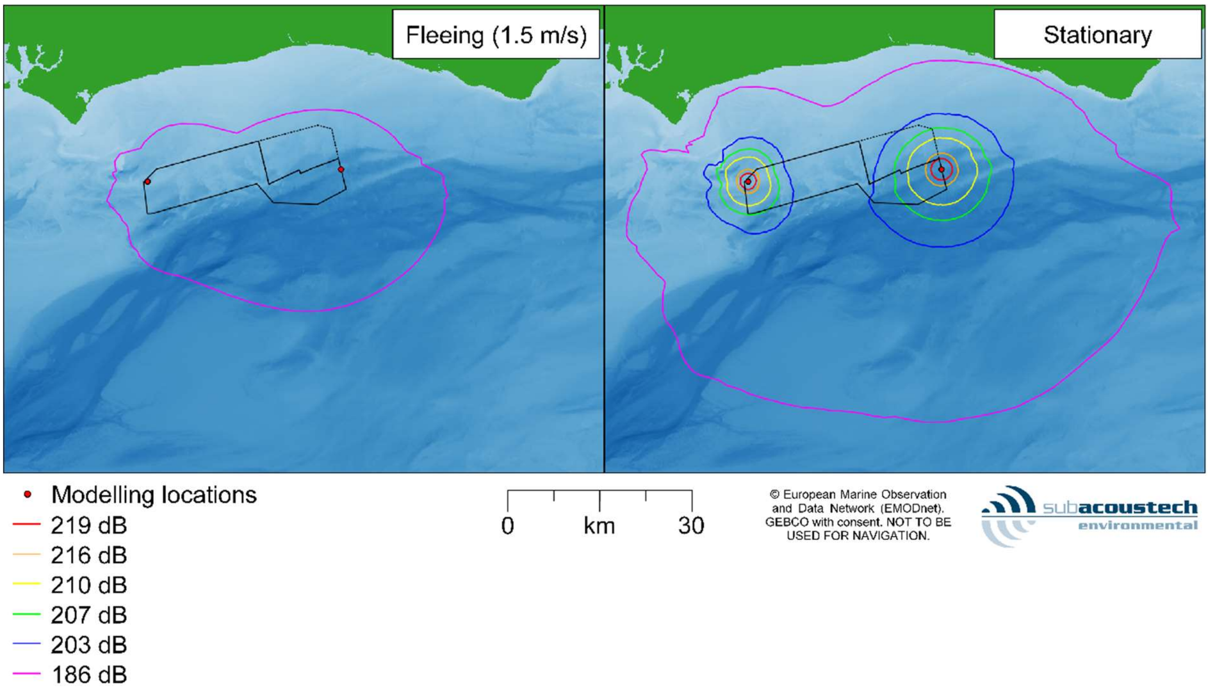


Figure 4-9 Contour plots showing the in-combination impacts of simultaneous installation of worst-case jacketmonopile foundations (based on 42 piles installed sequentially) at the E and W modelling locations for fish using the Popper et al. (2019) impact piling criteria, assuming fleeing and stationary receptors

Worst-case jacket pile foundation Popper *et al.* (2014) Unweighted SEL_{cum}		4 sequentially installed jacket piles		
		E area	W area	In-combination area
Fleeing (1.5 m/s)	219 dB	< 0.1 km^2	< 0.1 km^2	-
	216 dB	< 0.1 km^2	< 0.1 km^2	-
	210 dB	< 0.1 km^2	< 0.1 km^2	-
	207 dB	< 0.1 km^2	< 0.1 km^2	-
	203 dB	< 0.1 km^2	< 0.1 km^2	-
	186 dB	630 km^2	180 km^2	1300 km^2
Stationary	219 dB	9.3 km^2	5.3 km^2	15 km^2
	216 dB	22 km^2	11 km^2	33 km^2
	210 dB	96 km^2	45 km^2	140 km^2
	207 dB	180 km^2	82 km^2	270 km^2
	203 dB	390 km^2	160 km^2	560 km^2
	186 dB	3000 km^2	1500 km^2	3900 km^2

Table 4-37 Summary of the impact areas for the sequential installation of four jacketmonopile foundations using the worst-case monopile jacket parameters at each of the E and W modelling locations for fish using the Popper et al. (2019) SEL_{cum} impact piling criteria assuming both a fleeing and stationary receptor

4.4 Impact on human divers, dB(UW)

The various ranges for which humans underwater would hear various levels to are presented below in Table 4-38.

Attenuation	13.5 m monopile; Maximum hammer energy (4,400 kJ); South location		
	90 dB(UW)/145 dB SPL Max Range	110 dB(UW) Max Range	130 dB(UW) Max Range
Unmitigated	39 km	7.2 km	500 m
PULSE Hammer (-6 dB)	27 km	3.4 km	300 m
MENCK MNRU Hammer (-9 dB)	22 km	2.2 km	200 m
Double Bubble Curtain (DBBC) (-16 dB)	12 km	900 m	<200 m
PULSE Hammer and DBBC (-22 dB)	5.7 km	400 m	<200 m
MNRU Hammer and DBBC (-25 dB)	3.9 km	300 m	<200 m

Table 4-38 Summary of the impact areas for worst-case monopile (South location) for 90 dB(UW) (loud); 110 dB(UW) (startle) and 130 dB(UW) (potential injury) (4,400kJ)

The maximum ranges modelled for the three criteria presented in Table 4-38 are based on the maximum design scenario of 4,400 kJ hammer and 13.5m diameter monopile foundation. Ranges presented reflect unmitigated values to set the worst-case, along with the propagation distance reductions predicted arising from the application of example of noise mitigation measures that are considered for use at Rampion 2. The ranges presented are based on the worst-case piling location (South) and based on the initial energy blows from the 4400 kJ hammer during the soft-start procedure.

Table 4-39 presents ranges modelled for the same criteria at the commencement of piling, when a soft-start protocol will be adopted.

Attenuation	13.5 m monopile; initial soft start blow (880 kJ); South location		
	90 dB(UW)/145 dB SPL Max Range	110 dB(UW) Max Range	130 dB(UW) Max Range
Unmitigated	25 km	3.0 km	300 m
PULSE Hammer (-6 dB)	15.3 km	1.3 km	200 m
MENCK MNRU Hammer (-9 dB)	11.3 km	0.8 km	100 m
Double Bubble Curtain (DBBC) (-16 dB)	5.0 km	0.3 km	<100m
PULSE Hammer and DBBC (-22 dB)	2.2 km	0.13 km	<100m
MNRU Hammer and DBBC (-25 dB)	1.4 km	0.10 km	<100m

Table 4-39 Summary of the impact areas for worst-case monopile (South location) for 90 dB(UW) (loud); 110 dB(UW) (startle) and 130 dB(UW) (potential injury) (880kJ)

The use of the hammer blow energy on commencement of soft start has been adopted in the assessment as the risk of startle will be greatest at the commencement of piling, when a diver who may be in the vicinity would suddenly and unexpectedly be exposed to the noise.

5 Other noise sources

Although impact piling is expected to be the primary noise source during offshore wind farm construction and development (Bailey *et al.*, 2014), several other anthropogenic noise sources may be present. Each of these has been considered, and relevant biological noise criteria presented, in this section.

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 Rampion 2.

Activity	Description
Cable laying	Noise from the cable laying vessel and any other associated noise during the offshore cable installation.
Dredging	Dredging may be required on site for seabed preparation work for certain foundation options, as well as for the export cable, array cable and interconnector cable installation. Suction dredging has been assumed as a worst-case
Trenching	Plough trenching may be required during offshore cable installation.
Rock placement	Potentially required on site for installation of offshore cables (cable crossings and cable protection) and scour protection around foundation structures.
Vessel noise	Jack-up barges for piling substructure and WTG installation. Other large and medium sized vessels on site to carry out other construction tasks, and anchor handing. Other small vessel for crew transport and maintenance on site.
Operational WTG	Noise transmitted through the water from operation WTG. The project design envelope gives turbines with capacities of between 10 and 18 MW.
UXO detonation	Unexploded Ordnance (UXO) has been identified with the boundaries of Rampion 2, which need to be cleared before construction can begin.

