Outer Dowsing Offshore Wind

Offshore Restricted Build Area and Revision to the Offshore Export Cable Corridor

Appendix C Underwater Noise Modelling Report

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Outer Dowsing Offshore Wind: Additional Modelling Results

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This report is a controlled document. The report documentation page lists the version number, record of changes, referencing information, abstract and other documentation details.

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Technical 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 micro pascal (μPa).
Peak pressure	The highest pressure above or below ambient 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 of permanent total or partial loss of hearing caused by acoustic trauma. PTS results in irreversible damage to the sensory hair cells of the ear, and thus a permanent reduction of hearing acuity.
Root Mean Square (RMS)	The square root of the arithmetic average of a set of squared instantaneous values. Used for presentation of an average sound pressure level.
Sound Exposure Level (SEL)	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, 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 Exposure Level, single strike (SEL_{ss})	Calculation of the sound exposure level representative of a single noise impulse, typically a pile strike.
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 temporary 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 level of TTS as exposure to lower levels of sound over longer time periods.
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. E.g. 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.

Acronyms

Acronym	Definition
EIA	Environmental Impact Assessment
HF	High-Frequency Cetaceans (Marine mammal hearing group from Southall *et al*., 2019)
INSPIRE	Impulse Noise Sound Propagation and Range Estimator (Subacoustech Environmental's noise model for estimating impact piling noise)
LF	Low-Frequency Cetaceans (Marine mammal hearing group from Southall *et al*., 2019)
NOAA	National Oceanic and Atmospheric Administration
ORBA	Offshore Restricted Build Area
PCW	Phocid Carnivores in Water (Marine mammal hearing group from Southall *et al*., 2019)
PTS	Permanent Threshold Shift
RMS	Root Mean Square
SEL	Sound Exposure Level
SEL_{cum}	Cumulative Sound Exposure Level
SEL_{ss}	Single Strike Sound Exposure Level
SPL	Sound Pressure Level
SPL_{peak}	Peak Sound Pressure Level
SPL_{RMS}	Root Mean Square Sound Pressure Level
TTS	Temporary Threshold Shift
VHF	Very High-Frequency Cetaceans (Marine mammal hearing group from Southall *et al*., 2019)
WTG	Wind Turbine Generator

Units

Unit	Definition
dB	Decibel (sound pressure)
kJ	Kilojoule (energy)
km	Kilometre (distance)
km^2	Square kilometres (area)
m	Metre (distance)
Pa	Pascal (pressure)
Pa^2s	Pascal squared seconds (acoustic energy)
µPa	Micropascal (pressure)

1 Introduction

Outer Dowsing Offshore Wind ("the Project") is a proposed offshore windfarm in the southern North Sea. As part of the Environmental Impact Assessment (EIA) process, Subacoustech Environmental Ltd. has undertaken detailed modelling and analysis in relation to the effect of underwater noise on marine mammals and fish at the Project.

Since completing the original modelling, the north edge of the Array has been designated an Offshore Restricted Build Area (ORBA), and, as such, the previously modelled NE location is no longer situated inside the area where Wind Turbine Generators (WTGs) or Offshore Platforms (OPs) will be installed.

Figure 1-1 shows the layout of the Project along with the updated modelling locations. This report presents the updated impact ranges for the new NE location and should be considered in parallel with the modelled results presented in the previous report.

All modelling undertaken has used the same model (INSPIRE v5.1), same parameters, same flee speeds, and the same impact criteria as the previous modelling report, with just the modelling location being altered.

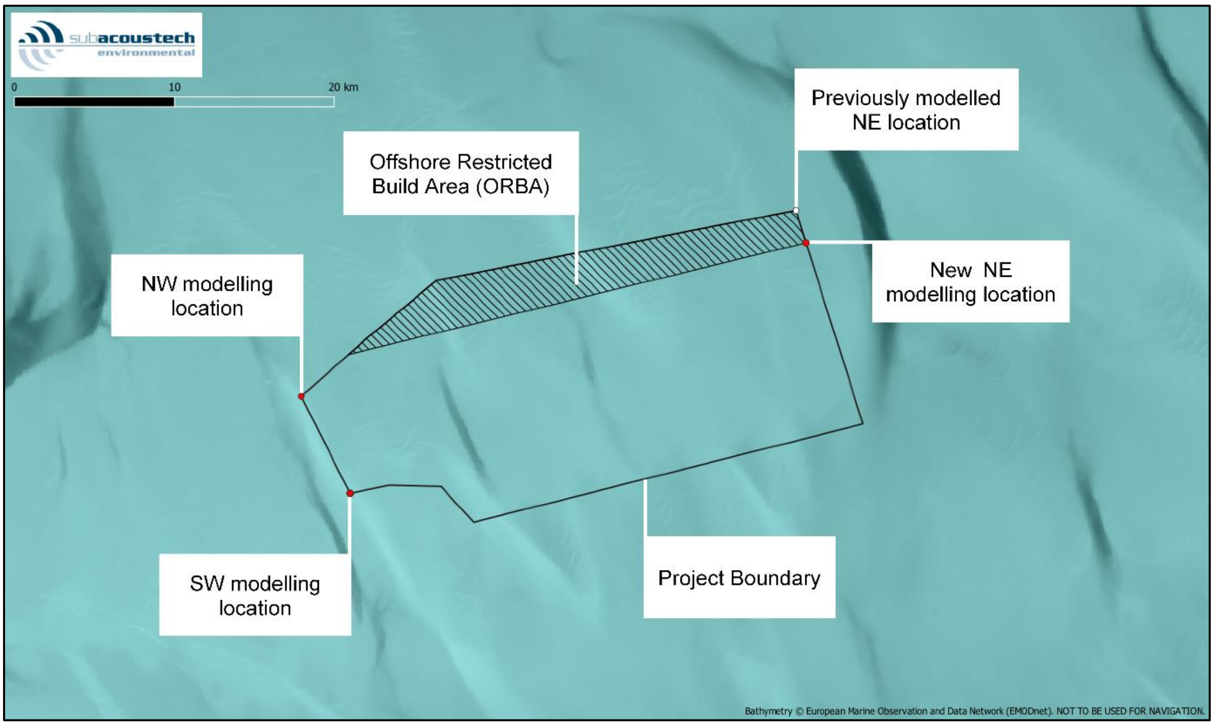

Figure 1-1 Overview map showing the Project boundary, ORBA, modelling locations and the surrounding bathymetry

2 Modelling parameters

Modelling for WTG and OP foundation impact piling has been undertaken at a single location on the edge of the ORBA. This location represents a small shift to the SSE of the of the location used in the ES and is identified in Figure 1-1 and detailed in Table 2-1.

