



EIAR Addendum

Appendix 9-C Underwater
Noise Modelling Assessment



Codling Wind Park: Underwater noise modelling assessment

Richard Barham, Tim Mason

24 March 2026

**Subacoustech Environmental Report No.
P284R0403**

Submitted to: Lesley Jamieson

Submitted by: Richard Barham

Tel: +44 (0)23 80 236 330

E-mail: lesleyj@naturalpower.com

E-mail: richard.barham@subacoustech.com

Website: www.naturalpower.com

Website: www.subacoustech.com

<i>Document No.</i>	<i>Date</i>	<i>Written</i>	<i>Approved</i>	<i>Distribution</i>
<i>P284R0401</i>	<i>14/01/2026</i>	<i>R Barham</i>	<i>T Mason</i>	<i>L Jamieson (Natural Power)</i>
<i>P284R0402</i>	<i>16/03/2026</i>	<i>R Barham</i>	<i>T Mason</i>	<i>L Jamieson (Natural Power)</i>
<i>P284R0403</i>	<i>24/03/2026</i>	<i>R Barham</i>	<i>T Mason</i>	<i>L Jamieson (Natural Power)</i>

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

Disclaimer

This report, with its associated works and services, has been designed solely to meet the requirements agreed between Subacoustech Environmental and the Client or Sponsor (contracting parties) detailed in the report documentation page. If used for any other circumstances, some or all the results may not be valid, and we can accept no liability for such use. Such circumstances include any use by third parties, or changes to any project parameters, including (but not limited to) site location, planned works, applicable legislation occurring after completion of this report. In case of doubt, please consult Subacoustech Environmental Limited.

Copyright Notice

All rights reserved. No part of this report may be reproduced, published, or distributed in any form without the prior written permission of Subacoustech Environmental Limited. This report was drafted on instruction, the rights and obligations of the contracting parties are subject to the relevant agreement concluded between the contracting parties. Submission of the report for inspection to third parties who have a direct interest is permitted. Publication and distribution for the purposes of statutory consultation is permitted where this is consistent with the intended purpose of the report.

Preface

Codling Wind Park Limited (CWPL) is proposing to develop the Codling Wind Park (CWP) Project, which is located in the Irish Sea approximately 13 - 22 km off the east coast of Ireland, at County Wicklow.

On Friday 6th September 2024 Codling Wind Park Ltd. (referred to hereafter as the 'Applicant') applied for planning permission to An Coimisiún Pleanála (ACP) (referred to hereafter as the 'Commission') under Section 291 of the Planning and Development Act (PDA) 2000, as amended, for the construction, operation and decommissioning of the CWP Project.

On 1st August 2025, having reviewed the application documentation, including the Environmental Impact Assessment Report (EIAR) and the Natura Impact Statement (NIS), the Commission issued a Further Information Request (FIR) in relation to the CWP Project.

This document supersedes Volume 4, Appendix 9.4 Appendix 9.4 Underwater Noise Assessment of the EIAR. It has been drafted to respond to inter alia Item 10a of the Commission's FIR, and the project commitment to underwater noise mitigation (169 dB LE,p,ss,05 at 750m at WTG and Offshore Substation (OSS) piling events).

This document is also accompanied by Annex A which has been drafted by the Sea Mammal Research Unit (SMRU) to further consider the comparison between different EU and non-EU jurisdictions, as requested within Item 10a of the FIR.

Executive Summary

Subacoustech Environmental, on behalf of Natural Power, has undertaken a study in order to assess the potential underwater noise and its effects during the construction and operation of the Codling Wind Park (CWP) Project. This includes consideration of the An Coimisiún Pleanála (ACP) Further Information Request [320768-FI Request], particularly items 10 a) and k).

The primary noise source considered as part of the assessment has been identified as impact piling to install monopile foundations. Modelling of underwater noise generated by impact piling was undertaken at four representative locations, with the loudest levels predicted at the southeast corner of the site due primarily to the deeper water found at that location.

The modelling results were analysed in terms of relevant noise metrics and criteria to assess the effects of impact piling noise on marine mammals and fish, which have been used to aid biological assessments. For marine mammals, the largest auditory injury onset ranges from impact piling (unmitigated) were predicted for receptors in the low-frequency (LF) cetacean hearing category, which includes minke whale, with maximum impact ranges out to 8.0 km. For fish, the largest recoverable injury ranges were predicted to be 4.0 km for a stationary receptor, reducing to less than 50 m considering a moving receptor. When considering the noise reduction from a mitigation system, reductions of up to 10 dB were included depending on the location; specific systems to be implemented at the CWP Project are not yet confirmed. When considering noise reduction from mitigation, the maximum injury range of any marine mammal species reduced to 140 m (position of the noise mitigation system from the pile notwithstanding), and the maximum recoverable injury ranges for stationary fish reduced to 1.6 km.

Noise sources other than impact piling were considered using higher-level methodologies, and these included cable laying, dredging, drilling, rock placement, trenching, vessel noise, and operational wind turbine generator (WTG) noise. All these sources were predicted to have a much smaller impact compared to impact piling noise.

Noise from unexploded ordnance (UXO) clearance showed there is a risk of auditory injury onset out to 990 m with use of the expected low-order UXO clearance technique. This considered the unweighted peak ($L_{p,pk}$) criteria for the very high-frequency (VHF) cetaceans hearing group, which includes harbour porpoise. In the event that a high-order detonation does occur, the maximum injury onset range is predicted to be 14 km from detonation of the largest considered device (750 kg + donor charge), using the same VHF cetacean criterion. High-order detonation is not a proposed UXO clearance methodology, although for completeness has been included in this assessment. It should be noted that this is likely to be highly precautionary as the impact range is based on a worst-case criterion and calculation methodology that does not account for any smoothing of the pulse over long ranges, which would reduce the pulse peak and other characteristics of the sound that cause injury. When mitigation is considered, the same high-order detonation impact range reduces to 5.1 km.

It should be stressed that, due to the nature of modelling, while the results present specific ranges at which each impact threshold is met, the ranges should be taken as indicative and worst case in determining where environmental effects may occur in receptors during the proposed operations.

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 assessments.

List of contents

1	Introduction	6
2	Underwater noise concepts	8
2.1	Units of measurement	8
2.2	Properties of sound	10
2.3	Analysis of environmental effects: Assessment criteria	11
2.4	Other requirements in the EU (marine mammals)	16
3	Modelling methodology.....	20
3.1	Modelling confidence.....	20
3.2	Input parameters	25
3.3	$L_{E,p,t}$ and fleeing receptors	30
3.4	Precaution in underwater noise modelling.....	33
4	Modelling results	35
4.1	Unmitigated impact piling results	37
4.2	Mitigated impact piling results	45
5	Other noise sources	54
5.1	Noise making activities (construction)	54
5.2	Operational WTG noise	58
5.3	UXO clearance	61
6	Summary and conclusions	68
	References	69
	Appendix A Additional modelling results.....	74
A.1	First strike results	74
A.2	Non-impulsive criteria.....	83
	Appendix B Contour plots.....	87
B.1	Unmitigated impact piling results	90
B.2	Mitigated impact piling results	105
B.3	Non-impulsive criteria.....	120
	Document Information	140

Terminology

Decibel (dB)	A customary scale commonly used (in various ways) for reporting levels of sound. The dB represents a ratio/comparison of a sound measurement (e.g., sound pressure) over a fixed reference level. The dB symbol is followed by a reference value (e.g., re 1 μ Pa).
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)	Noise threshold that represents the onset level of a permanent impairment 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 or $L_{E,p}$)	The constant sound level acting for one second, which has the same amount of acoustic energy, as indicated by the square of the sound pressure, as the original sound. It is the time-integrated, sound-pressure-squared level. SEL is typically used to compare transient sound events having different time durations, pressure levels, and temporal characteristics.
Sound Exposure Level, cumulative (SEL _{cum} or $L_{E,p,t}$)	Single value for the collected, combined total of sound exposure over a specified time or multiple instances of a noise source.
Sound Exposure Level, single strike (SEL _{ss} or $L_{E,p,ss}$)	Calculation of the sound exposure level representative of a single noise impulse, typically a pile strike.
Sound Pressure Level (SPL or L_p)	The sound pressure level is an expression of sound pressure using the decibel (dB) scale; the standard frequency pressures of which are 1 μ Pa for water and 20 μ Pa for air.
Sound Pressure Level Peak (SPL _{peak} or $L_{p,pk}$)	The highest (zero-peak) positive or negative sound pressure, in decibels.
Temporary Threshold Shift (TTS)	Onset threshold level for a temporary reduction of hearing acuity caused by exposure to sound over time.
Unweighted sound level	Sound levels which are “raw” or have not been adjusted in any way, for example to account for the hearing ability of a species.
Weighted sound level	A sound level which has been adjusted with respect to a “auditory weighting function” or “weighting envelope” in the frequency domain, typically to make an unweighted level relevant to a particular species.

Acronyms

ADD	Acoustic Deterrent Device
BBC	Big Bubble Curtain
BGS	British Geological Survey
CWP	Codling Wind Park
EIA	Environmental Impact Assessment
EMODnet	European Marine Observation and Data Network
FPSO	Floating Production Storage and Offloading (vessel)
GIS	Geographic Information System
HE	High Explosive
HF	High-Frequency Cetaceans
INSPIRE	Impulsive Noise Sound Propagation and Impact Range Estimator
ISO	International Organisation for Standardisation
LF	Low-Frequency Cetaceans
MTD	Marine Technical Directorate
NAS	Noise Abatement System
NEQ	Net Explosive Quantity
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPL	National Physical Laboratory
PCW	Phocid Carnivores in Water
PPV	Peak Particle Velocity
PTS	Permanent Threshold Shift
RMS	Root Mean Square
r_{safe}	A safe distance for marine mammals to from the pile at the start of piling (Danish regulations)
SE	Sound Exposure
SEL ($L_{E,p}$)	Sound Exposure Level
SEL _{cum} ($L_{E,p,t}$)	Cumulative Sound Exposure Level
SEL _{ss} ($L_{E,p,ss}$)	Single Strike Sound Exposure Level
SPL	Sound Pressure Level
SPL _{peak} ($L_{p,pk}$)	Peak Sound Pressure Level
SPL _{RMS} ($L_{p,RMS}$)	Root Mean Square Sound Pressure Level
TNT	Trinitrotoluene (explosive)
TTS	Temporary Threshold Shift
UXO	Unexploded Ordnance
VHF	Very High-Frequency Cetaceans
WTG	Wind Turbine Generator

Units

bl/min	Blows per minute (piling strike rate)
dB	Decibel (sound pressure)
Hz	Hertz (frequency)
kg	Kilogram (mass)
kHz	Kilohertz (frequency)
kJ	Kilojoule (energy)
km	Kilometre (distance)
km ²	Square kilometres (area)
kn	Knot (speed)
kW	Kilowatt (power)
m	Metre (distance)
mm/s	Millimetres per second (particle velocity)
m/s	Metres per second (speed)
MW	Megawatt (power)
Pa	Pascal (pressure)
Pa ² s	Pascal squared seconds (acoustic energy)
s	Seconds (duration)
μPa	Micropascal (pressure)

1 Introduction

The Codling Wind Park (CWP) Project is a proposed offshore wind farm development located in the Irish Sea, off the east coast of Ireland. As part of the Environmental Impact Assessment (EIA) process, Subacoustech Environmental Ltd has undertaken detailed modelling and analysis in relation to underwater noise and its effect on marine mammals and fish during the construction and operation of the CWP Project. This report includes consideration of the An Coimisiún Pleanála (ACP) Further Information Request (320768-FI Request), particularly items 10 a) and k).

The CWP Project has a proposed capacity of up to 1,300 MW comprising of up to 75 turbines and covers an area of 125 km². The site is situated approximately 13 km off the Irish coast near Wicklow, which is shown in Figure 1-1.

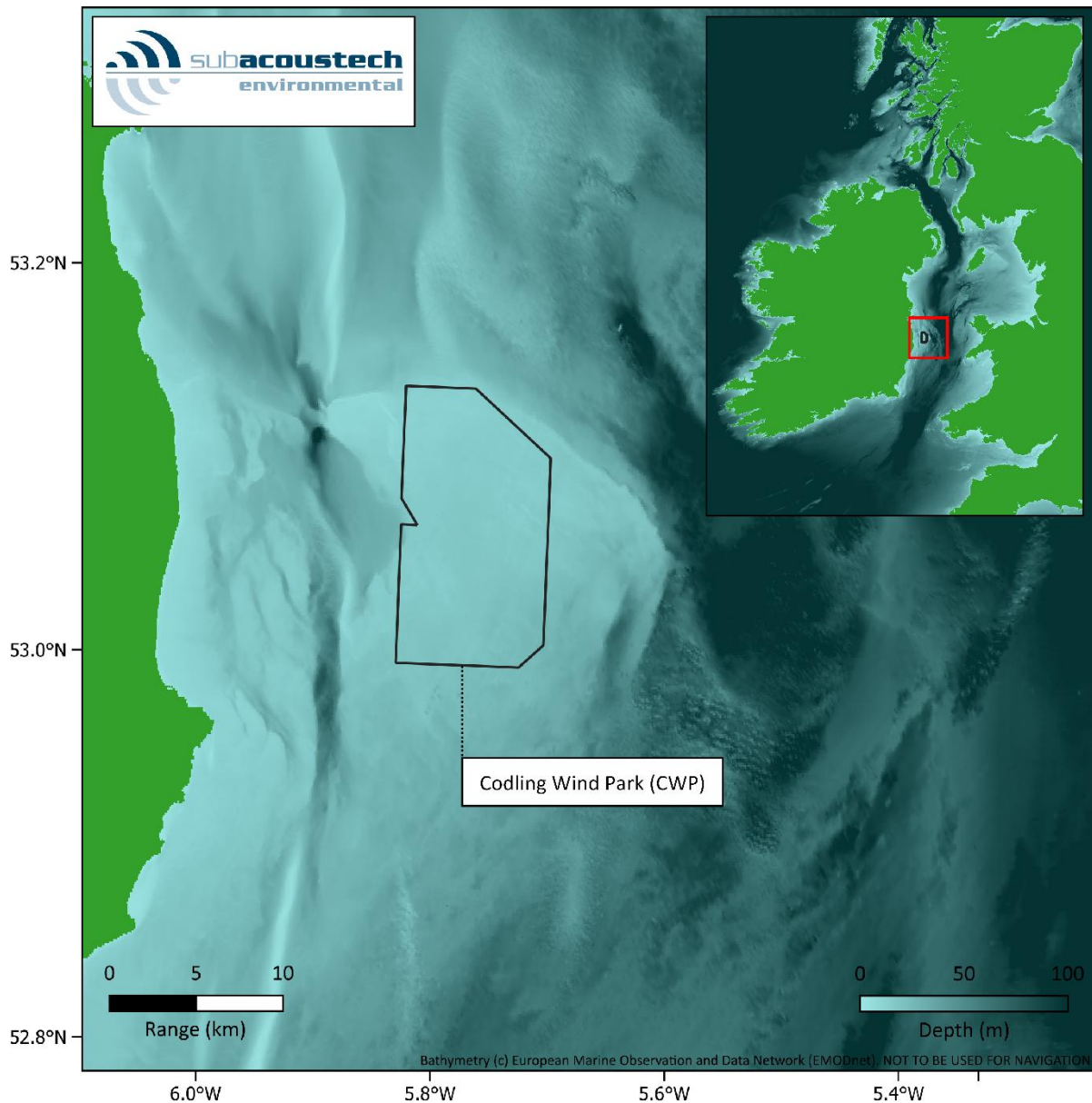


Figure 1-1: Overview map showing the CWP array site boundary, its location next to the Irish coast, and the surrounding bathymetry.

This report presents a detailed assessment of the potential underwater noise that could be expected during the construction and operational periods of the CWP Project, and includes the following:

- Background information covering the units for measuring and assessing underwater noise, and a review of the underwater noise metrics and criteria used to assess the possible environmental effects in marine receptors, as well as other approaches in the EU as per Item 10 a) ii) in the ACP's Request for Further Information (FIR) (section 2).
- Discussion of the approach, confidence, input parameters and assumptions for the detailed impact piling modelling undertaken (section 3).
- Presentation and interpretation of the detailed subsea noise modelling for impact piling with regards to its effect on marine mammals and fish, including potential mitigation (section 4).
- Modelling of the other noise sources expected around construction and operation of the CWP Project, including cable laying, dredging, drilling, rock placement, trenching, vessel noise, operational WTG noise and UXO clearance (section 5).
- Summary and conclusions (section 6).

Further modelling results covering noise from the first pile strike and for non-impulsive thresholds for impact piling (see sections 2.2.1 and 2.3.1) are presented in Appendix A. Contour plots of the modelled auditory injury and TTS criteria for impact piling noise are presented in Appendix B.

2 Underwater noise concepts

Sound travels much faster in water (approximately 1,500 m/s) than in air (340 m/s) as water is relatively incompressible and has a higher density than air. This affects the way in which sound measurements are expressed between the two mediums, which means that underwater sound levels are not directly comparable to airborne sound levels. This is noted for context; this report does not contain or include any reference to airborne sound levels.

2.1 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 as this better reflects how sound is perceived. For example, equal increments of sound pressure do not have an equal increase in the perceived sound. Instead, a doubling of sound pressure will cause a roughly equal increase of perceived loudness each time. Any quantity expressed in this dB scale is termed a “level.” For example, if the unit is sound pressure, it will be termed a “sound pressure level” on the dB scale.

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. 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 μ Pa is used for sound in air since that is the lower threshold of human hearing.

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

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

For underwater sound, a unit of 1 μ Pa 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.

2.1.1 Sound pressure level

The Sound Pressure Level (SPL or L_p) 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 ($L_{p,RMS}$) 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 explosions, it is critical that the period over which the RMS level is calculated is quoted (e.g., $L_{p,125ms}$). For instance, in the case of a pile strike lasting a tenth of a second, the mean taken over a tenth of a second will be ten times higher than the mean averaged over one second. Often, transient sounds such as these are quantified using “peak” SPLs ($L_{p,pk}$) or Sound Exposure Levels (SEL or $L_{E,p}$).

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

2.1.1.1 Peak sound pressure

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

2.1.2 Sound exposure level

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 (e.g., Popper *et al.*, 2014; Southall *et al.*, 2019; NMFS, 2024).

The $L_{E,p}$ sums the acoustic energy over a measurement period, and effectively takes account of both the L_p 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 sound in seconds, and t is time in seconds. The SE is a measurement of acoustic energy and has units of Pascal squared seconds (Pa^2s).

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

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

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

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

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

This means that, for continuous sounds of less than (i.e., fractions of) one second, the $L_{E,p}$ will be lower than the L_p . For periods greater than one second, the $L_{E,p}$ will be numerically greater than the L_p (i.e., for a continuous sound of 10 seconds duration, the $L_{E,p}$ will be 10 dB higher than the L_p ; for a sound of 100 seconds duration the $L_{E,p}$ will be 20 dB higher than the L_p , and so on).

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

$$\text{Cumulative } L_{E,p} = L_{E,p} + 10 \times \log_{10} X$$

Where $L_{E,p}$ is the sound exposure level of one impulse and X is the total number of impulses or strikes. Unless otherwise defined, all $L_{E,p}$ noise levels in this report are referenced to $1 \mu\text{Pa}^2\text{s}$.

2.2 Properties of sound

2.2.1 *Impulsive and non-impulsive sound*

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

These differences are important when considering the potential for auditory injury, as impulsive noise is more injurious than non-impulsive noise (Henderson and Hamernik, 1986; Hastie *et al.*, 2019).

Due to the differences between impulsive and non-impulsive noise sources, different metrics are appropriate, for example:

- Impulsive noises: $\text{SPL}_{\text{peak}}(L_{p,pk})$ and cumulative SEL ($L_{E,p,t}$).
- Non-impulsive noises: cumulative SEL ($L_{E,p,t}$) and $\text{SPL}_{\text{RMS}}(L_{p,\text{RMS}})$.

Objective categorisation of a noise as impulsive or non-impulsive is not always clear. This is particularly the case if sound is travelling over large distances. For example, when an impulsive sound propagates through an environment, the energy within the sound wave will scatter and dissipate, and it will become less impulsive with distance. This is important to consider regarding auditory injury and impact range calculations, as noise will become less injurious if it becomes less impulsive.

Research to define a range-dependent transition from impulsive to non-impulsive noise has been a significant field of study (see, for example, Martin *et al.*, 2020). Although the situation is complex, Hastie *et al.* (2019) concluded that an impulsive piling sound can be considered effectively non-impulsive at a range of 3.5 km from the source using some metrics. However, the recent study by Matei *et al.* (2024) concludes that there is still insufficient evidence to clearly define a transition point suitable for an assessment such as this. It is, however, reasonable to presume there is a fully impulsive region close to the source, and a fully non-impulsive region at some greater distance, and a transition region in between. The paper makes it clear that there is a substantial reduction in impulsiveness within the first 5 km. However, due to the uncertainty in identifying a transition point, no presumption of a change has been made in this report, although it is reasonable to assume that the sound can be considered not fully impulsive where injury onset ranges are calculated above 5 km. Where applicable, results in respect of both impulsive and non-impulsive criteria (see section 2.3.1 for marine mammals) have been presented in this report.

2.2.2 *Particle motion*

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

It has been identified by several researchers that many fish species (e.g., Popper and Hawkins, 2019; Nedelec *et al.*, 2016; Radford *et al.*, 2012), as well as marine invertebrates (see section 2.3.3) are sensitive to particle

motion. However, sound pressure metrics are still preferred and more widely used than particle motion due to a lack of supporting data (Popper and Hawkins, 2018). There continue to be calls for additional research on the levels of and effects on marine receptors with respect to levels of particle motion.

2.3 Analysis of environmental effects: Assessment criteria

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

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).
- Disturbance and behavioural responses.

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

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:

- NMFS (2024) marine mammal exposure criteria.
- Popper *et al.* (2014) sound exposure guidelines for fishes and sea turtles.

These include the most up-to-date and authoritative criteria for assessing environmental effects for use in impact assessments, at the time of writing. In addition, behavioural criteria from NOAA (2005), as well as consideration of various EU regulations have been considered in this study.

2.3.1 Marine mammals

The NMFS (2024) paper is the latest reference for marine mammal hearing and injury thresholds at the time of writing. It updates weightings and thresholds from the previously most-used and recognised references, Southall *et al.* (2019) and NMFS (2018).

The NMFS (2024) guidance categorises marine mammals into groups of similar species and applies filters to the unweighted noise to approximate the hearing sensitivities of the receptor in question. The hearing groups given by NMFS (2024) are summarised in Table 2-1 and the relevant auditory weighting functions are shown in Figure 2-1. Further groups for sirenians and otariid pinnipeds are given, but these have not been included in this study as they are not commonly found in the area around the CWP Project.

Table 2-1: Marine mammal hearing groups (from NMFS, 2024).

Hearing group	Generalised hearing range	Example species
Low-frequency cetaceans (LF)	7 Hz to 36 kHz	Baleen whales (including minke 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)	200 Hz to 165 kHz	True porpoises (including harbour porpoise)
Phocid pinnipeds (PW)	40 Hz to 90 kHz	True seals (including harbour seals)

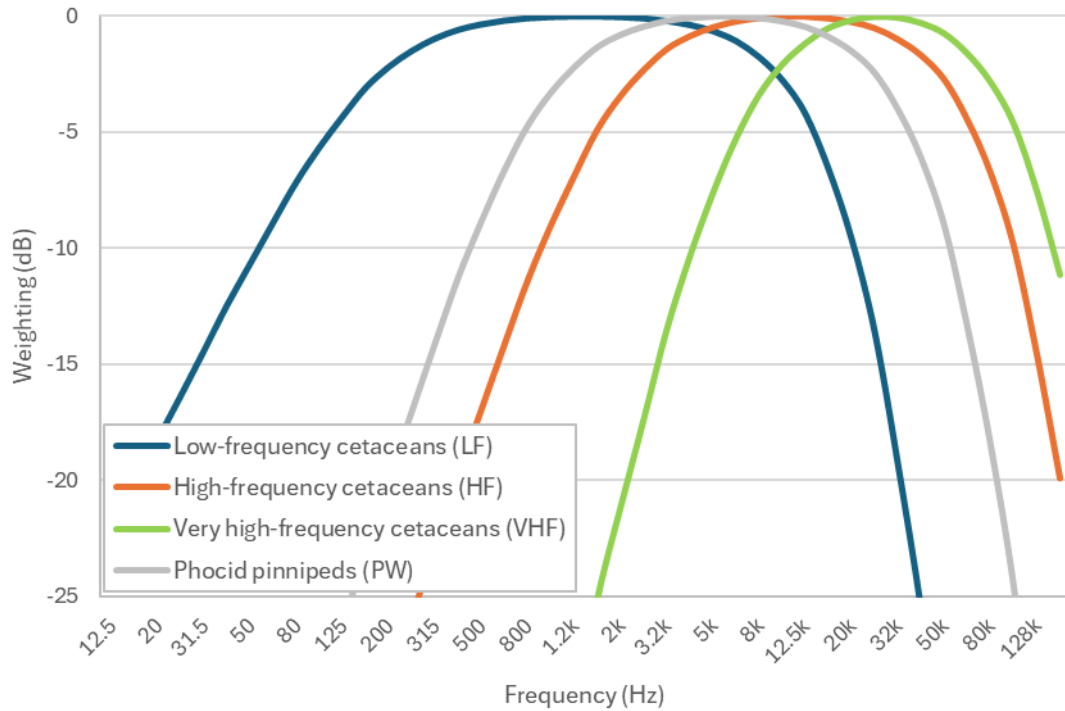


Figure 2-1: Auditory weighting functions for low-frequency cetaceans (LF), high-frequency cetaceans (HF), very high-frequency cetaceans (VHF), and phocid carnivores in water (PCW) (from NMFS, 2024)

Like the preceding NMFS (2018) and Southall *et al.* (2019) guidance, NMFS (2024) considers the nature of the sound in the context of whether it is an impulsive or non-impulsive source (see section 2.2.1 for details). Although the use of impact ranges derived using the impulsive criteria are recommended for all but clearly defined non-impulsive sources, it should be recognised that where calculated ranges are beyond 5 km (see section 2.2.1; Matei *et al.*, 2024), the sound is expected to be beyond the fully impulsive region and the real impact range is likely to be somewhere between the impulsive and non-impulsive impact criteria. Therefore, if the modelled impact range of an impulsive noise has been predicted to be greater than 5 km, it is unlikely to be ‘fully impulsive’ and the non-impulsive impact range should also be considered. Both impulsive and non-impulsive criteria have been presented in this study.

Table 2-2 and Table 2-3 present the impulsive and non-impulsive criteria set out in NMFS (2024) for auditory injury (AUD INJ) and temporary threshold shift (TTS) in marine mammals used for this study. The NMFS (2024) paper does not include TTS criteria for all the metrics and categories, however the remaining $L_{p,pk}$ and $L_{E,p,24h,wtd}$ criteria have been derived from Finneran (2024), which was in itself used to create the methodology and criteria used by NMFS (2024) and is also presented as an appendix in the same report.

Table 2-2: Unweighted $L_{p,pk}$ criteria for AUD INJ and TTS in marine mammals (NMFS, 2024).

NMFS (2024) Unweighted $L_{p,pk}$ (dB re 1 μ Pa)	Impulsive	
	AUD INJ	TTS
Low-frequency cetaceans (LF)	222	216
High frequency cetaceans (HF)	230	224
Very high-frequency cetaceans (VHF)	202	196
Phocid pinnipeds (PW)	223	217

Table 2-3: Weighted $L_{E,p,24h,wt}$ criteria for AUD INJ and TTS in marine mammals (NMFS, 2024).

NMFS (2024) Weighted $L_{E,p,24h,wt}$ (dB re 1 μ Pa ² s)	Impulsive		Non-impulsive	
	AUD INJ	TTS	AUD INJ	TTS
Low-frequency cetaceans (LF)	183	168	197	177
High frequency cetaceans (HF)	193	178	201	181
Very high-frequency cetaceans (VHF)	159	144	181	161
Phocid pinnipeds (PW)	183	168	195	175

Where $L_{E,p,t}$ thresholds are required for marine mammals, a fleeing animal model has been used. This assumes that a receptor, when exposed to high noise levels, will swim away from the noise source. A constant fleeing speed of 3.25 m/s 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 m/s 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 (Kastelein *et al.* 2018), especially at the start of any noisy process when the receptor will be closest.

The fleeing animal model, and assumptions related to it, are discussed in more detail in section 3.3.

Limited data is available for behavioural disturbance on species of marine mammal. To take this into account, the NOAA (2005) Level B (behavioural disturbance) harassment criterion for impulsive noise on marine mammals has been included to cover disturbance effects from impact piling noise. This criterion is 160 dB re 1 μ Pa ($L_{p,RMS}$) from a single pile strike.

2.3.2 Fish

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

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

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

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

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

Where $L_{E,p,t}$ thresholds are required for fish, both a stationary and a fleeing animal model has been used. Most species described by Popper *et al.* (2014) are likely to be able to move away from a sound that is loud enough to cause harm (Dahl *et al.*, 2015; Popper *et al.*, 2014). For those species that can swim away, a speed of 1.5 m/s (based on Hirata, 1999) has been considered as a speed at which to base a fleeing animal model. However, considering the diversity of species described by Popper *et al.* (2014), whether an animal flees or remains stationary in response to a loud noise will differ between species. It is recognised that there is limited evidence for fish fleeing from high level noise sources in the wild (Hubert *et al.*, 2024). The species that are likely to remain stationary are more likely to be benthic species of species without a swim bladder, due to their reduced hearing capabilities, making these species least sensitive to noise (Goertner *et al.*, 1994; Goertner *et al.*, 1978; Stephenson *et al.*, 2010; Halvorsen *et al.*, 2012).

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

The thresholds and relative risk descriptions given by Popper *et al.* (2014) used in this study are reproduced in Table 2-4 to Table 2-6, covering pile driving, explosions, and shipping and continuous noise sources. Similar to the NMFS (2024) criteria in section 2.3.1, the Popper *et al.* (2014) criteria use the SPL_{peak} , SEL_{cum} , and SPL_{RMS} notation, and this report will present the ISO 18405:2017 notation ($L_{p,pk}$, $L_{E,p,t}$, and L_p , respectively) for consistency.

Table 2-4: Recommended guidelines for pile driving according to Popper *et al.* (2014) for species of fish, sea turtles and eggs and larvae (N = near-field, I = intermediate-field, F = far-field).

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

Table 2-5: Recommended guidelines for explosions according to Popper *et al.* (2014) for species of fish, sea turtles and eggs and larvae (N = near-field, I = intermediate-field, F = far-field).

Receptor	Mortality and potential mortal injury	Impairment			Behaviour
		Recoverable injury	TTS	Masking	
Fish: no swim bladder	229 – 234 dB $L_{p,pk}$	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	N/A	(N) High (I) Moderate (F) Low
Fish: swim bladder not involved in hearing	229 – 234 dB $L_{p,pk}$	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	N/A	(N) High (I) Low (F) Low
Fish: swim bladder involved in hearing	229 – 234 dB $L_{p,pk}$	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	N/A	(N) High (I) Low (F) Low
Sea turtles	229 – 234 dB $L_{p,pk}$	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	N/A	(N) High (I) Low (F) Low
Eggs and larvae	> 13 mm/s peak velocity	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	N/A	(N) High (I) Low (F) Low

Table 2-6: Recommended guidelines for shipping and continuous noise according to Popper *et al.* (2014) for species of fish, sea turtles and eggs and larvae (N = near-field, I = intermediate-field, F = far-field).

Receptor	Mortality and potential mortal injury	Impairment			Behaviour
		Recoverable injury	TTS	Masking	
Fish: no swim bladder	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: swim bladder not involved in hearing	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: swim bladder involved in hearing	(N) Low (I) Low (F) Low	170 dB $L_{p,48h}$	158 dB $L_{p,12h}$	(N) High (I) High (F) high	(N) High (I) Moderate (F) Low
Sea turtles	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) High (I) Moderate (F) Low
Eggs and larvae	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) Moderate (I) Moderate (F) Low

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

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

2.3.3 Marine invertebrates

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

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

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

In its current state, research on the effects of anthropogenic noise on marine invertebrates is emerging, but more slowly than for marine mammals and fish. At this time, this research is in too early a stage to be used to accurately generate impact thresholds which would be satisfactory to regulators. The data available could potentially be referenced for some species but with caution, as there are still considerable gaps in the knowledge that would enable reliable conclusions for the impact of noise for most species. However, due to the degree of uncertainty, benthic species will not be considered further.

2.4 Other requirements in the EU (marine mammals)

While the primary focus of this report is the assessment of the underwater noise from piling to the criteria defined in NMFS 2024, other countries within the EU have their own thresholds, and on request from ACP, in their Further Information Request (FIR 10a ii), modelling has also been undertaken in respect of these thresholds. Please note this is only for marine mammals, no special requirements have been identified for fish.

In general, the intent of the underwater noise thresholds in other EU countries is to identify impact ranges in respect of harbour porpoise (the VHF hearing category in NMFS 2024). Three countries have clearly defined requirements that have been considered in this report: Germany, Belgium and Denmark.

2.4.1 Ireland

In Ireland, the National Parks and Wildlife Service (NPWS), as part of Department of the Arts, Heritage and the Gaeltacht (DAHG, now Dept. of Housing, Local Government and Heritage), published guidance to manage the risk that anthropogenic sound sources pose to marine mammals in Irish waters (DAHG, 2014). This guidance presents a process towards managing risk but does not require any specific process nor state explicit dB limits

to restrict noise impacts. Although it states that TTS “may constitute an injury” as it could “have negative effects on the ability to use natural sounds”, this is not a universally accepted definition (Tougaard *et al.*, 2025) and other countries do not consider the short-term effects an injury. The guidance offers suggestions for mitigation that can be applied to projects, including pre-piling monitoring for marine mammals and a soft start and ramp up process. This is similarly reflected in **Appendix 11-B SMRU Consulting TTS Position Statement Nov 2025** which accompanies this response to FIR.

The recent publication of Ireland’s Marine Strategy Part 1, Assessment of the Marine Environment (Annex III), Department of Housing, Local Government and Heritage (DHLGH, 2025) also notes a threshold for Level of Onset of Biologically Significant Effect (LOBE) in reference to the Marine Strategy Framework Directive (MSFD) Descriptor 11 (Underwater Noise) of 176 dB SEL. This was the “lowest reported sound level at which bottlenose dolphins begin to experience temporary hearing loss when exposed to impulsive noise” as presented in NMFS, 2018 (DHLGH, 2025). Bottlenose Dolphin was selected as a receptor organism for assessment of impulsive underwater noise “since it is found throughout the Irish maritime area and is sensitive to mid-frequency sounds such as those generated by impulsive noise sources” (DHLGH, 2025). It is important to note that the value of 176 dB SEL appears to have been selected erroneously: the results were derived from a table in NMFS (2018) that explicitly references continuous exposure to steady-state, non-impulsive noise, and therefore we do not recommend use of this threshold. A more appropriate threshold would be 178 dB SEL_{cum,wtd} which defines TTS onset in bottlenose dolphins in NMFS, 2024, or 170 dB SEL_{cum,wtd} as per NMFS, 2018, the document referenced in Ireland’s Marine Strategy Part 1; this is reflected in the response to **FIR Item 3 National Marine Planning Framework** that accompanies this response to FIR. Impact ranges as per the NMFS, 2024 threshold are included in this report.

Additionally, the recent GOMOREUS study (Tougaard *et al.*, 2025), prepared for the Marine Institute, concludes with an overarching recommendation towards the Danish requirements (see section 2.4.2) or a modified single figure SEL threshold, similar to the German requirements (see section 2.4.2). It is understood that this is intended to be the basis of upcoming revision to the underwater noise guidance in Ireland, although still must go through consultation.

2.4.2 [Denmark](#)

Unlike the German and Belgian noise limits, which while simple in concept are limited to prediction of impacts in relation to a single species and without consideration of their hearing sensitivity, the Danish requirements follow the prediction of impacts in relation to total noise exposure and use PTS SEL_{cum} thresholds as per Southall *et al.* (2019) as a basis. The method to avoid risk is to determine a safe distance (r_{safe}) for marine mammals to from the pile at the start of piling, and the project should demonstrate that the species under consideration will not be present within this range. This is typically done using marine mammal observers and acoustic deterrent devices.

Danish guidelines also include behavioural thresholds for harbour porpoise at 143 dB $L_{E,p,ss}$ (SEL_{ss}) or 103 dB $SPL_{RMS,125ms,VHF}$. For the purposes of this assessment, thresholds and weightings based on NMFS (2024) will be used as the update to Southall *et al.* (2019) (see section 2.3.1).

It is worth noting that although the FIR from ACP (section 10 a ii) states that PTS ranges of less than 200 m are required to be compliant with Danish guidance, this is a misreading of the guidelines. In effect, compliance requires attenuation sufficient to reduce the PTS range enough that it is mitigatable with an ADD. Indicative maximum ranges suitable for ADD effectiveness are 1 km (minimum) for minke whale (McGarry *et al.*, 2017) and 7.5 km for harbour porpoise (Brandt *et al.*, 2013).

2.4.3 Germany

The Bundesamt für Seeschifffahrt und Hydrographie (BSH) has defined strict requirements for the limitation of underwater noise from impact piling for longer than any other jurisdiction (Müller and Zerbs, 2013), effectively forcing the use of noise abatement to comply with noise limits of 190 dB $L_{p,pk}$ (SPL_{peak}) and 160 dB $L_{E,p,ss}$ (SEL_{ss}) at 750 m from the pile. This is interpreted as the upper 5th percentile of the measured levels though, to avoid the risk of exceedance due to isolated, potentially spurious results. Its primary intention is the reduction of the risk of harm to harbour porpoise, although the noise limits do not account for any marine mammal hearing sensitivity or frequency weighting.

Merchant (2019) reviewed the German approach and concluded that it was the most effective noise management model available at the time. However, as pile sizes and hammer energies are increasing, the German sound limit is becoming increasingly more difficult to achieve and is not always met even with the deployment of multiple noise abatement systems (NAS) (Tetra Tech RPS Energy Limited and Seiche, 2024). The German requirements are also criticised in the GOMOREUS (Tougaard *et al.* 2025) study for the Marine Institute as not accounting for cumulative effects or any consideration of the sensitivity to noise of any species. They would also be much harder to meet in Ireland due to the deeper water, larger piles and hammers currently proposed, and the fact that the most common NAS utilised in German waters, bubble curtains, will not be suitable for many locations in Irish waters due to currents.

2.4.4 Belgium

The noise limits in Belgian waters work in a similar way to those in Germany, although with a different administration. Belgian wind farms are subject to slightly different single strike noise limits: 185 dB $L_{p,pk}$ (SPL_{peak}) and 162 dB $L_{E,p,ss}$ (SEL_{ss}), with the intention of achieving Good Environmental Status as per the Marine Strategy Framework Directive such that underwater noise levels do not adversely affect the marine environment. Again, this is primarily focused on the risk to harbour porpoise, but without any frequency weighting to the limits.

2.4.5 Conclusions

Bearing in mind all of the details above, and in the absence of the revised underwater noise guidance for Ireland, it is considered that the Danish guidelines would be most appropriate and relevant to consider for the purpose of this assessment and in response to the FIR from ACP, which requested consideration of defined thresholds in other European jurisdictions. While the German, Belgian and Dutch regulations are relatively straightforward to interpret, in that they use single-figure criteria to define a simple acceptable/unacceptable threshold, they are also based on older and limited studies focused on harbour porpoise (primarily Lucke *et al.*, 2009) that does not take into account the variety of species in Irish waters, their sensitivity to sound frequencies, cumulative exposures or the latest research on PTS, TTS and auditory injury in marine mammals. Such factors are, however, incorporated into the Danish guidance, which has the advantage of easily incorporating better data for PTS and TTS in the event that this becomes available. Notwithstanding this, for the avoidance of doubt, the CWP Project commits to meet a noise limit of 169 dB $L_{E,p,ss}$ (SEL_{ss}), equivalent to a reduction of 10 dB at the maximum blow energy proposed in the worst case location. This is easy to follow and will provide a substantial benefit to the local environment over piling without attenuation, and will provide a substantial benefit to the local environment over piling without attenuation.

The Danish guidance is also discussed in the recommendations in the Irish GOMOREUS report (Tougaard *et al.*, 2025), which discusses the applicability and consequences of the various noise thresholds in use in the various jurisdictions. The GOMOREUS study primarily investigates the balance between the use of German (or German-logic) thresholds and the Danish guidance, but criticises the lack of species-specific thresholds and weightings in the German framework.

Additionally, the use of the TTS threshold for LOBE in Ireland's Marine Strategy Part 1 (2025) is not recommended before a review takes place, and instead the TTS threshold recommended for the specified species used in the guidance should be utilised.

3 Modelling methodology

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

Of those considered, the noise source of most importance is impact piling to install foundations, due to the potential noise levels and duration it will be present (Bailey *et al.*, 2014). As such, the noise related to impact piling activity is the primary focus of this study.

The modelling of impact piling has been undertaken using the INSPIRE underwater noise model, which has been widely used for windfarm assessments around the UK and Ireland. The INSPIRE model (currently version 6.0) is a semi-empirical underwater noise propagation model based around a combination of numerical modelling, a combined geometric energy flow/hysteresis loss method, and actual measured data. It is designed to calculate the propagation of noise in shallow (i.e., generally around 100 m or less), mixed water, typical of the conditions around the UK and Ireland and well-suited for use at the CWP Project.

INSPIRE provides estimates of unweighted $L_{p,pk}$, $L_{E,p,ss}$, and $L_{E,p,t}$ noise levels, as well as other weighted noise metrics. Calculations are made along 180 equally-spaced transects (one every two degrees). For each modelling run, a criterion level can be specified allowing a contour to be drawn, within which a given effect may occur. These results can then be plotted over digital bathymetry 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 to ensure accurate results are produced for the location and nature of the piling operation. It should also be noted that the results should be considered conservative as maximum design parameters and worst-case assumptions have been selected for:

- Piling hammer blow energies;
- Soft start, hammer energy ramp-up, and strike rate;
- Total duration of piling; and
- Receptor swim speeds.

Simpler modelling approaches have been used for noise sources other than impact piling. These are covered in section 5.

3.1 Modelling confidence

The INSPIRE model is semi-empirical, and as such validation is inherently built into the development process. Whenever a new set of reliable impact piling measurement data is gathered through offshore surveys, either by Subacoustech or a published by a third party, it is compared against the outputted levels from INSPIRE and, if necessary, the model can be adjusted.

Currently, 120 separate impact piling noise datasets, primarily from the North and Irish Seas, have been used as part of the development for the latest version of INSPIRE. For $L_{E,p}$, an average, or slightly above the average, fit to the data is used, meaning that for a given dataset some points in the measured dataset will be louder than the predicted level. When cumulative noise is considered, this is necessary to reduce conservatism due to the variations in level for individual pile strikes, which can be as much as 5 to 10 dB (Bailey *et al.*, 2010). Calculating

a cumulative SEL based on every pulse being the worst case would lead to an excessive prediction. For $L_{p,pk}$ however, a slightly more conservative fit to the data has been used to reduce any chance of underestimation. Designing a model to over-predict for all parameters would ultimately lead to an excessively precautionary and unrealistic model.

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

The largest pile diameter included in the analysis for development of INSPIRE v6.0 was 9.5 m in diameter, and the highest measured blow energy was 3,000 kJ. The model has been validated by comparing the noise levels outputted from the model with measurements and modelling undertaken by third parties, for example in Thompson *et al.* (2013) and Thompson *et al.* (2025). In Thompson *et al.* (2025), piles up to 10 m in diameter and blow energies up to 4,400 kJ were modelled using INSPIRE (v5.2) in blind testing against measured data, and a good agreement was found in general, although this earlier version of INSPIRE was found to over-estimate some impact ranges, especially closer to the pile (< 7 km) where the exposures to noise would have the greatest effect.

The version of INSPIRE used for the CWP Project (v6.0) is the product of reanalysing all the impact piling noise in Subacoustech Environmental's measurement database, in preparation for the NMFS (2024) guidance, and cross-referencing it with blow energy data from piling logs, and relevant parameters such as pile diameter, length and water depth. This gives a database of single strike noise levels referenced to a specific blow energy at a specific range and environmental conditions, primarily water depth.

Figure 3-1 and Figure 3-3 present a small selection of the measured impact piling noise data plotted against outputs from INSPIRE. The plots show data points from measured data (in blue) plotted alongside modelled data (in orange) from INSPIRE, matching the pile size, blow energy and position of the measured data. These show the fit to the data, with the modelled INSPIRE data points placed, more or less, in the middle (or slightly above, in the case of $L_{p,pk}$) of the measured noise levels at each range (this can also be seen in Figure 3-2 and Figure 3-4). When combined with precautionary assumptions in parameter selection, modelled results will remain precautionary. The greatest deviations from the model tend to be at the greatest distances (> 10 km), where INSPIRE appears over-precautionary in many cases, but due to the lower relative levels the influence on the overall $L_{E,p,t}$ exposure will be small.

Statistical analysis has been carried out of the fits between measured and modelled data to show the confidence present in INSPIRE v6.0. Figure 3-2 and Figure 3-4 show the distribution of the predicted levels against measured data with R^2 values of 0.81 for unweighted $L_{p,pk}$ and 0.89 for unweighted $L_{E,p,ss}$.

Codling Wind Park: Underwater noise modelling assessment

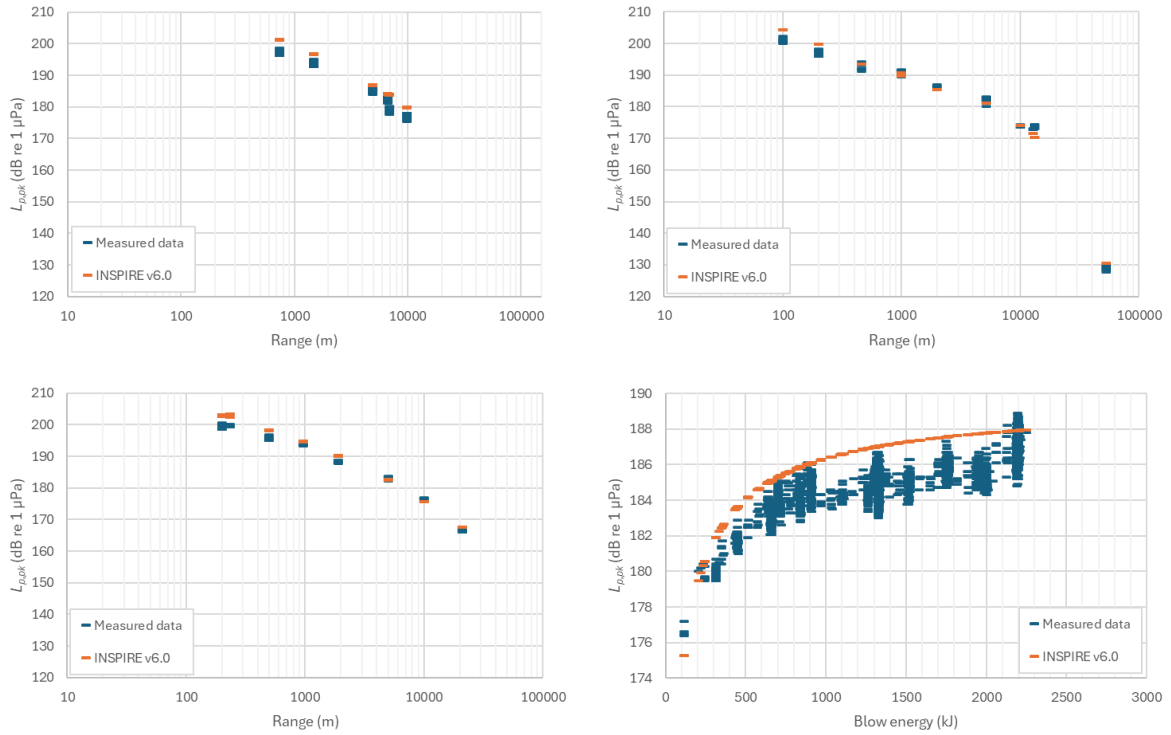


Figure 3-1: Comparison between example measured $L_{p,pk}$ impact piling data (blue) and modelled data using INSPIRE v6.0 (orange)¹

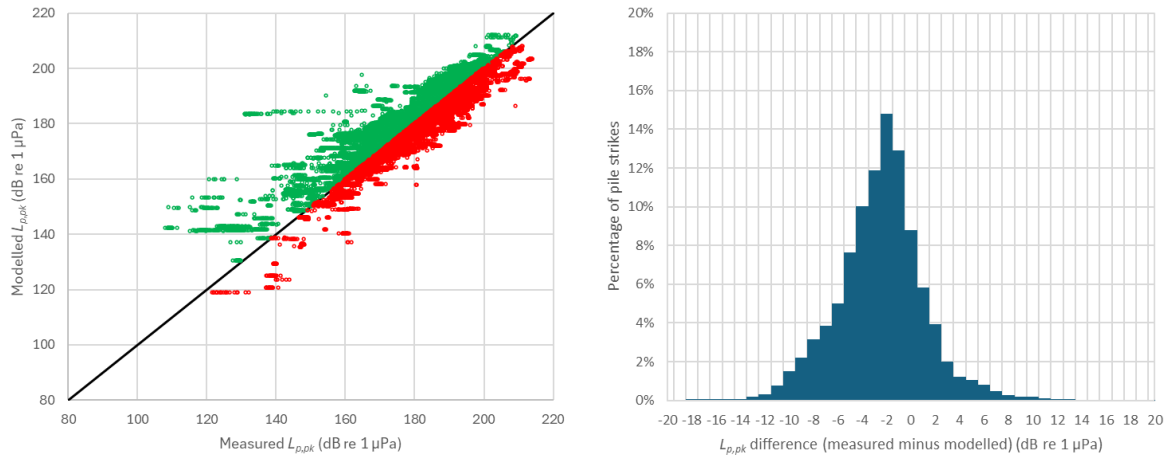


Figure 3-2: Distribution of measured impact piling data against modelled levels using INSPIRE v6.0 for unweighted $L_{p,pk}$ ($R^2 = 0.81$)

¹ Top left: 8.6 m diameter pile, 2,500 kJ max hammer energy, North Sea, 2024; Top right: 5.2 m diameter pile, 1,700 kJ max hammer energy, Lincolnshire Coast, 2011; Bottom left: 6.0 m diameter pile, 1,010 kJ max hammer energy, Suffolk Coast, 2009; Bottom right: 8.6 m diameter pile, 3.0 km range, 2,250 kJ max hammer energy, North Sea, 2024.

Codling Wind Park: Underwater noise modelling assessment

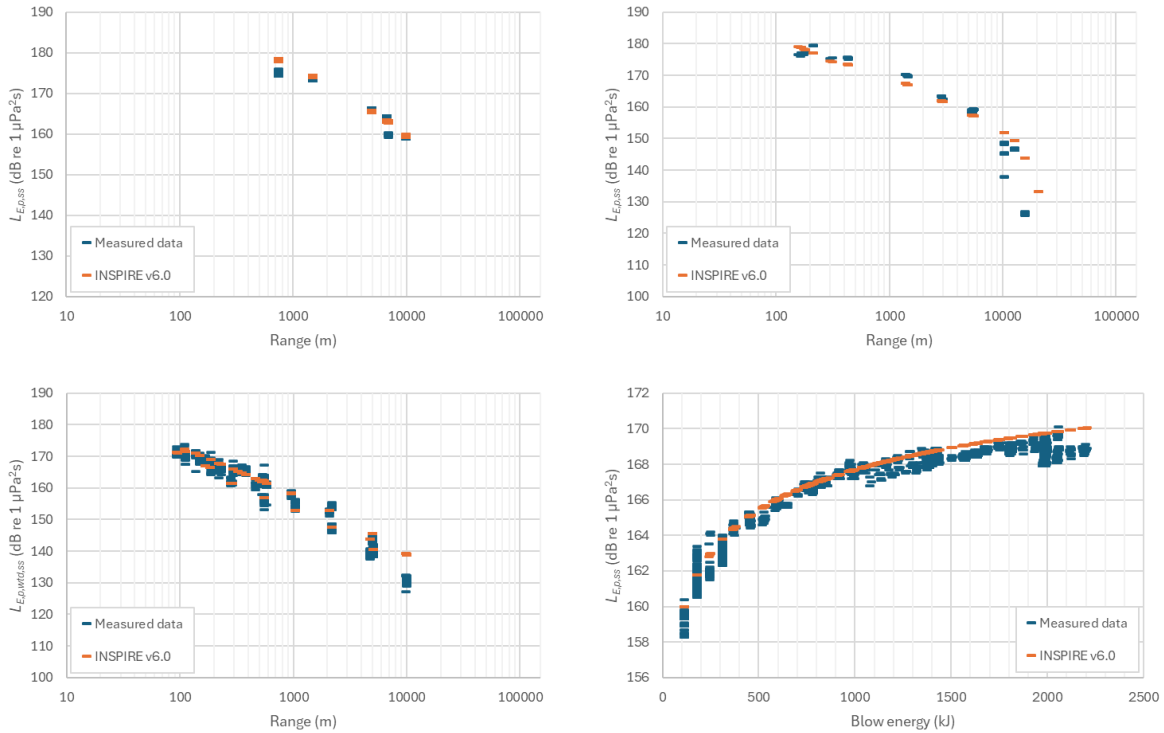


Figure 3-3: Comparison between example measured $L_{E,p,ss}$, impact piling data (blue) and modelled data using INSPIRE v6.0 (orange)²

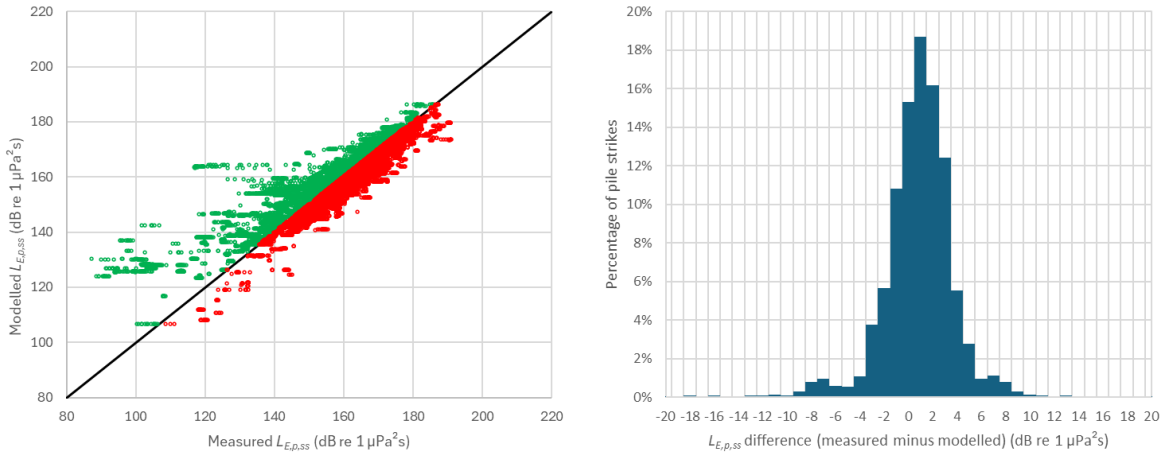


Figure 3-4: Distribution of measured impact piling data against modelled levels using INSPIRE v6.0 for unweighted $L_{E,p,ss}$ ($R^2 = 0.89$)

² Top left: 8.6 m diameter pile, 2,500 kJ max hammer energy, North Sea, 2024; Top right: 4.7 m diameter pile, 1,340 kJ max hammer energy, North Wales Coast, 2012; Bottom left: 1.4 m diameter pile, 620 kJ max hammer energy, Lincolnshire Coast, 2011; Bottom right: 8.6 m diameter pile, 2.1 km range, 2,200 kJ max hammer energy, North Sea, 2024.

