moray offshore renewables ltd

Environmental Statement

Technical Appendix 3.6 A - Underwater Noise Technical Report

Telford, Stevenson, MacColl Wind Farms and associated Transmission Infrastructure Environmental Statement

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APPENDIX 3.6 A

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Document Owner					
Document Status		**Final**			
File Name					
Revision	**Date**	**Description**	**Originated By**	**Checked By**	**Approved By**
A1	29/11/11	For review	TM		
A2	20/12/11	For release	CR		
A3	30/03/2012	For review	RB		
A4	20/06/2012	For release	CR		

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Contents

1. Introduction

This Technical Appendix presents in detail the results of modelling undertaken to provide a prediction of the likely extent of effects on marine fauna associated with underwater noise generated during the construction and operation of the proposed Telford, Stevenson and MacColl offshore wind farms in the MORL Zone and associated offshore transmission infrastructure (OfTI). It also provides a review of the literature relating to underwater noise and its impacts on marine fauna, the various metrics used in assessing impacts and additional details relating to the noise modelling methodology.

2. Measurement of Underwater Noise

2.1 Introduction

Sound travels much faster in water (approximately 1,500 m/s) than in air (340 m/s). Since water is a relatively incompressible, dense medium the pressures associated with underwater sound tend to be much higher than in air. As an example, background levels of sea noise of approximately 130 dB re 1 μPa for UK coastal waters are not uncommon (Nedwell *et al.*, 2003a and 2007a). This level equates to about 100 dB re 20 μPa in the units that would be used to describe a sound level in air. Such levels in air would be considered to be hazardous. However, marine mammals and fish have evolved to live in this environment and are thus relatively insensitive to sound pressure compared with terrestrial mammals. The most sensitive thresholds are often not below 100 dB re 1 μPa and typically not below 70 dB re 1 μPa (44 dB re 20 μPa using the reference unit that would be used in air).

2.2 Units of Measurement

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

Any quantity expressed in this scale is termed a "level". If the unit is sound pressure, expressed on the dB scale it will be termed the "Sound Pressure Level".
The fundamental definition of the dB scale is:

$$Level = 10\log_{10}(Q/Q_{ref}) \quad \text{.. eqn. 2-1}$$

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

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

A refinement is that the scale, when used with sound pressure, is applied to the pressure squared rather than the pressure. If this were not the case, if the acoustic power level of a source rose by 10 dB the Sound Pressure Level (SPL) would rise by 20 dB. So that variations in the units agree, the sound pressure must be specified in units of Root Mean Square (RMS) pressure *squared*. This is equivalent to expressing the sound as:

$$Sound\ Pressure\ Level = 20\log_{10}(P_{RMS}/P_{ref}) \quad \text{................ eqn. 2-2}$$

For underwater sound typically a unit of one microPascal (μPa) is used as the reference unit (a Pascal is equal to the pressure exerted by one Newton over one square metre. One microPascal equals one millionth of this). For the SPL, an increase in level of 6 dB means a doubling of pressure.

2.3 Quantities of Measurement

Sound may be expressed in many different ways depending upon the particular type of noise, and the parameters of the noise that allow it to be evaluated in terms of a biological effect. These are described in more detail below.

2.3.1 Peak Level

The peak level is the maximum level of the acoustic pressure, usually a positive pressure. This form of measurement is often used to characterise underwater blasts where there is a clear positive peak following the detonation of explosives. Examples of this type of measurement used to define underwater blast waves can be found in Bebb and Wright (1953, 1955), Richmond *et al.* (1973), Yelverton *et al.* (1973) and Yelverton (1981). The data from these studies have been widely interpreted in a number of reviews on the impact of high level underwater noise causing fatality and injury in human divers, marine mammals and fish (see for example Rawlins, 1974; Hill, 1978; Goertner, 1982; Richardson *et al.*, 1995; Cudahy and Parvin, 2001; Hastings and Popper, 2005). The peak sound level of a freely suspended charge of Tri-Nitro-Toluene (TNT) in water can be estimated from Arons (1954), as summarised by Urick (1983). For offshore operations, such as well head severance, typical charge weights of 40 kg may be used, giving a source peak pressure of 195 MPa or 285 dB re 1 µPa @ 1 m (Parvin *et al.*, 2007).

2.3.2 Peak-to-peak Level

The peak-to-peak level is usually calculated using the maximum variation of the pressure from positive to negative within the wave. This represents the maximum change in pressure (differential pressure from positive to negative) as the transient pressure wave propagates. Where the wave is symmetrically distributed in positive and negative pressure, the peak-to-peak level will be twice the peak level, and hence 6 dB higher.

Peak-to-peak levels of noise are often used to characterise sound transients from impulsive sources such as percussive impact piling and seismic airgun sources. Measurements during offshore impact piling operations to secure tubular steel piles into the seabed have indicated peak-to-peak source level noise from 244 to 252 dB re 1 µPa @ 1 m for piles from 4.0 to 4.7 m diameter (Parvin *et al.*, 2006, Nedwell *et al.*, 2007a).

2.3.3 Sound Pressure Level

The Sound Pressure Level is normally used to characterise noise and vibration of a continuous nature such as drilling, boring, continuous wave sonar, or background sea and river noise levels. To calculate the SPL, the variation in sound pressure is measured over a specific time period to determine the Root Mean Square (RMS) level of the time varying sound. The SPL can therefore be considered to be a measure of the average unweighted level of the sound over the measurement period.

As an example, small sea going vessels typically produce broadband noise at source SPLs from 170 to 180 dB re 1 µPa @ 1 m (Richardson *et al.*, 1995)), whereas a supertanker generates source SPLs of typically 198 dB re 1 µPa @ 1 m (Hildebrand, 2004)).

Where an SPL is used to characterise transient pressure waves such as that from seismic airguns, underwater blasting or piling, it is critical that the time period over which the RMS level is calculated is quoted. For instance, in the case of a pile strike lasting say a tenth of a second, the mean taken over a tenth of a second will be ten times higher than the mean taken over one second.

2.3.4 Sound Exposure Level

When assessing the noise from transient sources such as blast waves, impact piling or seismic airguns, the issue of the time duration of the pressure wave (highlighted above) is often addressed by measuring the energy flux density of the wave. This form of analysis was used by Bebb and Wright (1951 to 1955), and later by Rawlins (1987) to explain the apparent discrepancies in the biological effect of short and long range blast waves on human divers. More recently this form of analysis has been used to develop an interim exposure criterion for assessing the injury range for fish from impact piling operations (Hastings and Popper, 2005; Popper *et al.*, 2006).

The Sound Exposure sums the acoustic energy over a measurement period, and effectively takes account of both the SPL of the sound and the length of time the sound is present in the acoustic environment.

Sound Exposure (SE) is defined by the equation:

$$SE = \int_0^T p^2(t)dt$$
....eqn. 2-3

Sound Exposure is a proportional to the acoustic energy and has units of Pascal squared seconds (Pa^2s).

To express the Sound Exposure on a logarithmic scale by means of a dB, it is compared with a reference acoustic energy $(P_{ref})^2T_{ref}$, using 1 µPa for P_{ref} and 1 sec for T_{ref}. The Sound Exposure Level (SEL) is then defined by:

$$SEL = 10\log_{10}\left(\frac{\int_0^T p^2(t)dt}{P_{ref}^2 T_{ref}}\right)$$
.....................................eqn. 2-4

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

$SEL = SPL + 10\log_{10}T$ .... eqn. 2-5

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

Therefore, for continuous sounds of duration less than one second, the SEL will be numerically lower than the SPL. For periods greater than one second the SEL will be numerically greater than the SPL. For example, for a sound of 10 seconds duration the SEL will be 10 dB higher than the SPL, for a sound of 100 seconds duration the SEL will be 20 dB higher than the SPL, and so on.

2.3.5 Impulse

The Impulse (I) is defined as the integral of pressure over time and is given by the equation:

$$I = \int_0^\infty P(t)dt \text{ .... eqn. 2-6}$$

where *I* is the impulse in Pascal-seconds (Pa.s), *P(t)* is the acoustic pressure in Pa of the blast wave at time *t*. Impulse may be thought of as the average pressure of the wave multiplied by its duration. The importance of Impulse is that in many cases a wave acting for a given time will have the same effect as one of twice the pressure acting for half the time. The Impulse of both these waves would be the same.

3. Overview of Hearing in Fish and Marine Mammals

3.1 Introduction

The ways fish react following their exposure to underwater sound relate to the way in which they hear. Variation in the anatomy and physiology of the ears and associated structures in fish is extensive, indicating that different species detect sound in different ways (Popper and Fay, 1993). Furthermore, published data also indicate that, for fish which are sensitive to sound, there is a considerable variation in the hearing abilities, both in terms of the minimum levels of sound perceptible and the frequency range over which they can hear (e.g. Hawkins, 1981; Lovell *et al.,* 2005); Popper *et al.,* 2004; Hastings and Popper, 2005; Thomsen *et al.,* 2006; Madsen *et al.,* 2006). Any assessment of potential impacts on a particular species must therefore take this into account.

This variation appears to be linked to particular physiological adaptations in the distance of the swim bladder to the inner ear. The herring, for example, has an extension of the swim bladder that terminates within the inner ear (Blaxter *et al.*, 1981; Popper *et al.,* 2004). By comparison, the swim bladder in salmon is not in close proximity to the ear anatomy and, as such, this species has poorer hearing. Species such as dab and plaice do not have a swim bladder and thus tend to have a lower hearing ability than many other species of fish.

In general, fish that are considered hearing specialists, such as the herring, are able to perceive sounds in the frequency range 30 Hz to 4 kHz, though at the higher frequencies sensitivity is very low. Threshold levels, the minimum sound level at which a sound can be perceived, for these species are at approximately 75 dB re 1 μPa at frequencies between 30 Hz and 1 kHz.

In comparison, the less sensitive group, termed hearing generalists, including the dab and the bass, are only able to perceive sounds between 30 Hz and 400 Hz, with peak sensitivity at 118 dB re 1 μPa over this range, though the salmon, representing one of the more sensitive hearing generalists, has a threshold level of 95 dB re 1 μPa at 160 Hz. In comparison, the dab, a hearing generalist, has a threshold level of approximately 90 dB re 1 μPa at frequencies between 30 Hz and 200 Hz.

In contrast to fish, marine mammal species, such as the bottlenose dolphin, *Tursiops truncatus*, and harbour porpoise, *Phocoena phocoena*, are sensitive to a very broad bandwidth of sound. Audiogram data for the porpoise indicate that they are responsive at frequencies from 100 Hz to 170 kHz. Peak hearing sensitivity occurs over the frequency range 20 kHz to 150 kHz, where, for example, the audiogram for the harbour porpoise (Kastelein *et al.,* 2002) indicates that it is able to hear sounds below 40 dB re 1 μPa. This typically corresponds to sea noise levels at these frequencies.

3.2 Introduction to Audiograms

An audiogram is a means of showing a species' sensitivity to sound; it is the variation of hearing threshold level with frequency of sound stimulus. The principle of measuring an audiogram is that sound at a single frequency and a known level is presented to the test subject, typically in the form of a pulsed tone. A uniform, calibrated sound field is created, in air, by means of a loudspeaker or headphones, and in water by underwater projectors. A protocol is required to determine whether the subject has heard the sound stimulus. For humans this is normally in the form of the subject pressing a button if it has detected the sound (a behavioural response). The level of the stimulus is then reduced and the test repeated. (This method is generally known as the 'staircase method'). Eventually a level is reached at which the subject can no longer detect the sound, which is therefore below the subject's threshold of hearing. The actual threshold is taken to be the last level that evoked a repeatable response. The measurement is typically repeated at a range of frequencies.

3.3 Audiograms of Underwater Species

When measuring the audiogram of an animal it is necessary to determine the response to the sound by a technique that does not require cognitive compliance. Two principal techniques have been used to determine the audiograms of fish and marine mammal species. These involve either a behavioural response technique, or auditory evoked potential measurements (monitoring of the electrical activity of the animal's hearing mechanism; see, for example, Lovell *et al.,* 2005).

Behavioural response techniques rely on training an animal to provide a specific response when an auditory stimulus is heard. This can take the form of a reward-based procedure, usually involving the feeding of an animal, or obtaining a conditioned response by some form of aversion response — for example electric shocks have been used. When the animal hears the sound it is usually required to move into or out of a predetermined area. The disadvantage of this type of technique is that it relies upon the compliance of the subject and can only be used with animals that can easily be trained.

An alternative approach involves direct measurement of the Auditory Evoked Potential (AEP), a bio-electric impulse in the auditory nerves that results from stimulation of the sensory hair cells within the ear. In this approach either subcutaneous or cutaneous electrodes are attached to the animal to measure the response to the sound directly. This latter technique is referred to as the Auditory Brainstem Response, or ABR, method.