The change in NE location means new modelling results for the single location modelling, as well as the multiple location modelling which considers simultaneous piling at the NE and SW corners of the Project.

Table 2-1 Summary of the updated noise modelling location used in this report

Modelling locations	Latitude	Longitude	Water Depth
Array - North East location (NE)	53.6355°N	001.4890°E	24.5 m

Two foundation scenarios have been considered to cover the worst cases in the Array for this study:

- A monopile foundation scenario, installing a 14 m diameter pile with a maximum blow energy of 6600 kJ, with up to two monopiles installed in a 24-hour period; and
- A jacket pile foundation scenario, installing a 5 m diameter pile with a maximum blow energy of 3500 kJ, with up to six piles installed in a 24-hour period.

For SEL_{cum} criteria the soft start and ramp up of the blow energies along with the total duration of piling and strike rate must also be considered. The scenarios used for modelling are summarised in Table 2-2 and Table 2-3. These are unchanged from the previous modelling.

Table 2-2 Summary of the soft start and ramp up scenario used for the monopile foundation modelling at the Array

Monopile foundation	**660 kJ**	**1650 kJ**	**3300 kJ**	**4950 kJ**	**6600 kJ**
Number of strikes	100	450	900	1350	7800
Duration	10 mins	15 mins	30 mins	45 mins	260 mins
Strike rate	10 blows/min	30 blows/min			
Single pile: 10600 strikes, 6 hours duration 2 piles: 21200 strikes, 12 hours duration					

Table 2-3 Summary of the soft start and ramp up scenario used for the jacket pile foundation modelling at the Array

Jacket pile foundation	**350 kJ**	**875 kJ**	**1750 kJ**	**2625 kJ**	**3500 kJ**
Number of strikes	100	450	900	900	4650
Duration	10 mins	15 mins	30 mins	30 mins	155 mins
Strike rate	10 blows/min	30 blows/min			
Single pile: 7000 strikes, 4 hours duration 6 piles: 42000 strikes, 24 hours duration					

2.1 Apparent source levels

As per the previous report, the unweighted, single strike SPL_{peak} and SEL_{ss} apparent source levels estimated for this study are provided in Table 2-4. These figures are presented in accordance with typical requirements by regulatory authorities, although as indicated above they are not necessarily compatible or comparable with any other model or predicted source level. In each case, the differences in apparent source level for each location are minimal.

Table 2-4 Summary of the unweighted apparent source levels used for modelling

Apparent source levels	**Location**	**Monopile foundation** 14 m / 6600 kJ	**Jacket pile foundation** 5 m / 3500 kJ
Unweighted SPL_{peak}	NE	243.1 dB re 1 µPa @ 1 m	242.0 dB re 1 µPa @ 1 m
Unweighted SEL_{ss}	NE	224.3 dB re 1 µPa²s @ 1 m	222.9 dB re 1 µPa²s @ 1 m

2.2 Predicted noise levels at 750 m from the noise source

In addition to the source levels given in section 2.1, it is useful to look at the potential noise levels at a range of 750 m from the noise source, which although not a requirement in the UK sector, is a common consideration for underwater noise studies at offshore wind farms. It has the added advantage of being comparable with other modelling or on-site measurements. A summary of the modelled unweighted levels at a range of 750 m are given in Table 2-5 considering the transect with the greatest noise transmission at each location while piling at the maximum hammer energy.

Table 2-5 Summary of the maximum predicted unweighted SPL_{peak} and SEL_{ss} noise levels at a range of 750 m from the noise source when considering maximum hammer blow energy

Predicted level at 750 m range	**Location**	**Monopile foundation** 14 m / 6600 kJ	**Jacket pile foundation** 5 m / 3500 kJ
Unweighted SPL_{peak}	NE	201.2 dB re 1 µPa	200.1 dB re 1 µPa
Unweighted SEL_{ss}	NE	183.0 dB re 1 µPa²s	181.6 dB re 1 µPa²s

3 Modelling results

This section presents the modelled impact ranges for impact piling noise at the updated NE location following the parameters detailed in section 2, covering the Southall *et al*. (2019) and NOAA (2005) marine mammal criteria and the Popper *et al*. (2014) fish criteria. These are detailed in the Underwater Noise Technical Appendix to the EIA.

The modelling results for concurrent piling are presented in section 3.2, and the Southall *et al*. (2019) non-impulsive criteria are presented in Appendix A.

For the results presented throughout this report any 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. At ranges this close to the noise source, the modelling processes are unable to model to a sufficient level of accuracy due to complex acoustic effects present near the pile. These ranges are given as “less than” this limit (e.g., “<100 m”).

3.1 Single location modelling

Table 3-1 to Table 3-10 present the modelling results for the monopile and jacket pile foundation modelling scenarios at the updated NE location, in terms of the Southall *et al.* (2019) and NOAA (2005) marine mammal criteria, and the Popper *et al*. (2014) fish criteria.

The largest marine mammal impact ranges are predicted for the monopile scenario, with maximum Permanent Threshold Shift (PTS) ranges of up to 5.0 km predicted for LF cetaceans using the SEL_{cum} criteria. For fish, the largest recoverable injury ranges (203 dB) are predicted to be 8.8 km assuming a stationary receptor for the six sequential jacket pile scenario. If a fleeing animal is assumed, these ranges reduce to less than 100 m. These ranges are slightly smaller than those predicted for the previous NE location due to the shallower water present at the updated modelling location.

Also presented are the predicted impact ranges for both a single pile installation and multiple sequentially installed piles in order to show the effect of multiple piles being installed in a 24-hour period. These show that, when considering a fleeing animal, there are minimal differences in predicted impact ranges due to the fleeing receptor being at a great distance at the start of the second pile installation and receiving only a very small additional sound exposure following the first pile. The effect is greater when a stationary model is under consideration.

