Department for Business, Energy & Industrial Strategy

TECHNICAL NOTE

Noise Modelling for SNS SCI Habitat Assessment

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Project Title: **Noise Modelling for SNS SCI Habitat Assessment**
Document/Rev No: J74774B-Y-TN-24000/D1
Date: October, 2018

Rev	Date	Description	Issued by	Checked by	Approved by	Client Approval
B1	27/06/2018	Issued for client comment	AM	PB	PB	
B2	05/10/2018	Updated with client comments	AM	PB	PB	
D1	26/10/2018	Issued for use	AM	PB	PB	

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ABBREVIATIONS

ANSI	American National Standards Institute
BIPM	Bureau International des Poids et Mesures
EMODnet	European Marine Observation and Data Network
EPS	European Protected Species
HF	High Frequency
JNCC	Joint Nature Conservation Committee
LF	Low Frequency
MF	Mid Frequency
MU	Management Unit
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
PE	Parabolic Equation
PTS	Permanent Threshold Shift
RAM	Range-dependent Acoustic Model
Rms	Root Mean Square
SCI	Site of Community Importance
SEL	Sound Exposure Level
SI	Système international d'unités (International System of Units)
SNS	Southern North Sea
SPL	Sound Pressure Level
TTS	Temporary Threshold Shift
UK	United Kingdom
WOA	World Ocean Atlas

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UNITS

dB re 1 µPa	decibels relative to one micropascal (units of zero-to-peak sound pressure level, peak-to-peak sound pressure level, and root-mean-square sound pressure level)
dB re 1 µPa-m	decibels relative to one micropascal referred to one metre (units of source level expressed as zero-to-peak sound pressure level, peak-to-peak sound pressure level, and root-mean-square sound pressure level)
dB re 1 µPa^{2}s	decibels relative to one micropascal square second (units of sound exposure level)
dB re 1 µPa^{2}s-m	decibels relative to one micropascal square second referred to one metre (units of source level expressed as sound exposure level)
Hz	Hertz (SI units of frequency)
kHz	kilohertz (units of frequency equal to 1,000 Hz)
km	Kilometres (units of distance equal to 1,000 metres)
m	Metres (SI units of distance)
N/m^2	Newtons per square metre (unit of pressure that is equivalent to Pascals)
Pa	Pascals (SI units of pressure)
Pa^{2}s	Pascal square seconds (unit of sound exposure)
s	seconds (SI unit of time)
µPa	micropascal (unit of pressure equal to 1e-6 Pascals)
µPa^{2}s	micropascal square second (unit of sound exposure equal to 1e-6 Pascal square seconds)

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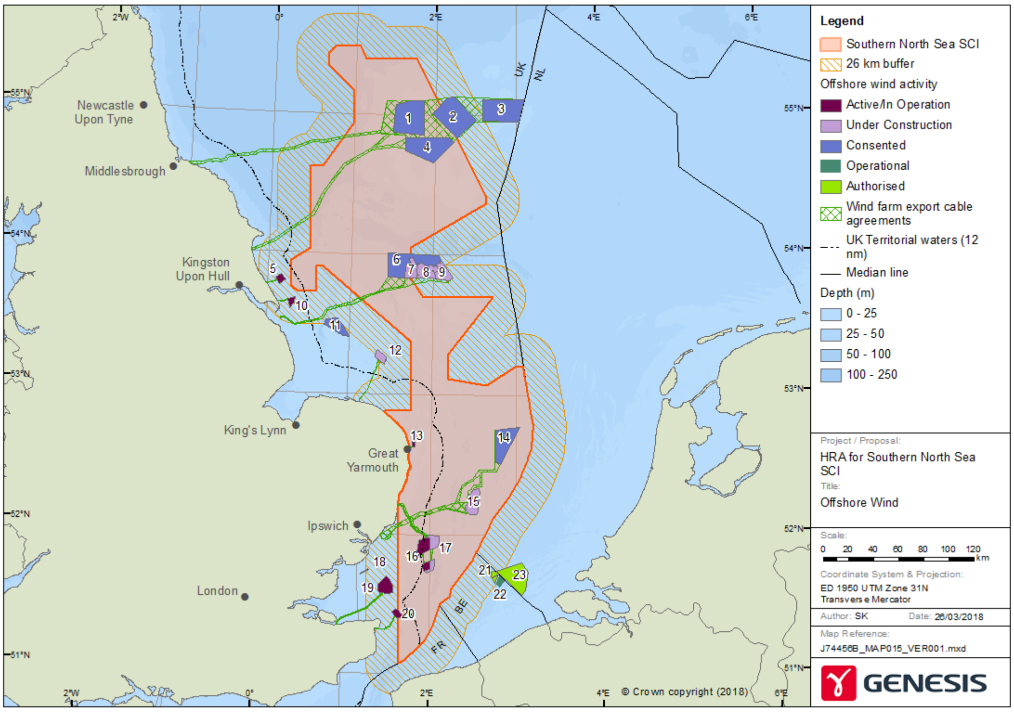
1.0 INTRODUCTION

1.1 Background

The Southern North Sea (SNS) Site of Community Importance (SCI) has been identified as an important area for harbour porpoise (*Phocoena phocoena*). Located to the east of England (see Figure 1-1), this site stretches from the central North Sea (north of Dogger Bank) to the Straits of Dover in the south. The site covers an area of approximately 36,951 km^2, making it the largest area of conservation in UK and European waters at the point of designation. The majority of the site lies offshore, though it extends into coastal areas of Norfolk and Suffolk crossing the 12 nautical mile boundary and hence, both Natural England and the Joint Nature Conservation Committee (JNCC) are responsible for providing statutory advice.

This SCI area supports an estimated 17.5% of the UK North Sea Management Unit (MU) population. Approximately two thirds of the site, the northern part, is recognised as important for harbour porpoise during the summer season, whilst the southern part support persistently higher densities during the winter. A mix of habitats, such as sandbanks and gravel beds, are included in the site and depths range from mean low water to 75 m, with the majority of the site being shallower than 40 m.



1. Creyke Beck B
2. Teesside (Lackenby) B
3. Teesside (Lackenby) A
4. Creyke Beck A
5. Westermost Rough
6. Hornsea Project Two
7. Hornsea Project One - Heron West
8. Hornsea Project One - Njord
9. Hornsea Project One - Heron East
10. Humber Gateway
11. Triton Knoll
12. Dudgeon
13. Scroby Sands
14. East Anglia Three
15. East Anglia One
16. Greater Gabbard
17. Galloper
18. Gunfleet Sands II
19. London Array 1
20. Thanet
21. THV Mermaid
22. Belwind I
23. Borssele II

Figure 1-1: Offshore wind farms located within the Southern North Sea SCI and 26 km of the site boundary.

1.2 Assessment Overview

A number of activities associated with offshore windfarm developments generate sound in the marine environment. Noise from pile-driving during the construction phase is generally the sound source that generates the highest levels of sound throughout the lifetime of a wind farm. Pile-driving involves driving the pile into the sea bed using an impact hammer, and is known to generate high levels of sound that may be distinguishable above ambient noise over large distances (Thomsen *et al.,* 2006; Nedwell *et al.,* 2007; Bailey *et al.,* 2010).

Underwater noise propagation modelling has been conducted to estimate any potential impacts to harbour porpoise and fish species during pile-driving at a number of wind farm projects in the SNS. The noise modelling has considered various scenarios involving pile-driving operations at wind farm developments in the SNS including:

- Creyke Beck A;
- Creyke Beck B;
- East Anglia One;
- East Anglia Three;
- Hornsea One;
- Hornsea Two;
- Teesside A;
- Teesside B; and
- Triton Knoll.

The modelling for each wind farm project has taken into account both the planned and consented project envelopes where possible, and takes into consideration the different hammer energies and pile installation durations. The assumptions that have been used in the modelling are largely based on information provided by the wind farm developers, as well as information available in existing Environmental Statements.

Predicted received sound levels from the noise modelling have been compared to the most up-to-date and internationally recognised impact thresholds for harbour porpoise. Received sound levels have been compared to the thresholds for Permanent Threshold Shift (PTS) and Temporary Threshold Shift (TTS) recently proposed by the National Oceanic and Atmospheric Administration (NOAA) (NMFS, 2016). For comparison, the predicted sound levels are also compared to the older PTS and TTS thresholds proposed by Southall *et al.* (2007).

Potential behavioural disturbance/displacement of harbour porpoise from pile-driving has been estimated by firstly comparing the predicted single pulse SEL to the disturbance threshold of 145 dB re 1 µPa^{2}s proposed by Lucke *et al*. (2009) and Thompson *et al.* (2013b). In addition to this behavioural disturbance threshold, the probability of disturbance for different received SEL bands has been evaluated using a dose-response approach.

The sound propagation modelling results have also been compared to the Popper *et al*. (2014) thresholds for potential injury to different fish species.

It is noted that, in line with the Joint Nature Conservation Committee (JNCC) guidance (JNCC, 2010), the criteria adopted for this assessment take into account the latest scientific evidence, and may result in different estimated impact ranges when compared to previous developments. The noise propagation modelling results will be used to inform the Habitats Regulation Assessment carried out for the SNS SCI.

The remainder of this report is organised as follows:

- Section 2.0 provides a brief introduction to underwater acoustic concepts, metrics and terminology used throughout this report;
- The assessment criteria that have been used to predict potential impacts to harbour porpoise and fish species are presented in Section 3.0;
- The underwater noise modelling methodology that has been adopted is described in Section 4.0;
- Section 5.0 to Section 14.0 present the main noise modelling results for the different wind farm projects that have been considered;
- A brief discussion of the modelling results is provided in Section 15.0;
- Noise modelling maps and figures are provided in the appendices of this report.

2.0 ACOUSTIC PRINCIPLES AND METRICS

This section briefly introduces some basic principles, terminology and metrics used in underwater acoustics, which will be relevant to the understanding of model based estimation of potential impacts to marine fauna. The purpose here is not to provide a thorough and comprehensive treatment of the complex topic of underwater acoustics, but simply to offer a brief overview of some of the main principles that will assist the reader in understanding the adopted methodology and presented results. There are numerous texts on underwater acoustics (e.g. Jensen *et al.*, 2011; Lurton, 2010; Urick, 1983; Kinsler *et al*., 1982) where a more complete introduction to the subject may be found.

2.1 Introduction

Sound is a disturbance in pressure that propagates through a compressible medium (solid or fluid) and propagates via the action of elastic stresses involving local compression and expansion of the medium (Robinson *et. al.,* 2014). Sound pressure, which is defined as the difference between instantaneous total pressure and the ambient pressure, is the most common quantity used to describe sound waves. The unit of sound pressure is the pascal (Pa), which is equivalent to a newton per square metre (N/m^2).

Before introducing different metrics to describe sound, a distinction is made between two different types of sound: impulsive sound and non-impulsive sound (Southall *et al.,* 2007; NMFS, 2016). The distinction between these two different sound types is important in determining the most appropriate sound metric to describe the sound, as well as the most suitable threshold for assessing potential impacts.

Impulsive sounds are typically transient, brief (less than 1 second), broadband, and consist of high zero-to-peak sound pressure with rapid rise time and rapid decay (NMFS, 2016; ANSI, 1986). Examples of impulsive sound includes pulses generated by during pile-driving operations, noise generated by airgun arrays, and noise from explosives.

Non-impulsive sounds can be broadband, narrowband or tonal, brief or prolonged, continuous or intermittent) and typically do not have a high zero-to-peak sound pressure with rapid rise/decay time that impulsive sounds do (NMFS, 2016; ANSI 1995). Examples of non-impulsive sound includes operational noise from wind farms, noise from vessels, dredging operations, and drilling operations.

It is important to note that the characteristics of sound at the receiver, rather than at the source, is the relevant consideration for determining potential impacts (NMFS, 2016). For example, the effect of sound propagation can cause a time dilation of individual pulses from an impulsive sound source such that the adjacent pulses merge in time, with the resulting waveform becoming more non-impulsive in nature. Thus, whilst sound from an impulsive source will be impulsive near the source, it will become non-impulsive at long ranges from the source.

2.2 Sound Level Metrics

Due to the different nature of sound sources and signals used in underwater acoustics, a number of different metrics are used to describe sound. The most commonly used metrics used to describe sound are introduced in this section.

2.2.1 Root-Mean-Square Sound Pressure

The root-mean-square (rms) sound pressure is defined as the square root of the mean square sound pressure, where the mean square sound pressure is equal to the time integral of the squared sound pressure over a defined time interval divided by the duration of the time interval (Robinson *et. al.,* 2014). The rms sound pressure, p_{rms}, has SI units of Pascals (Pa) (BIPM, 2006) and can be expressed mathematically as

$$p_{rms} = \sqrt{\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} p^2(t)\,dt} \quad , \tag{1}$$

where t_1 and t_2 are the start and end times, respectively, of the time interval that the rms sound pressure is computed over. The duration of the time interval for which the rms sound pressure is calculated is very important and it is necessary to state the time interval used when quoting rms sound pressure values. This is due to the fact that, for a given sound pressure signal, a change in the time interval can lead to an (often substantial) change in the resulting rms sound pressure. This is particularly true for impulsive/transient signals. For impulsive/transient signals, the time interval is typically selected to encompass the central portion of the pulse that contains 90% of the pulse energy (see e.g. Robinson *et. al.,* 2014). The rms sound pressure is shown graphically for an example waveform in Figure 2-1 (which also highlights some other metrics that will be described later).

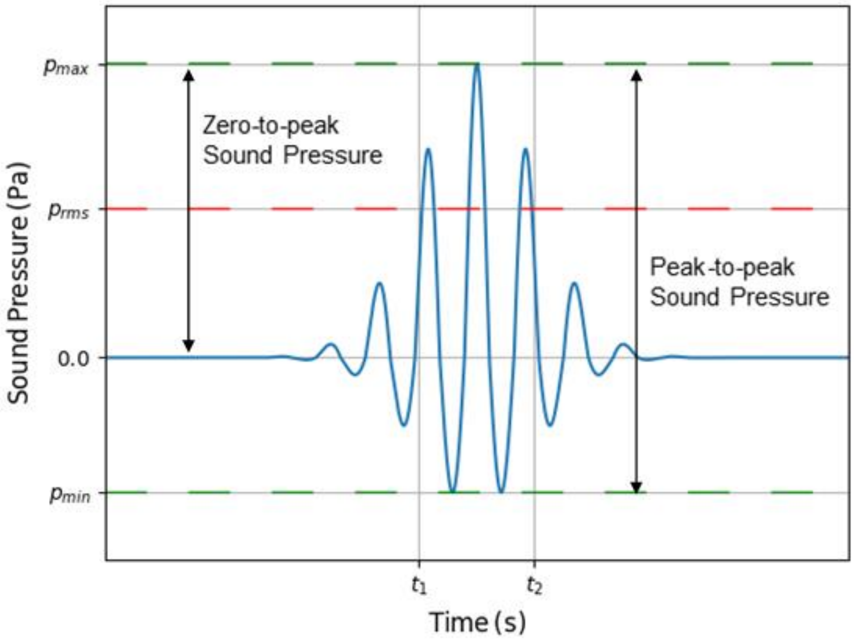


Figure 2-1: Zero-to-peak, peak-to-peak and rms sound pressures for an example sound signal.

2.2.2 Sound Pressure Level

A closely related quantity to the rms sound pressure is the Sound Pressure Level (SPL), which is defined as 20 time the base ten logarithm of the ratio of rms sound pressure to a reference sound pressure of one micropascal (μPa). The SPL can be stated mathematically as

$$SPL = 20log\left[\frac{p_{rms}}{p_0}\right] , \qquad (2)$$

where p_{rms} is the rms sound pressure given by equation (1), and p_0 is the reference sound pressure of 1 μPa. The SPL has units of decibels relative to one micropascal (dB re 1 μPa). By definition, the SPL is based on rms sound pressure. For this reason, and to avoid confusion or ambiguity, the SPL is commonly referred to more explicitly as the rms SPL (Southall *et al.,* 2007). The rms sound pressure and corresponding SPL are often the most useful quantities for describing non-impulsive or continuous sounds (Robinson *et. al.,* 2014).

2.2.3 Zero-to-peak Sound Pressure

The zero-to-peak sound pressure, which is also often referred to as the peak pressure (Southall *et al.,* 2007; NMFS, 2016), is the maximum magnitude (absolute value) of sound pressure during a stated time interval (Robinson *et. al.,* 2014). The zero-to-peak sound pressure, p_{pk}, has SI units of Pa (BIPM, 2006), and is mathematically given by

$$p_{pk} = max\{|p(t)|\} , \qquad (3)$$

where $p(t)$ is the sound pressure signal, $max\{.\}$ is the maximum of a series of values, and $|.|$ signifies the magnitude/absolute value. The zero-to-peak sound pressure is always stated as a positive value, but it is important to note that it can result from either a positive pressure or a negative pressure i.e. the zero-to-peak sound pressure is either equal to the largest positive pressure (which is shown by p_{max} in Figure 2-1), or the magnitude/absolute value of the largest negative pressure (the largest negative pressure being shown by p_{min} in Figure 2-1). The zero-to-peak sound pressure over a given time interval is always greater or equal to the rms sound pressure over the same interval.

2.2.4 Zero-to-peak Sound Pressure Level

The zero-to-peak SPLis equal to twenty times the base ten logarithm of the ratio of zero-to-peak sound pressure to a reference pressure of one micropascal (μPa). Mathematically, the zero-to-peak SPL, L_{pk}, is given by (see e.g. Robinson *et. al.,* 2014; Southall *et al.,* 2007; NMFS, 2016)

$$L_{pk} = 20log_{10}\left[\frac{p_{pk}}{p_0}\right] , \qquad (4)$$

where p_{pk} is the zero-to-peak sound pressure given by equation (3), and p_0 is the reference sound pressure of 1 μPa. The zero-to-peak SPL has units of dB re 1 μPa. The zero-to-peak sound pressure and zero-to-peak SPL are quantities that are typically most useful for describing impulsive sounds, but may also be used for describing non-impulsive sounds.

2.2.5 Peak-to-peak Sound Pressure

The peak-to-peak sound pressure is equal to the difference between the maximum sound pressure and the minimum sound pressure. The peak-to-peak sound pressure, p_{pk-pk}, has SI units of Pa (BIPM, 2006), and is mathematically given by

$$p_{pk-pk} = p_{max} - p_{min} \,, \tag{5}$$

where p_{max} and p_{min} are the maximum and minimum sound pressures, respectively. The peak-to-peak sound pressure is by definition positive valued and is always greater or equal to the zero-to-peak sound pressure. The zero-to-peak sound pressure is also shown graphically for the example waveform in Figure 2-1. By definition, the peak-to-peak sound pressure over a given time interval is always greater or equal to the zero-to-peak sound pressure (and consequently it is also greater or equal to the rms sound pressure) over the same interval.

2.2.6 Peak-to-peak Sound Pressure Level

The peak-to-peak SPL is equal to twenty times the base ten logarithm of the ratio of peak-to-peak sound pressure to the reference sound pressure of one micropascal. Mathematically, the peak-to-peak SPL, L_{pk-pk}, is given by (see e.g. Robinson *et. al.,* 2014)

$$L_{pk-pk} = 20log_{10}\left[\frac{p_{pk-pk}}{p_0}\right] \,, \tag{6}$$

where p_{pk-pk} is the peak-to-peak sound pressure given by equation (5), p_0 is the reference sound pressure of 1 μPa, and L_{pk-pk} has units of dB re 1 μPa. The peak-to-peak sound pressure and corresponding peak-to-peak SPL are quantities that are typically used for describing impulsive sounds, but may also be used for quantifying non-impulsive sounds.

2.2.7 Sound Exposure

The sound exposure is defined as the squared pressure integrated over a stated time interval (Robinson et. al., 2014). The sound exposure, E, has SI units of Pascal square seconds (Pa²s) (BIPM, 2006), and can be expressed mathematically as

$$E = \int_{t_1}^{t_2} p^2(t)\, dt \;\;, \tag{7}$$

where t_1 and t_2 are the start and end times, respectively, of the time interval that the sound exposure is calculated. The sound exposure is useful as a measure of the exposure of a marine receptor to sound, and is often used as a proxy for the sound energy (Robinson et. al., 2014). Similar to the rms sound pressure, the duration of the time interval for which the sound exposure is calculated is very important and it is necessary to state the time interval used when quoting sound exposure values. When sound exposure is used to describe a single acoustic pulse (i.e the single pulse sound exposure), the time interval is typically selected to contain the central portion of the pulse that contains 90% of the pulse energy (Robinson et. al., 2014).

2.2.8 Sound Exposure Level

The Sound Exposure Level (SEL) is equal to 10 times the base 10 logarithm of the ratio of sound exposure to a reference sound exposure of one micropascal square second (1 μPa²s). The SEL is mathematically given by

$$SEL = 10log_{10}\left[\frac{E}{E_0}\right] \ , \qquad (8)$$

where E is the sound exposure given by equation (7), and E_0 is the reference sound exposure of 1 μPa²s. The SEL has units of decibels relative to one micropascal square second (dB re 1 μPa²s) The sound exposure and corresponding SEL are useful for describing exposure to both impulsive and non-impulsive sounds.

2.2.9 Cumulative Sound Exposure

Sound exposure can be aggregated by summation over multiple acoustic events (e.g. over multiple pulses). In this case, it is referred to as the cumulative sound exposure (also known as the total sound exposure or sound exposure dose). The cumulative sound exposure, $E_{cum.}$, has units of Pa²s and is given by

$$E_{cum.} = \sum_{i=1}^{N} E_i \ , \qquad (9)$$

where E_i is the sound exposure of the i^{th} acoustic event (e.g. the i^{th} pulse) and N is the total number of acoustic events that the cumulative sound exposure is calculated over.

2.2.10 Cumulative Sound Exposure Level

The cumulative SEL is equal to ten times the base 10 logarithm of the ratio of cumulative sound exposure to the reference sound exposure of1 μPa²s. The cumulative SEL is mathematically given by

$$SEL_{cum.} = 10log_{10}\left[\frac{E_{cum.}}{E_0}\right] \ , \qquad (10)$$

where $E_{cum.}$ is the cumulative sound exposure given by equation (9), and E_0 is the reference sound exposure of 1 μPa²s. The cumulative SEL has units of dB re 1 μPa²s. The cumulative SEL is a commonly used metric for assessing potential impacts to marine mammals and fish, and is typically computed over the entire duration of the noise generating activity under consideration or over a 24-hour period for assessing the potential for injury (Southall *et al.*, 2007; NMFS, 2016).

2.3 Other Acoustic Concepts

2.3.1 Source Level

Source level is a metric used frequently in underwater acoustics to describe the acoustic output of a sound source. The source level can be considered as a characteristic property of the sound source itself and is independent of the propagation loss between the source and any receiver location. In practice, source levels can be calculated by measuring the SPL in the acoustic far field of the source and back propagating the measured SPL to a reference distance of 1 m using an appropriate propagation model (Robinson et. al., 2014). The adopted propagation model should account for all physical phenomena that affect propagation loss (e.g. spreading, reflection, refraction, absorption, scattering etc.) such that the derived source level is independent of the propagation environment. When simpler propagation algorithms (that do not account for all physical phenomena that influence propagation loss) are used for back propagation, the resulting source level is often termed an effective source level.

By definition, the source level is based on a back calculated SPL value and is expressed in units of decibels relative to one micropascal referred to one metre (dB re 1 µPa-m). However, depending on the type of sound source under consideration, it is often convenient to define source levels based on sound metrics other than SPL, in which case they are given modified names. When a zero-to-peak SPL is used, the resulting source level is referred to as a zero-to-peak SPL source level, which also has units of dB re 1 µPa-m. When an SEL is used, the resulting source level is referred to as an SEL source level, which has units of decibels relative to one micropascal squared referred to one metre (dB re 1 μPa^2s-m).

It is important to appreciate that the source level is an idealised acoustic far field parameter and only provides information of sound levels in the far field (it provides no information about the acoustic near field). When used as input to a propagation model, it is important to realise that the estimated received levels are only valid for the acoustic far field and do not provide an accurate description of received levels in the near field.

2.3.2 Propagation Loss

Propagation loss, which is also commonly referred to as transmission loss, is a description of the reduction in sound as it propagates away from the source. The propagation loss is dependent on all physical phenomena that influence sound propagation (such as spreading, reflection, refraction, absorption, scattering etc.). The physical phenomena that govern sound propagation are dependent on numerous environmental factors such as water depth, the speed of sound in the water column, bathymetry, and the geo-acoustic properties of the seabed. Since propagation loss is highly dependent on such environmental factors, it is desirable that the adopted noise used to predict propagation loss includes site-specific information of the environment, and incorporates all physical phenomena that affect sound propagation.

2.3.3 Frequency Bands

Sounds that are composed of a single frequency are called tonal sounds. However, most sounds are composed of a broad range of frequencies and are referred to as broadband sound. The frequency content of a sound signal can be represented by an energy spectrum, which shows the distribution of energy with frequency. Energy spectrums are typically computed with fine frequency resolution to describe the fine scale features of the signal.

For sound propagation modelling, it is important to take into account the different frequencies that compose the sound signal since different frequencies will exhibit different propagation characteristics. However, modelling broadband sound propagation over a wide range of frequencies can become prohibitively computationally expensive if the frequency resolution is too fine (since it involves the computation of propagation loss for a large number of individual frequencies). A coarser representation of the energy spectrum is a more efficient means to sound propagation modelling of broadband sound sources. Many acoustic metrics are calculated over various frequency bands. The most common frequency band analysis scheme used for this purpose is the third octave band system, which divides the energy spectrum into adjacent passbands that are approximately one-third of an octave wide. Given an energy spectrum $E(f)$, the third octave band levels can be computed from

$$E_i = \int_{f_{l,i}}^{f_{h,i}} E(f)\,df\ ,$$

where E_i is the energy in the i^{th} third octave band, and $f_{l,i}$ and $f_{h,i}$ are the lower and upper frequencies for the i^{th} third octave band. Standard third octave band lower, upper, and centre frequencies can be computed from

$$f_{c,i} = 10^{i/10}\ ,$$

$$f_{l,i} = 10^{-1/20}\, f_{c,i}\ ,$$

$$f_{h,i} = 10^{1/20}\, f_{c,i}\ ,$$

where $f_{c,i}$ is the centre frequency of the i^{th} third octave band. Modelling of sound propagation in third octave bands is an efficient computational procedure since it allows for a broadband sound source to be modelled without considering the entire frequency spectrum at discrete fine resolution frequency intervals.

3.0 IMPACT OF NOISE ON HARBOUR PORPOISE

This section discusses the impact assessment methodology that has been adopted in this report. In particular, this section presents the impact criteria that have been used to estimate potential impacts to harbour porpoise.

3.1 Background

The assessment method used here is largely based on the JNCC guidance on the protection of marine EPS from injury and disturbance (JNCC, 2010). The Offshore Marine Conservation Regulations 2007 (as amended, 2010) have a revised definition of 'disturbance' to European Protected Species (EPS). The Offshore Marine Conservation Regulations extended the offence to areas of UK jurisdiction beyond 12 nautical miles. It is now an offence under UK Regulations:

a) *to deliberately capture, injure, or kill any wild animal of a European protected species;* (termed 'the injury offence'),
b) *to deliberately disturb wild animals of any such species* (termed 'the disturbance offence').

Here, injury is defined as a permanent shift in the hearing of an EPS, and disturbance of animals includes any event that is likely:

a) *to impair their ability to survive, breed or reproduce, or to rear or nurture their young, or (in the case of animals hibernating or migratory species), to hibernate or migrate;*
b) *to affect significantly the local distribution or abundance of the species to which they belong.*

It has become increasingly evident that noise from human activities can have the potential to impact on marine species (e.g. OSPAR, 2009; Thomsen *et al.,* 2006; Richardson, *et al*., 1995; Southall *et al*., 2007; NMFS, 2016; Popper *et al.,* 2014). Sound is important for marine mammals for navigation, communication and prey detection, and the introduction of anthropogenic sound therefore has the potential to impact on marine mammals. Sound may also interfere with acoustic communication, predator avoidance, prey detection, reproduction and navigation in fish (e.g. Slabbekoorn *et al*., 2010).

The extent to which intense underwater sound might cause an adverse environmental impact in a particular species is dependent on numerous factors. JNCC recommends considering the following factors when assessing the impact of sound exposure:

a) Duration and frequency of the activity;
b) Intensity and frequency of sound and extent of the area where the disturbance and injury thresholds may be exceeded, taking into consideration species-specific sensitivities;
c) The interaction with other concurrent, preceding or subsequent activities in the area;
d) The most up to date thresholds for injury and behavioural responses; and
e) Whether the local abundance or distribution could significantly be affected.

The current assessment has used these guidelines and considered the factors mentioned above to assess the potential impacts of underwater sound.

3.2 Assessment Criteria

To determine if there could be potential consequences of received sound levels on marine fauna it is necessary to compare estimated received levels to impact thresholds. Various thresholds for different marine mammal have been proposed by numerous authors and scientific studies. The thresholds that have been adopted in this assessment for estimating potential impacts to harbour porpoise and fish species are based on a comprehensive review of scientific evidence and peer reviewed publications, and are discussed in the following.

3.2.1 Harbour Porpoise

3.2.1.1 Thresholds for PTS and TTS

Numerous studies have been conducted to estimate the sound levels that can potentially cause injury to marine mammals. The most commonly used approach in estimating potential impacts to marine mammals is by comparing received sound levels to the thresholds proposed by Southall *et al.* (2007) for the onset of PTS and TTS. Since its publication, comparison of received sound levels with the Southall thresholds has become common practice for impact estimation, and these thresholds have been endorsed by the JNCC guidelines (JNCC, 2010).

Southall *et al.* (2007) grouped marine mammals into four main functional hearing groups: low-frequency (LF) cetaceans, mid-frequency (MF) cetaceans, high-frequency (HF) cetaceans, and Phocid Pinnipeds. Different thresholds for the potential onset of PTS and TTS for these functional hearing groups were then proposed by Southall *et al.* (2007) based on the best available evidence at the time.

Since the publication of the Southall thresholds, further studies have investigated the sound levels that can potentially induce the onset of PTS and TTS in marine mammals. Lucke *et al.* (2009) suggested that the onset of PTS in harbour porpoise may occur at lower sound levels than other cetacean groups, and subsequently suggested that the thresholds for PTS and TTS in Southall *et al*. (2007) should be lowered for HF cetaceans. This work has been further supported by other more recent studies (e.g. Kastelein *et al*., 2012; Tougaard *et al*., 2014). Based on these and other more recent studies, new PTS and TTS thresholds for marine mammals have been adopted by the National Oceanic and Atmospheric Administration (NOAA) (NMFS, 2016). Similar to Southall *et al.* (2007), NOAA proposed different thresholds for marine mammals being categorised as LF cetaceans, MF cetaceans, HF cetaceans, and Phocid Pinnipeds.

Different thresholds were proposed by Southall *et al*. (2007) and NOAA (NMFS, 2016) for sound sources categorised as single pulse (i.e. impulsive sound sources), multiple pulse (i.e. impulsive sound sources emitting multiple waveforms), and non-pulse (i.e. non-impulsive or continuous sound sources). This assessment focuses on the estimation of impacts from pile-driving, which is classified as an impulsive sound source, and therefore only the impulsive thresholds suggested by Southall *et al*. (2007) and NOAA are considered.

The Southall *et al*. (2007) and NOAA (NMFS, 2016) thresholds that have been adopted in this assessment are summarised in Table 3-1. In terms of marine mammals, this assessment only considers potential impacts to harbour porpoise (which are classed as HF cetaceans), and therefore only the Southall and NOAA HF cetacean thresholds are considered.

Table 3-1: Southall *et al*. (2007) and NOAA (NMFS, 2016) thresholds for the potential onset of PTS and TTS in harbour porpoise.

Marine Mammal Species	Sound Metric	Threshold for potential PTS onset		Threshold for potential TTS onset	
		Southall	NOAA	Southall	NOAA
Harbour Porpoise	Unweighted zero-to peak SPL (dB re 1 µPa)	230	202	224	196
	Cumulative weighted SEL (dB re 1 µPa^{2}s)	198	155	183	140

The Southall and NOAA thresholds are dual-metric thresholds where potential impacts are assessed by comparing received levels to thresholds given in terms of both unweighted zero-to-peak SPL and cumulative weighted SEL. As dual-metric criteria, the onset of PTS or TTS is considered to have occurred when either one of the two metric thresholds are exceeded (JNCC, 2010; Southall *et al*., 2007; NMFS, 2016).

The unweighted zero-to-peak SPL thresholds are used to assess the potential for injury to occur in marine mammals due to instantaneous fluctuations in pressure and do not specifically take into consideration the hearing range of any marine mammals. In contrast, the cumulative weighted SEL metric takes into account the hearing capability of the species under consideration by weighting received SEL sound levels using generalised auditory weighting filters that have been derived for different species. Different weighting functions have been proposed by Southall *et al*. (2007) and NOAA (NMFS, 2016), and are shown in Figure 3-1.

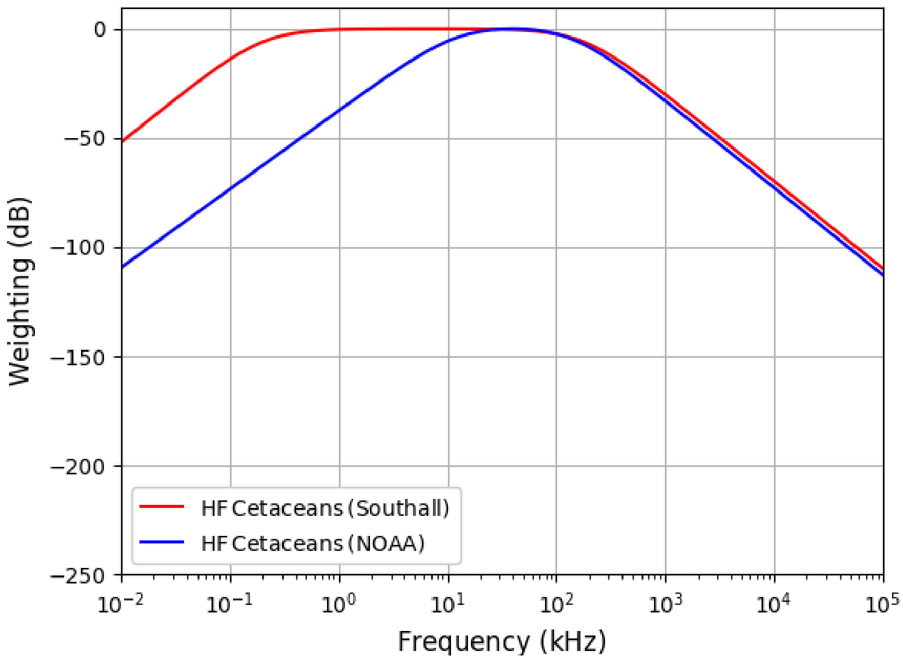


Figure 3-1: Auditory weighting functions for HF cetaceans (Southall *et al.*, 2007; NMFS, 2016).

There are two major differences between the Southall *et al*. (2007) and NOAA (NMFS, 2016) criteria for assessing potential impacts to harbour porpoise: the thresholds and the auditory weighting functions. The zero-to-peak SPL thresholds adopted by NOAA are substantially lower than those suggested by Southall (the NOAA thresholds are approximately a factor of 25 times lower than the corresponding Southall thresholds in terms of zero-to-peak pressure), and therefore will result in larger estimated impacts. Another major difference is that the NOAA auditory weighting filters are narrower than the corresponding Southall weighting filters and therefore will filter out more of the received signal (particularly at lower frequencies), resulting in lower estimated received SEL sound levels. For a given SEL threshold, this would mean that application of the NOAA auditory weighting filters would result in smaller impacts compared to the case that the Southall auditory weighting filters were used. However, it should be noted that the NOAA SEL threshold is also significantly smaller than the corresponding Southall SEL threshold (in fact the NOAA SEL threshold is approximately a factor of 20,000 times lower than the corresponding Southall threshold in terms of sound exposure).

3.2.1.2 Behavioural Disturbance

Another important consideration in assessing potential impacts of sound on marine mammals is the mammals' behavioural response. Behavioural disturbance can range greatly from minor disturbance, such as short term avoidance or changes in swimming behaviour and vocalisation, to higher levels of disturbance such as long term avoidance of an area or reduced breeding activity. It was concluded in Southall *et al.* (2007) that thresholds for behavioural disturbance were more difficult to conclusively define since, in general, behavioural responses to sound are highly variable and context-specific. Thus, it is difficult to justify proposing single disturbance criteria for broad categories of taxa and sounds. It is noted that even the recent guidance by NOAA (NMFS, 2016), which is based on the most up to date evidence, does not provide guidance for assessing behavioural responses/disturbance to marine mammals.

Despite the difficulty in proposing behavioural disturbance thresholds, there is still evidence for appropriate thresholds to use for predicting behavioural disturbance to harbour porpoise. An SEL behavioural disturbance threshold of 145 dB re 1 µPa^{2}s has become a commonly used threshold for disturbance to harbour porpoise. This was proposed by Lucke *et al*. (2009) as an appropriate threshold for behavioural disturbance to harbour porpoise based on observations made of a captive harbour porpoise subjected to airgun array stimuli. This threshold has been further corroborated by evidence of displacement to harbour porpoise from airgun array noise at this SEL during seismic activity in the Moray Firth (Thompson *et al.,* 2013b). An SEL threshold of 145 dB re 1 µPa^{2}s has been adopted in this assessment as a measure of the area where potential behavioural disturbance may occur in harbour porpoise.

A drawback of using a single threshold for estimating behavioural disturbance effects is that a single threshold cannot capture the range of possible behavioural disturbance effects that can occur at given sound levels e.g. some individuals may exhibit displacement or other behavioural effects at a given received sound level, whilst other individuals of the same species may not exhibit the same response. An alternative approach to utilising a single behavioural disturbance threshold is to define the probability of behavioural disturbance (e.g. displacement) for different received sound levels (Brandt *et al.,* 2016; Thompson *et al.,* 2013a).

As well as using the single behavioural disturbance SEL threshold of 145 dB re 1 µPa²s proposed by Lucke *et al*. (2009) and Thompson *et al.* (2013b) for disturbance to harbour porpoise, an alternative approach has also been utilised in this assessment, which makes an attempt to better define the probability of displacement at different received SEL sound levels. This approach uses a dose response curve that has been established using observations of harbour porpoise displacement from pile-driving during the construction of eight offshore wind farms within the German North Sea between 2009 and 2013 (Brandt *et al.,* 2016). Brandt *et al.* (2016) monitored harbour porpoise densities during pile-driving activities using passive acoustic monitoring and aerial surveillance. In addition to the harbour porpoise monitoring data, underwater noise measurements attributable to the pile-driving activities were made. The harbour porpoise monitoring data and underwater sound measurements were compared to baseline analyses in order to quantify the percentage of harbour porpoise disturbed during the pile-driving activity.

Table 3-2 shows the estimated harbour porpoise population percentages disturbed for different received SEL derived in Brandt *et al.* (2016). It is noted that there were two data points in Brandt *et al.* (2016) that were deemed to be "not significant" by the authors, and these data points have therefore been excluded here.

Table 3-2: Estimated percentage of harbour porpoise population disturbed during pile-driving events in the German North Sea (Brandt *et al.,* 2016).

SEL (dB re 1 µPa²s)	Percentage of population disturbed
> 170	93 %
160 – 170	78 %
150 – 160	48 %
145 – 150	25 %
140 – 145	14 %
130 – 140	14 %
120 – 130	8 %

To estimate the potential behavioural disturbance to harbour porpoise for different SEL sound levels, a similar approach to that used by Thompson *et al.* (2013a) has been adopted, whereby a sigmoidal function has been fitted to the data points shown in Table 3-2 to obtain a behavioural response curve (a.k.a. a dose response curve). The sigmoidal function has been fitted to the data points using a least squares minimisation algorithm initialised with the solution from a logistic regression model. It is noted that the data in Brandt *et al.* (2016) shown in Table 3-2 is provided using a range of SEL values i.e. the percentage of population disturbed is specified using banded SEL values. In deriving a behavioural response curve using the data provided by Brandt *et al.* (2016), the average of the SEL bands were used (i.e. the sigmoidal curve was fitted to the mid-value/average of the upper and lower bounds of the SEL bands shown in Table 3-2. The derived behavioural response curve is shown in Figure 3-2.

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The derived behavioural response curve has been used in this assessment to estimate the probability of displacement to harbour porpoise due to different received unweighted SEL sound levels. To this end, the probability of displacement has been estimated for different SEL bands (expressed in 5 dB intervals). The probability of displacement for different SEL sound bands that have been used in this assessment are shown in Table 3-3. It is noted that the behavioural response has been curtailed to SEL levels above 145 dB re 1 µPa²s in line with the threshold proposed by Lucke *et al.* (2009) and Thompson *et al.* (2013b). It should also be noted that there could potentially be some degree of behavioural disturbance below SEL levels of 145 dB re 1 µPa²s (Brandt *et al.*, 2016) but the level of behavioural disturbance at such levels is unlikely to be significant.

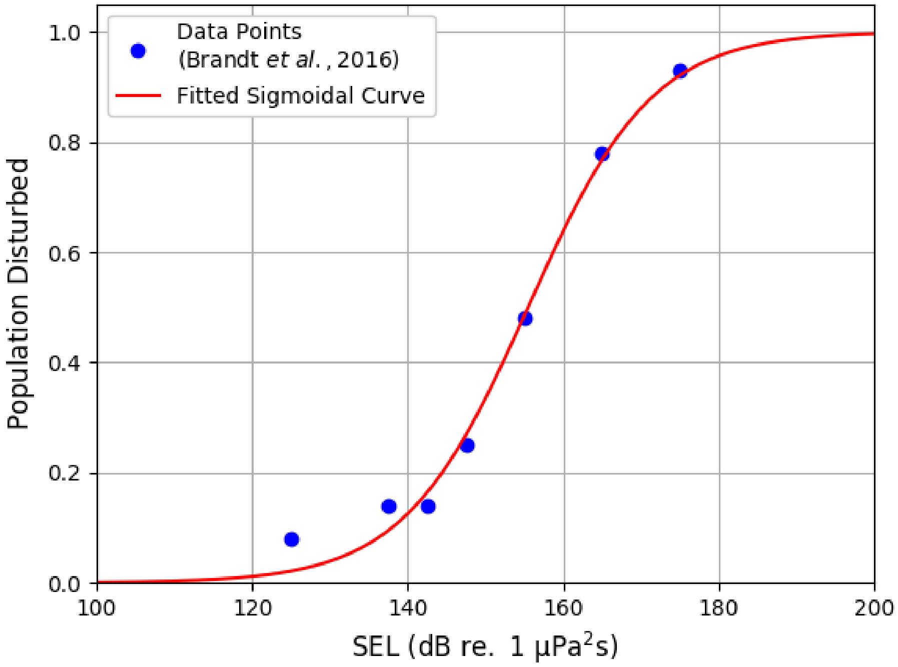

Figure 3-2: Behavioural dose response curve used for assessing potential behavioural disturbance to harbour porpoise.

Table 3-3: Probability of disturbance from different SEL bands derived from dose response curve based on data from Brandt *et al.* (2016).

SEL (dB re 1 µPa²s)	Probability of disturbance
> 210	99.9%
205 - 210	99.9%
200 - 205	99.7%
195 - 200	99.5%
190 - 195	99.0%
185 - 190	98.2%
180 - 185	96.7%
175 - 180	94.1%
170 - 175	89.4%
165 - 170	81.9%
160 - 165	70.7%
155 - 160	56.3%
150 - 155	40.7%
145 - 150	26.8%

3.2.2 Fish

Fish species differ in their hearing capabilities depending on the presence of a swim bladder, which acts as a pressure receiver, and whether the swim bladder is connected to the otolith hearing system, which further increases hearing sensitivity (McCauley, 1994). Most fish can hear within the range of 100 Hz to 1 kHz. Fish with a connection between the swim bladder and otolith system have more sensitive hearing and may detect frequencies up to 3 kHz. The potential impact and behavioural response of fish in the area to noise from pile-driving will depend on their hearing capabilities.

3.2.2.1 Fish Injury Thresholds

Popper *et al*. (2014) have defined criteria for injury to fish based on a review of publications related to impacts to fish, fish eggs, and larvae from various high-energy sources. As discussed previously, the hearing capability of fish largely depends on the presence or absence of a swim bladder, which is taken into consideration in the thresholds derived by Popper *et al*. (2014). Different injury thresholds are derived in Popper *et al*. (2014) for:

- Fishes with no swim bladder or other gas chamber;
- Fishes with swim bladders in which hearing *does not* involve the swim bladder or other gas volume; and
- Fishes with swim bladders in which hearing *does* involve a swim bladder or other gas volume.

The thresholds for mortality and potential mortal injury proposed in Popper *et al*. (2014) that have been used in this assessment are shown in Table 3-4.

Table 3-4: Popper *et al.* (2014) thresholds for fish mortality and injury.

Fish Group	Sound Metric	Threshold for potential mortal injury	Threshold for recoverable injury
Fishes with no swim bladder	Unweighted zero-to-peak SPL (dB re 1 µPa)	213	213
	Unweighted cumulative SEL (dB re 1 µPa^{2}s)	219	216
Fishes with swim bladder not involved in hearing	Unweighted zero-to-peak SPL (dB re 1 µPa)	207	207
	Unweighted cumulative SEL (dB re 1 µPa^{2}s)	210	203
Fishes with swim bladder involved in hearing	Unweighted zero-to-peak SPL (dB re 1 µPa)	207	207
	Unweighted cumulative SEL (dB re 1 µPa^{2}s)	207	203

3.2.2.2 Fish Disturbance

There are no established criteria or thresholds for assessing behavioural disturbance to fish. In fact, it was concluded in Popper *et al*. (2014) that there lacked sufficient evidence to recommend thresholds that correspond to behavioural disturbance for fish. Given this lack of evidence, behavioural disturbance to fish will not be considered further in this assessment, and only fish injury and mortality impacts will be assessed. However, it is noted that fish are mobile animals that would be expected to be able to move away from a sound source that had the potential to cause disturbance. If fish are disturbed by sound, evidence suggests they will return to an area once the activity has ceased (Slabbekoorn *et al*., 2010).

4.0 MODELLING METHODOLOGY

This section discusses the modelling methodology that has been adopted for assessing potential impacts from pile-driving operations in the SNS.

4.1 Source Characterisation

A pile under percussive driving is a very complex underwater acoustic source. The source level depends on many factors, such as hammer energy, mechanical properties and dimensions of the pile, water depth, and sea bed properties. It is possible to predict the source level if all the relevant information is available (Lippert *et al.,* 2014; Lippert *et al.,* 2016; Reinhall *et al.,* 2011; Zampolli *et al.,*2013). However, such approaches are necessarily complex and are not commonly adopted for the estimation of environmental impacts.

To derive source levels for use in the adopted propagation model, a representative frequency spectrum measured during pile-driving was taken from Ainslie *et al*. (2012), which is shown in Figure 4-1. The third octave band SEL frequency spectrum shown in Figure 4-1 was derived from measurements of pile-driving with an 800 kJ hammer (Ainslie *et al*., 2012). To account for noise generated during pile-driving with different hammer energies (e.g. due to different hammer sizes being used at different wind farm projects, and increasing hammer energy during pile-driving soft-start/ramp-up phases), it has been assumed that the source SEL scales linearly with hammer energy. Such a linear scaling of SEL source levels with hammer energy has been demonstrated by measurements made during pile-driving in Robinson *et al*. (2007 and 2009). In the linear scaling procedure adopted, it has been assumed that a doubling of hammer energy results in a doubling of SEL (i.e. a 3 dB increase in SEL).

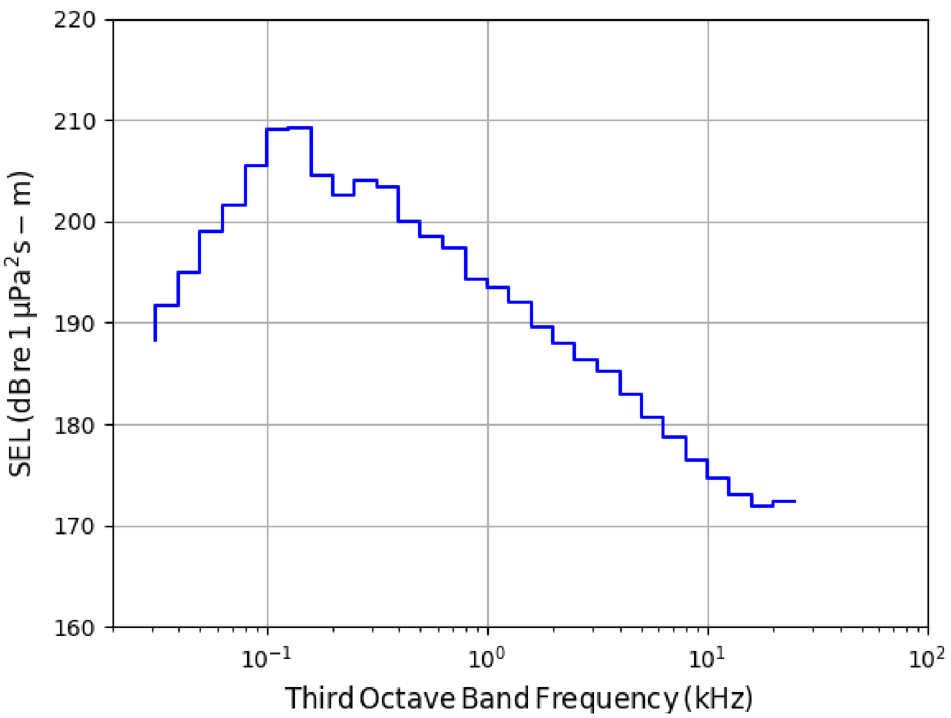

Figure 4-1: Third octave band spectral shape used in the modelling (Ainslie *et al*., 2012).

Using the shape of the spectrum shown in Figure 4-1, SEL and zero-to-peak SPL source levels have been derived by calibrating the output of the propagation model with measurements made at the Greater Gabbard wind farm (see Appendix A for further details of the calibration procedure).

Table 4-1 summarises the resulting broadband SEL and zero-to-peak SPL source levels used in this assessment for modelling noise generated during pile-driving with a number of different hammer energies. It is noted here that the spectral shape shown in Figure 4-1 has been used for all derived source levels i.e. it has been assumed that the spectral shape does not change with a change in hammer energy.

Table 4-1: Broadband SEL and zero-to-peak SPL source levels used in the modelling for pile-driving with different hammer energies.

Hammer Energy (kJ)	SEL Source Level (dB re 1 µPa^{2}s-m)	Zero-to-peak SPL Source Level (dB re 1 µPa-m)
900	216.1	242.1
1,200	217.3	243.3
1,800	219.1	245.1
1,900	219.3	245.3
2,300	220.2	246.2
2,400	220.4	246.3
2,700	220.9	246.9
3,000	221.3	247.3
4,000	222.6	248.6
5,500	224.0	249.9

4.2 Underwater Propagation Model

4.2.1 Introduction

There are a number of different underwater sound propagation models available which, generally speaking, can be categorised into the following types of model (see e.g. Jensen *et al.*, 2011):

- Simple spreading/lumped parameter algorithms;
- Ray tracing models;
- Normal mode models;
- Parabolic equation model;
- Wavenumber integration models; and
- Semi-empirical models.

The selection of algorithm (or choice of algorithms) for any given scenario is dependent on numerous factors such as frequency and range, the complexity of the modelling scenario, availability of environmental information, and properties of the sound sources being modelled (e.g. frequency content, directivity etc.).

For this propagation modelling and impact assessment study, a parabolic equation model has been utilised in conjunction with a ray tracing algorithm. As will be discussed in the following, the combination of these algorithms allows for a broad range of frequencies to be modelled, which is important due to the fact that sound energy from pile-driving can cover a wide range of frequencies (although it should be noted that the majority of energy from pile-driving occurs at lower frequency bands). Furthermore, both these algorithms account for range-dependent effects such as varying bathymetry and water column properties.

4.2.2 Parabolic Equation Model

Parabolic Equation (PE) models approximate the wave equation, allowing a solution to be found computationally (Jensen *et al*., 2011). The method is based on the assumptions that outgoing sound energy dominates over backscattered energy and the speed of sound varies weakly with distance from the source (Collins, 1993). The PE model is one of the most popular wave-theory techniques for modelling sound propagation in spatially-varying environments (Jensen *et al*., 2011). The computational scheme used in this assessment is based on the Range-dependent Acoustic Model (RAM) implementation of the PE (Collins, 1993).

PE techniques are complex and require careful selection of environmental parameters (e.g. variation in bathymetry and sound speed profiles) and computational parameters (e.g. depth and range resolution) to ensure that the solution is accurate. The PE model incorporates varying environmental conditions with depth and range, including a range-dependent sound speed depth profile and geo-acoustic model. By explicitly modelling these factors affecting sound propagation, results can be obtained that are more relevant to the area of interest than would be obtained with other simpler models.

The PE algorithm is best suited to calculation of low frequency sound propagation since the computational complexity (and hence implementation time) of the PE method significantly increases with frequency. The PE model is therefore generally restricted to modelling the propagation characteristics of low frequency sound sources, since modelling of high frequencies becomes prohibitively time consuming. Given this restriction, the PE model has only been utilised in this assessment to calculate the propagation of third octave frequency bands up to and including 500 Hz. Frequencies above 500 Hz have been modelled using a ray tracing method known as Bellhop (Porter and Liu, 1994).

4.2.3 Ray Tracing Model

Ray tracing is a method that is well suited for the modelling of higher frequency sound sources (Jensen *et al*., 2011). The theory of ray tracing is derived from the wave equation when some simplifying high frequency approximations/assumptions are introduced. Such high frequency approximation essentially means that ray tracing algorithms are inherently good at treating high frequency sources. Despite being derived under a high frequency approximation, ray tracing algorithms can also provide accurate results for low frequency sound propagation in certain circumstances (Porter and Liu, 1994).

The ray tracing algorithm that has been used in this assessment is known as the Bellhop Gaussian beam ray tracing model (Porter and Liu, 1994). Similar to the RAM PE algorithm discussed previously, Bellhop also incorporates acoustic propagation effects resulting from range dependent sound speed depth profiles and geo-acoustic properties. However, in contrast to the RAM PE algorithm, Bellhop also accounts for increased sound attenuation due to volume absorption. This type of sound attenuation becomes more prominent at higher frequencies and cannot be neglected without over estimating received sound levels at large distances from the sound source. Whereas the RAM PE model has been used to propagate third octave band frequencies up to and including 500 Hz, Bellhop has been used in the modelling to propagate third octave band frequencies above 500 Hz.

4.2.4 Environmental Input Data

The implemented propagation algorithms account for various site-specific environmental properties including varying bathymetry, geographically and depth varying sound speed profiles through the water column, and geo-acoustic properties of the sediment. In order to model the effects of these environmental properties, site-specific input data are required that describes the surrounding environment.

4.2.4.1 Sound Speed Profiles

A major factor that influences the propagation of sound in water is changes in the speed of sound through the water column, which influences how an acoustic wave refracts. For example, a positive sound velocity gradient near the sea surface can form a surface duct, where sound energy can get trapped. A surface duct can therefore prohibit the sound from interacting with the ocean bottom (Jensen *et al.,* 2011) and therefore significantly reduces transmission loss and consequently increases propagation distances. In deeper waters, a similar effect can occur due to the so called “deep water sound channel” where the sound essentially propagates through a waveguide. Conversely, a negative sound speed gradient refracts acoustic waves toward the ocean bottom where higher levels of attenuation occur. In this case, transmission loss increases and consequently propagation distances decrease. Due to the multitude of effects that sound speed profiles induce, it is important that sound speed profiles are accounted for in any propagation model (Jensen *et al.,* 2011; Farcas *et al.*, 2016).

The model used in this study allows for geographically and depth varying sound speed profiles through the water column. Sound speed data is typically not available through any databases, but can be derived from measurements/modelling of temperature and salinity which are more readily available. Sound speed profiles for the model location were derived from temperature and salinity profiles taken from the World Ocean Atlas (WOA) from 2013 (WOA, 2013). WOA is an objectively analysed 1° resolution database where temperature and salinity data are given based on historical data. Since the sound speed profile is a function of temperature, pressure (which is a function of depth) and salinity, this database can be used to calculate the sound speed profile through the water column. The empirical formula in (Jensen *et al*., 2011) has been used to calculate sound speed profiles for different locations based on temperature, salinity and depth.

4.2.4.2 Bathymetry and Seabed Properties

Accurate bathymetry data is important for sound modelling since the seabed strongly influences the propagation characteristics of sound. In shallow water regions, there is significant interaction of the sound with the sea bed through reflections and scattering effects, and strong attenuation may occur as sound penetrates the seabed. In deep water regions, there is typically less interaction of sound with the seabed and attenuation due to bottom loss is small, which can result in longer propagation distances. Thus, sound propagation is strongly influenced by the seabed bathymetry and sediment properties, which should be properly accounted for (Farcas *et. al*, 2016).

The bathymetry data that has been used in the noise modelling is the EMODnet Digital Bathymetry (Marine Information Service, 2016). The EMODnet Digital Bathymetry is a multilayer bathymetric product that is based upon more than 7,700 bathymetric survey data sets and composite digital terrain models. The EMODnet bathymetry is provided on a 7.5 arc second grid, which corresponds to a resolution of approximately 230 m.

The implemented propagation model accounts for attenuation effects of sound due to interactions with the seabed. However, it is noted that the adopted propagation model is limited to modelling with a single seabed substrate i.e. the model does not include variations of sediment with depth or range. Since the modelling has been carried out over a large area where there will be variations in the seabed type, assumptions have had to be made on the seabed substrate. For the wind farm project locations modelling in this assessment, the predominant sediment type in the wind farm development areas is sand, and the modelling has therefore assumed a sandy seabed. The geo-acoustic properties of the seabed that have been used in the modelling are shown in Table 4-2 (Jensen *et al.*, 2011).

Table 4-2: Geo-acoustic parameters that have been used in the model.

Geo-acoustic parameter	Value
Sound speed in sediment	1650.0 m/s
Sound attenuation in sediment	0.8 dB/wavelength
Sediment density	1,900 kg/m^3

4.2.5 Estimation of Received Sound Levels and Impacts

4.2.5.1 Single Pulse SEL

Both the RAM PE and the Bellhop ray tracing algorithms calculate transmission loss as a function of depth and range from the sound source (which has been modelled as a monopole sound source in the mid water column). Transmission loss is calculated for each third octave band centre frequency along 72 radial lines that extend outwards from the pile-driving location, and are set at an equi-spaced angular resolution of 5°. For each radial line, the broadband received SEL can be obtained by subtracting the third octave band transmission loss from the third octave band source SEL and then (logarithmically) summing the received levels over all third octave frequency bands. A three dimensional sound field can then be obtained by interpolating the data points for all radial lines onto a regular three dimensional grid. The computed three dimensional SEL sound fields are presented in this report as 2D surface contours showing either

- the depth-averaged SEL; or
- the maximum-over-depth (worst case) SEL.

The depth-averaged SEL contours shown in this report are obtained by averaging the received single-pulse SEL at each location over the whole water column. It is noted that the depth-averaged SEL is computed by considering only received sound levels in the water column, and received sound levels below the sediment line are removed from the computation of the depth-average. This is due to the fact that the received SEL will be significantly lower below the sediment line than in the water column. Inclusion of received sound levels below the sediment line in the depth average would therefore lower the computed depth-averaged level, and the result would not be representative of the average received SEL in the water column.

The maximum-over-depth (worst case) SEL contours presented in this report show the maximum received single-pulse SEL at each location over all depths. The resulting maximum-over-depth contours demonstrate the maximum single-pulse SEL that any marine receptor may receive at any location.

4.2.5.2 Single Pulse Zero-to-peak SPL

The algorithms utilised for sound propagation have been implemented to predict received sound levels in terms of SEL, and cannot straight forwardly be used to predict zero-to-peak SPL levels. This is due to the fact that zero-to-peak SPL is a time domain measure, whilst the propagation algorithms that have been utilised here are frequency domain solutions. One possible approach to estimating the time domain waveform (in order to predict the zero-to-peak SPL) is through the technique of Fourier synthesis (Jensen *et al*., 2011). This approach involves modelling sound propagation for the full frequency range of interest at sufficiently high frequency resolution. Subsequently, it then involves performing a substantial number of inverse Fourier Transforms to yield the time domain waveform at different geographical locations. For the broadband signals that are under consideration here, this approach was deemed impractical due to the very high computational expense that is involved.

A less computationally expensive approach has been used to estimate the zero-to-peak SPL from pile-driving. SEL sound fields have firstly been computed, and then a positive offset has been added to the SEL sound fields to estimate the zero-to-peak SPL. The positive offset is taken as the difference between the source SEL and the source zero-to-peak SPL (see Table 4-1). It is noted that, in general, the zero-to-peak SPL decays at a faster rate than the SEL due to the temporal dilation that results from multi-path propagation effects as the pulse propagates away from the sound source. The adopted methodology does not account for this faster decay rate of zero-to-peak SPL and will therefore likely overestimate the zero-to-peak SPL at large distances from the sound source and should be treated conservatively.

Zero-to-peak SPL sound fields are presented in this report showing the maximum-over-depth (worst case) zero-to-peak SPL, which show the maximum received zero-to-peak SPL at all locations throughout the whole water column.

In estimating potential impacts due to received zero-to-peak SPL sound levels, the distances to the zero-to-peak SPL thresholds (see Section 3.2) are computed for each radial line extending outwards from the sound source. The distances to the threshold under consideration are then presented to show the minimum distance to the threshold, the maximum distance to the threshold, and the average distance to the threshold (where the average is computed over all radial lines).

4.2.5.3 Cumulative SEL Modelling

The effect of prolonged exposure during pile-driving (i.e. exposure to more than a single sound pulse) is likely to cause auditory injury at greater distances than instantaneous injury from single pulses. The effect of received sound energy from multiple pulses can be modelled by summing the sound exposure over the whole pile-driving duration i.e. calculating the cumulative SEL received by an animal over the pile-driving sequence. The hammer soft-start/ramp-up procedure is included in the cumulative SEL modelling, where the hammer is assumed to operate at a lower energy at the start of pile-driving and increase over time until reaching maximum energy. In modelling the hammer soft-start/ramp-up, the durations at different hammer energies, hammer strike rate/interval, and total number of hammer blows are taken into account.

When estimating potential impacts from the cumulative SEL, an animal's behaviour should be taken into account. In this assessment, the distances to cumulative SEL threshold exceedance have been estimated using a "fleeing animal" model, where it is assumed that an animal will swim directly away from the pile-driving location at a constant swim speed, and will continue doing so until cessation of piling. The swim speeds that has been used in the modelling for estimation of cumulative SEL received by harbour porpoise and fish are shown in Table 4-3.

It is noted that the adopted swim speed is a typical cruising speed for harbour porpoise (Otani *et al.*, 2000) and is considered conservative for use in the cumulative SEL modelling. Swim speeds for harbour porpoise have been recorded at up to 6.2 m/s (Otani *et al.*, 2000), and average swim speeds of 1.7 m/s to 3.1 m/s have been recorded for harbour porpoise exhibiting avoidance responses to a seal-scarer (Brandt *et al.*, 2012). It is expected that harbour porpoise under stress would swim away from pile-driving at a faster swim speed than the adopted speed of 1.5 m/s. The relatively slow swim speed that has been used in the cumulative SEL modelling will result in the simulated animals being exposed to higher levels of SEL and will therefore result in larger impact distances/areas compared to a faster adopted swim speed.

Table 4-3: Harbour porpoise swim speed used for estimating cumulative SEL.

Marine Species	Swim Speed (m/s)	Data Source
Harbour porpoise	1.5	Cruising speed for harbour porpoise (Otani *et al.*, 2000)
Fish	1.5	Based on swim speeds presented in Hirata (1999)

In the cumulative SEL modelling, animals have been simulated as swimming away from the sound source in a number of different swim directions (i.e. bearing from the piling) and initial starting distances from the sound source. Furthermore, animals have been simulated as varying their swimming depth as they swim away from the pile-driving location. More specifically, in terms of depth, two different cumulative SEL modelling scenarios are considered in this assessment:

- Animals being exposed to depth-averaged received SEL as they swim away from the pile-driving location; and
- Animals being exposed to maximum-over-depth (worst case) SEL as they swim away from the pile-driving location.

For the depth-averaged scenario, it is assumed that the SEL received by an animal at each pile strike is equal to the depth-averaged SEL at the animals' location (i.e. range and bearing from the piling location) for each pile strike. For the maximum-over-depth (worst case) scenario, it is assumed that the SEL received by an animal for each pile strike is equal to the maximum SEL over depth at the animals' location (i.e. range and bearing from the piling location) for each pile strike. It is important to note that the maximum-over-depth scenario is an absolute worst case scenario, since it assumes that an animal will follow the depth trajectory that results in it being exposed to the maximum possible SEL (for the given swim direction) for every single pile strike.

For both the depth-averaged and maximum-over-depth (worst case) cumulative SEL scenarios, the impact distance (i.e. distance to threshold exceedance) for a given swim direction is calculated as being the furthest initial starting distance from the pile-driving location where the cumulative SEL threshold is exceeded. Results are then presented as contours, showing areas within which animals will be exposed to cumulative SEL above the considered threshold. Furthermore, for both the depth-averaged and maximum-over-depth (worst case) cumulative SEL scenarios, distances to cumulative SEL threshold exceedance are presented showing the minimum distance to threshold exceedance, the maximum distance to threshold exceedance, and an average distance to threshold exceedance. The minimum distance results when an animal swims away from the sound source at bearing that has lower sound levels, whilst the maximum distance results when an animal swims along the bearing with the highest sound levels. The average distance to threshold exceedance is obtained by averaging the impact distances over all simulated swim trajectories.

4.2.6 Concurrent Pile-driving

Concurrent pile-driving (i.e. the operation of multiple pile-driving vessels at the same time) is being considered for some of the wind farm projects covered in this assessment. The use of multiple pile-driving vessels at the same time may increase the area where potential impacts may occur. Such an increase in area is largely dependent on the separation distance of the pile-driving vessels, which influences the extent to which the individual impact areas from each vessel overlap. In general, larger impact areas result when the individual impact areas are completely separated (i.e. do not overlap), which occurs when the pile-driving vessels are spaced far apart.

Illustrative concurrent pile-driving modelling scenarios have been conducted for each of the wind farm projects considered in this assessment, where it has been assumed that two pile-driving vessels are operational at the same time. In these examples, it is considered unlikely that the individual sound pulses from the two pile-driving vessels would interfere constructively (i.e. overlap in time) and sound levels would therefore not be expected to increase as a result of summation. However, the overall areas of impact would be expected to increase due to the use of two installation vessels. The concurrent pile-driving scenarios considered in this assessment have been conducted to illustrate the potential increase in behavioural disturbance areas for harbour porpoise due to the use of multiple pile-driving vessels.

5.0 CREYKE BECK A

This section presents the underwater sound propagation modelling undertaken to predict potential impacts to harbour porpoise and fish from pile-driving at the Creyke Beck A development. Project specific model inputs (such as maximum hammer energy, model locations and hammer soft-start/ramp-up procedures) are firstly introduced, before the modelling results are presented. The propagation modelling has considered scenarios involving single pile-driving (i.e. the use of a single pile installation vessel), and concurrent pile-driving involving the use of two pile-driving vessels.

5.1 Model Inputs

A number of options have been considered for the installation of infrastructure (such as offshore platforms and wind turbine generators) associated with the Creyke Beck A wind farm development. A number of different modelling scenarios have therefore been considered to predict potential impacts due to pile-driving at Creyke Beck A.

The modelled scenarios that have been conducted for pile-driving at Creyke Beck A are summarised in Table 5-1, and were selected based on the information provided by Forewind (*pers. comm.*) as well as the consented project description (Forewind, 2013a) and previous noise modelling (Forewind, 2013b). The modelling scenarios in Table 5-1 have been selected to cover a range of possible pile-driving events at Creyke Beck A involving the use of different maximum hammer energies and different pile installation durations depending on the use of different foundation types (e.g. multi-leg jacket piles or monopiles).

No information was available with regards to how the Creyke Beck A planned project may differ from the consented project. Therefore, the modelling has only been conducted based on the information available for the Creyke Beck A consented application.

Table 5-1: Noise modelling scenarios for pile-driving at Creyke Beck A.

Infrastructure	Foundation type	Pile diameter (m)	Maximum hammer energy (kJ)	Duration to install a single pile (hours)
Consented Project				
Offshore platforms	Multi-leg jacket piles	2.744	1,900	3.5
Wind turbine generators	Multi-leg jacket piles	3.5	2,300	3.5
	Monopile	10	3,000	5.5

The propagation modelling has been conducted at a number of different locations within the Creyke Beck A wind farm development area in order to cover a broad area and to provide a range of estimates for potential injury and disturbance to harbour porpoise and fish. The modelling locations that have been used for pile-driving at Creyke Beck A are shown in Figure 5-1 and Table 5-2.

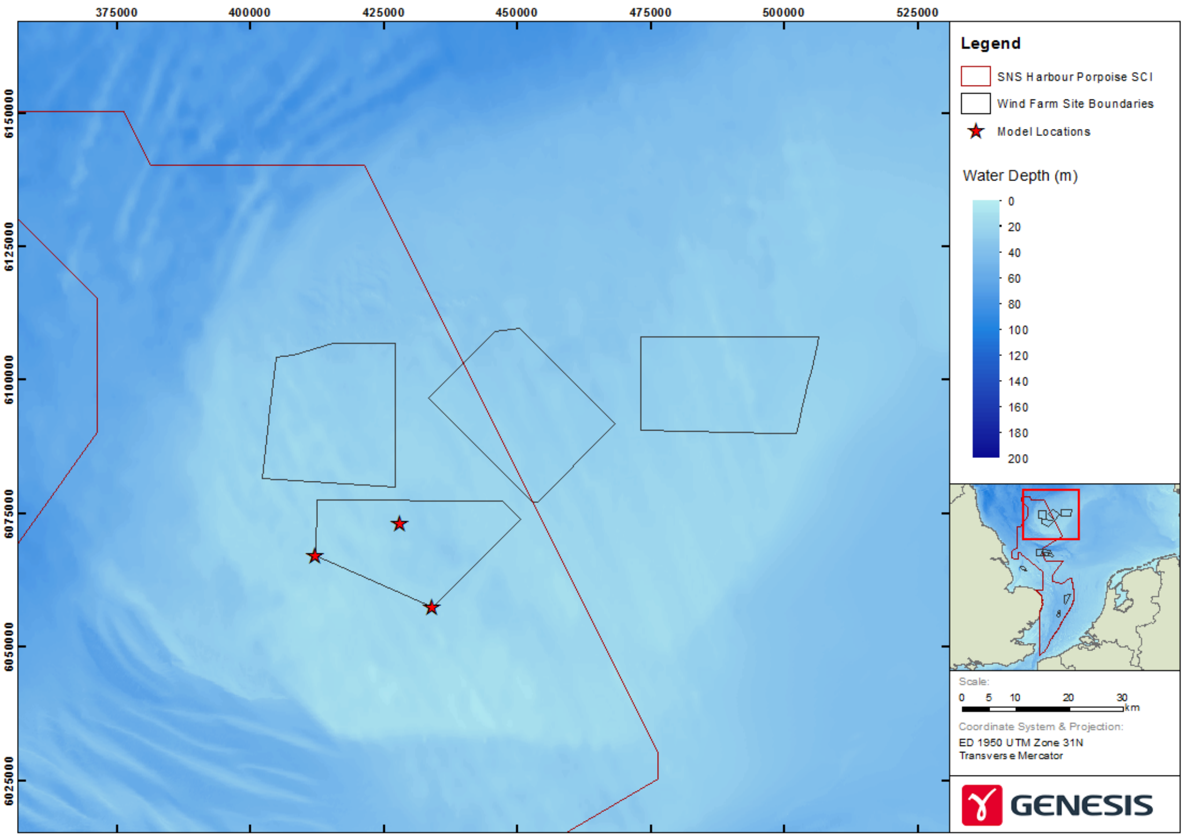

Figure 5-1: Noise modelling locations for pile-driving at Creyke Beck A.

Table 5-2: Noise modelling locations for pile-driving at Creyke Beck A.

Model Location	Longitude (Decimal degrees)	Latitude (Decimal degrees)
Location 1	1.63438	54.74244
Location 2	1.87960	54.80030
Location 3	1.97839	54.66004

The cumulative SEL modelling takes into consideration the pile-driving duration and includes the soft-start/ramp-up phase of the pile installation. The soft-start/ramp-up procedure included in the cumulative SEL modelling for installation of piles at Creyke Beck A is shown in Table 5-3. The ramp-up procedure shown in Table 5-3 is the same as that used in the noise modelling for the consented project application (Forewind, 2013b).

Table 5-3: Hammer soft-start/ramp-up procedure assumed in the modelling of pile-driving at Creyke Beck A.

Percentage of maximum hammer energy (%)	Duration (minutes)	Hammer strike rate (blows/minute)	Hammer strike interval (s)	Number of pile strikes
3.5-hour pile-driving duration				
10	30	20	3.0	600
100	180	40	1.5	7,200
5.5-hour pile-driving duration				
10	30	20	3.0	600
100	300	40	1.5	12,000

5.2 Single Pile-driving Modelling Results

Propagation modelling for single pile-driving (i.e. only using a single pile installation vessel) at Creyke Beck A has been conducted at the model locations shown in Figure 5-1 and Table 5-2, with the different maximum hammer energies shown in Table 5-1 being modelled.

Maximum-over-depth zero-to-peak SPL sound fields have been estimated (see Section 4.2.5.2) and compared to the Southall and NOAA thresholds for the potential onset of PTS and TTS to harbour porpoise. Distances and areas of potential PTS and TTS onset due to zero-to-peak SPL threshold exceedance have been calculated for different percentages of the maximum hammer energy, demonstrating the increase of potential injury zones with increasing hammer energy throughout the soft-start/ramp-up phase. The predicted distances and areas where the Southall and NOAA zero-to-peak SPL thresholds are exceeded are shown in Table 5-4 to Table 5-12 for the various maximum hammer energies that have been modelled for pile-driving at Creyke Beck A. Example maximum-over-depth zero-to-peak SPL sound fields are shown in Figure B-1 to Figure B-6 in Appendix B of this report for the modelling scenarios involving pile-driving at Creyke Beck A with maximum hammer energies of 1,900 kJ and 3,000 kJ.

Cumulative SEL scenarios have been conducted in order to predict potential PTS and TTS onset in harbour porpoise due to exposure to pulses from multiple pile-strikes by estimating areas where the Southall and NOAA cumulative SEL thresholds are exceeded. The cumulative SEL scenarios have been conducted using the “fleeing animal” modelling procedure discussed in Section 4.2.5.3, and take into account the hammer soft-start/ramp-up procedures outlined in Table 5-3. As discussed in Section 4.2.5.3, the cumulative SEL modelling has been conducted for animals receiving depth-averaged SEL for each piling pulse, as well as maximum-over-depth SEL for each piling pulse (which is the absolute worst case scenario). The predicted distances and areas where the Southall and NOAA cumulative SEL thresholds for PTS and TTS onset are exceeded during pile-driving at Creyke Beck A are detailed in Table 5-13 to Table 5-22. Example maps showing the predicted areas where the cumulative SEL thresholds are exceeded are also shown in Figure B-7 to Figure B-12 for pile-driving at Creyke Beck A with maximum hammer energies of 1,900 kJ and 3,000 kJ.

Depth-averaged and maximum-over-depth unweighted single pulse SEL sound fields have been predicted in order to estimate potential disturbance to harbour porpoise due to pile-driving at Creyke Beck A. Example depth-averaged and maximum-over-depth unweighted single pulse SEL sound fields for pile-driving at Creyke Beck A with maximum hammer energies of 1,900 kJ and 3,000 kJ are shown in Figure B-13 to Figure B-24 in Appendix B of this report.

The predicted depth-averaged and maximum-over-depth unweighted SEL sound fields have been compared to the behavioural disturbance threshold of 145 dB re 1 µPa^{2}s proposed by Lucke *et al*. (2009) and Thompson *et al.* (2013b). The predicted distances and areas of this threshold exceedance are shown in Table 5-22 for both the depth-averaged and maximum-over-depth results. The area of threshold exceedance has been calculated as the total area above the threshold, as well as the area within the SCI that is above the threshold.

The probability of displacement of harbour porpoise has been further evaluated using the behavioural/dose response curve discussed in Section 3.2.1.2. The predicted areas and probabilities of behavioural disturbance to harbour porpoise for different SEL contour bands are detailed in Table 5-23 to Table 5-31 for both the depth-averaged and maximum-over-depth SEL modelling results.

The predicted zero-to-peak SPL and cumulative SEL for the Creyke Beck A modelling scenarios have been compared to the Popper *et al*. (2014) thresholds for estimating potential injury to fish. The predicted distances and areas where injury to fish may potentially occur from pile-driving at Creyke Beck A with various hammer energies are shown in Table 5-32 to Table 5-40.

5.3 Concurrent Pile-driving Modelling Results

Example concurrent pile-driving scenarios at Creyke Beck A have been conducted to estimate the increase in potential behavioural disturbance zones for harbour porpoise due to the use of two installation vessels. The concurrent pile driving modelling scenarios involve piling at model locations 1 and 3 (see Figure 5-1 and Table 5-2) where the same hammer energy is used at each location. The concurrent pile-driving modelling has been conducted for the range of hammer energies shown in Table 5-1.

The predicted areas where the harbour porpoise behavioural disturbance threshold of 145 dB re 1 µPa^{2}s is exceeded for the concurrent pile-driving scenarios at Creyke Beck A are shown in Table 5-41. Table 5-42 to Table 5-44 further show the probability of potential displacement of harbour porpoise for different SEL bands (using the behavioural/dose response curve discussed in Section 3.2.1.2).

Table 5-4: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck A model location 1 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m²) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	190	1	1	1	3
	380	2	2	2	13
	760	2	2	2	13
	1,140	3	3	3	28
	1,520	4	4	4	50
	1,900	4	4	4	50
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	190	87	90	93	25,348
	380	153	159	162	79,072
	760	263	271	291	229,799
	1,140	372	391	406	480,858
	1,520	456	485	511	737,941
	1,900	511	564	593	1,001,151
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	190	2	2	2	13
	380	4	4	4	50
	760	6	6	6	113
	1,140	7	7	7	154
	1,520	9	9	9	254
	1,900	12	12	12	452
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	190	263	269	272	227,542
	380	455	482	499	730,561
	760	671	742	823	1,731,254
	1,140	912	975	1,028	2,982,639
	1,520	1,093	1,169	1,212	4,289,185
	1,900	1,196	1,308	1,408	5,371,571

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

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Table 5-5: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck A model location 1 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m²) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	230	1	1	1	3
	460	2	2	2	13
	920	3	3	3	28
	1,380	4	4	4	50
	1,840	4	4	4	50
	2,300	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	230	104	111	114	38,824
	460	165	175	186	95,611
	920	305	321	333	324,394
	1,380	448	472	492	699,019
	1,840	501	531	576	885,047
	2,300	578	622	661	1,213,653
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	230	3	3	3	28
	460	4	4	4	50
	920	7	7	7	154
	1,380	8	8	8	201
	1,840	12	12	12	452
	2,300	14	14	14	615
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	230	305	321	333	322,812
	460	501	530	575	883,474
	920	811	861	904	2,324,699
	1,380	1,048	1,099	1,144	3,790,981
	1,840	1,185	1,289	1,367	5,220,421
	2,300	1,330	1,434	1,555	6,455,535

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

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Table 5-6: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck A model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	300	1	1	1	3
	600	2	2	2	13
	1,200	3	3	3	28
	1,800	4	4	4	50
	2,400	5	5	5	78
	3,000	6	6	6	113
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	300	140	146	151	66,708
	600	215	222	237	154,696
	1,200	377	403	446	510,987
	1,800	500	528	572	876,521
	2,400	582	636	683	1,268,287
	3,000	669	740	819	1,719,444
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	300	3	3	3	28
	600	5	5	5	78
	1,200	7	7	7	154
	1,800	11	11	11	380
	2,400	15	15	15	706
	3,000	17	17	17	907
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	300	376	403	445	510,182
	600	581	635	682	1,264,847
	1,200	938	995	1,062	3,109,256
	1,800	1,178	1,276	1,350	5,110,340
	2,400	1,359	1,466	1,581	6,743,408
	3,000	1,534	1,656	1,819	8,608,220

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 5-7: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck A model location 2 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	190	1	1	1	3
	380	2	2	2	13
	760	2	2	2	13
	1,140	3	3	3	28
	1,520	4	4	4	50
	1,900	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	190	102	102	102	32,644
	380	140	140	140	61,497
	760	234	234	234	171,803
	1,140	358	358	358	402,128
	1,520	434	436	441	596,826
	1,900	453	456	475	651,831
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	190	2	2	2	13
	380	4	4	4	50
	760	6	6	6	113
	1,140	7	7	7	154
	1,520	10	10	10	314
	1,900	12	12	12	452
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	190	234	234	234	171,803
	380	433	435	440	594,207
	760	696	710	715	1,582,190
	1,140	880	918	984	2,643,483
	1,520	997	1,142	1,170	4,097,826
	1,900	1,185	1,304	1,351	5,334,931

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 5-8: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck A model location 2 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	230	1	1	1	3
	460	2	2	2	13
	920	3	3	3	28
	1,380	4	4	4	50
	1,840	4	4	4	50
	2,300	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	230	109	109	109	37,278
	460	182	182	182	103,930
	920	299	299	299	280,505
	1,380	373	373	373	436,532
	1,840	450	452	468	641,038
	2,300	546	549	560	947,022
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	230	3	3	3	28
	460	4	4	4	50
	920	7	7	7	154
	1,380	9	9	9	254
	1,840	12	12	12	452
	2,300	14	14	14	615
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	230	299	299	299	280,505
	460	450	452	468	640,290
	920	758	795	821	1,983,722
	1,380	988	1,067	1,119	3,574,674
	1,840	1,172	1,280	1,332	5,147,487
	2,300	1,286	1,436	1,494	6,470,066

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 5-9: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck A model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	300	1	1	1	3
	600	2	2	2	13
	1,200	3	3	3	28
	1,800	4	4	4	50
	2,400	5	5	5	78
	3,000	6	6	6	113
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	300	129	129	129	52,213
	600	226	226	226	160,256
	1,200	364	364	364	415,720
	1,800	449	450	461	635,719
	2,400	554	563	609	995,655
	3,000	696	709	714	1,578,224
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	300	3	3	3	28
	600	5	5	5	78
	1,200	8	8	8	201
	1,800	11	11	11	380
	2,400	14	14	14	615
	3,000	16	16	16	803
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	300	364	364	364	415,720
	600	553	561	608	989,262
	1,200	914	986	997	3,050,580
	1,800	1,157	1,266	1,319	5,030,253
	2,400	1,354	1,467	1,516	6,754,009
	3,000	1,549	1,668	1,738	8,726,792

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 5-10: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck A model location 3 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	190	1	1	1	3
	380	2	2	2	13
	760	2	2	2	13
	1,140	3	3	3	28
	1,520	4	4	4	50
	1,900	4	4	4	50
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	190	90	90	90	25,415
	380	161	161	164	81,414
	760	269	273	274	233,180
	1,140	342	394	404	488,298
	1,520	494	501	520	787,729
	1,900	521	580	592	1,055,355
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	190	2	2	2	13
	380	4	4	4	50
	760	6	6	6	113
	1,140	7	7	7	154
	1,520	9	9	9	254
	1,900	12	12	12	452
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	190	269	272	273	231,589
	380	493	500	519	785,024
	760	710	742	761	1,725,382
	1,140	948	987	1,022	3,058,418
	1,520	1,147	1,187	1,203	4,417,714
	1,900	1,272	1,315	1,413	5,425,817

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 5-11: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck A model location 3 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	230	1	1	1	3
	460	2	2	2	13
	920	3	3	3	28
	1,380	4	4	4	50
	1,840	4	4	4	50
	2,300	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	230	114	114	114	40,776
	460	173	173	180	94,226
	920	303	327	331	335,009
	1,380	417	475	492	708,252
	1,840	507	520	588	849,090
	2,300	610	616	633	1,189,239
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	230	3	3	3	28
	460	4	4	4	50
	920	7	7	7	154
	1,380	8	8	8	201
	1,840	12	12	12	452
	2,300	14	14	14	615
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	230	301	326	331	334,339
	460	506	520	588	848,368
	920	850	884	920	2,451,527
	1,380	1,081	1,107	1,136	3,847,266
	1,840	1,252	1,297	1,323	5,279,847
	2,300	1,387	1,450	1,545	6,597,338

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 5-12: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck A model location 3 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	300	1	1	1	3
	600	2	2	2	13
	1,200	3	3	3	28
	1,800	4	4	4	50
	2,400	5	5	5	78
	3,000	6	6	6	113
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	300	148	148	149	68,752
	600	223	223	223	156,030
	1,200	406	409	416	524,485
	1,800	505	518	584	842,908
	2,400	617	632	686	1,254,011
	3,000	710	740	758	1,720,083
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	300	3	3	3	28
	600	5	5	5	78
	1,200	7	7	7	154
	1,800	11	11	11	380
	2,400	15	15	15	706
	3,000	17	17	17	907
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	300	360	407	415	520,211
	600	616	631	685	1,250,212
	1,200	963	1,000	1,045	3,136,862
	1,800	1,238	1,286	1,313	5,186,992
	2,400	1,403	1,489	1,581	6,962,774
	3,000	1,630	1,673	1,746	8,780,361

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 5-13: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck A model location 1 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	0	0	0	0
		2	2	2	13
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	863	1,001	1,179	3,166,537
		1,557	1,753	1,982	9,680,379
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	2,680	3,199	3,992	32,507,175
		4,786	6,740	8,901	145,334,053
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	14,366	17,701	20,224	989,429,955
		17,764	22,802	27,051	1,644,620,720

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 5-14: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck A model location 1 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	0	0	0	0
		3	3	3	28
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	1,228	1,416	1,648	6,329,931
		2,080	2,313	2,582	16,837,444
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	3,227	3,907	4,793	48,474,985
		5,292	7,740	10,368	192,125,908
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	15,356	19,188	22,283	1,164,025,299
		18,945	24,782	29,219	1,943,460,103

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 5-15: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck A model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 5-3)	0	0	0	0
		4	5	5	67
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 5-3)	1,949	2,223	2,499	15,556,607
		3,184	3,431	3,655	36,978,843
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 5-3)	4,030	5,353	6,811	91,339,764
		6,130	10,317	14,232	345,407,781
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 5-3)	16,907	22,442	26,957	1,599,770,311
		21,846	30,803	38,594	3,016,468,091

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 5-16: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck A model location 2 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 5-3)	0	0	0	0
		2	2	2	13
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 5-3)	808	897	1,005	2,532,927
		1,636	1,737	1,822	9,471,166
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 5-3)	2,834	4,201	5,661	56,967,802
		5,494	8,529	12,700	236,421,665
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 5-3)	17,211	18,521	20,179	1,077,303,421
		20,552	23,131	26,110	1,683,165,115

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 5-17: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck A model location 2 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 5-3)	0	0	0	0
		3	3	3	28
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 5-3)	1,187	1,305	1,419	5,354,669
		2,181	2,330	2,433	17,046,044
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 5-3)	3,354	5,068	7,051	83,086,711
		6,358	9,665	14,244	302,870,066
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 5-3)	18,318	20,064	21,953	1,264,459,291
		22,098	25,060	28,614	1,976,720,012

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 5-18: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck A model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 5-3)	0	0	0	0
		4	5	5	72
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 5-3)	1,971	2,134	2,273	14,312,956
		3,215	3,439	3,641	37,155,928
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 5-3)	4,372	6,843	10,062	152,160,530
		8,274	12,324	17,139	491,048,712
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 5-3)	20,337	23,574	27,273	1,749,814,134
		25,893	30,523	36,755	2,943,407,762

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 5-19: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck A model location 3 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 5-3)	0	0	0	0
		2	2	2	13
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 5-3)	917	1,017	1,112	3,253,346
		1,785	1,882	1,984	11,120,953
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 5-3)	2,457	3,755	4,899	45,396,349
		4,331	8,020	12,051	213,673,206
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 5-3)	13,758	18,591	21,293	1,097,351,445
		17,116	22,652	26,637	1,626,721,227

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 5-20: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck A model location 3 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 5-3)	0	0	0	0
		3	3	3	28
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 5-3)	1,310	1,445	1,570	6,570,912
		2,304	2,466	2,608	19,095,969
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 5-3)	2,901	4,559	6,057	67,163,508
		4,869	9,153	13,893	279,060,565
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 5-3)	14,575	19,955	22,945	1,265,838,087
		18,249	24,505	28,984	1,903,805,812

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 5-21: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck A model location 3 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 5-3)	0	0	0	0
		4	5	6	83
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 5-3)	2,139	2,299	2,471	16,612,055
		3,117	3,601	3,931	40,742,760
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 5-3)	3,556	6,242	9,293	128,689,901
		5,813	11,433	18,033	443,153,060
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 5-3)	16,006	23,032	27,716	1,697,903,538
		21,669	29,933	36,190	2,841,540,002

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 5-22: Predicted distances and areas where harbour porpoise behavioural disturbance threshold of 145 dB re 1 μPa²s is exceeded during pile-driving at Creyke Beck A.

Model location	Hammer Energy (kJ)	Distance to 145 dB re 1 μPa²s SEL threshold (m)			Total area where SEL exceeds 145 dB re 1 μPa²s (m²)	Area of SCI where SEL exceeds 145 dB re 1 μPa²s (m²)
		Minimum	Average	Maximum		
Depth-averaged						
1	1,900	9,927	11,436	13,057	414,347,579	414,347,578
	2,300	10,380	12,242	14,384	476,903,033	476,903,033
	3,000	10,874	13,476	16,649	583,892,410	583,892,409
2	1,900	9,961	13,280	17,675	567,434,230	567,434,230
	2,300	10,661	14,253	18,833	651,815,498	651,815,498
	3,000	12,866	15,760	19,867	791,009,469	791,009,469
3	1,900	9,393	12,665	15,736	514,515,136	514,515,136
	2,300	10,146	13,717	17,291	598,666,132	598,666,132
	3,000	11,129	15,131	19,505	735,874,453	735,874,453
Maximum-over-depth/Worst case						
1	1,900	11,758	15,695	20,304	793,604,012	793,604,012
	2,300	12,150	16,795	21,504	915,934,203	915,934,203
	3,000	13,410	18,608	23,911	1,120,798,213	1,120,798,213
2	1,900	14,640	18,273	24,327	1,071,536,493	1,071,536,493
	2,300	15,332	19,414	25,413	1,208,452,933	1,208,452,933
	3,000	16,504	21,197	27,170	1,436,439,970	1,436,439,969
3	1,900	12,191	17,645	23,707	1,011,321,913	1,011,321,913
	2,300	12,782	18,669	25,545	1,136,573,479	1,136,573,479
	3,000	13,726	20,125	27,414	1,321,014,922	1,321,014,922

Table 5-23: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Creyke Beck A modelling location 1 with maximum hammer energy of 1,900 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	163	163	99.7%
195 - 200	817	817	99.5%
190 - 195	3,554	3,554	99.0%
185 - 190	13,296	13,296	98.2%
180 - 185	109,637	109,637	96.7%
175 - 180	874,341	874,341	94.1%
170 - 175	3,014,854	3,014,854	89.4%
165 - 170	8,452,733	8,452,733	81.9%
160 - 165	22,143,418	22,143,418	70.7%
155 - 160	53,260,287	53,260,287	56.3%
150 - 155	121,068,822	121,068,822	40.7%
145 - 150	305,573,215	305,573,215	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	111	111	99.9%
200 - 205	699	699	99.7%
195 - 200	3,582	3,582	99.5%
190 - 195	19,341	19,341	99.0%
185 - 190	104,100	104,100	98.2%
180 - 185	770,792	770,792	96.7%
175 - 180	2,670,391	2,670,391	94.1%
170 - 175	6,885,940	6,885,939	89.4%
165 - 170	17,740,887	17,740,887	81.9%
160 - 165	40,261,246	40,261,246	70.7%
155 - 160	91,402,775	91,402,775	56.3%
150 - 155	186,898,290	186,898,290	40.7%
145 - 150	446,845,860	446,845,860	26.8%

Table 5-24: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Creyke Beck A modelling location 1 with maximum hammer energy of 2,300 kJ.

SEL contour band (dB re 1 μPa²s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	66	66	99.9%
200 - 205	236	236	99.7%
195 - 200	945	945	99.5%
190 - 195	4,393	4,393	99.0%
185 - 190	21,834	21,834	98.2%
180 - 185	153,771	153,771	96.7%
175 - 180	1,197,817	1,197,817	94.1%
170 - 175	3,443,201	3,443,201	89.4%
165 - 170	9,425,118	9,425,118	81.9%
160 - 165	23,590,930	23,590,930	70.7%
155 - 160	54,788,640	54,788,640	56.3%
150 - 155	122,786,033	122,786,033	40.7%
145 - 150	261,490,049	261,490,049	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	155	155	99.9%
200 - 205	932	932	99.7%
195 - 200	5,499	5,499	99.5%
190 - 195	22,024	22,023	99.0%
185 - 190	143,058	143,058	98.2%
180 - 185	1,005,839	1,005,839	96.7%
175 - 180	3,098,678	3,098,678	94.1%
170 - 175	8,136,021	8,136,021	89.4%
165 - 170	20,475,826	20,475,826	81.9%
160 - 165	46,037,249	46,037,249	70.7%
155 - 160	104,408,649	104,408,649	56.3%
150 - 155	211,619,872	211,619,872	40.7%
145 - 150	520,980,402	520,980,401	26.8%

Table 5-25: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Creyke Beck A modelling location 1 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	105	105	99.9%
200 - 205	310	310	99.7%
195 - 200	1,324	1,324	99.5%
190 - 195	5,654	5,654	99.0%
185 - 190	45,501	45,501	98.2%
180 - 185	246,550	246,550	96.7%
175 - 180	1,659,444	1,659,444	94.1%
170 - 175	4,236,228	4,236,228	89.4%
165 - 170	11,865,041	11,865,041	81.9%
160 - 165	28,678,925	28,678,925	70.7%
155 - 160	65,999,303	65,999,303	56.3%
150 - 155	146,006,857	146,006,857	40.7%
145 - 150	325,147,168	325,147,167	26.8%
Maximum-over-depth/Worst case			
> 210	19	19	99.9%
205 - 210	226	226	99.9%
200 - 205	1,345	1,345	99.7%
195 - 200	8,174	8,174	99.5%
190 - 195	34,553	34,553	99.0%
185 - 190	199,697	199,697	98.2%
180 - 185	1,462,377	1,462,377	96.7%
175 - 180	3,781,490	3,781,490	94.1%
170 - 175	10,198,117	10,198,117	89.4%
165 - 170	24,840,385	24,840,385	81.9%
160 - 165	55,719,309	55,719,309	70.7%
155 - 160	123,210,877	123,210,877	56.3%
150 - 155	260,145,267	260,145,267	40.7%
145 - 150	641,196,376	641,196,376	26.8%

Table 5-26: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Creyke Beck A modelling location 2 with maximum hammer energy of 1,900 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	17	17	99.9%
200 - 205	219	219	99.7%
195 - 200	693	693	99.5%
190 - 195	3,127	3,127	99.0%
185 - 190	12,793	12,793	98.2%
180 - 185	123,907	123,906	96.7%
175 - 180	824,957	824,957	94.1%
170 - 175	3,076,512	3,076,512	89.4%
165 - 170	8,635,613	8,635,613	81.9%
160 - 165	25,166,867	25,166,867	70.7%
155 - 160	65,706,495	65,706,495	56.3%
150 - 155	144,088,625	144,088,625	40.7%
145 - 150	319,794,407	319,794,406	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	107	107	99.9%
200 - 205	611	611	99.7%
195 - 200	3,117	3,117	99.5%
190 - 195	21,413	21,413	99.0%
185 - 190	108,463	108,463	98.2%
180 - 185	750,850	750,850	96.7%
175 - 180	2,803,719	2,803,719	94.1%
170 - 175	7,614,508	7,614,508	89.4%
165 - 170	21,745,708	21,745,708	81.9%
160 - 165	56,876,320	56,876,320	70.7%
155 - 160	122,342,753	122,342,753	56.3%
150 - 155	276,407,832	276,407,832	40.7%
145 - 150	582,861,091	582,861,091	26.8%

Table 5-27: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Creyke Beck A modelling location 2 with maximum hammer energy of 2,300 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	46	46	99.9%
200 - 205	249	249	99.7%
195 - 200	903	903	99.5%
190 - 195	4,033	4,033	99.0%
185 - 190	16,000	16,000	98.2%
180 - 185	159,395	159,395	96.7%
175 - 180	1,110,689	1,110,689	94.1%
170 - 175	3,601,104	3,601,104	89.4%
165 - 170	10,422,900	10,422,900	81.9%
160 - 165	29,569,563	29,569,563	70.7%
155 - 160	75,735,198	75,735,198	56.3%
150 - 155	166,213,348	166,213,349	40.7%
145 - 150	364,982,070	364,982,070	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	149	149	99.9%
200 - 205	809	809	99.7%
195 - 200	3,978	3,978	99.5%
190 - 195	27,728	27,728	99.0%
185 - 190	141,731	141,731	98.2%
180 - 185	985,612	985,612	96.7%
175 - 180	3,287,306	3,287,306	94.1%
170 - 175	9,150,184	9,150,184	89.4%
165 - 170	25,562,000	25,562,000	81.9%
160 - 165	65,652,713	65,652,713	70.7%
155 - 160	141,484,466	141,484,466	56.3%
150 - 155	307,833,987	307,833,987	40.7%
145 - 150	654,322,270	654,322,270	26.8%

Table 5-28: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Creyke Beck A modelling location 2 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	89	89	99.9%
200 - 205	314	314	99.7%
195 - 200	1,270	1,270	99.5%
190 - 195	5,861	5,861	99.0%
185 - 190	22,617	22,617	98.2%
180 - 185	208,087	208,087	96.7%
175 - 180	1,653,474	1,653,474	94.1%
170 - 175	4,453,055	4,453,055	89.4%
165 - 170	13,510,774	13,510,774	81.9%
160 - 165	36,935,150	36,935,150	70.7%
155 - 160	90,946,735	90,946,734	56.3%
150 - 155	204,414,785	204,414,785	40.7%
145 - 150	438,857,258	438,857,258	26.8%
Maximum-over-depth/Worst case			
> 210	18	18	99.9%
205 - 210	216	216	99.9%
200 - 205	1,207	1,207	99.7%
195 - 200	5,809	5,809	99.5%
190 - 195	38,298	38,298	99.0%
185 - 190	226,550	226,551	98.2%
180 - 185	3,328,899	3,328,897	96.7%
175 - 180	2,149,076	2,149,078	94.1%
170 - 175	11,743,341	11,743,341	89.4%
165 - 170	31,850,291	31,850,291	81.9%
160 - 165	78,664,343	78,664,343	70.7%
155 - 160	172,882,075	172,882,075	56.3%
150 - 155	367,405,814	367,405,814	40.7%
145 - 150	768,144,031	768,144,031	26.8%

Table 5-29: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Creyke Beck A modelling location 3 with maximum hammer energy of 1,900 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	163	163	99.7%
195 - 200	817	817	99.5%
190 - 195	3,554	3,554	99.0%
185 - 190	13,296	13,296	98.2%
180 - 185	109,637	109,637	96.7%
175 - 180	874,341	874,341	94.1%
170 - 175	3,014,854	3,014,854	89.4%
165 - 170	8,452,733	8,452,733	81.9%
160 - 165	22,143,418	22,143,418	70.7%
155 - 160	53,260,287	53,260,287	56.3%
150 - 155	121,068,822	121,068,822	40.7%
145 - 150	305,573,215	305,573,215	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	80	80	99.9%
200 - 205	733	733	99.7%
195 - 200	3,540	3,540	99.5%
190 - 195	19,529	19,529	99.0%
185 - 190	106,295	106,294	98.2%
180 - 185	782,669	782,669	96.7%
175 - 180	2,690,818	2,690,818	94.1%
170 - 175	7,170,977	7,170,977	89.4%
165 - 170	19,036,795	19,036,796	81.9%
160 - 165	45,113,890	45,113,890	70.7%
155 - 160	102,894,290	102,894,290	56.3%
150 - 155	248,640,881	248,640,882	40.7%
145 - 150	584,861,414	584,861,414	26.8%

Table 5-30: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Creyke Beck A modelling location 3 with maximum hammer energy of 2,300 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	9	9	99.9%
205 - 210	229	229	99.9%
200 - 205	1,002	1,002	99.7%
195 - 200	4,409	4,409	99.5%
190 - 195	20,859	20,859	99.0%
185 - 190	153,826	153,826	98.2%
180 - 185	1,182,712	1,182,712	96.7%
175 - 180	3,498,400	3,498,400	94.1%
170 - 175	10,087,398	10,087,398	89.4%
165 - 170	25,561,639	25,561,639	81.9%
160 - 165	61,779,956	61,779,956	70.7%
155 - 160	136,843,538	136,843,538	56.3%
150 - 155	359,532,154	359,532,154	40.7%
145 - 150	737,572,287	737,572,286	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	123	123	99.9%
200 - 205	973	973	99.7%
195 - 200	5,360	5,360	99.5%
190 - 195	22,224	22,225	99.0%
185 - 190	142,535	142,535	98.2%
180 - 185	1,004,610	1,004,610	96.7%
175 - 180	3,155,211	3,155,211	94.1%
170 - 175	8,506,133	8,506,133	89.4%
165 - 170	22,109,676	22,109,676	81.9%
160 - 165	52,253,159	52,253,159	70.7%
155 - 160	115,878,433	115,878,434	56.3%
150 - 155	291,479,986	291,479,986	40.7%
145 - 150	642,015,058	642,015,057	26.8%

Table 5-31: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Creyke Beck A modelling location 3 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	36	36	99.9%
200 - 205	353	353	99.7%
195 - 200	1,386	1,386	99.5%
190 - 195	5,644	5,644	99.0%
185 - 190	45,949	45,949	98.2%
180 - 185	244,493	244,493	96.7%
175 - 180	1,641,100	1,641,100	94.1%
170 - 175	4,376,792	4,376,792	89.4%
165 - 170	12,800,774	12,800,774	81.9%
160 - 165	31,206,849	31,206,849	70.7%
155 - 160	75,132,638	75,132,638	56.3%
150 - 155	164,144,777	164,144,776	40.7%
145 - 150	446,273,665	446,273,665	26.8%
Maximum-over-depth/Worst case			
> 210	18	18	99.9%
205 - 210	216	216	99.9%
200 - 205	1,207	1,207	99.7%
195 - 200	5,809	5,809	99.5%
190 - 195	38,298	38,298	99.0%
185 - 190	226,550	226,551	98.2%
180 - 185	3,328,899	3,328,897	96.7%
175 - 180	2,149,076	2,149,078	94.1%
170 - 175	11,743,341	11,743,341	89.4%
165 - 170	31,850,291	31,850,291	81.9%
160 - 165	78,664,343	78,664,343	70.7%
155 - 160	172,882,075	172,882,075	56.3%
150 - 155	367,405,814	367,405,814	40.7%
145 - 150	768,144,031	768,144,031	26.8%

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Table 5-32: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Creyke Beck A model location 1 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	1,900	82	84	89	22,393
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,900	215	222	237	154,951
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,900	215	222	237	154,951
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

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Table 5-33: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Creyke Beck A model location 1 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,300	86	89	91	24,899
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	259	267	270	223,145
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	259	267	270	223,145
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

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Table 5-34: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Creyke Beck A model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m²)[1]
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	3,000	110	114	116	40,685
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	310	325	335	330,937
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	310	325	335	330,937
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 5-35: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Creyke Beck A model location 2 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	1,900	86	86	86	23,206
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,900	226	226	226	160,256
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,900	226	226	226	160,256
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 5-36: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Creyke Beck A model location 2 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,300	101	101	101	32,007
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	233	233	233	170,338
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	233	233	233	170,338
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 5-37: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Creyke Beck A model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	3,000	111	111	111	38,658
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	303	303	303	288,061
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	303	303	303	288,061
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 5-38: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Creyke Beck A model location 3 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	1,900	85	85	85	22,669
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,900	223	223	223	156,030
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,900	223	223	223	156,030
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 5-39: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Creyke Beck A model location 3 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,300	90	90	90	25,415
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 $\mu Pa^2 s$)	3.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 $\mu Pa^2 s$)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	265	269	270	227,703
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 $\mu Pa^2 s$)	3.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 $\mu Pa^2 s$)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	265	269	270	227,703
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 $\mu Pa^2 s$)	3.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 $\mu Pa^2 s$)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 5-40: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Creyke Beck A model location 3 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	3,000	115	115	115	41,495
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	330	333	334	347,289
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	330	333	334	347,289
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 5-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

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Table 5-41: Predicted areas where harbour porpoise behavioural disturbance threshold of 145 dB re 1 µPa²s is exceeded during concurrent pile-driving at Creyke Beck A.

Model location	Hammer Energy (kJ)	Total area where SEL exceeds 145 dB re 1 µPa²s (m²)	Area of SCI where SEL exceeds 145 dB re 1 µPa²s (m²)
Depth-averaged			
1 and 3	1,900	928,862,714	928,862,714
	2,300	1,070,691,704	1,070,691,704
	3,000	1,281,468,139	1,281,468,138
Maximum-over-depth/Worst case			
1 and 3	1,900	1,684,042,313	1,684,042,313
	2,300	1,869,752,408	1,869,752,408
	3,000	2,164,588,767	2,164,588,767

Table 5-42: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Creyke Beck A locations 1 and 3 with maximum hammer energy of 1,900 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	40	40	99.9%
200 - 205	365	365	99.7%
195 - 200	1,553	1,553	99.5%
190 - 195	7,122	7,122	99.0%
185 - 190	26,536	26,536	98.2%
180 - 185	219,706	219,705	96.7%
175 - 180	1,756,400	1,756,401	94.1%
170 - 175	6,016,578	6,016,578	89.4%
165 - 170	16,394,684	16,394,684	81.9%
160 - 165	42,603,861	42,603,861	70.7%
155 - 160	101,026,442	101,026,442	56.3%
150 - 155	229,913,089	229,913,088	40.7%
145 - 150	530,896,337	530,896,337	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	191	191	99.9%
200 - 205	1,432	1,432	99.7%
195 - 200	7,122	7,122	99.5%
190 - 195	38,870	38,870	99.0%
185 - 190	210,395	210,394	98.2%
180 - 185	1,553,460	1,553,461	96.7%
175 - 180	5,361,209	5,361,209	94.1%
170 - 175	14,056,917	14,056,917	89.4%
165 - 170	36,777,682	36,777,682	81.9%
160 - 165	85,375,135	85,375,135	70.7%
155 - 160	194,297,065	194,297,065	56.3%
150 - 155	435,539,172	435,539,172	40.7%
145 - 150	910,823,663	910,823,663	26.8%

Table 5-43: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Creyke Beck A locations 1 and 3 with maximum hammer energy of 2,300 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	75	75	99.9%
200 - 205	465	465	99.7%
195 - 200	1,947	1,947	99.5%
190 - 195	8,802	8,802	99.0%
185 - 190	42,693	42,693	98.2%
180 - 185	307,597	307,597	96.7%
175 - 180	2,380,529	2,380,529	94.1%
170 - 175	6,941,601	6,941,601	89.4%
165 - 170	19,512,516	19,512,516	81.9%
160 - 165	49,152,569	49,152,569	70.7%
155 - 160	116,568,596	116,568,596	56.3%
150 - 155	259,629,572	259,629,572	40.7%
145 - 150	616,144,743	616,144,742	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	277	277	99.9%
200 - 205	1,905	1,905	99.7%
195 - 200	10,859	10,859	99.5%
190 - 195	44,248	44,248	99.0%
185 - 190	285,593	285,593	98.2%
180 - 185	2,010,449	2,010,449	96.7%
175 - 180	6,253,889	6,253,889	94.1%
170 - 175	16,642,154	16,642,154	89.4%
165 - 170	42,585,502	42,585,502	81.9%
160 - 165	98,290,407	98,290,407	70.7%
155 - 160	220,287,082	220,287,082	56.3%
150 - 155	503,099,857	503,099,857	40.7%
145 - 150	980,240,186	980,240,185	26.8%

Table 5-44: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Creyke Beck A locations 1 and 3 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	141	141	99.9%
200 - 205	663	663	99.7%
195 - 200	2,710	2,710	99.5%
190 - 195	11,297	11,297	99.0%
185 - 190	91,449	91,450	98.2%
180 - 185	491,043	491,043	96.7%
175 - 180	3,300,544	3,300,544	94.1%
170 - 175	8,613,020	8,613,020	89.4%
165 - 170	24,665,814	24,665,814	81.9%
160 - 165	59,885,775	59,885,775	70.7%
155 - 160	141,131,941	141,131,941	56.3%
150 - 155	310,151,633	310,151,633	40.7%
145 - 150	733,122,108	733,122,108	26.8%
Maximum-over-depth/Worst case			
> 210	19	19	99.9%
205 - 210	441	441	99.9%
200 - 205	2,737	2,737	99.7%
195 - 200	16,327	16,327	99.5%
190 - 195	68,795	68,795	99.0%
185 - 190	406,380	406,380	98.2%
180 - 185	2,920,759	2,920,759	96.7%
175 - 180	7,655,174	7,655,174	94.1%
170 - 175	20,917,134	20,917,134	89.4%
165 - 170	51,878,088	51,878,088	81.9%
160 - 165	119,522,656	119,522,656	70.7%
155 - 160	260,110,188	260,110,187	56.3%
150 - 155	620,834,351	620,834,352	40.7%
145 - 150	1,080,255,718	1,080,255,718	26.8%

6.0 CREYKE BECK B

This section presents the underwater sound propagation modelling undertaken to predict potential impacts to harbour porpoise and fish from pile-driving at the Creyke Beck B development. Project specific model inputs (such as maximum hammer energy, model locations and hammer soft-start/ramp-up procedures) are firstly introduced in this section, before the modelling results are presented. The propagation modelling has considered scenarios involving single pile-driving (i.e. the use of a single pile installation vessel), and concurrent pile-driving involving the use of two pile-driving vessels.

6.1 Model Inputs

Similar to Creyke Beck A, a number of pile-driving options have been considered for the installation of infrastructure associated with the Creyke Beck B wind farm development. Numerous modelling scenarios have therefore been considered to predict potential impacts due to pile-driving at Creyke Beck B.

The modelled scenarios that have been conducted for pile-driving at Creyke Beck B are precisely the same as those conducted for Creyke Beck A and are summarised in Table 6-1. These scenarios were selected based on the information provided by Forewind (*pers. comm.*) as well as the consented project description (Forewind, 2013a) and previous noise modelling (Forewind, 2013b). The modelling scenarios in Table 6-1 have been selected to cover a range of possible pile-driving events at Creyke Beck B involving the use of different maximum hammer energies and different pile installation durations depending on the use of different foundation types (e.g. multi-leg jacket piles or monopiles).

No information was available with regards to how the Creyke Beck B planned project may differ from the consented project. Therefore, the modelling has only been conducted based on the information available for the Creyke Beck B consented application.

Table 6-1: Noise modelling scenarios for pile-driving at Creyke Beck B.

Infrastructure	Foundation type	Pile diameter (m)	Maximum Hammer Energy (kJ)	Duration to install a single pile (hours)
Consented Project				
Platform	Multi-leg jacket piles	2.744	1,900	3.5
Wind turbine generators	Multi-leg jacket piles	3.5	2,300	3.5
	Monopile	10	3,000	5.5

The propagation modelling has been conducted at a number of different locations within the Creyke Beck B wind farm development area in order to provide a range of estimates for potential injury and disturbance to harbour porpoise. The modelling locations that have been used to assess potential injury and disturbance to harbour porpoise due to pile-driving at Creyke Beck B are shown in Figure 6-1 and Table 6-2.

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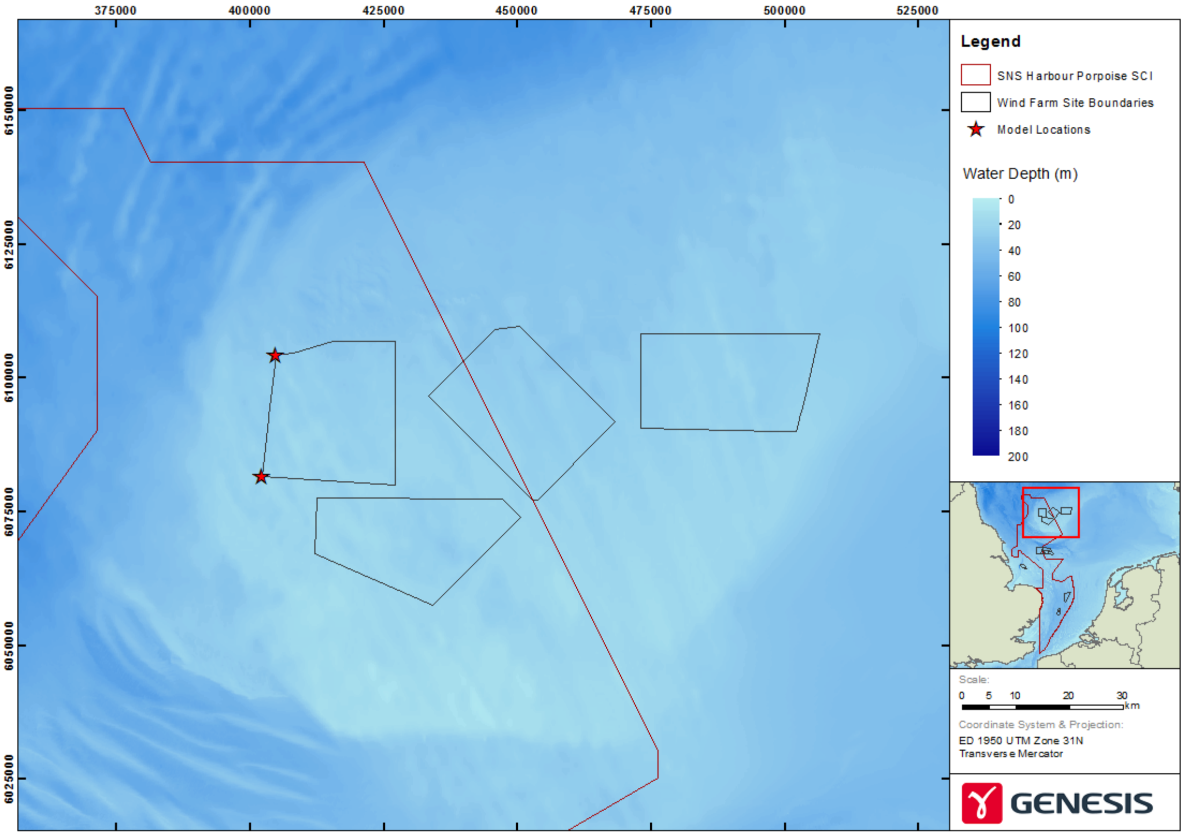

Figure 6-1: Noise modelling locations for pile-driving at Creyke Beck B.

Table 6-2: Noise modelling locations for pile-driving at Creyke Beck B.

Model Location	Longitude (Decimal degrees)	Latitude (Decimal degrees)
Location 1	1.47537	54.87170
Location 2	1.50699	55.07523

The cumulative SEL modelling takes into consideration the pile-driving duration and includes the soft-start/ramp-up phase of the pile installation. The soft-start/ramp-up procedure included in the cumulative SEL modelling for installation of piles at Creyke Beck B is shown in Table 6-3. The ramp-up procedure shown in Table 6-3 is the same as that used in the noise modelling for the consented project application (Forewind, 2013b).

Table 6-3: Hammer soft-start/ramp-up procedure assumed in the modelling of pile-driving at Creyke Beck B.

Percentage of maximum hammer energy (%)	Duration (minutes)	Hammer strike rate (blows/minute)	Hammer strike interval (s)	Number of pile strikes
3.5-hour pile-driving duration				
10	30	20	3.0	600
100	180	40	1.5	7,200
5.5-hour pile-driving duration				
10	30	20	3.0	600
100	300	40	1.5	12,000

6.2 Single Pile-driving Modelling Results

Propagation modelling for single pile-driving (i.e. only using a single pile installation vessel) at Creyke Beck B has been conducted at the model locations shown in Figure 6-1 and Table 6-2, with the different maximum hammer energies shown in Table 6-1 being modelled.

Maximum-over-depth zero-to-peak SPL sound fields have been estimated (see Section 4.2.5.2) and compared to the Southall and NOAA thresholds for the potential onset of PTS and TTS to harbour porpoise. Distances and areas of potential PTS and TTS onset due to zero-to-peak SPL threshold exceedance have been calculated for different percentages of the maximum hammer energy, demonstrating the increase of potential injury zones with increasing hammer energy throughout the soft-start/ramp-up phase. The predicted distances and areas where the Southall and NOAA zero-to-peak SPL thresholds are exceeded are shown in Table 6-4 to Table 6-9 for the various maximum hammer energies that have been modelled for pile-driving at Creyke Beck B. Example maximum-over-depth zero-to-peak SPL sound fields are shown in Figure C-1 to Figure C-4 in Appendix C of this report for the modelling scenarios involving pile-driving at Creyke Beck B with maximum hammer energies of 1,900 kJ and 3,000 kJ.

Cumulative SEL scenarios have been conducted in order to predict potential PTS and TTS onset in harbour porpoise due to exposure to pulses from multiple pile-strikes by estimating areas where the Southall and NOAA cumulative SEL thresholds are exceeded. The cumulative SEL scenarios have been conducted using the “fleeing animal” modelling procedure discussed in Section 4.2.5.3, and take into account the hammer soft-start/ramp-up procedures outlined in Table 6-3. As discussed in Section 4.2.5.3, the cumulative SEL modelling has been conducted for animals receiving depth-averaged SEL for each piling pulse, as well as maximum-over-depth SEL for each piling pulse (which is the absolute worst case scenario). The predicted distances and areas where the Southall and NOAA cumulative SEL thresholds for PTS and TTS onset are exceeded during pile-driving at Creyke Beck B are detailed in Table 6-10 to Table 6-15. Example maps showing the predicted areas where the cumulative SEL thresholds are exceeded are also shown in Figure C-5 to Figure C-9 for the pile-driving at Creyke Beck B with maximum hammer energies of 1,900 kJ and 3,000 kJ.

Depth-averaged and maximum-over-depth unweighted single pulse SEL sound fields have been predicted in order to estimate potential disturbance to harbour porpoise due to pile-driving at Creyke Beck B. Example depth-averaged and maximum-over-depth unweighted single pulse SEL sound fields for pile-driving at Creyke Beck B with maximum hammer energies of 1,900 kJ and 3,000 kJ are shown in Figure C-10 to Figure C-16 in Appendix C of this report.

The predicted depth-averaged and maximum-over-depth unweighted SEL sound fields have been compared to the behavioural disturbance threshold of 145 dB re 1 µPa²s proposed by Lucke *et al*. (2009) and Thompson *et al.* (2013b). The predicted distances and areas of this threshold exceedance are shown in Table 6-16 for both the depth-averaged and maximum-over-depth results. The area of threshold exceedance has been calculated as the total area above the threshold, as well as the area within the SCI that is above the threshold.

The probability of displacement of harbour porpoise has been further evaluated using the behavioural/dose response curve discussed in Section 3.2.1.2. The predicted areas and probabilities of behavioural disturbance to harbour porpoise for different SEL contour bands are detailed in Table 6-17 to Table 6-22 for both the depth-averaged and maximum-over-depth SEL modelling results.

The predicted zero-to-peak SPL and cumulative SEL for the Creyke Beck B modelling scenarios have been compared to the Popper *et al*. (2014) thresholds for estimating potential injury to fish. The predicted distances and areas where injury to fish may potentially occur from pile-driving at Creyke Beck B with various hammer energies are shown in Table 6-23 to Table 6-28.

6.3 Concurrent Pile-driving Modelling Results

Example concurrent pile-driving scenarios at Creyke Beck B have been conducted to estimate the increase in potential behavioural disturbance zones for harbour porpoise due to the use of two installation vessels. The concurrent pile driving modelling scenarios involve piling at model locations 1 and 2 (see Figure 6-1 and Table 6-2) where the same hammer energy is used at each location. The concurrent pile-driving modelling has been conducted for the range of hammer energies shown in Table 6-1.

The predicted areas where the harbour porpoise behavioural disturbance threshold of 145 dB re 1 µPa²s is exceeded for the concurrent pile-driving scenarios at Creyke Beck B are shown in Table 6-29. Table 6-30 to Table 6-32 further show the probability of potential displacement of harbour porpoise for different SEL bands (using the behavioural/dose response curve discussed in Section 3.2.1.2).

Table 6-4: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck B model location 1 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	190	1	1	1	3
	380	2	2	2	13
	760	2	2	2	13
	1,140	3	3	3	28
	1,520	4	4	4	50
	1,900	4	4	4	50
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	190	95	98	99	30,015
	380	162	164	169	84,594
	760	274	290	298	264,940
	1,140	373	413	443	536,378
	1,520	461	491	525	758,700
	1,900	512	568	597	1,011,718
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	190	2	2	2	13
	380	4	4	4	50
	760	6	6	6	113
	1,140	7	7	7	154
	1,520	10	10	10	314
	1,900	13	13	13	530
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	190	273	290	297	264,366
	380	461	480	518	723,191
	760	714	763	810	1,827,788
	1,140	914	979	1,019	3,005,452
	1,520	1,096	1,151	1,220	4,157,326
	1,900	1,212	1,309	1,401	5,380,104

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 6-5: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck B model location 1 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	230	1	1	1	3
	460	2	2	2	13
	920	3	3	3	28
	1,380	4	4	4	50
	1,840	4	4	4	50
	2,300	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	230	111	114	121	40,788
	460	182	188	202	110,317
	920	309	343	362	370,836
	1,380	421	460	491	664,328
	1,840	507	555	582	965,457
	2,300	589	634	685	1,262,868
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	230	3	3	3	28
	460	4	4	4	50
	920	6	6	6	113
	1,380	9	9	9	254
	1,840	12	12	12	452
	2,300	15	15	15	706
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	230	308	343	361	369,355
	460	506	552	580	957,769
	920	814	871	926	2,381,155
	1,380	1,054	1,090	1,130	3,726,015
	1,840	1,194	1,288	1,377	5,205,036
	2,300	1,368	1,440	1,529	6,509,300

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 6-6: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck B model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m²) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	300	1	1	1	3
	600	2	2	2	13
	1,200	3	3	3	28
	1,800	4	4	4	50
	2,400	5	5	5	78
	3,000	6	6	6	113
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	300	135	140	142	61,487
	600	229	240	259	181,428
	1,200	377	424	449	565,602
	1,800	502	543	578	927,656
	2,400	610	653	708	1,341,357
	3,000	702	757	806	1,801,316
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	300	3	3	3	28
	600	5	5	5	78
	1,200	8	8	8	201
	1,800	12	12	12	452
	2,400	15	15	15	706
	3,000	18	18	18	1,017
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	300	376	423	449	562,103
	600	609	650	707	1,329,062
	1,200	946	999	1,044	3,133,165
	1,800	1,186	1,273	1,359	5,086,704
	2,400	1,387	1,477	1,619	6,847,211
	3,000	1,547	1,653	1,825	8,580,686

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 6-7: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck B model location 2 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	190	1	1	1	3
	380	2	2	2	13
	760	2	2	2	13
	1,140	3	3	3	28
	1,520	4	4	4	50
	1,900	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	190	96	102	104	32,905
	380	137	141	144	62,546
	760	234	239	247	178,904
	1,140	323	333	342	348,120
	1,520	385	394	410	488,281
	1,900	463	473	488	702,968
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	190	2	2	2	13
	380	4	4	4	50
	760	6	6	6	113
	1,140	7	7	7	154
	1,520	10	10	10	314
	1,900	12	12	12	452
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	190	234	239	246	178,543
	380	385	394	409	486,833
	760	608	655	693	1,348,559
	1,140	809	880	976	2,437,614
	1,520	969	1,099	1,219	3,799,878
	1,900	1,185	1,289	1,418	5,216,942

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 6-8: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck B model location 2 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m²) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	230	1	1	1	3
	460	2	2	2	13
	920	3	3	3	28
	1,380	4	4	4	50
	1,840	4	4	4	50
	2,300	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	230	106	110	113	38,197
	460	149	175	183	96,009
	920	268	287	299	259,391
	1,380	380	387	403	471,197
	1,840	420	466	482	681,409
	2,300	477	507	532	808,144
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	230	3	3	3	28
	460	4	4	4	50
	920	7	7	7	154
	1,380	9	9	9	254
	1,840	12	12	12	452
	2,300	14	14	14	615
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	230	268	285	298	255,749
	460	420	465	482	677,725
	920	687	758	811	1,803,365
	1,380	933	1,014	1,108	3,229,881
	1,840	1,168	1,269	1,407	5,052,292
	2,300	1,359	1,450	1,531	6,597,658

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 6-9: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck B model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	300	1	1	1	3
	600	2	2	2	13
	1,200	3	3	3	28
	1,800	4	4	4	50
	2,400	5	5	5	78
	3,000	6	6	6	113
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	300	123	128	129	51,466
	600	205	215	226	145,401
	1,200	332	345	380	372,802
	1,800	419	459	479	662,007
	2,400	503	526	592	870,705
	3,000	608	651	688	1,332,182
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	300	3	3	3	28
	600	5	5	5	78
	1,200	8	8	8	201
	1,800	11	11	11	380
	2,400	14	14	14	615
	3,000	16	16	16	803
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	300	331	341	361	364,040
	600	502	522	589	855,407
	1,200	852	927	1,006	2,702,064
	1,800	1,138	1,253	1,335	4,931,628
	2,400	1,379	1,471	1,544	6,793,016
	3,000	1,560	1,639	1,738	8,433,510

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 6-10: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck B model location 1 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 6-3)	0	0	0	0
		2	2	2	13
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 6-3)	839	1,060	1,263	3,555,158
		1,764	2,149	2,450	14,551,124
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 6-3)	2,662	4,389	5,559	61,776,119
		5,991	9,111	12,654	265,924,181
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 6-3)	16,287	18,596	21,484	1,091,586,894
		23,081	26,365	28,360	2,186,920,528

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 6-11: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck B model location 1 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 6-3)	0	0	0	0
		3	3	3	28
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 6-3)	1,201	1,499	1,764	7,103,803
		2,421	2,906	3,204	26,584,380
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 6-3)	3,331	5,301	6,782	89,934,064
		6,984	10,436	14,403	348,814,478
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 6-3)	17,664	20,236	23,285	1,292,768,392
		25,149	28,763	30,732	2,603,999,916

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 6-12: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck B model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 6-3)	0	0	0	0
		4	5	6	96
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 6-3)	1,940	2,365	2,718	17,648,634
		3,697	4,200	4,641	55,493,791
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 6-3)	4,662	7,347	10,161	173,164,493
		9,084	14,582	20,034	687,848,898
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 6-3)	20,984	24,335	28,612	1,870,687,178
		28,942	36,876	41,119	4,298,220,894

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 6-13: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck B model location 2 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 6-3)	0	0	0	0
		2	2	2	13
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 6-3)	781	932	1,059	2,744,959
		1,804	1,935	2,044	11,760,720
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 6-3)	4,509	6,335	7,938	127,509,631
		9,430	13,882	18,012	621,207,463
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 6-3)	16,877	19,543	23,711	1,207,800,577
		23,770	28,157	31,489	2,496,453,768

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 6-14: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck B model location 2 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 6-3)	0	0	0	0
		3	3	3	28
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 6-3)	1,152	1,361	1,508	5,844,803
		2,361	2,569	2,721	20,732,635
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 6-3)	5,447	7,617	9,530	184,770,415
		10,794	16,316	21,228	861,640,611
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 6-3)	18,798	21,393	26,112	1,445,888,076
		25,981	31,027	34,802	3,033,969,472

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 6-15: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Creyke Beck B model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 6-3)	0	0	0	0
		5	6	6	96
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 6-3)	1,893	2,227	2,424	15,627,642
		3,602	3,810	3,944	45,562,837
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 6-3)	7,385	11,173	14,826	402,953,318
		13,086	26,929	41,406	2,487,254,123
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 6-3)	23,535	26,494	33,407	2,216,964,111
		32,408	42,403	47,964	5,722,867,602

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 6-16: Predicted distances and areas where harbour porpoise behavioural disturbance threshold of 145 dB re 1 μPa²s is exceeded during pile-driving at Creyke Beck B.