Audiograms for a number of species considered in this assessment are given in Figures A-1 to A-3 below.

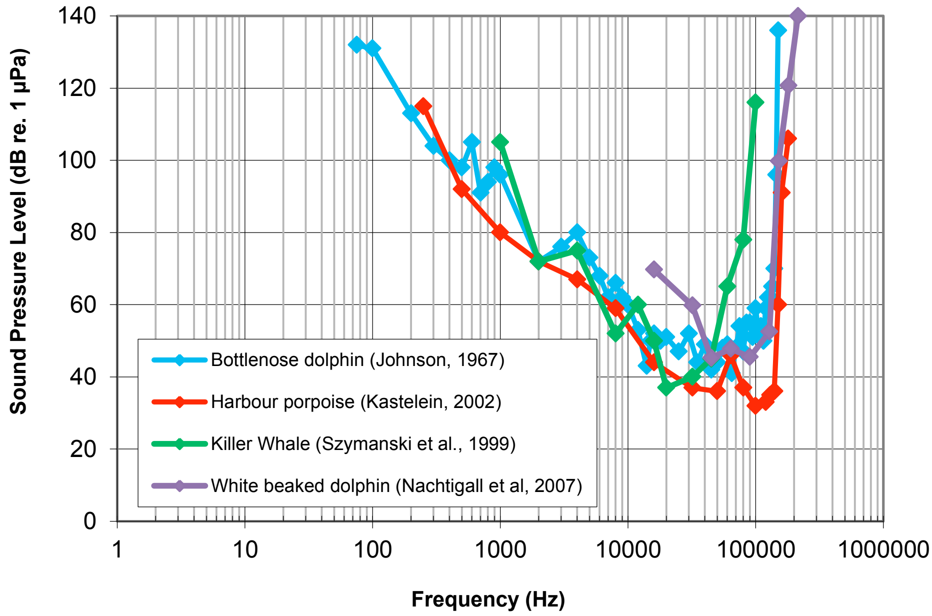


Figure A-1. Audiograms for species of marine mammal

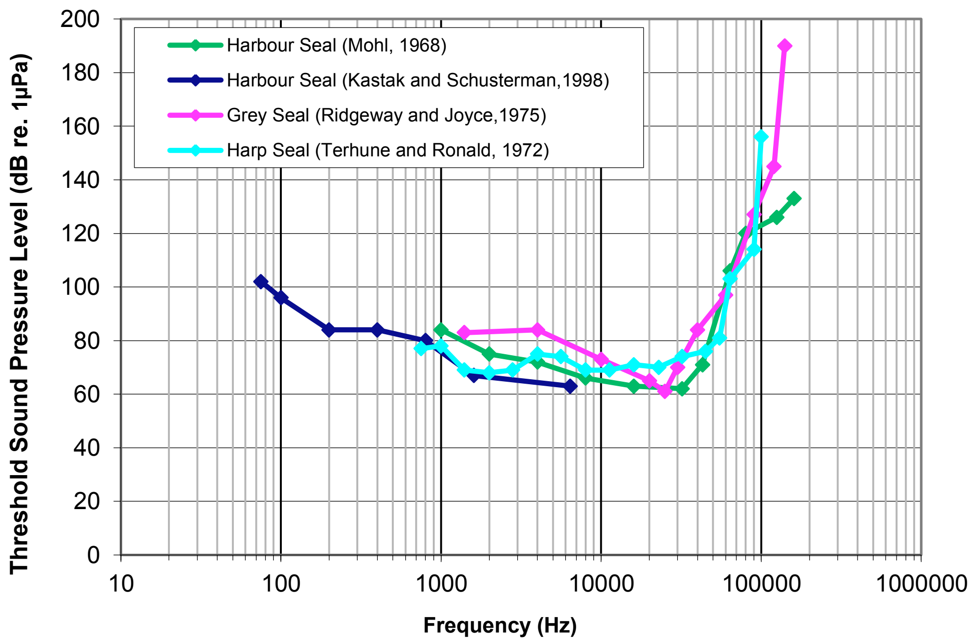


Figure A-2. Audiograms for species of seal

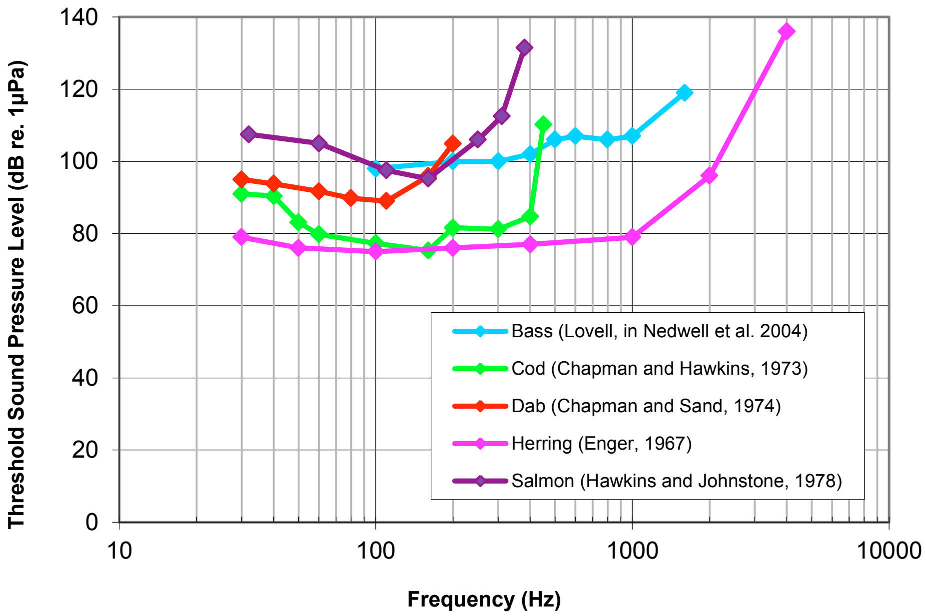


Figure A-3. Audiograms for species of fish

3.4 A metric which takes into account a species' hearing sensitivity: the dB$_{ht}$

Measurements of noise are frequently made using an unweighted RMS level of that sound, or its peak pressure. This, however, does not provide an indication of the impact that the sound will have upon a particular fish or marine mammal species. This is of fundamental importance when considering the behavioural response of animals to activities generating underwater noise, as avoidance is associated with the perceived level of loudness and vibration of the sound by the animals. Therefore, the same underwater noise may have a different impact on different species with different hearing sensitivities.

Where the intention is to estimate these more subtle behavioural or audiological effects of noise, caused by "loudness", hearing ability has to be taken into account and simple metrics based on unweighted measures are inadequate. For instance, it has been determined that in humans a metric incorporating a frequency weighting that parallels the sensitivity of the human ear is required to accurately assess the behavioural effects of noise, hence the use of frequency weighted measures by regulatory bodies worldwide, such as the Health and Safety Executive in the UK, as a method off assessing the impacts of noise in the workplace. The most widely used metric in this case is the dB(A), which incorporates a frequency weighting (the A-weighting), based on the 40-phon human hearing curve.

The dB$_{ht}$(*Species*) metric (Nedwell *et al.*, 2007b) has been developed as a means for quantifying the potential for a behavioural impact of a sound on a species in the underwater environment. It is similar to the dB(A) in that it uses a species' audiogram in its calculation. The dB$_{ht}$(*Species*) metric can be understood as the level above the minimum audible sound (threshold of hearing) which a species can hear. A level of 0 dB$_{ht}$(*Species*) represents the minimum audible sound, hence levels below this will not be perceived by the species.

As any given sound will be perceived differently by different species (since they have differing hearing abilities) the species name must be appended when specifying a level using this metric. For instance, the same construction event might have a level of 70 dB_{ht}(*Salmo salar*) for a salmon, and 110 dB_{ht}(*Tursiops truncatus)* for a bottlenose dolphin.

The perceived noise levels of sounds measured in dB_{ht}(*Species*) are usually much lower than the unweighted levels, both because the sound will contain frequency components that the species cannot detect, and also because most species that live in the underwater environment have high thresholds of perception (i.e. are relatively insensitive) of sound.

3.5 The M-weighting curves for marine mammals

Based on the evidence from numerous studies of auditory damage Southall *et al.* (2007) proposed a procedure for assessing the possible effects of sound on marine mammals when using the Sound Exposure metric. They proposed that the sound should be filtered into 'generic' frequency ranges or passbands for four groups of mammals, viz low, mid and high frequency cetaceans, and pinnipeds in water. The four passbands are shown in Figure A-4 below and the bandwidths are tabulated in Table A-1. The levels resulting from employing these are termed by the authors 'M-weighted Sound Exposure Levels', and are given in dB re 1 $\mu Pa^2.s$ (M_{lf}) for the low frequency hearers. The 'M_{lf}' is replaced by 'M_{mf}' and 'M_{hf}' for the other cetaceans as appropriate, and 'M_{pw}' for the pinnipeds. It should be noted that strictly the nomenclature is inaccurate as the sound is not *weighted* but rather *filtered* to remove low and high frequencies. Between these frequencies the sound is unweighted. The distinction is important as most marine animals have highly sloped audiograms, and an unweighted measure may tend to overestimate the effects of sound at low frequencies and underestimate it at high frequencies.

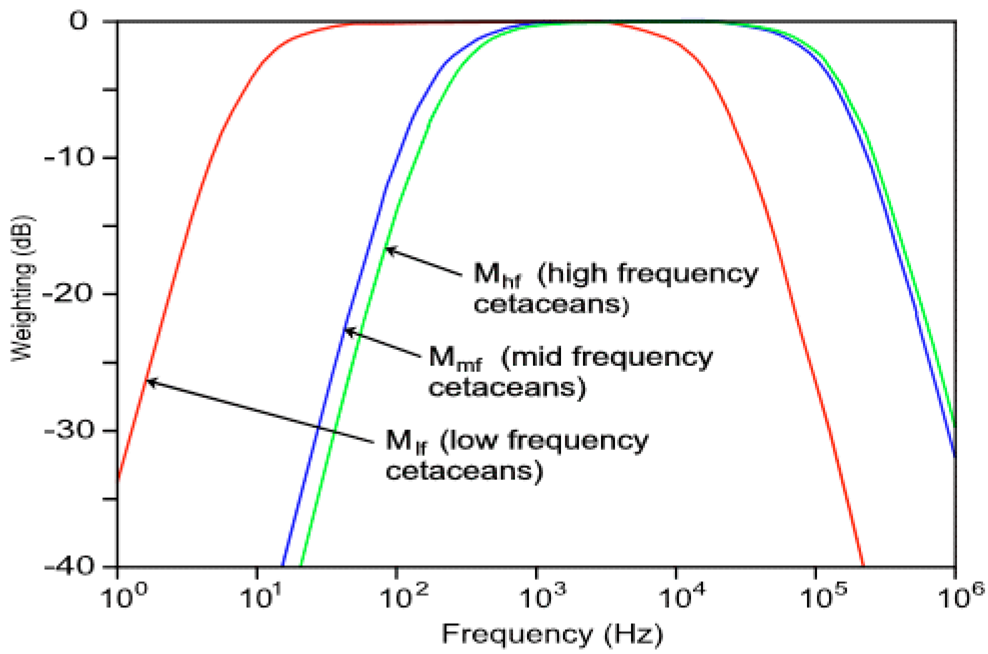


Figure A-4. The M weighting curves for cetaceans

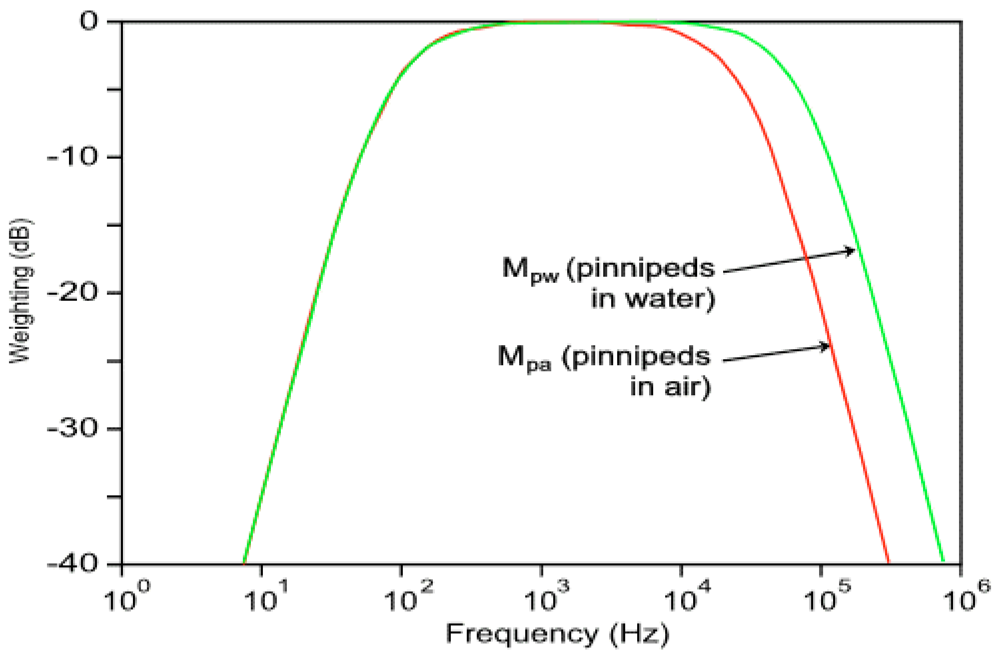


Figure A-5. The M-weighting curves for pinnipeds

Table A-1. Estimated auditory bandwidth of marine mammals

Marine Mammals	**Bandwidth**
Low Freqency Cetaceans (e.g minke whale)	7 Hz – 22 kHz
Mid Frequency Cetaceans (e.g. bottlenose dolphin)	150 Hz – 160 kHz
High Frequency Cetaceans (e.g. harbour porpoise)	200 Hz – 180 kHz
Pinnipeds (in water) (e.g. harbour seal)	75 Hz – 75 kHz