Table 5-1 Summary of the possible noise making activities at Rampion other than impact piling

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 acceptable. Such an approach has been used for these noise sources, which are variously either quiet compared to impact piling (e.g., cable laying and dredging), or where detailed modelling would imply unjustified accuracy (e.g., where data is limited such as with large operation WTG noise or UXO detonation). 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 model at this stage. The limitations of this approach are noted, including the lack of frequency or bathymetric dependence.

5.1 Noise making activities

For the purposes of identifying the greatest noise levels, 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 site and to the specific noise sources to be used. The calculation of underwater noise transmission loss for the non-impulsive sources is based on an empirical analysis of the noise measurements taken along transects around these sources by Subacoustech. The predictions use the following principle fitted to the measured data, where R is the range from the source in metres, N is the transmission loss, and α is the absorption loss.

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

The measured noise level and its transmission loss are affected not only by the environment, but also the size of the overall source, the location of the actual source within the structure (e.g. the position of an engine on a vessel) and its orientation.

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 SEL_{cum} criteria use the same assumptions as presented in section 2.2.1, and ranges smaller than 50 m (single strike) and 100 m (cumulative) have not been presented. It should be noted that this modelling approach does not take bathymetry or any other environmental conditions into account, and as such can be applied to any location in the Rampion 2 area. Noise from operational WTGs and UXO clearance have been reviewed separately in sections 5.2 and 5.3 respectively.

Source	Estimated unweighted source level	Approximate transmission loss	Comments
Cable laying	171 dB re 1 µPa @ 1 m (RMS)	$-13 \log_{10} R$ (no absorption)	Based on 11 datasets from a pipe laying vessel measuring 300 m in length; this is considered a worst-case noise source for cable laying operations
Suction Dredging	186 dB re 1 µPa @ 1 m (RMS)	$-19 \log_{10} R - 0.0009R$	Based on five datasets from suction and cutter suction dredgers
Trenching	172 dB re 1 µPa @ 1 m (RMS)	$-13 \log_{10} R - 0.0004R$	Based on three datasets of measurements from trenching vessels more than 100 m in length

Rock placement	172 dB re 1 μPa @ 1 m (RMS)	$-12\log_{10}R - 0.0005R$	Based on four datasets from rock placement vessel '*Rollingstone'*
Vessel noise (large)	168 dB re 1 μPa @ 1 m (RMS)	$-12\log_{10}R - 0.0021R$	Based on five datasets of large vessels including container ships, FPSOs and other vessels more than 100 m in length. Vessel speed assumed as 10 knots.
Vessel noise (medium)	161 dB re 1 μPa @ 1 m (RMS)	$-12\log_{10}R - 0.0021R$	Based on three datasets of moderate sized vessels less than 100 m in length. Vessel speed assumed as 10 knots

Table 5-2 Summary of the estimated unweighted source levels and transmission losses for the different construction noise sources considered

For SEL_{cum} calculations, the duration the noise is present also needs to be considered, with all sources operating for a worst-case 12 hours in any given 24-hour period apart from vessel noise which is assumed to be present for 24 hours a day.

To account for the weightings required for modelling using the Southall *et al*. (2019) criteria (section 2.2.1.1), reductions in source level have been applied to the various noise sources. Table 5-1 shows the representative noise measurements used, adjusted for the source levels in Table 5-2. Table 5-3 presents details of the reductions in source levels for each of the weightings used for modelling.

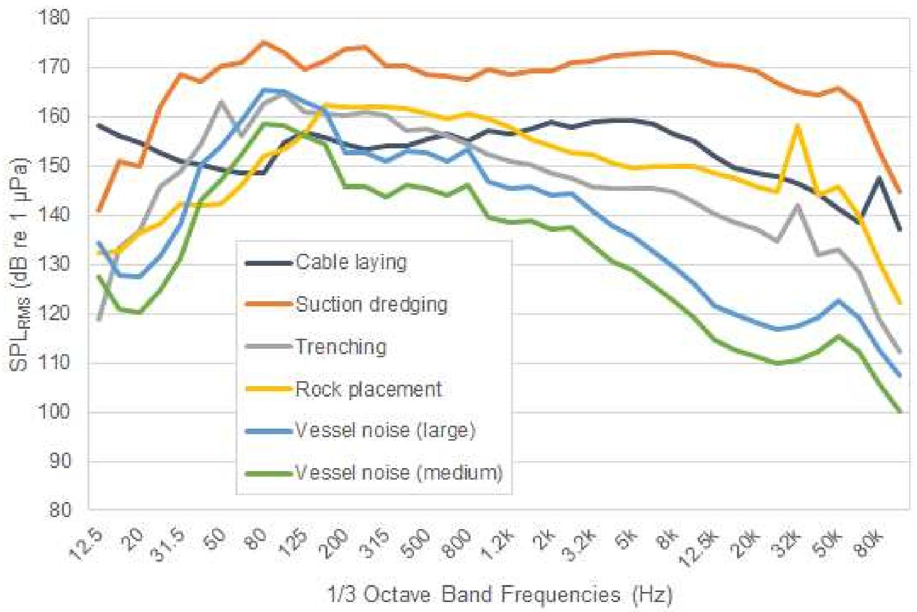


Figure 5-1 Summary of the 1/3 octave frequency bands used as a basis for the Southall et al. (2019) weightings used in the simple modelling

Source	Reduction in source level from the unweighted level			
	LF	HF	VHF	PCW
Cable laying	3.6 dB	22.9 dB	23.9 dB	13.2 dB
Suction Dredging	2.5 dB	7.9 dB	9.6 dB	4.2 dB
Trenching	4.1 dB	23.0 dB	25.0 dB	13.7 dB
Rock placement	1.6 dB	11.9 dB	12.5 dB	8.2 dB
Vessel noise	5.5 dB	34.4 dB	38.6 dB	17.4 dB

Table 5-3 Reductions in source level for the difference construction noise sources considered when the Southall et al. (2019) weightings are applied

Table 5-4 and Table 5-5 summarise the predicted impact ranges for these noise sources. It is worth noting that Southall *et al*. (2019) and Popper *et al*. (2014) both give alternative criteria for non-impulsive or continuous noise sources compared to impulsive noise (see section 2.2.1); all sources in this section are considered non-pulse or continuous.

Given the modelled impact ranges, any marine mammal would have to be less than 100 m from the continuous noise source at the start of the activity, in most cases, to acquire the necessary exposure to induce PTS as per Southall *et al*. (2019). The exposure calculation assumes the same receptor swim speed as the impact piling modelling in section 4. As explained in section 3.2.3, it should also be noted that this would only mean that 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 low enough that there is negligible risk.

For fish, there is a low to negligible risk of any injury or TTS in line with the SPL_{RMS} guidance for continuous noise sources in Popper *et al*. (2014).

All sources presented here are much quieter than those presented for impact piling in section 4.

Southall *et al.* (2019) Weighted SEL_{cum}		Cable laying	Suction dredging	Trenching	Rock placem't	Vessel (large)	Vessel (med)
PTS	199 dB (LF)	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
	198 dB (HF)	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
	173 dB (VHF)	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
	201 dB (PCW)	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
TTS	179 dB (LF)	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
	178 dB (HF)	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m
	153 dB (VHF)	< 100 m	200 m	< 100 m	1.0 km	200 m	< 100 m
	181 dB (PCW)	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m	< 100 m

Table 5-4 Summary of the impact ranges for the different construction noise sources using the non-impulsive criteria from Southall et al. (2019) for marine mammals

Popper *et al.* (2014) Unweighted SPL_{RMS}	Cable laying	Suction dredging	Trenching	Rock placem't	Vessel (large)	Vessel (med)
Recoverable Injury 170 dB (48 hours)	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m
TTS 158 dB (12 hours)	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m

Table 5-5 Summary of the impact ranges for fish from Popper et al. (2014) for shipping and continuous noise, covering the different noise sources

5.2 Operational WTG noise

The main source of underwater noise from operational WTGs will be mechanically generated vibration from the rotating machinery in the turbines, which is transmitted into the sea through the structure of the turbine tower and foundations (Nedwell *et al.*, 2003). Noise levels generated above the water surface are low enough that no significant airborne sound will pass from the air to the water.