Model location	Hammer Energy (kJ)	Distance to 145 dB re 1 μPa²s SEL threshold (m)			Total area where SEL exceeds 145 dB re 1 μPa²s (m²)	Area of SCI where SEL exceeds 145 dB re 1 μPa²s (m²)
		Minimum	Average	Maximum		
Depth-averaged						
1	1,900	10,885	13,694	16,629	593,998,757	593,998,757
	2,300	11,686	14,661	18,332	684,056,191	684,056,191
	3,000	12,727	16,040	20,517	823,341,115	823,341,115
2	1,900	14,615	18,048	22,906	1,023,544,563	1,023,544,563
	2,300	15,919	19,583	24,699	1,209,550,779	1,209,550,779
	3,000	17,162	21,813	27,048	1,497,640,607	1,497,640,606
Maximum-over-depth/Worst case						
1	1,900	14,820	19,137	24,504	1,202,706,795	1,202,706,795
	2,300	16,624	20,678	26,038	1,410,862,009	1,410,862,009
	3,000	17,591	22,974	28,718	1,779,209,310	1,779,209,310
2	1,900	18,755	28,202	38,534	2,836,991,497	2,785,605,935
	2,300	19,631	31,300	43,205	3,526,003,054	3,236,874,192
	3,000	20,941	36,268	54,660	4,806,200,740	3,737,575,325

Table 6-17: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Creyke Beck B modelling location 1 with maximum hammer energy of 1,900 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	168	168	99.7%
195 - 200	820	820	99.5%
190 - 195	3,436	3,436	99.0%
185 - 190	15,592	15,592	98.2%
180 - 185	113,418	113,417	96.7%
175 - 180	912,320	912,320	94.1%
170 - 175	3,024,061	3,024,061	89.4%
165 - 170	7,940,926	7,940,926	81.9%
160 - 165	23,162,324	23,162,324	70.7%
155 - 160	58,923,920	58,923,920	56.3%
150 - 155	154,616,467	154,616,467	40.7%
145 - 150	345,285,308	345,285,308	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	77	77	99.9%
200 - 205	757	757	99.7%
195 - 200	4,131	4,131	99.5%
190 - 195	16,350	16,350	99.0%
185 - 190	104,202	104,201	98.2%
180 - 185	765,278	765,278	96.7%
175 - 180	2,612,840	2,612,840	94.1%
170 - 175	6,772,821	6,772,821	89.4%
165 - 170	19,078,502	19,078,502	81.9%
160 - 165	50,051,932	50,051,932	70.7%
155 - 160	131,051,117	131,051,117	56.3%
150 - 155	286,961,676	286,961,676	40.7%
145 - 150	705,287,114	705,287,114	26.8%

Table 6-18: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Creyke Beck B modelling location 1 with maximum hammer energy of 2,300 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	14	14	99.9%
200 - 205	225	225	99.7%
195 - 200	1,026	1,025	99.5%
190 - 195	4,136	4,136	99.0%
185 - 190	26,977	26,977	98.2%
180 - 185	163,470	163,470	96.7%
175 - 180	1,222,672	1,222,672	94.1%
170 - 175	3,460,725	3,460,725	89.4%
165 - 170	9,500,687	9,500,687	81.9%
160 - 165	27,424,554	27,424,554	70.7%
155 - 160	67,803,158	67,803,158	56.3%
150 - 155	177,141,013	177,141,013	40.7%
145 - 150	397,307,535	397,307,535	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	120	120	99.9%
200 - 205	985	984	99.7%
195 - 200	5,633	5,633	99.5%
190 - 195	23,068	23,068	99.0%
185 - 190	135,578	135,578	98.2%
180 - 185	959,826	959,825	96.7%
175 - 180	3,063,901	3,063,901	94.1%
170 - 175	8,100,203	8,100,203	89.4%
165 - 170	22,655,603	22,655,603	81.9%
160 - 165	57,375,745	57,375,745	70.7%
155 - 160	150,357,635	150,357,634	56.3%
150 - 155	333,919,449	333,919,449	40.7%
145 - 150	834,264,263	834,264,263	26.8%

Table 6-19: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Creyke Beck B modelling location 1 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	42	42	99.9%
200 - 205	344	344	99.7%
195 - 200	1,412	1,412	99.5%
190 - 195	5,337	5,337	99.0%
185 - 190	45,432	45,432	98.2%
180 - 185	280,032	280,032	96.7%
175 - 180	1,670,088	1,670,088	94.1%
170 - 175	4,246,043	4,246,043	89.4%
165 - 170	12,222,362	12,222,362	81.9%
160 - 165	34,389,261	34,389,261	70.7%
155 - 160	86,656,845	86,656,845	56.3%
150 - 155	209,611,377	209,611,377	40.7%
145 - 150	474,212,539	474,212,539	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	226	226	99.9%
200 - 205	1,408	1,407	99.7%
195 - 200	7,523	7,523	99.5%
190 - 195	34,541	34,541	99.0%
185 - 190	210,772	210,772	98.2%
180 - 185	1,404,463	1,404,463	96.7%
175 - 180	3,700,678	3,700,678	94.1%
170 - 175	10,351,473	10,351,473	89.4%
165 - 170	28,829,795	28,829,795	81.9%
160 - 165	70,637,163	70,637,163	70.7%
155 - 160	180,294,085	180,294,085	56.3%
150 - 155	406,859,504	406,859,504	40.7%
145 - 150	1,076,877,680	1,076,877,680	26.8%

Table 6-20: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Creyke Beck B modelling location 2 with maximum hammer energy of 1,900 kJ.

SEL contour band (dB re 1 μPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	24	24	99.9%
200 - 205	215	215	99.7%
195 - 200	716	716	99.5%
190 - 195	3,081	3,082	99.0%
185 - 190	12,630	12,630	98.2%
180 - 185	122,560	122,560	96.7%
175 - 180	790,442	790,442	94.1%
170 - 175	3,082,537	3,082,537	89.4%
165 - 170	9,810,723	9,810,723	81.9%
160 - 165	33,627,781	33,627,782	70.7%
155 - 160	96,278,617	96,278,617	56.3%
150 - 155	246,650,729	246,650,729	40.7%
145 - 150	633,164,507	633,164,508	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	116	116	99.9%
200 - 205	607	607	99.7%
195 - 200	3,110	3,110	99.5%
190 - 195	20,400	20,400	99.0%
185 - 190	105,668	105,668	98.2%
180 - 185	827,268	827,268	96.7%
175 - 180	2,797,129	2,797,129	94.1%
170 - 175	8,259,986	8,259,986	89.4%
165 - 170	28,676,439	28,676,439	81.9%
160 - 165	82,221,271	82,221,271	70.7%
155 - 160	216,008,642	216,008,642	56.3%
150 - 155	555,746,961	555,746,962	40.7%
145 - 150	1,942,323,899	1,890,938,337	26.8%

Table 6-21: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Creyke Beck B modelling location 2 with maximum hammer energy of 2,300 kJ.

SEL contour band (dB re 1 μPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	54	54	99.9%
200 - 205	239	239	99.7%
195 - 200	915	915	99.5%
190 - 195	4,006	4,006	99.0%
185 - 190	15,757	15,757	98.2%
180 - 185	154,444	154,444	96.7%
175 - 180	1,062,069	1,062,070	94.1%
170 - 175	3,665,987	3,665,987	89.4%
165 - 170	12,174,166	12,174,166	81.9%
160 - 165	40,640,854	40,640,854	70.7%
155 - 160	113,761,325	113,761,325	56.3%
150 - 155	290,871,946	290,871,946	40.7%
145 - 150	747,199,017	747,199,017	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	160	160	99.9%
200 - 205	804	804	99.7%
195 - 200	3,957	3,957	99.5%
190 - 195	27,555	27,555	99.0%
185 - 190	140,238	140,238	98.2%
180 - 185	1,021,846	1,021,846	96.7%
175 - 180	3,341,903	3,341,903	94.1%
170 - 175	10,276,785	10,276,785	89.4%
165 - 170	34,568,586	34,568,586	81.9%
160 - 165	95,948,702	95,948,702	70.7%
155 - 160	248,433,613	248,433,613	56.3%
150 - 155	672,473,363	672,473,363	40.7%
145 - 150	2,459,765,542	2,170,636,680	26.8%

Table 6-22: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Creyke Beck B modelling location 2 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	98	98	99.9%
200 - 205	301	301	99.7%
195 - 200	1,276	1,276	99.5%
190 - 195	5,843	5,842	99.0%
185 - 190	21,967	21,967	98.2%
180 - 185	214,072	214,072	96.7%
175 - 180	1,588,969	1,588,970	94.1%
170 - 175	4,637,747	4,637,747	89.4%
165 - 170	16,400,236	16,400,236	81.9%
160 - 165	52,789,386	52,789,386	70.7%
155 - 160	142,386,977	142,386,977	56.3%
150 - 155	356,177,504	356,177,504	40.7%
145 - 150	923,416,231	923,416,231	26.8%
Maximum-over-depth/Worst case			
> 210	22	22	99.9%
205 - 210	225	225	99.9%
200 - 205	1,185	1,185	99.7%
195 - 200	5,728	5,728	99.5%
190 - 195	37,839	37,840	99.0%
185 - 190	253,531	253,531	98.2%
180 - 185	1,428,697	1,428,697	96.7%
175 - 180	4,154,088	4,154,088	94.1%
170 - 175	13,943,212	13,943,212	89.4%
165 - 170	44,455,021	44,455,021	81.9%
160 - 165	120,891,358	120,891,358	70.7%
155 - 160	312,153,029	312,153,029	56.3%
150 - 155	853,410,361	853,410,361	40.7%
145 - 150	3,455,466,443	2,386,841,028	26.8%

Table 6-23: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Creyke Beck B model location 1 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	1,900	74	77	78	18,643
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 6-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,900	229	241	259	181,698
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 6-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,900	229	241	259	181,698
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 6-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 6-24: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Creyke Beck B model location 1 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m²)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,300	93	96	97	28,825
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 6-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	265	282	294	250,760
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 6-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	265	282	294	250,760
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 6-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 6-25: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Creyke Beck B model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	3,000	114	117	131	42,859
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 6-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	311	348	363	380,858
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 6-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	311	348	363	380,858
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 6-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 6-26: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Creyke Beck B model location 2 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	1,900	81	84	85	22,202
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 6-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,900	205	215	226	145,817
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 6-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,900	205	215	226	145,817
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 6-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

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Table 6-27: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Creyke Beck B model location 2 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,300	95	101	102	32,070
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 6-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	232	236	241	175,032
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 6-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	232	236	241	175,032
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 6-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 6-28: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Creyke Beck B model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m²)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	3,000	107	112	115	39,513
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 6-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	270	296	304	275,815
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 6-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	270	296	304	275,815
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 6-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 6-29: Predicted areas where harbour porpoise behavioural disturbance threshold of 145 dB re 1 µPa^{2}s is exceeded during concurrent pile-driving at Creyke Beck B.

Model location	Hammer Energy (kJ)	Total area where SEL exceeds 145 dB re 1 µPa^{2}s (m^2)	Area of SCI where SEL exceeds 145 dB re 1 µPa^{2}s (m^2)
Depth-averaged			
1 and 2	1,900	1,486,631,684	1,486,631,684
	2,300	1,709,657,484	1,709,657,484
	3,000	2,041,675,831	2,041,675,831
Maximum-over-depth/Worst case			
1 and 2	1,900	3,490,440,265	3,439,265,119
	2,300	4,229,073,960	3,940,626,850
	3,000	5,579,792,283	4,507,188,507

Table 6-30: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Creyke Beck B locations 1 and 2 with maximum hammer energy of 1,900 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	24	24	99.9%
200 - 205	382	382	99.7%
195 - 200	1,536	1,536	99.5%
190 - 195	6,517	6,517	99.0%
185 - 190	28,222	28,222	98.2%
180 - 185	235,977	235,977	96.7%
175 - 180	1,702,762	1,702,762	94.1%
170 - 175	6,106,597	6,106,597	89.4%
165 - 170	17,751,649	17,751,649	81.9%
160 - 165	56,790,105	56,790,105	70.7%
155 - 160	155,202,537	155,202,537	56.3%
150 - 155	401,267,196	401,267,196	40.7%
145 - 150	847,538,180	847,538,179	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	192	192	99.9%
200 - 205	1,364	1,364	99.7%
195 - 200	7,241	7,241	99.5%
190 - 195	36,750	36,750	99.0%
185 - 190	209,869	209,869	98.2%
180 - 185	1,592,545	1,592,546	96.7%
175 - 180	5,409,968	5,409,968	94.1%
170 - 175	15,032,807	15,032,807	89.4%
165 - 170	47,754,942	47,754,942	81.9%
160 - 165	132,273,203	132,273,203	70.7%
155 - 160	347,059,760	347,059,759	56.3%
150 - 155	764,735,061	764,735,061	40.7%
145 - 150	2,176,326,562	2,125,151,416	26.8%

Table 6-31: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Creyke Beck B locations 1 and 2 with maximum hammer energy of 2,300 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	68	68	99.9%
200 - 205	464	464	99.7%
195 - 200	1,941	1,941	99.5%
190 - 195	8,142	8,142	99.0%
185 - 190	42,734	42,734	98.2%
180 - 185	317,914	317,914	96.7%
175 - 180	2,284,741	2,284,742	94.1%
170 - 175	7,126,712	7,126,712	89.4%
165 - 170	21,674,853	21,674,853	81.9%
160 - 165	68,065,407	68,065,407	70.7%
155 - 160	181,564,482	181,564,483	56.3%
150 - 155	468,012,959	468,012,959	40.7%
145 - 150	960,557,066	960,557,066	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	280	280	99.9%
200 - 205	1,789	1,789	99.7%
195 - 200	9,590	9,590	99.5%
190 - 195	50,623	50,623	99.0%
185 - 190	275,816	275,817	98.2%
180 - 185	1,981,672	1,981,671	96.7%
175 - 180	6,405,804	6,405,804	94.1%
170 - 175	18,376,988	18,376,988	89.4%
165 - 170	57,224,189	57,224,189	81.9%
160 - 165	153,324,448	153,324,448	70.7%
155 - 160	398,791,248	398,791,248	56.3%
150 - 155	883,206,113	883,206,114	40.7%
145 - 150	2,709,425,401	2,420,978,291	26.8%

Table 6-32: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Creyke Beck B locations 1 and 2 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	140	140	99.9%
200 - 205	645	645	99.7%
195 - 200	2,688	2,688	99.5%
190 - 195	11,179	11,179	99.0%
185 - 190	67,398	67,399	98.2%
180 - 185	494,104	494,103	96.7%
175 - 180	3,259,058	3,259,058	94.1%
170 - 175	8,883,791	8,883,791	89.4%
165 - 170	28,622,598	28,622,598	81.9%
160 - 165	87,178,647	87,178,647	70.7%
155 - 160	229,043,822	229,043,822	56.3%
150 - 155	559,610,704	559,610,704	40.7%
145 - 150	1,124,501,057	1,124,501,057	26.8%
Maximum-over-depth/Worst case			
> 210	22	22	99.9%
205 - 210	451	451	99.9%
200 - 205	2,593	2,593	99.7%
195 - 200	13,251	13,251	99.5%
190 - 195	72,380	72,380	99.0%
185 - 190	464,303	464,303	98.2%
180 - 185	2,833,159	2,833,159	96.7%
175 - 180	7,854,767	7,854,767	94.1%
170 - 175	24,294,685	24,294,685	89.4%
165 - 170	73,284,815	73,284,815	81.9%
160 - 165	191,528,521	191,528,521	70.7%
155 - 160	492,447,115	492,447,115	56.3%
150 - 155	1,260,269,865	1,260,269,865	40.7%
145 - 150	3,526,726,357	2,454,122,581	26.8%

7.0 EAST ANGLIA ONE

This section presents the underwater sound propagation modelling undertaken to predict potential impacts to harbour porpoise and fish from pile-driving at the East Anglia One development. Project specific model inputs (such as maximum hammer energy, model locations and hammer soft-start/ramp-up procedures) are firstly introduced, before the modelling results are presented. The propagation modelling has considered scenarios involving single pile-driving (i.e. the use of a single pile installation vessel), and concurrent pile-driving involving the use of two pile-driving vessels.

7.1 Model Inputs

A number of different modelling scenarios have been conducted to estimate potential impacts from pile-driving at the East Anglia One wind farm development, which take into account both the consented and planned project design envelopes. The modelled scenarios that have been conducted for pile-driving at East Anglia One are summarised in Table 7-1. These scenarios were selected based on the information provided by East Anglia Offshore Wind Limited (*pers. comm.*) as well as the consented project description (East Anglia Offshore Wind Limited, 2012a) and previous noise modelling (East Anglia Offshore Wind Limited, 2012b). The modelling scenarios have been selected to cover a broad range of possible pile-driving events at East Anglia One involving the use of different maximum hammer energies and different pile installation durations depending on the use of different foundation types (e.g. multi-leg jacket piles or monopiles).

Table 7-1: Noise modelling scenarios for pile-driving at East Anglia One.

Infrastructure	Foundation type	Pile diameter (m)	Maximum Hammer Energy (kJ)	Duration to install a single pile (hours)
Consented Project				
Wind turbine generators	Multi-leg jacket piles	2.5	900	3.5
Met mast	Monopile	6.5	1,800	5.5
Planned Project				
Wind turbine generators	Multi-leg jacket piles	2.5	1,200 (base case) 1,800 (contingency)	3.5
OSS	Multi-leg jacket piles	2.5	1,200 (base case) 2,400 (contingency)	4.0

The propagation modelling has been conducted at a number of different locations within the East Anglia One wind farm development area in order to provide a range of estimates for potential injury and disturbance to harbour porpoise. The modelling locations that have been used to assess potential injury and disturbance to harbour porpoise due to pile-driving at East Anglia One are shown in Figure 7-1 and Table 7-2.

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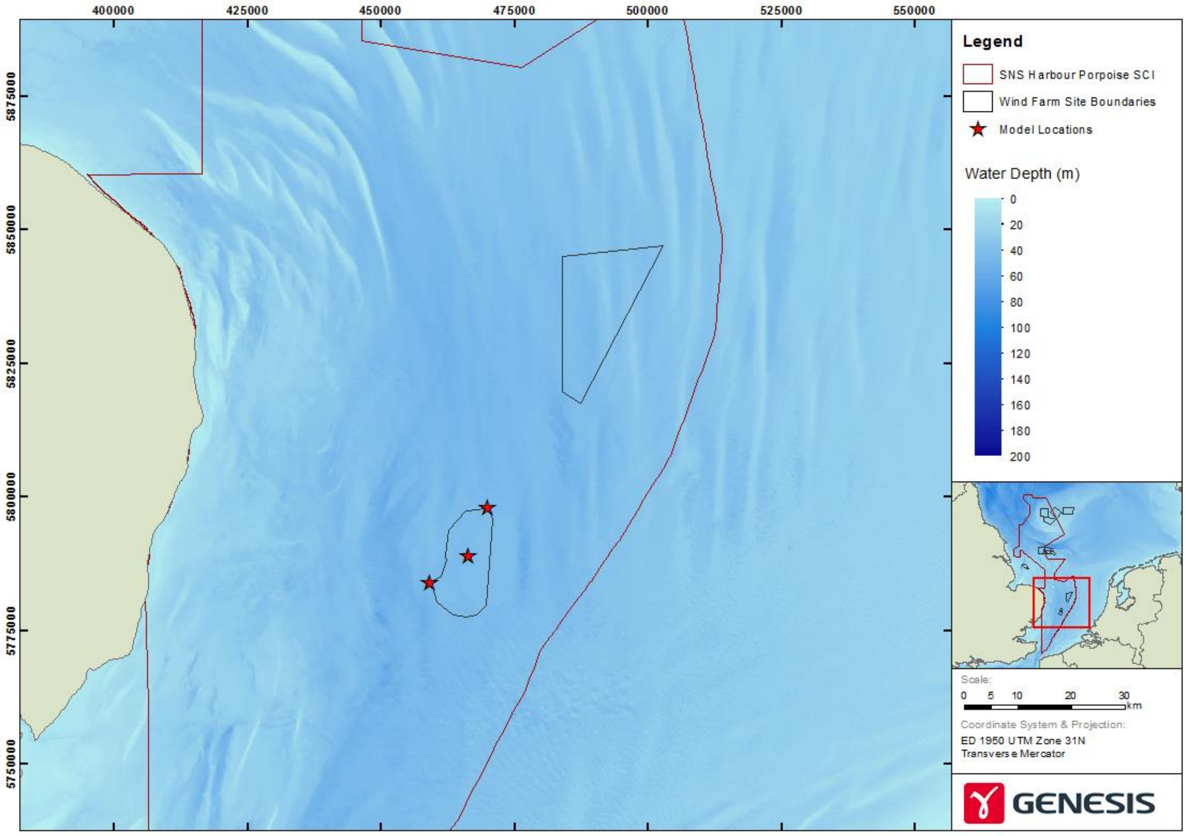

Figure 7-1: Noise modelling locations for pile-driving at East Anglia One.

Table 7-2: Noise modelling locations for pile-driving at East Anglia One.

Model Location	Longitude (Decimal degrees)	Latitude (Decimal degrees)
Location 1	2.40257	52.20422
Location 2	2.55935	52.33131
Location 3	2.50739	52.24935

The soft-start/ramp-up procedures that have been used to estimate the effect of cumulative SEL during pile-driving at East Anglia One are shown in Table 7-3. No information was supplied on a representative soft-start/ramp-up procedure for pile-driving at East Anglia One and assumptions therefore had to be made. The soft-start/ramp-up procedure assumed in the modelling was therefore selected based on the information provided by the other wind farm developments. It has been assumed that the pile-driving at East Anglia One will be initiated at 20% of the maximum hammer energy and ramp-up to 100% of the maximum energy over a period of 20 minutes (Table 7-3). Thereafter the pile-driving has been assumed to remain at 100% maximum energy until the piles have been installed. Different total pile-driving durations have been modelled depending on the estimated durations that may be required to install the piles (see Table 7-1).

Table 7-3: Hammer soft-start/ramp-up procedure assumed in the modelling of pile-driving at East Anglia One.

Percentage of maximum hammer energy (%)	Duration (minutes)	Hammer strike rate (blows/minute)	Hammer strike interval (s)	Number of pile strikes
3.5-hour pile-driving duration				
20	7.5	10	6	75
40	7.5	10	6	75
60	7.5	15	4	112
80	7.5	15	4	113
100	180	35	2	6,300
4.0-hour pile-driving duration				
20	7.5	10	6	75
40	7.5	10	6	75
60	7.5	15	4	112
80	7.5	15	4	113
100	210	35	2	7,350
5.5-hour pile-driving duration				
20	7.5	10	6	75
40	7.5	10	6	75
60	7.5	15	4	112
80	7.5	15	4	113
100	300	35	2	10,500

7.2 Single Pile-driving Modelling Results

Propagation modelling for single pile-driving (i.e. only using a single pile installation vessel) at East Anglia One has been conducted at the model locations shown in Figure 7-1 and Table 7-2, with the different maximum hammer energies shown in Table 7-1 being modelled.

Maximum-over-depth zero-to-peak SPL sound fields have been estimated (see Section 4.2.5.2) and compared to the Southall and NOAA thresholds for the potential onset of PTS and TTS to harbour porpoise. Distances and areas of potential PTS and TTS onset due to zero-to-peak SPL threshold exceedance have been calculated for different percentages of the maximum hammer energy, demonstrating the increase of potential injury zones with increasing hammer energy throughout the soft-start/ramp-up phase. The predicted distances and areas where the Southall and NOAA zero-to-peak SPL thresholds are exceeded are shown in Table 7-4 to Table 7-15 for the various maximum hammer energies that have been modelled for pile-driving at East Anglia One. Example maximum-over-depth zero-to-peak SPL sound fields are shown in Figure D-1 to Figure D-6 in Appendix C of this report for the modelling scenarios involving pile-driving at East Anglia One with maximum hammer energies of 1,200 kJ and 2,400 kJ.

Cumulative SEL scenarios have been conducted in order to predict potential PTS and TTS onset in harbour porpoise due to exposure to pulses from multiple pile-strikes by estimating areas where the Southall and NOAA cumulative SEL thresholds are exceeded. The cumulative SEL scenarios have been conducted using the “fleeing animal” modelling procedure discussed in Section 4.2.5.3, and take into account the hammer soft-start/ramp-up procedures outlined in Table 7-3. As discussed in Section 4.2.5.3, the cumulative SEL modelling has been conducted for animals receiving depth-averaged SEL for each piling pulse, as well as maximum-over-depth SEL for each piling pulse (which is the absolute worst case scenario). The predicted distances and areas where the Southall and NOAA cumulative SEL thresholds for PTS and TTS onset are exceeded during pile-driving at East Anglia One are detailed in Table 7-16 to Table 7-27. Example maps showing the predicted areas where the cumulative SEL thresholds are exceeded are also shown in Figure D-7 to Figure D-12 for the pile-driving at East Anglia One with maximum hammer energies of 1,200 kJ and 2,400 kJ.

Depth-averaged and maximum-over-depth unweighted single pulse SEL sound fields have been predicted in order to estimate potential disturbance to harbour porpoise due to pile-driving at East Anglia One. Example depth-averaged and maximum-over-depth unweighted single pulse SEL sound fields for pile-driving at East Anglia One with maximum hammer energies of 1,200 kJ and 2,400 kJ are shown in Figure D-13 to Figure D-24 in Appendix D of this report.

The predicted depth-averaged and maximum-over-depth unweighted SEL sound fields have been compared to the behavioural disturbance threshold of 145 dB re 1 $\mu Pa^2 s$ proposed by Lucke *et al*. (2009) and Thompson *et al.* (2013b). The predicted distances and areas of this threshold exceedance are shown in Table 7-28 for both the depth-averaged and maximum-over-depth results. The area of threshold exceedance has been calculated as the total area above the threshold, as well as the area within the SCI that is above the threshold.

The probability of displacement of harbour porpoise has been further evaluated using the behavioural/dose response curve discussed in Section 3.2.1.2. The predicted areas and probabilities of behavioural disturbance to harbour porpoise for different SEL contour bands are detailed in Table 7-29 to Table 7-40 for both the depth-averaged and maximum-over-depth SEL modelling results.

The predicted zero-to-peak SPL and cumulative SEL for the East Anglia One modelling scenarios have been compared to the Popper *et al*. (2014) thresholds for estimating potential injury to fish. The predicted distances and areas where injury to fish may potentially occur from pile-driving at East Anglia One with various hammer energies are shown in Table 7-41 to Table 7-52.

7.3 Concurrent Pile-driving Modelling Results

Example concurrent pile-driving scenarios at East Anglia One have been conducted to estimate the increase in potential behavioural disturbance zones for harbour porpoise due to the use of two installation vessels. The concurrent pile driving modelling scenarios involve piling at model locations 1 and 2 (see Figure 7-1 and Table 7-2) where the same hammer energy is used at each location. The concurrent pile-driving modelling has been conducted for the range of hammer energies shown in Table 7-1.

The predicted areas where the harbour porpoise behavioural disturbance threshold of 145 dB re 1 µPa^{2}s is exceeded for the concurrent pile-driving scenarios at East Anglia One are shown in Table 7-53. Table 7-54 to Table 7-57.further show the probability of potential displacement of harbour porpoise for different SEL bands (using the behavioural/dose response curve discussed in Section 3.2.1.2).

Table 7-4: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 1 with a maximum hammer energy of 900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	90	1	1	1	3
	180	1	1	1	3
	360	1	1	1	3
	540	2	2	2	13
	720	2	2	2	13
	900	3	3	3	28
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	90	41	42	42	5,499
	180	68	70	75	15,374
	360	102	105	107	34,733
	540	138	142	159	63,118
	720	182	202	225	128,598
	900	234	245	248	187,664
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	90	1	1	1	3
	180	2	2	2	13
	360	3	3	3	28
	540	4	4	4	50
	720	5	5	5	78
	900	7	7	7	154
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	90	102	105	107	34,706
	180	181	201	225	127,509
	360	321	336	345	354,706
	540	385	412	454	532,138
	720	517	572	634	1,027,524
	900	610	659	714	1,366,433

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 7-5: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 1 with a maximum hammer energy of 1,200 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	120	1	1	1	3
	240	1	1	1	3
	480	2	2	2	13
	720	2	2	2	13
	960	3	3	3	28
	1,200	3	3	3	28
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	120	44	44	44	6,074
	240	78	79	80	19,603
	480	115	138	141	59,443
	720	182	202	225	128,598
	960	245	249	253	193,868
	1,200	299	320	332	321,783
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	120	2	2	2	13
	240	3	3	3	28
	480	4	4	4	50
	720	5	5	5	78
	960	7	7	7	154
	1,200	9	9	9	254
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	120	114	137	140	58,755
	240	244	248	253	193,413
	480	375	391	406	480,855
	720	517	572	634	1,027,524
	960	628	670	719	1,412,127
	1,200	711	751	808	1,773,174

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 7-6: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 1 with a maximum hammer energy of 1,800 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	180	1	1	1	3
	360	1	1	1	3
	720	2	2	2	13
	1,080	3	3	3	28
	1,440	3	3	3	28
	1,800	4	4	4	50
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	180	68	70	75	15,374
	360	102	105	107	34,733
	720	182	202	225	128,598
	1,080	252	269	318	227,873
	1,440	321	337	345	355,463
	1,800	345	382	396	457,102
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	180	2	2	2	13
	360	3	3	3	28
	720	5	5	5	78
	1,080	8	8	8	201
	1,440	10	10	10	314
	1,800	10	10	10	314
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	180	181	201	225	127,509
	360	321	336	345	354,706
	720	517	572	634	1,027,524
	1,080	650	712	777	1,591,324
	1,440	799	863	942	2,337,018
	1,800	928	986	1,054	3,053,570

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 7-7: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 1 with a maximum hammer energy of 2,400 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	240	1	1	1	3
	480	2	2	2	13
	960	3	3	3	28
	1,440	3	3	3	28
	1,920	4	4	4	50
	2,400	4	4	4	50
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	240	78	79	80	19,603
	480	115	138	141	59,443
	960	245	249	253	193,868
	1,440	321	337	345	355,463
	1,920	376	392	406	481,989
	2,400	401	438	492	604,419
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	240	3	3	3	28
	480	4	4	4	50
	960	7	7	7	154
	1,440	10	10	10	314
	1,920	11	11	11	380
	2,400	11	11	11	380
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	240	244	248	253	193,413
	480	375	391	406	480,855
	960	628	670	719	1,412,127
	1,440	799	863	942	2,337,018
	1,920	978	1,041	1,117	3,403,702
	2,400	1,173	1,242	1,414	4,846,815

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 7-8: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 2 with a maximum hammer energy of 900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	90	1	1	1	3
	180	1	1	1	3
	360	2	2	2	13
	540	2	2	2	13
	720	2	2	2	13
	900	3	3	3	28
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	90	39	39	39	4,772
	180	64	67	68	14,024
	360	101	104	109	33,695
	540	147	158	161	78,197
	720	187	208	239	136,172
	900	243	259	273	211,600
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	90	2	2	2	13
	180	2	2	2	13
	360	3	3	3	28
	540	4	4	4	50
	720	5	5	5	78
	900	7	7	7	154
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	90	101	103	108	33,593
	180	183	207	239	134,585
	360	330	339	347	361,086
	540	388	437	487	602,790
	720	574	610	637	1,167,858
	900	590	637	714	1,274,970

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 7-9: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 2 with a maximum hammer energy of 1,200 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	120	1	1	1	3
	240	1	1	1	3
	480	2	2	2	13
	720	2	2	2	13
	960	3	3	3	28
	1,200	3	3	3	28
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	120	51	53	55	8,705
	240	83	87	90	23,624
	480	126	134	143	56,590
	720	187	208	239	136,172
	960	245	265	277	220,362
	1,200	290	320	334	320,502
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	120	2	2	2	13
	240	3	3	3	28
	480	4	4	4	50
	720	5	5	5	78
	960	7	7	7	154
	1,200	8	8	8	201
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	120	126	134	143	56,507
	240	245	265	277	220,022
	480	355	386	430	468,492
	720	574	610	637	1,167,858
	960	616	674	771	1,427,250
	1,200	720	776	806	1,891,580

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

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Table 7-10: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 2 with a maximum hammer energy of 1,800 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	180	1	1	1	3
	360	2	2	2	13
	720	2	2	2	13
	1,080	3	3	3	28
	1,440	3	3	3	28
	1,800	4	4	4	50
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	180	64	67	68	14,024
	360	101	104	109	33,695
	720	187	208	239	136,172
	1,080	274	294	314	271,545
	1,440	330	339	347	361,652
	1,800	342	368	391	426,555
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	180	2	2	2	13
	360	3	3	3	28
	720	5	5	5	78
	1,080	7	7	7	154
	1,440	9	9	9	254
	1,800	10	10	10	314
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	180	183	207	239	134,585
	360	330	339	347	361,086
	720	574	610	637	1,167,858
	1,080	672	737	788	1,708,193
	1,440	777	880	993	2,434,179
	1,800	937	1,037	1,109	3,381,050

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 7-11: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 2 with a maximum hammer energy of 2,400 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	240	1	1	1	3
	480	2	2	2	13
	960	3	3	3	28
	1,440	3	3	3	28
	1,920	4	4	4	50
	2,400	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	240	83	87	90	23,624
	480	126	134	143	56,590
	960	245	265	277	220,362
	1,440	330	339	347	361,652
	1,920	357	387	431	470,562
	2,400	475	510	584	818,861
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	240	3	3	3	28
	480	4	4	4	50
	960	7	7	7	154
	1,440	9	9	9	254
	1,920	10	10	10	314
	2,400	11	11	11	380
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	240	245	265	277	220,022
	480	355	386	430	468,492
	960	616	674	771	1,427,250
	1,440	777	880	993	2,434,179
	1,920	975	1,089	1,137	3,724,332
	2,400	1,144	1,276	1,438	5,113,147

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 7-12: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 3 with a maximum hammer energy of 900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	90	1	1	1	3
	180	1	1	1	3
	360	2	2	2	13
	540	2	2	2	13
	720	2	2	2	13
	900	3	3	3	28
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	90	39	39	40	4,824
	180	67	68	70	14,544
	360	101	102	104	32,594
	540	138	161	164	81,278
	720	193	216	222	146,985
	900	239	258	272	209,036
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	90	2	2	2	13
	180	2	2	2	13
	360	3	3	3	28
	540	4	4	4	50
	720	5	5	5	78
	900	7	7	7	154
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	90	101	102	104	32,478
	180	193	216	222	146,100
	360	336	341	345	365,370
	540	381	424	481	566,742
	720	542	616	636	1,190,284
	900	619	638	660	1,278,650

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 7-13: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 3 with a maximum hammer energy of 1,200 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	120	1	1	1	3
	240	1	1	1	3
	480	2	2	2	13
	720	2	2	2	13
	960	3	3	3	28
	1,200	3	3	3	28
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	120	53	54	56	9,141
	240	82	85	89	22,890
	480	130	132	136	54,581
	720	193	216	222	146,985
	960	246	263	277	216,786
	1,200	295	322	333	326,497
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	120	2	2	2	13
	240	3	3	3	28
	480	4	4	4	50
	720	5	5	5	78
	960	7	7	7	154
	1,200	8	8	8	201
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	120	130	132	136	54,511
	240	246	262	276	216,602
	480	351	378	391	449,277
	720	542	616	636	1,190,284
	960	628	677	775	1,441,471
	1,200	736	776	799	1,890,069

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 7-14: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 3 with a maximum hammer energy of 1,800 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	180	1	1	1	3
	360	2	2	2	13
	720	2	2	2	13
	1,080	3	3	3	28
	1,440	3	3	3	28
	1,800	4	4	4	50
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	180	67	68	70	14,544
	360	101	102	104	32,594
	720	193	216	222	146,985
	1,080	277	296	315	275,433
	1,440	336	341	345	365,520
	1,800	348	373	387	436,522
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	180	2	2	2	13
	360	3	3	3	28
	720	5	5	5	78
	1,080	7	7	7	154
	1,440	9	9	9	254
	1,800	10	10	10	314
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	180	193	216	222	146,100
	360	336	341	345	365,370
	720	542	616	636	1,190,284
	1,080	680	745	787	1,743,297
	1,440	794	845	934	2,247,063
	1,800	936	1,013	1,120	3,227,214

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 7-15: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 3 with a maximum hammer energy of 2,400 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	240	1	1	1	3
	480	2	2	2	13
	960	3	3	3	28
	1,440	3	3	3	28
	1,920	4	4	4	50
	2,400	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	240	82	85	89	22,890
	480	130	132	136	54,581
	960	246	263	277	216,786
	1,440	336	341	345	365,520
	1,920	351	379	392	450,045
	2,400	457	484	591	735,648
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	240	3	3	3	28
	480	4	4	4	50
	960	7	7	7	154
	1,440	9	9	9	254
	1,920	10	10	10	314
	2,400	11	11	11	380
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	240	246	262	276	216,602
	480	351	378	391	449,277
	960	628	677	775	1,441,471
	1,440	794	845	934	2,247,063
	1,920	980	1,078	1,312	3,666,374
	2,400	1,206	1,315	1,441	5,439,372

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 7-16: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 1 with a maximum hammer energy of 900 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	0	0	0	0
		1	1	1	3
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	38	39	41	4,804
		130	137	142	59,037
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	1,339	1,612	1,993	8,205,052
		4,643	5,419	6,494	92,832,216
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	8,481	9,681	10,573	294,766,712
		13,061	14,796	15,955	688,608,840

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 7-17: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 1 with a maximum hammer energy of 1,200 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	0	0	0	0
		2	2	2	13
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	96	102	109	32,869
		397	420	437	553,973
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	2,499	2,962	3,684	27,738,690
		7,093	8,419	10,333	224,508,140
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	10,202	11,831	13,227	440,658,732
		15,697	18,080	19,928	1,029,744,061

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 7-18: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 1 with a maximum hammer energy of 1,800 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 7-3)	0	0	0	0
		3	3	3	28
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 7-3)	352	380	405	454,568
		1,014	1,069	1,118	3,584,199
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 7-3)	5,127	6,080	7,362	117,238,877
		12,408	15,418	18,815	750,603,131
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 7-3)	13,079	15,968	19,745	806,185,716
		20,526	24,576	28,500	1,909,340,334

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 7-19: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 1 with a maximum hammer energy of 2,400 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 7-3)	0	0	0	0
		3	3	4	34
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 7-3)	668	723	767	1,640,564
		1,566	1,653	1,730	8,577,412
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 7-3)	6,424	7,509	8,871	178,683,251
		13,786	17,217	20,866	936,110,378
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 7-3)	14,575	17,518	21,367	969,297,368
		22,070	26,422	30,301	2,207,121,260

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 7-20: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 2 with a maximum hammer energy of 900 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	0	0	0	0
		1	1	1	3
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	41	43	45	5,922
		130	139	151	60,952
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	1,623	1,752	1,935	9,647,444
		5,198	5,673	6,321	101,186,910
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	9,787	10,247	10,884	329,641,754
		14,086	14,992	15,808	705,553,436

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 7-21: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 2 with a maximum hammer energy of 1,200 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	0	0	0	0
		2	2	2	13
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	111	116	122	42,574
		392	418	451	549,807
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	2,912	3,138	3,426	30,923,363
		7,802	8,743	10,055	240,513,925
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	11,990	12,647	13,912	502,357,584
		17,326	18,449	19,502	1,068,888,991

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 7-22: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 2 with a maximum hammer energy of 1,800 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 7-3)	0	0	0	0
		3	3	3	28
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 7-3)	406	429	446	576,710
		1,054	1,108	1,169	3,852,998
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 7-3)	5,740	6,360	7,028	127,195,991
		13,849	16,274	18,930	834,137,255
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 7-3)	15,862	17,323	19,317	944,424,902
		22,692	25,254	27,551	2,007,081,690

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 7-23: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 2 with a maximum hammer energy of 2,400 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 7-3)	0	0	0	0
		3	4	4	49
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 7-3)	756	795	824	1,985,081
		1,636	1,723	1,796	9,319,303
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 7-3)	7,030	7,766	8,566	189,673,979
		15,366	18,086	21,059	1,030,969,600
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 7-3)	17,271	19,062	21,301	1,143,339,922
		24,259	27,018	29,573	2,297,253,226

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 7-24: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 3 with a maximum hammer energy of 900 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	0	0	0	0
		1	1	1	3
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	43	44	45	6,068
		154	163	172	83,647
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	1,667	1,836	2,022	10,602,429
		5,767	6,276	6,766	123,690,014
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	9,802	10,280	10,874	331,780,502
		14,584	15,789	16,663	783,463,054

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 7-25: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 3 with a maximum hammer energy of 1,200 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	0	0	0	0
		2	2	2	13
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	114	118	123	43,922
		459	481	499	725,458
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	3,014	3,261	3,582	33,420,226
		9,353	10,004	10,939	314,130,674
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	12,053	12,912	13,936	523,901,985
		17,522	19,500	20,878	1,197,255,405

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 7-26: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 3 with a maximum hammer energy of 1,800 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 7-3)	0	0	0	0
		3	3	3	28
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 7-3)	419	437	459	598,538
		1,142	1,191	1,229	4,454,408
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 7-3)	6,090	6,566	7,171	135,371,578
		18,797	20,027	23,113	1,259,937,747
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 7-3)	15,658	18,080	21,013	1,032,982,953
		23,446	27,005	29,994	2,306,114,328

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 7-27: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia One model location 3 with a maximum hammer energy of 2,400 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 7-3)	0	0	0	0
		4	4	4	50
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 7-3)	776	809	843	2,054,059
		1,745	1,808	1,856	10,255,674
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 7-3)	7,359	7,924	8,354	197,124,208
		20,262	21,848	26,325	1,499,865,693
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 7-3)	17,266	19,782	23,036	1,235,439,798
		24,941	28,769	31,701	2,617,236,636

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 7-28: Predicted distances and areas where harbour porpoise behavioural disturbance threshold of 145 dB re 1 μPa²s is exceeded during pile-driving at East Anglia One.

Model location	Hammer Energy (kJ)	Distance to 145 dB re 1 μPa²s SEL threshold (m)			Total area where SEL exceeds 145 dB re 1 μPa²s (m²)	Area of SCI where SEL exceeds 145 dB re 1 μPa²s (m²)
		Minimum	Average	Maximum		
Depth-averaged						
1	900	14,163	16,240	18,618	831,255,006	831,255,006
	1,200	16,208	18,377	21,723	1,070,473,609	1,070,473,609
	1,800	18,660	22,215	25,104	1,554,330,772	1,554,330,772
	2,400	21,955	25,078	29,503	1,981,173,042	1,981,173,042
2	900	14,571	16,312	17,722	829,660,281	829,660,281
	1,200	16,237	18,710	20,522	1,091,609,428	1,091,609,428
	1,800	19,684	22,823	25,543	1,631,855,977	1,631,402,127
	2,400	23,210	25,983	27,951	2,098,968,482	2,062,090,630
3	900	14,859	16,421	18,172	847,629,094	847,629,094
	1,200	17,951	19,518	22,001	1,192,176,030	1,192,176,030
	1,800	21,562	23,752	26,251	1,797,158,603	1,764,524,299
	2,400	24,314	27,295	31,714	2,336,790,881	2,215,993,437
Maximum-over-depth/Worst case						
1	900	21,250	24,243	27,446	2,042,373,814	2,041,950,593
	1,200	24,526	27,946	32,660	2,685,259,219	2,625,841,421
	1,800	28,534	33,689	39,415	3,763,386,842	3,497,456,911
	2,400	33,045	38,171	46,420	4,807,661,596	4,294,544,723
2	900	21,667	25,319	28,041	2,186,186,076	2,136,234,058
	1,200	25,591	28,942	32,383	2,828,190,722	2,668,840,620
	1,800	30,735	35,045	39,108	4,052,619,339	3,650,799,465
	2,400	35,792	40,129	45,801	5,188,232,807	4,550,456,984
3	900	23,738	27,237	31,572	2,502,341,738	2,359,943,848
	1,200	29,102	31,576	45,516	3,306,222,132	2,987,972,394
	1,800	34,470	38,492	45,685	4,862,111,173	4,240,162,386
	2,400	39,335	43,995	52,668	6,231,411,995	5,247,430,602

Table 7-29: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at East Anglia One modelling location 1 with maximum hammer energy of 900 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	7	7	99.7%
195 - 200	150	150	99.5%
190 - 195	804	804	99.0%
185 - 190	4,169	4,169	98.2%
180 - 185	18,944	18,944	96.7%
175 - 180	116,354	116,354	94.1%
170 - 175	995,268	995,268	89.4%
165 - 170	4,267,898	4,267,898	81.9%
160 - 165	15,610,599	15,610,599	70.7%
155 - 160	55,170,749	55,170,749	56.3%
150 - 155	189,378,784	189,378,785	40.7%
145 - 150	565,691,279	565,691,279	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	145	145	99.7%
195 - 200	827	827	99.5%
190 - 195	4,091	4,091	99.0%
185 - 190	25,659	25,659	98.2%
180 - 185	155,109	155,108	96.7%
175 - 180	1,015,231	1,015,231	94.1%
170 - 175	3,918,957	3,918,957	89.4%
165 - 170	14,977,963	14,977,963	81.9%
160 - 165	48,916,301	48,916,301	70.7%
155 - 160	163,669,699	163,669,699	56.3%
150 - 155	490,464,587	490,464,586	40.7%
145 - 150	1,319,225,247	1,318,802,027	26.8%

Table 7-30: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at East Anglia One modelling location 1 with maximum hammer energy of 1,200 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	38	38	99.7%
195 - 200	188	188	99.5%
190 - 195	1,351	1,351	99.0%
185 - 190	6,167	6,167	98.2%
180 - 185	28,238	28,238	96.7%
175 - 180	169,485	169,485	94.1%
170 - 175	1,622,364	1,622,364	89.4%
165 - 170	5,836,281	5,836,281	81.9%
160 - 165	21,281,801	21,281,801	70.7%
155 - 160	75,128,780	75,128,780	56.3%
150 - 155	254,504,105	254,504,105	40.7%
145 - 150	711,894,812	711,894,811	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	18	18	99.9%
200 - 205	224	224	99.7%
195 - 200	1,212	1,212	99.5%
190 - 195	5,744	5,744	99.0%
185 - 190	35,416	35,416	98.2%
180 - 185	255,849	255,849	96.7%
175 - 180	1,498,443	1,498,443	94.1%
170 - 175	5,440,792	5,440,792	89.4%
165 - 170	20,573,598	20,573,598	81.9%
160 - 165	66,217,166	66,217,166	70.7%
155 - 160	217,176,905	217,176,905	56.3%
150 - 155	627,628,117	627,628,117	40.7%
145 - 150	1,746,425,733	1,687,007,935	26.8%

Table 7-31: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at East Anglia One modelling location 1 with maximum hammer energy of 1,800 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	86	86	99.7%
195 - 200	333	333	99.5%
190 - 195	2,396	2,396	99.0%
185 - 190	9,875	9,875	98.2%
180 - 185	57,758	57,758	96.7%
175 - 180	493,264	493,264	94.1%
170 - 175	2,552,002	2,552,002	89.4%
165 - 170	9,375,124	9,375,124	81.9%
160 - 165	33,626,372	33,626,372	70.7%
155 - 160	116,848,646	116,848,646	56.3%
150 - 155	375,051,800	375,051,800	40.7%
145 - 150	1,016,313,115	1,016,313,115	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	61	61	99.9%
200 - 205	423	423	99.7%
195 - 200	2,065	2,065	99.5%
190 - 195	12,186	12,186	99.0%
185 - 190	69,711	69,711	98.2%
180 - 185	573,909	573,909	96.7%
175 - 180	2,334,813	2,334,813	94.1%
170 - 175	8,806,032	8,806,032	89.4%
165 - 170	31,139,338	31,139,338	81.9%
160 - 165	102,389,194	102,389,194	70.7%
155 - 160	325,961,606	325,961,606	56.3%
150 - 155	883,469,698	883,469,698	40.7%
145 - 150	2,408,627,804	2,142,697,874	26.8%

Table 7-32: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at East Anglia One modelling location 1 with maximum hammer energy of 2,400 kJ.

SEL contour band (dB re 1 μPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	128	128	99.7%
195 - 200	578	578	99.5%
190 - 195	3,427	3,427	99.0%
185 - 190	14,689	14,689	98.2%
180 - 185	87,512	87,512	96.7%
175 - 180	786,584	786,584	94.1%
170 - 175	3,517,699	3,517,699	89.4%
165 - 170	12,973,289	12,973,289	81.9%
160 - 165	45,985,599	45,985,599	70.7%
155 - 160	155,881,227	155,881,227	56.3%
150 - 155	488,113,645	488,113,645	40.7%
145 - 150	1,273,808,665	1,273,808,665	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	107	107	99.9%
200 - 205	650	650	99.7%
195 - 200	3,280	3,280	99.5%
190 - 195	16,532	16,532	99.0%
185 - 190	118,857	118,857	98.2%
180 - 185	836,943	836,943	96.7%
175 - 180	3,209,746	3,209,746	94.1%
170 - 175	12,339,062	12,339,062	89.4%
165 - 170	41,058,146	41,058,146	81.9%
160 - 165	136,984,899	136,984,899	70.7%
155 - 160	420,978,485	420,978,484	56.3%
150 - 155	1,156,071,557	1,156,071,557	40.7%
145 - 150	3,036,043,332	2,522,926,459	26.8%

Table 7-33: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at East Anglia One modelling location 2 with maximum hammer energy of 900 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	0	0	99.7%
195 - 200	133	133	99.5%
190 - 195	940	940	99.0%
185 - 190	4,403	4,403	98.2%
180 - 185	19,548	19,549	96.7%
175 - 180	118,893	118,892	94.1%
170 - 175	1,000,405	1,000,405	89.4%
165 - 170	4,321,838	4,321,838	81.9%
160 - 165	16,354,468	16,354,468	70.7%
155 - 160	60,372,241	60,372,241	56.3%
150 - 155	191,647,067	191,647,067	40.7%
145 - 150	555,820,345	555,820,345	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	149	149	99.7%
195 - 200	832	832	99.5%
190 - 195	3,933	3,933	99.0%
185 - 190	26,886	26,886	98.2%
180 - 185	150,415	150,415	96.7%
175 - 180	1,238,598	1,238,598	94.1%
170 - 175	4,025,094	4,025,094	89.4%
165 - 170	15,798,935	15,798,935	81.9%
160 - 165	53,481,577	53,481,577	70.7%
155 - 160	164,830,987	164,830,987	56.3%
150 - 155	484,444,541	484,444,541	40.7%
145 - 150	1,462,184,130	1,412,232,112	26.8%

Table 7-34: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at East Anglia One modelling location 2 with maximum hammer energy of 1,200 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	6	6	99.7%
195 - 200	205	205	99.5%
190 - 195	1,455	1,455	99.0%
185 - 190	6,037	6,037	98.2%
180 - 185	31,397	31,397	96.7%
175 - 180	174,704	174,704	94.1%
170 - 175	1,616,945	1,616,945	89.4%
165 - 170	6,003,847	6,003,847	81.9%
160 - 165	22,641,242	22,641,242	70.7%
155 - 160	79,892,441	79,892,441	56.3%
150 - 155	258,799,052	258,799,052	40.7%
145 - 150	722,442,096	722,442,096	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	20	20	99.9%
200 - 205	225	225	99.7%
195 - 200	1,247	1,247	99.5%
190 - 195	6,941	6,941	99.0%
185 - 190	37,866	37,865	98.2%
180 - 185	247,399	247,400	96.7%
175 - 180	1,811,007	1,811,007	94.1%
170 - 175	5,399,334	5,399,334	89.4%
165 - 170	22,045,344	22,045,344	81.9%
160 - 165	70,498,849	70,498,849	70.7%
155 - 160	223,922,861	223,922,861	56.3%
150 - 155	626,723,398	626,723,398	40.7%
145 - 150	1,877,496,231	1,718,146,130	26.8%

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Table 7-35: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at East Anglia One modelling location 2 with maximum hammer energy of 1,800 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	57	57	99.7%
195 - 200	404	404	99.5%
190 - 195	2,501	2,501	99.0%
185 - 190	10,556	10,556	98.2%
180 - 185	57,444	57,443	96.7%
175 - 180	509,089	509,089	94.1%
170 - 175	2,539,087	2,539,087	89.4%
165 - 170	9,808,831	9,808,831	81.9%
160 - 165	37,308,311	37,308,311	70.7%
155 - 160	119,965,826	119,965,826	56.3%
150 - 155	369,073,756	369,073,756	40.7%
145 - 150	1,092,580,115	1,092,126,266	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	64	64	99.9%
200 - 205	419	419	99.7%
195 - 200	2,095	2,095	99.5%
190 - 195	10,775	10,775	99.0%
185 - 190	74,161	74,161	98.2%
180 - 185	533,688	533,688	96.7%
175 - 180	2,718,765	2,718,765	94.1%
170 - 175	8,809,748	8,809,748	89.4%
165 - 170	33,842,754	33,842,754	81.9%
160 - 165	103,675,711	103,675,711	70.7%
155 - 160	323,208,606	323,208,606	56.3%
150 - 155	947,211,614	947,211,614	40.7%
145 - 150	2,632,530,937	2,230,711,063	26.8%

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Table 7-36: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at East Anglia One modelling location 2 with maximum hammer energy of 2,400 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	101	101	99.7%
195 - 200	701	701	99.5%
190 - 195	3,604	3,604	99.0%
185 - 190	15,376	15,376	98.2%
180 - 185	89,810	89,810	96.7%
175 - 180	799,979	799,979	94.1%
170 - 175	3,528,603	3,528,603	89.4%
165 - 170	13,591,217	13,591,217	81.9%
160 - 165	51,147,671	51,147,670	70.7%
155 - 160	157,002,513	157,002,513	56.3%
150 - 155	477,335,775	477,335,775	40.7%
145 - 150	1,395,453,132	1,358,575,280	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	110	110	99.9%
200 - 205	646	646	99.7%
195 - 200	3,044	3,044	99.5%
190 - 195	21,004	21,004	99.0%
185 - 190	107,227	107,227	98.2%
180 - 185	936,469	936,470	96.7%
175 - 180	3,474,635	3,474,635	94.1%
170 - 175	12,752,730	12,752,730	89.4%
165 - 170	45,389,726	45,389,726	81.9%
160 - 165	137,665,946	137,665,946	70.7%
155 - 160	417,655,246	417,655,246	56.3%
150 - 155	1,252,868,715	1,233,980,948	40.7%
145 - 150	3,317,357,308	2,698,469,252	26.8%

Table 7-37: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at East Anglia One modelling location 3 with maximum hammer energy of 900 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	0	0	99.7%
195 - 200	151	151	99.5%
190 - 195	907	907	99.0%
185 - 190	4,399	4,399	98.2%
180 - 185	19,851	19,851	96.7%
175 - 180	118,007	118,008	94.1%
170 - 175	1,011,945	1,011,945	89.4%
165 - 170	4,483,701	4,483,701	81.9%
160 - 165	16,643,961	16,643,961	70.7%
155 - 160	61,270,205	61,270,205	56.3%
150 - 155	189,912,845	189,912,845	40.7%
145 - 150	574,163,121	574,163,121	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	150	150	99.7%
195 - 200	828	828	99.5%
190 - 195	3,833	3,833	99.0%
185 - 190	27,425	27,425	98.2%
180 - 185	156,141	156,141	96.7%
175 - 180	1,205,127	1,205,127	94.1%
170 - 175	4,102,411	4,102,411	89.4%
165 - 170	15,671,422	15,671,422	81.9%
160 - 165	54,268,920	54,268,920	70.7%
155 - 160	163,376,530	163,376,530	56.3%
150 - 155	493,282,257	493,282,257	40.7%
145 - 150	1,770,246,693	1,627,848,803	26.8%

Table 7-38: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at East Anglia One modelling location 3 with maximum hammer energy of 1,200 kJ.

SEL contour band (dB re 1 μPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	16	16	99.7%
195 - 200	213	213	99.5%
190 - 195	1,409	1,409	99.0%
185 - 190	6,091	6,091	98.2%
180 - 185	31,443	31,443	96.7%
175 - 180	174,772	174,772	94.1%
170 - 175	1,641,365	1,641,365	89.4%
165 - 170	6,233,894	6,233,894	81.9%
160 - 165	23,153,828	23,153,828	70.7%
155 - 160	81,412,549	81,412,549	56.3%
150 - 155	240,281,506	240,281,506	40.7%
145 - 150	839,238,944	839,238,944	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	19	19	99.9%
200 - 205	231	231	99.7%
195 - 200	1,218	1,218	99.5%
190 - 195	6,969	6,969	99.0%
185 - 190	38,610	38,610	98.2%
180 - 185	254,316	254,315	96.7%
175 - 180	1,778,946	1,778,946	94.1%
170 - 175	5,540,764	5,540,764	89.4%
165 - 170	22,026,764	22,026,764	81.9%
160 - 165	72,429,329	72,429,329	70.7%
155 - 160	209,427,248	209,427,248	56.3%
150 - 155	683,660,580	683,660,580	40.7%
145 - 150	2,311,057,138	1,992,807,400	26.8%

Table 7-39: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at East Anglia One modelling location 3 with maximum hammer energy of 1,800 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	71	71	99.7%
195 - 200	404	404	99.5%
190 - 195	2,421	2,420	99.0%
185 - 190	10,619	10,619	98.2%
180 - 185	58,594	58,594	96.7%
175 - 180	510,570	510,571	94.1%
170 - 175	2,604,424	2,604,424	89.4%
165 - 170	10,062,692	10,062,692	81.9%
160 - 165	37,776,552	37,776,553	70.7%
155 - 160	123,112,549	123,112,549	56.3%
150 - 155	350,626,509	350,626,509	40.7%
145 - 150	1,272,393,198	1,239,758,894	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	63	63	99.9%
200 - 205	425	425	99.7%
195 - 200	2,028	2,028	99.5%
190 - 195	11,197	11,197	99.0%
185 - 190	71,112	71,112	98.2%
180 - 185	550,258	550,258	96.7%
175 - 180	2,695,164	2,695,164	94.1%
170 - 175	8,917,191	8,917,191	89.4%
165 - 170	34,046,541	34,046,541	81.9%
160 - 165	107,325,048	107,325,048	70.7%
155 - 160	303,508,271	303,508,272	56.3%
150 - 155	1,121,425,417	1,117,462,332	40.7%
145 - 150	3,283,558,455	2,665,572,752	26.8%

Table 7-40: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at East Anglia One modelling location 3 with maximum hammer energy of 2,400 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	118	118	99.7%
195 - 200	682	682	99.5%
190 - 195	3,562	3,563	99.0%
185 - 190	15,661	15,661	98.2%
180 - 185	89,623	89,623	96.7%
175 - 180	806,852	806,852	94.1%
170 - 175	3,646,547	3,646,547	89.4%
165 - 170	13,837,322	13,837,322	81.9%
160 - 165	51,417,989	51,417,989	70.7%
155 - 160	160,154,651	160,154,651	56.3%
150 - 155	475,952,103	475,952,103	40.7%
145 - 150	1,630,865,772	1,510,068,328	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	111	111	99.9%
200 - 205	648	648	99.7%
195 - 200	2,974	2,974	99.5%
190 - 195	20,783	20,783	99.0%
185 - 190	103,002	103,002	98.2%
180 - 185	913,340	913,339	96.7%
175 - 180	3,521,780	3,521,780	94.1%
170 - 175	12,679,815	12,679,815	89.4%
165 - 170	45,817,483	45,817,483	81.9%
160 - 165	139,820,013	139,820,013	70.7%
155 - 160	409,275,007	409,275,007	56.3%
150 - 155	1,478,796,590	1,398,599,008	40.7%
145 - 150	4,140,460,448	3,236,676,638	26.8%

Table 7-41: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at East Anglia One model location 1 with a maximum hammer energy of 900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	900	39	39	39	4,772
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	900	83	89	100	24,784
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	900	83	89	100	24,784
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 7-42: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at East Anglia One model location 1 with a maximum hammer energy of 1,200 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	1,200	42	42	42	5,535
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,200	104	107	109	35,901
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,200	104	107	109	35,901
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 7-43: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at East Anglia One model location 1 with a maximum hammer energy of 1,800 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	1,800	59	61	61	11,497
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,800	140	149	190	69,764
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,800	140	149	190	69,764
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 7-44: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at East Anglia One model location 1 with a maximum hammer energy of 2,400 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m²)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,400	70	71	75	15,848
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 μPa^2s)	4.0 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 μPa^2s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,400	192	214	228	144,417
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 μPa^2s)	4.0 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 μPa^2s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,400	192	214	228	144,417
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 μPa^2s)	4.0 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 μPa^2s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 7-45: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at East Anglia One model location 2 with a maximum hammer energy of 900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	900	35	35	36	3,856
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 $\mu Pa^2 s$)	3.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 $\mu Pa^2 s$)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	900	89	92	95	26,647
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 $\mu Pa^2 s$)	3.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 $\mu Pa^2 s$)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	900	89	92	95	26,647
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 $\mu Pa^2 s$)	3.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 $\mu Pa^2 s$)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 7-46: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at East Anglia One model location 2 with a maximum hammer energy of 1,200 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	1,200	39	40	40	4,999
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,200	106	108	123	36,508
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,200	106	108	123	36,508
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 7-47: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at East Anglia One model location 2 with a maximum hammer energy of 1,800 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	1,800	55	56	56	9,791
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,800	154	160	186	80,656
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,800	154	160	186	80,656
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 7-48: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at East Anglia One model location 2 with a maximum hammer energy of 2,400 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m²)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,400	65	69	83	14,859
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,400	189	215	241	145,114
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,400	189	215	241	145,114
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 7-49: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at East Anglia One model location 3 with a maximum hammer energy of 900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	900	35	35	37	3,937
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	900	93	94	97	27,956
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	900	93	94	97	27,956
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 7-50: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at East Anglia One model location 3 with a maximum hammer energy of 1,200 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	1,200	40	40	40	5,020
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,200	105	106	107	35,405
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,200	105	106	107	35,405
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

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Table 7-51: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at East Anglia One model location 3 with a maximum hammer energy of 1,800 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m²)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	1,800	56	57	59	10,180
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,800	161	163	166	83,422
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,800	161	163	166	83,422
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 7-52: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at East Anglia One model location 3 with a maximum hammer energy of 2,400 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,400	68	69	71	14,937
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 $\mu Pa^2 s$)	4.0 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 $\mu Pa^2 s$)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,400	218	223	239	156,521
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 $\mu Pa^2 s$)	4.0 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 $\mu Pa^2 s$)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,400	218	223	239	156,521
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 $\mu Pa^2 s$)	4.0 hour pile-driving sequence (see Table 7-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 $\mu Pa^2 s$)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 7-53: Predicted areas where harbour porpoise behavioural disturbance threshold of 145 dB re 1 µPa²s is exceeded during concurrent pile-driving at East Anglia One.

Model location	Hammer Energy (kJ)	Total area where SEL exceeds 145 dB re 1 µPa²s (m^2)	Area of SCI where SEL exceeds 145 dB re 1 µPa²s (m^2)
Depth-averaged			
1 and 2	900	1,426,887,875	1,426,887,875
	1,200	1,797,636,603	1,797,636,603
	1,800	2,498,812,347	2,498,362,023
	2,400	3,052,814,914	3,015,885,829
Maximum-over-depth/Worst case			
1 and 2	900	3,159,377,330	3,108,938,743
	1,200	3,941,928,232	3,748,907,056
	1,800	5,291,003,150	4,809,994,383
	2,400	6,479,404,382	5,691,242,989

Table 7-54: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at East Anglia One locations 1 and 2 with maximum hammer energy of 900 kJ.

SEL contour band (dB re 1 μPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	7	7	99.7%
195 - 200	284	284	99.5%
190 - 195	1,744	1,744	99.0%
185 - 190	8,573	8,572	98.2%
180 - 185	38,492	38,493	96.7%
175 - 180	235,246	235,246	94.1%
170 - 175	1,995,673	1,995,673	89.4%
165 - 170	8,589,736	8,589,736	81.9%
160 - 165	31,965,067	31,965,067	70.7%
155 - 160	115,542,989	115,542,989	56.3%
150 - 155	379,325,126	379,325,126	40.7%
145 - 150	889,184,937	889,184,937	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	294	294	99.7%
195 - 200	1,659	1,659	99.5%
190 - 195	8,023	8,023	99.0%
185 - 190	52,545	52,545	98.2%
180 - 185	305,524	305,524	96.7%
175 - 180	2,253,829	2,253,829	94.1%
170 - 175	7,944,050	7,944,050	89.4%
165 - 170	30,776,898	30,776,898	81.9%
160 - 165	102,397,878	102,397,878	70.7%
155 - 160	328,500,686	328,500,685	56.3%
150 - 155	800,472,086	800,472,085	40.7%
145 - 150	1,886,663,858	1,836,225,272	26.8%

Table 7-55: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at East Anglia One locations 1 and 2 with maximum hammer energy of 1,200 kJ.

SEL contour band (dB re 1 μPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	44	44	99.7%
195 - 200	393	393	99.5%
190 - 195	2,807	2,807	99.0%
185 - 190	12,204	12,204	98.2%
180 - 185	59,634	59,635	96.7%
175 - 180	344,189	344,189	94.1%
170 - 175	3,239,309	3,239,309	89.4%
165 - 170	11,840,128	11,840,128	81.9%
160 - 165	43,923,043	43,923,043	70.7%
155 - 160	155,021,221	155,021,221	56.3%
150 - 155	488,418,176	488,418,176	40.7%
145 - 150	1,094,775,454	1,094,775,455	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	38	38	99.9%
200 - 205	449	449	99.7%
195 - 200	2,459	2,459	99.5%
190 - 195	12,685	12,685	99.0%
185 - 190	73,282	73,282	98.2%
180 - 185	503,248	503,249	96.7%
175 - 180	3,309,450	3,309,450	94.1%
170 - 175	10,840,126	10,840,126	89.4%
165 - 170	42,618,941	42,618,941	81.9%
160 - 165	136,716,015	136,716,015	70.7%
155 - 160	441,099,767	441,099,767	56.3%
150 - 155	1,254,351,515	1,254,351,515	40.7%
145 - 150	2,052,400,256	1,859,379,079	26.8%

Table 7-56: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at East Anglia One locations 1 and 2 with maximum hammer energy of 1,800 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	143	143	99.7%
195 - 200	737	737	99.5%
190 - 195	4,896	4,896	99.0%
185 - 190	20,432	20,432	98.2%
180 - 185	115,202	115,202	96.7%
175 - 180	1,002,353	1,002,353	94.1%
170 - 175	5,091,089	5,091,089	89.4%
165 - 170	19,183,955	19,183,955	81.9%
160 - 165	70,934,683	70,934,683	70.7%
155 - 160	236,814,472	236,814,472	56.3%
150 - 155	647,424,280	647,424,280	40.7%
145 - 150	1,518,220,105	1,517,769,781	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	125	125	99.9%
200 - 205	842	842	99.7%
195 - 200	4,160	4,160	99.5%
190 - 195	22,961	22,961	99.0%
185 - 190	143,872	143,872	98.2%
180 - 185	1,107,598	1,107,598	96.7%
175 - 180	5,053,578	5,053,578	94.1%
170 - 175	17,615,780	17,615,780	89.4%
165 - 170	64,982,092	64,982,092	81.9%
160 - 165	206,064,905	206,064,905	70.7%
155 - 160	649,170,213	649,170,213	56.3%
150 - 155	1,830,681,313	1,830,681,312	40.7%
145 - 150	2,516,155,710	2,035,146,944	26.8%

Table 7-57: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at East Anglia One locations 1 and 2 with maximum hammer energy of 2,400 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	228	228	99.7%
195 - 200	1,279	1,279	99.5%
190 - 195	7,031	7,031	99.0%
185 - 190	30,065	30,065	98.2%
180 - 185	177,322	177,322	96.7%
175 - 180	1,586,563	1,586,563	94.1%
170 - 175	7,046,302	7,046,302	89.4%
165 - 170	26,564,506	26,564,506	81.9%
160 - 165	97,133,270	97,133,270	70.7%
155 - 160	312,883,741	312,883,741	56.3%
150 - 155	795,832,732	795,832,732	40.7%
145 - 150	1,811,551,876	1,774,622,790	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	217	217	99.9%
200 - 205	1,296	1,296	99.7%
195 - 200	6,323	6,323	99.5%
190 - 195	37,536	37,536	99.0%
185 - 190	226,084	226,084	98.2%
180 - 185	1,773,412	1,773,413	96.7%
175 - 180	6,684,381	6,684,381	94.1%
170 - 175	25,091,792	25,091,792	89.4%
165 - 170	86,447,872	86,447,872	81.9%
160 - 165	274,650,846	274,650,846	70.7%
155 - 160	838,633,730	838,633,730	56.3%
150 - 155	2,408,940,273	2,390,052,505	40.7%
145 - 150	2,836,910,618	2,067,636,993	26.8%

8.0 EAST ANGLIA THREE

This section presents the underwater sound propagation modelling undertaken to predict potential impacts to harbour porpoise and fish from pile-driving at the East Anglia Three development. Project specific model inputs (such as maximum hammer energy, model locations and hammer soft-start/ramp-up procedures) are firstly introduced, before the modelling results are presented. The propagation modelling has considered scenarios involving single pile-driving (i.e. the use of a single pile installation vessel), and concurrent pile-driving involving the use of two pile-driving vessels.

8.1 Model Inputs

A number of different modelling scenarios have been conducted to estimate potential impacts from pile-driving at the East Anglia Three wind farm development, which take into account both the consented and planned project design envelopes. The modelled scenarios that have been conducted for pile-driving at East Anglia Three are based on those of the scenarios modelled for East Anglia One and are summarised in Table 8-1. These scenarios were selected based on the information provided by East Anglia Offshore Wind Limited (*pers. comm.*) as well as the consented project description (East Anglia Offshore Wind Limited, 2012a) and previous noise modelling (East Anglia Offshore Wind Limited, 2012b). The modelling scenarios have been selected to cover a broad range of possible pile-driving events at East Anglia Three involving the use of different maximum hammer energies and different pile installation durations depending on the use of different foundation types (e.g. multi-leg jacket piles or monopiles).

Table 8-1: Noise modelling scenarios for pile-driving at East Anglia Three.

Infrastructure	Foundation type	Pile diameter (m)	Maximum Hammer Energy (kJ)	Duration to install a single pile (hours)
Consented Project				
Met mast	Monopile	6.5	1,800	5.5
Planned Project				
Wind turbine generators	Multi-leg jacket piles	2.5	1,200 (base case) 1,800 (contingency)	3.5
OSS	Multi-leg jacket piles	2.5	1,200 (base case) 3,000 (contingency)	4.0

The propagation modelling has been conducted at a number of different locations within the East Anglia Three wind farm development area in order to provide a range of estimates for potential injury and disturbance to harbour porpoise. The modelling locations that have been used to assess potential injury and disturbance to harbour porpoise due to pile-driving at East Anglia Three are shown in Figure 8-1 and Table 8-2.

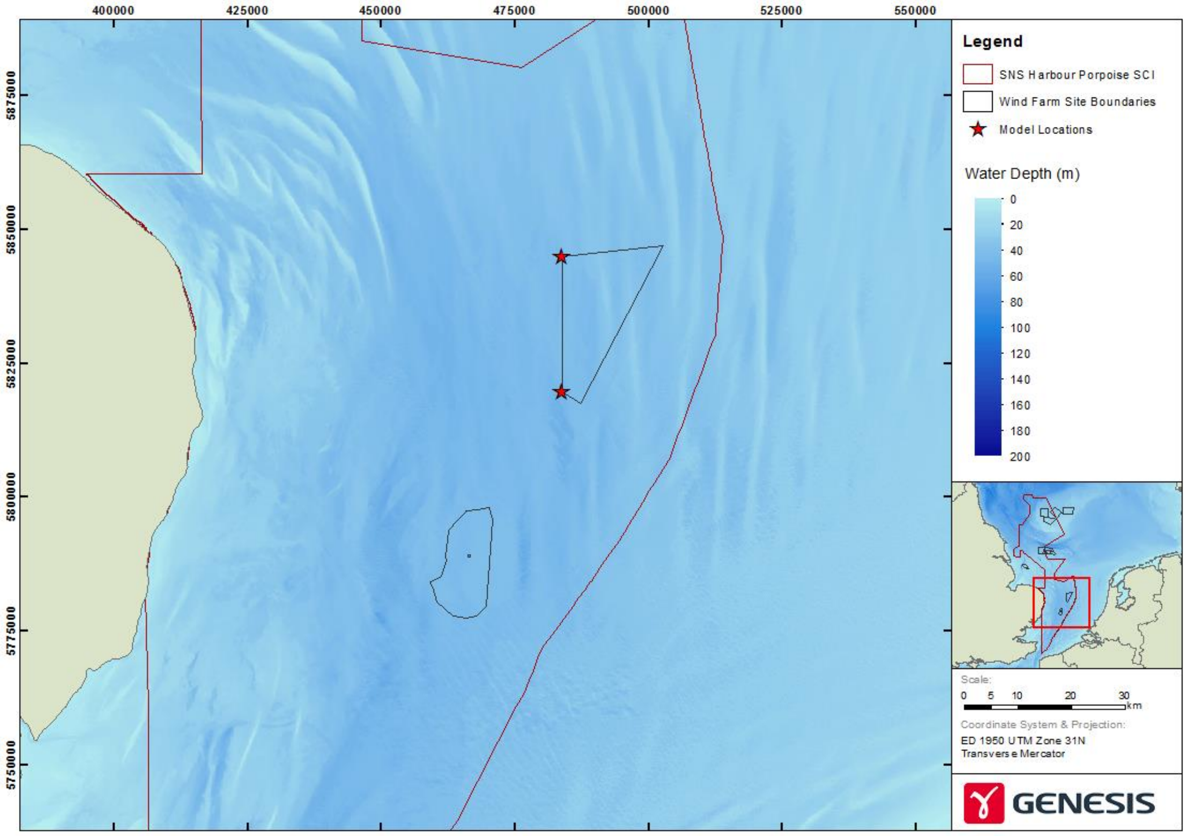

Figure 8-1: Noise modelling locations for pile-driving at East Anglia Three.

Table 8-2: Noise modelling locations for pile-driving at East Anglia Three.

Model Location	Longitude (Decimal degrees)	Latitude (Decimal degrees)
Location 1	2.76081	52.75370
Location 2	2.76027	52.52639

The soft-start/ramp-up procedures that have been used to estimate the effect of cumulative SEL during pile-driving at East Anglia Three are shown in Table 8-3. It has been assumed that the pile-driving at East Anglia One will be initiated at 20% of the maximum hammer energy and ramp-up to 100% of the maximum energy over a period of 20 minutes (Table 8-3). Thereafter the pile-driving has been assumed to remain at 100% maximum energy until the piles have been installed. Different total pile-driving durations have been modelled depending on the estimated durations that may be required to install the piles (see Table 8-1).

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Table 8-3: Hammer soft-start/ramp-up procedure assumed in the modelling of pile-driving at East Anglia Three.

Percentage of maximum hammer energy (%)	Duration (minutes)	Hammer strike rate (blows/minute)	Hammer strike interval (s)	Number of pile strikes
3.5-hour pile-driving duration				
20	7.5	10	6	75
40	7.5	10	6	75
60	7.5	15	4	112
80	7.5	15	4	113
100	180	35	2	6,300
4.0-hour pile-driving duration				
20	7.5	10	6	75
40	7.5	10	6	75
60	7.5	15	4	112
80	7.5	15	4	113
100	210	35	2	7,350
5.5-hour pile-driving duration				
20	7.5	10	6	75
40	7.5	10	6	75
60	7.5	15	4	112
80	7.5	15	4	113
100	300	35	2	10,500

8.2 Single Pile-driving Modelling Results

Propagation modelling for single pile-driving (i.e. only using a single pile installation vessel) at East Anglia Three has been conducted at the model locations shown in Figure 8-1 and Table 8-2, with the different maximum hammer energies shown in Table 8-1 being modelled.

Maximum-over-depth zero-to-peak SPL sound fields have been estimated (see Section 4.2.5.2) and compared to the Southall and NOAA thresholds for the potential onset of PTS and TTS to harbour porpoise. Distances and areas of potential PTS and TTS onset due to zero-to-peak SPL threshold exceedance have been calculated for different percentages of the maximum hammer energy, demonstrating the increase of potential injury zones with increasing hammer energy throughout the soft-start/ramp-up phase. The predicted distances and areas where the Southall and NOAA zero-to-peak SPL thresholds are exceeded are shown in Table 8-4 to Table 8-11 for the various maximum hammer energies that have been modelled for pile-driving at East Anglia Three. Example maximum-over-depth zero-to-peak

SPL sound fields are shown in Figure E-1 to Figure E-4 in Appendix E of this report for the modelling scenarios involving pile-driving at East Anglia Three with maximum hammer energies of 1,200 kJ and 3,000 kJ.

Cumulative SEL scenarios have been conducted in order to predict potential PTS and TTS onset in harbour porpoise due to exposure to pulses from multiple pile-strikes by estimating areas where the Southall and NOAA cumulative SEL thresholds are exceeded. The cumulative SEL scenarios have been conducted using the "fleeing animal" modelling procedure discussed in Section 4.2.5.3, and take into account the hammer soft-start/ramp-up procedures outlined in Table 8-3. As discussed in Section 4.2.5.3, the cumulative SEL modelling has been conducted for animals receiving depth-averaged SEL for each piling pulse, as well as maximum-over-depth SEL for each piling pulse (which is the absolute worst case scenario). The predicted distances and areas where the Southall and NOAA cumulative SEL thresholds for PTS and TTS onset are exceeded during pile-driving at East Anglia Three are detailed in Table 8-12 to Table 8-19. Example maps showing the predicted areas where the cumulative SEL thresholds are exceeded are also shown in Figure E-5 to Figure E-8 for the pile-driving at East Anglia Three with maximum hammer energies of 1,200 kJ and 3,000 kJ.

Depth-averaged and maximum-over-depth unweighted single pulse SEL sound fields have been predicted in order to estimate potential disturbance to harbour porpoise due to pile-driving at East Anglia Three. Example depth-averaged and maximum-over-depth unweighted single pulse SEL sound fields for pile-driving at East Anglia Three with maximum hammer energies of 1,200 kJ and 3,000 kJ are shown in Figure E-9 to Figure E-16 in Appendix E of this report.

The predicted depth-averaged and maximum-over-depth unweighted SEL sound fields have been compared to the behavioural disturbance threshold of 145 dB re 1 $\mu Pa^2 s$ proposed by Lucke *et al*. (2009) and Thompson *et al.* (2013b). The predicted distances and areas of this threshold exceedance are shown in Table 8-20 for both the depth-averaged and maximum-over-depth results. The area of threshold exceedance has been calculated as the total area above the threshold, as well as the area within the SCI that is above the threshold.

The probability of displacement of harbour porpoise has been further evaluated using the behavioural/dose response curve discussed in Section 3.2.1.2. The predicted areas and probabilities of behavioural disturbance to harbour porpoise for different SEL contour bands are detailed in Table 8-21 to Table 8-28 for both the depth-averaged and maximum-over-depth SEL modelling results.

The predicted zero-to-peak SPL and cumulative SEL for the East Anglia Three modelling scenarios have been compared to the Popper *et al*. (2014) thresholds for estimating potential injury to fish. The predicted distances and areas where injury to fish may potentially occur from pile-driving at East Anglia Three with various hammer energies are shown in Table 8-29 to Table 8-36.

8.3 Concurrent Pile-driving Modelling Results

Example concurrent pile-driving scenarios at East Anglia Three have been conducted to estimate the increase in potential behavioural disturbance zones for harbour porpoise due to the use of two installation vessels. The concurrent pile driving modelling scenarios involve piling at model locations 1 and 2 (see Figure 8-1 and Table 8-2) where the same hammer energy is used at each location. The concurrent pile-driving modelling has been conducted for the range of hammer energies shown in Table 8-1.

The predicted areas where the harbour porpoise behavioural disturbance threshold of 145 dB re 1 µPa^{2}s is exceeded for the concurrent pile-driving scenarios at East Anglia Three are shown in Table 8-37. Table 8-38 to Table 8-41 further show the probability of potential displacement of harbour porpoise for different SEL bands (using the behavioural/dose response curve discussed in Section 3.2.1.2).

Table 8-4: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia Three model location 1 with a maximum hammer energy of 1,200 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	120	1	1	1	3
	240	1	1	1	3
	480	2	2	2	13
	720	2	2	2	13
	960	2	2	2	13
	1,200	3	3	3	28
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	120	55	58	59	10,601
	240	87	88	89	24,193
	480	138	173	180	94,272
	720	196	198	199	123,526
	960	224	229	241	165,140
	1,200	257	306	347	299,284
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	120	2	2	2	13
	240	2	2	2	13
	480	4	4	4	50
	720	5	5	5	78
	960	7	7	7	154
	1,200	8	8	8	201
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	120	138	172	180	93,659
	240	223	229	240	165,001
	480	429	456	485	652,530
	720	521	598	655	1,128,346
	960	695	802	871	2,027,136
	1,200	879	955	1,010	2,862,855

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 8-5: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia Three model location 1 with a maximum hammer energy of 1,800 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	180	1	1	1	3
	360	1	1	1	3
	720	2	2	2	13
	1,080	3	3	3	28
	1,440	3	3	3	28
	1,800	4	4	4	50
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	180	64	66	67	13,661
	360	104	106	112	35,347
	720	196	198	199	123,526
	1,080	239	250	281	196,605
	1,440	304	352	374	390,425
	1,800	381	431	467	583,453
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	180	2	2	2	13
	360	3	3	3	28
	720	5	5	5	78
	1,080	8	8	8	201
	1,440	9	9	9	254
	1,800	10	10	10	314
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	180	195	198	199	123,440
	360	304	351	374	386,967
	720	521	598	655	1,128,346
	1,080	746	892	971	2,500,921
	1,440	906	1,006	1,107	3,180,304
	1,800	1,037	1,219	1,404	4,691,796

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 8-6: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia Three model location 1 with a maximum hammer energy of 2,400 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	240	1	1	1	3
	480	2	2	2	13
	960	2	2	2	13
	1,440	3	3	3	28
	1,920	4	4	4	50
	2,400	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	240	87	88	89	24,193
	480	138	173	180	94,272
	960	224	229	241	165,140
	1,440	304	352	374	390,425
	1,920	429	457	485	654,479
	2,400	481	490	503	753,622
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	240	2	2	2	13
	480	4	4	4	50
	960	7	7	7	154
	1,440	9	9	9	254
	1,920	10	10	10	314
	2,400	11	11	11	380
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	240	223	229	240	165,001
	480	429	456	485	652,530
	960	695	802	871	2,027,136
	1,440	906	1,006	1,107	3,180,304
	1,920	1,119	1,249	1,504	4,923,508
	2,400	1,298	1,570	1,728	7,760,838

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 8-7: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia Three model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	300	1	1	1	3
	600	2	2	2	13
	1,200	3	3	3	28
	1,800	4	4	4	50
	2,400	5	5	5	78
	3,000	6	6	6	113
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	300	94	100	103	31,123
	600	182	185	193	107,504
	1,200	257	306	347	299,284
	1,800	381	431	467	583,453
	2,400	481	490	503	753,622
	3,000	532	626	681	1,233,339
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	300	3	3	3	28
	600	4	4	4	50
	1,200	8	8	8	201
	1,800	10	10	10	314
	2,400	11	11	11	380
	3,000	12	12	12	452
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	300	257	306	347	298,073
	600	481	490	502	752,980
	1,200	879	955	1,010	2,862,855
	1,800	1,037	1,219	1,404	4,691,796
	2,400	1,298	1,570	1,728	7,760,838
	3,000	1,571	1,812	2,116	10,342,845

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 8-8: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia Three model location 2 with a maximum hammer energy of 1,200 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m²) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	120	1	1	1	3
	240	1	1	1	3
	480	2	2	2	13
	720	2	2	2	13
	960	3	3	3	28
	1,200	3	3	3	28
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	120	44	45	46	6,482
	240	75	78	79	18,896
	480	131	133	134	55,518
	720	175	209	219	137,633
	960	214	221	244	153,593
	1,200	245	253	289	200,452
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	120	2	2	2	13
	240	3	3	3	28
	480	4	4	4	50
	720	5	5	5	78
	960	6	6	6	113
	1,200	8	8	8	201
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	120	131	133	134	55,483
	240	213	221	244	153,268
	480	407	424	443	563,651
	720	579	605	689	1,150,806
	960	703	745	779	1,742,366
	1,200	727	781	886	1,913,484

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

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Table 8-9: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia Three model location 2 with a maximum hammer energy of 1,800 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m²) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	180	1	1	1	3
	360	1	1	1	3
	720	2	2	2	13
	1,080	3	3	3	28
	1,440	3	3	3	28
	1,800	4	4	4	50
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	180	63	65	69	13,315
	360	106	107	109	35,795
	720	175	209	219	137,633
	1,080	219	239	252	179,604
	1,440	291	323	352	327,101
	1,800	364	398	434	497,483
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	180	2	2	2	13
	360	3	3	3	28
	720	5	5	5	78
	1,080	7	7	7	154
	1,440	9	9	9	254
	1,800	10	10	10	314
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	180	175	209	219	137,127
	360	290	319	352	320,007
	720	579	605	689	1,150,806
	1,080	706	751	785	1,768,835
	1,440	794	901	958	2,546,752
	1,800	921	1,007	1,114	3,189,072

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 8-10: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia Three model location 2 with a maximum hammer energy of 2,400 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	240	1	1	1	3
	480	2	2	2	13
	960	3	3	3	28
	1,440	3	3	3	28
	1,920	4	4	4	50
	2,400	4	4	4	50
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	240	75	78	79	18,896
	480	131	133	134	55,518
	960	214	221	244	153,593
	1,440	291	323	352	327,101
	1,920	408	424	443	564,675
	2,400	432	511	590	829,575
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	240	3	3	3	28
	480	4	4	4	50
	960	6	6	6	113
	1,440	9	9	9	254
	1,920	10	10	10	314
	2,400	11	11	11	380
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	240	213	221	244	153,268
	480	407	424	443	563,651
	960	703	745	779	1,742,366
	1,440	794	901	958	2,546,752
	1,920	960	1,047	1,130	3,448,271
	2,400	1,156	1,238	1,401	4,810,214

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 8-11: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia Three model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m²) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	300	1	1	1	3
	600	2	2	2	13
	1,200	3	3	3	28
	1,800	4	4	4	50
	2,400	4	4	4	50
	3,000	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	300	82	94	105	27,680
	600	166	168	169	88,779
	1,200	245	253	289	200,452
	1,800	364	398	434	497,483
	2,400	432	511	590	829,575
	3,000	584	621	718	1,212,923
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	300	3	3	3	28
	600	4	4	4	50
	1,200	8	8	8	201
	1,800	10	10	10	314
	2,400	11	11	11	380
	3,000	12	12	12	452
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	300	244	252	289	199,606
	600	431	509	589	822,300
	1,200	727	781	886	1,913,484
	1,800	921	1,007	1,114	3,189,072
	2,400	1,156	1,238	1,401	4,810,214
	3,000	1,298	1,451	1,619	6,604,108

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 8-12: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia Three model location 1 with a maximum hammer energy of 1,200 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 8-3)	0	0	0	0
		5	5	5	78
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 8-3)	138	148	156	68,433
		473	496	524	772,383
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 8-3)	3,159	3,536	4,044	39,410,134
		8,704	9,944	11,458	311,700,973
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 8-3)	12,918	13,448	14,437	567,691,890
		17,647	18,509	19,383	1,075,433,072

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 8-13: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia Three model location 1 with a maximum hammer energy of 1,800 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 8-3)	0	0	0	0
		5	5	5	78
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 8-3)	472	508	539	812,036
		1,141	1,200	1,244	4,518,649
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 8-3)	5,743	6,700	7,805	141,827,112
		14,285	16,804	19,788	893,882,926
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 8-3)	17,290	18,041	19,178	1,021,554,313
		22,982	25,106	27,150	1,980,175,980

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 8-14: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia Three model location 1 with a maximum hammer energy of 2,400 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 8-3)	0	0	0	0
		5	5	5	78
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 8-3)	845	915	973	2,633,152
		1,715	1,809	1,888	10,274,866
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 8-3)	7,098	8,125	9,325	208,315,594
		16,136	18,636	21,591	1,096,789,953
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 8-3)	18,790	19,734	20,910	1,222,320,384
		24,981	26,994	29,064	2,288,450,560

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 8-15: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia Three model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 8-3)	0	0	0	0
		6	6	6	113
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 8-3)	1,292	1,394	1,469	6,100,987
		2,416	2,534	2,653	20,160,990
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 8-3)	9,659	11,396	13,295	410,561,092
		20,575	25,465	31,871	2,074,125,151
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 8-3)	21,948	23,704	25,221	1,764,085,941
		28,865	32,833	36,990	3,394,582,667

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 8-16: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia Three model location 2 with a maximum hammer energy of 1,200 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m²) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 8-3)	0	0	0	0
		5	5	5	78
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 8-3)	84	91	96	25,974
		440	473	517	703,266
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 8-3)	2,626	2,953	3,535	27,461,993
		7,861	8,575	9,708	231,022,800
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 8-3)	11,525	12,064	12,904	456,939,704
		17,218	18,048	19,508	1,022,527,075

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 8-17: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia Three model location 2 with a maximum hammer energy of 1,800 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m²) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 8-3)	0	0	0	0
		5	5	5	78
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 8-3)	326	354	380	392,865
		1,129	1,201	1,297	4,530,612
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 8-3)	5,231	5,935	6,974	110,980,388
		12,631	15,159	17,199	725,000,862
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 8-3)	15,533	16,292	17,682	833,527,801
		23,336	24,537	26,984	1,891,020,693

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 8-18: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia Three model location 2 with a maximum hammer energy of 2,400 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 8-3)	0	0	0	0
		5	5	5	78
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 8-3)	638	693	748	1,510,009
		1,672	1,772	1,907	9,863,019
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 8-3)	6,640	7,343	8,588	169,685,879
		14,256	16,875	19,222	897,508,000
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 8-3)	17,032	17,957	19,397	1,012,437,930
		25,256	26,435	28,988	2,194,445,524

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 8-19: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at East Anglia Three model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 8-3)	0	0	0	0
		5	5	5	78
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 8-3)	1,020	1,100	1,195	3,798,343
		2,315	2,423	2,616	18,441,085
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 8-3)	9,044	10,430	12,539	342,894,080
		19,369	23,797	28,516	1,796,629,010
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 8-3)	20,339	21,772	23,812	1,489,112,291
		29,209	32,155	35,739	3,250,747,791

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 8-20: Predicted distances and areas where harbour porpoise behavioural disturbance threshold of 145 dB re 1 µPa²s is exceeded during pile-driving at East Anglia Three.

Model location	Hammer Energy (kJ)	Distance to 145 dB re 1 µPa²s SEL threshold (m)			Total area where SEL exceeds 145 dB re 1 µPa²s (m²)	Area of SCI where SEL exceeds 145 dB re 1 µPa²s (m²)
		Minimum	Average	Maximum		
Depth-averaged						
1	1,200	16,878	18,999	21,404	1,125,708,593	1,125,708,593
	1,800	19,559	22,668	25,458	1,598,959,043	1,598,959,043
	2,400	21,793	26,100	39,346	2,017,567,119	2,017,567,119
	3,000	23,070	28,888	42,457	2,451,756,197	2,451,756,197
2	1,200	15,975	18,590	21,746	1,078,864,566	1,078,864,566
	1,800	18,804	22,148	26,869	1,527,270,349	1,527,270,349
	2,400	21,451	25,174	29,609	1,985,315,026	1,984,852,184
	3,000	23,459	27,577	32,251	2,401,360,405	2,370,505,823
Maximum-over-depth/Worst case						
1	1,200	23,885	29,642	42,570	2,718,135,008	2,718,135,008
	1,800	27,496	34,740	45,406	3,834,225,529	3,827,251,919
	2,400	31,718	39,366	50,606	4,895,978,075	4,758,044,837
	3,000	34,280	42,887	57,515	5,789,029,328	5,442,917,021
2	1,200	23,396	28,125	32,502	2,605,510,091	2,554,081,190
	1,800	27,320	34,118	51,547	3,670,280,679	3,451,532,170
	2,400	30,920	38,535	53,679	4,680,551,581	4,214,423,169
	3,000	33,619	42,078	54,123	5,530,629,268	4,818,879,767

Table 8-21: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at East Anglia Three modelling location 1 with maximum hammer energy of 1,200 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	35	35	99.7%
195 - 200	202	202	99.5%
190 - 195	1,453	1,453	99.0%
185 - 190	6,559	6,559	98.2%
180 - 185	35,829	35,829	96.7%
175 - 180	230,493	230,493	94.1%
170 - 175	1,797,859	1,797,859	89.4%
165 - 170	6,226,377	6,226,377	81.9%
160 - 165	25,660,784	25,660,784	70.7%
155 - 160	95,068,148	95,068,148	56.3%
150 - 155	272,722,186	272,722,186	40.7%
145 - 150	723,958,667	723,958,667	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	13	13	99.9%
200 - 205	202	202	99.7%
195 - 200	904	904	99.5%
190 - 195	6,797	6,797	99.0%
185 - 190	35,418	35,418	98.2%
180 - 185	303,853	303,853	96.7%
175 - 180	1,653,930	1,653,930	94.1%
170 - 175	5,534,763	5,534,763	89.4%
165 - 170	22,170,683	22,170,683	81.9%
160 - 165	78,691,404	78,691,404	70.7%
155 - 160	238,478,184	238,478,184	56.3%
150 - 155	643,653,329	643,653,329	40.7%
145 - 150	1,727,605,529	1,727,605,529	26.8%

Table 8-22: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at East Anglia Three modelling location 1 with maximum hammer energy of 1,800 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	84	84	99.7%
195 - 200	414	414	99.5%
190 - 195	2,418	2,418	99.0%
185 - 190	11,092	11,092	98.2%
180 - 185	68,565	68,565	96.7%
175 - 180	582,441	582,441	94.1%
170 - 175	2,754,988	2,754,988	89.4%
165 - 170	10,162,951	10,162,951	81.9%
160 - 165	41,814,570	41,814,570	70.7%
155 - 160	142,654,849	142,654,849	56.3%
150 - 155	389,253,871	389,253,871	40.7%
145 - 150	1,011,652,798	1,011,652,799	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	56	56	99.9%
200 - 205	336	336	99.7%
195 - 200	1,927	1,927	99.5%
190 - 195	13,199	13,199	99.0%
185 - 190	91,451	91,451	98.2%
180 - 185	619,553	619,553	96.7%
175 - 180	2,533,468	2,533,468	94.1%
170 - 175	8,785,508	8,785,508	89.4%
165 - 170	34,958,944	34,958,944	81.9%
160 - 165	121,782,035	121,782,035	70.7%
155 - 160	336,532,434	336,532,434	56.3%
150 - 155	909,165,108	909,165,108	40.7%
145 - 150	2,419,741,510	2,412,767,900	26.8%

Table 8-23: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at East Anglia Three modelling location 1 with maximum hammer energy of 2,400 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	127	127	99.7%
195 - 200	713	713	99.5%
190 - 195	3,452	3,452	99.0%
185 - 190	16,836	16,836	98.2%
180 - 185	105,353	105,353	96.7%
175 - 180	887,956	887,956	94.1%
170 - 175	3,775,781	3,775,781	89.4%
165 - 170	14,362,852	14,362,852	81.9%
160 - 165	57,450,161	57,450,161	70.7%
155 - 160	186,438,199	186,438,199	56.3%
150 - 155	493,946,800	493,946,801	40.7%
145 - 150	1,260,578,889	1,260,578,889	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	101	101	99.9%
200 - 205	480	480	99.7%
195 - 200	3,259	3,259	99.5%
190 - 195	21,622	21,622	99.0%
185 - 190	124,298	124,298	98.2%
180 - 185	912,507	912,507	96.7%
175 - 180	3,445,957	3,445,957	94.1%
170 - 175	12,542,864	12,542,864	89.4%
165 - 170	47,787,788	47,787,788	81.9%
160 - 165	159,826,203	159,826,203	70.7%
155 - 160	433,012,672	433,012,672	56.3%
150 - 155	1,147,758,183	1,147,758,183	40.7%
145 - 150	3,090,542,141	2,952,608,903	26.8%

Table 8-24: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at East Anglia Three modelling location 1 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	10	10	99.9%
200 - 205	160	160	99.7%
195 - 200	1,025	1,025	99.5%
190 - 195	4,720	4,720	99.0%
185 - 190	22,765	22,765	98.2%
180 - 185	148,222	148,222	96.7%
175 - 180	1,294,488	1,294,488	94.1%
170 - 175	4,764,051	4,764,051	89.4%
165 - 170	18,930,375	18,930,375	81.9%
160 - 165	73,612,434	73,612,434	70.7%
155 - 160	226,607,359	226,607,359	56.3%
150 - 155	595,542,923	595,542,922	40.7%
145 - 150	1,530,827,665	1,530,827,665	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	148	148	99.9%
200 - 205	639	639	99.7%
195 - 200	4,514	4,514	99.5%
190 - 195	27,152	27,152	99.0%
185 - 190	181,435	181,434	98.2%
180 - 185	1,215,309	1,215,309	96.7%
175 - 180	4,355,538	4,355,538	94.1%
170 - 175	16,656,403	16,656,403	89.4%
165 - 170	60,788,907	60,788,907	81.9%
160 - 165	195,672,787	195,672,787	70.7%
155 - 160	525,749,338	525,749,338	56.3%
150 - 155	1,376,402,949	1,376,402,949	40.7%
145 - 150	3,607,974,208	3,261,861,901	26.8%

Table 8-25: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at East Anglia Three modelling location 2 with maximum hammer energy of 1,200 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	29	29	99.7%
195 - 200	170	170	99.5%
190 - 195	1,158	1,158	99.0%
185 - 190	6,018	6,018	98.2%
180 - 185	27,220	27,220	96.7%
175 - 180	185,285	185,285	94.1%
170 - 175	1,500,031	1,500,031	89.4%
165 - 170	5,770,754	5,770,754	81.9%
160 - 165	23,062,383	23,062,383	70.7%
155 - 160	82,679,394	82,679,394	56.3%
150 - 155	264,465,684	264,465,684	40.7%
145 - 150	701,166,439	701,166,439	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	15	15	99.9%
200 - 205	189	189	99.7%
195 - 200	956	956	99.5%
190 - 195	5,839	5,839	99.0%
185 - 190	34,857	34,857	98.2%
180 - 185	234,715	234,715	96.7%
175 - 180	1,640,447	1,640,447	94.1%
170 - 175	5,457,794	5,457,794	89.4%
165 - 170	21,426,947	21,426,947	81.9%
160 - 165	73,046,614	73,046,614	70.7%
155 - 160	230,570,083	230,570,083	56.3%
150 - 155	623,762,188	623,762,188	40.7%
145 - 150	1,649,329,447	1,597,900,545	26.8%

Table 8-26: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at East Anglia Three modelling location 2 with maximum hammer energy of 1,800 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	78	78	99.7%
195 - 200	259	259	99.5%
190 - 195	2,244	2,244	99.0%
185 - 190	10,258	10,258	98.2%
180 - 185	55,178	55,178	96.7%
175 - 180	473,527	473,527	94.1%
170 - 175	2,419,946	2,419,946	89.4%
165 - 170	9,455,079	9,455,079	81.9%
160 - 165	37,217,878	37,217,878	70.7%
155 - 160	127,210,076	127,210,076	56.3%
150 - 155	379,285,174	379,285,174	40.7%
145 - 150	971,140,652	971,140,652	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	55	55	99.9%
200 - 205	336	336	99.7%
195 - 200	1,773	1,773	99.5%
190 - 195	12,045	12,045	99.0%
185 - 190	63,164	63,164	98.2%
180 - 185	558,500	558,500	96.7%
175 - 180	2,509,623	2,509,623	94.1%
170 - 175	8,806,635	8,806,635	89.4%
165 - 170	33,470,810	33,470,810	81.9%
160 - 165	111,170,990	111,170,990	70.7%
155 - 160	329,132,572	329,132,572	56.3%
150 - 155	862,992,849	862,992,849	40.7%
145 - 150	2,321,561,328	2,102,812,819	26.8%

Table 8-27: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at East Anglia Three modelling location 2 with maximum hammer energy of 2,400 kJ.

SEL contour band (dB re 1 μPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	117	117	99.7%
195 - 200	445	445	99.5%
190 - 195	3,301	3,301	99.0%
185 - 190	14,151	14,151	98.2%
180 - 185	94,348	94,348	96.7%
175 - 180	743,588	743,588	94.1%
170 - 175	3,366,003	3,366,003	89.4%
165 - 170	13,409,479	13,409,479	81.9%
160 - 165	51,213,723	51,213,723	70.7%
155 - 160	170,082,732	170,082,732	56.3%
150 - 155	487,911,887	487,911,886	40.7%
145 - 150	1,258,475,252	1,258,012,410	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	95	95	99.9%
200 - 205	500	500	99.7%
195 - 200	2,666	2,666	99.5%
190 - 195	19,385	19,385	99.0%
185 - 190	103,878	103,878	98.2%
180 - 185	835,143	835,143	96.7%
175 - 180	3,395,746	3,395,746	94.1%
170 - 175	12,515,459	12,515,459	89.4%
165 - 170	45,995,736	45,995,736	81.9%
160 - 165	147,608,853	147,608,853	70.7%
155 - 160	427,376,770	427,376,770	56.3%
150 - 155	1,130,796,955	1,130,796,956	40.7%
145 - 150	2,911,900,393	2,445,771,982	26.8%

Table 8-28: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at East Anglia Three modelling location 2 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	2	2	99.9%
200 - 205	150	150	99.7%
195 - 200	707	707	99.5%
190 - 195	4,494	4,494	99.0%
185 - 190	19,346	19,346	98.2%
180 - 185	126,220	126,220	96.7%
175 - 180	1,017,561	1,017,561	94.1%
170 - 175	4,402,593	4,402,593	89.4%
165 - 170	17,496,882	17,496,882	81.9%
160 - 165	65,220,014	65,220,014	70.7%
155 - 160	211,676,609	211,676,609	56.3%
150 - 155	585,873,172	585,873,172	40.7%
145 - 150	1,515,522,654	1,484,668,072	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	139	139	99.9%
200 - 205	679	679	99.7%
195 - 200	3,681	3,681	99.5%
190 - 195	23,348	23,349	99.0%
185 - 190	140,499	140,498	98.2%
180 - 185	1,187,492	1,187,492	96.7%
175 - 180	4,255,541	4,255,541	94.1%
170 - 175	16,366,349	16,366,349	89.4%
165 - 170	58,095,144	58,095,144	81.9%
160 - 165	183,020,246	183,020,246	70.7%
155 - 160	519,533,891	519,533,891	56.3%
150 - 155	1,365,986,509	1,361,276,916	40.7%
145 - 150	3,382,015,751	2,674,975,842	26.8%

Table 8-29: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at East Anglia Three model location 1 with a maximum hammer energy of 1,200 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	1,200	38	38	39	4,567
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,200	105	108	113	36,426
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,200	105	108	113	36,426
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

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Table 8-30: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at East Anglia Three model location 1 with a maximum hammer energy of 1,800 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	1,800	60	61	62	11,638
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,800	181	183	188	105,074
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,800	181	183	188	105,074
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

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Table 8-31: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at East Anglia Three model location 1 with a maximum hammer energy of 2,400 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,400	65	69	84	14,805
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	4.0 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,400	199	200	201	125,925
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	4.0 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,400	199	200	201	125,925
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	4.0 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 8-32: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at East Anglia Three model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	3,000	87	88	89	24,193
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	223	229	231	164,406
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	223	229	231	164,406
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 8-33: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at East Anglia Three model location 2 with a maximum hammer energy of 1,200 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	1,200	37	38	40	4,608
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,200	109	115	119	41,732
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,200	109	115	119	41,732
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 8-34: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at East Anglia Three model location 2 with a maximum hammer energy of 1,800 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m²)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	1,800	46	47	47	6,862
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,800	135	146	166	67,694
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,800	135	146	166	67,694
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 8-35: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at East Anglia Three model location 2 with a maximum hammer energy of 2,400 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m²)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,400	68	70	72	15,267
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,400	194	211	221	139,954
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,400	194	211	221	139,954
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

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Table 8-36: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at East Anglia Three model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	3,000	75	77	78	18,582
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^2s)	5.5 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^2s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	213	221	244	152,866
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^2s)	5.5 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^2s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	213	221	244	152,866
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^2s)	5.5 hour pile-driving sequence (see Table 8-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^2s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

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Table 8-37: Predicted areas where harbour porpoise behavioural disturbance threshold of 145 dB re 1 μPa^{2}s is exceeded during concurrent pile-driving at East Anglia Three.

Model location	Hammer Energy (kJ)	Total area where SEL exceeds 145 dB re 1 μPa^{2}s (m^2)	Area of SCI where SEL exceeds 145 dB re 1 μPa^{2}s (m^2)
Depth-averaged			
1 and 2	1,200	1,946,142,569	1,946,142,569
	1,800	2,586,166,101	2,586,166,101
	2,400	3,185,230,276	3,184,779,430
	3,000	3,743,707,056	3,712,965,292
Maximum-over-depth/Worst case			
1 and 2	1,200	4,030,421,627	3,979,086,238
	1,800	5,283,350,501	5,065,192,971
	2,400	6,439,168,093	5,845,151,073
	3,000	7,366,682,225	6,400,640,493

Table 8-38: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at East Anglia Three locations 1 and 2 with maximum hammer energy of 1,200 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	64	64	99.7%
195 - 200	373	373	99.5%
190 - 195	2,610	2,611	99.0%
185 - 190	12,577	12,577	98.2%
180 - 185	63,050	63,050	96.7%
175 - 180	415,777	415,778	94.1%
170 - 175	3,297,890	3,297,890	89.4%
165 - 170	11,997,131	11,997,131	81.9%
160 - 165	48,723,167	48,723,167	70.7%
155 - 160	177,747,543	177,747,543	56.3%
150 - 155	537,187,870	537,187,870	40.7%
145 - 150	1,166,694,517	1,166,694,517	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	28	28	99.9%
200 - 205	391	391	99.7%
195 - 200	1,860	1,860	99.5%
190 - 195	12,636	12,636	99.0%
185 - 190	70,275	70,275	98.2%
180 - 185	538,569	538,568	96.7%
175 - 180	3,294,376	3,294,376	94.1%
170 - 175	10,992,557	10,992,557	89.4%
165 - 170	43,597,630	43,597,630	81.9%
160 - 165	151,738,018	151,738,018	70.7%
155 - 160	469,048,267	469,048,267	56.3%
150 - 155	1,083,197,137	1,083,197,137	40.7%
145 - 150	2,267,929,883	2,216,594,494	26.8%

Table 8-39: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at East Anglia Three locations 1 and 2 with maximum hammer energy of 1,800 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	162	162	99.7%
195 - 200	674	674	99.5%
190 - 195	4,662	4,662	99.0%
185 - 190	21,351	21,351	98.2%
180 - 185	123,743	123,743	96.7%
175 - 180	1,055,968	1,055,968	94.1%
170 - 175	5,174,934	5,174,934	89.4%
165 - 170	19,618,030	19,618,030	81.9%
160 - 165	79,032,448	79,032,448	70.7%
155 - 160	269,864,925	269,864,925	56.3%
150 - 155	757,348,368	757,348,368	40.7%
145 - 150	1,453,920,837	1,453,920,837	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	111	111	99.9%
200 - 205	673	672	99.7%
195 - 200	3,700	3,700	99.5%
190 - 195	25,244	25,244	99.0%
185 - 190	154,615	154,615	98.2%
180 - 185	1,178,053	1,178,053	96.7%
175 - 180	5,043,090	5,043,090	94.1%
170 - 175	17,592,143	17,592,143	89.4%
165 - 170	68,429,754	68,429,754	81.9%
160 - 165	232,953,025	232,953,025	70.7%
155 - 160	665,665,006	665,665,006	56.3%
150 - 155	1,772,157,957	1,772,157,957	40.7%
145 - 150	2,520,147,131	2,301,989,600	26.8%

Table 8-40: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at East Anglia Three locations 1 and 2 with maximum hammer energy of 2,400 kJ.

SEL contour band (dB re 1 μPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	245	245	99.7%
195 - 200	1,158	1,158	99.5%
190 - 195	6,753	6,753	99.0%
185 - 190	30,988	30,988	98.2%
180 - 185	199,701	199,701	96.7%
175 - 180	1,631,544	1,631,544	94.1%
170 - 175	7,141,784	7,141,784	89.4%
165 - 170	27,772,331	27,772,331	81.9%
160 - 165	108,663,884	108,663,884	70.7%
155 - 160	356,520,931	356,520,931	56.3%
150 - 155	908,179,996	908,179,996	40.7%
145 - 150	1,775,080,963	1,774,630,117	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	196	196	99.9%
200 - 205	981	981	99.7%
195 - 200	5,925	5,925	99.5%
190 - 195	41,007	41,007	99.0%
185 - 190	228,176	228,176	98.2%
180 - 185	1,747,650	1,747,650	96.7%
175 - 180	6,841,703	6,841,703	94.1%
170 - 175	25,058,323	25,058,323	89.4%
165 - 170	93,783,524	93,783,524	81.9%
160 - 165	307,435,056	307,435,056	70.7%
155 - 160	860,389,442	860,389,442	56.3%
150 - 155	2,278,555,139	2,278,555,139	40.7%
145 - 150	2,865,080,972	2,271,063,951	26.8%

Table 8-41: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at East Anglia Three locations 1 and 2 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	13	13	99.9%
200 - 205	311	311	99.7%
195 - 200	1,732	1,732	99.5%
190 - 195	9,214	9,214	99.0%
185 - 190	42,111	42,111	98.2%
180 - 185	274,442	274,442	96.7%
175 - 180	2,312,049	2,312,049	94.1%
170 - 175	9,166,644	9,166,644	89.4%
165 - 170	36,427,258	36,427,258	81.9%
160 - 165	138,832,448	138,832,448	70.7%
155 - 160	438,283,969	438,283,968	56.3%
150 - 155	1,034,201,099	1,034,201,099	40.7%
145 - 150	2,084,155,768	2,053,414,004	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	287	287	99.9%
200 - 205	1,319	1,319	99.7%
195 - 200	8,194	8,194	99.5%
190 - 195	50,501	50,501	99.0%
185 - 190	321,934	321,932	98.2%
180 - 185	2,402,800	2,402,802	96.7%
175 - 180	8,611,079	8,611,079	94.1%
170 - 175	33,022,752	33,022,752	89.4%
165 - 170	118,884,051	118,884,051	81.9%
160 - 165	378,693,033	378,693,033	70.7%
155 - 160	1,045,283,229	1,045,283,229	56.3%
150 - 155	2,742,389,458	2,737,679,865	40.7%
145 - 150	3,037,013,588	2,075,681,449	26.8%

9.0 HORNSEA ONE

This section presents the underwater sound propagation modelling undertaken to predict potential impacts to harbour porpoise and fish from pile-driving at the Hornsea One development. Project specific model inputs (such as maximum hammer energy, model locations and hammer soft-start/ramp-up procedures) are firstly introduced, before the modelling results are presented. The propagation modelling has considered scenarios involving single pile-driving (i.e. the use of a single pile installation vessel), and concurrent pile-driving involving the use of two pile-driving vessels.

9.1 Model Inputs

A number of different modelling scenarios have been conducted to estimate potential impacts from pile-driving at the Hornsea One wind farm development, which take into account both the consented and planned project design envelopes. The modelled scenarios that have been conducted for pile-driving at Hornsea One are summarised in Table 9-1 and have been selected to cover a range of possible pile-driving events at Hornsea One involving the use of different maximum hammer energies and different pile installation durations depending on the use of different foundation types (e.g. multi-leg jacket piles or monopiles). The modelling scenarios for the consented Hornsea One project were selected based on the information provided by Smart Wind Limited (*pers. comm.*) as well as the consented project description (Smart Wind Limited, 2013a) and previous noise modelling (Smart Wind Limited, 2013b). The modelling for the planned Hornsea One project was based on information provided by Smart Wind (*pers. comm.*).

Table 9-1: Noise modelling scenarios for pile-driving at Hornsea One.

Infrastructure	Foundation type	Pile diameter (m)	Maximum Hammer Energy (kJ)	Duration to install a single pile (hours)
Consented Project				
Wind turbine generators	Multi-leg jacket piles	3.0	2,300	6.0
	Monopile	8.5	2,300	7.0
Planned Project				
Wind turbine generators	Monopile	8.1	3,000	4.0

The propagation modelling has been conducted at a number of different locations within the Hornsea One wind farm development site in order to provide a range of estimates for potential injury and disturbance to harbour porpoise. The modelling locations that have been used are shown in Figure 9-1 and Table 9-2.

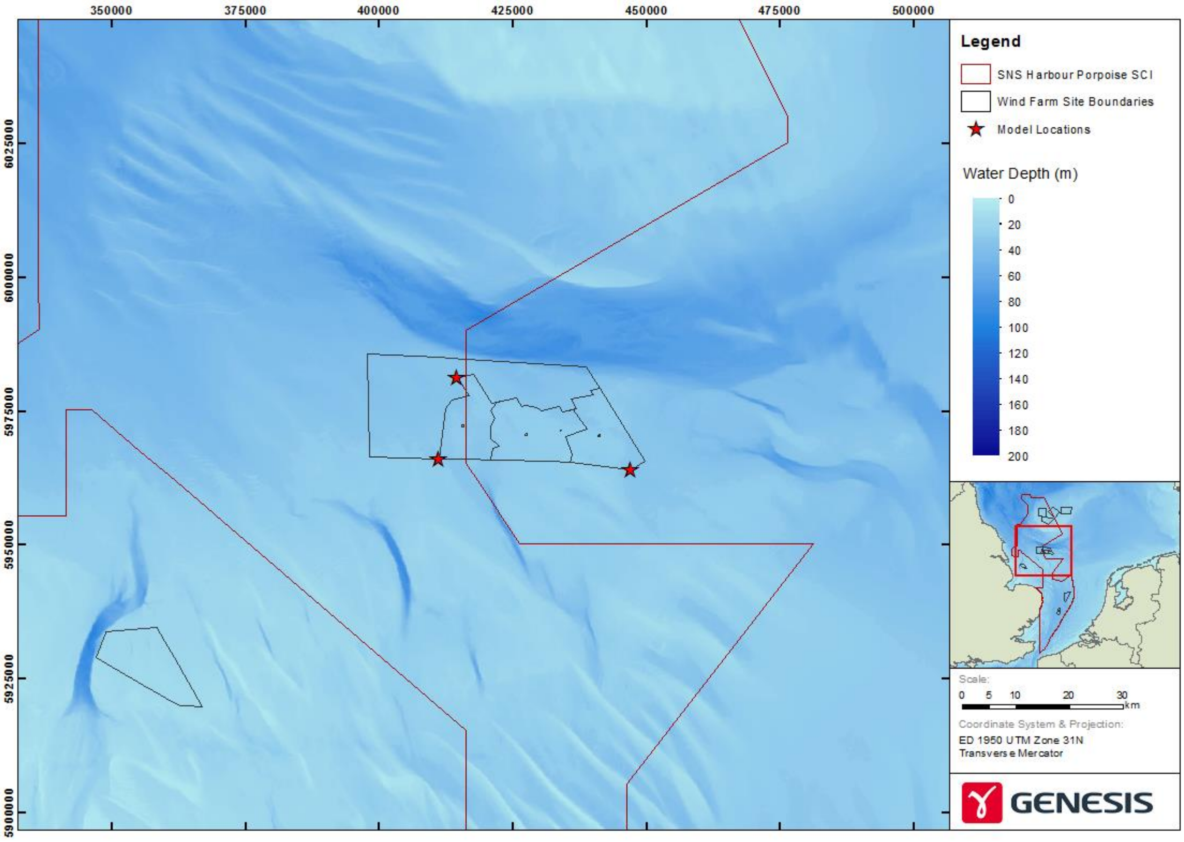

Figure 9-1: Noise modelling locations for pile-driving at Hornsea One.

Table 9-2: Noise modelling locations for pile-driving at Hornsea One.

Model Location	Longitude (Decimal degrees)	Latitude (Decimal degrees)
Location 1	1.65108	53.83556
Location 2	1.69783	53.97237
Location 3	2.19493	53.82152

The soft-start/ramp-up procedures that have been used in the cumulative SEL modelling for pile-driving at Hornsea One are shown in Table 9-3 and are based on the soft-start/ramp-up procedure used in previous modelling for the consented project (Smart Wind Limited, 2013b).

Table 9-3: Hammer soft-start/ramp-up procedure assumed in the modelling of pile-driving at Hornsea One.

Percentage of maximum hammer energy (%)	Duration (minutes)	Hammer strike rate (blows/minute)	Hammer strike interval (s)	Number of pile strikes
4.0-hour pile-driving duration				
20	7.5	10	6	75
40	7.5	10	6	75
60	7.5	15	4	113
80	7.5	15	4	113
100	210.0	35	2	7,350
7.0-hour pile-driving duration				
20	7.5	10	6	75
40	7.5	10	6	75
60	7.5	15	4	113
80	7.5	15	4	113
100	390.0	35	2	13,650

9.2 Single Pile-driving Modelling Results

Propagation modelling for single pile-driving (i.e. only using a single pile installation vessel) at Hornsea One has been conducted at the model locations shown in Figure 9-1 and Table 9-2, with the different maximum hammer energies shown in Table 9-1 being modelled.

Maximum-over-depth zero-to-peak SPL sound fields have been estimated (see Section 4.2.5.2) and compared to the Southall and NOAA thresholds for the potential onset of PTS and TTS to harbour porpoise. Distances and areas of potential PTS and TTS onset due to zero-to-peak SPL threshold exceedance have been calculated for different percentages of the maximum hammer energy, demonstrating the increase of potential injury zones with increasing hammer energy throughout the soft-start/ramp-up phase. The predicted distances and areas where the Southall and NOAA zero-to-peak SPL thresholds are exceeded are shown in Table 9-4 to Table 9-9 for the various maximum hammer energies that have been modelled for pile-driving at Hornsea One. Maximum-over-depth zero-to-peak SPL sound fields are shown in Figure F-1 to Figure F-6 in Appendix F of this report for the modelling scenarios involving pile-driving at Hornsea One with maximum hammer energies of 2,300 kJ and 3,000 kJ.

Cumulative SEL scenarios have been conducted in order to predict potential PTS and TTS onset in harbour porpoise due to exposure to pulses from multiple pile-strikes by estimating areas where the Southall and NOAA cumulative SEL thresholds are exceeded. The cumulative SEL scenarios have been conducted using the "fleeing animal" modelling procedure discussed in Section 4.2.5.3, and take into account the hammer soft-start/ramp-up procedures outlined in Table 9-3. As discussed in Section 4.2.5.3, the cumulative SEL modelling has been conducted for animals receiving depth-averaged SEL for each piling pulse, as well as maximum-over-depth SEL for each piling pulse (which is the absolute worst case scenario). The predicted distances and areas where the Southall and NOAA cumulative SEL thresholds for PTS and TTS onset are exceeded during pile-driving at Hornsea One are detailed in Table 9-10 to Table 9-15. Maps showing the predicted areas where the cumulative SEL thresholds are exceeded are also shown in Figure F-7 to Figure F-12 for the pile-driving at Hornsea One with maximum hammer energies of 2,300 kJ and 3,000 kJ.

Depth-averaged and maximum-over-depth unweighted single pulse SEL sound fields have been predicted in order to estimate potential disturbance to harbour porpoise due to pile-driving at Hornsea One. Depth-averaged and maximum-over-depth unweighted single pulse SEL sound fields for pile-driving at Hornsea One with maximum hammer energies of 2,300 kJ and 3,000 kJ are shown in Figure F-13 to Figure F-27 in Appendix F of this report.

The predicted depth-averaged and maximum-over-depth unweighted SEL sound fields have been compared to the behavioural disturbance threshold of 145 dB re 1 µPa²s proposed by Lucke *et al*. (2009) and Thompson *et al.* (2013b). The predicted distances and areas of this threshold exceedance are shown in Table 9-16 for both the depth-averaged and maximum-over-depth results. The area of threshold exceedance has been calculated as the total area above the threshold, as well as the area within the SCI that is above the threshold.

The probability of displacement of harbour porpoise has been further evaluated using the behavioural/dose response curve discussed in Section 3.2.1.2. The predicted areas and probabilities of behavioural disturbance to harbour porpoise for different SEL contour bands are detailed in Table 9-17 to Table 9-22 for both the depth-averaged and maximum-over-depth SEL modelling results.

The predicted zero-to-peak SPL and cumulative SEL for the Hornsea One modelling scenarios have been compared to the Popper *et al*. (2014) thresholds for estimating potential injury to fish. The predicted distances and areas where injury to fish may potentially occur from pile-driving at Hornsea One with various hammer energies are shown in Table 9-23 to Table 9-28.

9.3 Concurrent Pile-driving Modelling Results

Example concurrent pile-driving scenarios at Hornsea One have been conducted to estimate the increase in potential behavioural disturbance zones for harbour porpoise due to the use of two installation vessels. The concurrent pile driving modelling scenarios involve piling at model locations 1 and 2 (see Figure 9-1 and Table 9-2) where the same hammer energy is used at each location. The concurrent pile-driving modelling has been conducted for the range of hammer energies shown in Table 9-1.

The predicted areas where the harbour porpoise behavioural disturbance threshold of 145 dB re 1 µPa²s is exceeded for the concurrent pile-driving scenarios at Hornsea One are shown in Table 9-29. Table 9-30 and Table 9-31 further show the probability of potential displacement of harbour porpoise for different SEL bands (using the behavioural/dose response curve discussed in Section 3.2.1.2).

Table 9-4: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Hornsea One model location 1 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	230	1	1	1	3
	460	2	2	2	13
	920	3	3	3	28
	1,380	4	4	4	50
	1,840	4	4	4	50
	2,300	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	230	79	79	81	19,776
	460	135	152	155	72,570
	920	245	261	277	213,533
	1,380	323	343	357	368,632
	1,840	373	423	456	562,910
	2,300	517	570	604	1,019,568
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	230	3	3	3	28
	460	4	4	4	50
	920	6	6	6	113
	1,380	8	8	8	201
	1,840	9	9	9	254
	2,300	10	10	10	314
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	230	245	260	277	212,642
	460	372	420	446	555,761
	920	695	752	803	1,773,958
	1,380	909	968	1,053	2,946,906
	1,840	1,092	1,242	1,330	4,845,065
	2,300	1,318	1,490	1,620	6,971,062

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 9-5: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Hornsea One model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	300	1	1	1	3
	600	2	2	2	13
	1,200	3	3	3	28
	1,800	4	4	4	50
	2,400	5	5	5	78
	3,000	6	6	6	113
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	300	95	102	105	32,639
	600	178	195	198	119,129
	1,200	293	316	324	313,449
	1,800	372	414	442	539,418
	2,400	547	576	609	1,040,978
	3,000	597	668	722	1,405,403
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	300	3	3	3	28
	600	5	5	5	78
	1,200	7	7	7	154
	1,800	9	9	9	254
	2,400	11	11	11	380
	3,000	13	13	13	530
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	300	293	311	324	302,911
	600	547	575	609	1,039,853
	1,200	883	937	1,018	2,756,143
	1,800	1,086	1,221	1,324	4,686,731
	2,400	1,352	1,540	1,634	7,443,370
	3,000	1,651	1,777	1,926	9,919,916

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 9-6: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Hornsea One model location 2 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	230	1	1	1	3
	460	2	2	2	13
	920	3	3	3	28
	1,380	4	4	4	50
	1,840	4	4	4	50
	2,300	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	230	76	78	85	19,309
	460	148	152	156	72,618
	920	268	272	275	231,365
	1,380	336	343	352	368,588
	1,840	412	439	456	604,257
	2,300	533	558	579	977,181
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	230	3	3	3	28
	460	4	4	4	50
	920	6	6	6	113
	1,380	8	8	8	201
	1,840	9	9	9	254
	2,300	10	10	11	324
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	230	267	271	275	230,918
	460	411	437	456	598,533
	920	675	707	737	1,567,383
	1,380	939	996	1,051	3,117,769
	1,840	1,069	1,168	1,313	4,284,339
	2,300	1,340	1,406	1,526	6,205,491

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

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Table 9-7: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Hornsea One model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m²) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	300	1	1	1	3
	600	2	2	2	13
	1,200	3	3	3	28
	1,800	4	4	4	50
	2,400	5	5	5	78
	3,000	6	6	6	113
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	300	94	100	113	31,663
	600	177	195	205	119,337
	1,200	297	319	334	319,810
	1,800	410	429	453	578,869
	2,400	540	562	585	990,226
	3,000	557	650	712	1,332,848
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	300	3	3	3	28
	600	5	5	5	78
	1,200	7	7	7	154
	1,800	9	9	9	254
	2,400	11	11	11	380
	3,000	13	13	13	530
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	300	297	313	333	307,444
	600	539	561	584	988,803
	1,200	805	966	1,020	2,930,385
	1,800	1,051	1,149	1,305	4,151,760
	2,400	1,359	1,475	1,614	6,835,628
	3,000	1,666	1,725	1,823	9,335,284

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 9-8: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Hornsea One model location 3 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	230	1	1	1	3
	460	2	2	2	13
	920	3	3	3	28
	1,380	4	4	4	50
	1,840	4	4	4	50
	2,300	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	230	80	80	80	20,081
	460	143	143	143	64,161
	920	240	245	265	189,274
	1,380	331	340	367	362,582
	1,840	387	396	398	490,905
	2,300	487	502	534	791,628
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	230	3	3	3	28
	460	4	4	4	50
	920	6	6	6	113
	1,380	8	8	8	201
	1,840	9	9	9	254
	2,300	10	10	10	314
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	230	239	245	265	187,896
	460	387	395	398	490,736
	920	625	742	754	1,727,042
	1,380	888	914	931	2,619,454
	1,840	1,042	1,130	1,300	4,010,842
	2,300	1,289	1,420	1,602	6,325,687

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 9-9: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Hornsea One model location 3 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	300	1	1	1	3
	600	2	2	2	13
	1,200	3	3	3	28
	1,800	4	4	4	50
	2,400	5	5	5	78
	3,000	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	300	97	97	97	29,522
	600	194	195	197	119,393
	1,200	305	312	313	305,088
	1,800	386	395	397	488,426
	2,400	490	510	539	817,128
	3,000	610	626	631	1,231,352
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	300	3	3	3	28
	600	5	5	5	78
	1,200	7	7	7	154
	1,800	9	9	9	254
	2,400	11	11	11	380
	3,000	13	13	13	530
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	300	305	312	313	304,954
	600	490	510	539	814,960
	1,200	773	813	896	2,075,348
	1,800	1,027	1,114	1,173	3,900,345
	2,400	1,361	1,448	1,616	6,585,194
	3,000	1,654	1,729	1,815	9,384,824

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 9-10: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Hornsea One model location 1 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	7.0 hour pile-driving sequence (see Table 9-3)	0	0	0	0
		4	4	4	50
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	7.0 hour pile-driving sequence (see Table 9-3)	945	1,027	1,106	3,314,709
		2,239	2,339	2,459	17,179,057
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	7.0 hour pile-driving sequence (see Table 9-3)	5,622	7,201	8,964	164,881,263
		10,858	17,055	22,888	944,178,465
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	7.0 hour pile-driving sequence (see Table 9-3)	17,068	20,783	23,964	1,365,395,071
		26,145	32,510	37,116	3,345,450,945

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 9-11: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Hornsea One model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 9-3)	0	0	0	0
		6	6	6	113
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 9-3)	1,407	1,500	1,589	7,068,319
		2,889	3,017	3,176	28,566,356
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 9-3)	6,621	8,104	10,043	208,276,129
		11,875	16,845	21,581	906,877,396
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 9-3)	16,606	21,446	24,871	1,457,387,972
		27,267	32,228	35,707	3,273,981,927

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 9-12: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Hornsea One model location 2 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	7.0 hour pile-driving sequence (see Table 9-3)	0	0	0	0
		4	4	4	50
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	7.0 hour pile-driving sequence (see Table 9-3)	695	921	1,088	2,718,726
		2,066	2,293	2,564	16,558,164
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	7.0 hour pile-driving sequence (see Table 9-3)	7,280	10,037	15,779	334,733,715
		16,495	24,569	41,647	2,004,697,366
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	7.0 hour pile-driving sequence (see Table 9-3)	17,954	23,183	27,781	1,695,457,832
		28,986	34,766	40,765	3,816,639,821

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 9-13: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Hornsea One model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 9-3)	0	0	0	0
		5	6	6	102
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 9-3)	1,006	1,346	1,598	5,812,239
		2,642	2,951	3,317	27,439,713
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 9-3)	7,202	10,697	16,044	378,717,500
		17,364	23,707	38,378	1,831,242,503
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 9-3)	18,024	23,702	28,264	1,771,399,128
		29,888	34,367	39,160	3,721,816,169

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 9-14: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Hornsea One model location 3 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	7.0 hour pile-driving sequence (see Table 9-3)	0	0	0	0
		4	4	4	50
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	7.0 hour pile-driving sequence (see Table 9-3)	905	976	1,021	2,991,097
		2,123	2,184	2,244	14,968,077
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	7.0 hour pile-driving sequence (see Table 9-3)	4,886	6,665	8,168	141,982,057
		11,100	15,621	24,559	794,458,297
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	7.0 hour pile-driving sequence (see Table 9-3)	16,022	19,759	22,360	1,234,037,020
		26,207	30,866	36,622	3,006,597,322

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 9-15: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Hornsea One model location 3 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 9-3)	0	0	0	0
		5	5	6	90
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 9-3)	1,354	1,443	1,504	6,534,688
		2,725	2,818	2,926	24,917,603
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 9-3)	5,723	7,512	9,196	179,998,505
		12,342	15,328	21,255	750,130,960
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 9-3)	15,747	20,366	23,484	1,316,316,926
		27,193	30,729	35,982	2,972,311,568

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 9-16: Predicted distances and areas where harbour porpoise behavioural disturbance threshold of 145 dB re 1 μPa²s is exceeded during pile-driving at Hornsea One.