4. Impact of Underwater Sound on Marine Species: Assessment Criteria

4.1 Introduction

Over the past 20 years it has become increasingly evident that noise from human activities in and around underwater environments may have an impact on the marine species in the area. The extent to which intense underwater sound might cause an adverse environmental impact on a particular species is dependent upon the level of the incident sound, its frequency content, its duration and/or its repetition rate (see, for example Hastings and Popper, 2005). As a result scientific interest in the hearing abilities of aquatic animal species has increased.

A review by Popper *et al.* (2006) suggests the use of unweighted sound exposure metrics, such as the peak level and the SEL of the noise, to develop interim guidance for estimating the injury range for fish from pile driving operations. Similarly, a review of the effects of underwater noise from offshore wind farms on marine mammals (Madsen *et al.*, 2006) discusses the use of frequency weighting of the underwater noise in assessing its impact. The authors comment that the impact of underwater sound on the auditory system is frequency dependent and, ideally, noise levels should (as for humans) be weighted using the defined frequency responses of the auditory system of the animal in question.

The approach that has been adopted in this study has been to use unweighted sound level metrics to define the potential for gross damage, such as fatality, swim bladder rupture or tissue damage, since hearing is not involved in those impacts. To assess ranges at which an aversive response to the piling would be expected, frequency weighted measures of the sound, based on the hearing thresholds of the affected species, have been used.

4.2 Lethality and Physical Injury Impacts and their Associated Sound Levels

4.2.1 Introduction

At the highest level, typically during underwater blast from explosives, sound has the ability to cause injury and, in extreme cases, the death of exposed animals.

Due to the current lack of information on potential lethal and physical injury effects from impact piling, this study has used the data from blast exposures to estimate impact zones. The waveforms from these two noise sources are rather different. The transient pressure wave from an impact piling operation has roughly equal positive and negative pressure amplitude components and a relatively long duration of up to a few hundred milliseconds. By contrast, blast waves have a very high positive pressure peak followed by a much lower amplitude, negative wave due to the momentum imparted to the water surrounding the explosive gas bubble. The pressure of a blast wave is normally quantified therefore in terms of the peak level, due to the dominance of the positive peak of the waveform. There is, therefore, a level of uncertainty as to whether a blast wave criterion can be directly applied to a transient waveform arising from an impact piling operation.

4.2.2 Criteria for Assessing Lethality and Physical Injury

The following criteria have been applied in this study for levels of noise likely to cause physical effects on marine biological receptors (Parvin *et al.*, 2007), based on data in the studies of Yelverton (1975), Turnpenny *et al.* (1994) and Hastings and Popper (2005):

- lethal effect may occur where peak-to-peak levels exceed 240 dB re 1 µPa, or an impulse of 100 Pa.s; and
- physical injury may occur where peak-to-peak levels exceed 220 dB re 1 µPa, or an impulse of 35 Pa.s.

It should be noted however that for smaller fish sizes of mass 0.01 g Hastings and Popper (2005), and Popper *et al*. (2006) recommend an interim "no injury" criteria for fish exposed to impact piling noise of 208 dB re 1 µPa peak level (equivalent to 214 dB re 1 µPa peak-to-peak level) or a Sound Exposure Level of 187 dB re 1 µPa^{2}s. In view of the very small fish size that this limit addresses, and the fact that it is extrapolated from limited data, it has not been used in the present study.

4.3 Audiological Injury and its Associated Sound Levels

4.3.1 Introduction

The concept of auditory injury from exposure to noise is well established for airborne sound exposure of humans. At a high enough level of sound traumatic hearing injury may occur even where the duration of exposure is short. Injury also occurs at lower levels of noise where the duration of exposure is long. In this case the degree of hearing damage depends on both the level of the noise and the duration of exposure to it.

4.3.2 Criteria for the Assessment of Audiological Injury

On the basis of a large body of measurements of fish avoidance of noise (Maes *et al.* (2004)), and from re-analysis of marine mammal behavioural response to underwater sound, Nedwell *et al.* (2007) has suggested that the use of a level of 130 dB_{ht}, similar to that used for human exposure in air, provides a suitable criterion for predicting the onset of traumatic hearing damage (i.e. where immediate traumatic and irreversible damage occurs), which recognises the varying hearing sensitivity of differing species.

Another set of criteria, based on the evidence from numerous studies of auditory damage, has been proposed by Southall *et al.* (2007). That study, however, considers the likelihood of hearing damage (permanent threshold shift, or PTS) caused by accumulated noise exposure, rather than occurring as a result of a single event. Their auditory injury criteria, for various groups of marine mammals, are based on Peak Pressure Levels and M-weighted Sound Exposure Levels (dB re 1 µPa^2.s (M)). The criteria are given in Table A-2. The results of the present study have also been presented in terms of this metric.

Table A-2. Proposed injury criteria for various marine mammal groups

	Sound type	
Marine mammal group	**Single pulse**	**Multiple pulses**
Low Frequency Cetaceans		
Peak Pressure Level	230 dB re 1 µPa	230 dB re 1 µPa
Sound Exposure Level	198 dB re 1 µPa^2.s (M_{lf})	198 dB re 1 µPa^2.s (M_{lf})
Mid Frequency Cetaceans		
Peak Pressure Level	230 dB re 1 µPa	230 dB re 1 µPa
Sound Exposure Level	198 dB re 1 µPa^2.s (M_{mf})	198 dB re 1 µPa^2.s (M_{mf})
High Frequency Cetaceans		
Peak Pressure Level	230 dB re 1 µPa	230 dB re 1 µPa
Sound Exposure Level	198 dB re 1 µPa^2.s (M_{hf})	198 dB re 1 µPa^2.s (M_{hf})
Pinnipeds (in water)		
Peak Pressure Level	218 dB re 1 µPa	218 dB re 1 µPa
Sound Exposure Level	186 dB re 1 µPa^2.s (M_{pw})	186 dB re 1 µPa^2.s (M_{pw})
Source: Southall *et al.* (2007)		

The Southall study criteria can be used for both single pulse noise sources and multiple pulse sources. This report presents estimated ranges of effect for impact pile driving using Southall *et al.*'s multiple impact SEL criteria. This modelling is carried out by assuming a swim speed and starting range for the animals and hence calculating the accumulated exposure as the animal moves away from the noise source. The M-weighted Sound Exposure Level at each range as the animal moves is calculated using the INSPIRE model.

These figures suggest that pinnipeds are significantly more sensitive than cetaceans, with an adverse impact occurring at much lower noise levels. However, recent research by Thompson and Hastie (2011) has demonstrated evidence that pinnipeds actually respond much more like the cetaceans, and that the same sound exposure level, 198 dB re 1 µPa^2.s (M_{pw}), would be just as appropriate for the pinnipeds. This approach has been taken and 198 dB SEL has been used in the modelling for all cetaceans and pinnipeds. More detail on this is provided within the Marine Mammal Technical Appendix, 7.3 A.

4.4 Behavioural Impacts and their Associated Sound Levels

4.4.1 Introduction

At levels lower than those that cause physical injury or permanent threshold shift (PTS), noise may nevertheless have important behavioural effects on a species, of which the most significant is avoidance of the insonified area (the region within which noise from the source of interest is above ambient underwater noise levels). The significance of the effect requires an understanding of its consequences. For instance, avoidance may be significant if it impedes the migration of a species. However, in other cases the movement of species from one area to another may be of no consequence.

Avoidance appears to be associated with a sensation of "unbearable loudness". Hence, in order to judge the potential of a noise to cause avoidance, it is necessary to be able to ascertain the perception of the sound by the species, i.e. how loud the sound appears to individuals of that species. Individuals of species having poor hearing may perceive the level as low, and hence not react to the noise, whereas a species that is sensitive may find the level unbearably loud and react by swimming away. Therefore, of key importance in the process is an understanding of the hearing ability of the species that may be affected.

4.4.2 Criteria for Assessing Behavioural Response

If the level of sound is sufficiently high on the dB_{ht}(*Species*) scale, it is likely that an avoidance reaction will occur. The response from a species will be probabilistic in nature (e.g. at 75 dB_{ht}(*Species*) one individual from a species may react, whereas another individual may not: the metric indicates the *probability* of an individual reacting), and may also vary depending upon the type of signal. A level of 0 dB_{ht}(*Species*) represents a sound that is at the hearing threshold for that species and is, therefore, at a level at which sound will start to be 'heard'. At this and lower perceived sound levels no response occurs as the receptor cannot hear the sound.

Currently, on the basis of a large body of measurements of fish avoidance of noise (Maes *et al.,* 2004), and from re-analysis of marine mammal behavioural response to underwater sound, the following assessment criteria were published by the Department of Business, Enterprise and Regulatory Reform (BERR) (Nedwell *et al.*, 2007b) to assess the potential impact of the underwater noise on marine species:

Table A3. Assessment criteria used to assess the potential impact of underwater noise on marine species

Level in dB_{ht}(*Species*)	Effect
75 and above	Mild avoidance reaction by the majority of individuals. (See Seal Framework Document, Technical Appendix 7.3 B)
90 and above	Strong avoidance reaction by virtually all individuals.
Above 110	Tolerance limit of sound; unbearably loud.
Above 130	Possibility of traumatic hearing damage from single event.

Source: Nedwell *et al.* (2007)

4.5 Species considered in the assessment

Table A-4 below presents a summary of the species of interest to this study, along with some information regarding the availability of data concerning their sensitivity to underwater sound. The species considered in the modelling are highlighted in green and yellow in Table A-4.

Table A-4. Summary of marine species relevant to the Moray Firth region

Species common to area	Audiogram available?	Surrogate used	Comments	Reference
Common (Harbour) seal	Yes	-	No single audiogram dataset covering full audiometric range available. Data from two studies used	Kastak and Schusterman (1998); Mohl (1968)
Grey seal	Partial – only upper frequencies	Harbour seal	No single audiogram dataset covering full audiometric range available. Data from two studies used	Kastak and Schusterman (1998); Mohl (1968)
Harbour porpoise	Yes	-	-	Kastelein (2002)
Minke whale	No	None	Used a theoretical audiogram of the Humpback Whale as a surrogate	Erbe, 2002
Killer whale	Yes	-	-	Szymanski et al., (1999)
Risso's dolphin	Yes	Bottlenose dolphin	Existing audiogram data indicates higher threshold than other dolphin species but high background noise levels during audiogram tests	Risso's dolphin – Nachtigall et al., (1995) Striped dolphin – Kastelein (2003)
White-sided dolphin	No	Bottlenose dolphin	Audiogram data suggest bottlenose dolphin are most sensitive dolphin species to sound so may provide conservative indication of impacts	Johnson (1967)
White beaked dolphin	Partial – only upper frequencies	Bottlenose dolphin	Partial audiogram data for white-beaked dolphin indicates close match to striped dolphin data	White beaked dolphin – Nachtigall et al., 2007 Striped dolphin - Kastelein (2003)
Bottlenose dolphin	Yes	-	-	Johnson (1967)
Herring	Yes	-	-	Enger, 1967
Plaice	No	Dab		Chapman and Sand (1974)
Whiting	No	Cod	Of the same taxonomical family as cod so the audiogram data for cod is the best available information on which to base the impact assessment for this species.	
Cod	Yes	-	-	Chapman and Hawkins (1973)

Species common to area	Audiogram available?	Surrogate used	Comments	Reference
Salmon	Yes	-	-	Hawkins and Johnstone (1978)
Sandeels	No			
Mackerel	No			
Ling	No			
Sea lamprey	No			
Elasmobranchs	Yes - various			
Guillemot	No			
Razorbill	No			
Puffin	No			
Gannet	No			
Arctic tern	No			

Species specific assessment | Inferred hearing abilities or species grouped | Not assessed

Audiograms for the species listed in the table, where available, have been presented in Figures A-2 to A-4 above.