3.1.1 Monopile foundations

Table 3-1 Summary of the unweighted SPL_{peak} impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the NE location

Southall *et al*. (2019) Unweighted SPL_{peak}		**Area**	**Maximum range**	**Minimum range**	**Mean range**
PTS	LF (219 dB)	0.01 km^2	< 50 m	< 50 m	< 50 m
	HF (230 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	VHF (202 dB)	1.0 km^2	580 m	570 m	570 m
	PCW (218 dB)	0.01 km^2	50 m	50 m	50 m
TTS	LF (213 dB)	0.04 km^2	110 m	110 m	110 m
	HF (224 dB)	< 0.01 km^2	< 50 m	< 50 m	< 50 m
	VHF (196 dB)	5.3 km^2	1.3 km	1.3 km	1.3 km
	PCW (212 dB)	0.05 km^2	130 m	130 m	130 m

Table 3-2 Summary of the weighted SEL_{cum} impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the NE location assuming a fleeing animal

Southall *et al*. (2019) Weighted SEL_{cum}			**Area**	**Maximum range**	**Minimum range**	**Mean range**
Single pile	**PTS**	LF (183 dB)	49 km²	5.0 km	3.2 km	3.9 km
		HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	22 km²	3.0 km	2.3 km	2.6 km
		PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	LF (168 dB)	720 km²	19 km	12 km	15 km
		HF (170 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	530 km²	16 km	11 km	13 km
		PCW (170 dB)	87 km²	6.3 km	4.5 km	5.2 km
2 sequential piles	**PTS**	LF (183 dB)	49 km²	5.0 km	3.2 km	3.9 km
		HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	22 km²	3.0 km	2.3 km	2.6 km
		PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	LF (168 dB)	720 km²	19 km	12 km	15 km
		HF (170 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	530 km²	16 km	11 km	13 km
		PCW (170 dB)	87 km²	6.3 km	4.5 km	5.3 km

Table 3-3 Summary of the unweighted SEL_{cum} impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the NE location assuming both a fleeing and stationary animal

Popper *et al*. (2014) Unweighted SEL_{cum}			**Area**	**Maximum range**	**Minimum range**	**Mean range**
Single pile	**Fleeing** (1.5 m/s)	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		186 dB	200 km²	9.7 km	6.6 km	7.9 km
	Stationary (0 m/s)	219 dB	1.8 km²	780 m	750 m	760 m
		216 dB	4.2 km²	1.2 km	1.1 km	1.2 km
		210 dB	19 km²	2.5 km	2.5 km	2.5 km
		207 dB	38 km²	3.6 km	3.4 km	3.5 km
		203 dB	89 km²	5.9 km	5.1 km	5.3 km
		186 dB	920 km²	20 km	15 km	17 km
2 sequential piles	**Fleeing** (1.5 m/s)	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		186 dB	200 km²	9.7 km	6.6 km	7.9 km
	Stationary (0 m/s)	219 dB	4.2 km²	1.2 km	1.2 km	1.2 km
		216 dB	9.2 km²	1.8 km	1.7 km	1.7 km
		210 dB	38 km²	3.6 km	3.4 km	3.5 km
		207 dB	73 km²	5.3 km	4.6 km	4.8 km
		203 dB	150 km²	7.8 km	6.5 km	7.0 km
		186 dB	1200 km²	23 km	17 km	20 km

Table 3-4 Summary of the unweighted SPL_{RMS} impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the monopile foundation modelling at the NE location

NOAA (2005) Unweighted SPL_{RMS}		**Area**	**Maximum range**	**Minimum range**	**Mean range**
Level B	160 dB	610 km²	16 km	12 km	14 km

Table 3-5 Summary of the unweighted SPL_{peak} impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the NE location

Popper *et al*. (2014) Unweighted SPL_{peak}	**Area**	**Maximum range**	**Minimum range**	**Mean range**
213 dB	0.04 km²	110 m	110 m	110 m
207 dB	0.24 km²	280 m	270 m	280 m

3.1.2 Jacket pile foundations

Table 3-6 Summary of the unweighted SPL_{peak} impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the NE location

Southall *et al*. (2019) Unweighted SPL_{peak}		**Area**	**Maximum range**	**Minimum range**	**Mean range**
PTS	LF (219 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	HF (230 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF (202 dB)	0.75 km²	490 m	490 m	490 m
	PCW (218 dB)	0.01 km²	< 50 m	< 50 m	< 50 m
TTS	LF (213 dB)	0.03 km²	100 m	90 m	90 m
	HF (224 dB)	< 0.01 km²	< 50 m	< 50 m	< 50 m
	VHF (196 dB)	4.0 km²	1.1 km	1.1 km	1.1 km
	PCW (212 dB)	0.04 km²	110 m	110 m	110 m

Table 3-7 Summary of the weighted SEL_{cum} impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the NE location assuming a fleeing animal

Southall *et al*. (2019) Weighted SEL_{cum}			**Area**	**Maximum range**	**Minimum range**	**Mean range**
Single pile	**PTS**	LF (183 dB)	21 km²	3.3 km	2.0 km	2.6 km
		HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	9.7 km²	2.0 km	1.6 km	1.8 km
		PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	LF (168 dB)	560 km²	17 km	10 km	13 km
		HF (170 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	420 km²	14 km	9.4 km	12 km
		PCW (170 dB)	65 km²	5.5 km	3.9 km	4.5 km
6 sequential piles	**PTS**	LF (183 dB)	21 km²	3.3 km	2.0 km	2.6 km
		HF (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (155 dB)	9.7 km²	2.0 km	1.6 km	1.8 km
		PCW (185 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	LF (168 dB)	560 km²	17 km	10 km	13 km
		HF (170 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (140 dB)	430 km²	14 km	9.4 km	12 km
		PCW (170 dB)	66 km²	5.5 km	3.9 km	4.6 km

Table 3-8 Summary of the unweighted SEL_{cum} impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the NE location assuming both a fleeing and stationary animal

Popper *et al*. (2014) Unweighted SEL_{cum}			**Area**	**Maximum range**	**Minimum range**	**Mean range**
Single pile	**Fleeing** (1.5 m/s)	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		186 dB	130 km²	8.0 km	5.4 km	6.5 km
	Stationary (0 m/s)	219 dB	0.7 km²	480 m	450 m	460 m
		216 dB	1.6 km²	730 m	700 m	710 m
		210 dB	8.2 km²	1.7 km	1.6 km	1.6 km
		207 dB	17 km²	2.4 km	2.3 km	2.3 km
		203 dB	42 km²	3.8 km	3.6 km	3.7 km
		186 dB	650 km²	16 km	12 km	14 km
6 sequential piles	**Fleeing** (1.5 m/s)	219 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		216 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		210 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		207 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		203 dB	< 0.1 km²	< 100 m	< 100 m	< 100 m
		186 dB	130 km²	8.1 km	5.4 km	6.5 km
	Stationary (0 m/s)	219 dB	6 km²	1.4 km	1.4 km	1.4 km
		216 dB	13 km²	2.1 km	2.0 km	2.0 km
		210 dB	50 km²	4.2 km	3.9 km	4.0 km
		207 dB	95 km²	6.1 km	5.2 km	5.5 km
		203 dB	190 km²	8.8 km	7.2 km	7.8 km
		186 dB	1400 km²	24 km	18 km	21 km