Model location	Hammer Energy (kJ)	Distance to 145 dB re 1 μPa²s SEL threshold (m)			Total area where SEL exceeds 145 dB re 1 μPa²s (m²)	Area of SCI where SEL exceeds 145 dB re 1 μPa²s (m²)
		Minimum	Average	Maximum		
Depth-averaged						
1	2,300	15,775	19,549	23,910	1,193,539,336	847,754,506
	3,000	17,821	21,536	25,384	1,430,615,636	1,009,197,805
2	2,300	19,601	25,621	39,926	2,117,923,405	1,365,634,337
	3,000	21,766	28,494	45,749	2,603,598,351	1,696,030,317
3	2,300	15,385	18,734	22,527	1,103,654,828	83,012,030
	3,000	17,510	20,883	34,402	1,329,966,961	139,076,987
Maximum-over-depth/Worst case						
1	2,300	21,713	31,528	49,201	3,025,853,946	2,204,348,738
	3,000	22,396	34,635	51,590	3,880,168,165	2,821,919,333
2	2,300	28,666	40,003	62,039	5,230,858,449	3,520,891,170
	3,000	31,333	44,807	79,236	6,565,825,894	4,407,654,820
3	2,300	21,713	31,528	49,201	3,025,853,946	2,204,348,738
	3,000	22,396	34,635	51,590	3,880,168,165	2,821,919,333

Table 9-17: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Hornsea One modelling location 1 with maximum hammer energy of 2,300 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	162	162	99.7%
195 - 200	824	824	99.5%
190 - 195	3,692	3,692	99.0%
185 - 190	18,397	18,397	98.2%
180 - 185	99,184	99,183	96.7%
175 - 180	960,799	960,799	94.1%
170 - 175	3,888,454	3,888,454	89.4%
165 - 170	13,715,251	13,715,251	81.9%
160 - 165	43,379,172	43,379,172	70.7%
155 - 160	116,415,295	99,655,473	56.3%
150 - 155	310,312,210	214,089,123	40.7%
145 - 150	704,745,897	471,943,976	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	90	90	99.9%
200 - 205	610	610	99.7%
195 - 200	3,684	3,684	99.5%
190 - 195	17,562	17,562	99.0%
185 - 190	134,305	134,305	98.2%
180 - 185	948,931	948,930	96.7%
175 - 180	3,473,711	3,473,711	94.1%
170 - 175	11,715,668	11,715,668	89.4%
165 - 170	37,401,169	37,401,169	81.9%
160 - 165	100,252,752	88,685,238	70.7%
155 - 160	267,292,863	187,737,538	56.3%
150 - 155	653,389,411	438,620,290	40.7%
145 - 150	1,951,223,191	1,435,609,942	26.8%

Table 9-18: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Hornsea One modelling location 1 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 μPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	19	19	99.9%
200 - 205	222	222	99.7%
195 - 200	1,188	1,187	99.5%
190 - 195	5,110	5,110	99.0%
185 - 190	26,836	26,836	98.2%
180 - 185	175,265	175,265	96.7%
175 - 180	1,455,496	1,455,496	94.1%
170 - 175	5,050,847	5,050,847	89.4%
165 - 170	18,451,736	18,451,736	81.9%
160 - 165	54,733,906	54,480,793	70.7%
155 - 160	146,655,600	118,299,966	56.3%
150 - 155	387,757,664	263,604,517	40.7%
145 - 150	816,301,747	547,645,810	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	148	148	99.9%
200 - 205	937	937	99.7%
195 - 200	5,619	5,619	99.5%
190 - 195	28,726	28,726	99.0%
185 - 190	187,051	187,051	98.2%
180 - 185	1,436,965	1,436,965	96.7%
175 - 180	4,442,103	4,442,103	94.1%
170 - 175	15,714,173	15,714,173	89.4%
165 - 170	47,133,045	47,133,045	81.9%
160 - 165	125,245,395	104,870,744	70.7%
155 - 160	335,677,700	229,300,986	56.3%
150 - 155	767,390,628	514,422,310	40.7%
145 - 150	2,582,905,676	1,904,376,526	26.8%

Table 9-19: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Hornsea One modelling location 2 with maximum hammer energy of 2,300 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	106	106	99.7%
195 - 200	861	861	99.5%
190 - 195	3,664	3,664	99.0%
185 - 190	18,518	18,518	98.2%
180 - 185	97,287	97,287	96.7%
175 - 180	969,779	969,779	94.1%
170 - 175	3,862,185	3,862,185	89.4%
165 - 170	13,253,015	11,232,819	81.9%
160 - 165	44,309,790	30,001,014	70.7%
155 - 160	129,377,374	80,069,592	56.3%
150 - 155	557,246,699	376,619,560	40.7%
145 - 150	1,368,784,126	862,758,952	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	81	81	99.9%
200 - 205	606	606	99.7%
195 - 200	3,625	3,625	99.5%
190 - 195	17,761	17,761	99.0%
185 - 190	132,124	132,124	98.2%
180 - 185	910,724	910,724	96.7%
175 - 180	3,382,001	3,382,001	94.1%
170 - 175	11,996,394	10,412,224	89.4%
165 - 170	38,179,739	26,295,813	81.9%
160 - 165	108,997,343	68,155,801	70.7%
155 - 160	475,551,049	316,311,564	56.3%
150 - 155	1,267,548,600	812,925,310	40.7%
145 - 150	3,324,138,403	2,282,343,535	26.8%

Table 9-20: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Hornsea One modelling location 2 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	201	201	99.7%
195 - 200	1,218	1,218	99.5%
190 - 195	5,130	5,130	99.0%
185 - 190	27,136	27,136	98.2%
180 - 185	171,936	171,936	96.7%
175 - 180	1,457,570	1,457,570	94.1%
170 - 175	5,015,074	5,015,074	89.4%
165 - 170	17,927,989	14,167,692	81.9%
160 - 165	56,254,234	37,015,807	70.7%
155 - 160	170,282,061	102,343,965	56.3%
150 - 155	742,090,919	505,516,019	40.7%
145 - 150	1,610,364,883	1,030,308,569	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	142	142	99.9%
200 - 205	912	912	99.7%
195 - 200	5,617	5,617	99.5%
190 - 195	28,901	28,901	99.0%
185 - 190	190,530	190,530	98.2%
180 - 185	1,376,149	1,376,149	96.7%
175 - 180	4,367,664	4,367,664	94.1%
170 - 175	15,961,547	12,845,077	89.4%
165 - 170	48,644,682	32,608,317	81.9%
160 - 165	145,639,024	88,613,973	70.7%
155 - 160	644,941,314	439,638,372	56.3%
150 - 155	1,501,765,654	958,078,127	40.7%
145 - 150	4,202,903,760	2,869,901,039	26.8%

Table 9-21: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Hornsea One modelling location 3 with maximum hammer energy of 2,300 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	107	0	99.7%
195 - 200	850	0	99.5%
190 - 195	3,446	0	99.0%
185 - 190	18,208	0	98.2%
180 - 185	89,370	0	96.7%
175 - 180	924,129	0	94.1%
170 - 175	3,772,422	0	89.4%
165 - 170	13,384,073	0	81.9%
160 - 165	44,153,907	0	70.7%
155 - 160	118,320,330	0	56.3%
150 - 155	281,745,375	0	40.7%
145 - 150	641,242,613	83,012,030	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	93	0	99.9%
200 - 205	660	0	99.7%
195 - 200	3,187	0	99.5%
190 - 195	18,169	0	99.0%
185 - 190	118,095	0	98.2%
180 - 185	877,507	0	96.7%
175 - 180	3,446,749	0	94.1%
170 - 175	12,286,615	0	89.4%
165 - 170	38,213,326	0	81.9%
160 - 165	103,422,289	0	70.7%
155 - 160	245,365,250	0	56.3%
150 - 155	586,710,085	54,560,935	40.7%
145 - 150	1,848,926,436	321,774,023	26.8%

Table 9-22: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Hornsea One modelling location 3 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	205	0	99.7%
195 - 200	1,189	0	99.5%
190 - 195	4,936	0	99.0%
185 - 190	27,167	0	98.2%
180 - 185	150,694	0	96.7%
175 - 180	1,387,473	0	94.1%
170 - 175	4,972,162	0	89.4%
165 - 170	18,089,127	0	81.9%
160 - 165	56,097,907	0	70.7%
155 - 160	144,198,354	0	56.3%
150 - 155	350,664,469	2,997,166	40.7%
145 - 150	754,373,277	136,079,820	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	162	0	99.9%
200 - 205	961	0	99.7%
195 - 200	5,066	0	99.5%
190 - 195	26,794	0	99.0%
185 - 190	174,593	0	98.2%
180 - 185	1,337,602	0	96.7%
175 - 180	4,505,755	0	94.1%
170 - 175	16,465,730	0	89.4%
165 - 170	48,695,887	0	81.9%
160 - 165	126,399,708	0	70.7%
155 - 160	305,857,413	0	56.3%
150 - 155	698,115,141	101,079,081	40.7%
145 - 150	2,491,009,907	448,391,782	26.8%

Table 9-23: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Hornsea One model location 1 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,300	66	68	68	14,321
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	7.0 hour pile-driving sequence (see Table 9-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	206	209	236	136,534
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	7.0 hour pile-driving sequence (see Table 9-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	206	209	236	136,534
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	7.0 hour pile-driving sequence (see Table 9-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 9-24: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Hornsea One model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	3,000	80	82	82	20,913
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	4.0 hour pile-driving sequence (see Table 9-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	246	267	287	224,283
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	4.0 hour pile-driving sequence (see Table 9-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	246	267	287	224,283
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	4.0 hour pile-driving sequence (see Table 9-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 9-25: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Hornsea One model location 2 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,300	68	69	72	14,931
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	4.0 hour pile-driving sequence (see Table 9-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	203	209	235	136,875
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	4.0 hour pile-driving sequence (see Table 9-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	203	209	235	136,875
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	4.0 hour pile-driving sequence (see Table 9-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 9-26: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Hornsea One model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	3,000	77	81	86	20,609
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	4.0 hour pile-driving sequence (see Table 9-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	270	273	277	234,212
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	4.0 hour pile-driving sequence (see Table 9-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	270	273	277	234,212
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	4.0 hour pile-driving sequence (see Table 9-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 9-27: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Hornsea One model location 3 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m²)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,300	69	69	69	14,938
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	7.0 hour pile-driving sequence (see Table 9-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	221	222	233	154,766
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	7.0 hour pile-driving sequence (see Table 9-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	221	222	233	154,766
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	7.0 hour pile-driving sequence (see Table 9-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

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Table 9-28: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Hornsea One model location 3 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	3,000	80	80	80	20,081
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 9-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	263	294	303	271,874
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 9-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	263	294	303	271,874
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 9-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

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Table 9-29: Predicted areas where harbour porpoise behavioural disturbance threshold of 145 dB re 1 μPa²s is exceeded during concurrent pile-driving at Hornsea One.

Model location	Hammer Energy (kJ)	Total area where SEL exceeds 145 dB re 1 μPa²s (m²)	Area of SCI where SEL exceeds 145 dB re 1 μPa²s (m²)
Depth-averaged			
1 and 2	2,300	2,550,724,081	1,703,273,304
	3,000	3,073,029,801	2,051,863,295
Maximum-over-depth/Worst case			
1 and 2	2,300	5,748,523,064	3,934,341,383
	3,000	7,110,337,695	4,860,261,149

Table 9-30: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Hornsea One locations 1 and 2 with maximum hammer energy of 2,300 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	268	268	99.7%
195 - 200	1,685	1,685	99.5%
190 - 195	7,356	7,356	99.0%
185 - 190	36,915	36,915	98.2%
180 - 185	196,471	196,470	96.7%
175 - 180	1,930,578	1,930,578	94.1%
170 - 175	7,750,639	7,750,639	89.4%
165 - 170	26,968,267	24,948,071	81.9%
160 - 165	87,688,962	73,380,185	70.7%
155 - 160	244,589,935	178,578,630	56.3%
150 - 155	704,952,143	467,095,589	40.7%
145 - 150	1,476,600,863	949,346,918	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	171	171	99.9%
200 - 205	1,216	1,216	99.7%
195 - 200	7,309	7,309	99.5%
190 - 195	35,324	35,324	99.0%
185 - 190	266,429	266,429	98.2%
180 - 185	1,859,654	1,859,654	96.7%
175 - 180	6,855,712	6,855,712	94.1%
170 - 175	23,712,062	22,127,892	89.4%
165 - 170	75,580,908	63,696,982	81.9%
160 - 165	209,250,095	156,841,039	70.7%
155 - 160	623,336,454	410,128,699	56.3%
150 - 155	1,398,292,177	899,128,245	40.7%
145 - 150	3,409,325,553	2,373,392,711	26.8%

Table 9-31: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Hornsea One locations 1 and 2 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	19	19	99.9%
200 - 205	423	423	99.7%
195 - 200	2,405	2,405	99.5%
190 - 195	10,240	10,240	99.0%
185 - 190	53,972	53,972	98.2%
180 - 185	347,201	347,201	96.7%
175 - 180	2,913,066	2,913,066	94.1%
170 - 175	10,065,922	10,065,922	89.4%
165 - 170	36,379,725	32,619,428	81.9%
160 - 165	110,988,140	91,496,600	70.7%
155 - 160	301,794,481	206,350,505	56.3%
150 - 155	891,843,938	599,093,263	40.7%
145 - 150	1,718,630,270	1,108,910,253	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	290	290	99.9%
200 - 205	1,849	1,849	99.7%
195 - 200	11,236	11,236	99.5%
190 - 195	57,627	57,626	99.0%
185 - 190	377,581	377,582	98.2%
180 - 185	2,813,114	2,813,114	96.7%
175 - 180	8,809,766	8,809,766	94.1%
170 - 175	31,675,720	28,559,251	89.4%
165 - 170	95,777,727	79,741,362	81.9%
160 - 165	266,028,190	188,528,435	70.7%
155 - 160	791,490,919	527,686,987	56.3%
150 - 155	1,617,123,216	1,038,326,648	40.7%
145 - 150	4,296,170,461	2,985,347,004	26.8%

10.0 HORNSEA TWO

This section presents the underwater sound propagation modelling undertaken to predict potential impacts to harbour porpoise and fish from pile-driving at the Hornsea Two development. Project specific model inputs (such as maximum hammer energy, model locations and hammer soft-start/ramp-up procedures) are firstly introduced, before the modelling results are presented. The propagation modelling has considered scenarios involving single pile-driving (i.e. the use of a single pile installation vessel), and concurrent pile-driving involving the use of two pile-driving vessels.

10.1 Model Inputs

The modelling scenarios that have been used to assess potential impacts from pile-driving at Hornsea Two are summarised in Table 10-1, and take into account the design envelopes for both the consented application and the planned project. The modelling scenarios have been selected to cover a range of possible pile-driving events at Hornsea, and were selected based on the information provided by Smart Wind Limited (*pers. comm.*) as well as the consented project description (Smart Wind Limited, 2015a) and previous noise modelling (Smart Wind Limited, 2015b).

Table 10-1: Noise modelling scenarios for pile-driving at Hornsea Two.

Infrastructure	Foundation type	Pile diameter (m)	Maximum Hammer Energy (kJ)	Estimated duration to install a single pile (hours)
Consented Project				
Wind turbine generators	Monopile	10.0	3,000	9.0
Other infrastructure	Multi-leg jacket piles	3.5	2,300	4.0
Planned Project				
Wind turbine generators	Monopile	8.5	3,000	4.0
Other infrastructure	Multi-leg jacket piles	3.5	2,300	4.0

The propagation modelling has been conducted at a number of different locations within the Hornsea Two wind farm development site in order to provide a range of estimates for potential injury and disturbance to harbour porpoise. The modelling locations that have been used to assess potential injury and disturbance to harbour porpoise due to pile-driving at Hornsea Two are shown in Figure 10-1 and Table 10-2.

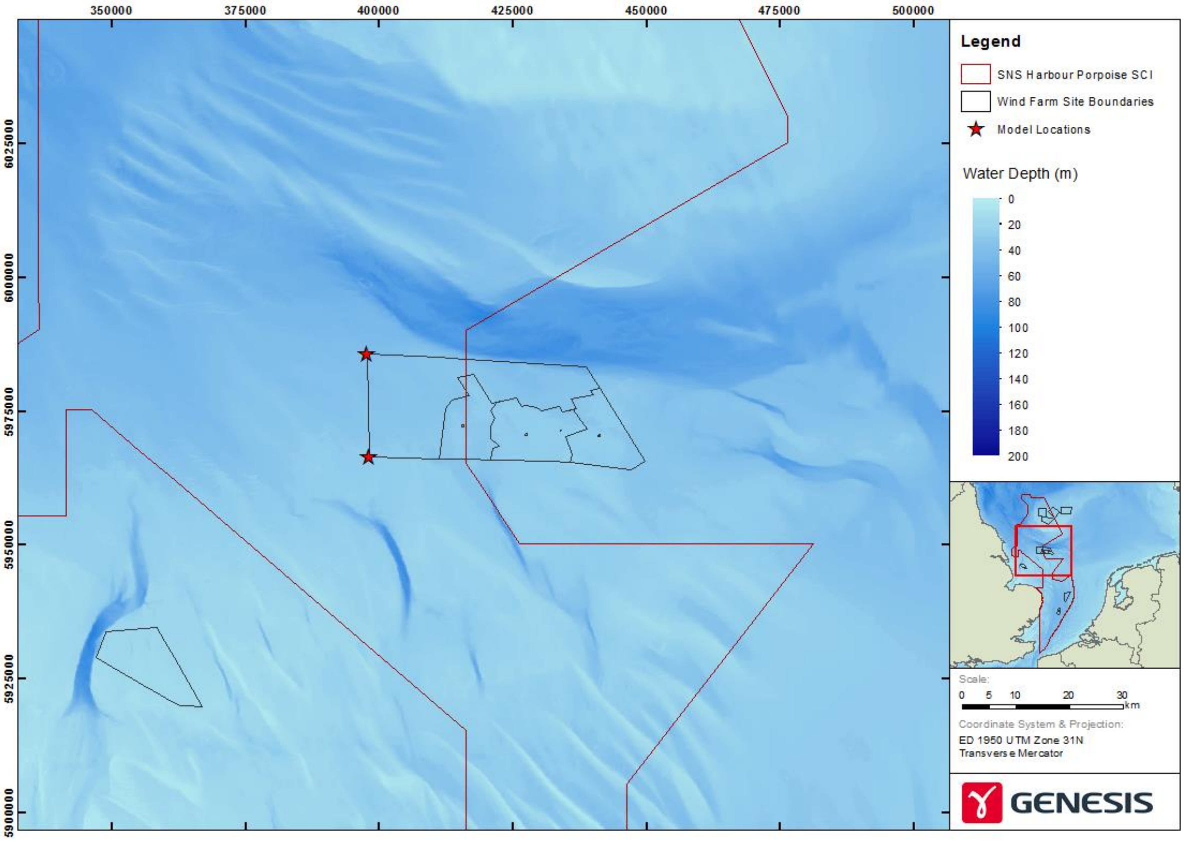

Figure 10-1: Noise modelling locations for pile-driving at Hornsea Two.

Table 10-2: Noise modelling locations for pile-driving at Hornsea Two.

Model Location	Longitude (Decimal degrees)	Latitude (Decimal degrees)
Location 1	1.45143	53.83611
Location 2	1.44033	54.00955

The soft-start/ramp-up procedures that have been used in the cumulative SEL modelling for pile-driving at Hornsea Two are shown in Table 10-3 and are based on the soft-start/ramp-up procedure used in previous modelling for the consented project (Smart Wind Limited, 2015b).

Table 10-3: Hammer soft-start/ramp-up procedure assumed in the modelling of pile-driving at Hornsea Two.

Percentage of maximum hammer energy (%)	Duration (minutes)	Hammer strike rate (blows/minute)	Hammer strike interval (s)	Number of pile strikes
4.0-hour pile-driving duration				
20	30	38	1.6	1,140
40	30	38	1.6	1,140
60	15	32	1.9	480
80	60	32	1.9	1,920
100	405	32	1.9	12,960
7.0-hour pile-driving duration				
20	30	38	1.6	1,140
40	30	38	1.6	1,140
60	15	32	1.9	480
80	60	32	1.9	1,920
100	105	32	1.9	3,360

10.2 Single Pile-driving Modelling Results

Propagation modelling for single pile-driving (i.e. only using a single pile installation vessel) at Hornsea One has been conducted at the model locations shown in Figure 10-1 and Table 10-2, with the different maximum hammer energies shown in Table 10-1 being modelled.

Maximum-over-depth zero-to-peak SPL sound fields have been estimated (see Section 4.2.5.2) and compared to the Southall and NOAA thresholds for the potential onset of PTS and TTS to harbour porpoise. Distances and areas of potential PTS and TTS onset due to zero-to-peak SPL threshold exceedance have been calculated for different percentages of the maximum hammer energy, demonstrating the increase of potential injury zones with increasing hammer energy throughout the soft-start/ramp-up phase. The predicted distances and areas where the Southall and NOAA zero-to-peak SPL thresholds are exceeded are shown in Table 10-4 to Table 10-7 for the various maximum hammer energies that have been modelled for pile-driving at Hornsea Two. Maximum-over-depth zero-to-peak SPL sound fields are shown in Figure G-1 to Figure G-4 in Appendix G of this report for the modelling scenarios involving pile-driving at Hornsea Two with maximum hammer energies of 2,300 kJ and 3,000 kJ.

Cumulative SEL scenarios have been conducted in order to predict potential PTS and TTS onset in harbour porpoise due to exposure to pulses from multiple pile-strikes by estimating areas where the Southall and NOAA cumulative SEL thresholds are exceeded. The cumulative SEL scenarios have been conducted using the "fleeing animal" modelling procedure discussed in Section 4.2.5.3, and take into account the hammer soft-start/ramp-up procedures outlined in Table 10-3. As discussed in Section 4.2.5.3, the cumulative SEL modelling has been conducted for animals receiving depth-averaged SEL for each piling pulse, as well as maximum-over-depth SEL for each piling pulse (which is the absolute worst case scenario). The predicted distances and areas where the Southall and NOAA cumulative SEL thresholds for PTS and TTS onset are exceeded during pile-driving at Hornsea Two are detailed in Table 10-8 to Table 10-11. Maps showing the predicted areas where the cumulative SEL thresholds are exceeded are also shown in Figure G-5 to Figure G-8 for the pile-driving at Hornsea Two with maximum hammer energies of 2,300 kJ and 3,000 kJ.

Depth-averaged and maximum-over-depth unweighted single pulse SEL sound fields have been predicted in order to estimate potential disturbance to harbour porpoise due to pile-driving at Hornsea Two. Depth-averaged and maximum-over-depth unweighted single pulse SEL sound fields for pile-driving at Hornsea Two with maximum hammer energies of 2,300 kJ and 3,000 kJ are shown in Figure G-9 to Figure G-16 in Appendix G of this report.

The predicted depth-averaged and maximum-over-depth unweighted SEL sound fields have been compared to the behavioural disturbance threshold of 145 dB re 1 $\mu Pa^2 s$ proposed by Lucke *et al*. (2009) and Thompson *et al.* (2013b). The predicted distances and areas of this threshold exceedance are shown in Table 10-12 for both the depth-averaged and maximum-over-depth results. The area of threshold exceedance has been calculated as the total area above the threshold, as well as the area within the SCI that is above the threshold.

The probability of displacement of harbour porpoise has been further evaluated using the behavioural/dose response curve discussed in Section 3.2.1.2. The predicted areas and probabilities of behavioural disturbance to harbour porpoise for different SEL contour bands are detailed in Table 10-13 to Table 10-16 for both the depth-averaged and maximum-over-depth SEL modelling results.

The predicted zero-to-peak SPL and cumulative SEL for the Hornsea Two modelling scenarios have been compared to the Popper *et al*. (2014) thresholds for estimating potential injury to fish. The predicted distances and areas where injury to fish may occur from pile-driving at Hornsea Two with various hammer energies are shown in Table 10-17 to Table 10-20.

10.3 Concurrent Pile-driving Modelling Results

Example concurrent pile-driving scenarios at Hornsea Two have been conducted to estimate the increase in potential behavioural disturbance zones for harbour porpoise due to the use of two installation vessels. The concurrent pile driving modelling scenarios involve piling at model locations 1 and 2 (see Figure 10-1 and Table 10-2) where the same hammer energy is used at each location. The concurrent pile-driving modelling has been conducted for the range of hammer energies shown in Table 10-1.

The predicted areas where the harbour porpoise behavioural disturbance threshold of 145 dB re 1 $\mu Pa^2 s$ is exceeded for the concurrent pile-driving scenarios at Hornsea Two are shown in Table 10-21. Table 10-22 and Table 10-23 further show the probability of potential displacement of harbour porpoise for different SEL bands (using the behavioural/dose response curve discussed in Section 3.2.1.2).

Table 10-4: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Hornsea Two model location 1 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	230	1	1	1	3
	460	2	2	2	13
	920	3	3	3	28
	1,380	4	4	4	50
	1,840	4	4	4	50
	2,300	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	230	99	99	99	30,752
	460	143	159	159	78,848
	920	271	273	277	234,044
	1,380	363	429	459	580,490
	1,840	475	551	586	955,660
	2,300	563	585	608	1,075,887
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	230	3	3	3	28
	460	4	4	4	50
	920	6	6	6	113
	1,380	8	8	8	201
	1,840	9	9	9	254
	2,300	11	11	11	380
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	230	271	273	277	233,996
	460	468	548	586	944,131
	920	790	826	861	2,140,311
	1,380	1,024	1,063	1,205	3,547,299
	1,840	1,103	1,258	1,377	4,968,998
	2,300	1,352	1,511	1,703	7,159,819

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

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Table 10-5: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Hornsea Two model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	300	1	1	1	3
	600	2	2	2	13
	1,200	3	3	3	28
	1,800	4	4	4	50
	2,400	5	5	5	78
	3,000	6	6	6	113
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	300	115	116	116	42,169
	600	173	216	231	148,722
	1,200	349	351	356	387,121
	1,800	467	537	583	907,065
	2,400	569	593	654	1,103,058
	3,000	689	761	835	1,822,334
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	300	3	3	3	28
	600	5	5	5	78
	1,200	7	7	7	154
	1,800	9	9	9	254
	2,400	11	11	11	380
	3,000	14	14	14	615
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	300	348	350	355	385,043
	600	569	591	650	1,098,242
	1,200	864	1,001	1,044	3,149,401
	1,800	1,095	1,242	1,351	4,846,615
	2,400	1,487	1,565	1,717	7,689,690
	3,000	1,679	1,808	1,900	10,261,010

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 10-6: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Hornsea Two model location 2 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	230	1	1	1	3
	460	2	2	2	13
	920	3	3	3	28
	1,380	3	3	3	28
	1,840	4	4	4	50
	2,300	4	4	4	50
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	230	76	78	86	19,225
	460	123	128	132	51,576
	920	260	268	273	225,261
	1,380	302	328	394	339,628
	1,840	402	472	507	701,102
	2,300	491	510	524	817,628
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	230	3	3	3	28
	460	4	4	4	50
	920	6	6	6	113
	1,380	8	8	8	201
	1,840	10	10	10	314
	2,300	11	11	11	380
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	230	260	267	273	224,046
	460	402	470	506	696,140
	920	638	669	695	1,405,657
	1,380	897	928	962	2,703,631
	1,840	977	1,047	1,170	3,448,686
	2,300	1,090	1,184	1,308	4,405,228

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 10-7: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Hornsea Two model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m²) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	300	1	1	1	3
	600	2	2	2	13
	1,200	3	3	3	28
	1,800	4	4	4	50
	2,400	5	5	5	78
	3,000	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	300	95	98	100	29,922
	600	164	180	182	101,934
	1,200	284	294	313	271,616
	1,800	399	451	503	640,819
	2,400	494	513	525	824,889
	3,000	593	621	640	1,208,837
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	300	3	3	3	28
	600	5	5	5	78
	1,200	7	7	7	154
	1,800	10	10	10	314
	2,400	11	11	11	380
	3,000	13	13	13	530
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	300	284	294	313	271,082
	600	494	512	525	824,260
	1,200	748	786	888	1,941,421
	1,800	975	1,035	1,163	3,366,514
	2,400	1,118	1,231	1,336	4,757,022
	3,000	1,369	1,468	1,714	6,769,700

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 10-8: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Hornsea Two model location 1 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 10-3)	0	0	0	0
		15	16	16	784
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 10-3)	1,032	1,071	1,117	3,599,319
		1,700	1,748	1,786	9,583,684
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 10-3)	4,027	5,395	6,234	91,899,811
		10,441	13,279	16,972	563,313,665
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 10-3)	12,979	18,419	20,832	1,068,955,146
		21,710	26,297	29,213	2,179,701,968

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 10-9: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Hornsea Two model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	9.0 hour pile-driving sequence (see Table 10-3)	0	0	0	0
		36	40	44	4,961
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	9.0 hour pile-driving sequence (see Table 10-3)	1,463	1,534	1,601	7,388,905
		2,529	2,594	2,650	21,119,929
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	9.0 hour pile-driving sequence (see Table 10-3)	7,128	9,196	11,984	272,057,201
		13,530	26,093	44,735	2,437,220,819
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	9.0 hour pile-driving sequence (see Table 10-3)	21,203	24,853	29,222	1,944,580,861
		25,030	38,988	49,486	4,919,597,135

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 10-10: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Hornsea Two model location 2 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 10-3)	0	0	0	0
		10	11	11	362
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 10-3)	834	892	925	2,496,234
		1,728	1,770	1,796	9,832,993
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 10-3)	4,990	6,333	7,197	126,531,622
		12,349	17,156	23,100	943,054,957
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 10-3)	12,880	17,990	21,100	1,021,204,788
		25,471	27,638	30,360	2,401,696,391

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 10-11: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Hornsea Two model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	9.0 hour pile-driving sequence (see Table 10-3)	0	0	0	0
		24	25	26	1,908
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	9.0 hour pile-driving sequence (see Table 10-3)	1,222	1,304	1,365	5,339,565
		2,545	2,593	2,640	21,091,622
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	9.0 hour pile-driving sequence (see Table 10-3)	8,994	12,999	17,853	549,000,242
		20,660	33,092	55,012	3,667,630,996
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	9.0 hour pile-driving sequence (see Table 10-3)	16,893	25,075	29,268	1,983,364,407
		31,208	41,682	50,148	5,535,123,223

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 10-12: Predicted distances and areas where harbour porpoise behavioural disturbance threshold of 145 dB re 1 µPa²s is exceeded during pile-driving at Hornsea Two.

Model location	Hammer Energy (kJ)	Distance to 145 dB re 1 µPa²s SEL threshold (m)			Total area where SEL exceeds 145 dB re 1 µPa²s (m²)	Area of SCI where SEL exceeds 145 dB re 1 µPa²s (m²)
		Minimum	Average	Maximum		
Depth-averaged						
1	2,300	15,040	20,678	24,118	1,350,070,277	1,324,919,777
	3,000	19,181	23,323	38,738	1,659,305,116	1,587,242,242
2	2,300	19,962	26,800	48,733	2,251,426,082	2,132,675,964
	3,000	22,963	29,517	49,747	2,794,202,636	2,563,917,674
Maximum-over-depth/Worst case						
1	2,300	23,166	33,884	55,635	3,565,166,918	3,208,095,039
	3,000	25,127	38,039	70,404	4,594,171,852	3,980,321,976
2	2,300	30,319	42,032	63,647	5,633,569,958	4,864,054,715
	3,000	34,476	47,309	71,464	7,339,082,827	6,239,580,196

Table 10-13: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Hornsea Two modelling location 1 with maximum hammer energy of 2,300 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	162	162	99.7%
195 - 200	876	876	99.5%
190 - 195	3,561	3,561	99.0%
185 - 190	19,727	19,727	98.2%
180 - 185	122,092	122,092	96.7%
175 - 180	1,019,326	1,019,326	94.1%
170 - 175	3,868,907	3,868,907	89.4%
165 - 170	13,131,152	13,131,152	81.9%
160 - 165	44,203,369	44,203,369	70.7%
155 - 160	123,761,586	123,761,586	56.3%
150 - 155	314,878,372	314,878,371	40.7%
145 - 150	849,061,147	823,910,647	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	100	100	99.9%
200 - 205	688	688	99.7%
195 - 200	3,811	3,811	99.5%
190 - 195	23,396	23,396	99.0%
185 - 190	134,223	134,223	98.2%
180 - 185	835,783	835,783	96.7%
175 - 180	3,285,467	3,285,467	94.1%
170 - 175	11,083,446	11,083,446	89.4%
165 - 170	36,481,996	36,481,996	81.9%
160 - 165	107,488,717	107,488,717	70.7%
155 - 160	270,452,257	270,452,257	56.3%
150 - 155	771,886,474	766,045,187	40.7%
145 - 150	2,363,490,560	2,012,259,967	26.8%

Table 10-14: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Hornsea Two modelling location 1 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	11	11	99.9%
200 - 205	253	253	99.7%
195 - 200	1,249	1,249	99.5%
190 - 195	5,104	5,104	99.0%
185 - 190	28,784	28,784	98.2%
180 - 185	198,048	198,048	96.7%
175 - 180	1,515,834	1,515,834	94.1%
170 - 175	5,002,951	5,002,951	89.4%
165 - 170	17,597,866	17,597,866	81.9%
160 - 165	56,501,186	56,501,186	70.7%
155 - 160	154,410,857	154,410,858	56.3%
150 - 155	399,911,236	399,911,236	40.7%
145 - 150	1,024,131,736	952,068,863	26.8%
Maximum-over-depth/Worst case			
> 210	1	1	99.9%
205 - 210	162	162	99.9%
200 - 205	1,034	1,034	99.7%
195 - 200	5,803	5,802	99.5%
190 - 195	38,935	38,936	99.0%
185 - 190	175,899	175,898	98.2%
180 - 185	1,235,567	1,235,568	96.7%
175 - 180	4,279,823	4,279,823	94.1%
170 - 175	14,673,067	14,673,067	89.4%
165 - 170	47,424,671	47,424,671	81.9%
160 - 165	133,771,832	133,771,832	70.7%
155 - 160	344,774,809	344,774,809	56.3%
150 - 155	952,941,012	909,040,347	40.7%
145 - 150	3,094,849,238	2,524,900,027	26.8%

Table 10-15: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Hornsea Two modelling location 2 with maximum hammer energy of 2,300 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	125	125	99.7%
195 - 200	655	655	99.5%
190 - 195	3,315	3,315	99.0%
185 - 190	15,217	15,218	98.2%
180 - 185	91,834	91,834	96.7%
175 - 180	811,449	811,449	94.1%
170 - 175	3,628,353	3,628,353	89.4%
165 - 170	12,883,193	12,883,193	81.9%
160 - 165	48,201,888	48,201,888	70.7%
155 - 160	159,482,472	159,482,472	56.3%
150 - 155	544,136,505	544,136,505	40.7%
145 - 150	1,482,171,076	1,363,420,957	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	96	96	99.9%
200 - 205	539	539	99.7%
195 - 200	3,259	3,259	99.5%
190 - 195	19,243	19,243	99.0%
185 - 190	114,620	114,619	98.2%
180 - 185	847,687	847,687	96.7%
175 - 180	3,363,806	3,363,806	94.1%
170 - 175	11,756,373	11,756,373	89.4%
165 - 170	42,616,250	42,616,250	81.9%
160 - 165	139,444,427	139,444,426	70.7%
155 - 160	448,089,090	448,089,090	56.3%
150 - 155	1,354,258,093	1,277,917,151	40.7%
145 - 150	3,633,056,475	2,939,882,175	26.8%

Table 10-16: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Hornsea Two modelling location 2 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	183	183	99.7%
195 - 200	1,019	1,019	99.5%
190 - 195	4,894	4,894	99.0%
185 - 190	21,123	21,123	98.2%
180 - 185	129,866	129,866	96.7%
175 - 180	1,253,952	1,253,952	94.1%
170 - 175	4,854,146	4,854,146	89.4%
165 - 170	17,597,816	17,597,816	81.9%
160 - 165	64,502,896	64,502,896	70.7%
155 - 160	196,272,352	196,272,352	56.3%
150 - 155	755,024,834	755,024,834	40.7%
145 - 150	1,754,539,555	1,524,254,593	26.8%
Maximum-over-depth/Worst case			
> 210	1	1	99.9%
205 - 210	149	149	99.9%
200 - 205	814	814	99.7%
195 - 200	4,571	4,571	99.5%
190 - 195	25,807	25,807	99.0%
185 - 190	174,752	174,752	98.2%
180 - 185	1,274,645	1,274,645	96.7%
175 - 180	4,324,943	4,324,943	94.1%
170 - 175	16,081,986	16,081,986	89.4%
165 - 170	56,526,422	56,526,422	81.9%
160 - 165	174,583,207	174,583,207	70.7%
155 - 160	648,049,704	648,049,703	56.3%
150 - 155	1,658,091,216	1,475,867,485	40.7%
145 - 150	4,779,944,611	3,862,665,711	26.8%

Table 10-17: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Hornsea Two model location 1 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m²)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,300	65	65	65	13,256
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 10-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	238	242	255	183,539
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 10-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		29	31	32	3,004
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	238	242	255	183,539
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 10-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		29	31	32	3,004

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 10-18: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Hornsea Two model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	3,000	100	100	100	31,376
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	9.0 hour pile-driving sequence (see Table 10-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	100	100	100	31,376
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	9.0 hour pile-driving sequence (see Table 10-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	100	100	100	31,376
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	9.0 hour pile-driving sequence (see Table 10-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 10-19: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Hornsea Two model location 2 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,300	67	72	73	16,222
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 10-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	188	195	223	118,963
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 10-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		21	22	22	1,492
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	188	195	223	118,963
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 10-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		21	22	22	1,492

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 10-20: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Hornsea Two model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	3,000	77	79	87	19,461
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 μPa^2s)	9.0 hour pile-driving sequence (see Table 10-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 μPa^2s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	261	272	278	231,490
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 μPa^2s)	9.0 hour pile-driving sequence (see Table 10-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 μPa^2s)		44	47	50	6,789
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	261	272	278	231,490
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 μPa^2s)	9.0 hour pile-driving sequence (see Table 10-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 μPa^2s)		44	47	50	6,789

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 10-21: Predicted areas where harbour porpoise behavioural disturbance threshold of 145 dB re 1 μPa^{2}s is exceeded during concurrent pile-driving at Hornsea Two.

Model location	Hammer Energy (kJ)	Total area where SEL exceeds 145 dB re 1 μPa^{2}s (m^2)	Area of SCI where SEL exceeds 145 dB re 1 μPa^{2}s (m^2)
Depth-averaged			
1 and 2	2,300	2,818,959,393	2,685,526,609
	3,000	3,420,427,234	3,159,984,580
Maximum-over-depth/Worst case			
1 and 2	2,300	6,309,446,331	5,465,709,102
	3,000	7,936,817,956	6,734,096,756

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Table 10-22: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Hornsea Two locations 1 and 2 with maximum hammer energy of 2,300 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	287	287	99.7%
195 - 200	1,531	1,531	99.5%
190 - 195	6,876	6,876	99.0%
185 - 190	34,945	34,945	98.2%
180 - 185	213,926	213,926	96.7%
175 - 180	1,830,775	1,830,775	94.1%
170 - 175	7,497,260	7,497,260	89.4%
165 - 170	26,014,345	26,014,345	81.9%
160 - 165	92,405,256	92,405,256	70.7%
155 - 160	283,244,058	283,244,058	56.3%
150 - 155	730,930,860	730,930,860	40.7%
145 - 150	1,676,779,273	1,543,346,489	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	196	196	99.9%
200 - 205	1,227	1,227	99.7%
195 - 200	7,070	7,070	99.5%
190 - 195	42,639	42,639	99.0%
185 - 190	248,843	248,843	98.2%
180 - 185	1,683,470	1,683,470	96.7%
175 - 180	6,649,273	6,649,273	94.1%
170 - 175	22,839,819	22,839,819	89.4%
165 - 170	79,098,247	79,098,247	81.9%
160 - 165	246,933,144	246,933,144	70.7%
155 - 160	630,467,252	630,467,252	56.3%
150 - 155	1,545,009,023	1,462,920,273	40.7%
145 - 150	3,776,466,129	3,014,817,650	26.8%

Table 10-23: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Hornsea Two locations 1 and 2 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	11	11	99.9%
200 - 205	436	436	99.7%
195 - 200	2,267	2,267	99.5%
190 - 195	9,997	9,997	99.0%
185 - 190	49,907	49,907	98.2%
180 - 185	327,914	327,915	96.7%
175 - 180	2,769,787	2,769,786	94.1%
170 - 175	9,857,097	9,857,097	89.4%
165 - 170	35,195,683	35,195,683	81.9%
160 - 165	121,004,082	121,004,082	70.7%
155 - 160	350,683,209	350,683,209	56.3%
150 - 155	933,293,839	933,293,839	40.7%
145 - 150	1,967,233,004	1,706,790,350	26.8%
Maximum-over-depth/Worst case			
> 210	2	2	99.9%
205 - 210	311	311	99.9%
200 - 205	1,848	1,848	99.7%
195 - 200	10,374	10,373	99.5%
190 - 195	64,742	64,742	99.0%
185 - 190	350,650	350,650	98.2%
180 - 185	2,510,212	2,510,212	96.7%
175 - 180	8,604,766	8,604,766	94.1%
170 - 175	30,755,054	30,755,054	89.4%
165 - 170	103,951,092	103,951,092	81.9%
160 - 165	308,355,040	308,355,040	70.7%
155 - 160	828,620,130	828,620,130	56.3%
150 - 155	1,856,776,698	1,654,680,363	40.7%
145 - 150	4,796,817,039	3,796,192,174	26.8%

11.0 TEESSIDE A

This section presents the underwater sound propagation modelling undertaken to predict potential impacts to harbour porpoise and fish from pile-driving at the Teesside A development. Project specific model inputs (such as maximum hammer energy, model locations and hammer soft-start/ramp-up procedures) are firstly introduced, before the modelling results are presented. The propagation modelling has considered scenarios involving single pile-driving (i.e. the use of a single pile installation vessel), and concurrent pile-driving involving the use of two pile-driving vessels.

11.1 Model Inputs

A number of pile-driving options have been considered for the installation of infrastructure (such as offshore platforms and wind turbine generators) associated with the Teesside A wind farm development. A number of different modelling scenarios have therefore been considered to predict potential impacts due to pile-driving at Teesside A.

The modelled scenarios that have been conducted for pile-driving at Teesside A are summarised in Table 11-1, and were selected based on the information provided by Forewind (*pers. comm.*) as well as the consented project description (Forewind, 2013c) and previous noise modelling (Forewind, 2013d). The modelling scenarios in Table 11-1 have been selected to cover a range of possible pile-driving events at Teesside A involving the use of different maximum hammer energies and different pile installation durations.

Table 11-1: Noise modelling scenarios for pile-driving at Teesside A.

Infrastructure	Foundation type	Pile diameter (m)	Maximum Hammer Energy (kJ)	Estimated duration to install a single pile (hours)
Consented Project				
Wind turbine generators	Monopile	12.0	3,000	5.5
	Multi-leg jacket piles	3.5	2,300	3.5
Met masts	Monopile	12.0	3,000	5.5
	Multi-leg jacket piles	3.5	1,900	3.5
Planned Project				
Wind turbine generators	Monopile	12.0	5,500	5.5
	Multi-leg jacket piles	3.5	2,300	3.5

The modelling has been conducted at different locations within the Teesside A site in order to provide a range of estimates for potential injury and disturbance to harbour porpoise. The modelling locations that have been used to assess potential injury and disturbance to harbour porpoise due to pile-driving at Teesside A are shown in Figure 11-1 and Table 11-2.

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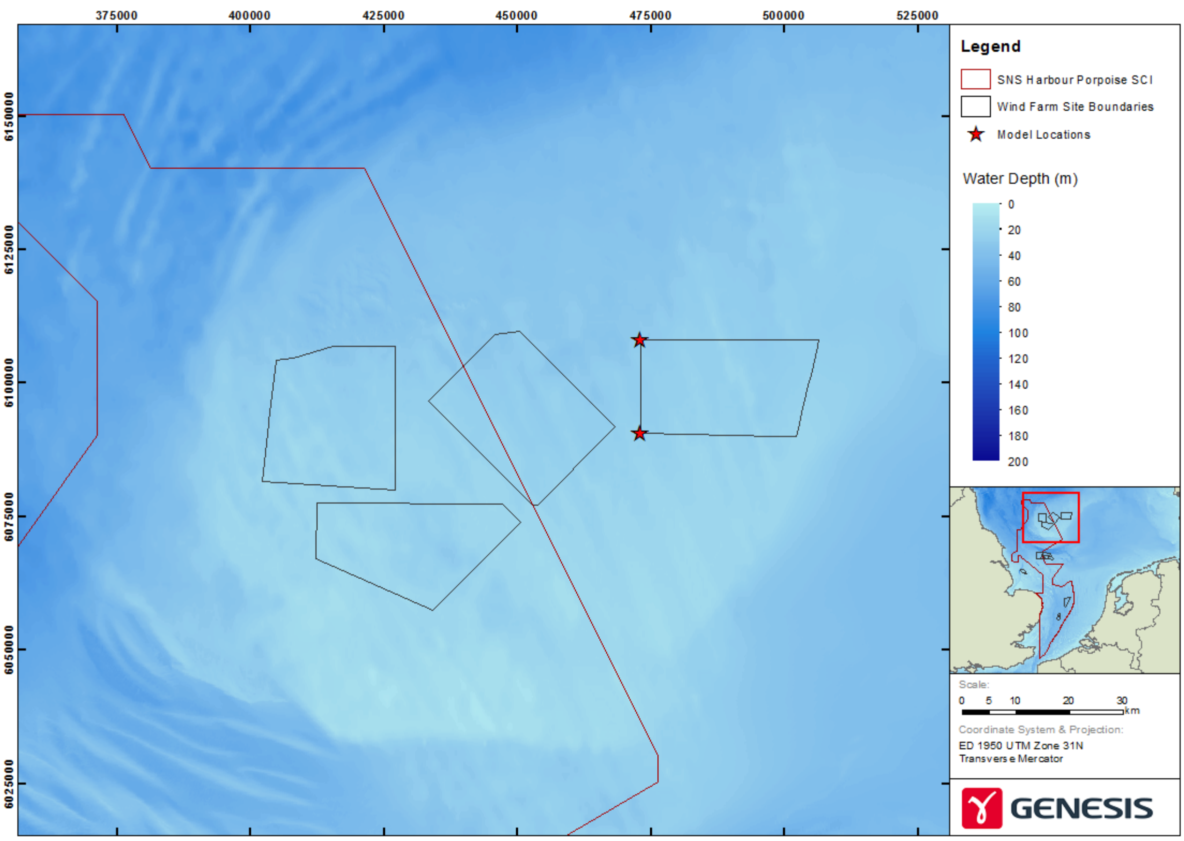

Figure 11-1: Noise modelling locations for pile-driving at Teesside A.

Table 11-2: Noise modelling locations for pile-driving at Teesside A.

Model Location	Longitude (Decimal degrees)	Latitude (Decimal degrees)
Location 1	2.57835	54.96083
Location 2	2.57669	55.11861

The cumulative SEL modelling takes into consideration the pile-driving duration and includes the soft-start/ramp-up phase of the pile installation. The soft-start/ramp-up procedures utilised in the cumulative SEL modelling for installation of piles at Teesside A are shown in Table 11-3 and is based on the ramp-up procedure that was used in the noise modelling for the consented project application (Forewind, 2013d).

Table 11-3: Hammer soft-start/ramp-up procedure assumed in the modelling of pile-driving at Teesside A.

Percentage of maximum hammer energy (%)	Duration (minutes)	Hammer strike rate (blows/minute)	Hammer strike interval (s)	Number of pile strikes
3.5-hour pile-driving duration				
10	30	20	3.0	600
100	180	40	1.5	7,200
5.5-hour pile-driving duration				
10	30	20	3.0	600
100	300	40	1.5	12,000

11.2 Single Pile-driving Modelling Results

Propagation modelling for single pile-driving (i.e. only using a single pile installation vessel) at Teesside A has been conducted at the model locations shown in Figure 11-1 and Table 11-2, with the different maximum hammer energies shown in Table 11-1 being modelled.

Maximum-over-depth zero-to-peak SPL sound fields have been estimated (see Section 4.2.5.2) and compared to the Southall and NOAA thresholds for the potential onset of PTS and TTS to harbour porpoise. Distances and areas of potential PTS and TTS onset due to zero-to-peak SPL threshold exceedance have been calculated for different percentages of the maximum hammer energy, demonstrating the increase of potential injury zones with increasing hammer energy throughout the soft-start/ramp-up phase. The predicted distances and areas where the Southall and NOAA zero-to-peak SPL thresholds are exceeded are shown in Table 11-4 to Table 11-11 for the various maximum hammer energies that have been modelled for pile-driving at Teesside A. Example maximum-over-depth zero-to-peak SPL sound fields are shown in Figure H-1 to Figure H-4 in Appendix H of this report for the modelling scenarios involving pile-driving at Teesside A with maximum hammer energies of 1,900 kJ and 5,500 kJ.

Cumulative SEL scenarios have been conducted in order to predict potential PTS and TTS onset in harbour porpoise due to exposure to pulses from multiple pile-strikes by estimating areas where the Southall and NOAA cumulative SEL thresholds are exceeded. The cumulative SEL scenarios have been conducted using the “fleeing animal” modelling procedure discussed in Section 4.2.5.3, and take into account the hammer soft-start/ramp-up procedures outlined in Table 11-3. As discussed in Section 4.2.5.3, the cumulative SEL modelling has been conducted for animals receiving depth-averaged SEL for each piling pulse, as well as maximum-over-depth SEL for each piling pulse (which is the absolute worst case scenario). The predicted distances and areas where the Southall and NOAA cumulative SEL thresholds for PTS and TTS onset are exceeded during pile-driving at Teesside A are detailed in Table 10-8 to Table 10-11. Example maps showing the predicted areas where the cumulative SEL thresholds are exceeded are also shown in Figure H-5 to Figure H-8 for the pile-driving at Teesside A with maximum hammer energies of 1,900 kJ and 5,500 kJ.

Depth-averaged and maximum-over-depth unweighted single pulse SEL sound fields have been predicted in order to estimate potential disturbance to harbour porpoise due to pile-driving at Teesside A. Example depth-averaged and maximum-over-depth unweighted single pulse SEL sound fields for pile-driving at Teesside A with maximum hammer energies of 1,900 kJ and 5,500 kJ are shown in Figure H-9 to Figure H-16 in Appendix H of this report.

The predicted depth-averaged and maximum-over-depth unweighted SEL sound fields have been compared to the behavioural disturbance threshold of 145 dB re 1 µPa²s proposed by Lucke *et al*. (2009) and Thompson *et al.* (2013b). The predicted distances and areas of this threshold exceedance are shown in Table 11-20 for both the depth-averaged and maximum-over-depth results. The area of threshold exceedance has been calculated as the total area above the threshold, as well as the area within the SCI that is above the threshold.

The probability of displacement of harbour porpoise has been further evaluated using the behavioural/dose response curve discussed in Section 3.2.1.2. The predicted areas and probabilities of behavioural disturbance to harbour porpoise for different SEL contour bands are detailed in Table 11-21 to Table 11-28 for both the depth-averaged and maximum-over-depth SEL modelling results.

The predicted zero-to-peak SPL and cumulative SEL for the Teesside A modelling scenarios have been compared to the Popper *et al*. (2014) thresholds for estimating potential injury to fish. The predicted distances and areas where injury to fish may occur from pile-driving at Teesside A with various hammer energies are shown in Table 11-29 to Table 11-36.

11.3 Concurrent Pile-driving Modelling Results

Example concurrent pile-driving scenarios at Teesside A have been conducted to estimate the increase in potential behavioural disturbance zones for harbour porpoise due to the use of two installation vessels. The concurrent pile driving modelling scenarios involve piling at model locations 1 and 2 (see Figure 11-1 and Table 11-2) where the same hammer energy is used at each location. The concurrent pile-driving modelling has been conducted for the range of hammer energies shown in Table 11-1.

The predicted areas where the harbour porpoise behavioural disturbance threshold of 145 dB re 1 µPa²s is exceeded for the concurrent pile-driving scenarios at Teesside A are shown in Table 11-37. Table 11-38 to Table 11-41 further show the probability of potential displacement of harbour porpoise for different SEL bands (using the behavioural/dose response curve discussed in Section 3.2.1.2).

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Table 11-4: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside A model location 1 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	190	1	1	1	3
	380	2	2	2	13
	760	2	2	2	13
	1,140	3	3	3	28
	1,520	4	4	4	50
	1,900	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	190	102	102	102	32,644
	380	140	140	140	61,497
	760	234	237	277	176,310
	1,140	321	353	363	390,862
	1,520	377	423	437	561,625
	1,900	442	456	473	653,515
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	190	2	2	2	13
	380	4	4	4	50
	760	6	6	6	113
	1,140	7	7	7	154
	1,520	10	10	10	314
	1,900	12	12	12	452
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	190	234	236	274	174,824
	380	377	422	437	559,625
	760	631	684	717	1,470,896
	1,140	872	923	967	2,674,940
	1,520	991	1,120	1,179	3,950,600
	1,900	1,155	1,279	1,330	5,138,547

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

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Table 11-5: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside A model location 1 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	230	1	1	1	3
	460	2	2	2	13
	920	3	3	3	28
	1,380	4	4	4	50
	1,840	4	4	4	50
	2,300	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	230	109	109	109	37,278
	460	182	182	182	103,930
	920	279	299	308	280,360
	1,380	365	379	421	449,945
	1,840	440	453	467	644,707
	2,300	488	534	560	896,948
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	230	3	3	3	28
	460	4	4	4	50
	920	7	7	7	154
	1,380	9	9	9	254
	1,840	12	12	12	452
	2,300	14	14	14	615
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	230	279	298	308	279,476
	460	439	453	465	643,354
	920	734	776	804	1,890,664
	1,380	956	1,059	1,127	3,527,126
	1,840	1,123	1,248	1,308	4,901,264
	2,300	1,346	1,455	1,489	6,640,953

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 11-6: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside A model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	300	1	1	1	3
	600	2	2	2	13
	1,200	3	3	3	28
	1,800	4	4	4	50
	2,400	5	5	5	78
	3,000	6	6	6	113
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	300	129	129	129	52,213
	600	226	226	226	160,256
	1,200	332	363	367	414,252
	1,800	437	451	460	638,723
	2,400	513	561	616	987,717
	3,000	630	682	716	1,460,213
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	300	3	3	3	28
	600	5	5	5	78
	1,200	8	8	8	201
	1,800	11	11	11	380
	2,400	14	14	14	615
	3,000	16	16	16	803
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	300	332	361	366	410,028
	600	512	558	615	977,303
	1,200	925	971	1,001	2,962,191
	1,800	1,098	1,232	1,293	4,778,388
	2,400	1,374	1,485	1,522	6,919,383
	3,000	1,567	1,656	1,716	8,609,220

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 11-7: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside A model location 1 with a maximum hammer energy of 5,500 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	550	2	2	2	13
	1,100	3	3	3	28
	2,200	5	5	5	78
	3,300	6	6	6	113
	4,400	7	7	7	154
	5,500	9	9	9	254
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	550	204	204	204	130,575
	1,100	312	330	360	341,250
	2,200	481	505	555	801,589
	3,300	658	729	773	1,667,815
	4,400	865	911	964	2,607,528
	5,500	957	1,060	1,128	3,531,950
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	550	5	5	5	78
	1,100	7	7	7	154
	2,200	13	13	13	530
	3,300	17	17	17	907
	4,400	21	21	21	1,384
	5,500	26	26	26	2,121
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	550	481	504	554	798,453
	1,100	864	911	964	2,604,244
	2,200	1,315	1,419	1,438	6,319,747
	3,300	1,596	1,742	1,841	9,522,318
	4,400	1,930	2,062	2,146	13,349,010
	5,500	2,173	2,293	2,423	16,503,453

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 11-8: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside A model location 2 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	190	1	1	1	3
	380	2	2	2	13
	760	2	2	2	13
	1,140	3	3	3	28
	1,520	4	4	4	50
	1,900	4	4	4	50
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	190	76	88	92	24,270
	380	146	153	160	73,606
	760	212	215	223	144,852
	1,140	310	317	325	316,118
	1,520	356	361	377	407,799
	1,900	459	471	501	695,437
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	190	2	2	2	13
	380	4	4	4	50
	760	6	6	6	113
	1,140	7	7	7	154
	1,520	9	10	10	302
	1,900	12	12	12	452
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	190	212	215	222	144,586
	380	355	360	369	406,105
	760	605	648	698	1,320,225
	1,140	754	803	827	2,025,502
	1,520	945	969	1,124	2,944,116
	1,900	1,101	1,201	1,302	4,534,645

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 11-9: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside A model location 2 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	230	1	1	1	3
	460	2	2	2	13
	920	3	3	3	28
	1,380	4	4	4	50
	1,840	4	4	4	50
	2,300	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	230	110	111	114	38,678
	460	166	173	178	93,656
	920	250	274	301	236,226
	1,380	344	345	353	374,387
	1,840	412	446	499	626,903
	2,300	493	505	520	800,859
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	230	3	3	3	28
	460	4	4	4	50
	920	6	7	7	141
	1,380	9	9	9	254
	1,840	11	12	12	436
	2,300	14	14	14	615
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	230	247	273	301	234,915
	460	412	444	498	620,485
	920	705	724	753	1,645,048
	1,380	882	904	962	2,566,864
	1,840	1,080	1,184	1,240	4,415,300
	2,300	1,410	1,490	1,612	6,972,382

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 11-10: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside A model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	300	1	1	1	3
	600	2	2	2	13
	1,200	3	3	3	28
	1,800	4	4	4	50
	2,400	5	5	5	78
	3,000	6	6	6	113
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	300	126	127	129	50,990
	600	186	194	203	117,722
	1,200	318	323	332	326,672
	1,800	407	441	497	611,476
	2,400	509	537	566	906,208
	3,000	591	646	697	1,312,292
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	300	3	3	3	28
	600	5	5	5	78
	1,200	8	8	8	201
	1,800	11	11	11	380
	2,400	14	14	15	650
	3,000	16	16	17	835
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	300	318	323	332	326,587
	600	505	536	551	900,947
	1,200	775	827	891	2,147,588
	1,800	1,064	1,174	1,231	4,341,315
	2,400	1,508	1,562	1,629	7,654,372
	3,000	1,568	1,637	1,781	8,414,725

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 11-11: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside A model location 2 with a maximum hammer energy of 5,500 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m²) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	550	2	2	2	13
	1,100	3	3	3	28
	2,200	5	5	5	78
	3,300	6	6	6	113
	4,400	7	7	7	154
	5,500	9	9	9	254
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	550	180	182	185	103,926
	1,100	305	313	323	308,527
	2,200	490	501	515	786,587
	3,300	648	685	734	1,473,650
	4,400	720	762	814	1,822,660
	5,500	883	905	962	2,567,338
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	550	5	5	5	78
	1,100	7	7	7	154
	2,200	13	13	14	564
	3,300	17	17	17	907
	4,400	20	21	21	1,325
	5,500	24	24	26	1,880
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	550	490	500	515	784,850
	1,100	719	762	813	1,819,933
	2,200	1,297	1,461	1,517	6,706,557
	3,300	1,682	1,776	1,907	9,912,713
	4,400	1,879	1,949	2,101	11,923,418
	5,500	2,099	2,206	2,500	15,268,057

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

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Table 11-12: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside A model location 1 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 11-3)	0	0	0	0
		2	2	2	13
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 11-3)	779	903	1,005	2,572,909
		1,673	1,837	1,987	10,615,336
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 11-3)	4,317	5,199	6,146	85,392,834
		8,707	11,184	14,556	397,868,787
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 11-3)	18,454	19,878	22,566	1,242,472,625
		22,971	25,351	28,146	2,019,440,091

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 11-13: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside A model location 1 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 11-3)	0	0	0	0
		3	3	3	28
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 11-3)	1,141	1,316	1,462	5,460,939
		2,202	2,405	2,592	18,181,035
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 11-3)	5,184	6,299	7,529	125,380,356
		9,834	12,844	16,980	526,209,525
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 11-3)	19,778	21,624	24,514	1,470,623,087
		24,792	27,594	30,530	2,392,381,699

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

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Table 11-14: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside A model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 11-3)	0	0	0	0
		5	5	5	78
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 11-3)	1,886	2,169	2,401	14,822,324
		3,320	3,662	3,888	42,134,288
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 11-3)	6,851	8,987	11,585	257,058,446
		12,109	17,529	25,012	1,001,767,390
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 11-3)	22,417	26,101	29,379	2,147,110,130
		30,043	34,816	38,097	3,815,015,075

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 11-15: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside A model location 1 with a maximum hammer energy of 5,500 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 11-3)	3	3	4	30
		61	82	98	21,488
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 11-3)	3,945	4,459	4,777	62,520,415
		6,100	6,677	7,034	140,060,060
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 11-3)	10,402	14,179	19,181	645,638,014
		16,395	25,292	37,314	2,118,245,199
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 11-3)	26,656	33,177	37,678	3,483,302,591
		36,617	45,953	53,267	6,671,724,853

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 11-16: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside A model location 2 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 11-3)	0	0	0	0
		2	2	2	13
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 11-3)	661	708	762	1,575,274
		1,525	1,621	1,687	8,247,142
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 11-3)	4,754	5,413	6,421	92,517,118
		9,147	11,396	13,800	411,927,405
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 11-3)	17,486	19,062	21,785	1,143,404,123
		23,622	25,467	28,512	2,039,360,828

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 11-17: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside A model location 2 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 11-3)	0	0	0	0
		3	3	3	28
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 11-3)	1,016	1,074	1,152	3,625,146
		2,099	2,215	2,300	15,393,341
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 11-3)	5,650	6,570	7,795	136,411,800
		10,536	13,272	16,184	559,919,531
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 11-3)	19,090	20,933	23,863	1,379,247,041
		25,855	27,890	30,943	2,445,368,659

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

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Table 11-18: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside A model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 11-3)	0	0	0	0
		4	4	5	51
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 11-3)	1,749	1,838	1,935	10,605,698
		3,219	3,349	3,615	35,210,891
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 11-3)	7,666	9,597	11,559	293,015,830
		14,008	18,943	23,483	1,153,086,573
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 11-3)	22,807	25,898	30,012	2,114,349,870
		31,760	35,418	39,252	3,946,021,390

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 11-19: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside A model location 2 with a maximum hammer energy of 5,500 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 11-3)	2	2	2	13
		40	48	60	7,245
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 11-3)	3,807	3,997	4,242	50,164,318
		6,067	6,308	6,783	124,945,111
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 11-3)	11,889	15,426	18,629	760,327,638
		19,876	28,196	36,909	2,579,934,197
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 11-3)	29,141	33,484	38,337	3,537,921,509
		38,603	47,121	53,763	7,020,439,916

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

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Table 11-20: Predicted distances and areas where harbour porpoise behavioural disturbance threshold of 145 dB re 1 μPa²s is exceeded during pile-driving at Teesside A.

Model location	Hammer Energy (kJ)	Distance to 145 dB re 1 μPa²s SEL threshold (m)			Total area where SEL exceeds 145 dB re 1 μPa²s (m²)	Area of SCI where SEL exceeds 145 dB re 1 μPa²s (m²)
		Minimum	Average	Maximum		
Depth-averaged						
1	1,900	13,355	15,396	17,871	750,084,740	0
	2,300	14,369	16,579	19,642	869,872,087	0
	3,000	15,477	18,387	21,778	1,072,036,007	0
	5,500	19,467	23,456	29,330	1,751,957,377	2,851,784
2	1,900	14,241	16,656	19,306	867,390,304	0
	2,300	14,984	17,867	20,807	1,001,822,242	0
	3,000	16,560	19,737	22,904	1,225,584,950	0
	5,500	20,514	25,003	29,015	1,964,292,481	0
Maximum-over-depth/Worst case						
1	1,900	18,161	22,316	27,167	1,628,362,357	0
	2,300	19,535	24,118	30,412	1,883,959,151	11,694,863
	3,000	21,222	26,581	34,110	2,302,126,046	63,062,065
	5,500	24,863	33,647	44,566	3,687,584,419	294,331,458
2	1,900	19,435	23,465	27,120	1,874,424,370	0
	2,300	20,621	25,560	31,026	2,187,029,581	0
	3,000	22,142	28,607	34,114	2,757,419,394	4,206,879
	5,500	27,925	36,983	44,534	4,508,485,407	222,163,560

Table 11-21: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Teesside A modelling location 1 with maximum hammer energy of 1,900 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	16	0	99.9%
200 - 205	219	0	99.7%
195 - 200	696	0	99.5%
190 - 195	3,136	0	99.0%
185 - 190	12,899	0	98.2%
180 - 185	124,517	0	96.7%
175 - 180	829,266	0	94.1%
170 - 175	3,078,809	0	89.4%
165 - 170	8,989,875	0	81.9%
160 - 165	27,666,881	0	70.7%
155 - 160	76,326,450	0	56.3%
150 - 155	182,615,880	0	40.7%
145 - 150	450,436,094	0	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	107	0	99.9%
200 - 205	616	0	99.7%
195 - 200	3,110	0	99.5%
190 - 195	21,546	0	99.0%
185 - 190	109,067	0	98.2%
180 - 185	749,061	0	96.7%
175 - 180	2,778,591	0	94.1%
170 - 175	7,837,563	0	89.4%
165 - 170	23,640,346	0	81.9%
160 - 165	64,863,483	0	70.7%
155 - 160	156,677,685	0	56.3%
150 - 155	392,658,691	0	40.7%
145 - 150	979,022,491	0	26.8%

Table 11-22: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Teesside A modelling location 1 with maximum hammer energy of 2,300 kJ.

SEL contour band (dB re 1 μPa²s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	45	0	99.9%
200 - 205	249	0	99.7%
195 - 200	903	0	99.5%
190 - 195	4,044	0	99.0%
185 - 190	16,112	0	98.2%
180 - 185	160,636	0	96.7%
175 - 180	1,113,920	0	94.1%
170 - 175	3,617,349	0	89.4%
165 - 170	10,934,824	0	81.9%
160 - 165	33,133,911	0	70.7%
155 - 160	87,928,720	0	56.3%
150 - 155	213,924,933	0	40.7%
145 - 150	519,036,441	0	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	149	0	99.9%
200 - 205	817	0	99.7%
195 - 200	3,963	0	99.5%
190 - 195	27,826	0	99.0%
185 - 190	142,987	0	98.2%
180 - 185	976,346	0	96.7%
175 - 180	3,270,823	0	94.1%
170 - 175	9,492,619	0	89.4%
165 - 170	28,114,876	0	81.9%
160 - 165	75,963,175	0	70.7%
155 - 160	181,477,243	0	56.3%
150 - 155	449,495,307	0	40.7%
145 - 150	1,134,993,020	11,694,863	26.8%

Table 11-23: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Teesside A modelling location 1 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	89	0	99.9%
200 - 205	315	0	99.7%
195 - 200	1,262	0	99.5%
190 - 195	5,865	0	99.0%
185 - 190	22,938	0	98.2%
180 - 185	209,903	0	96.7%
175 - 180	1,653,853	0	94.1%
170 - 175	4,512,314	0	89.4%
165 - 170	14,294,560	0	81.9%
160 - 165	41,856,719	0	70.7%
155 - 160	108,513,727	0	56.3%
150 - 155	268,360,471	0	40.7%
145 - 150	632,603,993	0	26.8%
Maximum-over-depth/Worst case			
> 210	18	0	99.9%
205 - 210	217	0	99.9%
200 - 205	1,214	0	99.7%
195 - 200	5,837	0	99.5%
190 - 195	38,489	0	99.0%
185 - 190	227,351	0	98.2%
180 - 185	1,428,753	0	96.7%
175 - 180	4,040,397	0	94.1%
170 - 175	12,318,470	0	89.4%
165 - 170	35,581,116	0	81.9%
160 - 165	93,491,873	0	70.7%
155 - 160	225,786,056	0	56.3%
150 - 155	547,355,239	0	40.7%
145 - 150	1,381,851,015	63,062,065	26.8%

Table 11-24: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Teesside A modelling location 1 with maximum hammer energy of 5,500 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	3	0	99.9%
205 - 210	209	0	99.9%
200 - 205	620	0	99.7%
195 - 200	2,790	0	99.5%
190 - 195	11,710	0	99.0%
185 - 190	108,524	0	98.2%
180 - 185	737,438	0	96.7%
175 - 180	2,850,465	0	94.1%
170 - 175	8,195,489	0	89.4%
165 - 170	25,415,554	0	81.9%
160 - 165	71,329,963	0	70.7%
155 - 160	170,244,158	0	56.3%
150 - 155	424,375,453	0	40.7%
145 - 150	1,048,685,001	2,851,784	26.8%
Maximum-over-depth/Worst case			
> 210	91	0	99.9%
205 - 210	541	0	99.9%
200 - 205	2,727	0	99.7%
195 - 200	17,895	0	99.5%
190 - 195	90,768	0	99.0%
185 - 190	678,131	0	98.2%
180 - 185	2,560,465	0	96.7%
175 - 180	7,174,076	0	94.1%
170 - 175	21,797,742	0	89.4%
165 - 170	60,238,553	0	81.9%
160 - 165	146,246,947	0	70.7%
155 - 160	369,613,498	0	56.3%
150 - 155	908,919,898	0	40.7%
145 - 150	2,170,243,087	294,331,458	26.8%

Table 11-25: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Teesside A modelling location 2 with maximum hammer energy of 1,900 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	0	0	99.9%
200 - 205	177	0	99.7%
195 - 200	641	0	99.5%
190 - 195	2,814	0	99.0%
185 - 190	12,390	0	98.2%
180 - 185	86,752	0	96.7%
175 - 180	751,711	0	94.1%
170 - 175	3,015,717	0	89.4%
165 - 170	8,981,668	0	81.9%
160 - 165	29,419,973	0	70.7%
155 - 160	84,167,533	0	56.3%
150 - 155	214,479,020	0	40.7%
145 - 150	526,471,908	0	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	101	0	99.9%
200 - 205	576	0	99.7%
195 - 200	2,696	0	99.5%
190 - 195	16,070	0	99.0%
185 - 190	87,753	0	98.2%
180 - 185	756,975	0	96.7%
175 - 180	2,837,027	0	94.1%
170 - 175	8,490,462	0	89.4%
165 - 170	25,520,065	0	81.9%
160 - 165	72,519,919	0	70.7%
155 - 160	185,999,396	0	56.3%
150 - 155	459,416,523	0	40.7%
145 - 150	1,118,776,806	0	26.8%

Table 11-26: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Teesside A modelling location 2 with maximum hammer energy of 2,300 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	12	0	99.9%
200 - 205	211	0	99.7%
195 - 200	840	0	99.5%
190 - 195	3,562	0	99.0%
185 - 190	15,847	0	98.2%
180 - 185	127,786	0	96.7%
175 - 180	963,329	0	94.1%
170 - 175	3,619,455	0	89.4%
165 - 170	11,128,589	0	81.9%
160 - 165	35,262,386	0	70.7%
155 - 160	98,685,042	0	56.3%
150 - 155	248,073,877	0	40.7%
145 - 150	603,941,305	0	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	141	0	99.9%
200 - 205	754	0	99.7%
195 - 200	3,709	0	99.5%
190 - 195	21,493	0	99.0%
185 - 190	120,292	0	98.2%
180 - 185	951,765	0	96.7%
175 - 180	3,449,257	0	94.1%
170 - 175	10,026,263	0	89.4%
165 - 170	30,735,969	0	81.9%
160 - 165	85,290,086	0	70.7%
155 - 160	215,141,071	0	56.3%
150 - 155	538,544,341	0	40.7%
145 - 150	1,302,744,439	0	26.8%

Table 11-27: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Teesside A modelling location 2 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	52	0	99.9%
200 - 205	260	0	99.7%
195 - 200	1,193	0	99.5%
190 - 195	4,957	0	99.0%
185 - 190	22,372	0	98.2%
180 - 185	200,008	0	96.7%
175 - 180	1,445,353	0	94.1%
170 - 175	4,525,565	0	89.4%
165 - 170	14,845,774	0	81.9%
160 - 165	44,854,588	0	70.7%
155 - 160	125,847,475	0	56.3%
150 - 155	298,408,990	0	40.7%
145 - 150	735,428,364	0	26.8%
Maximum-over-depth/Worst case			
> 210	16	0	99.9%
205 - 210	206	0	99.9%
200 - 205	1,096	0	99.7%
195 - 200	5,815	0	99.5%
190 - 195	36,410	0	99.0%
185 - 190	180,393	0	98.2%
180 - 185	1,421,654	0	96.7%
175 - 180	4,406,062	0	94.1%
170 - 175	12,826,052	0	89.4%
165 - 170	39,355,354	0	81.9%
160 - 165	107,222,592	0	70.7%
155 - 160	263,003,858	0	56.3%
150 - 155	656,642,950	0	40.7%
145 - 150	1,672,316,939	4,206,879	26.8%

Table 11-28: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Teesside A modelling location 2 with maximum hammer energy of 5,500 kJ.

SEL contour band (dB re 1 μPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	158	0	99.9%
200 - 205	566	0	99.7%
195 - 200	2,516	0	99.5%
190 - 195	11,257	0	99.0%
185 - 190	69,383	0	98.2%
180 - 185	662,237	0	96.7%
175 - 180	2,780,158	0	94.1%
170 - 175	8,136,669	0	89.4%
165 - 170	26,984,817	0	81.9%
160 - 165	77,916,736	0	70.7%
155 - 160	200,800,864	0	56.3%
150 - 155	488,665,024	0	40.7%
145 - 150	1,158,262,097	0	26.8%
Maximum-over-depth/Worst case			
> 210	86	0	99.9%
205 - 210	507	0	99.9%
200 - 205	2,379	0	99.7%
195 - 200	14,819	0	99.5%
190 - 195	78,361	0	99.0%
185 - 190	668,630	0	98.2%
180 - 185	2,599,091	0	96.7%
175 - 180	7,846,637	0	94.1%
170 - 175	23,402,702	0	89.4%
165 - 170	67,241,816	0	81.9%
160 - 165	173,773,395	0	70.7%
155 - 160	428,522,315	0	56.3%
150 - 155	1,039,200,003	0	40.7%
145 - 150	2,765,134,666	222,163,560	26.8%

Table 11-29: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Teesside A model location 1 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	1,900	86	86	86	23,206
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,900	226	226	226	160,256
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,900	226	226	226	160,256
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 11-30: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Teesside A model location 1 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,300	101	101	101	32,007
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	233	233	233	170,338
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	233	233	233	170,338
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 11-31: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Teesside A model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	3,000	112	112	112	39,358
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 $\mu Pa^2 s$)	5.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 $\mu Pa^2 s$)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	283	302	315	286,757
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 $\mu Pa^2 s$)	5.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 $\mu Pa^2 s$)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	283	302	315	286,757
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 $\mu Pa^2 s$)	5.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 $\mu Pa^2 s$)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 11-32: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Teesside A model location 1 with a maximum hammer energy of 5,500 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	5,500	181	181	181	102,791
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	5,500	435	448	458	629,137
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		46	62	82	12,263
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	5,500	435	448	458	629,137
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		46	62	82	12,263

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 11-33: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Teesside A model location 2 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	1,900	73	75	78	17,622
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,900	186	194	203	117,738
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,900	186	194	203	117,738
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

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Table 11-34: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Teesside A model location 2 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m²)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,300	76	80	83	20,281
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	210	213	217	141,793
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	210	213	217	141,793
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 11-35: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Teesside A model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	3,000	112	113	116	39,899
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	252	276	303	239,741
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	252	276	303	239,741
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 11-36: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Teesside A model location 2 with a maximum hammer energy of 5,500 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	5,500	163	164	175	84,722
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	5,500	388	417	450	547,006
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		42	49	60	7,485
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	5,500	388	417	450	547,006
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 11-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		42	49	60	7,485

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 11-37: Predicted areas where harbour porpoise behavioural disturbance threshold of 145 dB re 1 µPa²s is exceeded during concurrent pile-driving at Teesside A.

Model location	Hammer Energy (kJ)	Total area where SEL exceeds 145 dB re 1 µPa²s (m^2)	Area of SCI where SEL exceeds 145 dB re 1 µPa²s (m^2)
Depth-averaged			
1 and 2	1,900	1,333,504,261	0
	2,300	1,502,054,011	0
	3,000	1,776,653,423	0
	5,500	2,656,818,534	2,825,937
Maximum-over-depth/Worst case			
1 and 2	1,900	2,517,908,931	0
	2,300	2,869,745,082	11,653,730
	3,000	3,483,982,495	63,019,884
	5,500	5,328,933,651	385,706,785

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Table 11-38: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Teesside A locations 1 and 2 with maximum hammer energy of 1,900 kJ.

SEL contour band (dB re 1 μPa²s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	16	0	99.9%
200 - 205	396	0	99.7%
195 - 200	1,338	0	99.5%
190 - 195	5,950	0	99.0%
185 - 190	25,289	0	98.2%
180 - 185	211,269	0	96.7%
175 - 180	1,580,977	0	94.1%
170 - 175	6,094,527	0	89.4%
165 - 170	17,971,544	0	81.9%
160 - 165	57,086,854	0	70.7%
155 - 160	160,493,983	0	56.3%
150 - 155	378,106,412	0	40.7%
145 - 150	711,925,708	0	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	208	0	99.9%
200 - 205	1,193	0	99.7%
195 - 200	5,806	0	99.5%
190 - 195	37,616	0	99.0%
185 - 190	196,820	0	98.2%
180 - 185	1,506,036	0	96.7%
175 - 180	5,615,618	0	94.1%
170 - 175	16,328,025	0	89.4%
165 - 170	49,160,411	0	81.9%
160 - 165	137,383,402	0	70.7%
155 - 160	337,166,218	0	56.3%
150 - 155	641,468,554	0	40.7%
145 - 150	1,329,039,024	0	26.8%

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Table 11-39: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Teesside A locations 1 and 2 with maximum hammer energy of 2,300 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	57	0	99.9%
200 - 205	460	0	99.7%
195 - 200	1,743	0	99.5%
190 - 195	7,607	0	99.0%
185 - 190	31,958	0	98.2%
180 - 185	288,422	0	96.7%
175 - 180	2,077,250	0	94.1%
170 - 175	7,236,805	0	89.4%
165 - 170	22,063,413	0	81.9%
160 - 165	68,396,297	0	70.7%
155 - 160	186,613,761	0	56.3%
150 - 155	422,210,375	0	40.7%
145 - 150	793,125,864	0	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	291	0	99.9%
200 - 205	1,571	0	99.7%
195 - 200	7,672	0	99.5%
190 - 195	49,320	0	99.0%
185 - 190	263,279	0	98.2%
180 - 185	1,928,111	0	96.7%
175 - 180	6,720,080	0	94.1%
170 - 175	19,518,882	0	89.4%
165 - 170	58,850,844	0	81.9%
160 - 165	161,253,261	0	70.7%
155 - 160	376,869,329	0	56.3%
150 - 155	717,639,001	0	40.7%
145 - 150	1,526,643,442	11,653,730	26.8%

Table 11-40: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Teesside A locations 1 and 2 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	141	0	99.9%
200 - 205	575	0	99.7%
195 - 200	2,455	0	99.5%
190 - 195	10,822	0	99.0%
185 - 190	45,309	0	98.2%
180 - 185	409,911	0	96.7%
175 - 180	3,099,206	0	94.1%
170 - 175	9,037,879	0	89.4%
165 - 170	29,140,334	0	81.9%
160 - 165	86,711,306	0	70.7%
155 - 160	234,361,203	0	56.3%
150 - 155	487,360,214	0	40.7%
145 - 150	926,474,070	0	26.8%
Maximum-over-depth/Worst case			
> 210	34	0	99.9%
205 - 210	422	0	99.9%
200 - 205	2,310	0	99.7%
195 - 200	11,651	0	99.5%
190 - 195	74,899	0	99.0%
185 - 190	407,744	0	98.2%
180 - 185	2,850,406	0	96.7%
175 - 180	8,446,459	0	94.1%
170 - 175	25,144,522	0	89.4%
165 - 170	74,936,470	0	81.9%
160 - 165	200,714,465	0	70.7%
155 - 160	436,881,736	0	56.3%
150 - 155	837,046,714	0	40.7%
145 - 150	1,897,464,662	63,019,884	26.8%

Table 11-41: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Teesside A locations 1 and 2 with maximum hammer energy of 5,500 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	3	0	99.9%
205 - 210	367	0	99.9%
200 - 205	1,186	0	99.7%
195 - 200	5,306	0	99.5%
190 - 195	22,967	0	99.0%
185 - 190	177,907	0	98.2%
180 - 185	1,399,675	0	96.7%
175 - 180	5,630,623	0	94.1%
170 - 175	16,332,158	0	89.4%
165 - 170	52,400,371	0	81.9%
160 - 165	149,246,699	0	70.7%
155 - 160	359,290,061	0	56.3%
150 - 155	678,769,871	0	40.7%
145 - 150	1,393,541,340	2,825,937	26.8%
Maximum-over-depth/Worst case			
> 210	177	0	99.9%
205 - 210	1,048	0	99.9%
200 - 205	5,106	0	99.7%
195 - 200	32,715	0	99.5%
190 - 195	169,129	0	99.0%
185 - 190	1,346,761	0	98.2%
180 - 185	5,159,556	0	96.7%
175 - 180	15,020,713	0	94.1%
170 - 175	45,200,444	0	89.4%
165 - 170	127,480,370	0	81.9%
160 - 165	319,402,839	0	70.7%
155 - 160	611,746,320	0	56.3%
150 - 155	1,244,092,862	0	40.7%
145 - 150	2,959,275,612	385,706,785	26.8%

12.0 TEESSIDE B

This section presents the underwater sound propagation modelling undertaken to predict potential impacts to harbour porpoise and fish from pile-driving at the Teesside B development. Project specific model inputs (such as maximum hammer energy, model locations and hammer soft-start/ramp-up procedures) are firstly introduced, before the modelling results are presented. The propagation modelling has considered scenarios involving single pile-driving (i.e. the use of a single pile installation vessel), and concurrent pile-driving involving the use of two pile-driving vessels.

12.1 Model Inputs

The modelled scenarios that have been conducted for pile-driving at Teesside B are summarised in Table 12-1, and were selected based on the information provided by Forewind (*pers. comm.*) as well as the consented project description (Forewind, 2013c) and previous noise modelling for the consented project (Forewind, 2013d). The modelling scenarios have been selected to cover a range of possible pile-driving events at Teesside B involving the use of different maximum hammer energies and different pile installation durations that may be required for installing multi-leg jacket piles or monopiles.

Table 12-1: Noise modelling scenarios for pile-driving at Teesside B.

Infrastructure	Foundation type	Pile diameter (m)	Maximum Hammer Energy (kJ)	Estimated duration to install a single pile (hours)
Consented Project				
Wind turbine generators	Monopile	12.0	3,000	5.5
	Multi-leg jacket piles	3.5	2,300	3.5
Met masts	Monopile	12.0	3,000	5.5
	Multi-leg jacket piles	3.5	1,900	3.5
Planned Project				
Wind turbine generators	Monopile	12.0	5,500	5.5
	Multi-leg jacket piles	3.5	2,300	3.5

The propagation modelling has been conducted at a number of different locations within the Teesside B area in order to provide a range of estimates for potential injury and disturbance to harbour porpoise. The modelling locations that have been used to assess potential injury and disturbance to harbour porpoise due to pile-driving at Teesside B are shown in Figure 12-1 and Table 12-2.

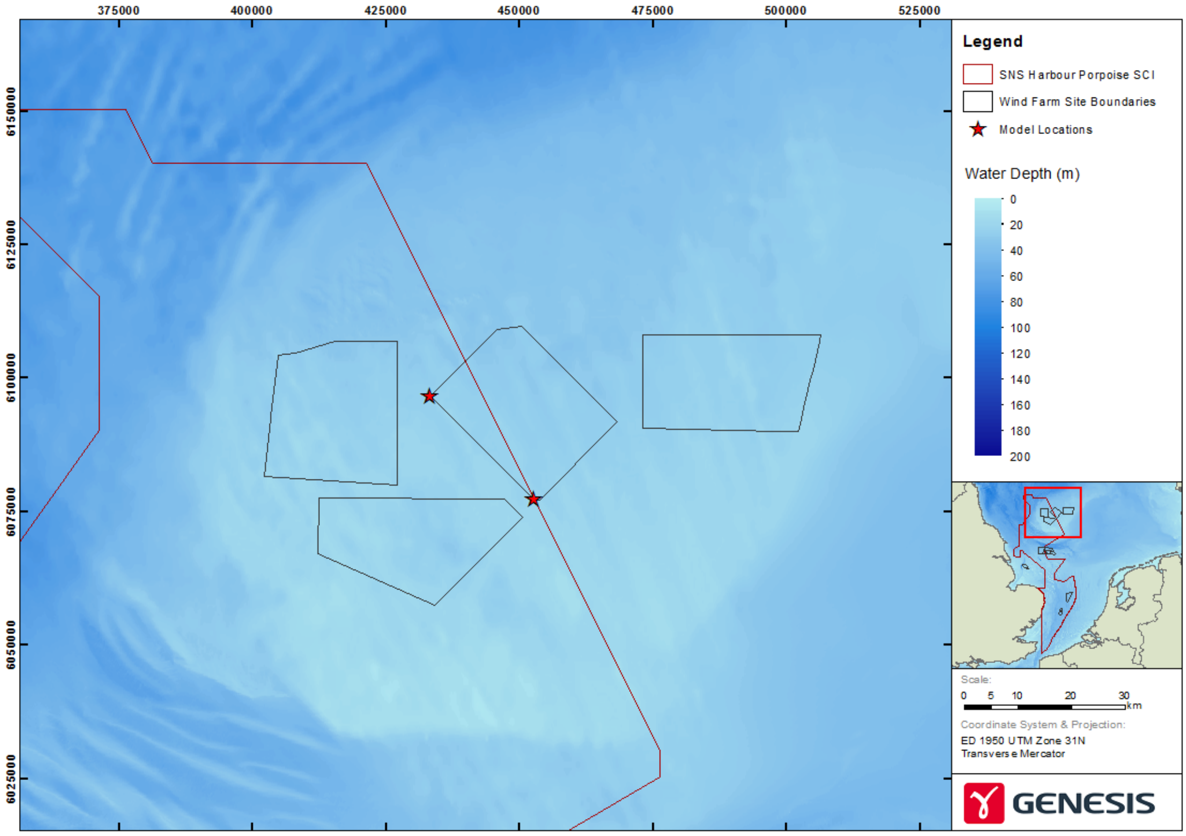

Figure 12-1: Noise modelling locations for pile-driving at Teesside B.

Table 12-2: Noise modelling locations for pile-driving at Teesside B.

Model Location	Longitude (Decimal degrees)	Latitude (Decimal degrees)
Location 1	1.95600	55.01183
Location 2	2.26400	54.83980

The soft-start/ramp-up procedures utilised in the cumulative SEL modelling for installation of piles at Teesside B are shown in Table 12-3 and is based on the ramp-up procedure that was used in the noise modelling for the consented project application (Forewind, 2013d).

Table 12-3: Hammer soft-start/ramp-up procedure assumed in the modelling of pile-driving at Teesside B.

Percentage of maximum hammer energy (%)	Duration (minutes)	Hammer strike rate (blows/minute)	Hammer strike interval (s)	Number of pile strikes
3.5-hour pile-driving duration				
10	30	20	3.0	600
100	180	40	1.5	7,200
5.5-hour pile-driving duration				
10	30	20	3.0	600
100	300	40	1.5	12,000

12.2 Single Pile-driving Modelling Results

Propagation modelling for single pile-driving (i.e. only using a single pile installation vessel) at Teesside B has been conducted at the model locations shown in Figure 12-1 and Table 12-2, with the different maximum hammer energies shown in Table 12-1 being modelled.

Maximum-over-depth zero-to-peak SPL sound fields have been estimated (see Section 4.2.5.2) and compared to the Southall and NOAA thresholds for the potential onset of PTS and TTS to harbour porpoise. Distances and areas of potential PTS and TTS onset due to zero-to-peak SPL threshold exceedance have been calculated for different percentages of the maximum hammer energy, demonstrating the increase of potential injury zones with increasing hammer energy throughout the soft-start/ramp-up phase. The predicted distances and areas where the Southall and NOAA zero-to-peak SPL thresholds are exceeded are shown in Table 12-4 to Table 12-11 for the various maximum hammer energies that have been modelled for pile-driving at Teesside B. Example maximum-over-depth zero-to-peak SPL sound fields are shown in Figure I-1 to Figure I-4 in Appendix I of this report for the modelling scenarios involving pile-driving at Teesside B with maximum hammer energies of 1,900 kJ and 5,500 kJ.

Cumulative SEL scenarios have been conducted in order to predict potential PTS and TTS onset in harbour porpoise due to exposure to pulses from multiple pile-strikes by estimating areas where the Southall and NOAA cumulative SEL thresholds are exceeded. The cumulative SEL scenarios have been conducted using the "fleeing animal" modelling procedure discussed in Section 4.2.5.3, and take into account the hammer soft-start/ramp-up procedures outlined in Table 12-3. As discussed in Section 4.2.5.3, the cumulative SEL modelling has been conducted for animals receiving depth-averaged SEL for each piling pulse, as well as maximum-over-depth SEL for each piling pulse (which is the absolute worst case scenario). The predicted distances and areas where the Southall and NOAA cumulative SEL thresholds for PTS and TTS onset are exceeded during pile-driving at Teesside B are detailed in Table 12-12 to Table 12-19. Example maps showing the predicted areas where the cumulative SEL thresholds are exceeded are also shown in Figure I-5 to Figure I-8 for the pile-driving at Teesside B with maximum hammer energies of 1,900 kJ and 5,500 kJ.

Depth-averaged and maximum-over-depth unweighted single pulse SEL sound fields have been predicted in order to estimate potential disturbance to harbour porpoise due to pile-driving at Teesside B. Example depth-averaged and maximum-over-depth unweighted single pulse SEL sound fields for pile-driving at Teesside B with maximum hammer energies of 1,900 kJ and 5,500 kJ are shown in Figure I-9 to Figure I-16 in Appendix I of this report.

The predicted depth-averaged and maximum-over-depth unweighted SEL sound fields have been compared to the behavioural disturbance threshold of 145 dB re 1 µPa²s proposed by Lucke *et al*. (2009) and Thompson *et al.* (2013b). The predicted distances and areas of this threshold exceedance are shown in Table 12-20 for both the depth-averaged and maximum-over-depth results. The area of threshold exceedance has been calculated as the total area above the threshold, as well as the area within the SCI that is above the threshold.

The probability of displacement of harbour porpoise has been further evaluated using the behavioural/dose response curve discussed in Section 3.2.1.2. The predicted areas and probabilities of behavioural disturbance to harbour porpoise for different SEL contour bands are detailed in Table 12-21 to Table 12-28 for both the depth-averaged and maximum-over-depth SEL modelling results.

The predicted zero-to-peak SPL and cumulative SEL for the Teesside B modelling scenarios have been compared to the Popper *et al*. (2014) thresholds for estimating potential injury to fish. The predicted distances and areas where injury to fish may occur from pile-driving at Teesside B with various hammer energies are shown in Table 12-29 to Table 12-36.

12.3 Concurrent Pile-driving Modelling Results

Example concurrent pile-driving scenarios at Teesside B have been conducted to estimate the increase in potential behavioural disturbance zones for harbour porpoise due to the use of two installation vessels. The concurrent pile driving modelling scenarios involve piling at model locations 1 and 2 (see Figure 12-1 and Table 12-2) where the same hammer energy is used at each location. The concurrent pile-driving modelling has been conducted for the range of hammer energies shown in Table 12-1.

The predicted areas where the harbour porpoise behavioural disturbance threshold of 145 dB re 1 µPa²s is exceeded for the concurrent pile-driving scenarios at Teesside B are shown in Table 12-37. Table 12-38 to Table 12-41 further show the probability of potential displacement of harbour porpoise for different SEL bands (using the behavioural/dose response curve discussed in Section 3.2.1.2).

Table 12-4: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside B model location 1 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	190	1	1	1	3
	380	1	1	1	3
	760	2	2	2	13
	1,140	3	3	3	28
	1,520	4	4	4	50
	1,900	4	4	4	50
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	190	103	103	103	33,287
	380	147	147	147	67,801
	760	243	246	250	189,606
	1,140	321	335	348	352,175
	1,520	388	401	415	505,783
	1,900	462	482	501	730,779
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	190	2	2	2	13
	380	4	4	4	50
	760	6	6	6	113
	1,140	7	7	7	154
	1,520	9	9	9	254
	1,900	12	12	12	452
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	190	242	245	249	188,512
	380	387	401	414	505,188
	760	619	645	676	1,307,503
	1,140	882	921	1,004	2,659,800
	1,520	983	1,132	1,218	4,026,261
	1,900	1,148	1,293	1,361	5,250,170

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 12-5: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside B model location 1 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	230	1	1	1	3
	460	2	2	2	13
	920	3	3	3	28
	1,380	3	3	3	28
	1,840	4	4	4	50
	2,300	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	230	114	114	115	40,986
	460	155	155	155	75,381
	920	259	284	305	253,425
	1,380	383	395	409	488,775
	1,840	414	479	498	719,195
	2,300	494	513	560	827,248
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	230	3	3	3	28
	460	4	4	4	50
	920	7	7	7	154
	1,380	8	8	8	201
	1,840	11	11	11	380
	2,300	13	13	13	530
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	230	259	283	304	251,334
	460	414	477	498	715,321
	920	709	750	810	1,765,948
	1,380	962	1,059	1,115	3,521,118
	1,840	1,103	1,279	1,344	5,135,219
	2,300	1,326	1,380	1,470	5,973,821

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 12-6: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside B model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m²) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	300	1	1	1	3
	600	2	2	2	13
	1,200	3	3	3	28
	1,800	4	4	4	50
	2,400	5	5	5	78
	3,000	6	6	6	113
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	300	128	128	128	51,407
	600	208	209	225	137,201
	1,200	331	345	352	373,185
	1,800	413	471	496	696,237
	2,400	497	527	565	871,567
	3,000	618	643	667	1,297,066
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	300	3	3	3	28
	600	5	5	5	78
	1,200	8	8	8	201
	1,800	11	11	11	380
	2,400	14	14	14	615
	3,000	16	16	16	803
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	300	327	344	351	371,470
	600	496	526	565	868,263
	1,200	920	966	1,022	2,933,538
	1,800	1,096	1,265	1,332	5,022,148
	2,400	1,350	1,398	1,498	6,138,119
	3,000	1,479	1,575	1,707	7,789,870

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 12-7: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside B model location 1 with a maximum hammer energy of 5,500 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	550	2	2	2	13
	1,100	3	3	3	28
	2,200	5	5	5	78
	3,300	6	6	6	113
	4,400	7	7	7	154
	5,500	8	8	8	201
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	550	204	205	205	131,769
	1,100	316	326	336	334,372
	2,200	478	497	513	774,350
	3,300	666	705	757	1,560,678
	4,400	832	901	958	2,548,304
	5,500	962	1,059	1,115	3,523,823
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	550	5	5	5	78
	1,100	7	7	7	154
	2,200	13	13	13	530
	3,300	17	17	17	907
	4,400	21	21	21	1,384
	5,500	24	24	24	1,807
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	550	476	496	512	772,460
	1,100	831	894	957	2,507,817
	2,200	1,284	1,356	1,444	5,773,029
	3,300	1,629	1,722	1,807	9,305,595
	4,400	1,865	1,976	2,103	12,257,367
	5,500	2,082	2,252	2,403	15,937,698

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 12-8: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside B model location 2 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	190	1	1	1	3
	380	2	2	2	13
	760	2	2	2	13
	1,140	3	3	3	28
	1,520	4	4	4	50
	1,900	4	4	4	50
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	190	97	97	97	29,522
	380	170	170	170	90,677
	760	253	253	253	200,835
	1,140	364	364	364	415,720
	1,520	454	454	454	646,711
	1,900	551	551	551	952,581
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	190	2	2	2	13
	380	4	4	4	50
	760	5	5	5	78
	1,140	7	7	7	154
	1,520	9	9	9	254
	1,900	11	11	11	380
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	190	252	252	252	199,251
	380	454	454	454	646,711
	760	681	706	783	1,565,529
	1,140	953	977	1,003	2,996,931
	1,520	1,082	1,165	1,211	4,256,301
	1,900	1,257	1,341	1,396	5,647,788

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 12-9: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside B model location 2 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	230	1	1	1	3
	460	2	2	2	13
	920	3	3	3	28
	1,380	3	3	3	28
	1,840	4	4	4	50
	2,300	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	230	102	102	102	32,644
	460	177	177	177	98,298
	920	302	302	302	286,162
	1,380	447	447	447	626,922
	1,840	547	547	547	938,800
	2,300	592	631	637	1,251,426
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	230	3	3	3	28
	460	4	4	4	50
	920	6	6	6	113
	1,380	8	8	8	201
	1,840	11	11	11	380
	2,300	13	13	13	530
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	230	302	302	302	286,162
	460	546	546	546	935,371
	920	797	810	865	2,060,083
	1,380	998	1,080	1,122	3,657,333
	1,840	1,237	1,321	1,375	5,477,291
	2,300	1,390	1,452	1,522	6,613,633

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 12-10: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside B model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	300	1	1	1	3
	600	2	2	2	13
	1,200	3	3	3	28
	1,800	4	4	4	50
	2,400	5	5	5	78
	3,000	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	300	129	129	129	52,213
	600	198	198	198	123,007
	1,200	368	368	368	424,907
	1,800	543	543	543	925,120
	2,400	598	649	656	1,323,451
	3,000	680	704	753	1,554,663
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	300	3	3	3	28
	600	5	5	5	78
	1,200	7	7	7	154
	1,800	10	10	10	314
	2,400	14	14	14	615
	3,000	17	17	17	907
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	300	368	368	368	424,907
	600	598	648	655	1,319,329
	1,200	970	986	1,035	3,052,378
	1,800	1,223	1,308	1,361	5,369,362
	2,400	1,442	1,482	1,548	6,890,060
	3,000	1,609	1,707	1,821	9,149,972

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

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Table 12-11: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside B model location 2 with a maximum hammer energy of 5,500 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	550	2	2	2	13
	1,100	3	3	3	28
	2,200	4	4	4	50
	3,300	6	6	6	113
	4,400	7	7	7	154
	5,500	8	8	8	201
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	550	188	188	188	110,896
	1,100	359	359	359	404,378
	2,200	563	563	563	994,524
	3,300	767	796	807	1,986,952
	4,400	901	966	996	2,927,420
	5,500	1,031	1,082	1,123	3,675,875
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	550	4	4	4	50
	1,100	7	7	7	154
	2,200	12	12	12	452
	3,300	18	18	18	1,017
	4,400	23	23	23	1,660
	5,500	26	26	26	2,121
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	550	562	562	562	990,994
	1,100	900	962	995	2,901,184
	2,200	1,365	1,425	1,494	6,369,792
	3,300	1,717	1,806	1,911	10,232,720
	4,400	1,972	2,085	2,214	13,640,713
	5,500	2,198	2,308	2,507	16,716,419

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

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Table 12-12: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside B model location 1 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 12-3)	0	0	0	0
		2	2	2	13
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 12-3)	714	808	914	2,056,824
		1,811	1,955	2,102	12,007,927
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 12-3)	3,689	4,929	6,255	77,207,245
		8,021	11,022	14,542	390,134,998
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 12-3)	16,462	19,763	21,785	1,232,793,078
		24,997	27,468	30,013	2,373,028,842

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 12-13: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside B model location 1 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 12-3)	0	0	0	0
		3	3	3	28
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 12-3)	1,064	1,192	1,341	4,478,135
		2,447	2,675	2,837	22,492,070
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 12-3)	4,505	6,029	7,658	115,585,763
		9,276	12,901	17,080	536,878,678
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 12-3)	18,061	21,649	23,764	1,478,890,863
		27,267	30,013	32,803	2,833,681,908

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 12-14: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside B model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 12-3)	0	0	0	0
		4	5	5	74
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 12-3)	1,798	1,988	2,170	12,435,307
		3,596	3,982	4,240	49,842,034
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 12-3)	6,356	8,936	11,969	256,990,719
		12,229	18,644	25,826	1,150,144,858
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 12-3)	23,393	26,782	30,652	2,257,239,977
		32,467	38,320	43,815	4,640,117,860

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 12-15: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside B model location 1 with a maximum hammer energy of 5,500 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 12-3)	2	3	3	26
		34	62	85	12,658
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 12-3)	3,727	4,170	4,477	54,677,783
		6,582	7,149	7,576	160,537,561
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 12-3)	10,409	14,783	19,634	710,072,867
		16,993	28,233	41,196	2,698,413,103
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 12-3)	31,704	34,558	41,180	3,762,917,117
		39,983	51,537	64,154	8,513,101,161

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 12-16: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside B model location 2 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 12-3)	0	0	0	0
		2	2	2	13
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 12-3)	886	975	1,029	2,985,188
		1,823	1,899	1,969	11,318,398
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 12-3)	3,408	4,441	5,717	63,085,219
		6,898	9,472	12,747	289,591,242
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 12-3)	16,854	19,438	21,752	1,188,870,657
		21,713	24,983	28,034	1,964,449,696

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 12-17: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside B model location 2 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 12-3)	0	0	0	0
		3	3	3	28
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 12-3)	1,291	1,395	1,469	6,115,295
		2,367	2,464	2,536	19,050,924
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 12-3)	4,089	5,360	6,934	91,953,993
		7,923	10,865	14,685	381,540,693
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 12-3)	18,287	21,268	24,351	1,423,732,978
		23,606	27,102	30,432	2,311,934,445

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 12-18: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside B model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 12-3)	0	0	0	0
		5	5	6	88
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 12-3)	2,107	2,240	2,339	15,751,612
		3,546	3,698	3,836	42,915,314
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 12-3)	5,544	7,526	10,262	182,741,103
		9,727	14,630	20,927	700,021,894
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 12-3)	21,765	25,717	29,239	2,083,741,609
		27,807	33,013	38,019	3,437,816,867

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 12-19: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Teesside B model location 2 with a maximum hammer energy of 5,500 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 12-3)	3	4	4	50
		58	85	98	23,150
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 12-3)	4,201	4,456	4,708	62,328,679
		6,258	6,602	7,006	136,832,068
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 12-3)	8,598	11,996	16,533	466,612,814
		12,524	21,344	30,203	1,502,427,099
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 12-3)	27,732	32,555	36,133	3,342,785,992
		33,145	41,692	49,478	5,501,578,790

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 12-20: Predicted distances and areas where harbour porpoise behavioural disturbance threshold of 145 dB re 1 μPa²s is exceeded during pile-driving at Teesside B.

Model location	Hammer Energy (kJ)	Distance to 145 dB re 1 μPa²s SEL threshold (m)			Total area where SEL exceeds 145 dB re 1 μPa²s (m²)	Area of SCI where SEL exceeds 145 dB re 1 μPa²s (m²)
		Minimum	Average	Maximum		
Depth-averaged						
1	1,900	12,726	15,234	18,184	728,900,884	600,249,681
	2,300	13,955	16,547	19,763	861,988,424	687,135,300
	3,000	15,170	18,674	23,617	1,097,728,209	837,230,984
	5,500	18,472	24,080	30,007	1,842,034,159	1,276,635,911
2	1,900	11,579	13,719	16,801	596,957,277	262,521,508
	2,300	12,347	14,752	18,311	691,610,242	300,060,217
	3,000	13,641	16,396	20,275	850,266,364	364,969,910
	5,500	16,658	20,663	26,701	1,351,134,828	575,013,009
Maximum-over-depth/Worst case						
1	1,900	17,618	22,847	28,969	1,731,048,985	1,212,248,488
	2,300	18,607	24,589	31,428	2,027,381,770	1,373,010,175
	3,000	21,366	27,777	35,428	2,574,317,814	1,657,652,532
	5,500	25,639	35,856	46,901	4,331,562,869	2,479,470,631
2	1,900	15,774	19,434	25,577	1,218,276,535	511,363,745
	2,300	16,700	21,017	28,114	1,426,167,824	599,511,463
	3,000	17,652	23,320	30,046	1,758,842,109	750,646,082
	5,500	19,661	29,891	38,126	2,872,005,308	1,242,021,221

Table 12-21: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Teesside B modelling location 1 with maximum hammer energy of 1,900 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	34	34	99.9%
200 - 205	192	192	99.7%
195 - 200	655	655	99.5%
190 - 195	3,083	3,083	99.0%
185 - 190	12,871	12,871	98.2%
180 - 185	116,221	116,221	96.7%
175 - 180	795,801	795,802	94.1%
170 - 175	3,020,037	3,020,037	89.4%
165 - 170	8,683,811	8,683,811	81.9%
160 - 165	26,257,762	26,257,762	70.7%
155 - 160	69,901,574	69,901,573	56.3%
150 - 155	177,470,720	174,922,363	40.7%
145 - 150	442,638,123	316,535,277	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	92	92	99.9%
200 - 205	580	580	99.7%
195 - 200	3,058	3,058	99.5%
190 - 195	17,478	17,478	99.0%
185 - 190	108,608	108,607	98.2%
180 - 185	827,039	827,039	96.7%
175 - 180	2,670,485	2,670,485	94.1%
170 - 175	7,591,884	7,591,884	89.4%
165 - 170	22,506,819	22,506,819	81.9%
160 - 165	60,226,052	60,226,052	70.7%
155 - 160	150,465,826	150,416,166	56.3%
150 - 155	377,079,254	284,393,753	40.7%
145 - 150	1,109,551,810	683,486,475	26.8%

Table 12-22: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Teesside B modelling location 1 with maximum hammer energy of 2,300 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	61	61	99.9%
200 - 205	212	212	99.7%
195 - 200	863	863	99.5%
190 - 195	3,997	3,997	99.0%
185 - 190	15,961	15,960	98.2%
180 - 185	156,208	156,208	96.7%
175 - 180	1,035,114	1,035,113	94.1%
170 - 175	3,590,563	3,590,563	89.4%
165 - 170	10,512,930	10,512,930	81.9%
160 - 165	31,165,379	31,165,379	70.7%
155 - 160	81,915,864	81,915,864	56.3%
150 - 155	206,265,918	195,355,068	40.7%
145 - 150	527,325,355	363,383,081	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	129	129	99.9%
200 - 205	782	782	99.7%
195 - 200	4,263	4,263	99.5%
190 - 195	27,151	27,151	99.0%
185 - 190	142,919	142,919	98.2%
180 - 185	1,022,282	1,022,282	96.7%
175 - 180	3,186,417	3,186,417	94.1%
170 - 175	9,115,189	9,115,189	89.4%
165 - 170	26,775,064	26,775,064	81.9%
160 - 165	69,877,067	69,877,067	70.7%
155 - 160	176,449,927	173,325,771	56.3%
150 - 155	443,055,808	315,457,690	40.7%
145 - 150	1,297,724,772	774,075,451	26.8%

Table 12-23: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Teesside B modelling location 1 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 μPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	101	101	99.9%
200 - 205	260	260	99.7%
195 - 200	1,247	1,247	99.5%
190 - 195	5,789	5,789	99.0%
185 - 190	22,471	22,471	98.2%
180 - 185	219,689	219,689	96.7%
175 - 180	1,556,519	1,556,520	94.1%
170 - 175	4,461,693	4,461,693	89.4%
165 - 170	13,707,604	13,707,604	81.9%
160 - 165	39,779,312	39,779,312	70.7%
155 - 160	100,188,644	100,188,644	56.3%
150 - 155	253,992,122	225,049,391	40.7%
145 - 150	683,792,758	452,238,264	26.8%
Maximum-over-depth/Worst case			
> 210	10	10	99.9%
205 - 210	197	197	99.9%
200 - 205	1,182	1,182	99.7%
195 - 200	5,794	5,794	99.5%
190 - 195	37,995	37,995	99.0%
185 - 190	249,915	249,915	98.2%
180 - 185	1,371,811	1,371,811	96.7%
175 - 180	4,022,887	4,022,887	94.1%
170 - 175	11,745,173	11,745,173	89.4%
165 - 170	33,975,107	33,975,107	81.9%
160 - 165	85,568,874	85,568,874	70.7%
155 - 160	217,241,933	201,971,836	56.3%
150 - 155	573,869,642	390,617,080	40.7%
145 - 150	1,646,227,293	928,084,671	26.8%

Table 12-24: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Teesside B modelling location 1 with maximum hammer energy of 5,500 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	22	22	99.9%
205 - 210	185	185	99.9%
200 - 205	576	576	99.7%
195 - 200	2,727	2,727	99.5%
190 - 195	11,795	11,795	99.0%
185 - 190	98,732	98,732	98.2%
180 - 185	704,045	704,045	96.7%
175 - 180	2,795,548	2,795,548	94.1%
170 - 175	7,939,954	7,939,954	89.4%
165 - 170	24,260,176	24,260,176	81.9%
160 - 165	65,094,964	65,094,964	70.7%
155 - 160	165,106,576	164,045,034	56.3%
150 - 155	410,063,037	301,100,816	40.7%
145 - 150	1,165,955,823	710,581,337	26.8%
Maximum-over-depth/Worst case			
> 210	77	77	99.9%
205 - 210	504	504	99.9%
200 - 205	2,665	2,665	99.7%
195 - 200	15,789	15,790	99.5%
190 - 195	92,201	92,201	99.0%
185 - 190	745,616	745,616	98.2%
180 - 185	2,458,187	2,458,187	96.7%
175 - 180	6,982,600	6,982,600	94.1%
170 - 175	20,773,521	20,773,521	89.4%
165 - 170	56,124,792	56,124,792	81.9%
160 - 165	139,475,190	139,475,189	70.7%
155 - 160	349,806,591	272,311,857	56.3%
150 - 155	1,033,496,929	642,534,025	40.7%
145 - 150	2,721,588,208	1,337,953,606	26.8%

Table 12-25: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Teesside B modelling location 2 with maximum hammer energy of 1,900 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	53	38	99.9%
200 - 205	200	114	99.7%
195 - 200	706	334	99.5%
190 - 195	3,488	1,762	99.0%
185 - 190	11,757	5,876	98.2%
180 - 185	118,562	59,322	96.7%
175 - 180	900,252	450,622	94.1%
170 - 175	3,166,616	1,586,406	89.4%
165 - 170	8,803,061	4,281,592	81.9%
160 - 165	25,379,224	12,117,051	70.7%
155 - 160	65,214,619	30,448,984	56.3%
150 - 155	143,014,744	65,072,812	40.7%
145 - 150	350,343,996	148,496,598	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	112	61	99.9%
200 - 205	643	316	99.7%
195 - 200	3,381	1,690	99.5%
190 - 195	20,510	10,286	99.0%
185 - 190	108,220	54,173	98.2%
180 - 185	781,479	396,735	96.7%
175 - 180	2,747,664	1,363,739	94.1%
170 - 175	7,555,729	3,692,815	89.4%
165 - 170	21,862,253	10,484,824	81.9%
160 - 165	55,221,793	25,843,066	70.7%
155 - 160	121,869,987	55,497,010	56.3%
150 - 155	295,056,949	124,703,496	40.7%
145 - 150	713,047,815	289,315,531	26.8%

Table 12-26: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Teesside B modelling location 2 with maximum hammer energy of 2,300 kJ.

SEL contour band (dB re 1 μPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	80	54	99.9%
200 - 205	230	125	99.7%
195 - 200	914	443	99.5%
190 - 195	4,467	2,238	99.0%
185 - 190	17,590	8,794	98.2%
180 - 185	139,368	69,713	96.7%
175 - 180	1,253,989	627,708	94.1%
170 - 175	3,649,107	1,825,532	89.4%
165 - 170	10,627,814	5,146,367	81.9%
160 - 165	30,086,935	14,363,859	70.7%
155 - 160	74,573,650	34,748,784	56.3%
150 - 155	166,399,971	74,862,684	40.7%
145 - 150	404,856,127	168,403,915	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	156	83	99.9%
200 - 205	857	420	99.7%
195 - 200	4,457	2,220	99.5%
190 - 195	25,604	12,851	99.0%
185 - 190	139,902	69,989	98.2%
180 - 185	1,005,394	502,770	96.7%
175 - 180	3,234,977	1,608,296	94.1%
170 - 175	9,079,963	4,429,644	89.4%
165 - 170	25,702,182	12,228,398	81.9%
160 - 165	63,436,538	29,671,511	70.7%
155 - 160	139,768,031	62,900,975	56.3%
150 - 155	341,344,851	143,015,739	40.7%
145 - 150	842,424,913	345,068,565	26.8%

Table 12-27: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Teesside B modelling location 2 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	119	77	99.9%
200 - 205	302	151	99.7%
195 - 200	1,287	643	99.5%
190 - 195	6,004	3,003	99.0%
185 - 190	41,126	20,577	98.2%
180 - 185	257,767	128,932	96.7%
175 - 180	1,712,262	857,521	94.1%
170 - 175	4,546,539	2,263,644	89.4%
165 - 170	13,684,578	6,594,818	81.9%
160 - 165	37,758,441	17,999,202	70.7%
155 - 160	89,222,604	41,196,263	56.3%
150 - 155	204,129,508	90,279,077	40.7%
145 - 150	498,905,827	205,626,001	26.8%
Maximum-over-depth/Worst case			
> 210	21	13	99.9%
205 - 210	223	113	99.9%
200 - 205	1,270	623	99.7%
195 - 200	7,916	3,975	99.5%
190 - 195	33,316	16,640	99.0%
185 - 190	223,909	113,738	98.2%
180 - 185	1,455,600	726,436	96.7%
175 - 180	3,981,461	1,968,843	94.1%
170 - 175	11,677,678	5,682,689	89.4%
165 - 170	31,972,494	15,020,344	81.9%
160 - 165	76,625,809	35,746,058	70.7%
155 - 160	172,360,245	76,145,956	56.3%
150 - 155	418,563,869	172,354,768	40.7%
145 - 150	1,041,938,298	442,865,886	26.8%

Table 12-28: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Teesside B modelling location 2 with maximum hammer energy of 5,500 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	42	30	99.9%
205 - 210	190	110	99.9%
200 - 205	628	295	99.7%
195 - 200	3,087	1,560	99.5%
190 - 195	10,420	5,200	99.0%
185 - 190	109,748	54,924	98.2%
180 - 185	789,606	392,449	96.7%
175 - 180	2,936,921	1,474,220	94.1%
170 - 175	8,063,605	3,932,178	89.4%
165 - 170	23,457,241	11,200,590	81.9%
160 - 165	61,064,269	28,565,442	70.7%
155 - 160	134,078,062	61,082,024	56.3%
150 - 155	326,520,075	139,830,392	40.7%
145 - 150	794,100,934	328,473,596	26.8%
Maximum-over-depth/Worst case			
> 210	96	53	99.9%
205 - 210	562	276	99.9%
200 - 205	2,951	1,477	99.7%
195 - 200	17,804	8,918	99.5%
190 - 195	94,411	47,345	99.0%
185 - 190	699,933	355,400	98.2%
180 - 185	2,538,578	1,260,915	96.7%
175 - 180	6,943,986	3,397,276	94.1%
170 - 175	20,235,084	9,736,906	89.4%
165 - 170	51,750,656	24,207,869	81.9%
160 - 165	114,832,223	52,408,853	70.7%
155 - 160	275,680,777	117,048,436	56.3%
150 - 155	664,188,211	269,268,847	40.7%
145 - 150	1,735,020,034	764,278,649	26.8%

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Table 12-29: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Teesside B model location 1 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	1,900	81	81	81	20,586
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,900	208	209	225	137,564
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,900	208	209	225	137,564
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 12-30: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Teesside B model location 1 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,300	100	100	100	31,376
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 $\mu Pa^2 s$)	3.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 $\mu Pa^2 s$)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	239	241	245	182,069
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 $\mu Pa^2 s$)	3.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 $\mu Pa^2 s$)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	239	241	245	182,069
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 $\mu Pa^2 s$)	3.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 $\mu Pa^2 s$)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 12-31: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Teesside B model location 1 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m²)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	3,000	116	116	116	42,220
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	262	295	312	272,549
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	262	295	312	272,549
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	5.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 12-32: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Teesside B model location 1 with a maximum hammer energy of 5,500 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	5,500	153	153	153	73,448
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	5,500	410	448	477	632,474
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		34	50	67	8,227
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	5,500	410	448	477	632,474
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		34	50	67	8,227

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 12-33: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Teesside B model location 2 with a maximum hammer energy of 1,900 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	1,900	85	85	85	22,669
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,900	198	198	198	123,007
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	1,900	198	198	198	123,007
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	3.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 12-34: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Teesside B model location 2 with a maximum hammer energy of 2,300 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,300	96	96	96	28,916
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	249	249	249	194,535
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,300	249	249	249	194,535
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	3.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 12-35: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Teesside B model location 2 with a maximum hammer energy of 3,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	3,000	104	104	104	33,936
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	306	306	306	293,793
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	3,000	306	306	306	293,793
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

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Table 12-36: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Teesside B model location 2 with a maximum hammer energy of 5,500 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	5,500	175	175	175	96,089
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	5,500	537	537	537	904,789
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		41	57	82	10,785
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	5,500	537	537	537	904,789
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	5.5 hour pile-driving sequence (see Table 12-3)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		41	57	82	10,785

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 12-37: Predicted areas where harbour porpoise behavioural disturbance threshold of 145 dB re 1 µPa²s is exceeded during concurrent pile-driving at Teesside B.

Model location	Hammer Energy (kJ)	Total area where SEL exceeds 145 dB re 1 µPa²s (m²)	Area of SCI where SEL exceeds 145 dB re 1 µPa²s (m²)
Depth-averaged			
1 and 2	1,900	1,325,186,779	861,946,007
	2,300	1,530,882,810	966,430,180
	3,000	1,854,865,262	1,135,353,313
	5,500	2,806,349,619	1,633,364,643
Maximum-over-depth/Worst case			
1 and 2	1,900	2,642,202,503	1,547,447,867
	2,300	3,016,565,181	1,735,817,302
	3,000	3,680,905,153	2,073,178,153
	5,500	5,669,268,495	3,024,227,054

Table 12-38: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Teesside B locations 1 and 2 with maximum hammer energy of 1,900 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	87	72	99.9%
200 - 205	392	306	99.7%
195 - 200	1,361	989	99.5%
190 - 195	6,571	4,845	99.0%
185 - 190	24,628	18,747	98.2%
180 - 185	234,783	175,542	96.7%
175 - 180	1,696,054	1,246,423	94.1%
170 - 175	6,186,653	4,606,443	89.4%
165 - 170	17,486,872	12,965,403	81.9%
160 - 165	51,636,986	38,374,812	70.7%
155 - 160	135,116,193	100,350,557	56.3%
150 - 155	320,485,464	239,995,175	40.7%
145 - 150	792,310,736	464,206,693	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	204	153	99.9%
200 - 205	1,223	896	99.7%
195 - 200	6,438	4,748	99.5%
190 - 195	37,988	27,764	99.0%
185 - 190	216,828	162,781	98.2%
180 - 185	1,608,518	1,223,774	96.7%
175 - 180	5,418,149	4,034,224	94.1%
170 - 175	15,147,613	11,284,699	89.4%
165 - 170	44,369,072	32,991,644	81.9%
160 - 165	115,447,845	86,069,118	70.7%
155 - 160	272,335,813	205,913,176	56.3%
150 - 155	672,136,204	409,097,250	40.7%
145 - 150	1,515,476,608	796,637,639	26.8%

Table 12-39: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Teesside B locations 1 and 2 with maximum hammer energy of 2,300 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	141	115	99.9%
200 - 205	442	337	99.7%
195 - 200	1,777	1,306	99.5%
190 - 195	8,464	6,235	99.0%
185 - 190	33,551	24,755	98.2%
180 - 185	295,576	225,921	96.7%
175 - 180	2,289,103	1,662,821	94.1%
170 - 175	7,239,670	5,416,096	89.4%
165 - 170	21,140,744	15,659,297	81.9%
160 - 165	61,252,314	45,529,238	70.7%
155 - 160	156,489,514	116,664,648	56.3%
150 - 155	372,665,889	270,217,752	40.7%
145 - 150	909,465,626	511,021,659	26.8%
Maximum-over-depth/Worst case			
> 210	0	0	99.9%
205 - 210	286	213	99.9%
200 - 205	1,638	1,202	99.7%
195 - 200	8,720	6,484	99.5%
190 - 195	52,755	40,002	99.0%
185 - 190	282,821	212,908	98.2%
180 - 185	2,027,676	1,525,052	96.7%
175 - 180	6,421,394	4,794,713	94.1%
170 - 175	18,195,152	13,544,833	89.4%
165 - 170	52,477,246	39,003,462	81.9%
160 - 165	133,313,605	99,548,577	70.7%
155 - 160	316,217,958	236,226,746	56.3%
150 - 155	784,214,208	458,473,429	40.7%
145 - 150	1,703,351,721	882,439,680	26.8%

Table 12-40: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Teesside B locations 1 and 2 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	220	179	99.9%
200 - 205	562	411	99.7%
195 - 200	2,534	1,890	99.5%
190 - 195	11,792	8,792	99.0%
185 - 190	63,598	43,048	98.2%
180 - 185	477,456	348,621	96.7%
175 - 180	3,268,781	2,414,041	94.1%
170 - 175	9,008,231	6,725,337	89.4%
165 - 170	27,392,182	20,302,422	81.9%
160 - 165	77,537,753	57,778,514	70.7%
155 - 160	189,411,248	141,384,907	56.3%
150 - 155	458,121,630	315,328,468	40.7%
145 - 150	1,089,569,274	591,016,684	26.8%
Maximum-over-depth/Worst case			
> 210	30	23	99.9%
205 - 210	420	309	99.9%
200 - 205	2,453	1,805	99.7%
195 - 200	13,710	9,768	99.5%
190 - 195	71,311	54,635	99.0%
185 - 190	473,824	363,653	98.2%
180 - 185	2,827,411	2,098,247	96.7%
175 - 180	8,004,349	5,991,731	94.1%
170 - 175	23,422,852	17,427,862	89.4%
165 - 170	65,947,601	48,995,451	81.9%
160 - 165	162,194,682	121,314,932	70.7%
155 - 160	389,602,178	278,117,792	56.3%
150 - 155	961,671,142	534,211,192	40.7%
145 - 150	2,066,673,190	1,064,590,752	26.8%

Table 12-41: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Teesside B locations 1 and 2 with maximum hammer energy of 5,500 kJ.

SEL contour band (dB re 1 μPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	63	52	99.9%
205 - 210	375	295	99.9%
200 - 205	1,204	871	99.7%
195 - 200	5,814	4,287	99.5%
190 - 195	22,215	16,995	99.0%
185 - 190	208,480	153,656	98.2%
180 - 185	1,493,650	1,096,494	96.7%
175 - 180	5,732,468	4,269,768	94.1%
170 - 175	16,003,559	11,872,132	89.4%
165 - 170	47,717,417	35,460,766	81.9%
160 - 165	126,159,233	93,660,406	70.7%
155 - 160	299,184,638	225,127,058	56.3%
150 - 155	736,583,113	440,931,208	40.7%
145 - 150	1,573,237,388	820,770,657	26.8%
Maximum-over-depth/Worst case			
> 210	173	130	99.9%
205 - 210	1,067	781	99.9%
200 - 205	5,616	4,142	99.7%
195 - 200	33,594	24,707	99.5%
190 - 195	186,612	139,546	99.0%
185 - 190	1,445,549	1,101,016	98.2%
180 - 185	4,996,765	3,719,102	96.7%
175 - 180	13,926,585	10,379,875	94.1%
170 - 175	41,008,605	30,510,427	89.4%
165 - 170	107,875,449	80,332,662	81.9%
160 - 165	254,307,413	191,884,042	70.7%
155 - 160	625,487,368	389,360,293	56.3%
150 - 155	1,442,353,063	761,568,372	40.7%
145 - 150	3,177,640,637	1,555,201,958	26.8%

13.0 TRITON KNOLL

This section presents the underwater sound propagation modelling undertaken to predict potential impacts to harbour porpoise and fish from pile-driving at the Triton Knoll development. Project specific model inputs (such as maximum hammer energy, model locations and hammer soft-start/ramp-up procedures) are firstly introduced, before the modelling results are presented. The propagation modelling has considered scenarios involving single pile-driving (i.e. the use of a single pile installation vessel), and concurrent pile-driving involving the use of two pile-driving vessels.

13.1 Model Inputs

The modelled scenarios that have been conducted for pile-driving at Triton Knoll are summarised in Table 13-1, and were selected based on the information provided by Triton Knoll Offshore Windfarm Limited (*pers. comm.*) as well as the consented project description (Triton Knoll Offshore Windfarm Limited, 2012a). The modelling scenarios have been selected to cover different possible hammer energies that may be used for the installation of monopoles at Triton Knoll.

Table 13-1: Noise modelling scenarios for pile-driving at Triton Knoll.

Infrastructure	Foundation type	Pile diameter (m)	Maximum Hammer Energy (kJ)	Estimated duration to install a single pile (hours)
Consented Project				
Wind turbine generators and other infrastructure	Monopile	8.5	2,700	4.0
Planned Project				
Wind turbine generators and other infrastructure	Monopile	8.5	4,000	4.0

The propagation modelling has been conducted at a number of different locations within the Triton Knoll area in order to provide a range of estimates for potential injury and disturbance to harbour porpoise. The modelling locations that have been used to assess potential injury and disturbance to harbour porpoise due to pile-driving at Triton Knoll are shown in Figure 13-1 and Table 13-2.

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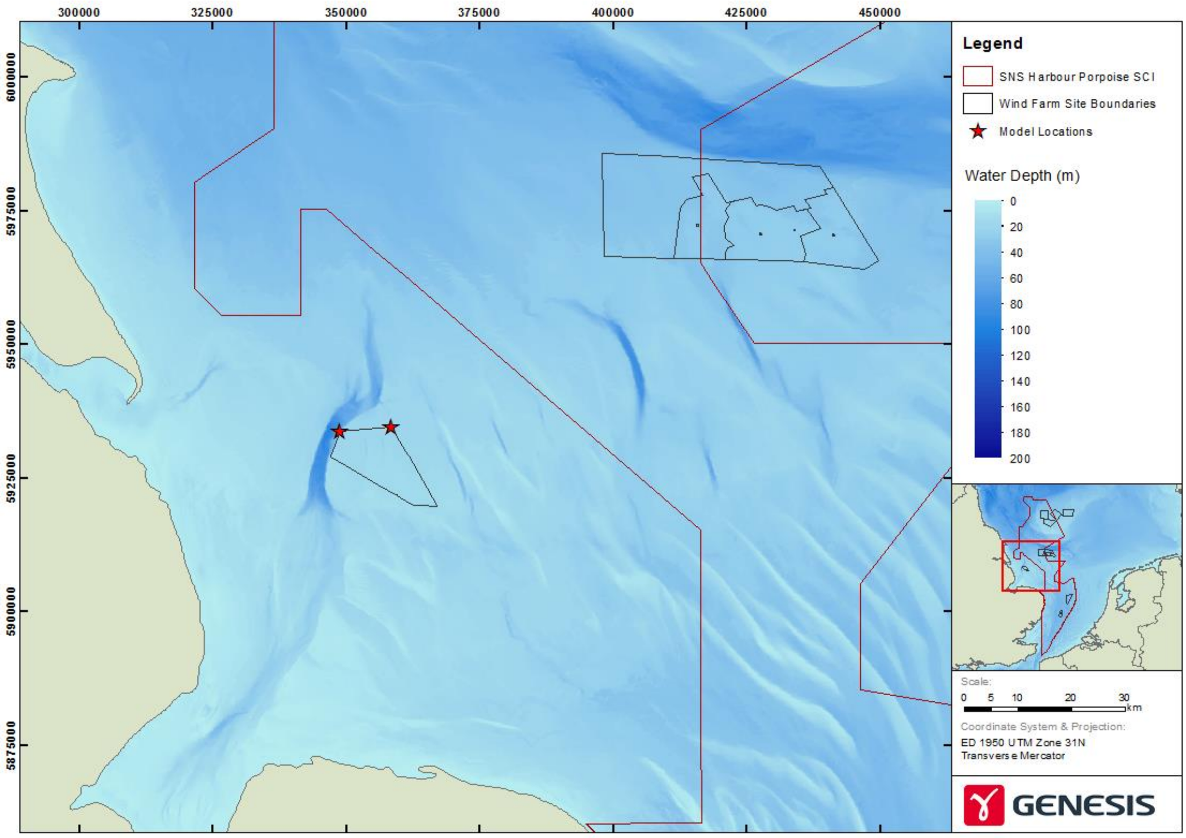

Figure 13-1: Noise modelling locations for pile-driving at Triton Knoll.

Table 13-2: Noise modelling locations for pile-driving at Triton Knoll.

Model Location	Longitude (Decimal degrees)	Latitude (Decimal degrees)
Location 1	0.86347	53.53939
Location 2	0.71822	53.53024

The soft-start/ramp-up procedures utilised in the cumulative SEL modelling for installation of piles at Triton Knoll are shown in Table 13-3 and is based on information provided by Triton Knoll Offshore Windfarm Limited (*pers. comm.*).

Table 13-3: Hammer soft-start/ramp-up procedure assumed in the modelling of pile-driving at Triton Knoll.

Percentage of maximum hammer energy (%)	Duration (minutes)	Hammer strike rate (blows/minute)	Hammer strike interval (s)	Number of pile strikes
4.0-hour pile-driving duration				
20	7.5	10	6	75
40	7.5	10	6	75
60	7.5	15	4	112
80	7.5	15	4	113
100	210	35	2	7,350

13.2 Single Pile-driving Modelling Results

Propagation modelling for single pile-driving (i.e. only using a single pile installation vessel) at Triton Knoll has been conducted at the model locations shown in Figure 13-1 and Table 13-2, with the different maximum hammer energies shown in Table 13-1 being modelled.

Maximum-over-depth zero-to-peak SPL sound fields have been estimated (see Section 4.2.5.2) and compared to the Southall and NOAA thresholds for the potential onset of PTS and TTS to harbour porpoise. Distances and areas of potential PTS and TTS onset due to zero-to-peak SPL threshold exceedance have been calculated for different percentages of the maximum hammer energy, demonstrating the increase of potential injury zones with increasing hammer energy throughout the soft-start/ramp-up phase. The predicted distances and areas where the Southall and NOAA zero-to-peak SPL thresholds are exceeded are shown in Table 13-4 to Table 13-7 for the various maximum hammer energies that have been modelled for pile-driving at Triton Knoll. Maximum-over-depth zero-to-peak SPL sound fields are shown in Figure J-1 to Figure J-4 in Appendix J of this report for the modelling scenarios involving pile-driving at Triton Knoll with maximum hammer energies of 2,700 kJ and 4,400 kJ.

Cumulative SEL scenarios have been conducted in order to predict potential PTS and TTS onset in harbour porpoise due to exposure to pulses from multiple pile-strikes by estimating areas where the Southall and NOAA cumulative SEL thresholds are exceeded. The cumulative SEL scenarios have been conducted using the “fleeing animal” modelling procedure discussed in Section 4.2.5.3, and take into account the hammer soft-start/ramp-up procedures outlined in Table 13-3. As discussed in Section 4.2.5.3, the cumulative SEL modelling has been conducted for animals receiving depth-averaged SEL for each piling pulse, as well as maximum-over-depth SEL for each piling pulse (which is the absolute worst case scenario). The predicted distances and areas where the Southall and NOAA cumulative SEL thresholds for PTS and TTS onset are exceeded during pile-driving at Triton Knoll are detailed in Table 13-8 to Table 13-11. Maps showing the predicted areas where the cumulative SEL thresholds are exceeded are also shown in Figure J-5 to Figure J-8 for the pile-driving at Triton Knoll with maximum hammer energies of 2,700 kJ and 4,400 kJ.

Depth-averaged and maximum-over-depth unweighted single pulse SEL sound fields have been predicted in order to estimate potential disturbance to harbour porpoise due to pile-driving at Triton Knoll. Depth-averaged and maximum-over-depth unweighted single pulse SEL sound fields for pile-driving at Triton Knoll with maximum hammer energies of 2,700 kJ and 4,400 kJ are shown in Figure J-9 to Figure J-16 in Appendix J of this report.

The predicted depth-averaged and maximum-over-depth unweighted SEL sound fields have been compared to the behavioural disturbance threshold of 145 dB re 1 µPa²s proposed by Lucke *et al*. (2009) and Thompson *et al.* (2013b). The predicted distances and areas of this threshold exceedance are shown in Table 13-12 for both the depth-averaged and maximum-over-depth results. The area of threshold exceedance has been calculated as the total area above the threshold, as well as the area within the SCI that is above the threshold.