4.5.1 The use of surrogates

In the Table A-4 it is shown that, for instance, there is no known audiogram for the plaice and the audiogram for the dab has been used when making calculations for the plaice.

The dab is in the family *Pleuronectidae*. It is common in the shell grit and sandy seabeds surrounding Great Britain and Ireland towards Scandinavia. It is able to live in water depths of a few metres to around 100 m. The dab is found in temperate waters and usually grows to around 35 cm in length and weighs up to a kilogram. Spawning depends on water temperature and occurs during early summer. It is known to prey on crustaceans, small fishes, brittlestars, sea urchins and molluscs. The audiogram for the dab (*L. Limanda*), (from Chapman & Sand, 1974) is presented in Figure A-3, converted to units of sound pressure by Popper & Fay (1993). As can be seen in the figure, dab detect frequencies from below 30 Hz up to around 200 Hz, with sensitivities of around 90 dB re 1 μPa at 110 Hz. This indicates that dab have relatively poor hearing sensitivity compared to clupeids and therefore, in common with plaice and lemon sole, they may be classed as hearing generalists.

The plaice, too, is in the family *Pleuronectidae*. The geographical range of the European plaice is off all coasts from the Barents Sea to the Mediterranean. It is a common flatfish, occurring on the sandy and muddy bottoms of the European shelf, usually at depths between 10 and 50 m, where they tend to burrow in sediment during day time and remain stationary for long periods. They can be found at depths up to approximately 200 m. Young fish in particular come right inshore in very shallow water. Its maximum length is about 1 m, but adults, caught in fishing nets, are usually between 50 and 60 cm in length. Its maximum published weight is 7 kg.

Because of the similarities between the two species, the dab has been used as a surrogate for the plaice.

5. Underwater Noise Modelling Methodology

5.1 Introduction

The general approach to estimating the levels of subsea noise from offshore wind farm developments has been undertaken in two phases. In the first a broad-brush modelling approach has been used to rank order a wide range of offshore wind farm-related sources of underwater noise. This was done using the proprietary Simple Propagation Estimator And Ranking model (SPEAR) developed specifically for the Moray Firth developers (Moray Offshore Renewables Ltd, MORL, and Beatrice Offshore Windfarm Ltd, BOWL). In the main, the information used to validate this model has come from the very substantial database of recordings of various noise sources compiled by Subacoustech Environmental over the last 20 years. The model uses estimates from this database of the typical frequency content, source level and transmission losses associated with each type of noise source. These data have been used to determine the impact of each noise source on the marine environment, by using the estimate of noise level and a suitable criterion for a level above which it will have an effect to estimate the area which is affected by the noise source for each class or species of marine animal.

The rank ordering showed that most of the activities had a negligible adverse effect, so they could be eliminated from further consideration in the second phase of the assessment, where the focus was on sources of noise that have the capacity to cause a significant adverse effect. Section 8.3 gives detail of this finding. The activity that generated the highest noise levels (impact piling) was modelled in detail to provide an assessment of the area which would be affected. The results of this detailed modelling were combined with population and behavioural data to allow a biological assessment of the significance of any effects on fish and marine mammals to be made.

It may be noted, however, that although most of the relatively low level noise sources could be eliminated from detailed modelling in the second phase of the assessment, their significance has been re-assessed in the context of the cumulative impact assessment, where they may be considered of greater importance.

5.2 Modelling of Sound Propagation

Sound levels underwater are usually quantified in terms of the Source Level, which is a measure of the sound energy released by the source, and the Transmission Loss, which is a measure of the rate at which that energy is lost. Sound propagation is thus described by the simple equation:

$$L(r) = SL - TL \qquad \text{eqn. 5-1}$$

where $L(r)$ is the Sound Pressure Level at distance r from a source in metres, SL is the source level, which may be thought of as the "effective" level of sound at one metre from the source, and TL is the transmission loss (Kinsler *et al.,* 1982). Transmission Loss (TL) is defined as:

$$TL = 20\log\left(\frac{P_0}{P_R}\right) \text{ .... eqn. 5-2}$$

where P_o is the effective acoustic pressure at a point at 1 m from the source, as per the Source Level above, and P_R is the acoustic pressure at range R away from it. The Transmission Loss is therefore a measure of the rate at which the sound energy decreases with increasing range.

Frequently a simplification is made by assuming that the Transmission Loss may be approximated due to spreading and absorption losses such that:

$TL = N\log(r) + \alpha$ .... eqn. 5-3

where *r* is the distance from the source in metres, *N* is the constant factor for attenuation due to geometric spreading, and α is a factor for the absorption of sound in water and at boundaries in dB/m (Urick (1983); Kinsler *et al.* (1982)).

For instance, spherical spreading gives a value of *N*=20. By combining equations 2-6 and 2-8 the level of sound at any point in the water space can be estimated from the expression:

$L(r) = SL - N\log_{10}(r) - ar$ .... eqn. 5-4

Over short distances absorption effects have little influence on the Transmission Loss and can often be ignored. The Source Level itself may be quoted in any physical quantity, e.g. a piling source may be expressed as having a "peak-to-peak Source Level of 200 dB re 1 µPa @ 1m".

This simple but convenient formulation ignores the practical difficulty of estimating the Source Level. Since the measurements are usually made at some distance from the source (in the acoustic far field) and extrapolated back to the source, the true level at 1 m may actually be very different from the Source Level used in these equations.

It is often not realised that, since the value of Source Level quoted for a particular source is obtained by extrapolation, the value will depend on the model that is used to perform the extrapolation. Figure A-6 illustrates this point. The diagram illustrates a set of measurements made of the noise from piling. In the simplest case, in order to draw conclusions about the data, a straight-line model may be fitted to it — this is shown in the figure by the green line. Such a model effectively assumes that the noise level, NL, behaves as $L(r) = SL - N\log_{10}(r)$. This, however, will generally over-estimate the levels for low and high ranges, since it ignores the effects of absorption of the noise. The improved model including absorption, $L(r) = SL - N\log_{10}(r) - ar$ (red line in the figure), gives a better fit to the data, and indeed this simple form is usually adequate for modelling sound propagation from a source in deep water of roughly constant depth. However, in the case of the shallow coastal waters where wind farms are typically situated, the depth may rapidly fluctuate between shallow water of a few metres and deeper water of tens of metres or more. In these circumstances the Transmission Loss becomes a more complex function of depth that depends heavily on the local bathymetry and hence must be calculated using a more sophisticated model, such as INSPIRE. Where these effects are included, as illustrated by the blue line in the figure, yet another value of Source Level may result; typically, lower levels of noise may be predicted near to the pile.

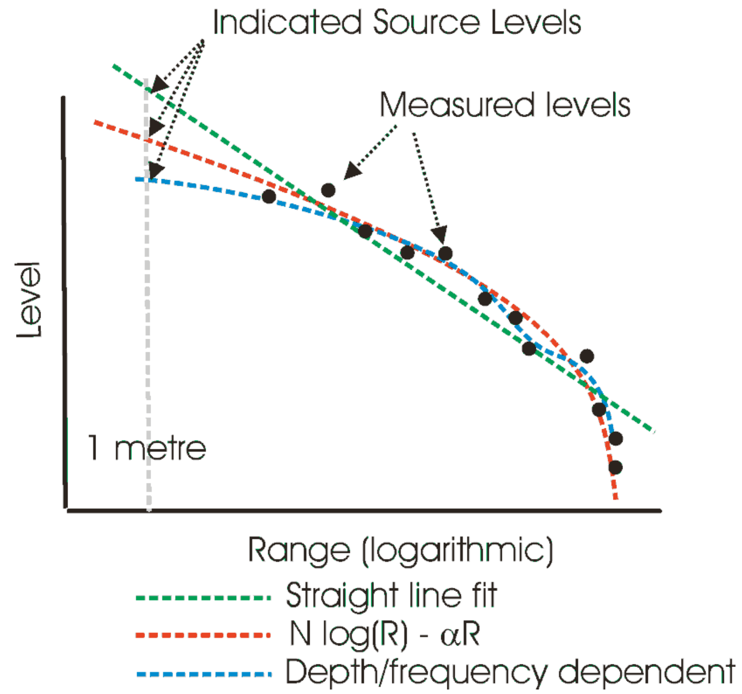


Figure A-6. Differences in Source Level estimation based on various models

Source Levels can also be expressed in the dB$_{ht}$ metric, e.g. 170 dB$_{ht}$ (*Clupea harengus*) @ 1 m.

This approach is very convenient, as it allows the relative significance of various sources to be easily compared for different species or pile sizes. The levels can be analysed using the SPEAR and/or INSPIRE models to determine impact ranges for fish and marine mammal species.

5.3 Phase 1 of the Modelling: Rank-ordering of Noise Sources

The first phase of the underwater noise modelling was carried out using the simple yet realistic broad-brush Source Level-Transmission Loss (SL-TL) model, SPEAR. The model is based on Subacoustech Environmental's substantial database of noise sources, and provides an indication of the typical levels of underwater noise generated by wind farm related activities. The model allows the significance of a wide range of sources of underwater noise to be rank-ordered for a wide range of marine animals.

As has been previously noted, as sound propagates through water it reduces in level as a result of losses relating to energy dissipation (absorption) and to geometric spreading. This latter is the acoustician's terminology for the effect of the area of the notional surface surrounding the sound source increasing as distance from the source increases; the sound energy consequently is flowing through a larger area and its intensity will accordingly reduce.

At a particular point in the water space the level to which an animal is subjected, the Received Level (*RL*), is, in logarithmic terms, the Source Level minus the Transmission Loss:

$RL = SL - TL$ .... eqn. 5-5

Over short distances absorption effects have little influence on the Transmission Loss and can often be ignored, and in that case, and over a defined spread of range, it is reasonably accurate to use a linear fit of the form:

$RL = SL - N\log_{10}(r)$ .... eqn. 5-6

where *N* is generally characterised as being a term associated with the spreading of sound. The Source Level itself may be quoted in any physical quantity, for instance, a piling source may be expressed as having a "peak-to-peak Source Level of 200 dB re 1 µPa @ 1 m". It may be also specified in terms of a frequency weighted level for a particular animal species, allowing the "loudness" or effect of the sound to be evaluated. This approach is inherent in both the Nedwell dB_{ht} formulation and the Southall SEL approach.

It will therefore be appreciated that this simple model has been chosen in the main because it allows the evaluation of the significance of the noise for a wide range of marine animals having greatly varying acuity of hearing and frequency range over which they can hear. This is critical to any realistic investigation, because noise sources with a significant content of high frequency sound will tend to selectively affect high frequency hearers, such as the harbour porpoise, while sources with a significant content of low frequency sound will tend to affect low frequency hearers, such as fish. The effect of any given noise source may therefore be greatly different for different species, and it is therefore essential to use a modelling process that considers the hearing acuity of the affected species.

Although the formula is simple, obtaining accurate values to insert into it from actual data from a wide range of experimental measurements requires processing of the data for a large range of animal types, and is both complex and onerous. For instance, consideration must be given to the factors detailed in *Section 5.2* of this Appendix relating to the estimation of source levels using different models.

For the purposes of the methodology of this assessment, the calculations in Phase 1 used a simple $L(r)=N\log_{10}(r)-ar$ formulation.

The simple model also takes into account variations in the parameters affecting the source level. For instance, currently available information suggests that the level of underwater noise from impact piling operations is closely related to the pile diameter, with sound levels increasing with diameter. The blow energy applied to the pile also influences the noise levels produced. Figure A-7 shows a summary of Source Levels extrapolated from measured data obtained on a number of impact piling operations which used various pile sizes. It can be seen that as the diameter of the pile increases the Source Level also increases, although it may be commented that two results for small pile diameters that lie beneath the general curve are now believed to be anomalous. The fitted curve has been used as an input to the SPEAR model to provide a reasonably accurate estimation of the sound energy generated by striking of different sized piles. This is adequate for the purposes of ranking the significance of the various noise sources required in Phase 1. In the SPEAR model this information is included explicitly, whereas in the INSPIRE model, where it is also used, it is taken into account via an inbuilt source function.