Table 3-9 Summary of the unweighted SPL_{RMS} impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the jacket pile foundation modelling at the NE location

NOAA (2005) Unweighted SPL_{RMS}		**Area**	**Maximum range**	**Minimum range**	**Mean range**
Level B	160 dB	520 km²	15 km	11 km	13 km

Table 3-10 Summary of the unweighted SPL_{peak} impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the NE location

Popper *et al*. (2014) Unweighted SPL_{peak}	**Area**	**Maximum range**	**Minimum range**	**Mean range**
213 dB	0.03 km²	100 m	90 m	90 m
207 dB	0.17 km²	240 m	230 m	230 m

3.2 Multiple location modelling

Using the monopile and jacket pile foundation piling scenarios, separately, modelling has been carried out for simultaneous piling at the SW and NE locations, representing a maximum geographical spread of locations. All modelling in this section assumes that the two piling operations start at the same time and that the maximum number of sequential piles are installed at each location. This means for the concurrent location monopile scenario, two piles are installed at each location and a total of four piles are installed in a 24-hour period. For the concurrent location jacket pile scenario, six piles are installed at each location resulting in a total of 12 piles installed in a 24-hour period.

Figure 3-1 to Figure 3-4 present contour plots for the multiple location piling scenarios alongside tables showing the increases in overall area (Table 3-11 to Table 3-14). 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 piling occurs at the two locations simultaneously, generally where the individual ranges are small enough that the distant site does not produce an influencing additional exposure. In the figures, contours that are too small to be seen clearly at the scale of the figures have not been included. In the impact range tables only areas are provided, as there is no individual single ‘impact range’ from multiple locations.

As with the other impact piling results, the non-impulsive criteria from Southall *et al*. (2019) have also been modelled and are presented in Appendix A.

3.2.1 *Monopile foundations*

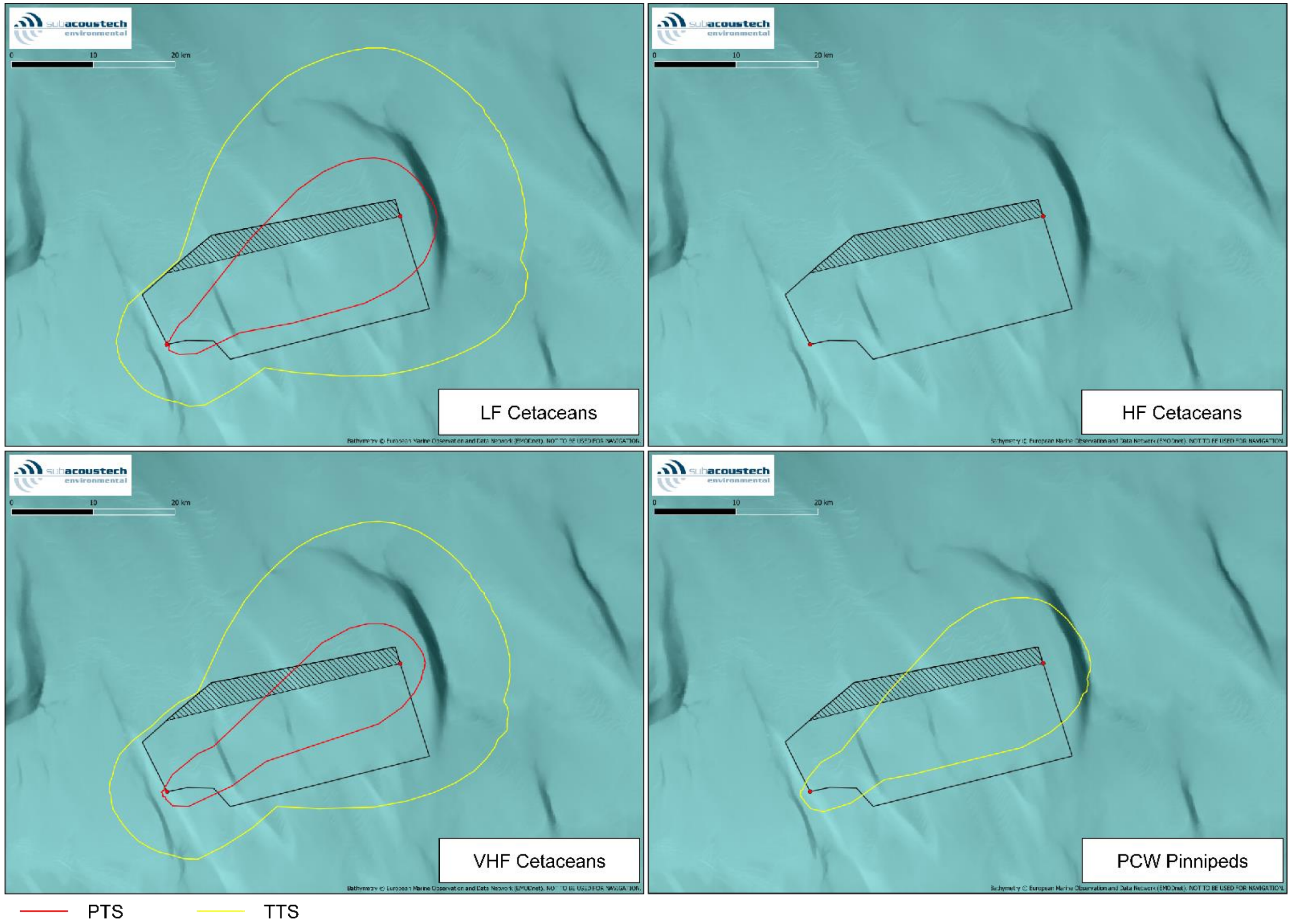

Figure 3-1 Contour plots showing the in-combination impacts of simultaneous installation of monopile foundations at the SW and NE modelling locations for marine mammals using the impulsive Southall et al. (2019) criteria assuming a fleeing animal