The probability of displacement of harbour porpoise has been further evaluated using the behavioural/dose response curve discussed in Section 3.2.1.2. The predicted areas and probabilities of behavioural disturbance to harbour porpoise for different SEL contour bands are detailed in Table 13-13 to Table 13-16 for both the depth-averaged and maximum-over-depth SEL modelling results.

The predicted zero-to-peak SPL and cumulative SEL for the Triton Knoll modelling scenarios have been compared to the Popper *et al*. (2014) thresholds for estimating potential injury to fish. The predicted distances and areas where injury to fish may occur from pile-driving at Triton Knoll with various hammer energies are shown in Table 13-17 to Table 13-20.

13.3 Concurrent Pile-driving Modelling Results

Example concurrent pile-driving scenarios at Triton Knoll have been conducted to estimate the increase in potential behavioural disturbance zones for harbour porpoise due to the use of two installation vessels. The concurrent pile driving modelling scenarios involve piling at model locations 1 and 2 (see Figure 13-1 and Table 13-2) where the same hammer energy is used at each location. The concurrent pile-driving modelling has been conducted for the range of hammer energies shown in Table 13-1.

The predicted areas where the harbour porpoise behavioural disturbance threshold of 145 dB re 1 µPa²s is exceeded for the concurrent pile-driving scenarios at Triton Knoll are shown in Table 13-21. Table 13-22 and Table 13-23 further show the probability of potential displacement of harbour porpoise for different SEL bands (using the behavioural/dose response curve discussed in Section 3.2.1.2).

Table 13-4: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Triton Knoll model location 1 with a maximum hammer energy of 2,700 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	270	1	1	1	3
	540	2	2	2	13
	1,080	3	3	3	28
	1,620	4	4	4	50
	2,160	5	5	5	78
	2,700	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	270	105	121	124	46,131
	540	195	211	238	139,836
	1,080	314	321	339	324,186
	1,620	433	439	455	604,449
	2,160	540	565	600	1,000,666
	2,700	599	640	722	1,286,844
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	270	3	3	3	28
	540	5	5	5	78
	1,080	8	8	8	201
	1,620	11	11	11	380
	2,160	13	13	13	530
	2,700	16	16	16	803
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	270	314	321	339	324,070
	540	540	563	599	995,164
	1,080	850	891	988	2,488,708
	1,620	1,067	1,145	1,209	4,118,052
	2,160	1,240	1,282	1,407	5,161,715
	2,700	1,413	1,474	1,515	6,819,511

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

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Table 13-5: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Triton Knoll model location 1 with a maximum hammer energy of 4,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	400	2	2	2	13
	800	2	2	2	13
	1,600	4	4	4	50
	2,400	5	5	5	78
	3,200	6	6	6	113
	4,000	8	8	8	201
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	400	162	164	166	83,908
	800	259	301	323	284,760
	1,600	432	438	454	601,386
	2,400	577	591	613	1,097,547
	3,200	712	728	751	1,661,433
	4,000	834	866	899	2,352,990
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	400	4	4	4	50
	800	6	6	6	113
	1,600	11	11	11	380
	2,400	14	14	14	615
	3,200	18	18	18	1,017
	4,000	23	23	23	1,660
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	400	432	437	453	598,909
	800	712	727	750	1,658,132
	1,600	1,062	1,139	1,204	4,077,760
	2,400	1,275	1,380	1,455	5,977,867
	3,200	1,483	1,567	1,713	7,710,710
	4,000	1,683	1,777	1,864	9,915,376

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 13-6: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Triton Knoll model location 2 with a maximum hammer energy of 2,700 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	270	1	1	1	3
	540	2	2	2	13
	1,080	3	3	3	28
	1,620	4	4	4	50
	2,160	5	5	5	78
	2,700	5	5	5	78
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	270	108	121	128	45,766
	540	162	174	194	94,946
	1,080	233	280	359	248,489
	1,620	295	348	512	384,273
	2,160	349	417	547	551,044
	2,700	402	494	626	771,744
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	270	3	3	3	28
	540	5	5	5	78
	1,080	9	9	9	254
	1,620	11	12	12	416
	2,160	14	14	14	615
	2,700	16	16	17	846
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	270	233	279	358	247,649
	540	348	416	546	548,086
	1,080	546	668	802	1,408,685
	1,620	704	895	1,140	2,534,906
	2,160	894	1,100	1,330	3,815,197
	2,700	1,076	1,249	1,514	4,916,897

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 13-7: Predicted distances and areas where Southall and NOAA unweighted zero-to-peak SPL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Triton Knoll model location 2 with a maximum hammer energy of 4,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ)	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 230 dB re 1 µPa)	400	2	2	2	13
	800	2	2	2	13
	1,600	4	4	4	50
	2,400	5	5	5	78
	3,200	6	6	6	113
	4,000	8	8	8	201
NOAA HF cetacean PTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 202 dB re 1 µPa)	400	144	150	161	71,021
	800	205	227	310	162,494
	1,600	295	346	509	380,092
	2,400	360	454	606	650,889
	3,200	438	542	646	926,925
	4,000	526	642	763	1,299,778
Southall HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 224 dB re 1 µPa)	400	4	4	4	50
	800	6	6	6	113
	1,600	11	11	11	380
	2,400	15	15	15	706
	3,200	17	18	19	1,043
	4,000	20	21	22	1,367
NOAA HF cetacean TTS thresholds					
Instantaneous PTS onset (Unweighted zero-to-peak SPL of 196 dB re 1 µPa)	400	291	345	508	377,973
	800	438	540	646	921,810
	1,600	701	886	1,134	2,482,972
	2,400	958	1,165	1,404	4,280,914
	3,200	1,240	1,370	1,652	5,918,991
	4,000	1,398	1,643	1,979	10,285,631

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case unweighted zero-to-peak SPL sound levels.

Table 13-8: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Triton Knoll model location 1 with a maximum hammer energy of 2,700 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 14-4)	0	0	0	0
		5	5	5	78
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 14-4)	1,169	1,565	1,761	7,776,111
		2,115	2,474	2,690	19,273,470
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 14-4)	3,416	4,387	7,760	62,537,812
		6,295	9,170	19,409	287,663,630
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 14-4)	15,126	19,898	23,454	1,253,022,853
		19,428	24,458	33,025	1,919,624,145

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 13-9: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Triton Knoll model location 1 with a maximum hammer energy of 4,000 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 14-4)	2	2	2	13
		11	12	14	485
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 14-4)	1,868	2,541	2,854	20,529,759
		3,347	3,769	4,115	44,715,338
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 14-4)	4,721	6,461	10,826	139,396,743
		7,988	11,755	25,480	476,241,155
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 14-4)	19,739	23,410	27,890	1,730,699,628
		22,358	29,131	42,020	2,750,063,680

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 13-10: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Triton Knoll model location 2 with a maximum hammer energy of 2,700 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 14-4)	0	0	0	0
		4	5	5	65
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 14-4)	718	1,732	2,612	10,365,652
		2,336	3,020	4,017	29,456,253
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 14-4)	2,083	4,940	11,147	94,452,229
		4,104	8,185	18,145	248,955,639
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 14-4)	16,517	20,584	23,747	1,336,305,457
		20,247	25,167	32,717	2,033,469,336

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 13-11: Predicted distances and areas where Southall and NOAA weighted cumulative SEL thresholds for potential PTS and TTS onset in harbour porpoise are exceeded during pile-driving at Triton Knoll model location 2 with a maximum hammer energy of 4,000 kJ.

Impact Criterion (Threshold)	Pile-driving Sequence	Distance to threshold (m) [1]			Area of threshold exceedance (m^2) [1]
		Minimum	Average	Maximum	
Southall HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 198 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 14-4)	1	1	2	5
		7	10	16	353
NOAA HF cetacean PTS thresholds					
PTS onset (Weighted cumulative SEL of 155 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 14-4)	1,353	2,522	2,900	20,468,724
		3,560	4,460	5,845	63,449,193
Southall HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 183 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 14-4)	3,002	6,542	14,695	159,655,119
		5,408	10,348	22,709	395,363,008
NOAA HF cetacean TTS thresholds					
TTS onset (Weighted cumulative SEL of 140 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 14-4)	20,727	23,727	27,451	1,777,920,110
		22,126	29,091	39,052	2,742,748,650

[1] Distances and areas of threshold exceedance have been calculated for harbour porpoise swimming away from the piling at a constant speed of 1.5 m/s through the modelled depth-averaged SEL sound field (results shown by the white cells), and the maximum-over-depth/worst case SEL sound field (results shown by the grey cells).

Table 13-12: Predicted areas where harbour porpoise behavioural disturbance threshold of 145 dB re 1 μPa²s is exceeded during pile-driving at Triton Knoll.

Model location	Hammer Energy (kJ)	Distance to 145 dB re 1 μPa²s SEL threshold (m)			Total area where SEL exceeds 145 dB re 1 μPa²s (m²)	Area of SCI where SEL exceeds 145 dB re 1 μPa²s (m²)
		Minimum	Average	Maximum		
Depth-averaged						
1	2,700	11,446	14,771	22,287	699,974,295	0
	4,000	12,760	16,923	26,703	934,476,455	0
2	2,700	8,204	14,187	24,899	689,948,993	0
	4,000	10,175	16,083	27,611	881,027,168	0
Maximum-over-depth/Worst case						
1	2,700	14,118	19,888	33,919	1,315,465,722	2,301,455
	4,000	15,422	22,491	41,742	1,704,011,000	58,794,853
2	2,700	10,355	18,247	33,552	1,181,456,917	10,496,329
	4,000	10,820	20,743	38,966	1,543,677,993	104,540,627

Table 13-13: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Triton Knoll modelling location 1 with maximum hammer energy of 2,700 kJ.

SEL contour band (dB re 1 μPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	116	0	99.9%
200 - 205	276	0	99.7%
195 - 200	1,172	0	99.5%
190 - 195	4,596	0	99.0%
185 - 190	38,121	0	98.2%
180 - 185	218,573	0	96.7%
175 - 180	1,378,101	0	94.1%
170 - 175	3,585,560	0	89.4%
165 - 170	9,902,019	0	81.9%
160 - 165	25,285,065	0	70.7%
155 - 160	59,592,020	0	56.3%
150 - 155	156,416,970	0	40.7%
145 - 150	443,551,704	0	26.8%
Maximum-over-depth/Worst case			
> 210	14	0	99.9%
205 - 210	216	0	99.9%
200 - 205	1,150	0	99.7%
195 - 200	7,140	0	99.5%
190 - 195	31,145	0	99.0%
185 - 190	187,377	0	98.2%
180 - 185	1,287,321	0	96.7%
175 - 180	3,277,693	0	94.1%
170 - 175	8,570,681	0	89.4%
165 - 170	21,671,045	0	81.9%
160 - 165	51,290,289	0	70.7%
155 - 160	122,534,665	0	56.3%
150 - 155	380,307,869	0	40.7%
145 - 150	726,299,116	2,301,455	26.8%

Table 13-14: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Triton Knoll modelling location 1 with maximum hammer energy of 4,000 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	5	0	99.9%
205 - 210	178	0	99.9%
200 - 205	430	0	99.7%
195 - 200	2,019	0	99.5%
190 - 195	6,868	0	99.0%
185 - 190	75,921	0	98.2%
180 - 185	475,441	0	96.7%
175 - 180	1,996,437	0	94.1%
170 - 175	4,953,001	0	89.4%
165 - 170	13,780,225	0	81.9%
160 - 165	34,575,437	0	70.7%
155 - 160	77,353,581	0	56.3%
150 - 155	250,322,324	0	40.7%
145 - 150	550,934,585	0	26.8%
Maximum-over-depth/Worst case			
> 210	57	0	99.9%
205 - 210	382	0	99.9%
200 - 205	1,897	0	99.7%
195 - 200	12,652	0	99.5%
190 - 195	65,692	0	99.0%
185 - 190	438,630	0	98.2%
180 - 185	1,827,113	0	96.7%
175 - 180	4,528,484	0	94.1%
170 - 175	11,663,333	0	89.4%
165 - 170	29,760,224	0	81.9%
160 - 165	65,908,689	0	70.7%
155 - 160	199,679,650	0	56.3%
150 - 155	473,425,930	0	40.7%
145 - 150	916,698,268	58,794,853	26.8%

Table 13-15: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Triton Knoll modelling location 2 with maximum hammer energy of 2,700 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	30	0	99.9%
200 - 205	237	0	99.7%
195 - 200	972	0	99.5%
190 - 195	4,617	0	99.0%
185 - 190	17,099	0	98.2%
180 - 185	142,444	0	96.7%
175 - 180	1,122,770	0	94.1%
170 - 175	3,486,545	0	89.4%
165 - 170	17,288,041	0	81.9%
160 - 165	49,225,722	0	70.7%
155 - 160	99,163,494	0	56.3%
150 - 155	181,514,250	0	40.7%
145 - 150	337,982,773	0	26.8%
Maximum-over-depth/Worst case			
> 210	7	0	99.9%
205 - 210	196	0	99.9%
200 - 205	988	0	99.7%
195 - 200	4,483	0	99.5%
190 - 195	29,711	0	99.0%
185 - 190	133,607	0	98.2%
180 - 185	1,058,714	0	96.7%
175 - 180	3,306,067	0	94.1%
170 - 175	16,621,549	0	89.4%
165 - 170	43,700,401	0	81.9%
160 - 165	84,419,393	0	70.7%
155 - 160	150,544,919	0	56.3%
150 - 155	281,876,889	0	40.7%
145 - 150	599,759,994	10,496,329	26.8%

Table 13-16: Predicted areas and probability of disturbance to harbour porpoise for pile-driving at Triton Knoll modelling location 2 with maximum hammer energy of 4,000 kJ.

SEL contour band (dB re 1 μPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	94	0	99.9%
200 - 205	364	0	99.7%
195 - 200	1,673	0	99.5%
190 - 195	7,290	0	99.0%
185 - 190	36,814	0	98.2%
180 - 185	307,642	0	96.7%
175 - 180	1,831,413	0	94.1%
170 - 175	4,836,260	0	89.4%
165 - 170	28,549,904	0	81.9%
160 - 165	64,913,446	0	70.7%
155 - 160	126,285,860	0	56.3%
150 - 155	210,384,485	0	40.7%
145 - 150	443,871,924	0	26.8%
Maximum-over-depth/Worst case			
> 210	45	0	99.9%
205 - 210	354	0	99.9%
200 - 205	1,548	0	99.7%
195 - 200	8,615	0	99.5%
190 - 195	50,688	0	99.0%
185 - 190	346,157	0	98.2%
180 - 185	1,674,300	0	96.7%
175 - 180	4,585,301	0	94.1%
170 - 175	26,911,557	0	89.4%
165 - 170	56,865,792	0	81.9%
160 - 165	99,204,924	0	70.7%
155 - 160	182,159,215	0	56.3%
150 - 155	365,172,578	0	40.7%
145 - 150	806,696,919	104,540,627	26.8%

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Table 13-17: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Triton Knoll model location 1 with a maximum hammer energy of 2,700 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,700	97	99	100	30,812
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 $\mu Pa^2 s$)	4.0 hour pile-driving sequence (see Table 14-4)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 $\mu Pa^2 s$)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,700	301	311	327	303,367
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 $\mu Pa^2 s$)	4.0 hour pile-driving sequence (see Table 14-4)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 $\mu Pa^2 s$)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,700	301	311	327	303,367
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 $\mu Pa^2 s$)	4.0 hour pile-driving sequence (see Table 14-4)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 $\mu Pa^2 s$)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 13-18: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Triton Knoll model location 1 with a maximum hammer energy of 4,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	4,000	137	148	150	68,584
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	4.0 hour pile-driving sequence (see Table 14-4)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	4,000	341	384	401	462,244
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	4.0 hour pile-driving sequence (see Table 14-4)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		16	17	19	900
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	4,000	341	384	401	462,244
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	4.0 hour pile-driving sequence (see Table 14-4)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		16	17	19	900

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 13-19: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Triton Knoll model location 2 with a maximum hammer energy of 2,700 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	2,700	92	104	115	34,319
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 14-4)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,700	211	236	311	175,105
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 14-4)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	2,700	211	236	311	175,105
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa²s)	4.0 hour pile-driving sequence (see Table 14-4)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa²s)		< 10	< 10	< 10	< 314

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

Table 13-20: Predicted distances and areas where Popper thresholds for fish mortality and potential mortal injury are exceeded during pile-driving at Triton Knoll model location 2 with a maximum hammer energy of 4,000 kJ.

Impact Criterion (Threshold)	Hammer Energy (kJ) / Pile-driving Sequence	Distance to threshold exceedance (m)			Area of threshold exceedance (m^2)
		Minimum	Average	Maximum	
Fish with no swim bladder					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 213 dB re 1 µPa)	4,000	128	135	144	57,155
Mortality and potential mortal injury (Unweighted cumulative SEL of 219 dB re 1 µPa^{2}s)	4.0 hour pile-driving sequence (see Table 14-4)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 216 dB re 1 µPa^{2}s)		< 10	< 10	< 10	< 314
Fish with swim bladder not involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	4,000	258	303	414	290,548
Mortality and potential mortal injury (Unweighted cumulative SEL of 210 dB re 1 µPa^{2}s)	4.0 hour pile-driving sequence (see Table 14-4)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		11	19	43	1,454
Fish with swim bladder involved in hearing					
Mortality and potential mortal injury (Unweighted zero-to-peak SPL of 207 dB re 1 µPa)	4,000	258	303	414	290,548
Mortality and potential mortal injury (Unweighted cumulative SEL of 207 dB re 1 µPa^{2}s)	4.0 hour pile-driving sequence (see Table 14-4)	< 10	< 10	< 10	< 314
Recoverable injury (Unweighted cumulative SEL of 203 dB re 1 µPa^{2}s)		11	19	43	1,454

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case sound field.

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Table 13-21: Predicted distances and areas where harbour porpoise behavioural disturbance threshold of 145 dB re 1 µPa²s is exceeded during concurrent pile-driving at Triton Knoll.

Model location	Hammer Energy (kJ)	Total area where SEL exceeds 145 dB re 1 µPa²s (m^2)	Area of SCI where SEL exceeds 145 dB re 1 µPa²s (m^2)
Depth-averaged			
1 and 2	2,700	947,149,428	0
	4,000	1,191,924,410	0
Maximum-over-depth/Worst case			
1 and 2	2,700	1,558,986,966	11,920,565
	4,000	1,994,947,790	155,481,023

Table 13-22: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Triton Knoll locations 1 and 2 with maximum hammer energy of 2,700 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	146	0	99.9%
200 - 205	513	0	99.7%
195 - 200	2,144	0	99.5%
190 - 195	9,213	0	99.0%
185 - 190	55,220	0	98.2%
180 - 185	361,016	0	96.7%
175 - 180	2,500,871	0	94.1%
170 - 175	7,072,106	0	89.4%
165 - 170	27,190,060	0	81.9%
160 - 165	74,510,787	0	70.7%
155 - 160	156,236,714	0	56.3%
150 - 155	239,756,549	0	40.7%
145 - 150	439,454,088	0	26.8%
Maximum-over-depth/Worst case			
> 210	21	0	99.9%
205 - 210	412	0	99.9%
200 - 205	2,137	0	99.7%
195 - 200	11,623	0	99.5%
190 - 195	60,856	0	99.0%
185 - 190	320,984	0	98.2%
180 - 185	2,346,035	0	96.7%
175 - 180	6,583,760	0	94.1%
170 - 175	25,192,230	0	89.4%
165 - 170	65,371,445	0	81.9%
160 - 165	135,709,682	0	70.7%
155 - 160	208,910,008	0	56.3%
150 - 155	371,163,439	0	40.7%
145 - 150	743,314,334	11,920,565	26.8%

Table 13-23: Predicted areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Triton Knoll locations 1 and 2 with maximum hammer energy of 4,000 kJ.

SEL contour band (dB re 1 μPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	5	0	99.9%
205 - 210	273	0	99.9%
200 - 205	794	0	99.7%
195 - 200	3,692	0	99.5%
190 - 195	14,158	0	99.0%
185 - 190	112,735	0	98.2%
180 - 185	783,084	0	96.7%
175 - 180	3,827,851	0	94.1%
170 - 175	9,789,261	0	89.4%
165 - 170	42,330,129	0	81.9%
160 - 165	99,488,883	0	70.7%
155 - 160	187,977,396	0	56.3%
150 - 155	286,855,503	0	40.7%
145 - 150	560,740,647	0	26.8%
Maximum-over-depth/Worst case			
> 210	102	0	99.9%
205 - 210	737	0	99.9%
200 - 205	3,445	0	99.7%
195 - 200	21,267	0	99.5%
190 - 195	116,379	0	99.0%
185 - 190	784,786	0	98.2%
180 - 185	3,501,414	0	96.7%
175 - 180	9,113,785	0	94.1%
170 - 175	38,574,890	0	89.4%
165 - 170	86,626,017	0	81.9%
160 - 165	161,081,456	0	70.7%
155 - 160	245,443,509	0	56.3%
150 - 155	469,697,662	0	40.7%
145 - 150	979,982,340	155,481,023	26.8%

14.0 CONCURRENT PILING AT DIFFERENT PROJECTS

It is possible that concurrent piling at different wind farm projects may occur (e.g. if different wind farms are constructing at the same time), which may lead to "in-combination" effects. To identify realistic in-combination impacts, the construction schedules for each of the relevant developments has been used. Based on the predicted construction schedules of each of the wind farms, the following potential in-combination impacts with respect to construction noise have been assessed:

- Creyke Beck A and Creyke Beck B;
- Creyke Beck A and Hornsea Two;
- Creyke Beck A and Teesside B;
- Creyke Beck A and Triton Knoll;
- Creyke Beck A and East Anglia Three;
- East Anglia Three and Hornsea Two;
- East Anglia Three and Triton Knoll;
- East Anglia Three and Teesside B;
- Teesside A and Teesside B; and
- Creyke Beck A, Creyke Beck B, and Teesside B.

Concurrent pile-driving scenarios at different wind farm projects have been conducted in order to estimate potential behavioural disturbance zones to harbour porpoise. In each scenario, the largest hammer energy for each wind farm has been used. The scenarios that have been modelled for concurrent pile-driving at different projects are summarised in Table 14-1.

The unweighted single pulse SEL sound fields due to concurrent pile-driving at the different wind farm projects are presented in Appendix K. The predicted areas where the harbour porpoise behavioural disturbance threshold of 145 dB re 1 μPa^{2}s is exceeded for the concurrent pile-driving scenarios are shown in Table 14-2 and Table 14-3, for depth-averaged and maximum-over-depth SEL, respectively. Table 14-4 to Table 14-13 further show the probability of potential displacement of harbour porpoise for different SEL bands (using the behavioural/dose response curve discussed in Section 3.2.1.2.) for the concurrent pile-driving scenarios using different hammer energies.

Table 14-1: Modelling scenarios for concurrent pile-driving at different wind farm projects.

Concurrent Pile-driving Scenario	Model Locations	Hammer Energy (kJ)
Creyke Beck A and Creyke Beck B	Creyke Beck A – Model Location 2	Creyke Beck A – 3,000 kJ
	Creyke Beck B – Model Location 2	Creyke Beck B – 3,000 kJ
Creyke Beck A and Hornsea Two	Creyke Beck A – Model Location 2	Creyke Beck A – 3,000 kJ
	Hornsea Two – Model Location 2	Hornsea Two – 3,000 kJ
Creyke Beck A and Teesside B	Creyke Beck A – Model Location 2	Creyke Beck A – 3,000 kJ
	Teesside B – Model Location 1	Teesside B – 5,500 kJ
Creyke Beck A and Triton Knoll	Creyke Beck A – Model Location 2	Creyke Beck A – 3,000 kJ
	Triton Knoll – Model Location 2	Triton Knoll – 4,000 kJ
Creyke Beck A and East Anglia Three	Creyke Beck A – Model Location 2	Creyke Beck A – 3,000 kJ
	East Anglia Three – Model Location 1	East Anglia Three – 3,000 kJ
East Anglia Three and Hornsea Two	East Anglia Three – Model Location 1	East Anglia Three – 3,000 kJ
	Hornsea Two – Model Location 2	Hornsea Two – 3,000 kJ
East Anglia Three and Triton Knoll	East Anglia Three – Model Location 1	East Anglia Three – 3,000 kJ
	Triton Knoll – Model Location 2	Triton Knoll – 4,000 kJ
East Anglia Three and Teesside B	East Anglia Three – Model Location 1	East Anglia Three – 3,000 kJ
	Teesside B – Model Location 1	Teesside B – 5,500 kJ
Teesside A and Teesside B	Teesside A – Model Location 1	Teesside A – 5.500 kJ
	Teesside B – Model Location 1	Teesside B – 5,500 kJ
Creyke Beck A, Creyke Beck B, and Teesside B	Creyke Beck A – Model Location 2	Creyke Beck A – 3,000 kJ
	Creyke Beck B – Model Location 2	Creyke Beck B – 3,000 kJ
	Teesside B – Model Location 1	Teesside B – 5,500 kJ

Table 14-2: Areas where harbour porpoise behavioural disturbance threshold of 145 dB re 1 μPa²s is exceeded during concurrent pile-driving at different wind farm projects (depth-averaged results).

Concurrent Pile-driving Scenario	Hammer Energy (kJ)	Total area where SEL exceeds 145 dB re 1 μPa²s (m²) [1]	Area of SCI where SEL exceeds 145 dB re 1 μPa²s (m²) [1]
Creyke Beck A and Creyke Beck B	Creyke Beck A – 3,000 kJ Creyke Beck B – 3,000 kJ	2,288,650,076	2,288,650,076
Creyke Beck A and Hornsea Two	Creyke Beck A – 3,000 kJ Hornsea Two – 3,000 kJ	3,585,212,105	3,354,927,143
Creyke Beck A and Teesside B	Creyke Beck A – 3,000 kJ Teesside B – 5,500 kJ	2,403,521,822	1,838,330,233
Creyke Beck A and Triton Knoll	Creyke Beck A – 3,000 kJ Triton Knoll – 4,000 kJ	1,672,036,637	791,009,469
Creyke Beck A and East Anglia Three	Creyke Beck A – 3,000 kJ East Anglia Three – 3,000 kJ	3,242,765,666	3,242,765,666
East Anglia Three and Hornsea Two	East Anglia Three – 3,000 kJ Hornsea Two – 3,000 kJ	5,245,958,833	5,015,673,871
East Anglia Three and Triton Knoll	East Anglia Three – 3,000 kJ Triton Knoll – 4,000 kJ	3,332,783,365	2,451,756,197
East Anglia Three and Teesside B	East Anglia Three – 3,000 kJ Teesside B – 5,500 kJ	4,293,790,357	3,728,392,108
Teesside A and Teesside B	Teesside A – 5.500 kJ Teesside B – 5,500 kJ	3,417,402,883	1,277,411,327
Creyke Beck A, Creyke Beck B, and Teesside B	Creyke Beck A – 3,000 kJ Creyke Beck B – 3,000 kJ Teesside B – 5,500 kJ	3,435,649,223	2,870,658,323

[1] Distances and areas of threshold exceedance have been calculated using the modelled depth-averaged SEL sound levels.

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Table 14-3: Areas where harbour porpoise behavioural disturbance threshold of 145 dB re 1 µPa^{2}s is exceeded during concurrent pile-driving at different wind farm projects (maximum-over-depth/worst case results).

Concurrent Pile-driving Scenario	Hammer Energy (kJ)	Total area where SEL exceeds 145 dB re 1 µPa^{2}s (m^2) [1]	Area of SCI where SEL exceeds 145 dB re 1 µPa^{2}s (m^2) [1]
Creyke Beck A and Creyke Beck B	Creyke Beck A – 3,000 kJ Creyke Beck B – 3,000 kJ	6,077,455,452	5,015,962,333
Creyke Beck A and Hornsea Two	Creyke Beck A – 3,000 kJ Hornsea Two – 3,000 kJ	8,775,522,797	7,676,020,165
Creyke Beck A and Teesside B	Creyke Beck A – 3,000 kJ Teesside B – 5,500 kJ	4,941,919,080	3,090,311,534
Creyke Beck A and Triton Knoll	Creyke Beck A – 3,000 kJ Triton Knoll – 4,000 kJ	2,980,117,963	1,540,980,596
Creyke Beck A and East Anglia Three	Creyke Beck A – 3,000 kJ East Anglia Three – 3,000 kJ	7,225,469,297	6,879,356,990
East Anglia Three and Hornsea Two	East Anglia Three – 3,000 kJ Hornsea Two – 3,000 kJ	13,128,112,155	11,682,497,217
East Anglia Three and Triton Knoll	East Anglia Three – 3,000 kJ Triton Knoll – 4,000 kJ	7,332,707,321	5,547,457,648
East Anglia Three and Teesside B	East Anglia Three – 3,000 kJ Teesside B – 5,500 kJ	10,120,592,197	7,922,387,652
Teesside A and Teesside B	Teesside A – 5.500 kJ Teesside B – 5,500 kJ	6,547,402,743	2,542,575,406
Creyke Beck A, Creyke Beck B, and Teesside B	Creyke Beck A – 3,000 kJ Creyke Beck B – 3,000 kJ Teesside B – 5,500 kJ	7,738,426,751	5,124,306,236

[1] Distances and areas of threshold exceedance have been calculated using the modelled maximum-over-depth/worst case SEL sound levels.

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Table 14-4: Areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Creyke Beck A model location 2 with maximum hammer energy of 3,000 kJ and Creyke Beck B model location 2 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	187	187	99.9%
200 - 205	615	615	99.7%
195 - 200	2,547	2,547	99.5%
190 - 195	11,703	11,703	99.0%
185 - 190	44,583	44,583	98.2%
180 - 185	422,159	422,158	96.7%
175 - 180	3,242,443	3,242,444	94.1%
170 - 175	9,090,802	9,090,802	89.4%
165 - 170	29,911,010	29,911,010	81.9%
160 - 165	89,724,537	89,724,537	70.7%
155 - 160	233,333,711	233,333,711	56.3%
150 - 155	560,592,289	560,592,289	40.7%
145 - 150	1,362,273,489	1,362,273,489	26.8%
Maximum-over-depth/Worst case			
> 210	40	40	99.9%
205 - 210	442	442	99.9%
200 - 205	2,393	2,393	99.7%
195 - 200	11,537	11,537	99.5%
190 - 195	76,137	76,137	99.0%
185 - 190	480,081	480,081	98.2%
180 - 185	4,757,596	4,757,594	96.7%
175 - 180	6,303,165	6,303,166	94.1%
170 - 175	25,686,553	25,686,553	89.4%
165 - 170	76,305,312	76,305,312	81.9%
160 - 165	199,555,700	199,555,700	70.7%
155 - 160	485,035,104	485,035,105	56.3%
150 - 155	1,220,816,175	1,220,816,175	40.7%
145 - 150	4,058,425,217	2,996,932,098	26.8%

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Table 14-5: Areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Creyke Beck A model location 2 with maximum hammer energy of 3,000 kJ and Hornsea Two model location 2 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 μPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	89	89	99.9%
200 - 205	498	498	99.7%
195 - 200	2,289	2,289	99.5%
190 - 195	10,754	10,754	99.0%
185 - 190	43,740	43,740	98.2%
180 - 185	337,953	337,953	96.7%
175 - 180	2,907,426	2,907,426	94.1%
170 - 175	9,307,200	9,307,201	89.4%
165 - 170	31,108,591	31,108,591	81.9%
160 - 165	101,438,046	101,438,046	70.7%
155 - 160	287,219,087	287,219,086	56.3%
150 - 155	959,439,619	959,439,620	40.7%
145 - 150	2,193,396,813	1,963,111,851	26.8%
Maximum-over-depth/Worst case			
> 210	19	19	99.9%
205 - 210	365	365	99.9%
200 - 205	2,022	2,022	99.7%
195 - 200	10,380	10,380	99.5%
190 - 195	64,104	64,104	99.0%
185 - 190	401,302	401,303	98.2%
180 - 185	4,603,544	4,603,542	96.7%
175 - 180	6,474,019	6,474,021	94.1%
170 - 175	27,825,327	27,825,327	89.4%
165 - 170	88,376,713	88,376,713	81.9%
160 - 165	253,247,550	253,247,550	70.7%
155 - 160	820,931,779	820,931,779	56.3%
150 - 155	2,025,497,030	1,843,273,298	40.7%
145 - 150	5,548,088,641	4,630,809,742	26.8%

Table 14-6: Areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Creyke Beck A model location 2 with maximum hammer energy of 3,000 kJ and Teesside B model location 1 with maximum hammer energy of 5,500 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	22	22	99.9%
205 - 210	275	275	99.9%
200 - 205	890	890	99.7%
195 - 200	3,997	3,997	99.5%
190 - 195	17,655	17,655	99.0%
185 - 190	121,349	121,349	98.2%
180 - 185	912,132	912,132	96.7%
175 - 180	4,449,022	4,449,022	94.1%
170 - 175	12,393,009	12,393,009	89.4%
165 - 170	37,770,950	37,770,950	81.9%
160 - 165	102,030,115	102,030,115	70.7%
155 - 160	256,053,310	254,991,769	56.3%
150 - 155	614,477,823	505,515,601	40.7%
145 - 150	1,375,291,274	920,123,449	26.8%
Maximum-over-depth/Worst case			
> 210	95	95	99.9%
205 - 210	721	721	99.9%
200 - 205	3,872	3,872	99.7%
195 - 200	21,598	21,598	99.5%
190 - 195	130,498	130,498	99.0%
185 - 190	972,166	972,166	98.2%
180 - 185	5,787,086	5,787,084	96.7%
175 - 180	9,131,676	9,131,678	94.1%
170 - 175	32,516,862	32,516,862	89.4%
165 - 170	87,975,084	87,975,084	81.9%
160 - 165	218,139,532	218,139,532	70.7%
155 - 160	522,688,666	445,193,933	56.3%
150 - 155	1,251,171,833	861,859,237	40.7%
145 - 150	2,813,379,390	1,428,579,173	26.8%

Table 14-7: Areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Creyke Beck A model location 2 with maximum hammer energy of 3,000 kJ and Triton Knoll model location 2 with maximum hammer energy of 5,500 kJ.

SEL contour band (dB re 1 µPa²s)	Total area of SEL contour band (m²)	Area of SEL contour band that overlaps with SCI (m²)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	183	89	99.9%
200 - 205	679	314	99.7%
195 - 200	2,943	1,270	99.5%
190 - 195	13,150	5,861	99.0%
185 - 190	59,431	22,617	98.2%
180 - 185	515,729	208,087	96.7%
175 - 180	3,484,887	1,653,474	94.1%
170 - 175	9,289,314	4,453,055	89.4%
165 - 170	42,060,678	13,510,774	81.9%
160 - 165	101,848,596	36,935,150	70.7%
155 - 160	217,232,594	90,946,734	56.3%
150 - 155	414,799,270	204,414,785	40.7%
145 - 150	882,729,182	438,857,258	26.8%
Maximum-over-depth/Worst case			
> 210	63	18	99.9%
205 - 210	571	216	99.9%
200 - 205	2,755	1,207	99.7%
195 - 200	14,424	5,809	99.5%
190 - 195	88,985	38,298	99.0%
185 - 190	572,707	226,551	98.2%
180 - 185	5,003,199	3,328,897	96.7%
175 - 180	6,734,378	2,149,078	94.1%
170 - 175	38,654,898	11,743,341	89.4%
165 - 170	88,716,084	31,850,291	81.9%
160 - 165	177,869,267	78,664,343	70.7%
155 - 160	355,041,290	172,882,075	56.3%
150 - 155	732,578,392	367,405,814	40.7%
145 - 150	1,574,840,949	872,684,658	26.8%

Table 14-8: Areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Creyke Beck A model location 2 with maximum hammer energy of 3,000 kJ and East Anglia Three model location 1 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	100	100	99.9%
200 - 205	475	475	99.7%
195 - 200	2,296	2,296	99.5%
190 - 195	10,581	10,581	99.0%
185 - 190	45,381	45,382	98.2%
180 - 185	356,309	356,309	96.7%
175 - 180	2,947,962	2,947,962	94.1%
170 - 175	9,217,105	9,217,105	89.4%
165 - 170	32,441,150	32,441,150	81.9%
160 - 165	110,547,584	110,547,584	70.7%
155 - 160	317,554,094	317,554,094	56.3%
150 - 155	799,957,708	799,957,708	40.7%
145 - 150	1,969,684,923	1,969,684,922	26.8%
Maximum-over-depth/Worst case			
> 210	18	18	99.9%
205 - 210	364	364	99.9%
200 - 205	1,847	1,847	99.7%
195 - 200	10,323	10,323	99.5%
190 - 195	65,450	65,450	99.0%
185 - 190	407,985	407,985	98.2%
180 - 185	4,544,208	4,544,207	96.7%
175 - 180	6,504,615	6,504,616	94.1%
170 - 175	28,399,744	28,399,744	89.4%
165 - 170	92,639,199	92,639,199	81.9%
160 - 165	274,337,130	274,337,130	70.7%
155 - 160	698,631,413	698,631,413	56.3%
150 - 155	1,743,808,763	1,743,808,763	40.7%
145 - 150	4,376,118,239	4,030,005,932	26.8%

Table 14-9: Areas and probability of disturbance to harbour porpoise for concurrent pile-driving at East Anglia Three model location 1 with maximum hammer energy of 3,000 kJ and Hornsea Two model location 2 with maximum hammer energy of 3,000 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	10	10	99.9%
200 - 205	344	344	99.7%
195 - 200	2,044	2,044	99.5%
190 - 195	9,614	9,614	99.0%
185 - 190	43,888	43,888	98.2%
180 - 185	278,088	278,088	96.7%
175 - 180	2,548,441	2,548,440	94.1%
170 - 175	9,618,196	9,618,196	89.4%
165 - 170	36,528,192	36,528,192	81.9%
160 - 165	138,115,330	138,115,330	70.7%
155 - 160	422,879,711	422,879,711	56.3%
150 - 155	1,350,567,757	1,350,567,757	40.7%
145 - 150	3,285,367,220	3,055,082,257	26.8%
Maximum-over-depth/Worst case			
> 210	1	1	99.9%
205 - 210	297	297	99.9%
200 - 205	1,454	1,454	99.7%
195 - 200	9,085	9,085	99.5%
190 - 195	52,959	52,959	99.0%
185 - 190	356,186	356,186	98.2%
180 - 185	2,489,954	2,489,954	96.7%
175 - 180	8,680,481	8,680,481	94.1%
170 - 175	32,738,389	32,738,389	89.4%
165 - 170	117,315,329	117,315,329	81.9%
160 - 165	370,255,995	370,255,995	70.7%
155 - 160	1,173,799,042	1,173,799,041	56.3%
150 - 155	3,034,494,165	2,852,270,434	40.7%
145 - 150	8,387,918,819	7,124,527,612	26.8%

Table 14-10: Areas and probability of disturbance to harbour porpoise for concurrent pile-driving at East Anglia Three model location 1 with maximum hammer energy of 3,000 kJ and Triton Knoll model location 2 with maximum hammer energy of 4,000 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	0	0	99.9%
205 - 210	105	10	99.9%
200 - 205	525	160	99.7%
195 - 200	2,698	1,025	99.5%
190 - 195	12,009	4,720	99.0%
185 - 190	59,579	22,765	98.2%
180 - 185	455,864	148,222	96.7%
175 - 180	3,125,902	1,294,488	94.1%
170 - 175	9,600,310	4,764,051	89.4%
165 - 170	47,480,279	18,930,375	81.9%
160 - 165	138,525,880	73,612,434	70.7%
155 - 160	352,893,219	226,607,359	56.3%
150 - 155	805,927,407	595,542,922	40.7%
145 - 150	1,974,699,588	1,530,827,665	26.8%
Maximum-over-depth/Worst case			
> 210	45	0	99.9%
205 - 210	502	148	99.9%
200 - 205	2,188	639	99.7%
195 - 200	13,129	4,514	99.5%
190 - 195	77,840	27,152	99.0%
185 - 190	527,591	181,434	98.2%
180 - 185	2,889,609	1,215,309	96.7%
175 - 180	8,940,840	4,355,538	94.1%
170 - 175	43,567,960	16,656,403	89.4%
165 - 170	117,654,700	60,788,907	81.9%
160 - 165	294,877,711	195,672,787	70.7%
155 - 160	707,908,553	525,749,338	56.3%
150 - 155	1,741,575,527	1,376,402,949	40.7%
145 - 150	4,414,671,127	3,366,402,529	26.8%

Table 14-11: Areas and probability of disturbance to harbour porpoise for concurrent pile-driving at East Anglia Three model location 1 with maximum hammer energy of 3,000 kJ and Teesside B model location 1 with maximum hammer energy of 5,500 kJ.

SEL contour band (dB re 1 µPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	22	22	99.9%
205 - 210	196	196	99.9%
200 - 205	736	736	99.7%
195 - 200	3,752	3,752	99.5%
190 - 195	16,515	16,515	99.0%
185 - 190	121,497	121,496	98.2%
180 - 185	852,267	852,267	96.7%
175 - 180	4,090,036	4,090,036	94.1%
170 - 175	12,704,005	12,704,005	89.4%
165 - 170	43,190,551	43,190,551	81.9%
160 - 165	138,707,398	138,707,398	70.7%
155 - 160	391,713,935	390,652,394	56.3%
150 - 155	1,005,605,960	896,643,738	40.7%
145 - 150	2,696,783,488	2,241,409,002	26.8%
Maximum-over-depth/Worst case			
> 210	77	77	99.9%
205 - 210	652	652	99.9%
200 - 205	3,304	3,304	99.7%
195 - 200	20,303	20,303	99.5%
190 - 195	119,353	119,353	99.0%
185 - 190	927,050	927,050	98.2%
180 - 185	3,673,496	3,673,496	96.7%
175 - 180	11,338,138	11,338,138	94.1%
170 - 175	37,429,924	37,429,924	89.4%
165 - 170	116,913,700	116,913,700	81.9%
160 - 165	335,147,977	335,147,977	70.7%
155 - 160	875,555,929	798,061,195	56.3%
150 - 155	2,409,899,878	2,018,936,974	40.7%
145 - 150	6,329,562,416	4,599,815,508	26.8%

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Table 14-12: Areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Teesside A model location 1 with maximum hammer energy of 5,500 kJ and Teesside B model location 1 with maximum hammer energy of 5,500 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	25	22	99.9%
205 - 210	394	185	99.9%
200 - 205	1,196	576	99.7%
195 - 200	5,516	2,727	99.5%
190 - 195	23,504	11,795	99.0%
185 - 190	207,256	98,732	98.2%
180 - 185	1,441,483	704,045	96.7%
175 - 180	5,646,013	2,795,548	94.1%
170 - 175	16,135,443	7,939,954	89.4%
165 - 170	49,675,730	24,260,176	81.9%
160 - 165	136,424,928	65,094,964	70.7%
155 - 160	335,350,733	164,045,034	56.3%
150 - 155	834,438,490	301,100,816	40.7%
145 - 150	2,038,052,171	711,356,754	26.8%
Maximum-over-depth/Worst case			
> 210	169	77	99.9%
205 - 210	1,045	504	99.9%
200 - 205	5,392	2,665	99.7%
195 - 200	33,685	15,790	99.5%
190 - 195	182,969	92,201	99.0%
185 - 190	1,423,747	745,616	98.2%
180 - 185	5,018,652	2,458,187	96.7%
175 - 180	14,156,676	6,982,600	94.1%
170 - 175	42,571,263	20,773,521	89.4%
165 - 170	116,363,346	56,124,792	81.9%
160 - 165	285,722,137	139,475,189	70.7%
155 - 160	719,420,088	272,311,857	56.3%
150 - 155	1,859,667,389	642,122,546	40.7%
145 - 150	3,502,836,187	1,401,469,861	26.8%

Table 14-13: Areas and probability of disturbance to harbour porpoise for concurrent pile-driving at Creyke Beck A model location 2 with maximum hammer energy of 3,000 kJ, Creyke Beck B model location 2 with maximum hammer energy of 3,000 kJ, and Teesside B model location 1 with maximum hammer energy of 5,500 kJ.

SEL contour band (dB re 1 μPa^{2}s)	Total area of SEL contour band (m^2)	Area of SEL contour band that overlaps with SCI (m^2)	Probability of disturbance
Depth-averaged			
> 210	22	22	99.9%
205 - 210	373	373	99.9%
200 - 205	1,191	1,191	99.7%
195 - 200	5,273	5,273	99.5%
190 - 195	23,498	23,498	99.0%
185 - 190	143,315	143,315	98.2%
180 - 185	1,126,204	1,126,204	96.7%
175 - 180	6,037,991	6,037,991	94.1%
170 - 175	17,030,756	17,030,756	89.4%
165 - 170	54,171,186	54,171,186	81.9%
160 - 165	154,819,501	154,819,501	70.7%
155 - 160	398,440,287	397,378,746	56.3%
150 - 155	970,655,327	861,693,105	40.7%
145 - 150	1,833,194,300	1,378,227,164	26.8%
Maximum-over-depth/Worst case			
> 210	117	117	99.9%
205 - 210	946	946	99.9%
200 - 205	5,057	5,057	99.7%
195 - 200	27,327	27,327	99.5%
190 - 195	168,338	168,338	99.0%
185 - 190	1,225,697	1,225,697	98.2%
180 - 185	7,215,783	7,215,781	96.7%
175 - 180	13,285,765	13,285,766	94.1%
170 - 175	46,460,074	46,460,074	89.4%
165 - 170	132,430,104	132,430,104	81.9%
160 - 165	339,030,890	339,030,890	70.7%
155 - 160	834,841,695	757,346,962	56.3%
150 - 155	1,761,631,485	1,370,906,200	40.7%
145 - 150	4,602,103,474	2,456,202,976	26.8%

15.0 DISCUSSION AND CONCLUSIONS

This document has presented underwater sound propagation modelling to estimate potential impacts to harbour porpoise and fish from pile-driving operations at a number of wind farm developments in the vicinity of SNS SCI. A number of different scenarios were considered in the modelling including single and concurrent pile-driving operations at each wind farm development, as well as concurrent pile-driving at multiple wind farm projects.

The modelling was conducted using a parabolic equation model for modelling the propagation of low frequency sound up to and including 500 Hz, as well as a ray tracing algorithm for modelling the propagation of sound above 500 Hz. The modelling took into account a wide range of environmental parameters that influence sound propagation such as bathymetry, seabed sediments, water column temperature and salinity, and also accounted for other parameters such as hammer blow energy, soft-start/ramp-up procedures, and frequency content of sound generated during pile-driving.

The predicted received sound levels from the propagation modelling were compared to the thresholds proposed by NOAA (NMFS, 2016) to predict areas where the potential onset of PTS and TTS may occur in harbour porpoise. For comparison, the predicted sound levels were also compared to the older PTS and TTS thresholds proposed by Southall *et al.* (2007). In general, the cumulative SEL metric resulted in larger predicted areas of impact when compared to the single pulse unweighted peak SPL metric. However, it should be noted that the cumulative SEL modelling that has been conducted is considered to be highly precautionary, and the predicted areas of potential impact should be treated with caution. The cumulative SEL modelling used a very conservative swim speed of 1.5 m/s for harbour porpoise. It is expected that harbour porpoise would swim away from any pile-driving activities at a faster swim speed that this if the noise from the activity was causing any stress or discomfort. For example, harbour porpoise have been recorded swimming at speeds of up to 4.3 m/s to 6.2 m/s (Culik *et al.,* 2001; Otani *et al.,* 2001). The use of a relatively low swim speed in the cumulative SEL modelling (along with other conservative measures that were used in the modelling) results in significantly larger predicted areas of impact than would likely occur in practice. It is suggested therefore that these results are highly precautionary and unlikely to occur in practice.

Potential impacts to fish species were also assessed by comparing the predicted received sound levels to the thresholds established in Popper *et al*. (2014). The modelling showed that potential mortality or mortal injury to fish species was either negligible or limited to within short distances from the pile-driving operation.

The outputs of the propagation modelling have been used to further investigate potential impacts to harbour porpoise in the Habitats Regulation Assessment.

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APPENDIX A: MODEL CALIBRATION

This appendix discusses the procedure that has been used to calibrate the utilised underwater noise propagation model. The adopted procedure essentially adjusts the pile-driving source levels such that the predicted received levels from the propagation model are calibrated to those that have been reported from measurements of pile-driving in the field. The calibration procedure is intrinsically linked to the source levels that have been used in the modelling. In other words, calibration of the underwater noise model with measurements made in the field not only serves to validate the transmission loss predicted by the propagation model, but also serves to estimate appropriate source levels for use with the model.

The calibration of the adopted propagation model has been conducted using underwater sound measurements made at the Greater Gabbard wind farm development. During the construction of the Greater Gabbard wind farm, underwater noise monitoring measurements were made that reported received sound levels in terms of both peak-to-peak SPL and SEL (Gardline, 2010). These measurements were made for a number of different bearings from the pile-driving location. The measurements that were made along the “westerly transect” in Gardline, (2010) were used for the purposes of calibrating the adopted noise model. The measurements made in Gardline, (2010) were fitted with best-fit curves using a simple lumped parameter model of the form

$$RL = SL - N\log(r) - \alpha r\ ,$$

where RL is the received sound level (which can be expressed as a peak-to-peak SPL or SEL), SL is the corresponding source level, r is the distance/range from the sound source, and N and α are parameters of the lumped parameter model that describe spreading and attenuation, respectively. The measurements that were made during pile-driving at the Greater Gabbard wind farm yielded the parameters shown in Table A-1 for the previous lumped parameter model.

Table A-1: Parameters for lumped parameter model derived from measurements at Greater Gabbard.

Received Level	Source Level	N	α
SEL	211 dB re 1 μPa^{2}s-m	13	0.0005
Peak-to-peak SPL	243 dB re 1 μPa-m	14	0.0007
Zero-peak SPL (see Note 1)	237 dB re 1 μPa-m	14	0.0007

Note 1: The zero-peak SPL was not reported in Gardline, (2010). It has been assumed that the zero-peak SPL is related to the peak-to-peak SPL through a 6 dB reduction i.e. the zero-peak SPL is half that of the peak-to-peak SPL.

The measurements made at Greater Gabbard have been used to calibrate the adopted propagation model for this assessment, and to establish appropriate source levels for use with the adopted model. To this end, the adopted noise model was used to estimate of the received SEL from Greater Gabbard. The model was initially run to predict the received SEL for Greater Gabbard using the third octave band spectrum and broadband SEL source level provided by Ainslie *et al*. (2012). The SEL spectrum of Ainslie *et al*. (2012) was scaled to a hammer energy

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of 1,072 kJ, which was the hammer energy used during the Greater Gabbard measurements (Gardline, 2010), and then propagated using the adopted propagation model. The predicted received SEL (as a function of range) was then compared to the received SEL predicted by the Greater Gabbard lumped parameter model. Initially, the prediction from the adopted propagation model under-estimated the received SEL sound levels compared to the Greater Gabbard lumped parameter model. The broadband SEL source level was therefore adjusted in order to provide a better prediction. The SEL was adjusted by minimising the mean squared error between the initial SEL estimate and that predicted by the lumped parameter model i.e. the model prediction was calibrated to the measurements made at Greater Gabbard. A comparison of the calibrated noise model SEL estimate and the measurements at Greater Gabbard are shown in Figure A-1.

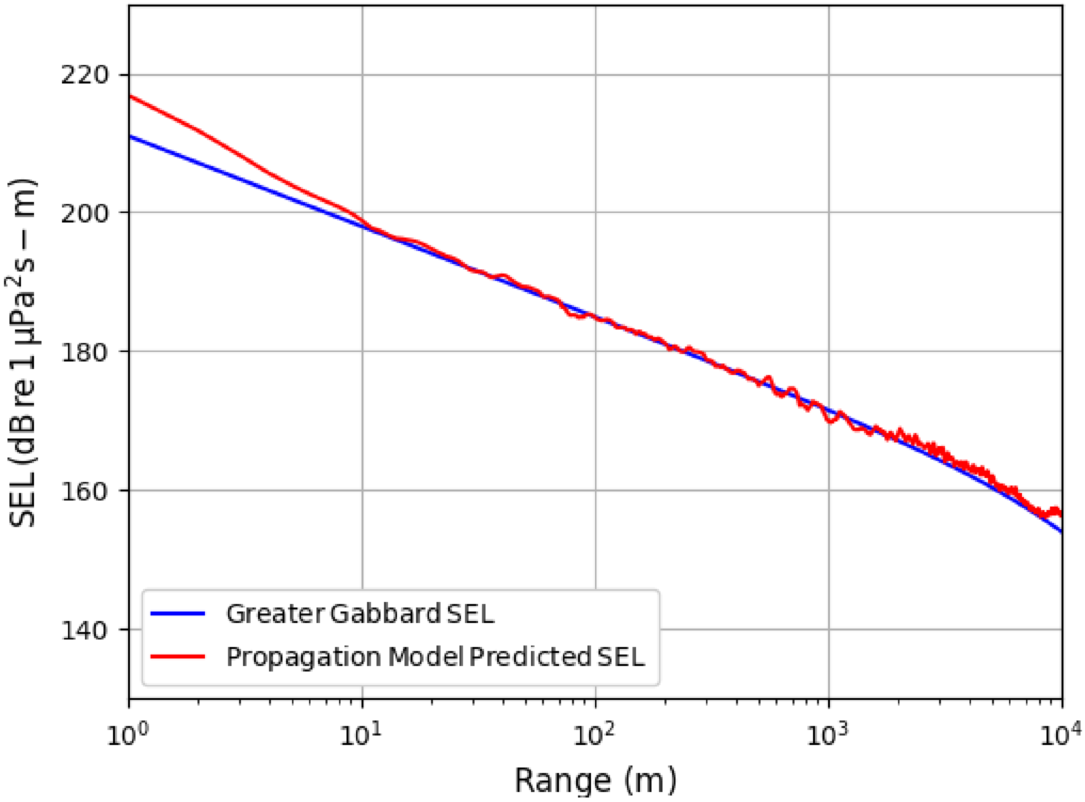

Figure A-1: Comparison of propagation model prediction and measurements made at Greater Gabbard.

The adopted propagation model over-estimates the received SEL for distances close to the sound source (i.e. for distances less than 10 m). However, it should be noted that the adopted propagation model treats the pile-driving source as a monopole. The adopted propagation model assumes spherical spreading at close distances to the pile-driving location. Such spherical spreading is not realistic of the actual acoustic field that would be expected at close distances to the pile (due to the pile being a highly complex sound source that cannot be represented as a monopole source).

For distances beyond 10 m, it is evident that the predicted SEL from the adopted propagation model provides a reasonable match to the measurements made at Greater Gabbard (although it is noted that the propagation model may over-estimate the sound levels for large distances beyond several kilometres). It is noted that the predicted SEL from the propagation model exhibits more fluctuations compared to that shown for the measurements at Greater Gabbard. This is due to the fact that the measurements at Greater Gabbard were only made at a few discrete measurement distances and a best-fit curve was fitted to the measurements. On the other hand, the propagation model calculates the SEL at finely spaced distances of 1 m and therefore fluctuation of SEL with range is more apparent.

The previously discussed calibration yielded an SEL source level of 216.9 dB re 1 μPa^{2}s-m for the hammer energy of 1,072 kJ (i.e. the hammer energy that was used during the measurements at Greater Gabbard). This SEL source level has been scaled to different hammer energies by assuming a linear scaling of SEL with hammer energy (see e.g. Robinson *et al*. 2007 and 2009). Furthermore, the zero-to-peak SPL source level has been estimated by adding an offset to the SEL source level. An offset of 26 dB has been used here, which is the difference between the SEL and zero-to-peak SPL source levels for the Greater Gabbard lumped parameter model. The SEL and zero-to-peak source levels that have been used in the adopted propagation model are shown in Table A-2 for a number of different hammer energies that have been used throughout the modelling.

Table A-2: Broadband SEL and zero-to-peak SPL source levels used in the modelling for pile-driving with different hammer energies.

Hammer Energy (kJ)	SEL Source Level (dB re 1 μPa^{2}s-m)	Zero-to-peak SPL Source Level (dB re 1 μPa-m)
900	216.1	242.1
1200	217.3	243.3
1800	219.1	245.1
1900	219.3	245.3
2300	220.2	246.2
2400	220.4	246.3
2700	220.9	246.9
3000	221.3	247.3
4000	222.6	248.6
5500	224.0	249.9

APPENDIX B: MODELLING MAPS FOR CREYKE BECK A

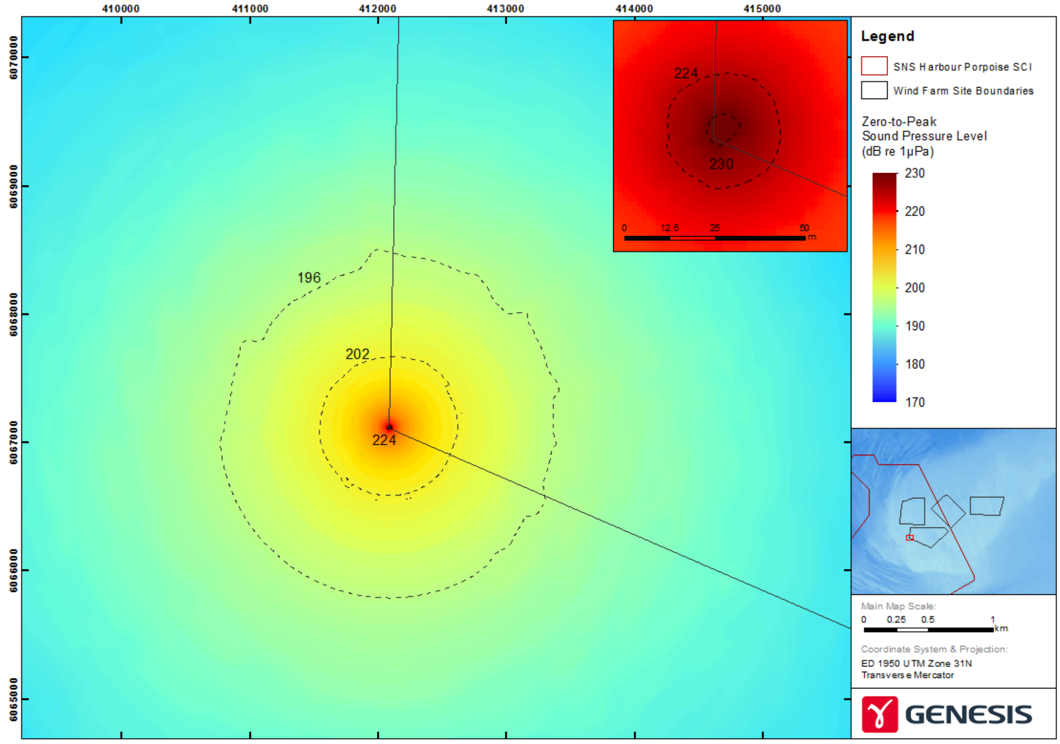

Figure B-1: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Creyke Beck A model location 1 with hammer energy of 1,900 kJ.

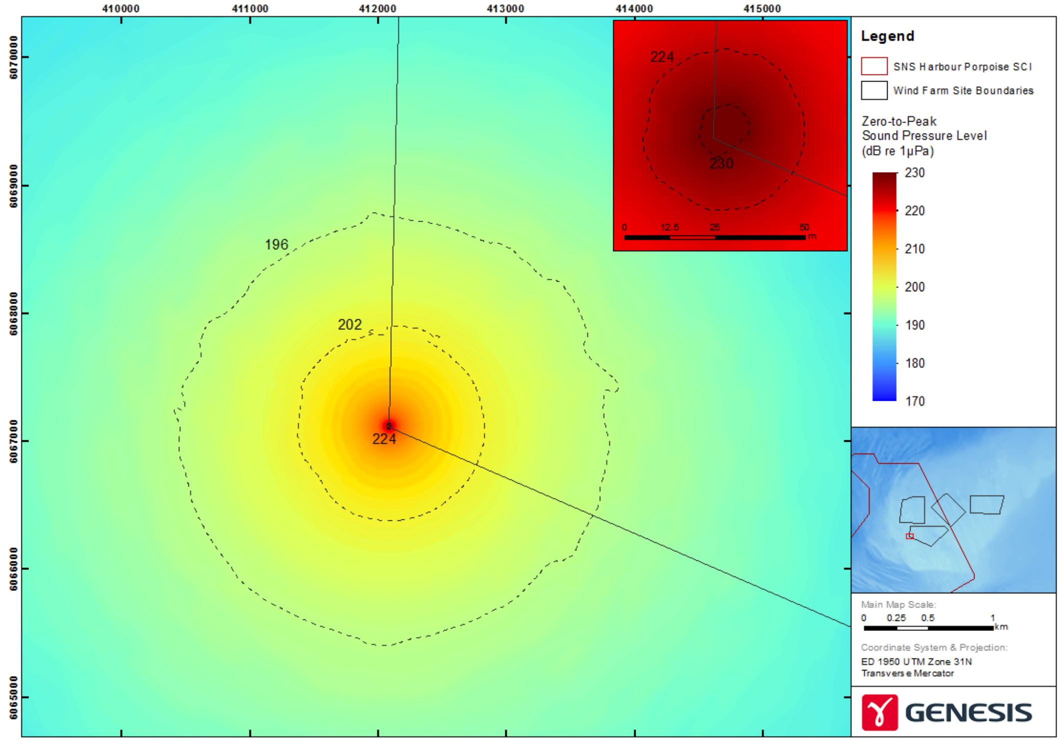

Figure B-2: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Creyke Beck A model location 1 with hammer energy of 3,000 kJ.

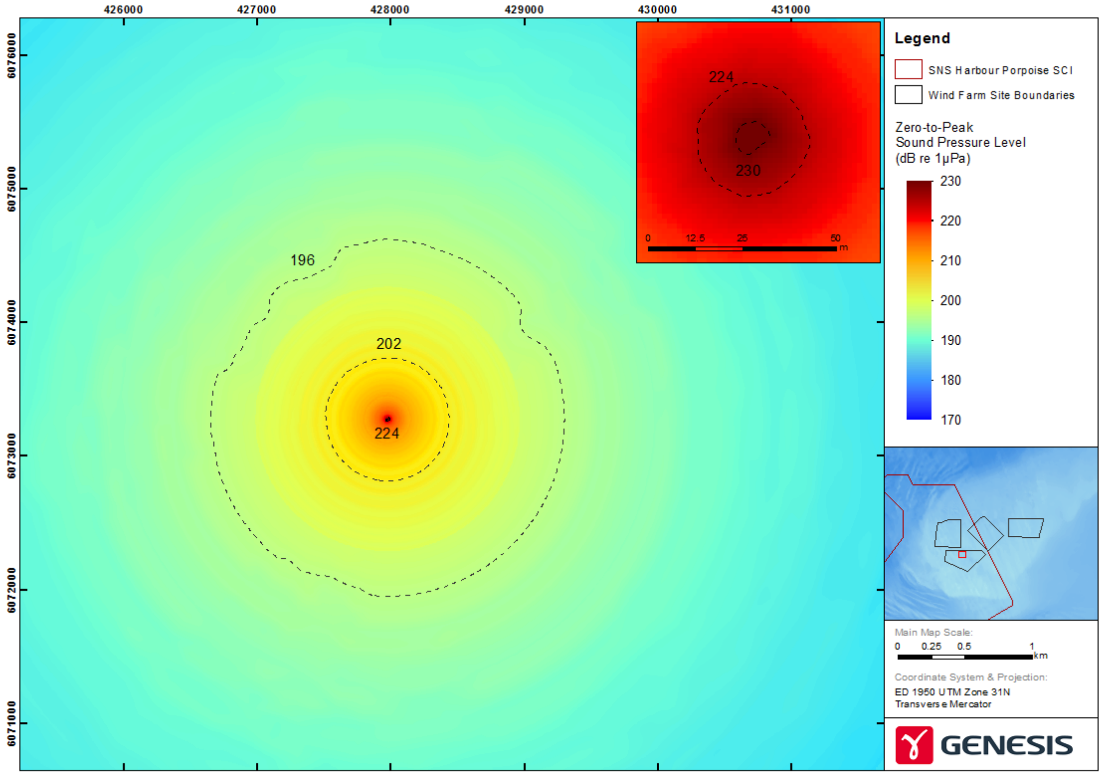

Figure B-3: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Creyke Beck A model location 2 with hammer energy of 1,900 kJ.

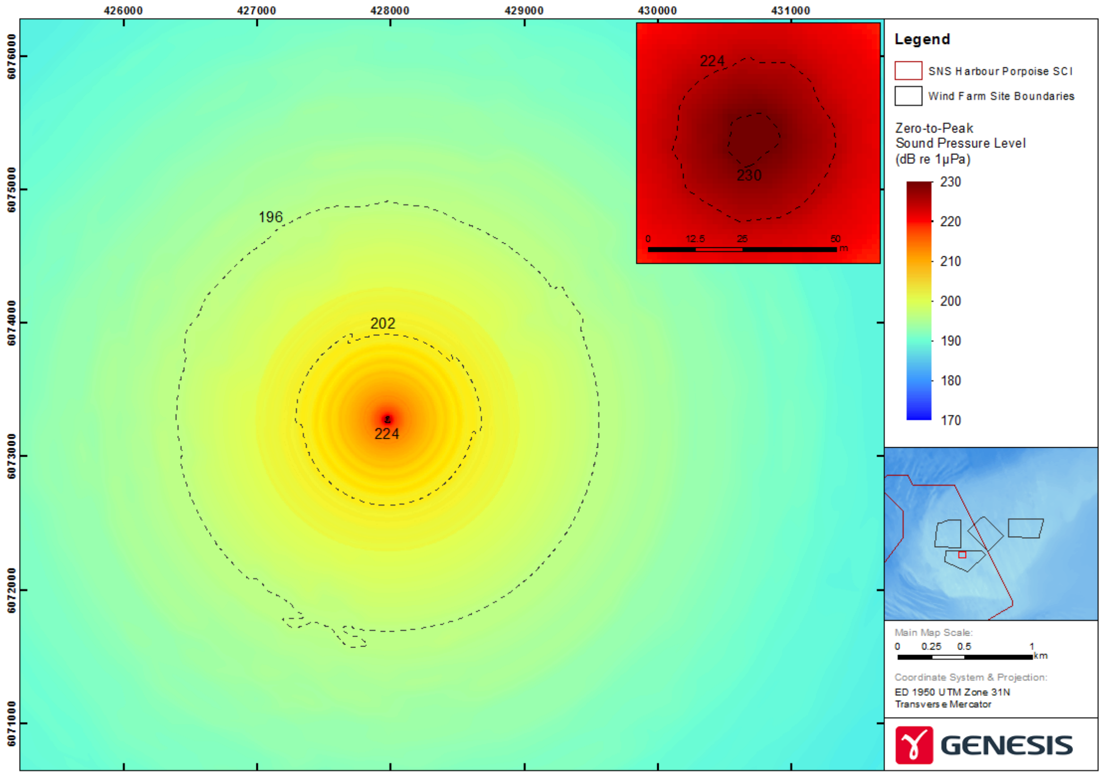

Figure B-4: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Creyke Beck A model location 2 with hammer energy of 3,000 kJ.

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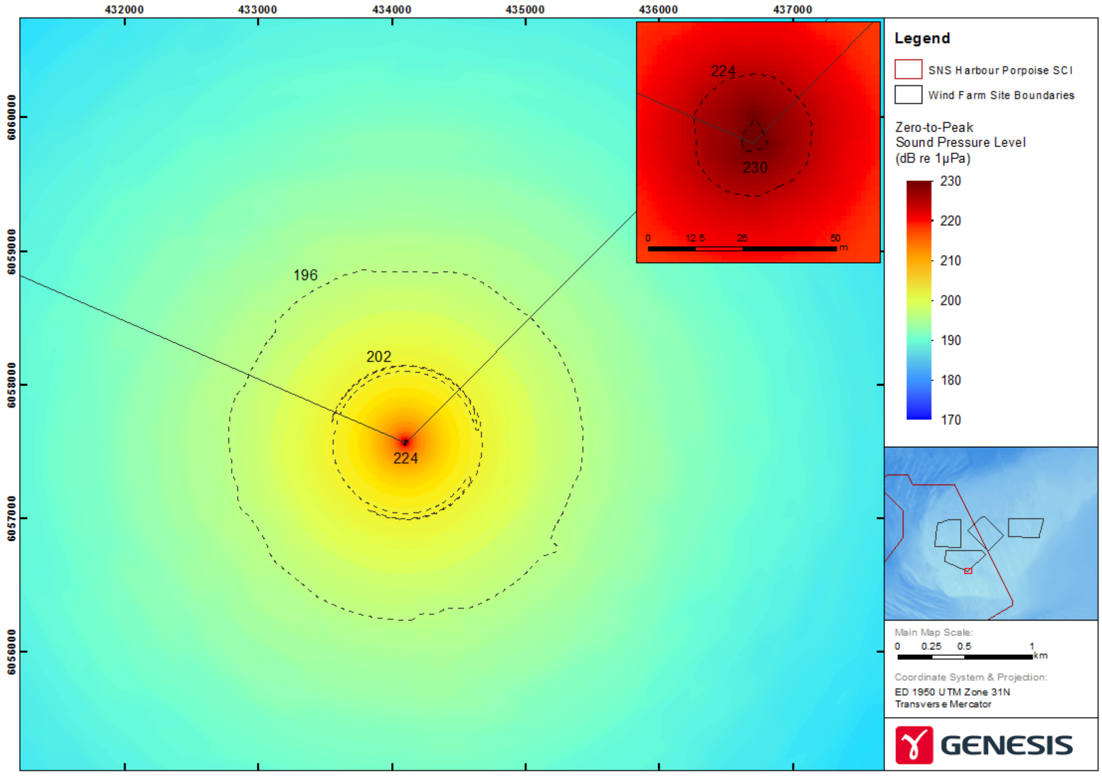

Figure B-5: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Creyke Beck A model location 3 with hammer energy of 1,900 kJ.

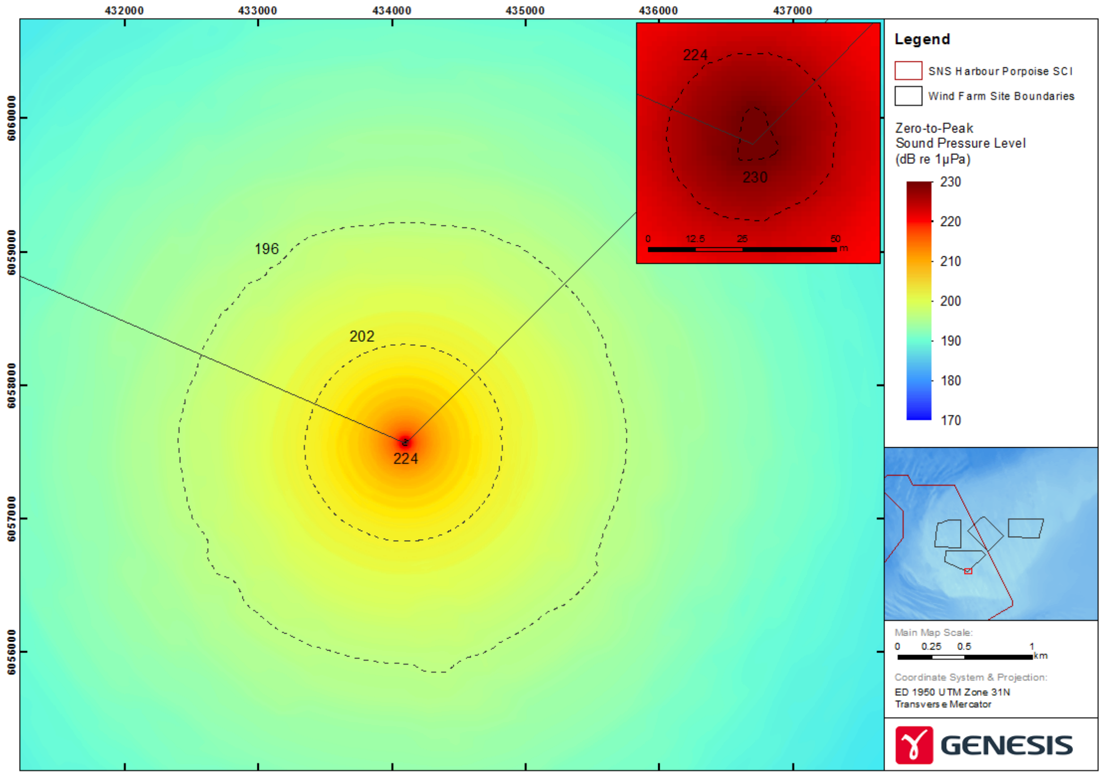

Figure B-6: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Creyke Beck A model location 3 with hammer energy of 3,000 kJ.

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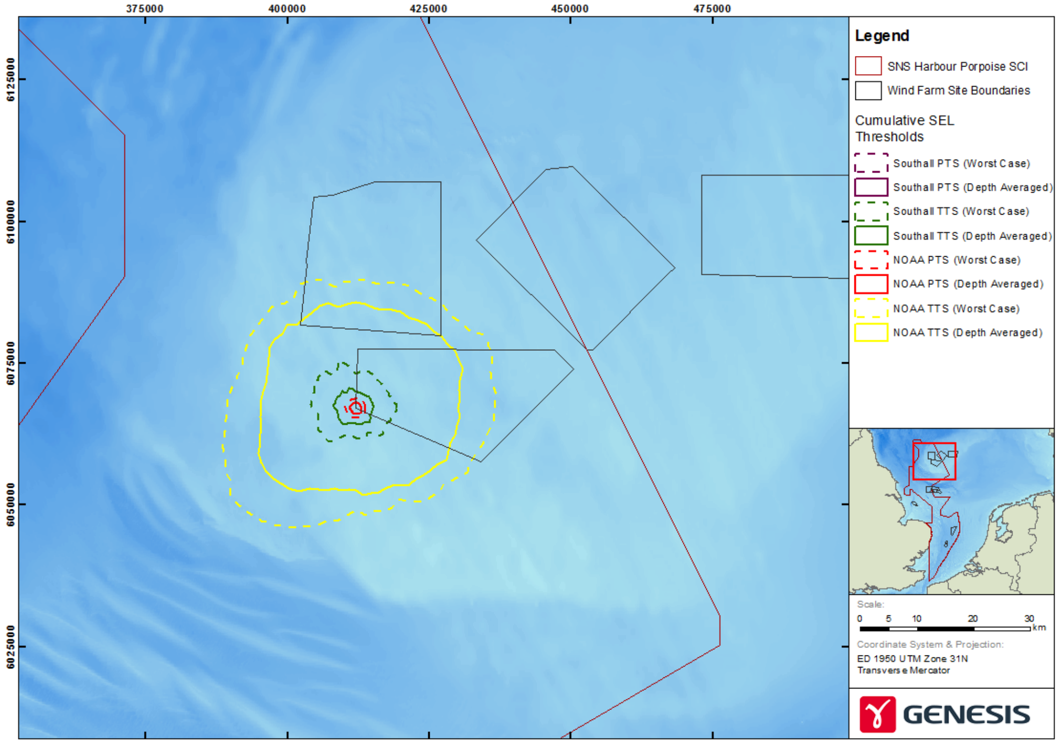

Figure B-7: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Creyke Beck A model location 1 with maximum hammer energy of 1,900 kJ.

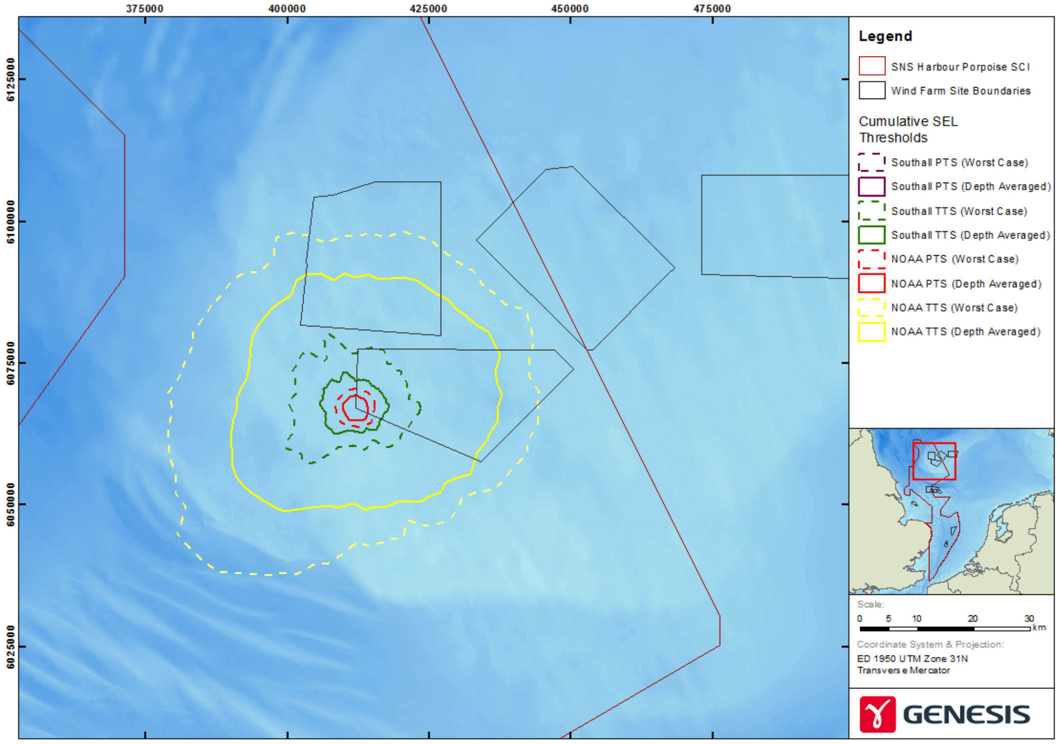

Figure B-8: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Creyke Beck A model location 1 with maximum hammer energy of 3,000 kJ.

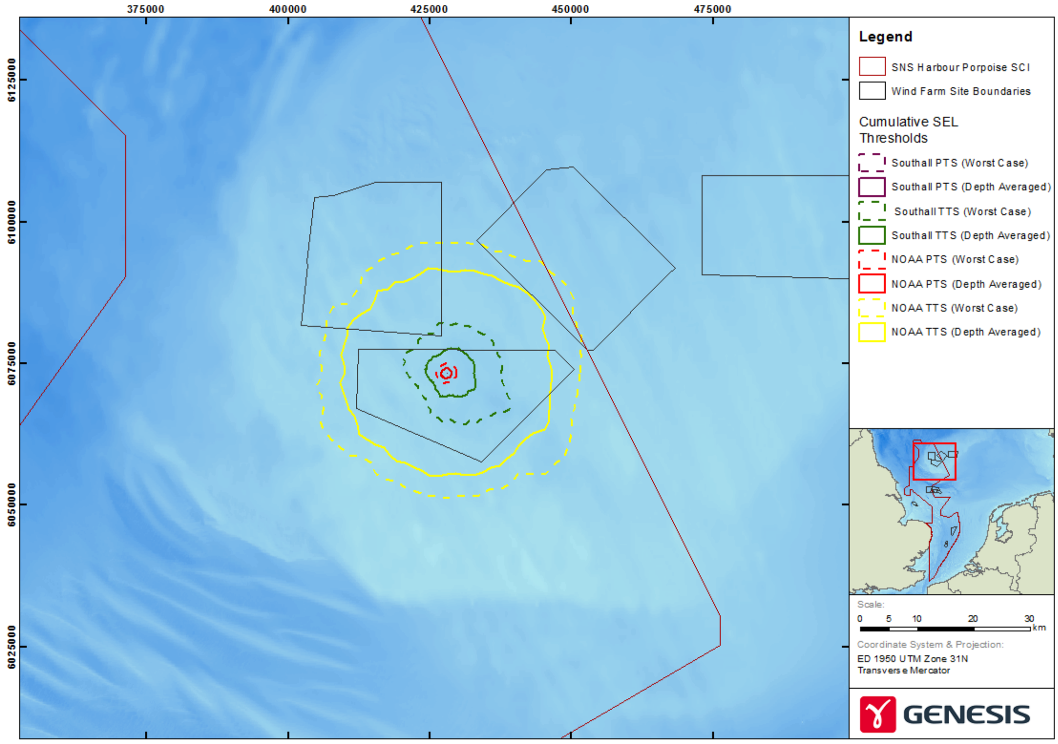

Figure B-9: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Creyke Beck A model location 2 with maximum hammer energy of 1,900 kJ.

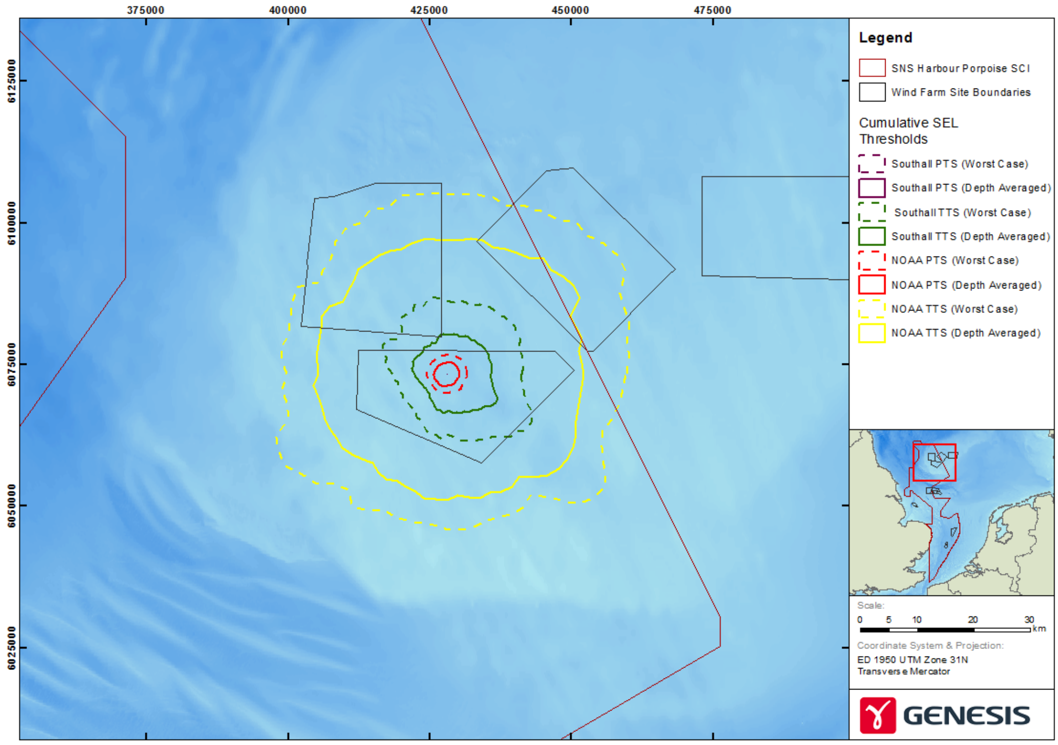

Figure B-10: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Creyke Beck A model location 2 with maximum hammer energy of 3,000 kJ.

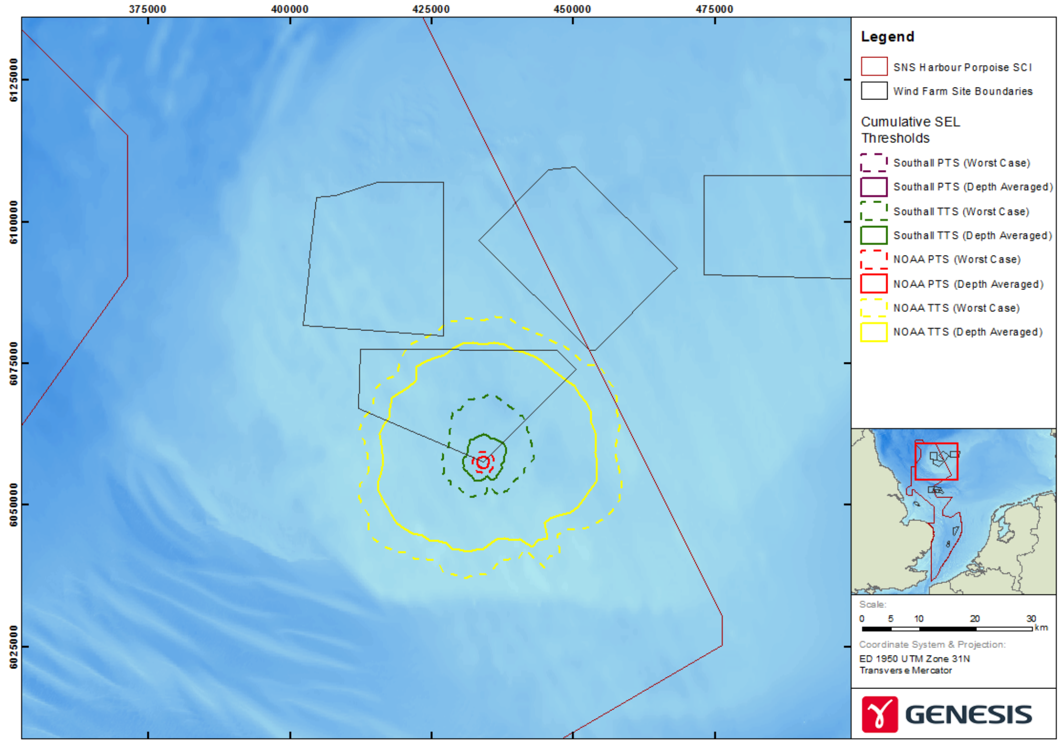

Figure B-11: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Creyke Beck A model location 3 with maximum hammer energy of 1,900 kJ.

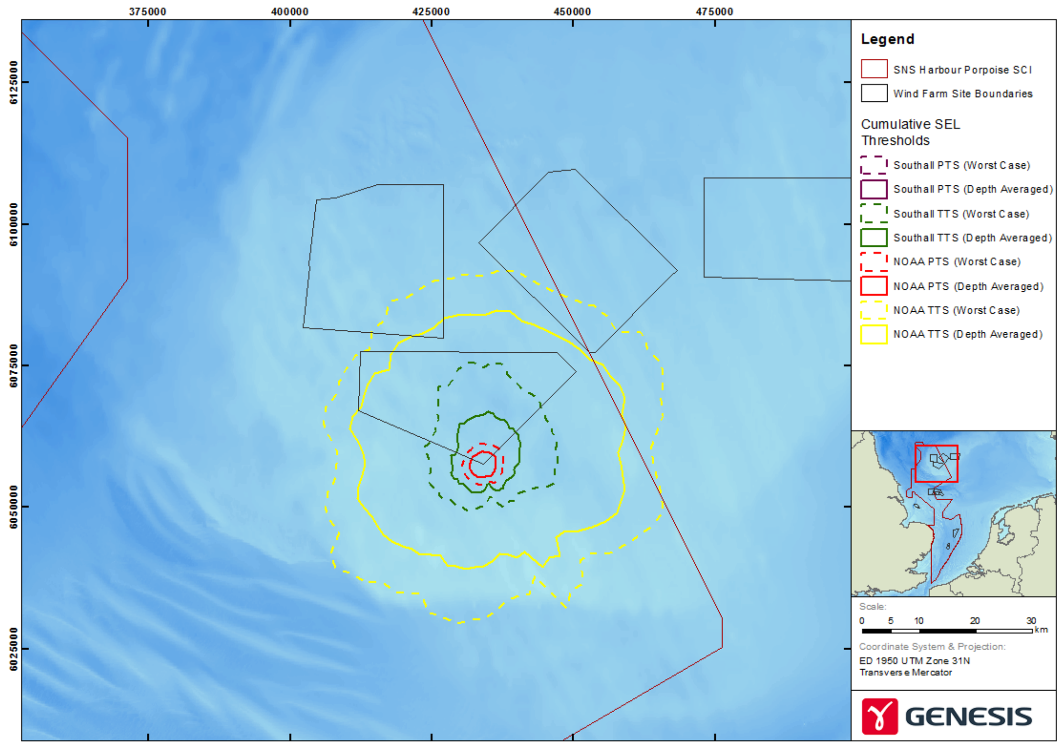

Figure B-12: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Creyke Beck A model location 3 with maximum hammer energy of 3,000 kJ.

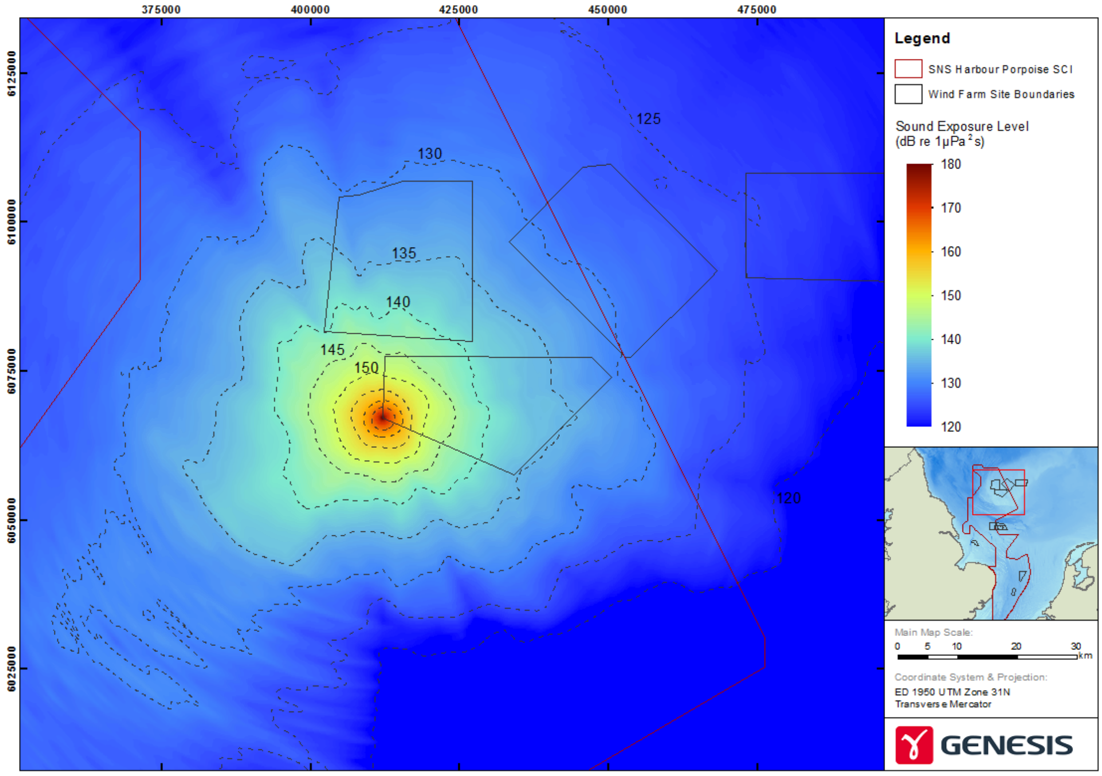

Figure B-13: Depth-averaged unweighted single-pulse SEL for pile-driving at Creyke Beck A model location 1 with hammer energy of 1,900 kJ.

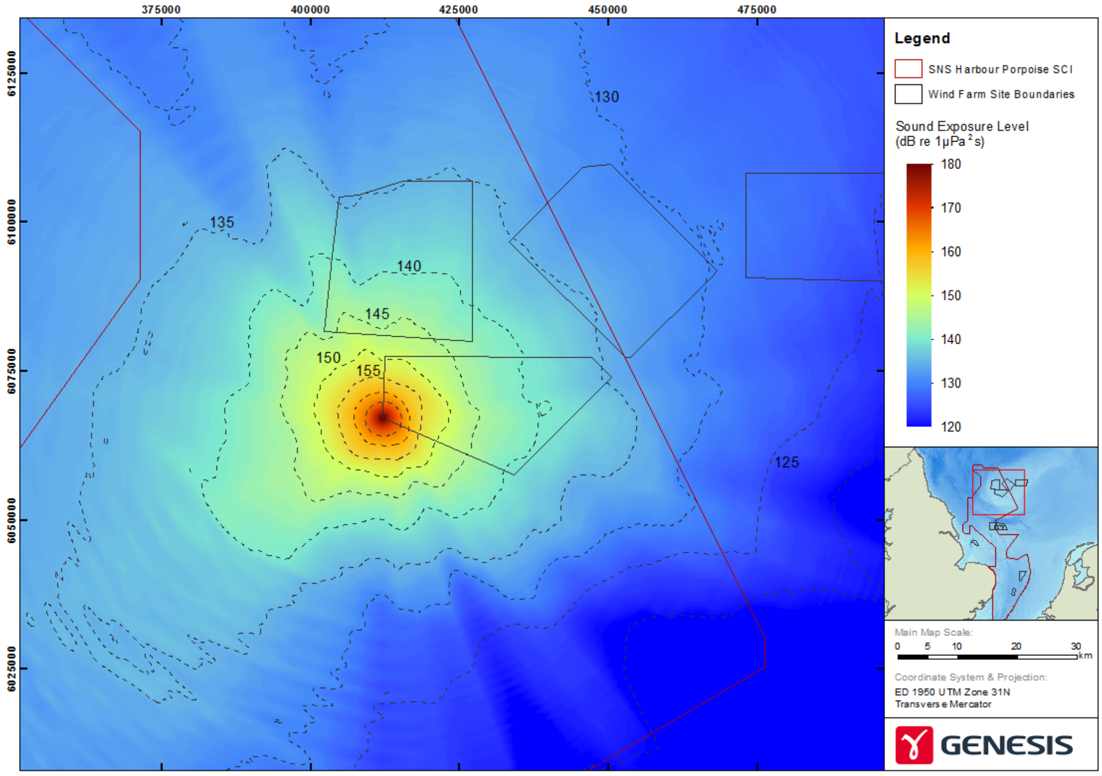

Figure B-14: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Creyke Beck A model location 1 with hammer energy of 1,900 kJ.

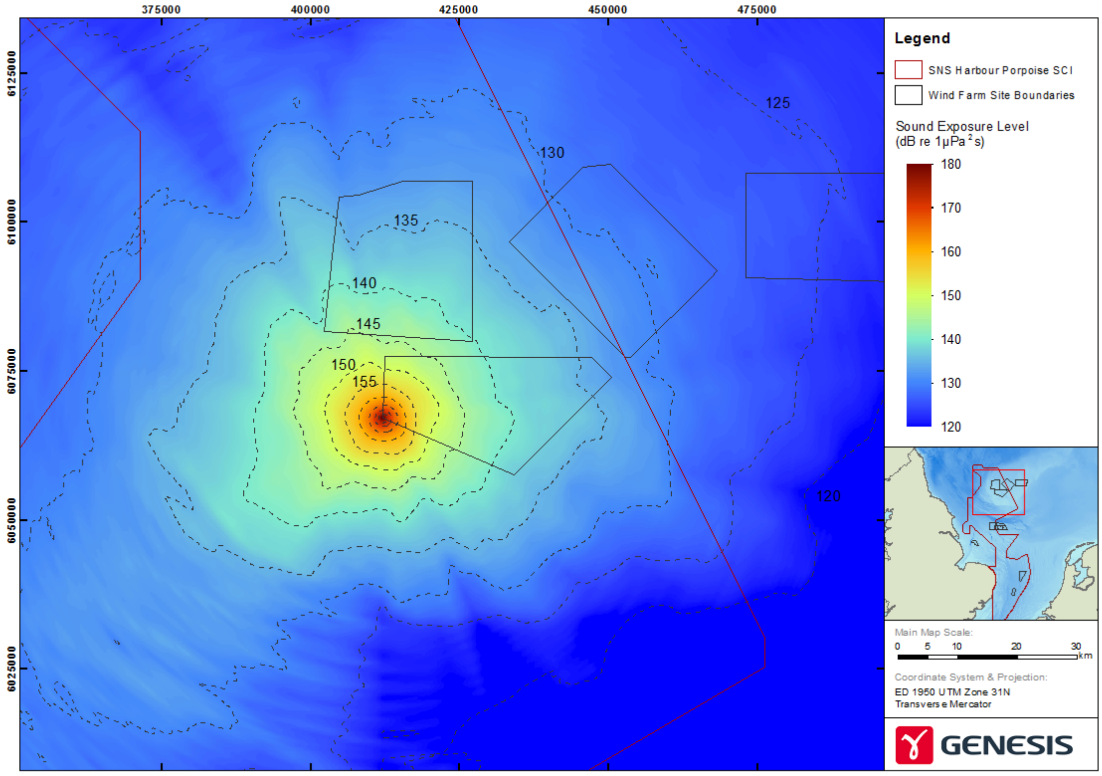

Figure B-15: Depth-averaged unweighted single-pulse SEL for pile-driving at Creyke Beck A model location 1 with hammer energy of 3,000 kJ.

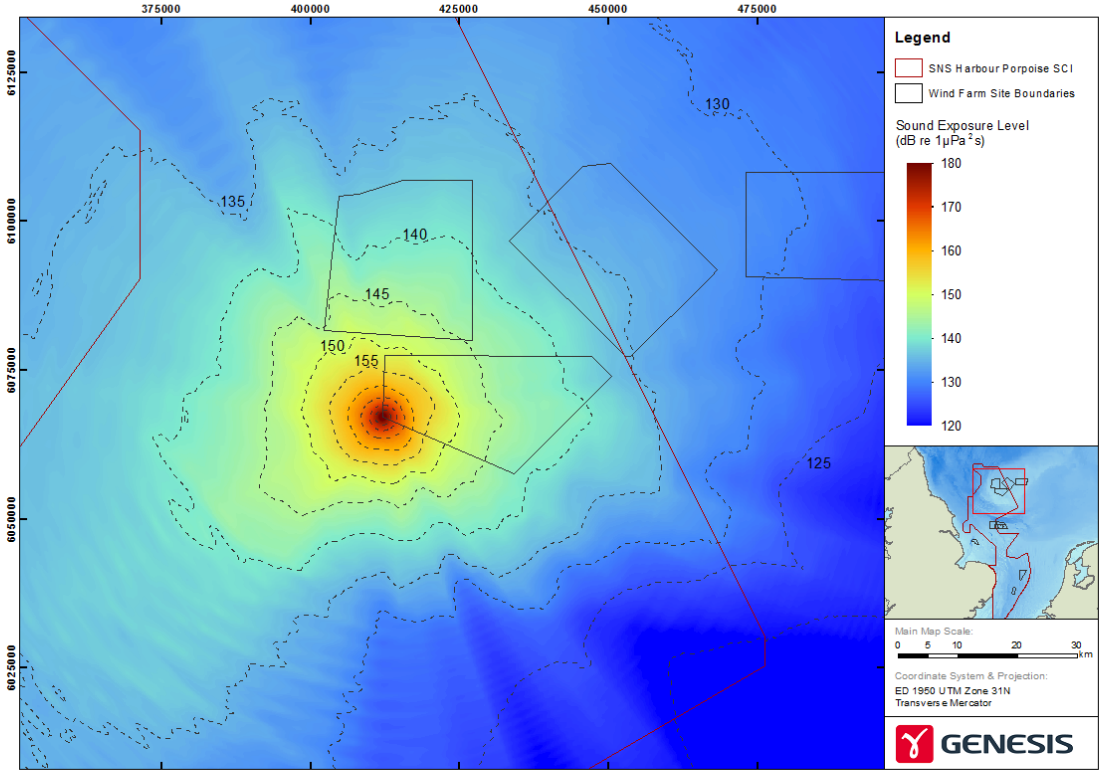

Figure B-16: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Creyke Beck A model location 1 with hammer energy of 3,000 kJ.

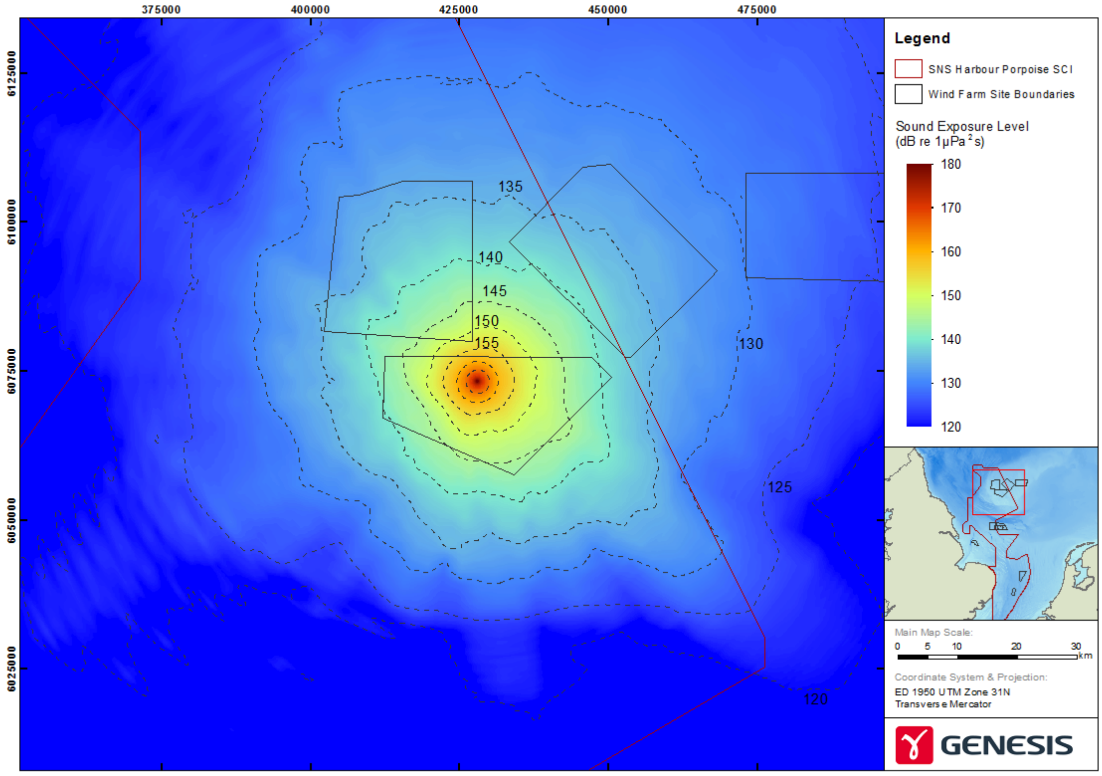

Figure B-17: Depth-averaged unweighted single-pulse SEL for pile-driving at Creyke Beck A model location 2 with hammer energy of 1,900 kJ.

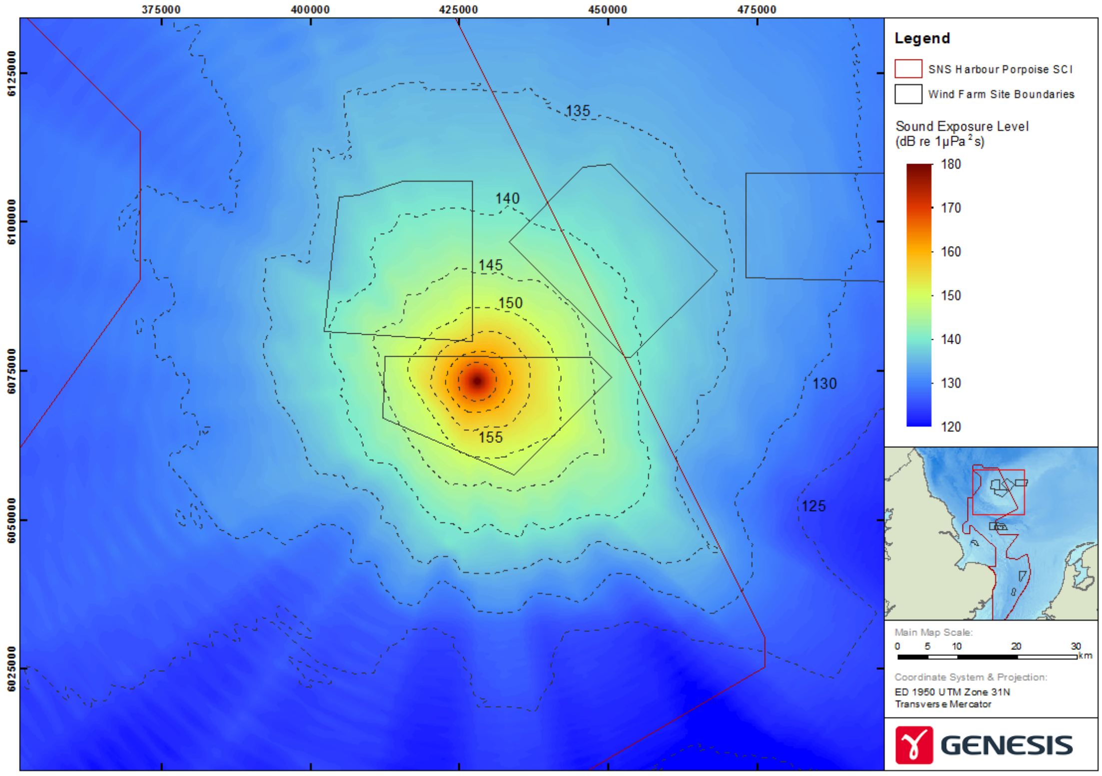

Figure B-18: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Creyke Beck A model location 2 with hammer energy of 1,900 kJ.

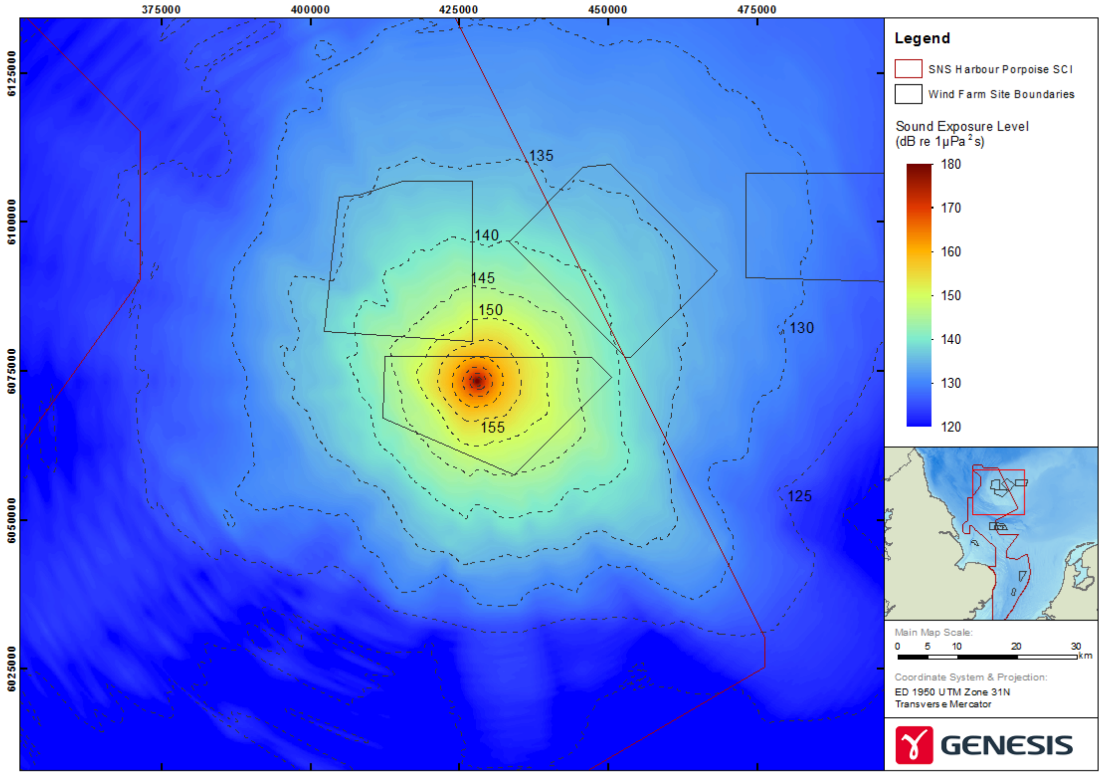

Figure B-19: Depth-averaged unweighted single-pulse SEL for pile-driving at Creyke Beck A model location 2 with hammer energy of 3,000 kJ.

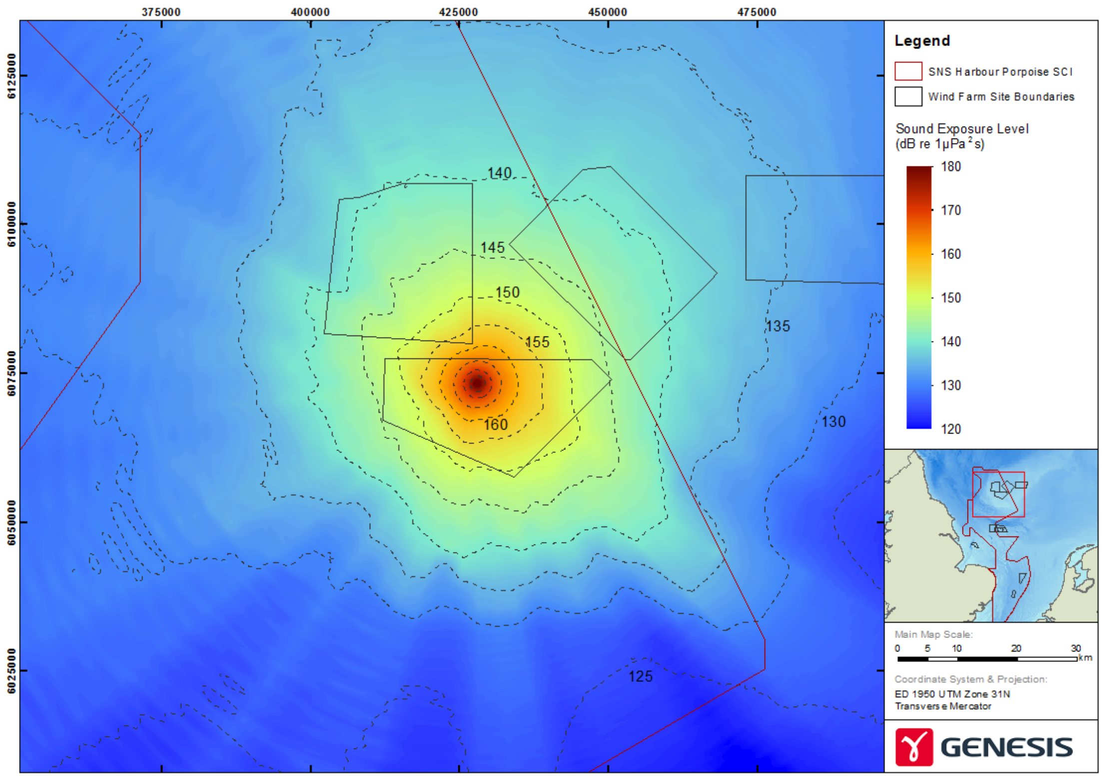

Figure B-20: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Creyke Beck A model location 2 with hammer energy of 3,000 kJ.

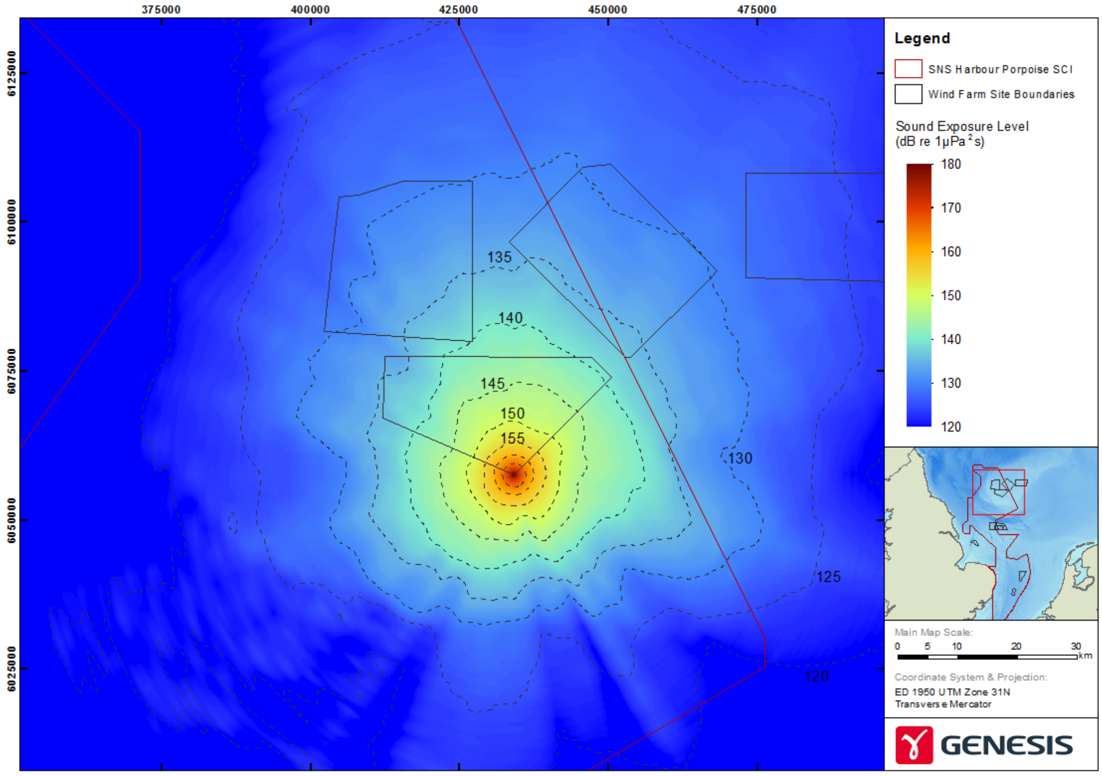

Figure B-21: Depth-averaged unweighted single-pulse SEL for pile-driving at Creyke Beck A model location 3 with hammer energy of 1,900 kJ.

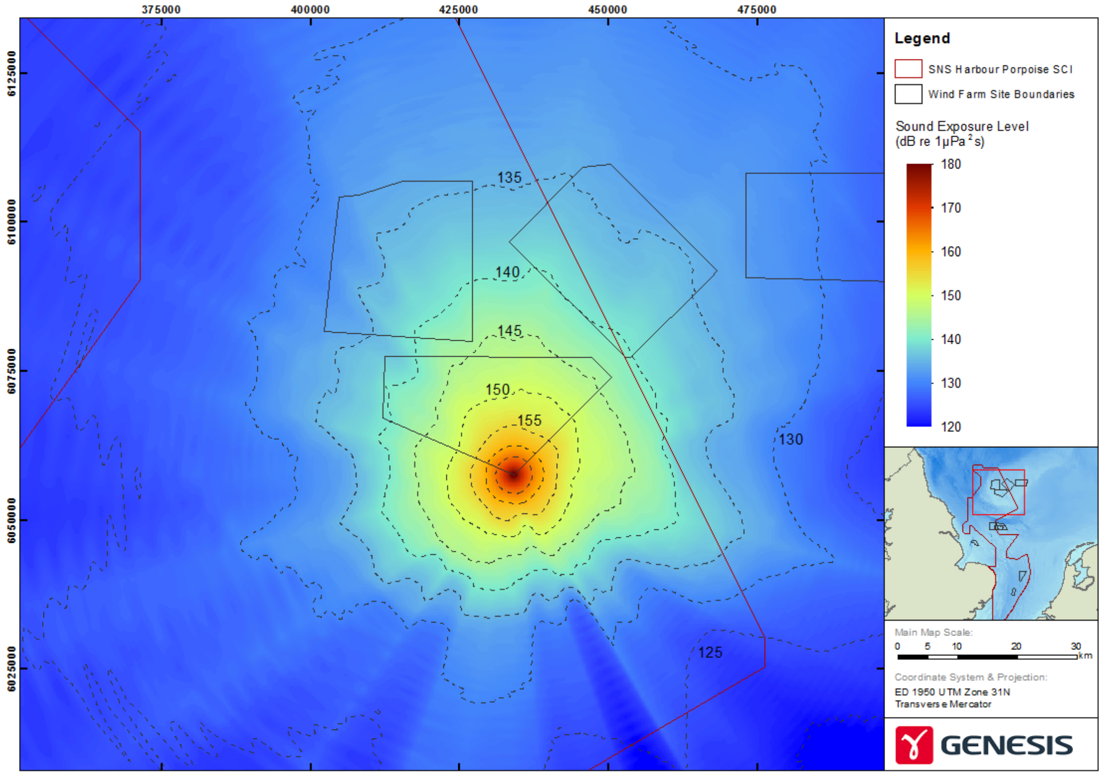

Figure B-22: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Creyke Beck A model location 3 with hammer energy of 1,900 kJ.

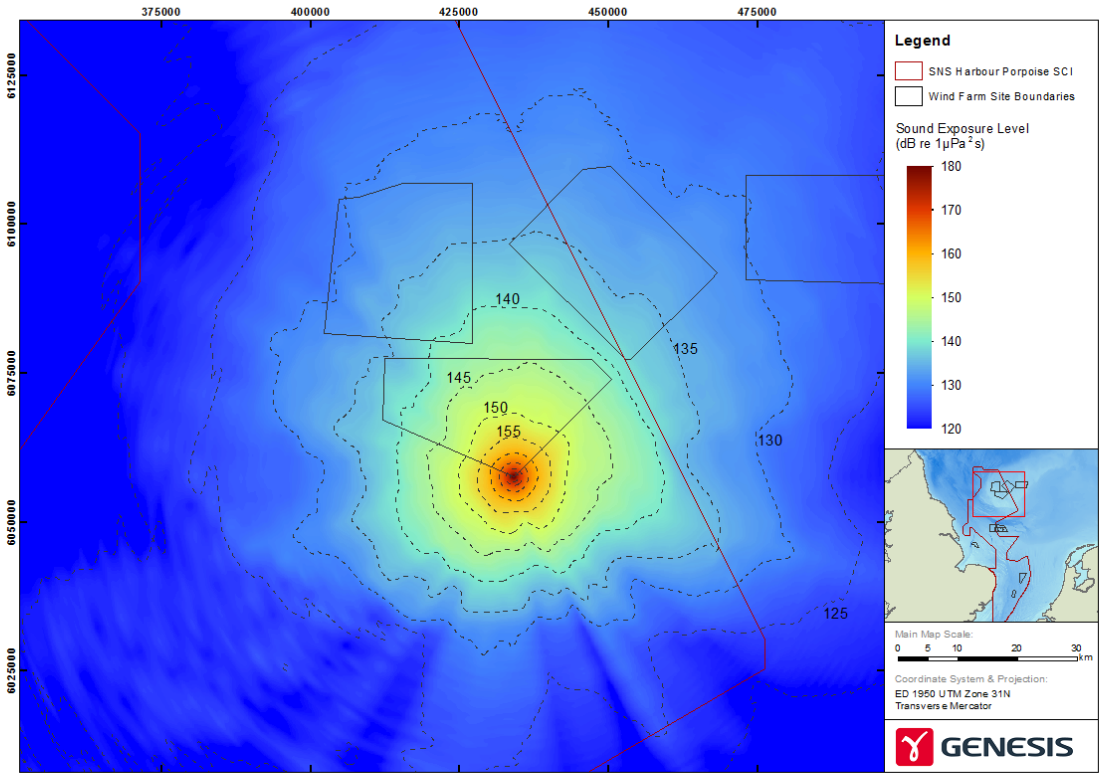

Figure B-23: Depth-averaged unweighted single-pulse SEL for pile-driving at Creyke Beck A model location 3 with hammer energy of 3,000 kJ.

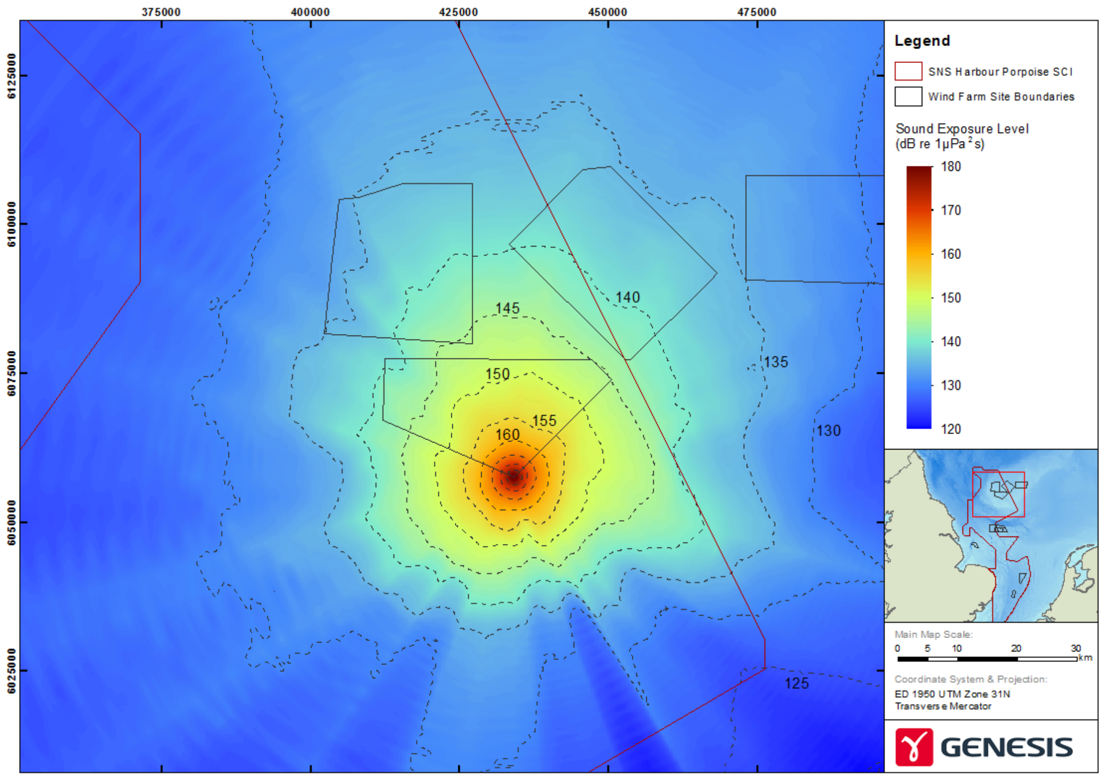

Figure B-24: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Creyke Beck A model location 3 with hammer energy of 3,000 kJ.

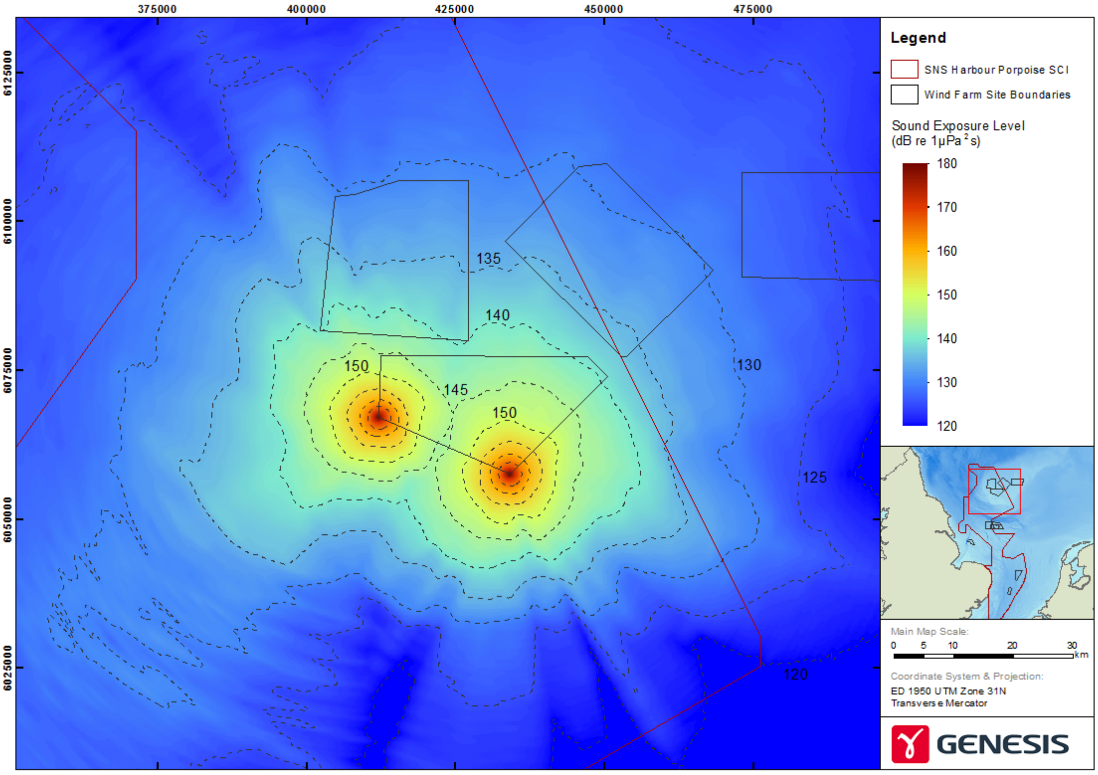

Figure B-25: Depth-averaged unweighted single-pulse SEL for concurrent pile-driving at Creyke Beck A model locations 1 and 3 with hammer energy of 1,900 kJ.

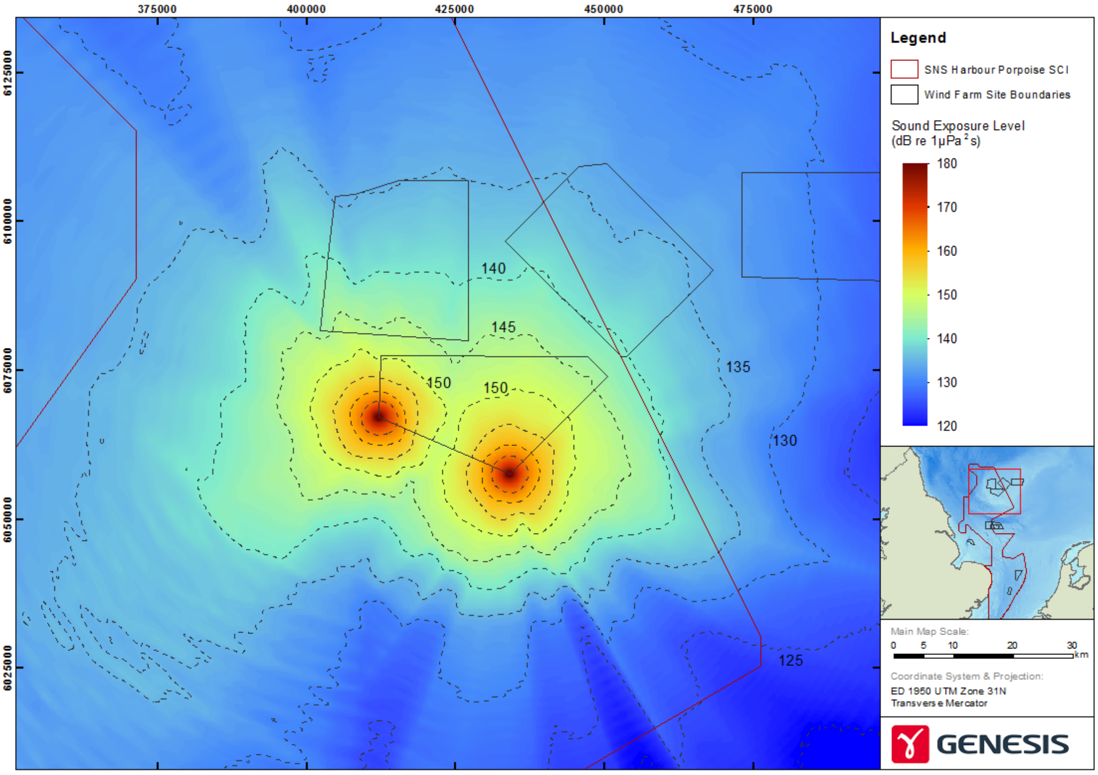

Figure B-26: Maximum-over-depth unweighted single-pulse SEL for concurrent pile-driving at Creyke Beck A model locations 1 and 3 with hammer energy of 1,900 kJ.

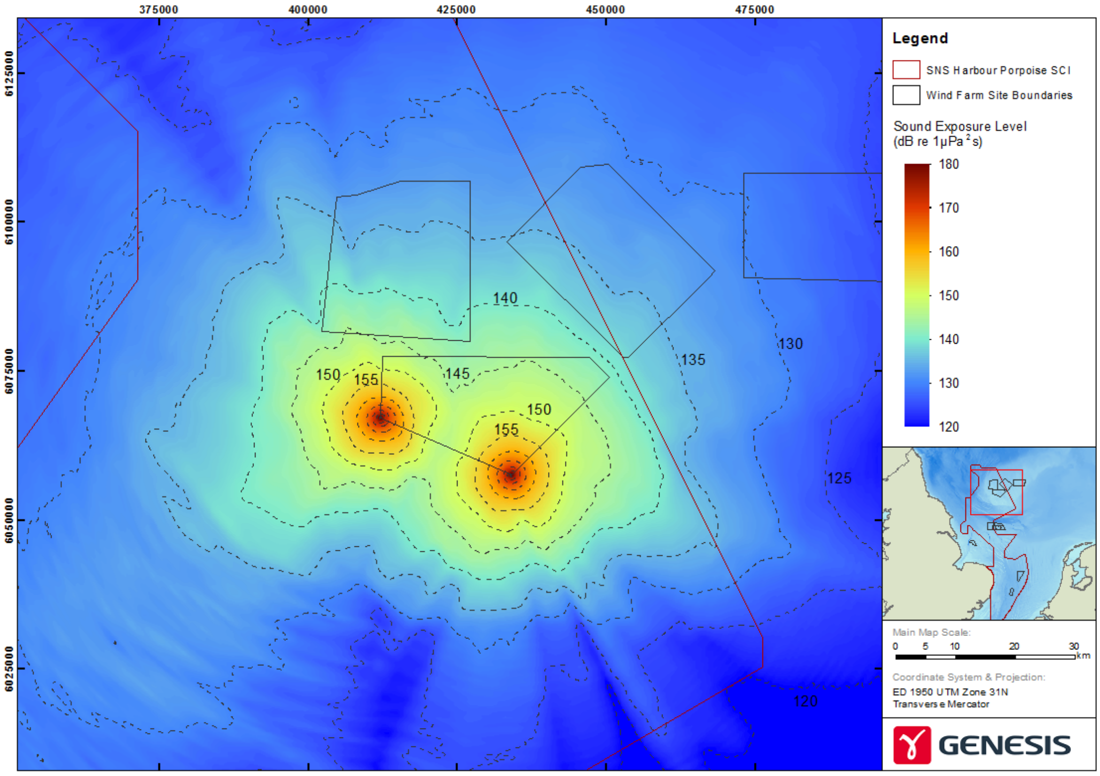

Figure B-27: Depth-averaged unweighted single-pulse SEL for concurrent pile-driving at Creyke Beck A model locations 1 and 3 with hammer energy of 3,000 kJ.