A summary of sites where operational WTG measurements have been collected is given in Table 5-6.

Wind farm	Lynn	Inner Dowsing	Gunfleet Sands 1 & 2	Gunfleet Sands 3
Type of turbine used	Siemens SWT-3.6-107	Siemens SWT-3.6-107	Siemens SWT-3.6-107	Siemens SWT-6.0-120
Number of turbines	27	27	48	2
Power rating	3.6 MW	3.6 MW	3.6 MW	6 MW
Rotor diameter	107 m	107 m	107 m	120 m
Water depths	6 to 8 m	6 to 14 m	0 to 15 m	5 to 12 m
Representative sediment type	Sandy gravel / muddy sandy gravel	Sandy gravel / muddy sandy gravel	Sand / muddy sand / muddy sandy gravel	Sand / muddy sand / muddy sandy gravel
Turbine separation	500 m	500 m	890 m	435 m

Table 5-6 Characteristics of measured operational WTGs used as a basis for modelling

The estimation of the effects of operational WTG noise in these situations has two features that make it harder to predict compared with noise sources such as impact piling. Primarily, the problem is one of level; noise measurements made at many operational wind farms have demonstrated that the operational noise produced was at such a low level that it was difficult to measure relative to background noise at distances of a few hundred metres (Cheesman, 2016). Secondly, the multiple turbines of an offshore wind farm could be considered as an extended, distributed noise source, as opposed to a “point source,” as would be appropriate for piling driving at a single location for example. The measurement techniques used at the sites above have dealt with these issues by considering the operational WTG noise spectra in terms of levels within and on the edge of the wind farm (but relatively close to the turbines, so that some noise above background can be detected).

The turbine sizes for modelling at Rampion 2 are larger than those shown in Table 5-6, with turbines between 10 and 18 MW being considered. The Rampion 2 site is also situated in greater water depths, and as such, estimations of a scaling factor must be conservative to minimise the risk of underestimating the noise. However, it is recognised that the available data on which to base the scaling factor is limited and the extrapolation that must be made is significant.

The operational source levels (as SPL_{RMS}) for the measured sites are given in Table 5-7 (Cheesman, 2016), with estimated source levels for Rampion 2 at the bottom of the table. To predict operational WTG noise levels at Rampion 2, the extrapolated source level from the measured data at each of the sites has been taken and then a linear correction factor has been included to scale up the source levels (Figure 5-2). A linear fit was applied to the data to keep conservatism in the extrapolation and to take account of the deeper water depths, leading to the highest, and thus worst-case, estimation of sources level noise from the larger turbines. This resulted in estimated source levels of 151.6 dB re 1 µPa (SPL$_{RMS}$) @ 1 m for a 10 MW WTG and 162.7 dB re 1 µPa (SPL$_{RMS}$) @ 1 m for 18 MW WTGs; 5.6 and 16.7 dB higher, respectively, than the 6 MW turbines for which measurements were available.

Site	Unweighted source level
Lynn (3.6 MW)	141 dB re 1 µPa (SPL$_{RMS}$) @ 1 m
Inner Dowsing (3.6 MW)	142 dB re 1 µPa (SPL$_{RMS}$) @ 1 m
Gunfleet Sands 1 & 2 (3.6 MW)	145 dB re 1 µPa (SPL$_{RMS}$) @ 1 m
Gunfleet Sands 3 (6 MW)	146 dB re 1 µPa (SPL$_{RMS}$) @ 1 m
Rampion 2 (10 MW)	151.6 dB re 1 µPa (SPL$_{RMS}$) @ 1 m
Rampion 2 (18 MW)	162.7 dB re 1 µPa (SPL$_{RMS}$) @ 1 m

Table 5-7 Measured operational WTG noise taken at operational wind farms, and the predicted source level for the turbine sizes considered at Rampion 2

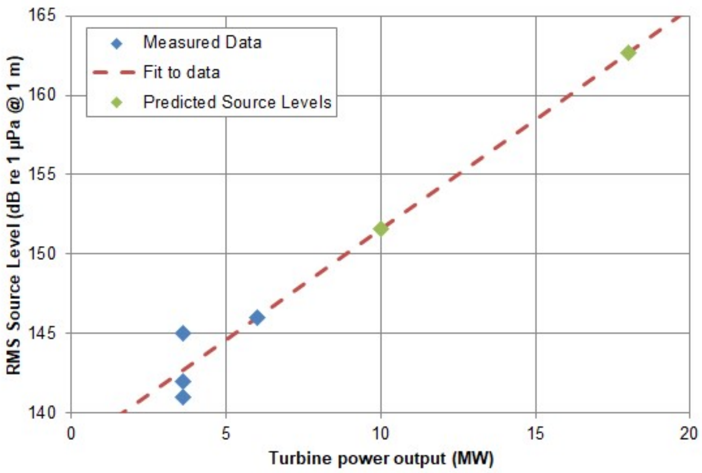


Figure 5-2 Extrapolated source levels from operational WTGs plotted with a linear fit to estimated the source levels for 10 to 18 MW WTGs

It is acknowledged that this fit is speculative: the available data is very limited. Newer, larger, direct drive (gearbox-less) designs tend to be more efficient and losses (e.g. in energy which produce noise and vibration) are significantly reduced. Preliminary measurements of such direct-drive WTGs have been collected off the east coast of the United States (HDR, 2019), showing extrapolated source levels of 136 dB re 1 µPa (SPL$_{RMS}$) @ 1 m for a 6 MW turbine. Thus, the linear extrapolation represents a considerably greater noise output and can be considered conservative.

A summary of the predicted impact ranges is given in Table 5-8 and Table 5-9. All SEL_{cum} criteria use the same assumptions as presented in section 2.2.1, and ranges smaller than 50 m (single strike) and 100 m (cumulative) have not been presented. The operational WTG source is considered a non-impulsive sound by Southall *et al*. (2010) and a continuous source by Popper *et al*. (2014). For SEL_{cum} calculations it has been assumed that the operational WTG noise is present 24 hours a day and a receptor remains stationary in the vicinity for the duration.

Southall *et al*. (2019)		**Operational WTG (10 MW)**	**Operational WTG (18 MW)**
PTS Weighted SEL_{cum}	199 dB (LF)	< 100 m	< 100 m
	198 dB (HF)	< 100 m	< 100 m
	173 dB (VHF)	< 100 m	< 100 m
	201 dB (PCW)	< 100 m	< 100 m
TTS Weighted SEL_{cum}	179 dB (LF)	< 100 m	150 m
	178 dB (HF)	< 100 m	< 100 m
	153 dB (VHF)	< 100 m	440 m
	181 dB (PCW)	< 100 m	< 100 m

Table 5-8 Summary of the impact range for the proposed operational WTGs using the non-impulsive noise criteria from Southall et al. (2019) for marine mammals using a stationary animal model

Popper *et al*. (2014)	**Operational WTG (10 MW)**	**Operational WTG (18 MW)**
Recoverable injury 170 dB (48 hours), Unweighted SPL_{RMS}	< 100 m	< 100 m
TTS 158 dB (12 hours), Unweighted SPL_{RMS}	< 100 m	< 100 m

Table 5-9 Summary of the impact ranges for the proposed operational WTGs using the continuous noise criteria from Popper et al. (2014) for fish (swim bladder involved in hearing)

These results show that, for noise from operational WTGs, injury risk is minimal, with only TTS ranges for LF and VHF cetaceans being calculated above 100 m, and importantly this assumes a stationary animal model over a full 24-hour period. This is a highly unlikely scenario; when the animal is able to move, these results are reduced to less than 100 m.