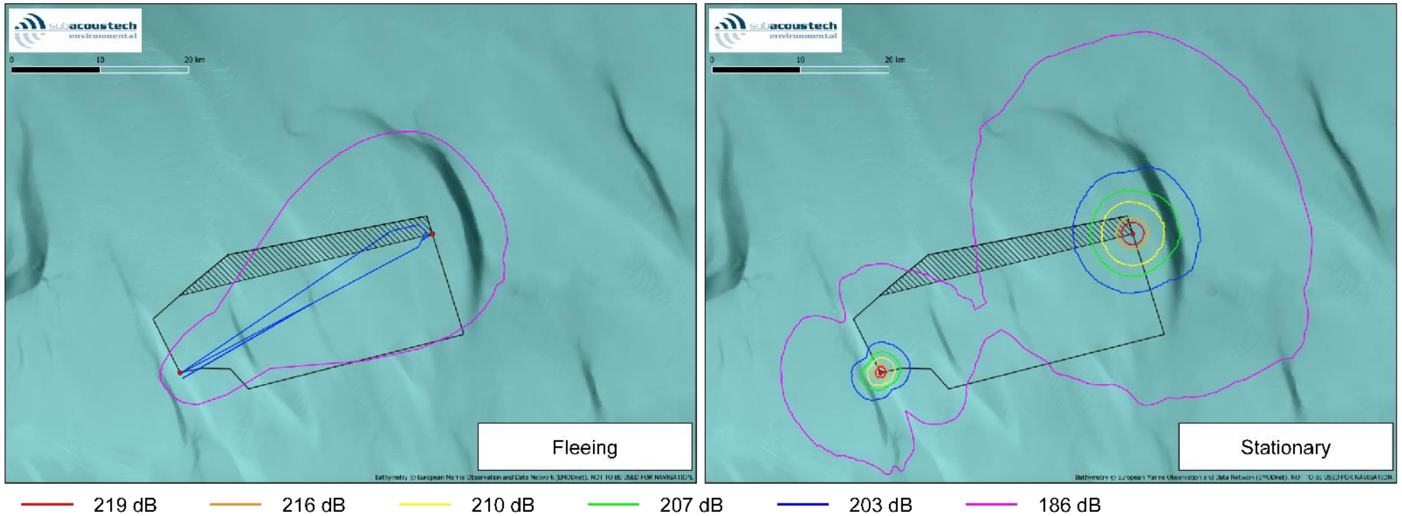

Figure 3-2 Contour plots showing the in-combination impacts of simultaneous installation of monopile foundations at the SW and NE modelling locations for fish using the Popper et al. (2014) impact piling criteria assuming both a fleeing and stationary animal

Table 3-11 Summary of the impact areas for the installation of monopile foundations at the SW and NE modelling locations for marine mammals using the impulsive Southall et al. (2019) SEL_{cum} criteria assuming a fleeing animal

Monopile foundation Southall *et al*. (2019) Weighted SEL_{cum}		**SW area**	**NE area**	**In-combination area**
PTS (Impulsive)	LF (183 dB)	< 0.1 km^2	49 km^2	400 km^2
	HF (185 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (155 dB)	0.9 km^2	22 km^2	280 km^2
	PCW (185 dB)	< 0.1 km^2	< 0.1 km^2	-
TTS (Impulsive)	LF (168 dB)	95 km^2	720 km^2	1500 km^2
	HF (170 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (140 dB)	130 km^2	530 km^2	1300 km^2
	PCW (170 dB)	3.1 km^2	87 km^2	450 km^2

Table 3-12 Summary of the impact areas for the installation of monopile foundations at the SW and NE modelling locations for fish using the Popper et al. (2014) SEL_{cum} impact piling criteria assuming both a fleeing and stationary animal

Monopile foundation Popper *et al*. (2014) Unweighted SEL_{cum}		**SW area**	**NE 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	51 km^2
	186 dB	12 km^2	200 km^2	680 km^2
Stationary (0 m/s)	219 dB	0.8 km^2	4.2 km^2	5.9 km^2
	216 dB	1.6 km^2	9.2 km^2	12 km^2
	210 dB	6.4 km^2	38 km^2	47 km^2
	207 dB	12 km^2	73 km^2	89 km^2
	203 dB	28 km^2	150 km^2	190 km^2
	186 dB	340 km^2	1200 km^2	1600 km^2