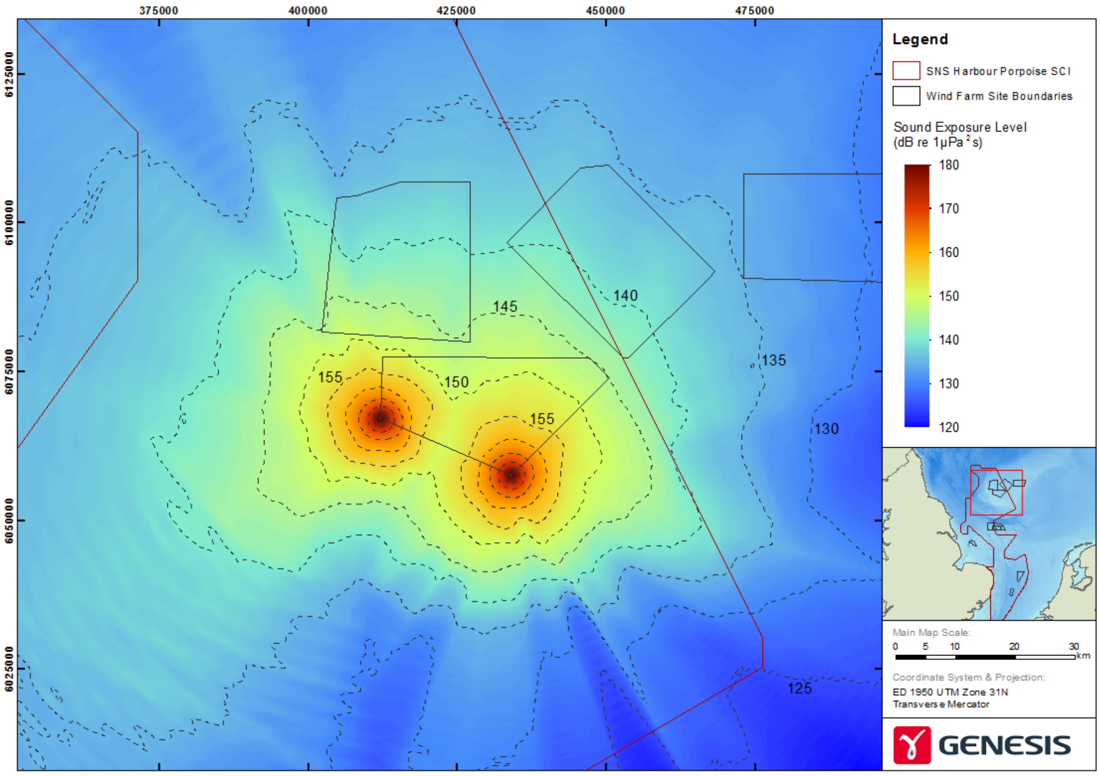

Figure B-28: Maximum-over-depth unweighted single-pulse SEL for concurrent pile-driving at Creyke Beck A model locations 1 and 3 with hammer energy of 3,000 kJ.

APPENDIX C: MODELLING MAPS FOR CREYKE BECK B

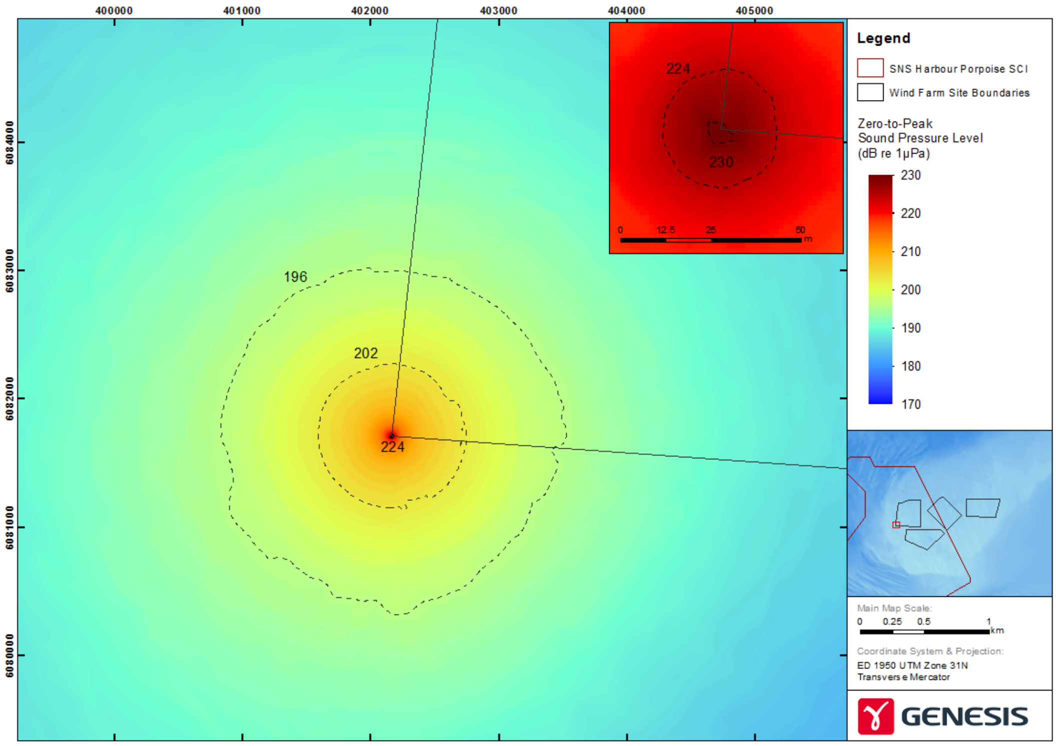

Figure C-1: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Creyke Beck B model location 1 with hammer energy of 1,900 kJ.

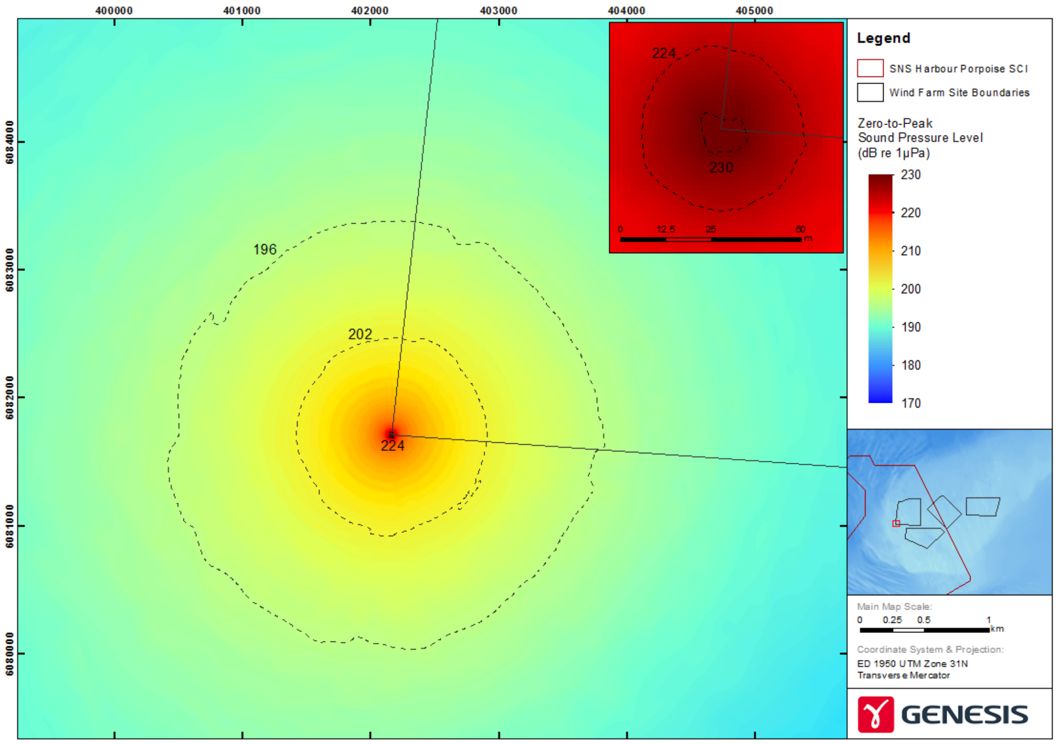

Figure C-2: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Creyke Beck B model location 1 with hammer energy of 3,000 kJ.

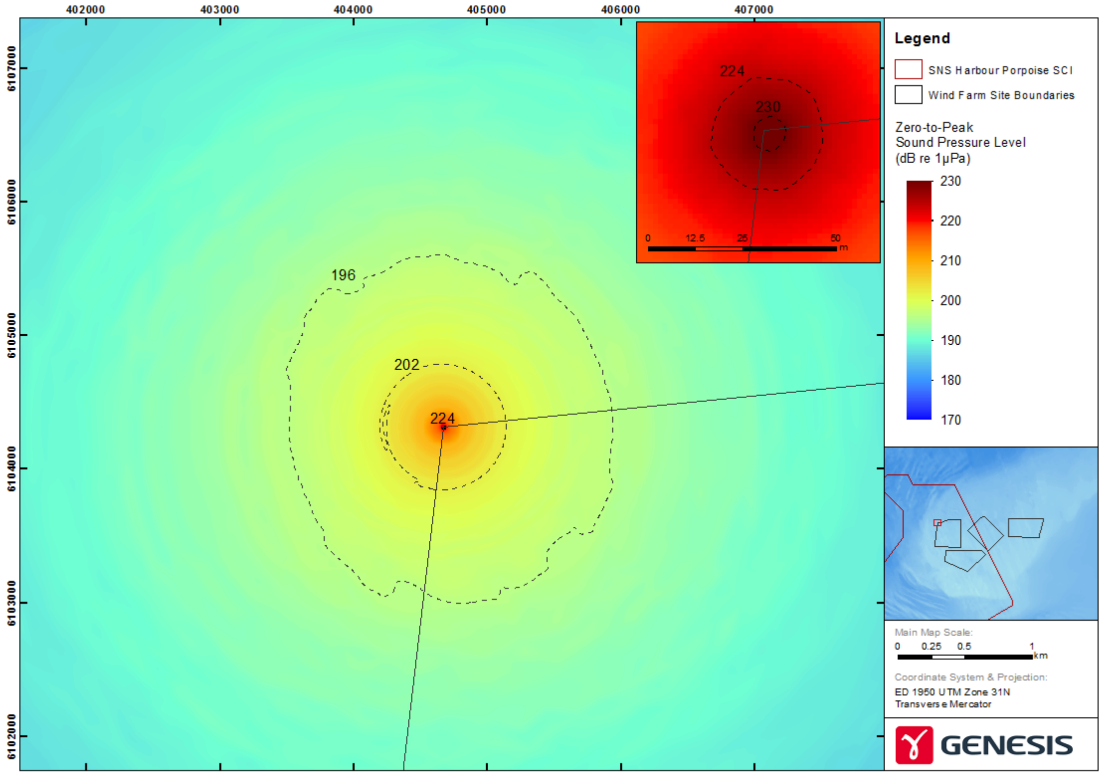

Figure C-3: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Creyke Beck B model location 2 with hammer energy of 1,900 kJ.

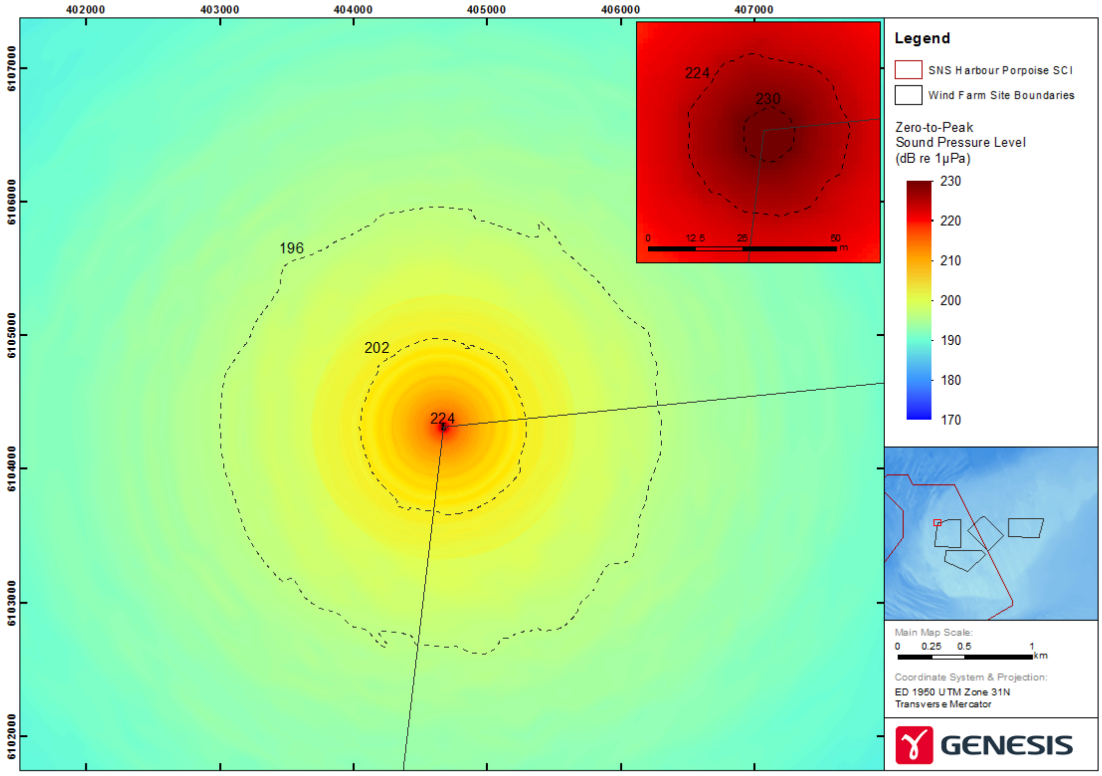

Figure C-4: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Creyke Beck B model location 2 with hammer energy of 3,000 kJ.

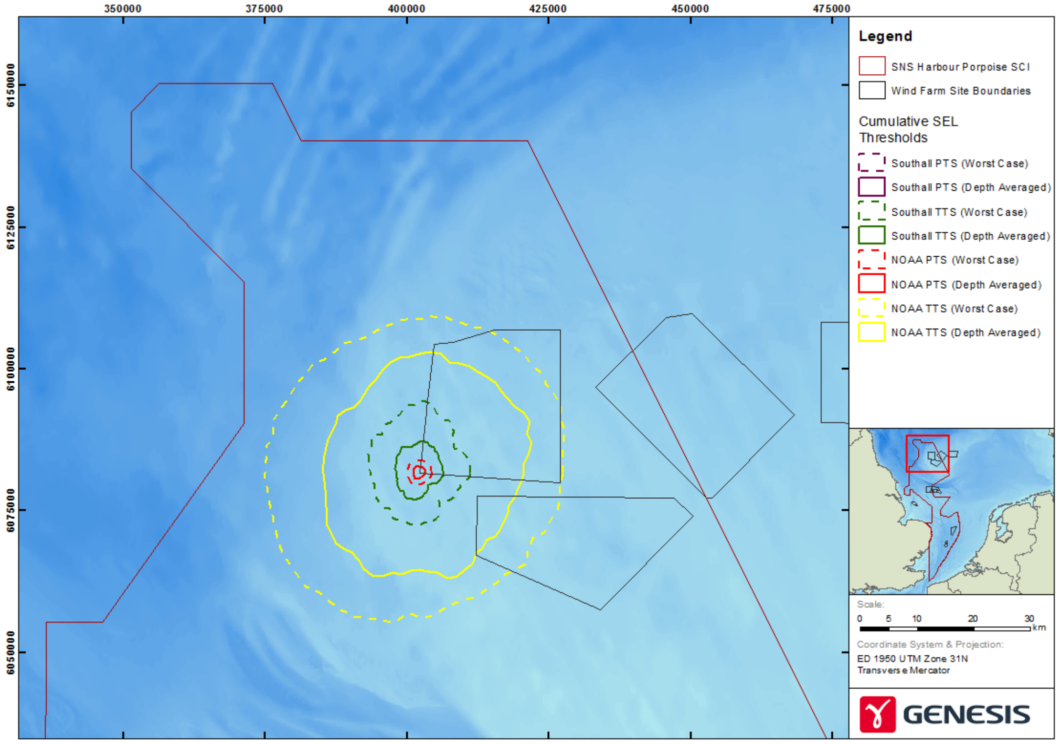

Figure C-5: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Creyke Beck B model location 1 with maximum hammer energy of 1,900 kJ.

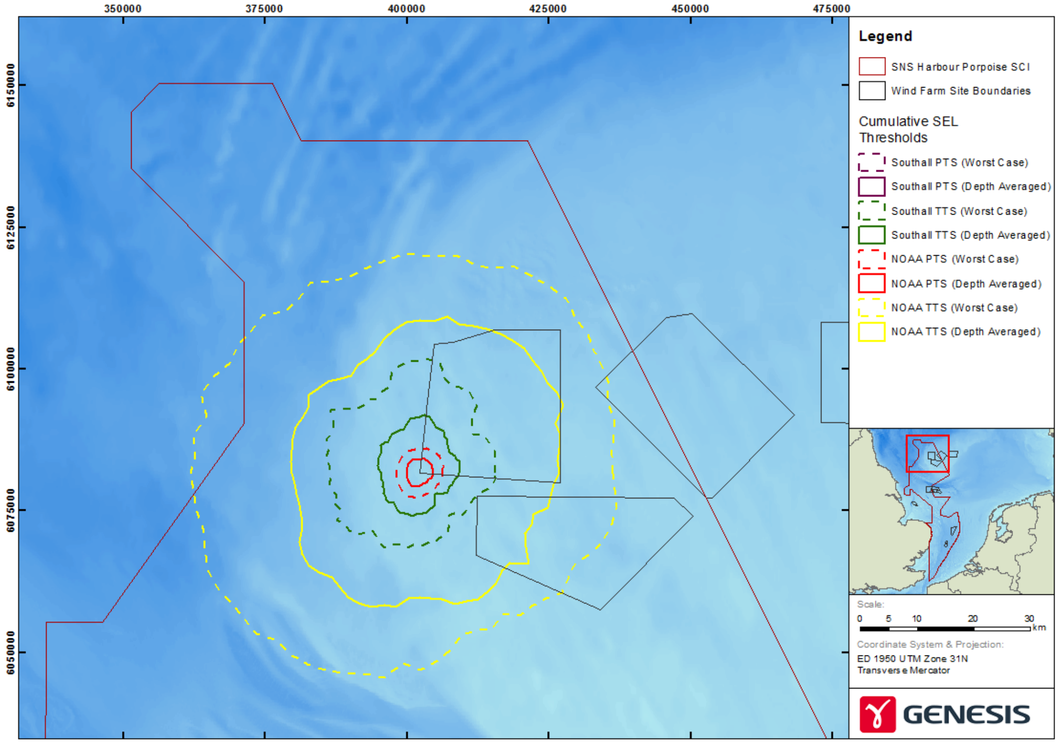

Figure C-6: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Creyke Beck B model location 1 with maximum hammer energy of 3,000 kJ.

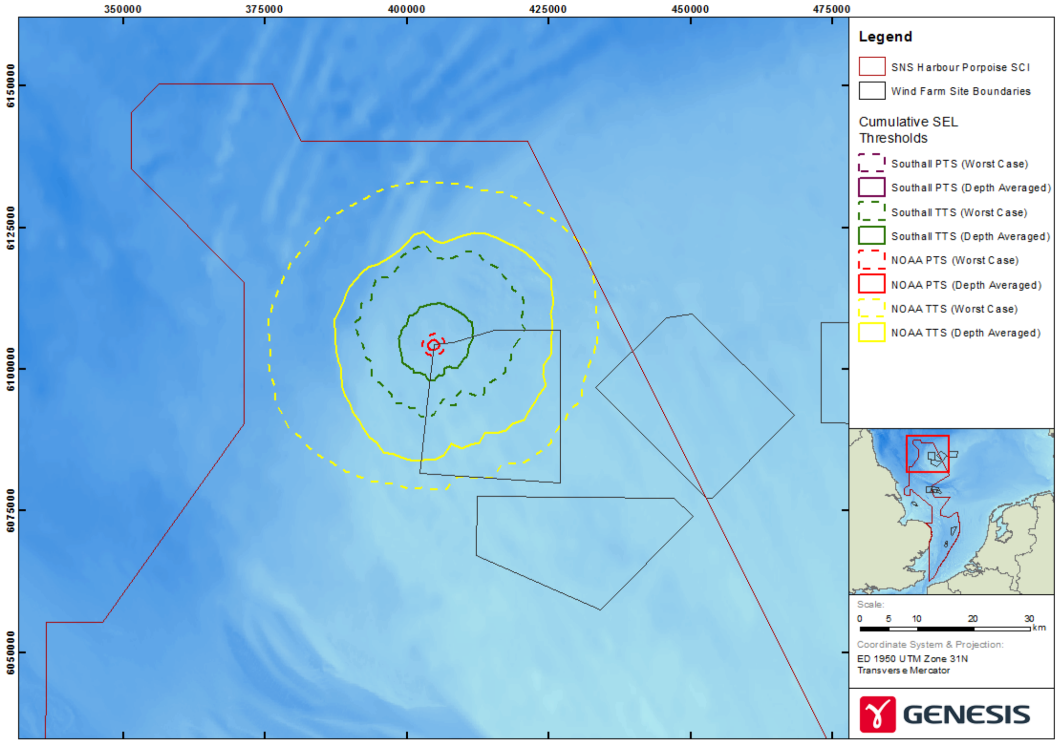

Figure C-7: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Creyke Beck B model location 2 with maximum hammer energy of 1,900 kJ.

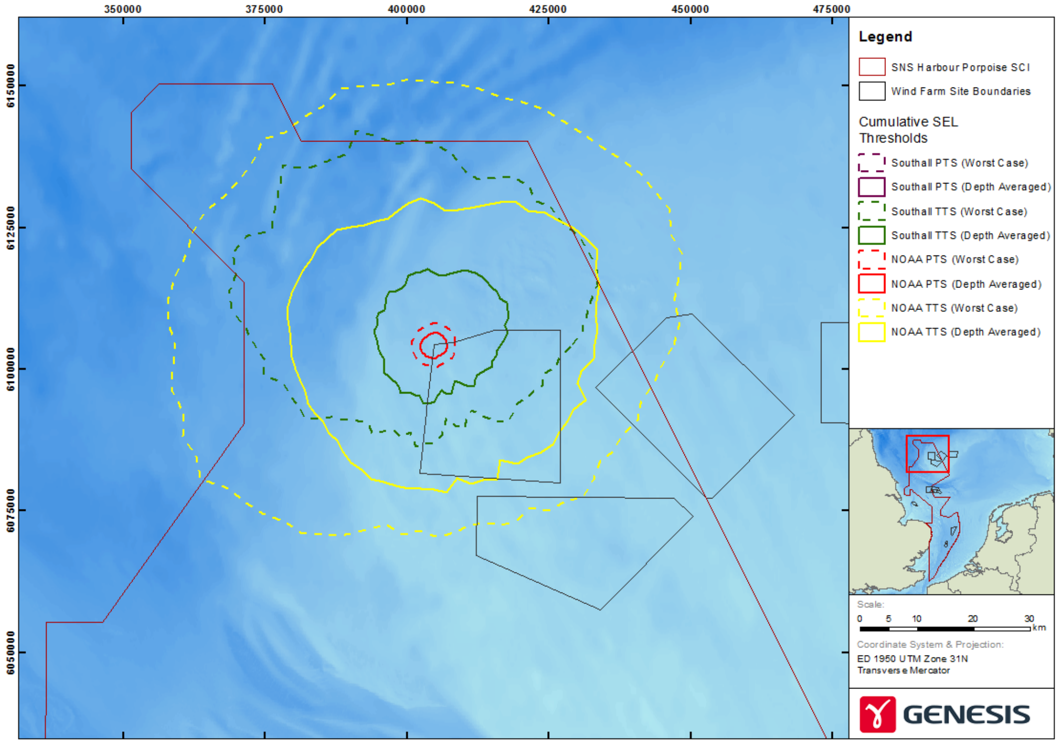

Figure C-8: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Creyke Beck B model location 2 with maximum hammer energy of 3,000 kJ.

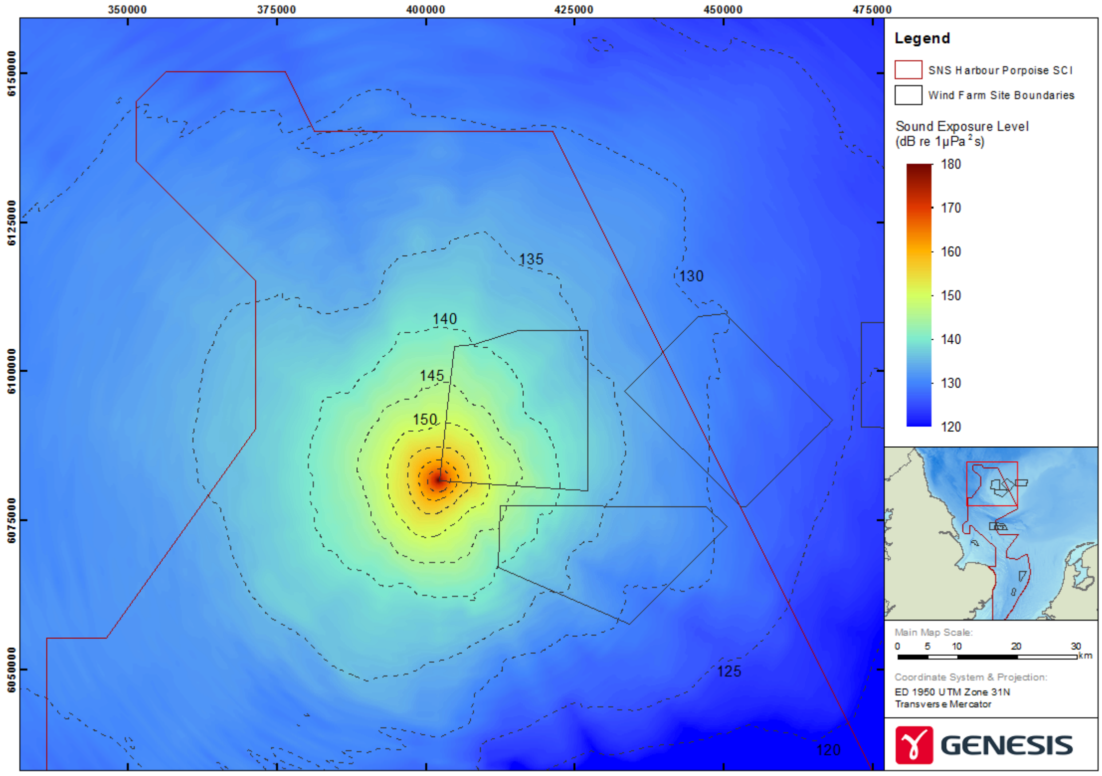

Figure C-9: Depth-averaged unweighted single-pulse SEL for pile-driving at Creyke Beck B model location 1 with hammer energy of 1,900 kJ.

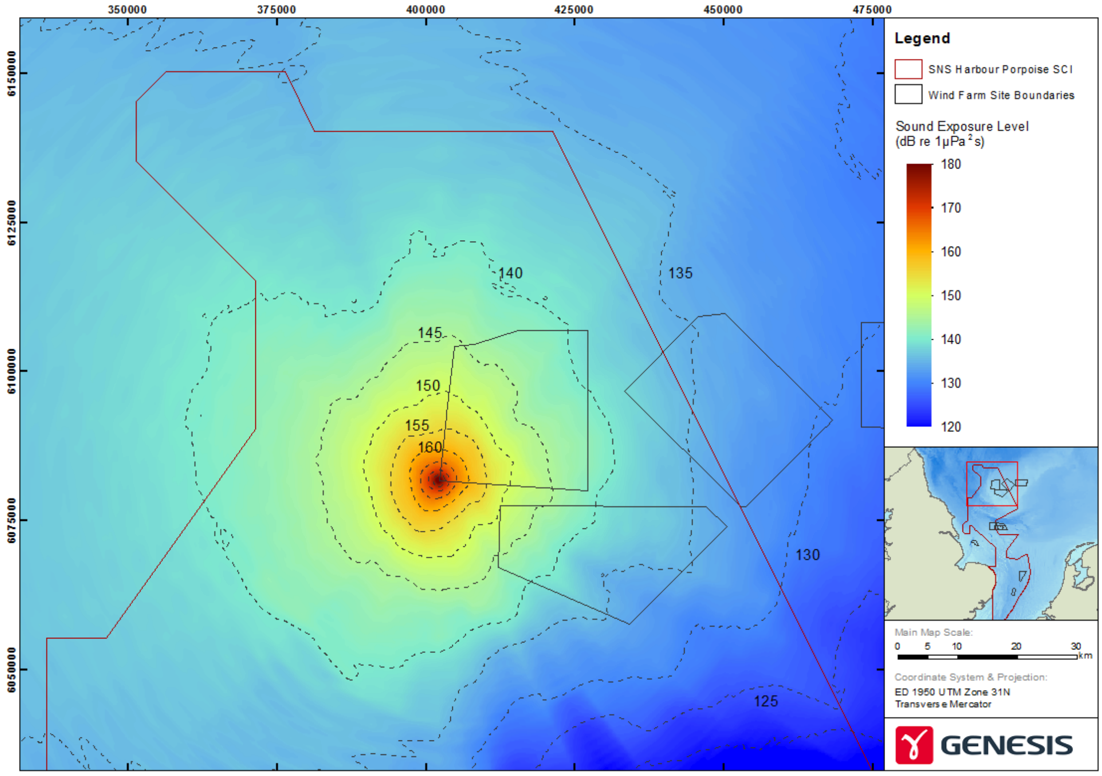

Figure C-10: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Creyke Beck B model location 1 with hammer energy of 1,900 kJ.

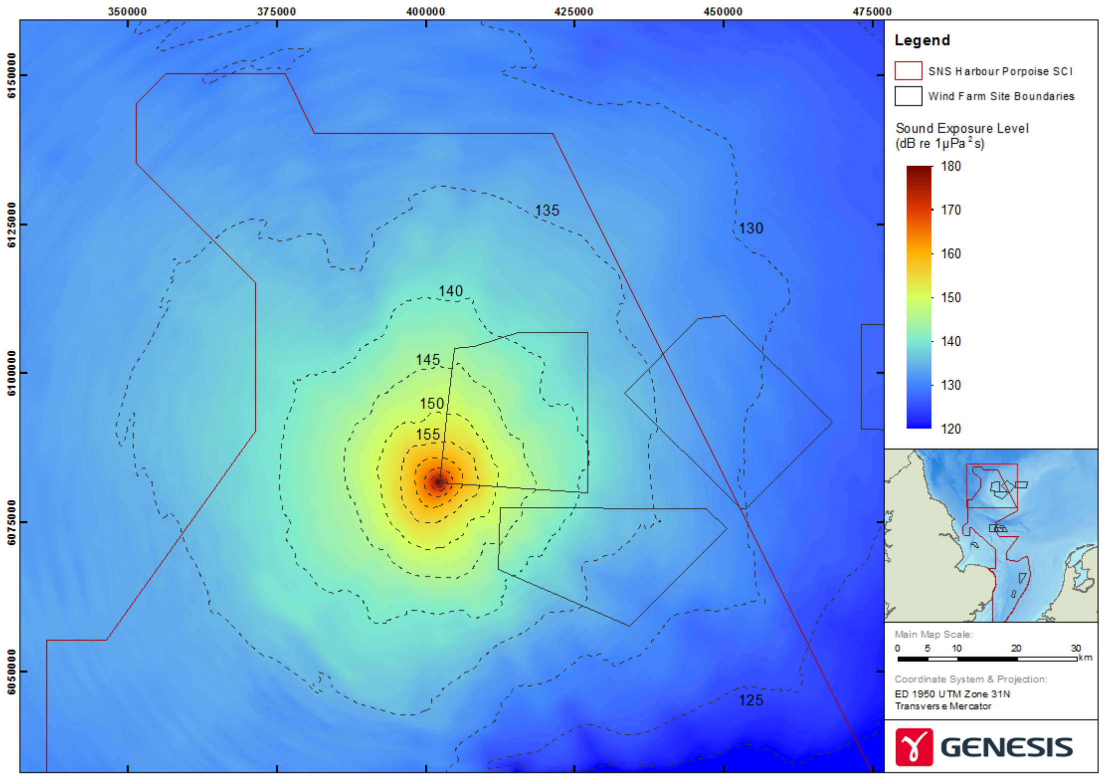

Figure C-11: Depth-averaged unweighted single-pulse SEL for pile-driving at Creyke Beck B model location 1 with hammer energy of 3,000 kJ.

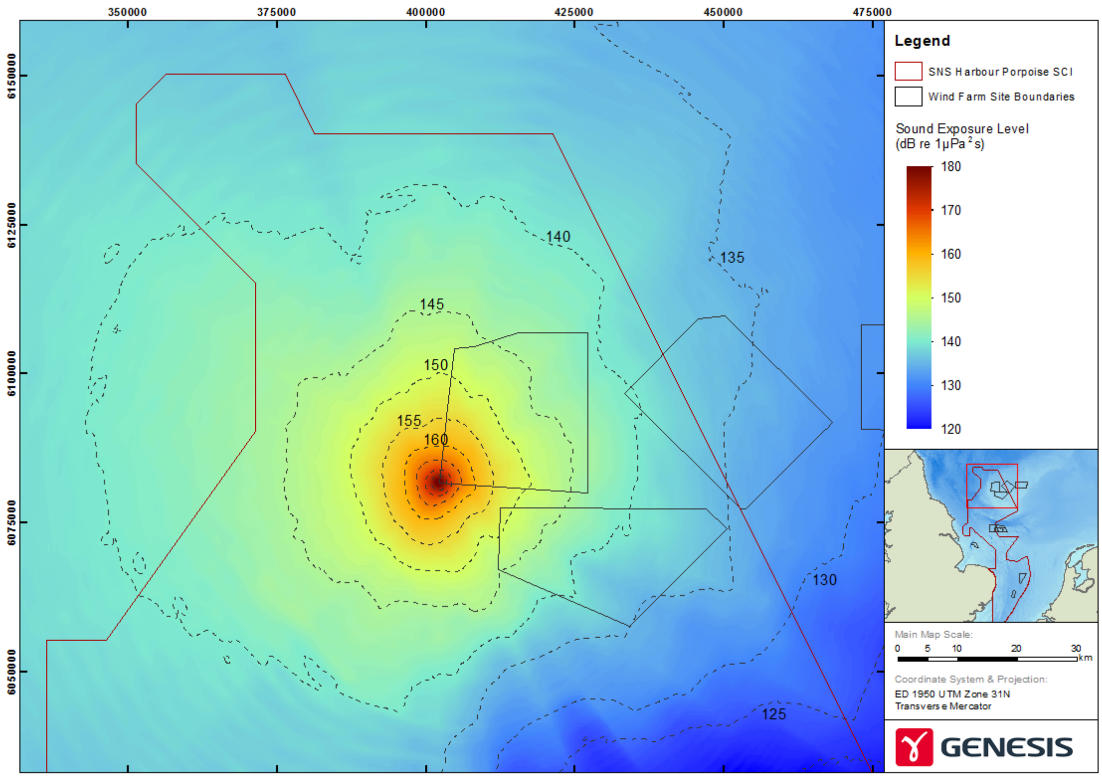

Figure C-12: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Creyke Beck B model location 1 with hammer energy of 3,000 kJ.

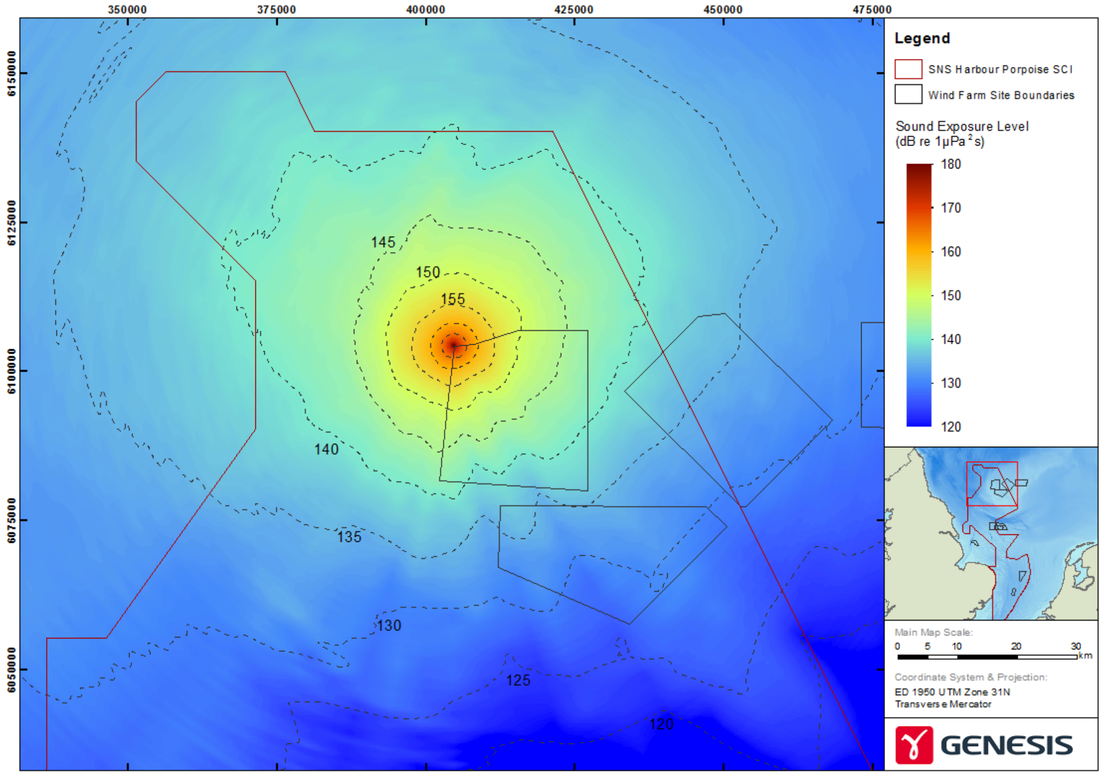

Figure C-13: Depth-averaged unweighted single-pulse SEL for pile-driving at Creyke Beck B model location 2 with hammer energy of 1,900 kJ.

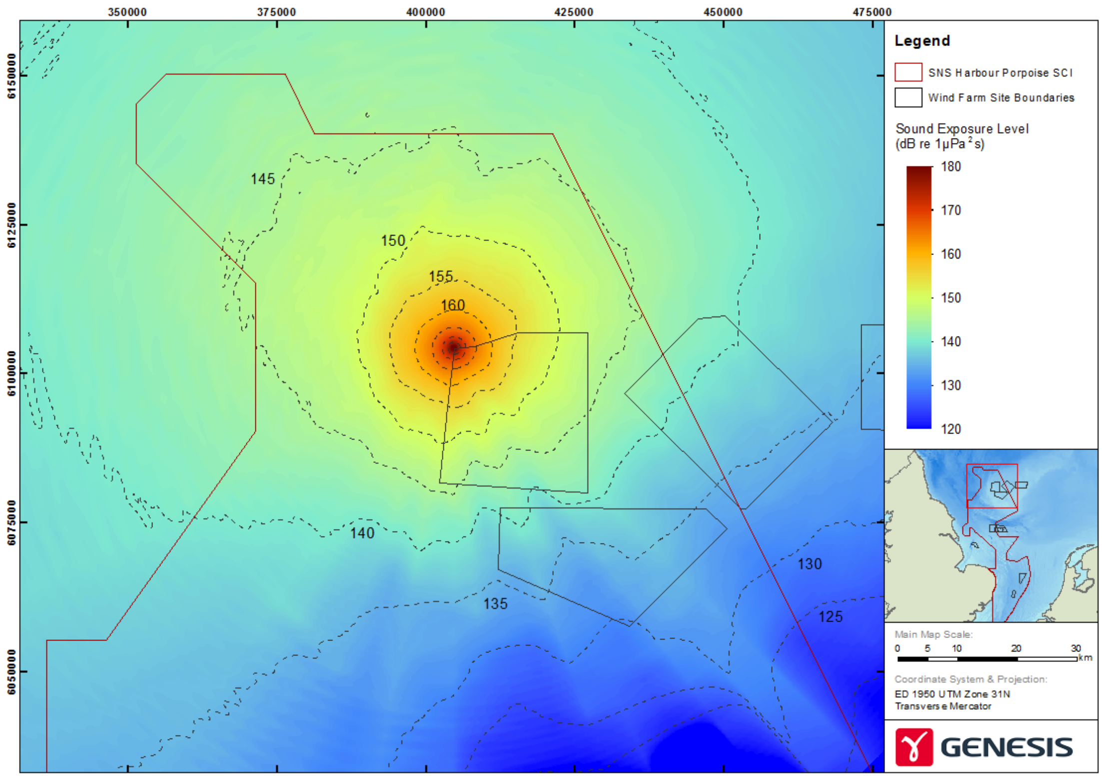

Figure C-14: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Creyke Beck B model location 2 with hammer energy of 1,900 kJ.

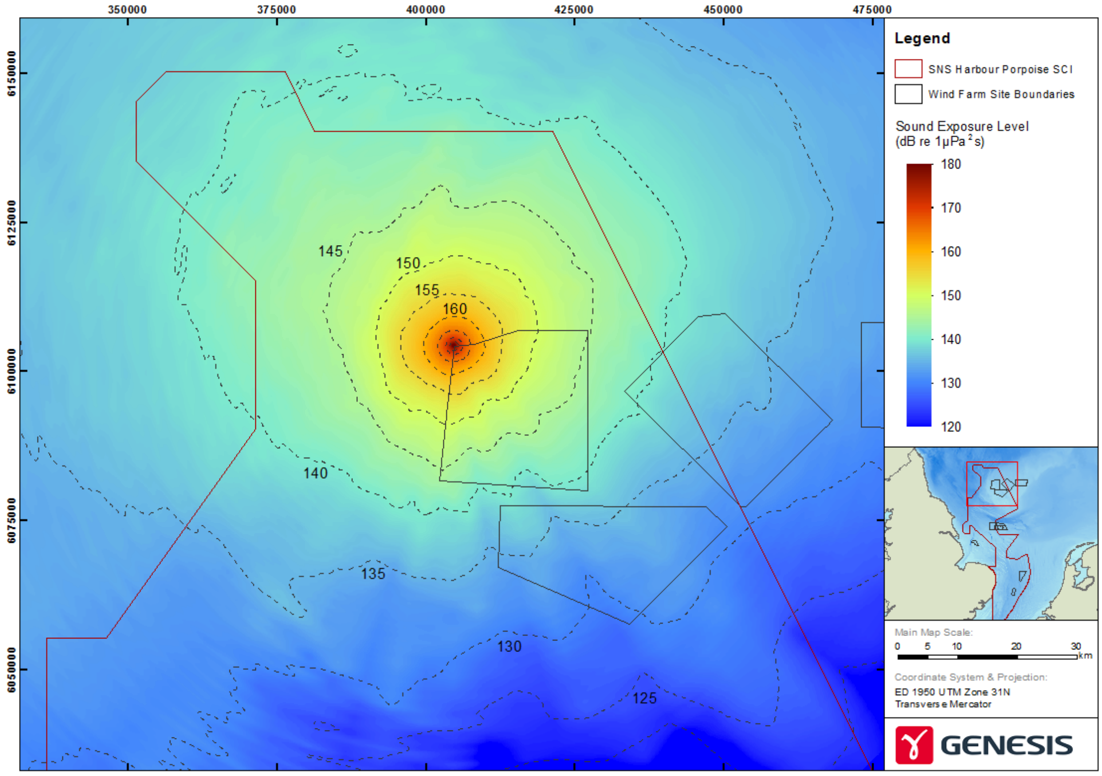

Figure C-15: Depth-averaged unweighted single-pulse SEL for pile-driving at Creyke Beck B model location 2 with hammer energy of 3,000 kJ.

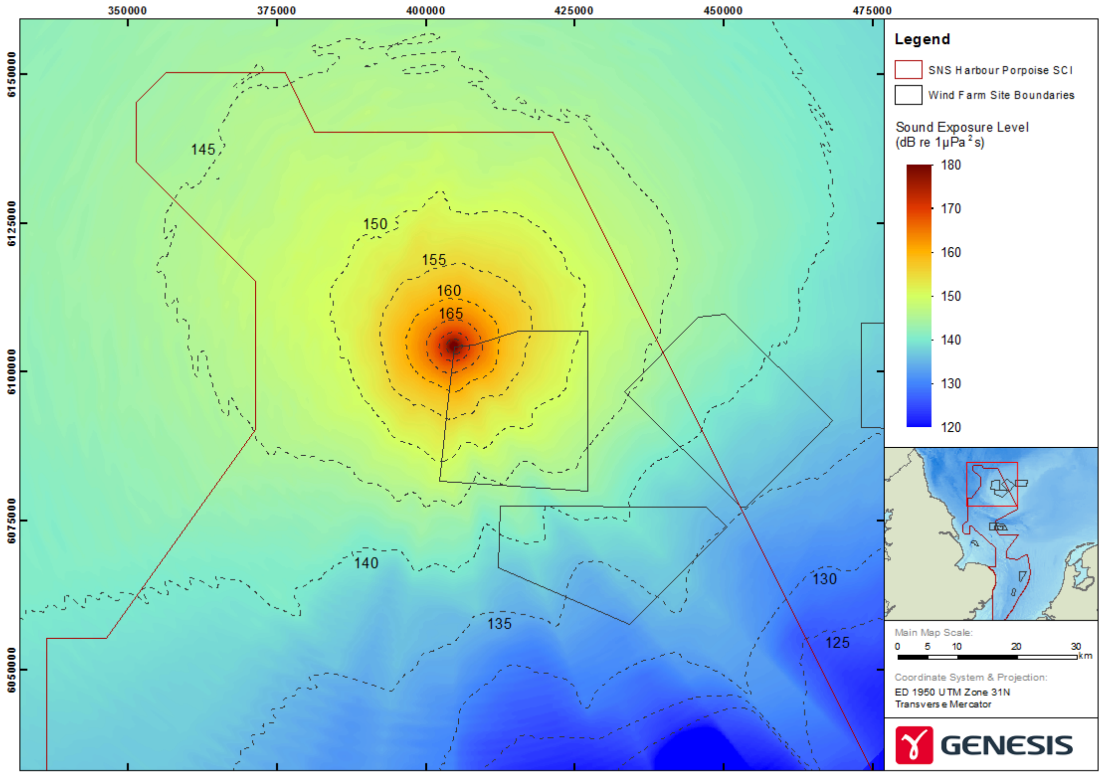

Figure C-16: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Creyke Beck B model location 2 with hammer energy of 3,000 kJ.

Department for Business, Energy & Industrial Strategy

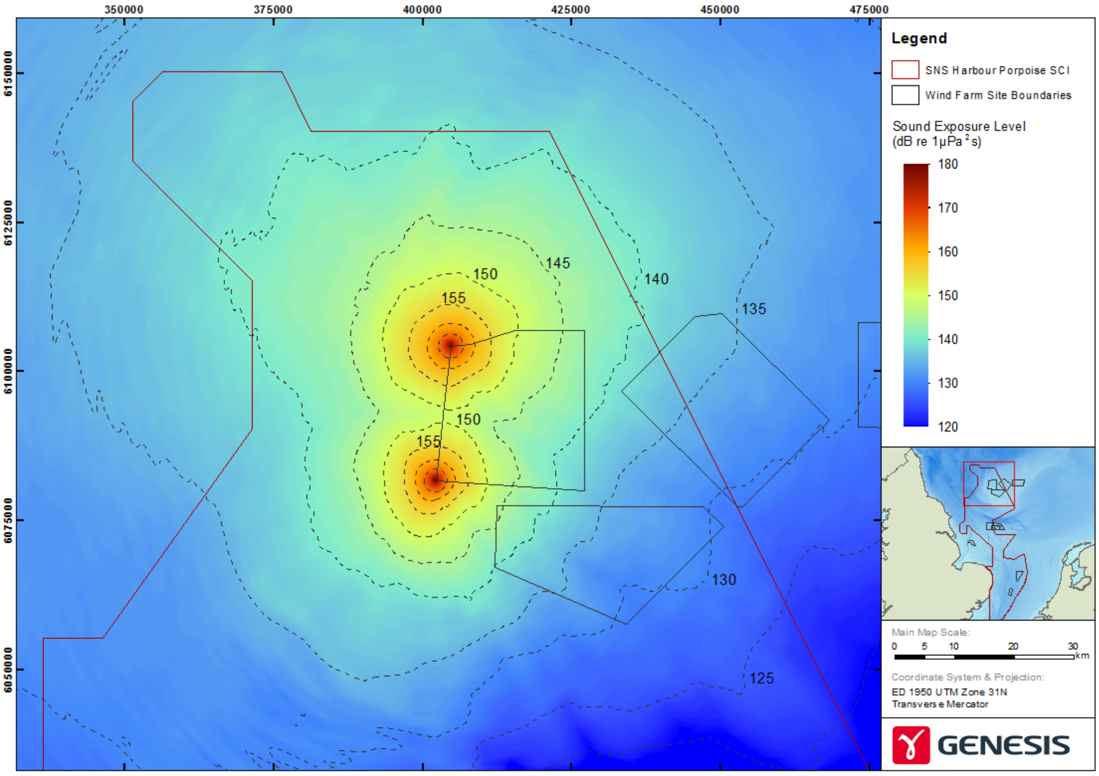

Figure C-17: Depth-averaged unweighted single-pulse SEL for concurrent pile-driving at Creyke Beck B model locations 1 and 2 with hammer energy of 1,900 kJ.

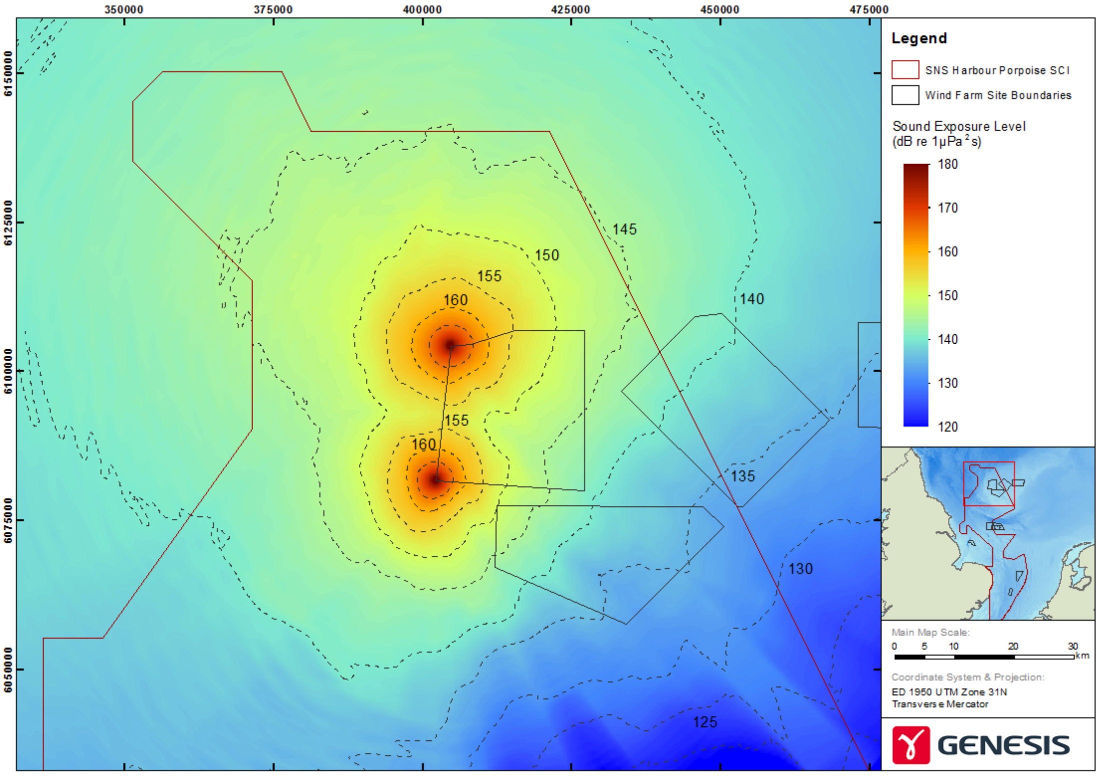

Figure C-18: Maximum-over-depth unweighted single-pulse SEL for concurrent pile-driving at Creyke Beck B model locations 1 and 2 with hammer energy of 1,900 kJ.

GENESIS

Department for Business, Energy & Industrial Strategy

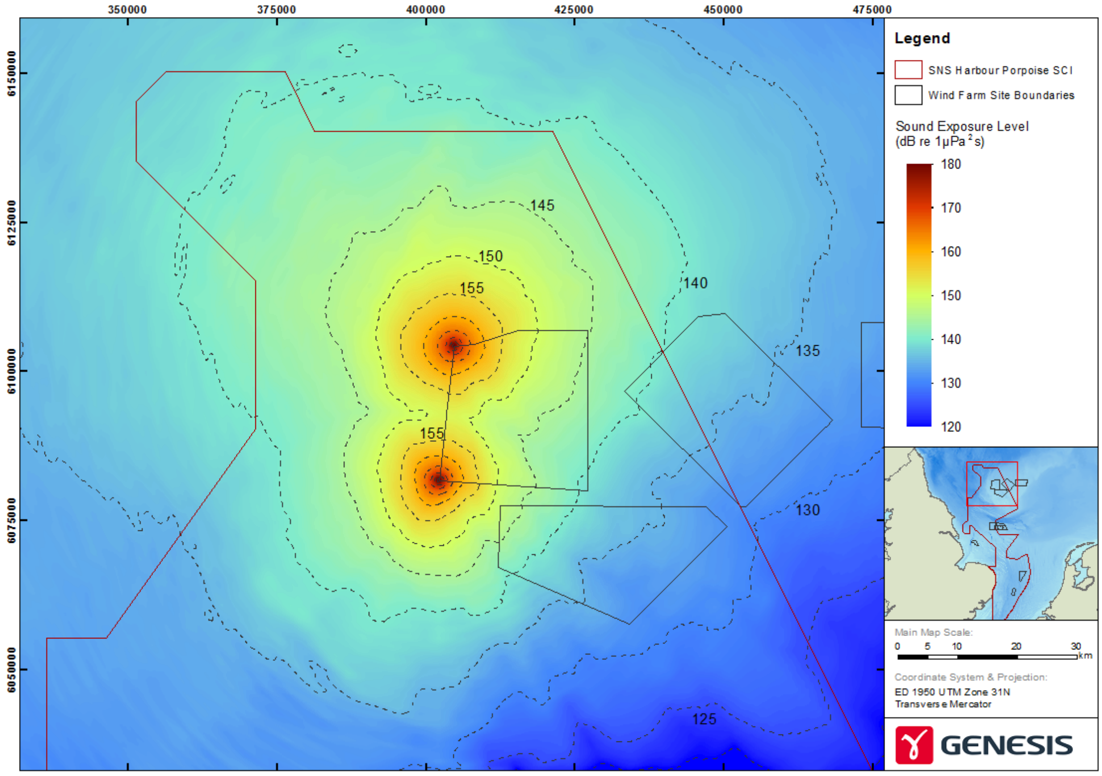

Figure C-19: Depth-averaged unweighted single-pulse SEL for concurrent pile-driving at Creyke Beck B model locations 1 and 2 with hammer energy of 3,000 kJ.

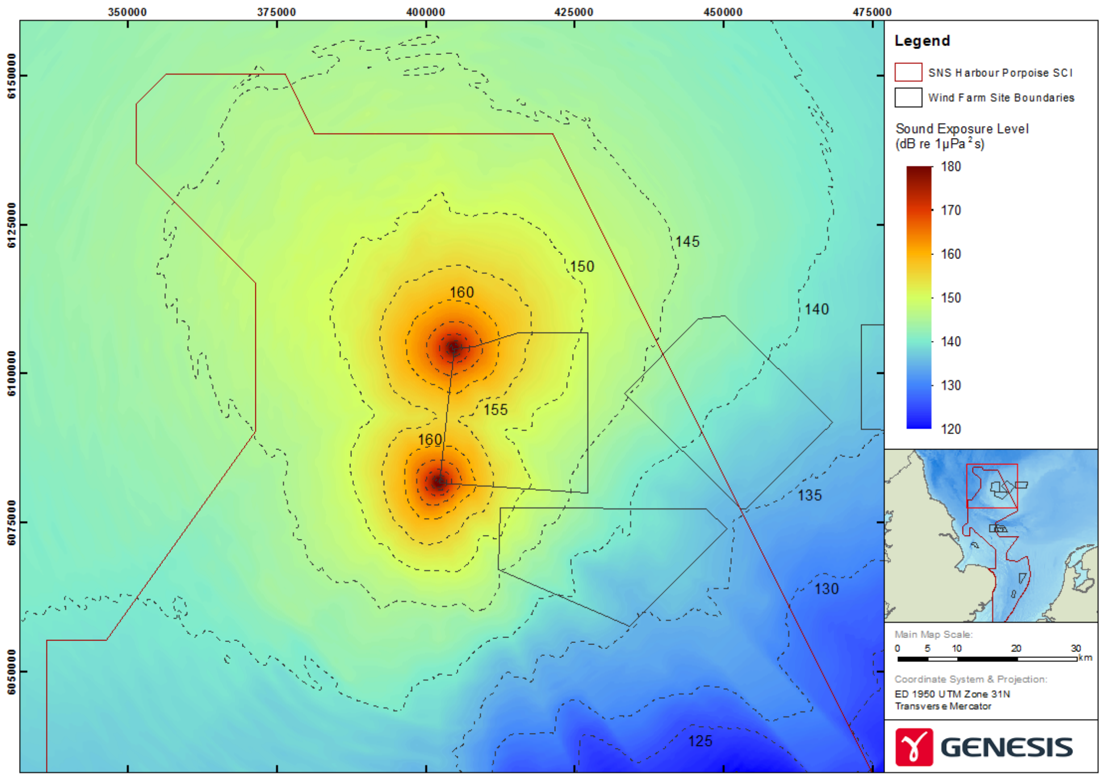

Figure C-20: Maximum-over-depth unweighted single-pulse SEL for concurrent pile-driving at Creyke Beck B model locations 1 and 2 with hammer energy of 3,000 kJ.

GENESIS

APPENDIX D: MODELLING MAPS FOR EAST ANGLIA ONE

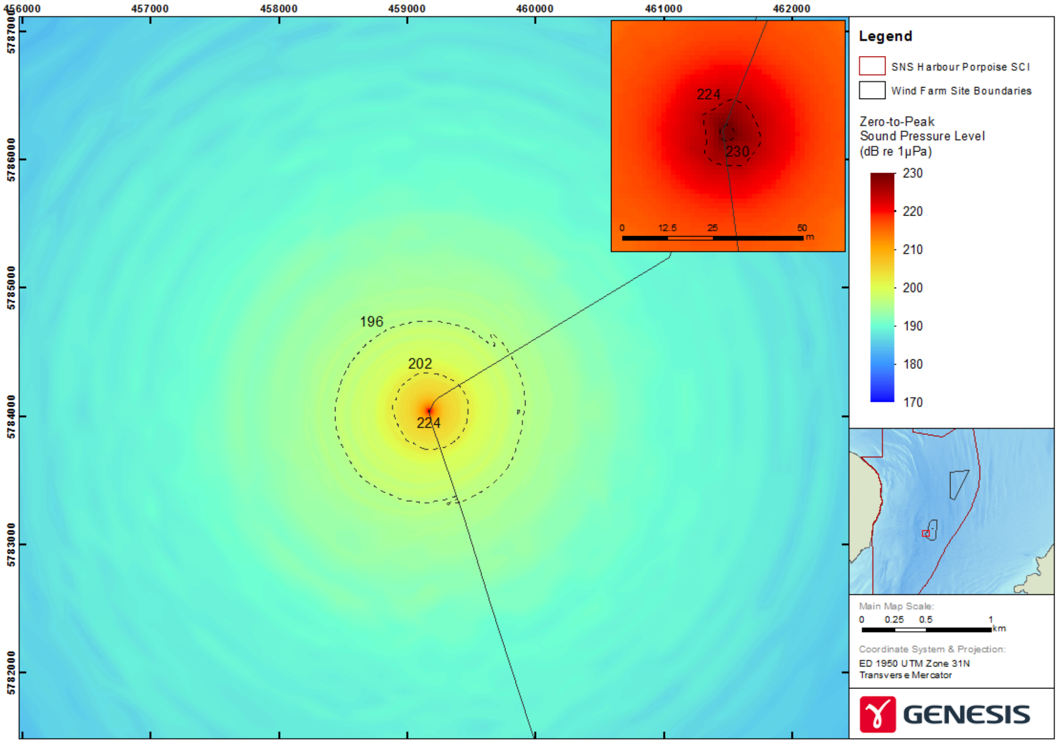

Figure D-1: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at East Anglia One model location 1 with hammer energy of 1,200 kJ.

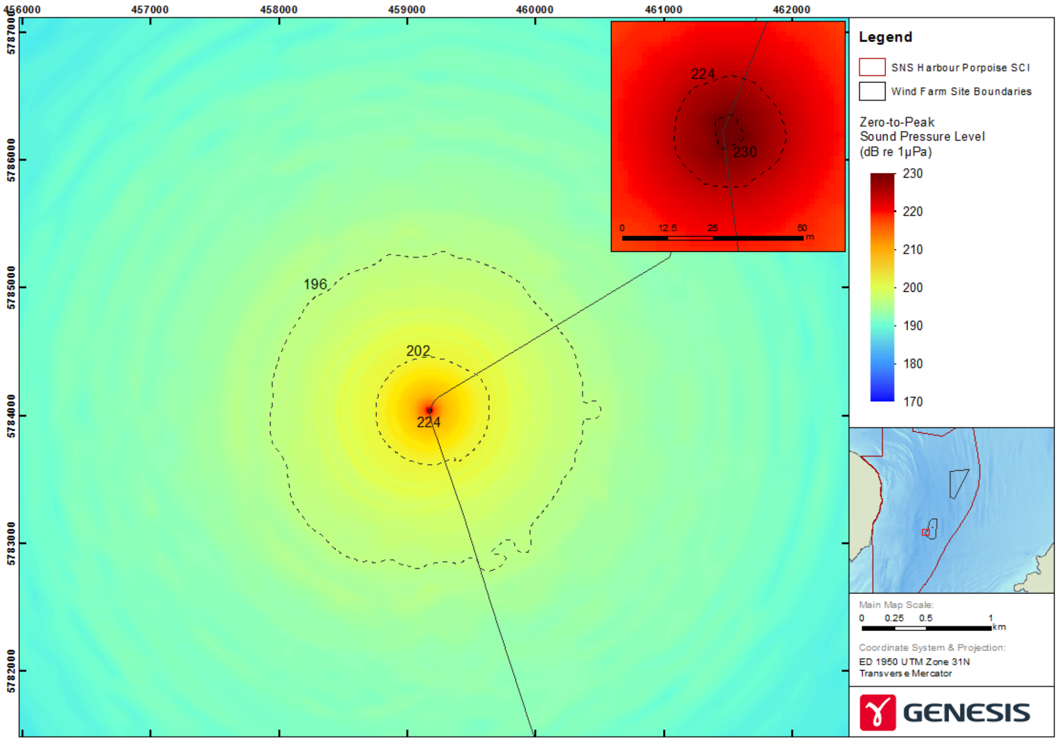

Figure D-2: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at East Anglia One model location 1 with hammer energy of 2,400 kJ.

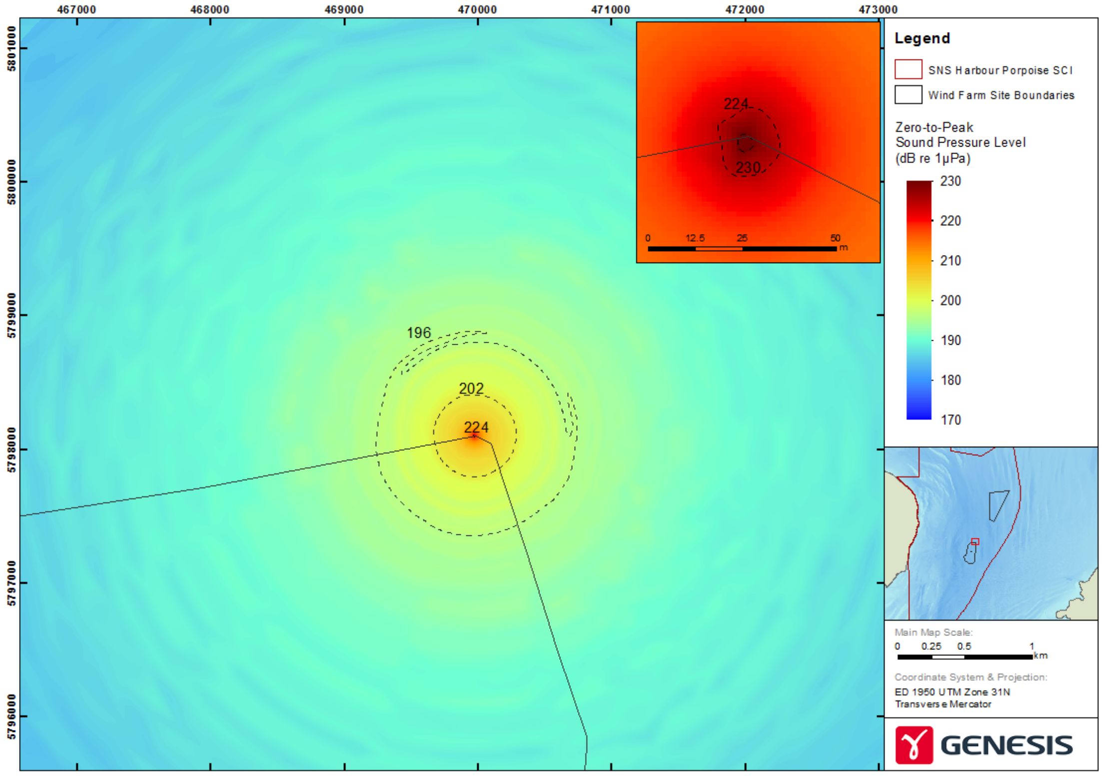

Figure D-3: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at East Anglia One model location 2 with hammer energy of 1,200 kJ.

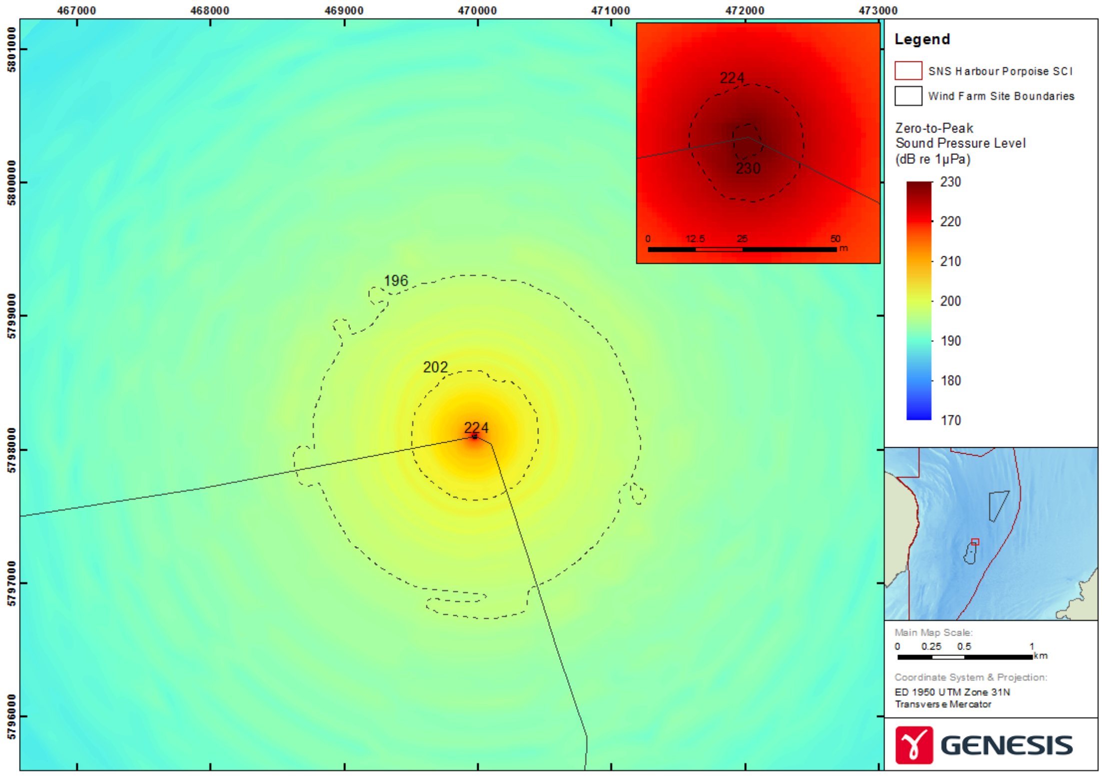

Figure D-4: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at East Anglia One model location 2 with hammer energy of 2,400 kJ.

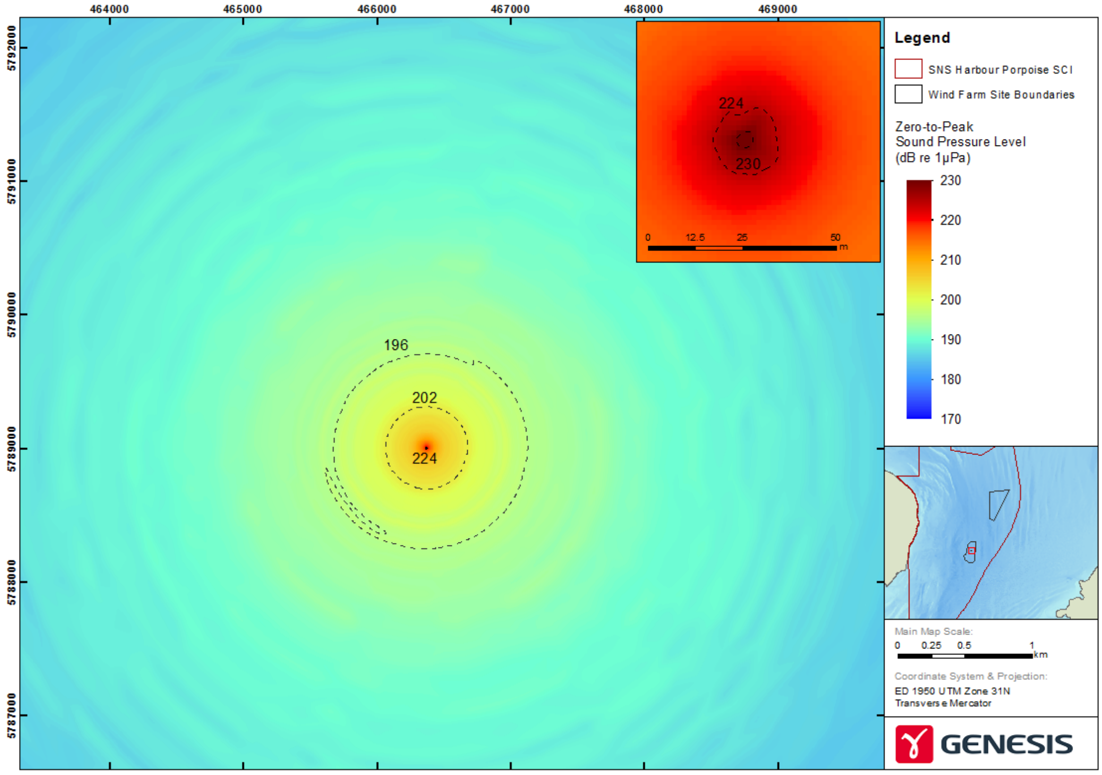

Figure D-5: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at East Anglia One model location 3 with hammer energy of 1,200 kJ.

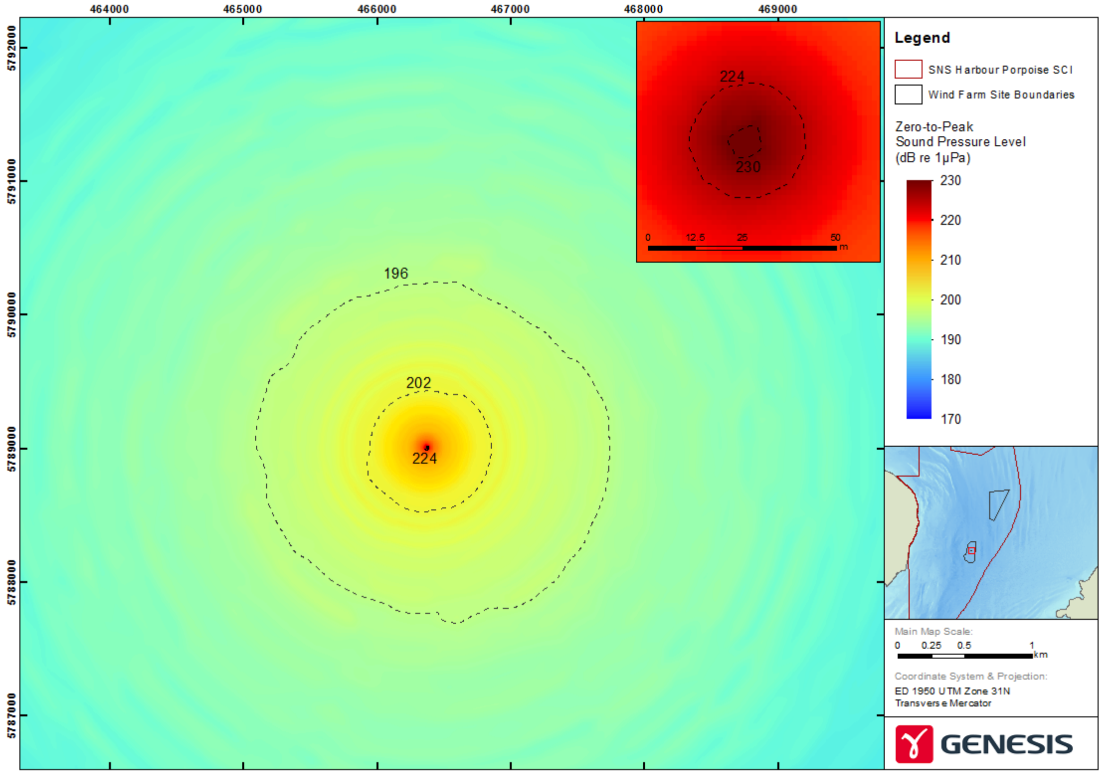

Figure D-6: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at East Anglia One model location 3 with hammer energy of 2,400 kJ.

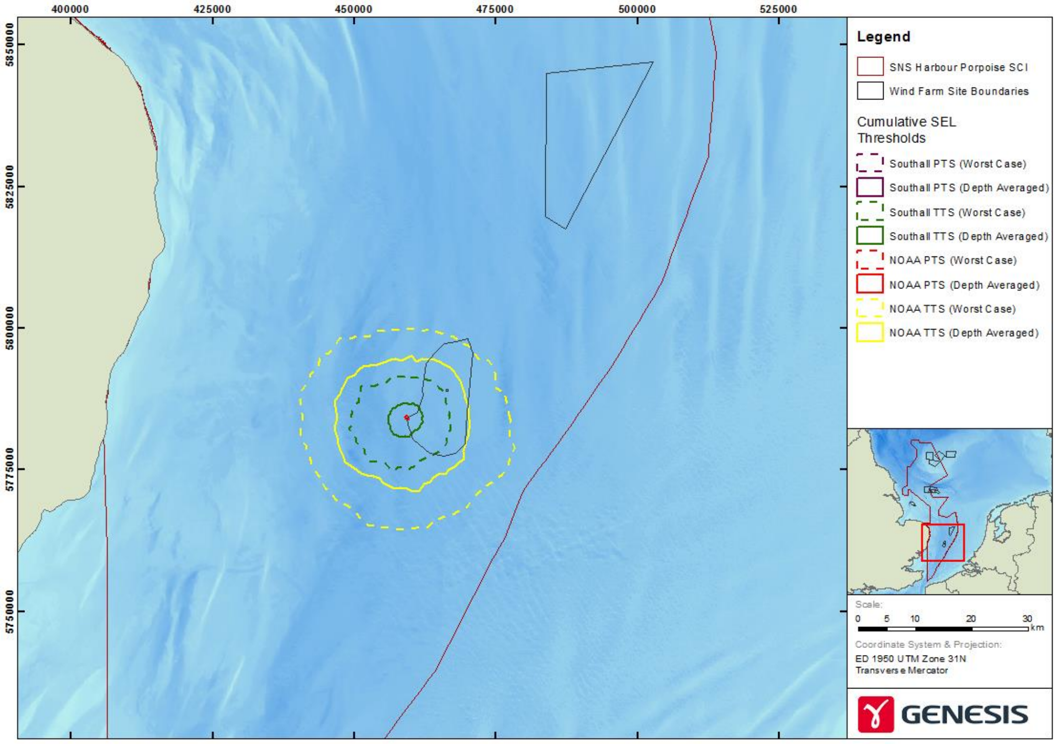

Figure D-7: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at East Anglia One model location 1 with maximum hammer energy of 1,200 kJ.

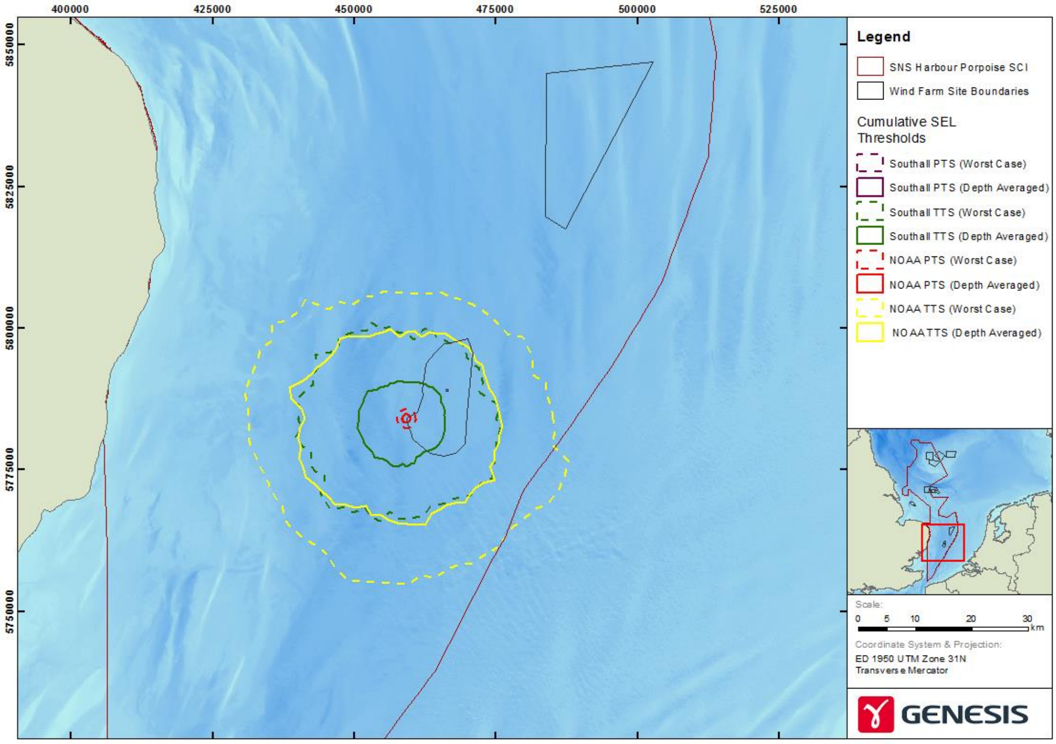

Figure D-8: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at East Anglia One model location 1 with maximum hammer energy of 2,400 kJ.

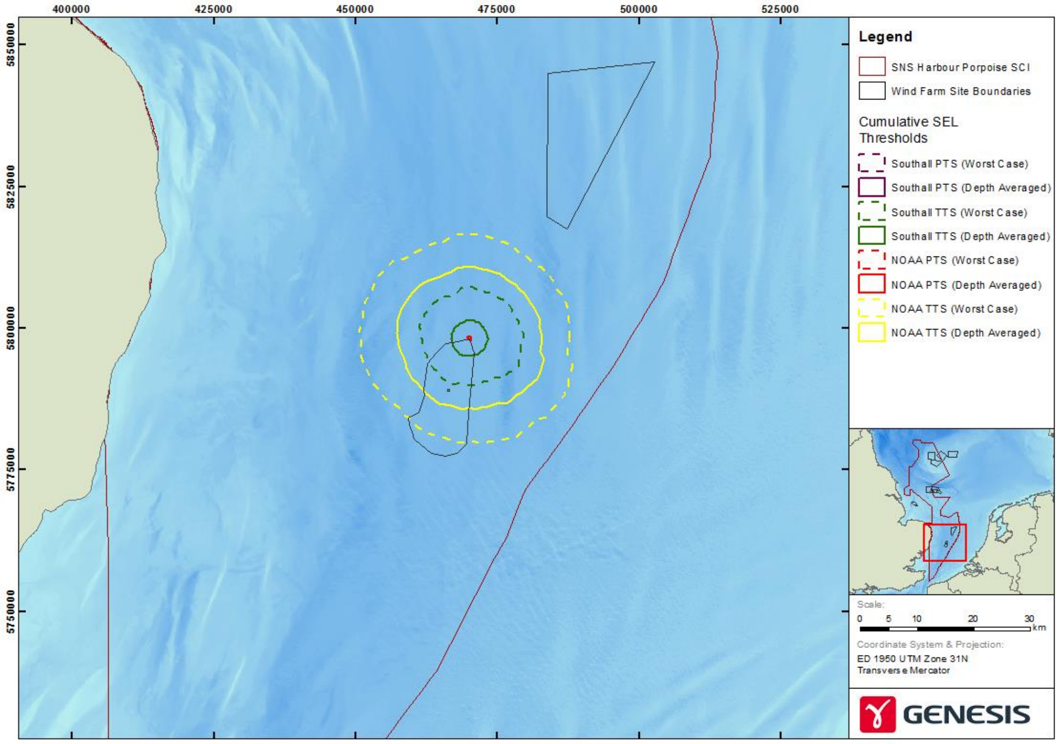

Figure D-9: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at East Anglia One model location 2 with maximum hammer energy of 1,200 kJ.

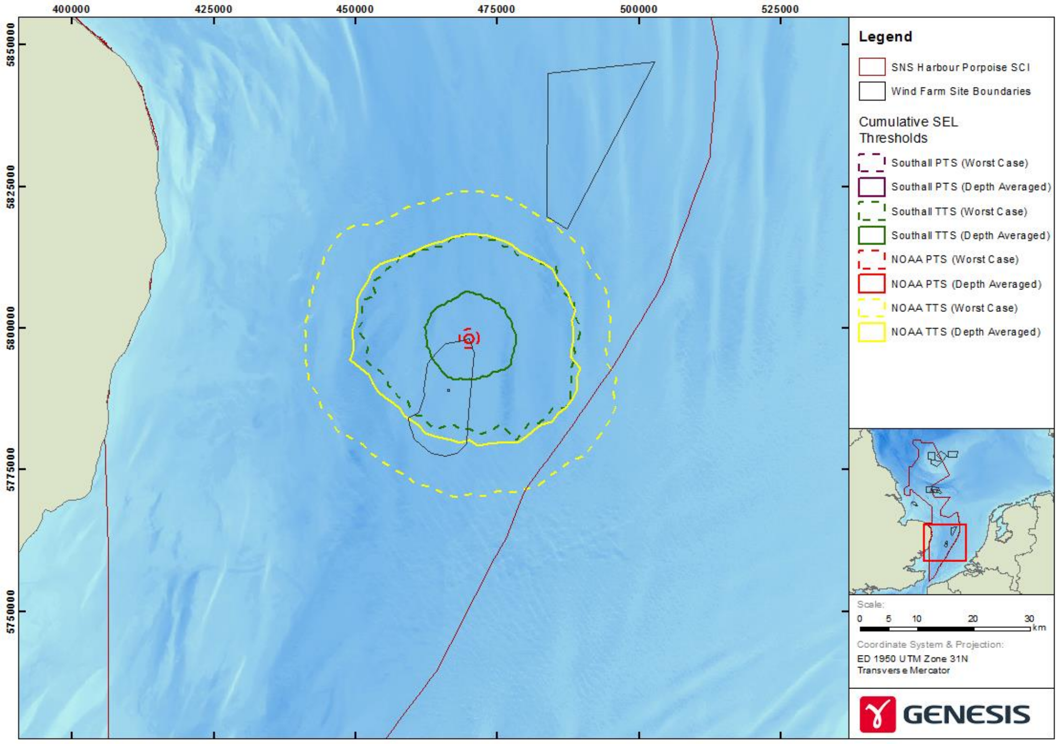

Figure D-10: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at East Anglia One model location 2 with maximum hammer energy of 2,400 kJ.

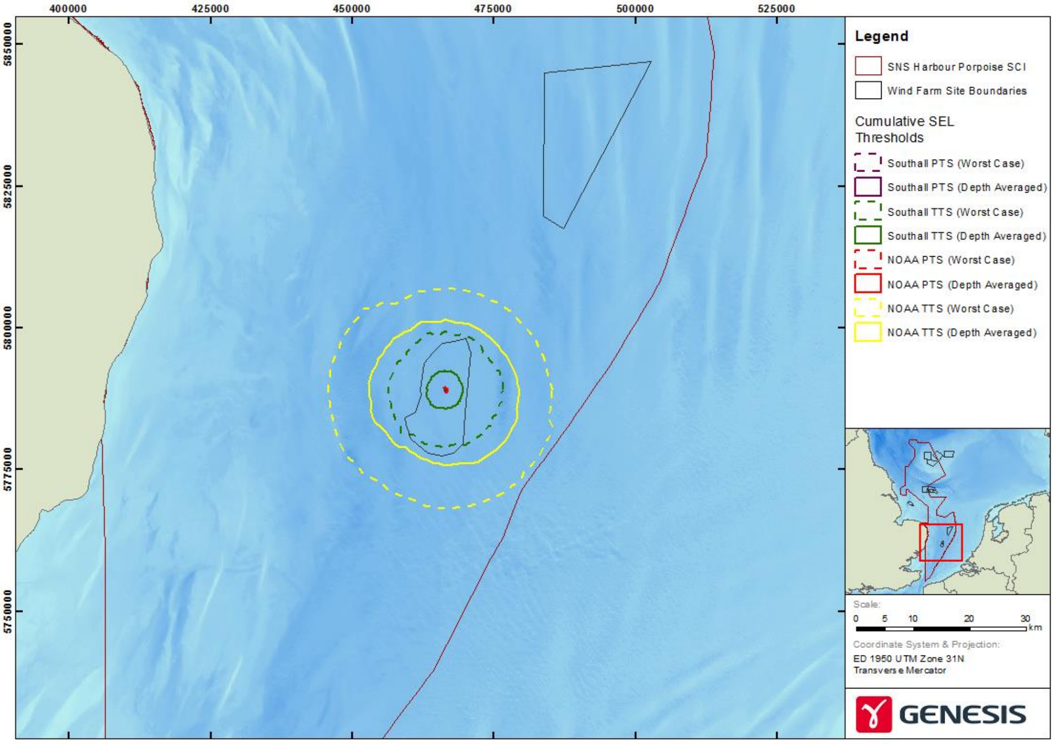

Figure D-11: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at East Anglia One model location 3 with maximum hammer energy of 1,200 kJ.

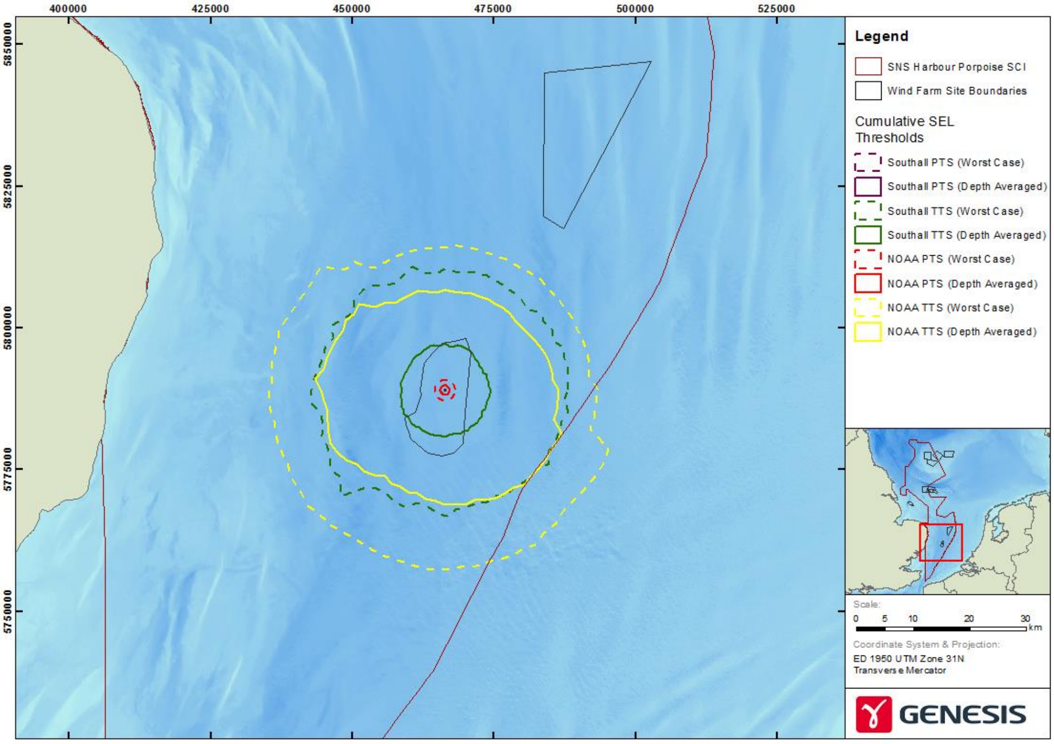

Figure D-12: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at East Anglia One model location 3 with maximum hammer energy of 2,400 kJ.

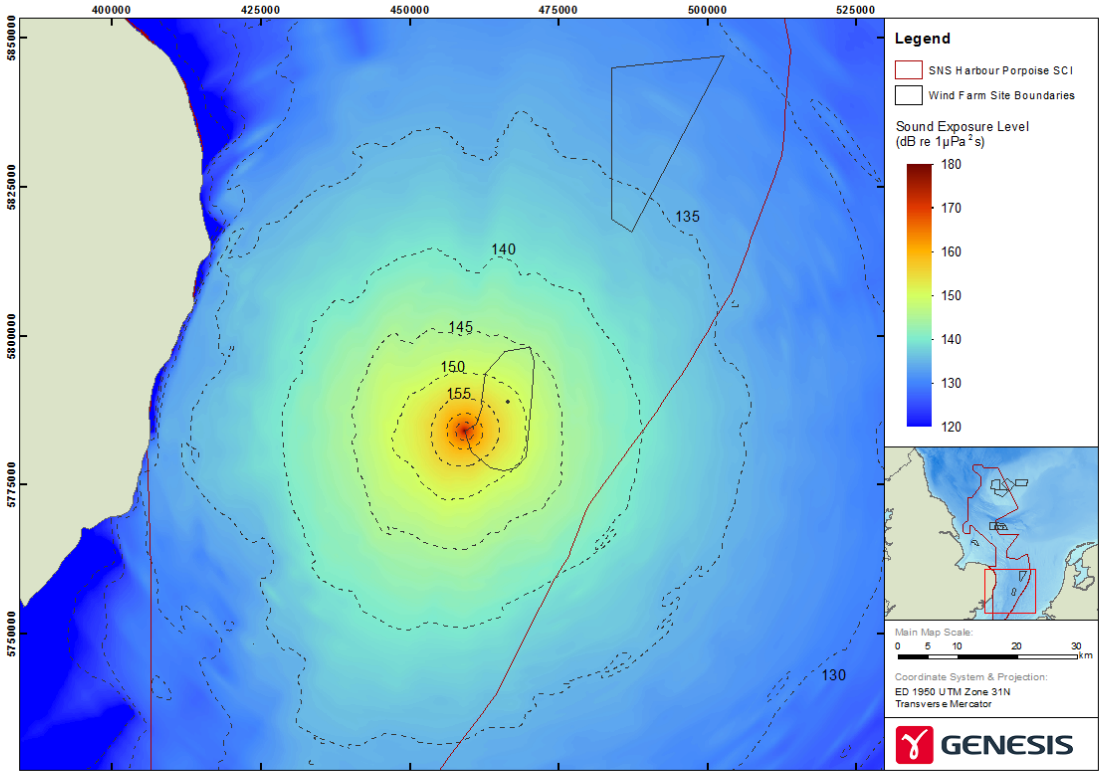

Figure D-13: Depth-averaged unweighted single-pulse SEL for pile-driving at East Anglia One model location 1 with hammer energy of 1,200 kJ.

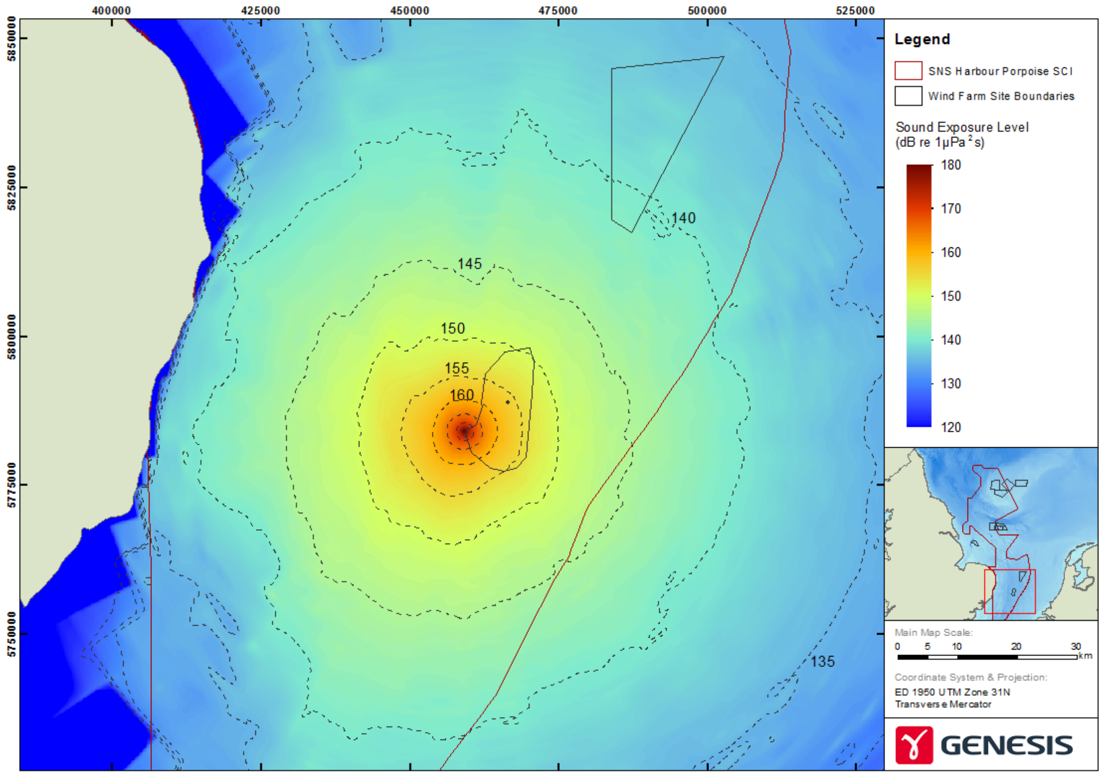

Figure D-14: Maximum-over-depth unweighted single-pulse SEL for pile-driving at East Anglia One model location 1 with hammer energy of 1,200 kJ.

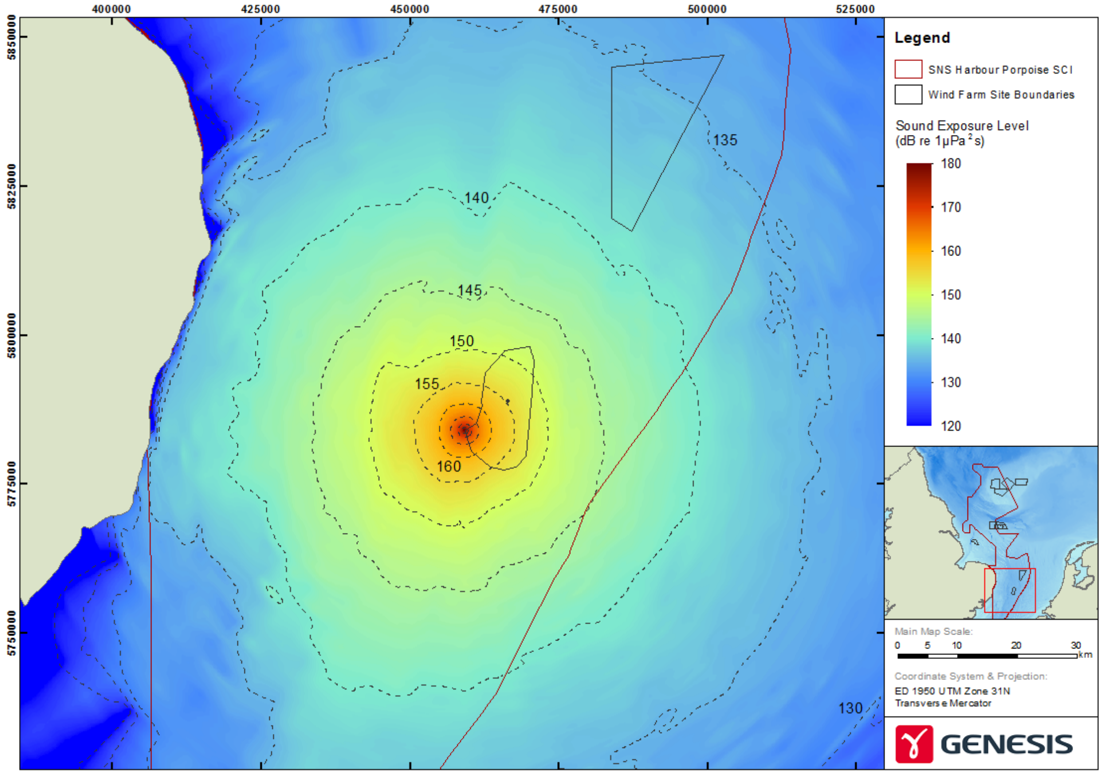

Figure D-15: Depth-averaged unweighted single-pulse SEL for pile-driving at East Anglia One model location 1 with hammer energy of 2,400 kJ.

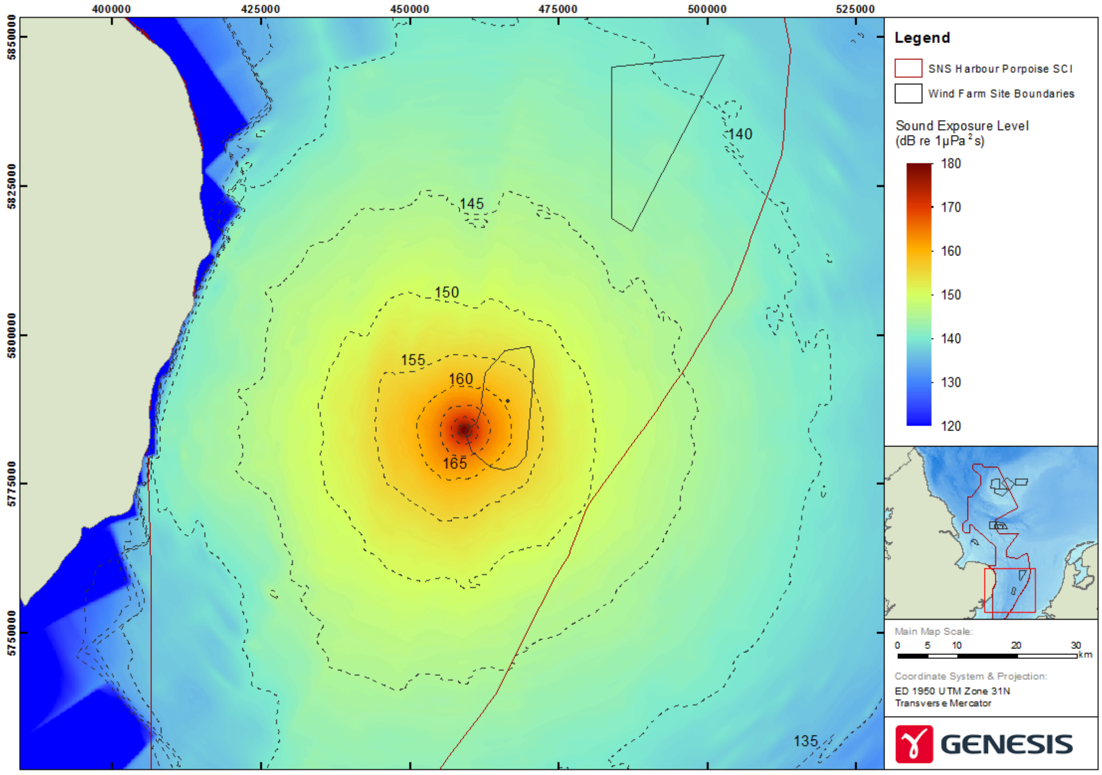

Figure D-16: Maximum-over-depth unweighted single-pulse SEL for pile-driving at East Anglia One model location 1 with hammer energy of 2,400 kJ.

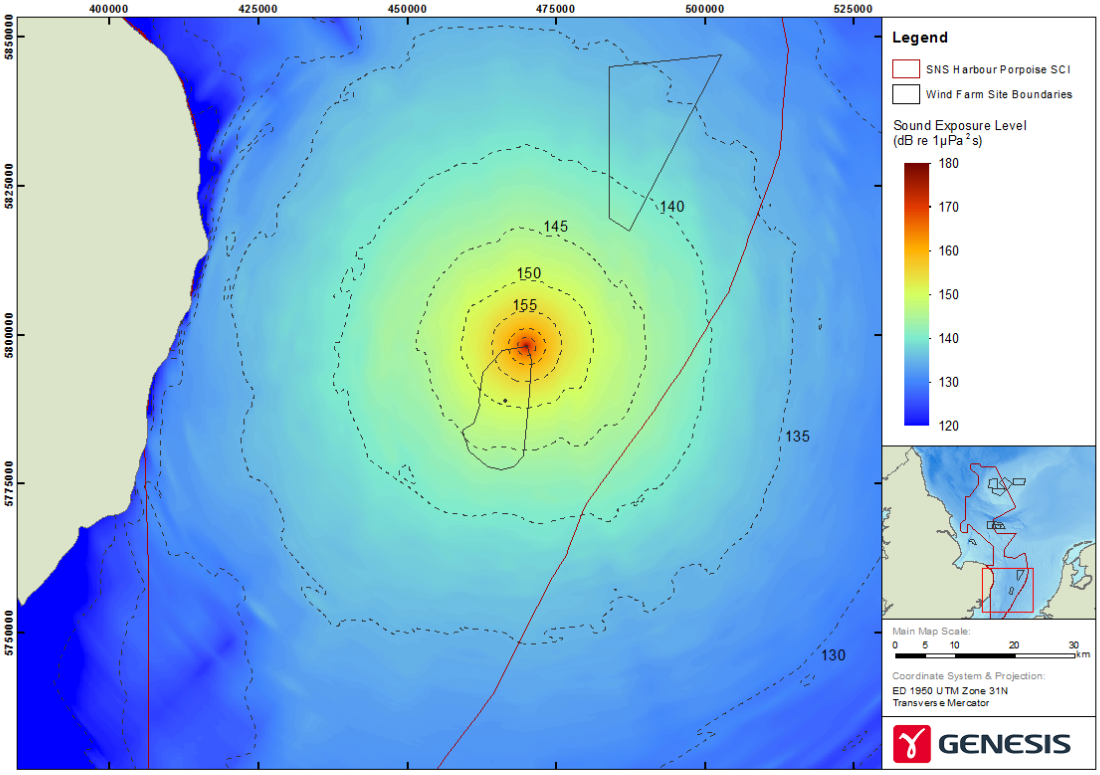

Figure D-17: Depth-averaged unweighted single-pulse SEL for pile-driving at East Anglia One model location 2 with hammer energy of 1,200 kJ.

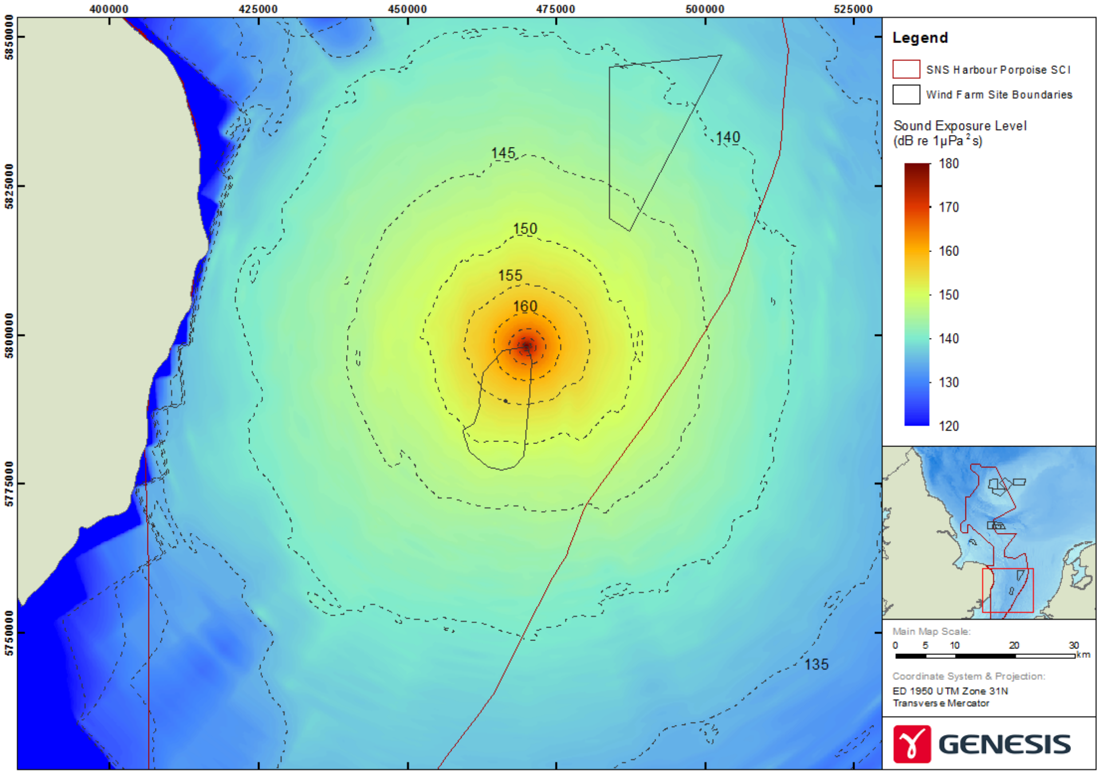

Figure D-18: Maximum-over-depth unweighted single-pulse SEL for pile-driving at East Anglia One model location 2 with hammer energy of 1,200 kJ.

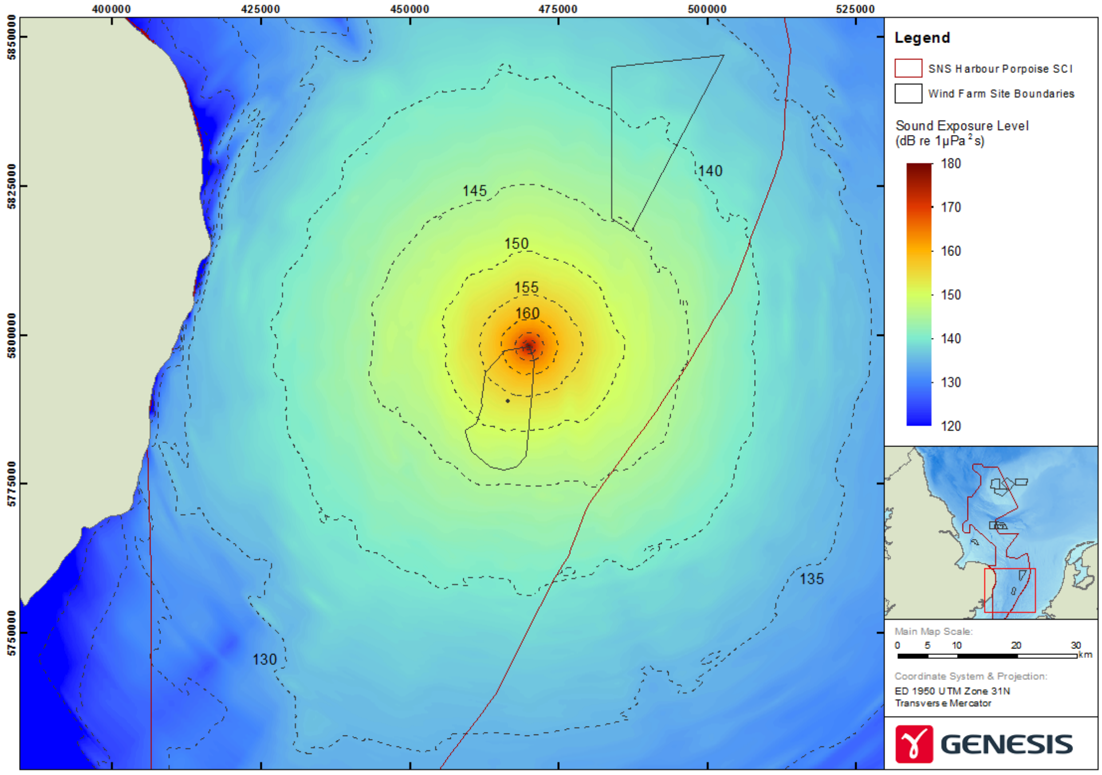

Figure D-19: Depth-averaged unweighted single-pulse SEL for pile-driving at East Anglia One model location 2 with hammer energy of 2,400 kJ.

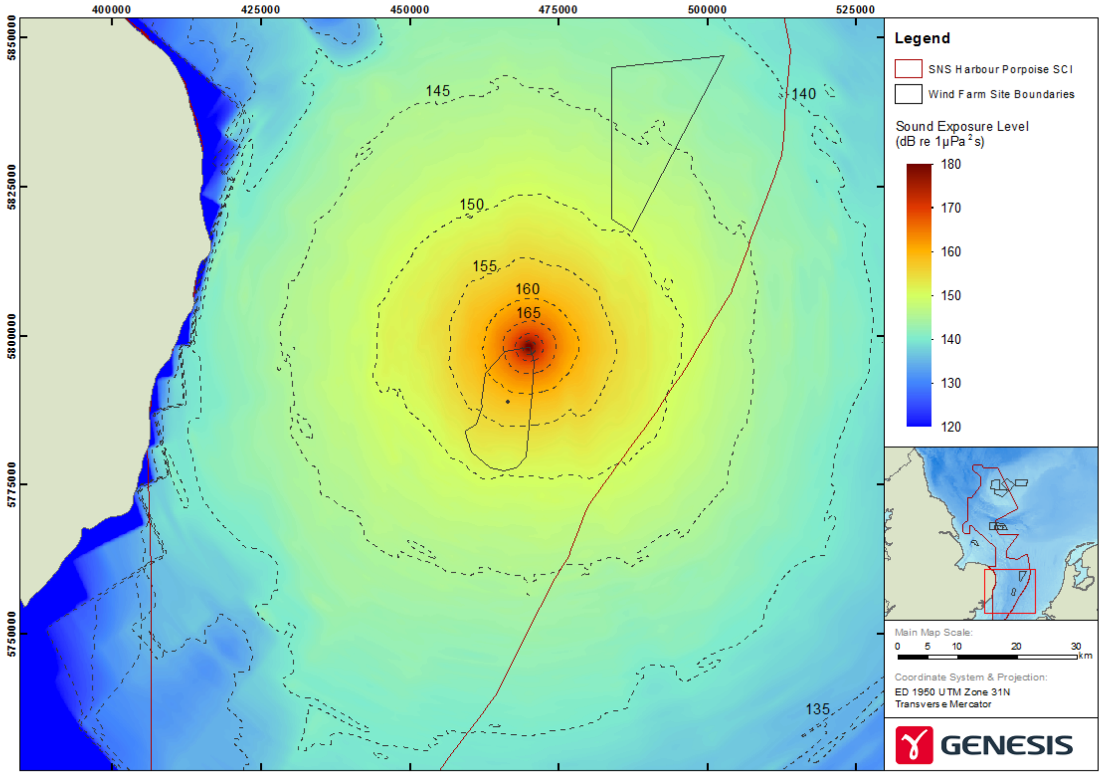

Figure D-20: Maximum-over-depth unweighted single-pulse SEL for pile-driving at East Anglia One model location 2 with hammer energy of 2,400 kJ.

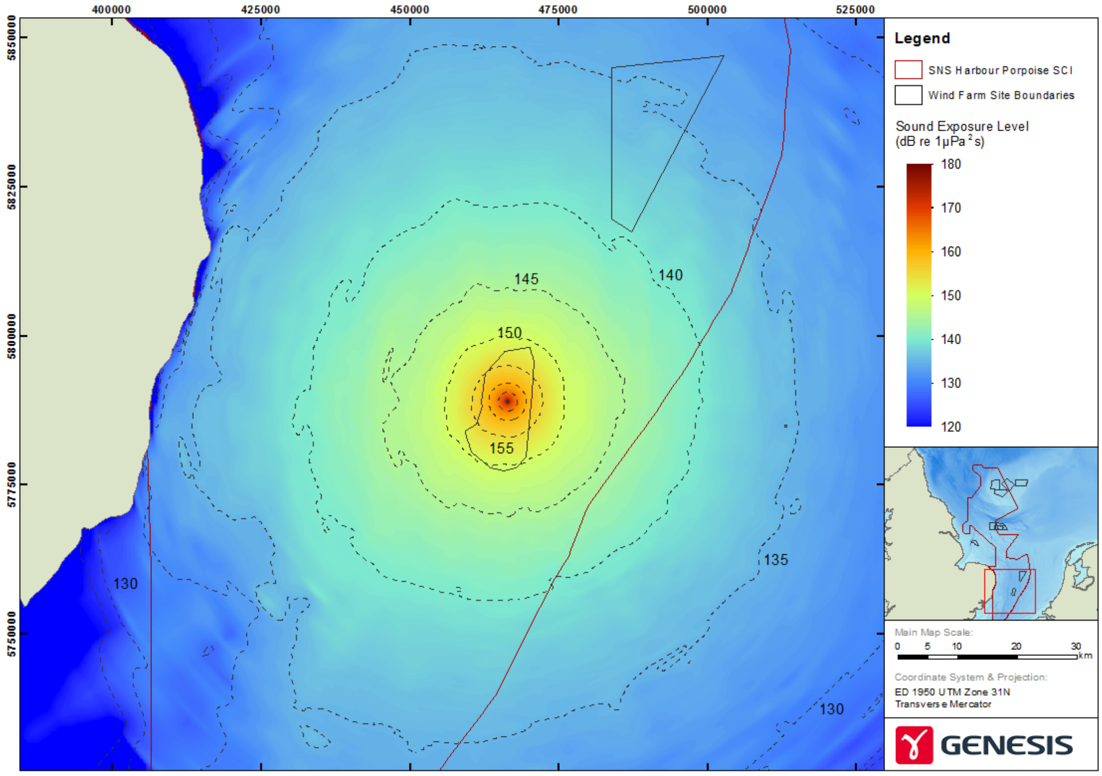

Figure D-21: Depth-averaged unweighted single-pulse SEL for pile-driving at East Anglia One model location 3 with hammer energy of 1,200 kJ.

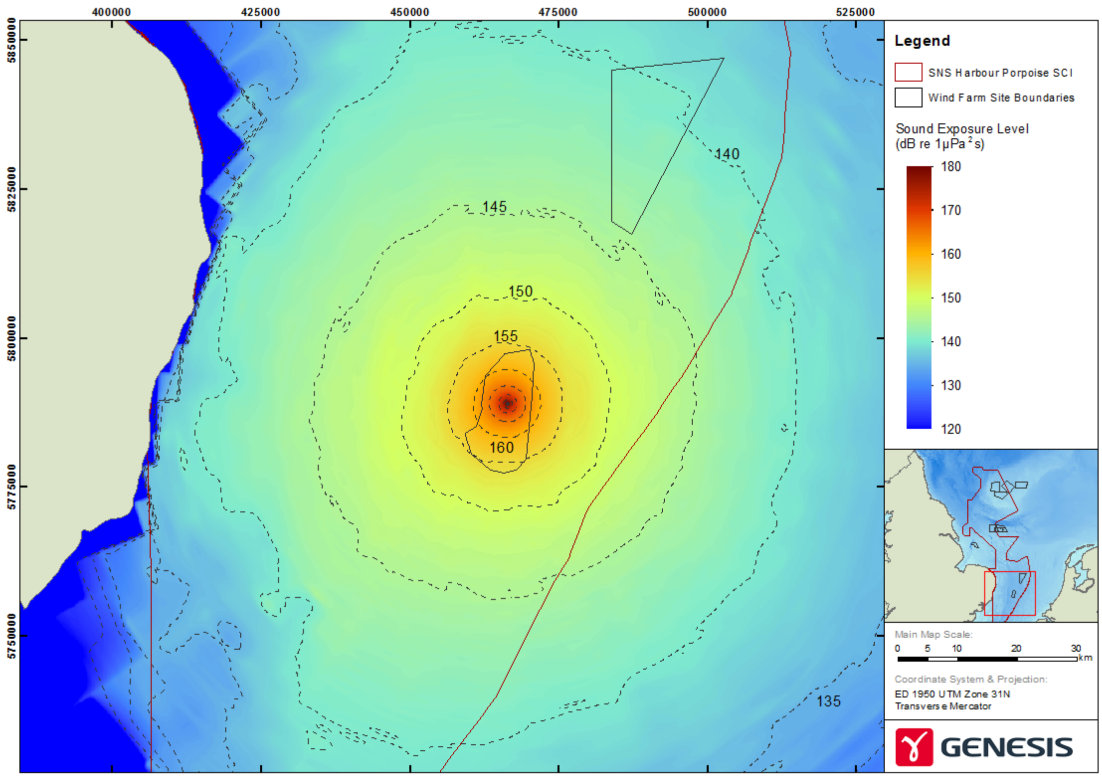

Figure D-22: Maximum-over-depth unweighted single-pulse SEL for pile-driving at East Anglia One model location 3 with hammer energy of 1,200 kJ.

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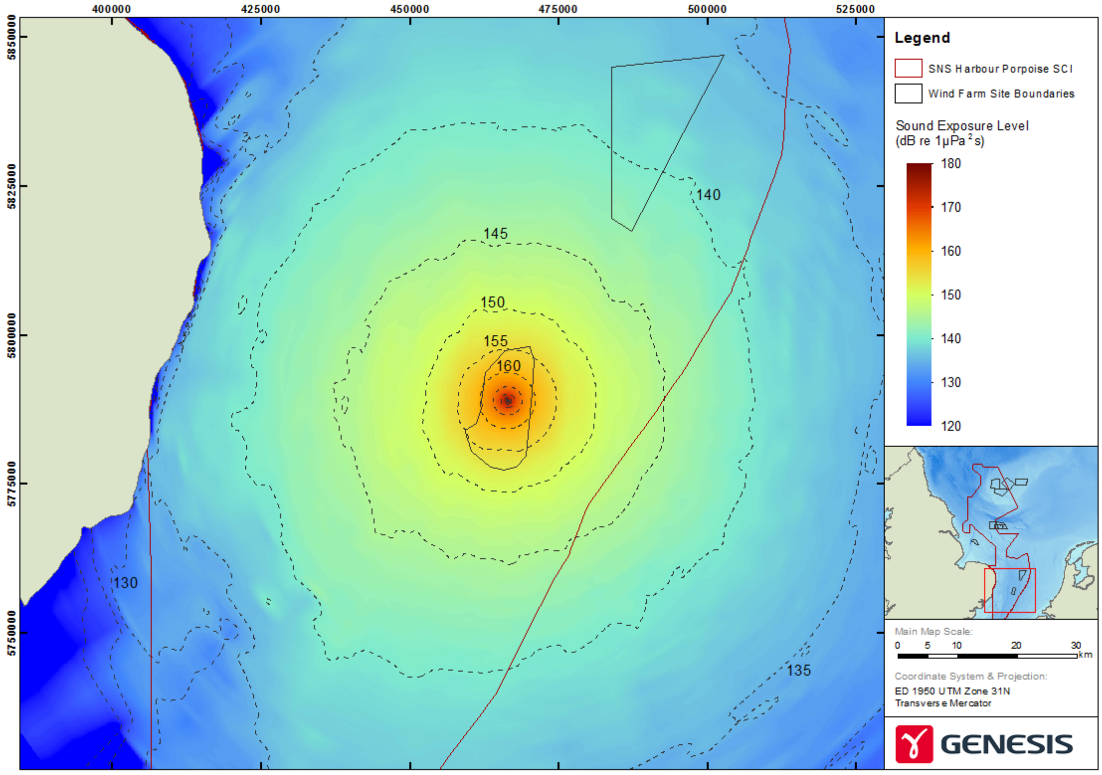

Figure D-23: Depth-averaged unweighted single-pulse SEL for pile-driving at East Anglia One model location 3 with hammer energy of 2,400 kJ.

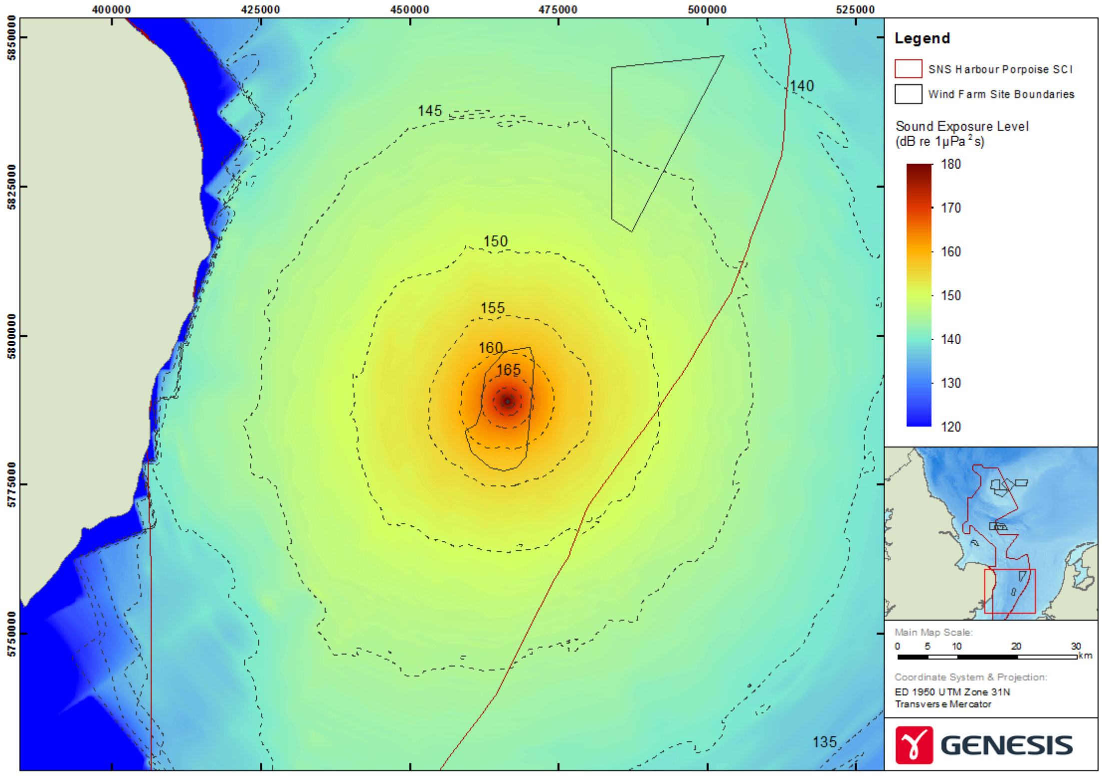

Figure D-24: Maximum-over-depth unweighted single-pulse SEL for pile-driving at East Anglia One model location 3 with hammer energy of 2,400 kJ.

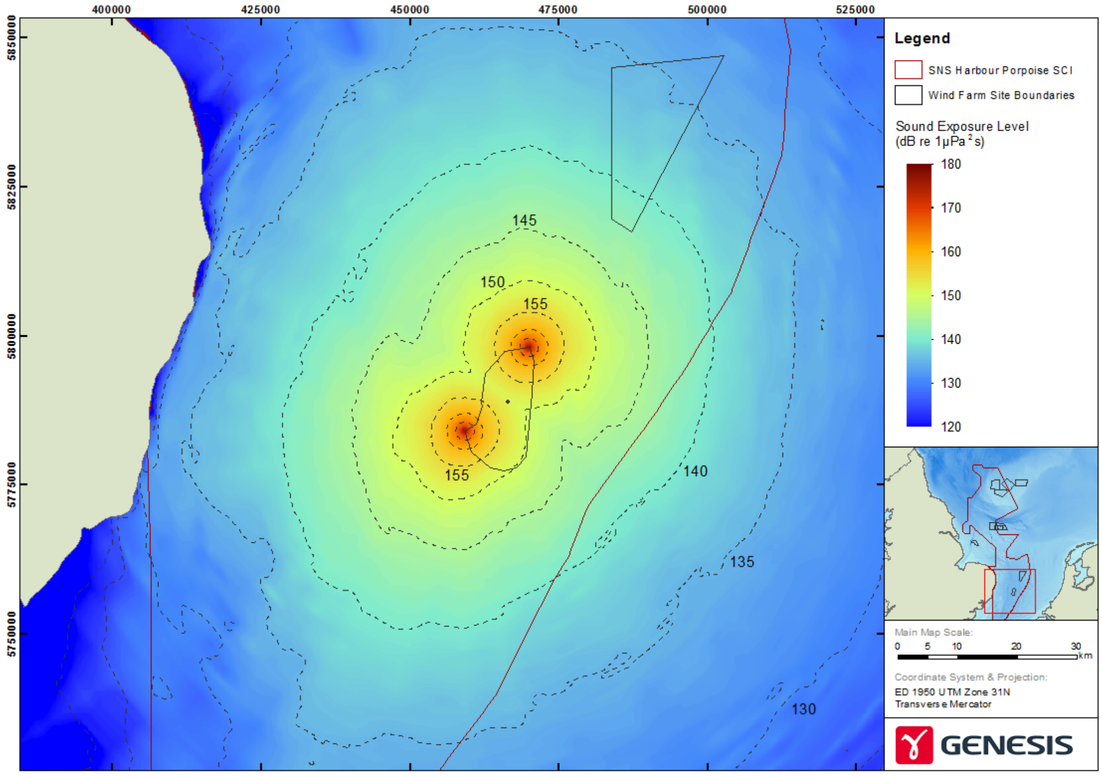

Figure D-25: Depth-averaged unweighted single-pulse SEL for concurrent pile-driving at East Anglia One model locations 1 and 2 with hammer energy of 1,200 kJ.

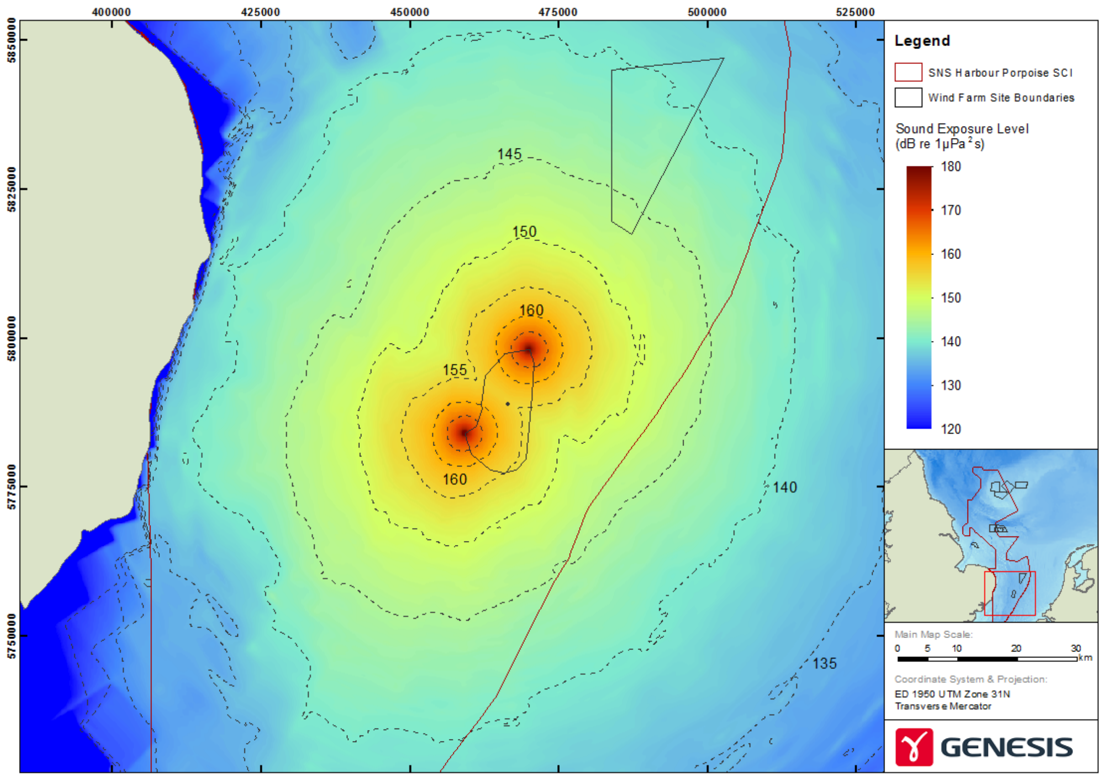

Figure D-26: Maximum-over-depth unweighted single-pulse SEL for concurrent pile-driving at East Anglia One model locations 1 and 2 with hammer energy of 1,200 kJ.