Taking the results from this and the previous section (5.1), and comparing them to the impact piling results in section 4 and Appendix A, it is clear that impact piling results in much greater noise levels and impact ranges, and hence should be considered the activity which has the potential to have the greatest effect during the construction and lifecycle of Rampion 2.

5.3 UXO clearance

Several UXO devices with a range of charge weights (or quantity of contained explosive) have been identified within the boundaries of the Rampion 2 site. These need to be cleared before any construction can begin. There are expected to be a variety of explosive types, many of which 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. A selection of explosive sizes have been considered based on what has been found at similar sites and, in each case, it has been assumed that the maximum explosive charge in each device is present and detonates with the clearance.

5.3.1 Estimation of underwater noise levels

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 in 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 it will affect the sound produced by detonation, are usually unknown and cannot be directly considered in this type of assessment. 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.

The consequence is that the noise levels produced, particularly by the larger explosives under consideration, are likely to be over-estimated as some degree of degradation would be expected.

The range of equivalent charge weights for the potential UXO devices that could be present at Rampion 2 have been estimated as 25, 55, 120, 240, and 525 kg. 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 (MTD) (1996).

5.3.2 Estimation of underwater noise propagation

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 SPL_{peak}:

$$SPL_{peak} = 52.4 \times 10^6 \left(\frac{R}{W^{1/3}}\right)^{-1.13}$$

and for SEL_{ss}:

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

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

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 and Irish Seas in similar depths to those present at Rampion 2.

Despite this attenuation correction, the resulting noise levels still need to be considered carefully. For example, SPL_{peak} 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 equations above for small charges at ranges of less than 1 km, although the results do agree with measurements presented by von Benda-Beckmann *et al*. (2015). At these larger ranges, greater confidence is expected with the SEL calculations compared to the SPL_{peak} calculations.

A further limitation in the Soloway and Dahl (2014) equations that must be considered 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.

Additionally, an impulsive wave tends to be smoother (i.e., the pulse becomes longer) over distance (Cudahy and Parvin, 2001), meaning that injurious potential of a wave at greater ranges 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 smoothing of the peak is less critical.

The selection of assessment criteria must also be considered in light of this; as discussed in section 2.2.1.1, the smoothing of the pulse at range means that a pulse may be considered a non-pulse at greater distance. This study has presented impact ranges for both impulsive and non-impulsive criteria, suggesting that, at greater ranges, it may be more appropriate to use the non-pulse criteria.

A summary of the unweighted UXO source levels calculated using the equations above are given in Table 5-10.

Charge weight	25 kg	55 kg	120 kg	240 kg	525 kg
SPL_{peak} source level	284.9	287.4	290.0	292.2	294.8

(dB re 1 μPa @ 1 m)					
SEL_{ss} source level (dB re 1 μPa^{2}s @ 1 m)	227.9	230.1	232.3	234.2	236.4

Table 5-10 Summary of the unweighted SPL_{peak} and SEL_{ss} source levels used for UXO modelling

5.3.3 Impact ranges

Table 5-11 to Table 5-14 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 2-9). A UXO detonation source is defined as a single pulse, and as such the SEL_{cum} criteria from Southall *et al*. (2019) have been given as SEL_{ss} in the tables below. Thus, fleeing animal assumptions do not apply.

Although the impact ranges presented in the following tables 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.

As with the previous sections, ranges smaller than 50 m have not been presented.

Southall *et al.* (2019) Unweighted SPL_{peak}		**25 kg**	**55 kg**	**120 kg**	**240 kg**	**525 kg**
PTS	219 dB (LF)	810 m	1.0 km	1.3 km	1.7 km	2.2 km
	230 dB (HF)	260 m	340 m	450 m	560 m	730 m
	202 dB (VHF)	4.6 km	6.0 km	7.7 km	9.8 km	13 km
	218 dB (PCW)	900 m	1.1 km	1.5 km	1.9 km	2.5 km
TTS	213 dB (LF)	1.5 km	1.9 km	2.5 km	3.2 km	4.1 km
	224 dB (HF)	490 m	640 m	830 m	1.0 km	1.3 km
	196 dB (VHF)	8.5 km	11 km	14 km	18 km	23 km
	212 dB (PCW)	1.6 km	2.1 km	2.8 km	3.5 km	4.6 km

Table 5-11 Summary of the PTS and TTS impact ranges for UXO detonation using the impulsive, unweighted SPL_{peak} noise criteria from Southall et al. (2019) for marine mammals

Southall *et al.* (2019) Weighted SEL_{ss}		**25 kg**	**55 kg**	**120 kg**	**240 kg**	**525 kg**
PTS (Impulsive)	183 dB (LF)	2.1 km	3.2 km	4.6 km	6.5 km	9.5 km
	185 dB (HF)	< 50 m	< 50 m	< 50 m	< 50 m	50 m
	155 dB (VHF)	560 m	740 m	950 m	1.1 km	1.4 km
	185 dB (PCW)	380 m	560 m	830 m	1.1 km	1.6 km
TTS (Impulsive)	168 dB (LF)	29 km	41 km	57 km	76 km	103 km
	170 dB (HF)	150 m	210 m	300 m	390 m	530 m
	140 dB (VHF)	2.4 km	2.8 km	3.2 km	3.5 km	4.0 km
	170 dB (PCW)	5.2 km	7.4 km	11 km	14 km	20 km

Table 5-12 Summary of the PTS and TTS impact ranges for UXO detonation using the impulsive, weighted SEL_{ss} noise criteria from Southall et al. (2019) for marine mammals

Southall *et al.* (2019) Weighted SEL$_{ss}$		**25 kg**	**55 kg**	**120 kg**	**240 kg**	**525 kg**
PTS (Non-impulsive)	199 dB (LF)	120 m	190 m	280 m	390 m	570 m
	198 dB (HF)	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m
	173 dB (VHF)	< 50 m	< 50 m	70 m	100 m	130 m
	201 dB (PCW)	< 50 m	< 50 m	< 50 m	70 m	100 m
TTS (Non-impulsive)	179 dB (LF)	4.4 km	6.4 km	9.3 km	13 km	19 km
	178 dB (HF)	< 50 m	60 m	80 m	110 m	160 m
	153 dB (VHF)	730 m	940 m	1.1 km	1.4 km	1.7 km
	181 dB (PCW)	780 m	1.1 km	1.6 km	2.3 km	3.3 km

Table 5-13 Summary of the PTS and TTS impact ranges for UXO detonation using the non-impulsive, weighted SEL$_{ss}$ noise criteria from Southall et al. (2019) for marine mammals

Popper *et al.* (2014) Unweighted SPL$_{peak}$		**25 kg**	**55 kg**	**120 kg**	**240 kg**	**525 kg**
Mortality and potential mortal injury	234 dB	170 m	230 m	290 m	370 m	490 m
	229 dB	290 m	380 m	490 m	620 m	810 m

Table 5-14 Summary of the impact ranges for UXO detonation using the unweighted SPL$_{peak}$ explosion noise criteria from Popper et al. (2014) for species of fish.

The maximum PTS range calculated her for the largest, 525 kg TNT equivalent, UXO is 9.5 km for the LF cetacean category, based on the weighted SEL criteria. As explained earlier, this assumes no degradation of the UXO and no smoothing of the pulse over that 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-impulsive criteria is 570 m), 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 very precautionary.

6 Summary and conclusions

Subacoustech Environmental have undertaken a study on behalf of GoBe Consultants to assess potential underwater noise, and its effects, created during the construction and operation of the proposed Rampion 2 offshore wind farm.

The level of underwater noise from the installation of monopile and jacket foundations during construction has been estimated using the INSPIRE semi-empirical underwater noise model. The modelling considers a wide variety of input parameters including bathymetry, hammer blow energy, strike rate and receptor fleeing speed.

Three representative modelling locations were chosen to give spatial variation as well as accounting for changes in water depth around the site. At each location worst-case and most likely monopile and jacket foundations were considered. These are listed below.