Additional validation has been undertaken using data presented by von Pein *et al.* (2022), which studied trends in noise level with changes in piling parameters using data primarily acquired in the North Sea and Baltic Sea. The data showed a strong correlation with blow energy, and a lower correlation with pile diameter, which Subacoustech agrees with, although the calculated correlation based on that data appears to have overestimated the trend. Figure 3-5 and Figure 3-6 are adapted from von Pein *et al.* (2022), replicating their results and overlaying with measured data from Subacoustech's measurement database (selecting samples taken at the same reference distance) and results at equivalent datapoints using INSPIRE v6.0.

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

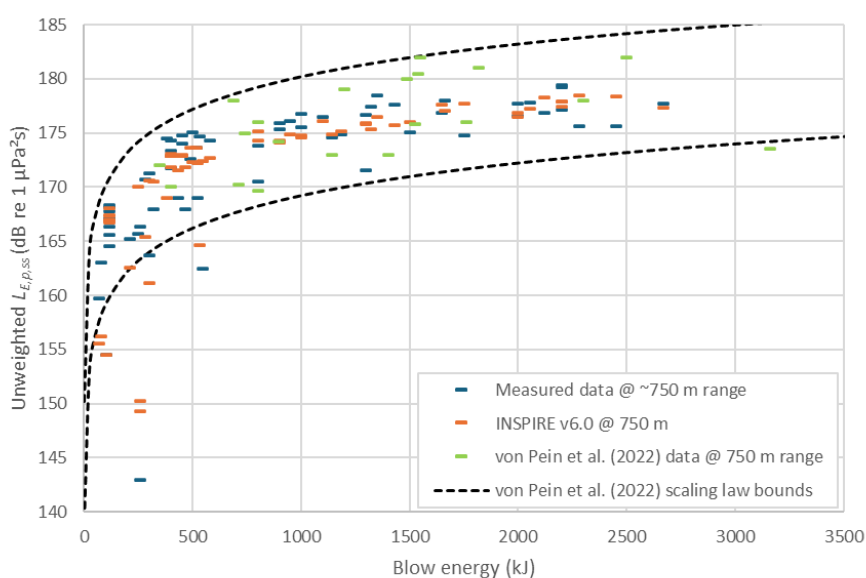


Figure 3-5: Data relating blow energy to noise level ($L_{E,p,ss}$) adapted from von Pein *et al.* (2022) (green) overlaid with Subacoustech measured data (blue) and INSPIRE v6.0 predictions (orange). Upper and lower scaling law bounds from von Pein (2022).

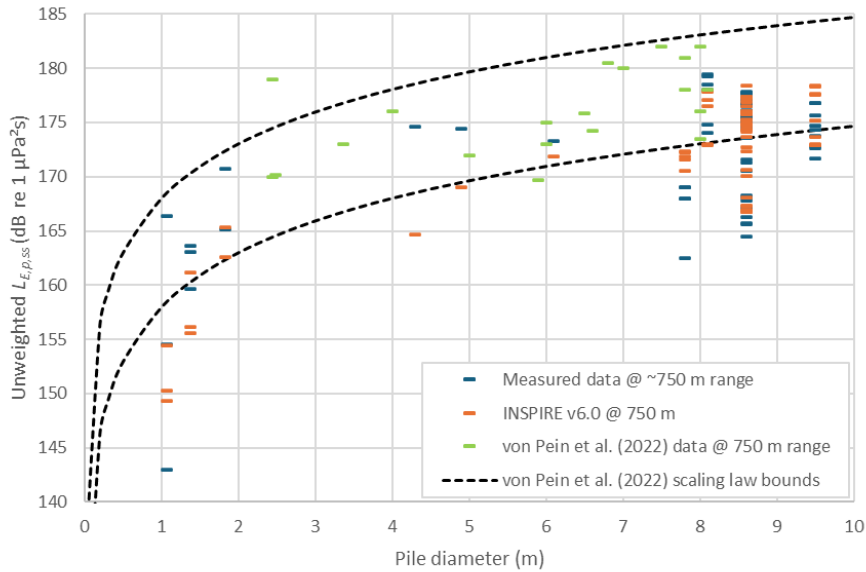


Figure 3-6: Data relating pile diameter to noise level ($L_{E,p,ss}$) adapted from von Pein (2022) (green) overlaid with Subacoustech measured data (blue) and INSPIRE v6.0 predictions (orange). Upper and lower scaling law bounds from von Pein (2022).

3.2 Input parameters

3.2.1 Modelling locations

Modelling for impact piling noise to install monopile foundations has been undertaken at four representative locations covering the extents of the CWP Project, giving a spread of water depths, distances to shore and bathymetry stretching into deeper water around the site. These locations are summarised in Table 3-1 and illustrated in Figure 3-7.

Table 3-1: Summary of the underwater noise modelling locations used for this assessment.

Modelling locations	Latitude	Longitude	Water depth
South East (SE)	53.013°N	005.719°W	26.0 m
South West (SW)	53.002°N	005.841°W	17.2 m
North East (NE)	53.107°N	005.719°W	14.4 m
North West (NW)	53.142°N	005.841°W	13.8 m

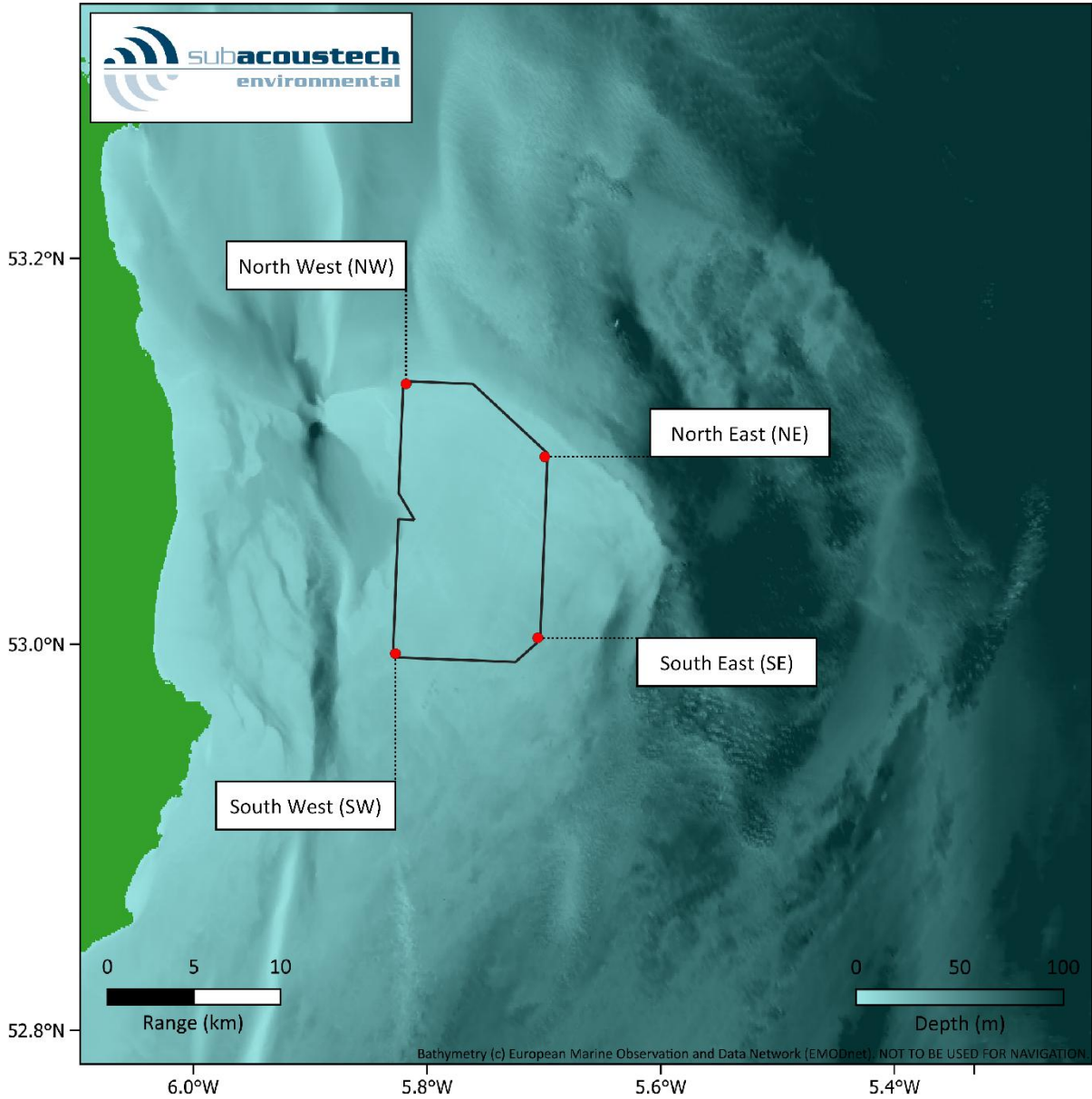


Figure 3-7: Approximate positions of the modelling locations used at the CWP Project.

3.2.2 Environmental conditions

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

Digital bathymetry from the European Marine Observation and Data Network (EMODnet, 2024) has been used for this modelling.

3.2.3 Impact piling parameters

Several impact piling scenarios have been considered in this study, based on the modelling location used; each scenario assumes a 9.5 m diameter monopile installed using a maximum blow energy of 4,400 kJ, but with different ramp-up scenarios. Table 3-2 summarises the ‘Most Restrictive’ ramp-up, which has been considered in the SE corner of the CWP Project array site, which is located in and in the vicinity of the deepest water in and around the CWP Project. Table 3-3 summarises a ‘Less Restrictive’ ramp-up, with a faster ramp-up to full energy, which has been used for the remainder of the modelling locations. An additional ‘Less Restrictive’ scenario has been used for the NW modelling location, which is the same other than considering two sequentially installed piles. For this scenario, no break has been assumed between each pile as a worst-case.

Table 3-2: Summary of the soft start and ramp-up used for the most restrictive ramp-up modelling scenario (SE modelling location only).

Most restrictive ramp-up	440 kJ		1,100 kJ	2,200 kJ	3,300 kJ	4,400 kJ
No. of strikes	200	1,248	1,151	1,143	899	953
Duration (mins)	20	36	33	33	30	38
Strike rate (bl/min)	10	~35	~35	~35	30	~25
5,594 strikes over 3 hours 10 minutes per pile						

Table 3-3: Summary of the soft start and ramp-up used for the less restrictive ramp-up modelling scenario SW, NE, and NW modelling locations).

Less restrictive ramp-up	440 kJ		1,100 kJ	2,200 kJ	3,300 kJ	4,400 kJ
No. of strikes	200	277	279	277	240	3,461
Duration (mins)	20	8	8	8	8	138
Strike rate (bl/min)	10	~35	~35	~35	30	~25
4,734 strikes over 3 hours 10 minutes per pile						
9,468 strikes over 6 hours 20 minutes for two sequentially installed piles						

3.2.4 Mitigation

The effect of using noise abatement systems (NAS) as mitigation for impact piling noise has also been investigated. Generic broadband dB reductions in source level have been applied to the noise modelling to give a representation of the benefits of various NAS without committing to a specific methodology or piece of equipment.

The CWP Project is committed to achieving a noise level of 169 dB ($L_{E,p,ss}$) at 750 m for piling of foundations within the array to mitigate the risk of impact on marine life, in a German-style. Further to this the CWP Project commits to implementing low order UXO clearance where feasible, and implementing Noise Abatement Systems where high order UXO clearance is required (**FIR Response Document**).

For this study reductions of up to 10 dB have been assumed, depending on the location, in order to achieve a level of 169 dB ($L_{E,p,ss}$) at a range of 750 m during impact piling at maximum energy (see section 3.2.6).

10 dB is an achievable estimate based on data presented in Verfuss *et al.* (2019). In this paper, data for a big bubble curtain (BBC), a commonly deployed method, show that it provides a minimum of 10 dB attenuation in the frequency bands where marine mammals are most sensitive (i.e., 250 Hz and above). While it is noted that use of a BBC is dependent on water depth and tidal speed, other methodologies such as piling sleeves, Hydro Sound Dampers or hammer attachments could also potentially be used to achieve reductions of up to 10 dB at the CWP Project. This value is the maximum attenuation needed to achieve the CWP Project’s commitment in the worst-case piling location; other locations would require less.

3.2.5 Apparent source levels

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

The INSPIRE model requires an apparent source level, which is estimated based on the pile diameter and the blow energy imparted on the pile by the hammer. This is adjusted depending on the water depth at the modelling location to allow for the length of the pile (and effective surface area) in contact with the water, which can affect the amount of noise that is transmitted from the pile into its surroundings. The unweighted and unmitigated single strike $L_{p,pk}$ and $L_{E,p,ss}$ apparent source levels estimated for this study are provided in Table 3-4 and Table 3-5 for the maximum hammer energy and first pile strike hammer energy respectively.

These figures are presented in accordance with requests commonly made by regulatory authorities, although as indicated above, they are not necessarily compatible with any other model or predicted apparent source level.

Table 3-4: Summary of the unweighted and unmitigated apparent source levels used for modelling at maximum hammer energy.

Apparent source levels	Modelling location	$L_{p,pk}$ @ 1 m	$L_{E,p,ss}$ @ 1 m
Monopile (9.5 m diameter pile / 4,400 kJ maximum energy)	SE	246.8 dB re 1 μ Pa	219.3 dB re 1 μ Pa ² s
	SW	246.7 dB re 1 μ Pa	219.1 dB re 1 μ Pa ² s
	NE	246.6 dB re 1 μ Pa	219.0 dB re 1 μ Pa ² s
	NW	246.6 dB re 1 μ Pa	219.0 dB re 1 μ Pa ² s

Table 3-5: Summary of the unweighted and unmitigated apparent source levels used for modelling at the first pile strike.

Apparent source levels	Modelling location	$L_{p,pk}$ @ 1 m	$L_{E,p,ss}$ @ 1 m
Monopile (9.5 m diameter pile / 440 kJ energy)	SE	241.7 dB re 1 μ Pa	212.4 dB re 1 μ Pa ² s
	SW	241.5 dB re 1 μ Pa	212.2 dB re 1 μ Pa ² s
	NE	241.4 dB re 1 μ Pa	212.1 dB re 1 μ Pa ² s
	NW	241.4 dB re 1 μ Pa	212.1 dB re 1 μ Pa ² s

3.2.6 Predicted noise levels at 750 m from the noise source

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

These levels have the added advantage of being comparable with other modelling or measurements (as a valid measurement can be taken at this range; for example, von Pein *et al.*, 2022), where the source level (or apparent source level) may not. A summary of the modelled unweighted levels at a range of 750 m are given in Table 3-6 and Table 3-7, considering the transect with the greatest noise transmission at each location while piling at the maximum hammer energy and the hammer energy at first pile strike with no mitigation considered.

Table 3-6: Summary of the maximum predicted $L_{p,pk}$ and $L_{E,p,ss}$ (single strike) noise levels at a range of 750 m from the noise source when considering the maximum hammer blow energy, unmitigated.

Predicted levels	Modelling location	$L_{p,pk}$ @ 750 m	$L_{E,p,ss}$ @ 750 m
Monopile (9.5 m diameter pile / 4,400 kJ maximum energy)	SE	199.9 dB re 1 μ Pa	179.0 dB re 1 μ Pa ² s
	SW	197.2 dB re 1 μ Pa	177.3 dB re 1 μ Pa ² s
	NE	195.2 dB re 1 μ Pa	175.7 dB re 1 μ Pa ² s
	NW	195.3 dB re 1 μ Pa	175.8 dB re 1 μ Pa ² s

Table 3-7: Summary of the maximum predicted $L_{p,pk}$ and $L_{E,p,ss}$ (single strike) noise levels at a range of 750 m from the noise source when considering the hammer blow energy at the first pile strike, unmitigated.

Predicted levels	Modelling location	$L_{p,pk}$ @ 750 m	$L_{E,p,ss}$ @ 750 m
Monopile (9.5 m diameter pile / 440 kJ energy)	SE	194.8 dB re 1 μ Pa	172.2 dB re 1 μ Pa ² s
	SW	192.1 dB re 1 μ Pa	170.4 dB re 1 μ Pa ² s
	NE	190.0 dB re 1 μ Pa	168.8 dB re 1 μ Pa ² s
	NW	190.1 dB re 1 μ Pa	168.9 dB re 1 μ Pa ² s

It should be noted that all the mitigation values chosen in section 3.2.4 are targeted to achieve a noise level of 169 dB ($L_{E,p,ss}$) at 750 m range during impact piling at full power when mitigation is applied.

3.2.7 Predicted noise levels against range

Figure 3-8 has been provided in order to show the modelled noise transmission, which can be used as a basis to compare and validate the levels against future noise monitoring. This plot presents the predicted unweighted $L_{p,pk}$ and $L_{E,p,ss}$ noise levels against range over the longest calculated transect (116°; ESE) from the SE modelling location during installation of a monopile using the maximum hammer energy (4,400 kJ). It should not be assumed necessarily comparable to any other transect or blow energy, although it is expected to present a precautionary scenario.

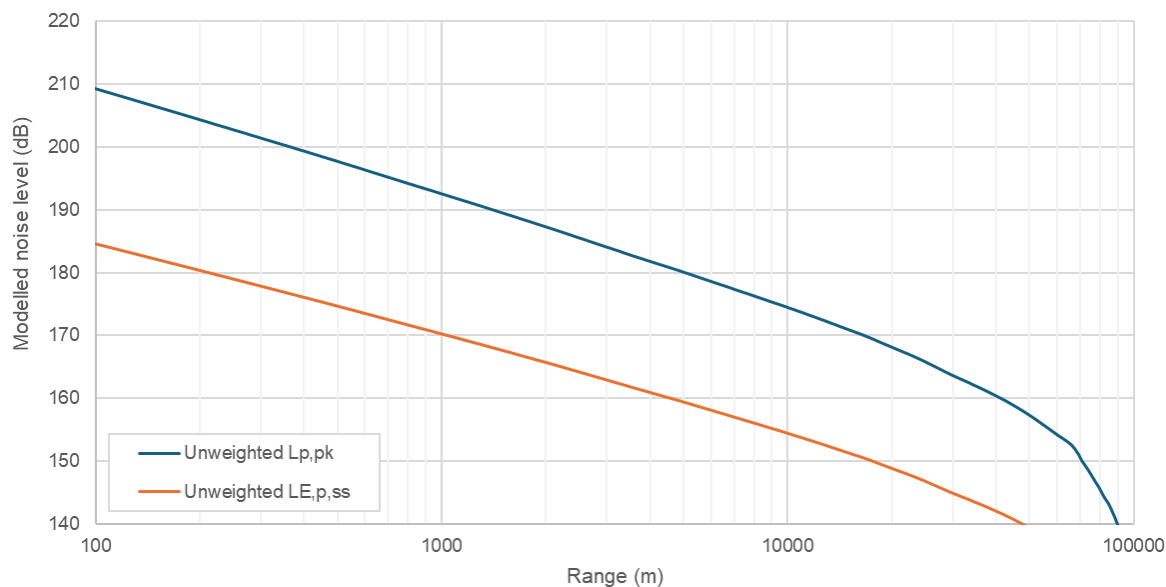


Figure 3-8: Modelled unweighted $L_{p,pk}$ and $L_{E,p,ss}$ noise levels with range for the monopile scenario assuming maximum blow energy along a ESE transect (116°) from the SE modelling location.

3.3 $L_{E,p,t}$ and fleeing receptors

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

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

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

For a fleeing model, the varying distance from the noise source relative to the receptor is also considered. To model this, a nominal starting point close to the source is chosen and the received noise level for each noise event (e.g., pile strike) is noted; the receptor moves away from the source at a defined speed through the piling operation. For example, if a noise (i.e., a pulse from a pile strike) occurs every six seconds, and an animal is fleeing at a rate of 1.5 m/s, it is 9 m further from the noise source after each noise pulse, resulting in a slightly reduced noise level each time. These values are then aggregated into a $L_{E,p,t}$ value over the entire operation. The faster an animal is fleeing, the greater the distance travelled between noise events. The impact range outputted by the model for this represents the location the receptor must be at the start of the operation to exactly meet the exposure threshold.

As an example, the graphs in Figure 3-9 and Figure 3-10 show the difference in the received $L_{E,p,ss}$ and $L_{E,p,t}$ from a stationary receptor and a fleeing receptor travelling at a constant speed of 1.5 m/s using the transect with the largest transmission (116°) for the monopile installation at the SE modelling location.

The received single strike $L_{E,p,ss}$ from the stationary receptor, as illustrated in Figure 3-9, shows the noise levels rising as the blow energy increases throughout the monopile installation. These step changes are also visible for the fleeing receptor, but as the fleeing receptor is further from the noise source by the time the levels increase, the total received exposure reduces, resulting in lower cumulative levels. As an example, for the first 20 minutes of piling, a receptor fleeing at a rate of 1.5 m/s has the potential to move 1.8 km away from the noise source. After the full installation of 3 hours and 10 minutes, a receptor has the potential to be over 17 km from the noise source.

Figure 3-10 shows the effect that these differing single strike received levels have when calculating the $L_{E,p,t}$, clearly showing the difference in the cumulative levels between a receptor remaining still as opposed to fleeing. To use an extreme example, starting at a range of 1 m, the first strike results in a received level of 212.4 dB re 1 $\mu\text{Pa}^2\text{s}$. If the receptor were to remain stationary for the entire piling operation it would receive a cumulative noise exposure of 254.4 dB re 1 $\mu\text{Pa}^2\text{s}$, whereas when a receptor flees at a constant speed of 1.5 m/s over the same scenario, the cumulative received exposure is calculated to be just 213.1 dB re 1 $\mu\text{Pa}^2\text{s}$, only 0.7 dB higher than the first pile strike.

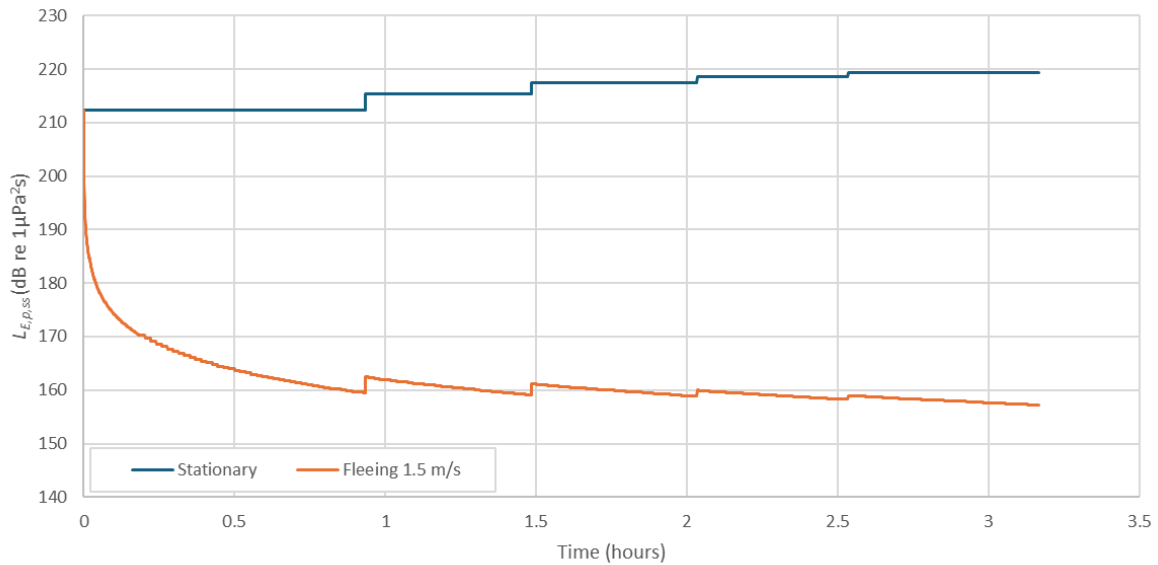


Figure 3-9: Received single strike noise levels ($L_{E,p,ss}$) for receptors during monopile installation at the SE modelling location, assuming both stationary and fleeing receptors starting at a location 1 m from the noise source.

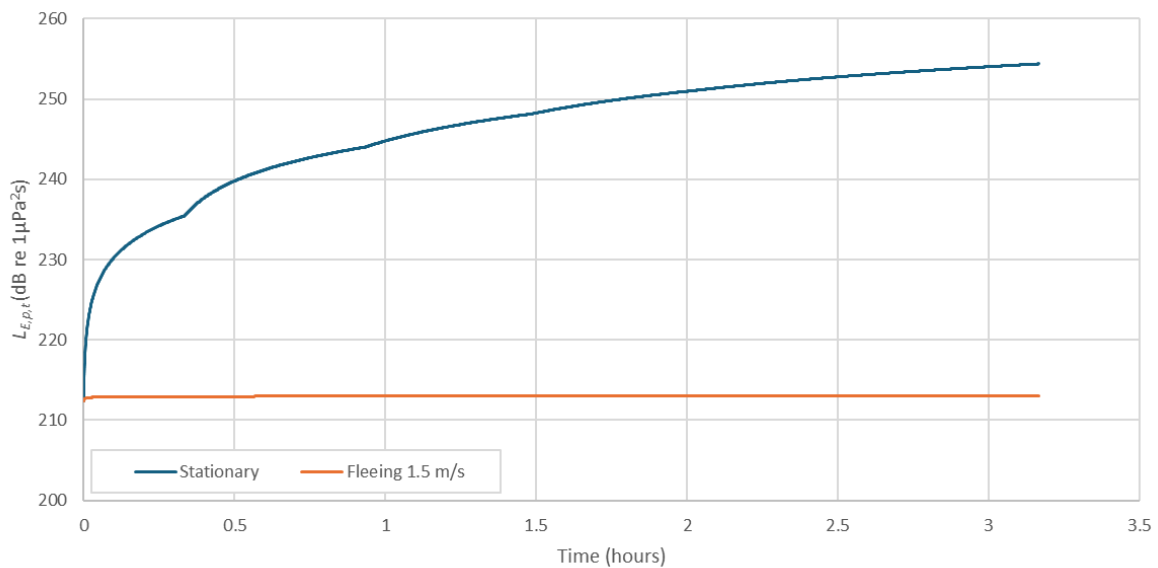


Figure 3-10: Cumulative received noise level ($L_{E,p,t}$) for receptors during monopile installation at the SE modelling location, assuming both stationary and fleeing receptors starting at a location 1 m from the noise source.

To summarise, if a receptor were to start fleeing in a straight line away from the noise source starting at a range closer than the modelled impact range, it would receive a noise exposure in excess of the criterion, and if the receptor were to start fleeing from a range further than the modelled value, it would receive a noise exposure below the criterion. This is illustrated in Figure 3-11.

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. This is not recommended for inclusion in modelling, as there are many ADDs with different performances, species-specific reactions and effectiveness,

and a defined ADD operation plan would need to be presumed. Instead the efficacy requirement from an ADD can be inferred from the results. For example, if a receptor were to flee for 20 minutes from an ADD at a rate of 1.5 m/s, it would travel 1.8 km before piling begins. If a calculated cumulative $L_{E,p,t}$ impact range was below 1.8 km, it can be assumed that the ADD will therefore be effective in eliminating the risk of exceedance of the threshold. The noise from an ADD is of a much lower level than impact piling, and as such its overall effect on the total $L_{E,p,t}$ exposure would be minimal.

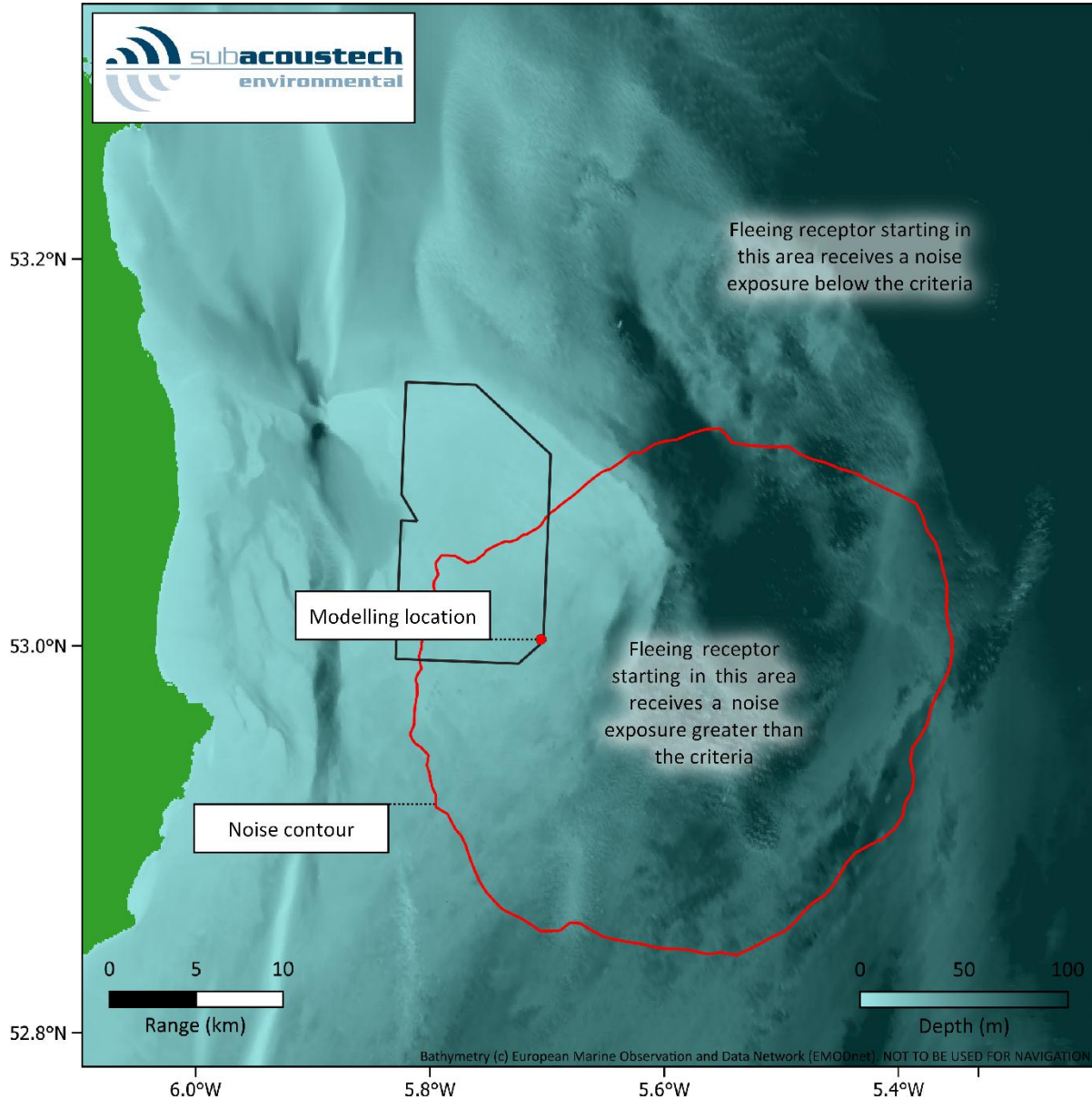


Figure 3-11: Example plot showing a fleeing animal $L_{E,p,t}$ criteria contour and the areas where the cumulative noise exposure will exceed a given impact.

3.3.1 The effects of parameters on cumulative levels and fleeing receptors

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

Hammer blow energy can have a clear effect on the impact ranges, with higher energies resulting in high apparent source noise levels and therefore larger impact ranges. When considering cumulative noise levels, these higher levels are compounded, sometimes thousands of times, due to the number of pile strikes. With this in mind, the ramp up from lower to higher blow energies requires careful consideration for fleeing receptors, as levels while the receptor is closer to the noise source will have a greater effect on the overall cumulative exposure level. This is why the 'more restrictive' ramp-up has been considered for the SE modelling location at the CWP Project.

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

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

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

3.4 Precaution in underwater noise modelling

It is worth reiterating the precaution that is included in the modelling when assessing environmental impacts. In an effort to minimise the risk of under-prediction for potential impact ranges that occur in respect of sensitive marine mammal and fish receptors, conservative parameters are included for every element, which can be broken down into three basic steps (source, transmission path and receiver) for acoustic modelling. The possibility that the worst-case conservative parameters could all occur together is highly unlikely, but necessary for the purposes of the assessment.

3.4.1 Source

The modelling locations were chosen to provide the greatest extents of the site, and specifically the locations likely to lead to underwater noise transmission over the greatest distances. The largest diameter for all types of pile has been used for the worst case. The maximum blow energies were used for a duration unlikely to occur in practice. The total piling duration is at the top of expectations and not expected to be exceeded on site.

3.4.2 Transmission path

Sound attenuates over distance from the source. The model considers fundamental acoustic spreading predictions adjusted to empirical data, accounting for frequency content, water depth, and other environmental factors, but fits to this data can still overestimate levels (see section 3.1).

3.4.3 Receiver

The thresholds used for the sensitivity of marine mammals and fish are based on respective guidance for species groups (e.g., NMFS, 2024; Popper *et al.*, 2014). However, these tend to be precautionary in themselves. Frequency specific hearing thresholds are not used for fish as they are with marine mammals, effectively assuming that fish are sensitive to sound at all frequencies, which is not the case. Also, the thresholds calculated for auditory injury and TTS are the 'onset' to these effects for both fish and marine mammals, which means that this is the threshold at which the effect starts to be detected in test species, rather than where this effect is widespread.

Concerning the flee speeds used in the modelling, studies have shown that these are typical swimming speeds (Williams, 2009), however flee speeds would be expected to be much faster during high noise conditions (McGarry *et al.*, 2017; Kastelein *et al.*, 2018). Using a faster flee speed would lead to much smaller cumulative impact ranges and consequently fewer impacted individuals.

The risk of injury will not remain constant throughout a modelled range either, although the model cannot account for this. The further away from the noise source the lower the risk will be, and thus at the impact contour, this is effectively the position of onset of effect and therefore negligible risk.

Modelling does not include any assessment of impulsiveness, as criteria do not yet exist to specify a transition (Matei *et al.*, 2024), this means that any injury (or PTS) or TTS onset thresholds beyond a distance of the order of 3.5 km to 5 km (Hastie *et al.*, 2019, Matei *et al.*, 2024) are likely to over-estimate the risk to marine mammals, especially at greater distances.

All of these elements are not acting in isolation but will combine (i.e., at the greatest ranges there is a low risk of injury, and reduced impulsivity, and are unlikely due to the slower-than-expected swim speeds) and contribute to the significant degree of precaution in the assessment.

4 Modelling results

This section presents the modelling results from impact piling noise to install monopile foundations at the CWP Project following the parameters detailed in section 3.2. The calculated impact ranges and areas cover the various criteria detailed in section 2.3 for species of marine mammals and fish. To aid navigation, Table 4-1 gives a list of the results tables presented in this section. The largest modelled ranges from impact piling at the CWP Project are generally predicted at the SE location due to the deep water at and surrounding that location.

Although unmitigated results are presented in the first sets of results below, underwater noise mitigation to achieve a noise limit of 169 dB $L_{E,p,ss}$ at 750 m is proposed at the CWP Project, and so the unmitigated results in section 4.1 are presented for information.

Throughout this report any predicted ranges smaller than 50 m have not been presented in detail. At ranges this close to the noise source, the modelling processes are unable to model to a sufficient level of accuracy due to complex acoustic effects present near the source. These ranges are given as “less than” this limit (e.g., < 50 m). Similarly, areas smaller than 0.01 km² have not been presented.

Table 4-1: List of the impact piling modelling results tables presented in this section.

Table (page)	Scenario	Criteria / requirements		
Table 4-2 (p37)	Monopile, unmitigated SE (most restrictive ramp-up) (4.1.1)	NMFS (2024)	Unweighted $L_{p,pk}$ (Impulsive)	
Table 4-3 (p37)			Weighted $L_{E,p,24h,wtd}$ (Impulsive) (Single pile)	
Table 4-4 (p37)		NOAA (2005)	Unweighted $L_{p,RMS}$ (Level B)	
Table 4-5 (p37)			Unweighted $L_{p,pk}$ (Pile driving)	
Table 4-6 (p38)		Popper <i>et al.</i> (2014)	Unweighted $L_{E,p,24h}$ (Pile driving) (Single pile)	
Table 4-7 (p38)			German requirements	
Table 4-8 (p38)			Belgian requirements	
Table 4-9 (p38)			Danish behavioural requirements	
Table 4-10 (p39)		Monopile, unmitigated SW (less restrictive ramp-up) (4.1.2)	NMFS (2024)	Unweighted $L_{p,pk}$ (Impulsive)
Table 4-11 (p39)	Weighted $L_{E,p,24h,wtd}$ (Impulsive) (Single pile)			
Table 4-12 (p39)	NOAA (2005)		Unweighted $L_{p,RMS}$ (Level B)	
Table 4-13 (p39)			Unweighted $L_{p,pk}$ (Pile driving)	
Table 4-14 (p40)	Popper <i>et al.</i> (2014)		Unweighted $L_{E,p,24h}$ (Pile driving) (Single pile)	
Table 4-15 (p40)			German requirements	
Table 4-16 (p40)			Belgian requirements	
Table 4-17 (p40)			Danish behavioural requirements	
Table 4-18 (p41)	Monopile, unmitigated NE (less restrictive ramp-up) (4.1.3)		NMFS (2024)	Unweighted $L_{p,pk}$ (Impulsive)
Table 4-19 (p41)		Weighted $L_{E,p,24h,wtd}$ (Impulsive) (Single pile)		
Table 4-20 (p41)		NOAA (2005)	Unweighted $L_{p,RMS}$ (Level B)	
Table 4-21 (p41)			Unweighted $L_{p,pk}$ (Pile driving)	
Table 4-22 (p42)		Popper <i>et al.</i> (2014)	Unweighted $L_{E,p,24h}$ (Pile driving) (Single pile)	
Table 4-23 (p42)			German requirements	
Table 4-24 (p42)			Belgian requirements	
Table 4-25 (p42)			Danish behavioural requirements	

Table (page)	Scenario	Criteria / requirements		
Table 4-26 (p43)	Monopile, unmitigated NW (less restrictive ramp-up, two sequential piles) (4.1.4)	NMFS (2024)	Unweighted $L_{p,pk}$ (Impulsive)	
Table 4-27 (p43)			Weighted $L_{E,p,24h,wtd}$ (Impulsive) (Single pile)	
Table 4-28 (p43)			Weighted $L_{E,p,24h,wtd}$ (Impulsive) (2 piles)	
Table 4-29 (p43)		NOAA (2005)	Unweighted $L_{p,RMS}$ (Level B)	
Table 4-30 (p44)		Popper <i>et al.</i> (2014)	Unweighted $L_{p,pk}$ (Pile driving)	
Table 4-31 (p44)			Unweighted $L_{E,p,24h}$ (Pile driving) (Single pile)	
Table 4-32 (p44)			Unweighted $L_{E,p,24h}$ (Pile driving) (2 piles)	
Table 4-33 (p44)		German requirements		
Table 4-34 (p45)		Belgian requirements		
Table 4-35 (p45)		Danish behavioural requirements		
Table 4-36 (p45)		Monopile, mitigated SE (most restrictive ramp-up) (4.2.1)	NMFS (2024)	Unweighted $L_{p,pk}$ (Impulsive)
Table 4-37 (p45)				Weighted $L_{E,p,24h,wtd}$ (Impulsive) (Single pile)
Table 4-38 (p46)			NOAA (2005)	Unweighted $L_{p,RMS}$ (Level B)
Table 4-39 (p46)			Popper <i>et al.</i> (2014)	Unweighted $L_{p,pk}$ (Pile driving)
Table 4-40 (p46)	Unweighted $L_{E,p,24h}$ (Pile driving) (Single pile)			
Table 4-41 (p46)	German requirements			
Table 4-42 (p46)	Belgian requirements			
Table 4-43 (p47)	Danish behavioural requirements			
Table 4-44 (p47)	Monopile, mitigated SW (less restrictive ramp-up) (4.2.2)		NMFS (2024)	Unweighted $L_{p,pk}$ (Impulsive)
Table 4-45 (p47)				Weighted $L_{E,p,24h,wtd}$ (Impulsive) (Single pile)
Table 4-46 (p47)			NOAA (2005)	Unweighted $L_{p,RMS}$ (Level B)
Table 4-47 (p48)			Popper <i>et al.</i> (2014)	Unweighted $L_{p,pk}$ (Pile driving)
Table 4-48 (p48)				Unweighted $L_{E,p,24h}$ (Pile driving) (Single pile)
Table 4-49 (p48)			German requirements	
Table 4-50 (p48)		Belgian requirements		
Table 4-51 (p48)		Danish behavioural requirements		
Table 4-52 (p49)		Monopile, mitigated) NE (less restrictive ramp-up) (4.2.3)	NMFS (2024)	Unweighted $L_{p,pk}$ (Impulsive)
Table 4-53 (p49)				Weighted $L_{E,p,24h,wtd}$ (Impulsive) (Single pile)
Table 4-54 (p49)			NOAA (2005)	Unweighted $L_{p,RMS}$ (Level B)
Table 4-55 (p49)			Popper <i>et al.</i> (2014)	Unweighted $L_{p,pk}$ (Pile driving)
Table 4-56 (p50)				Unweighted $L_{E,p,24h}$ (Pile driving) (Single pile)
Table 4-57 (p50)			German requirements	
Table 4-58 (p50)	Belgian requirements			
Table 4-59 (p50)	Danish behavioural requirements			
Table 4-60 (p51)	Monopile, mitigated NW (less restrictive ramp-up, two sequential piles) (4.2.4)		NMFS (2024)	Unweighted $L_{p,pk}$ (Impulsive)
Table 4-61 (p51)				Weighted $L_{E,p,24h,wtd}$ (Impulsive) (Single pile)
Table 4-62 (p51)				Weighted $L_{E,p,24h,wtd}$ (Impulsive) (2 piles)
Table 4-63 (p51)			NOAA (2005)	Unweighted $L_{p,RMS}$ (Level B)
Table 4-64 (p52)			Popper <i>et al.</i> (2014)	Unweighted $L_{p,pk}$ (Pile driving)
Table 4-65 (p52)				Unweighted $L_{E,p,24h}$ (Pile driving) (Single pile)
Table 4-66 (p52)		Unweighted $L_{E,p,24h}$ (Pile driving) (2 piles)		
Table 4-67 (p52)		German requirements		
Table 4-68 (p53)		Belgian requirements		
Table 4-69 (p53)		Danish behavioural requirements		

The modelling results for the first pile strike and the NMFS (2024) non-impulsive criteria are presented in Appendix A. Contour plots for the NMFS (2024) and Popper *et al.* (2014) $L_{E,p,24h}$ criteria are presented in Appendix B.

Table 4-2 to Table 4-69 present the impact piling modelling results for the CWP Project covering unmitigated and mitigated scenarios. For these scenarios, the largest marine mammal impact ranges are predicted at the SE modelling location during monopile installation using the most restrictive ramp-up scenario, with maximum unmitigated auditory injury onset ranges for LF cetaceans out to 8.0 km. When considering noise reduction from mitigation, the maximum injury range of any marine mammal species reduced to 140 m. For fish, the largest

recoverable injury ranges (203 dB $L_{E,p,24h}$) are predicted out to 4.0 km when considering a stationary receptor during unmitigated sequential installation of two monopiles at the NW modelling location, reducing to 1.6 km when mitigation is considered. When a fleeing receptor is considered all recoverable injury ranges at all modelling locations, both unmitigated and mitigated, are predicted to be less than 50 m.

4.1 Unmitigated impact piling results

4.1.1 SE

Table 4-2: Unweighted $L_{p,pk}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the maximum expected hammer blow energy during the monopile installation at the SE modelling location.

NMFS (2024) Unweighted $L_{p,pk}$		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	222 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	230 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	202 dB (VHF)	1.0 km ²	570 m	550 m	560 m
	223 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	216 dB (LF)	0.02 km ²	80 m	80 m	80 m
	224 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	196 dB (VHF)	4.9 km ²	1.3 km	1.2 km	1.2 km
	217 dB (PW)	0.02 km ²	70 m	70 m	70 m

Table 4-3: Weighted $L_{E,p,24h,wtd}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the monopile installation (single pile) at the SE modelling location assuming fleeing receptors.

NMFS (2024) Weighted $L_{E,p,24h,wtd}$		Monopile foundation, unmitigated (single pile)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	183 dB (LF)	67 km ²	8.0 km	1.6 km	4.0 km
	193 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	159 dB (VHF)	0.24 km ²	530 m	90 m	230 m
	183 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	168 dB (LF)	4,800 km ²	60 km	11 km	35 km
	178 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	144 dB (VHF)	2,100 km ²	39 km	8.1 km	23 km
	168 dB (PW)	440 km ²	19 km	4.6 km	11 km

Table 4-4: Unweighted $L_{p,RMS}$ impact areas and ranges for marine mammals using the NOAA (2005) Level B criteria for the maximum expected hammer blow energy during the monopile installation at the SE modelling location.

NOAA (2005) Unweighted $L_{p,RMS}$		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Level B	160 dB	1,200 km ²	27 km	12 km	19 km

Table 4-5: Unweighted $L_{p,pk}$ impact areas and ranges for fish using the Popper et al (2014) pile driving criteria for the maximum expected hammer blow energy during the monopile installation at the SE modelling location.

Popper et al. (2014) Unweighted $L_{p,pk}$		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	0.05 km ²	120 m	120 m	120 m
	207 dB	0.25 km ²	280 m	280 m	280 m

Table 4-6: Unweighted $L_{E,p,24h}$ impact areas and ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile installation (single pile) at the SE modelling location assuming both fleeing and stationary receptors.

Popper et al. (2014) Unweighted $L_{E,p,24h}$		Monopile foundation, unmitigated (single pile)			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	186 dB	700 km ²	24 km	5.9 km	13 km
Stationary (0 m/s)	219 dB	0.38 km ²	350 m	340 m	350 m
	216 dB	0.98 km ²	560 m	550 m	560 m
	210 dB	6.5 km ²	1.5 km	1.4 km	1.4 km
	207 dB	16 km ²	2.3 km	2.1 km	2.2 km
	203 dB	44 km ²	4.0 km	3.5 km	3.8 km
	186 dB	1,800 km ²	34 km	14 km	23 km

Table 4-7: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the German underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation at the SE modelling location.

German requirements		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	190 dB	21 km ²	2.8 km	2.5 km	2.6 km
Unweighted $L_{E,p,ss}$	160 dB	280 km ²	12 km	7.5 km	9.3 km

Table 4-8: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the Belgian underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation at the SE modelling location.

Belgian requirements		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	185 dB	66 km ²	5.2 km	4.1 km	4.6 km
Unweighted $L_{E,p,ss}$	162 dB	180 km ²	9.2 km	6.4 km	7.5 km

Table 4-9: Unweighted $L_{E,p,ss}$ and $L_{p,RMS,wtd,125ms}$ impact areas and ranges for the Danish behavioural underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation at the SE modelling location.

Danish behavioural requirements		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{E,p,ss}$	143 dB	6,000 km ²	63 km	17 km	40 km
Weighted $L_{p,RMS,wtd,125ms}$	103 dB (VHF)	11,000 km ²	85 km	20 km	53 km

The AUD INJ results modelled as per Table 4-3 represent the r_{safe} ranges under the Danish requirements

4.1.2 SW

Table 4-10: Unweighted $L_{p,pk}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the maximum expected hammer blow energy during the monopile installation at the SW modelling location.

NMFS (2024) Unweighted $L_{p,pk}$		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	222 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	230 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	202 dB (VHF)	0.5 km ²	410 m	400 m	400 m
	223 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	216 dB (LF)	0.01 km ²	60 m	60 m	60 m
	224 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	196 dB (VHF)	2.4 km ²	880 m	850 m	870 m
	217 dB (PW)	< 0.01 km ²	50 m	50 m	50 m

Table 4-11: Weighted $L_{E,p,24h,wt}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the monopile installation (single pile) at the SW modelling location assuming fleeing receptors.

NMFS (2024) Weighted $L_{E,p,24h,wt}$		Monopile foundation, unmitigated (single pile)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	183 dB (LF)	17 km ²	3.6 km	1.2 km	2.2 km
	193 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	159 dB (VHF)	1.3 km ²	1.0 km	240 m	590 m
	183 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	168 dB (LF)	2,700 km ²	49 km	7.7 km	25 km
	178 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	144 dB (VHF)	1,300 km ²	32 km	7.3 km	18 km
	168 dB (PW)	270 km ²	14 km	5.1 km	8.8 km

Table 4-12: Unweighted $L_{p,RMS}$ impact areas and ranges for marine mammals using the NOAA (2005) Level B criteria for the maximum expected hammer blow energy during the monopile installation at the SW modelling location.

NOAA (2005) Unweighted $L_{p,RMS}$		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Level B	160 dB	510 km ²	15 km	9.9 km	13 km

Table 4-13: Unweighted $L_{p,pk}$ impact areas and ranges for fish using the Popper et al (2014) pile driving criteria for the maximum expected hammer blow energy during the monopile installation at the SW modelling location.

Popper et al. (2014) Unweighted $L_{p,pk}$		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	0.03 km ²	90 m	90 m	90 m
	207 dB	0.14 km ²	210 m	210 m	210 m

Table 4-14: Unweighted $L_{E,p,24h}$ impact areas and ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile installation (single pile) at the SW modelling location assuming both fleeing and stationary receptors.

Popper et al. (2014) Unweighted $L_{E,p,24h}$		Monopile foundation, unmitigated (single pile)			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	186 dB	250 km ²	13 km	5.1 km	8.5 km
Stationary (0 m/s)	219 dB	0.32 km ²	320 m	320 m	320 m
	216 dB	0.81 km ²	510 m	500 m	510 m
	210 dB	5.3 km ²	1.3 km	1.2 km	1.3 km
	207 dB	11 km ²	2.0 km	1.8 km	1.9 km
	203 dB	31 km ²	3.3 km	2.9 km	3.1 km
	186 dB	860 km ²	22 km	12 km	16 km

Table 4-15: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the German underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation at the SW modelling location.

German requirements		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	190 dB	10 km ²	1.8 km	1.7 km	1.8 km
Unweighted $L_{E,p,ss}$	160 dB	140 km ²	7.5 km	5.8 km	6.7 km

Table 4-16: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the Belgian underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation at the SW modelling location.

Belgian requirements		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	185 dB	29 km ²	3.3 km	2.8 km	3.1 km
Unweighted $L_{E,p,ss}$	162 dB	93 km ²	6.0 km	4.7 km	5.4 km

Table 4-17: Unweighted $L_{E,p,ss}$ and $L_{p,RMS,wtd,125ms}$ impact areas and ranges for the Danish behavioural underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation at the SW modelling location.

Danish behavioural requirements		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{E,p,ss}$	143 dB	2,400 km ²	41 km	11 km	26 km
Weighted $L_{p,RMS,wtd,125ms}$	103 dB (VHF)	6,500 km ²	71 km	11 km	40 km

The AUD INJ results modelled as per Table 4-11 represent the r_{safe} ranges under the Danish requirements

4.1.3 NE

Table 4-18: Unweighted $L_{p,pk}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the maximum expected hammer blow energy during the monopile installation at the NE modelling location.

NMFS (2024) Unweighted $L_{p,pk}$		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	222 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	230 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	202 dB (VHF)	0.3 km ²	320 m	310 m	320 m
	223 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	216 dB (LF)	< 0.01 km ²	50 m	50 m	50 m
	224 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	196 dB (VHF)	1.4 km ²	680 m	640 m	660 m
	217 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table 4-19: Weighted $L_{E,p,24h,wt}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the monopile installation (single pile) at the NE modelling location assuming fleeing receptors.

NMFS (2024) Weighted $L_{E,p,24h,wt}$		Monopile foundation, unmitigated (single pile)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	183 dB (LF)	11 km ²	4.0 km	440 m	1.4 km
	193 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	159 dB (VHF)	0.59 km ²	1.0 km	50 m	300 m
	183 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	168 dB (LF)	3,000 km ²	55 km	5.8 km	26 km
	178 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	144 dB (VHF)	1,800 km ²	41 km	6.0 km	21 km
	168 dB (PW)	400 km ²	20 km	3.2 km	9.6 km

Table 4-20: Unweighted $L_{p,RMS}$ impact areas and ranges for marine mammals using the NOAA (2005) Level B criteria for the maximum expected hammer blow energy during the monopile installation at the NE modelling location.

NOAA (2005) Unweighted $L_{p,RMS}$		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Level B	160 dB	430 km ²	17 km	7.2 km	11 km

Table 4-21: Unweighted $L_{p,pk}$ impact areas and ranges for fish using the Popper et al (2014) pile driving criteria for the maximum expected hammer blow energy during the monopile installation at the NE modelling location.

Popper et al. (2014) Unweighted $L_{p,pk}$		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	0.02 km ²	80 m	80 m	80 m
	207 dB	0.09 km ²	170 m	170 m	170 m

Table 4-22: Unweighted $L_{E,p,24h}$ impact areas and ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile installation (single pile) at the NE modelling location assuming both fleeing and stationary receptors.