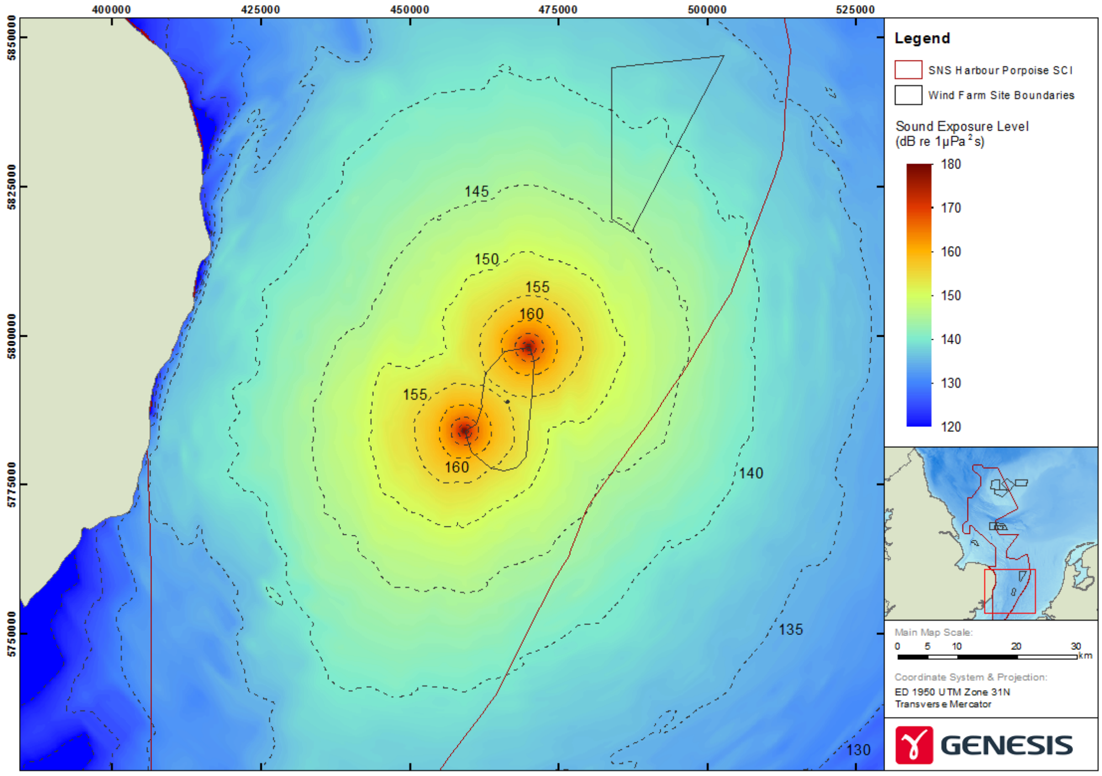

Figure D-27: Depth-averaged unweighted single-pulse SEL for concurrent pile-driving at East Anglia One model locations 1 and 2 with hammer energy of 2,400 kJ.

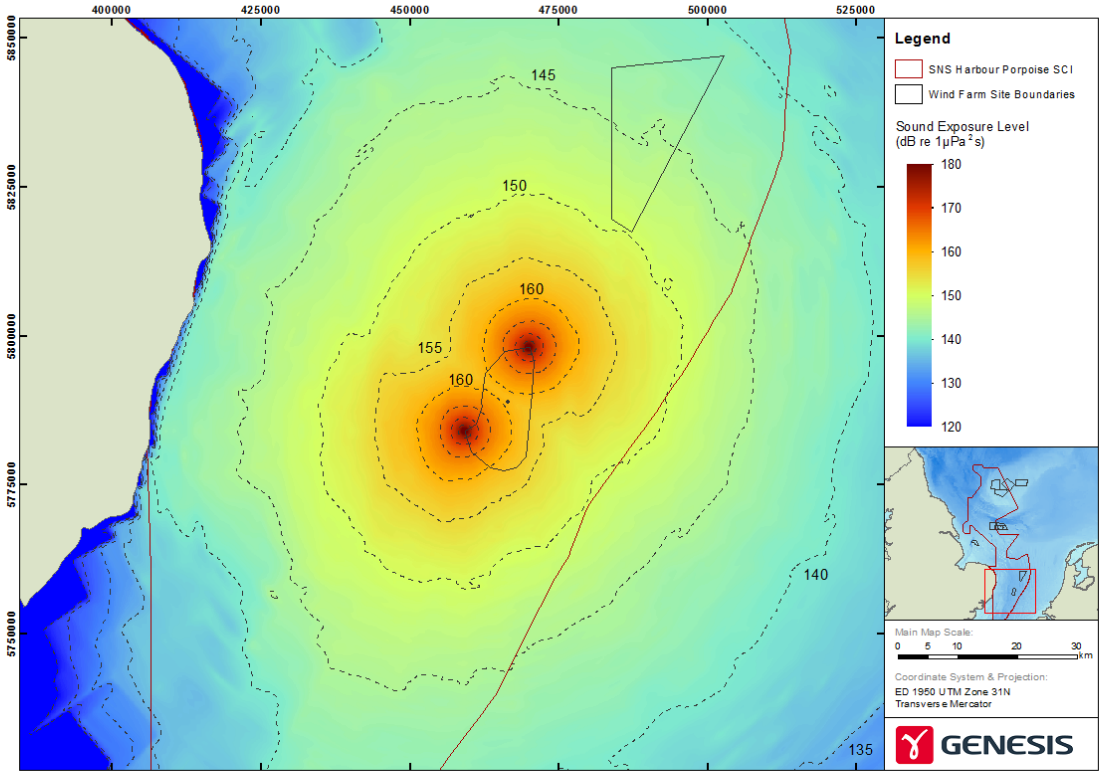

Figure D-28: Maximum-over-depth unweighted single-pulse SEL for concurrent pile-driving at East Anglia One model locations 1 and 2 with hammer energy of 2,400 kJ.

APPENDIX E: MODELLING MAPS FOR EAST ANGLIA THREE

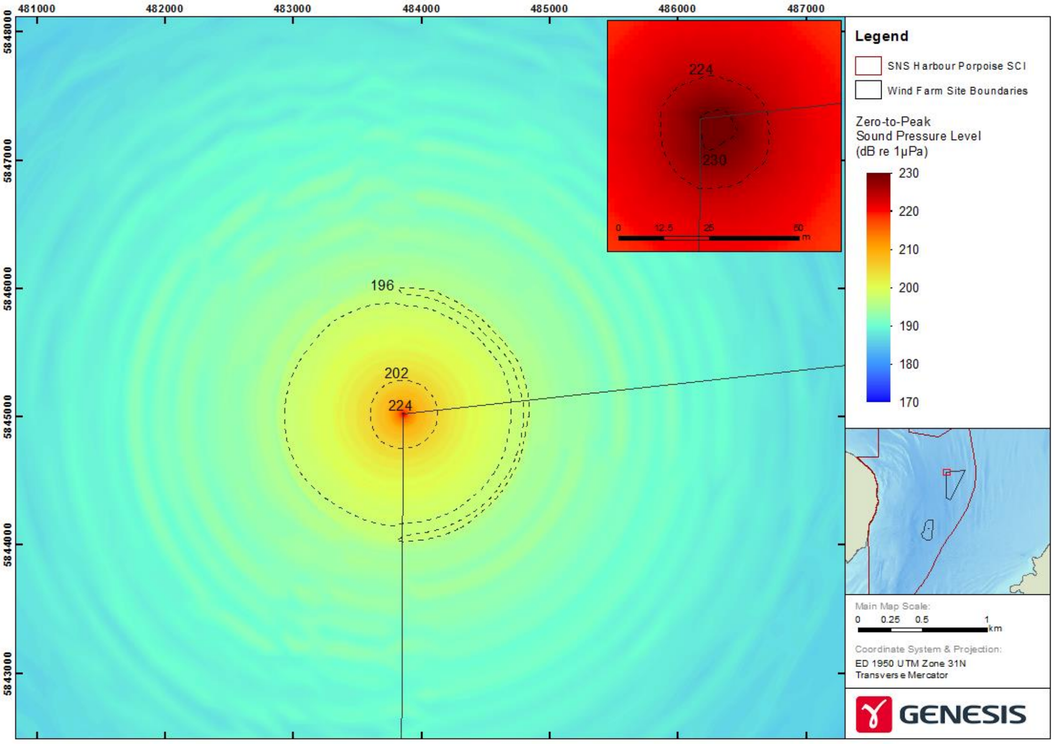

Figure E-1: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at East Anglia Three model location 1 with hammer energy of 1,200 kJ.

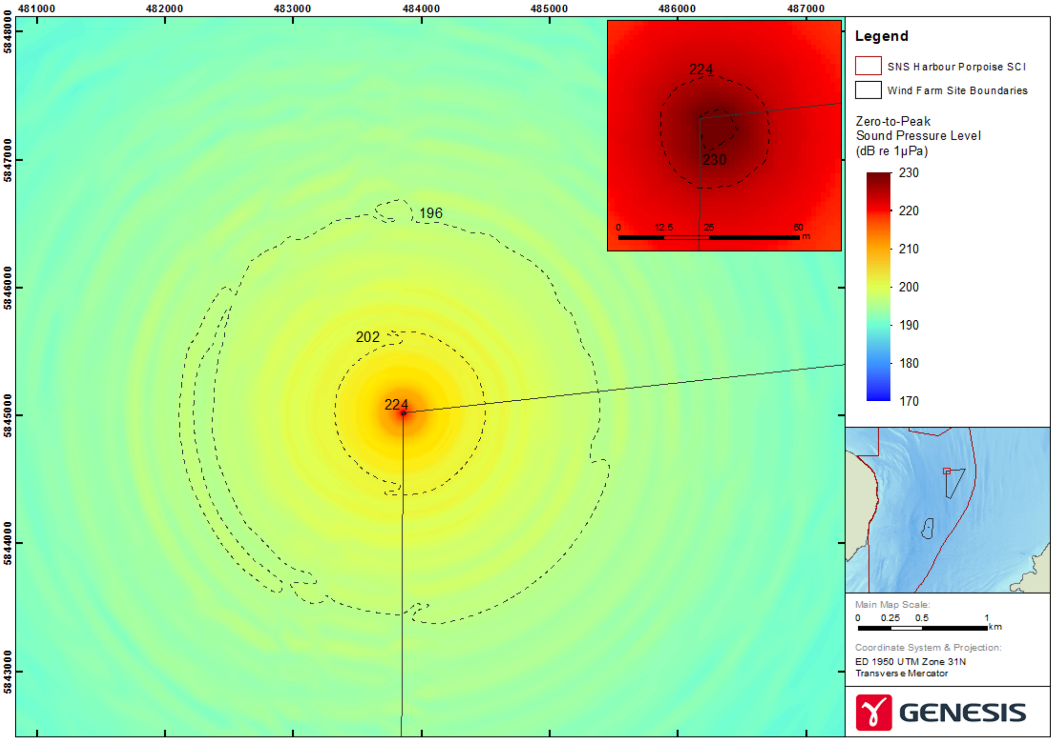

Figure E-2: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at East Anglia Three model location 1 with hammer energy of 3,000 kJ.

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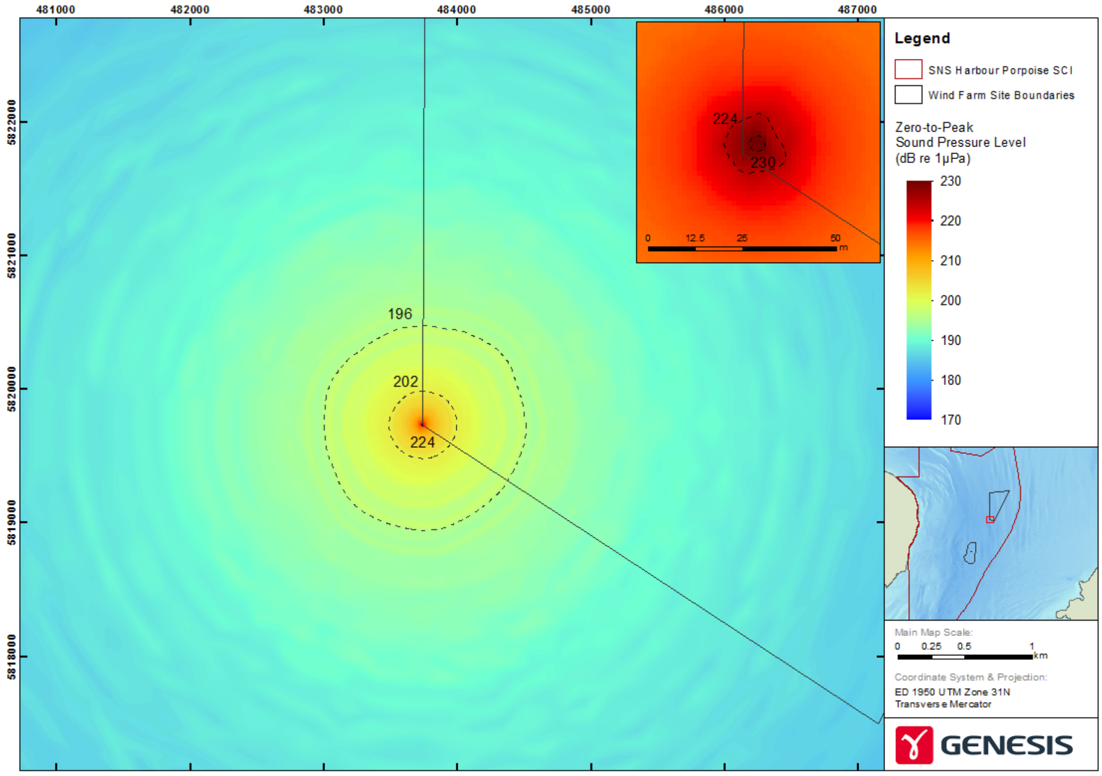

Figure E-3: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at East Anglia Three model location 2 with hammer energy of 1,200 kJ.

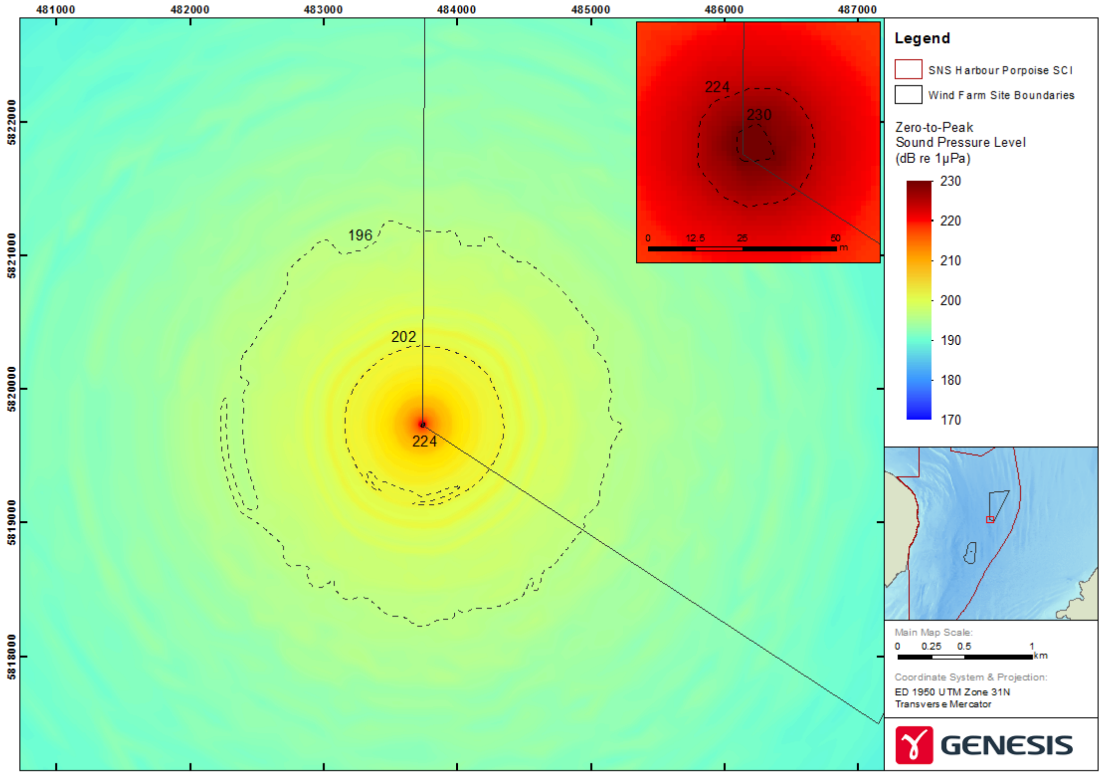

Figure E-4: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at East Anglia Three model location 2 with hammer energy of 3,000 kJ.

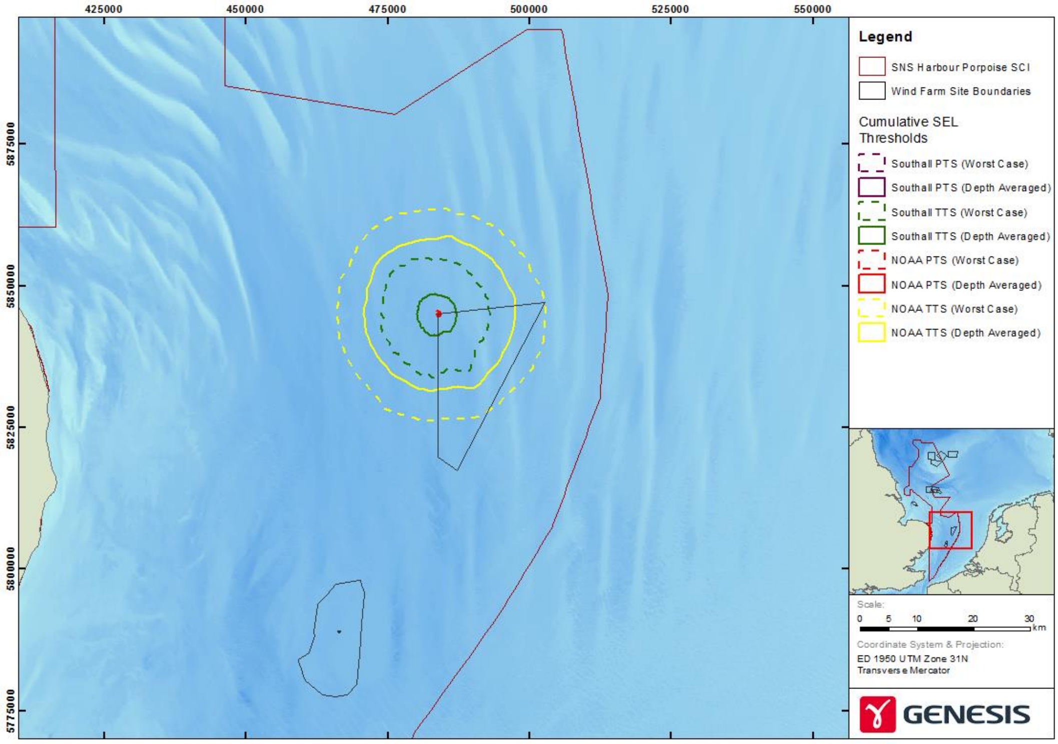

Figure E-5: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at East Anglia Three model location 1 with maximum hammer energy of 1,200 kJ.

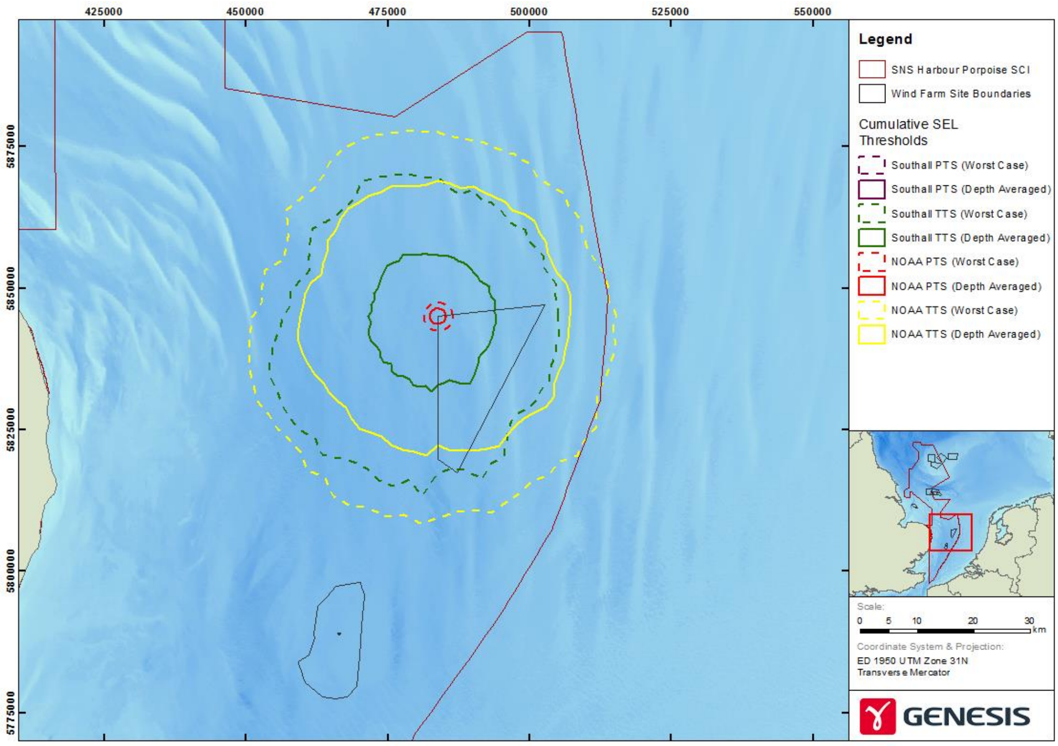

Figure E-6: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at East Anglia Three model location 1 with maximum hammer energy of 3,000 kJ.

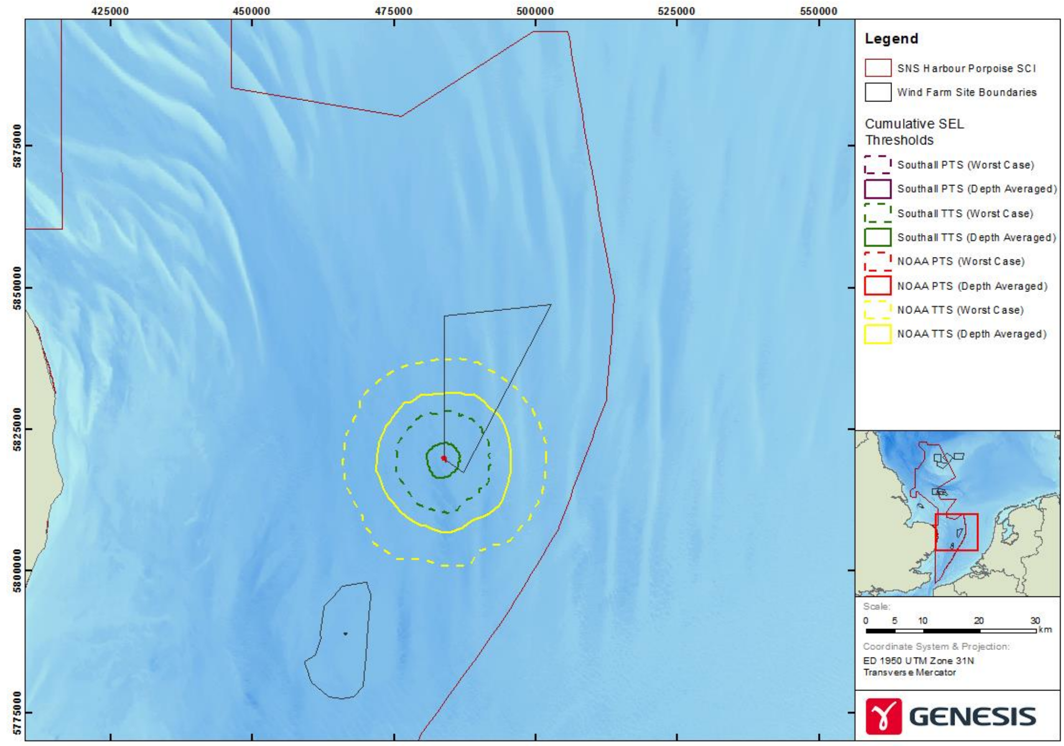

Figure E-7: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at East Anglia Three model location 2 with maximum hammer energy of 1,200 kJ.

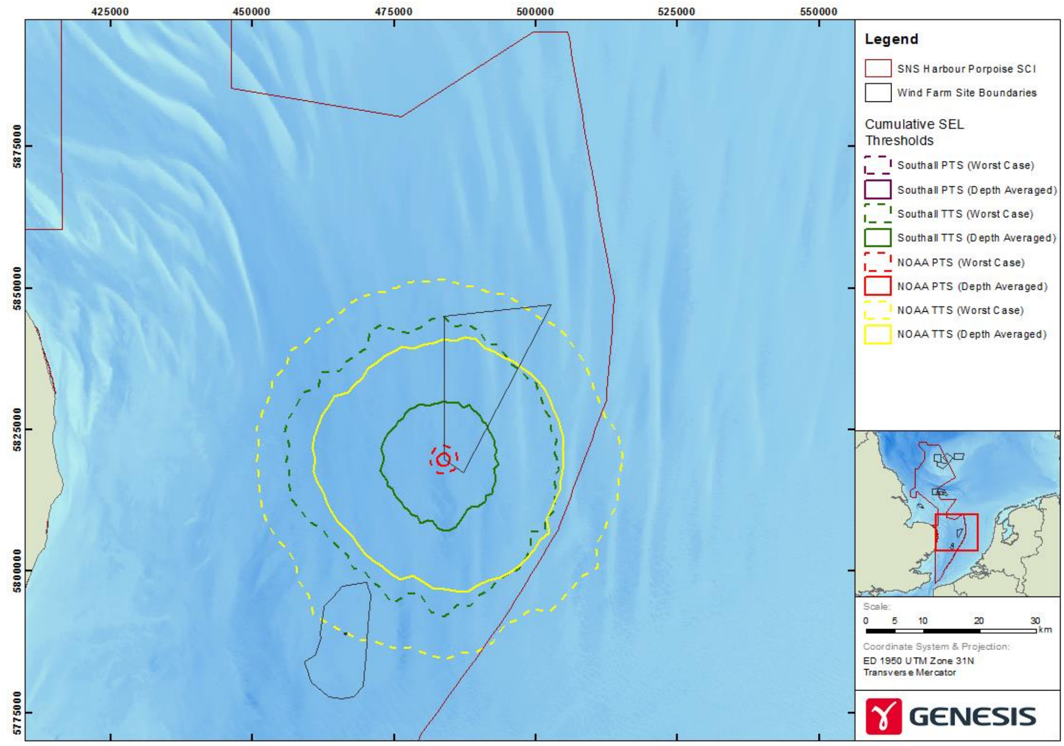

Figure E-8: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at East Anglia Three model location 2 with maximum hammer energy of 3,000 kJ.

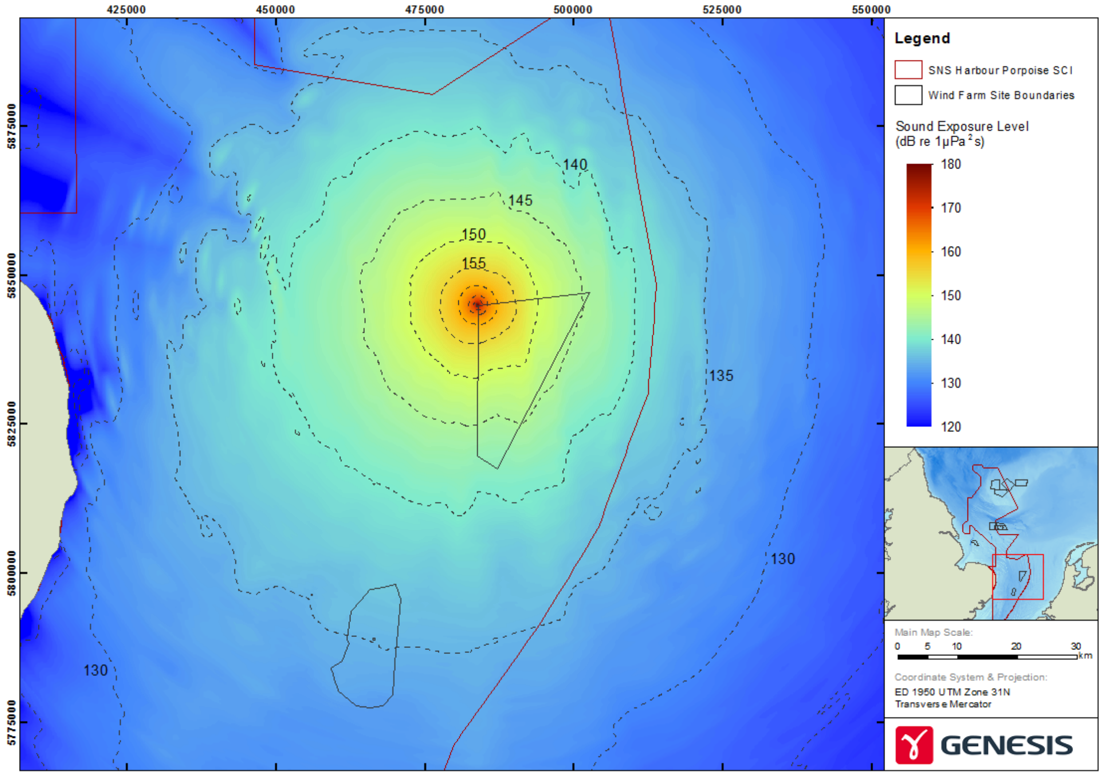

Figure E-9: Depth-averaged unweighted single-pulse SEL for pile-driving at East Anglia Three model location 1 with hammer energy of 1,200 kJ.

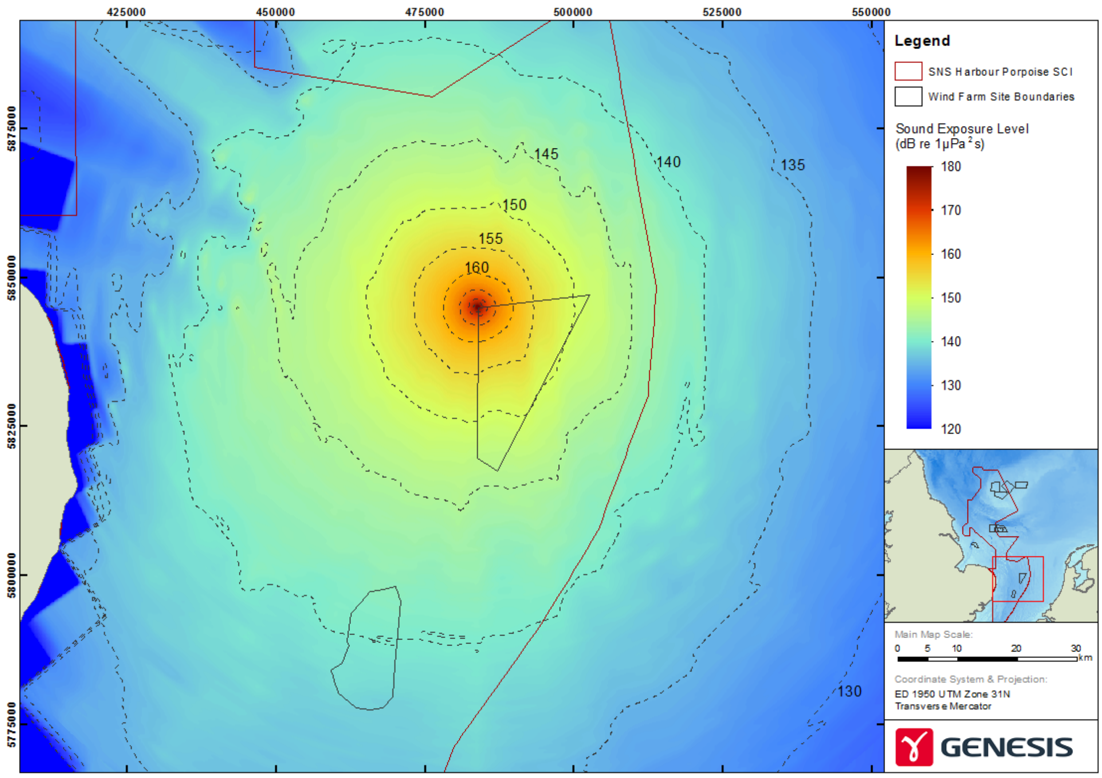

Figure E-10: Maximum-over-depth unweighted single-pulse SEL for pile-driving at East Anglia Three model location 1 with hammer energy of 1,200 kJ.

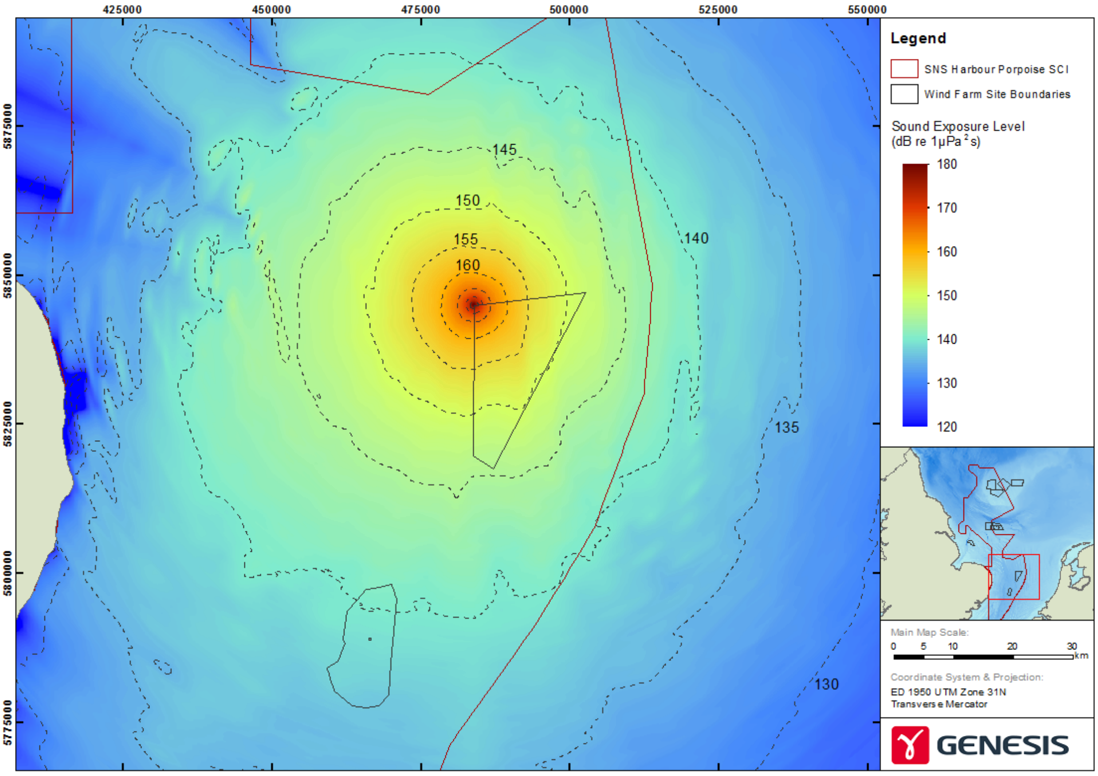

Figure E-11: Depth-averaged unweighted single-pulse SEL for pile-driving at East Anglia Three model location 1 with hammer energy of 3,000 kJ.

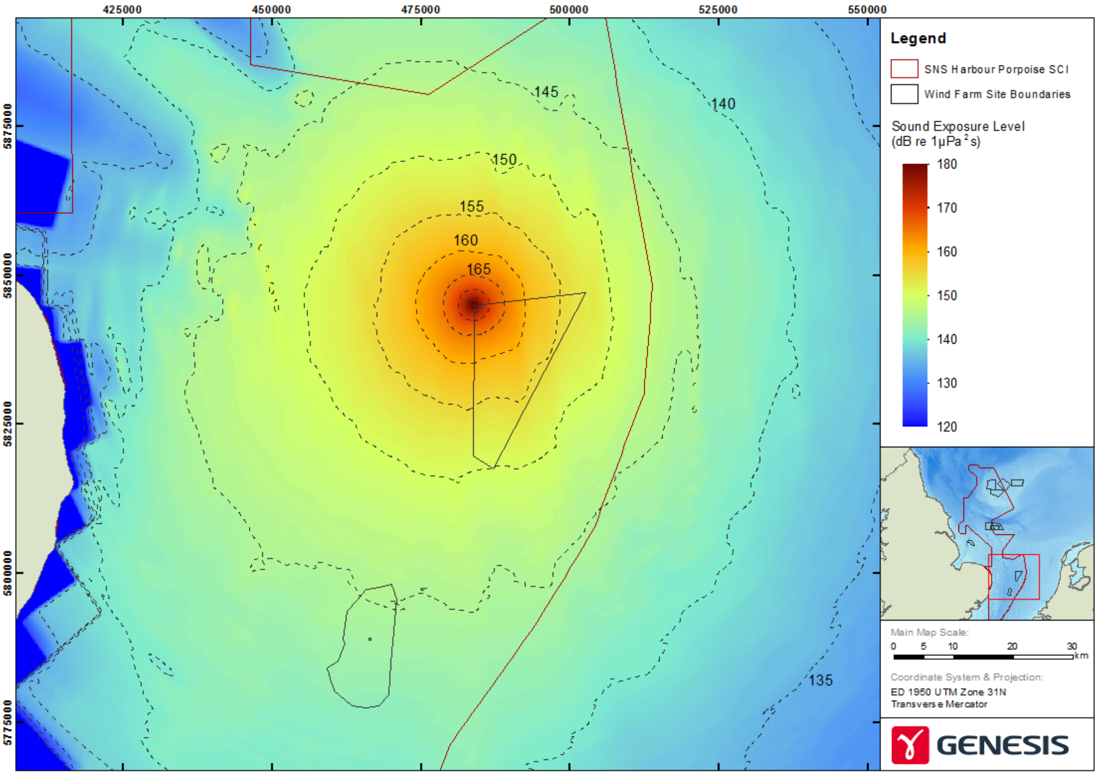

Figure E-12: Maximum-over-depth unweighted single-pulse SEL for pile-driving at East Anglia Three model location 1 with hammer energy of 3,000 kJ.

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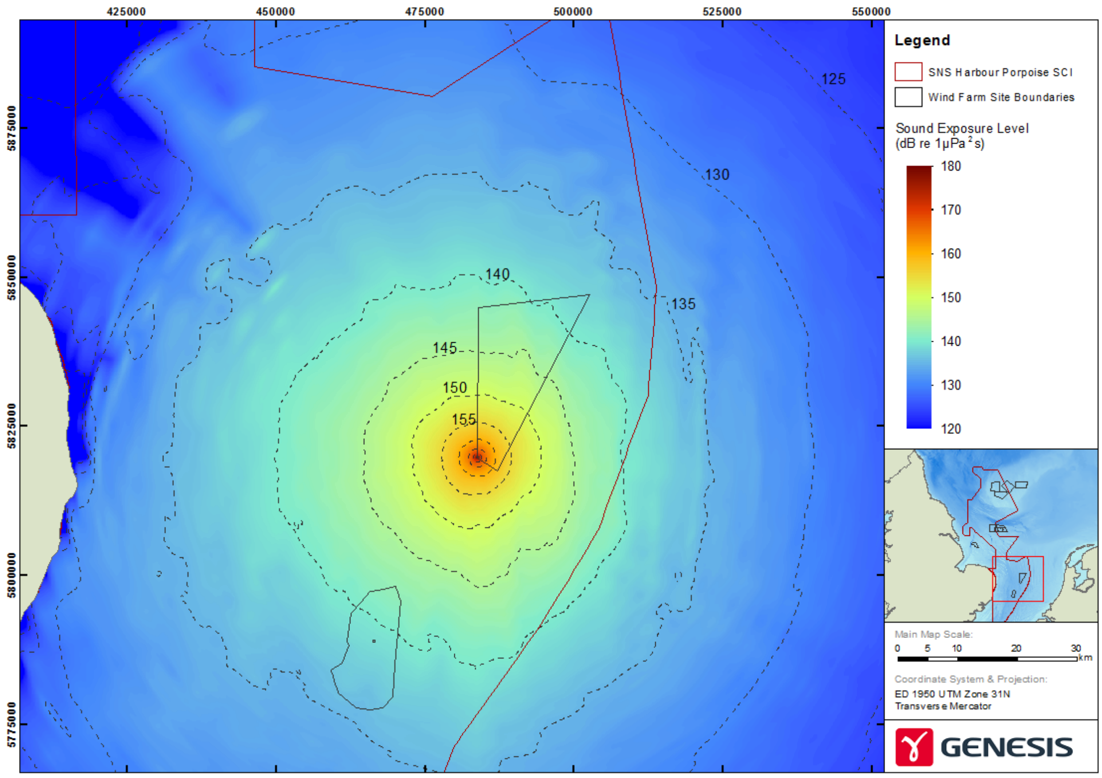

Figure E-13: Depth-averaged unweighted single-pulse SEL for pile-driving at East Anglia Three model location 2 with hammer energy of 1,200 kJ.

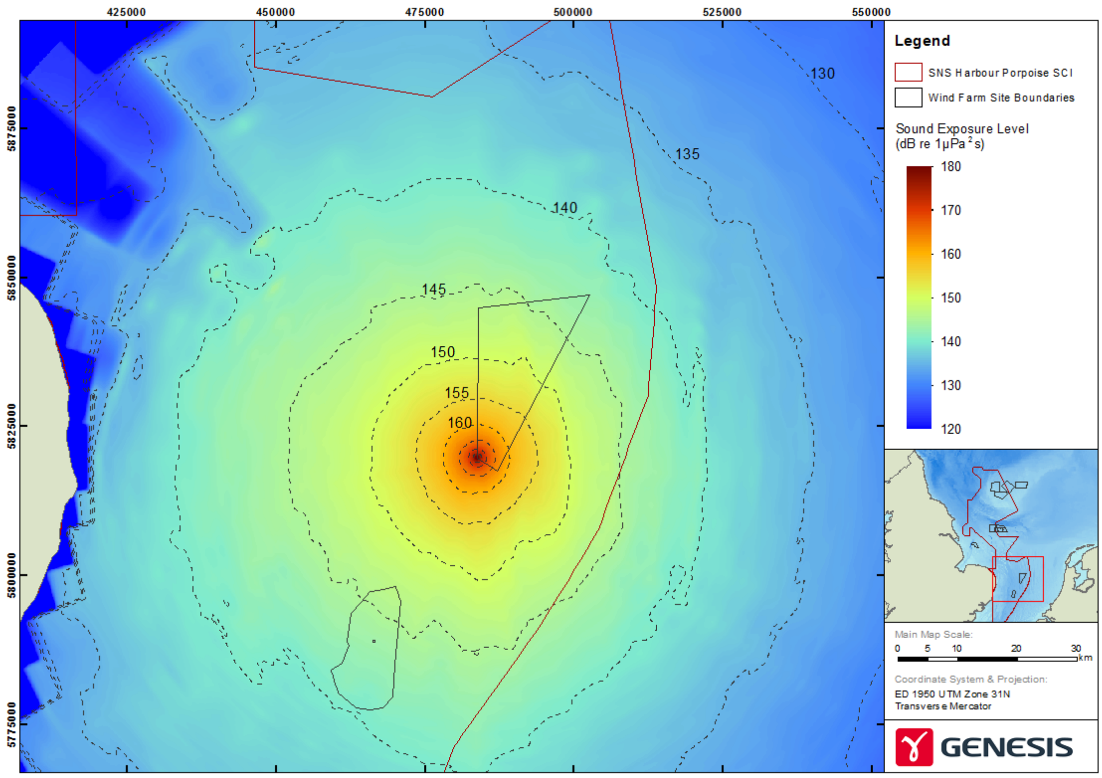

Figure E-14: Maximum-over-depth unweighted single-pulse SEL for pile-driving at East Anglia Three model location 2 with hammer energy of 1,200 kJ.

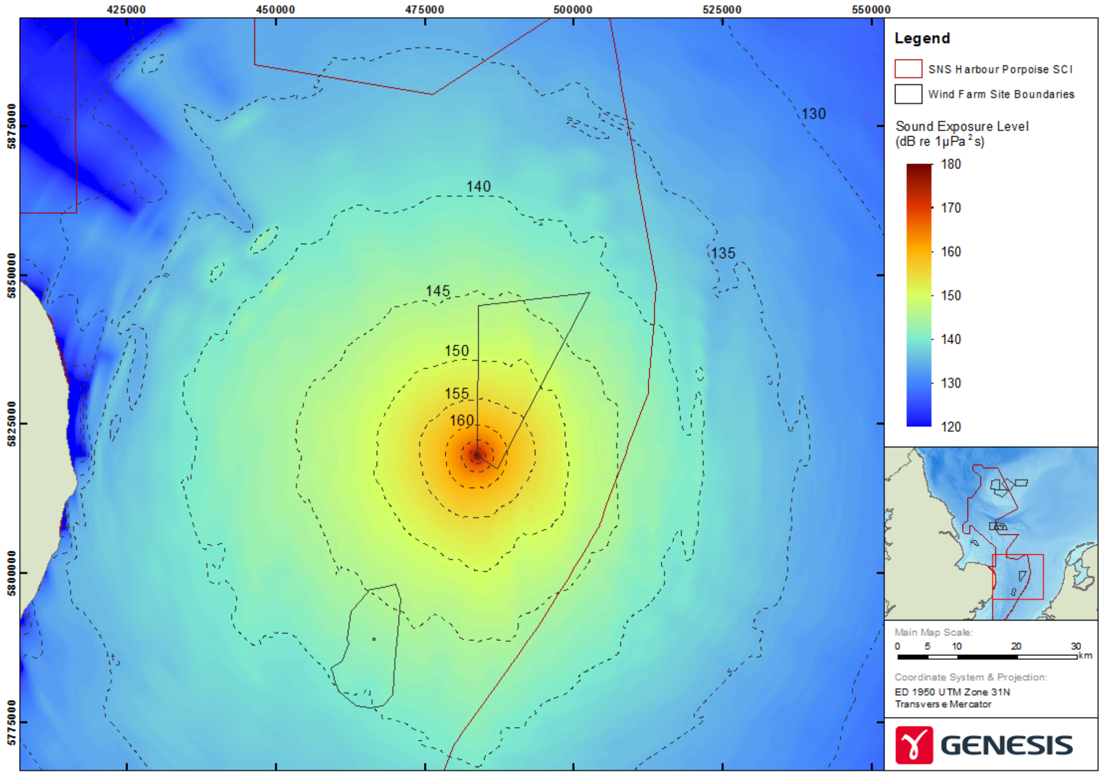

Figure E-15: Depth-averaged unweighted single-pulse SEL for pile-driving at East Anglia Three model location 2 with hammer energy of 3,000 kJ.

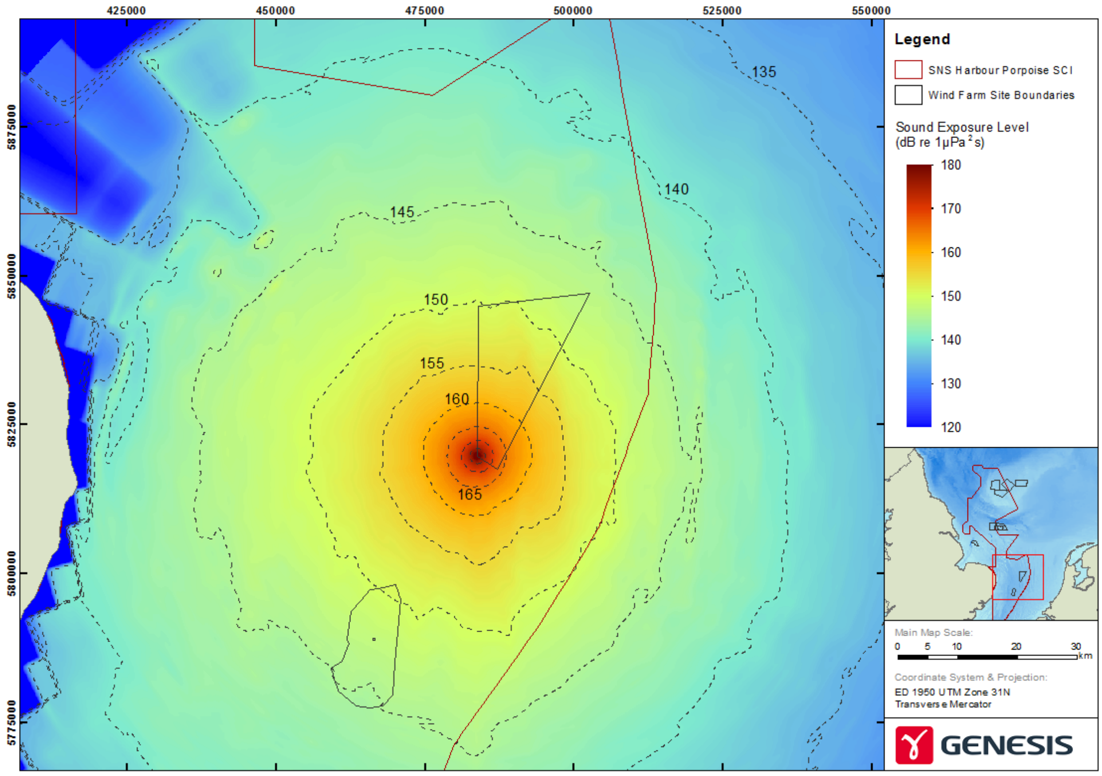

Figure E-16: Maximum-over-depth unweighted single-pulse SEL for pile-driving at East Anglia Three model location 2 with hammer energy of 3,000 kJ.

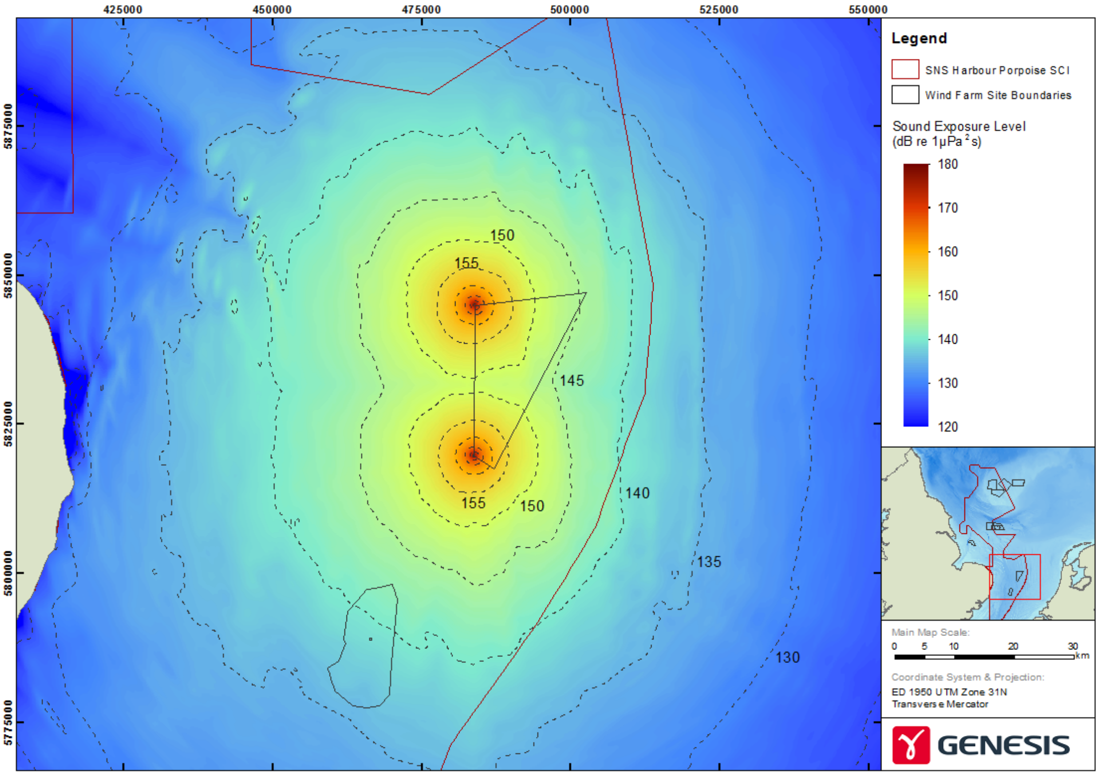

Figure E-17: Depth-averaged unweighted single-pulse SEL for concurrent pile-driving at East Anglia Three model locations 1 and 2 with hammer energy of 1,200 kJ.

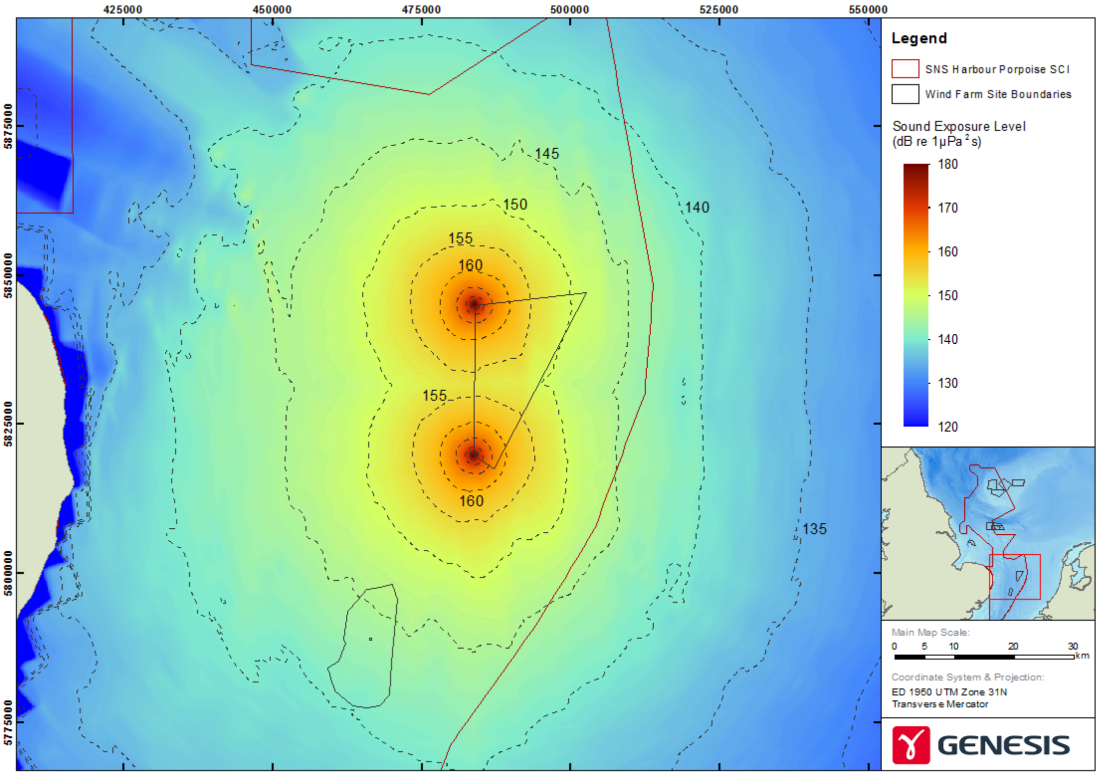

Figure E-18: Maximum-over-depth unweighted single-pulse SEL for concurrent pile-driving at East Anglia Three model locations 1 and 2 with hammer energy of 1,200 kJ.

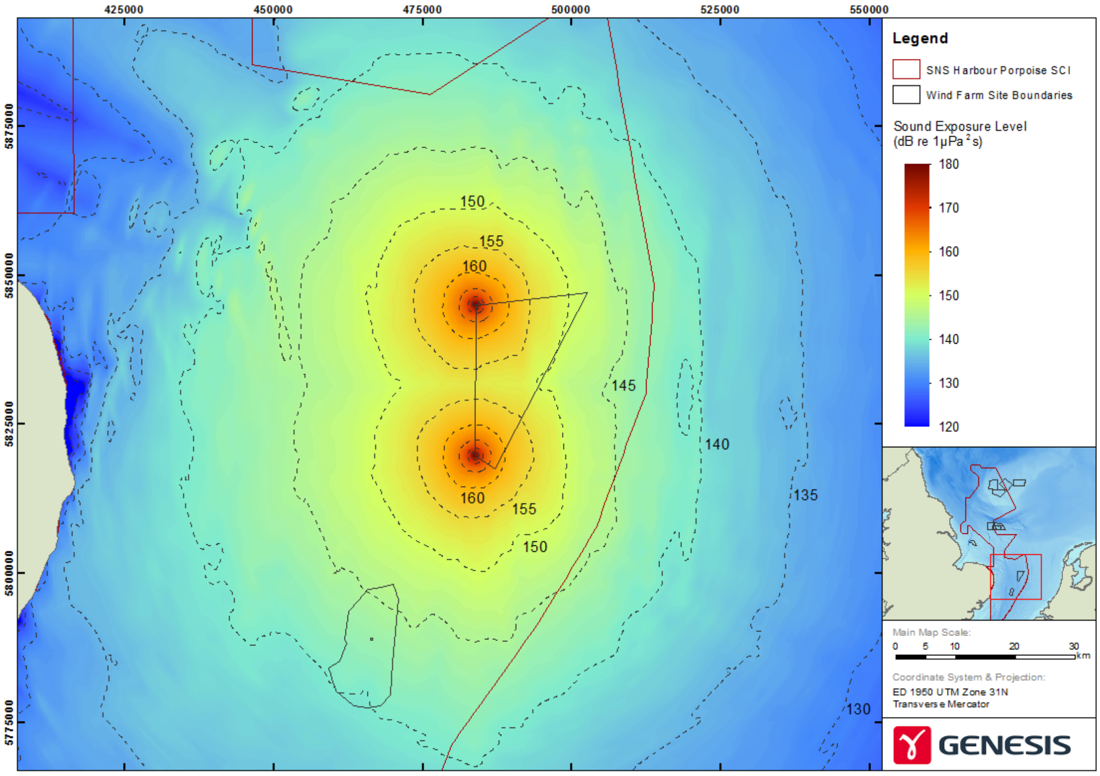

Figure E-19: Depth-averaged unweighted single-pulse SEL for concurrent pile-driving at East Anglia Three model locations 1 and 2 with hammer energy of 3,000 kJ.

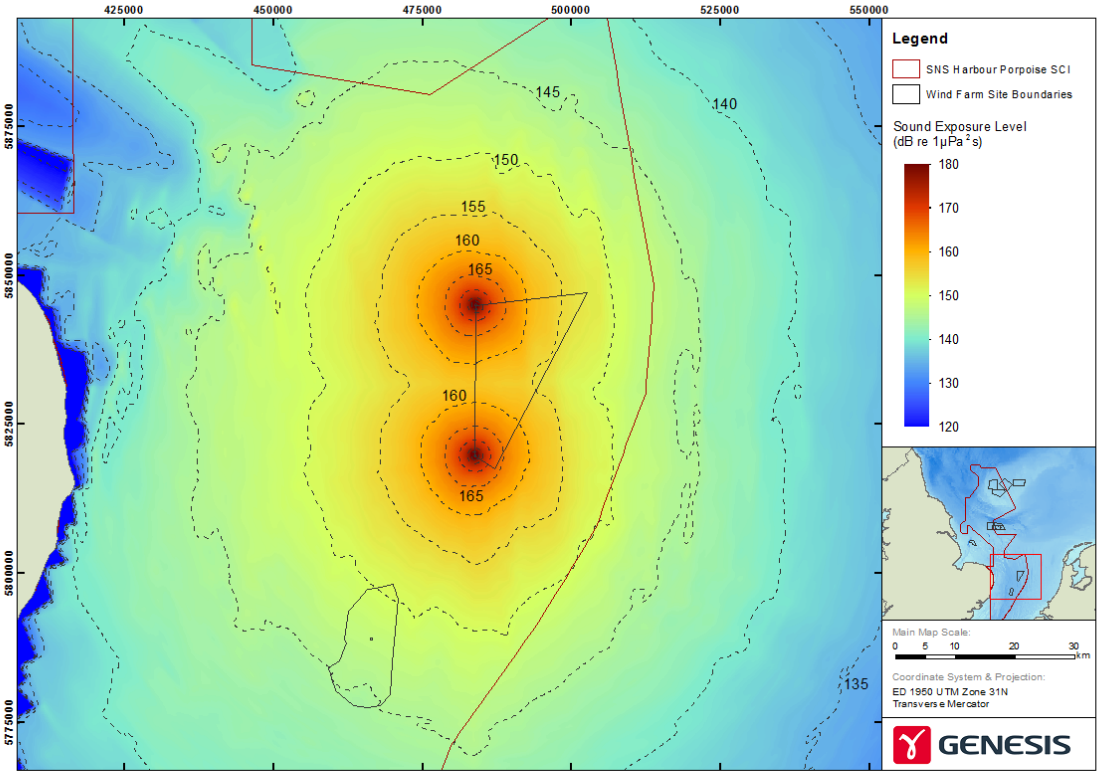

Figure E-20: Maximum-over-depth unweighted single-pulse SEL for concurrent pile-driving at East Anglia Three model locations 1 and 2 with hammer energy of 3,000 kJ.

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APPENDIX F: MODELLING MAPS FOR HORNSEA ONE

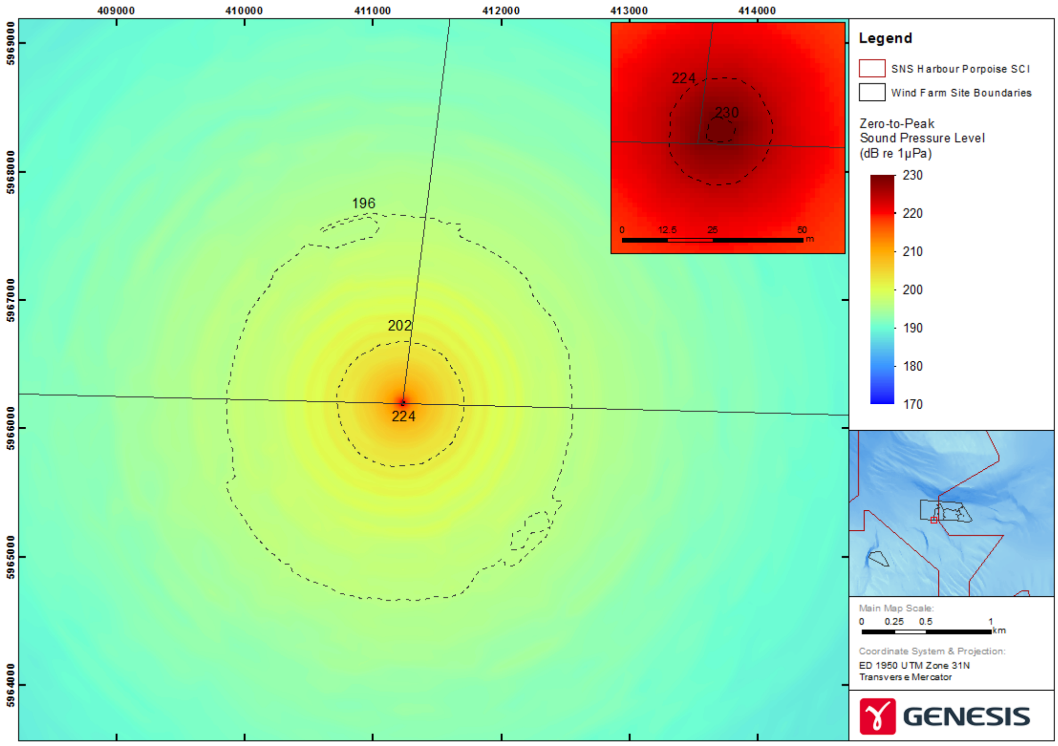

Figure F-1: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Hornsea One model location 1 with hammer energy of 2,300 kJ.

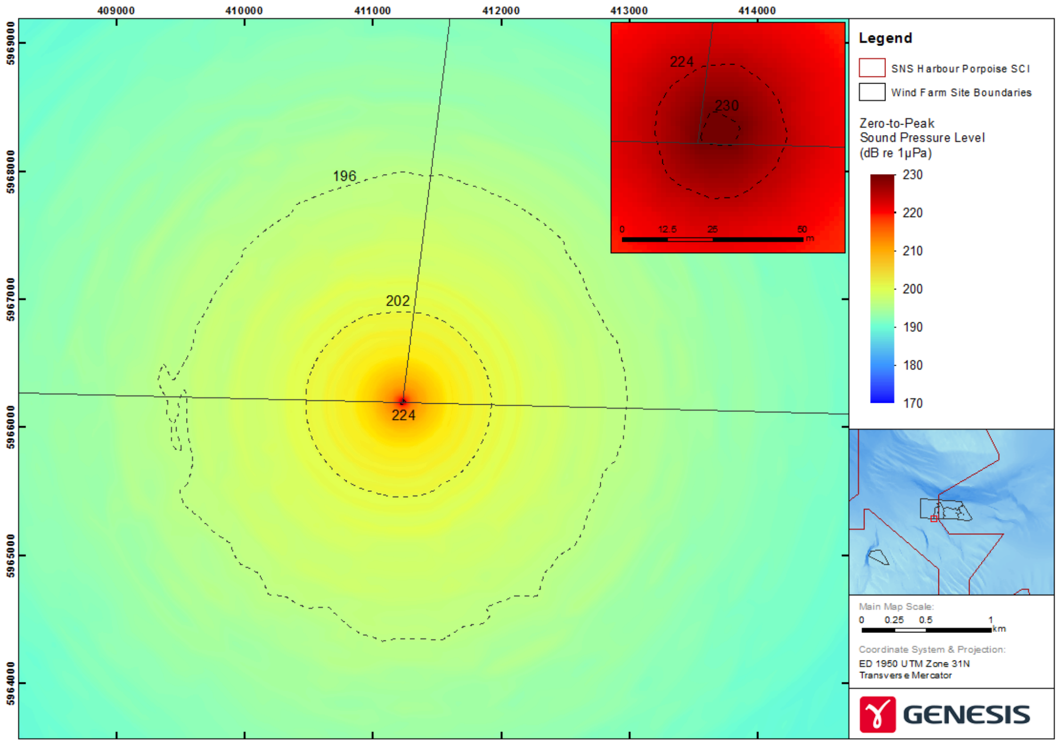

Figure F-2: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Hornsea One model location 1 with hammer energy of 3,000 kJ.

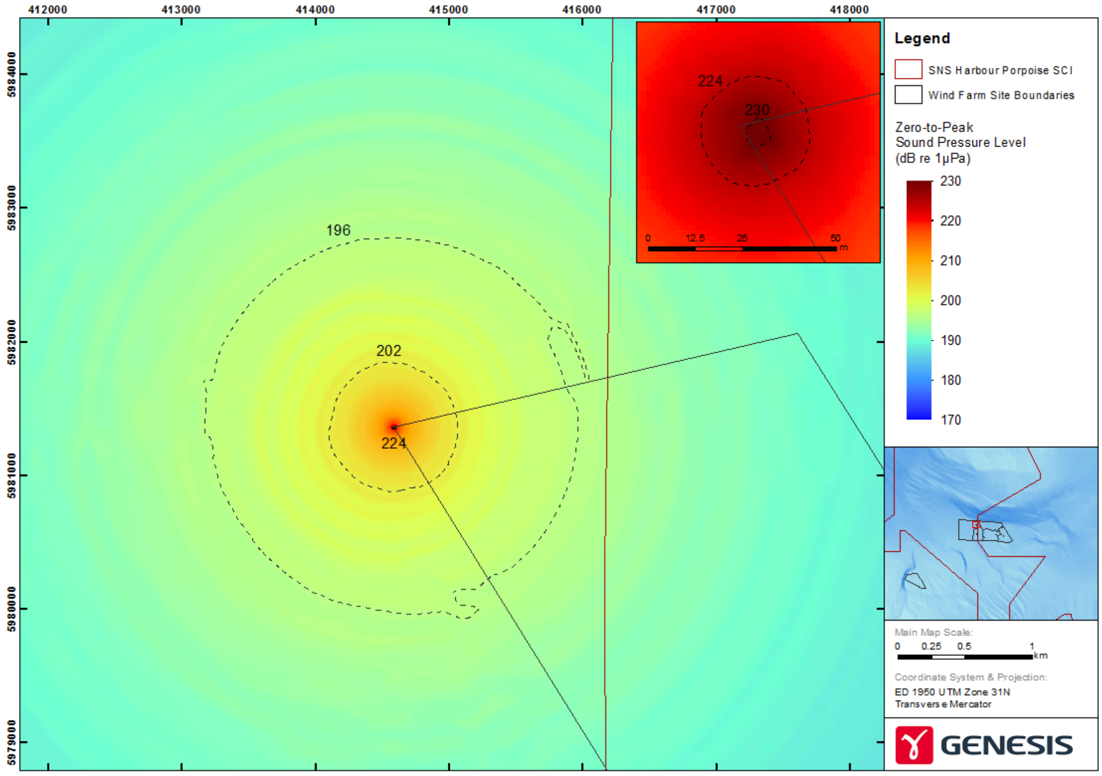

Figure F-3: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Hornsea One model location 2 with hammer energy of 2,300 kJ.

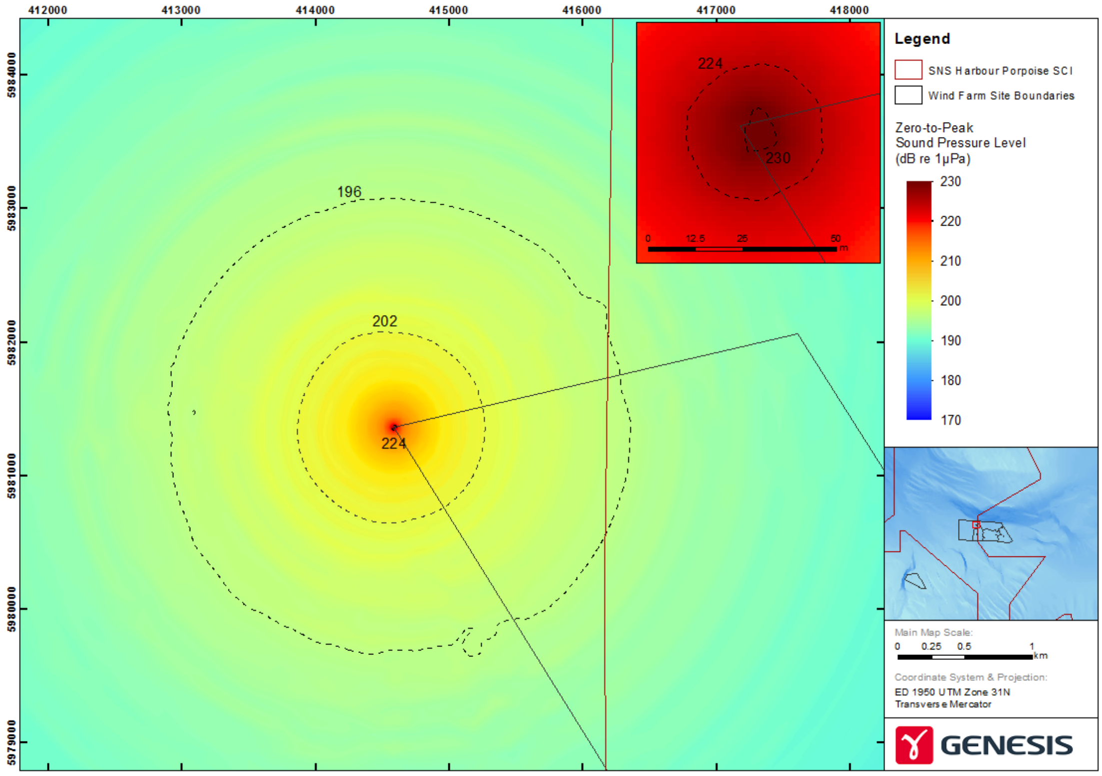

Figure F-4: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Hornsea One model location 2 with hammer energy of 3,000 kJ.

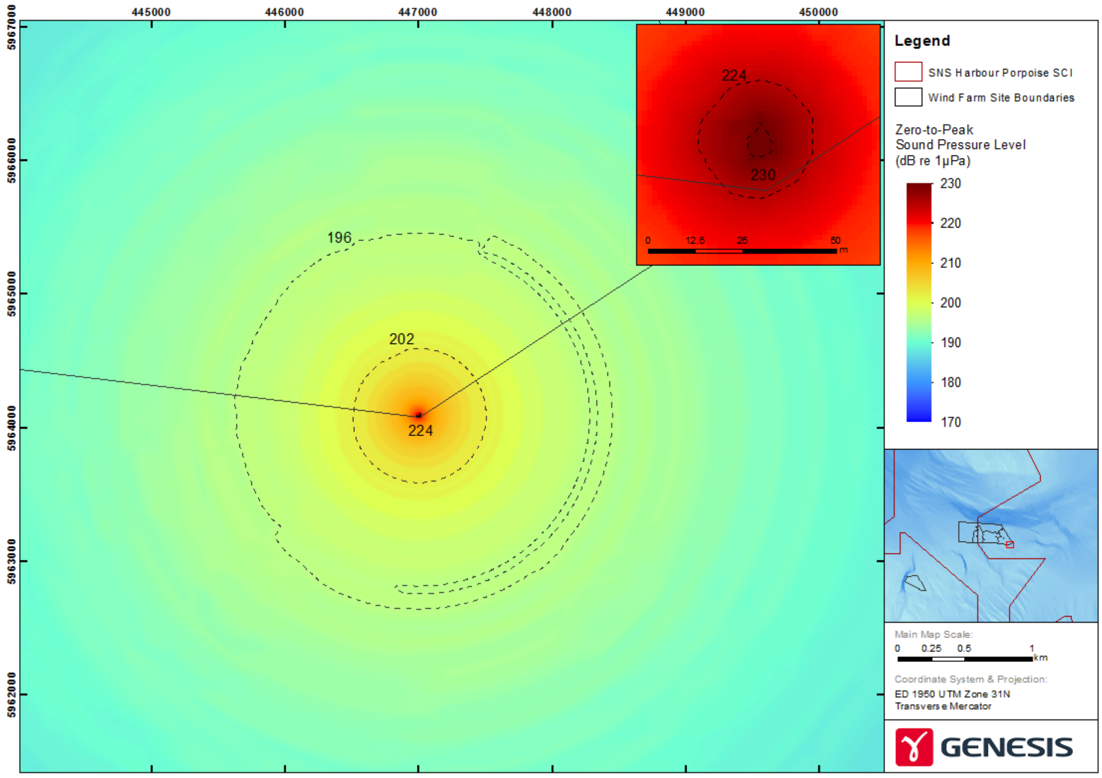

Figure F-5: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Hornsea One model location 3 with hammer energy of 2,300 kJ.

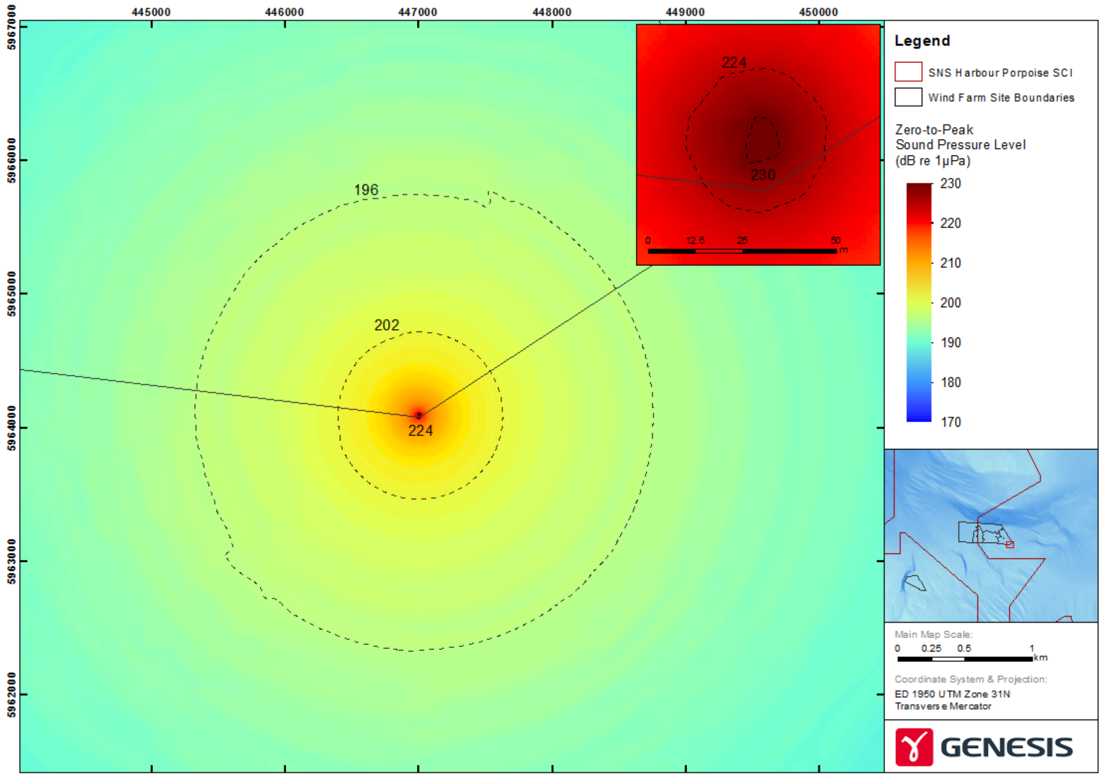

Figure F-6: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Hornsea One model location 3 with hammer energy of 3,000 kJ.

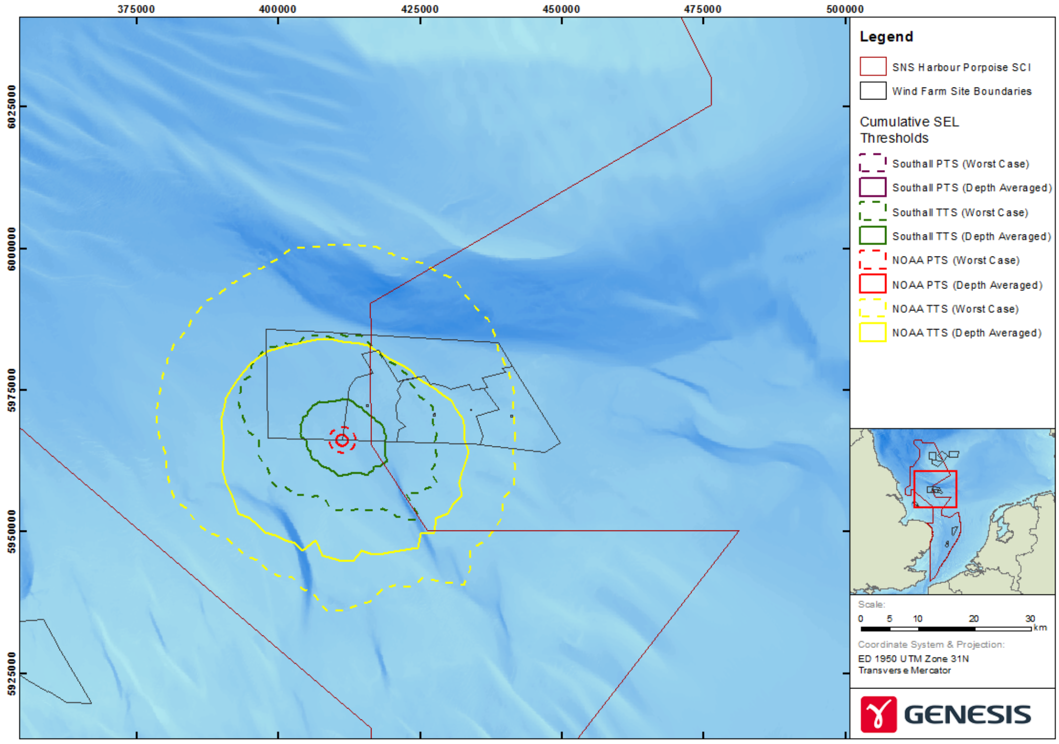

Figure F-7: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Hornsea One model location 1 with maximum hammer energy of 2,300 kJ.

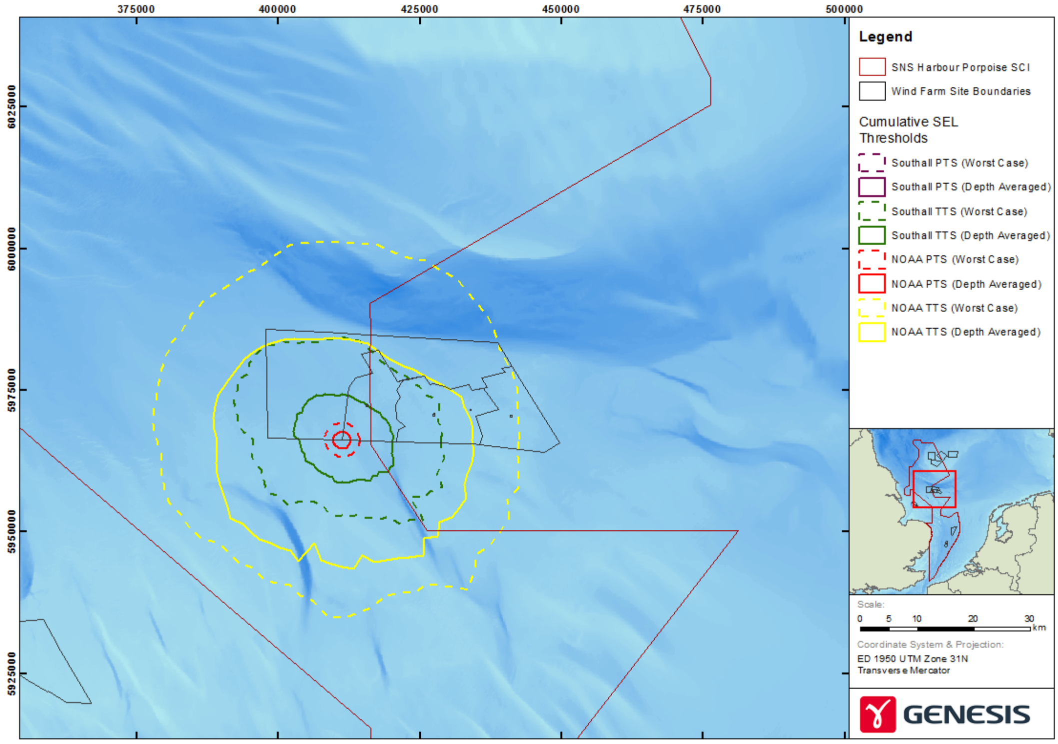

Figure F-8: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Hornsea One model location 1 with maximum hammer energy of 3,000 kJ.

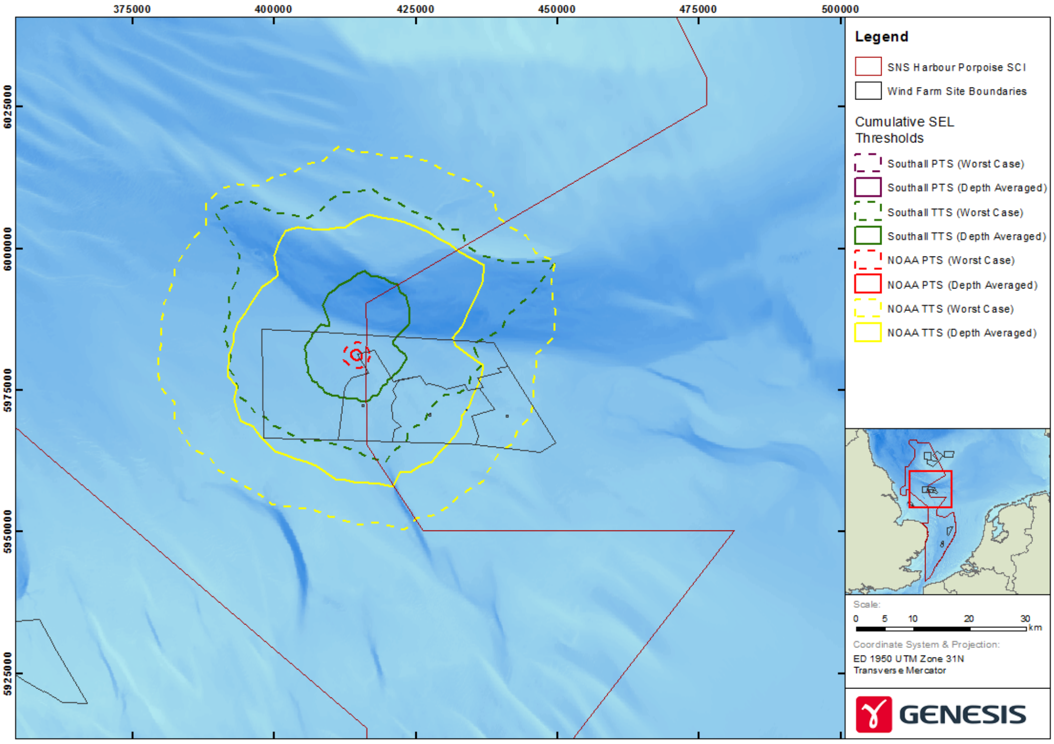

Figure F-9: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Hornsea One model location 2 with maximum hammer energy of 2,300 kJ.

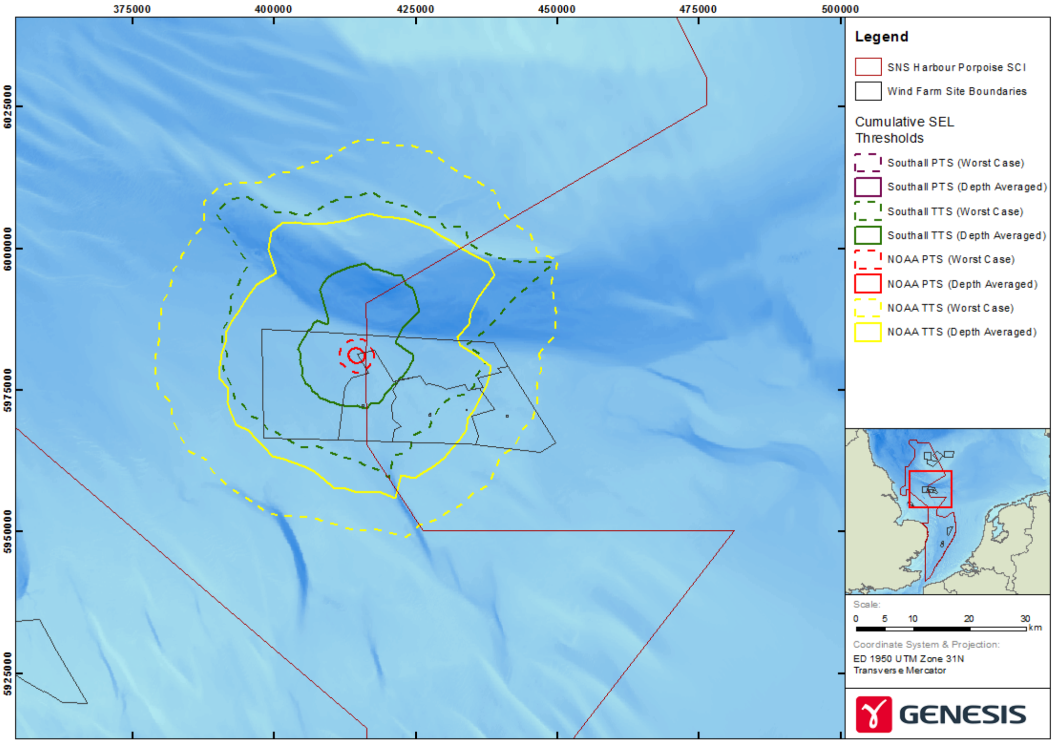

Figure F-10: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Hornsea One model location 2 with maximum hammer energy of 3,000 kJ.

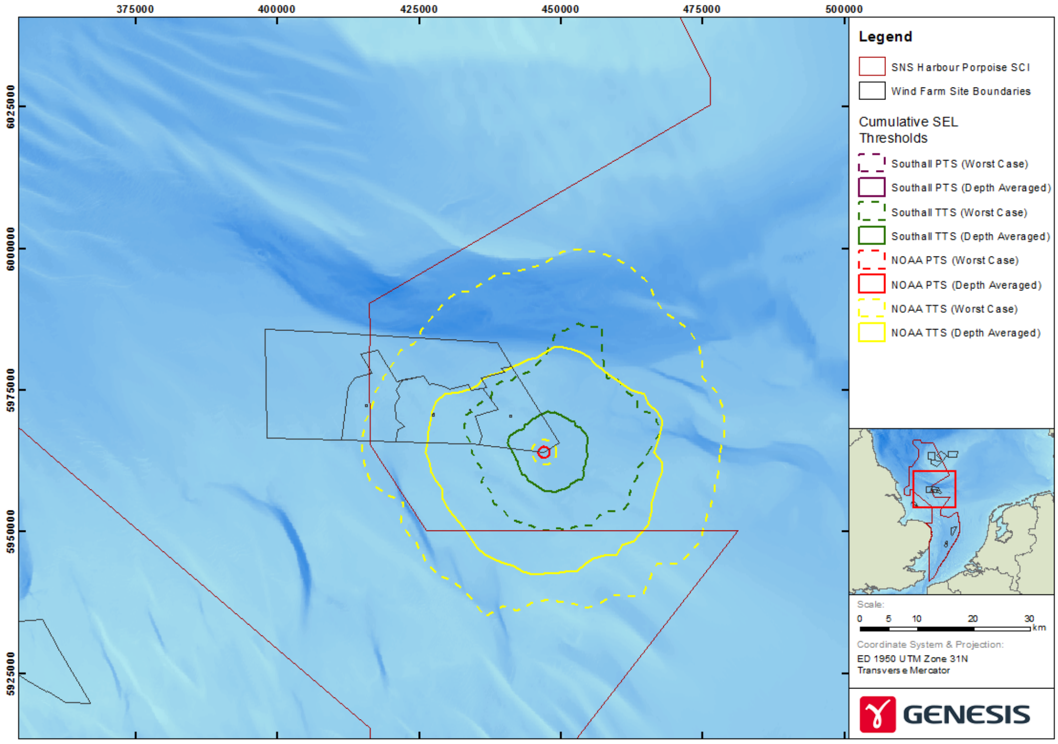

Figure F-11: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Hornsea One model location 3 with maximum hammer energy of 2,300 kJ.

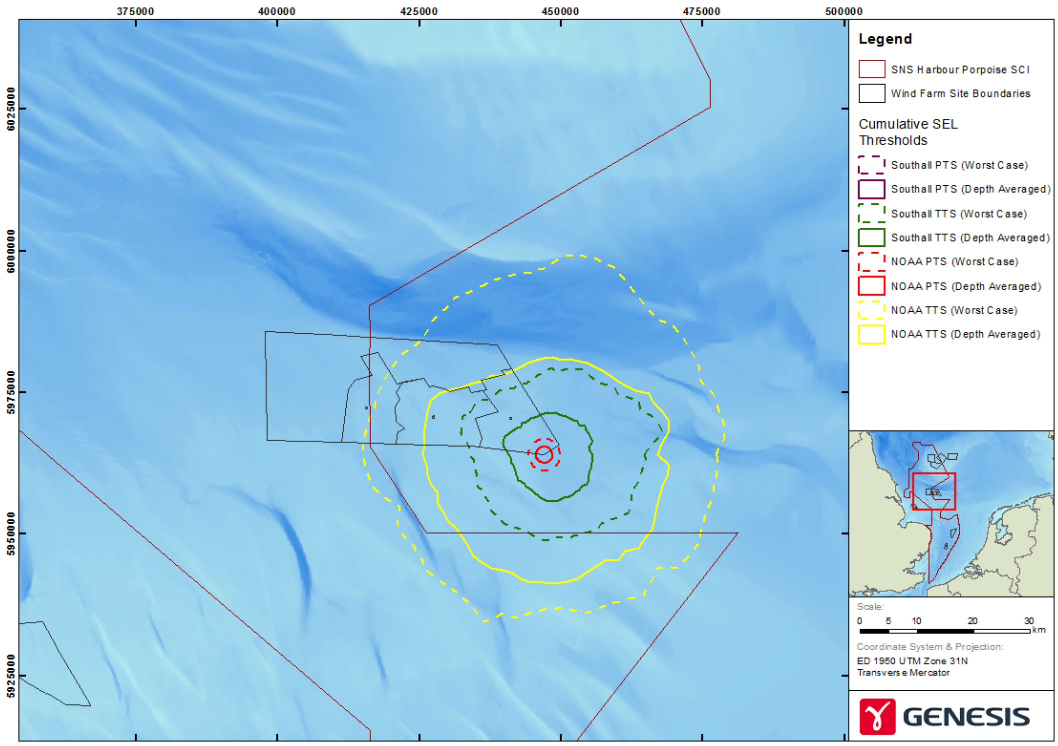

Figure F-12: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Hornsea One model location 3 with maximum hammer energy of 3,000 kJ.

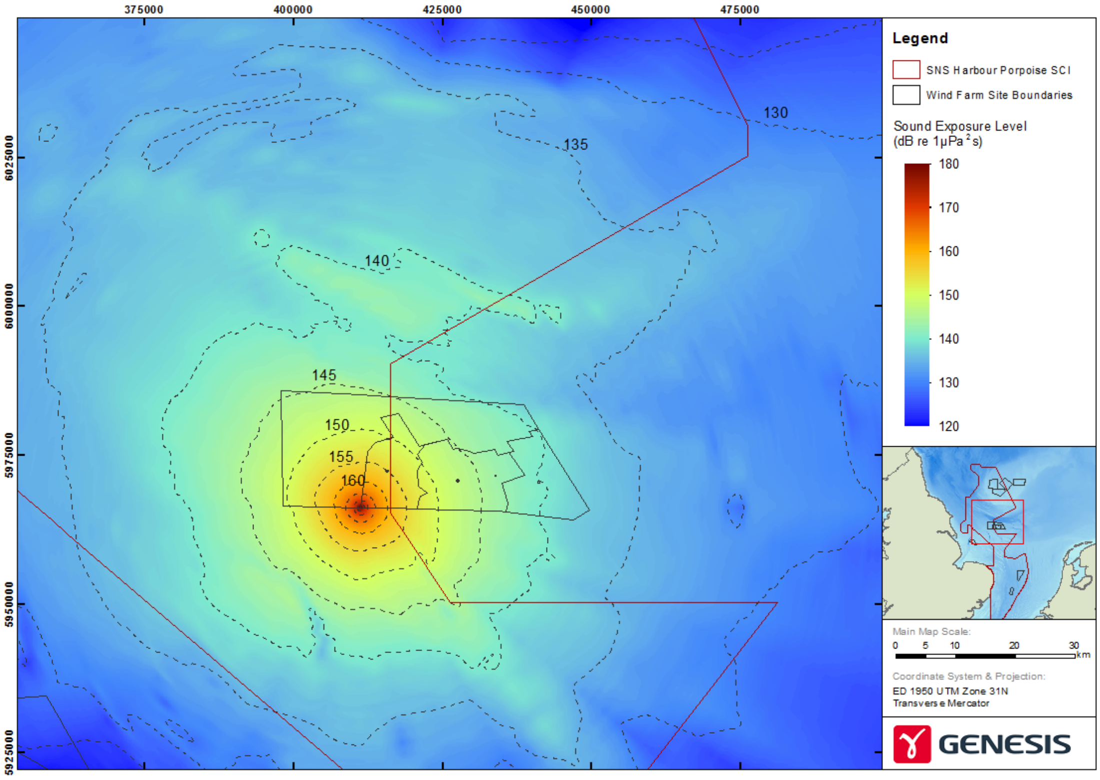

Figure F-13: Depth-averaged unweighted single-pulse SEL for pile-driving at Hornsea One model location 1 with hammer energy of 2,300 kJ.

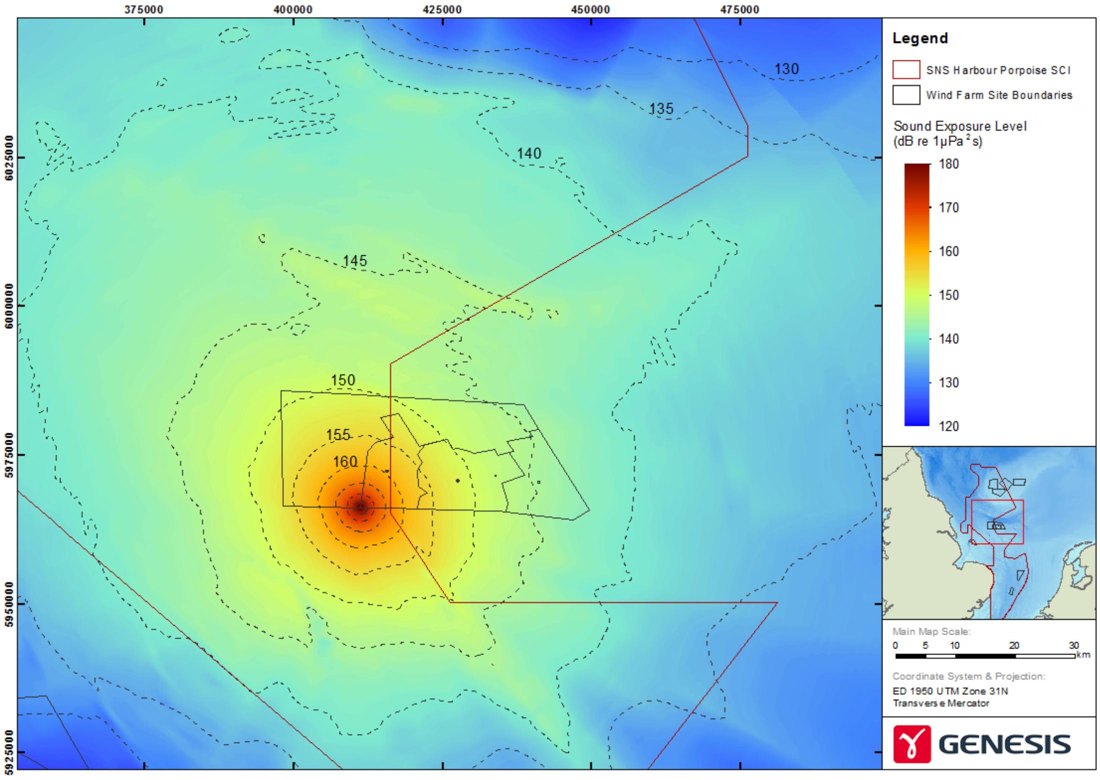

Figure F-14: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Hornsea One model location 1 with hammer energy of 2,300 kJ.

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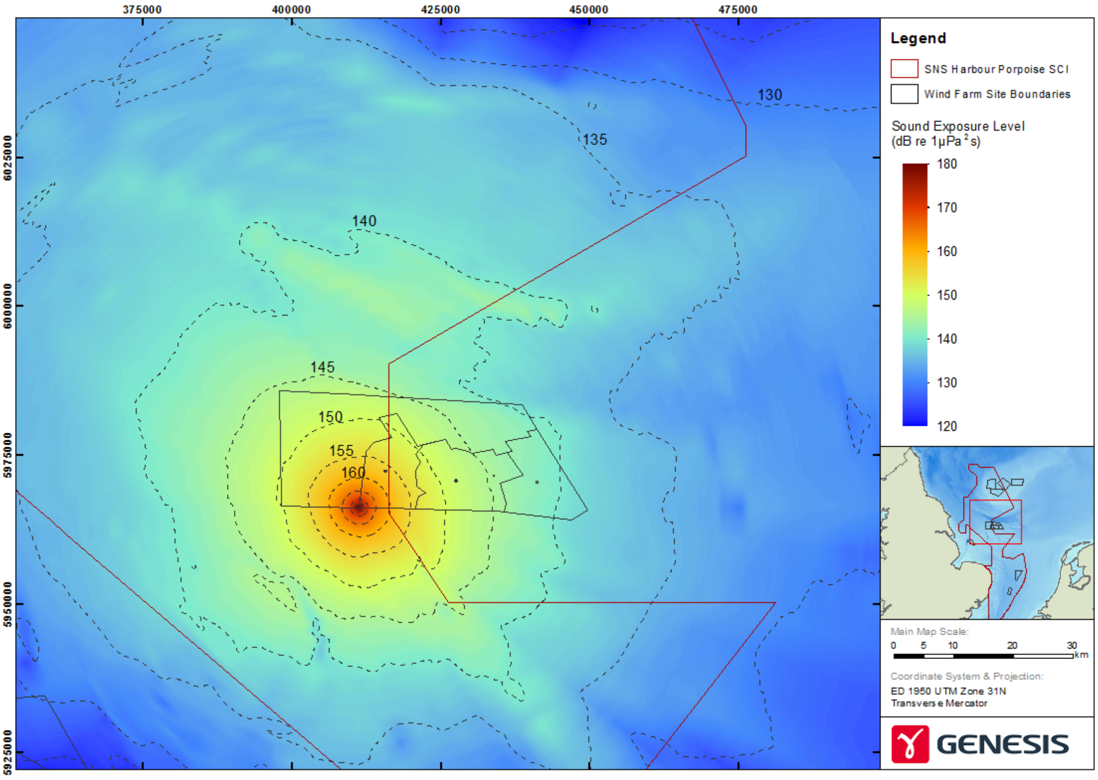

Figure F-15: Depth-averaged unweighted single-pulse SEL for pile-driving at Hornsea One model location 1 with hammer energy of 3,000 kJ.

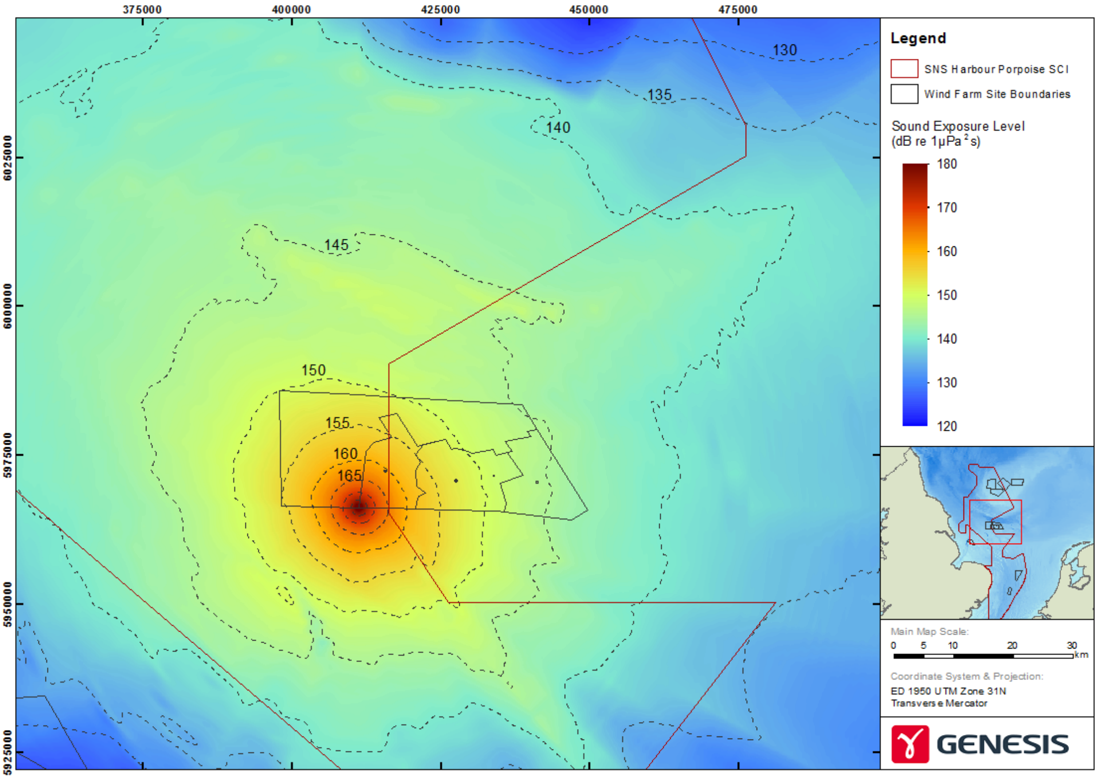

Figure F-16: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Hornsea One model location 1 with hammer energy of 3,000 kJ.

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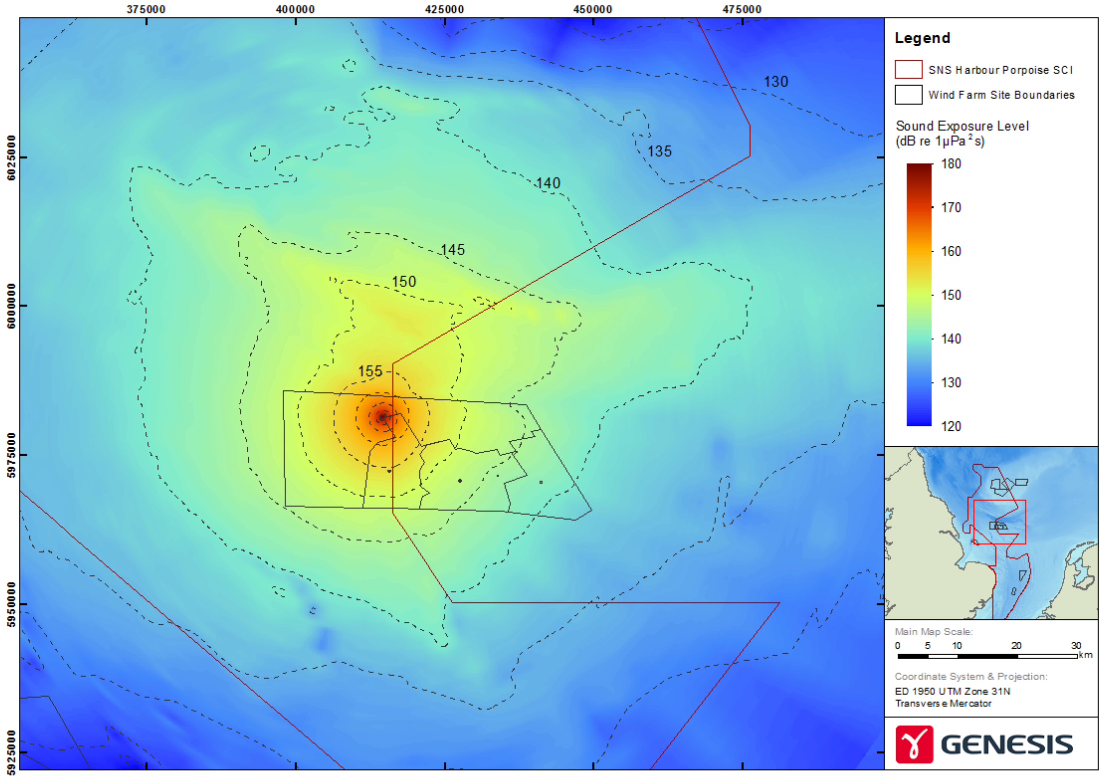

Figure F-17: Depth-averaged unweighted single-pulse SEL for pile-driving at Hornsea One model location 2 with hammer energy of 2,300 kJ.

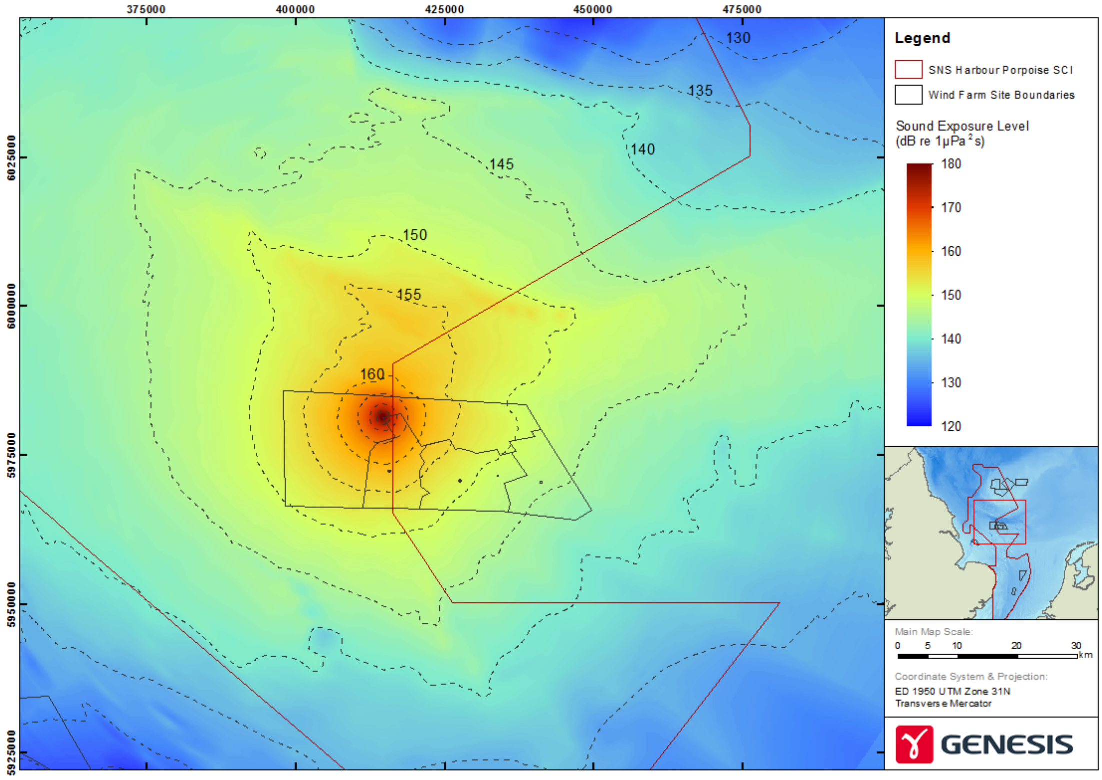

Figure F-18: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Hornsea One model location 2 with hammer energy of 2,300 kJ.

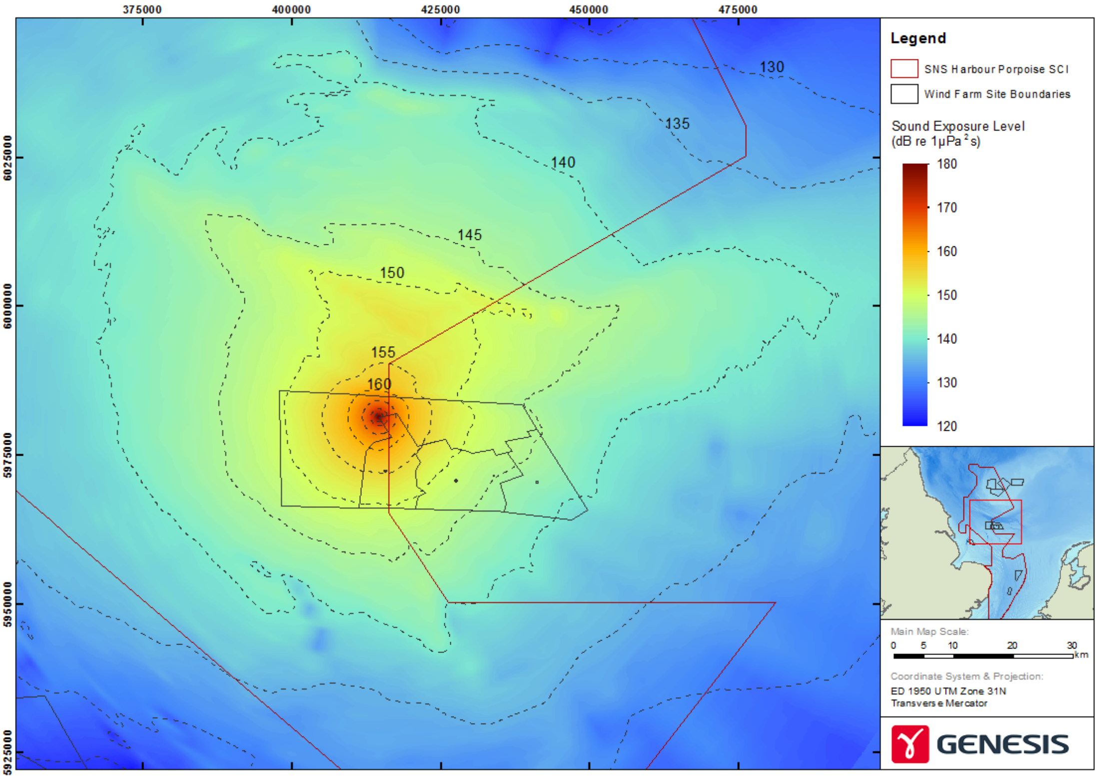

Figure F-19: Depth-averaged unweighted single-pulse SEL for pile-driving at Hornsea One model location 2 with hammer energy of 3,000 kJ.

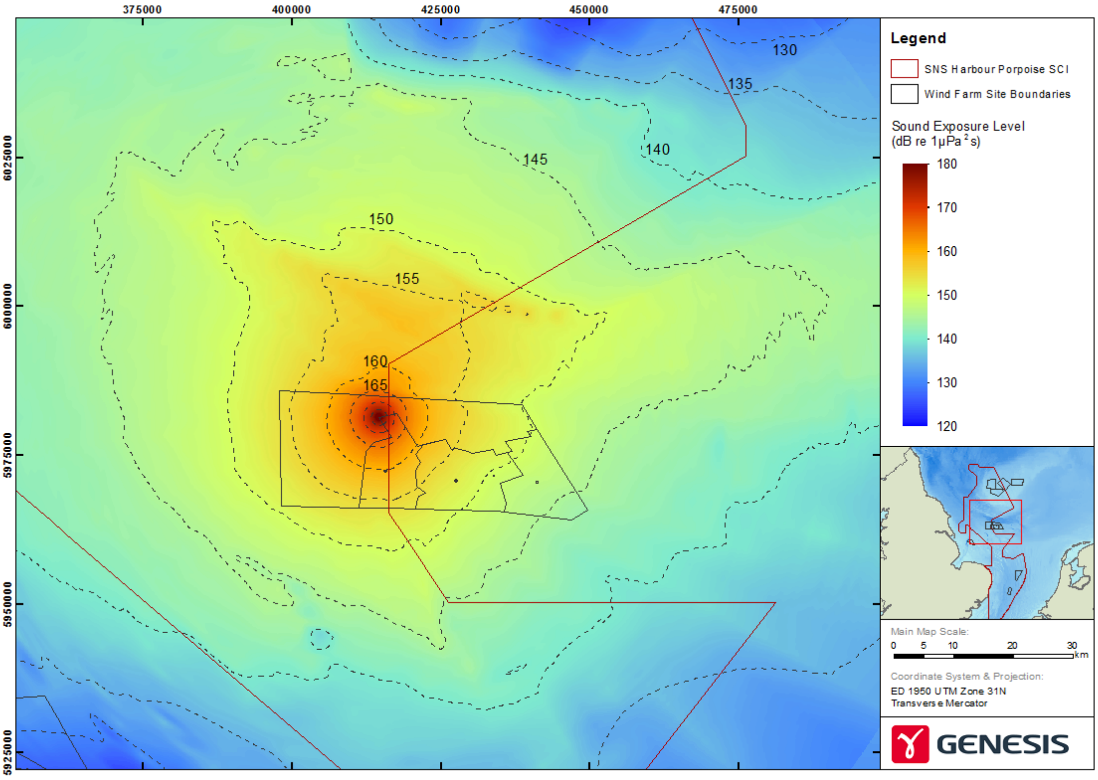

Figure F-20: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Hornsea One model location 2 with hammer energy of 3,000 kJ.

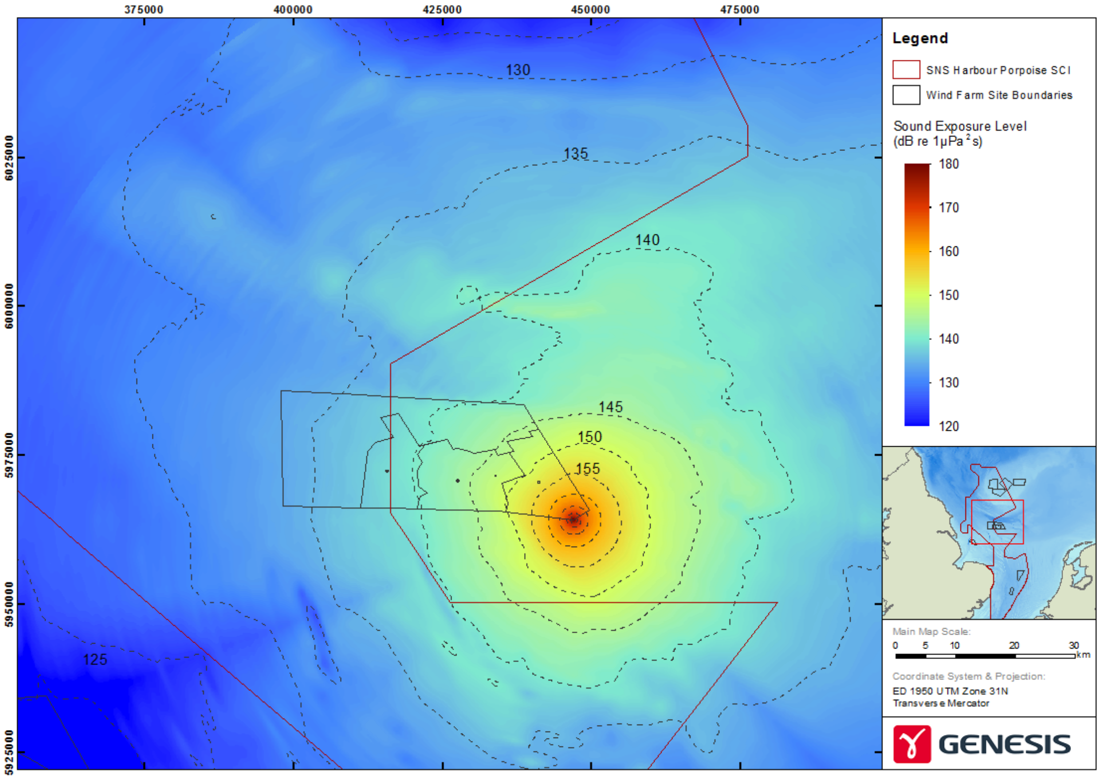

Figure F-21: Depth-averaged unweighted single-pulse SEL for pile-driving at Hornsea One model location 3 with hammer energy of 2,300 kJ.

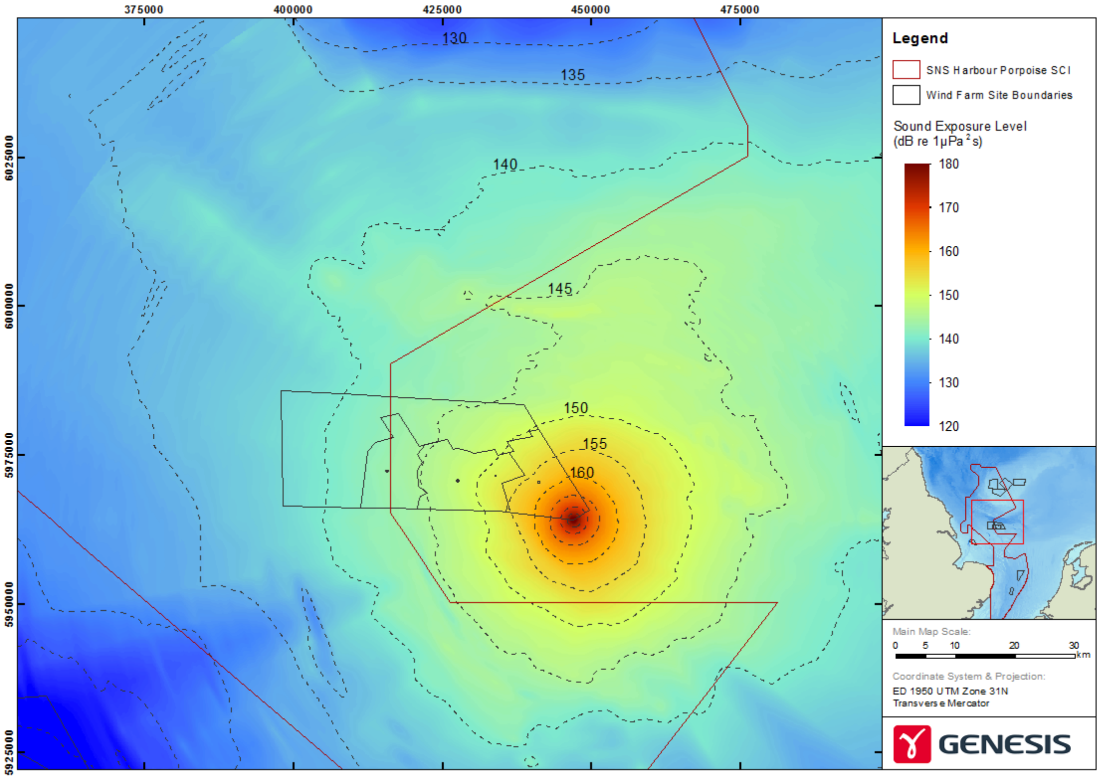

Figure F-22: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Hornsea One model location 3 with hammer energy of 2,300 kJ.

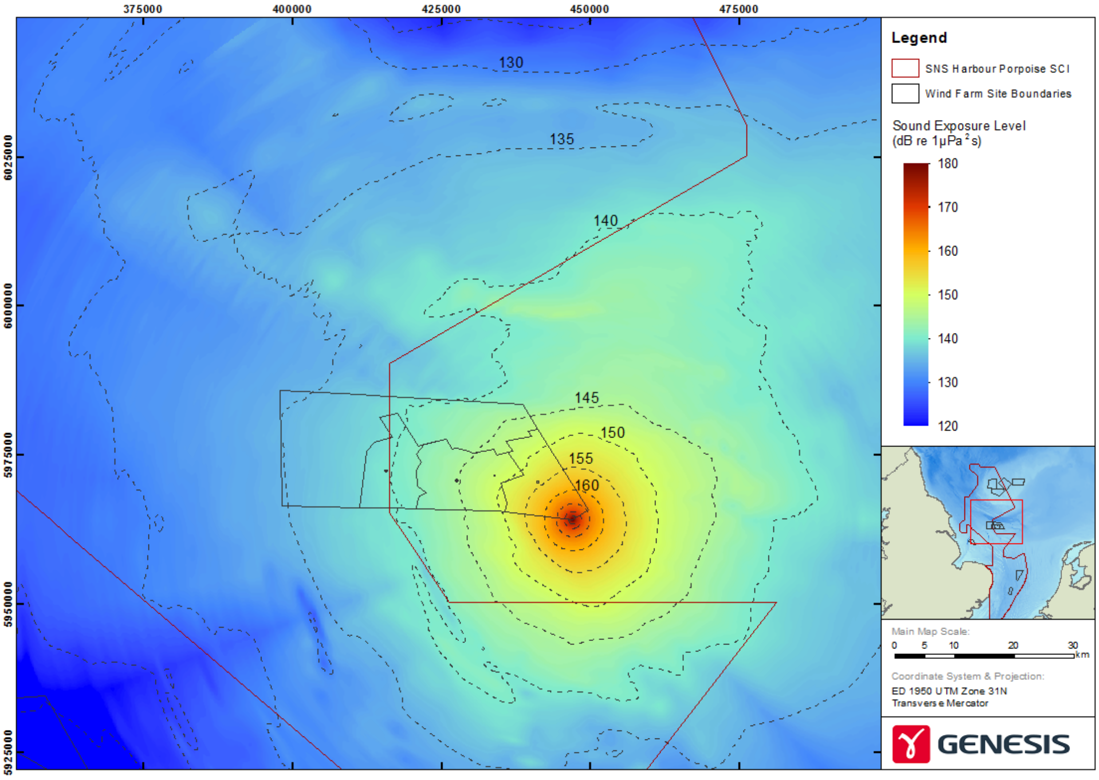

Figure F-23: Depth-averaged unweighted single-pulse SEL for pile-driving at Hornsea One model location 3 with hammer energy of 3,000 kJ.

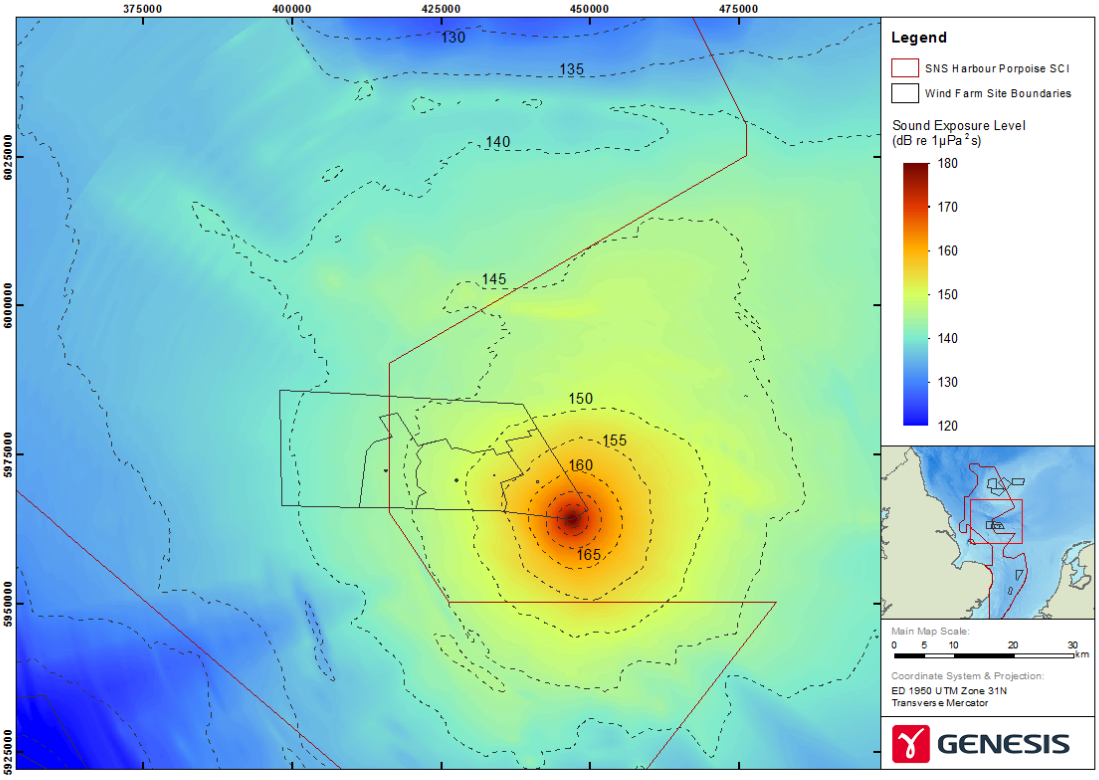

Figure F-24: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Hornsea One model location 3 with hammer energy of 3,000 kJ.

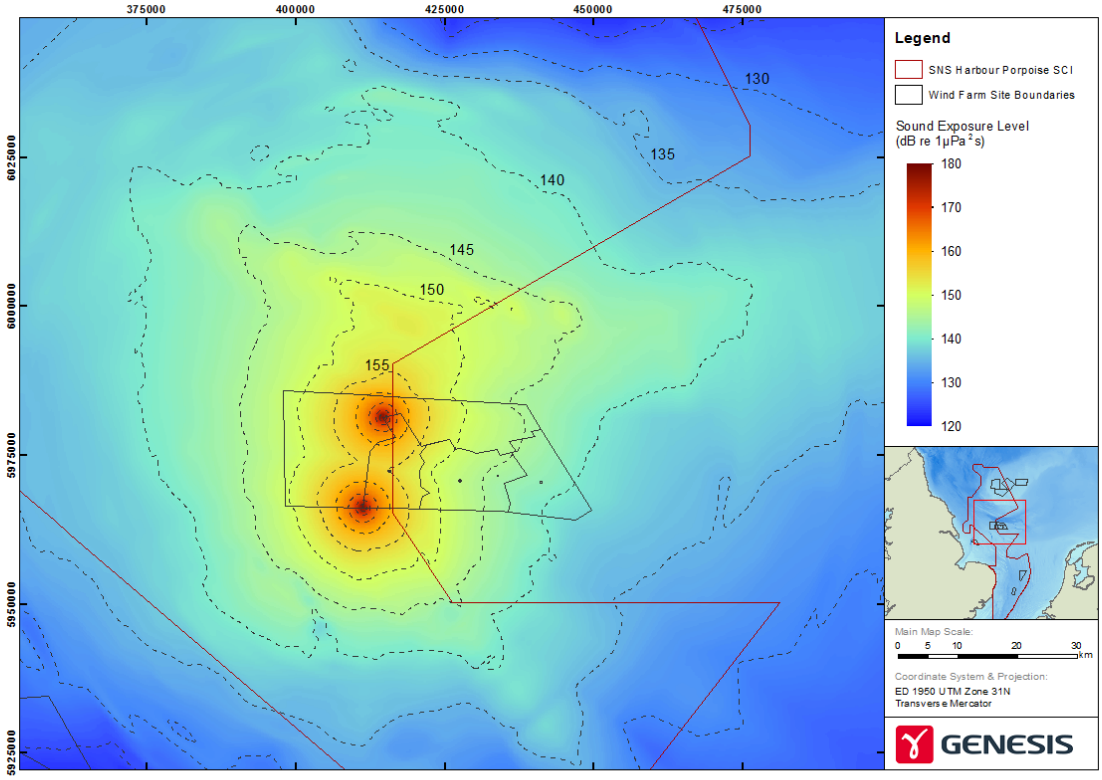

Figure F-25: Depth-averaged unweighted single-pulse SEL for concurrent pile-driving at Hornsea One model locations 1 and 2 with hammer energy of 2,300 kJ.

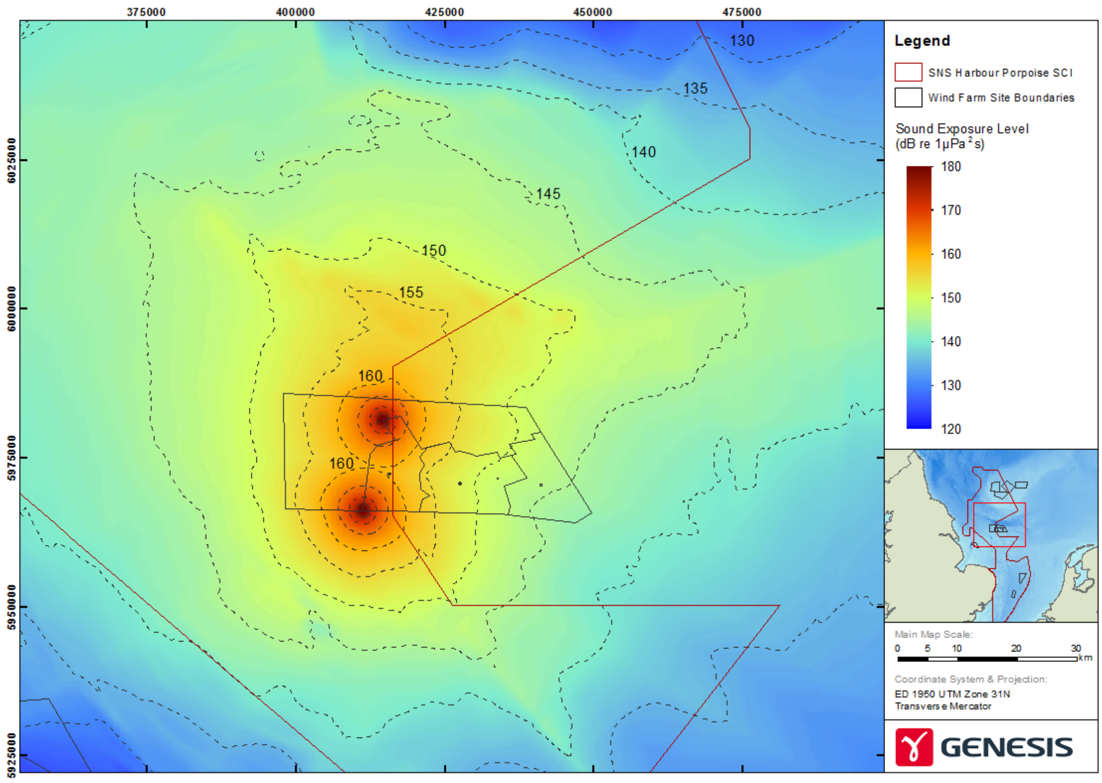

Figure F-26: Maximum-over-depth unweighted single-pulse SEL for concurrent pile-driving at Hornsea One model locations 1 and 2 with hammer energy of 2,300 kJ.