3.2.2 Jacket pile foundations

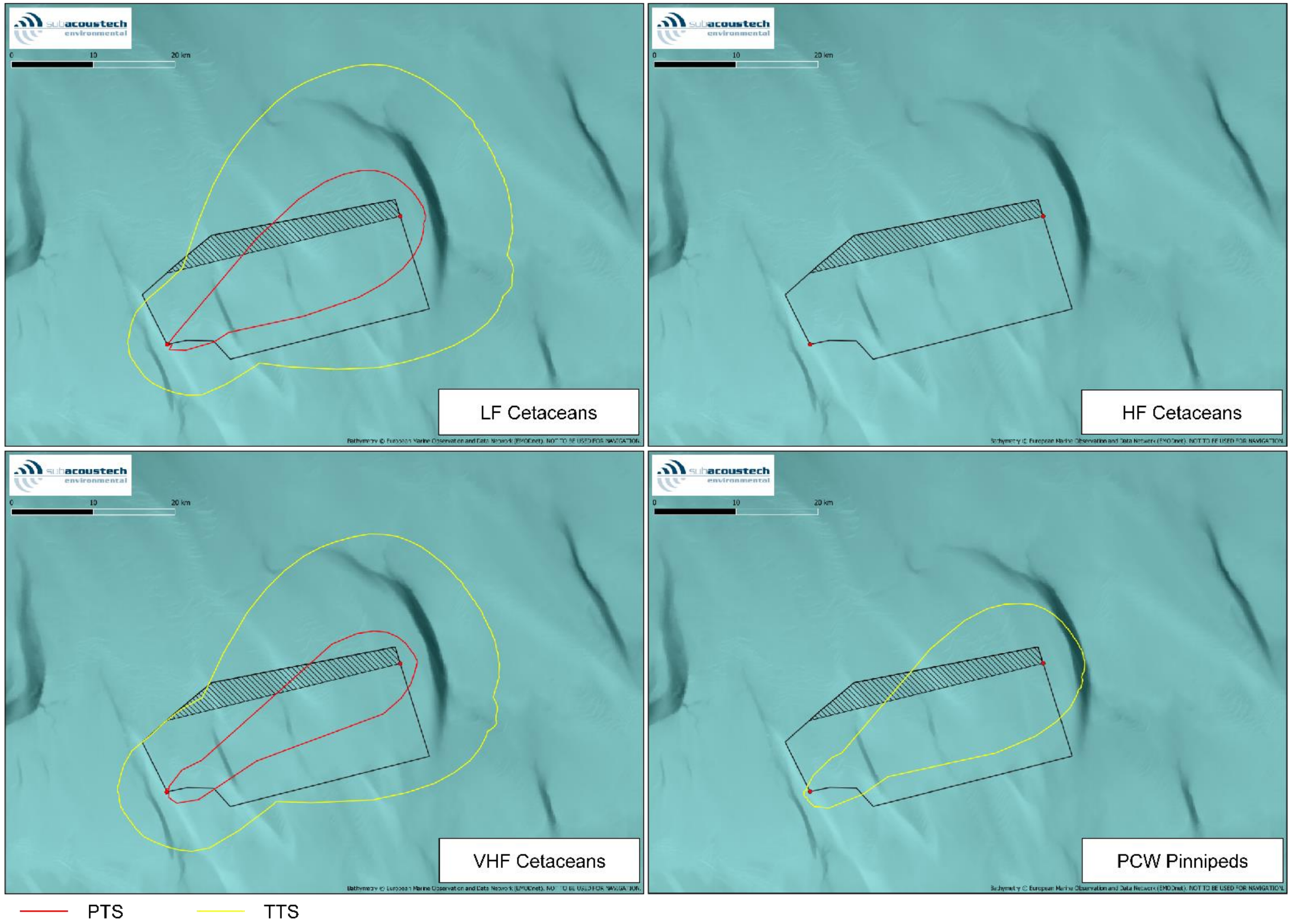

Figure 3-3 Contour plots showing the in-combination impacts of simultaneous installation of jacket pile foundations at the SW and NE modelling locations for marine mammals using the impulsive Southall et al. (2019) criteria assuming a fleeing animal

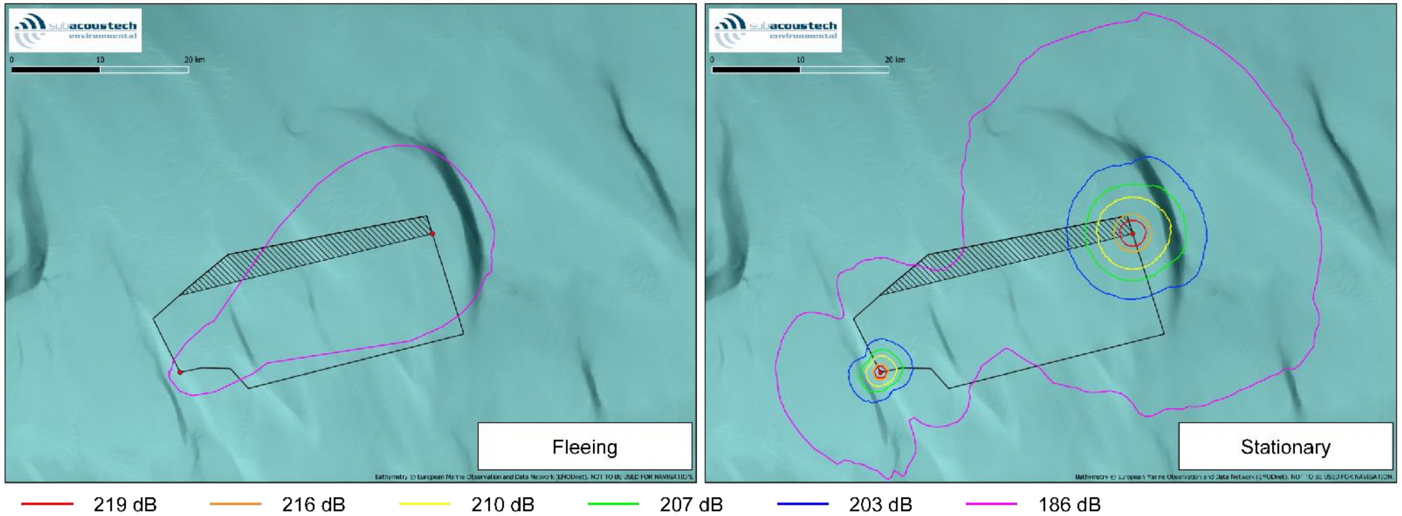

Figure 3-4 Contour plots showing the in-combination impacts of simultaneous installation of jacket pile foundations at the SW and NE modelling locations for fish using the Popper et al. (2014) impact piling criteria assuming both a fleeing and stationary animal

Table 3-13 Summary of the impact areas for the installation of jacket pile foundations at the SW and NE modelling locations for marine mammals using the impulsive Southall et al. (2019) SEL_{cum} criteria assuming a fleeing animal

Jacket pile foundation Southall *et al*. (2019) Weighted SEL_{cum}		**SW area**	**NE area**	**In-combination area**
PTS (Impulsive)	LF (183 dB)	< 0.1 km^2	21 km^2	330 km^2
	HF (185 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (155 dB)	< 0.1 km^2	9.7 km^2	220 km^2
	PCW (185 dB)	< 0.1 km^2	< 0.1 km^2	-
TTS (Impulsive)	LF (168 dB)	55 km^2	560 km^2	1300 km^2
	HF (170 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (140 dB)	92 km^2	430 km^2	1100 km^2
	PCW (170 dB)	1.2 km^2	66 km^2	410 km^2

Table 3-14 Summary of the impact areas for the installation of jacket pile foundations at the SW and NE modelling locations for fish using the Popper et al. (2014) SEL_{cum} impact piling criteria assuming both a fleeing and stationary animal

Jacket pile foundation Popper *et al*. (2014) Unweighted SEL_{cum}		**SW area**	**NE 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	3.4 km^2	130 km^2	570 km^2
Stationary (0 m/s)	219 dB	1.0 km^2	6.0 km^2	7.9 km^2
	216 dB	2.0 km^2	13 km^2	16 km^2
	210 dB	7.8 km^2	50 km^2	61 km^2
	207 dB	15 km^2	95 km^2	110 km^2
	203 dB	34 km^2	190 km^2	230 km^2
	186 dB	380 km^2	1400 km^2	1800 km^2

4 Summary and conclusions

Subacoustech Environmental have undertaken a study on behalf of GoBe Consultants to support the analysis of the potential underwater noise and its effects during the construction of the Project, located in the North Sea.

Due to the addition of an ORBA, the previously modelled NE location in the array has been moved, and additional modelling undertaken.

All modelling undertaken has used the same model (INSPIRE v5.1), same parameters, same flee speeds, and the same impact criteria as the previous modelling report, with just the modelling location being altered.

The ranges for the new location are slightly smaller than those predicted for the previous NE location due to the shallower water present at the updated modelling location for all modelled fish and marine mammal receptors.