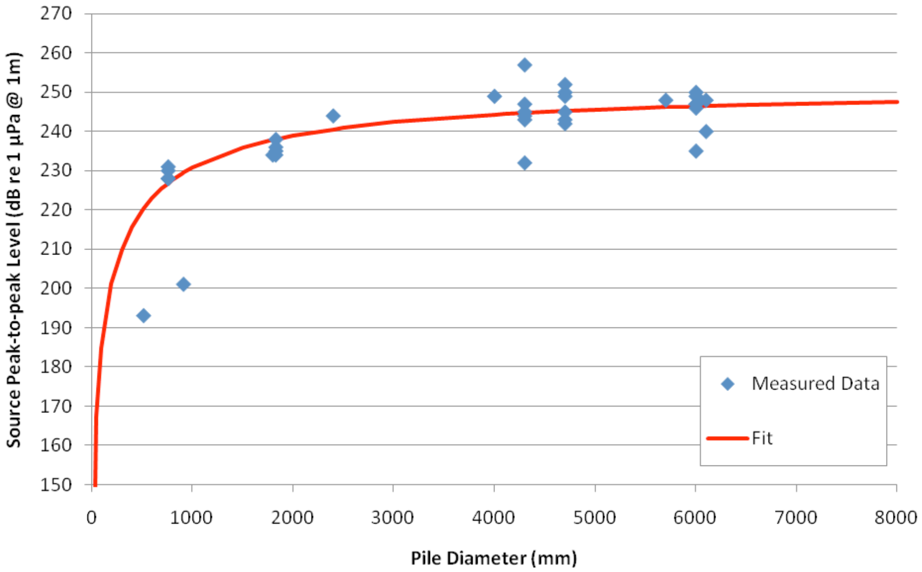


Figure A-7. Plot showing the asymptotic best fit to Source Level calculated from measured piling noise data for various pile sizes

In summary, the initial ranking process was based on the simple yet representative SPEAR model, which enabled an evaluation to be made of the impact of a wide range of noise sources on a range of marine species in terms of the level of the noise, the area affected and the duration of activity.

The results provided by this model allowed the elimination of most of the construction activities from further consideration as they were shown to have a negligible likelihood of causing an environmental impact when compared with impact piling. Thus in Phase 2 of the modelling programme only impact piling was considered.

5.4 Phase 2 of the Modelling: Detailed Modelling of Impact Piling

Impact piling is known to generate high levels of underwater noise. It is therefore important to make an accurate estimate of its likely level so that its impact can be accurately assessed. There are a variety of acoustic models for the estimation of underwater noise propagation in coastal and offshore regions, mainly developed as a result of military interests. However, the authors are not aware of any underwater broadband noise propagation models suitable for the much shallower environments typical of wind farm construction, or for the highly impulsive time histories encountered from impact piling. In these environments and with these source types there is a greater capacity for underwater sound to be affected by absorptive processes in the seabed, resulting in propagation losses which typically increase with frequency but decrease with depth.

The Impulse Noise Sound Propagation and Impact Range Estimator (INSPIRE) model has been developed specifically to model the propagation of impulsive broadband underwater noise in shallow waters. It uses a combined geometric and energy flow/hysteresis loss model to conservatively predict propagation in relatively shallow coastal water environments, and has been tested against measurements from a large number of other offshore wind farm piling operations (Nedwell *et al.,* 2011) {validation report ref. E287R0619}.

Transmission Losses are calculated by the model on a fully range and depth dependent basis. The model imports electronic bathymetry data as a primary input to allow it to calculate the transmission losses along transects extending from the pile location. Other simple physical data are also supplied as input to the model. The model is able to provide a wide range of outputs, including the peak pressure, impulse, dB_{ht}, SEL, etc. of the noise.

As well as calculating the SEL variation with range, the model incorporates a "fleeing animal receptor" extension which enables the noise dose an animal receives as it is moves away from a piling operation to be calculated. This feature permits the calculation of the nearest distance from a pile from which an animal must start fleeing such that its noise dose just reaches the criterion value at the cessation of the piling operation.

In Phase 2 the INSPIRE model was used to assess in detail the ranges at which fatality, physical injury, auditory injury and behavioural avoidance was likely to occur for a range of animal species.

6. Introduction to noise modelling scenarios for marine mammal and fish impact assessments.

An extensive database of measured noise levels within the water column is held that have been recorded during offshore construction activities. The use of this database enables a comparison of underwater noise associated with a variety of construction related activities, as shown in Figure A-8 below, and indicates that the noise from piling activity is the most significant from the identified activities.

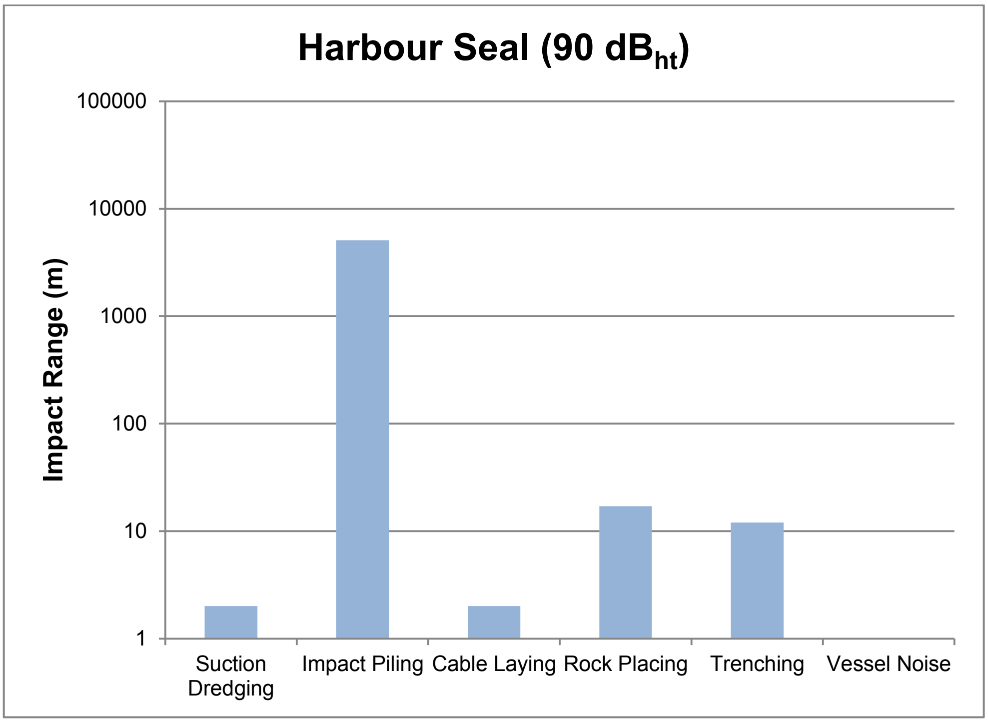


Figure A-8. SPEAR model to illustrate typical source noise associated with a range of construction related activities.

The impact ranges shown in Figure A-8 indicate that impact piling gives by far the largest impact ranges, with impact ranges given in kilometres whereas the other noise sources, including cable laying and trenching have estimated impact ranges that stretch to a few tens of meters at most.

Subacoustech have taken on site measurements of impact piling of a 1.8 m pin pile at a range of 250 m and ambient noise from a 300 m long container ship at a similar range. The recorded noise levels of sound in terms of dB_{ht} for Harbour Seal are 122 dB_{ht} peak-to-peak for the impact piling and 66 dB_{ht} RMS for vessel noise.

As a consequence of the above, it is assumed that where pile driving has the potential to occur the noise associated with this activity will be dominant over other noise and will therefore be the main source of impact within the vicinity[1]. The impact assessment of wind farm construction related noise within the three proposed wind farms on marine mammals and fish will concentrate upon impacts arising from pile driving activity. The impacts of construction activity associated to the grid connection works outside of the EDA will include activities other than piling.

6.1 Modelling requirements of the Rochdale Envelope

As described in Chapter 2.2: Project Description of the ES, the foundation designs included within the Rochdale Envelope for the three proposed wind farms include gravity base structure and jackets with pin piles. For the offshore substation platforms, OSPs (offshore transmission infrastructure) jack–ups with pin piles or suction caissons are also considered. Figure A-8 above shows that the noise associated with piling is greater than that with rock placing for gravity foundations. It can also be assumed that, due to the methods involved, suction caissons would also be quieter than impact piling. However, as using suction caissons is a relatively new construction technique, insufficient data is available to reasonably assess performance.

With regards to predicting noise impacts, the noise levels associated with driving the pin piles is proportional to the blow energies required for their installation. A preliminary pile design study was undertaken to understand the sensitivity of pile length and the required driving energy in relation to pile diameter, soil type, soil strength, substructure type, wind turbine size and design method and to estimate the most credible worst case pile driving scenario. The study concluded that required pile length and therefore driving energy varies with turbine size, with larger turbines requiring longer piles and greater piling energy. The blow energies required to drive pin piles into the substrate also vary with soil strength, with stiffer / denser soils generally requiring greater blow energies.

Analysis of the geophysical and geotechnical survey data indicated that the soil type across the three proposed wind farm sites falls into three geological provinces of differing soil profiles. The geotechnical parameters were derived based on the data from 19 boreholes across the three proposed wind farm sites (Figure A-9). Therefore, the parameters used in the noise modelling studies represent an indication of the likely soil conditions across the site. Within each geological province there will be some level of variation in the soil composition which may affect the required pile driving energy (impact energy) and therefore pile hammer size.

Stiffer denser soils generally require greater blow energies. This will have an impact upon the predicted dB_{ht} levels for each species considered. However, it should be noted that softer / looser soils are likely to require slightly longer pin pile to securely tie the foundations into the sea floor, possibly resulting in a greater duration of piling but at lower energy to drive the piles to depth. This will have an impact upon the predicted SEL levels. Province 3 soil is the stiffest soil type found across the three proposed wind farm sites, and driving piles into it will require the highest blow energy.

[1] The potential impact of injury to seals arising from vessels utilising ducted propellers is considered separately to noise impacts within the marine mammal impact assessment.

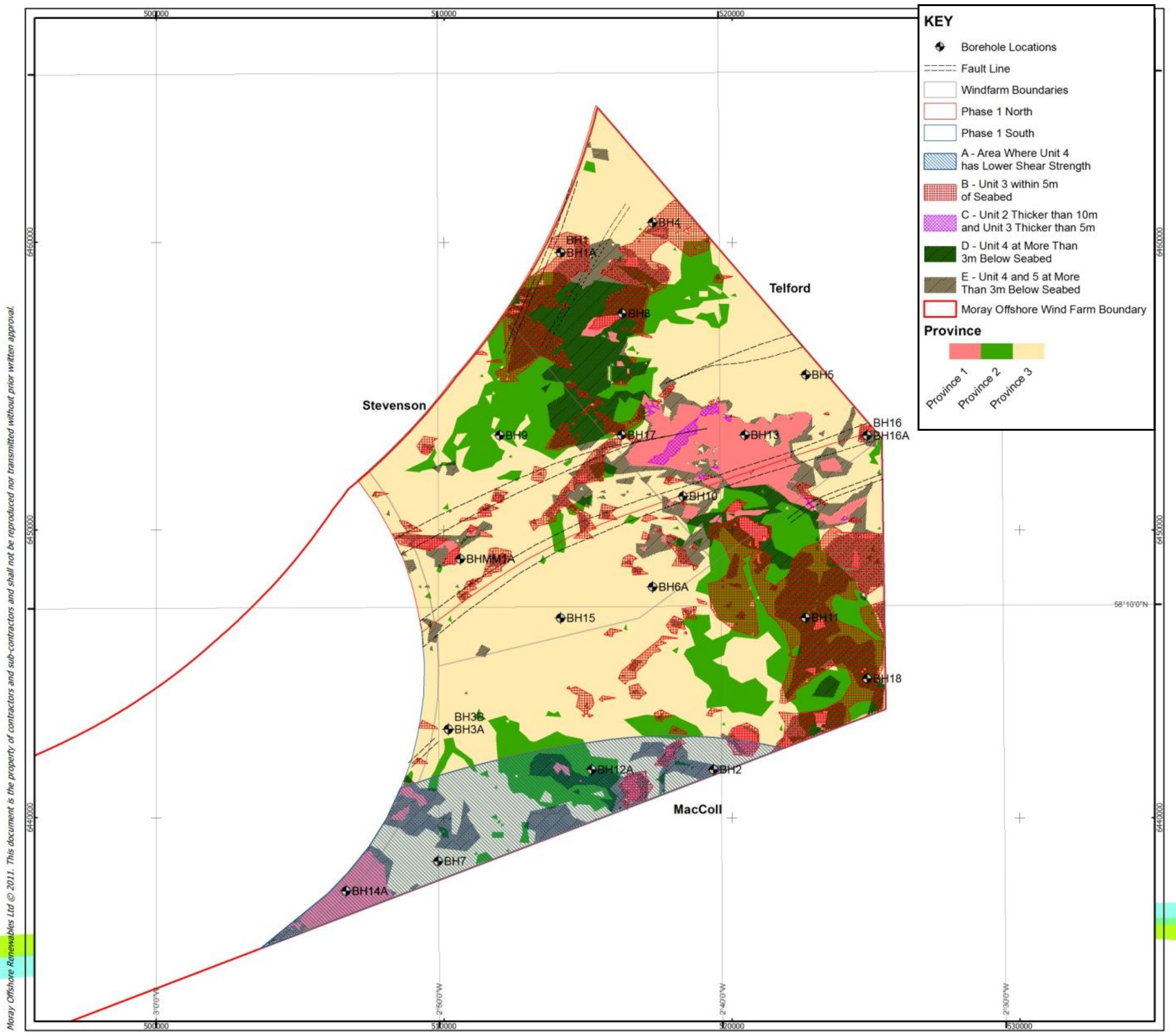


Figure A-9. Soil province map of the three proposed wind farms

A workshop was held with MORL engineers, marine mammal specialists and the noise modellers in order to investigate the noise implications associated with changes in both soil type and turbine size, with regards to pin pile requirements. During the workshop predictions of the noise levels arising from driving different diameter pins into the same location (same soil type), and the same diameter pin pile into the three different soil types, were modelled to determine the most credible worst case scenario.