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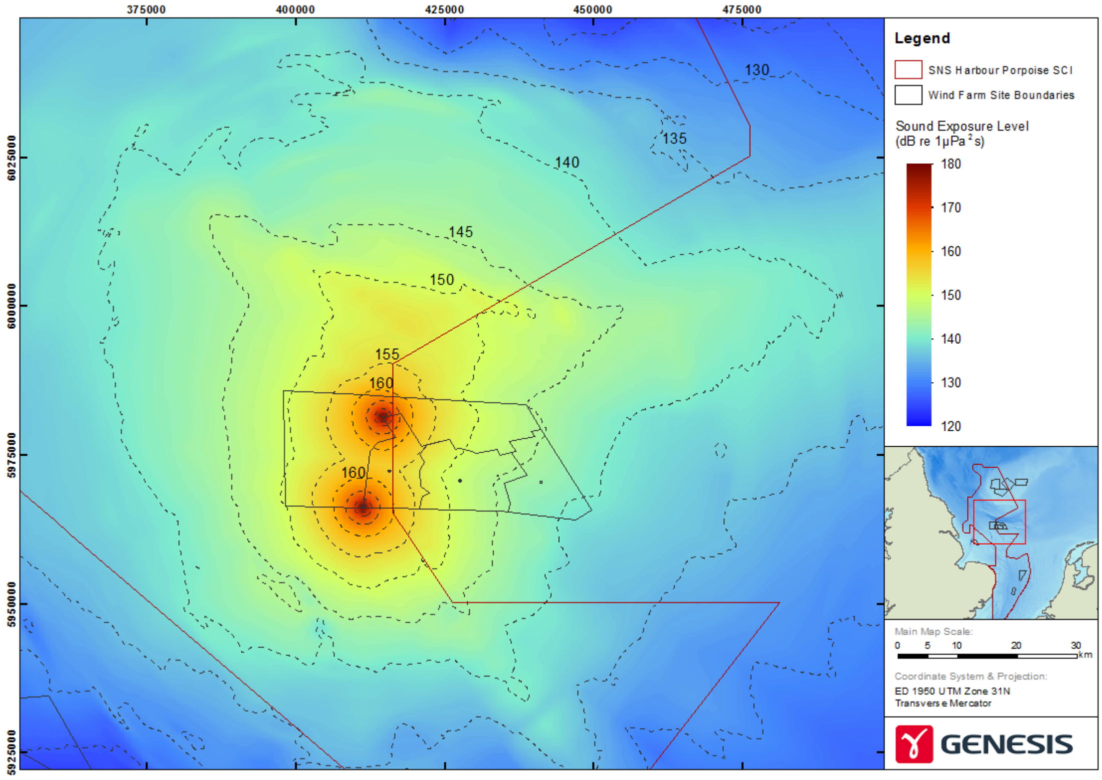

Figure F-27: Depth-averaged unweighted single-pulse SEL for concurrent pile-driving at Hornsea One model locations 1 and 2 with hammer energy of 3,000 kJ.

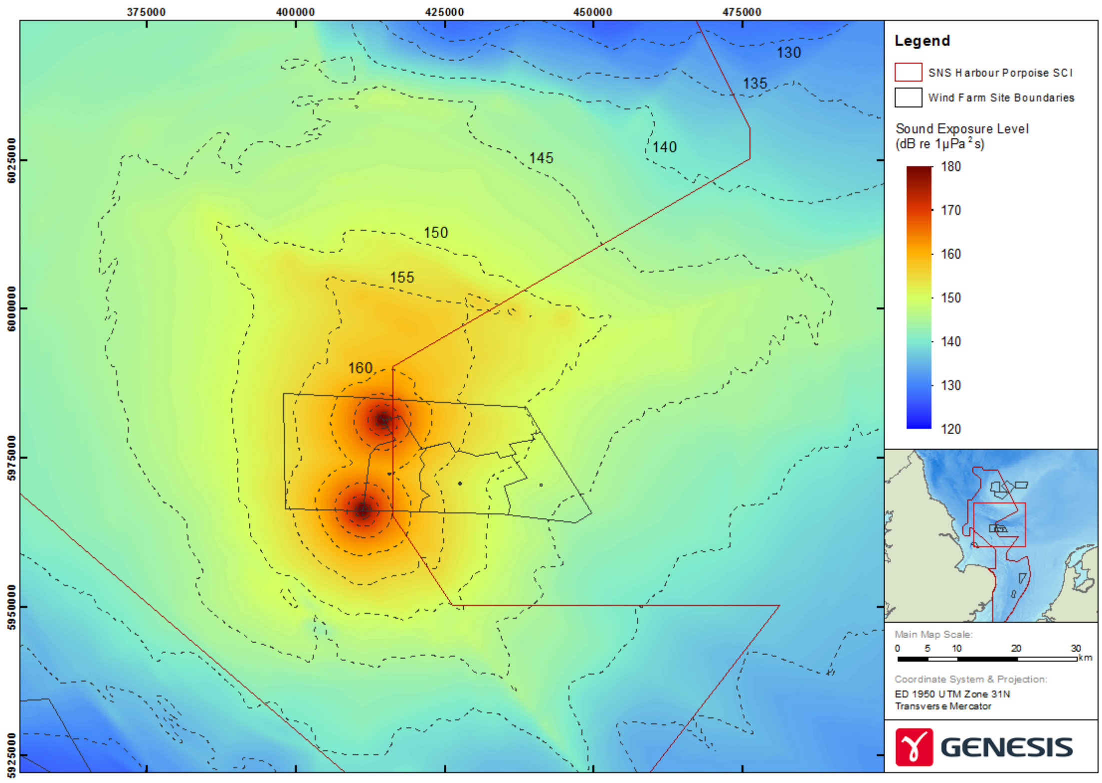

Figure F-28: Maximum-over-depth unweighted single-pulse SEL for concurrent pile-driving at Hornsea One model locations 1 and 2 with hammer energy of 3,000 kJ.

APPENDIX G: MODELLING MAPS FOR HORNSEA TWO

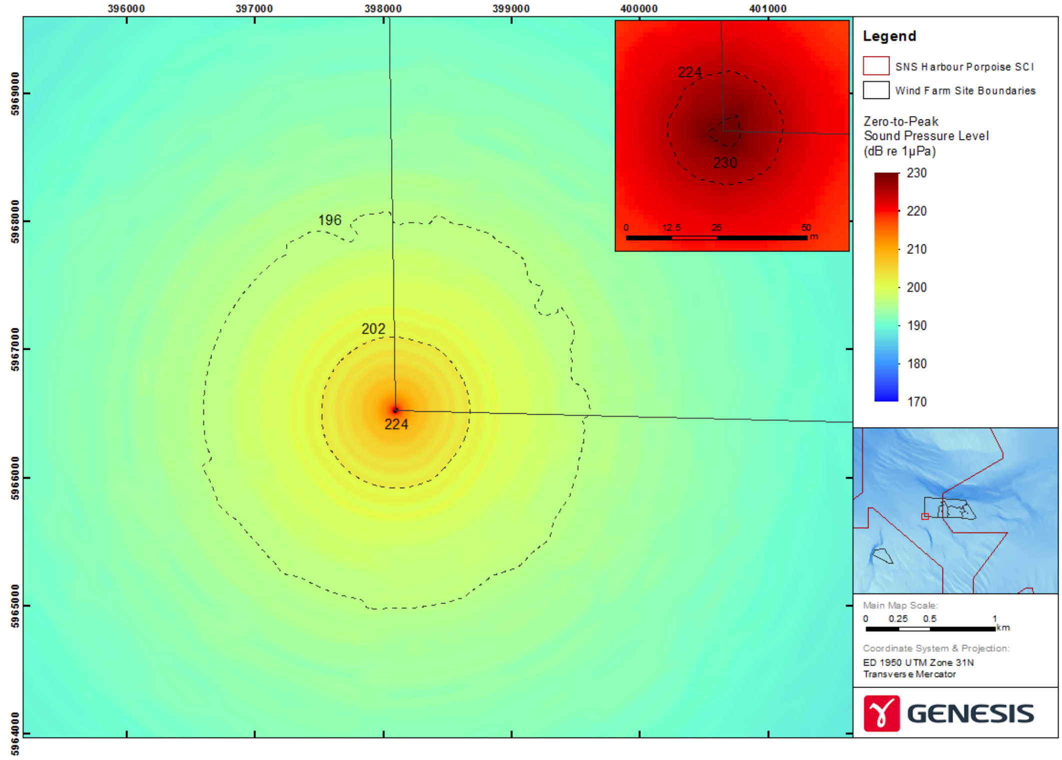

Figure G-1: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Hornsea Two model location 1 with hammer energy of 2,300 kJ.

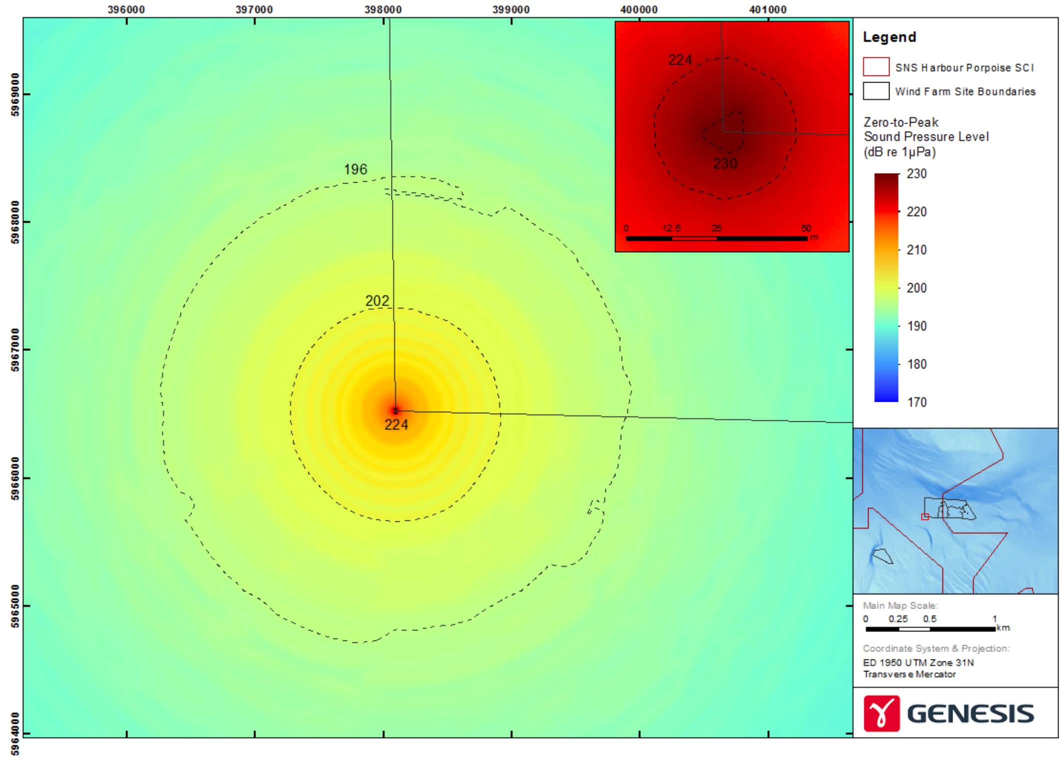

Figure G-2: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Hornsea Two model location 1 with hammer energy of 3,000 kJ.

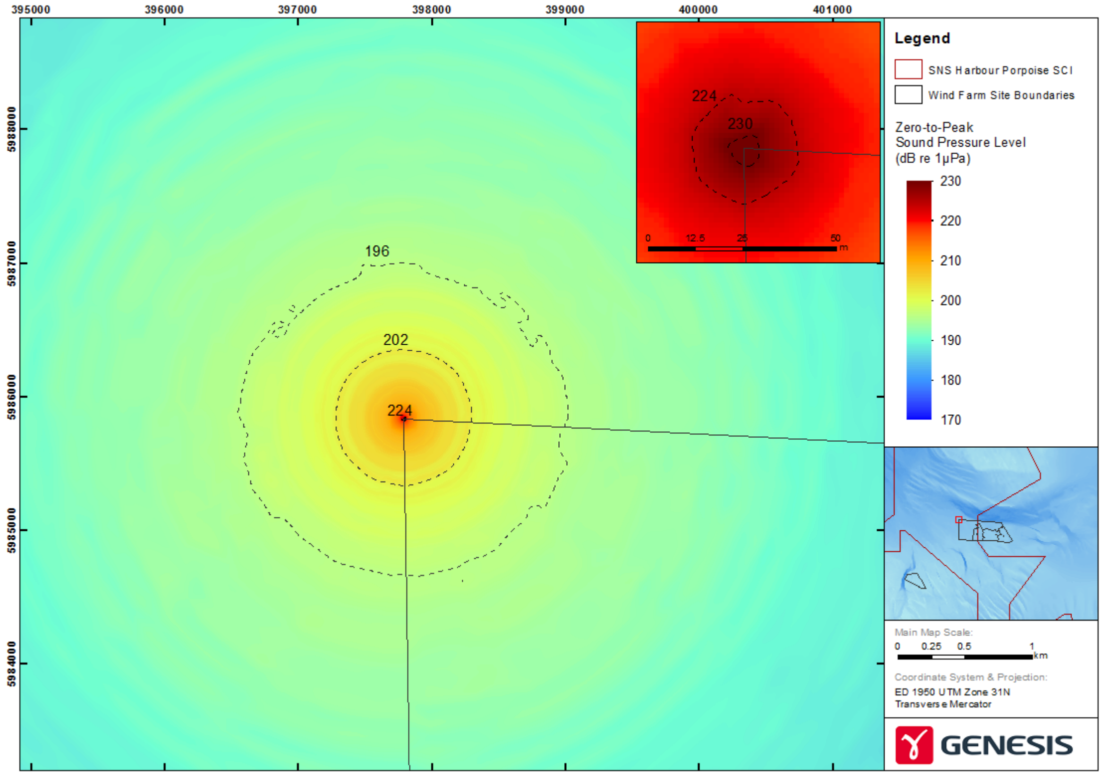

Figure G-3: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Hornsea Two model location 2 with hammer energy of 2,300 kJ.

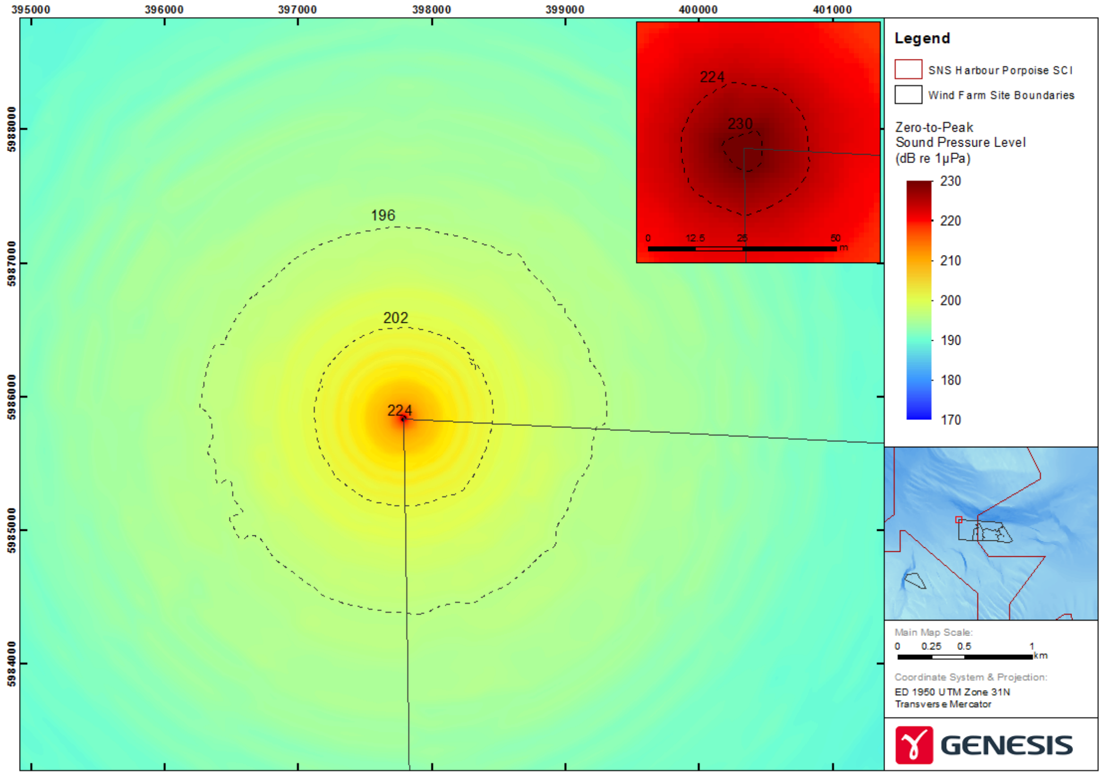

Figure G-4: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Hornsea Two model location 2 with hammer energy of 3,000 kJ.

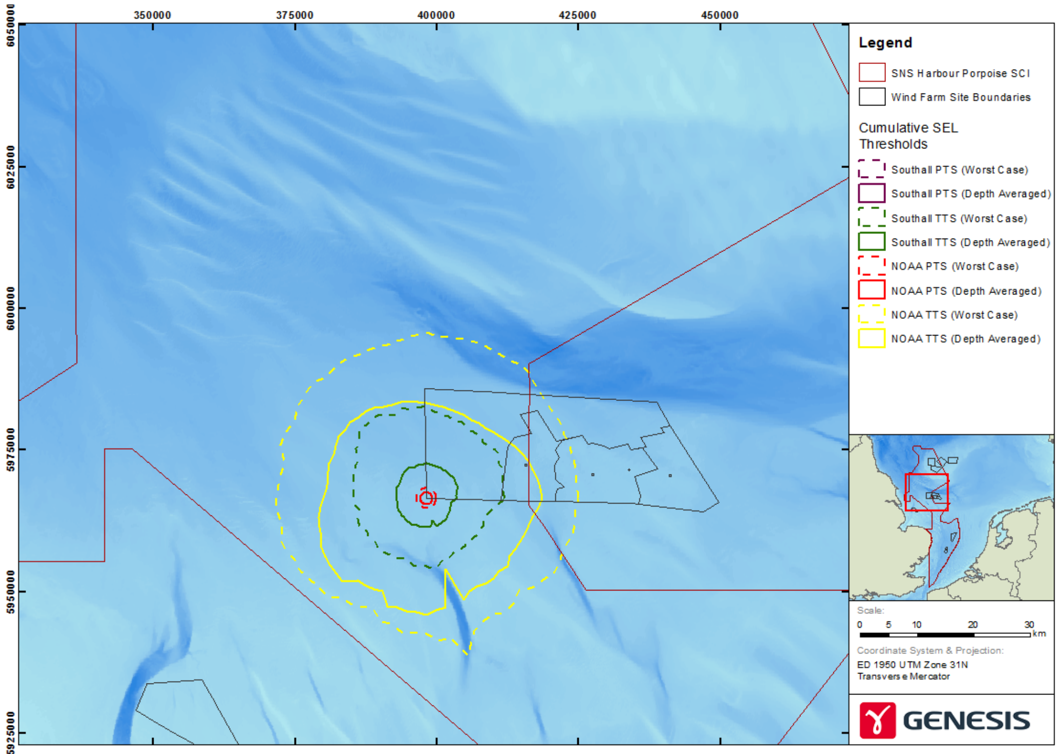

Figure G-5: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Hornsea Two model location 1 with maximum hammer energy of 2,300 kJ.

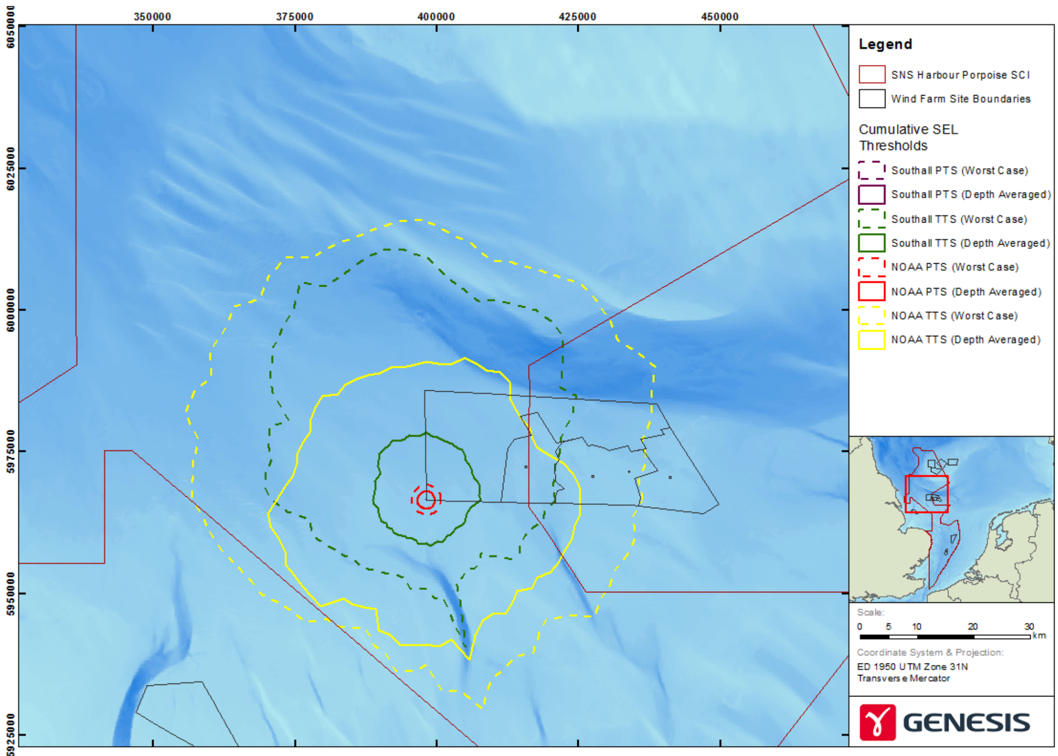

Figure G-6: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Hornsea Two model location 1 with maximum hammer energy of 3,000 kJ.

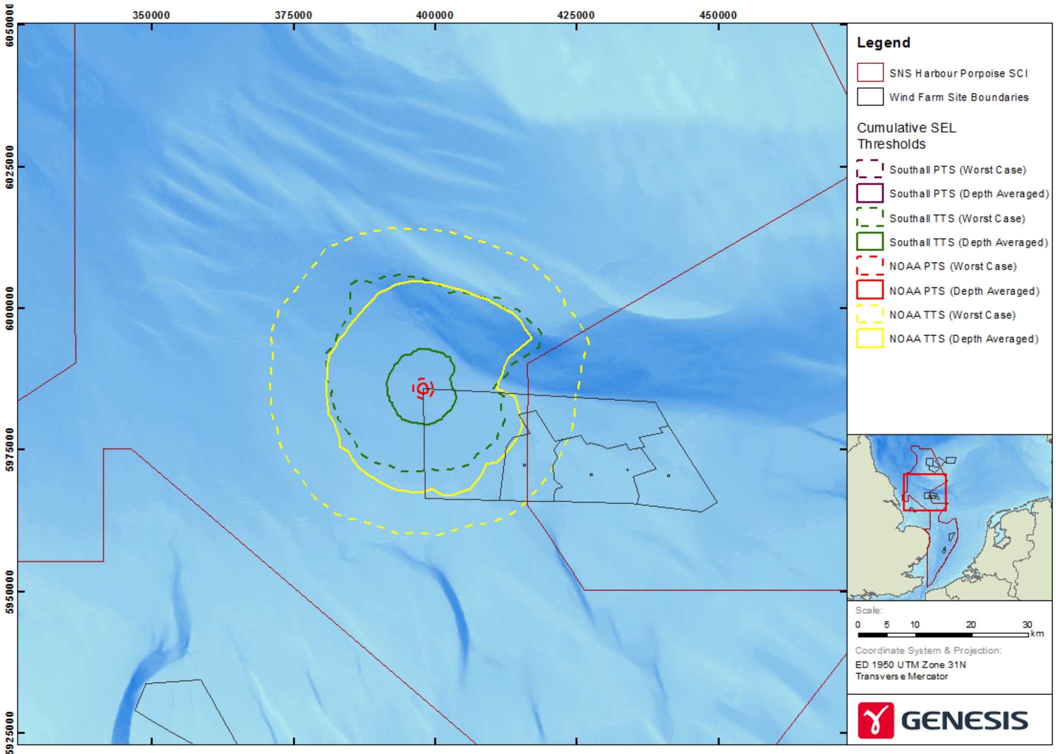

Figure G-7: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Hornsea Two model location 2 with maximum hammer energy of 2,300 kJ.

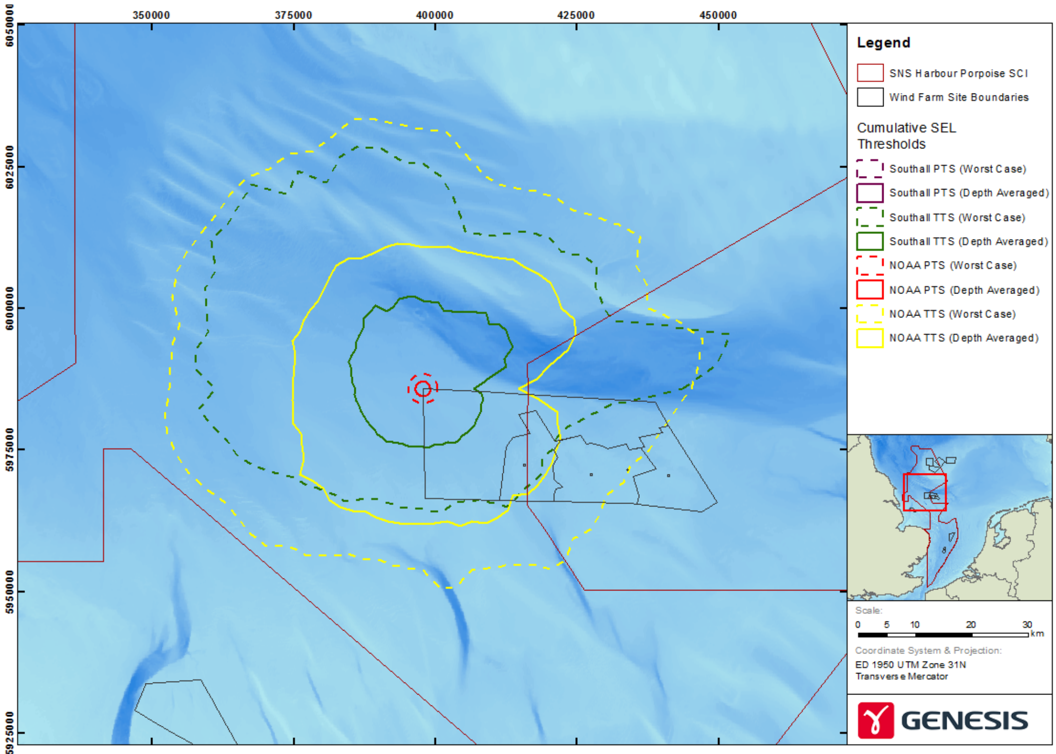

Figure G-8: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Hornsea Two model location 2 with maximum hammer energy of 3,000 kJ.

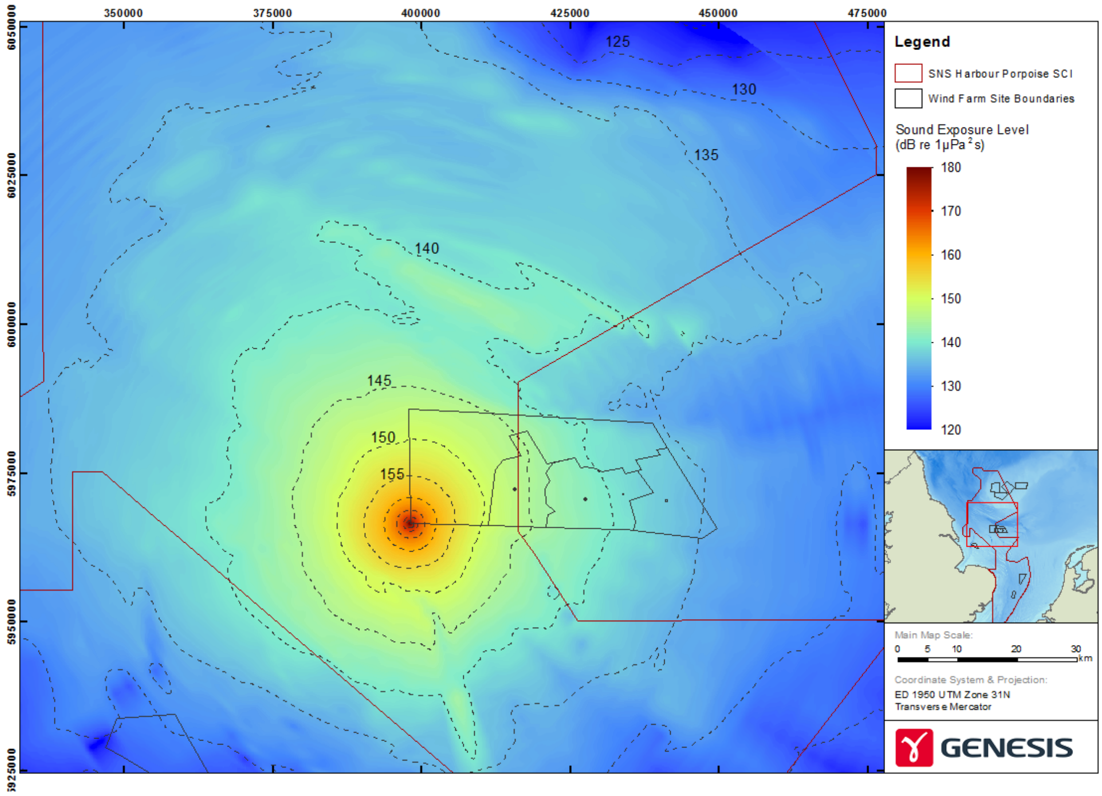

Figure G-9: Depth-averaged unweighted single-pulse SEL for pile-driving at Hornsea Two model location 1 with hammer energy of 2,300 kJ.

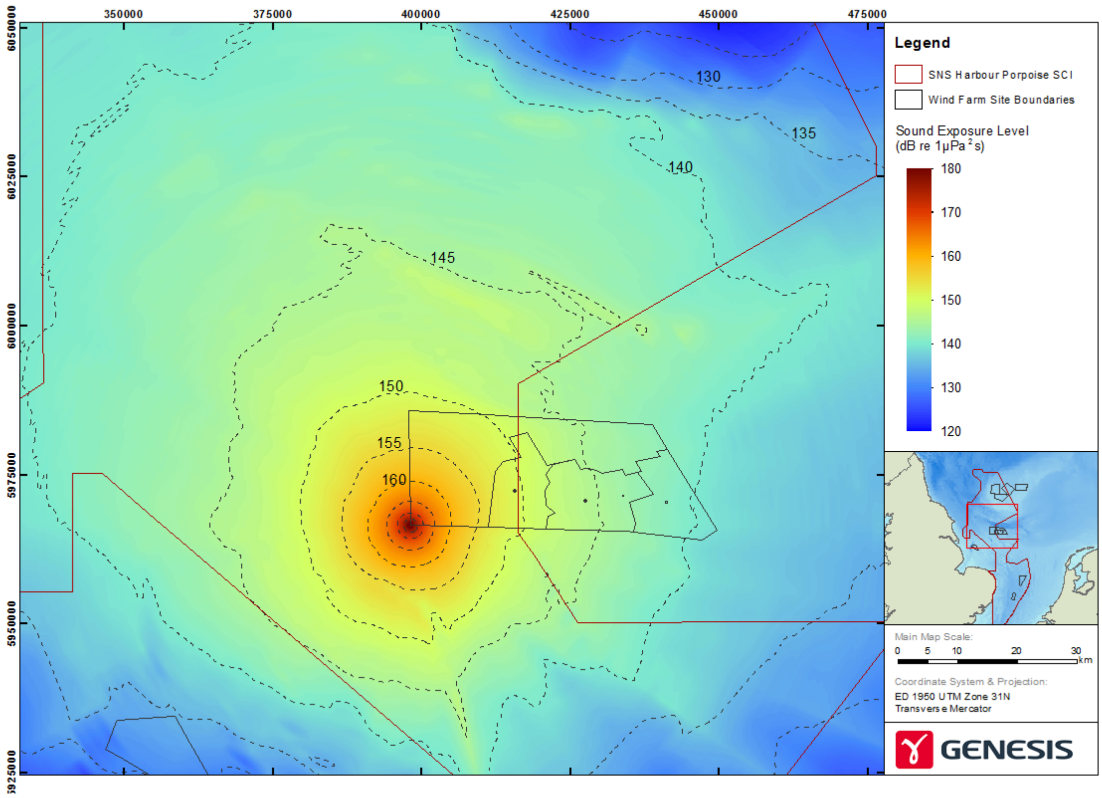

Figure G-10: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Hornsea Two model location 1 with hammer energy of 2,300 kJ.

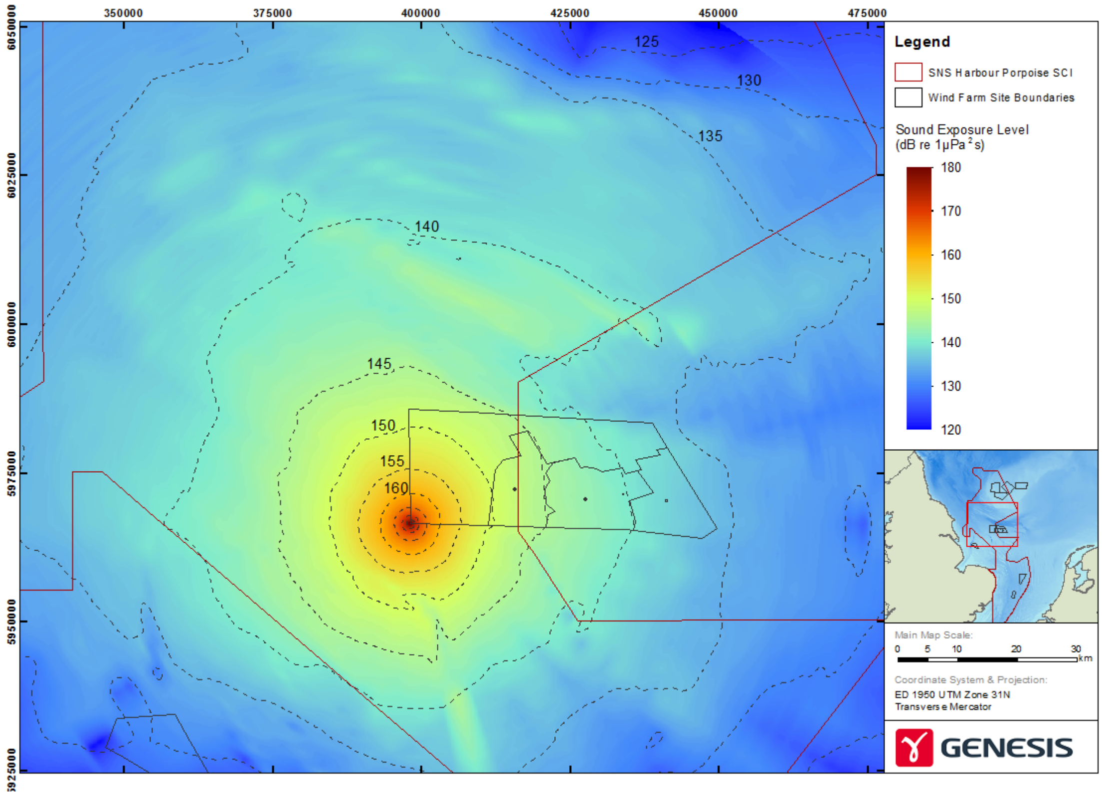

Figure G-11: Depth-averaged unweighted single-pulse SEL for pile-driving at Hornsea Two model location 1 with hammer energy of 3,000 kJ.

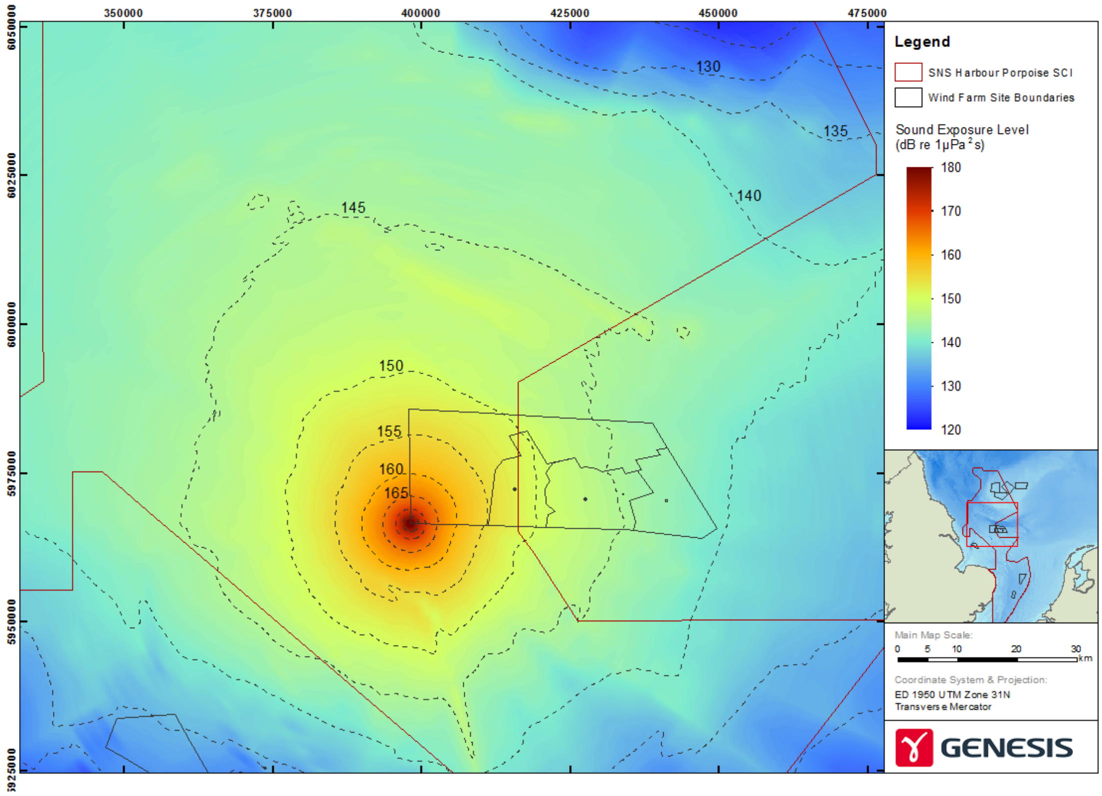

Figure G-12: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Hornsea Two model location 1 with hammer energy of 3,000 kJ.

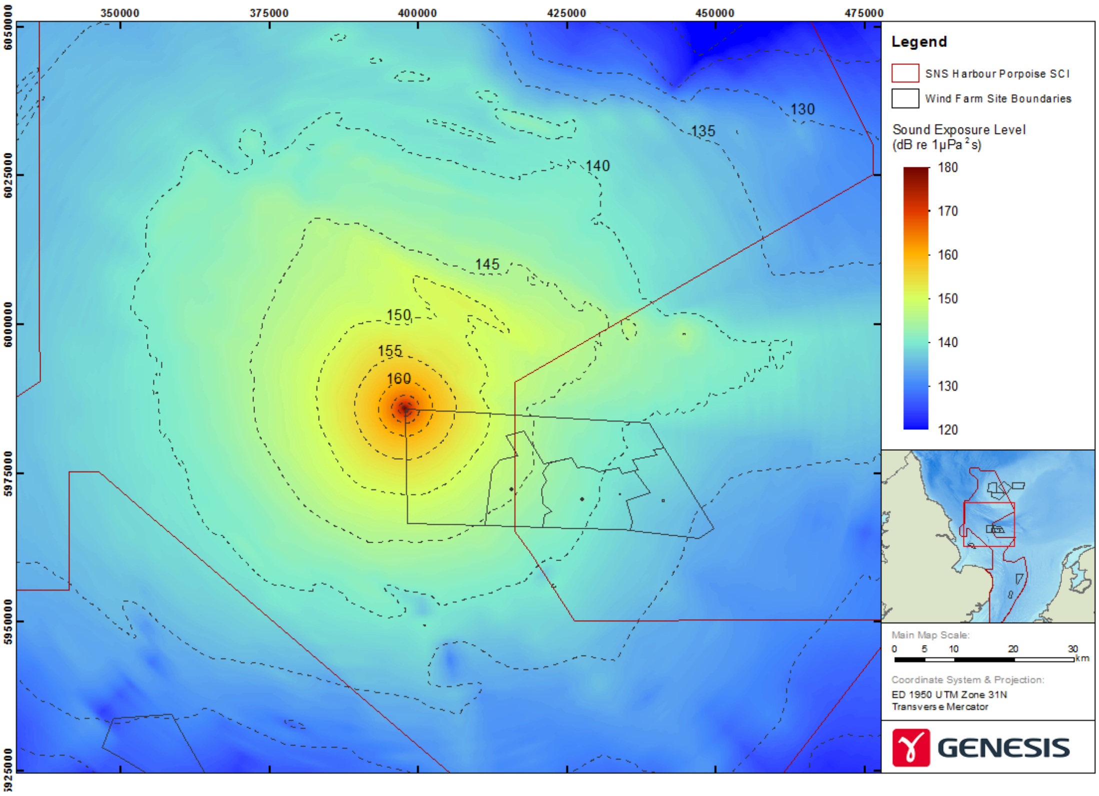

Figure G-13: Depth-averaged unweighted single-pulse SEL for pile-driving at Hornsea Two model location 2 with hammer energy of 2,300 kJ.

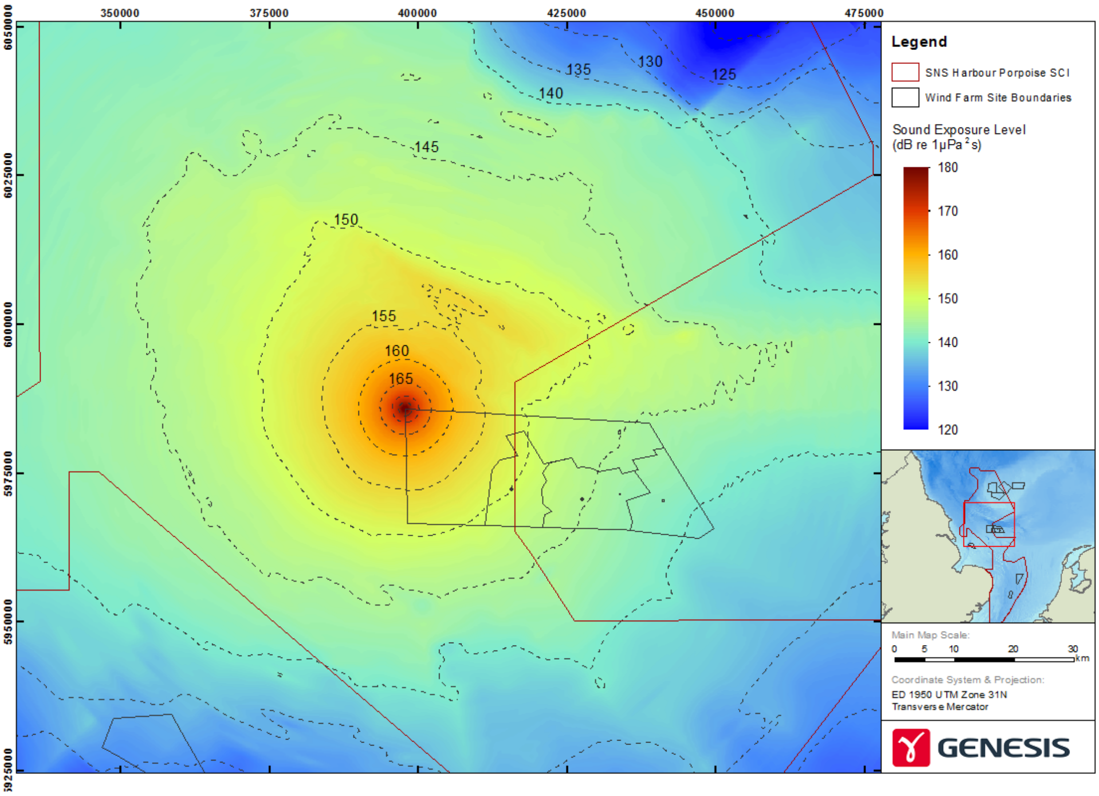

Figure G-14: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Hornsea Two model location 2 with hammer energy of 2,300 kJ.

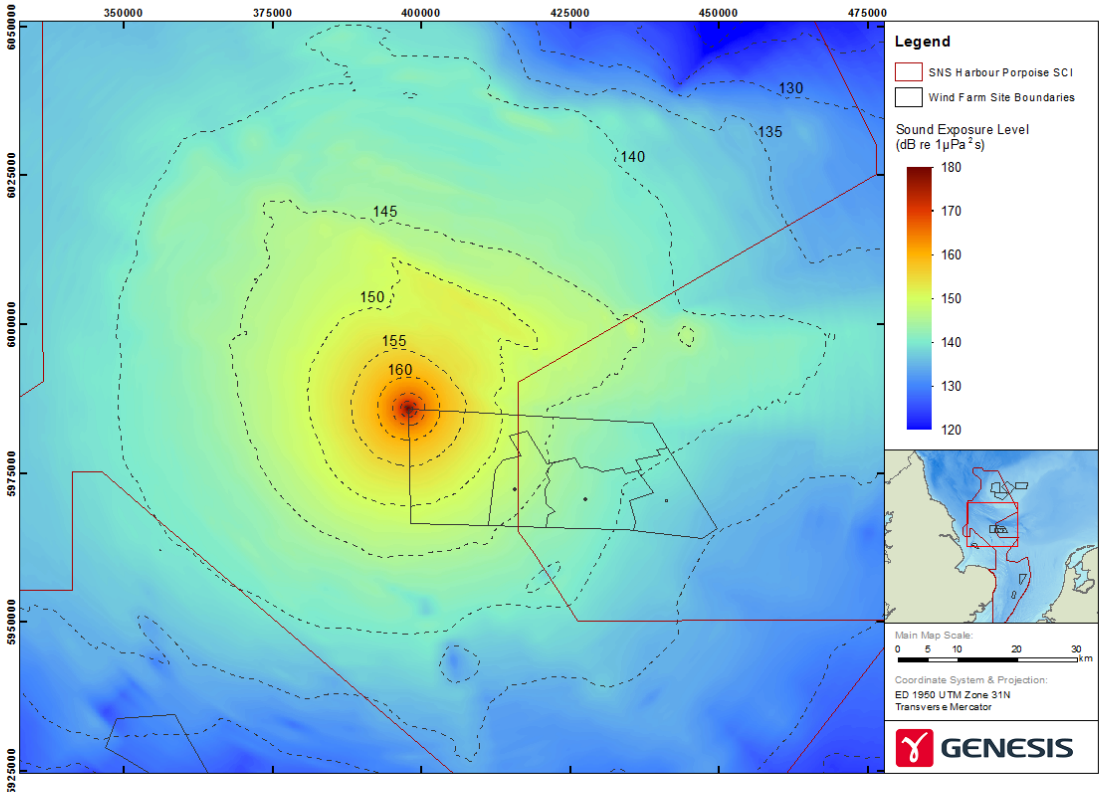

Figure G-15: Depth-averaged unweighted single-pulse SEL for pile-driving at Hornsea Two model location 2 with hammer energy of 3,000 kJ.

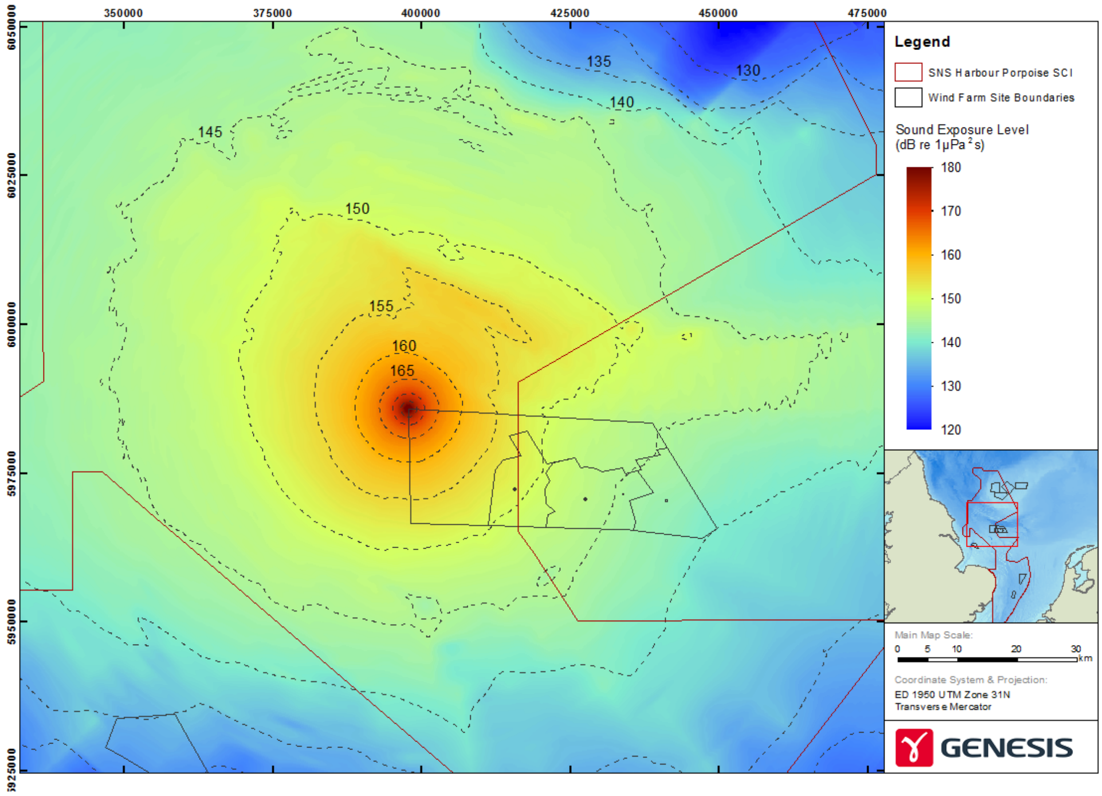

Figure G-16: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Hornsea Two model location 2 with hammer energy of 3,000 kJ.

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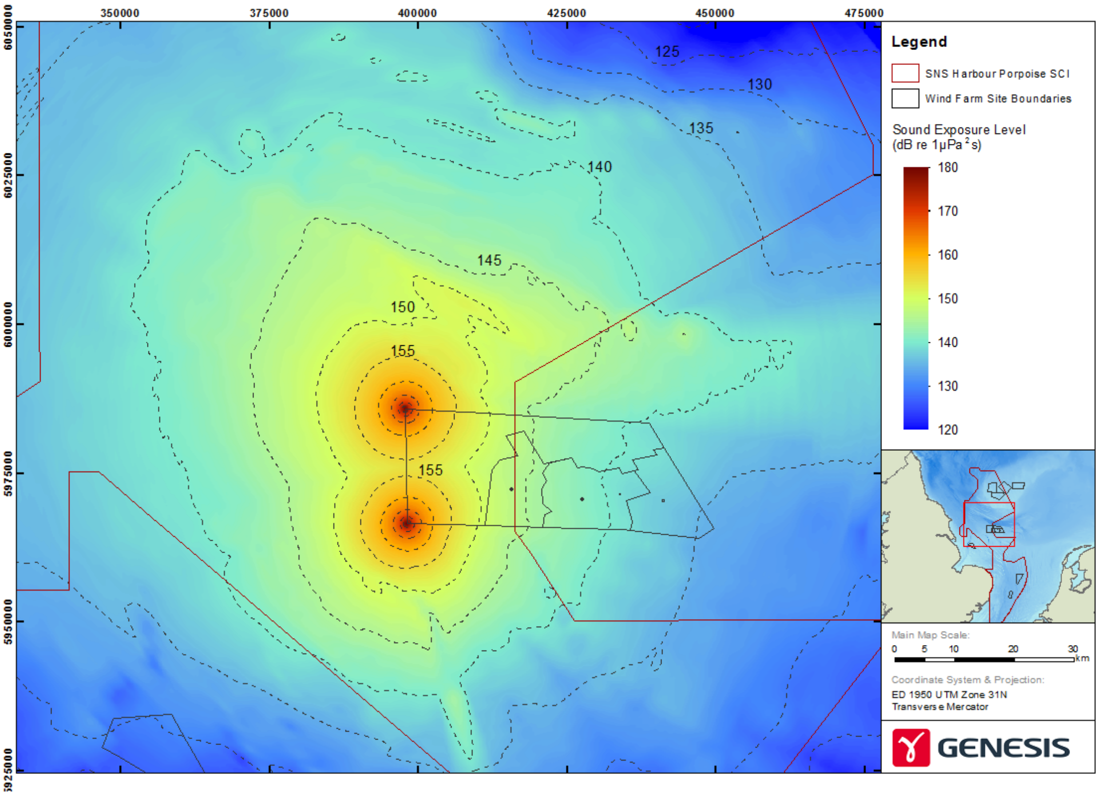

Figure G-17: Depth-averaged unweighted single-pulse SEL for concurrent pile-driving at Hornsea Two model locations 1 and 2 with hammer energy of 2,300 kJ.

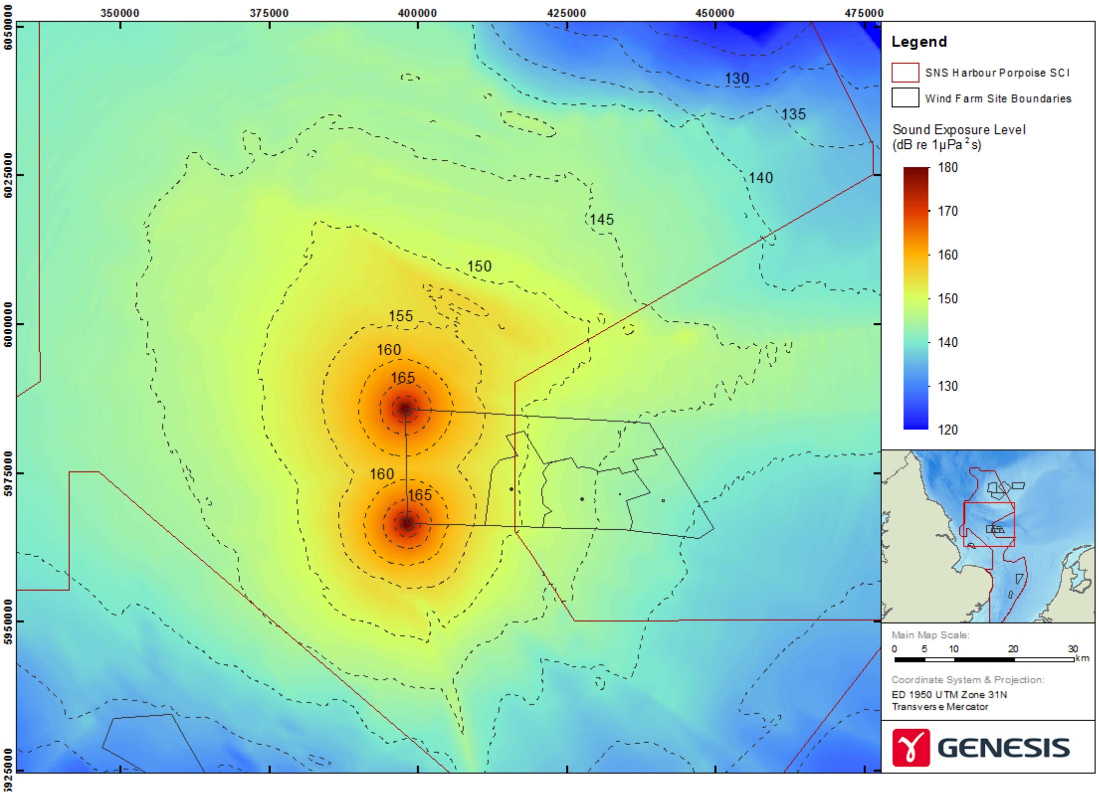

Figure G-18: Maximum-over-depth unweighted single-pulse SEL for concurrent pile-driving at Hornsea Two model locations 1 and 2 with hammer energy of 2,300 kJ.

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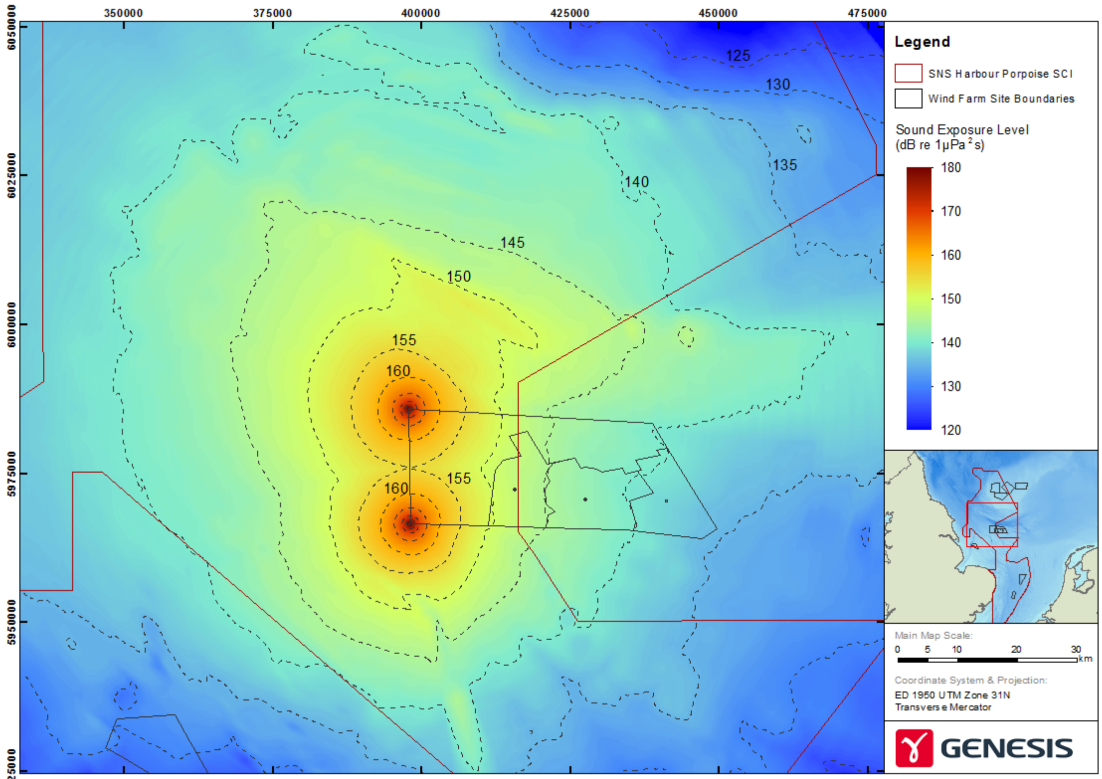

Figure G-19: Depth-averaged unweighted single-pulse SEL for concurrent pile-driving at Hornsea Two model locations 1 and 2 with hammer energy of 3,000 kJ.

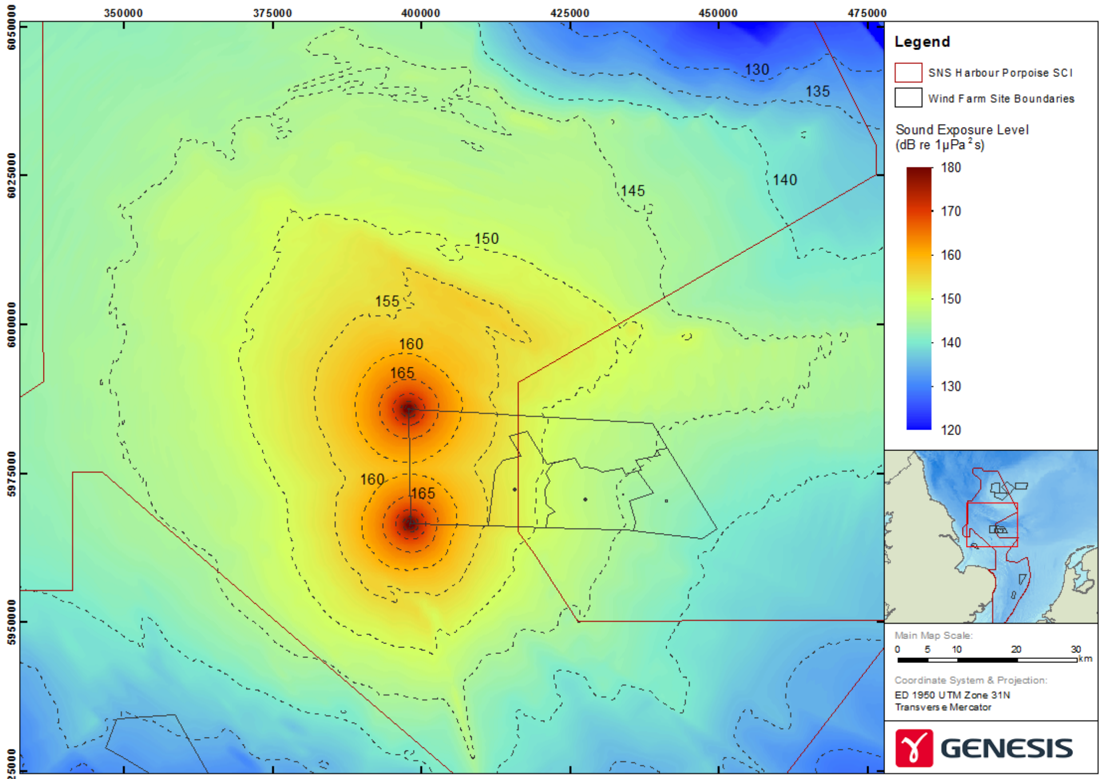

Figure G-20: Maximum-over-depth unweighted single-pulse SEL for concurrent pile-driving at Hornsea Two model locations 1 and 2 with hammer energy of 3,000 kJ.

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APPENDIX H: MODELLING MAPS FOR TEESSIDE A

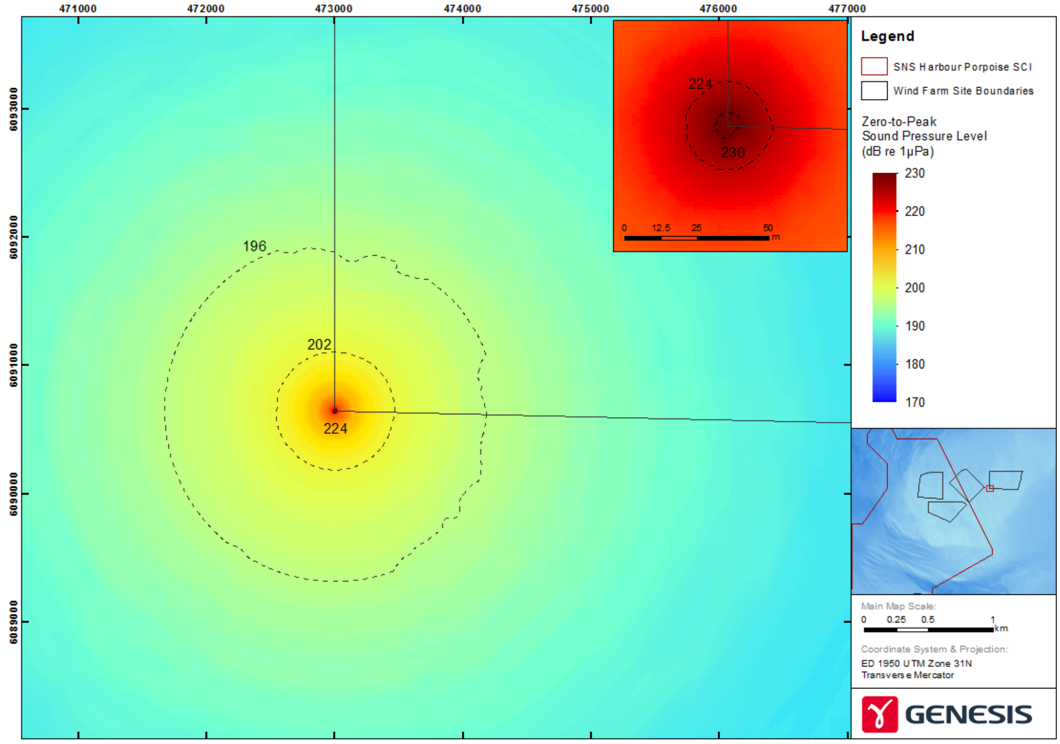

Figure H-1: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Teesside A model location 1 with hammer energy of 1,900 kJ.

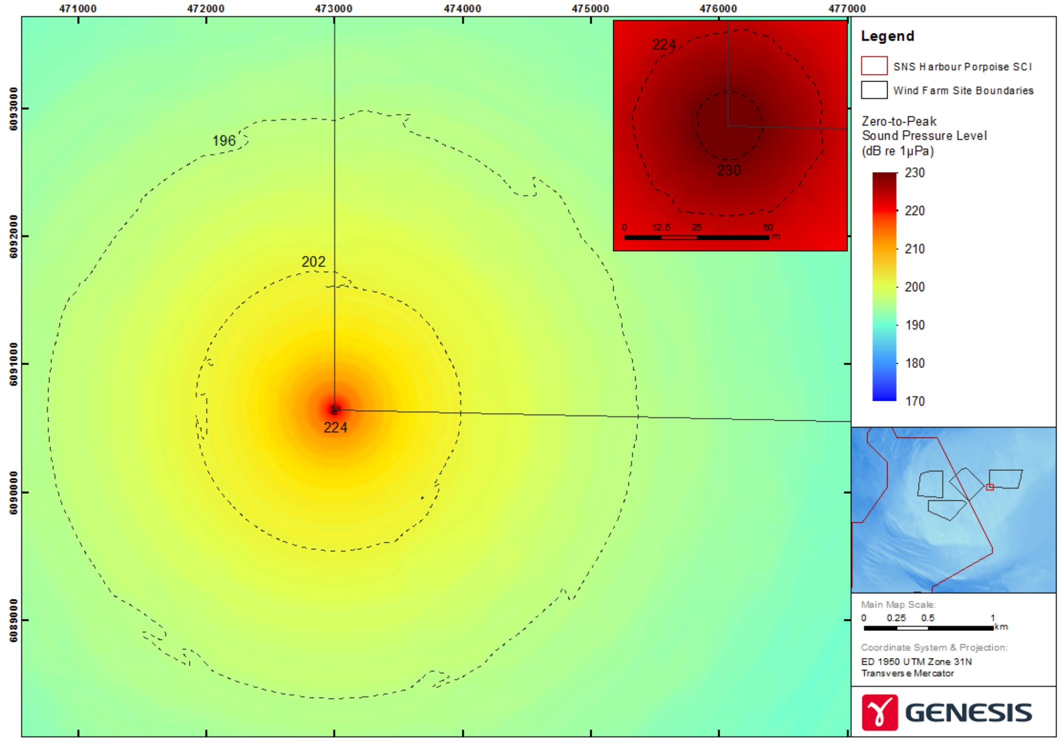

Figure H-2: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Teesside A model location 1 with hammer energy of 5,500 kJ.

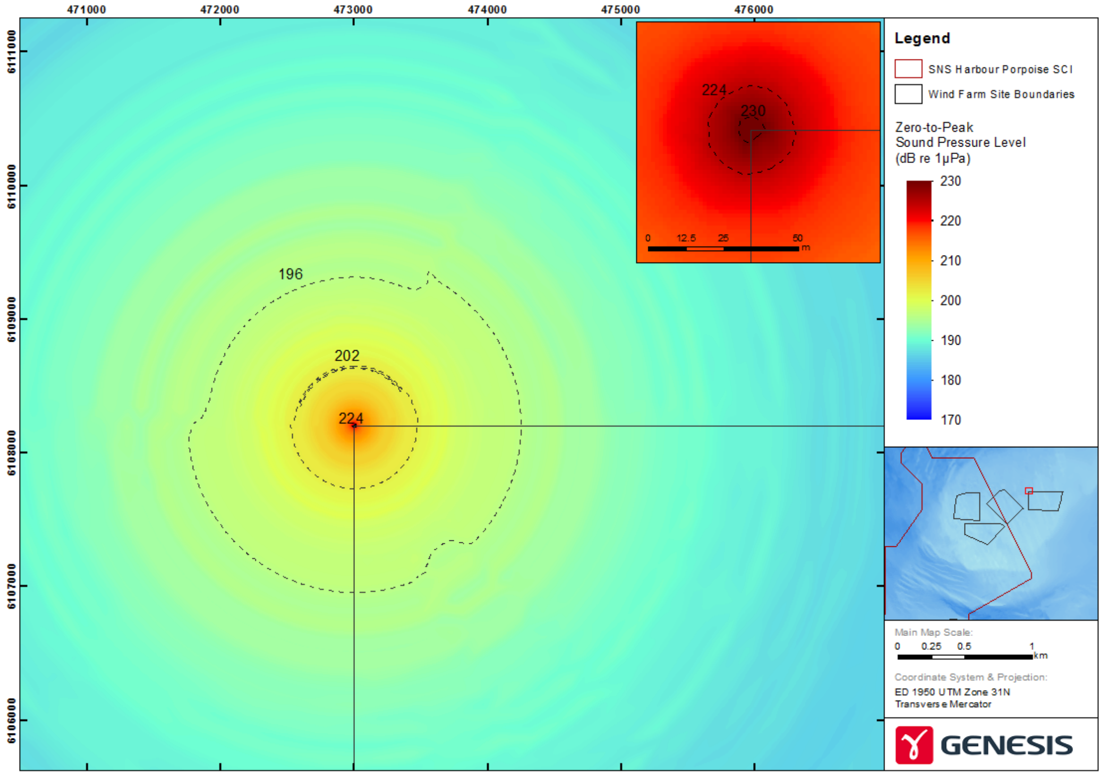

Figure H-3: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Teesside A model location 2 with hammer energy of 1,900 kJ.

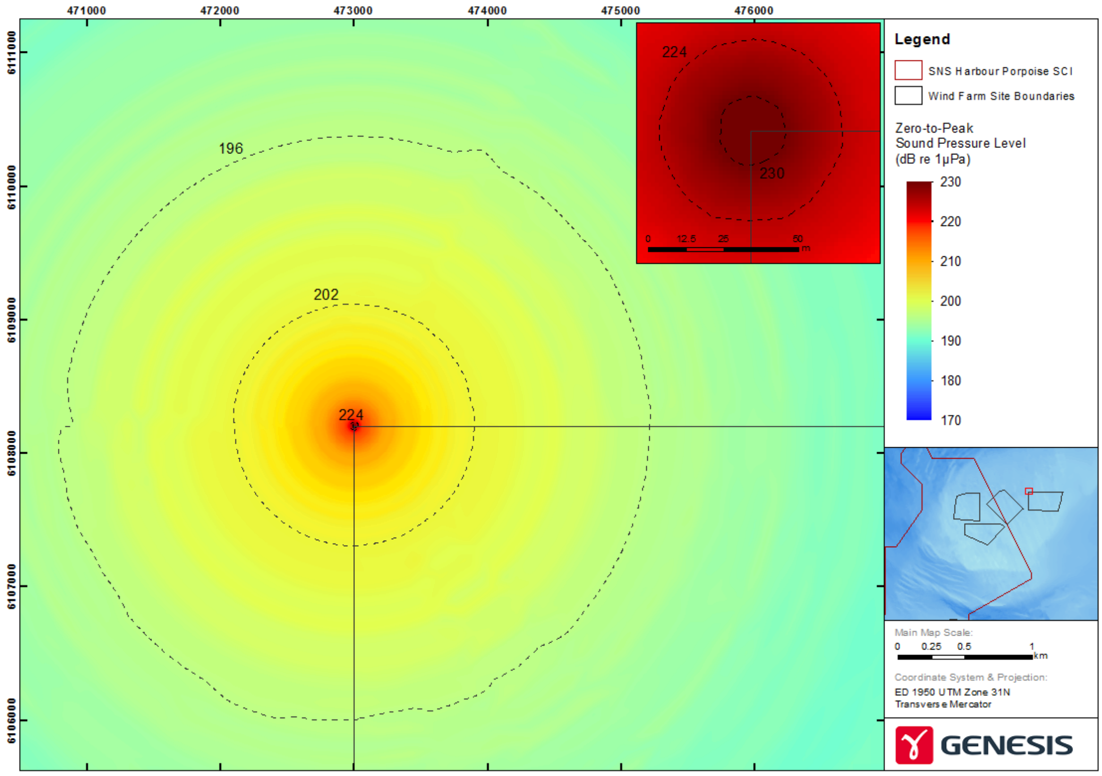

Figure H-4: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Teesside A model location 2 with hammer energy of 5,500 kJ.

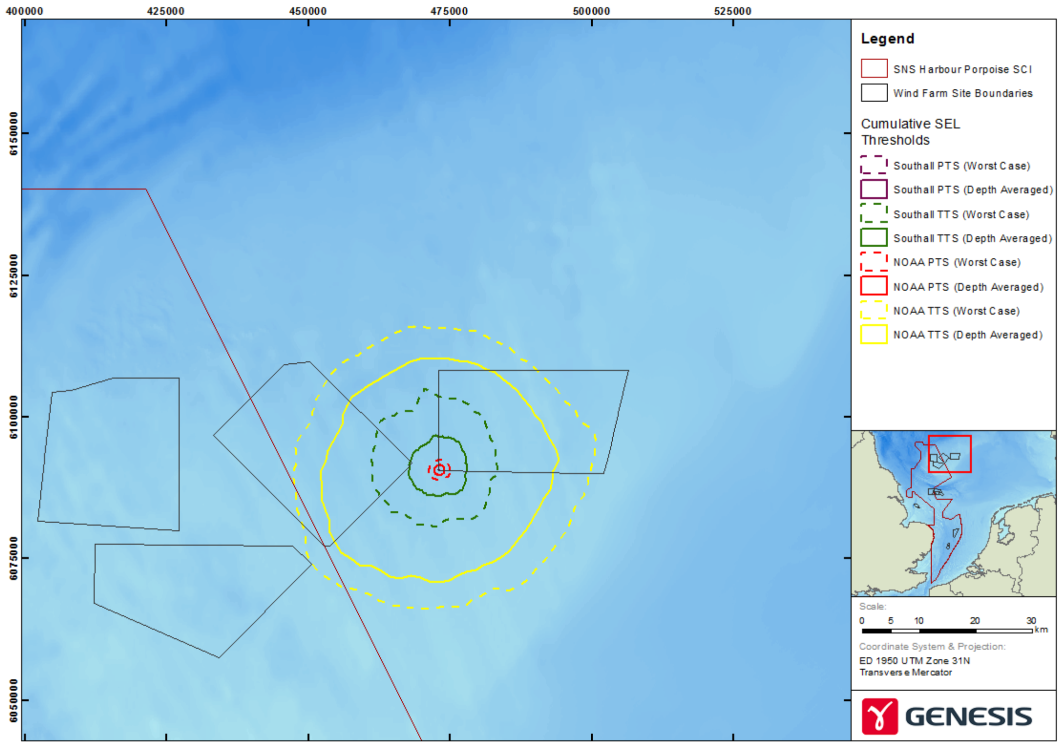

Figure H-5: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Teesside A model location 1 with maximum hammer energy of 1,900 kJ.

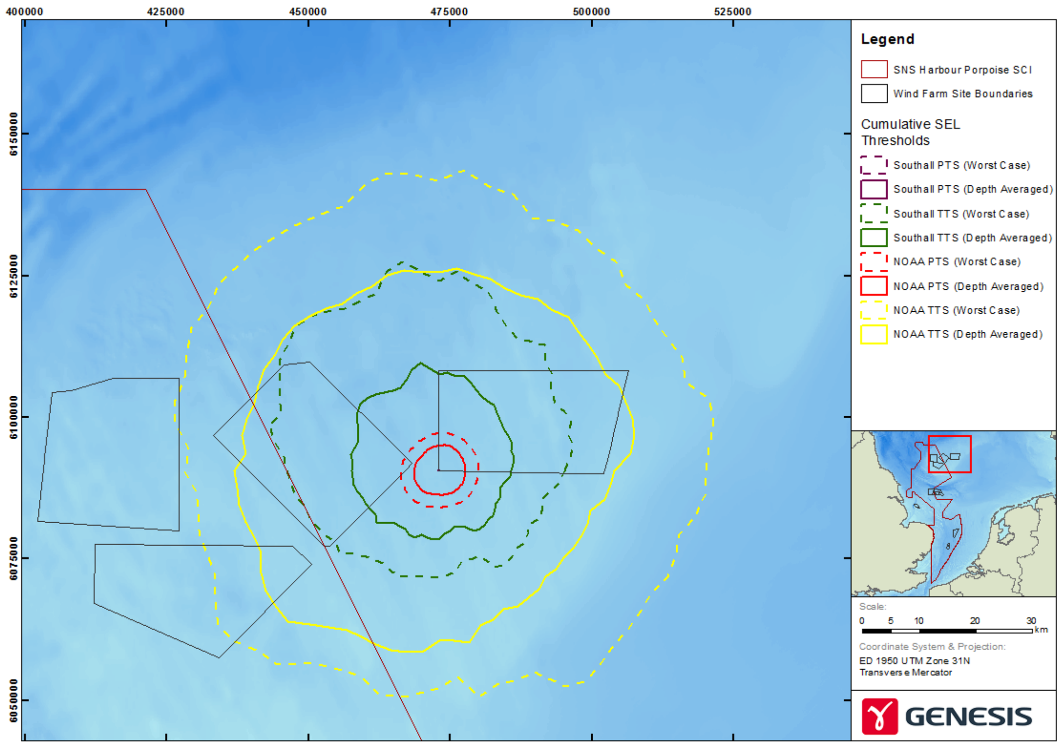

Figure H-6: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Teesside A model location 1 with maximum hammer energy of 5,500 kJ.

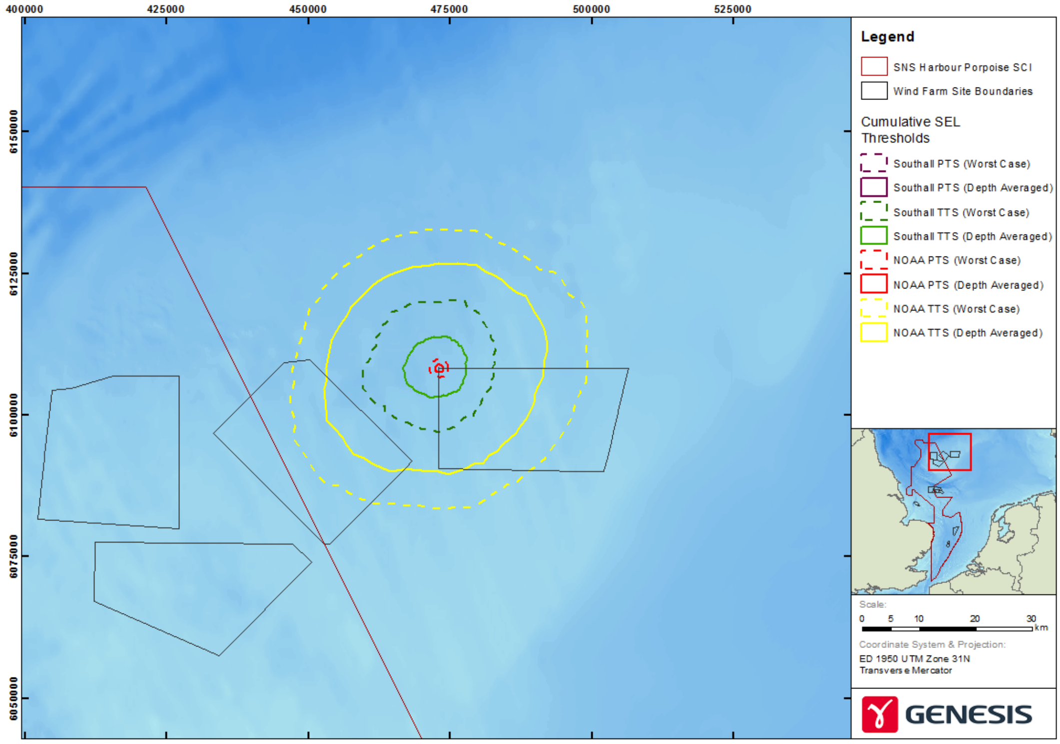

Figure H-7: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Teesside A model location 2 with maximum hammer energy of 1,900 kJ.

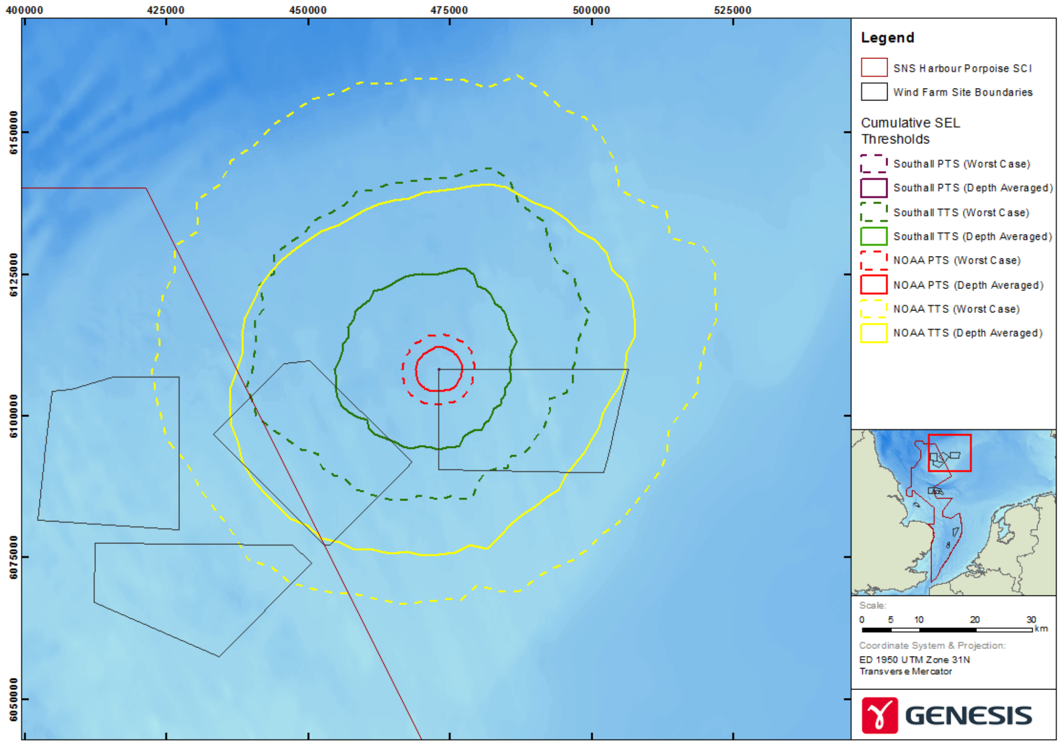

Figure H-8: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Teesside A model location 2 with maximum hammer energy of 5,500 kJ.

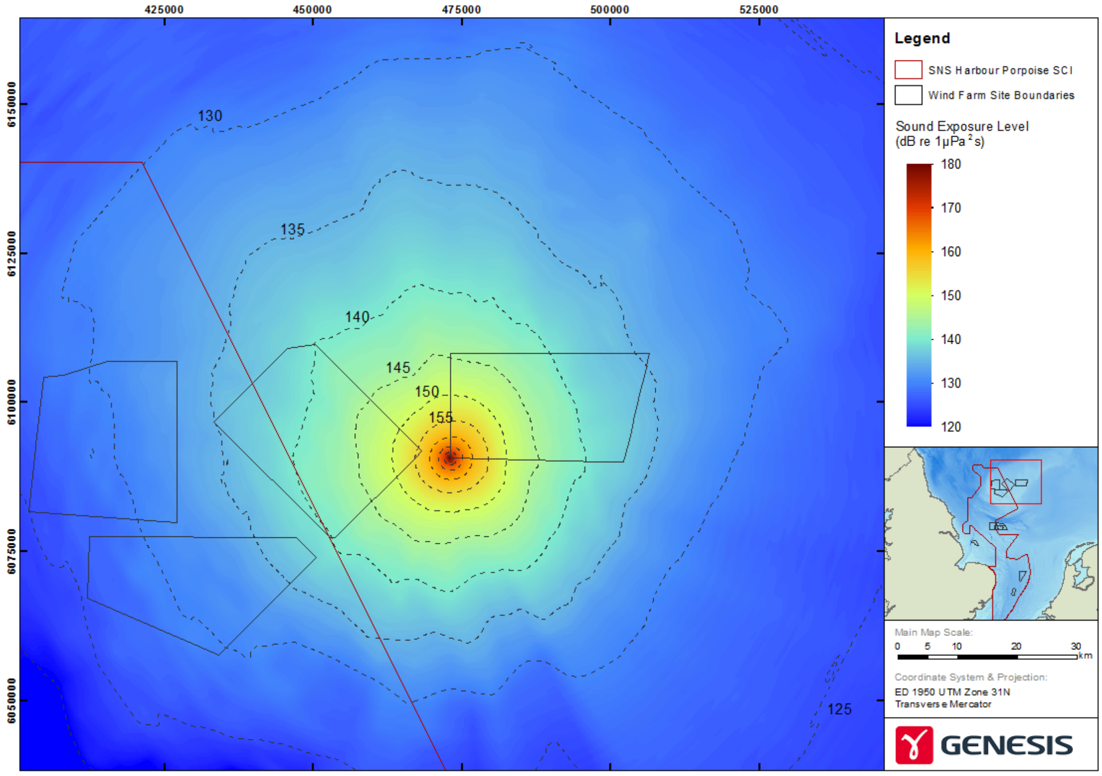

Figure H-9: Depth-averaged unweighted single-pulse SEL for pile-driving at Teesside A model location 1 with hammer energy of 1,900 kJ.

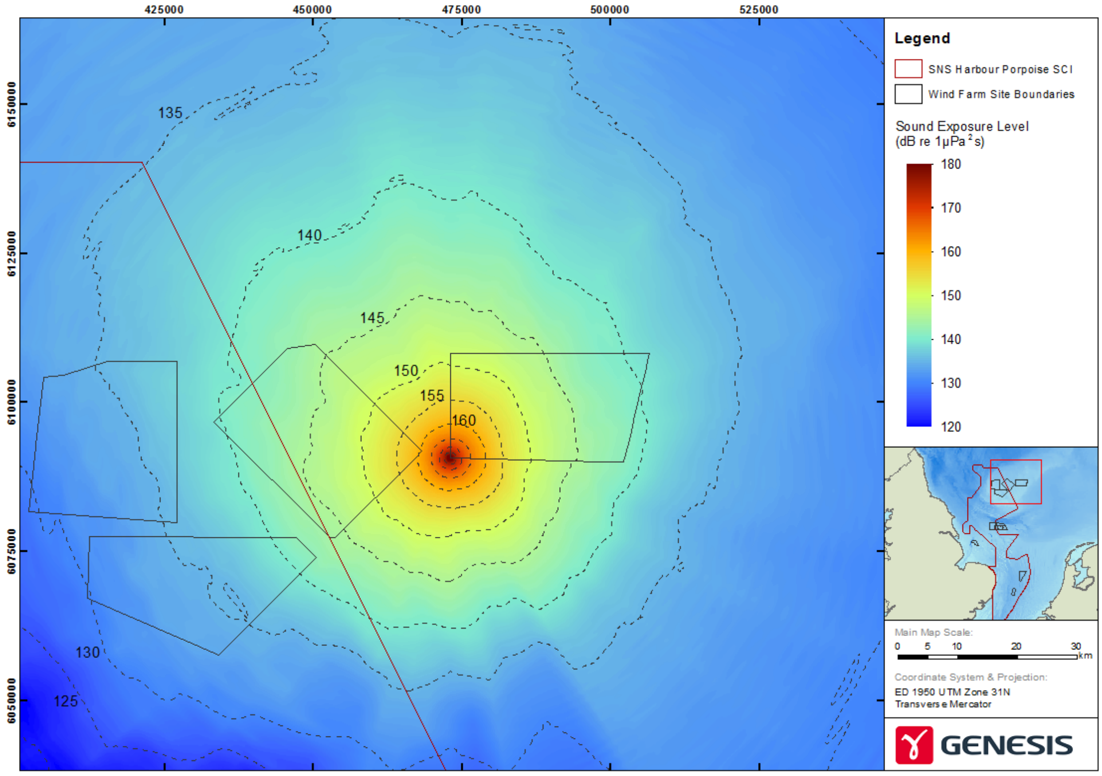

Figure H-10: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Teesside A model location 1 with hammer energy of 1,900 kJ.

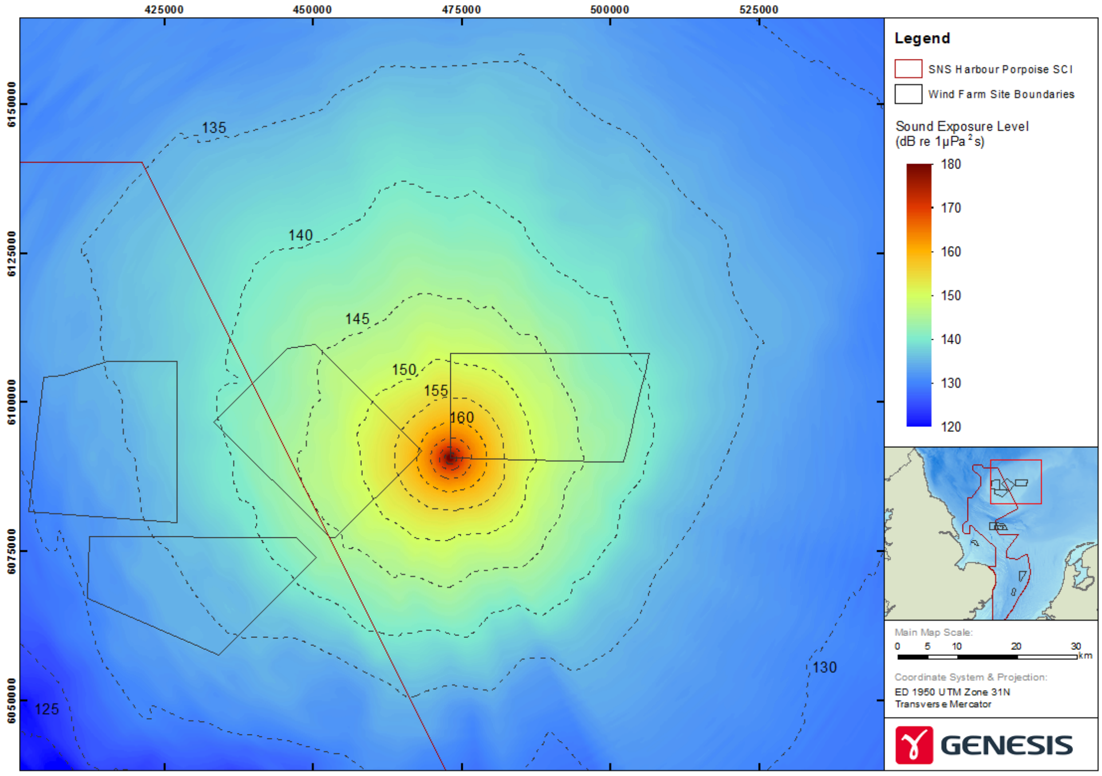

Figure H-11: Depth-averaged unweighted single-pulse SEL for pile-driving at Teesside A model location 1 with hammer energy of 5,500 kJ.

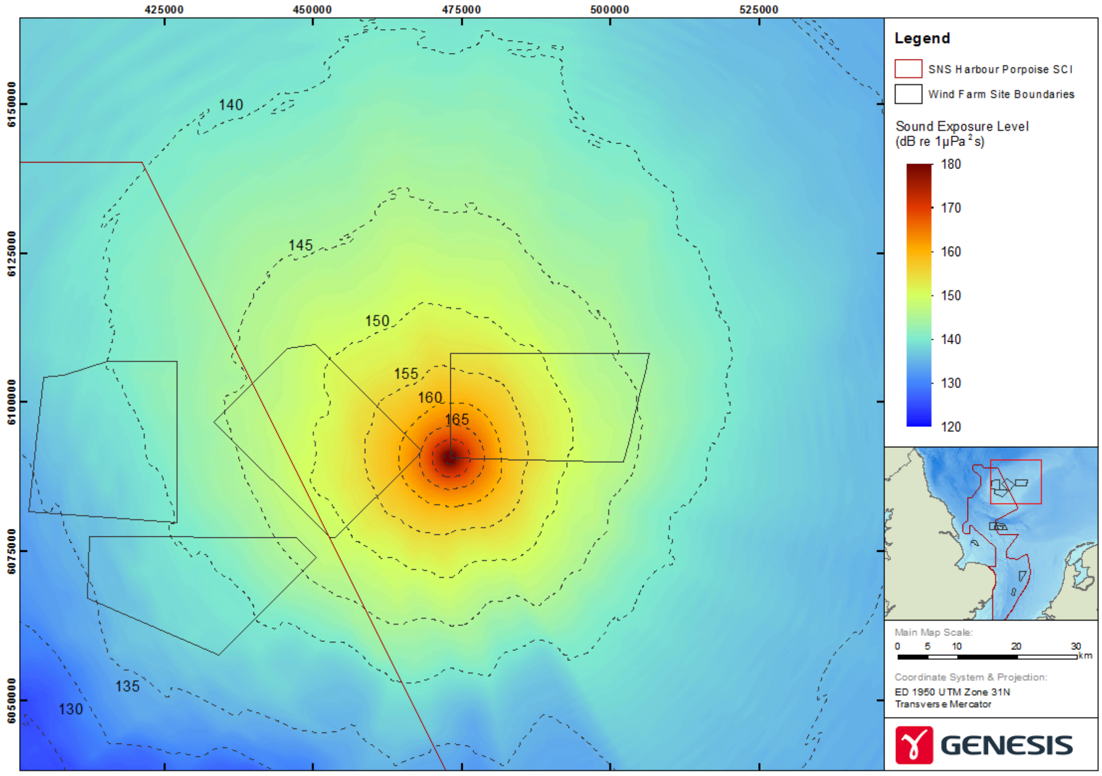

Figure H-12: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Teesside A model location 1 with hammer energy of 5,500 kJ.

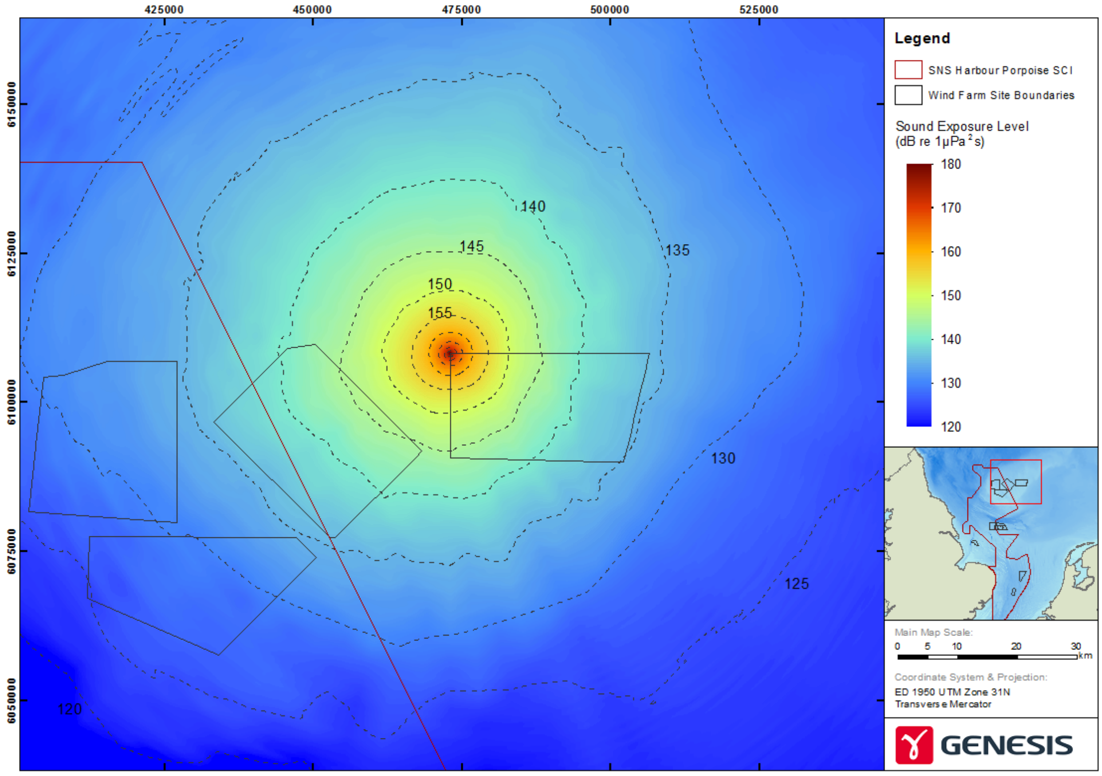

Figure H-13: Depth-averaged unweighted single-pulse SEL for pile-driving at Teesside A model location 2 with hammer energy of 1,900 kJ.

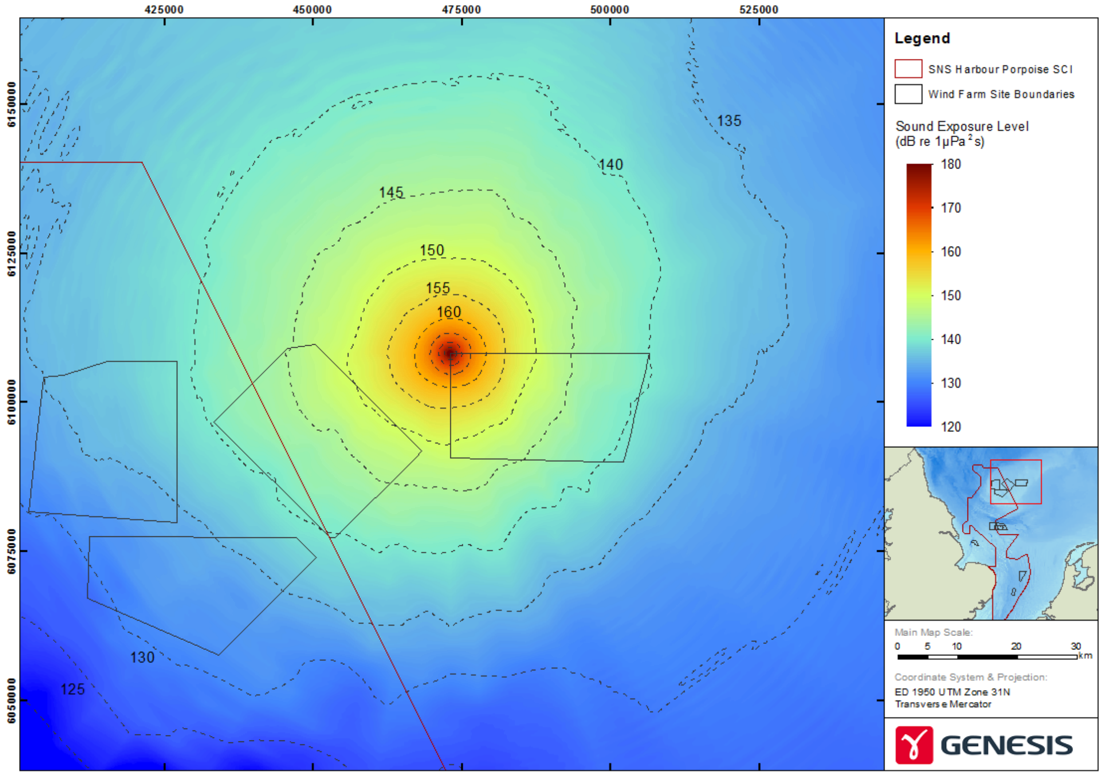

Figure H-14: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Teesside A model location 2 with hammer energy of 1,900 kJ.

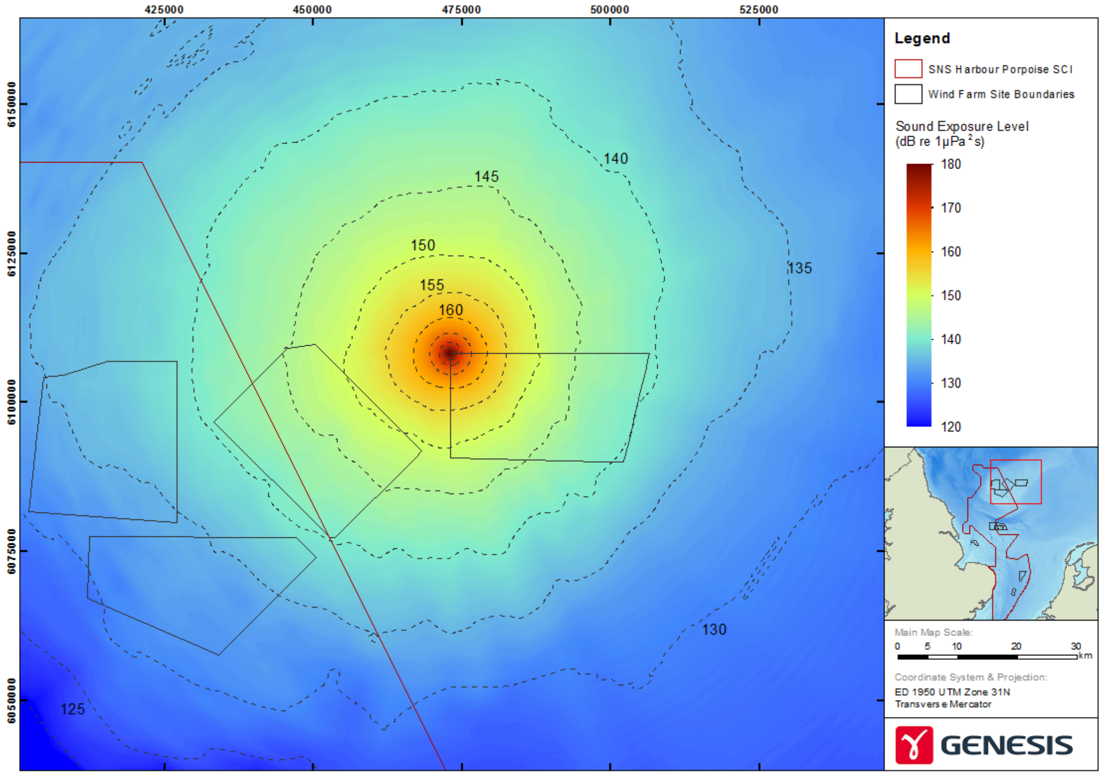

Figure H-15: Depth-averaged unweighted single-pulse SEL for pile-driving at Teesside A model location 2 with hammer energy of 5,500 kJ.

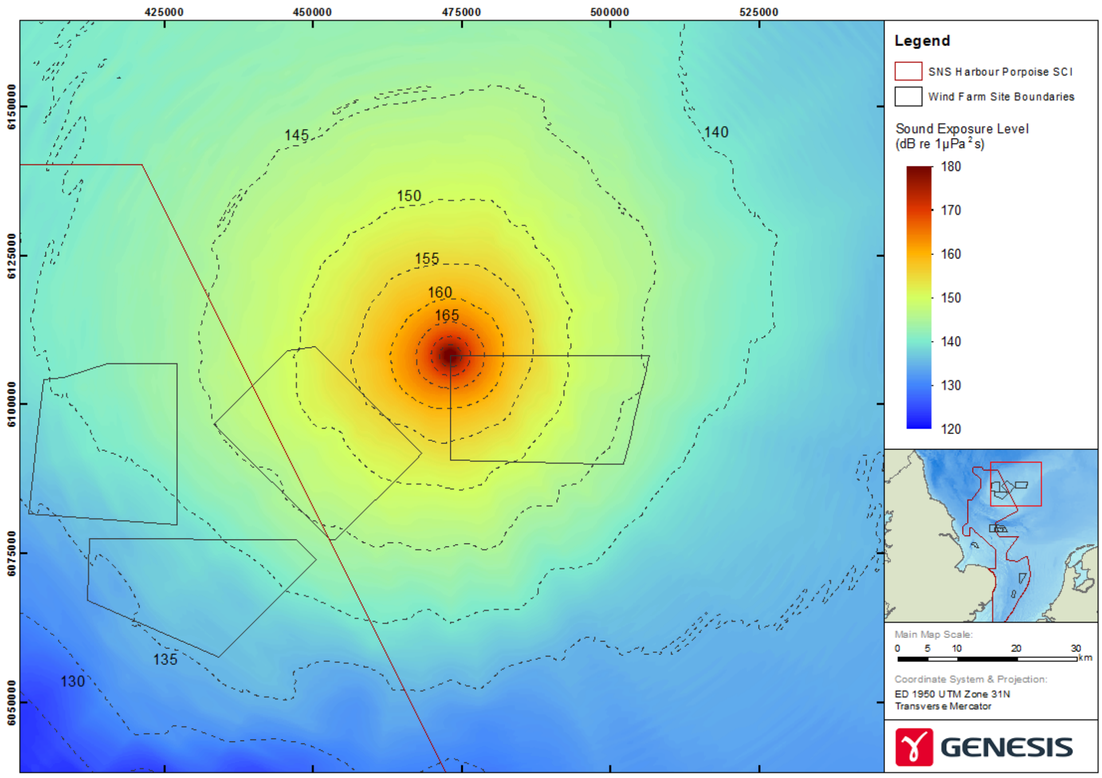

Figure H-16: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Teesside A model location 2 with hammer energy of 5,500 kJ.

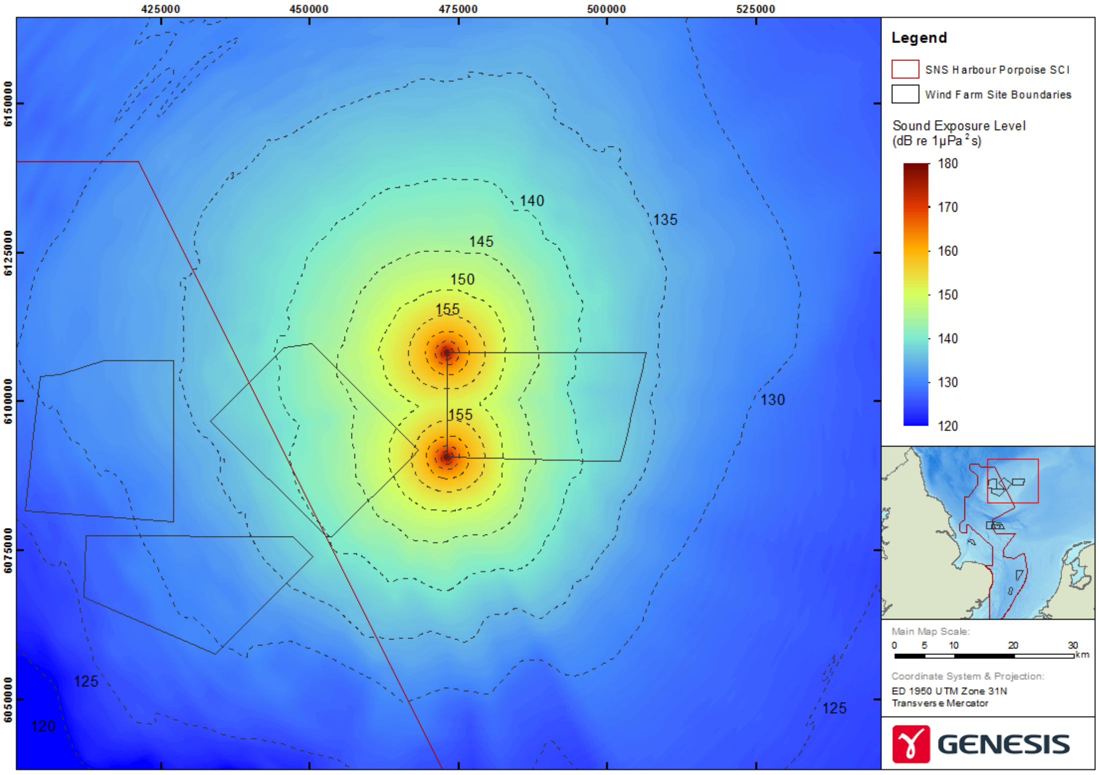

Figure H-17: Depth-averaged unweighted single-pulse SEL for concurrent pile-driving at Teesside A model locations 1 and 2 with hammer energy of 1,900 kJ.

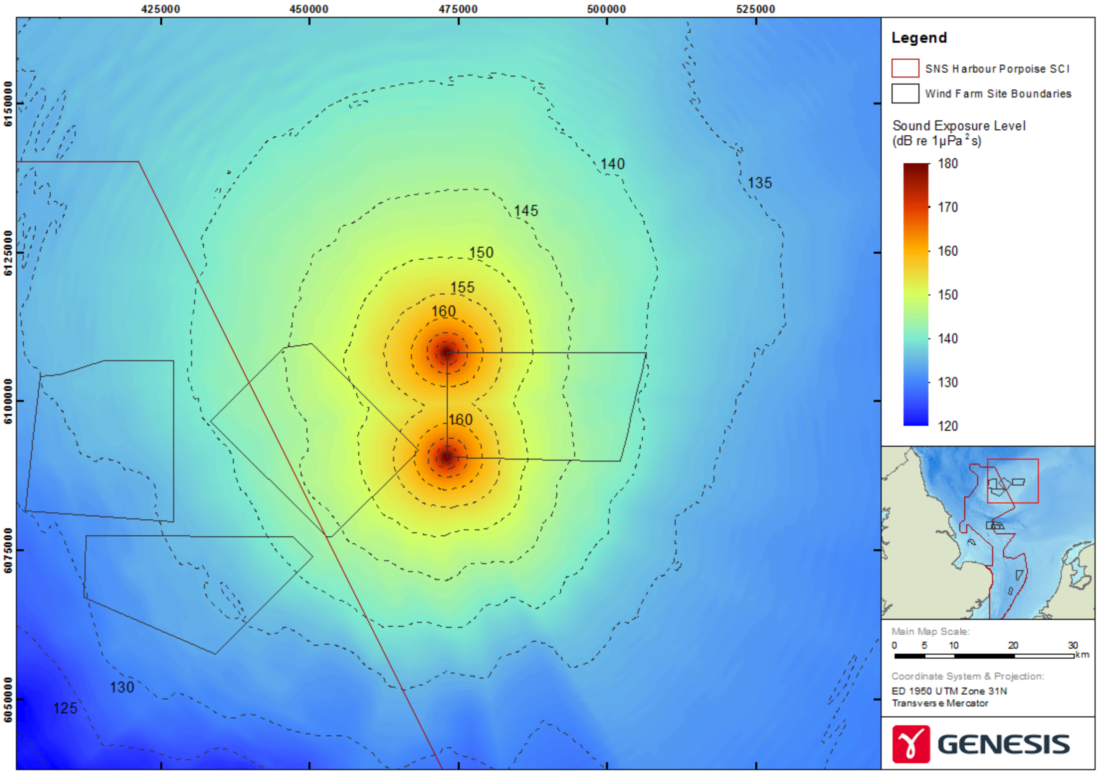

Figure H-18: Maximum-over-depth unweighted single-pulse SEL for concurrent pile-driving at Teesside A model locations 1 and 2 with hammer energy of 1,900 kJ.

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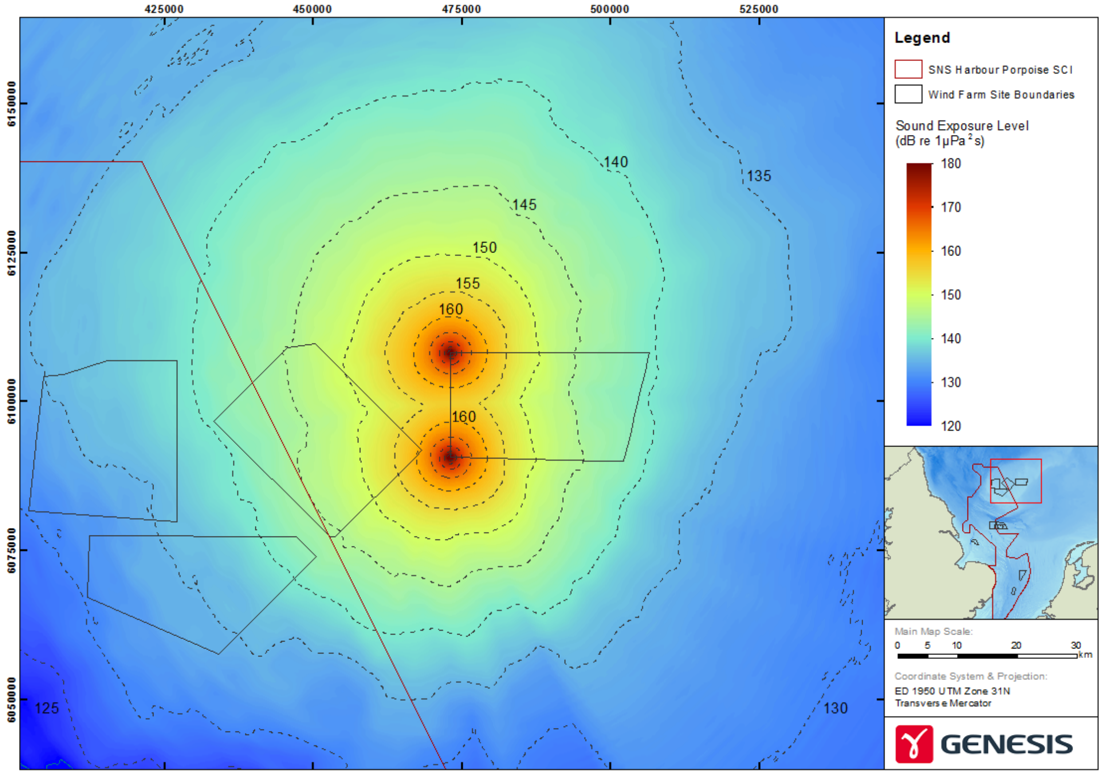

Figure H-19: Depth-averaged unweighted single-pulse SEL for concurrent pile-driving at Teesside A model locations 1 and 2 with hammer energy of 5,500 kJ.

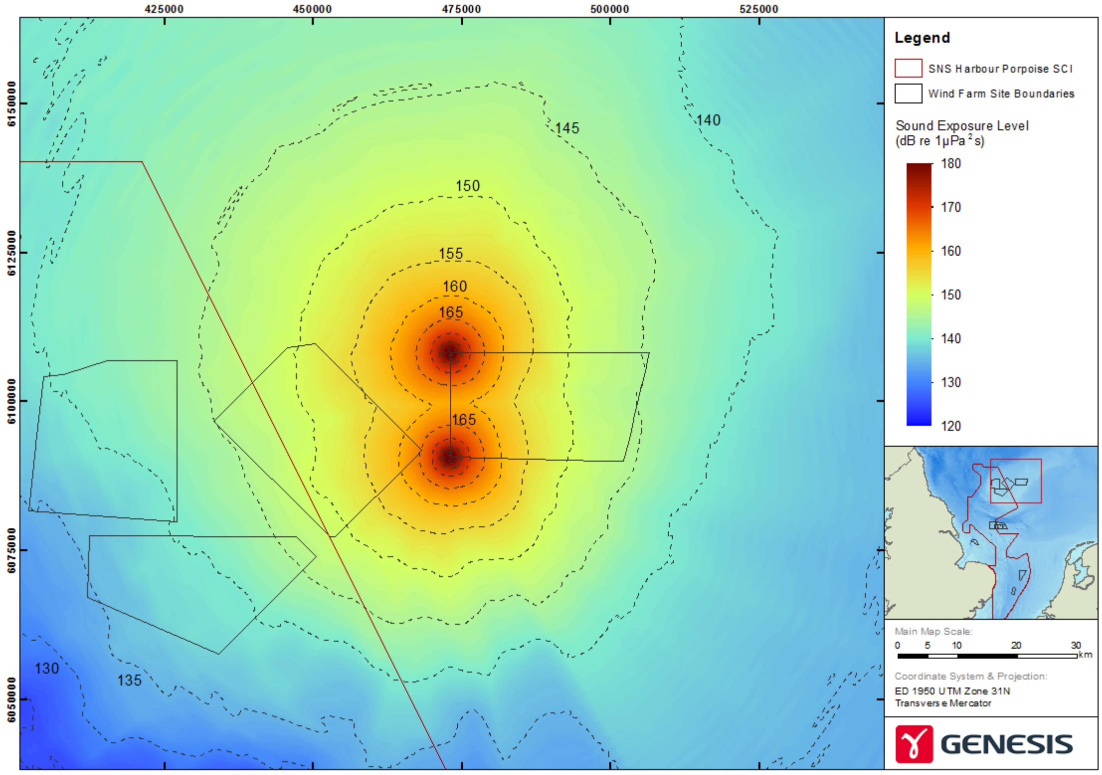

Figure H-20: Maximum-over-depth unweighted single-pulse SEL for concurrent pile-driving at Teesside A model locations 1 and 2 with hammer energy of 5,500 kJ.

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APPENDIX I: MODELLING MAPS FOR TEESSIDE B

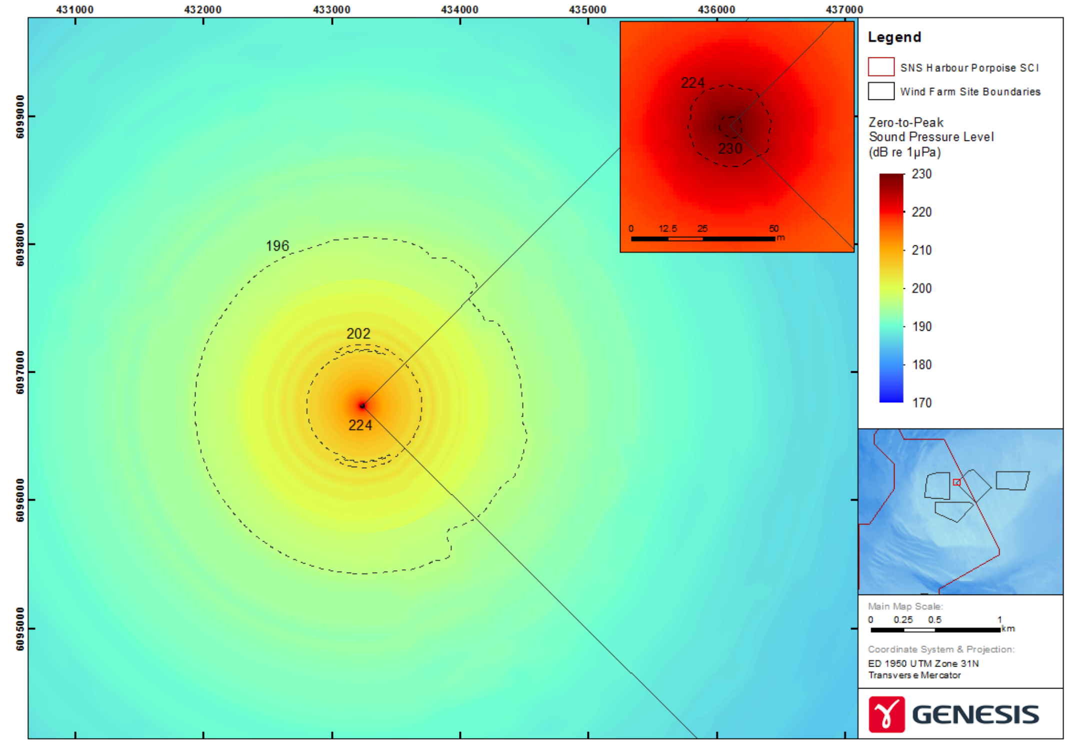

Figure I-1: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Teesside B model location 1 with hammer energy of 1,900 kJ.

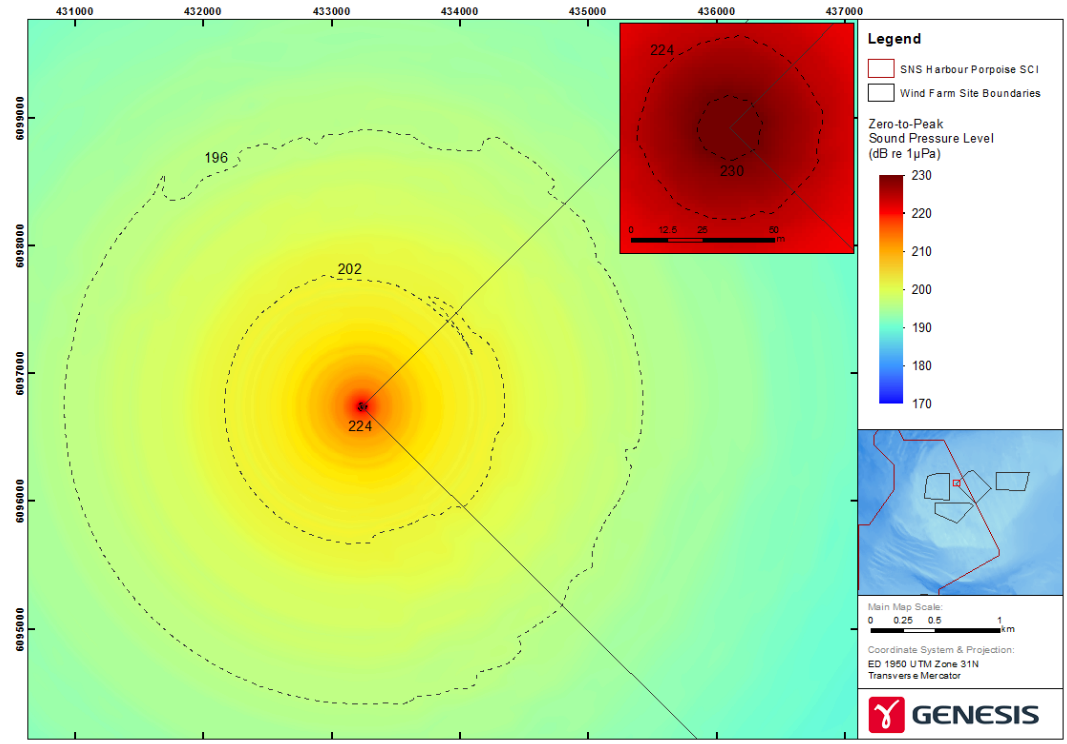

Figure I-2: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Teesside B model location 1 with hammer energy of 5,500 kJ.

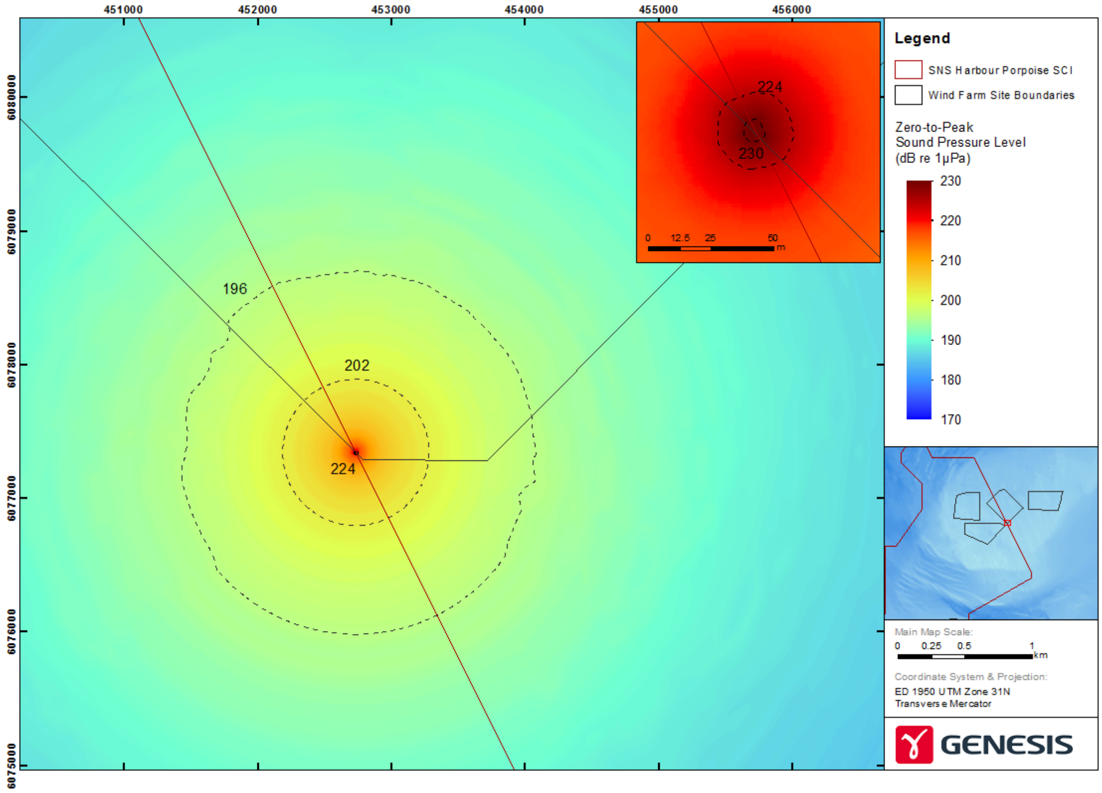

Figure I-3: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Teesside B model location 2 with hammer energy of 1,900 kJ.

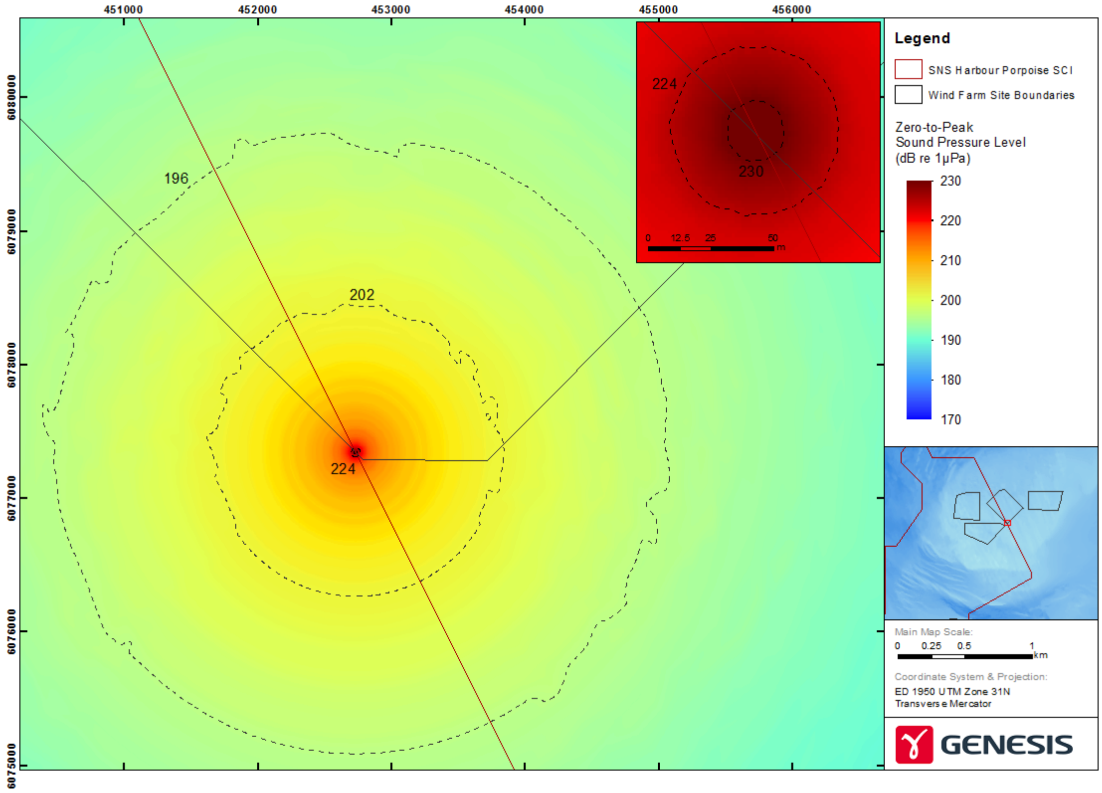

Figure I-4: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Teesside B model location 2 with hammer energy of 5,500 kJ.

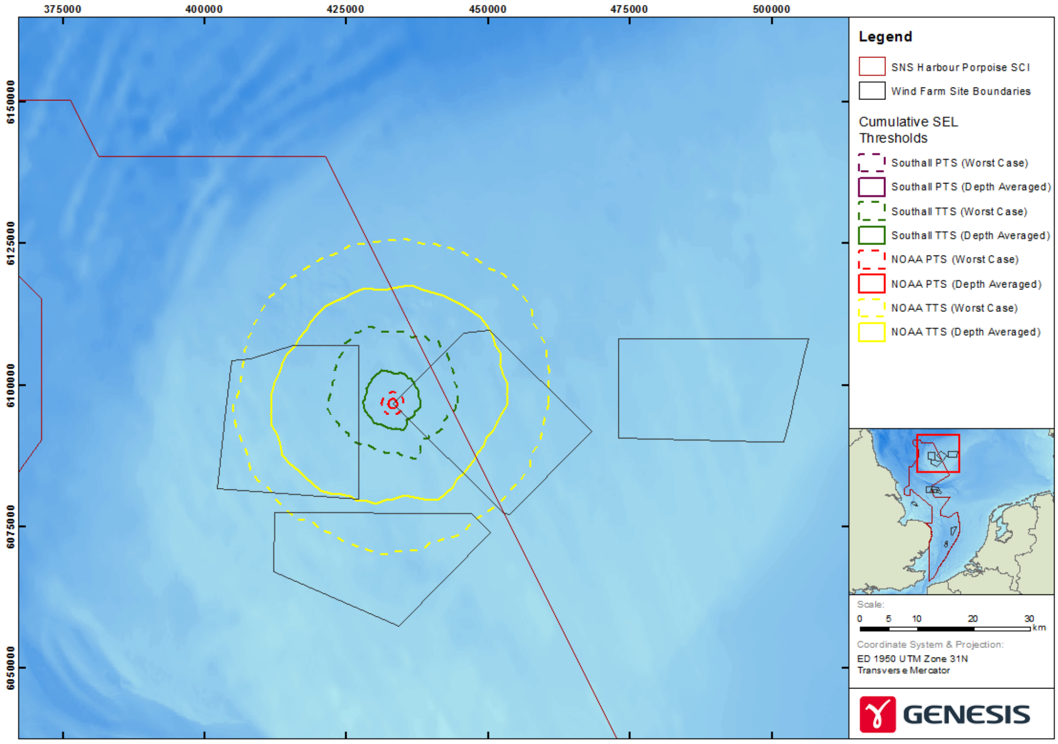

Figure I-5: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Teesside B model location 1 with maximum hammer energy of 1,900 kJ.