- Worst-case monopile foundation – a 13.5 m diameter pile installed with a maximum blow energy of 4,400 kJ over 4.5 hours, with a maximum of two foundations installed in a single 24-hour period;
- Most likely monopile foundation – a 13.5 m diameter pile installed with a maximum blow energy of 4,000 kJ in just under 3 hours, with a maximum of two foundations installed in a single 24-hour period;
- Worst-case jacket foundation – a 4.5 m diameter pile installed with a maximum blow energy of 2,500 kJ over 4.5 hours, with a maximum of four foundations installed in a single 24-hour period; and
- Most likely jacket foundation – a 4.5 m diameter pile installed with a maximum blow energy of 2,000 kJ in just under 3 hours, with a maximum of four foundations installed in a single 24-hour period.

The loudest levels of noise and greatest impact ranges have been predicted for worst-case monopile foundations at the South and East locations. Smaller ranges are predicted at the North West and West locations due to the shallower water depths and proximity to the coastline, and for the most likely installation scenarios.

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

For marine mammals, maximum PTS ranges were predicted for LF cetaceans, with ranges up to 15 km when considering the worst-case monopile foundation scenario in the South location. For fish, the largest TTS ranges were predicted to be 25 km for a fleeing receptor, increasing to 44 km for a stationary receptor. A disturbance response may occur in fish out to a most precautionary 67 km from the source, based on reported values from Hawkins *et al.* (2014), although this is from a limited study under different conditions to those that will be present at the wind farm site, and should be treated with caution.

When comparing impact ranges for a single pile installation and sequential pile installations for these scenarios, the overall increase is negligible when considering a fleeing animal.

The potential effects on human divers in water has been assessed by using the dB(UW) metric. 130, 110 and 90 dB(UW) levels have been presented. The maximum range to which 130 dB(UW) level has been estimated to occur using the maximum hammer energy (4,400 kJ) and largest diameter monopile (13.5m) is 500 m (unmitigated). The greatest range at which a diver may be exposed to levels of 110 dB(UW) for 'startle' is 7,200 m for the same scenario and 39 km for the 90 dB(UW) threshold, again without the application of noise abatement techniques. All other modelled locations and pile sizes have a smaller impact range. Using the soft start commencement scenario, unmitigated ranges for 130 dB(UW), 110 dB(UW) and 90 dB(UW) were predicted to be 300m, 3000m, and 25 km respectively.. All other modelled locations and pile sizes have a smaller impact range.

Noise sources other than piling were considered using a high-level, simple modelling approach, including cable laying, suction dredging, trenching, rock placement, vessel noise and operational WTG noise. The predicted noise levels for these other construction noise sources and during WTG operation are well below those predicted for impact piling noise. The risk of any potentially injurious effects to fish or marine mammals from these sources are expected to be negligible as the noise emissions from these are close to, or below, the appropriate injury criteria when very close to the source of the noise.

UXO detonation has also been considered at the Rampion 2 site, and for the expected UXO detonation noise, there is a risk of PTS up to 9.5 km from the largest UXO considered, a 525 kg device using the impulsive Southall *et al*. (2019) criteria for LF cetaceans using SEL criteria, or 13 km for VHF cetaceans using SPL_{peak} criteria. However, this is likely to be very precautionary as the impact range is based on worst case criteria that do not account for any smoothing of the pulse over long ranges, which reduces the pulse peak and other characteristics of the sound that cause injury.

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

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Appendix A Additional results

A.1 Non-impulsive impact piling results

Following from the Southall et al. (2019) impact ranges presented in section 4.1 of the main report, Table A 1 to Table A 8 present the modelling results for non-impulsive criteria from impact piling noise at Rampion 2, as discussed in section 2.2.1.1. The predicted ranges are lower than the impulsive criteria presented in the main report.

Southall *et al.* (2019) Weighted SEL_{cum} (non-impulsive)		Worst-case monopile foundation – single pile							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	61 km^2	8.1 km	1.3 km	3.8 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	18 km^2	3.6 km	1.3 km	2.3 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
S	LF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	790 km^2	23 km	8.3 km	15 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	210 km^2	9.8 km	5.8 km	8.0 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	2.8 km^2	1.2 km	650 m	920 m
E	LF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	620 km^2	21 km	6.0 km	13 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	160 km^2	9.2 km	4.4 km	6.8 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	1.4 km^2	950 m	300 m	620 m
W	LF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	160 km^2	13 km	1.9 km	6.1 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	42 km^2	5.6 km	1.8 km	3.5 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	150 m	< 100 m	120 m

Table A 1 Summary of the impact ranges from the worst-case monopile foundation modelling at Rampion 2 for a single pile using the Southall et al. (2019) weighted SEL_{cum} non-impulsive criteria for marine mammals

Southall *et al.* (2019) Weighted SEL_{cum} (non-impulsive)		**Worst-case monopile foundation – 2 sequentially installed piles**							
		PTS				**TTS**			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	61 km^2	8.1 km	1.3 km	3.8 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	18 km^2	3.6 km	1.3 km	2.3 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
S	LF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	790 km^2	23 km	8.3 km	15 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	210 km^2	10 km	5.8 km	8.1 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	3.0 km^2	1.2 km	650 m	950 m
E	LF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	620 km^2	21 km	6.0 km	13 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	160 km^2	9.5 km	4.4 km	6.9 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	1.4 km^2	1.0 km	300 m	640 m
W	LF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	160 km^2	13 km	1.9 km	6.1 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	42 km^2	5.7 km	1.8 km	3.5 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	150 m	< 100 m	120 m

Table A 2 Summary of the impact ranges from the worst-case monopile foundation modelling at Rampion 2 for two sequentially installed piles using the Southall et al. (2019) weighted SEL_{cum} non-impulsive criteria for marine mammals

Southall *et al.* (2019) Weighted SELcum (non-impulsive)		Most likely monopile foundation – single pile							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	56 km²	7.7 km	1.2 km	3.6 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	16 km²	3.2 km	1.3 km	2.1 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
S	LF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	760 km²	22 km	8.2 km	15 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	180 km²	9.1 km	5.7 km	7.6 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	2.0 km²	950 m	600 m	780 m
E	LF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	590 km²	21 km	5.9 km	13 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	140 km²	8.4 km	4.3 km	6.4 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	0.9 km²	750 m	300 m	520 m
W	LF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	150 km²	13 km	1.8 km	5.9 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	36 km²	5.1 km	1.8 km	3.3 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	150 m	< 100 m	110 m

Table A 3 Summary of the impact ranges from the most likely monopile foundation modelling at Rampion 2 for a single pile using the Southall et al. (2019) weighted SEL_{cum} non-impulsive criteria for marine mammals

Southall *et al.* (2019) Weighted SEL_{cum} (non-impulsive)		**Most likely monopile foundation – 2 sequentially installed piles**							
		PTS				**TTS**			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	56 km^2	7.8 km	1.2 km	3.6 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	16 km^2	3.4 km	1.3 km	2.2 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
S	LF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	760 km^2	22 km	8.2 km	15 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	200 km^2	9.5 km	5.7 km	7.8 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	2.4 km^2	1.1 km	600 m	850 m
E	LF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	600 km^2	21 km	5.9 km	24 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	150 km^2	8.9 km	4.3 km	6.6 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	1.1 km^2	850 m	300 m	570 m
W	LF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	150 km^2	13 km	1.8 km	6.0 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	37 km^2	5.1 km	1.8 km	3.3 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	150 m	< 100 m	110 m

Table A 4 Summary of the impact ranges from the most likely monopile foundation modelling at Rampion 2 for two sequentially installed piles using the Southall et al. (2019) weighted SEL_{cum} non-impulsive criteria for marine mammals