Popper et al. (2014) Unweighted $L_{E,p,24h}$		Monopile foundation, unmitigated (single pile)			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	186 dB	250 km ²	16 km	2.9 km	7.7 km
Stationary (0 m/s)	219 dB	0.21 km ²	260 m	260 m	260 m
	216 dB	0.51 km ²	410 m	400 m	400 m
	210 dB	2.8 km ²	980 m	920 m	940 m
	207 dB	6.5 km ²	1.5 km	1.4 km	1.4 km
	203 dB	18 km ²	2.6 km	2.2 km	2.4 km
	186 dB	810 km ²	24 km	8.8 km	15 km

Table 4-23: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the German underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation at the NE modelling location.

German requirements		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	190 dB	5.4 km ²	1.4 km	1.3 km	1.3 km
Unweighted $L_{E,p,ss}$	160 dB	89 km ²	7.0 km	4.3 km	5.3 km

Table 4-24: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the Belgian underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation at the NE modelling location.

Belgian requirements		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	185 dB	16 km ²	2.5 km	2.1 km	2.2 km
Unweighted $L_{E,p,ss}$	162 dB	56 km ²	5.2 km	3.6 km	4.2 km

Table 4-25: Unweighted $L_{E,p,ss}$ and $L_{p,RMS,wtd,125ms}$ impact areas and ranges for the Danish behavioural underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation at the NE modelling location.

Danish behavioural requirements		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{E,p,ss}$	143 dB	3,000 km ²	49 km	11 km	28 km
Weighted $L_{p,RMS,wtd,125ms}$	103 dB (VHF)	8,600 km ²	84 km	19 km	48 km

The AUD INJ results modelled as per Table 4-19 represent the r_{safe} ranges under the Danish requirements

4.1.4 [NW](#)

Table 4-26: Unweighted $L_{p,pk}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the maximum expected hammer blow energy during the monopile installation at the NW modelling location.

NMFS (2024) Unweighted $L_{p,pk}$		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	222 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	230 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	202 dB (VHF)	0.3 km ²	320 m	300 m	310 m
	223 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	216 dB (LF)	< 0.01 km ²	50 m	50 m	50 m
	224 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	196 dB (VHF)	1.3 km ²	680 m	600 m	640 m
	217 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table 4-27: Weighted $L_{E,p,24h,wt}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the monopile installation (single pile) at the NW modelling location assuming fleeing receptors.

NMFS (2024) Weighted $L_{E,p,24h,wt}$		Monopile foundation, unmitigated (single pile)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	183 dB (LF)	2.1 km ²	2.0 km	350 m	710 m
	193 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	159 dB (VHF)	0.11 km ²	550 m	< 50 m	140 m
	183 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	168 dB (LF)	1,100 km ²	39 km	4.9 km	16 km
	178 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	144 dB (VHF)	680 km ²	27 km	5.9 km	13 km
	168 dB (PW)	120 km ²	12 km	2.1 km	5.8 km

Table 4-28: Weighted $L_{E,p,24h,wt}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the monopile installation (2 sequential piles) at the NW modelling location assuming fleeing receptors.

NMFS (2024) Weighted $L_{E,p,24h,wt}$		Monopile foundation, unmitigated (2 sequential piles)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	183 dB (LF)	2.2 km ²	2.0 km	350 m	730 m
	193 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	159 dB (VHF)	0.15 km ²	670 m	< 50 m	150 m
	183 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	168 dB (LF)	1,200 km ²	40 km	4.9 km	16 km
	178 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	144 dB (VHF)	880 km ²	33 km	5.9 km	15 km
	168 dB (PW)	150 km ²	12 km	2.1 km	6.2 km

Table 4-29: Unweighted $L_{p,RMS}$ impact areas and ranges for marine mammals using the NOAA (2005) Level B criteria for the maximum expected hammer blow energy during the monopile installation at the NW modelling location.

NOAA (2005) Unweighted $L_{p,RMS}$		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Level B	160 dB	270 km ²	14 km	6.2 km	9.0 km

Table 4-30: Unweighted $L_{p,pk}$ impact areas and ranges for fish using the Popper et al (2014) pile driving criteria for the maximum expected hammer blow energy during the monopile installation at the NW modelling location.

Popper et al. (2014) Unweighted $L_{p,pk}$	Monopile foundation, unmitigated (maximum energy: 4,400 kJ)				
	Area	Maximum range	Minimum range	Mean range	
Pile driving	213 dB	0.02 km ²	80 m	80 m	80 m
	207 dB	0.09 km ²	170 m	170 m	170 m

Table 4-31: Unweighted $L_{E,p,24h}$ impact areas and ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile installation (single pile) at the NW modelling location assuming both fleeing and stationary receptors.

Popper et al. (2014) Unweighted $L_{E,p,24h}$	Monopile foundation, unmitigated (single pile)				
	Area	Maximum range	Minimum range	Mean range	
Fleeing (1.5 m/s)	219 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
Stationary (0 m/s)	186 dB	88 km ²	9.9 km	2.0 km	4.8 km
	219 dB	0.2 km ²	260 m	250 m	260 m
	216 dB	0.49 km ²	410 m	380 m	390 m
	210 dB	2.6 km ²	990 m	840 m	910 m
	207 dB	6.2 km ²	1.6 km	1.3 km	1.4 km
	203 dB	16 km ²	2.7 km	1.9 km	2.3 km
186 dB	480 km ²	18 km	8.4 km	12 km	

Table 4-32: Unweighted $L_{E,p,24h}$ impact areas and ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile installation (2 sequential piles) at the NW modelling location assuming both fleeing and stationary receptors.

Popper et al. (2014) Unweighted $L_{E,p,24h}$	Monopile foundation, unmitigated (2 sequential piles)				
	Area	Maximum range	Minimum range	Mean range	
Fleeing (1.5 m/s)	219 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
Stationary (0 m/s)	186 dB	100 km ²	11 km	2.0 km	5.0 km
	219 dB	0.49 km ²	410 m	380 m	390 m
	216 dB	1.1 km ²	640 m	570 m	600 m
	210 dB	6.2 km ²	1.6 km	1.3 km	1.4 km
	207 dB	13 km ²	2.4 km	1.8 km	2.0 km
	203 dB	31 km ²	4.0 km	2.5 km	3.1 km
186 dB	770 km ²	23 km	10 km	15 km	

Table 4-33: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the German underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation at the NW modelling location.

German requirements	Monopile foundation, unmitigated (maximum energy: 4,400 kJ)				
	Area	Maximum range	Minimum range	Mean range	
Unweighted $L_{p,pk}$	190 dB	5.1 km ²	1.4 km	1.1 km	1.3 km
Unweighted $L_{E,p,ss}$	160 dB	69 km ²	6.3 km	3.4 km	4.6 km

Table 4-34: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the Belgian underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation at the NW modelling location.

Belgian requirements		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	185 dB	15 km ²	2.6 km	1.8 km	2.1 km
Unweighted $L_{E,p,ss}$	162 dB	46 km ²	5.0 km	2.9 km	3.8 km

Table 4-35: Unweighted $L_{E,p,ss}$ and $L_{p,RMS,wtd,125ms}$ impact areas and ranges for the Danish behavioural underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation at the NW modelling location.

Danish behavioural requirements		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{E,p,ss}$	143 dB	1,300 km ²	33 km	13 km	20 km
Weighted $L_{p,RMS,wtd,125ms}$	103 dB (VHF)	4,600 km ²	69 km	14 km	34 km

The AUD INJ results modelled as per Table 4-27 and Table 4-28 represent the r_{safe} ranges under the Danish requirements

4.2 Mitigated impact piling results

4.2.1 SE

Table 4-36: Unweighted $L_{p,pk}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the maximum expected hammer blow energy during the monopile installation including the commitment to mitigate noise by the introduction of the 169 dB $L_{E,p,ss}$ (SEL_{ss}) limit at all locations.

NMFS (2024)		Monopile foundation, mitigated (maximum energy: 4,400 kJ)			
Unweighted $L_{p,pk}$		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	222 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	230 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	202 dB (VHF)	0.1 km ²	140 m	140 m	140 m
	223 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	216 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	224 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	196 dB (VHF)	0.33 km ²	330 m	320 m	320 m
	217 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table 4-37: Weighted $L_{E,p,24h,wtd}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the monopile installation (single pile) including mitigation at the SE modelling location assuming fleeing receptors.

NMFS (2024)		Monopile foundation, mitigated (single pile)			
Weighted $L_{E,p,24h,wtd}$		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	183 dB (LF)	0.01 km ²	70 m	50 m	60 m
	193 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	159 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	183 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	168 dB (LF)	580 km ²	22 km	4.2 km	12 km
	178 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	144 dB (VHF)	63 km ²	7.5 km	1.6 km	3.9 km
	168 dB (PW)	1.2 km ²	1.1 km	240 m	530 m

Table 4-38: Unweighted $L_{p,RMS}$ impact areas and ranges for marine mammals using the NOAA (2005) Level B criteria for the maximum expected hammer blow energy during the monopile installation including mitigation at the SE modelling location.

NOAA (2005)		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
Unweighted $L_{p,RMS}$		Area	Maximum range	Minimum range	Mean range
Level B	160 dB	140 km ²	8.0 km	5.9 km	6.7 km

Table 4-39: Unweighted $L_{p,pk}$ impact areas and ranges for fish using the Popper et al (2014) pile driving criteria for the maximum expected hammer blow energy during the monopile installation including mitigation at the SE modelling location.

Popper et al. (2014)		Monopile foundation, mitigated (maximum energy: 4,400 kJ)			
Unweighted $L_{p,pk}$		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	0.02 km ²	70 m	70 m	70 m

Table 4-40: Unweighted $L_{E,p,24h}$ impact areas and ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile installation (single pile) including mitigation at the SE modelling location assuming both fleeing and stationary receptors.

Popper et al. (2014)		Monopile foundation, mitigated (single pile)			
Unweighted $L_{E,p,24h}$		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	186 dB	5.7 km ²	2.3 km	600 m	1.2 km
Stationary (0 m/s)	219 dB	0.02 km ²	70 m	70 m	70 m
	216 dB	0.04 km ²	110 m	110 m	110 m
	210 dB	0.28 km ²	300 m	290 m	300 m
	207 dB	0.72 km ²	480 m	470 m	480 m
	203 dB	2.5 km ²	900 m	880 m	890 m
	186 dB	230 km ²	11 km	7.0 km	8.5 km

Table 4-41: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the German underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation including mitigation at the SE modelling location.

German requirements		Monopile foundation, mitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	190 dB	1.7 km ²	740 m	720 m	730 m
Unweighted $L_{E,p,ss}$	160 dB	25 km ²	2.9 km	2.7 km	2.8 km

Table 4-42: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the Belgian underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation including mitigation at the SE modelling location.

Belgian requirements		Monopile foundation, mitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	185 dB	6.3 km ²	1.5 km	1.4 km	1.4 km
Unweighted $L_{E,p,ss}$	162 dB	14 km ²	2.2 km	2.1 km	2.1 km

Table 4-43: Unweighted $L_{E,p,ss}$ and $L_{p,RMS,wd,125ms}$ impact areas and ranges for the Danish behavioural underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation including mitigation at the SE modelling location.

Danish behavioural requirements	Monopile foundation, mitigated -10 dB (maximum energy: 4,400 kJ)				
	Area	Maximum range	Minimum range	Mean range	
Unweighted $L_{E,p,ss}$	143 dB	1,200 km ²	27 km	12 km	19 km
Weighted $L_{p,RMS,wd,125ms}$	103 dB (VHF)	3,700 km ²	49 km	16 km	32 km

The AUD INJ results modelled as per Table 4-37 represent the r_{safe} ranges under the Danish requirements

4.2.2 SW

Table 4-44: Unweighted $L_{p,pk}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the maximum expected hammer blow energy during the monopile installation including the commitment to mitigate noise by the introduction of the 169 dB $L_{E,p,ss}$ (SEL_{ss}) limit at all locations.

NMFS (2024) Unweighted $L_{p,pk}$	Monopile foundation, mitigated (maximum energy: 4,400 kJ)				
	Area	Maximum range	Minimum range	Mean range	
AUD INJ (Impulsive)	222 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	230 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	202 dB (VHF)	0.05 km ²	120 m	120 m	120 m
	223 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	216 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	224 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	196 dB (VHF)	0.23 km ²	270 m	270 m	270 m
	217 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table 4-45: Weighted $L_{E,p,24h,wd}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the monopile installation (single pile) including mitigation at the SW modelling location assuming fleeing receptors.

NMFS (2024) Weighted $L_{E,p,24h,wd}$	Monopile foundation, mitigated (single pile)				
	Area	Maximum range	Minimum range	Mean range	
AUD INJ (Impulsive)	183 dB (LF)	< 0.01 km ²	60 m	50 m	60 m
	193 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	159 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	183 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	168 dB (LF)	290 km ²	16 km	4.1 km	8.7 km
	178 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	144 dB (VHF)	99 km ²	7.8 km	3.2 km	5.4 km
	168 dB (PW)	6.1 km ²	1.9 km	750 m	1.4 km

Table 4-46: Unweighted $L_{p,RMS}$ impact areas and ranges for marine mammals using the NOAA (2005) Level B criteria for the maximum expected hammer blow energy during the monopile installation including mitigation at the SW modelling location.

NOAA (2005) Unweighted $L_{p,RMS}$	Monopile foundation, unmitigated (maximum energy: 4,400 kJ)				
	Area	Maximum range	Minimum range	Mean range	
Level B	160 dB	93 km ²	6.0 km	4.7 km	5.4 km

Table 4-47: Unweighted $L_{p,pk}$ impact areas and ranges for fish using the Popper et al (2014) pile driving criteria for the maximum expected hammer blow energy during the monopile installation including mitigation at the SW modelling location.

Popper et al. (2014) Unweighted $L_{p,pk}$	Monopile foundation, mitigated (maximum energy: 4,400 kJ)				
	Area	Maximum range	Minimum range	Mean range	
Pile driving	213 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	0.01 km ²	60 m	60 m	60 m

Table 4-48: Unweighted $L_{E,p,24h}$ impact areas and ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile installation (single pile) including mitigation at the SW modelling location assuming both fleeing and stationary receptors.

Popper et al. (2014) Unweighted $L_{E,p,24h}$	Monopile foundation, mitigated (single pile)				
	Area	Maximum range	Minimum range	Mean range	
Fleeing (1.5 m/s)	219 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
Stationary (0 m/s)	186 dB	4.0 km ²	1.6 km	650 m	1.1 km
	219 dB	0.02 km ²	80 m	80 m	80 m
	216 dB	0.05 km ²	130 m	130 m	130 m
	210 dB	0.32 km ²	320 m	320 m	320 m
	207 dB	0.81 km ²	510 m	500 m	510 m
	203 dB	2.6 km ²	930 m	900 m	920 m
	186 dB	180 km ²	8.5 km	6.4 km	7.5 km

Table 4-49: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the German underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation including mitigation at the SW modelling location.

German requirements	Monopile foundation, mitigated (maximum energy: 4,400 kJ)				
	Area	Maximum range	Minimum range	Mean range	
Unweighted $L_{p,pk}$	190 dB	1.1 km ²	600 m	580 m	590 m
Unweighted $L_{E,p,ss}$	160 dB	18 km ²	2.5 km	2.2 km	2.4 km

Table 4-50: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the Belgian underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation including mitigation at the SW modelling location.

Belgian requirements	Monopile foundation, mitigated (maximum energy: 4,400 kJ)				
	Area	Maximum range	Minimum range	Mean range	
Unweighted $L_{p,pk}$	185 dB	3.9 km ²	1.1 km	1.1 km	1.1 km
Unweighted $L_{E,p,ss}$	162 dB	10 km ²	1.9 km	1.8 km	1.8 km

Table 4-51: Unweighted $L_{E,p,ss}$ and $L_{p,RMS,wtd,125ms}$ impact areas and ranges for the Danish behavioural underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation including mitigation at the SW modelling location.

Danish behavioural requirements	Monopile foundation, mitigated (maximum energy: 4,400 kJ)				
	Area	Maximum range	Minimum range	Mean range	
Unweighted $L_{E,p,ss}$	143 dB	600 km ²	17 km	10 km	14 km
Weighted $L_{p,RMS,wtd,125ms}$	103 dB (VHF)	2,000 km ²	37 km	11 km	24 km

The AUD INJ results modelled as per Table 4-45 represent the r_{safe} ranges under the Danish requirements

4.2.3 NE

Table 4-52: Unweighted $L_{p,pk}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the maximum expected hammer blow energy during the monopile installation including the commitment to mitigate noise by the introduction of the 169 dB $L_{E,p,ss}$ (SEL_{ss}) limit at all locations.

NMFS (2024) Unweighted $L_{p,pk}$		Monopile foundation, mitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	222 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	230 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	202 dB (VHF)	0.05 km ²	130 m	130 m	130 m
	223 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	216 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	224 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	196 dB (VHF)	0.25 km ²	280 m	280 m	280 m
	217 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table 4-53: Weighted $L_{E,p,24h,wtd}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the monopile installation (single pile) including mitigation at the NE modelling location assuming fleeing receptors.

NMFS (2024) Weighted $L_{E,p,24h,wtd}$		Monopile foundation, mitigated (single pile)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	183 dB (LF)	0.02 km ²	90 m	60 m	70 m
	193 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	159 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	183 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	168 dB (LF)	630 km ²	26 km	2.7 km	12 km
	178 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	144 dB (VHF)	230 km ²	15 km	2.5 km	7.5 km
	168 dB (PW)	23 km ²	5.1 km	670 m	2.2 km

Table 4-54: Unweighted $L_{p,RMS}$ impact areas and ranges for marine mammals using the NOAA (2005) Level B criteria for the maximum expected hammer blow energy during the monopile installation including mitigation at the NE modelling location.

NOAA (2005) Unweighted $L_{p,RMS}$		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Level B	160 dB	89 km ²	6.9 km	4.3 km	5.2 km

Table 4-55: Unweighted $L_{p,pk}$ impact areas and ranges for fish using the Popper et al (2014) pile driving criteria for the maximum expected hammer blow energy during the monopile installation including mitigation at the NE modelling location.

Popper et al. (2014) Unweighted $L_{p,pk}$		Monopile foundation, mitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	0.01 km ²	70 m	70 m	70 m

Table 4-56: Unweighted $L_{E,p,24h}$ impact areas and ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile installation (single pile) including mitigation at the NE modelling location assuming both fleeing and stationary receptors.

Popper et al. (2014)		Monopile foundation, mitigated (single pile)			
Unweighted $L_{E,p,24h}$		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 m/s)	219 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	186 dB	7.0 km ²	2.9 km	440 m	1.2 km
Stationary (0 m/s)	219 dB	0.03 km ²	90 m	90 m	90 m
	216 dB	0.07 km ²	150 m	140 m	140 m
	210 dB	0.39 km ²	360 m	350 m	350 m
	207 dB	0.91 km ²	550 m	530 m	540 m
	203 dB	2.8 km ²	980 m	920 m	940 m
	186 dB	190 km ²	11 km	5.6 km	7.5 km

Table 4-57: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the German underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation including mitigation at the NE modelling location.

German requirements		Monopile foundation, mitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	190 dB	1.1 km ²	600 m	570 m	580 m
Unweighted $L_{E,p,ss}$	160 dB	17 km ²	2.5 km	2.1 km	2.3 km

Table 4-58: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the Belgian underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation including mitigation at the NE modelling location.

Belgian requirements		Monopile foundation, mitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	185 dB	3.5 km ²	1.1 km	1.0 km	1.1 km
Unweighted $L_{E,p,ss}$	162 dB	10 km ²	1.9 km	1.7 km	1.8 km

Table 4-59: Unweighted $L_{E,p,ss}$ and $L_{p,RMS,wtd,125ms}$ impact areas and ranges for the Danish behavioural underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation including mitigation at the NE modelling location.

Danish behavioural requirements		Monopile foundation, mitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{E,p,ss}$	143 dB	790 km ²	24 km	8.6 km	15 km
Weighted $L_{p,RMS,wtd,125ms}$	103 dB (VHF)	3,900 km ²	56 km	12 km	32 km

The AUD INJ results modelled as per Table 4-53 represent the r_{safe} ranges under the Danish requirements

4.2.4 NW

Table 4-60: Unweighted $L_{p,pk}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the maximum expected hammer blow energy during the monopile installation including the commitment to mitigate noise by the introduction of the 169 dB $L_{E,p,ss}$ (SEL_{ss}) limit at all locations.

NMFS (2024) Unweighted $L_{p,pk}$		Monopile foundation, mitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	222 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	230 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	202 dB (VHF)	0.05 km ²	130 m	130 m	130 m
	223 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	216 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	224 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	196 dB (VHF)	0.23 km ²	280 m	270 m	270 m
	217 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table 4-61: Weighted $L_{E,p,24h,wtd}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the monopile installation (single pile) including mitigation at the NW modelling location assuming fleeing receptors.

NMFS (2024) Weighted $L_{E,p,24h,wtd}$		Monopile foundation, mitigated (single pile)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	183 dB (LF)	0.01 km ²	80 m	50 m	60 m
	193 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	159 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	183 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	168 dB (LF)	150 km ²	13 km	2.1 km	5.9 km
	178 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	144 dB (VHF)	86 km ²	9.6 km	1.7 m	4.7 km
	168 dB (PW)	7.3 km ²	3.3 km	340 m	1.2 km

Table 4-62: Weighted $L_{E,p,24h,wtd}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the monopile installation (2 sequential piles) including mitigation at the NW modelling location assuming fleeing receptors.

NMFS (2024) Weighted $L_{E,p,24h,wtd}$		Monopile foundation, mitigated (2 sequential piles)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	183 dB (LF)	0.01 km ²	80 m	50 m	60 m
	193 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	159 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	183 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	168 dB (LF)	170 km ²	14 km	2.1 km	6.1 km
	178 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	144 dB (VHF)	100 km ²	11 km	1.7 km	5.1 km
	168 dB (PW)	8.0 km ²	3.5 km	340 m	1.3 km

Table 4-63: Unweighted $L_{p,RMS}$ impact areas and ranges for marine mammals using the NOAA (2005) Level B criteria for the maximum expected hammer blow energy during the monopile installation including mitigation at the NW modelling location.

NOAA (2005) Unweighted $L_{p,RMS}$		Monopile foundation, unmitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Level B	160 dB	69 km ²	6.3 km	3.4 km	4.6 km

Table 4-64: Unweighted $L_{p,pk}$ impact areas and ranges for fish using the Popper et al (2014) pile driving criteria for the maximum expected hammer blow energy during the monopile installation including mitigation at the NW modelling location.

Popper et al. (2014) Unweighted $L_{p,pk}$	Monopile foundation, mitigated (maximum energy: 4,400 kJ)				
	Area	Maximum range	Minimum range	Mean range	
Pile driving	213 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	0.01 km ²	70 m	70 m	70 m

Table 4-65: Unweighted $L_{E,p,24h}$ impact areas and ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile installation (single pile) including mitigation at the NW modelling location assuming both fleeing and stationary receptors.

Popper et al. (2014) Unweighted $L_{E,p,24h}$	Monopile foundation, mitigated (single pile)				
	Area	Maximum range	Minimum range	Mean range	
Fleeing (1.5 m/s)	219 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	186 dB	2.6 km ²	2.0 km	280 m	760 m
Stationary (0 m/s)	219 dB	0.03 km ²	90 m	90 m	90 m
	216 dB	0.06 km ²	140 m	140 m	140 m
	210 dB	0.36 km ²	350 m	330 m	340 m
	207 dB	0.86 km ²	550 m	500 m	520 m
	203 dB	2.6 km ²	990 m	840 m	910 m
	186 dB	130 km ²	9.1 km	4.1 km	6.3 km

Table 4-66: Unweighted $L_{E,p,24h}$ impact areas and ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile installation (2 sequential piles) including mitigation at the NW modelling location assuming both fleeing and stationary receptors.

Popper et al. (2014) Unweighted $L_{E,p,24h}$	Monopile foundation, mitigated (2 sequential piles)				
	Area	Maximum range	Minimum range	Mean range	
Fleeing (1.5 m/s)	219 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	216 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	210 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	203 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	186 dB	2.9 km ²	2.2 km	290 m	790 m
Stationary (0 m/s)	219 dB	0.06 km ²	140 m	140 m	140 m
	216 dB	0.15 km ²	230 m	220 m	220 m
	210 dB	0.86 km ²	550 m	500 m	520 m
	207 dB	2.0 km ²	860 m	740 m	790 m
	203 dB	6.2 km ²	1.6 km	1.3 km	1.4 km
	186 dB	230 km ²	13 km	5.5 km	8.3 km

Table 4-67: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the German underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation including mitigation at the NW modelling location.

German requirements	Monopile foundation, mitigated (maximum energy: 4,400 kJ)				
	Area	Maximum range	Minimum range	Mean range	
Unweighted $L_{p,pk}$	190 dB	1.0 km ²	600 m	540 m	570 m
Unweighted $L_{E,p,ss}$	160 dB	15 km ²	2.6 km	1.9 km	2.2 km

Table 4-68: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the Belgian underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation including mitigation at the NW modelling location.

Belgian requirements		Monopile foundation, mitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	185 dB	3.2 km ²	1.1 km	930 m	1.0 km
Unweighted $L_{E,p,ss}$	162 dB	9.3 km ²	2.0 km	1.5 km	1.7 km

Table 4-69: Unweighted $L_{E,p,ss}$ and $L_{p,RMS,wt,125ms}$ impact areas and ranges for the Danish behavioural underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation including mitigation at the NW modelling location.

Danish behavioural requirements		Monopile foundation, mitigated (maximum energy: 4,400 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{E,p,ss}$	143 dB	470 km ²	18 km	8.2 km	12 km
Weighted $L_{p,RMS,wt,125ms}$	103 dB (VHF)	1,900 km ²	42 km	13 km	23 km

The AUD INJ results modelled as per Table 4-61 and Table 4-62 represent the r_{safe} ranges under the Danish requirements

5 Other noise sources

Although impact piling is expected to generate the greatest overall noise levels during construction and development (Bailey *et al.*, 2014), several other anthropogenic underwater noise sources have the potential to be present and need to be considered. These noise sources have been presented alongside relevant biological criteria (see section 2.3) in this section.

Table 5-1 provides a list of the various noise producing sources, aside from impact piling, that are expected to be present during the construction and operation of the CWP Project.

Table 5-1: Summary of the possible noise making activities, other than impact piling, present during the construction and operation of the CWP Project.

Activity	Description
Cable laying	Noise from the cable laying vessel and other associated sounds produced during the offshore cable installation.
Dredging	Dredging may be required to prepare the seabed for certain foundation types as well as export cable, array site cable and interconnector cable installation. Both backhoe and suction dredging have been considered for this study.
Drilling	There is the potential for WTG foundations to be installed, or partially installed, using drilling depending on seabed type or if a pile refuses during impact piling operations.
Rock placement	Rock placement may be required on site for the installation of offshore cables (cable crossings and cable protection), and scour protection around foundation structures.
Trenching	Plough trenching may be utilised during the installation of offshore cables.
Vessel noise	Jack-up barges and dynamic positioning vessels are expected to be used for piling substructure and foundation installation. Other large and medium sized vessels will be required to carry out other construction tasks such as anchor handling and survey work. Small vessels will be required for crew transport and maintenance on site.
Operational WTGs	Noise transmitted through the water from operational WTGs. Currently, the CWP Project is considering fixed-bottom turbines with power outputs of between 15 and 21 MW.
UXO clearance	There is a possibility that UXO may exist within the CWP array site and offshore export cable corridor boundaries. This would need to be cleared before construction can begin, likely using a low-order clearance technique.

The majority of these activities are covered in section 5.1, with potential operational WTG noise and UXO clearance assessed in sections 5.2 and 5.3 respectively.

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

5.1 Noise making activities (construction)

For the purposes of identifying the greatest effects from noise, approximate underwater noise levels have been predicted using a simple modelling approach. This is based on measurement data from Subacoustech Environmental's underwater noise measurement database scaled to relevant parameters for the CWP Project and to the specific noise sources to be used. The calculation of underwater noise transmission loss for these non-impulsive sources is based on empirical analysis of the noise measurements taken along transects around

these sources. The predictions use the following principle fitted to the measured data, where R is the range from the source, N is the transmission loss coefficient, and α is the absorption loss coefficient:

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

Predicted source levels and propagation calculations for the construction, and construction-adjacent, noise making activities are presented in Table 5-2 along with a summary of the datasets used for the calculations. Impact ranges have been calculated using the NMFS (2024) non-impulsive criteria for marine mammals (Table 2-3) and the Popper *et al.* (2014) shipping and continuous noise criteria for fish (Table 2-6). As before, ranges smaller than 50 m have not been presented. It should be reiterated that this modelling approach does not take location-specific bathymetry or other environmental conditions into account, and as such can be applied to any location at or surrounding the CWP Project.

Table 5-2: Summary of the estimated unweighted source levels and transmission losses for the considered construction activities

Activity	Estimated L_p source level @ 1 m	Transmission loss coefficients	Comments
Cable laying	171 dB re 1 μ Pa	$N: 13, \alpha: 0.0$ (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.
Dredging (backhoe)	165 dB re 1 μ Pa	$N: 19, \alpha: 0.0009$	Based on three datasets from backhoe dredgers.
Dredging (suction)	186 dB re 1 μ Pa	$N: 19, \alpha: 0.0009$	Based on five datasets from suction and cutter-suction dredgers.
Drilling	169 dB re 1 μ Pa	$N: 16, \alpha: 0.0006$	Based on six datasets from various drilling operations covering ground investigations and pile installation. A 200 kW drill has been assumed for modelling.
Rock placement	166 dB re 1 μ Pa	$N: 9, \alpha: 0.0025$	Based on four datasets from rock placement vessel <i>Rollingstone</i> .
Trenching	172 dB re 1 μ Pa	$N: 13, \alpha: 0.0004$	Based on three datasets from trenching vessels more than 100 m in length.
Vessel noise (large)	168 dB re 1 μ Pa	$N: 12, \alpha: 0.0021$	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 kn.
Vessel noise (medium)	161 dB re 1 μ Pa	$N: 12, \alpha: 0.0021$	Based on three datasets of moderate sized vessels below 100 m in length. Vessel speed assumed as 10 kn.

All values of N and α are empirically derived and will be linked to the size and shape of the machinery, the transect on which the measurements were taken and the local environment at the time. It is noted that the depths at the CWP Project are deep relative to the locations where the original data here was derived, although the noise levels relative to the thresholds under consideration will mean that the relatively low impact ranges predicted are unlikely to be significantly affected.

For $L_{E,p,t}$ calculations in this section, the duration the noise is present also needs to be considered, with all sources assumed to operate constantly for 24 hours to give a worst-case assessment of noise. Due to the relatively low level of noise from these sources, both moving and stationary receptors have been included for all $L_{E,p,t}$ criteria; the same swim speeds as presented in section 2.3 have been assumed here.

To account for the weightings required for modelling using the NMFS (2024) $L_{E,p,t}$ criteria (see section 2.3.1), reductions have been applied to the source levels of the various noise sources. Figure 5-1 shows the

representative noise measurements used to calculate these reductions, which have been adjusted based on the source levels given in Table 5-2. Details of the reductions in source level for each of the NMFS (2024) marine mammal weightings are given in Table 5-3.

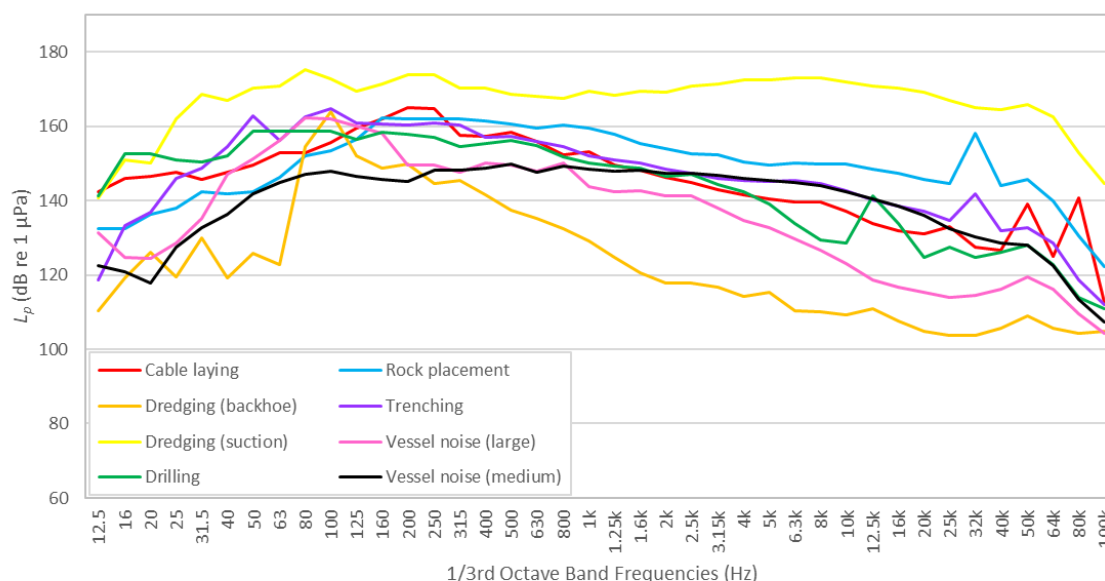


Figure 5-1: Summary of the unweighted 1/3rd octave frequency bands to which the weightings from NMFS (2024) have been applied.

Table 5-3: Reductions in source level for the different construction activities considered when the weightings from NMFS (2024) are applied.

Activity	Reduction in L_p source level from the unweighted level (NMFS, 2024)			
	LF	HF	VHF	PW
Cable laying	2.0 dB re 1 µPa	17.3 dB re 1 µPa	25.4 dB re 1 µPa	12.4 dB re 1 µPa
Dredging (backhoe)	5.2 dB re 1 µPa	32.4 dB re 1 µPa	46.9 dB re 1 µPa	24.7 dB re 1 µPa
Dredging (suction)	2.4 dB re 1 µPa	4.1 dB re 1 µPa	7.4 dB re 1 µPa	3.6 dB re 1 µPa
Drilling	3.5 dB re 1 µPa	15.8 dB re 1 µPa	25.5 dB re 1 µPa	11.7 dB re 1 µPa
Rock placement	1.4 dB re 1 µPa	8.9 dB re 1 µPa	11.7 dB re 1 µPa	6.7 dB re 1 µPa
Trenching	3.5 dB re 1 µPa	15.9 dB re 1 µPa	22.5 dB re 1 µPa	12.4 dB re 1 µPa
Vessel noise (large)	4.7 dB re 1 µPa	20.9 dB re 1 µPa	34.4 dB re 1 µPa	16.2 dB re 1 µPa
Vessel noise (medium)	1.2 dB re 1 µPa	6.1 dB re 1 µPa	12.6 dB re 1 µPa	4.1 dB re 1 µPa

The modelled impact ranges for these sources are presented in in Table 5-4 to Table 5-6.

Given the modelled impact ranges, almost all marine mammals would have to be closer than 50 m from the noise sources at the start of the activity to acquire the necessary exposure for injury onset as per NMFS (2024), with the possible exception of suction dredging and rock placement for stationary receptors. As previously iterated, these ranges only represent a range where the receptor reaches the ‘onset’ stage, which is the minimum exposure that could potentially lead to the start of an effect and may only be marginal. In most hearing groups the noise levels are low enough that this only represents a minimal risk, especially bearing in mind that many sources above are mobile. For fish, there is only a minimal risk of any injury or TTS, using the $L_{p,RMS}$ guidance for shipping and continuous noise sources in Popper *et al.* (2014), with all impact ranges predicted to be smaller than 50 m.

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

Table 5-4: Weighted $L_{E,p,24h, wtd}$ impact ranges for marine mammals using the NMFS (2024) non-impulsive criteria for the various noise-making activities assuming a fleeing receptor.

NMFS (2024) $L_{E,p,24h, wtd}$ (Fleeing)	AUD INJ (Non-impulsive)				TTS (Non-impulsive)			
	LF (197 dB)	HF (201 dB)	VHF (181 dB)	PW (195 dB)	LF (177 dB)	HF (181 dB)	VHF (161 dB)	PW (175 dB)
Cable laying	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m
Dredging (backhoe)	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m
Dredging (suction)	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	60 m	< 50 m
Drilling	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m
Rock placement	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m
Trenching	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m
Vessel noise (large)	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m
Vessel noise (medium)	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m

Table 5-5: Weighted $L_{E,p,24h, wtd}$ impact ranges for marine mammals using the NMFS (2024) non-impulsive criteria for the various noise-making activities assuming a stationary receptor.

NMFS (2024) $L_{E,p,24h, wtd}$ (Stationary)	AUD INJ (Non-impulsive)				TTS (Non-impulsive)			
	LF (197 dB)	HF (201 dB)	VHF (181 dB)	PW (195 dB)	LF (177 dB)	HF (181 dB)	VHF (161 dB)	PW (175 dB)
Cable laying	< 50 m	< 50 m	< 50 m	< 50 m	1.5 km	50 m	400 m	340 m
Dredging (backhoe)	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m
Dredging (suction)	80 m	< 50 m	280 m	80 m	800 m	410 m	2.5 km	870 m
Drilling	< 50 m	< 50 m	< 50 m	< 50 m	220 m	< 50 m	100 m	90 m
Rock placement	70 m	< 50 m	270 m	< 50 m	2.5 km	490 m	4.0 km	1.7 km
Trenching	< 50 m	< 50 m	< 50 m	< 50 m	1.2 km	80 m	770 m	400 m
Vessel noise (large)	< 50 m	< 50 m	< 50 m	< 50 m	700 m	< 50 m	70 m	140 m
Vessel noise (medium)	< 50 m	< 50 m	< 50 m	< 50 m	400 m	80 m	820 m	350 m

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

Table 5-6: Unweighted L_p impact ranges for fish using the Popper *et al* (2014) shipping and continuous noise criteria for the various noise-making activities.

Popper <i>et al.</i> (2014) $L_{p,RMS}$	Recoverable injury 170 dB re 1 μ Pa (48 hours)	TTS 158 dB re 1 μ Pa (12 hours)
Cable laying	< 50 m	< 50 m
Dredging (backhoe)	< 50 m	< 50 m
Dredging (suction)	< 50 m	< 50 m
Drilling	< 50 m	< 50 m
Rock placement	< 50 m	< 50 m
Trenching	< 50 m	< 50 m
Vessel noise (large)	< 50 m	< 50 m
Vessel noise (medium)	< 50 m	< 50 m

5.2 Operational WTG noise

When considering the noise from operational WTG, the primary noise source is a consequence of mechanically generated vibration from the rotating machinery in the WTG transmitted into the water through the structure of the WTG tower and foundations (Nedwell *et al.*, 2003; Tougaard *et al.*, 2020). For a fixed-bottom foundation, this is the surface area of the cylindrical pile in the water column (or piles for multi-leg designs). The complexities of the acoustics in large structures such as these make it difficult to predict their effect on the resulting noise output (Tougaard *et al.*, 2020). Noise levels generated above the water surface are low enough that no significant airborne sound will pass from the air to the water.

Tougaard *et al.* (2020) published a study investigating noise data from 17 operational WTGs in Europe and the United States, from 0.2 MW to 6.15 MW nominal power output. The paper identified the nominal power output and wind speed as the 2 primary driving factors for underwater noise generation. Although the datasets were acquired under different conditions, the authors devised a formula based on the published data for the operational windfarms, allowing a broadband noise level to be estimated based on the application of wind speed, turbine size (by nominal power output) and distance from the turbine:

$$L_{eq} = C + \alpha \log_{10} \left(\frac{\text{distance}}{100m} \right) + \beta \log_{10} \left(\frac{\text{wind speed}}{10m_s^{-1}} \right) + \gamma \log_{10} \left(\frac{\text{turbine size}}{1 MW} \right)$$

where C is a fixed constant and the coefficients α , β , and γ are derived from the empirical data from the 17 datasets.

Indicative power outputs have been used to calculate the impacts for this study. For the CWP Project, WTGs with power outputs from 15 to 21 MW have been used.

The WTG sizes under consideration at the CWP Project are much larger than those used to develop the estimation above, so caution must be taken when considering the results presented in this section; no empirical data is available for large wind turbines close to the specification proposed here.

Stöber and Thomsen (2021) produced a similar study of operational WTG noise datasets and raised the potential for behavioural disturbance caused by larger WTGs. While prospective WTG sizes are increasing, Stöber and Thomsen (2021) concluded that these might only have limited impacts related to behavioural responses in marine mammals and fish, although there is considerable uncertainty in the criteria available to assess this, based on the highly precautionary NOAA Level B behavioural threshold (120 dB re 1 μ Pa ($L_{p,RMS}$) for non-impulsive noise; see NOAA, 2005) that the study utilises. For the CWP Project, and using that threshold, it is estimated that larger WTG may only reach the Level B behavioural threshold at ranges of 190 m using the Tougaard *et al.* (2020) equation (Figure 5-2). As the distance between turbines at the CWP Project is expected to be much greater than this, any array effect from the turbines is not expected.

To consider more up to date research since Tougaard *et al.* (2020), the most pertinent articles published have been by Holme *et al.* (2023) and Bellmann *et al.* (2023), which largely come to similar conclusions. Holme *et al.* (2023) study the underwater noise from 6.3 MW and 8.3 MW turbines in two wind farms using an array of hydrophones, the closest being 70 m to 150 m from the turbines, over 5 weeks and a variety of meteorological conditions. Bellmann *et al.* (2023) review operational noise studies from 24 offshore wind farms, the largest turbines being 8 MW. Both studies show a lack of strong correlation with underwater noise output and turbine size; in fact the larger Bellmann *et al.* (2023) study shows that the smaller turbines were actually slightly louder on average than their larger counterparts. This may be because of newer designs, and a move from gearbox to modern direct drive (gearboxless) designs, which are generally quieter.

Holme *et al.* (2023) found that there was no obvious correlation with the overall underwater noise level and turbine activity, and changes in noise were mostly associated with natural conditions (e.g., wind and tidal changes) or vessel activities (shipping lanes). While the speed of the turbine rotation would theoretically increase noise output, it is naturally caused by increased wind speed, which further increases ambient noise, masking the turbine noise. For the sizes of turbines measured, Holme *et al.* (2023) indicated that the Tougaard *et al.* (2020) calculation substantially overestimates the actual noise produced by the larger turbines, in some cases by 8 dB, giving an extra level of conservatism for the estimations.

Figure 5-2 presents a level against range plot for the WTG sizes at the CWP Project using the Tougaard *et al.* (2020) equation, assuming an average wind speed of 10 m/s.

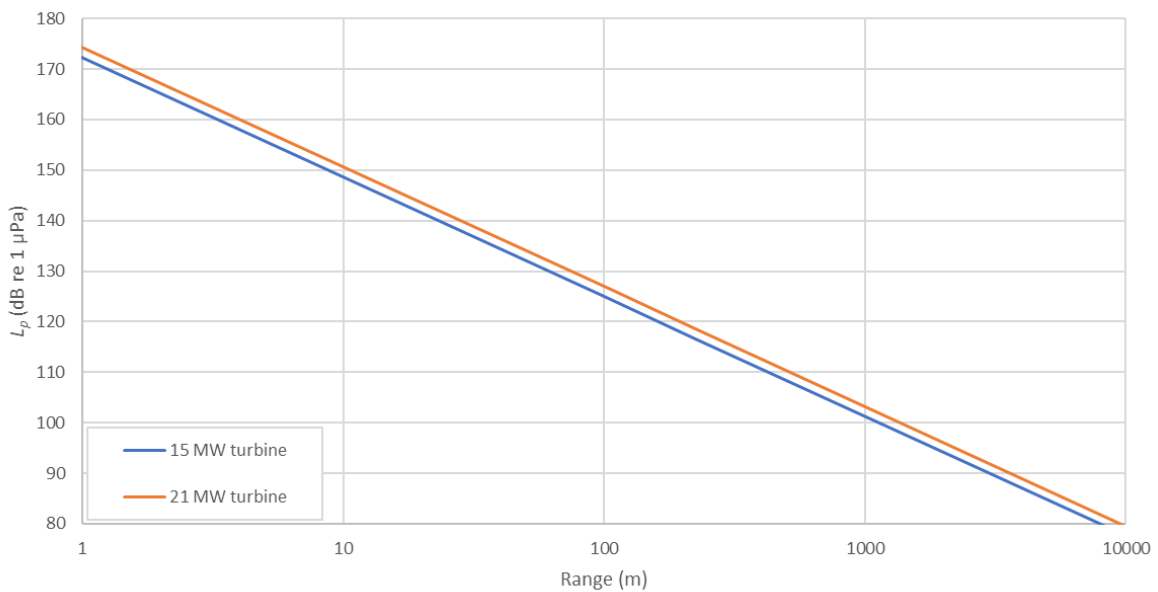


Figure 5-2: Predicted unweighted L_p from operational WTGs using the calculation from Tougaard *et al.* (2020).

Using this data, a summary of the predicted impact ranges for operational WTG noise has been produced, presented in

Table 5-7 and Table 5-8. The operational WTG source is considered non-impulsive or continuous. For $L_{E,p,t}$ calculations, a worst-case stationary animal receptor has been used, and it is assumed that the operational WTG noise is present 24 hours a day.

Table 5-7: Weighted $L_{E,p,24h,wtd}$ impact ranges for marine mammals using the NMFS (2024) non-impulsive criteria for operational WTG noise assuming a stationary receptor.

NMFS (2024) $L_{E,p,24h,wtd}$ (Stationary)	AUD INJ (Non-impulsive)				TTS (Non-impulsive)			
	LF (197 dB)	HF (201 dB)	VHF (181 dB)	PW (195 dB)	LF (177 dB)	HF (181 dB)	VHF (161 dB)	PW (175 dB)
15 MW turbine	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m
21 MW turbine	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m	< 50 m

Based on the NMFS (2024) non-impulsive criteria, a marine mammal would need to remain within 50 m of the operational WTG for 24 hours to exceed threshold.

Table 5-8: Unweighted L_p impact ranges for fish using the Popper *et al* (2014) shipping and continuous noise criteria for the various noise-making activities.

Popper <i>et al.</i> (2014) L_p	Recoverable injury 170 dB re 1 μ Pa (48 hours)	TTS 158 dB re 1 μ Pa (12 hours)
15 MW turbine	< 50 m	< 50 m
21 MW turbine	< 50 m	< 50 m

Using the Popper *et al.* (2014) criteria for continuous noise, any individual would have to be closer than 50 m to the operational WTG for 12 hours to achieve the for TTS onset criteria.

5.3 UXO clearance

It is possible that UXO devices, with a range of charge weights (or quantity of contained explosive), are present within and around the CWP Project. These would need to be cleared before any construction can begin. When modelling potential noise from UXO clearance, a variety of explosive types need to be considered, with the potential that many have been subject to degradation and burying over time. Two otherwise identical explosive devices are likely to produce different blasts in the case where one has spent an extended period on the seabed or sits in a different topographical situation.

A selection of explosive sizes has been considered based on what might be present and, in each case, it has been assumed that in the first instance a low-order technique will be used (see below), and following this, to include the worst case (although not anticipated) scenario, where the maximum explosive charge in each device is present and either detonates with the clearance (high-order). A low-order technique will be the primary method of UXO clearance, with high-order clearance only to occur in exceptional circumstances.

5.3.1 Estimation of underwater noise levels

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

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

orientation) would be expected. Notwithstanding this the CWP Project has, in the event of high order detonation being required, committed to implementing Noise Abatement Systems (NAS) to mitigate the potential underwater noise.

5.3.1.1 Low-order clearance

The primary choice for any UXO clearance at the CWP Project will be a low-order technique, in order to reduce the consequences of noise caused by detonation of the main charge of the UXO. Deflagration is one such alternative technique, intended to result in a low-order burn of the explosive material in a UXO, which destroys, but does not detonate, the internal explosive material.

Where the technique proceeds as intended, it is still not without noise impact. The process requires an initial shaped explosive donor charge, typically less than 0.25 kg, to breach the casing and ignite the internal high explosive (HE) material without full detonation. The shaped charge and burn will both produce noise, although it will be significantly less than the high-order detonation of the UXO. Deflagration may not destroy all of the HE, which would necessitate further low-order clearance events or collection of the remnants. There is also the possibility (although rare) that the deflagration could produce an unintentional high-order event.

For calculation of the deflagration scenario, resulting in total destruction of the HE material, it is anticipated that the initial shaped charge is the greatest source of noise (Cheong *et al.*, 2020). The shaped charge is treated as a bulk charge with a net explosive quantity (NEQ) determined according to the size of UXO on which it is placed. The prediction of this impact is based on a charge weight of 0.25 kg. The worst-case scenario would, of course, be a high-order detonation with maximum pressures from complete detonation of the UXO.

5.3.1.2 High-order clearance

High-order clearance technique is not a proposed UXO clearance methodology, although for completeness has been included in this assessment. The only reason for a high-order clearance at the CWP Project would be as a last resort if the use of a less intrusive or quieter technique is not possible, or if the low-order technique accidentally results in a high-order detonation. A high-order clearance would involve detonating the UXO including all the HE material contained within.

The maximum equivalent charge weight for the potential UXO devices that could be present at UXO has been estimated as 750 kg. This has been modelled alongside a range of smaller devices, at charge weights of 25, 55, 120, 240, 525, and 698 kg, which have been chosen to give a spread of potential devices that could potentially be present in Irish waters. In each case, an additional donor charge weighing 0.5 kg has been included to initiate detonation. A generic mitigation reduction of 10 dB has also been considered for the high-order detonation calculations (section 5.3.3.2) to reflect the CWP Project commitment to implement NAS in the event high order UXO clearance is required.

Estimation of the source noise level for each charge weight has been carried out in accordance with the methodology from Soloway and Dahl (2014), which follows Arons (1954) and the Marine Technical Directorate (MTD) (1996). This is covered in more detail in section 5.3.2.

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 $L_{p,pk}$:

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

and for $L_{E,p}$:

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

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

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 the 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 typical sound frequencies associated with UXO explosives. This uses standard frequency-based absorption coefficients for the seawater conditions expected in the region.

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

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

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

In light of this, the selection of assessment criteria needs careful consideration. As discussed in section 2.2.1, the smoothing of the pulse at range means that a pulse may be considered non-impulsive at distance, suggesting that, at greater ranges, it may be more appropriate to use the non-impulsive criteria. Based on impulsive noise from piling, this consideration may begin at ranges of 3.5 km (Hastie *et al.*, 2019) to 5 km (Matei *et al.*, 2024), although, as blast noise is inherently more impulsive than piling, the transition from full impulsivity may occur at a greater distance from the UXO source location.

A summary of the unweighted UXO clearance source levels, calculated using the equations above, are given in Table 5-9.

Table 5-9: List of the $L_{p,pk}$ and $L_{E,p}$ source levels used for UXO clearance modelling.

Charge weight	$L_{p,pk}$ @ 1 m	$L_{E,p}$ @ 1 m
Low order (0.25 kg)	269.8 dB re 1 μ Pa	215.2 dB re 1 μ Pa ² s
25 kg (+ donor)	284.9 dB re 1 μ Pa	228.0 dB re 1 μ Pa ² s
55 kg (+ donor)	287.5 dB re 1 μ Pa	230.1 dB re 1 μ Pa ² s
120 kg (+ donor)	290.0 dB re 1 μ Pa	232.3 dB re 1 μ Pa ² s
240 kg (+ donor)	292.3 dB re 1 μ Pa	234.2 dB re 1 μ Pa ² s
525 kg (+ donor)	294.8 dB re 1 μ Pa	236.4 dB re 1 μ Pa ² s
698 kg (+ donor)	295.7 dB re 1 μ Pa	237.1 dB re 1 μ Pa ² s
750 kg (+ donor)	296.0 dB re 1 μ Pa	237.3 dB re 1 μ Pa ² s

5.3.3 Impact ranges

5.3.3.1 Unmitigated

Table 5-10 to Table 5-13 present the unmitigated impact ranges for UXO clearance, considering various charge weights and impact criteria. It should be noted that Popper *et al.* (2014) gives specific impact criteria for explosions (Table 2-5). A UXO detonation source is defined as a single pulse, as such the $L_{E,p,wt}$ criteria from NMFS (2024) have been given as single pulse values in the following tables, and fleeing animal assumptions do not apply.

Although the impact ranges in Table 5-10 to Table 5-13 are large, the duration the noise is present must also be considered. For the clearance of a UXO, each explosion is a single noise event, compared to the multiple pulse nature and longer durations of impact piling. Additionally, results including 10 dB mitigation for high-order detonations are presented in section 5.3.3.2.

Table 5-10: Unweighted $L_{p,pk}$ impact ranges for marine mammals using the NMFS (2024) impulsive criteria for UXO clearance noise.

NMFS (2024) $L_{p,pk}$	AUD INJ (Impulsive)				TTS (Impulsive)			
	LF (222 dB)	HF (230 dB)	VHF (202 dB)	PW (223 dB)	LF (216 dB)	HF (224 dB)	VHF (196 dB)	PW (217 dB)
Low order (0.25 kg)	130 m	60 m	990 m	110 m	230 m	100 m	1.8 km	210 m
25 kg (+ donor)	600 m	260 m	4.6 km	540 m	1.1 km	490 m	8.5 km	1.0 km
55 kg (+ donor)	780 m	340 m	6.0 km	710 m	1.4 km	640 m	11 km	1.3 km
120 kg (+ donor)	1.0 km	450 m	7.8 km	920 m	1.8 km	830 m	14 km	1.6 km
240 kg (+ donor)	1.2 km	560 m	9.8 km	1.1 km	2.3 km	1.0 km	18 km	2.1 km
525 kg (+ donor)	1.6 km	730 m	12 km	1.5 km	3.0 km	1.3 km	23 km	2.7 km
698 kg (+ donor)	1.8 km	810 m	13 km	1.6 km	3.3 km	1.4 km	25 km	3.0 km
750 kg (+ donor)	1.8 km	830 m	14 km	1.6 km	3.4 km	1.5 km	26 km	3.1 km

Table 5-11: Weighted $L_{E,p,wt}$ (single pulse) impact ranges for marine mammals using the NMFS (2024) impulsive criteria for UXO clearance noise.