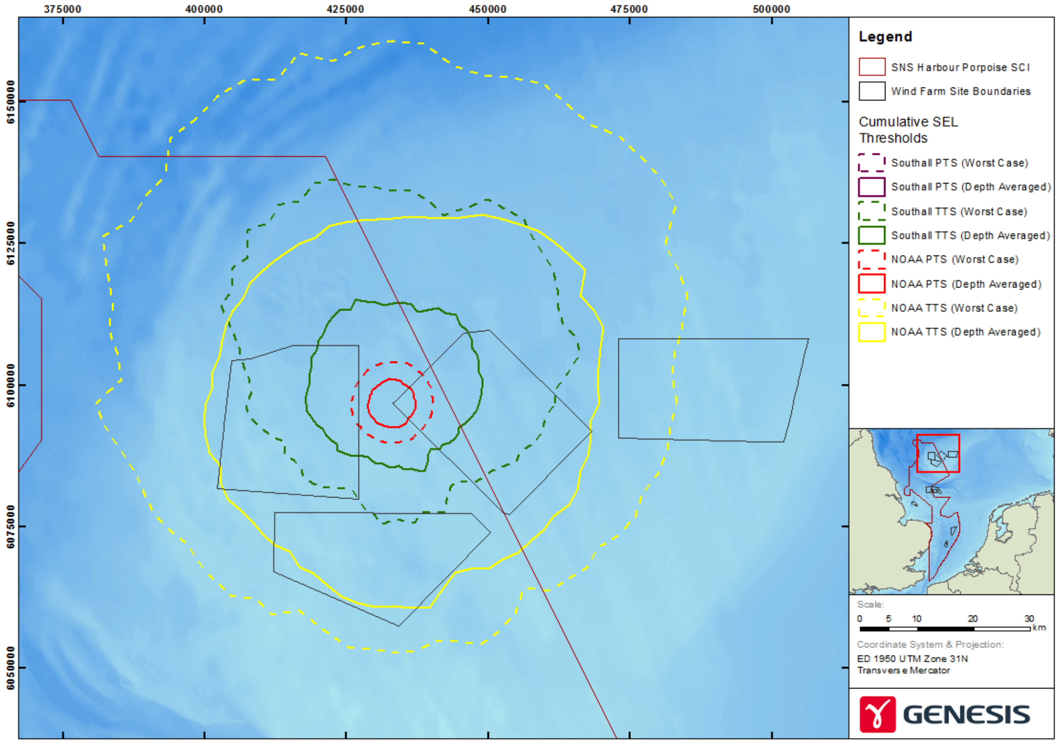

Figure I-6: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Teesside B model location 1 with maximum hammer energy of 5,500 kJ.

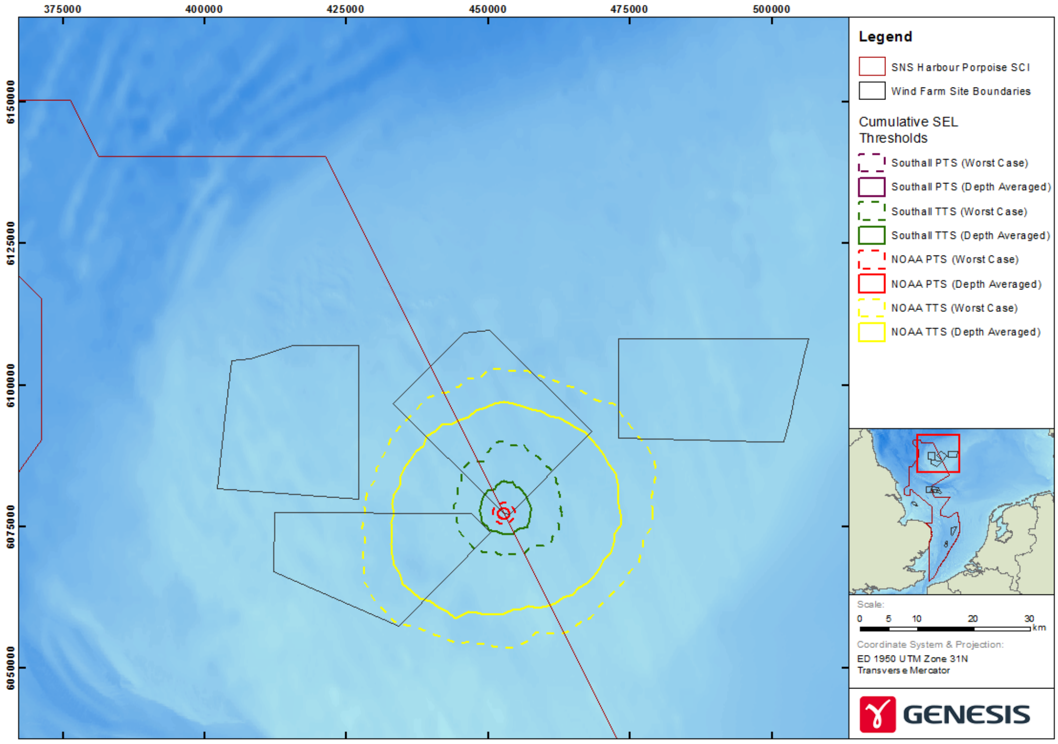

Figure I-7: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Teesside B model location 2 with maximum hammer energy of 1,900 kJ.

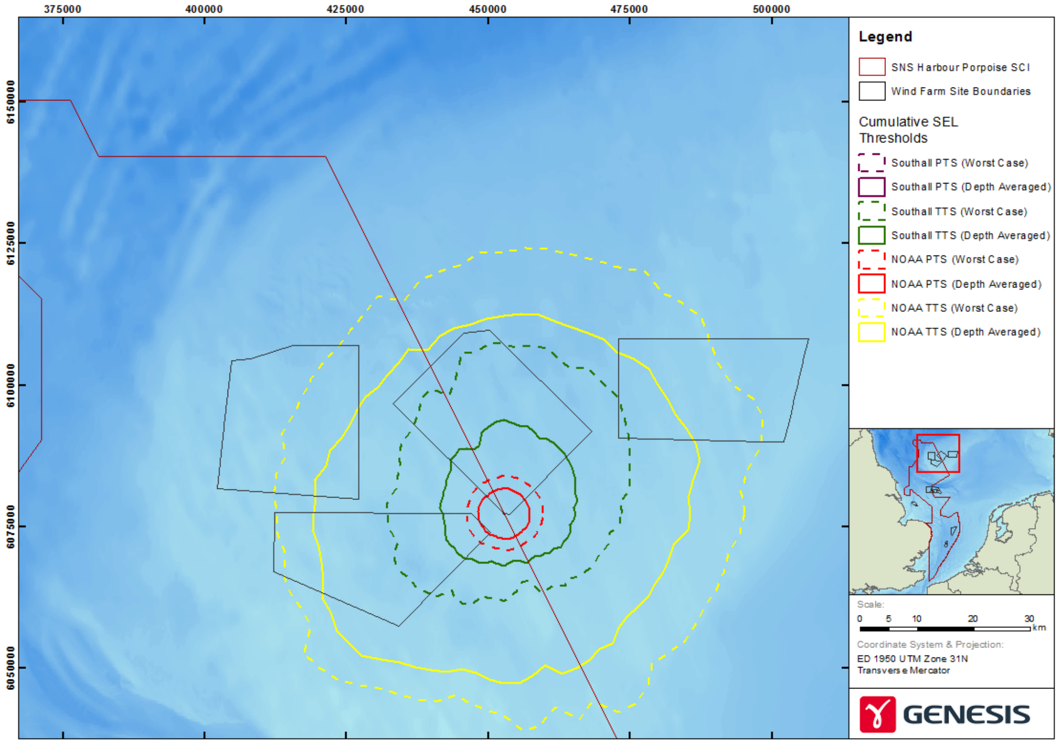

Figure I-8: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Teesside B model location 2 with maximum hammer energy of 5,500 kJ.

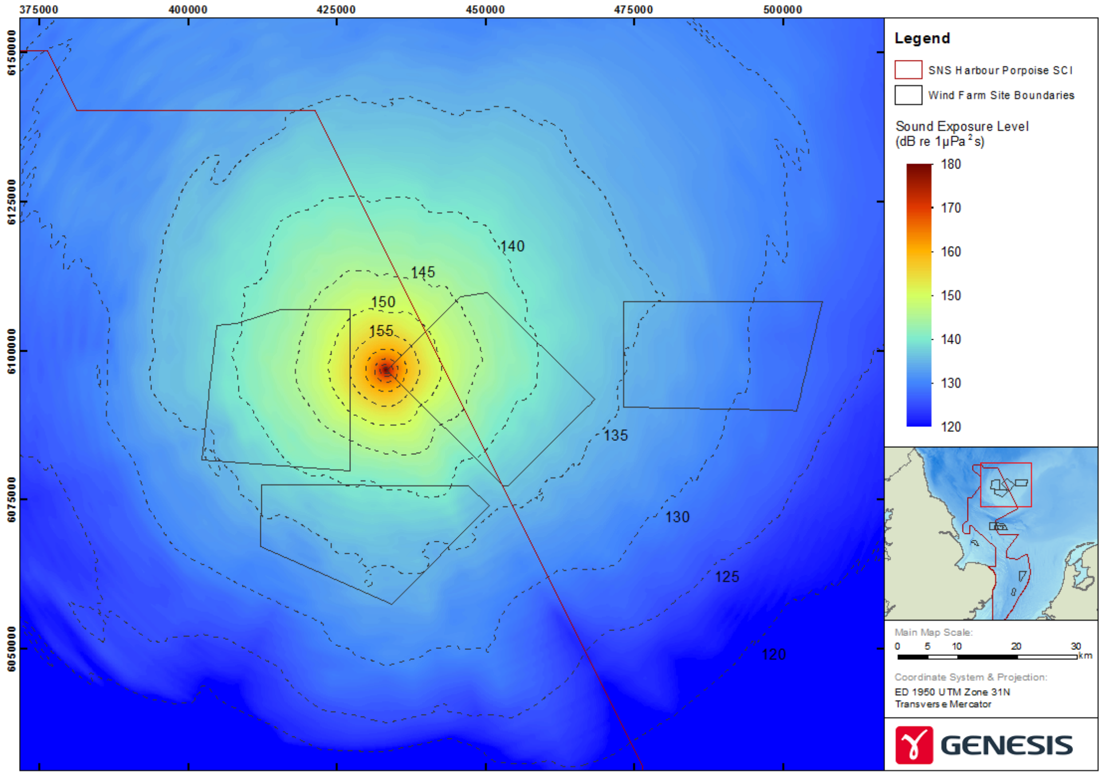

Figure I-9: Depth-averaged unweighted single-pulse SEL for pile-driving at Teesside B model location 1 with hammer energy of 1,900 kJ.

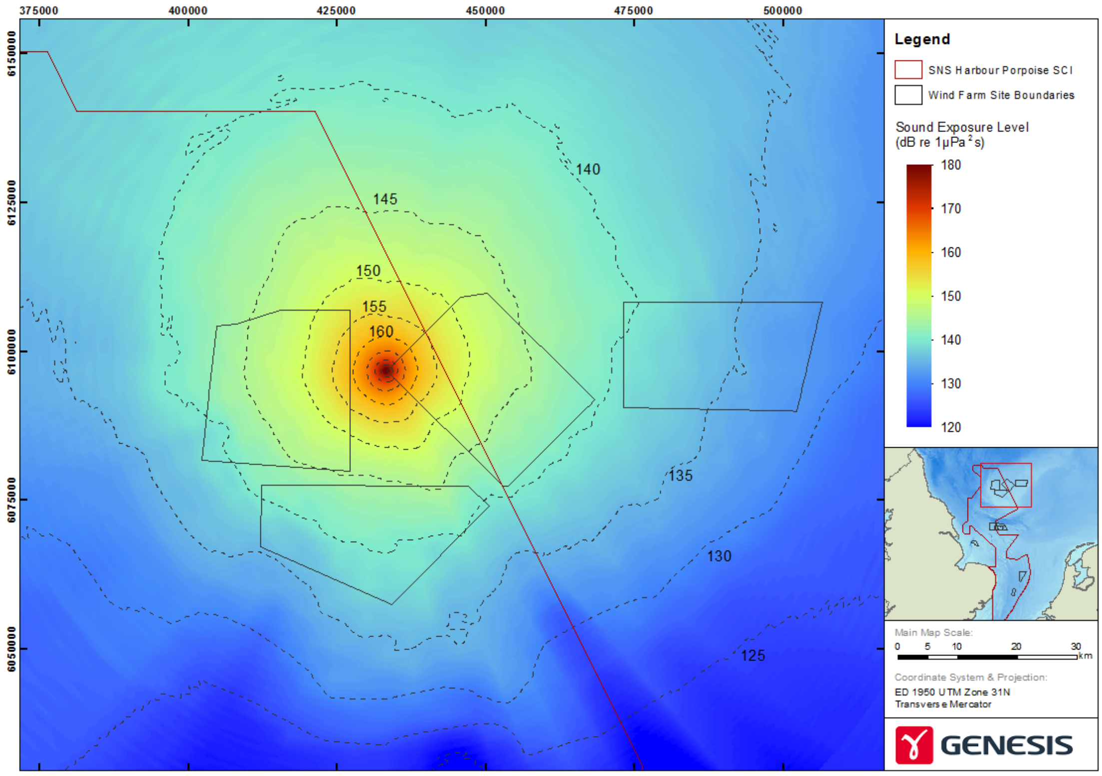

Figure I-10: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Teesside B model location 1 with hammer energy of 1,900 kJ.

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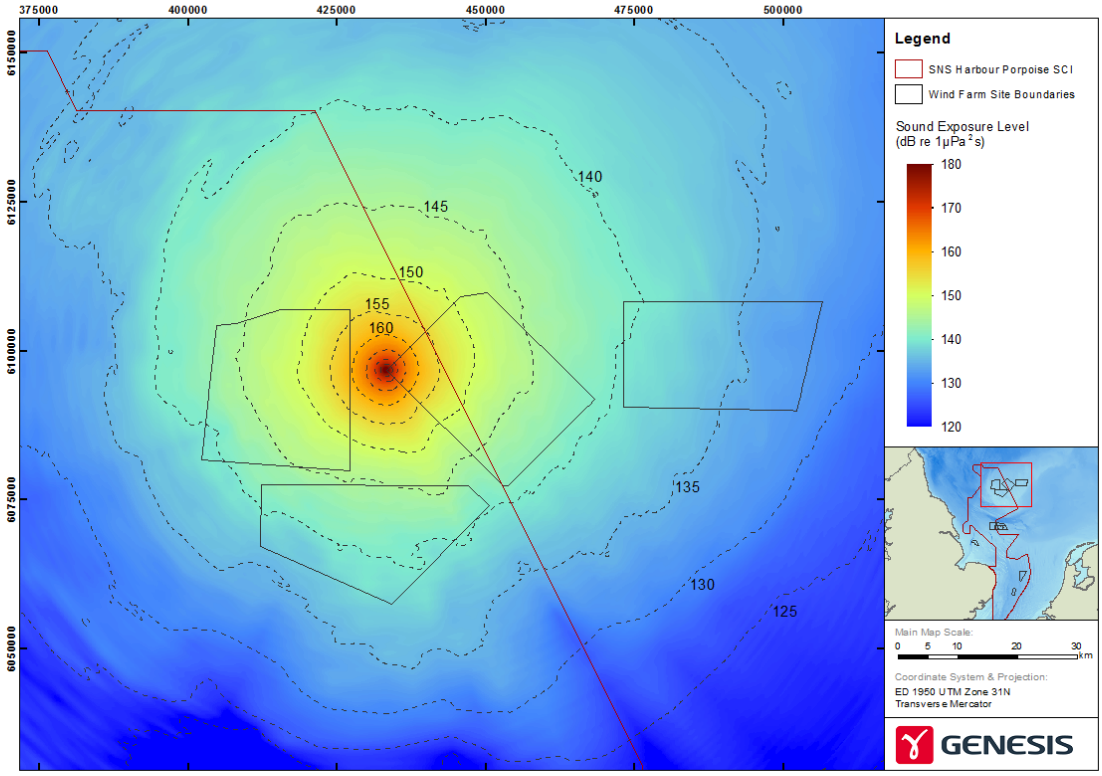

Figure I-11: Depth-averaged unweighted single-pulse SEL for pile-driving at Teesside B model location 1 with hammer energy of 5,500 kJ.

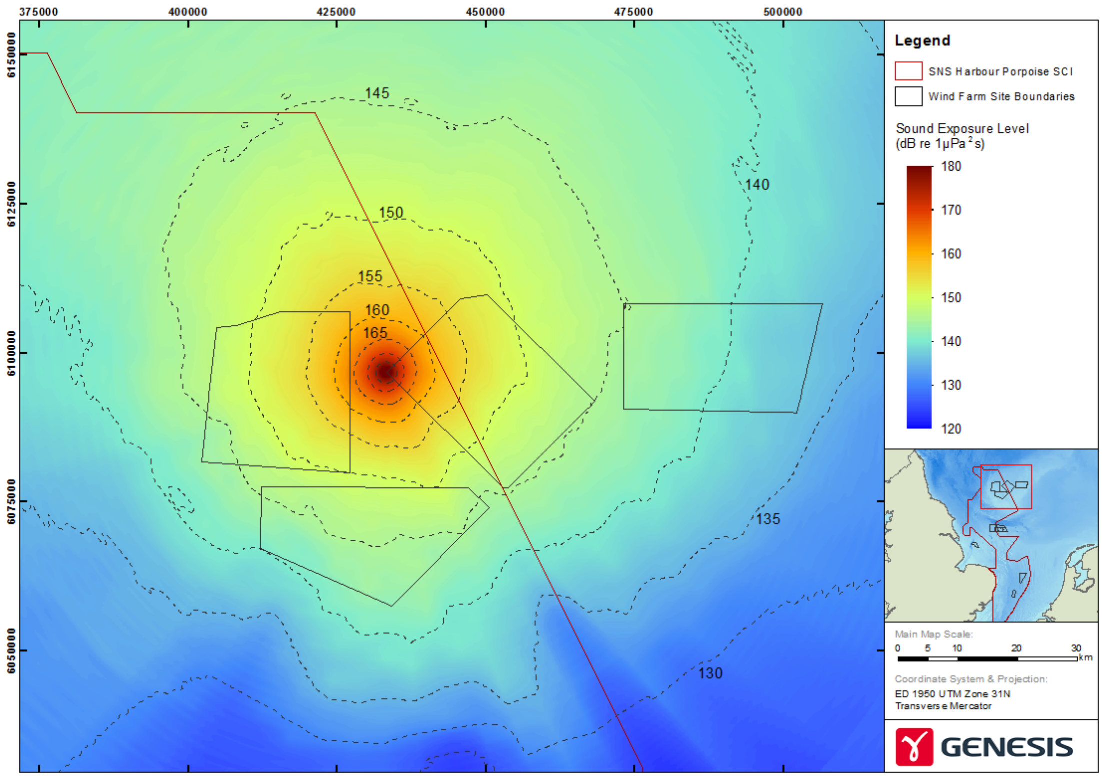

Figure I-12: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Teesside B model location 1 with hammer energy of 5,500 kJ.

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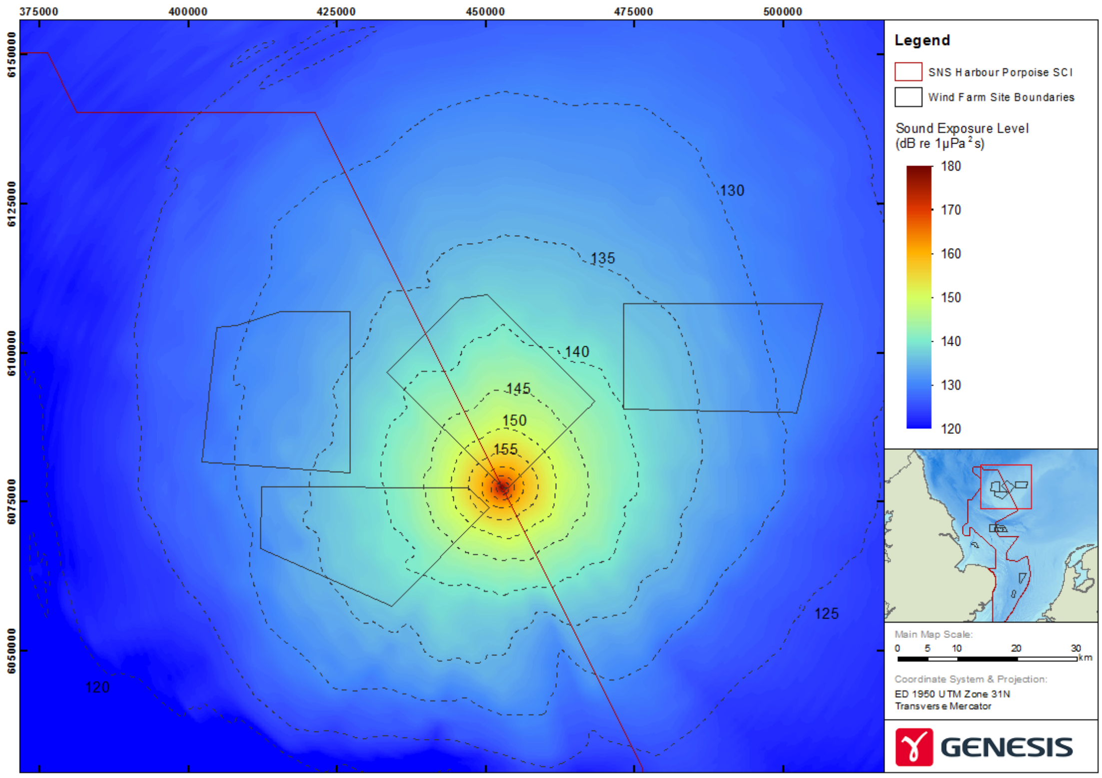

Figure I-13: Depth-averaged unweighted single-pulse SEL for pile-driving at Teesside B model location 2 with hammer energy of 1,900 kJ.

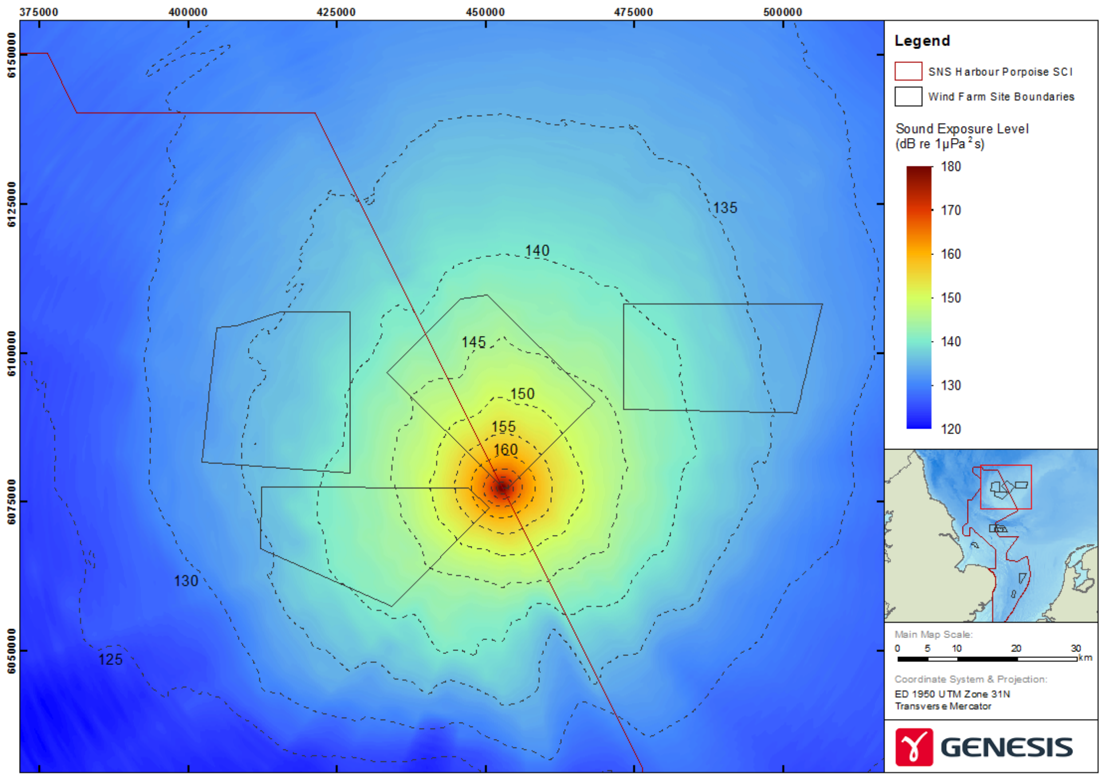

Figure I-14: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Teesside B model location 2 with hammer energy of 1,900 kJ.

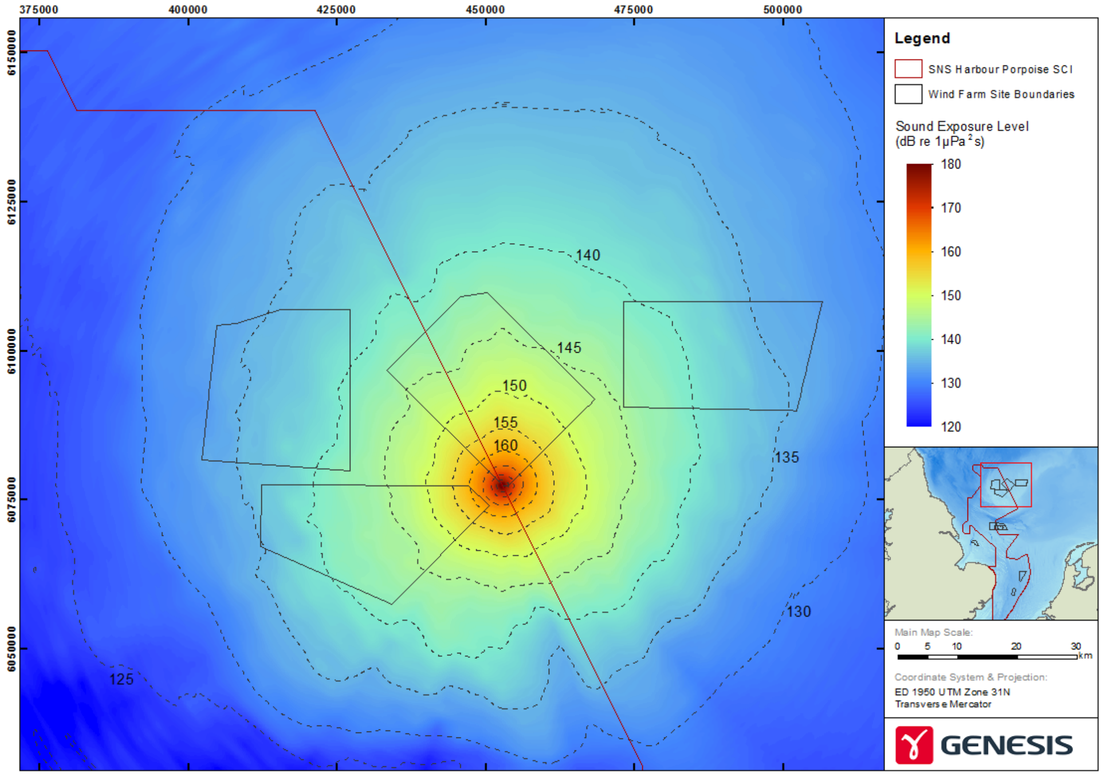

Figure I-15: Depth-averaged unweighted single-pulse SEL for pile-driving at Teesside B model location 2 with hammer energy of 5,500 kJ.

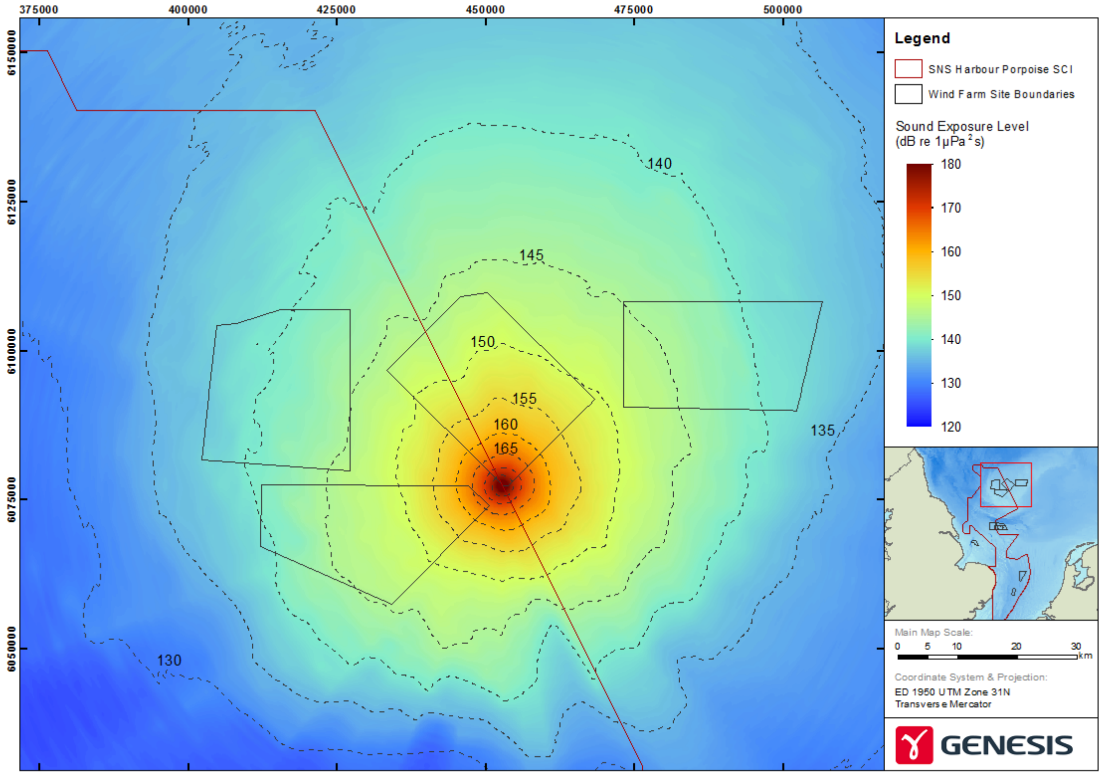

Figure I-16: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Teesside B model location 2 with hammer energy of 5,500 kJ.

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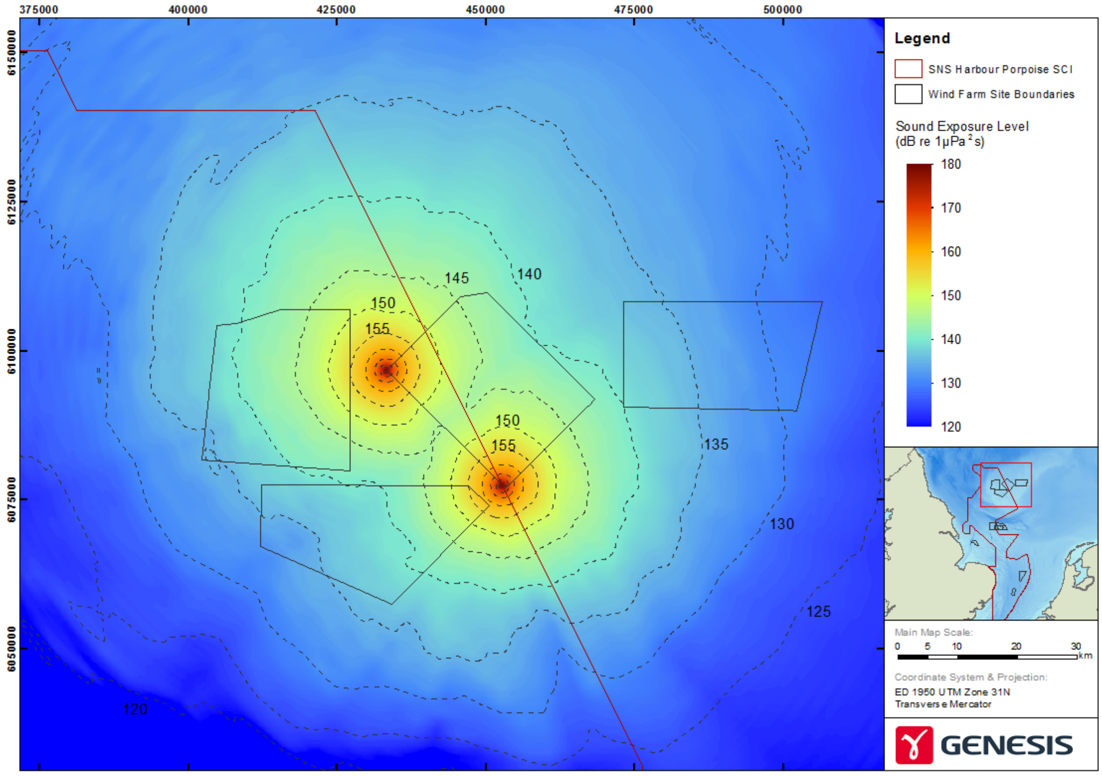

Figure I-17: Depth-averaged unweighted single-pulse SEL for concurrent pile-driving at Teesside B model locations 1 and 2 with hammer energy of 1,900 kJ.

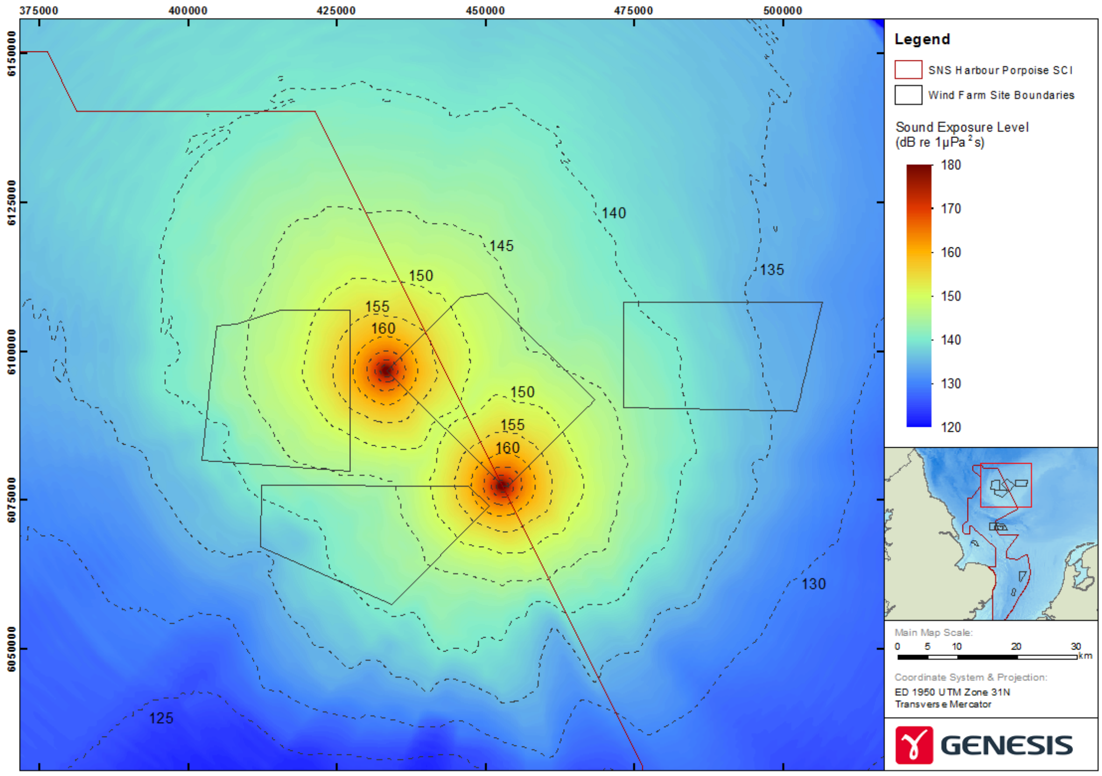

Figure I-18: Maximum-over-depth unweighted single-pulse SEL for concurrent pile-driving at Teesside B model locations 1 and 2 with hammer energy of 1,900 kJ.

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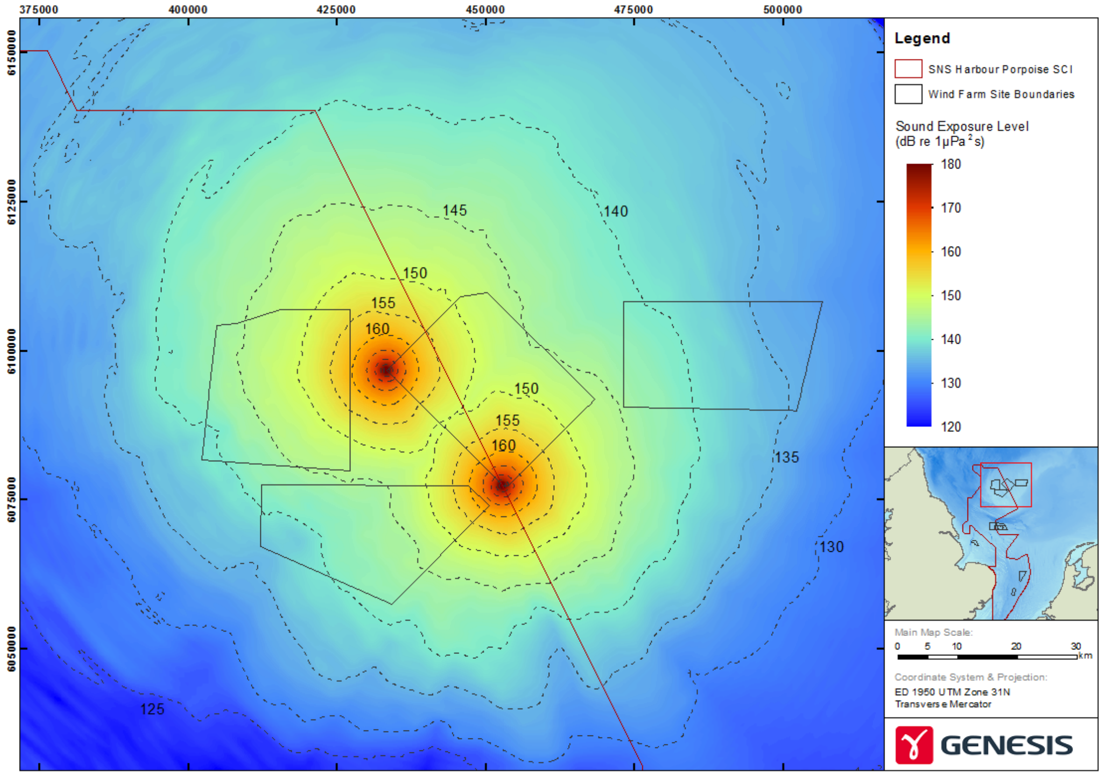

Figure I-19: Depth-averaged unweighted single-pulse SEL for concurrent pile-driving at Teesside B model locations 1 and 2 with hammer energy of 5,500 kJ.

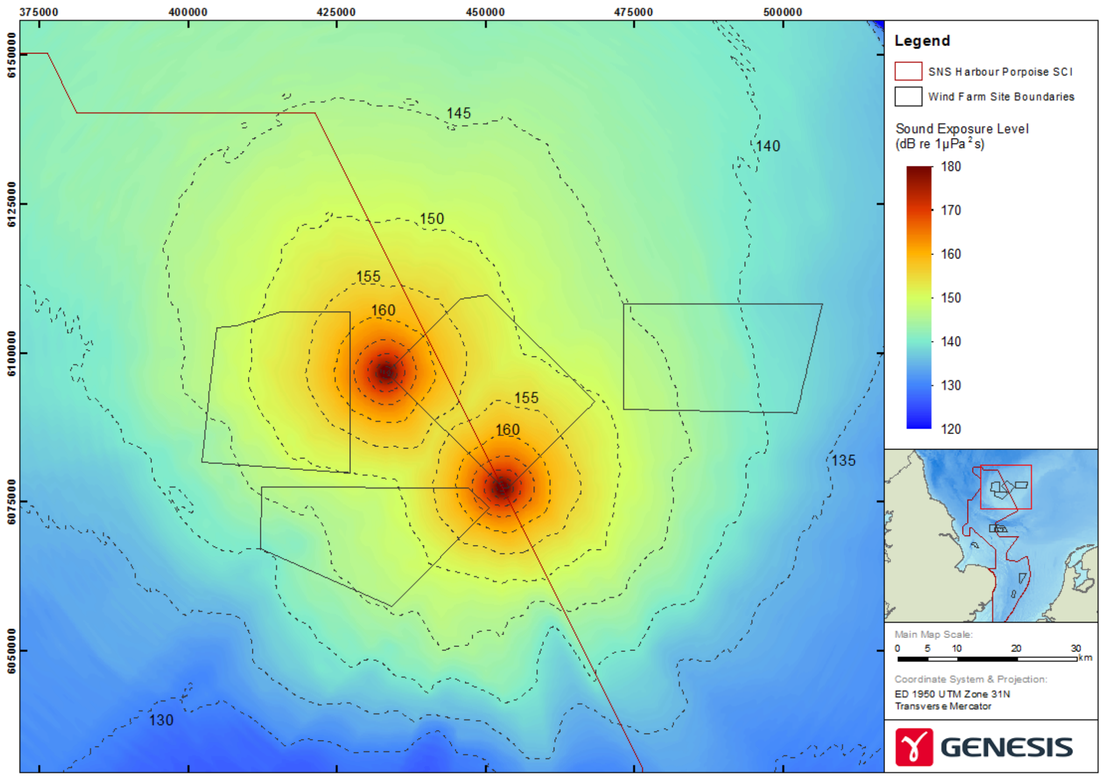

Figure I-20: Maximum-over-depth unweighted single-pulse SEL for concurrent pile-driving at Teesside B model locations 1 and 2 with hammer energy of 5,500 kJ.

APPENDIX J: MODELLING MAPS FOR TRITON KNOLL

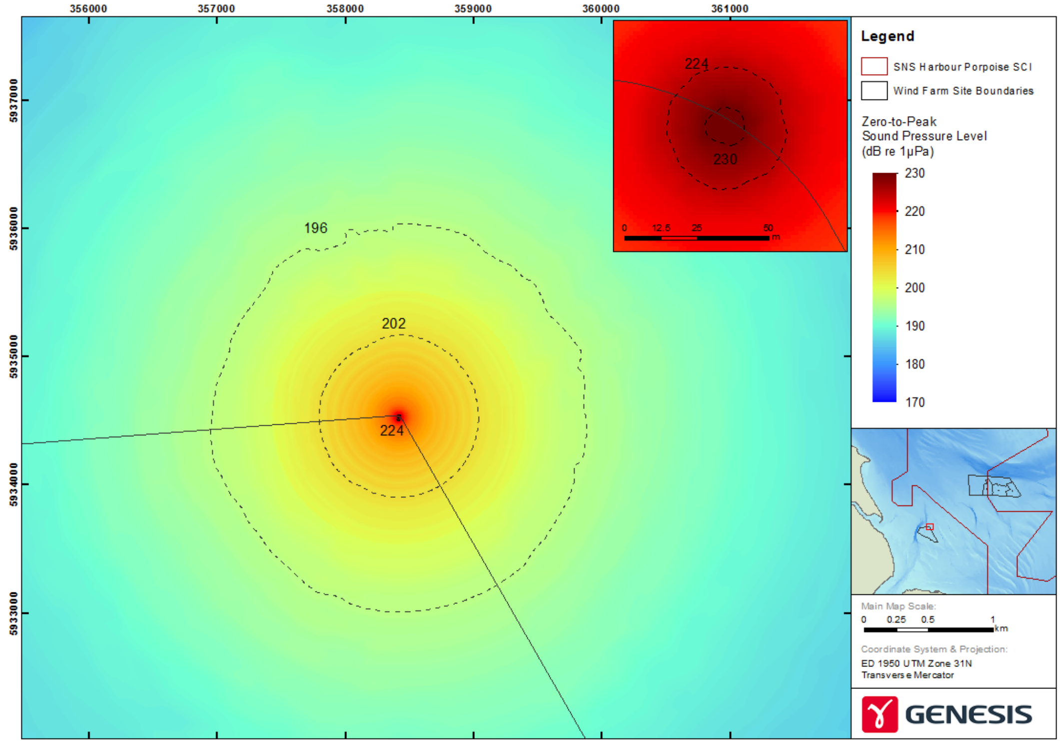

Figure J-1: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Triton Knoll model location 1 with hammer energy of 2,700 kJ.

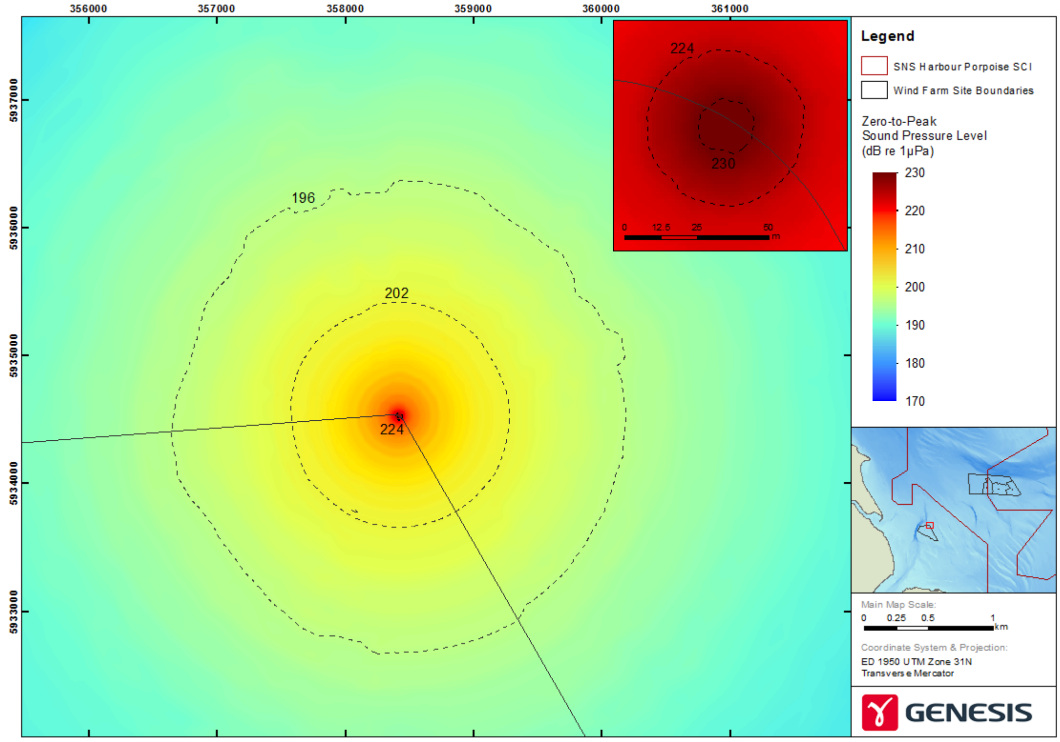

Figure J-2: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Triton Knoll model location 1 with hammer energy of 4,000 kJ.

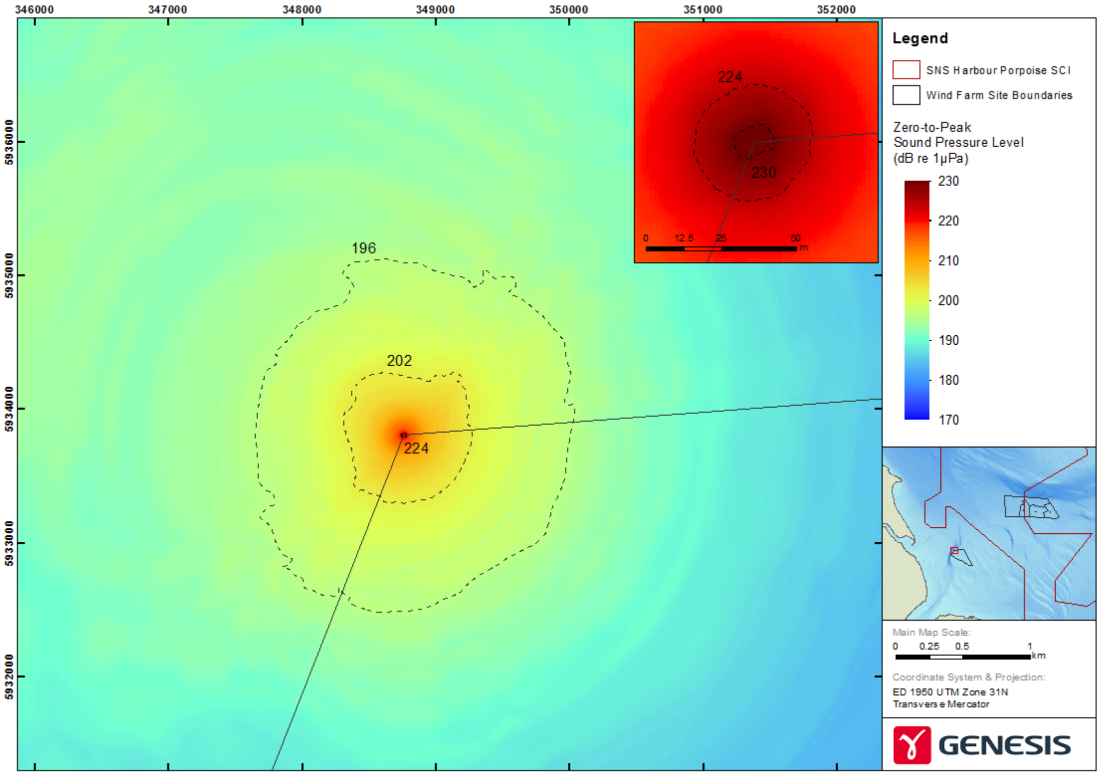

Figure J-3: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Triton Knoll model location 2 with hammer energy of 2,700 kJ.

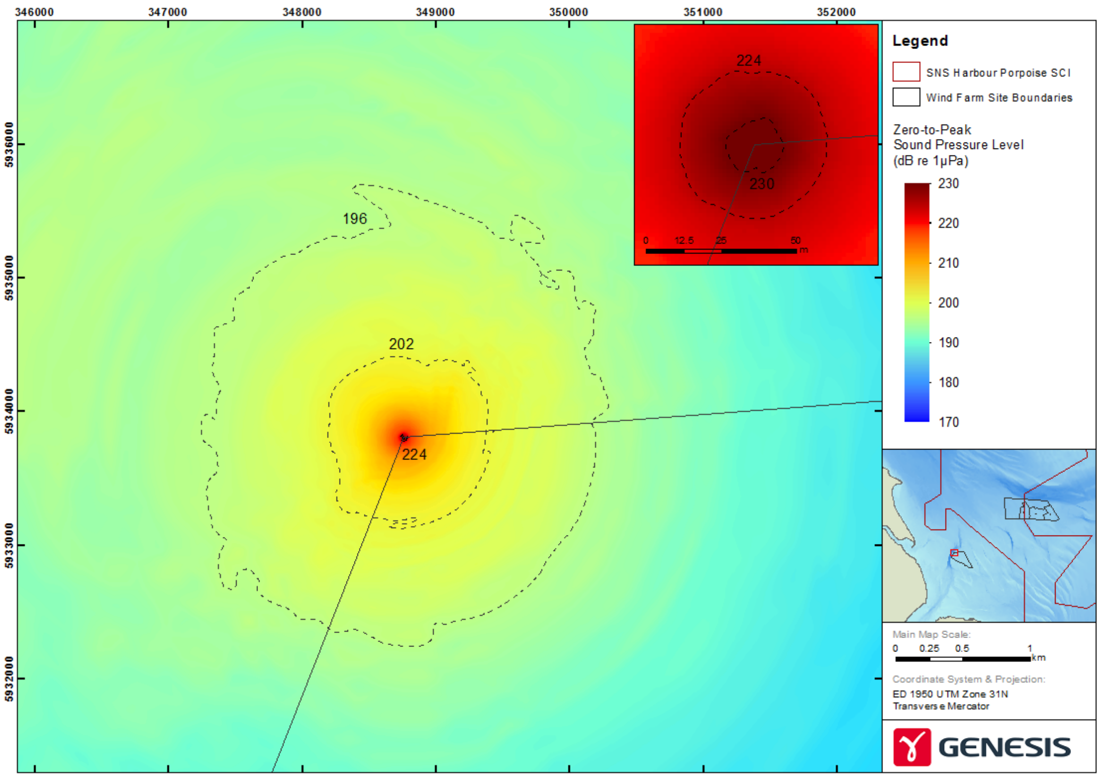

Figure J-4: Maximum-over-depth unweighted zero-to-peak SPL for pile-driving at Triton Knoll model location 2 with hammer energy of 4,000 kJ.

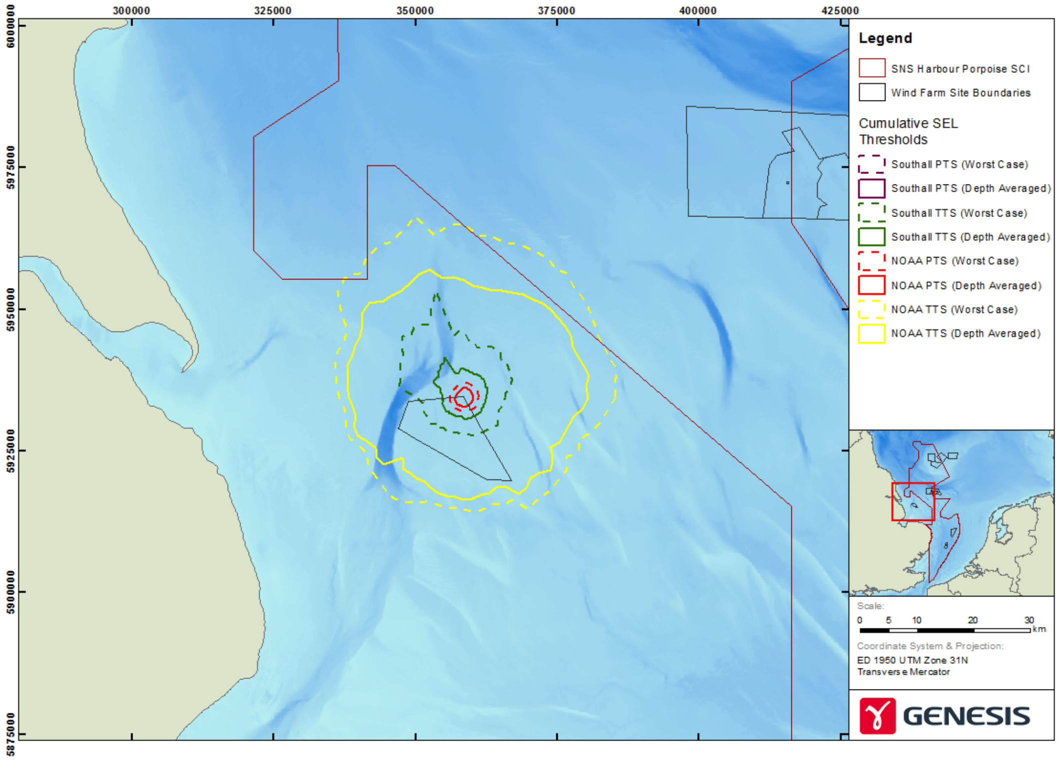

Figure J-5: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Triton Knoll model location 1 with maximum hammer energy of 2,700 kJ.

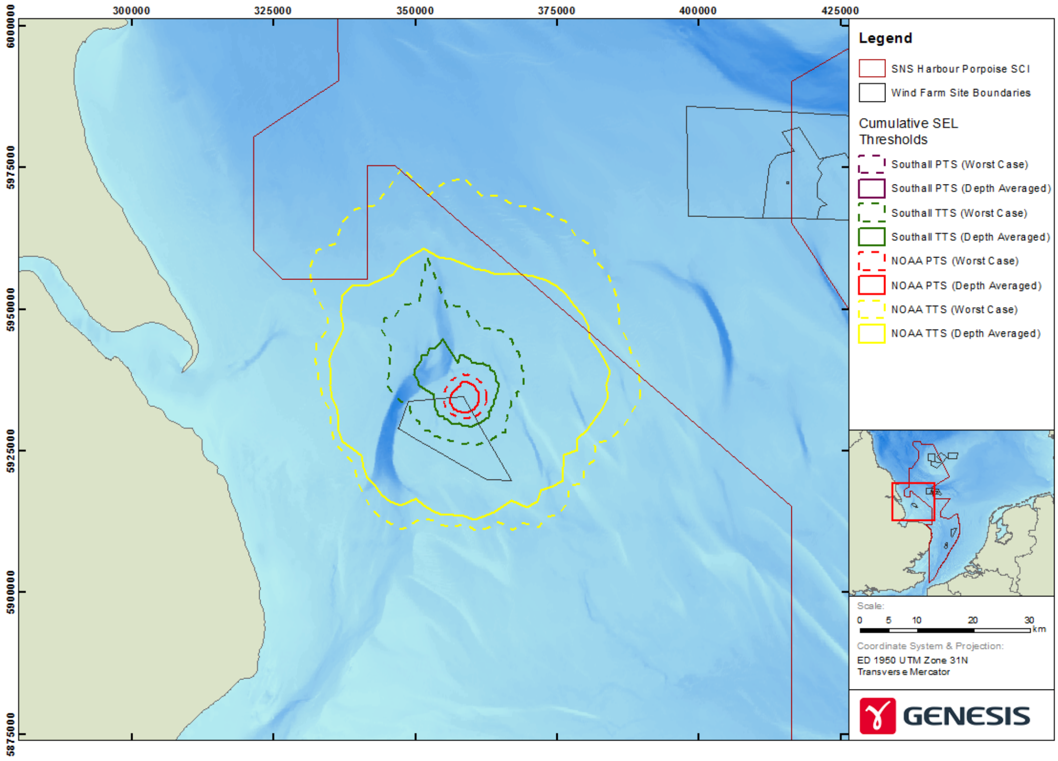

Figure J-6: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Triton Knoll model location 1 with maximum hammer energy of 4,000 kJ.

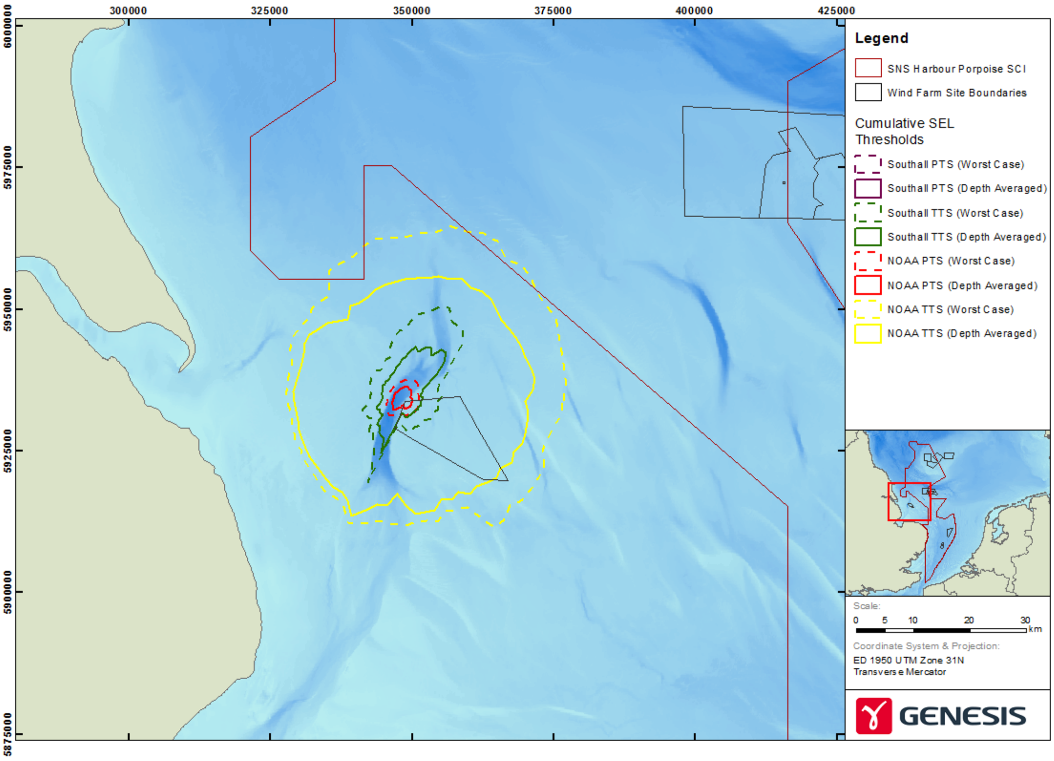

Figure J-7: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Triton Knoll model location 2 with maximum hammer energy of 2,700 kJ.

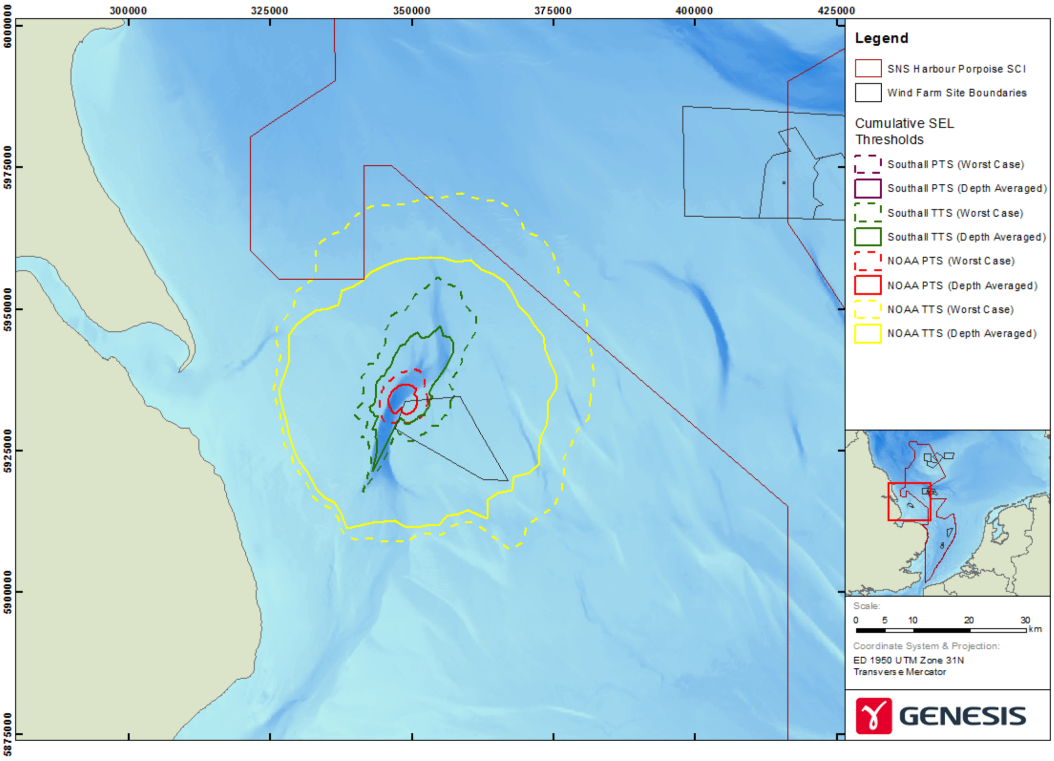

Figure J-8: Areas where Southall and NOAA cumulative SEL thresholds are exceeded for fleeing harbour porpoise during pile-driving at Triton Knoll model location 2 with maximum hammer energy of 4,000 kJ.

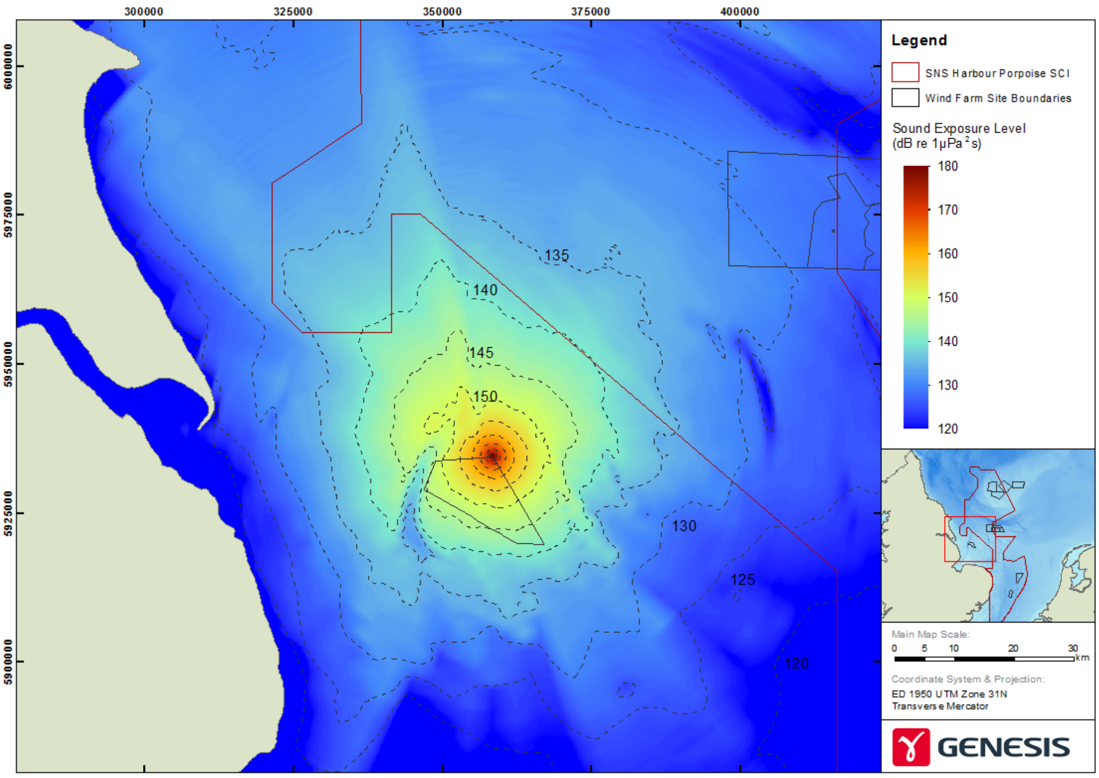

Figure J-9: Depth-averaged unweighted single-pulse SEL for pile-driving at Triton Knoll model location 1 with hammer energy of 2,700 kJ.

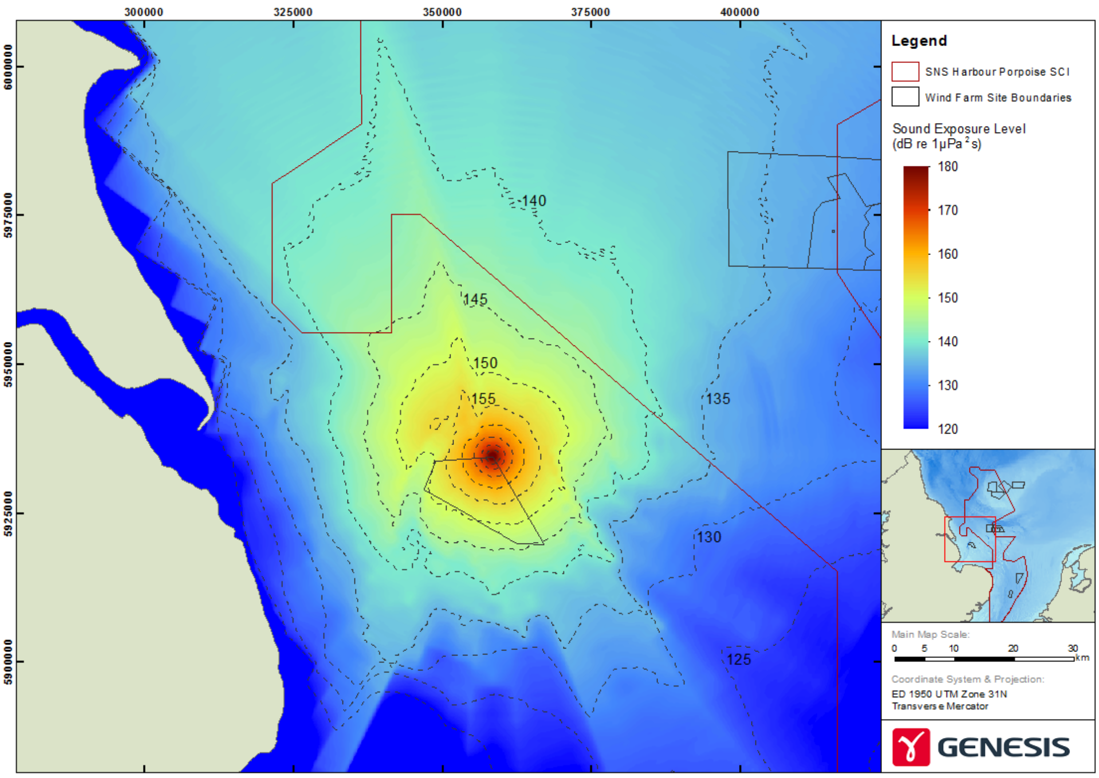

Figure J-10: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Triton Knoll model location 1 with hammer energy of 2,700 kJ.

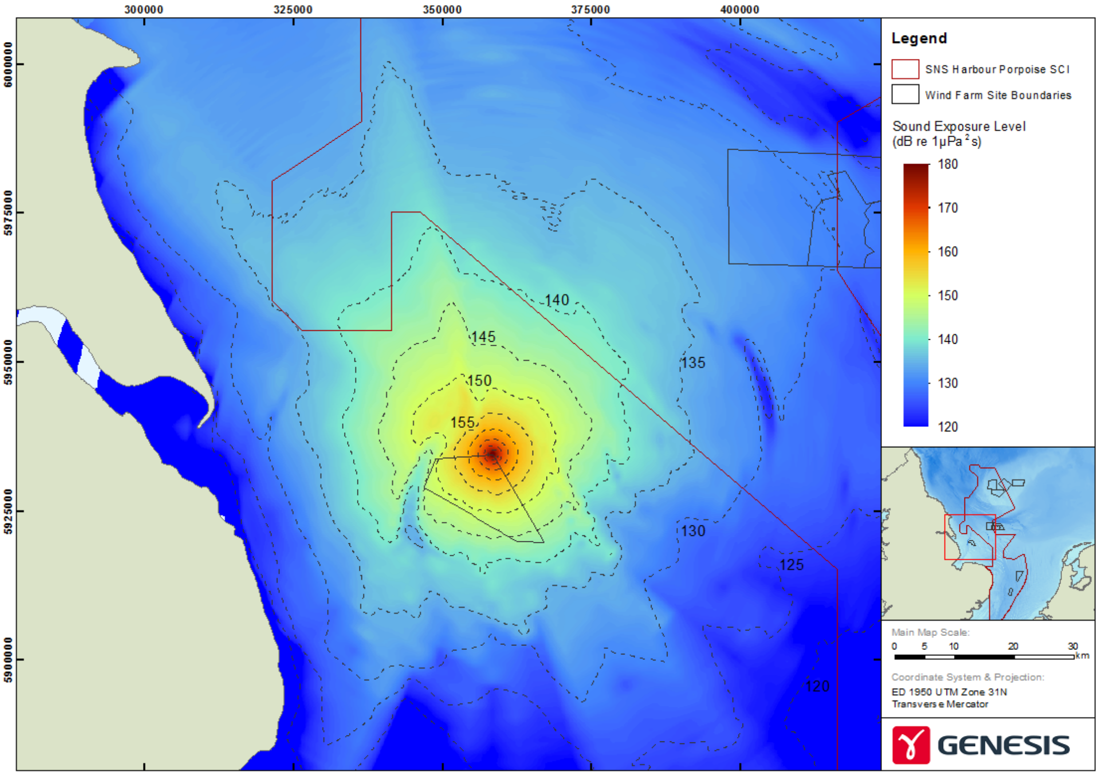

Figure H-11: Depth-averaged unweighted single-pulse SEL for pile-driving at Triton Knoll model location 1 with hammer energy of 4,000 kJ.

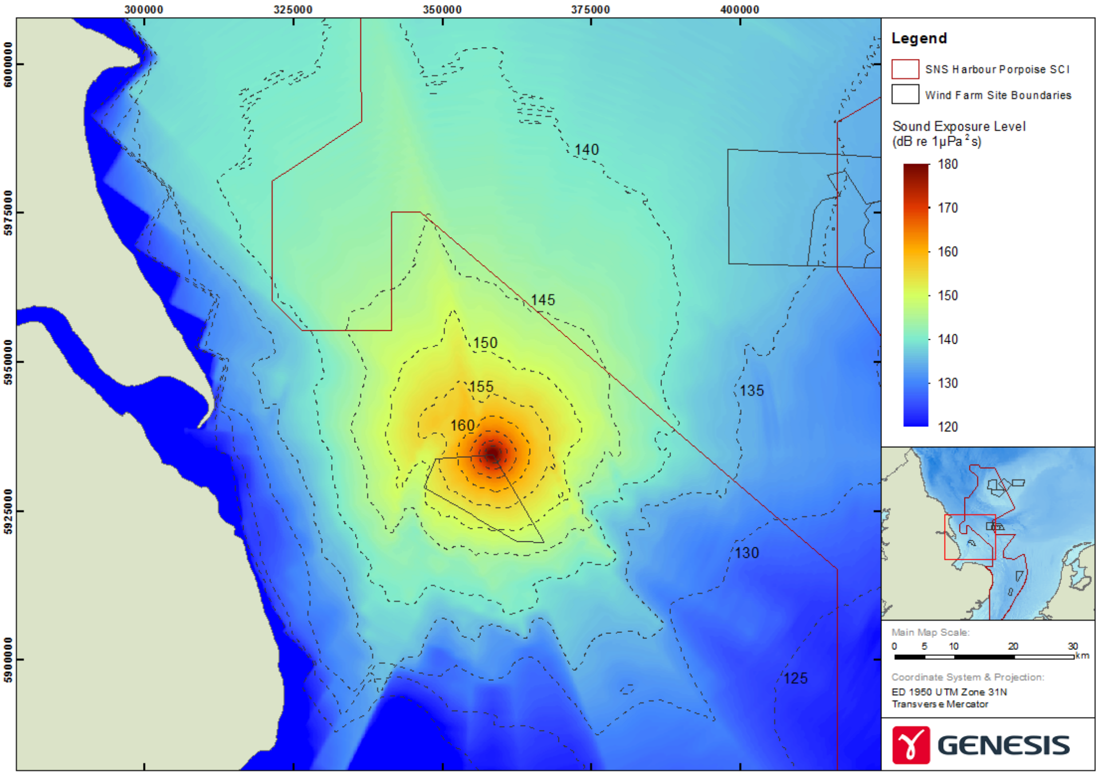

Figure J-12: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Triton Knoll model location 1 with hammer energy of 4,000 kJ.

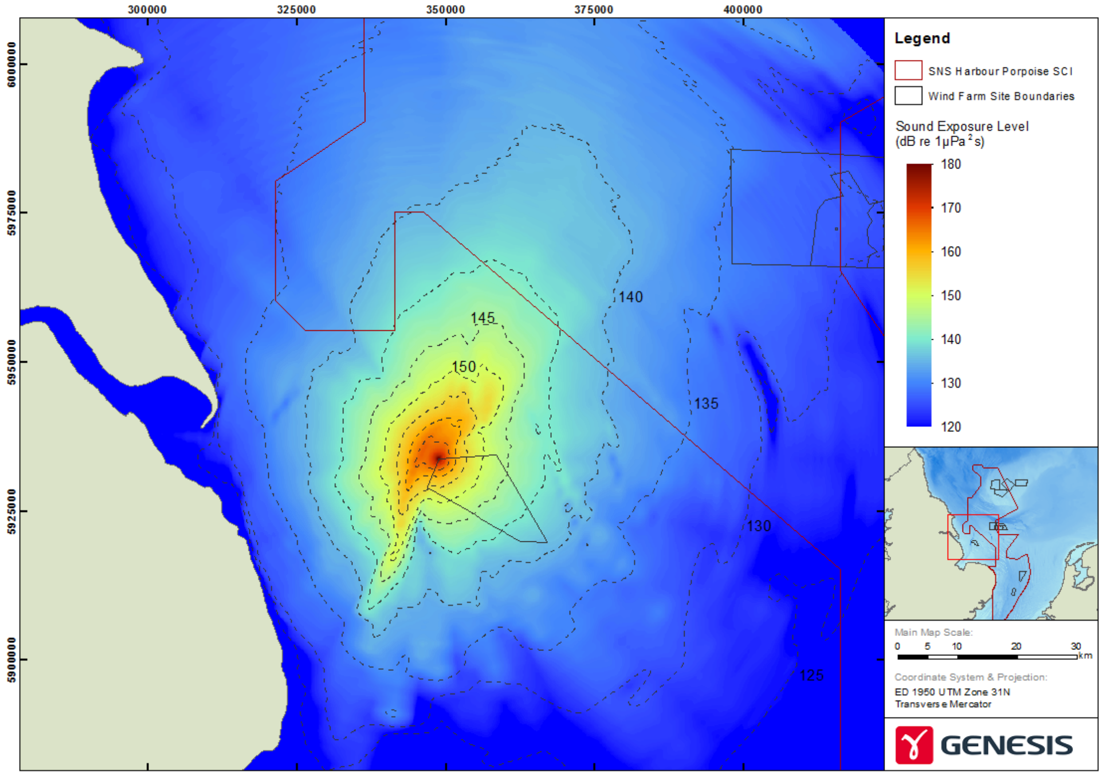

Figure J-13: Depth-averaged unweighted single-pulse SEL for pile-driving at Triton Knoll model location 2 with hammer energy of 2,700 kJ.

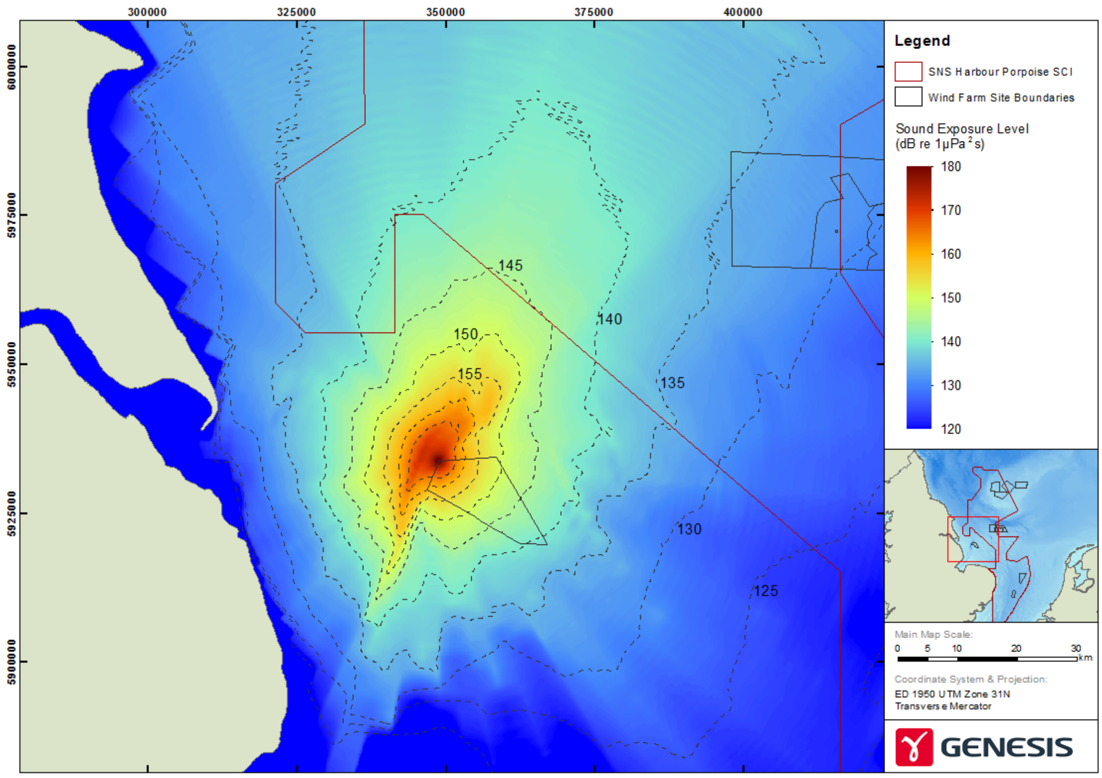

Figure J-14: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Triton Knoll model location 2 with hammer energy of 2,700 kJ.

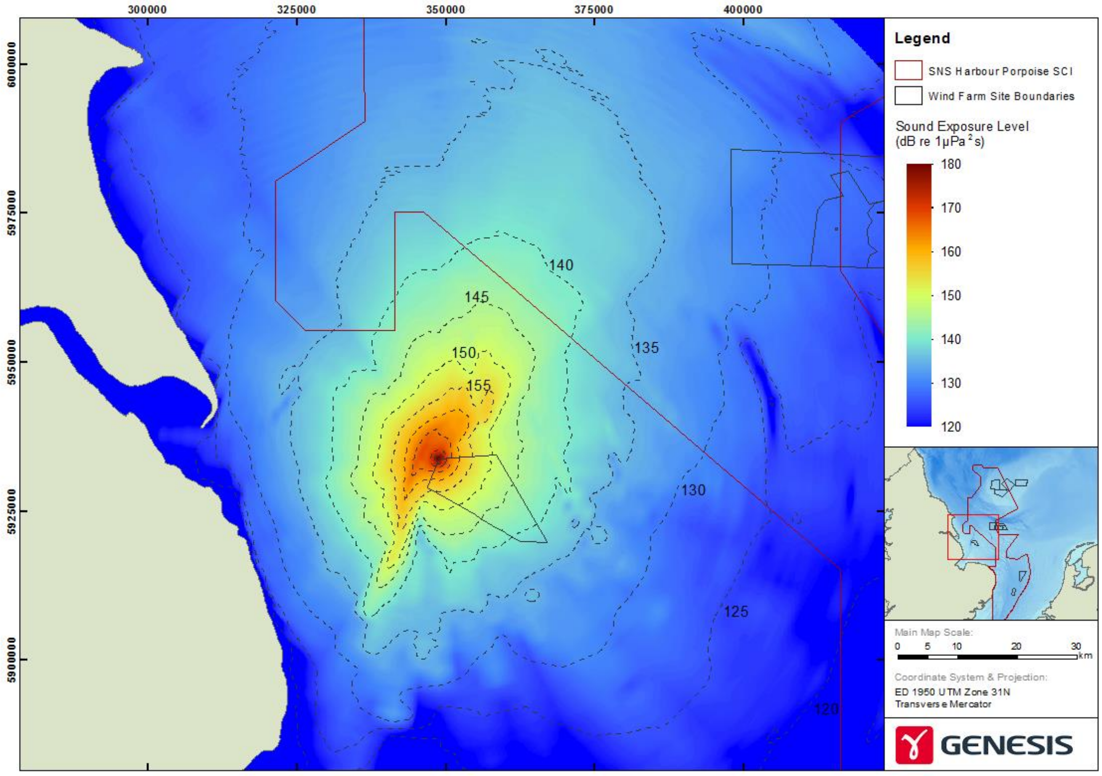

Figure J-15: Depth-averaged unweighted single-pulse SEL for pile-driving at Triton Knoll model location 2 with hammer energy of 4,000 kJ.

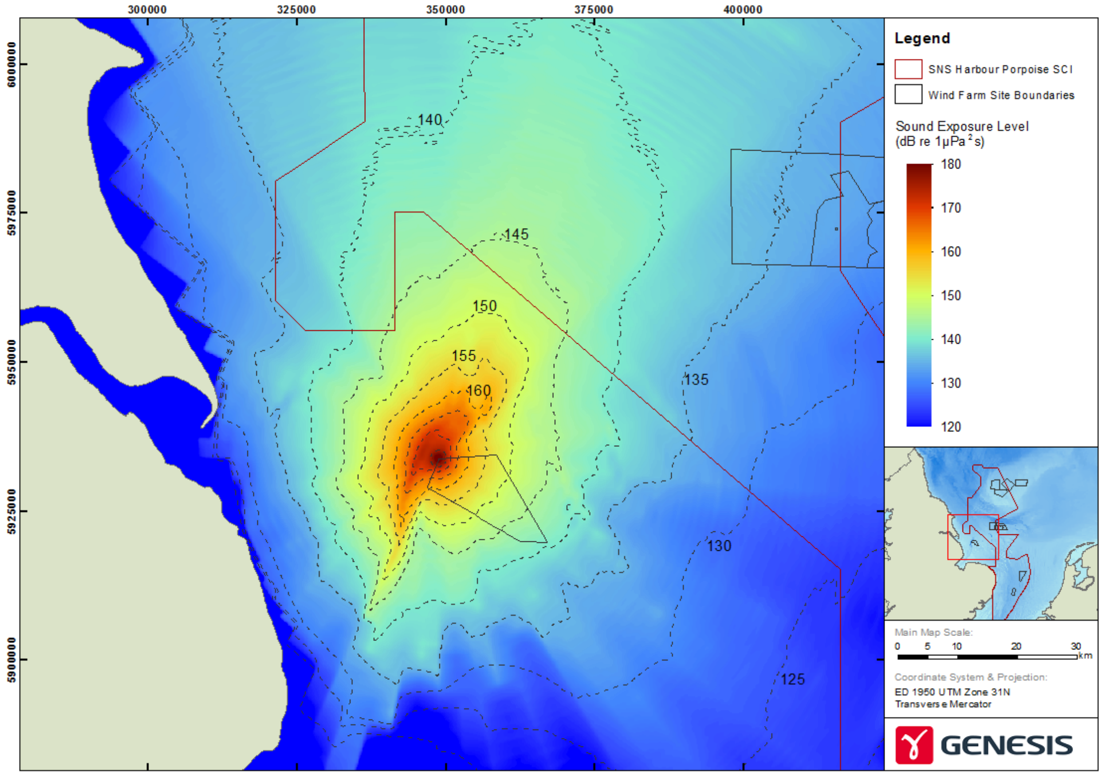

Figure J-16: Maximum-over-depth unweighted single-pulse SEL for pile-driving at Triton Knoll model location 2 with hammer energy of 4,000 kJ.

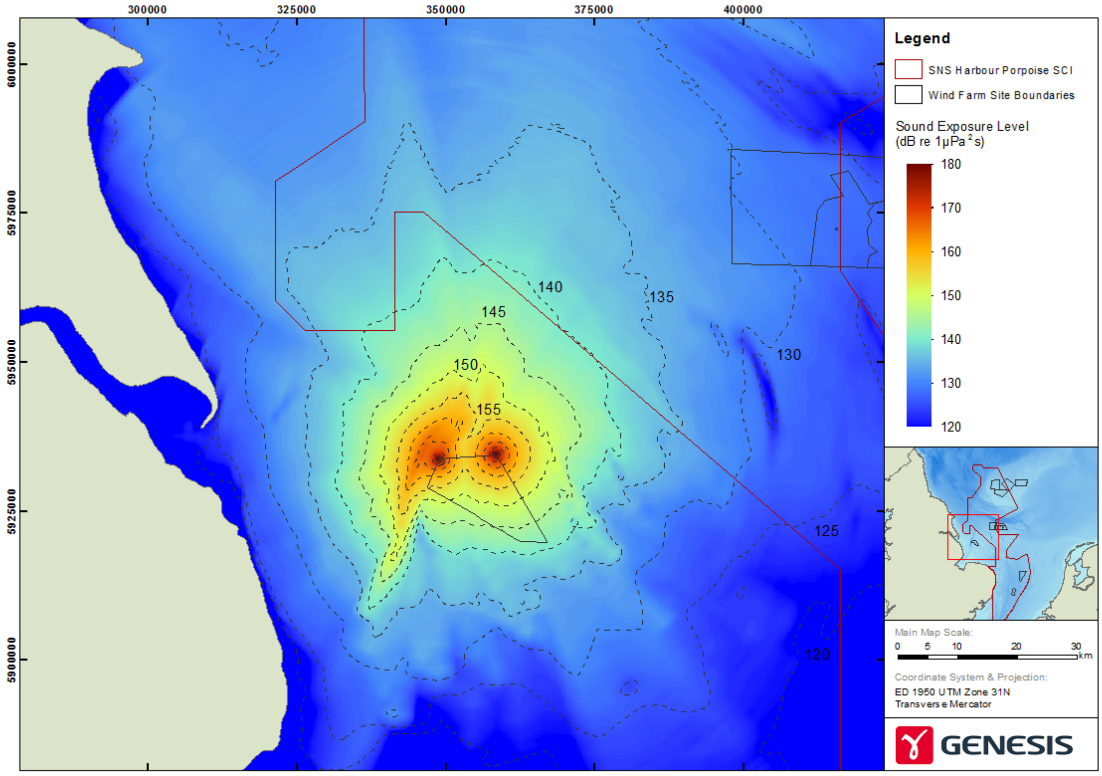

Figure J-17: Depth-averaged unweighted single-pulse SEL for concurrent pile-driving at Triton Knoll model locations 1 and 2 with hammer energy of 2,700 kJ.

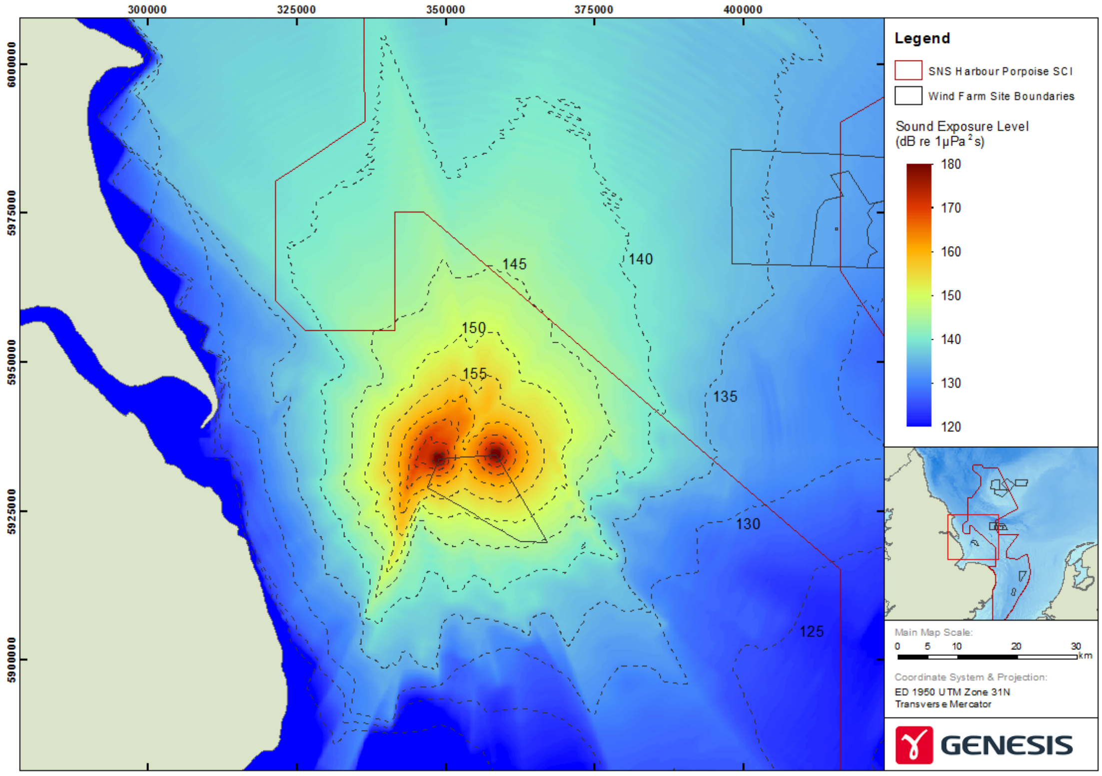

Figure J-18: Maximum-over-depth unweighted single-pulse SEL for concurrent pile-driving at Triton Knoll model locations 1 and 2 with hammer energy of 2,700 kJ.

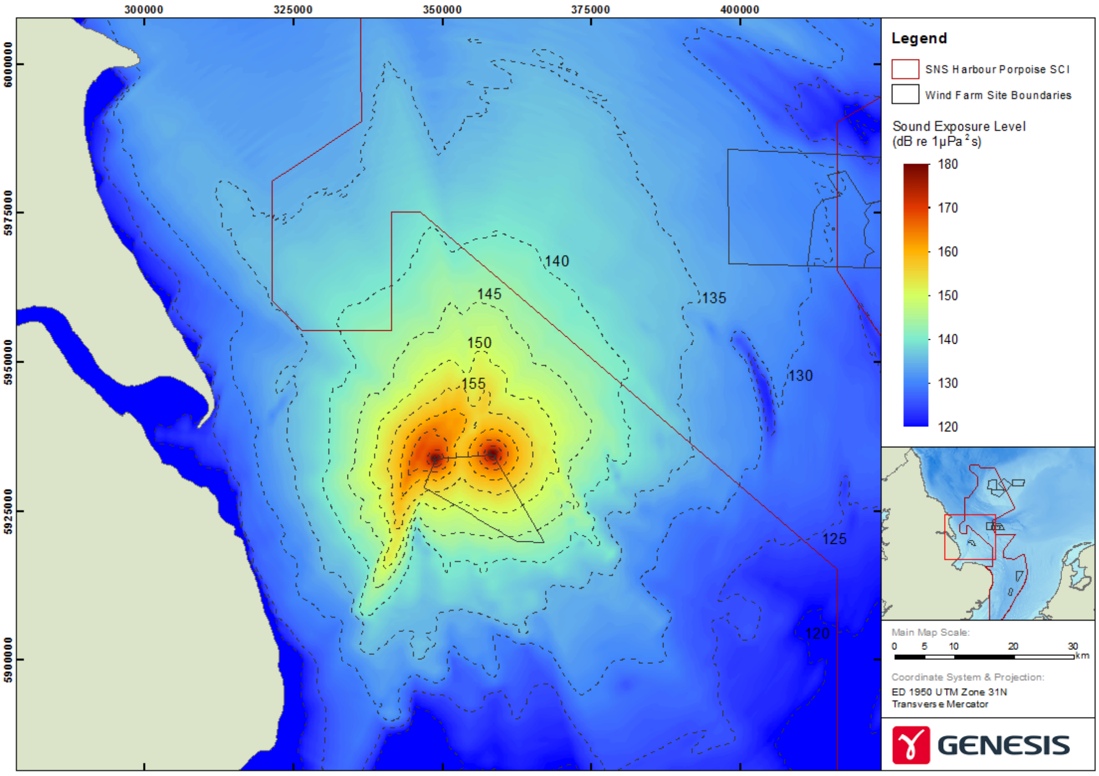

Figure J-19: Depth-averaged unweighted single-pulse SEL for concurrent pile-driving at Triton Knoll model locations 1 and 2 with hammer energy of 4,000 kJ.

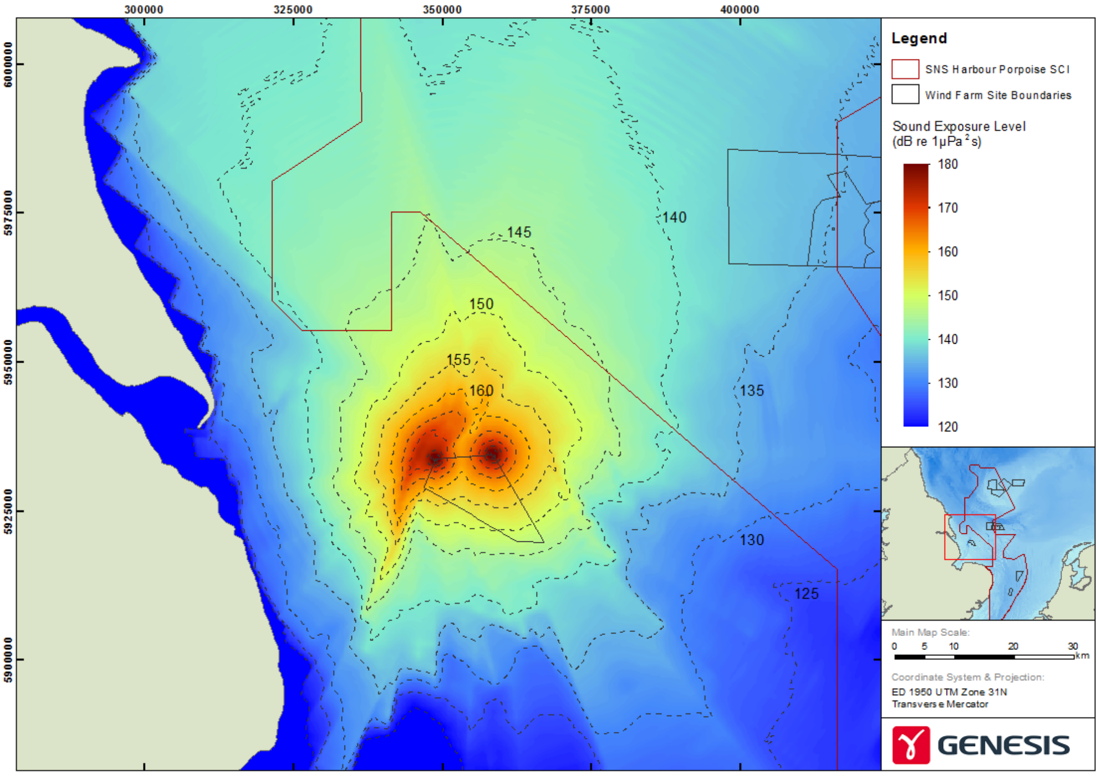

Figure J-20: Maximum-over-depth unweighted single-pulse SEL for concurrent pile-driving at Triton Knoll model locations 1 and 2 with hammer energy of 4,000 kJ.

APPENDIX K: MODELLING MAPS FOR IN-COMBINATION PILING SCENARIOS

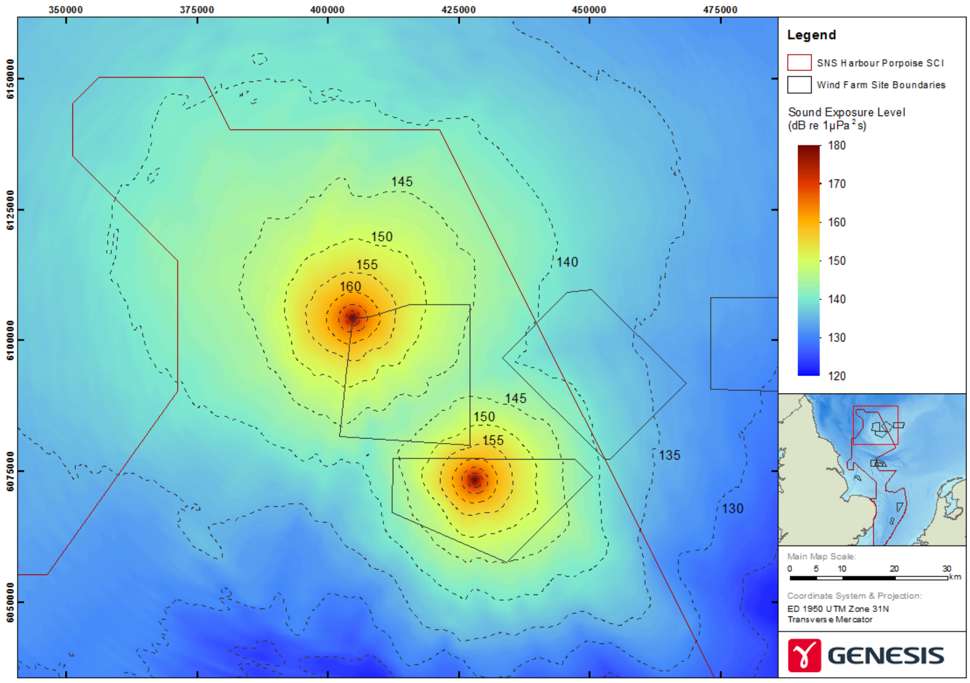

Figure K-1: Depth-averaged unweighted SEL for concurrent pile-driving at Creyke Beck A model location 2 with maximum hammer energy of 3,000 kJ and Creyke Beck B model location 2 with maximum hammer energy of 3,000 kJ.

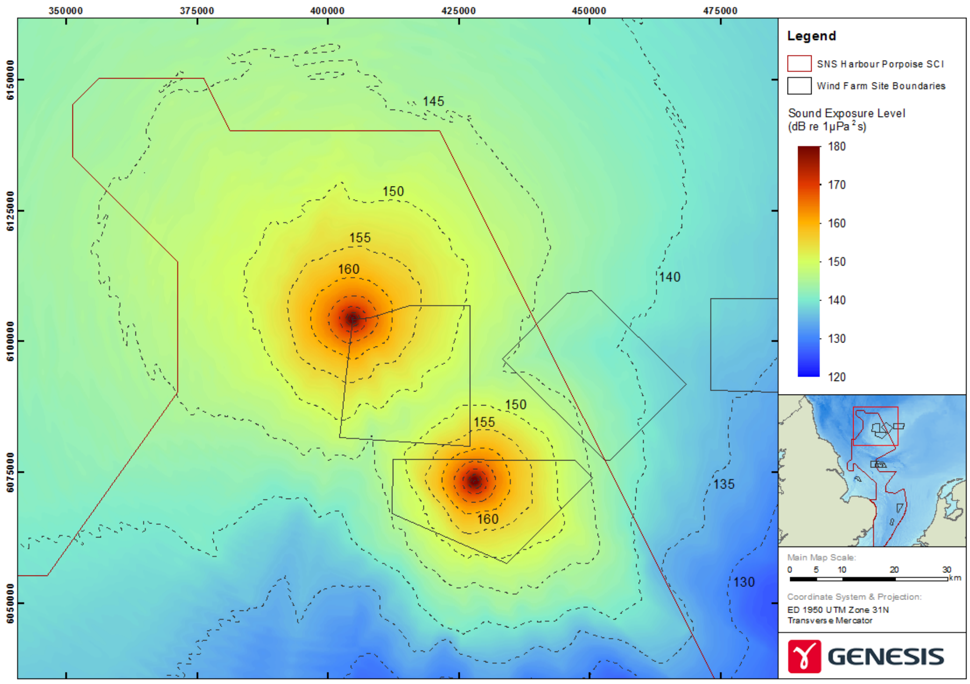

Figure K-2: Maximum-over-depth unweighted SEL for concurrent pile-driving at Creyke Beck A model location 2 with maximum hammer energy of 3,000 kJ and Creyke Beck B model location 2 with maximum hammer energy of 3,000 kJ.

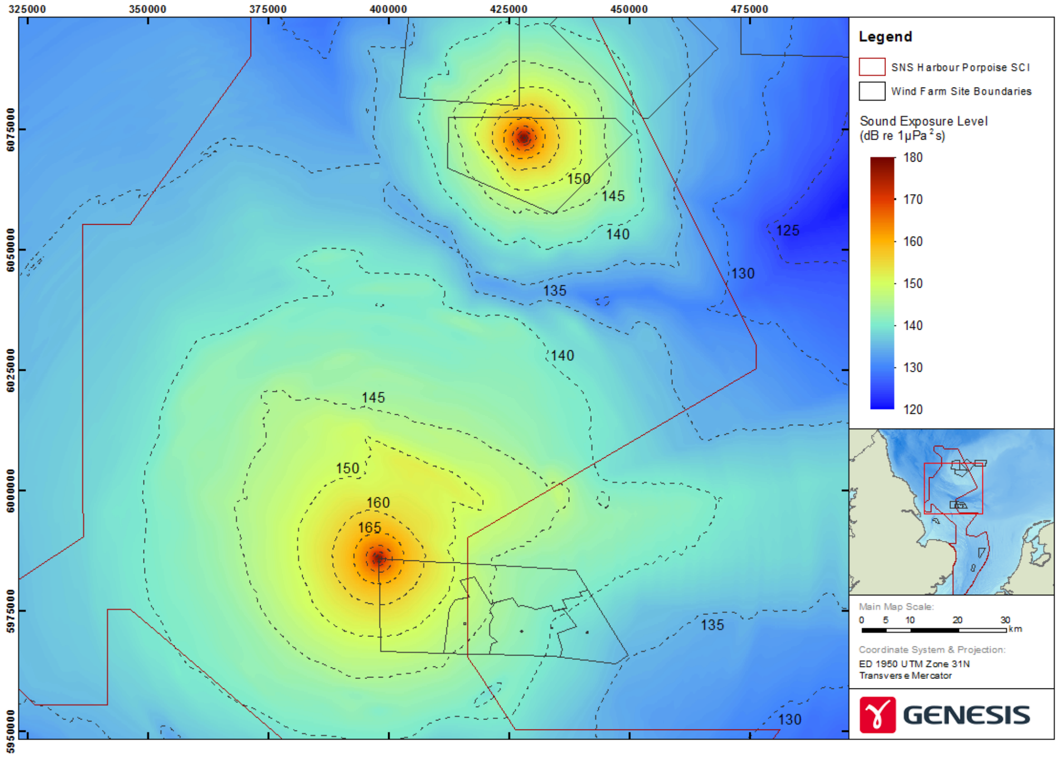

Figure K3: Depth-averaged unweighted SEL for concurrent pile-driving at Creyke Beck A model location 2 with maximum hammer energy of 3,000 kJ and Hornsea Two model location 2 with maximum hammer energy of 3,000 kJ.

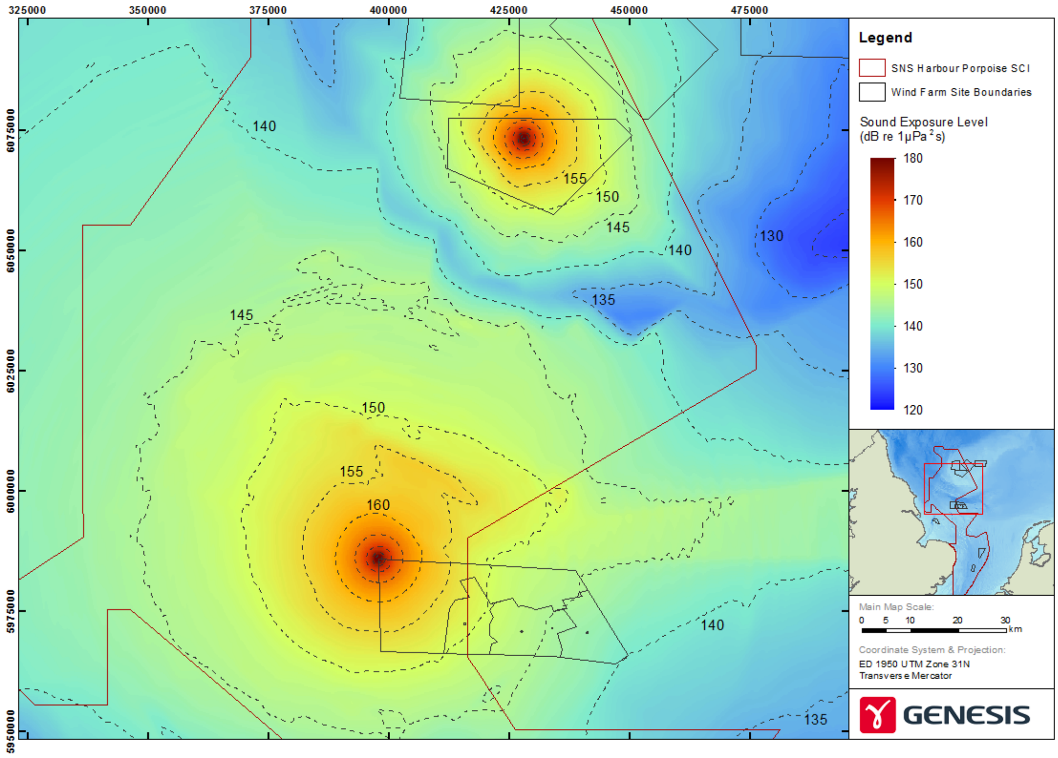

Figure K-4: Maximum-over-depth unweighted SEL for concurrent pile-driving at Creyke Beck A model location 2 with maximum hammer energy of 3,000 kJ and Hornsea Two model location 2 with maximum hammer energy of 3,000 kJ.

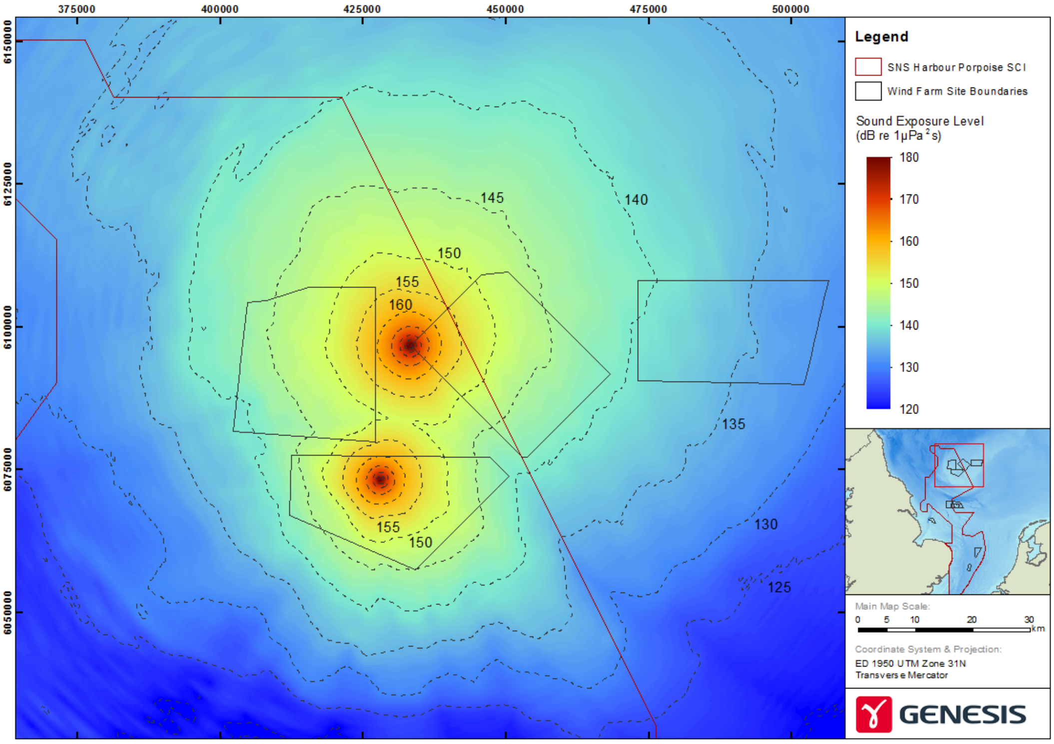

Figure K-5: Depth-averaged unweighted SEL for concurrent pile-driving at Creyke Beck A model location 2 with maximum hammer energy of 3,000 kJ and Teesside B model location 1 with maximum hammer energy of 5,500 kJ.

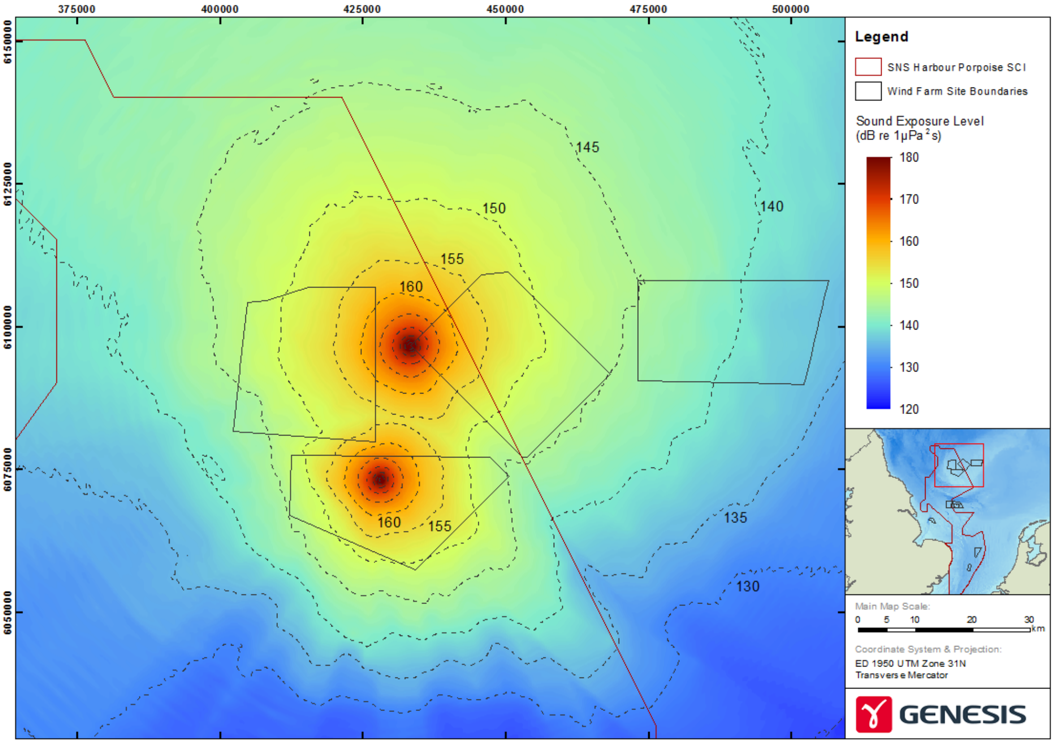

Figure K-6: Maximum-over-depth unweighted SEL for concurrent pile-driving at Creyke Beck A model location 2 with maximum hammer energy of 3,000 kJ and Teesside B model location 1 with maximum hammer energy of 5,500 kJ.

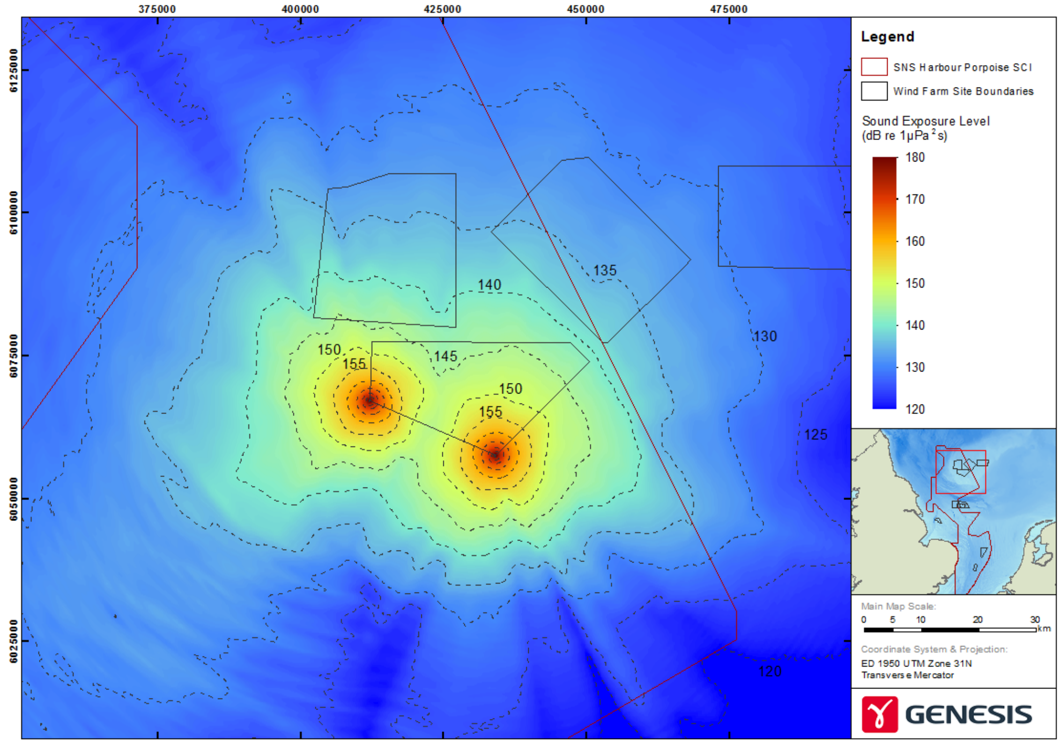

Figure K-7: Depth-averaged unweighted SEL for concurrent pile-driving at Teesside A model location 1 with maximum hammer energy of 5,500 kJ and Teesside B model location 1 with maximum hammer energy of 5,500 kJ.

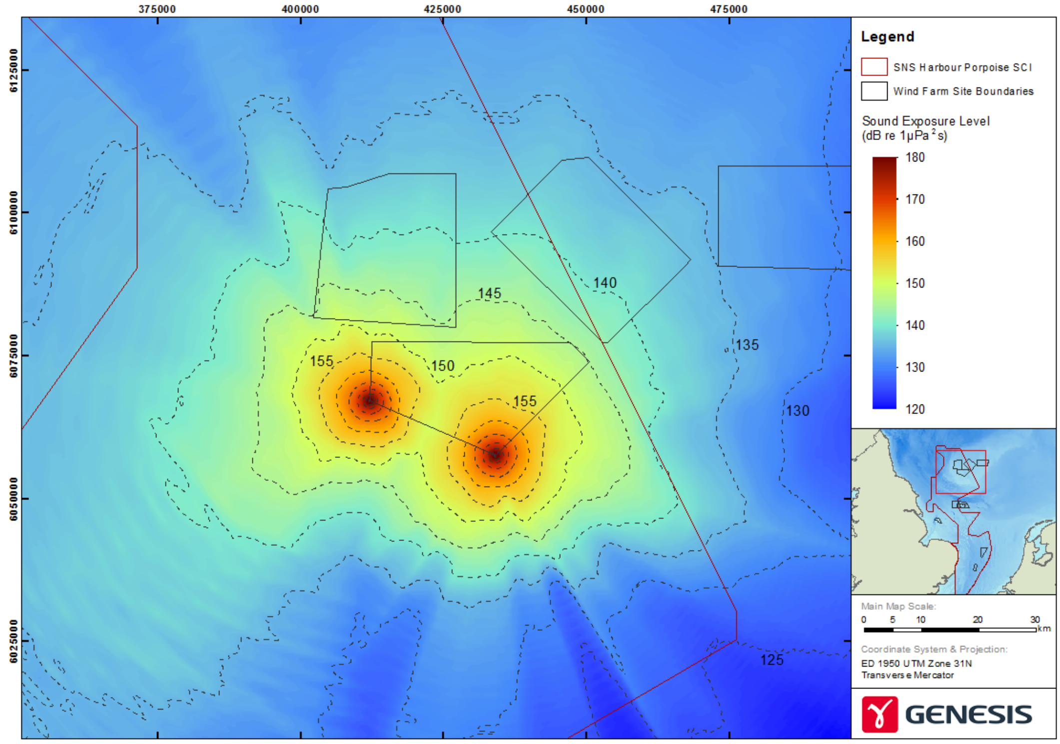

Figure K-8: Maximum-over-depth unweighted SEL for concurrent pile-driving at Teesside A model location 1 with maximum hammer energy of 5,500 kJ and Teesside B model location 1 with maximum hammer energy of 5,500 kJ.

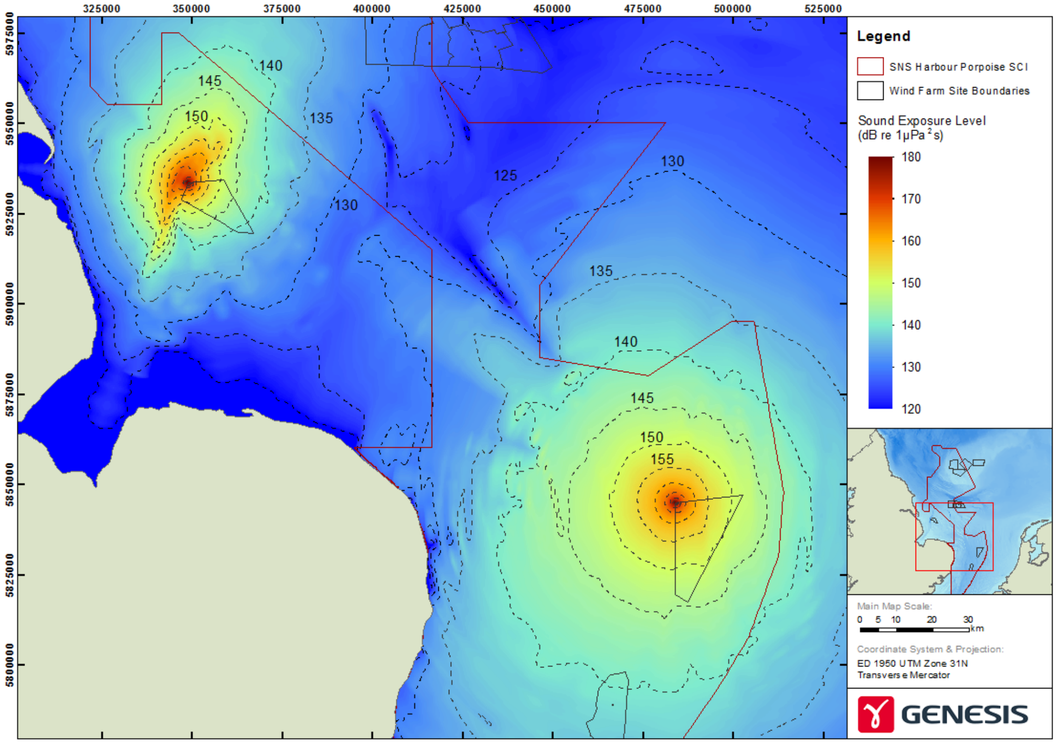

Figure K-9: Depth-averaged unweighted SEL for concurrent pile-driving at East Anglia Three model location 1 with maximum hammer energy of 3,000 kJ and Triton Knoll model location 2 with maximum hammer energy of 4,000 kJ.

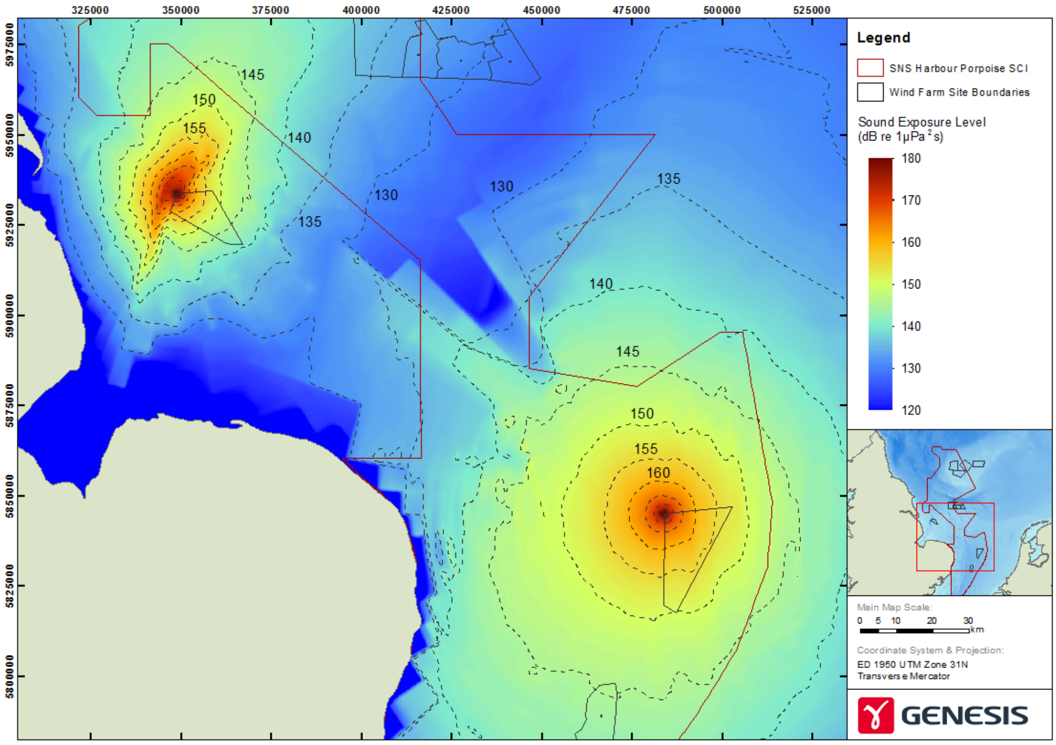

Figure K10: Maximum-over-depth unweighted SEL for concurrent pile-driving at East Anglia Three model location 1 with maximum hammer energy of 3,000 kJ and Triton Knoll model location 2 with maximum hammer energy of 4,000 kJ.

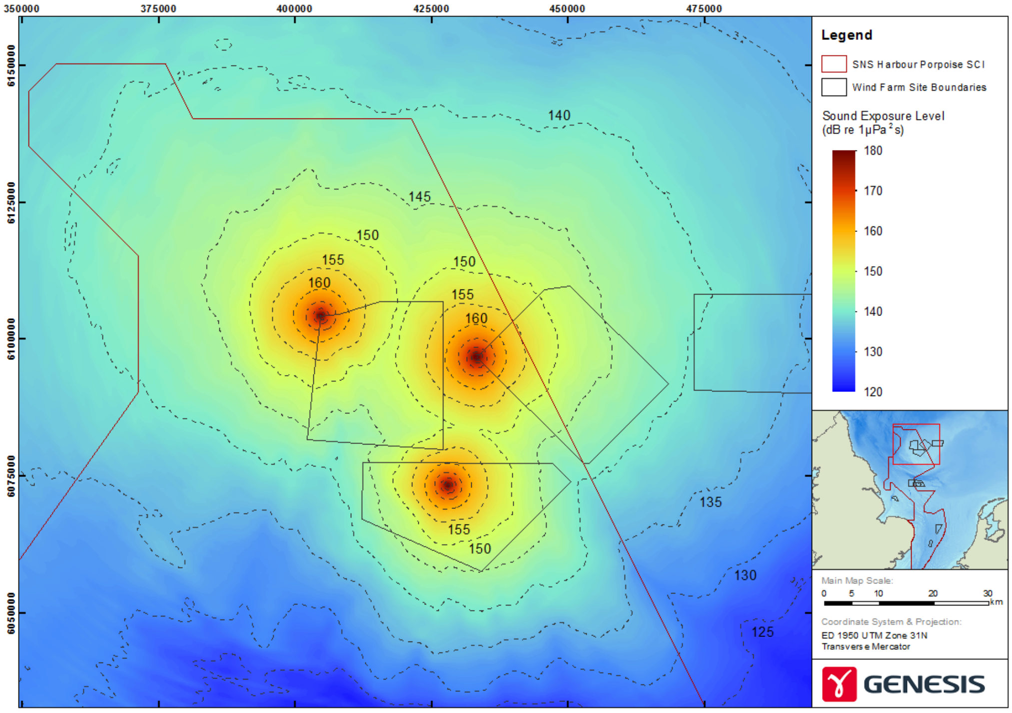

Figure K11: Depth-averaged unweighted SEL for concurrent pile-driving at Creyke Beck A model location 2 with maximum hammer energy of 3,000 kJ, Creyke Beck B model location 2 with maximum hammer energy of 3,000 kJ, and Teesside B model location 1 with maximum hammer energy of 5,500 kJ.

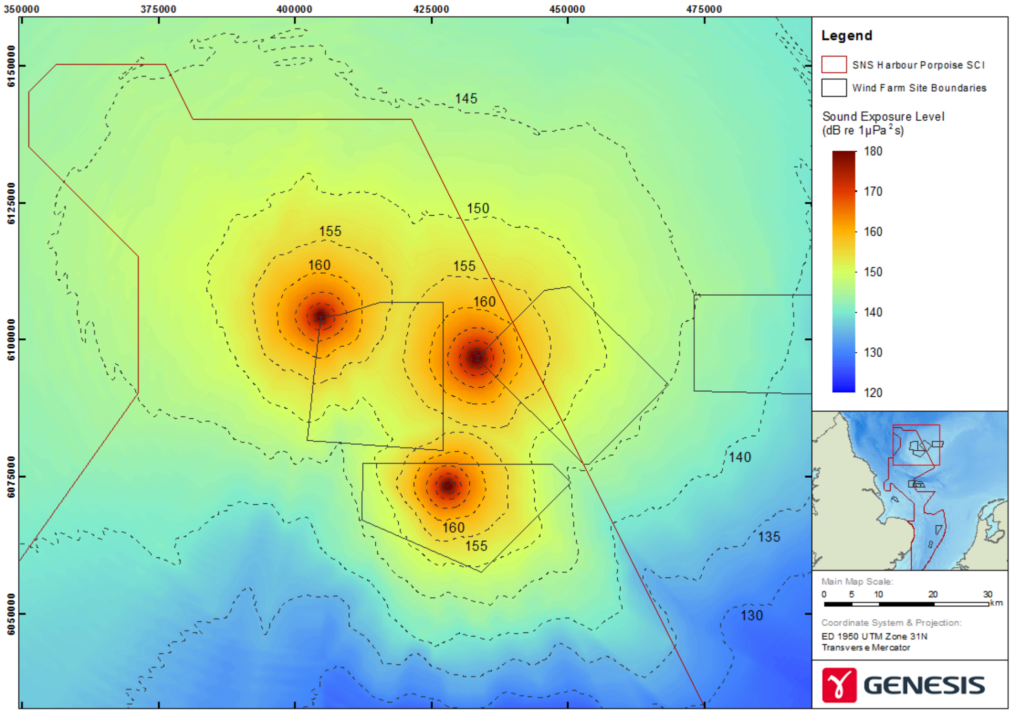

Figure K-12: Maximum-over-depth unweighted SEL for concurrent pile-driving at Creyke Beck A model location 2 with maximum hammer energy of 3,000 kJ, Creyke Beck B model location 2 with maximum hammer energy of 3,000 kJ, and Teesside B model location 1 with maximum hammer energy of 5,500 kJ.