Southall *et al.* (2019) Weighted SEL_{cum} (non-impulsive)		Worst-case jacket foundation – single pile							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	31 km²	6.0 km	750 m	2.6 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	9.4 km²	2.6 km	900 m	1.6 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
S	LF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	630 km²	20 km	7.4 km	14 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	150 km²	8.1 km	5.0 km	6.7 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	1.0 km²	750 m	350 m	560 m
E	LF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	480 km²	19 km	5.2 km	11 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	110 km²	7.6 km	3.7 km	5.6 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	0.4 km²	550 m	150 m	340 m
W	LF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	100 km²	11 km	1.3 km	4.9 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	25 km²	4.4 km	1.5 km	2.7 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m

Table A 5 Summary of the impact ranges from the worst-case jacket foundation modelling at Rampion 2 for a single pile using the Southall et al. (2019) weighted SEL_{cum} non-impulsive criteria for marine mammals

Southall *et al.* (2019) Weighted SEL_{cum} (non-impulsive)		Worst-case jacket foundation – 4 sequentially installed piles							
		PTS				**TTS**			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	31 km^2	6.0 km	750 m	2.6 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	9.6 km^2	2.7 km	900 m	1.7 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
S	LF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	630 km^2	20 km	7.4 km	14 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	150 km^2	8.3 km	5.0 km	6.8 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	1.1 km^2	800 m	350 m	580 m
E	LF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	480 km^2	19 km	5.2 km	11 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	110 km^2	7.8 km	3.7 km	5.7 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	0.4 km^2	550 m	150 m	310 m
W	LF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	100 km^2	11 km	1.3 km	4.9 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	26 km^2	4.4 km	1.5 km	2.8 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m

Table A 6 Summary of the impact ranges from the worst-case jacket foundation modelling at Rampion 2 for four sequentially installed piles using the Southall et al. (2019) weighted SEL_{cum} non-impulsive criteria for marine mammals

Southall *et al.* (2019) Weighted SELcum (non-impulsive)		Most likely jacket foundation – single pile							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	22 km²	5.1 km	550 m	2.2 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	6.0 km²	2.1 km	700 m	1.3 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
S	LF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	560 km²	19 km	7.0 km	13 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	110 km²	6.9 km	4.5 km	5.8 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	0.4 km²	450 m	200 m	320 m
E	LF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	420 km²	18 km	4.8 km	11 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	78 km²	6.3 km	3.3 km	4.9 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	0.1 km²	300 m	100 m	200 m
W	LF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	82 km²	9.8 km	1.1 km	4.3 km
	HF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km²	< 100 m	< 100 m	< 100 m	18 km²	3.5 km	1.3 km	2.3 km
	PCW Pinniped	< 0.1 km²	< 100 m	< 100 m	< 100 m	< 0.1 km²	< 100 m	< 100 m	< 100 m

Table A 7 Summary of the impact ranges from the most likely jacket foundation modelling at Rampion 2 for a single pile using the Southall et al. (2019) weighted SEL$_{cum}$ non-impulsive criteria for marine mammals

Southall *et al.* (2019) Weighted SEL_{cum} (non-impulsive)		Most likely jacket foundation – 4 sequentially installed piles							
		PTS				TTS			
		Area	Max	Min	Mean	Area	Max	Min	Mean
NW	LF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	22 km^2	5.1 km	550 m	2.2 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	6.4 km^2	2.2 km	700 m	1.3 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
S	LF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	560 km^2	19 km	7.0 km	13 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	120 km^2	7.3 km	4.5 km	6.1 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	0.4 km^2	500 m	200 m	340 m
E	LF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	420 km^2	18 km	4.8 km	11 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	85 km^2	6.8 km	3.3 km	5.1 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	0.2 km^2	400 m	100 m	220 m
W	LF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	82 km^2	9.9 km	1.1 km	4.4 km
	HF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m
	VHF Cetacean	< 0.1 km^2	< 100 m	< 100 m	< 100 m	19 km^2	3.8 km	1.3 km	2.4 km
	PCW Pinniped	< 0.1 km^2	< 100 m	< 100 m	< 100 m	< 0.1 km^2	< 100 m	< 100 m	< 100 m

Table A 8 Summary of the impact ranges from the most likely jacket foundation modelling at Rampion 2 for four sequentially installed piles using the Southall et al. (2019) weighted SEL_{cum} non-impulsive criteria for marine mammals

A.2 Multiple location modelling

Figure A 1 to Figure A 4 and Table A 9 to Table A 12 expand on the results presented in section 4.3 for multiple location piling, covering the non-impulsive criteria from Southall *et al*. (2019) for marine mammals. As before, contours too small to be seen at scale have not been included, impact ranges have not been presented as there are two starting points for receptors, and fields denoted with a dash "-" show where there is no in-combination effect when the two piles are installed simultaneously.

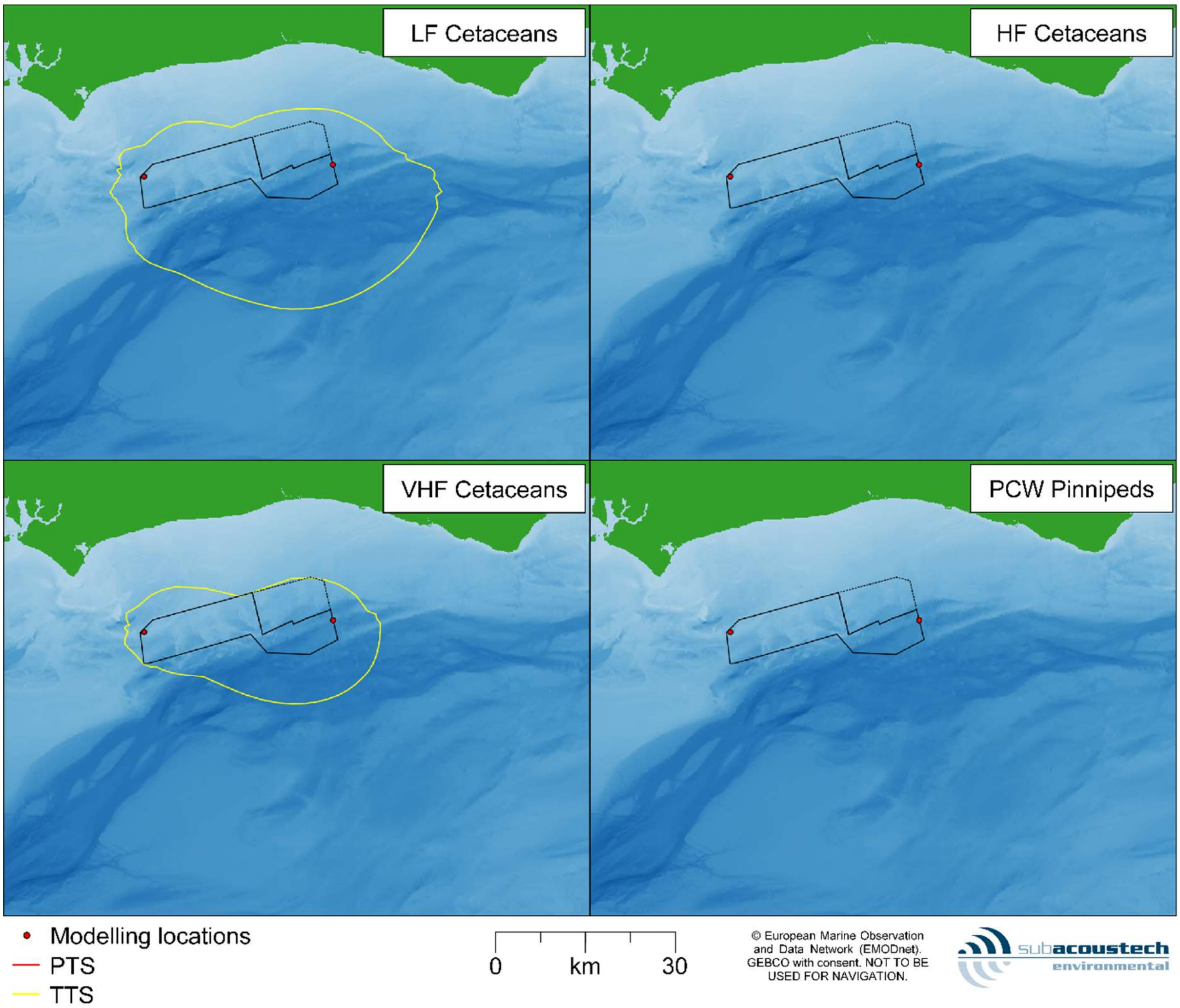

Figure A 1 Contour plots showing the in-combination impacts of simultaneous installation of worst-case monopile foundations (based on a single pile) at the E and W modelling locations for marine mammals using the Southall et al. (2019) non-impulsive criteria, assuming a fleeing receptor