NMFS (2024) $L_{E,p,wt}$ (Single pulse)	AUD INJ (Impulsive)				TTS (Impulsive)			
	LF (183 dB)	HF (193 dB)	VHF (159 dB)	PW (183 dB)	LF (168 dB)	HF (178 dB)	VHF (144 dB)	PW (168 dB)
Low order (0.25 kg)	130 m	< 50 m	170 m	< 50 m	1.8 km	< 50 m	1.2 km	380 m
25 kg (+ donor)	1.2 km	< 50 m	980 m	260 m	17 km	100 m	3.2 km	3.6 km
55 kg (+ donor)	1.8 km	< 50 m	1.2 km	380 m	24 km	140 m	3.6 km	5.1 km
120 kg (+ donor)	2.6 km	< 50 m	1.5 km	560 m	34 km	200 m	4.0 km	7.4 km
240 kg (+ donor)	3.7 km	< 50 m	1.7 km	780 m	47 km	270 m	4.4 km	10 km
525 kg (+ donor)	5.5 km	< 50 m	2.1 km	1.1 km	65 km	370 m	4.9 km	14 km
698 kg (+ donor)	6.3 km	< 50 m	2.2 km	1.3 km	73 km	410 m	5.1 km	15 km
750 kg (+ donor)	6.5 km	< 50 m	2.2 km	1.3 km	76 km	420 m	5.1 km	16 km

Table 5-12: Weighted L_{E,p,wt_d} (single pulse) impact ranges for marine mammals using the NMFS (2024) non-impulsive criteria for UXO clearance noise.

NMFS (2024) L_{E,p,wt_d} (Single pulse)	AUD INJ (Non-impulsive)				TTS (Non-impulsive)			
	LF (197 dB)	HF (201 dB)	VHF (181 dB)	PW (195 dB)	LF (177 dB)	HF (181 dB)	VHF (161 dB)	PW (175 dB)
Low order (0.25 kg)	< 50 m	< 50 m	< 50 m	< 50 m	370 m	< 50 m	120 m	110 m
25 kg (+ donor)	100 m	< 50 m	< 50 m	< 50 m	3.6 km	60 m	780 m	1.0 km
55 kg (+ donor)	150 m	< 50 m	50 m	< 50 m	5.2 km	90 m	1.0 km	1.5 km
120 kg (+ donor)	220 m	< 50 m	80 m	70 m	7.6 km	120 m	1.2 km	2.2 km
240 kg (+ donor)	310 m	< 50 m	100 m	90 m	10 km	160 m	1.4 km	3.1 km
525 kg (+ donor)	460 m	< 50 m	150 m	130 m	15 km	230 m	1.8 km	4.5 km
698 kg (+ donor)	530 m	< 50 m	170 m	160 m	17 km	260 m	1.9 km	5.2 km
750 kg (+ donor)	550 m	< 50 m	170 m	160 m	18 km	270 m	1.9 km	5.3 km

Table 5-13: Unweighted $L_{p,pk}$ impact ranges for fish using the Popper et al. (2014) explosions criteria for UXO clearance noise.

Popper et al. (2014) $L_{p,pk}$	Mortality and potential mortal injury	
	234 dB	229 dB
Low order (0.25 kg)	< 50 m	60 m
25 kg (+ donor)	170 m	290 m
55 kg (+ donor)	230 m	380 m
120 kg (+ donor)	300 m	490 m
240 kg (+ donor)	370 m	620 m
525 kg (+ donor)	490 m	810 m
698 kg (+ donor)	530 m	890 m
750 kg (+ donor)	550 m	910 m

5.3.3.2 *Mitigated (high-order detonations only)*

Table 5-14 to Table 5-17 present the impact ranges for high-order detonations considering a generic 10 dB reduction at source from mitigation. With these reductions the maximum auditory injury results for LF cetaceans reduce from 6.5 km to 1.1 km, using the SEL criteria. The maximum auditory injury range for any species is 5.1 km for VHF cetaceans, using the $L_{p,pk}$ criteria.

Table 5-14: Mitigated unweighted $L_{p,pk}$ impact ranges for marine mammals using the NMFS (2024) impulsive criteria for UXO clearance noise.

NMFS (2024) $L_{p,pk}$	AUD INJ (Impulsive)				TTS (Impulsive)			
	LF (222 dB)	HF (230 dB)	VHF (202 dB)	PW (223 dB)	LF (216 dB)	HF (224 dB)	VHF (196 dB)	PW (217 dB)
25 kg (+ donor)	210 m	100 m	1.6 km	190 m	400 m	170 m	3.1 km	360 m
55 kg (+ donor)	280 m	120 m	2.1 km	250 m	520 m	230 m	4.0 km	470 m
120 kg (+ donor)	360 m	160 m	2.8 km	330 m	670 m	300 m	5.1 km	610 m
240 kg (+ donor)	460 m	200 m	3.5 km	410 m	850 m	370 m	6.5 km	770 m
525 kg (+ donor)	600 m	260 m	4.6 km	540 m	1.1 km	490 m	8.4 km	1.0 km
698 kg (+ donor)	660 m	290 m	5.0 km	590 m	1.2 km	530 m	9.3 km	1.1 km
750 kg (+ donor)	670 m	290 m	5.1 km	610 m	1.2 km	550 m	9.5 km	1.1 km

Table 5-15: Mitigated weighted $L_{E,p,wt}$ (single pulse) impact ranges for marine mammals using the NMFS (2024) impulsive criteria for UXO clearance noise.

NMFS (2024) $L_{E,p,wt}$ (Single pulse)	AUD INJ (Impulsive)				TTS (Impulsive)			
	LF (183 dB)	HF (193 dB)	VHF (159 dB)	PW (183 dB)	LF (168 dB)	HF (178 dB)	VHF (144 dB)	PW (168 dB)
25 kg (+ donor)	210 m	< 50 m	260 m	< 50 m	3.0 km	< 50 m	1.6 km	630 m
55 kg (+ donor)	310 m	< 50 m	360 m	70 m	4.4 km	< 50 m	1.9 km	920 m
120 kg (+ donor)	460 m	< 50 m	490 m	100 m	6.4 km	< 50 m	2.2 km	1.3 km
240 kg (+ donor)	640 m	< 50 m	630 m	130 m	8.9 km	50 m	2.5 km	1.8 km
525 kg (+ donor)	950 m	< 50 m	820 m	190 m	13 km	80 m	2.9 km	2.7 km
698 kg (+ donor)	1.0 km	< 50 m	890 m	220 m	14 km	90 m	3.1 km	3.1 km
750 kg (+ donor)	1.1 km	< 50 m	910 m	230 m	15 km	90 m	3.1 km	3.2 km

Table 5-16: Mitigated weighted $L_{E,p,wt}$ (single pulse) impact ranges for marine mammals using the NMFS (2024) non-impulsive criteria for UXO clearance noise.

NMFS (2024) $L_{E,p,wt}$ (Single pulse)	AUD INJ (Non-impulsive)				TTS (Non-impulsive)			
	LF (197 dB)	HF (201 dB)	VHF (181 dB)	PW (195 dB)	LF (177 dB)	HF (181 dB)	VHF (161 dB)	PW (175 dB)
25 kg (+ donor)	< 50 m	< 50 m	< 50 m	< 50 m	620 m	< 50 m	190 m	180 m
55 kg (+ donor)	< 50 m	< 50 m	< 50 m	< 50 m	910 m	< 50 m	270 m	270 m
120 kg (+ donor)	< 50 m	< 50 m	< 50 m	< 50 m	1.3 km	< 50 m	370 m	390 m
240 kg (+ donor)	50 m	< 50 m	< 50 m	< 50 m	1.8 km	< 50 m	480 m	550 m
525 kg (+ donor)	80 m	< 50 m	< 50 m	< 50 m	2.7 km	< 50 m	640 m	810 m
698 kg (+ donor)	90 m	< 50 m	< 50 m	< 50 m	3.1 km	50 m	710 m	930 m
750 kg (+ donor)	100 m	< 50 m	< 50 m	< 50 m	3.2 km	50 m	720 m	960 m

Table 5-17: Mitigated unweighted $L_{p,pk}$ impact ranges for fish using the Popper et al. (2014) explosions criteria for UXO clearance noise.

Popper et al. (2014) $L_{p,pk}$	Mortality and potential mortal injury	
	234 dB	229 dB
25 kg (+ donor)	60 m	100 m
55 kg (+ donor)	80 m	130 m
120 kg (+ donor)	100 m	180 m
240 kg (+ donor)	130 m	220 m
525 kg (+ donor)	170 m	290 m
698 kg (+ donor)	190 m	320 m
750 kg (+ donor)	190 m	330 m

5.3.4 Summary

A low-order clearance would produce a maximum auditory injury onset impact range of 990 m for VHF cetaceans using the $L_{p,pk}$ criteria, with all other species groups lower than this. A low-order methodology is expected to be used for UXO clearance at the CWP Project, with high-order being a last resort.

The maximum auditory injury onset ranges calculated for the largest high-order UXO clearance is 14 km for the VHF cetacean category when considering the NMFS (2024) $L_{p,pk}$ criteria, although this is unmitigated, and mitigation will be used in the event of the necessity to use a high order clearance technique. For $L_{E,p,wtd}$ criteria, the largest injury onset range is calculated for LF cetaceans with a predicted impact range of 6.5 km using the NMFS (2024) impulsive noise criteria. Additionally, the inclusion of mitigation reduces these maximum impact ranges to 5.1 km (VHF cetacean impulsive $L_{p,pk}$ criteria) and 1.1 km (LF cetacean impulsive $L_{E,p,wtd}$ criteria). As previously mentioned, this assumes no degradation of the UXO and no smoothing of the pulse over distance, which is a very precautionary approach. Although using the non-impulsive criteria could underestimate the potential impact (Martin et al., 2020) (the equivalent non-impulsive criteria range for LF cetaceans is 550 m), it is likely that the long-range smoothing of the pulse peak would reduce its potential harm, making the impulsive range precautionary.

6 Summary and conclusions

Subacoustech Environmental has undertaken a study on behalf of Natural Power to model the potential underwater noise and its effects on marine fauna during the construction and operation of the CWP Project, off the east coast of Ireland.

The level of underwater noise from the installation of monopile foundations using impact piling during construction has been modelled using the INSPIRE semi-empirical underwater noise prediction software. This industry standard approach considers a wide variety of precautionary input parameters including bathymetry, pile diameter, hammer blow energy, strike rate and the flee speed of the receptor.

Four modelling locations were selected to give spatial variation across the CWP Project as well as accounting for changes in water depth. Each scenario considered 9.5 m diameter piles installed with a maximum blow energy of 4,400 kJ, with different soft-start and ramp up process depending on the modelling location.

The impact piling modelling results were analysed in terms of relevant noise metrics and criteria to assess the effects on marine mammals (NMFS, 2024) and fish (Popper *et al.*, 2014), which have been used to inform biological assessments. The CWP Project has committed to achieving a mitigated noise level of 169 dB $L_{E,p,ss}$ at 750 m from piles during installation. Consideration of noise mitigation systems was included in the modelling.

For marine mammals, with no mitigation as a reference, the largest auditory injury onset ranges from impact piling were predicted for LF cetaceans, with maximum impact ranges of 8.0 km. For fish, the largest recoverable injury (203 dB $L_{E,p,24h}$) ranges were predicted to be 4.0 km for a stationary receptor, reducing to less than 50 m considering a moving receptor. When considering noise reduction from mitigation, the maximum injury range of any marine mammal species reduced to 140 m, and the maximum recoverable injury ranges for stationary fish reduced to 1.6 km. The equivalent impact ranges calculated using the non-impulsive thresholds are substantially lower, although these would only be relevant for the unmitigated condition, which is not proposed.

Noise sources other than impact piling have been considered using several high-level modelling approaches, these include noise from cable laying, dredging, drilling, rock placement, trenching, vessel noise, and operational WTGs. The risk of any potentially injurious effects to fish or marine mammals from these sources are expected to be minimal as the noise emissions from these are close to, or below, the appropriate injury criteria, even when very close to the source of the noise.

Potential noise from UXO clearance was also considered across the CWP Project. There is a risk of auditory injury onset up to 990 m for VHF cetaceans (unweighted $L_{p,pk}$ criteria) with the use of the expected technique of low-order clearance. In the event that a high-order detonation is used as the clearance method, the maximum auditory injury onset range is up to 14 km from the largest UXO device considered (750 kg + donor charge), using the unweighted $L_{p,pk}$ criteria for VHF cetaceans. This is an unmitigated impact range, and if high-order clearance is used, then noise reduction will be applied. When mitigation is considered, the same high-order detonation impact range reduces to 5.1 km. High-order detonation is not a proposed UXO clearance methodology, although for completeness has been included in this assessment.

By its nature, numerical modelling will produce results that indicate a precise range at which a criterion will be reached, but this does not reflect the inherent uncertainty in the physical processes, including many that change constantly under real world conditions. While the results present specific ranges at which each impact threshold is met based on the modelling results, the ranges should be taken as indicative in determining where environmental effects may occur in receptors during the proposed operations.

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

References

- Andersson M H, Andersson S, Ahlsén J, Andersson B L, Hammar J, Persson L K G, Pihl J, Sigraý P, Wilkström A (2017). *A framework for regulating underwater noise during pile driving*. A technical Vindval report, ISBN 978-91-620-6775-5, Swedish Environmental Protection Agency, Stockholm, Sweden.
- André M, Solé M, Lenoir M, Durfort M, Quero C, Mas A, Lombarte A, van der Schaar M, Lopez-Bejar M, Morell M, Zaugg S, Houegnigan L (2011). *Low-frequency sounds induce acoustic trauma in cephalopods*. *Front. Ecol. Environ.* 9 (9).
- André M, Kaifu K, Solé M, van der Schaar M, Akamatsu T (2016). *Contribution to the understanding of particle motion perception in marine invertebrates* In: *The Effects of Noise on Aquatic Life II. Advances in Experimental Medicine and Biology*. Eds A. N. Popper and A. Hawkins (New York: Springer). P. 47–55.
- Arons A B (1954). *Underwater explosion shock wave parameters at large distances from the charge*. *J. Acoust. Soc. Am.* 26, 343-346.
- Bailey H, Senior B, Simmons D, Rusin J, Picken G, Thompson P M (2010). *Assessing underwater noise levels during pile-driving at an offshore wind farm and its potential effects on marine mammals*. *Marine Pollution Bulletin* 60 (2010), pp 888-897.
- Bailey H, Brookes K L, Thompson P M (2014). *Assessing environmental impacts of offshore wind farms: lessons learned and recommendations for the future*. *Aquatic Biosystems* 2014, 10:8.
- Bebb A H, Wright H C (1953). *Injury to animals from underwater explosions*. Medical Research Council, Royal Navy Physiological Report 53/732, Underwater Blast Report 31, January 1953.
- Bebb A H, Wright H C (1954a). *Lethal conditions from underwater explosion blast*. RNP Report 51/654, RNPL 3/51, National Archives Reference ADM 298/109, March 1954.
- Bebb A H, Wright H C (1954b). *Protection from underwater explosion blast: III. Animal experiments and physical measurements*. RNP Report 57/792, RNPL 2/54m March 1954.
- Bebb A H, Wright H C (1955). *Underwater explosion blast data from the Royal Navy Physiological Labs 1950/1955*. Medical Research Council, April 1955.
- Bellman M A, Müller T, Scheiblich K, Betke K (2023). *Experience report on operational noise - Cross-project evaluation and assessment of underwater noise measurements from the operational phase of offshore wind farms*, itap report no. 3926.
- Blix A S, Folkow L P (1995): Daily energy expenditure in free living minke whales. *Acta Physio. Scand.*, 153: 61-66.
- Cheong S-H, Wang L., Lepper P, Robinson S (2020). *Characterization of Acoustic Fields Generated by UXO Removal, Phase 2*. NPL Report AC 19, National Physical Laboratory.
- Cudahy E, Parvin S (2001). *The effects of underwater blast on divers*. Naval Submarine Medical Research Laboratory Report #1218.
- Dahl P H, de Jong C A, Popper A N (2015). *The underwater sound field from impact pile driving and its potential effects on marine life*. *Acoustics Today*, Spring 2015, Volume 11, Issue 2.
- Fields D M, Handegard N O, Dalen J, Eichner C, Malde K, Karlsen Ø, Skiftesvik A, Durif C, Browman H (2019). *Airgun blasts used in marine seismic surveys have limited effects on mortality, and no sublethal effects on behaviour or gene expression, in the copepod Calanus finmarchicus*. *ICES J. Mar. Sci.* 76 (7), 2033–2044.

Finneran J J (2024). *Marine mammal auditory weighting functions and exposure functions for US Navy Phase 4 acoustic effects analyses*. NIWC Pacific, 26 Feb 2024.

Goertner J F (1978). *Dynamical model for explosion injury to fish*. Naval Surface Weapons Center, White Oak Lab, Silver Spring, MD. Report No. NSWC/WOL.TR-76-155.

Goertner J F, Wiley M L, Young G A, McDonald W W (1994). *Effects of underwater explosions on fish without swim bladders*. Naval Surface Warfare Center. Report No. NSWC/TR-76-155.

Halvorsen M B, Casper B C, Matthew D, Carlson T J, Popper A N (2012). *Effects of exposure to pile driving sounds on the lake sturgeon, Nila tilapia, and hogchoker*. Proc. Roy. Soc. B 279: 4705-4714.

Hastie G, Merchant N D, Götz T, Russell D J F, Thompson P, Janik V M (2019). *Effects of impulsive noise on marine mammals: Investigating range-dependent risk*. DOI: 10.1002/eap.1906.

Hastings M C, Popper A N (2005). *Effects of sound on fish*. Report to the California Department of Transport, under Contract No. 43A01392005, January 2005.

Hawkins A D, Popper A N (2017). *A sound approach to assessing the impact of underwater noise on marine fishes and invertebrates*. ICES J. Mar. Sci. 74 (3), 635-651 doi: 10.1093/icesjms.fsw205.

Heaney K D, Ainslie M A, Halvorsen M B, Seger K D, Müller, R A J, Nijhof M J J, Lippert T (2020). *A Parametric Analysis and Sensitivity Study of the Acoustic Propagation for Renewable Energy Sources*. Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. Prepared by CSA Ocean Sciences Inc. OCS Study BOEM 2020-011, 165 p.

Henderson D, Hamernik R P (1986). *Impulse noise: Critical review*. The Journal of the Acoustical Society of America 80:569-584.

Hirata K (1999). *Swimming speeds of some common fish*. National Maritime Research Institute (Japan). Data sourced from Iwai T, Hisada M (1998). *Fishes – Illustrated book of Gakken* (in Japanese). Accessed on 14th December 2022 at <https://www.nmri.go.jp/archives/eng/khirata/fish/general/speed/speede.htm>

Holme C T, Simurda, M, Gerlach S, Bellmann M A (2023). *Relation Between Underwater Noise and Operating Offshore Wind Turbines*. The Effects of Noise on Aquatic Life, conference, Berlin, Germany.

Hubert J, van Bemmelen J J, Slabbekoorn H (2021). *No negative effects of boat sound playbacks on olfactory-mediated food finding behaviour of shore crabs in a T-maze*. Environ. Pollut. 270, 116184.

Hubert J, Demuyck J M, Rimmelzwaal M R, Muñiz C, Debusschere E, Berges B, Slabbekoorn H (2024). *An experimental sound exposure study at sea: No spatial deterrence of free-ranging pelagic fish*. J. Acoust. Soc. Am. 155, 1151–1161 (2024).

International Organisation for Standardisation (2017). *Underwater acoustics – Terminology (ISO standard no. 18405:2017)*. <https://www.iso.org/standard/62406.html>

Kastelein R A, van de Voorde S, Jennings N (2018). *Swimming speed of a harbor porpoise (Phocoena phocoena) during playbacks of offshore pile driving sounds*. Aquatic Mammals. 2018, 44(1), 92-99, DOI 10.1578/AM.44.1.2018.92.

Marine Technical Directorate (MTD) (1996). *Guidelines for the safe use of explosives underwater*. MTD Publication 96/101. ISBN 1 870553 23 3.

Martin S B, Lucke K, Barclay D R (2020). *Techniques for distinguishing between impulsive and non-impulsive sound in the context of regulating sound exposure for marine mammals*. The Journal of the Acoustical Society of America 147, 2159.

Matei M, Chudzińska M, Remmers P, Bellman M, Darias-O'Hara A K, Verfuss U, Wood J, Hardy N, Wilder F, Booth C (2024). *Range dependent nature of impulsive noise (RaDIN)*. Report on behalf of the Carbon Trust and Offshore Renewables Joint Industry Programme (ORJIP) for Offshore Wind.

McCauley R D, Day R D, Swadling K M, Fitzgibbon Q P, Watson R A, Semmens J M (2017). *Widely used marine seismic survey air gun operations negatively impact zooplankton*. Nat. Ecol. Evol. 1 (7), 1–8.

McGarry T, Boisseau O, Stephenson S, Compton R (2017). *Understanding the Effectiveness of Acoustic Deterrent Devices (ADDs) on Minke Whale (Balaenoptera acutorostrata), a Low Frequency Cetacean*. ORJIP Project 4, Phase 2. RPS Report EOR0692. Prepared on behalf of The Carbon Trust. November 2017.

National Marine Fisheries Service (NMFS) (2018). *Revisions to: Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing (version 2.0): Underwater thresholds for onset of permanent and temporary threshold shifts*. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OPR-59.

National Marine Fisheries Service (NMFS) (2024). *2024 update to: Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing (version 3.0): Underwater and in-air criteria for onset of auditory injury and temporary threshold shifts*. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OPR-71.

National Oceanic and Atmospheric Administration (NOAA) (2005). *Endangered fish and wildlife: Notice of intent to prepare an Environmental Impact Statement*. Federal Register 70: 1871-1875.

Nedelec S L, Campbell J, Radford A N, Simpson S D, Merchant N D (2016). *Particle motion: The missing link in underwater acoustic ecology*. Methods Ecol. Evol. 7, 836 – 842.

Nedwell J R, Langworthy J, Howell D (2003). *Assessment of subsea noise and vibration from offshore wind turbines and its impact on marine wildlife. Initial measurements of underwater noise during construction of offshore wind farms, and comparisons with background noise*. Subacoustech Report No. 544R0423, published by COWRIE, May 2003.

Ocean Winds (2024). *Low order deflagration of unexploded ordnance reduces underwater noise impacts from offshore wind farm construction*. Report for Ocean Winds, in collaboration with EODEX.

Otani S, Naito T, Kato A, Kawamura A (2000). *Diving behaviour and swimming speed of a free-ranging harbour porpoise (Phocoena phocoena)*. Marine Mammal Science, Volume 16, Issue 4, pp 811-814, October 2000.

Popper A N, Hawkins A D, Fay R R, Mann D A, Bartol S, Carlson T J, Coombs S, Ellison W T, Gentry R L, Halvorsen M B, Løkkeborg S, Rogers P H, Southall B L, Zeddies D G, Tavolga W N (2014). *Sound exposure guidelines for Fishes and Sea Turtles*. Springer Briefs in Oceanography, DOI 10.1007/978-3-319-06659-2.

Popper A N, Hawkins A D (2018). *The importance of particle motion to fishes and invertebrates*. J. Acoust. Soc. Am. 143, 470 – 486.

Popper A N, Hawkins A D (2019). *An overview in fish bioacoustics and the impacts of anthropogenic sounds on fishes*. Journal of Fish Biology, 1-22. DOI: 10.1111/jfp.13948.

Radford C A, Montgomery J C, Caiger P, Higgs D M (2012). *Pressure and particle motion detection thresholds in fish: a re-examination of salient auditory cues in teleosts*. Journal of Experimental Biology, 215, 3429 – 3435.

Rawlins J S P (1987). *Problems in predicting safe ranges from underwater explosions*. Journal of Naval Science, Volume 13, No. 4, pp 235-246.

Robinson S P, Lepper P A, Hazelwood R A (2014). *Good practice guide for underwater noise measurement*. National Measurement Office, Marine Scotland, The Crown Estate. NPL Good Practice Guide No. 133, ISSN 1368-6550.

Solé M, Lenoir M, Durfort M, López-Bejar M, Lombarte A, André M (2013). *Ultrastructural damage of Loligo vulgaris and Illex coindetii statocysts after low frequency sound exposure*. PloS One 8 (10), 1–12.

Solé M, Lenoir M, Fortuño J-M, van der Schaar M, André M (2018). *A critical period of susceptibility to sound in the sensory cells of cephalopod hatchlings*. Biol. Open 7 (10), bio033860.

Solé M, Monge M, André M, Quero C (2019). *A proteomic analysis of the statocyst endolymph in common cuttlefish (Sepia officinalis): An assessment of acoustic trauma after exposure to sound*. Sci. Rep. 9 (1), 9340.

Solé M, Kaifu K, Mooney T A, Nedelec, S L, Olivier F, Radford A N, Vazzana M, Wale M A, Semmens J M, Simpson S D, Buscaino G, Hawkins A, Aguilar de Soto N, Akamatsu T, Chauvaud L, Day R D, Fitzgibbon Q, McCauley R D, André M (2023) *Marine invertebrates and noise*. Frontiers in Marine Science, 10.

Soloway A G, Dahl P H (2014). *Peak sound pressure and sound exposure level from underwater explosions in shallow water*. The Journal of the Acoustical Society of America, 136(3), EL219 – EL223. <http://dx.doi.org/10.1121/1.4892668>.

Southall B L, Finneran J J, Reichmuth C, Nachtigall P E, Ketten D R, Bowles A E, Ellison W T, Nowacek D P, Tyack P L (2019). *Marine mammal noise exposure criteria: Updated scientific recommendations for residual hearing effects*. Aquatic Mammals 2019, 45 (20, 125-232) DOI 10.1578/AM.45.2.2019.125.

Spiga I, Caldwell G S, Brintjes R (2016). *Influence of pile driving on the clearance rate of the blue mussel, Mytilus edulis (L.)*. Proc. Meetings Acoustics 27 (1).

Stephenson J R, Gingerich A J, Brown R S, Pflugrath B D, Deng Z, Carlson T J, Langeslay M J, Ahmann M L, Johnson R L, Seaburg A G (2010). *Assessing barotrauma in neutrally and negatively buoyant juvenile salmonids exposed to simulated hydro-turbine passage using a mobile aquatic barotrauma laboratory*. Fisheries Research Volume 106, Issue 3, pp 271-278, December 2010.

Stöber U, Thomsen F (2021). *How could operational underwater sound from future offshore wind turbines impact marine life?* The Journal of the Acoustical Society of America, 149, 1791-1795. <https://doi.org/10.1121/10.0003760>.

Thompson P M, Hastie G D, Nedwell J, Barham R, Brookes K L, Cordes L S, Bailey H, McLean N (2013). *Framework for assessing impacts of pile-driving noise from offshore wind farm construction on a harbour seal population*. Environmental Impact Assessment Review 43 (2013) 73-85.

Thompson P M, Benhemma-Le Gall A, Lee R, Stephenson S, Mason T (2025). *Predicted and observed responses of harbour porpoises to pile driving noise at Moray West Offshore Wind Farm. PrePARED Report, No. 008. June 2025*.

Tougaard J, Hermannsen L, Madsen P T (2020), *How loud is the underwater noise from operating offshore wind turbines?* J. Acoust. Soc. Am. 148 (5). doi.org/10.1121/10.0002453.

Verfuss U K, Sinclair R R, Sparling C E (2019). *A review of noise abatement systems for offshore wind farm construction noise, and the potential for their application in Scottish Waters*. Scottish Natural Heritage Research Report No. 1070.

von Benda-Beckmann A M, Aarts G, Sertlek H Ö, Lucke K, Verboom W C, Kastelein R A, Ketten D R, van Bemmelen R, Lamm F-P A, Kirkwood R J, Ainslie M A (2015). *Assessing the impact of underwater clearance of unexploded*

ordnance on harbour porpoises (Phocoena phocoena) in the southern North Sea. Aquatic Mammals 2015, 41(4), pp 503-523, DOI 10.1578/ AM.41.4.2015.503.

von Pein J, Lippert T, Lippert S, von Estorff O (2022). *Scaling laws for unmitigated pile driving: Dependence of underwater noise on strike energy, pile diameter, ram weight, and water depth. Applied Acoustics 198 (2022) 108986.*

Williams T (2009). *Swimming. Encyclopedia of Marine Mammals. 1140-1147. 10.1016/B978-0-12-373553-9.00262-5.*

Appendix A Additional modelling results

A.1 First strike results

Table A 1 to Table A 48 present the single strike ($L_{p,pk}$ and $L_{p,RMS}$) impact ranges for impact piling when considering the first pile strike of the monopile installation scenarios.

A.1.1 Unmitigated impact piling results

SE

Table A 1: Unweighted $L_{p,pk}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the first strike hammer blow energy during the monopile installation at the SE modelling location.

NMFS (2024)		Monopile foundation, unmitigated (first strike: 440 kJ)			
Unweighted $L_{p,pk}$		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	222 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	230 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	202 dB (VHF)	0.24 km ²	280 m	270 m	280 m
	223 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	216 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	224 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	196 dB (VHF)	1.2 km ²	640 m	620 m	630 m
	217 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table A 2: Unweighted $L_{p,RMS}$ impact areas and ranges for marine mammals using the NOAA (2005) Level B criteria for the first strike hammer blow energy during the monopile installation at the SE modelling location.

NOAA (2005)		Monopile foundation, unmitigated (first strike: 440 kJ)			
Unweighted $L_{p,RMS}$		Area	Maximum range	Minimum range	Mean range
Level B	160 dB	290 km ²	12 km	7.6 km	9.4 km

Table A 3: Unweighted $L_{p,pk}$ impact areas and ranges for fish using the Popper et al (2014) pile driving criteria for the first strike hammer blow energy during the monopile installation at the SE modelling location.

Popper et al. (2014)		Monopile foundation, unmitigated (first strike: 440 kJ)			
Unweighted $L_{p,pk}$		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	0.01 km ²	60 m	60 m	60 m
	207 dB	0.06 km ²	140 m	140 m	140 m

Table A 4: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the German underwater noise requirements when considering the first strike hammer blow energy during the monopile installation at the SE modelling location.

German requirements		Monopile foundation, unmitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	190 dB	6.0 km ²	1.4 km	1.4 km	1.4 km
Unweighted $L_{E,p,ss}$	160 dB	56 km ²	4.6 km	3.9 km	4.2 km

Table A 5: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the Belgian underwater noise requirements when considering the first strike hammer blow energy during the monopile installation at the SE modelling location.

Belgian requirements		Monopile foundation, unmitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	185 dB	21 km ²	2.7 km	2.4 km	2.6 km
Unweighted $L_{E,p,ss}$	162 dB	33 km ²	3.4 km	3.1 km	3.3 km

Table A 6: Unweighted $L_{p,ss}$ and $L_{p,RMS,wtd,125ms}$ impact areas and ranges for the Danish behavioural underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation at the SE modelling location.

Danish behavioural requirements	Monopile foundation, unmitigated (first strike: 440 kJ)				
	Area	Maximum range	Minimum range	Mean range	
Unweighted $L_{E,p,ss}$	143 dB	2,100 km ²	37 km	14 km	25 km
Weighted $L_{p,RMS,wtd,125ms}$	103 dB (VHF)	4,200 km ²	53 km	16 km	34 km

SW

Table A 7: Unweighted $L_{p,pk}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the first strike hammer blow energy during the monopile installation at the SW modelling location.

NMFS (2024) Unweighted $L_{p,pk}$	Monopile foundation, unmitigated (first strike: 440 kJ)				
	Area	Maximum range	Minimum range	Mean range	
AUD INJ (Impulsive)	222 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	230 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	202 dB (VHF)	0.13 km ²	210 m	200 m	200 m
	223 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	216 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	224 dB (HF)	0.63 km ²	450 m	440 m	450 m
	196 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	217 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table A 8: Unweighted $L_{p,RMS}$ impact areas and ranges for marine mammals using the NOAA (2005) Level B criteria for the first strike hammer blow energy during the monopile installation at the SW modelling location.

NOAA (2005) Unweighted $L_{p,RMS}$	Monopile foundation, unmitigated (first strike: 440 kJ)				
	Area	Maximum range	Minimum range	Mean range	
Level B	160 dB	150 km ²	7.6 km	5.9 km	6.8 km

Table A 9: Unweighted $L_{p,pk}$ impact areas and ranges for fish using the Popper et al (2014) pile driving criteria for the first strike hammer blow energy during the monopile installation at the SW modelling location.

Popper et al. (2014) Unweighted $L_{p,pk}$	Monopile foundation, unmitigated (first strike: 440 kJ)				
	Area	Maximum range	Minimum range	Mean range	
Pile driving	213 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	0.03 km ²	110 m	100 m	100 m

Table A 10: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the German underwater noise requirements when considering the first strike hammer blow energy during the monopile installation at the SW modelling location.

German requirements	Monopile foundation, unmitigated (first strike: 440 kJ)				
	Area	Maximum range	Minimum range	Mean range	
Unweighted $L_{p,pk}$	190 dB	2.9 km ²	980 m	940 m	960 m
Unweighted $L_{E,p,ss}$	160 dB	30 km ²	3.3 km	2.8 km	3.1 km

Table A 11: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the Belgian underwater noise requirements when considering the first strike hammer blow energy during the monopile installation at the SW modelling location.

Belgian requirements	Monopile foundation, unmitigated (first strike: 440 kJ)				
	Area	Maximum range	Minimum range	Mean range	
Unweighted $L_{p,pk}$	185 dB	9.6 km ²	1.8 km	1.7 km	1.7 km
Unweighted $L_{E,p,ss}$	162 dB	18 km ²	2.5 km	2.3 km	2.4 km

Table A 12: Unweighted $L_{p,pk}$ and $L_{p,RMS,wtd,125ms}$ impact areas and ranges for the Danish behavioural underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation at the SW modelling location.

Danish behavioural requirements	Monopile foundation, unmitigated (first strike: 440 kJ)				
	Area	Maximum range	Minimum range	Mean range	
Unweighted $L_{E,p,ss}$	143 dB	840 km ²	22 km	11 km	16 km
Weighted $L_{p,RMS,wtd,125ms}$	103 dB (VHF)	2,000 km ²	38 km	11 km	24 km

NE

Table A 13: Unweighted $L_{p,pk}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the first strike hammer blow energy during the monopile installation at the NE modelling location.

NMFS (2024) Unweighted $L_{p,pk}$	Monopile foundation, unmitigated (first strike: 440 kJ)				
	Area	Maximum range	Minimum range	Mean range	
AUD INJ (Impulsive)	222 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	230 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	202 dB (VHF)	0.09 km ²	170 m	160 m	170 m
	223 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	216 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	224 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	196 dB (VHF)	0.39 km ²	360 m	350 m	350 m
	217 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table A 14: Unweighted $L_{p,RMS}$ impact areas and ranges for marine mammals using the NOAA (2005) Level B criteria for the first strike hammer blow energy during the monopile installation at the NE modelling location.

NOAA (2005) Unweighted $L_{p,RMS}$	Monopile foundation, unmitigated (first strike: 440 kJ)				
	Area	Maximum range	Minimum range	Mean range	
Level B	160 dB	91 km ²	7.1 km	4.3 km	5.3 km

Table A 15: Unweighted $L_{p,pk}$ impact areas and ranges for fish using the Popper et al (2014) pile driving criteria for the first strike hammer blow energy during the monopile installation at the NE modelling location.

Popper et al. (2014) Unweighted $L_{p,pk}$	Monopile foundation, unmitigated (first strike: 440 kJ)				
	Area	Maximum range	Minimum range	Mean range	
Pile driving	213 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	0.02 km ²	90 m	90 m	90 m

Table A 16: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the German underwater noise requirements when considering the first strike hammer blow energy during the monopile installation at the NE modelling location.

German requirements	Monopile foundation, unmitigated (first strike: 440 kJ)				
	Area	Maximum range	Minimum range	Mean range	
Unweighted $L_{p,pk}$	190 dB	1.7 km ²	750 m	710 m	730 m
Unweighted $L_{E,p,ss}$	160 dB	17 km ²	2.6 km	2.2 km	2.3 km

Table A 17: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the Belgian underwater noise requirements when considering the first strike hammer blow energy during the monopile installation at the NE modelling location.

Belgian requirements		Monopile foundation, unmitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	185 dB	5.3 km ²	1.4 km	1.2 km	1.3 km
Unweighted $L_{E,p,ss}$	162 dB	10 km ²	1.9 km	1.7 km	1.8 km

Table A 18: Unweighted $L_{E,p,ss}$ and $L_{p,RMS,wtd,125ms}$ impact areas and ranges for the Danish behavioural underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation at the NE modelling location.

Danish behavioural requirements		Monopile foundation, unmitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{E,p,ss}$	143 dB	800 km ²	24 km	8.6 km	15 km
Weighted $L_{p,RMS,wtd,125ms}$	103 dB (VHF)	3,000 km ²	49 km	11 km	28 km

NW

Table A 19: Unweighted $L_{p,pk}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the first strike hammer blow energy during the monopile installation at the NW modelling location.

NMFS (2024) Unweighted $L_{p,pk}$		Monopile foundation, unmitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	222 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	230 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	202 dB (VHF)	0.08 km ²	170 m	160 m	160 m
	223 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	216 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	224 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	196 dB (VHF)	0.37 km ²	360 m	330 m	340 m
	217 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table A 20: Unweighted $L_{p,RMS}$ impact areas and ranges for marine mammals using the NOAA (2005) Level B criteria for the first strike hammer blow energy during the monopile installation at the NW modelling location.

NOAA (2005) Unweighted $L_{p,RMS}$		Monopile foundation, unmitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Level B	160 dB	71 km ²	6.4 km	3.4 km	4.6 km

Table A 21: Unweighted $L_{p,pk}$ impact areas and ranges for fish using the Popper et al (2014) pile driving criteria for the first strike hammer blow energy during the monopile installation at the NW modelling location.

Popper et al. (2014) Unweighted $L_{p,pk}$		Monopile foundation, unmitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	0.02 km ²	90 m	90 m	90 m

Table A 22: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the German underwater noise requirements when considering the first strike hammer blow energy during the monopile installation at the NW modelling location.

German requirements		Monopile foundation, unmitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	190 dB	1.6 km ²	760 m	660 m	700 m
Unweighted $L_{E,p,ss}$	160 dB	15 km ²	2.7 km	1.9 km	2.2 km

Table A 23: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the Belgian underwater noise requirements when considering the first strike hammer blow energy during the monopile installation at the NW modelling location.

Belgian requirements		Monopile foundation, unmitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	185 dB	4.9 km ²	1.4 km	1.1 km	1.2 km
Unweighted $L_{E,p,ss}$	162 dB	9.6 km ²	2.0 km	1.5 km	1.7 km

Table A 24: Unweighted $L_{E,p,ss}$ and $L_{p,RMS,wtd,125ms}$ impact areas and ranges for the Danish behavioural underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation at the NW modelling location.

Danish behavioural requirements		Monopile foundation, unmitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{E,p,ss}$	143 dB	470 km ²	18 km	8.3 km	12 km
Weighted $L_{p,RMS,wtd,125ms}$	103 dB (VHF)	1,400 km ²	35 km	13 km	20 km

A.1.2 Mitigated impact piling results

SE

Table A 25: Unweighted $L_{p,pk}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the first strike hammer blow energy during the monopile installation including mitigation at the SE modelling location.

NMFS (2024)		Monopile foundation, mitigated (first strike: 440 kJ)			
Unweighted $L_{p,pk}$		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	222 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	230 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	202 dB (VHF)	0.01 km ²	70 m	70 m	70 m
	223 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	216 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	224 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	196 dB (VHF)	0.08 km ²	160 m	160 m	160 m
	217 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table A 26: Unweighted $L_{p,RMS}$ impact areas and ranges for marine mammals using the NOAA (2005) Level B criteria for the first strike hammer blow energy during the monopile installation including mitigation at the SE modelling location.

NOAA (2005)		Monopile foundation, mitigated (first strike: 440 kJ)			
Unweighted $L_{p,RMS}$		Area	Maximum range	Minimum range	Mean range
Level B	160 dB	26 km ²	3.0 km	2.7 km	2.9 km

Table A 27: Unweighted $L_{p,pk}$ impact areas and ranges for fish using the Popper et al (2014) pile driving criteria for the first strike hammer blow energy during the monopile installation including mitigation at the SE modelling location.

Popper et al. (2014)		Monopile foundation, mitigated (first strike: 440 kJ)			
Unweighted $L_{p,pk}$		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table A 28: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the German underwater noise requirements when considering the first strike hammer blow energy during the monopile installation including mitigation at the SE modelling location.

German requirements		Monopile foundation, mitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	190 dB	0.42 km ²	370 m	360 m	360 m
Unweighted $L_{E,p,ss}$	160 dB	3.4 km ²	1.1 km	1.0 km	1.0 km

Table A 29: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the Belgian underwater noise requirements when considering the first strike hammer blow energy during the monopile installation including mitigation at the SE modelling location.

Belgian requirements		Monopile foundation, mitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	185 dB	1.6 km ²	730 m	710 m	720 m
Unweighted $L_{E,p,ss}$	162 dB	1.8 km ²	770 m	750 m	760 m

Table A 30: Unweighted $L_{E,p,ss}$ and $L_{p,RMS,wt,125ms}$ impact areas and ranges for the Danish behavioural underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation including mitigation at the SE modelling location.

Danish behavioural requirements		Monopile foundation, mitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{E,p,ss}$	143 dB	290 km ²	12 km	7.6 km	9.4 km
Weighted $L_{p,RMS,wt,125ms}$	103 dB (VHF)	780 km ²	22 km	11 km	15 km

SW (mitigated)

Table A 31: Unweighted $L_{p,pk}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the first strike hammer blow energy during the monopile installation including mitigation at the SW modelling location.

NMFS (2024)		Monopile foundation, mitigated (first strike: 440 kJ)			
Unweighted $L_{p,pk}$		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	222 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	230 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	202 dB (VHF)	0.01 km ²	60 m	60 m	60 m
	223 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	216 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	224 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	196 dB (VHF)	0.06 km ²	140 m	140 m	140 m
	217 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table A 32: Unweighted $L_{p,RMS}$ impact areas and ranges for marine mammals using the NOAA (2005) Level B criteria for the first strike hammer blow energy during the monopile installation including mitigation at the SW modelling location.

NOAA (2005)		Monopile foundation, mitigated (first strike: 440 kJ)			
Unweighted $L_{p,RMS}$		Area	Maximum range	Minimum range	Mean range
Level B	160 dB	18 km ²	2.5 km	2.3 km	2.4 km

Table A 33: Unweighted $L_{p,pk}$ impact areas and ranges for fish using the Popper et al (2014) pile driving criteria for the first strike hammer blow energy during the monopile installation including mitigation at the SW modelling location.

Popper et al. (2014)		Monopile foundation, mitigated (first strike: 440 kJ)			
Unweighted $L_{p,pk}$		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table A 34: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the German underwater noise requirements when considering the first strike hammer blow energy during the monopile installation including mitigation at the SW modelling location.

German requirements		Monopile foundation, mitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	190 dB	0.29 km ²	310 m	300 m	300 m
Unweighted $L_{E,p,ss}$	160 dB	2.6 km ²	920 m	900 m	920 m

Table A 35: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the Belgian underwater noise requirements when considering the first strike hammer blow energy during the monopile installation including mitigation at the SW modelling location.

Belgian requirements		Monopile foundation, mitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	185 dB	1.1 km ²	590 m	570 m	580 m
Unweighted $L_{E,p,ss}$	162 dB	1.5 km ²	690 m	670 m	680 m

Table A 36: Unweighted $L_{E,p,ss}$ and $L_{p,RMS,wtd,125ms}$ impact areas and ranges for the Danish behavioural underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation including mitigation at the SW modelling location.

Danish behavioural requirements		Monopile foundation, mitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{E,p,ss}$	143 dB	180 km ²	8.5 km	6.4 km	7.5 km
Weighted $L_{p,RMS,wtd,125ms}$	103 dB (VHF)	530 km ²	16 km	13 km	10 km

NE

Table A 37: Unweighted $L_{p,pk}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the first strike hammer blow energy during the monopile installation including mitigation at the NE modelling location.

NMFS (2024)		Monopile foundation, mitigated (first strike: 440 kJ)			
Unweighted $L_{p,pk}$		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	222 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	230 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	202 dB (VHF)	0.01 km ²	70 m	70 m	70 m
	223 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	216 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	224 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	196 dB (VHF)	0.07 km ²	150 m	150 m	150 m
	217 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table A 38: Unweighted $L_{p,RMS}$ impact areas and ranges for marine mammals using the NOAA (2005) Level B criteria for the first strike hammer blow energy during the monopile installation including mitigation at the NE modelling location.

NOAA (2005)		Monopile foundation, mitigated (first strike: 440 kJ)			
Unweighted $L_{p,RMS}$		Area	Maximum range	Minimum range	Mean range
Level B	160 dB	17 km ²	2.6 km	2.2 km	2.3 km

Table A 39: Unweighted $L_{p,pk}$ impact areas and ranges for fish using the Popper et al (2014) pile driving criteria for the first strike hammer blow energy during the monopile installation including mitigation at the NE modelling location.

Popper et al. (2014)		Monopile foundation, mitigated (first strike: 440 kJ)			
Unweighted $L_{p,pk}$		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table A 40: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the German underwater noise requirements when considering the first strike hammer blow energy during the monopile installation including mitigation at the NE modelling location.

German requirements		Monopile foundation, mitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	190 dB	0.3 km ²	320 m	310 m	310 m
Unweighted $L_{E,p,ss}$	160 dB	2.8 km ²	980 m	920 m	940 m

Table A 41: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the Belgian underwater noise requirements when considering the first strike hammer blow energy during the monopile installation including mitigation at the NE modelling location.

Belgian requirements		Monopile foundation, mitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	185 dB	1.0 km ²	590 m	560 m	570 m
Unweighted $L_{E,p,ss}$	162 dB	1.6 km ²	730 m	700 m	710 m

Table A 42: Unweighted $L_{E,p,ss}$ and $L_{p,RMS,wt,d,125ms}$ impact areas and ranges for the Danish behavioural underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation including mitigation at the NE modelling location.

Danish behavioural requirements		Monopile foundation, mitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{E,p,ss}$	143 dB	180 km ²	11 km	5.5 km	7.4 km
Weighted $L_{p,RMS,wt,d,125ms}$	103 dB (VHF)	840 km ²	25 km	8.8 km	15 km

NW

Table A 43: Unweighted $L_{p,pk}$ impact areas and ranges for marine mammals using the NMFS (2024) impulsive criteria for the first strike hammer blow energy during the monopile installation including mitigation at the NW modelling location.

NMFS (2024) Unweighted $L_{p,pk}$		Monopile foundation, mitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Impulsive)	222 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	230 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	202 dB (VHF)	0.01 km ²	70 m	70 m	70 m
	223 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Impulsive)	216 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	224 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	196 dB (VHF)	0.06 km ²	150 m	140 m	140 m
	217 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table A 44: Unweighted $L_{p,RMS}$ impact areas and ranges for marine mammals using the NOAA (2005) Level B criteria for the first strike hammer blow energy during the monopile installation including mitigation at the NW modelling location.

NOAA (2005) Unweighted $L_{p,RMS}$		Monopile foundation, mitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Level B	160 dB	15 km ²	2.7 km	1.9 km	2.2 km

Table A 45: Unweighted $L_{p,pk}$ impact areas and ranges for fish using the Popper et al (2014) pile driving criteria for the first strike hammer blow energy during the monopile installation including mitigation at the NW modelling location.

Popper et al. (2014) Unweighted $L_{p,pk}$		Monopile foundation, mitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Pile driving	213 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	207 dB	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table A 46: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the German underwater noise requirements when considering the first strike hammer blow energy during the monopile installation including mitigation at the NW modelling location.

German requirements		Monopile foundation, mitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	190 dB	0.3 km ²	310 m	290 m	300 m
Unweighted $L_{E,p,ss}$	160 dB	2.6 km ²	990 m	840 m	900 m

Table A 47: Unweighted $L_{p,pk}$ and $L_{E,p,ss}$ impact areas and ranges for the Belgian underwater noise requirements when considering the first strike hammer blow energy during the monopile installation including mitigation at the NW modelling location.

Belgian requirements		Monopile foundation, mitigated (first strike: 440 kJ)			
		Area	Maximum range	Minimum range	Mean range
Unweighted $L_{p,pk}$	185 dB	0.97 km ²	590 m	530 m	560 m
Unweighted $L_{E,p,ss}$	162 dB	1.5 km ²	740 m	650 m	690 m

Table A 48: Unweighted $L_{E,p,ss}$ and $L_{p,RMS,wd,125ms}$ impact areas and ranges for the Danish behavioural underwater noise requirements when considering the maximum expected hammer blow energy during the monopile installation including mitigation at the NW modelling location.

Danish behavioural requirements	Monopile foundation, mitigated (first strike: 440 kJ)				
	Area	Maximum range	Minimum range	Mean range	
Unweighted $L_{E,p,ss}$	143 dB	130 km ²	9.1 km	4.1 km	6.2 km
Weighted $L_{p,RMS,wd,125ms}$	103 dB (VHF)	510 km ²	18 km	8.7 km	12 km

A.2 Non-impulsive criteria

Following the discussion around impulsive and non-impulsive noise sources in section 2.2.1, Table A 49 to Table A 58 present the modelling impact piling noise in terms of the non-impulsive criteria from NMFS (2024). $L_{p,pk}$ criteria are not suitable for non-impulsive consideration so are not included. Note that although the impact ranges below have been calculated to the non-impulsive thresholds, in practice they should only be considered where the impact range is in excess of 5 km. This is therefore limited to LF cetacean TTS with the unmitigated scenarios.

Contour plots for these results are presented in Appendix B.

A.2.1 Unmitigated impact piling results

Table A 49: Weighted $L_{E,p,24h,wd}$ impact areas and ranges for marine mammals using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) at the SE modelling location assuming fleeing receptors.

NMFS (2024) Weighted $L_{E,p,24h,wd}$	Monopile foundation, unmitigated (single pile)				
	Area	Maximum range	Minimum range	Mean range	
AUD INJ (Non-impulsive)	197 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	201 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	181 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	195 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Non-impulsive)	177 dB (LF)	790 km ²	26 km	4.8 km	14 km
	181 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	161 dB (VHF)	< 0.01 km ²	70 m	< 50 m	< 50 m
	175 dB (PW)	21 km ²	4.4 km	1.1 km	2.3 km

Table A 50: Weighted $L_{E,p,24h,wd}$ impact areas and ranges for marine mammals using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) at the SW modelling location assuming fleeing receptors.

NMFS (2024) Weighted $L_{E,p,24h,wd}$	Monopile foundation, unmitigated (single pile)				
	Area	Maximum range	Minimum range	Mean range	
AUD INJ (Non-impulsive)	197 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	201 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	181 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	195 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Non-impulsive)	177 dB (LF)	280 km ²	16 km	3.9 km	8.5 km
	181 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	161 dB (VHF)	0.02 km ²	140 m	< 50 m	80 m
	175 dB (PW)	21 km ²	3.5 km	1.5 km	2.5 km

Table A 51: Weighted $L_{E,p,24h,wt}$ impact areas and ranges for marine mammals using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) at the NE modelling location assuming fleeing receptors.

NMFS (2024) Weighted $L_{E,p,24h,wt}$		Monopile foundation, unmitigated (single pile)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Non-impulsive)	197 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	201 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	181 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	195 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Non-impulsive)	177 dB (LF)	310 km ²	19 km	1.8 km	7.9 km
	181 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	161 dB (VHF)	< 0.01 km ²	90 m	< 50 m	< 50 m
	175 dB (PW)	22 km ²	5.1 km	650 m	2.2 km

Table A 52: Weighted $L_{E,p,24h,wt}$ impact areas and ranges for marine mammals using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) at the NW modelling location assuming fleeing receptors.

NMFS (2024) Weighted $L_{E,p,24h,wt}$		Monopile foundation, unmitigated (single pile)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Non-impulsive)	197 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	201 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	181 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	195 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Non-impulsive)	177 dB (LF)	68 km ²	9.6 km	1.5 km	3.9 km
	181 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	161 dB (VHF)	< 0.01 km ²	60 m	< 50 m	< 50 m
	175 dB (PW)	7.1 km ²	3.2 km	330 m	1.2 km

Table A 53: Weighted $L_{E,p,24h,wt}$ impact areas and ranges for marine mammals using the NMFS (2024) non-impulsive criteria for the monopile installation (2 sequential piles) at the NW modelling location assuming fleeing receptors.

NMFS (2024) Weighted $L_{E,p,24h,wt}$		Monopile foundation, unmitigated (2 sequential piles)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Non-impulsive)	197 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	201 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	181 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	195 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Non-impulsive)	177 dB (LF)	73 km ²	9.8 km	1.5 km	4.1 km
	181 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	161 dB (VHF)	< 0.01 km ²	60 m	< 50 m	< 50 m
	175 dB (PW)	7.8 km ²	3.5 km	330 m	1.3 km

A.2.2 Mitigated impact piling results

Table A 54: Weighted $L_{E,p,24h,wtd}$ impact areas and ranges for marine mammals using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) including mitigation at the SE modelling location assuming fleeing receptors.

NMFS (2024) Weighted $L_{E,p,24h,wtd}$		Monopile foundation, mitigated (single pile)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Non-impulsive)	197 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	201 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	181 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	195 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Non-impulsive)	177 dB (LF)	3.2 km ²	1.7 km	480 m	910 m
	181 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	161 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	175 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table A 55: Weighted $L_{E,p,24h,wtd}$ impact areas and ranges for marine mammals using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) including mitigation at the SW modelling location assuming fleeing receptors.

NMFS (2024) Weighted $L_{E,p,24h,wtd}$		Monopile foundation, mitigated (single pile)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Non-impulsive)	197 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	201 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	181 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	195 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Non-impulsive)	177 dB (LF)	1.8 km ²	1.1 km	430 m	710 m
	181 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	161 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	175 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table A 56: Weighted $L_{E,p,24h,wtd}$ impact areas and ranges for marine mammals using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) including mitigation at the NE modelling location assuming fleeing receptors.

NMFS (2024) Weighted $L_{E,p,24h,wtd}$		Monopile foundation, mitigated (single pile)			
		Area	Maximum range	Minimum range	Mean range
AUD INJ (Non-impulsive)	197 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	201 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	181 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	195 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Non-impulsive)	177 dB (LF)	4.6 km ²	2.6 km	330 m	950 m
	181 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	161 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	175 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table A 57: Weighted $L_{E,p,24h,wt}$ impact areas and ranges for marine mammals using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) including mitigation at the NW modelling location assuming fleeing receptors.