6.2 Soil type implications upon source level noise and predicted noise propagation from piling activity

The modelling scenario in Figure A-10 below shows the predicted noise contour for 75 dB_{ht} for harbour seals[2] from piling a 2 m, 2.5 m and 3 m diameter pile into the same location in a

[2] Please see marine mammal impact assessment (Chapter 7.3 of the ES) for a discussion on the impact of noise on harbour seals.

province 3 soil type. Province 3 soil represents the stiffest soil type found across the three proposed wind farms, and thus driving the pile into this substrate would require the highest blow energies of the three provinces. The location of the pile driving event is the south-western corner of the three proposed wind farms, closest to known seal haul out sites.

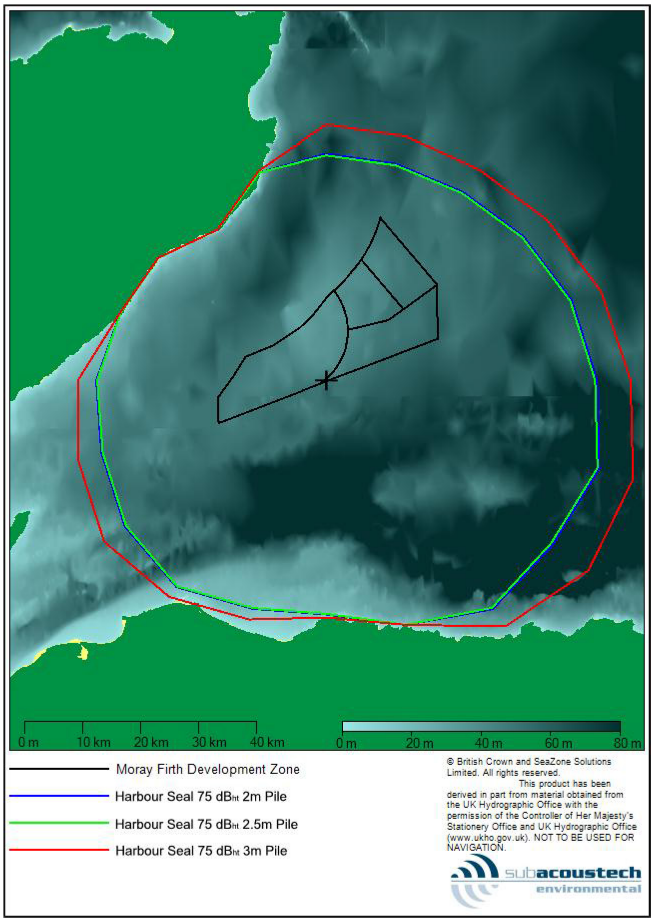


Figure A-10: Predicted 75dB$_{ht}$ radii for seals for the 2 m, 2.5 m and 3 m diameter pile driven into province 3 soil type.

The Figure A-10 above shows that while there is a relatively small difference (at most up to 6 km) between the 75 dB$_{ht}$ radii between the 2.5 m and 3 m pile, the radii from the 2 m and 2.5 m pile are very similar.

6.3 Soil type implications upon the length of pin pile, and so durations of piling and SELs.

As described above, the softer soil types are likely to require a longer pin pile to securely tie the foundation to the sea floor. The number of blows required to drive a pile into the sea floor is dependent upon the length of the pile in addition to the stiffness of the soil type. To analyse the difference in predicted SELs from a longer pin pile being driven into a softer soil type compared to a shorter pin pile being driven into a stiffer soil type, the PTS[3] SEL radii for seals from the blow energy profiles predicted for driving a 2.5 m diameter pile into Province 1, 2 and 3 soil types were modelled. The modelling was undertaken on one pile being driven per 24 hr period. The modelling outputs from this scenario are shown below in Figure A-11.

[3] See section 4 for description of PTS

As for Figure A-10, the location of the pile driving event is the south-western corner of the three proposed wind farms closest to known seal haul out sites.

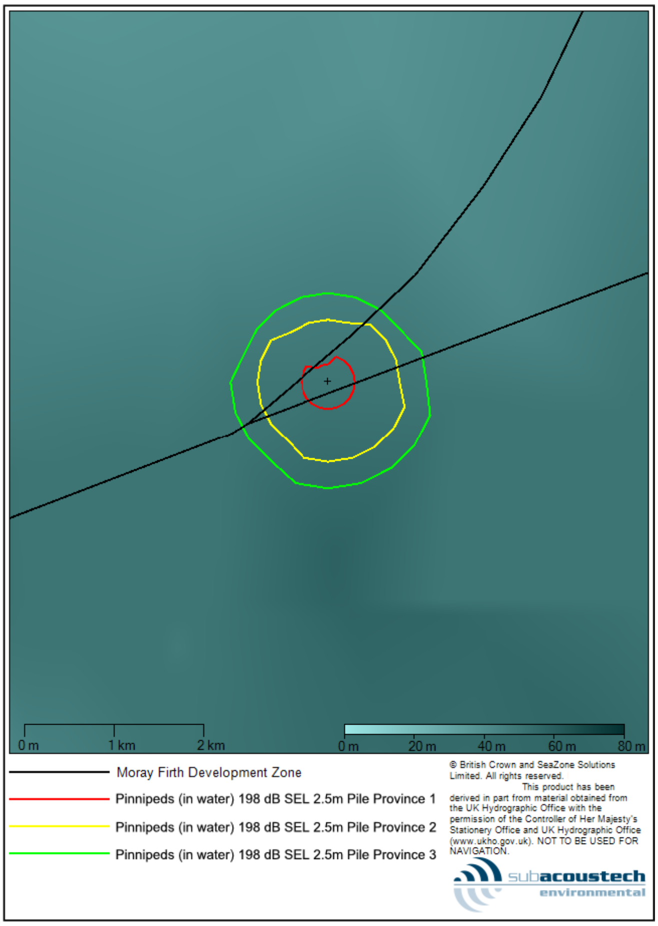


Figure A-11. Predicted PTS SEL radii for fleeing seals from likely blow energies required to drive 2.5 m diameter pin piles into province 1, 2 and 3 soil types.

Figure A-11 above shows that predicted PTS SEL radii for seals vary with soil type. In diameter of predicted radii, the PTS SELs for soil types province 3 > province 2 > province 1, illustrating that predicted SELs are more strongly correlated to the predicted blow energy required to pile the pins than to the length of the pins.

6.4 Modelled scenario for impact assessments

As described in Chapter 2.2: Project Description of the ES, the size (and so number) of turbines within each of the three proposed wind farms are yet to be defined. The Rochdale Envelope includes for between 216 and 339 turbines, of between 3.6-7/8 MW in size. Each turbine foundation would require up to four pin piles of either 2 m or 2.5 m diameter. The Rochdale Envelope also includes up to eight OSPs that would require up to 16 3 m diameter pin piles (jack-up foundation type). As shown above, these turbines could be driven into each of three soil provinces.

Whilst recognising that the EIA process should use credible worst case scenarios, it was considered that the complexity arising from modelling a larger number of small turbines compared to a smaller number of large turbines was not warranted. Instead impact assessments from pile driving activity centred around driving the 2.5 m diameter pile into province 3 soilswere undertaken, recognising that this represents a conservative impact assessment for the three proposed wind farms. Separate modelling has been undertaken for the OSPs using a 3 m pile diameter. The modelling has been undertaken for two piles being driven in any 24 hr period for the purposes of SELs.

The modelled blow energy profiles for the 2.5 m and 3 m pin piles into province 3 soils are provided in Table A-5 and Table A-6 below. It should be noted that is an indicative breakdown of impact energy and duration to inform the impact assessment. While all the engineering information available has been used, including the piling records from the Beatrice Demonstrator project, the actual piling operations will be conducted in accordance with JNCC guidelines[4] but at the discretion of the installation contractor.

Table A-5: Assumed blow energy profile required to drive a 2.5 m diameter pin pile to a depth of 26 m into province 3 soils.

Penetration Depth	Hammer Efficiency	Impact Energy (kJ)	No of blows	Time
0 to 4m	15%	170	260	15mins
4 to 14m	40%	450	2400	45mins
14 to 16m	80%	890	1000	15mins
16 to 26m	95%	1080	7000	2hrs

Table A-6: Assumed blow energy profile required to drive a 3 mdiameter pin pile to a depth of 23 m into province 3 soils.

Penetration Depth	Hammer Efficiency	Impact Energy (kJ)	No of blows	Time
0 to 5 m	15%	280	222	15 mins
5 to 14 m	40%	750	2200	1 hr
14 to 19 m	85%	1600	1900	1 hr
19 to 23 m	95%	1800	3700	2 hr

The Project Description (Chapter 2.2 of the ES) also provides information upon the temporal scale of predicted impacts. The Rochdale Envelope includes piling throughout the year, with the build programme show piling at full intensity possible during the summer and at half intensity during the winter to allow for weather windows. The foundation installation programme modelled will represent three scenarios;

1. A five year build programme utilising one installation vessel, installing 2 pin piles in a 24 hr period.

2. A three year build programme utilising two vessels for the majority of the period, also installing 2 pin piles in a 24 hr period.

3. A two year build programme if six vessels are used, each installing two pin piles in a 24 hr period. Each site may be constructed independently of the other two, and as such it is necessary for the impact assessment to include the scenario of construction of all three at the time.

[4] https://www.og.decc.gov.uk/environment/jncc_pprotocol.pdf

An average of 13% of piling days for the wind turbines and 1% for the OSPs are estimated for scenario 1 assuming maximum piling duration (approximately15 % of overall piling days over 5 years).

Each site may ultimately be constructed independently of the other two, and as such it is necessary for the impact assessment to include the scenario of construction of all three at the same time so as to account for any coordination issues between the projects. Scenario 3 would only occur to mitigate delays in the building schedule or result from supply chain constraints. It is recognised therefore that the probability of six simultaneous piling events (scenario 3) is very low and if occurring would be of very short duration.

All of the above scenarios are therefore extremely conservative, assuming maximum number of turbines and offshore platforms (339 turbines and eight platforms), longest estimated piling duration (per pin pile), weather constraints and mobilisation and demobilisation activities. Further refinement of these parameters (engineering information, build programmes) will be undertaken during determination/post consent as the engineering studies progress and preferred contractors are identified in order to provide a more 'realistic' worst case.

The locations chosen to represent the spread of piling activities associated to each scenario are shown in Figure A-12 below.