Worst-case monopile foundation Southall *et al.* (2019) Weighted SEL_{cum}		**Single monopile**		
		E area	**W area**	**In-combination area**
PTS	LF (199 dB)	< 0.1 km^2	< 0.1 km^2	-
	HF (198 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (173 dB)	< 0.1 km^2	< 0.1 km^2	-
	PCW (201 dB)	< 0.1 km^2	< 0.1 km^2	-
TTS	LF (179 dB)	620 km^2	160 km^2	1400 km^2
	HF (178 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (153 dB)	160 km^2	42 km^2	660 km^2
	PCW (181 dB)	1.4 km^2	< 0.1 km^2	-

Table A 9 Summary of the impact areas for the installation of a single monopile foundation using the worst-case monopile parameters at the E and W modelling locations for marine mammals using the non-impulsive Southall et al. (2019) SEL_{cum} criteria assuming a fleeing receptor

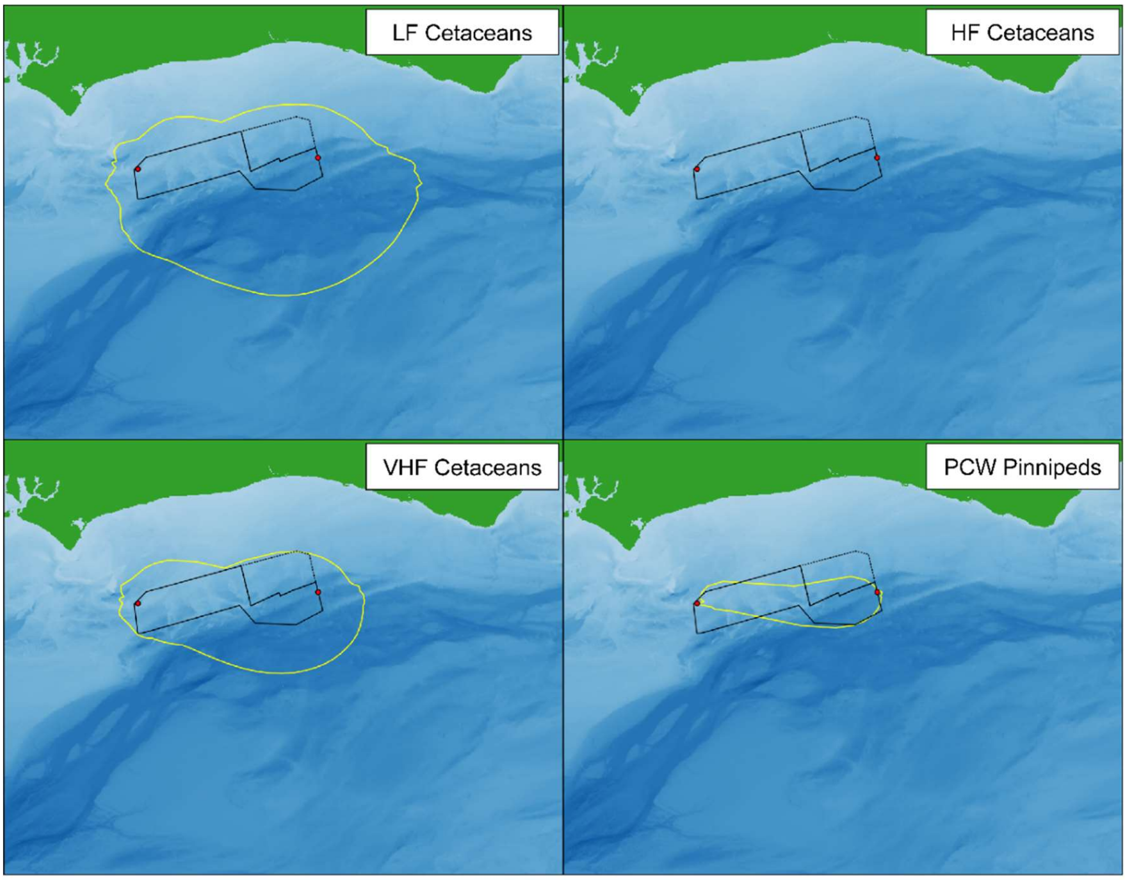

Figure A 2 Contour plots showing the in-combination impacts of simultaneous installation of worst-case monopile foundations (based on 2 piles installed sequentially) at the E and W modelling locations for marine mammals using the Southall et al. (2019) non-impulsive criteria, assuming a fleeing receptor

Worst-case monopile foundation Southall *et al.* (2019) Weighted SEL_{cum}		**2 sequentially installed monopiles**		
		E area	**W area**	**In-combination area**
PTS	LF (199 dB)	< 0.1 km^2	< 0.1 km^2	-
	HF (198 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (173 dB)	< 0.1 km^2	< 0.1 km^2	-
	PCW (201 dB)	< 0.1 km^2	< 0.1 km^2	-
TTS	LF (179 dB)	620 km^2	160 km^2	1400 km^2
	HF (178 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (153 dB)	160 km^2	42 km^2	680 km^2
	PCW (181 dB)	1.4 km^2	< 0.1 km^2	200 km^2

Table A 10 Summary of the impact areas for the sequential installation of two monopile foundations using the worst-case monopile parameters at each of the E and W modelling locations for marine mammals using the non-impulsive Southall et al. (2019) SEL_{cum} criteria assuming a fleeing receptor