NMFS (2024)		Monopile foundation, mitigated (single pile)			
Weighted $L_{E,p,24h,wt}$		Area	Maximum range	Minimum range	Mean range
AUD INJ (Non-impulsive)	197 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	201 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	181 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	195 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Non-impulsive)	177 dB (LF)	0.99 km ²	1.3 km	270 m	500 m
	181 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	161 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	175 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Table A 58: Weighted $L_{E,p,24h,wt}$ impact areas and ranges for marine mammals using the NMFS (2024) non-impulsive criteria for the monopile installation (2 sequential piles) including mitigation at the NW modelling location assuming fleeing receptors.

NMFS (2024)		Monopile foundation, mitigated (2 sequential piles)			
Weighted $L_{E,p,24h,wt}$		Area	Maximum range	Minimum range	Mean range
AUD INJ (Non-impulsive)	197 dB (LF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	201 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	181 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	195 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
TTS (Non-impulsive)	177 dB (LF)	1.0 km ²	1.3 km	270 m	500 m
	181 dB (HF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	161 dB (VHF)	< 0.01 km ²	< 50 m	< 50 m	< 50 m
	175 dB (PW)	< 0.01 km ²	< 50 m	< 50 m	< 50 m

Appendix B Contour plots

The following sections present contour plots for the impact piling modelling from sections 4 and A.2, each showing the results for the NMFS (2024) and Popper *et al.* (2014) $L_{E,p,24h}$ criteria. Table B 1 lists all the figures over the following pages and cross-references them with the impact range tables in the previous sections. Note that for many scenarios in this section, the contours are small enough that they cannot be seen due to the scale of the maps used.

Table B 1: Summary of the contour plots presented in this appendix, cross-referenced with the relevant tables in the previous sections

Figure (page)	Parameters	Criteria		Corresponding results table (page)
Figure B 1 (p90)	Monopile, unmitigated SE (most restrictive ramp-up) (B.1.1)	NMFS (2024)	LF Impulsive	Table 4-3 (p37)
Figure B 2 (p91)			HF Impulsive	
Figure B 3 (p92)			VHF Impulsive PW Impulsive	
Figure B 4 (p93)	Monopile, unmitigated SW (less restrictive ramp-up) (B.1.2)	Popper <i>et al.</i> (2014)	Fish (fleeing)	Table 4-6 (p38)
Figure B 5 (p94)			Fish (stationary)	
Figure B 6 (p95)			LF Impulsive HF Impulsive	
Figure B 7 (p96)	Monopile, unmitigated NE (less restrictive ramp-up) (B.1.3)	NMFS (2024)	VHF Impulsive	Table 4-11 (p39)
Figure B 8 (p97)			PW Impulsive	
Figure B 9 (p98)			Fish (fleeing) Fish (stationary)	
Figure B 10 (p99)	Monopile, unmitigated NW (less restrictive ramp-up, two sequential piles) (B.1.4)	NMFS (2024) (single pile)	LF Impulsive	Table 4-14 (p40)
Figure B 11 (p100)			HF Impulsive	
Figure B 12 (p101)			VHF Impulsive PW Impulsive	
Figure B 13 (p102)	Monopile, unmitigated NW (less restrictive ramp-up, two sequential piles) (B.1.4)	Popper <i>et al.</i> (2014) (single pile)	Fish (fleeing)	Table 4-19 (p41)
Figure B 14 (p103)			Fish (stationary)	
Figure B 15 (p104)			LF Impulsive HF Impulsive	
Figure B 16 (p105)	Monopile, mitigated SE (most restrictive ramp-up) (B.2.1)	NMFS (2024) (2 sequential piles)	VHF Impulsive	Table 4-22 (p42)
Figure B 17 (p106)			PW Impulsive	
Figure B 18 (p107)			Fish (fleeing) Fish (stationary)	
Figure B 19 (p108)	Monopile, mitigated SW (less restrictive ramp-up) (B.2.2)	Popper <i>et al.</i> (2014) (2 sequential piles)	LF Impulsive	Table 4-27 (p43)
Figure B 20 (p109)			HF Impulsive	
Figure B 21 (p110)			VHF Impulsive PW Impulsive	
Figure B 16 (p105)	Monopile, mitigated SE (most restrictive ramp-up) (B.2.1)	NMFS (2024)	Fish (fleeing)	Table 4-28 (p43)
Figure B 17 (p106)			Fish (stationary)	
Figure B 18 (p107)			LF Impulsive HF Impulsive	
Figure B 19 (p108)	Monopile, mitigated SW (less restrictive ramp-up) (B.2.2)	Popper <i>et al.</i> (2014)	VHF Impulsive	Table 4-31 (p44)
Figure B 20 (p109)			PW Impulsive	
Figure B 21 (p110)			Fish (fleeing) Fish (stationary)	

Figure (page)	Parameters	Criteria		Corresponding results table (page)
Figure B 22 (p111)	Monopile, mitigated NE (less restrictive ramp-up) (B.2.3)	NMFS (2024)	LF Impulsive	Table 4-53 (p49)
Figure B 23 (p112)			HF Impulsive	
Figure B 24 (p113)		Popper <i>et al.</i> (2014)	Fish (fleeing)	Table 4-56 (p50)
Figure B 25 (p114)	Monopile, mitigated NW (less restrictive ramp-up, two sequential piles) (B.2.4)	NMFS (2024) (single pile)	LF Impulsive	Table 4-61 (p51)
Figure B 26 (p115)			HF Impulsive	
Figure B 27 (p116)		Popper <i>et al.</i> (2014) (single pile)	VHF Impulsive	Table 4-65 (p52)
Figure B 28 (p117)		Fish (fleeing)		
Figure B 29 (p118)		NMFS (2024) (2 sequential piles)	PW Impulsive	Table 4-62 (p51)
Figure B 30 (p119)		Popper <i>et al.</i> (2014) (2 sequential piles)	Fish (stationary)	
Figure B 31 (p120)		Monopile, unmitigated SE (most restrictive ramp-up) (B.3.1)	NMFS (2024)	LF Non-impulsive
Figure B 32 (p121)	HF Non-impulsive			
Figure B 33 (p122)	Monopile, unmitigated SW (less restrictive ramp-up) (B.3.1)	NMFS (2024)	VHF Non-impulsive	Table A 50 (p83)
Figure B 34 (p123)			PW Non-impulsive	
Figure B 35 (p124)	Monopile, unmitigated NE (less restrictive ramp-up) (B.3.1)	NMFS (2024)	LF Non-impulsive	Table A 51 (p84)
Figure B 36 (p125)			HF Non-impulsive	
Figure B 37 (p126)	Monopile, unmitigated NW (less restrictive ramp-up, two sequential piles) (B.3.1)	NMFS (2024) (single pile)	VHF Non-impulsive	Table A 52 (p84)
Figure B 38 (p127)			PW Non-impulsive	
Figure B 39 (p128)		NMFS (2024) (2 sequential piles)	LF Non-impulsive	Table A 53 (p84)
Figure B 40 (p129)	HF Non-impulsive			
Figure B 41 (p130)	Monopile, mitigated SE (most restrictive ramp-up) (B.3.2)	NMFS (2024)	VHF Non-impulsive	Table A 54 (p85)
Figure B 42 (p131)			PW Non-impulsive	
Figure B 43 (p132)	Monopile, mitigated SW (less restrictive ramp-up) (B.3.2)	NMFS (2024)	LF Non-impulsive	Table A 55 (p85)
Figure B 44 (p133)			HF Non-impulsive	
Figure B 45 (p134)	Monopile, mitigated NE (less restrictive ramp-up) (B.3.2)	NMFS (2024)	VHF Non-impulsive	Table A 56 (p85)
Figure B 46 (p135)			PW Non-impulsive	

Figure (page)	Parameters	Criteria		Corresponding results table (page)
Figure B 47 (p136)	Monopile, mitigated NW (less restrictive ramp-up, two sequential piles) (B.3.2)	NMFS (2024) (single pile)	LF Non-impulsive	Table A 57 (p86)
Figure B 48 (p137)			HF Non-impulsive	
Figure B 49 (p138)		NMFS (2024) (2 sequential piles)	VHF Non-impulsive	Table A 58 (p86)
Figure B 50 (p139)			PW Non-impulsive	

B.1 Unmitigated impact piling results

B.1.1 SE

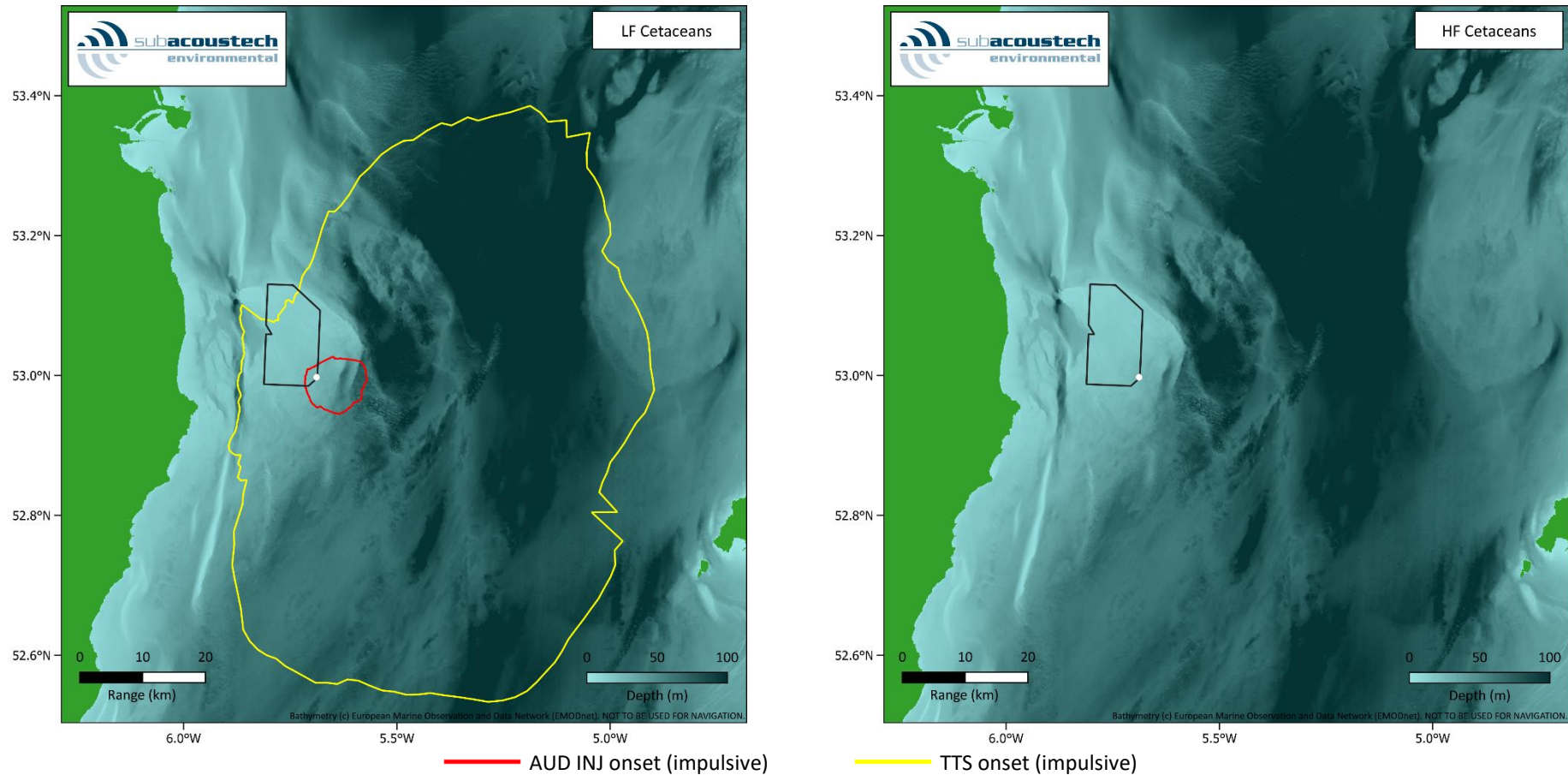


Figure B 1: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for LF and HF cetaceans using the NMFS (2024) impulsive criteria for the monopile installation (single pile) scenario at the SE modelling location assuming fleeing receptors.

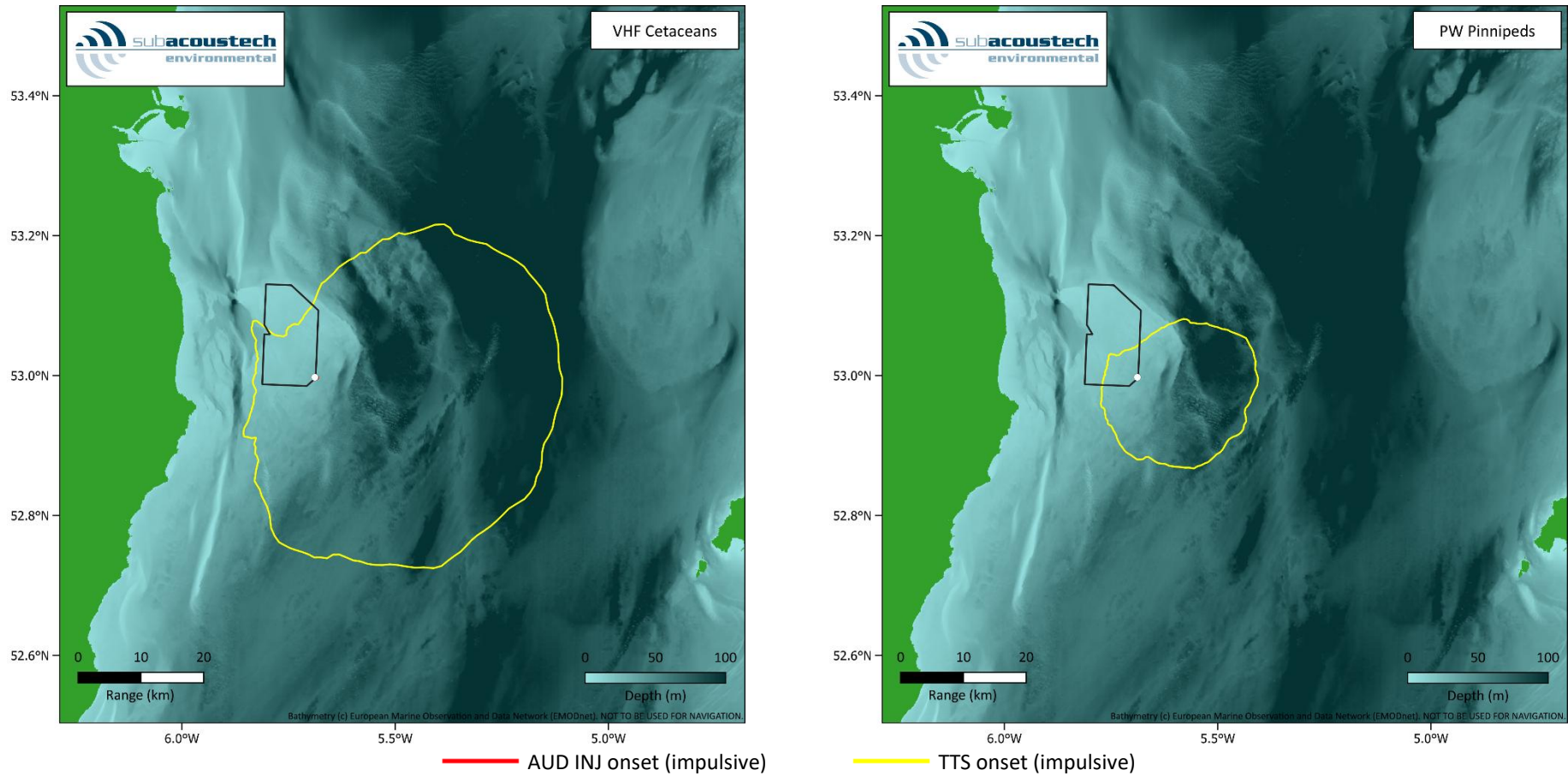


Figure B 2: Contour plots showing the weighted $L_{E,p,24h,wdt}$ impact ranges for VHF cetaceans and PW pinnipeds using the NMFS (2024) impulsive criteria for the monopile installation (single pile) scenario at the SE modelling location assuming fleeing receptors.

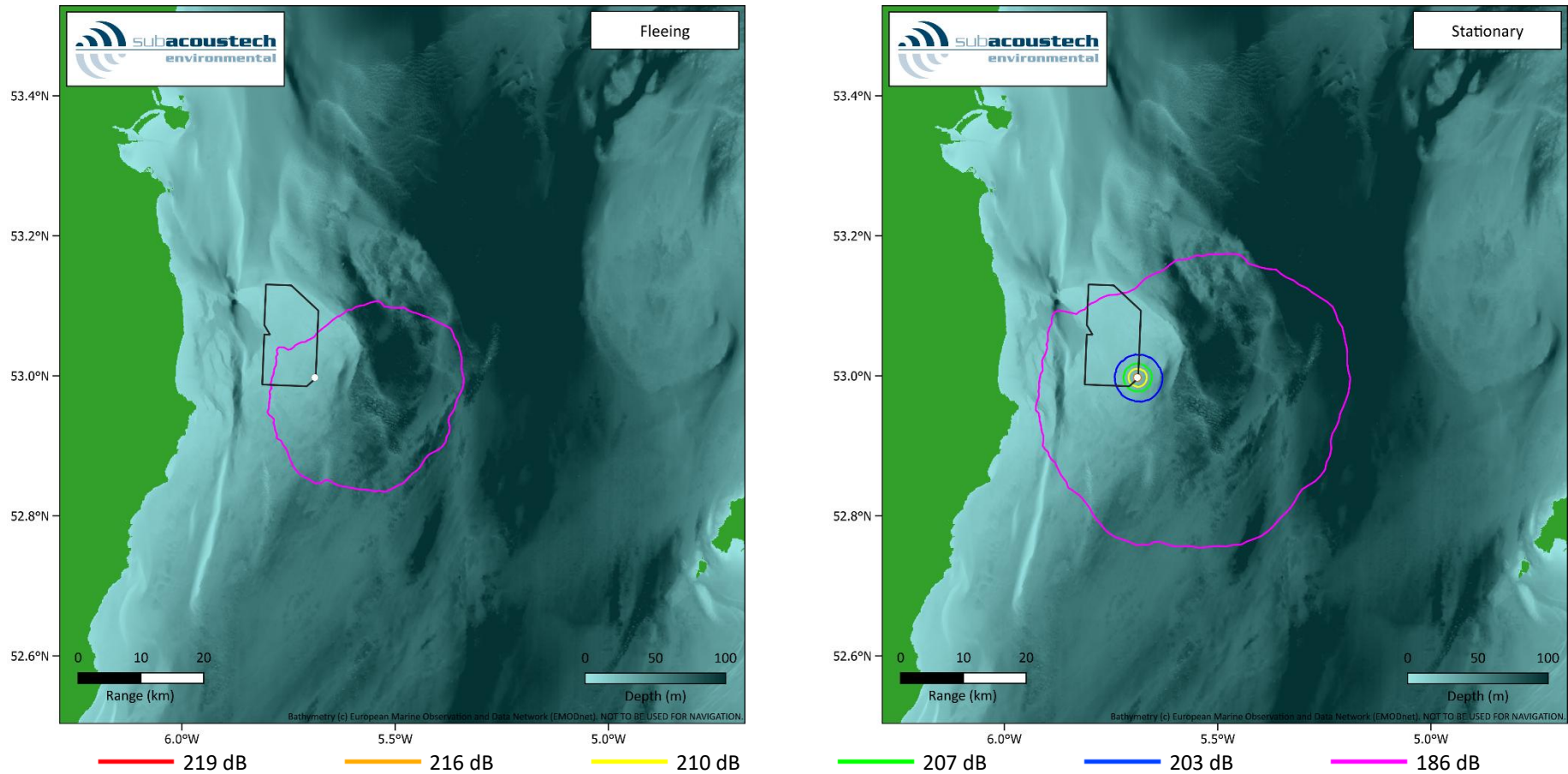


Figure B 3: Contour plots showing the unweighted $L_{E,p,24h,wtd}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile installation (single pile) scenario at the SE modelling location assuming both fleeing and stationary receptors.

B.1.2 SW

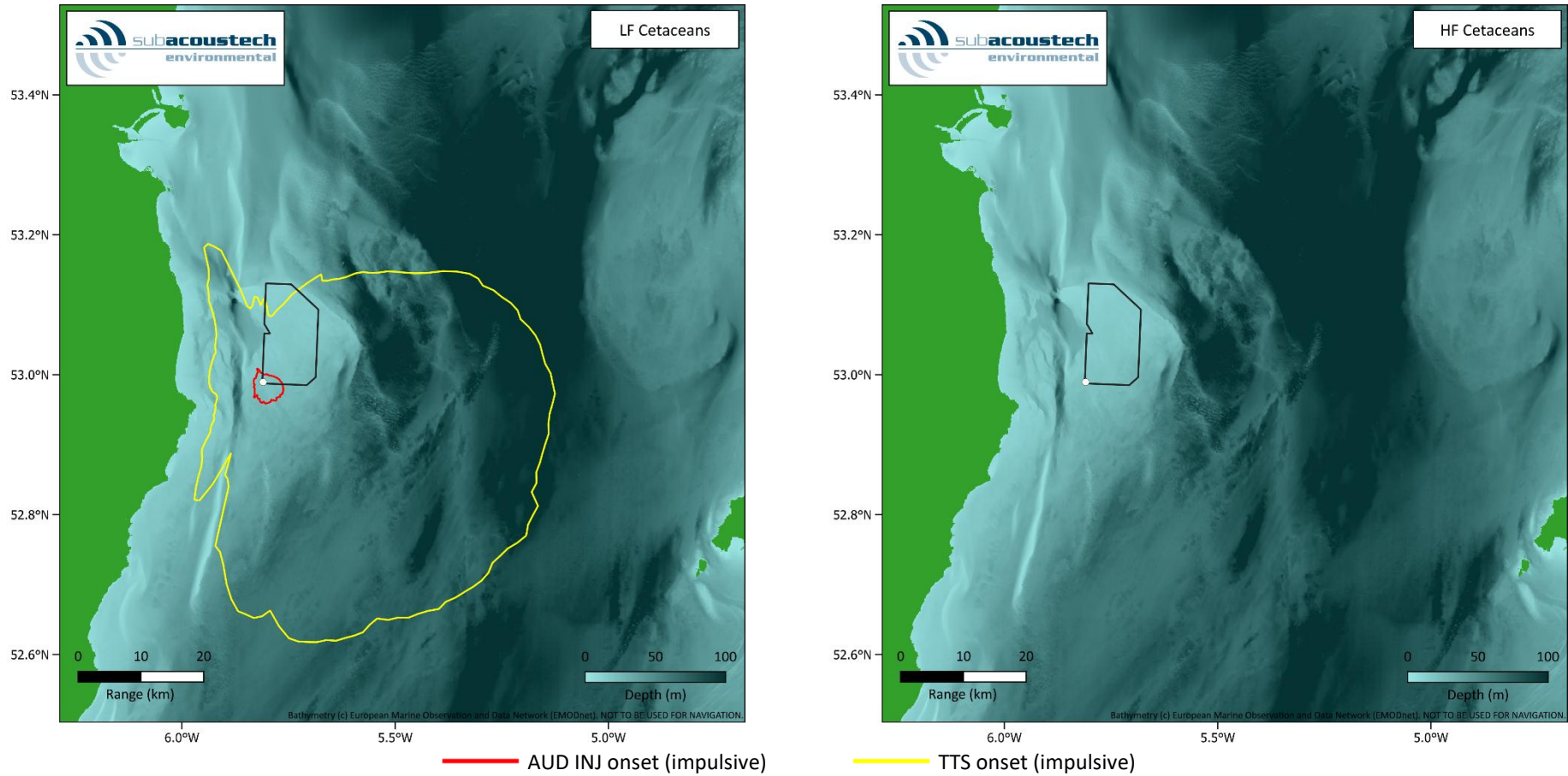


Figure B 4: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for LF and HF cetaceans using the NMFS (2024) impulsive criteria for the monopile installation (single pile) scenario at the SW modelling location assuming fleeing receptors.

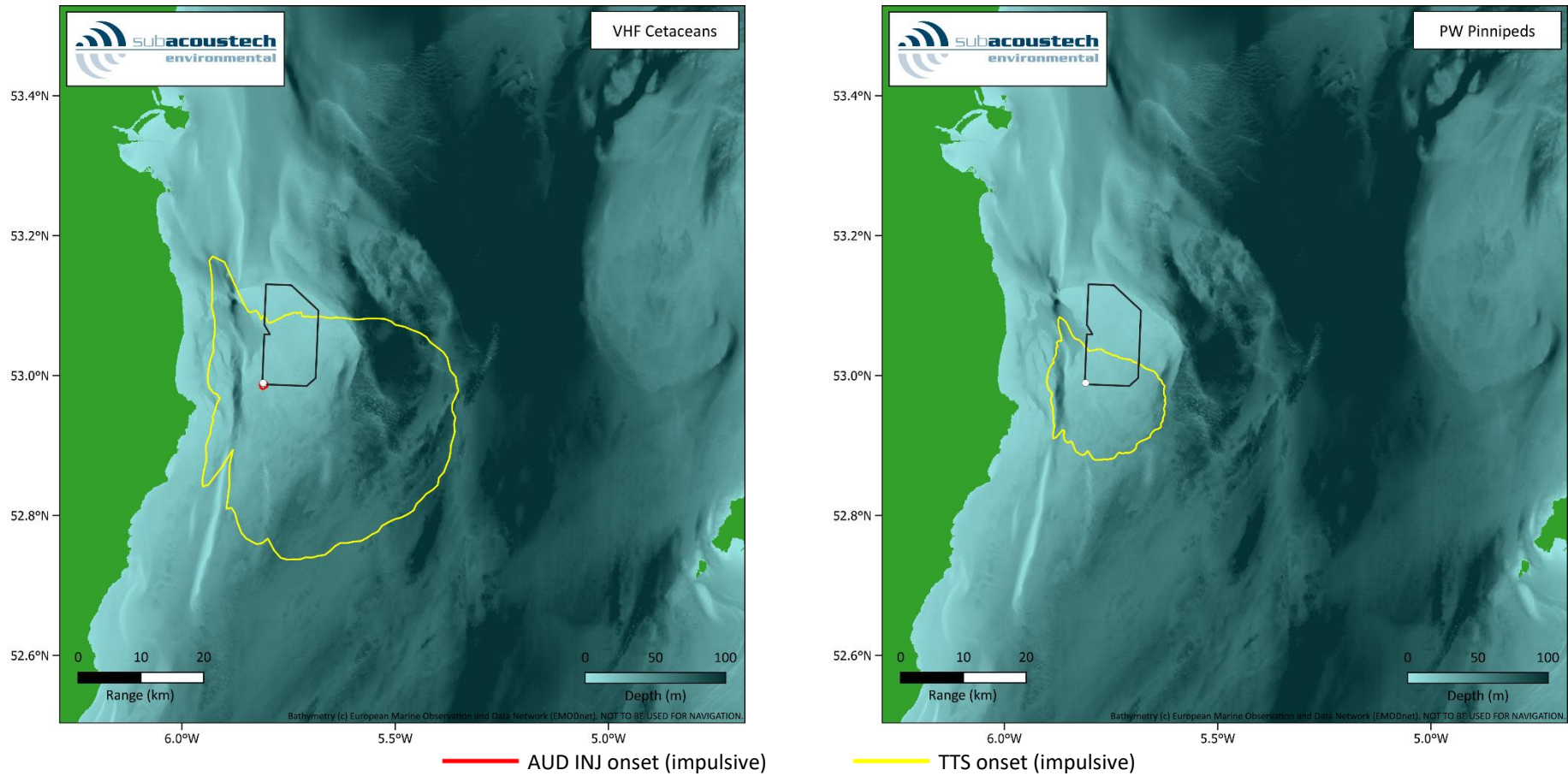


Figure B 5: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for VHF cetaceans and PW pinnipeds using the NMFS (2024) impulsive criteria for the monopile installation (single pile) scenario at the SW modelling location assuming fleeing receptors.

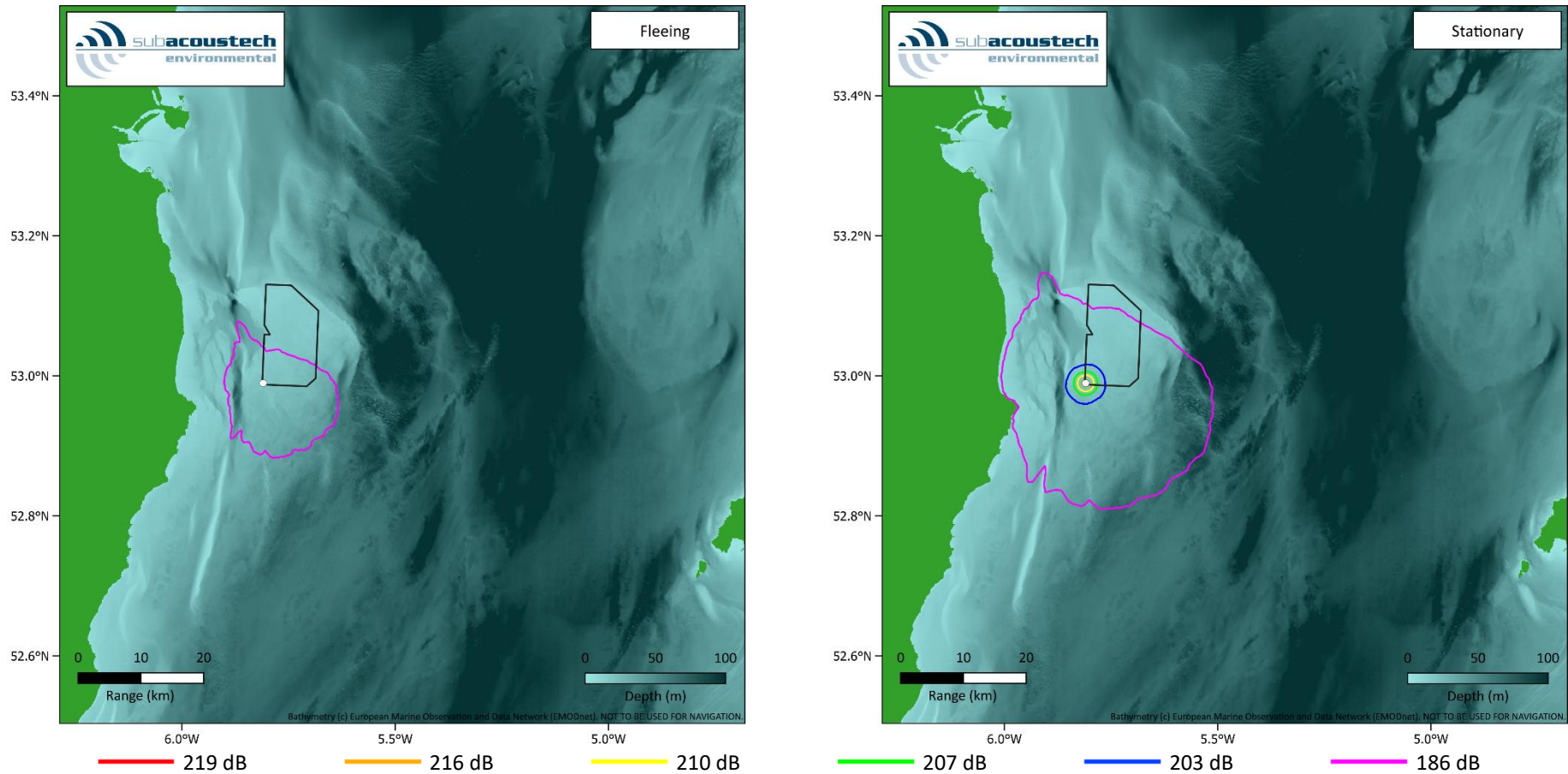


Figure B 6: Contour plots showing the unweighted $L_{E,p,24h,wtd}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile installation (single pile) scenario at the SW modelling location assuming both fleeing and stationary receptors.

B.1.3 NE

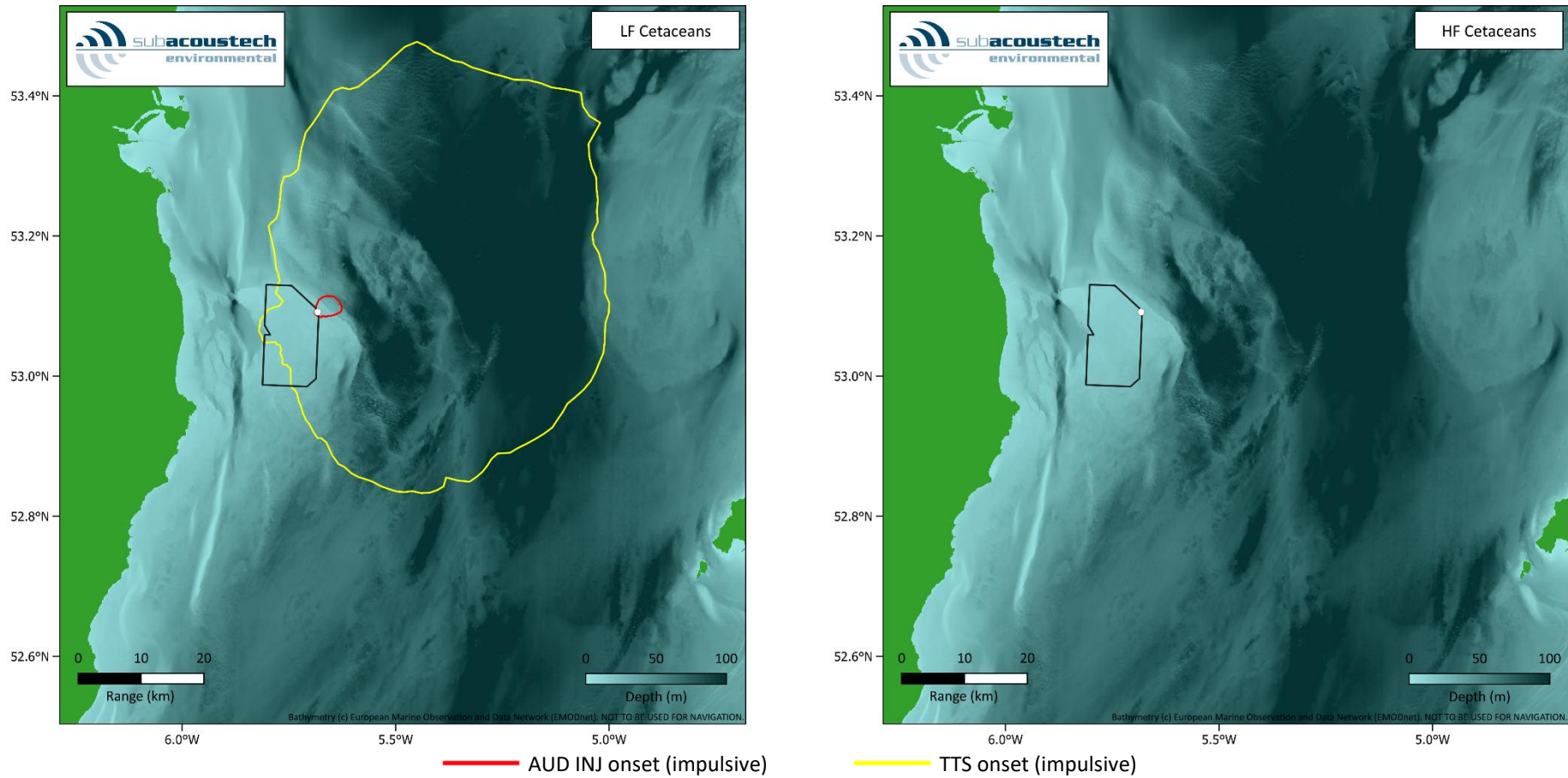


Figure B 7: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for LF and HF cetaceans using the NMFS (2024) impulsive criteria for the monopile installation (single pile) scenario at the NE modelling location assuming fleeing receptors.

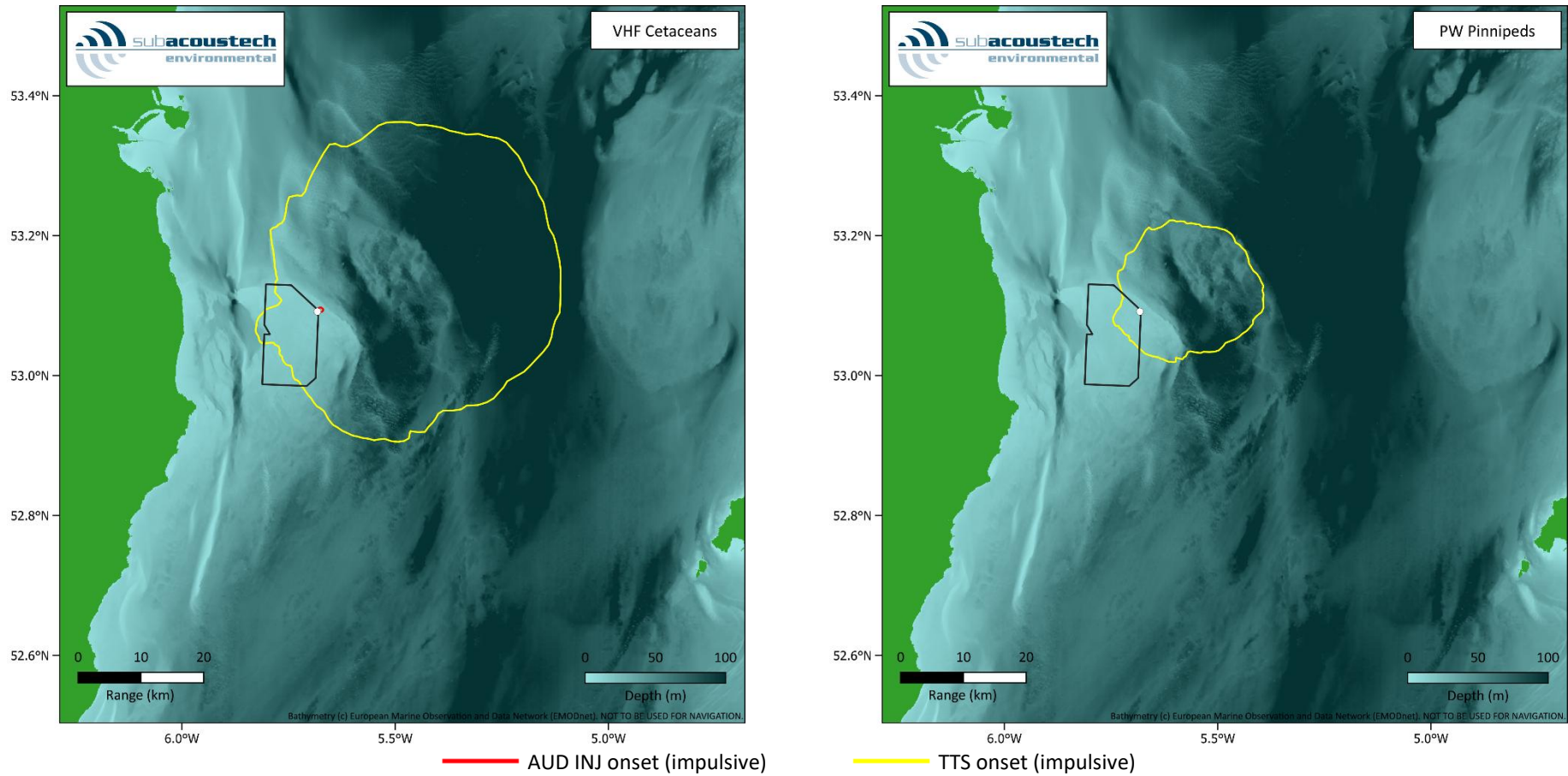


Figure B 8: Contour plots showing the weighted $L_{E,p,24h,wdt}$ impact ranges for VHF cetaceans and PW pinnipeds using the NMFS (2024) impulsive criteria for the monopile installation (single pile) scenario at the NE modelling location assuming fleeing receptors.

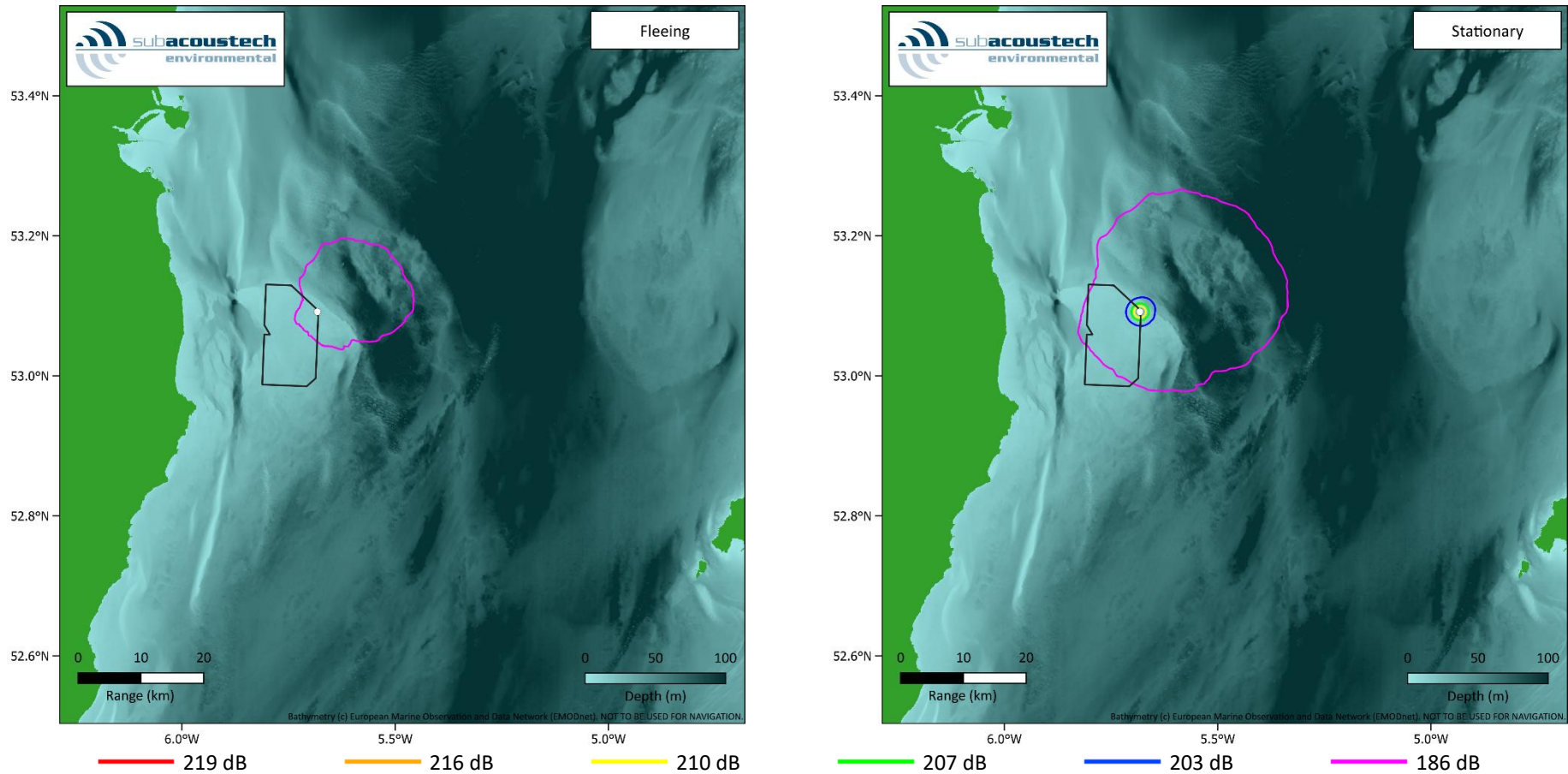


Figure B 9: Contour plots showing the unweighted $L_{E,p,24h,wtd}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile installation (single pile) scenario at the NE modelling location assuming both fleeing and stationary receptors.

B.1.4 NW

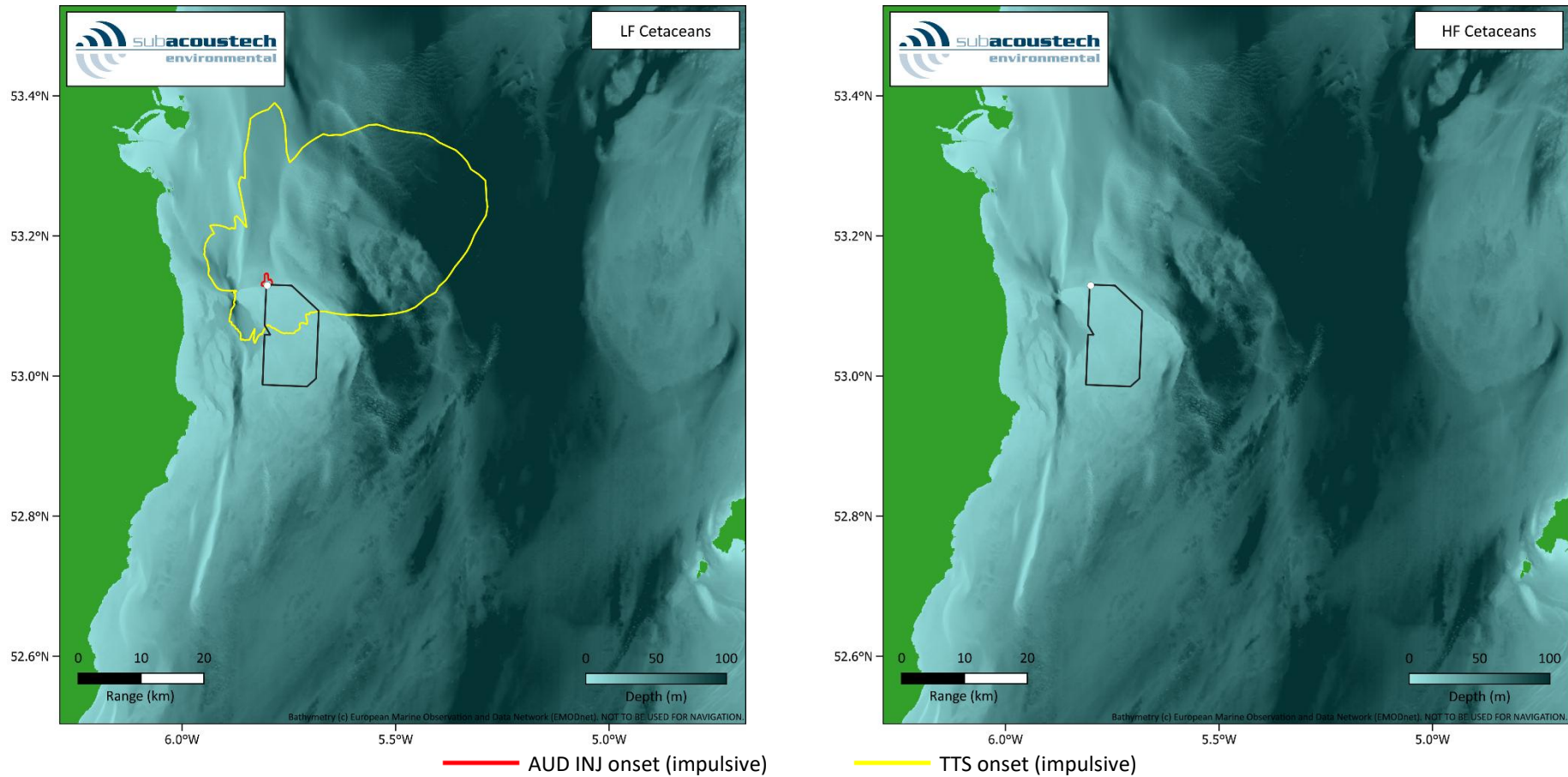


Figure B 10: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for LF and HF cetaceans using the NMFS (2024) impulsive criteria for the monopile installation (single pile) scenario at the NW modelling location assuming fleeing receptors.

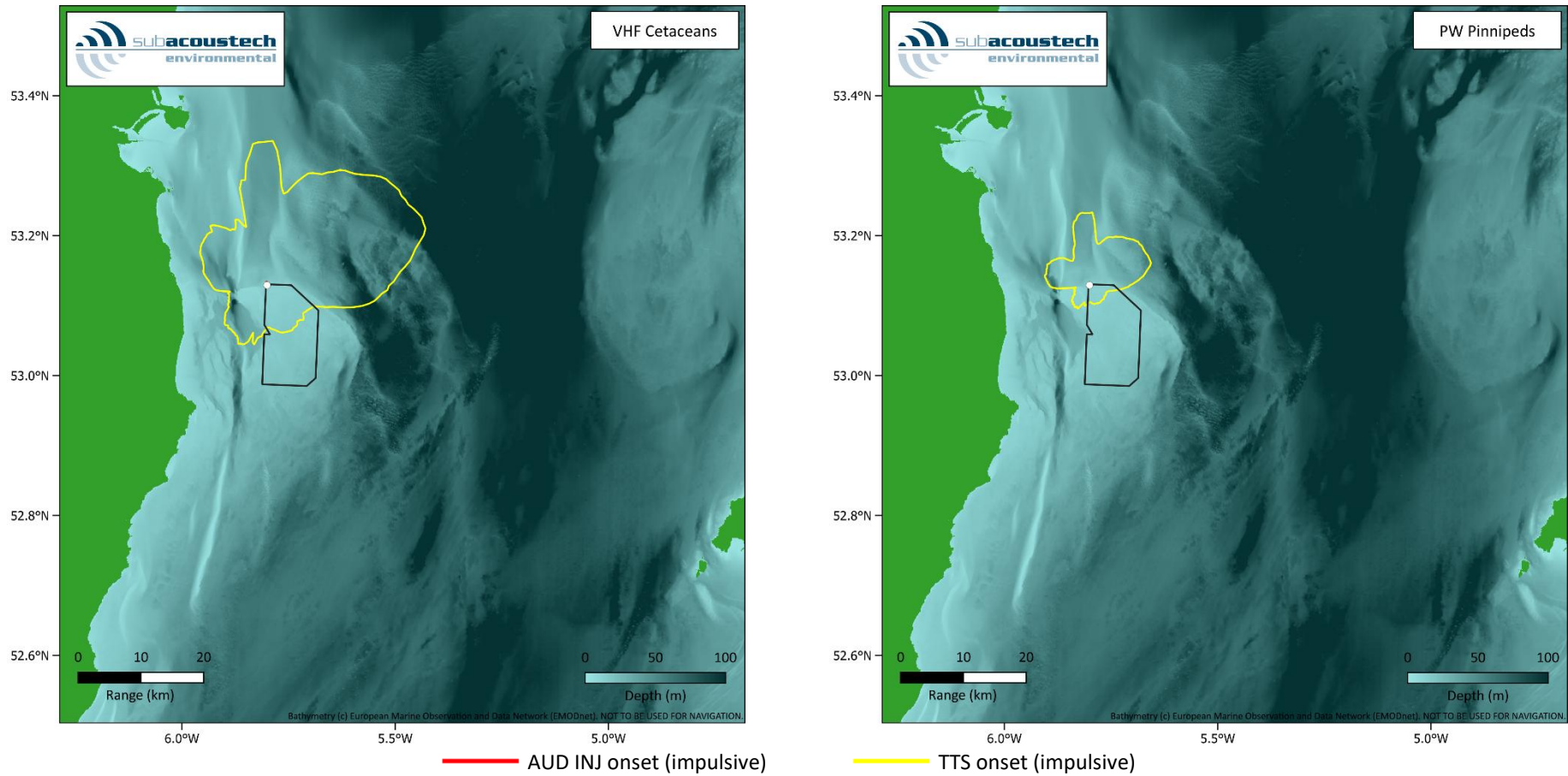


Figure B 11: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for VHF cetaceans and PW pinnipeds using the NMFS (2024) impulsive criteria for the monopile installation (single pile) scenario at the NW modelling location assuming fleeing receptors.

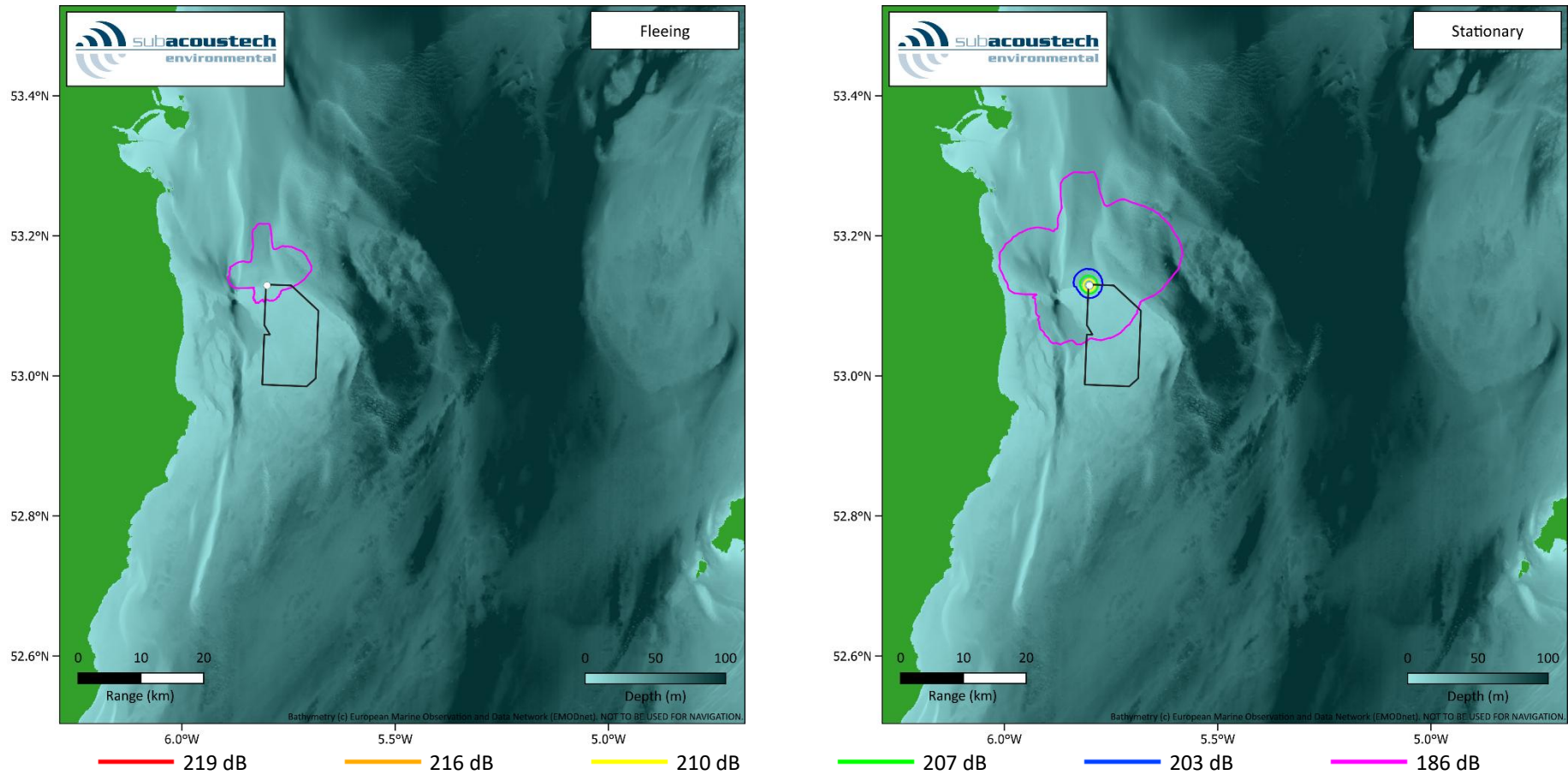


Figure B 12: Contour plots showing the unweighted $L_{E,p,24h,wtd}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile installation (single pile) scenario at the NW modelling location assuming both fleeing and stationary receptors.