The largest marine mammal impact ranges are predicted for the monopile scenario, with maximum PTS ranges of up to 5.0 km predicted for LF cetaceans using the SEL_{cum} criteria. For fish, the largest recoverable injury ranges (203 dB) are predicted to be 8.8 km assuming a stationary receptor for the six sequential jacket pile scenario, for a fleeing animal, these ranges reduce to less than 100 m.

The largest TTS impact ranges (186 dB) for fish are predicted for the six sequential jacket pile scenario, with maximum ranges of up 24 km predicted for stationary receptors. for fleeing receptors, these ranges reduce to 8.1 km.

References

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3. Southall, B. L., Bowles, A. E., Ellison, W. T., Finneran, J. J., Gentry, R. L., Green Jr., C. R., Kastak, D., Ketten, D. R., Miller, J. H., Nachtigall, P. E., Richardson, W. J., Thomas, J. A. and Tyack, P. L. (2007), 'Marine mammal noise exposure criteria: Initial scientific recommendations', Aquatic Mammals, 33 (4), pp 411-509.

Appendix A Non-impulsive results

Following from the Southall *et al*. (2019) modelled impact piling ranges presented in section 3 of the main report, the modelling results for non-impulsive criteria from impact piling noise at the Project, is presented below. The predicted ranges here fall well below the impulsive criteria presented in the main report.

A.1 Single location modelling

Table A 1 and Table A 2 present the modelling results considering single locations for the non-impulsive Southall *et al*. (2019) criteria.

Table A 1 Summary of the weighted SEL_{cum} impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at the NE location assuming a fleeing animal

Southall *et al*. (2019) Weighted SEL_{cum}			**Area**	**Maximum range**	**Minimum range**	**Mean range**
Single pile	**PTS**	LF (199 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		HF (198 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (173 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		PCW (201 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	LF (179 dB)	140 km²	8.4 km	5.3 km	6.6 km
		HF (178 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (153 dB)	43 km²	4.3 km	3.2 km	3.7 km
		PCW (181 dB)	0.1 km²	200 m	150 m	180 m
2 sequential piles	**PTS**	LF (199 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		HF (198 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (173 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		PCW (201 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	LF (179 dB)	140 km²	8.4 km	5.3 km	6.6 km
		HF (178 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (153 dB)	43 km²	4.3 km	3.2 km	3.7 km
		PCW (181 dB)	0.1 km²	200 m	150 m	180 m

Table A 2 Summary of the weighted SEL_{cum} impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the jacket pile foundation modelling at the NE location assuming a fleeing animal

Southall *et al*. (2019) Weighted SEL_{cum}			**Area**	**Maximum range**	**Minimum range**	**Mean range**
Single pile	**PTS**	LF (199 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		HF (198 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (173 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		PCW (201 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	LF (179 dB)	81 km²	6.6 km	4.0 km	5.0 km
		HF (178 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (153 dB)	23 km²	3.1 km	2.4 km	2.7 km
		PCW (181 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
6 sequential piles	**PTS**	LF (199 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		HF (198 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (173 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		PCW (201 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
	TTS	LF (179 dB)	81 km²	6.6 km	4.0 km	5.0 km
		HF (178 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m
		VHF (153 dB)	23 km²	3.1 km	2.4 km	2.7 km
		PCW (181 dB)	< 0.1 km²	< 100 m	< 100 m	< 100 m

A.2 Multiple location modelling

Figure A 1 and Figure A 2, Table A 3 and Table A 4 expand on the results presented in section 3.2 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 this scale have not been included, impact ranges have not been presented as there are two starting points for fleeing receptors, and fields donated with a dash "-" show where there is no in-combination effect when the two piles are installed simultaneously.