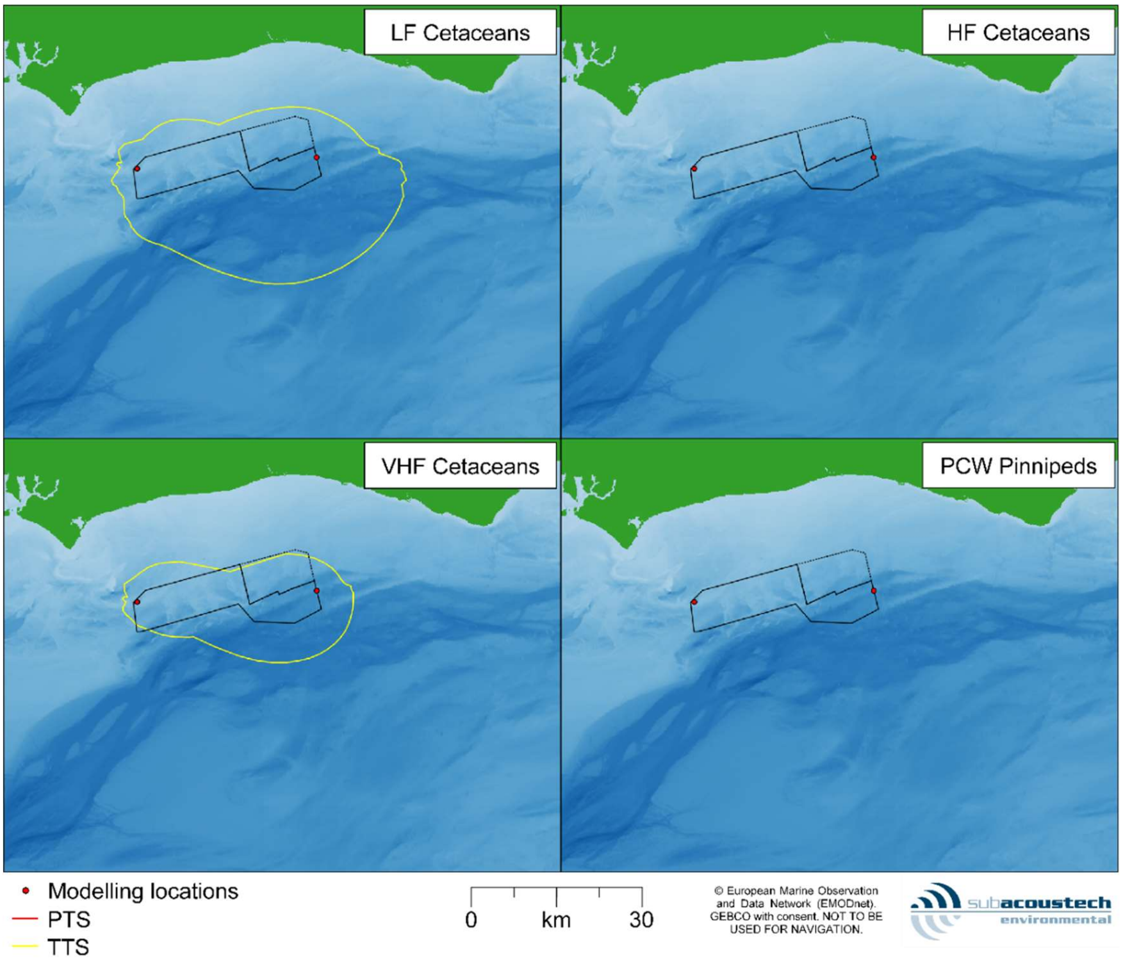

Figure A 3 Contour plots showing the in-combination impacts of simultaneous installation of worst-case jacket foundations (based on a single pile) at the E and W modelling locations for marine mammals using the Southall et al. (2019) non-impulsive criteria, assuming a fleeing receptor

Worst-case jacket pile foundation Southall *et al.* (2019) Weighted SEL_{cum}		**Single jacket pile**		
		E area	**W area**	**In-combination area**
PTS	LF (199 dB)	< 0.1 km^2	< 0.1 km^2	-
	HF (198 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (173 dB)	< 0.1 km^2	< 0.1 km^2	-
	PCW (201 dB)	< 0.1 km^2	< 0.1 km^2	-
TTS	LF (179 dB)	480 km^2	100 km^2	1200 km^2
	HF (178 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (153 dB)	110 km^2	25 km^2	560 km^2
	PCW (181 dB)	0.4 km^2	< 0.1 km^2	-

Table A 11 Summary of the impact areas for the installation of a single monopile foundation using the worst-case monopile parameters at the E and W modelling locations for marine mammals using the non-impulsive Southall et al. (2019) SEL_{cum} criteria assuming a fleeing receptor

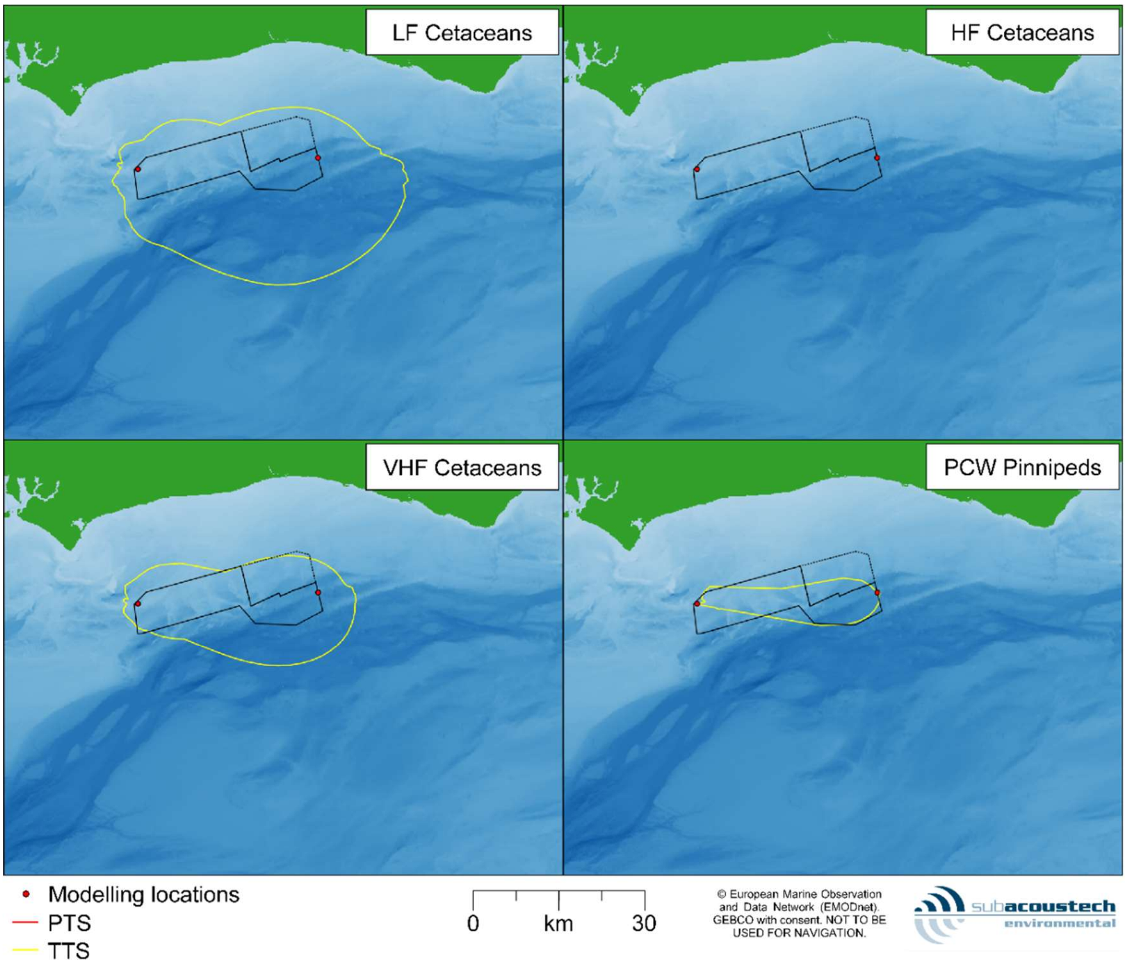

Figure A 4 Contour plots showing the in-combination impacts of simultaneous installation of worst-case monopile foundations (based on 2 piles installed sequentially) at the E and W modelling locations for marine mammals using the Southall et al. (2019) non-impulsive criteria, assuming a fleeing receptor

Worst-case jacket pile foundation Southall *et al*. (2019) Weighted SEL_{cum}		**4 sequentially installed jacket piles**		
		E area	**W area**	**In-combination area**
PTS	LF (199 dB)	< 0.1 km^2	< 0.1 km^2	-
	HF (198 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (173 dB)	< 0.1 km^2	< 0.1 km^2	-
	PCW (201 dB)	< 0.1 km^2	< 0.1 km^2	-
TTS	LF (179 dB)	460 km^2	100 km^2	1200 km^2
	HF (178 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (153 dB)	110 km^2	26 km^2	580 km^2
	PCW (181 dB)	0.5 km^2	< 0.1 km^2	170 km^2

Table A 12 Summary of the impact areas for the sequential installation of four monopile foundations using the worst-case monopile parameters at each of the E and W modelling locations for marine mammals using the non-impulsive Southall et al. (2019) SEL_{cum} criteria assuming a fleeing receptor

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P267R0100	02	11/02/2021	Initial writing and internal review.
P267R0101	01	01/03/2021	First issue to client, amendments following review, including adding Hawkins *et al.* (2014) results.
P267R0102	01	26/04/2021	Added new West modelling location.
P267R0103	03	20/06/2022	New East location following change to RLB, additional monopile modelling and simultaneous piling results added.
P267R0104	01	20/09/2022	Updates following changes to pile diameters.
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