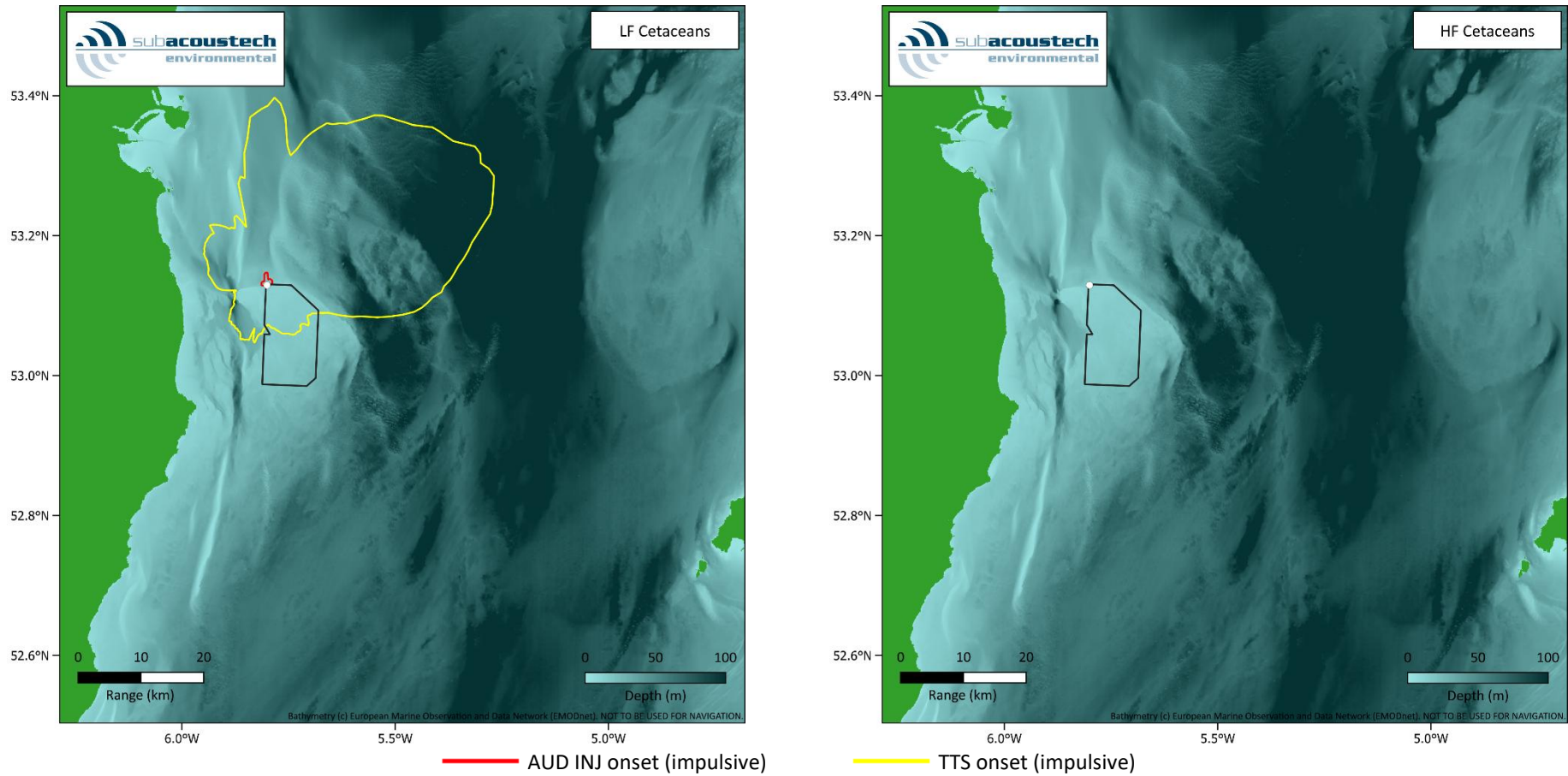


Figure B 13: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for LF and HF cetaceans using the NMFS (2024) impulsive criteria for the monopile installation (2 sequential piles) scenario at the NW modelling location assuming fleeing receptors.

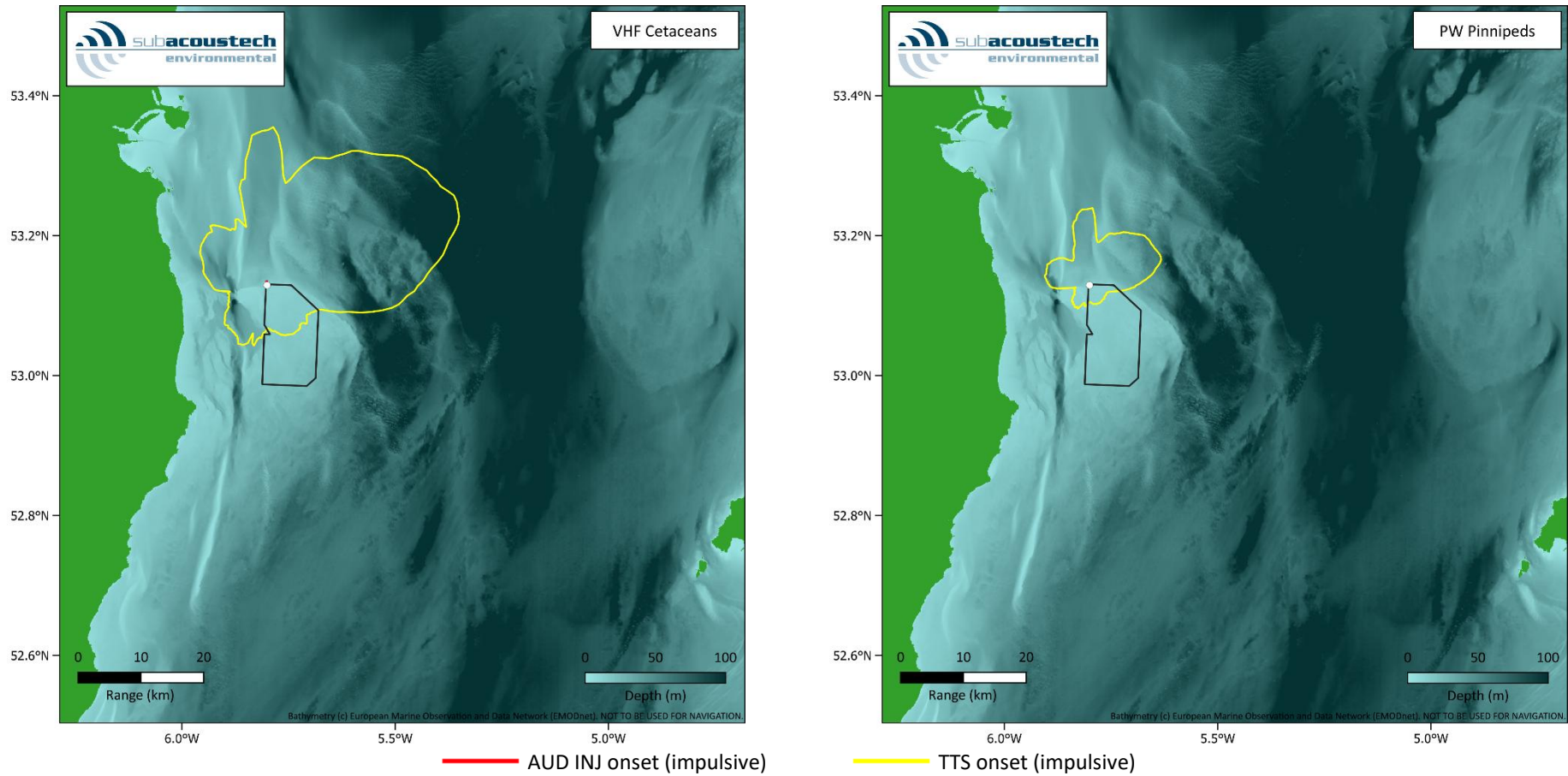


Figure B 14: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for VHF cetaceans and PW pinnipeds using the NMFS (2024) impulsive criteria for the monopile installation (2 sequential piles) scenario at the NW modelling location assuming fleeing receptors.

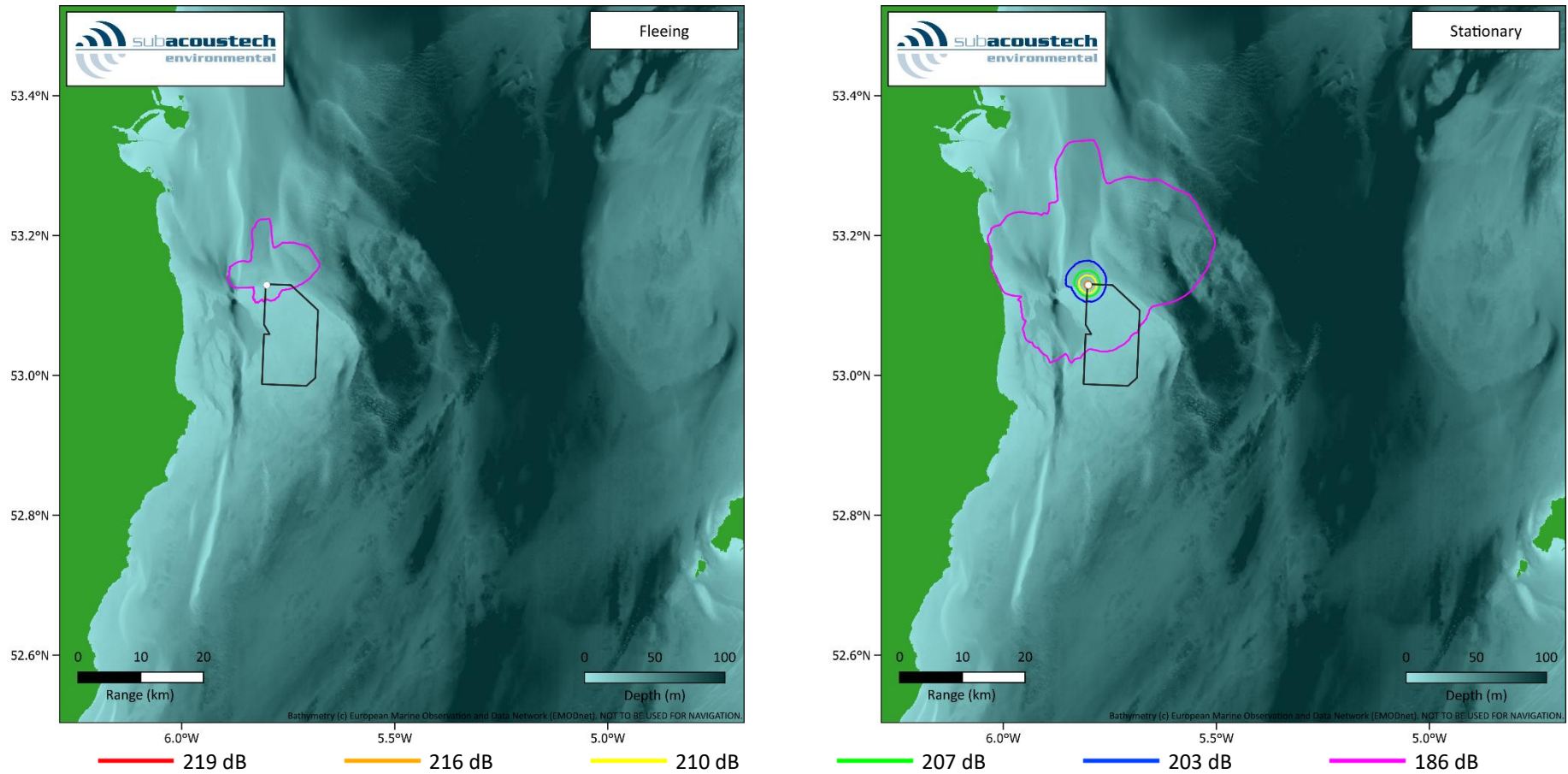


Figure B 15: Contour plots showing the unweighted $L_{E,p,24h,wt,d}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile installation (2 sequential piles) scenario at the NW modelling location assuming both fleeing and stationary receptors.

B.2 Mitigated impact piling results

B.2.1 SE

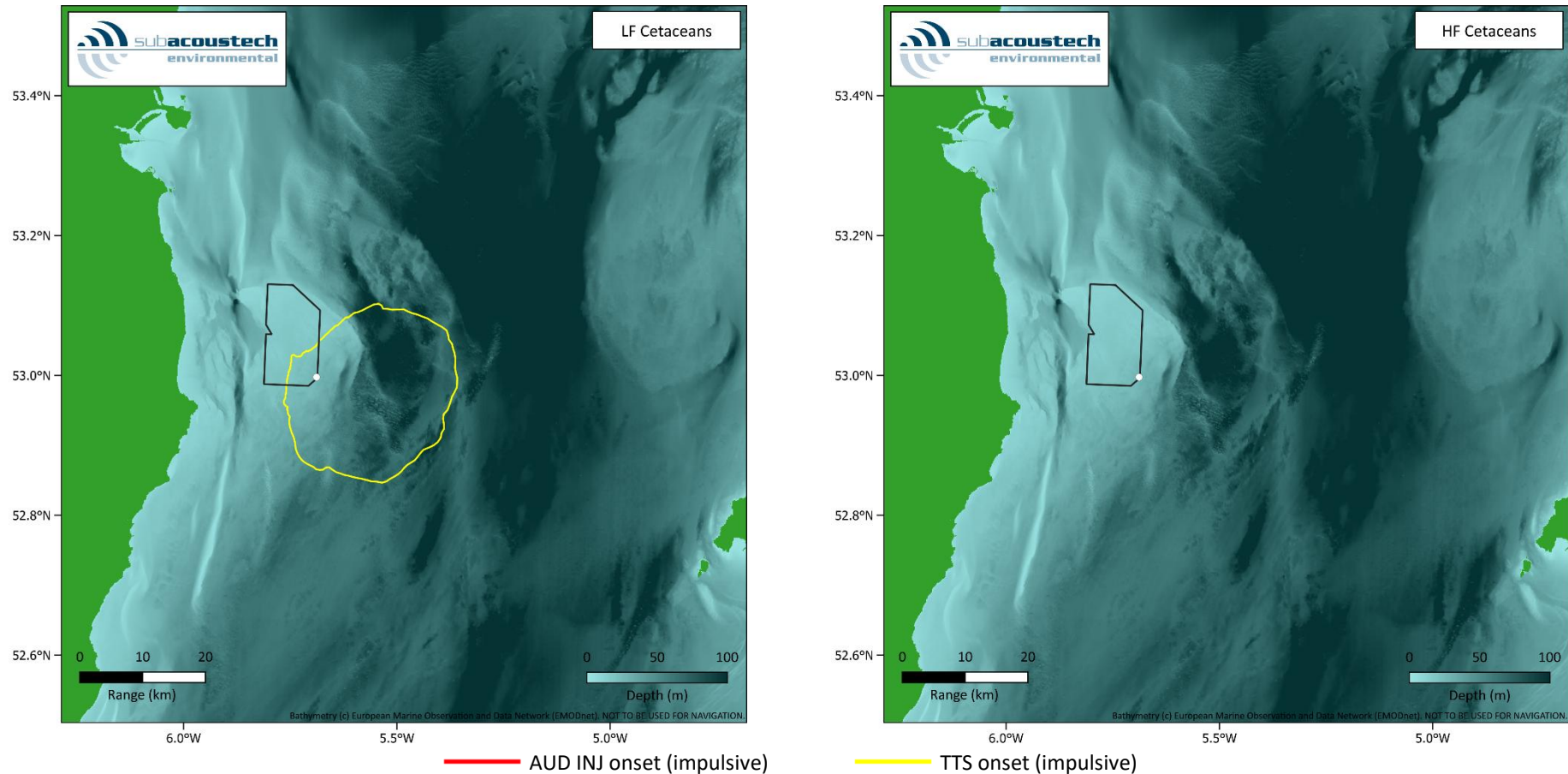


Figure B 16: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for LF and HF cetaceans using the NMFS (2024) impulsive criteria for the monopile installation (single pile) scenario, including mitigation, at the SE modelling location assuming fleeing receptors.

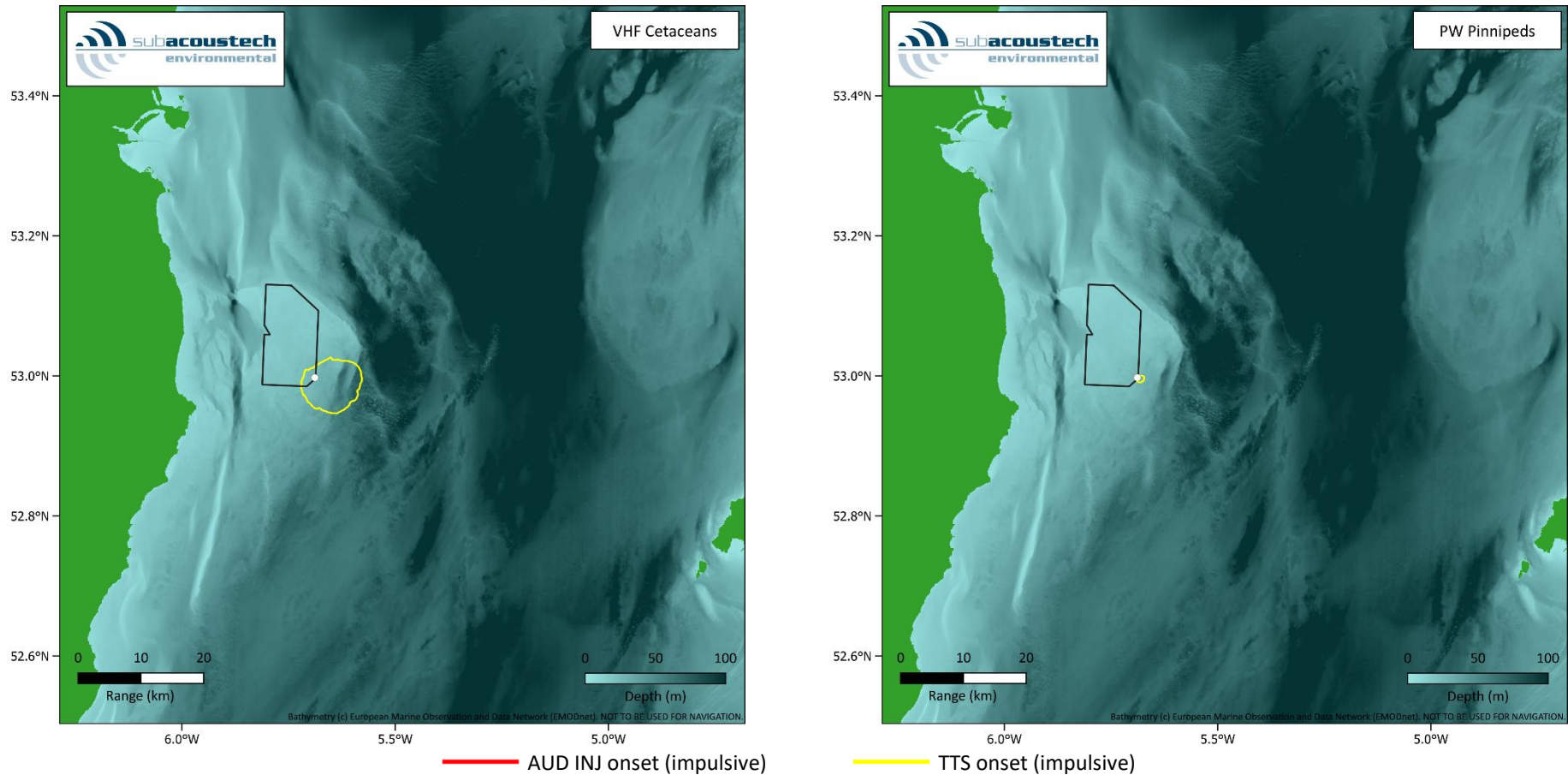


Figure B 17: Contour plots showing the weighted $L_{E,p,24h,wdt}$ impact ranges for VHF cetaceans and PW pinnipeds using the NMFS (2024) impulsive criteria for the monopile installation (single pile) scenario, including mitigation, at the SE modelling location assuming fleeing receptors.

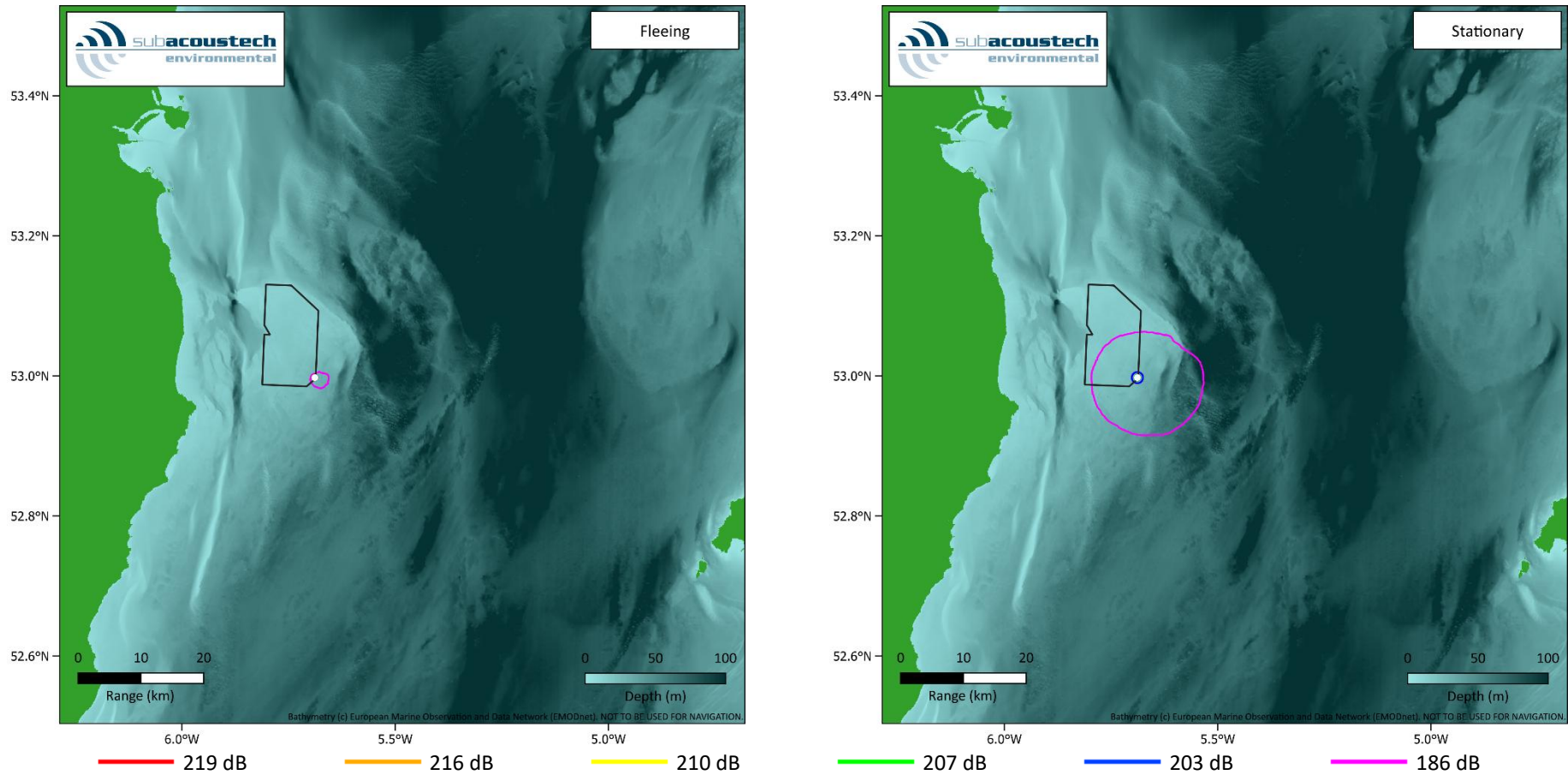


Figure B 18: Contour plots showing the unweighted $L_{E,p,24h,wtd}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile installation (single pile) scenario, including mitigation, at the SE modelling location assuming both fleeing and stationary receptors.

B.2.2 SW

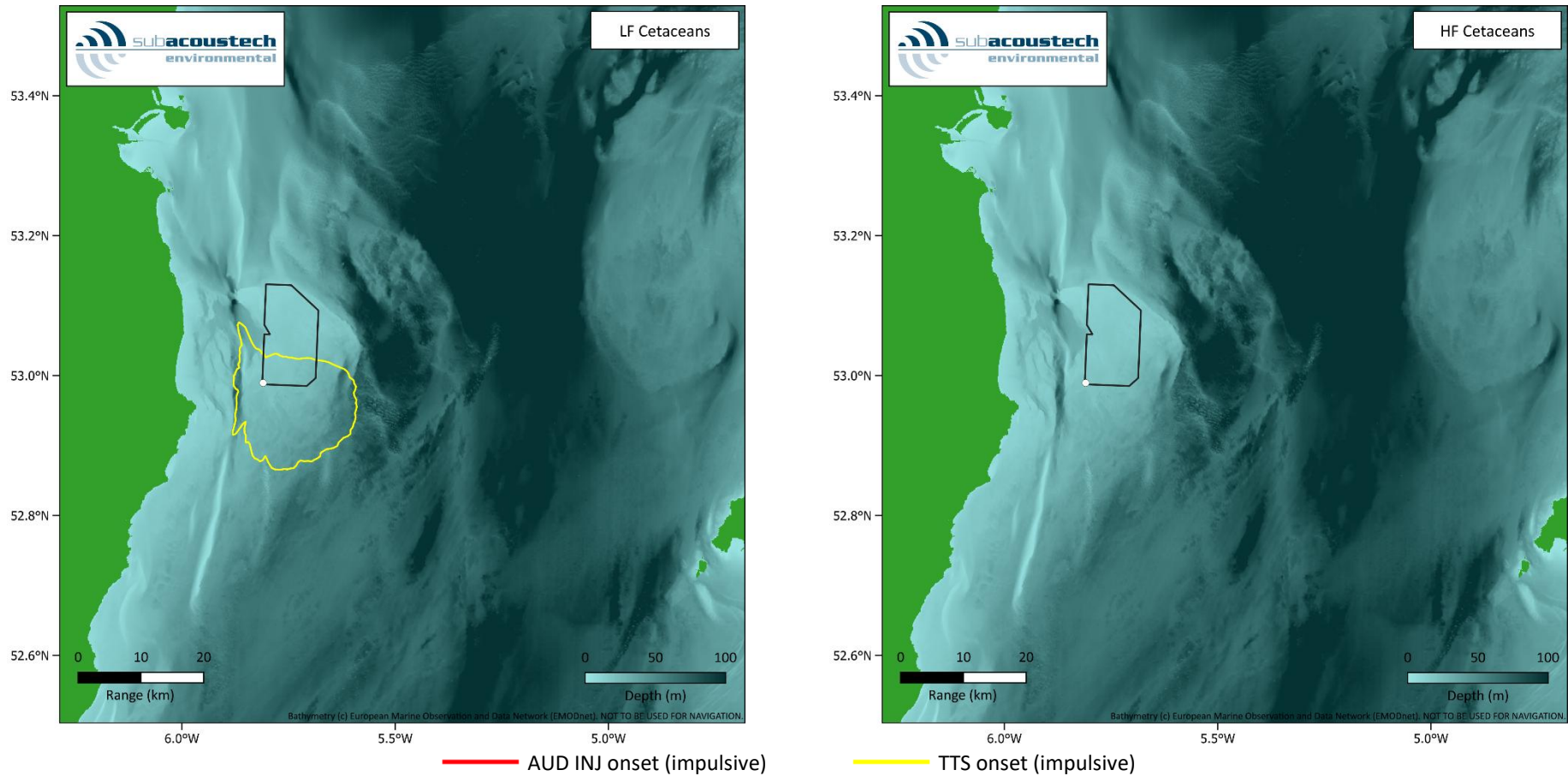


Figure B 19: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for LF and HF cetaceans using the NMFS (2024) impulsive criteria for the monopile installation (single pile) scenario, including mitigation, at the SW modelling location assuming fleeing receptors.

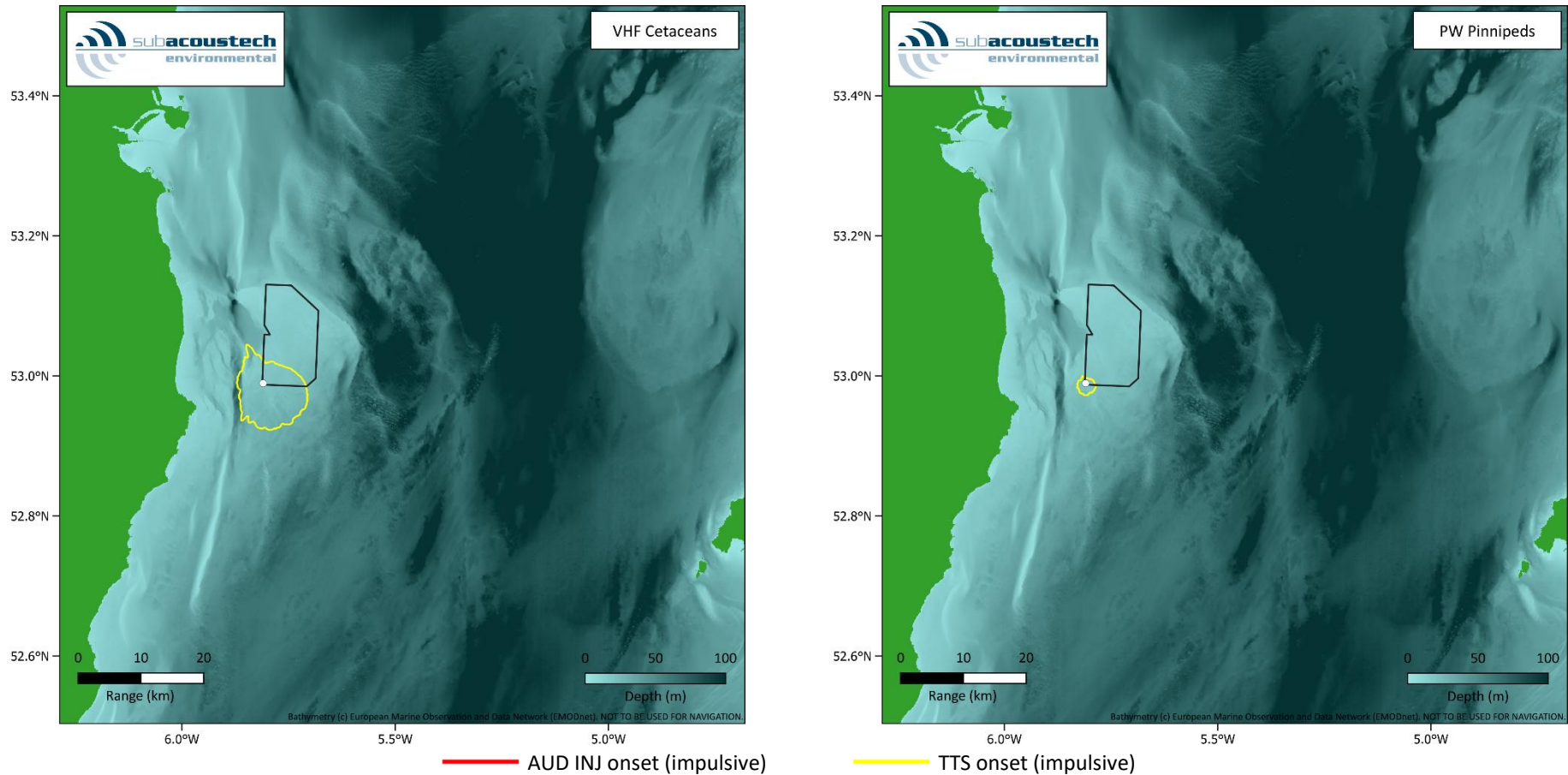


Figure B 20: Contour plots showing the weighted $L_{E,p,24h,wtD}$ impact ranges for VHF cetaceans and PW pinnipeds using the NMFS (2024) impulsive criteria for the monopile installation (single pile) scenario, including mitigation, at the SW modelling location assuming fleeing receptors.

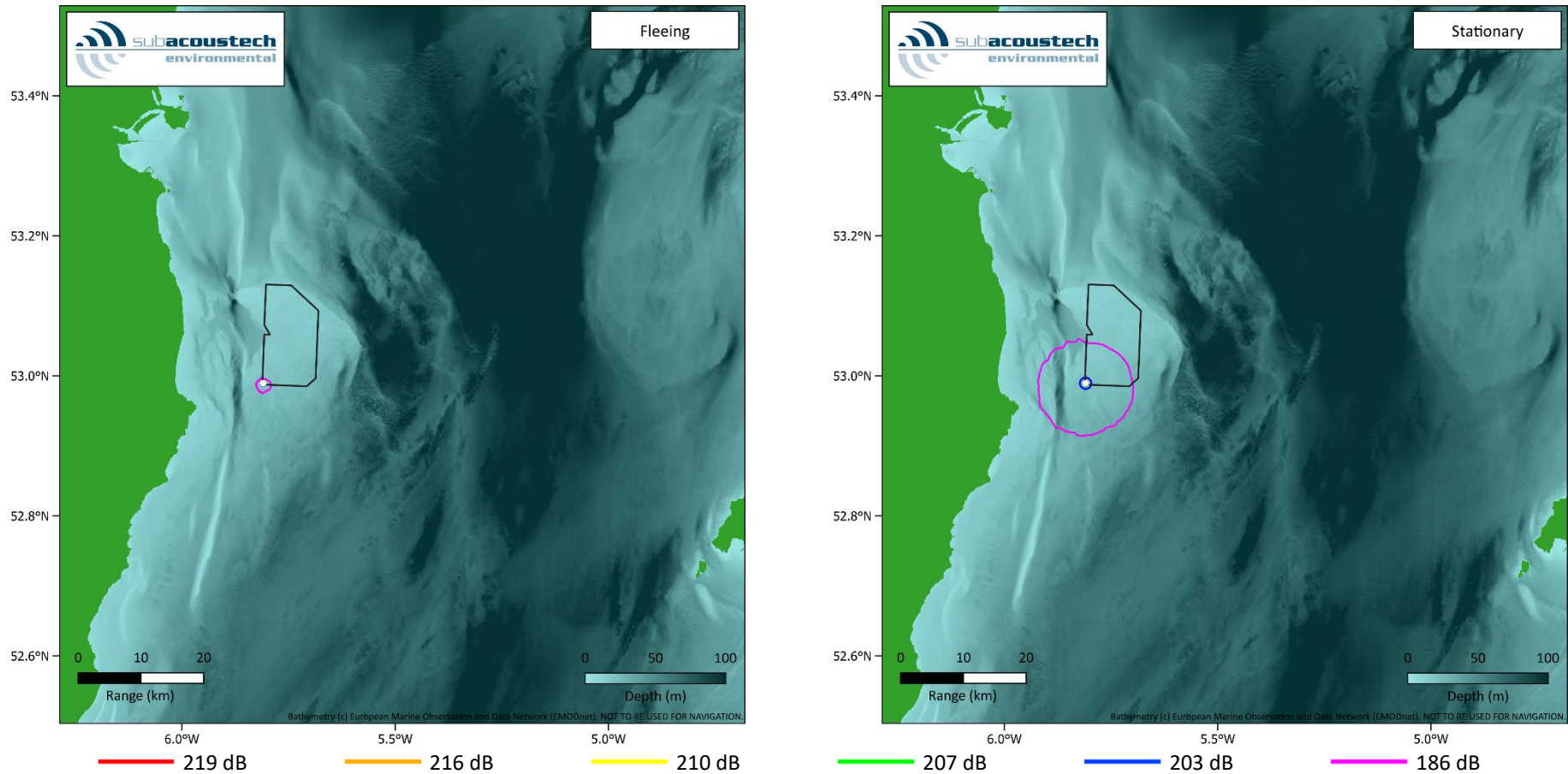


Figure B 21: Contour plots showing the unweighted $L_{E,p,24h,wtd}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile installation (single pile) scenario, including mitigation, at the SW modelling location assuming both fleeing and stationary receptors.

B.2.3 NE

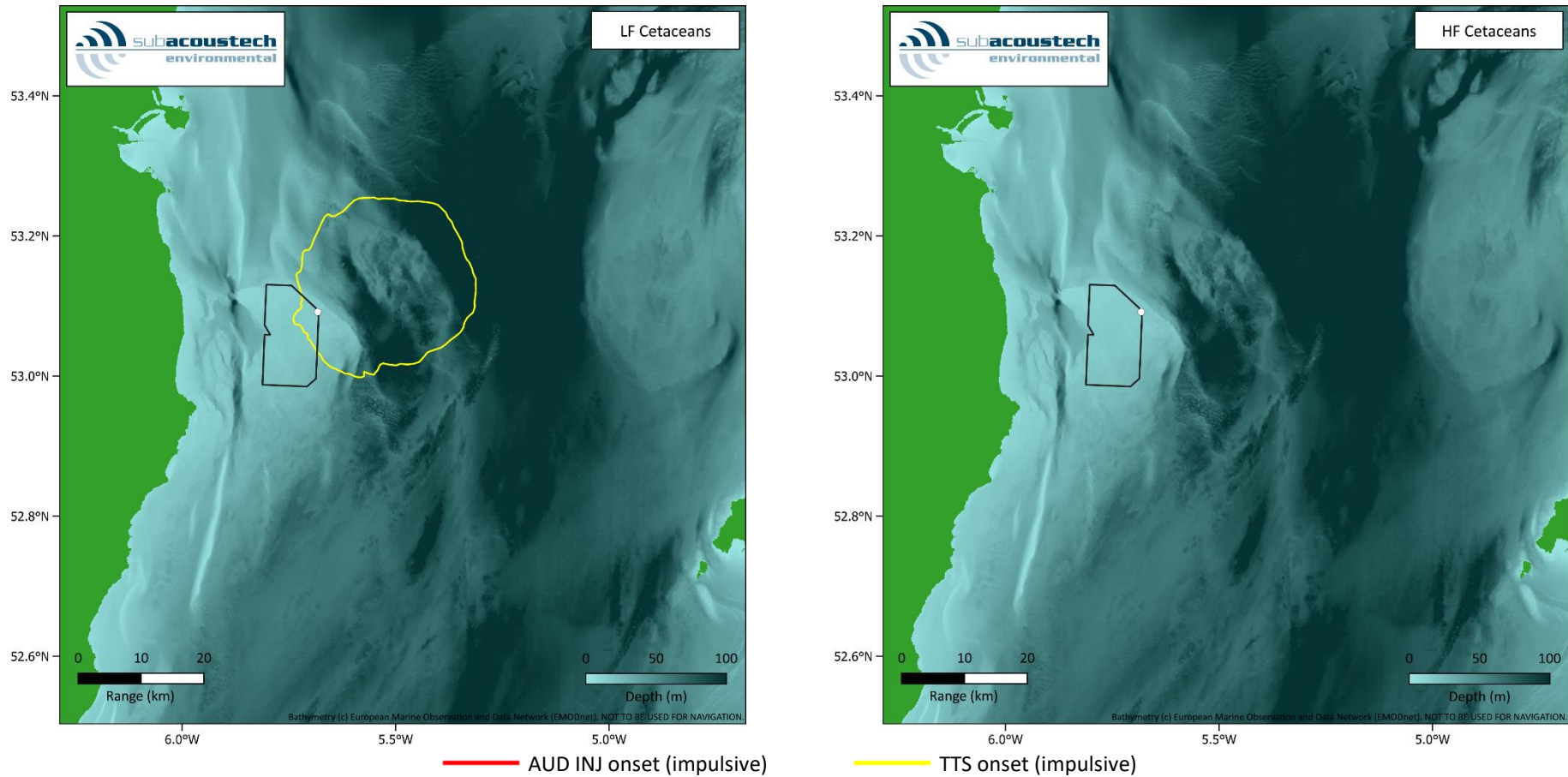


Figure B 22: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for LF and HF cetaceans using the NMFS (2024) impulsive criteria for the monopile installation (single pile) scenario, including mitigation, at the NE modelling location assuming fleeing receptors.

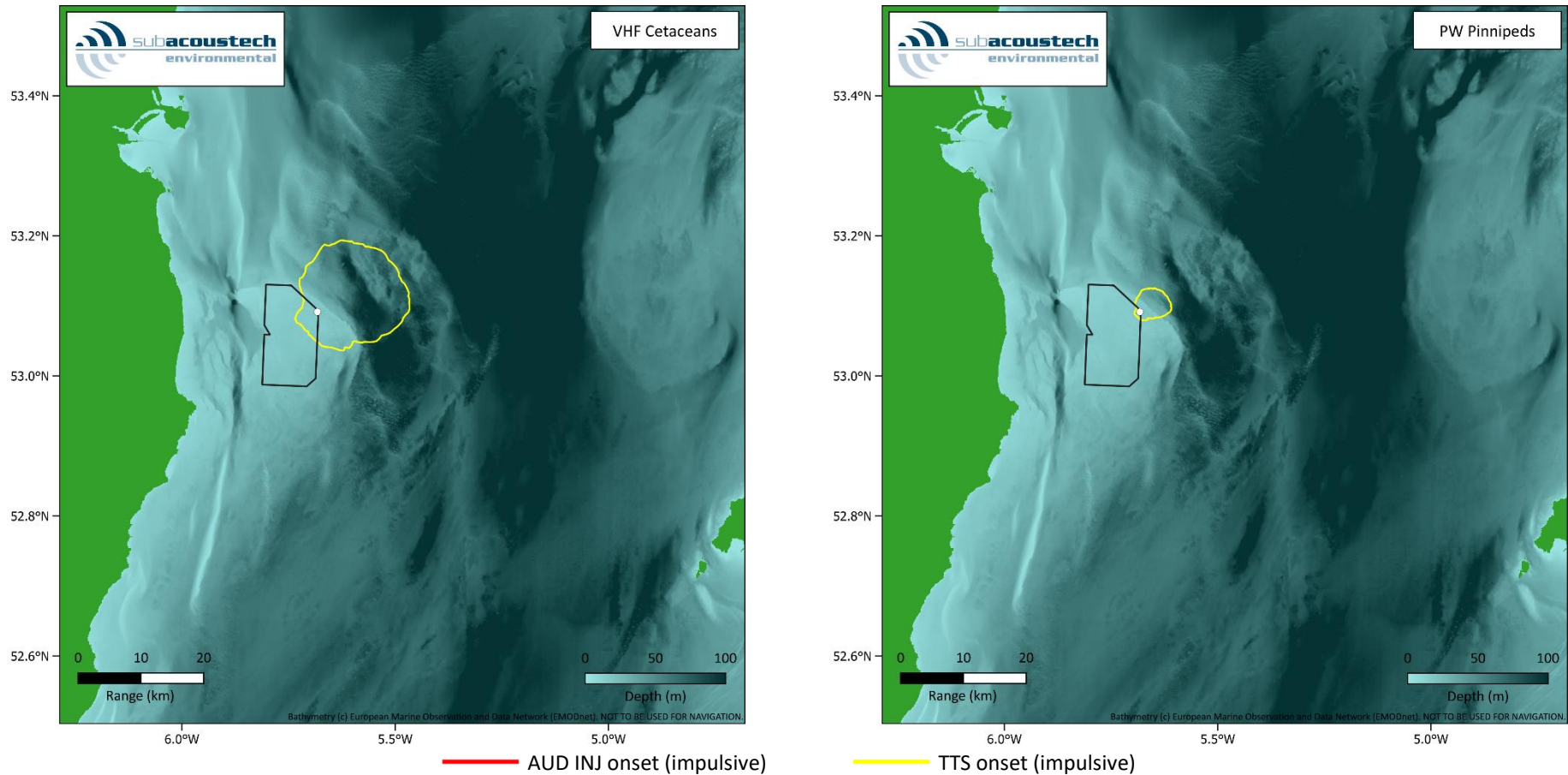


Figure B 23: Contour plots showing the weighted $L_{E,p,24h,wt,d}$ impact ranges for VHF cetaceans and PW pinnipeds using the NMFS (2024) impulsive criteria for the monopile installation (single pile) scenario, including mitigation, at the NE modelling location assuming fleeing receptors.

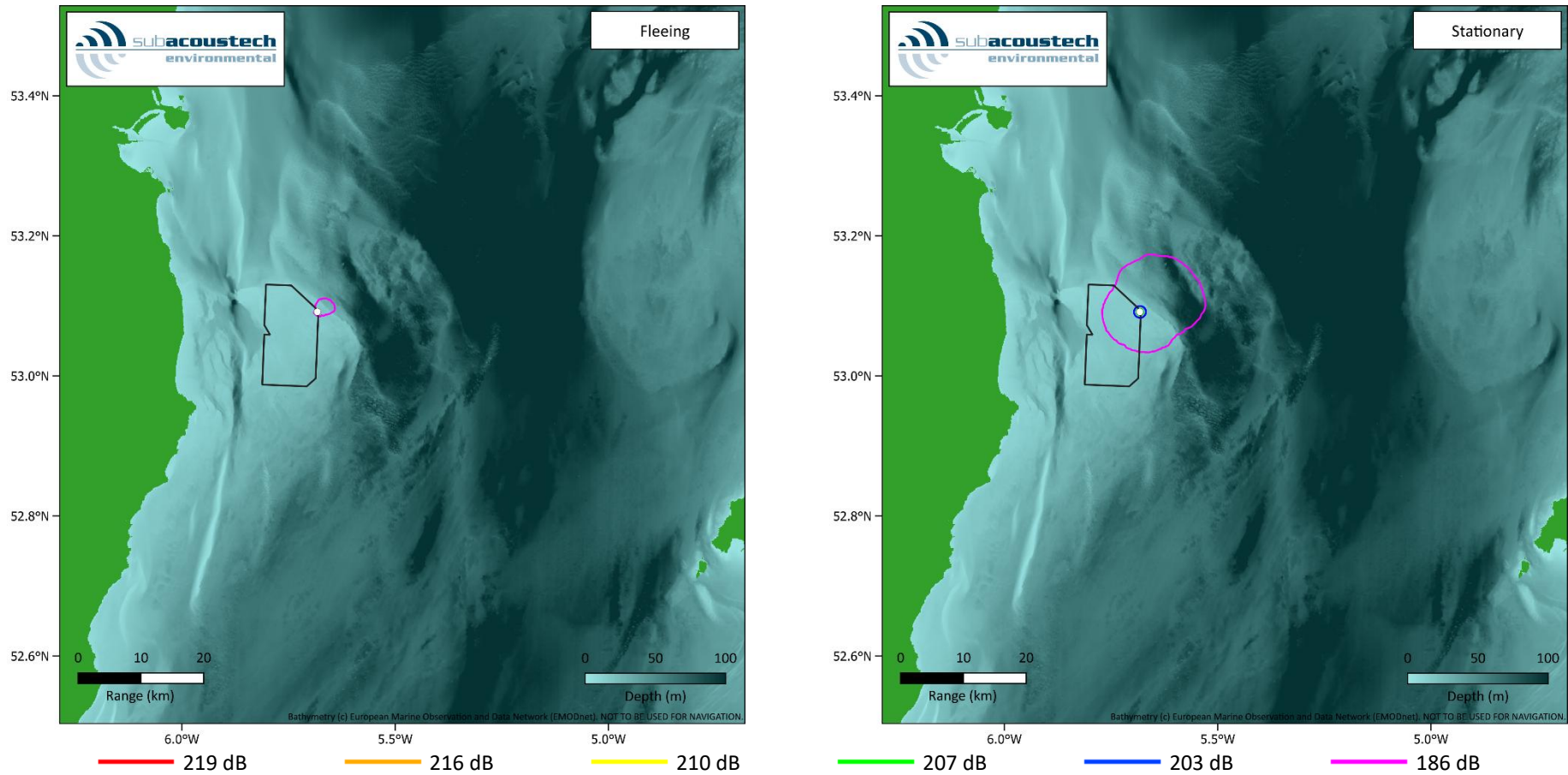


Figure B 24: Contour plots showing the unweighted $L_{E,p,24h,wtd}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile installation (single pile) scenario, including mitigation, at the NE modelling location assuming both fleeing and stationary receptors.

B.2.4 NW

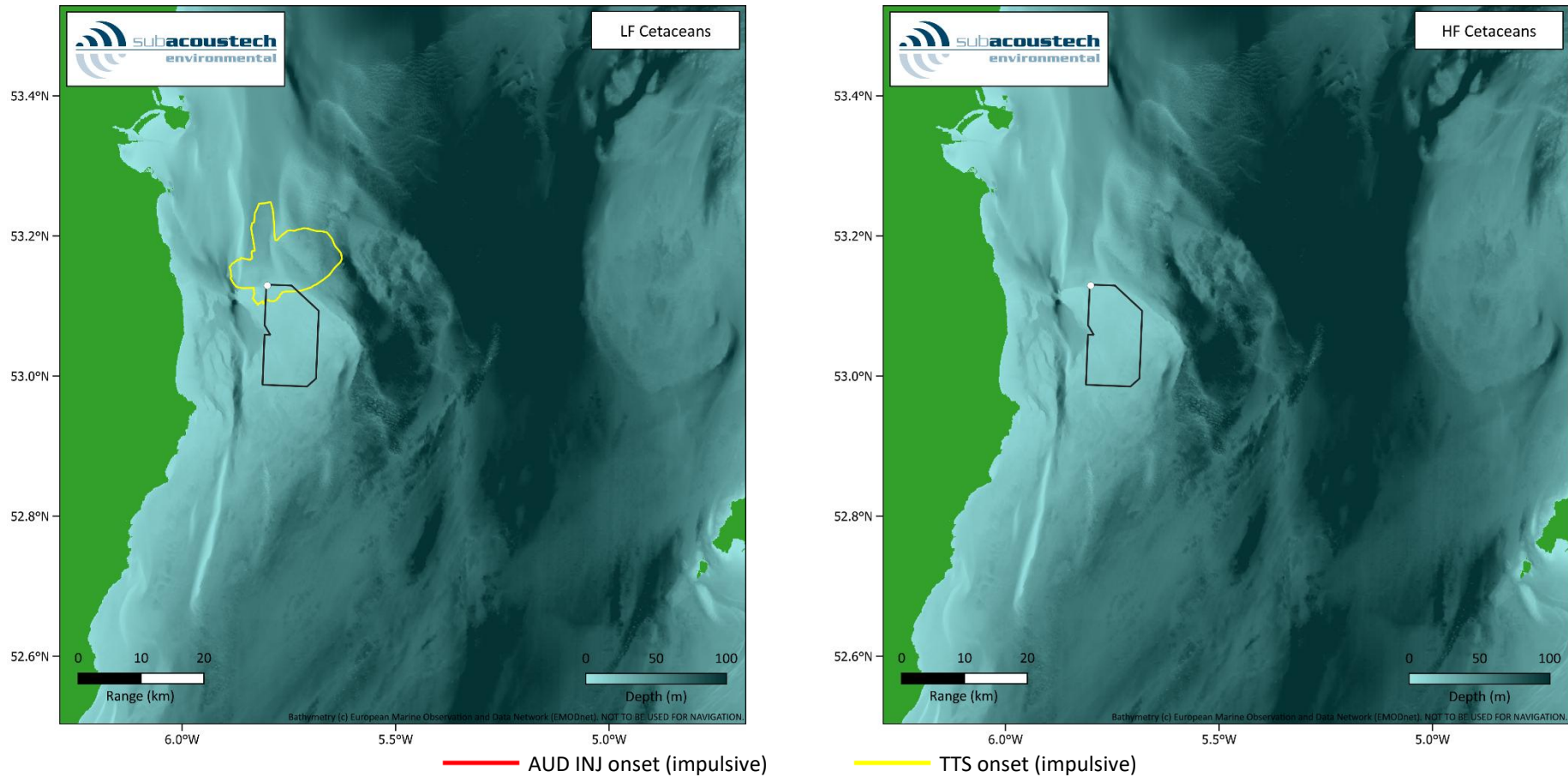


Figure B 25: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for LF and HF cetaceans using the NMFS (2024) impulsive criteria for the monopile installation (single pile) scenario, including mitigation, at the NW modelling location assuming fleeing receptors.