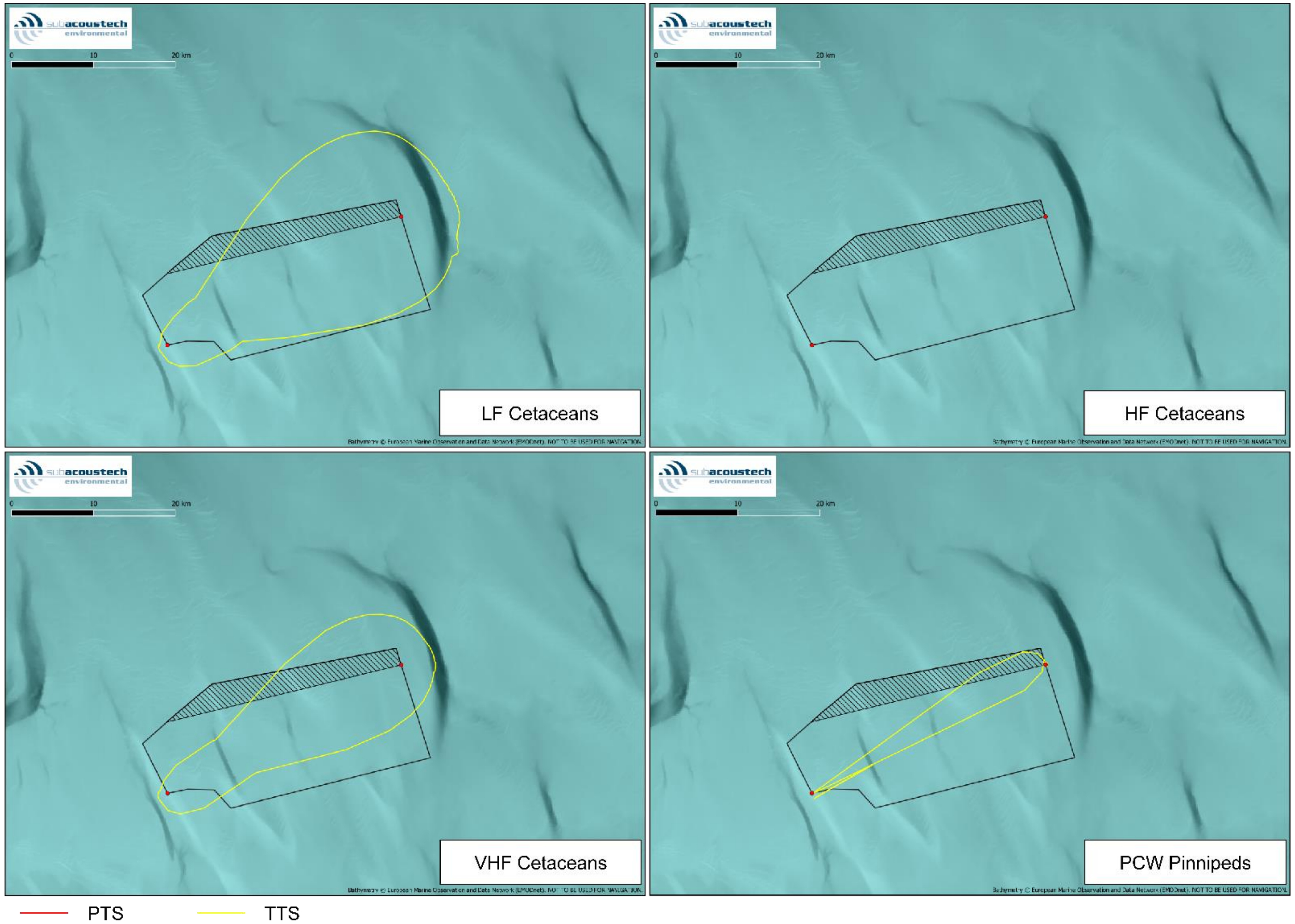

Figure A 1 Contour plots showing the in-combination impacts of simultaneous installation of monopile foundations at the SW and NE modelling locations for marine mammals using the non-impulsive Southall et al. (2019) criteria assuming a fleeing animal

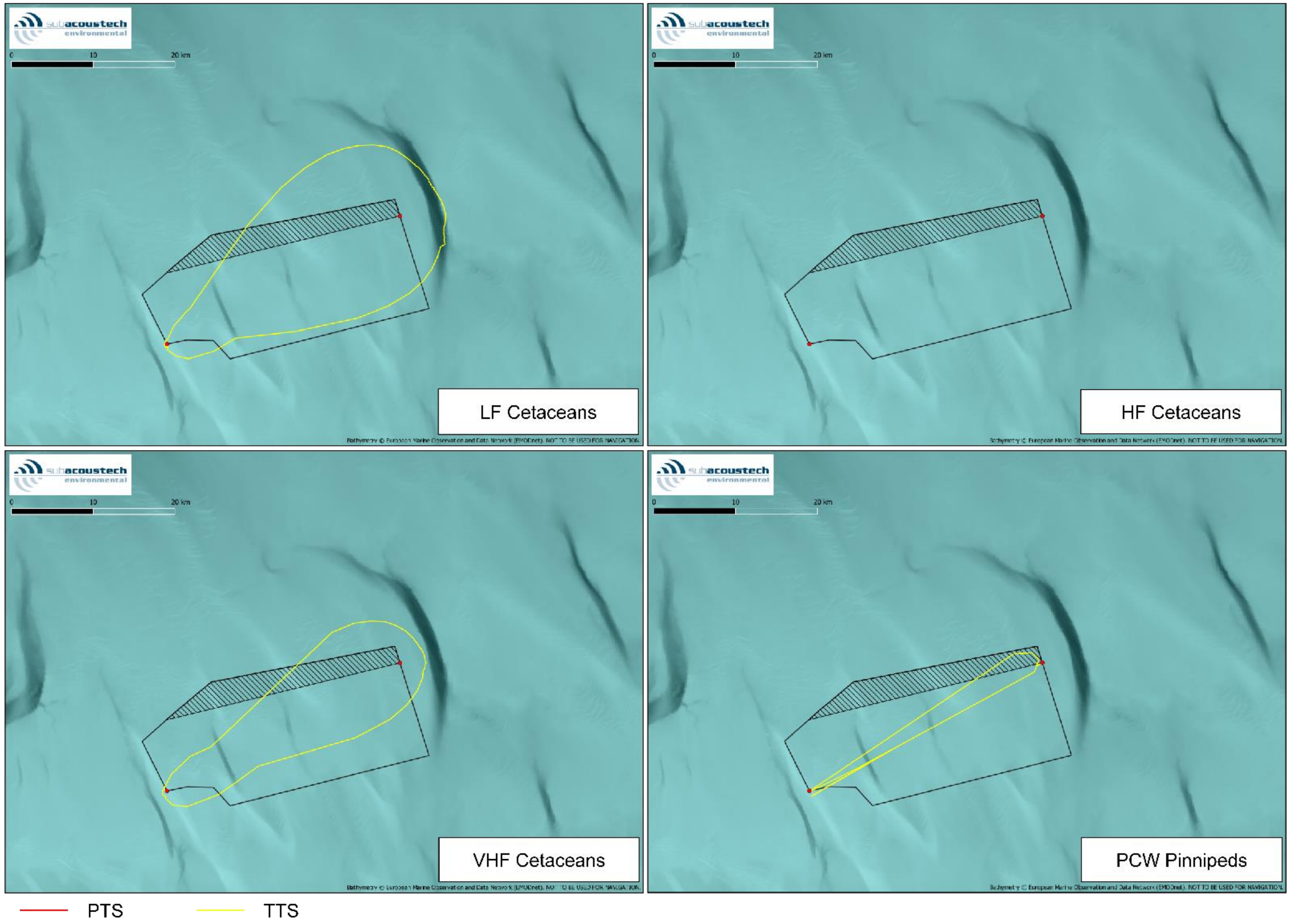

Figure A 2 Contour plots showing the in-combination impacts of simultaneous installation of jacket pile foundations at the SW and NE modelling locations for marine mammals using the non-impulsive Southall et al. (2019) criteria assuming a fleeing animal

Table A 3 Summary of the impact areas for the installation of monopile foundations at the SW and NE modelling locations for marine mammals using the non-impulsive Southall et al. (2019) SEL_{cum} criteria assuming a fleeing animal

Monopile foundation Southall *et al*. (2019) Weighted SEL_{cum}		**SW area**	**NE area**	**In-combination area**
PTS (Non-impulsive)	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 (Non-impulsive)	LF (179 dB)	2.4 km^2	140 km^2	600 km^2
	HF (178 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (153 dB)	3.1 km^2	43 km^2	360 km^2
	PCW (181 dB)	< 0.1 km^2	0.1 km^2	84 km^2

Table A 4 Summary of the impact areas for the installation of jacket pile foundations at the SW and NE modelling locations for marine mammals using the non-impulsive Southall et al. (2019) SEL_{cum} criteria assuming a fleeing animal

Jacket pile foundation Southall *et al*. (2019) Weighted SEL_{cum}		**SW area**	**NE area**	**In-combination area**
PTS (Non-impulsive)	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 (Non-impulsive)	LF (179 dB)	0.2 km^2	81 km^2	500 km^2
	HF (178 dB)	< 0.1 km^2	< 0.1 km^2	-
	VHF (153 dB)	0.7 km^2	23 km^2	300 km^2
	PCW (181 dB)	< 0.1 km^2	< 0.1 km^2	57 km^2

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