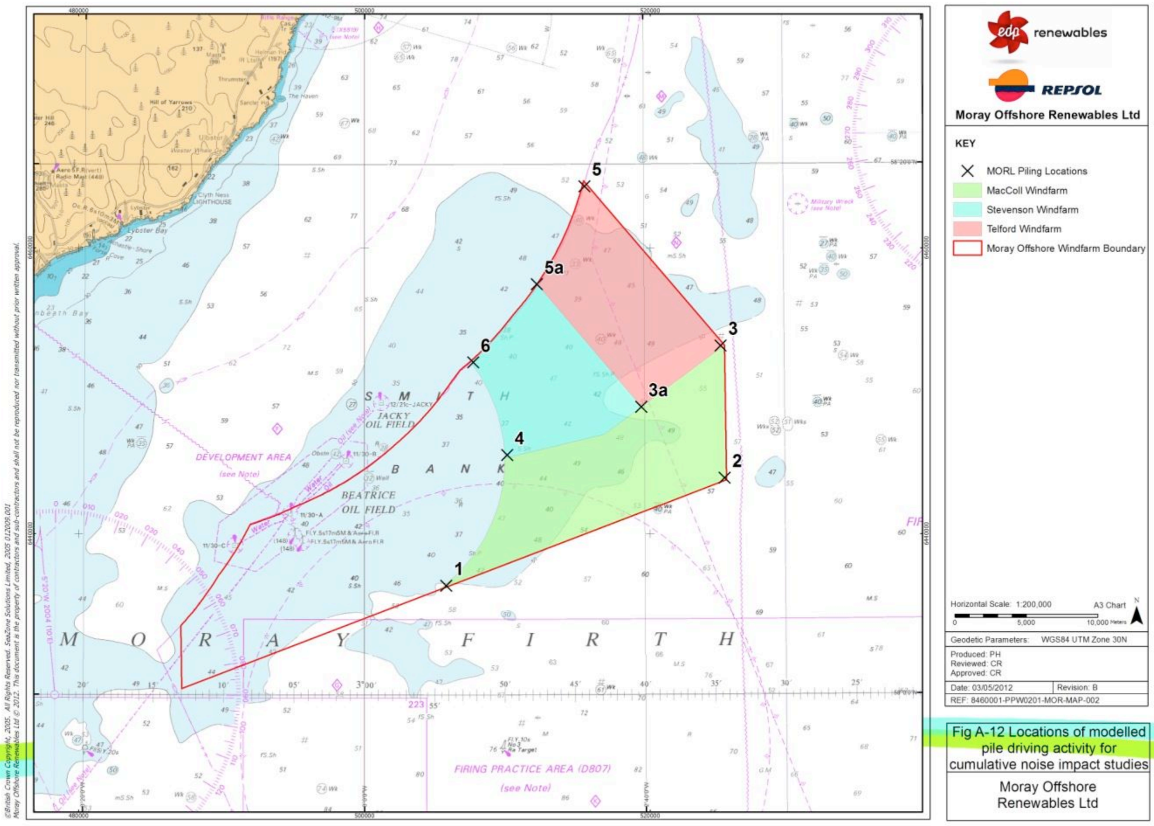


Figure A-12. Locations of modelled pile driving activity for scenarios 1, 2 and 3 above.

The rationale behind the choice of pile locations has been driven by ensuring worst case is modelled at each point.

- Worst case for one vessel is location 1 in Figure A-12 as it is closest to the harbour seal and bottlenose dolphin SACs, and thus sensitive receptors. It will be assumed that the noise contours from piling activities at this location occur over the five year installation programme. Additional positions have been modelled to show predicted impacts for impact piling operations of each of the sites; position 1a in MacColl, position 4 in Stevenson, and position 3a in Telford. A final position in the south east of the site has been modelled to show the impact of installing a 3 m pile with an 1800 kJ hammer in Province 3 soils as part of the OfTI study.

- Worst case for up to two vessels are locations 1 and 5 in Figure A-12, as this gives the greatest extent of noise propagation across the three proposed wind farms and Moray Firth. It will be assumed that the noise contours from piling activities at these two locations occur over the three year installation programme. Additional positions have been modelled for this scenario to show the predicted impacts for two vessels operating in the same site; positions 1 and 2 in MacColl, positions 4 and 6 in Stevenson, and positions 3a and 5a in Telford.

- Worst case for all six vessels are locations 1, 2, 3, 4, 5 and 6 in Figure A-12, as this gives the greatest extent of noise propagation across the three proposed wind farms and Moray Firth. Whilst it is recognised that it is unlikely that all six vessels will be installing foundations for the full two years, it will be assumed that the noise contours from piling activities at these locations occur over the two year installation programme.

6.4.1 Cumulative scenario to be modelled.

In addition to the up to six vessels operating within the three proposed wind farms described above, BOWL may also be piling foundations within the Moray Firth during the expected construction phase. Information from BOWL indicates that the Developer is considering up to two construction vessels to be in operation at any one time on the site. BOWL have provided the blow energy profiles presented below in Table A-7 as indicative for the requirements of driving a 2.4 m pile into the soils within the site boundary.

Table A-7: Assumed blow energy profile provided by BOWL as being required to drive a 2.4m diameter pin into the soils of the Beatrice site

Impact Energy (kJ)	No of blows	Time
280	1200	20mins
920	3700	1hr
1380	3700	1hr
1840	3700	1hr
2300	3700	1hr

BOWL estimate that the construction period associated to each pin would last for eight hours, and that up to two pins would be piled in any 24 hr period. The construction phase for the up to 277 turbines could last up to three years.

In order to model the predicted noise impact from the additional up to two construction vessels on the BOWL site, MORL have undertaken noise modelling of the blow energy profiles provided in Table A-7 above at the locations provided in Figure A-13 below. Additionally modelling has been carried out to show the impact of one vessel piling in the MORL site simultaneously as one at the BOWL site (positions 1 and A), as well as two vessels in the MORL site with two operating at the BOWL site (position 1, 5, A and B).

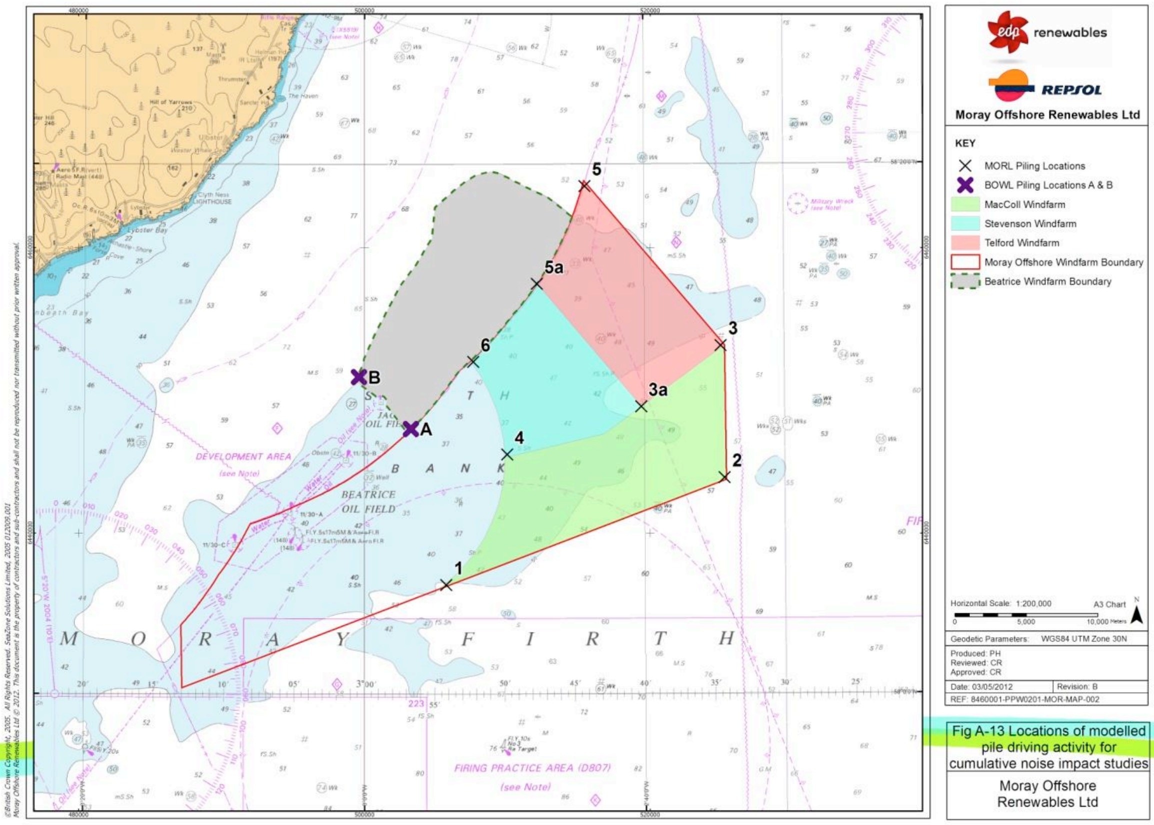


Figure A-13. Locations of modelled pile driving activity for cumulative noise impact studies

6.5 Modelling for installation of a meteorological mast

Subsea noise modelling of underwater noise from the installation of foundations to install a meteorological mast (met mast) also in the Moray Firth has been undertaken in order to determine any potential adverse effect on any marine wildlife in the area. It is likely that the technique that will be used to install the foundations of the met mast will be impact piling. Therefore, the process will be similar to that described above. The parameters likely to be used are a 4.5 m diameter pile with using either a mean blow energy of 720 kJ or a maximum blow energy of 1800 kJ.

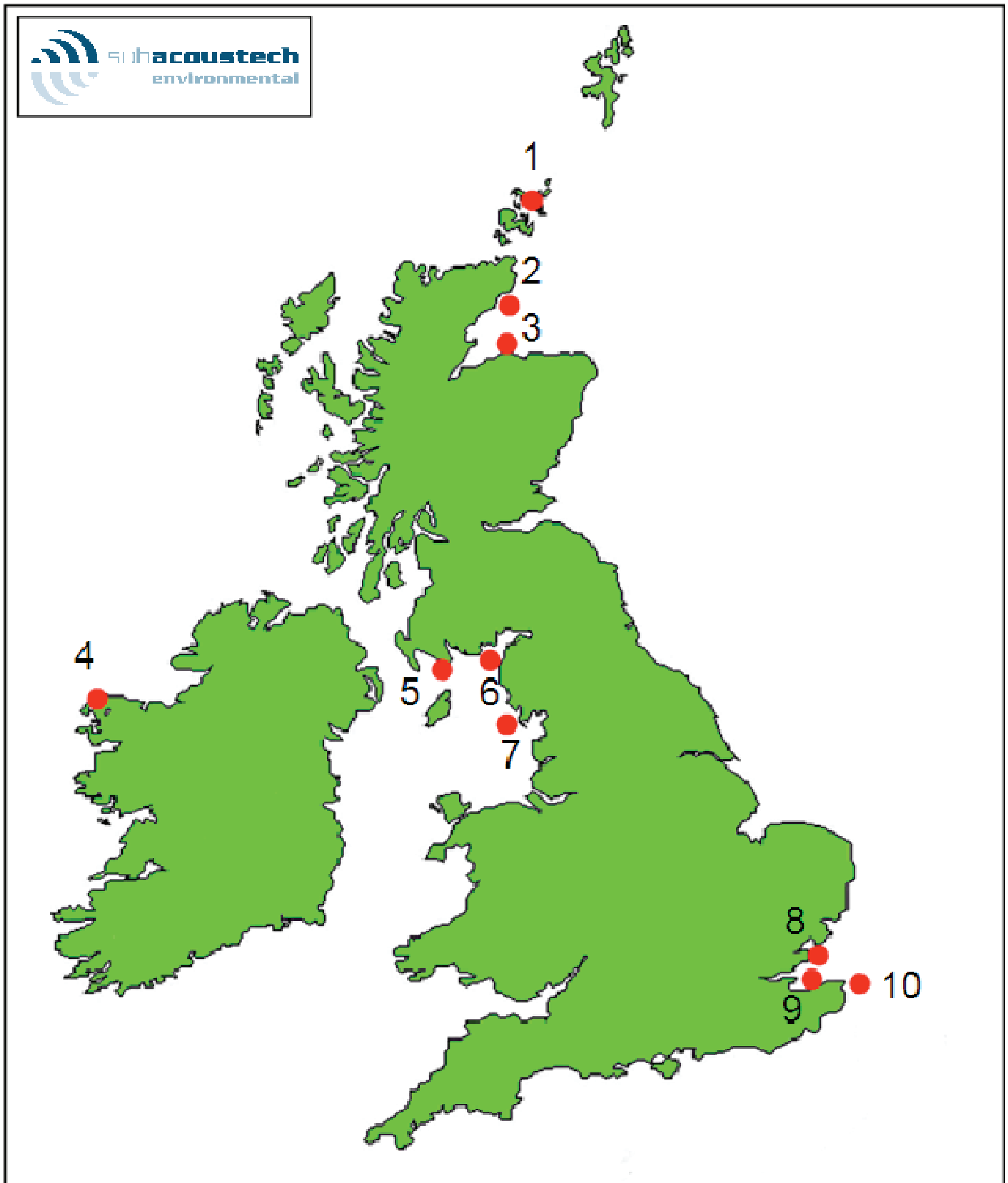
7. Baseline Environment

As a result of military research oceanic ambient noise is relatively well understood. However, the information from these studies may not be directly relevant to coastal waters, where ambient underwater noise can be more variable and significantly louder or quieter than in the deep oceans. In the underwater acoustics field it is commonly considered that shallow water is any water depth less than 200 m. However, it may be argued that a more useful definition of deep water should be related to the wavelength of the sound. Using this approach, assuming a frequency of 50 Hz, water may be considered shallow in depths of about 30 m or less, which corresponds more closely to the sort of water depths in areas where offshore wind farms are built.