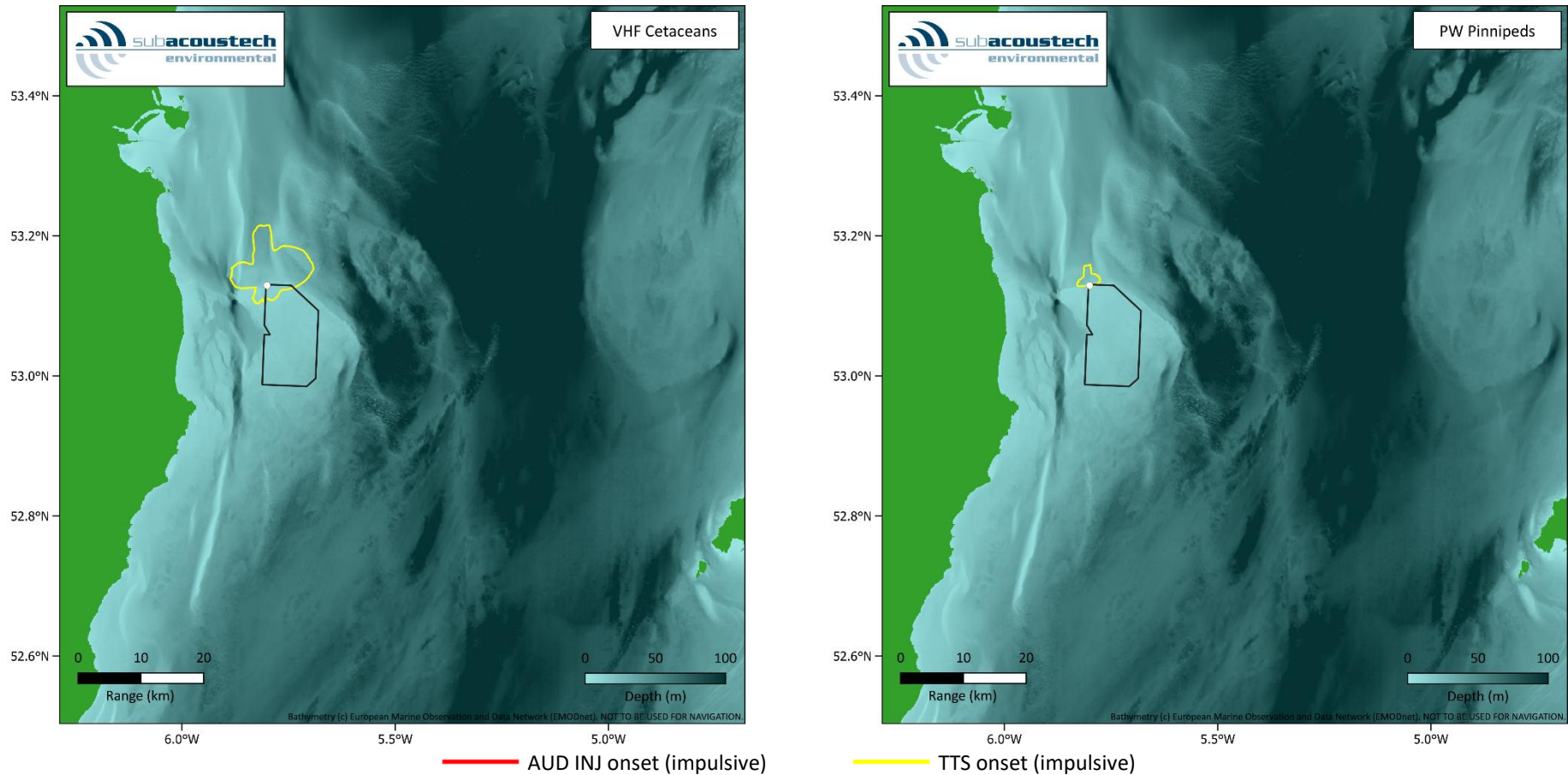


Figure B 26: Contour plots showing the weighted $L_{E,p,24h,wt,d}$ impact ranges for VHF cetaceans and PW pinnipeds using the NMFS (2024) impulsive criteria for the monopile installation (single pile) scenario, including mitigation, at the NW modelling location assuming fleeing receptors.

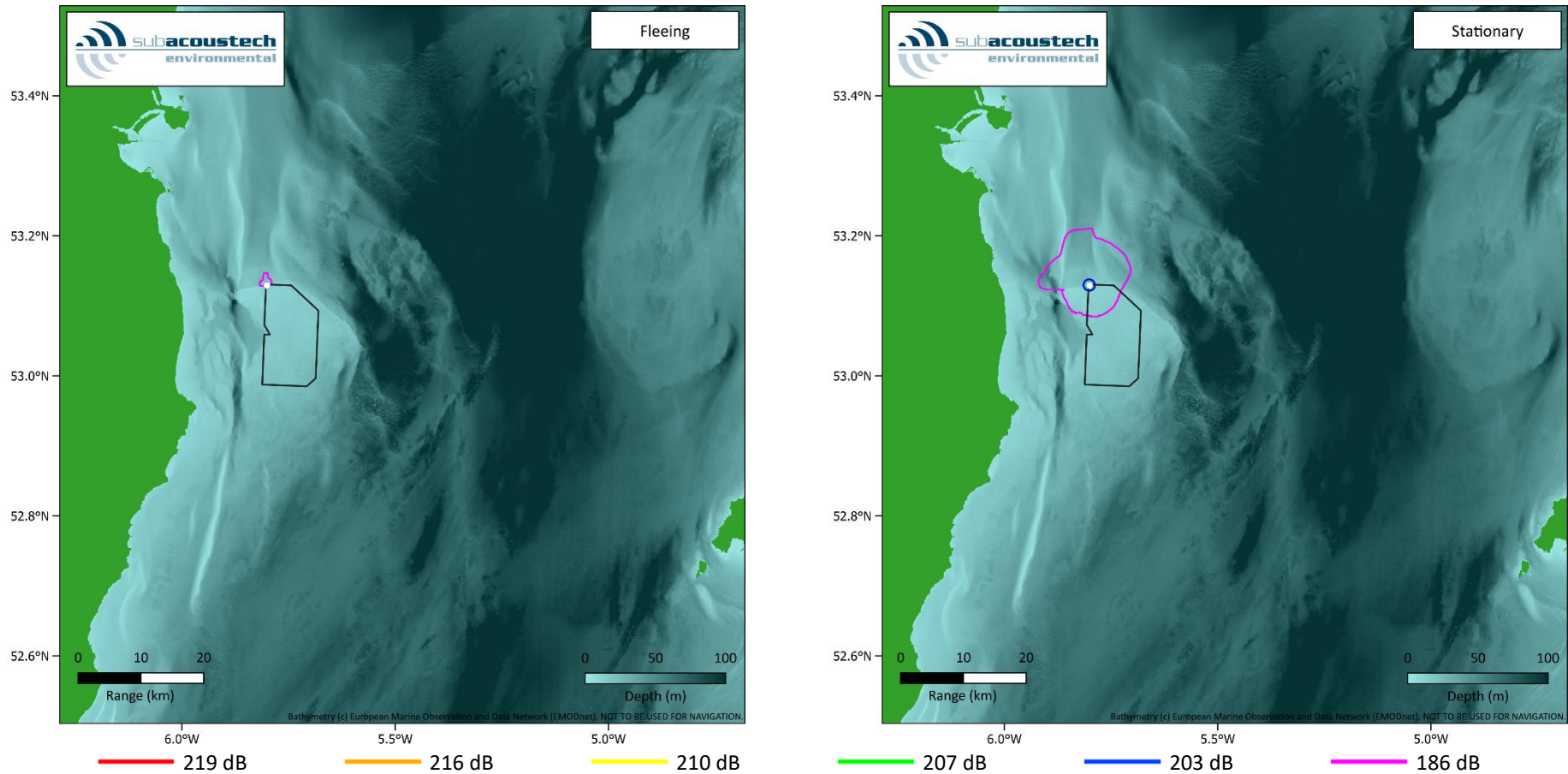


Figure B 27: Contour plots showing the unweighted $L_{E,p,24h,wtd}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile installation (single pile) scenario, including mitigation, at the NW modelling location assuming both fleeing and stationary receptors.

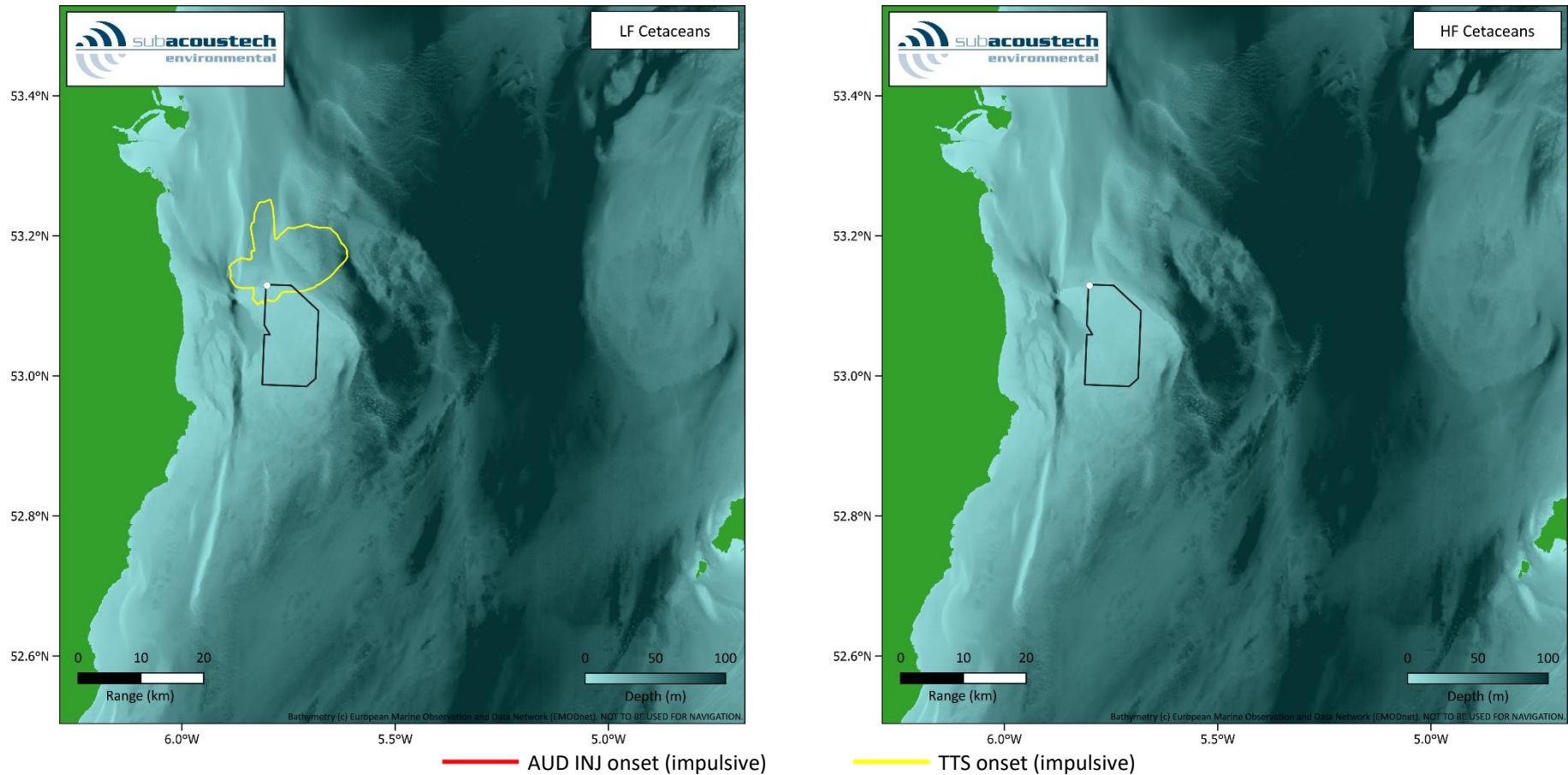


Figure B 28: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for LF and HF cetaceans using the NMFS (2024) impulsive criteria for the monopile installation (2 sequential piles) scenario, including mitigation, at the NW modelling location assuming fleeing receptors.

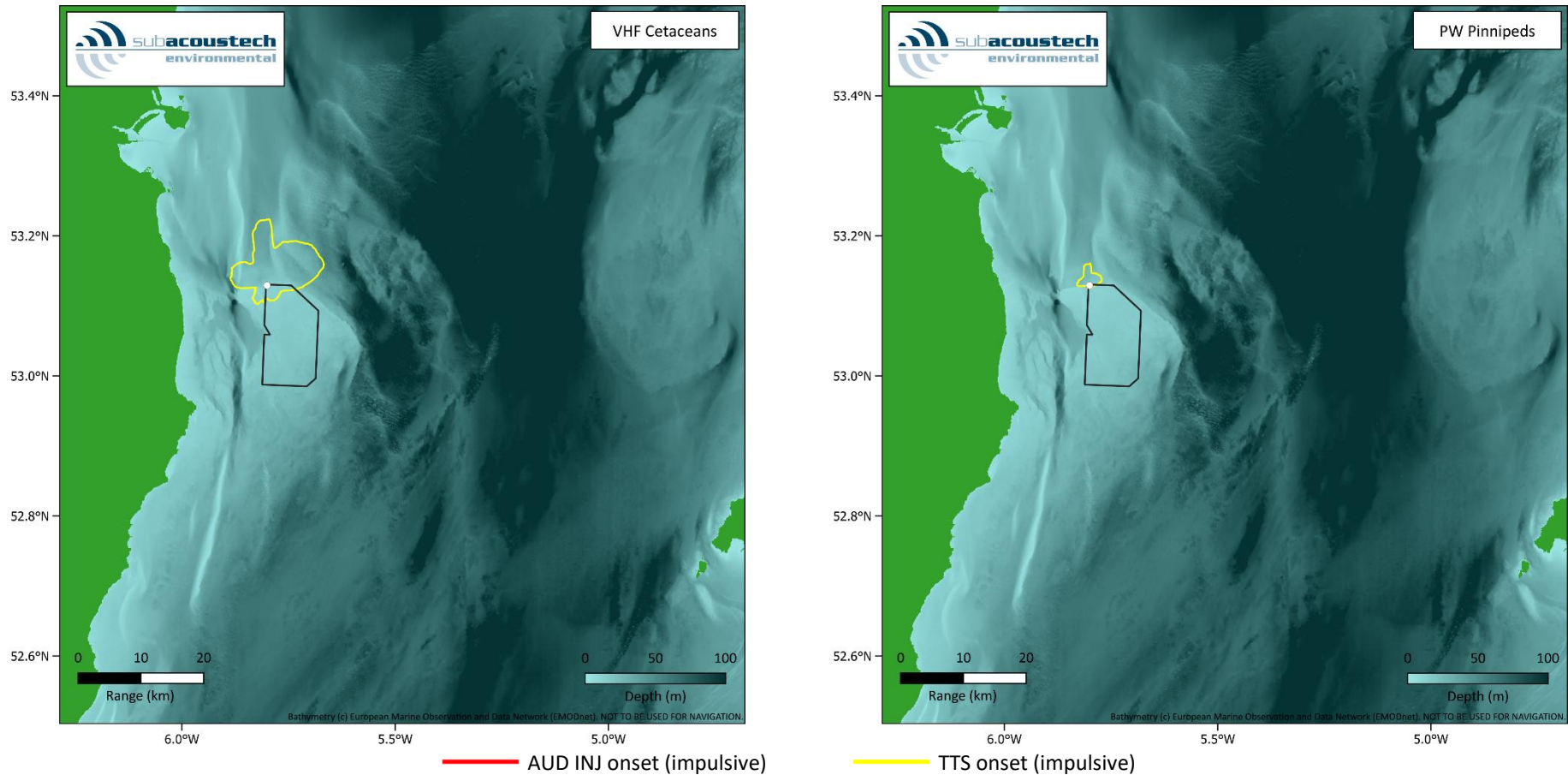


Figure B 29: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for VHF cetaceans and PW pinnipeds using the NMFS (2024) impulsive criteria for the monopile installation (2 sequential piles) scenario, including mitigation, at the NW modelling location assuming fleeing receptors.

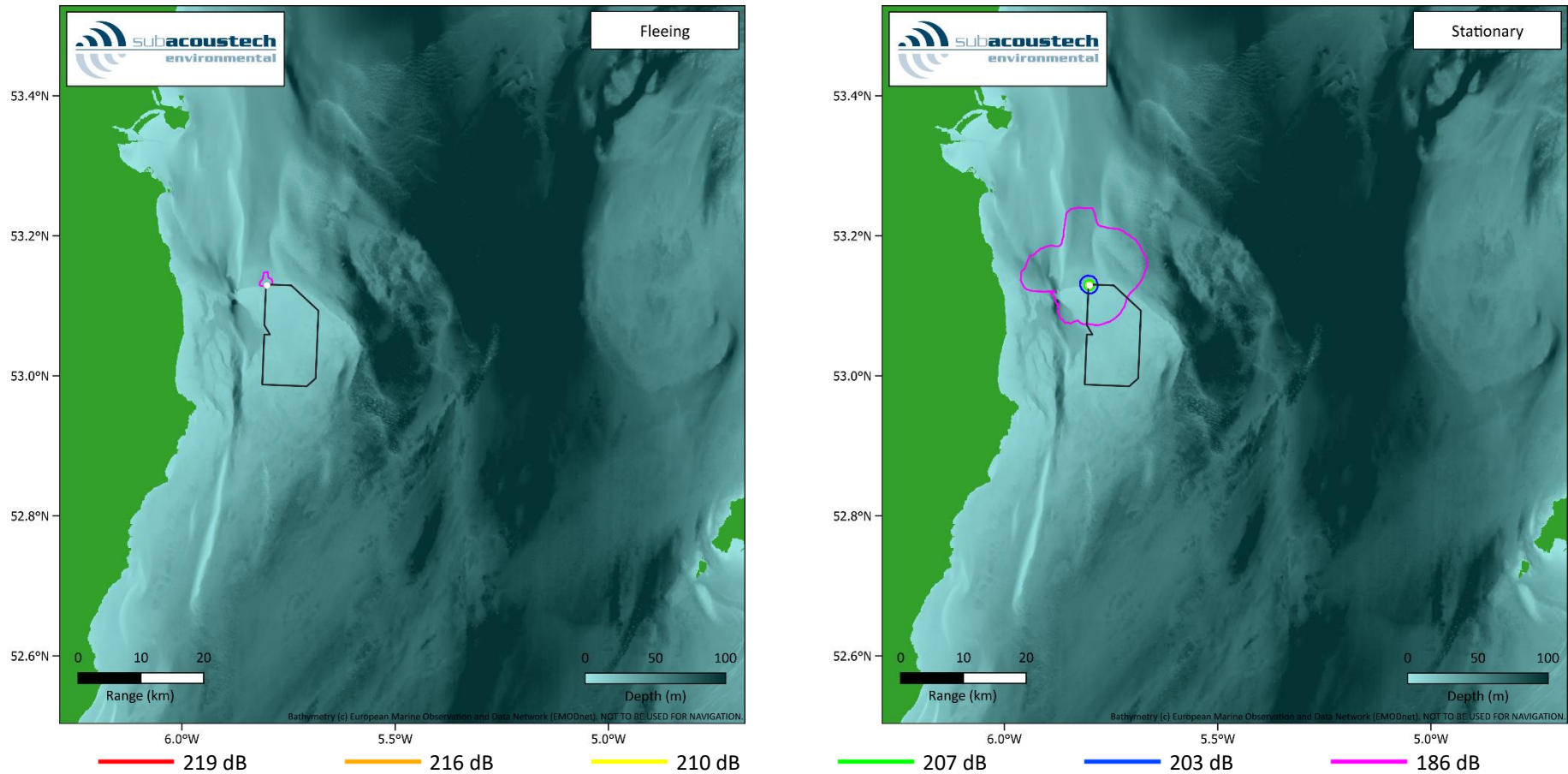


Figure B 30: Contour plots showing the unweighted $L_{E,p,24h,wtd}$ impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile installation (2 sequential piles) scenario, including mitigation, at the NW modelling location assuming both fleeing and stationary receptors.

B.3 Non-impulsive criteria

B.3.1 Unmitigated impact piling results

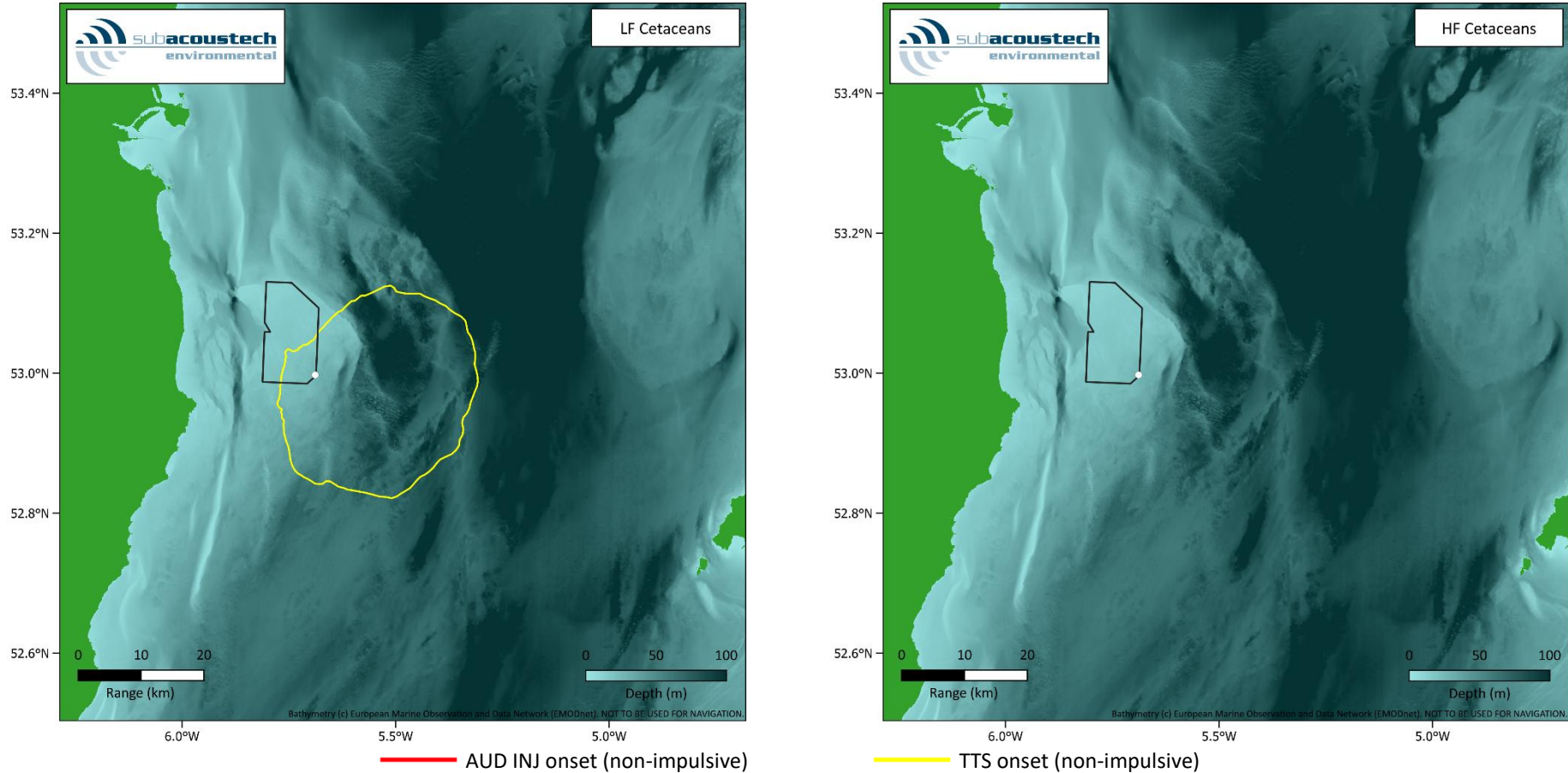


Figure B 31: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for LF and HF cetaceans using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) scenario at the SE modelling location assuming fleeing receptors.

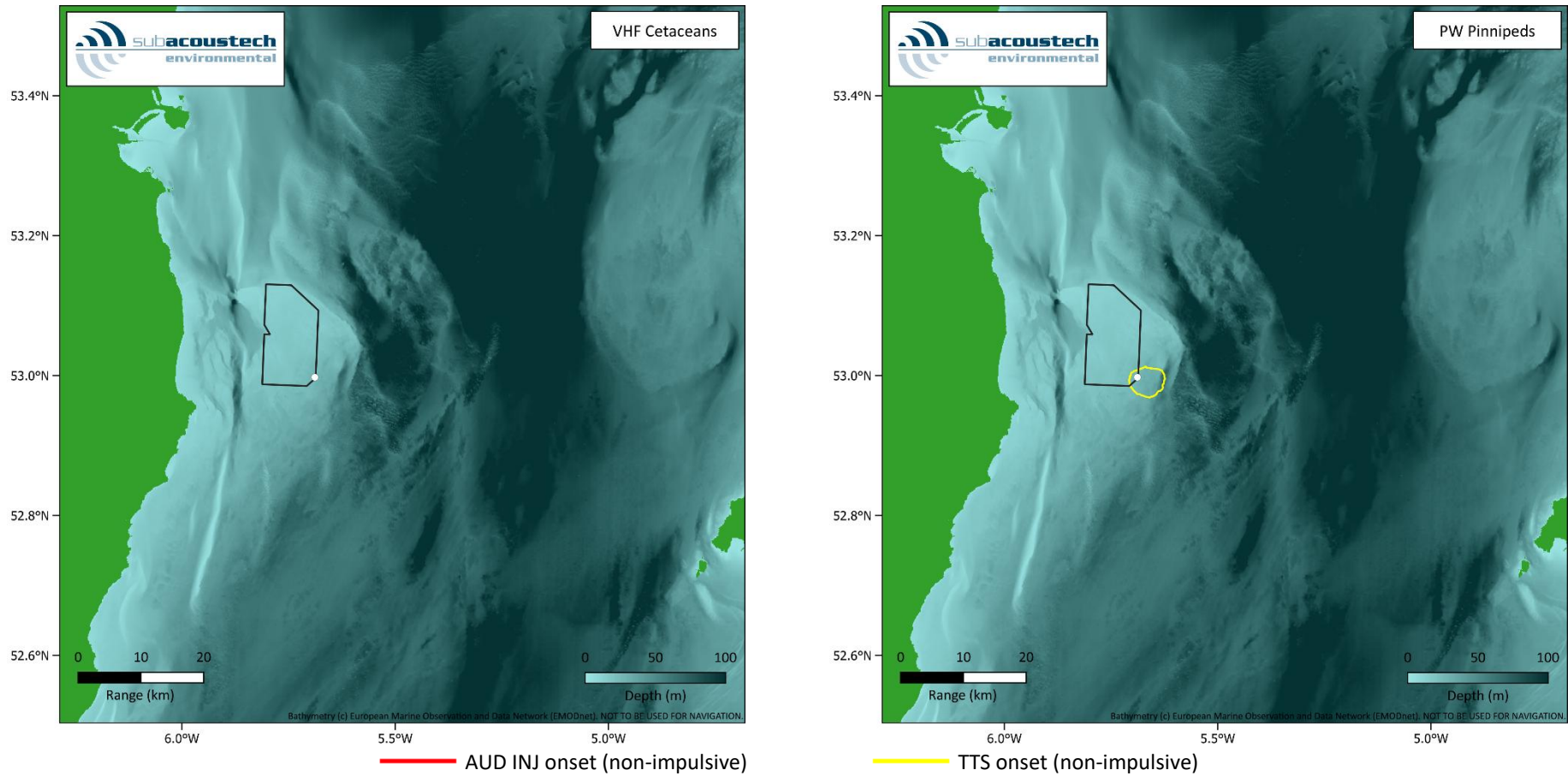


Figure B 32: Contour plots showing the weighted $L_{E,p,24h,wt,d}$ impact ranges for VHF cetaceans and PW pinnipeds using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) scenario at the SE modelling location assuming fleeing receptors.

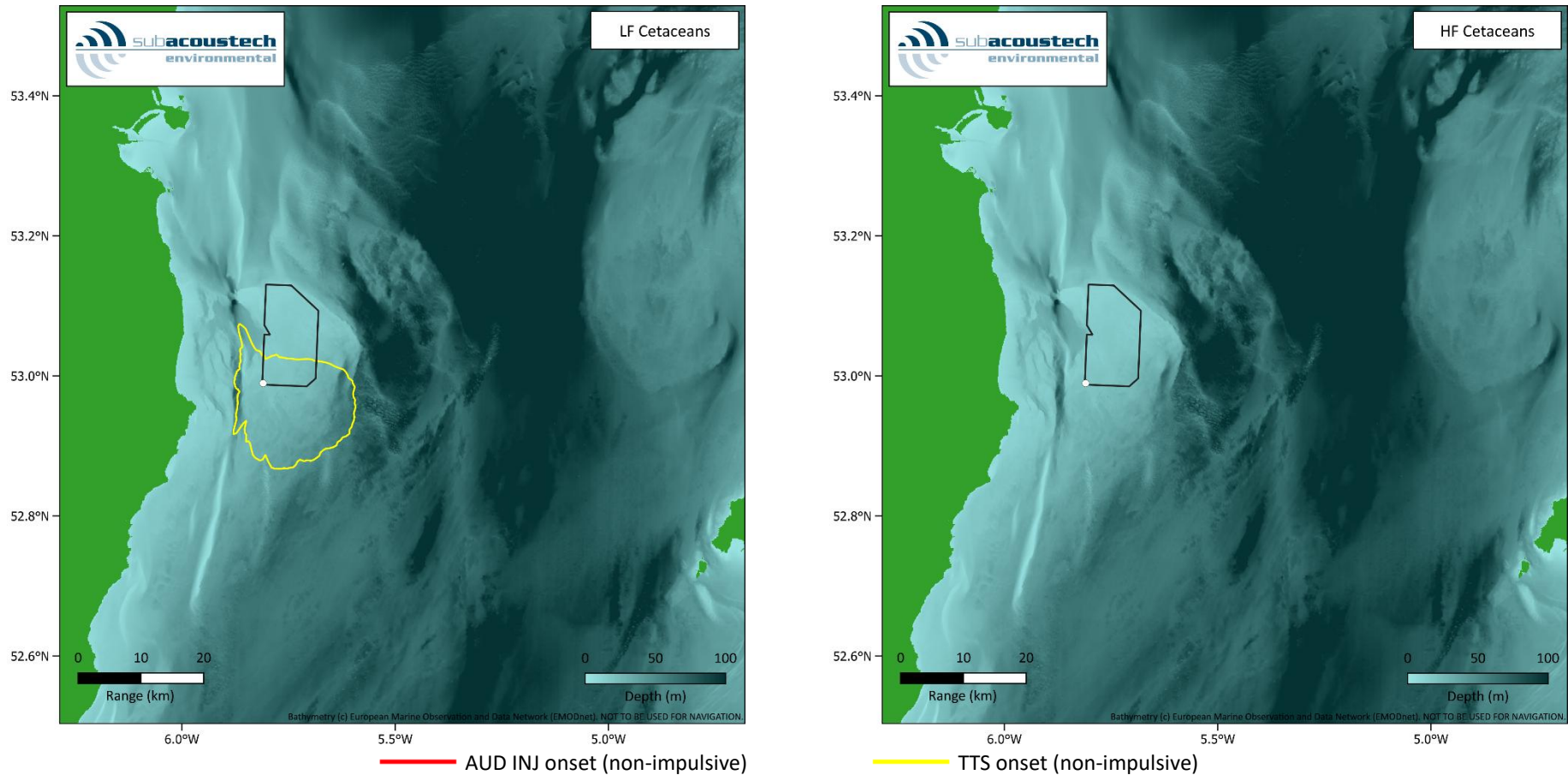


Figure B 33: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for LF and HF cetaceans using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) scenario at the SW modelling location assuming fleeing receptors.

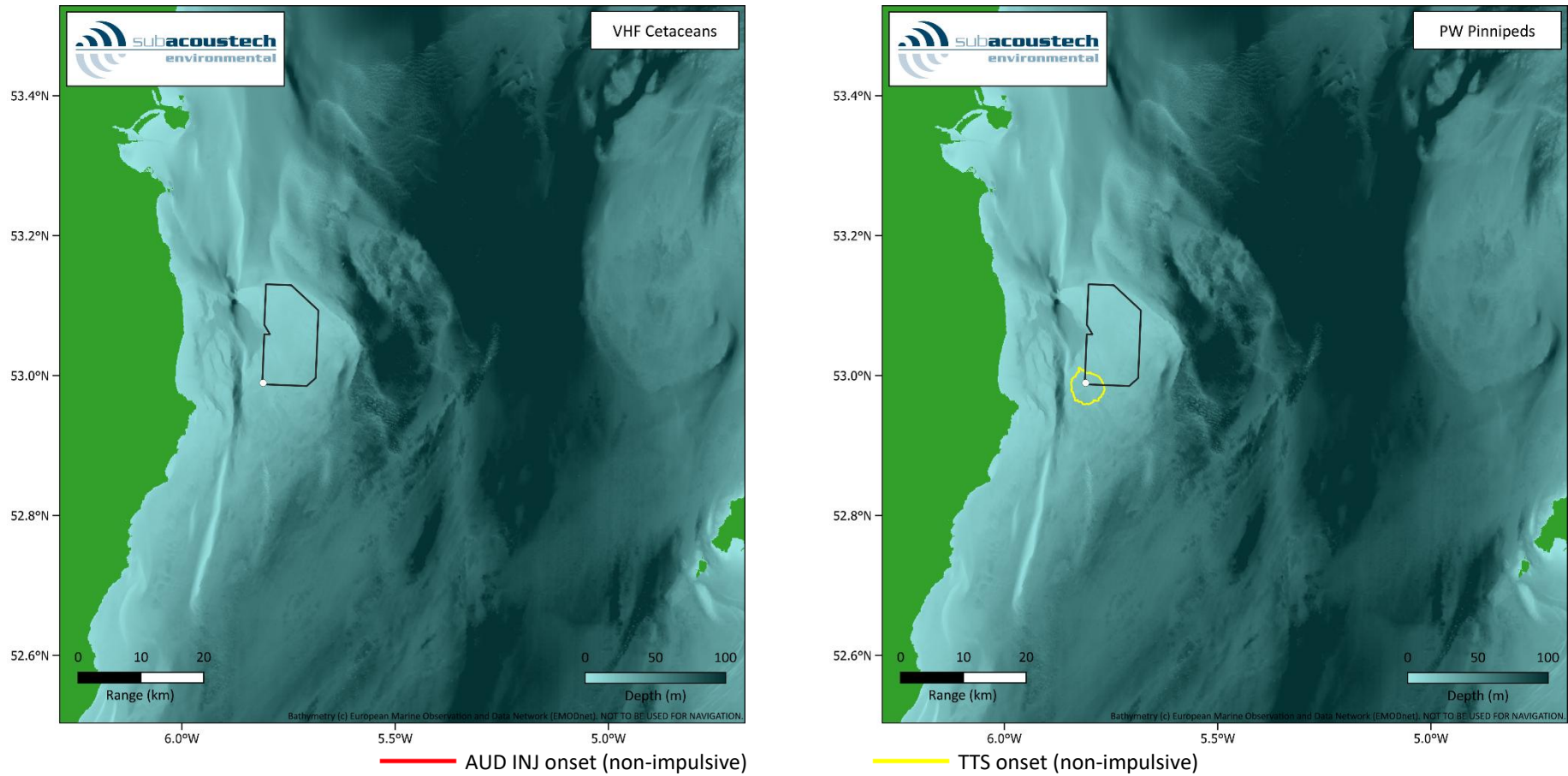


Figure B 34: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for VHF cetaceans and PW pinnipeds using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) scenario at the SW modelling location assuming fleeing receptors.

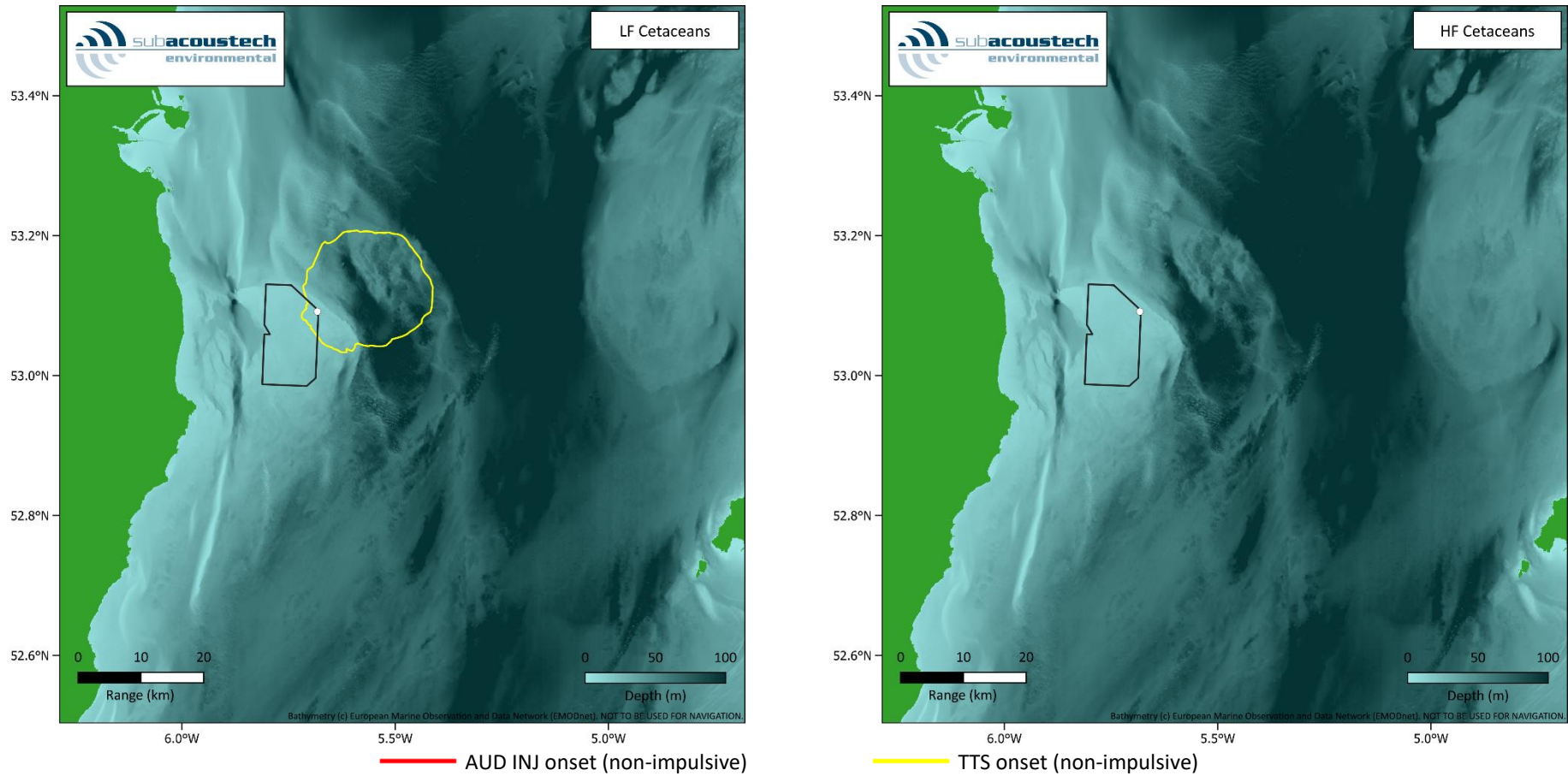


Figure B 35: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for LF and HF cetaceans using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) scenario at the NE modelling location assuming fleeing receptors.

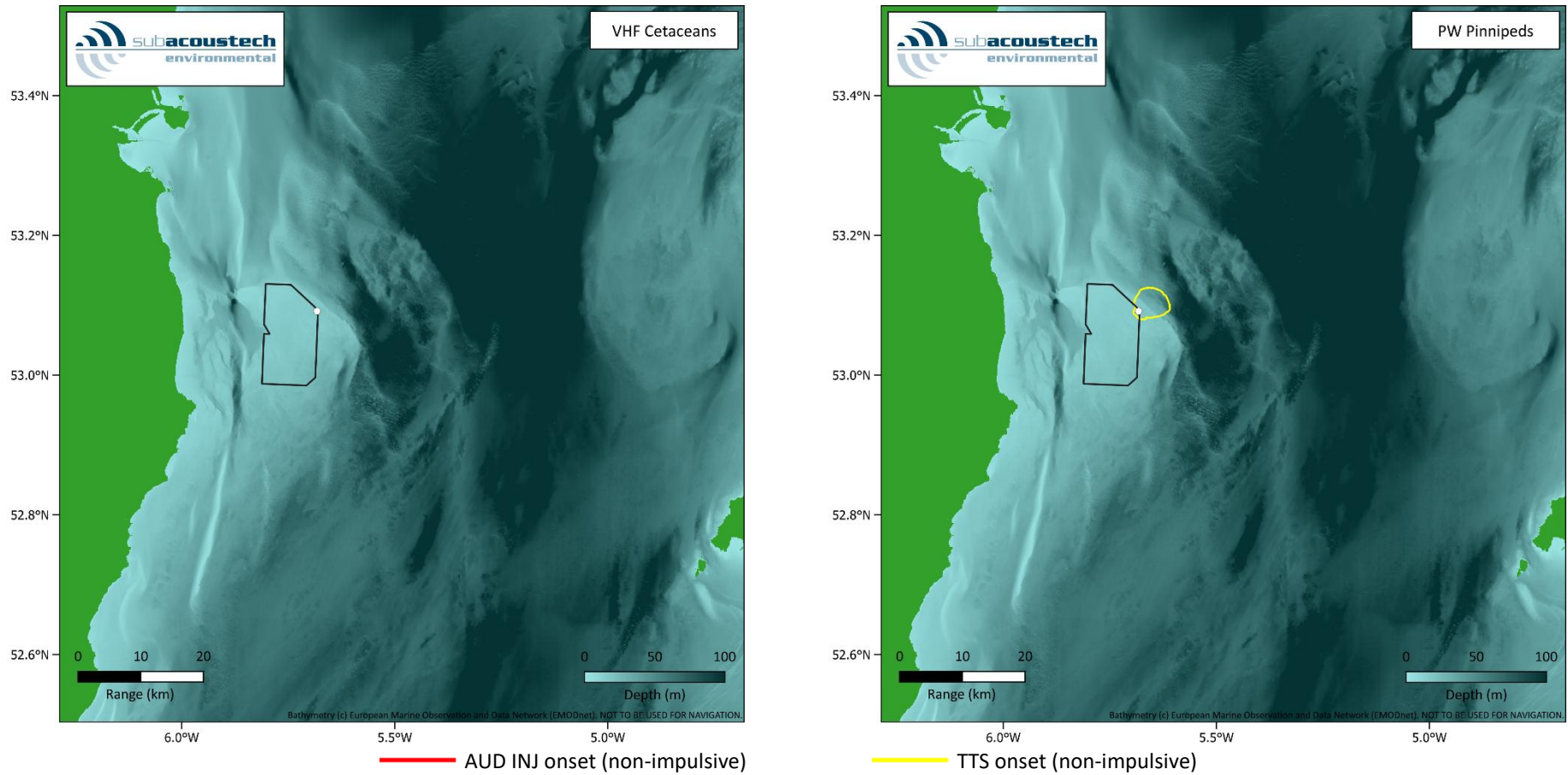


Figure B 36: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for VHF cetaceans and PW pinnipeds using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) scenario at the NE modelling location assuming fleeing receptors.

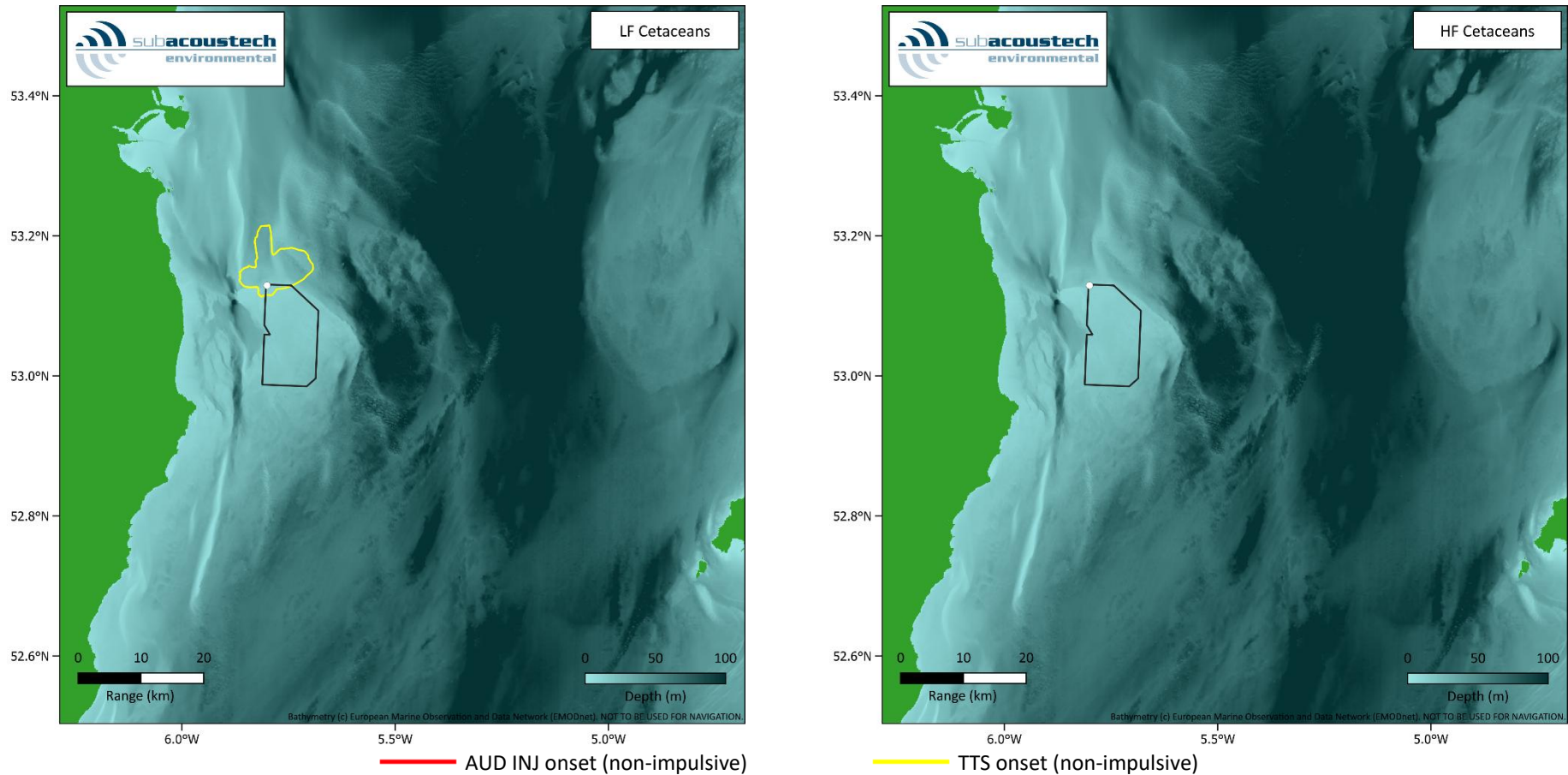


Figure B 37: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for LF and HF cetaceans using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) scenario at the NW modelling location assuming fleeing receptors.

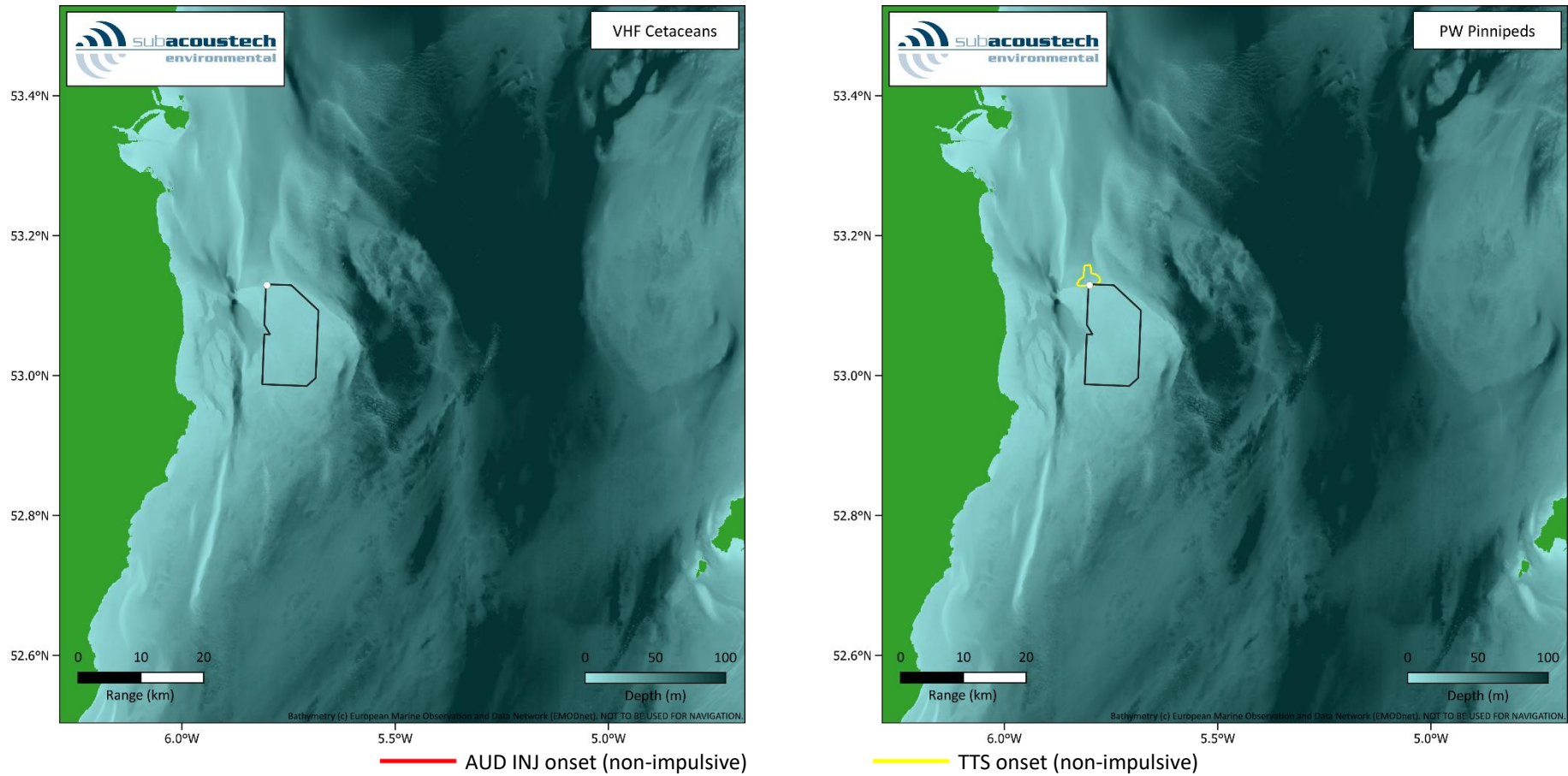


Figure B 38: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for VHF cetaceans and PW pinnipeds using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) scenario at the NW modelling location assuming fleeing receptors.

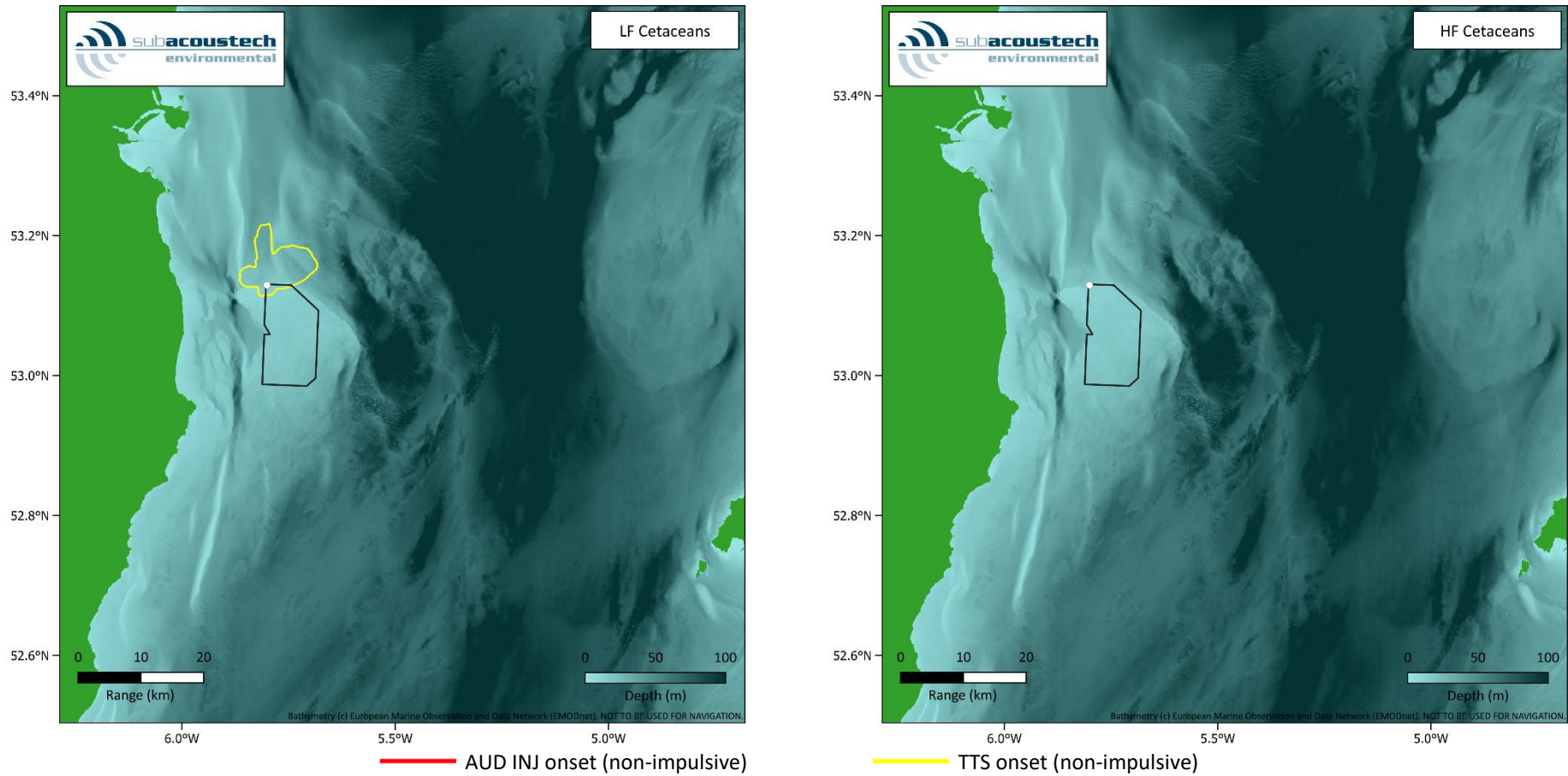


Figure B 39: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for LF and HF cetaceans using the NMFS (2024) non-impulsive criteria for the monopile installation (2 sequential piles) scenario at the NW modelling location assuming fleeing receptors.

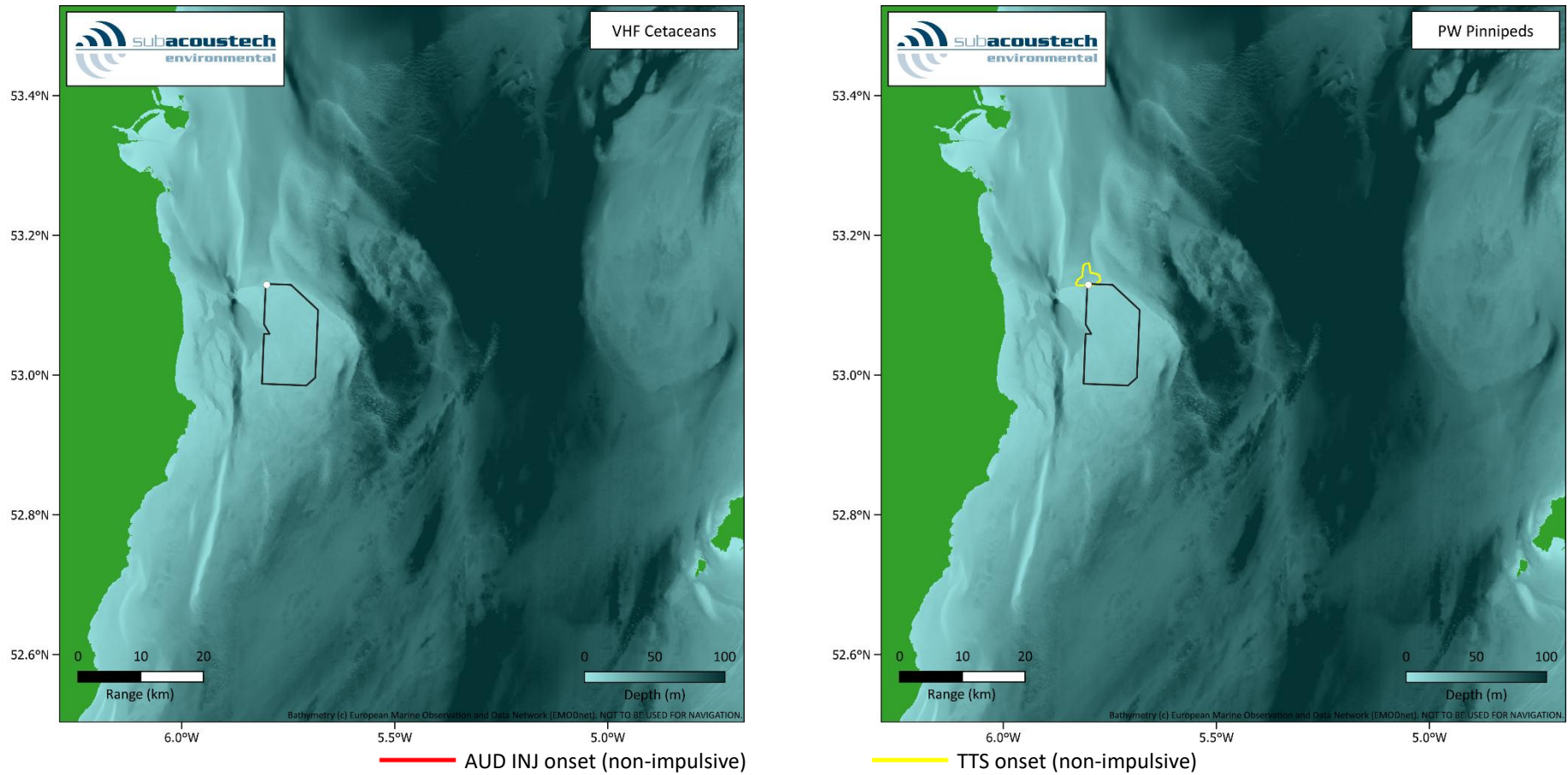


Figure B 40: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for VHF cetaceans and PW pinnipeds using the NMFS (2024) non-impulsive criteria for the monopile installation (2 sequential piles) scenario at the NW modelling location assuming fleeing receptors.

B.3.2 Mitigated impact piling results

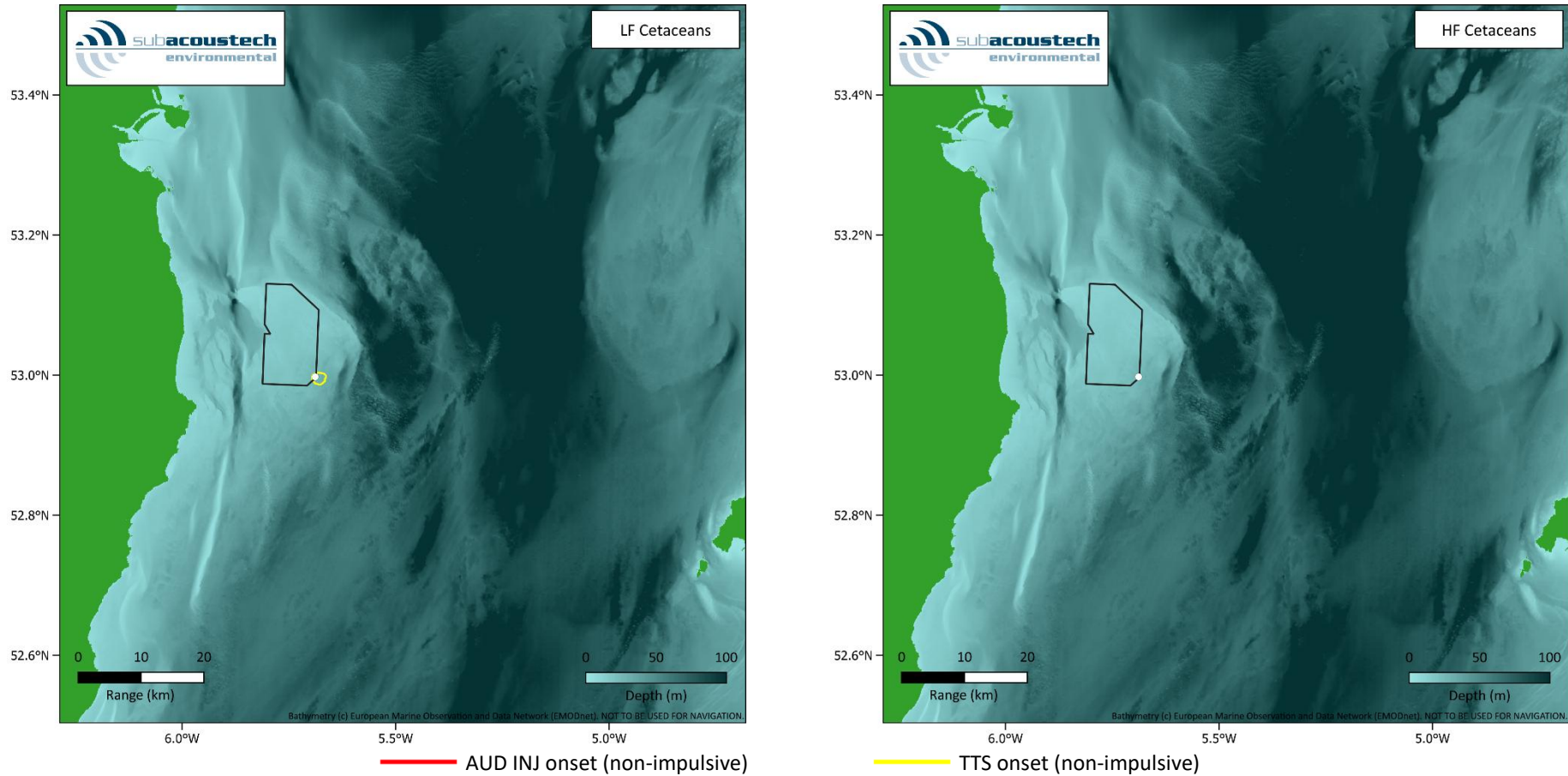


Figure B 41: Contour plots showing the weighted $LE_{p,24h,wtd}$ impact ranges for LF and HF cetaceans using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) scenario, including mitigation, at the SE modelling location assuming fleeing receptors.

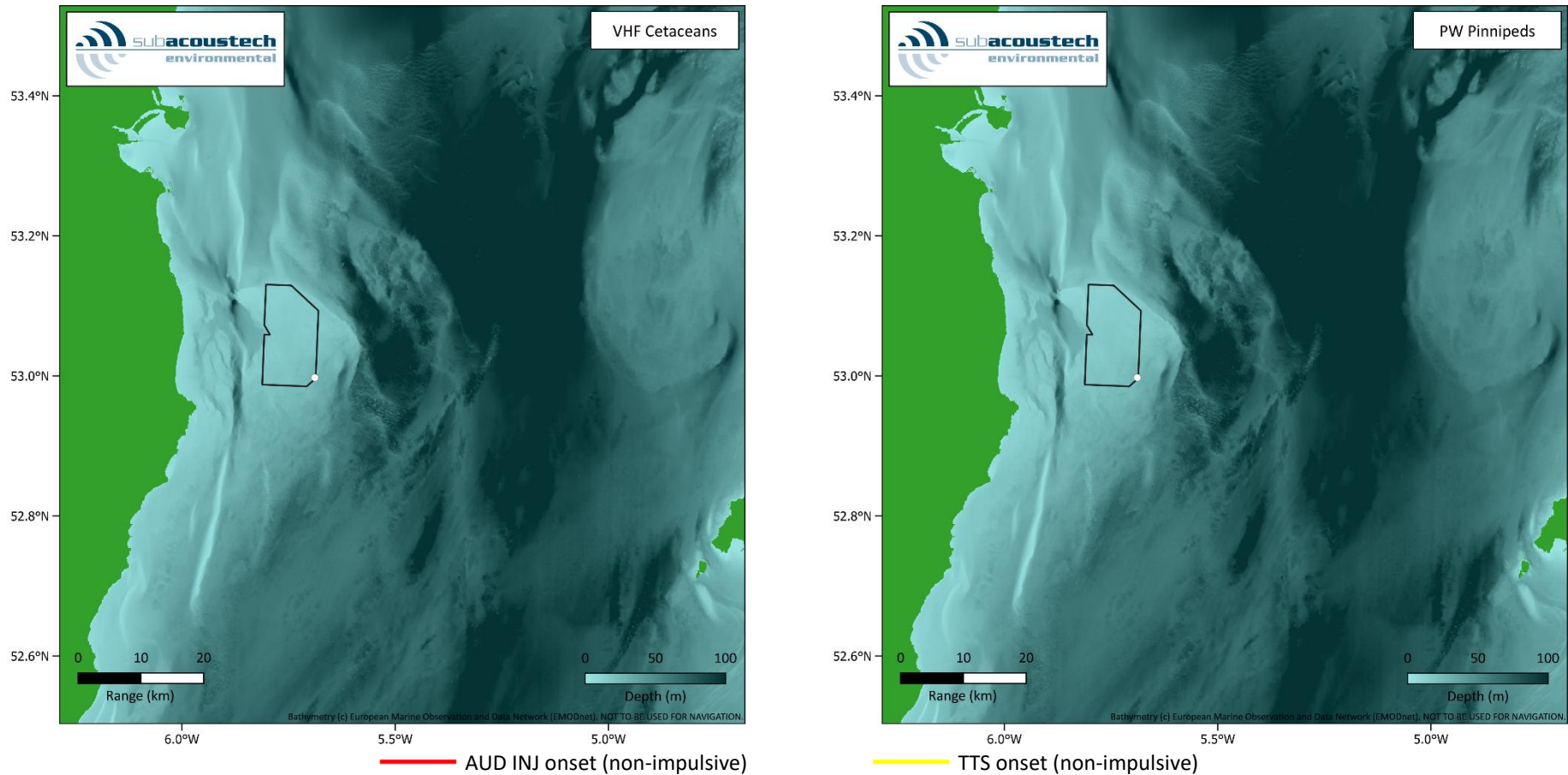


Figure B 42: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for VHF cetaceans and PW pinnipeds using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) scenario, including mitigation, at the SE modelling location assuming fleeing receptors.

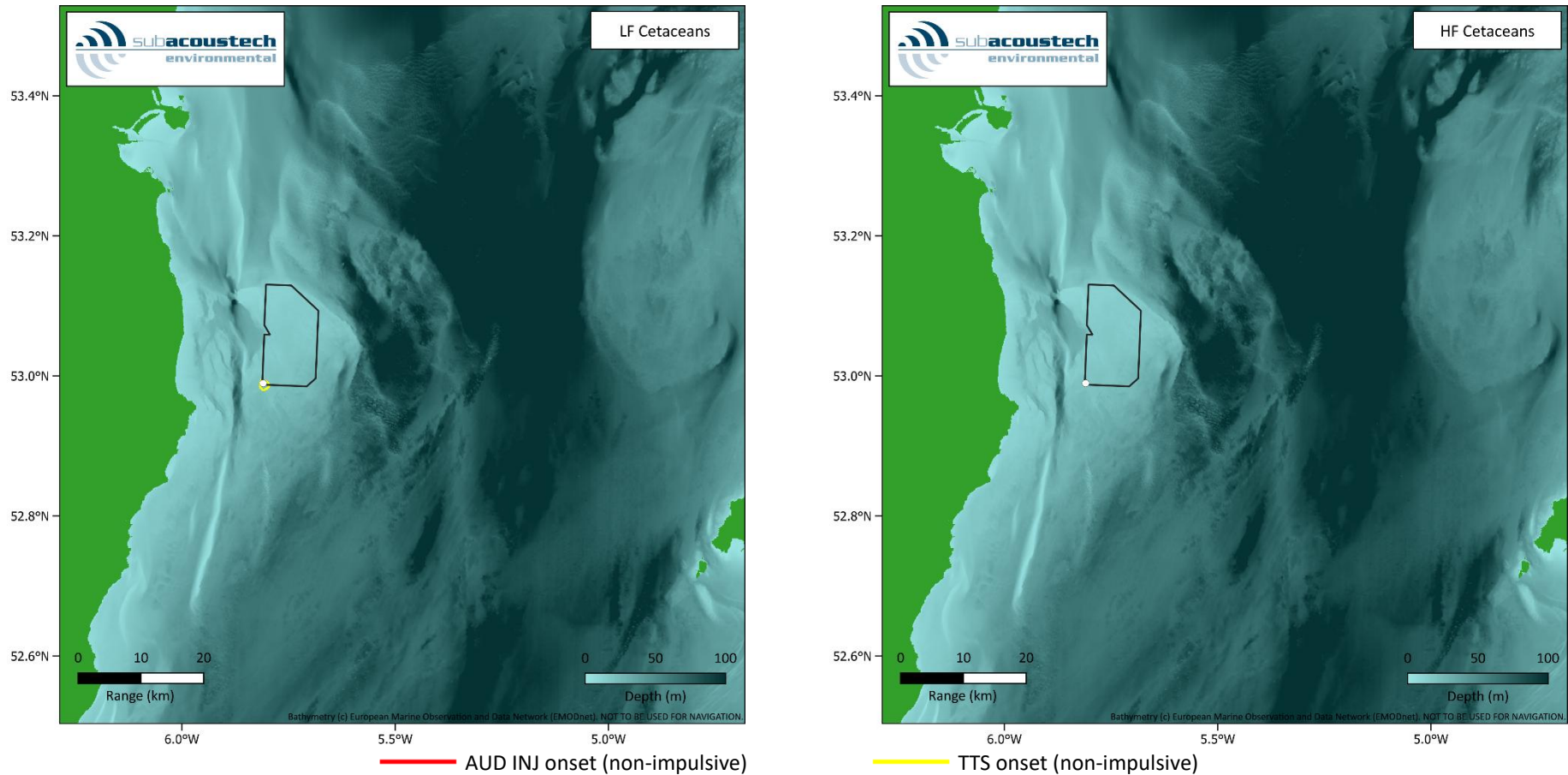


Figure B 43: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for LF and HF cetaceans using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) scenario, including mitigation, at the SW modelling location assuming fleeing receptors.

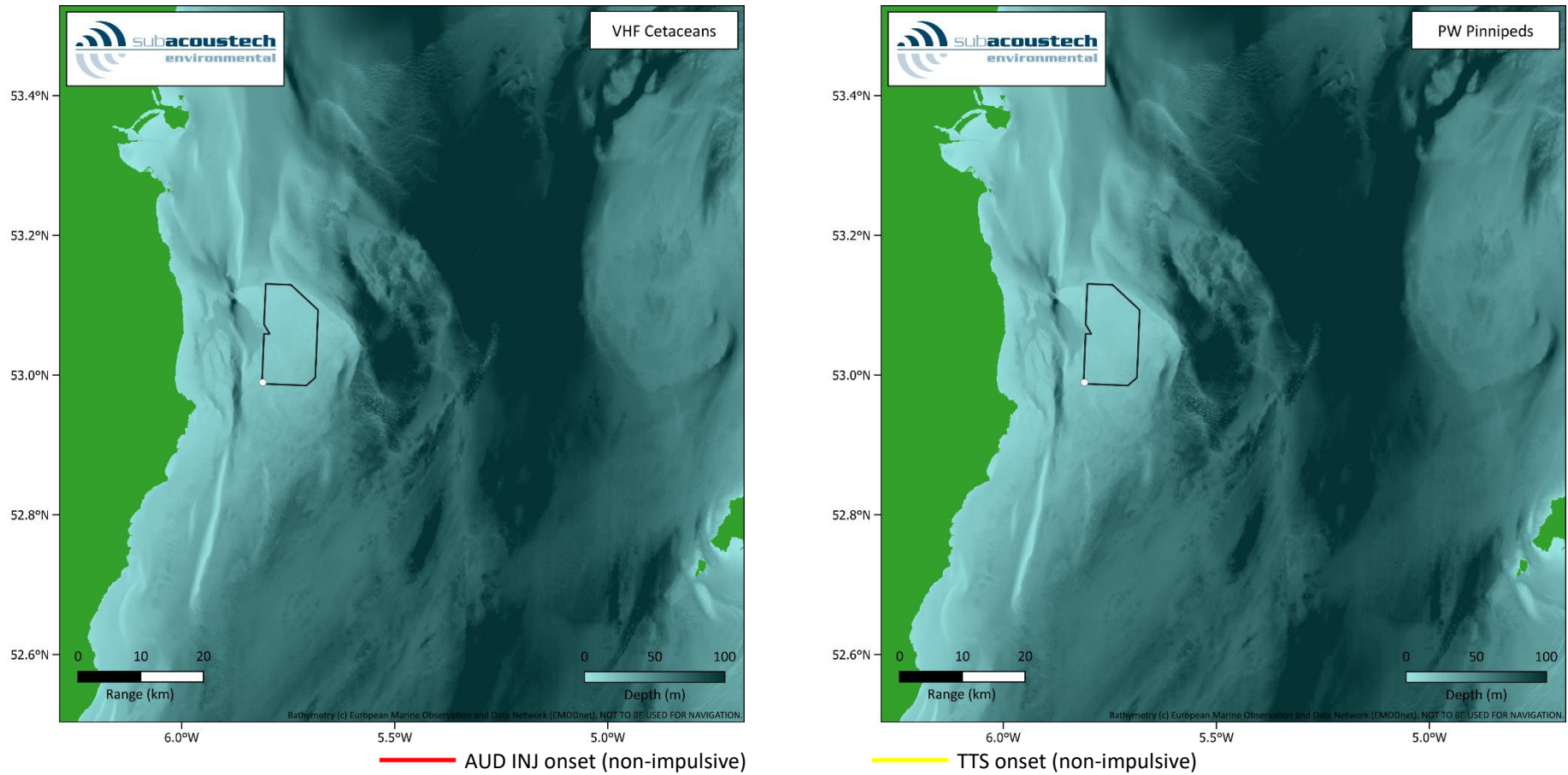


Figure B 44: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for VHF cetaceans and PW pinnipeds using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) scenario, including mitigation, at the SW modelling location assuming fleeing receptors.

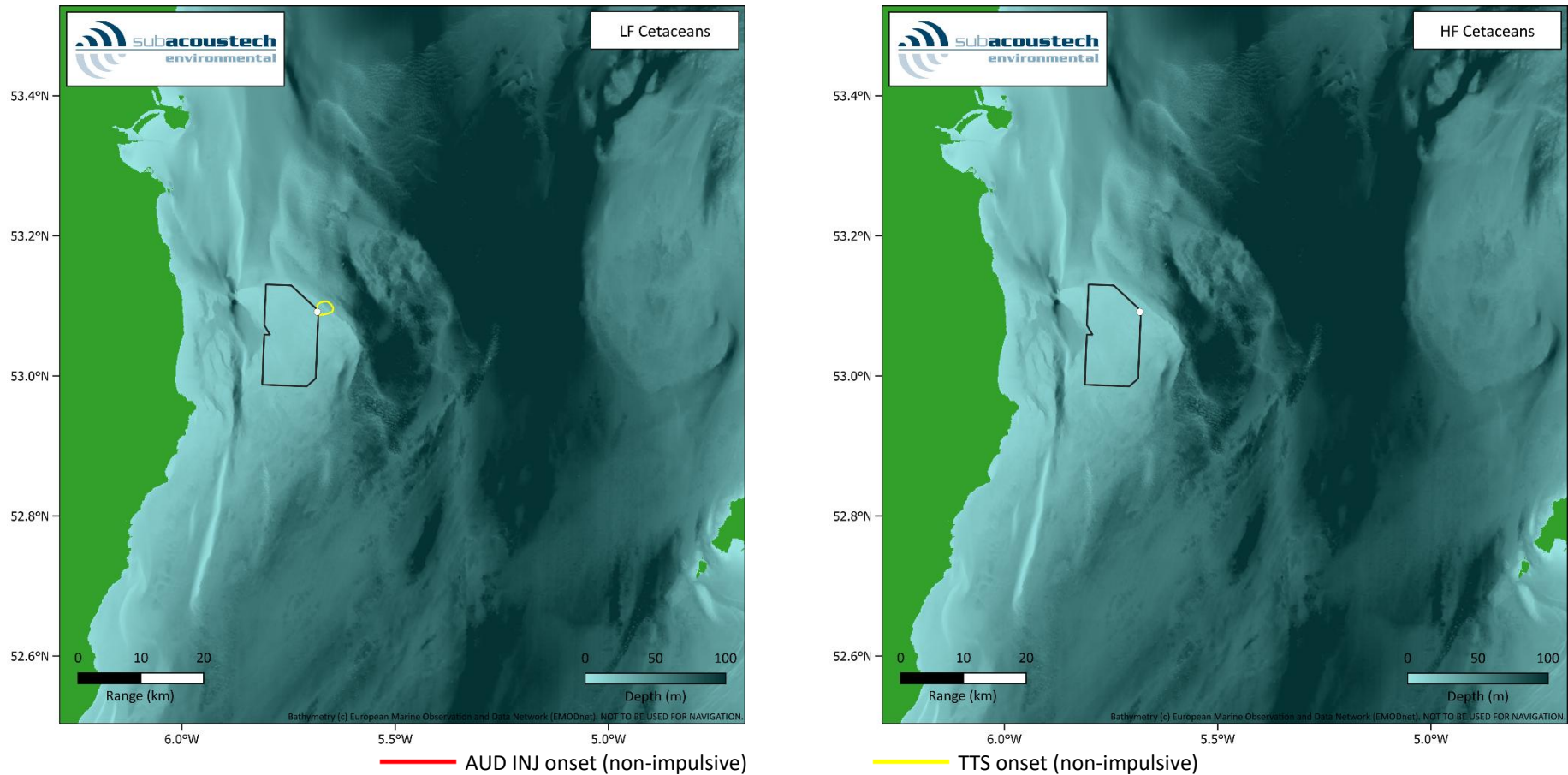


Figure B 45: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for LF and HF cetaceans using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) scenario, including mitigation, at the NE modelling location assuming fleeing receptors.

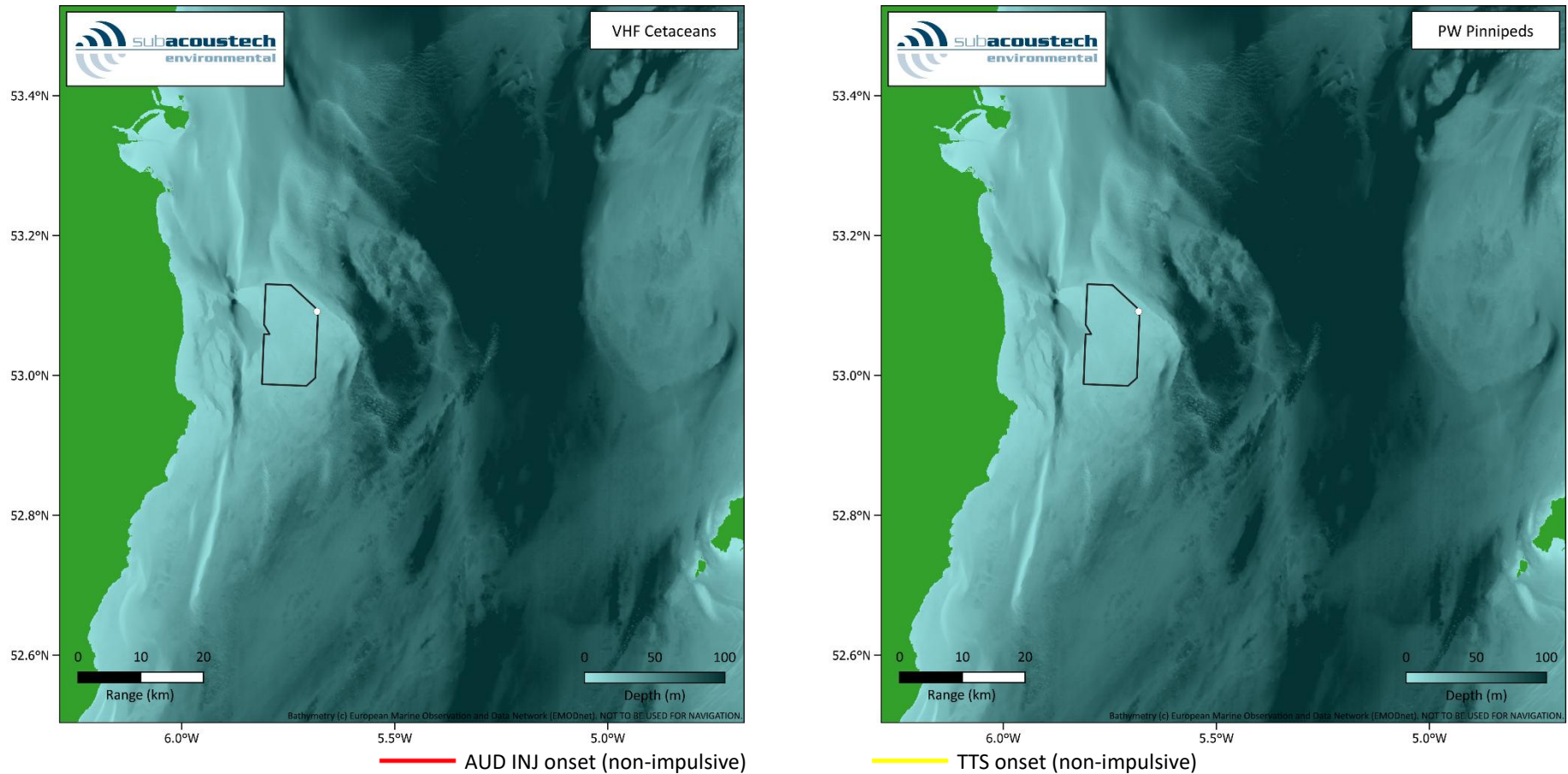


Figure B 46: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for VHF cetaceans and PW pinnipeds using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) scenario, including mitigation, at the NE modelling location assuming fleeing receptors.

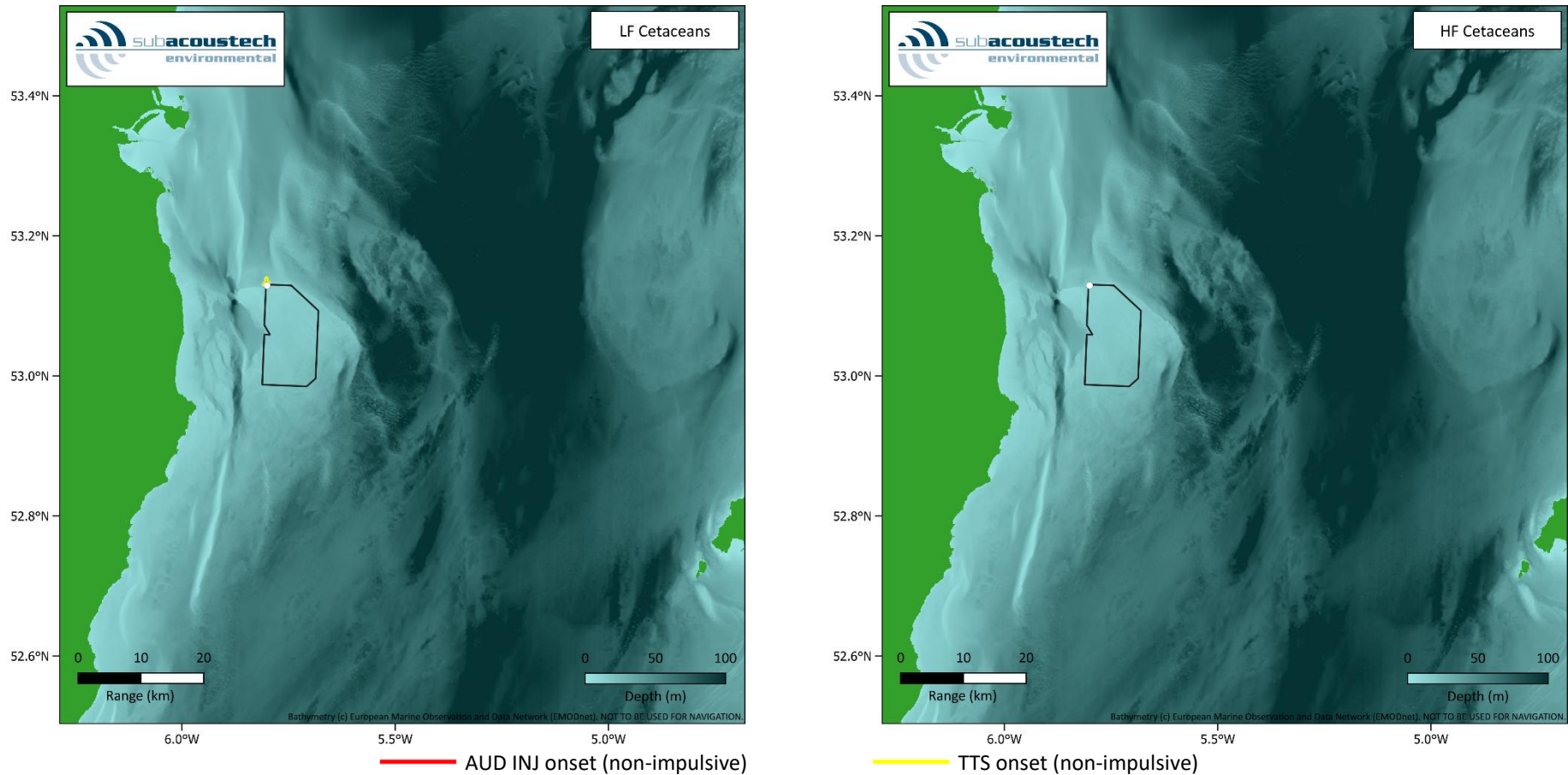


Figure B 47: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for LF and HF cetaceans using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) scenario, including mitigation, at the NW modelling location assuming fleeing receptors.

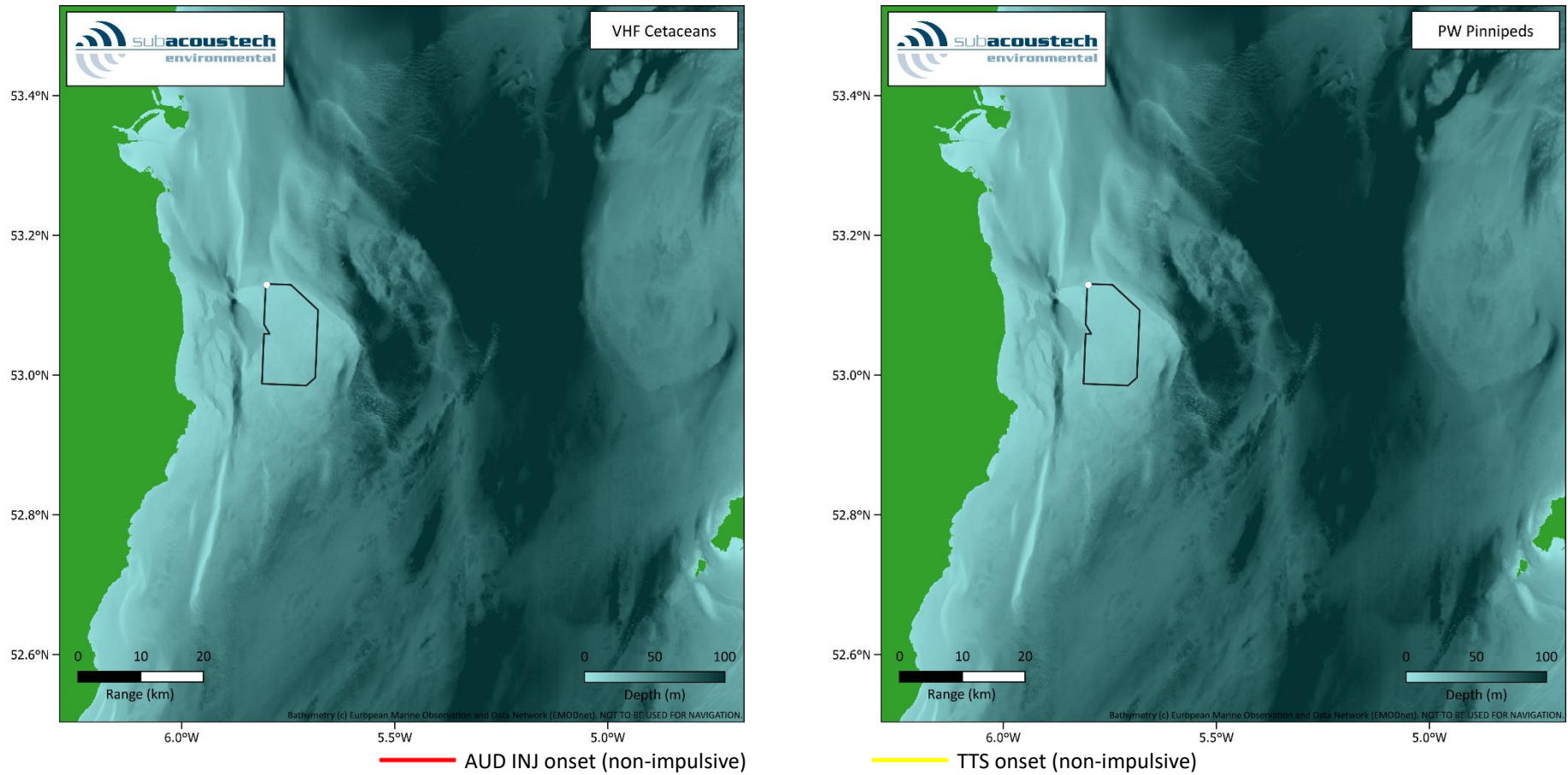


Figure B 48: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for VHF cetaceans and PW pinnipeds using the NMFS (2024) non-impulsive criteria for the monopile installation (single pile) scenario, including mitigation, at the NW modelling location assuming fleeing receptors.

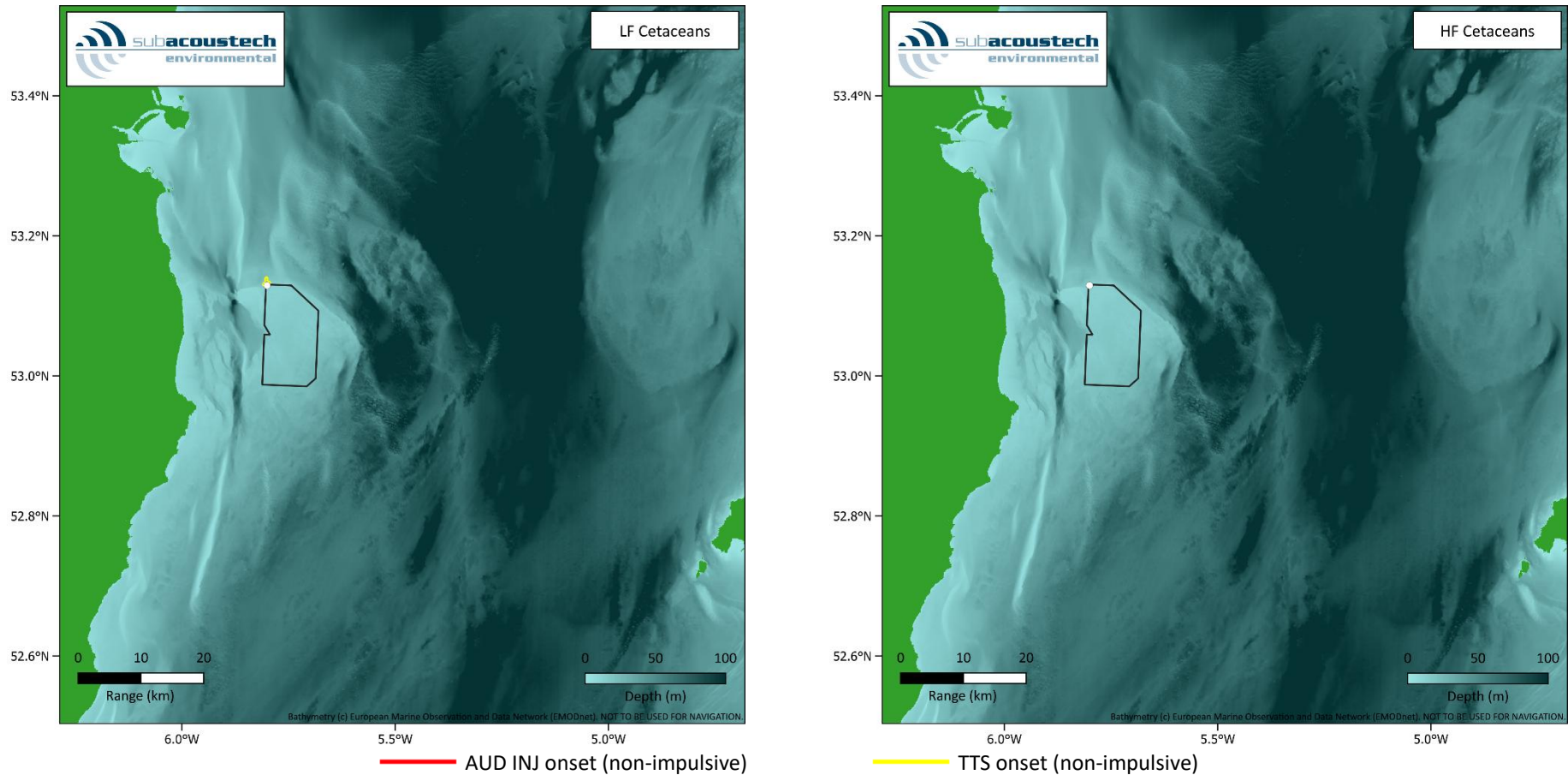


Figure B 49: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for LF and HF cetaceans using the NMFS (2024) non-impulsive criteria for the monopile installation (2 sequential piles) scenario, including mitigation, at the NW modelling location assuming fleeing receptors.

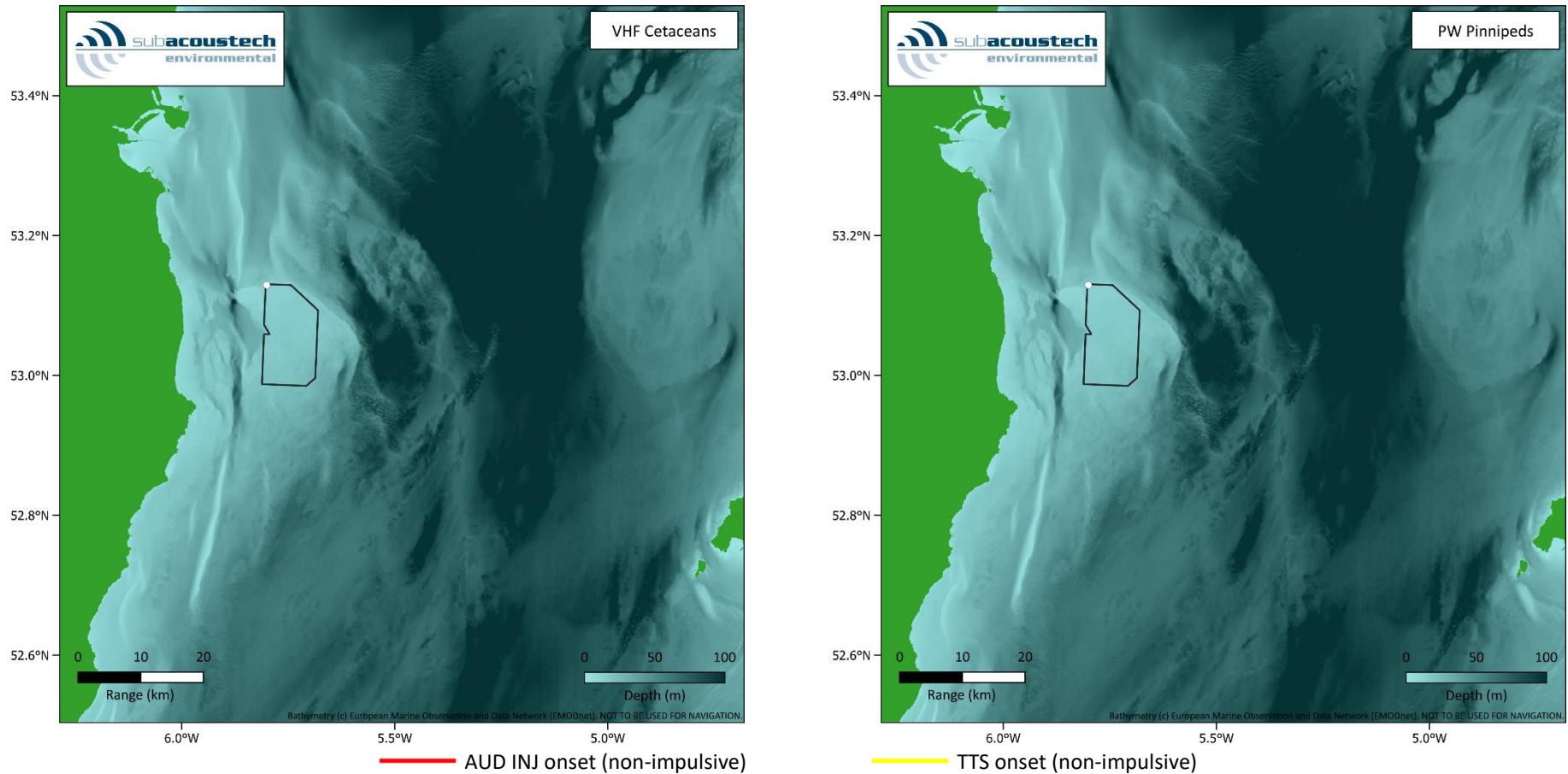


Figure B 50: Contour plots showing the weighted $L_{E,p,24h,wtd}$ impact ranges for VHF cetaceans and PW pinnipeds using the NMFS (2024) non-impulsive criteria for the monopile installation (2 sequential piles) scenario, including mitigation, at the NW modelling location assuming fleeing receptors.

Document Information

- This is a controlled document.
- Any electronic copy not stored on Subacoustech Environmental's system is considered uncontrolled.
- Amendment shall be by whole document revision and re-issue.
- Requests for changes to this document or its classification should be sent to Subacoustech Environmental.

Document No.	Draft	Date	Details of change
P284R0400	02	06/11/2025	Initial writing and internal review.
P284R0401	-	14/01/2026	First issue to client.
P284R0402	-	16/03/2026	Updated impact piling mitigation modelling.
P284R0403	-	24/03/2026	Updates for FIR, clarification of noise commitment.

Originator's current report number	P284R0403
Originator's name and location	R Barham; Subacoustech Environmental Ltd.
Contract number and period covered	P284; March 2022 – March 2026
Sponsor's name and location	L Jamieson; Natural Power
Report classification and caveats in use	UNRESTRICTED – <i>For distribution within the project team only</i>
Date written	November – March 2026
Pagination	Cover + vi + 140
References	65
Report title	Codling Wind Park: Underwater noise modelling assessment
Translation/Conference details (if translation, give foreign title/if part of a conference, give conference particulars)	
Title classification	UNRESTRICTED
Author(s)	Richard Barham, Tim Mason
Descriptors/keywords	
Abstract	
Abstract classification	UNRESTRICTED

Annex A - Noise limits/thresholds in other EU jurisdictions

FIR 10a(ii) states the following: *The applicant must also consider and draw on the best available technology and thresholds, including as applied in other EU jurisdictions (e.g., Germany; Belgium; Netherlands; Denmark), to identify and provide for suitable noise abatement to reduce the level and extent of potential noise impacts arising from the proposed development. Examples include the German 160 dB re 1 $\mu\text{Pa}^2\text{s}$ SEL_{ss} and 190 dB re 1 μPa SPL_{peak} thresholds that must not be exceeded at a distance of 750 m from a piling site; or the frequency weighted SEL_{cum} PTS thresholds (e.g., harbour porpoise 155 dB re 1 $\mu\text{Pa}^2\text{s}$) that must not be exceeded for a fleeing animal with a starting distance of 200m in Denmark.*

This note has been produced to further consider the underwater noise impacts of pile driving at the CWP Project in relation to noise limits/thresholds in other EU jurisdictions.

It is noted that to mitigate potential impacts associated with permanent auditory injury (permanent threshold shift (PTS)) from cumulative sound exposure¹ from underwater noise during the construction of the project, the Applicant has committed to a limit on underwater noise of 169 dB $\text{L}_{\text{E,p,ss,05}}$ at 750m at WTG and OSS piling events. Given the lack of guidance in Ireland on mitigation measures or noise limits, the Applicant considers this commitment to achieve the primary objective of the guidance referred to in both the Further Information Request (FIR) and this document, which is to negate the risk of auditory injury (PTS). It is however also relevant to note that recent studies such as *ORJIP: Range dependent nature of impulsive noise (RaDIN)*², and *RADIN2*, have demonstrated that the conservatism in the modelling of the SEL_{cum} PTS threshold has been shown to result in cumulative PTS-onset ranges which are frequently twice as large as the equivalent real world piling logs, and as such resulting in excessive actions to mitigate cumulative PTS-onset.

UK proposed thresholds

The DEFRA funded project: "[A noise limit for offshore wind piling driving: feasibility assessment and pilot programme design](#)" includes proposed options for a decibel limit in England and Wales (Barber *et al.*, 2024) as listed below. It is of note that this policy is currently subject to scientific scrutiny by the Offshore Wind Industry Council (OWIC).

- SEL_{ss} 170 dB re 1 $\mu\text{Pa}^2\text{s}$ (unweighted) at 750 m
- $\text{L}_{0-\text{pk}}$ 190 dB re 1 μPa at 750 m (same as in German waters)

By limiting underwater noise to 169 dB $\text{L}_{\text{E,p,ss,05}}$ at 750m at WTG and OSS piling events, CWP is **fully compliant** with the proposed UK dB limit of $\text{L}_{\text{p,peak}}$ @ 750 m 190 dB re 1 μPa .

¹ Defined as Cumulative Sound Exposure Level (SEL_{cum}): The SEL summed up over multiple exposures / multiple impulsive events such as for a pile driving sequence.

² <https://www.carbontrust.com/our-work-and-impact/guides-reports-and-tools/orjip-range-dependent-nature-of-impulsive-noise-radin>

By limiting underwater noise to 169 dB $L_{E,p,ss,05}$ at 750m at WTG and OSS piling events, CWP is **fully compliant** with the proposed UK dB limit of $L_{E,ss}$ @ 750 m 170 dB re $1\mu Pa^2s$.

Denmark

The Danish guidelines (Danish Energy Agency, 2022, Lützen *et al.*, 2024) are marine mammal hearing group specific and do not set a specific noise limit. Instead, the noise exposure limits are based on ensuring no animals are present within the predicted cumulative PTS impact range using the $L_{E,cum,weighted}$ (SEL_{cum}) metric at the start of piling. This concept is termed r_{safe} which is the distance (within the predicted cumulative PTS impact range) within which no relevant species are present prior to piling commencing. The GOMOREUS project (Tougaard *et al.*, 2025) provided indicative modelling using the Southall *et al.* (2019) cumulative PTS thresholds and a fixed swimming speed of 1.5 m/s for all species. The predictive modelling conducted for the CWP Project used the updated NMFS (2024) cumulative PTS thresholds for all species and a higher swimming speed of 3.25 m/s for minke whales (as 1.5 m/s was considered to be unrealistically slow).

By limiting underwater noise to 169 dB $L_{E,p,ss,05}$ at 750m at WTG and OSS piling events, CWP is **fully compliant** with the Danish guidelines for all species groups as PTS impact ranges are all <100 m.

Germany

The German guidelines (BSH, 2011, ASCOBANS, 2014) outline fixed exposure limits that cannot be exceeded. The noise limits were based on TTS thresholds in harbour porpoise, as reported in Lucke *et al.* (2009). The noise limits are:

- $L_{E,ss}$ @ 750 m 160 dB re $1\mu Pa^2s$ unweighted
- L_{peak} @ 750 m 190 dB re $1\mu Pa$ unweighted

By limiting underwater noise to 169 dB $L_{E,p,ss,05}$ at 750m at WTG and OSS piling events, the CWP Project is **fully compliant** with the German guidelines for L_{peak} .

To fully comply with the German guidelines for $L_{E,ss}$, additional noise reduction would be required at the CWP Project. However, the Applicant considers the noise limit commitment to achieve the objective of the German guidelines which is to negate the risk of auditory injury (PTS).

Belgium

The Belgian guidelines (Rumes *et al.*, 2016) outline fixed exposure limits that cannot be exceeded.

- $L_{E,ss}$ @ 750 m 162 dB re $1\mu Pa^2s$ unweighted
- L_{peak} @ 750 m 185 dB re $1\mu Pa$ unweighted

To fully comply with the Belgian guidelines for both $L_{E,ss}$ and L_{peak} , additional noise reduction would be required at the CWP Project. However, the Applicant considers the noise limit commitment to achieve the objective of the Belgian guidelines which is to negate the risk of auditory injury (PTS)

Netherlands

The Dutch underwater noise guidelines (Heinis *et al.*, 2015, Heinis *et al.*, 2025) do not set a specific noise threshold, but instead use a population level management objective: *With the construction of offshore wind farms, the populations of harbour porpoises, harbour seals and grey seals on the Dutch Continental Shelf (DCS) must be maintained at a minimum of 95% of the present level with a high degree of certainty (>95%) (in other words, the probability of a population reduction \geq 5% must be \leq 5%).* Using population modelling scenarios in iPCoD, an exposure limit at 750 m distance was back-calculated, resulting in a limit of $L_{E,SS}$ @ 750 m of 160 dB re 1 $\mu\text{Pa}^2\text{s}$ which is identical to the German threshold.

To fully comply with the Dutch guidelines for $L_{E,SS}$, additional noise reduction would be required at CWP. However, the Applicant considers the noise limit commitment to achieve the objective of the Dutch guidelines which is to negate the risk of auditory injury (PTS)

References

- ASCOBANS. (2014). Concept for the protection of harbour porpoises from sound exposures during the construction of offshore wind farms in the German North Sea (sound protection concept). Page 35 *in* Germany, editor. 21st ASCOBANS Advisory Committee meeting, Gothenburg, Sweden.
- Barber, R., S. Stephenson, D. Jervis, C. Birch, R. Lee, and A. Gregory. (2024). A noise limit for offshore wind pile driving: feasibility assessment and pilot programme design. Part 2 - Feasibility of applying a piling noise decibel limit in English and Welsh waters. Report P1804-REPT-02-R02 to Defra. Seiche Ltd, 135pp.
- BSH. (2011). Offshore wind farms: Measuring instruction for underwater sound monitoring. Federal Maritime and Hydrographic Agency (BSH).
- Danish Energy Agency. (2022). Guideline for underwater noise. Installation of impact or vibratory driven piles. Rev. 1. Danish Ministry of Energy, Copenhagen.
- Heinis, F., C. de Jong, and S. v. Benda-Beckermann. (2025). KEC 5.0 report, Part B, marine mammals. TNO.
- Heinis, F., C. De Jong, and Rijkswaterstaat Underwater Sound Working Group. (2015). Framework for assessing ecological and cumulative effects of offshore wind farms: Cumulative effects of impulsive underwater sound on marine mammals. Project number: 060.11480 & 060.14412. Report number: TNO 2015 R10335-A, TNO.
- Lützen, R. S., S. Keller, and J. Tougaard. (2024). Revised Danish Guidelines for Underwater Noise from Installation of Impact or Vibratory Driven Piles. Pages 1585-1599 *in* A. N. Popper, J. A. Sisneros, A. D. Hawkins, and F. Thomsen, editors. The Effects of Noise on Aquatic Life: Principles and Practical Considerations. Springer International Publishing, Cham.
- NMFS. (2024). Update to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 3.0): Underwater and In Air Criteria for Onset of Auditory Injury and Temporary Threshold Shifts.
- Rumes, B., A. Erkman, and J. Haelters. (2016). Evaluating underwater noise regulations for piling noise in Belgium and The Netherlands. Environmental impacts of offshore wind farms in the Be part of the North Sea: Environmental impact monitoring reloaded:37-48.
- Southall, B., J. J. Finneran, C. Reichmuth, P. E. Nachtigall, D. R. Ketten, A. E. Bowles, W. T. Ellison, D. Nowacek, and P. Tyack. (2019). Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. *Aquatic Mammals* **45**:125-232.

Tougaard, J., M. Mikaelson, and E. Griffiths. (2025). GOMOREUS – Guidance on Managing Offshore Renewable Energy Underwater Sound. Modelling of impact ranges for pile driving in Irish waters. Technical Report from DCE – Danish Centre for Environment and Energy.