A review has been undertaken of currently available information relating to background sea noise around UK coastal waters. Public domain sources of information were searched and some sources relevant to the Moray Firth were found (see, for example, Kongsberg, 2010 and Senior *et al.,* 2008). However, very little information was available and, in the case of the two references cited, the data presented are from measurements taken by Subacoustech Ltd.

Over the past 20 years Subacoustech Ltd has taken several thousand noise measurements of background underwater noise during offshore construction projects in United Kingdom (UK) territorial waters. The set of measurements is unique, in that they all span a broad frequency range from 1 Hz to over 100 kHz, and also have a wide dynamic range in excess of 70 dB. All of the measurements are traceable to International Standards. These measurements have been conducted in a large range of different geographical locations and sea states around UK waters, and may be regarded as giving a realistic representation of background sound in UK territorial waters.

Some of this data have been analysed to yield typical spectra for underwater coastal background sound. Analyses have been made of recordings of underwater noise taken at 10 different sites, all of which are between 1 km and 20 km from the UK coast. These are shown on a map of the UK in Figure A-14.



1 - Orkney Islands, near Eday island
2 - North Moray Firth
3 - South Moray Firth
4 - Broadhaven Bay, Ireland
5 - Mull of Galloway
6 - Solway Firth
7 - West of Morcambe Bay
8 - North Thames Estuary
9 - South Thames Estuary
10 - Southern North Sea

Figure A-14. Map of the UK showing sites where background sound measurements have been collected and analysed.

All of these underwater noise measurements were made using a Bruel & Kjaer Type 8106 hydrophone, connected to a proprietary Subacoustech hydrophone power supply/amplifier. This amplifier provided power to, as well as conditioning and amplifying the acoustic signal from, the hydrophone, and also could pre-emphasise recordings where this was required in order to achieve an adequate dynamic range. The measurements presented in this study are based on analysis over the frequency range from 1 Hz to 120 kHz. All of the measurements presented were taken in the absence of precipitation, with no other noticeable sources of underwater noise, such as nearby shipping, and at either Sea State 1 or 3, with the hydrophone at half water depth (typically 10 m to 15 m below the surface).

Figures A-15 and A-16 below present a summary of the Power Spectral Density levels of underwater noise measured at the various sites, with the data from the Moray Firth highlighted and an average of all the data also shown. Figure A-15 presents data for measurements during Sea State 1 conditions and Figure A-16 presents data for slightly rougher Sea State 3 conditions.

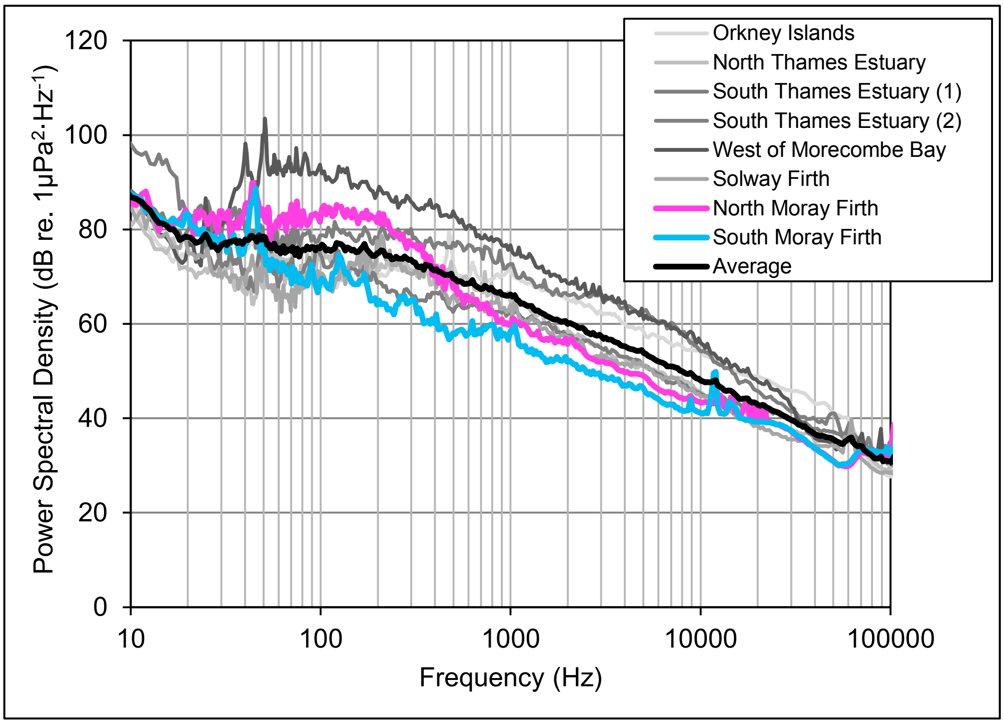


Figure A-15. Summary of Power Spectral Density levels of background underwater noise at Sea State 1 at sites around the UK coast

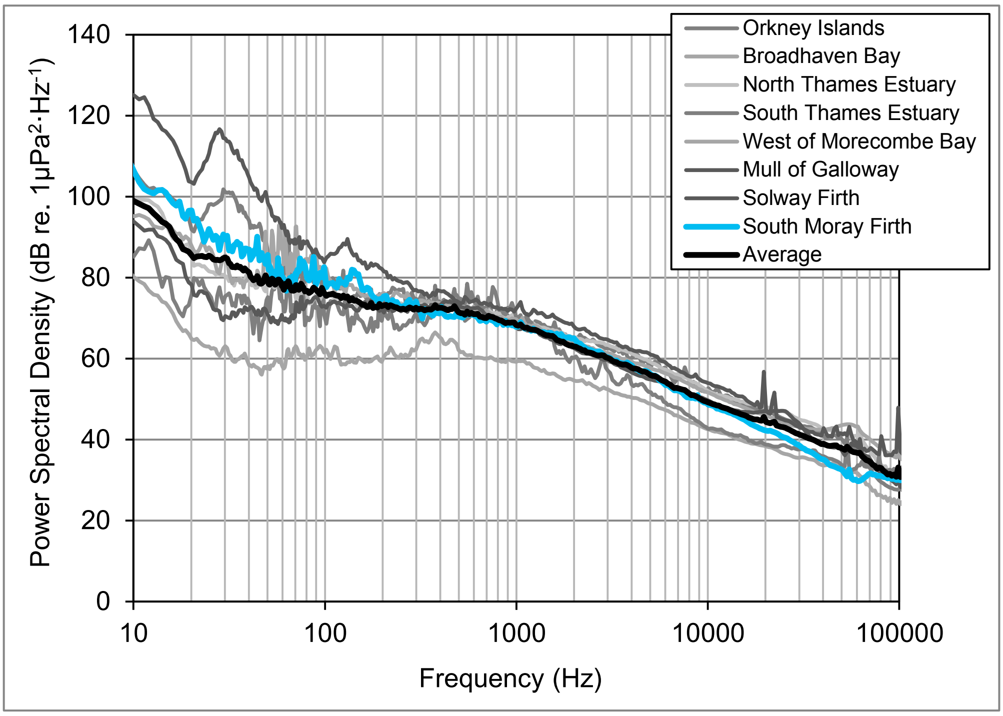


Figure A-16. Summary of Power Spectral Density levels of background underwater noise at Sea State 3 at sites around the UK coast

It can be seen from these figures that the typical levels of background underwater noise in the Moray Firth region are very close to the overall average for the UK coast. In order to provide an estimate of the typical levels of background noise levels that may occur in the Moray Firth taking into account natural variation, it is therefore appropriate to use the averages, in terms of both weighted and unweighted metrics, presented in Table A-8 and A-9 below.

Table A-8. Summary of average background levels of noise around the UK coast and in the Moray Firth at Sea State 1

	Unweighted dB re. 1µPa	Bass dB_{ht}- (*Micropterus salmoides*)	Cod dB_{ht}(*Gadus morhua*)	Dab dB_{ht}(*Limanda limanda*)	Herring dB_{ht}- (*Clupea harengus*)	Salmon dB_{ht}(*Salmo salar*)	Bottlenose Dolphin dB_{ht}(*Tursiops*)	Harbour Porpoise dB_{ht}(*Phocoen phocoena*)	Harbour Seal dB_{ht}- (*Phoca vitulina*)	Killer Whale dB_{ht}- (*Orcinus orca*)
Overall Average Background Noise Levels – Sea State 1										
Max	126	15	39	26	42	17	66	74	43	66
Min	92	0	1	0	9	0	36	44	21	37
Mean	111	5	23	10	28	5	44	54	31	47
South Moray Firth Averages – Sea State 1										
Max	115	5	30	20	36	8	40	53	27	44
Min	103	1.5	23	7	27	2	38	53	24	41
Mean	106	3.5	26	11	29	5	39	53	25	42
North Moray Firth Averages – Sea State 1										
Max	111	3	27	17	33	6	42	54	31	47
Min	92	0	5	0	10	0	39	53	21	41
Mean	99	0	15	2	20	0	40	53	24	42

Table A-9. Summary of average background levels of noise around the UK coast and in the Moray Firth at Sea State 3

	Unweighted dB re. 1µPa	Bass dB_{ht}- (*Micropterus salmoides*)	Cod dB_{ht}(*Gadus morhua*)	Dab dB_{ht}(*Limanda limanda*)	Herring dB_{ht}(*Clupea harengus*)	Salmon dB_{ht}(*Salmo salar*)	Bottlenose Dolphin dB_{ht}(*Tursiops*)	Harbour Porpoise dB_{ht}(*Phocoen phocoena*)	Harbour Seal dB_{ht}- (*Phoca vitulina*)	Killer Whale dB_{ht}- (*Orcinus orca*)
Overall Average Background Noise Levels – Sea State 3										
Max	132	15	42	31	47	19	50	60	38	53
Min	94	0	3	0	11	0	30	42	7	29
Mean	112	4	22	11	28	5	41	52	27	43
South Moray Firth Averages – Sea State 3										
Max	120	15	42	30	45	19	44	54	38	50
Min	101	0	15	0	21	0	40	53	29	46
Mean	109	4	26	11	30	4	42	53	32	47

8. Predicted impacts – Phase 1: Rank-ordering of Noise Sources

8.1 Introduction

The SPEAR model has been used to make prediction runs for a number of representative scenarios for the various activities related to offshore wind farms. A summary of the various considerations relating to construction activity is given in the table below.

8.2 Summary of noise scenarios for SPEAR modelling

Table A-10 below provides a summary of the various parameters that have been input into the SPEAR model to account for the various scenarios presented above. Detailed information relating to the exact amount of time that activities will be carried out, for example duration of time a vessel will be on site or how long dredging may take, is not available at this stage. It has therefore been necessary to take a very worst case estimation in terms of noise generation.

Table A-10. Summary of parameters taken into account in the SPEAR modelling

Activity	Parameters used for SPEAR modelling
Impact piling	• 4.4 hours driving per pile • 2,500 mm (WTG), 3,000 mm (OSPs) and 4,500mm met mast) diameter piles • 2 piles installed per day
Vessel noise	• DP jack up barges for piling, substructure and WTG installation • Other large and medium sized vessels will be on site to carry out other construction jobs, diving support and anchor handling. • Other small vessels for crew transport and survey work on site
Trenching	• Required during the export cable installation
Cable laying	• Required during the export cable installation
Drilling	• Necessary in case impact piling refuses
Rock placing	• Required on site for installation of the export cable • Also required if Gravity Base structures are to be used
Dredging	• Trailer Suction Hopper Dredger required on site for export cable installation
Operational noise	• Assume 24 hours a day for operational wind turbines

8.3 Results of the Phase 1, SPEAR, modelling

The SPEAR programme produced as output an 'index figure' which represents the area of ocean which is rendered unusable by a species as a result of a particular activity. The results shown below show 90 dB_{ht} impact ranges which illustrate the differences between all the species for a single activity (pile driving a 2.5 m diameter pile) and the differences between different noise source for a single species of interest.

It is clear from the figures that impact piling is the dominant noise source and hence the activity that will have the greatest impact. This activity has therefore been studied in more detail using the INSPIRE model; the results from that are presented in the following Section.

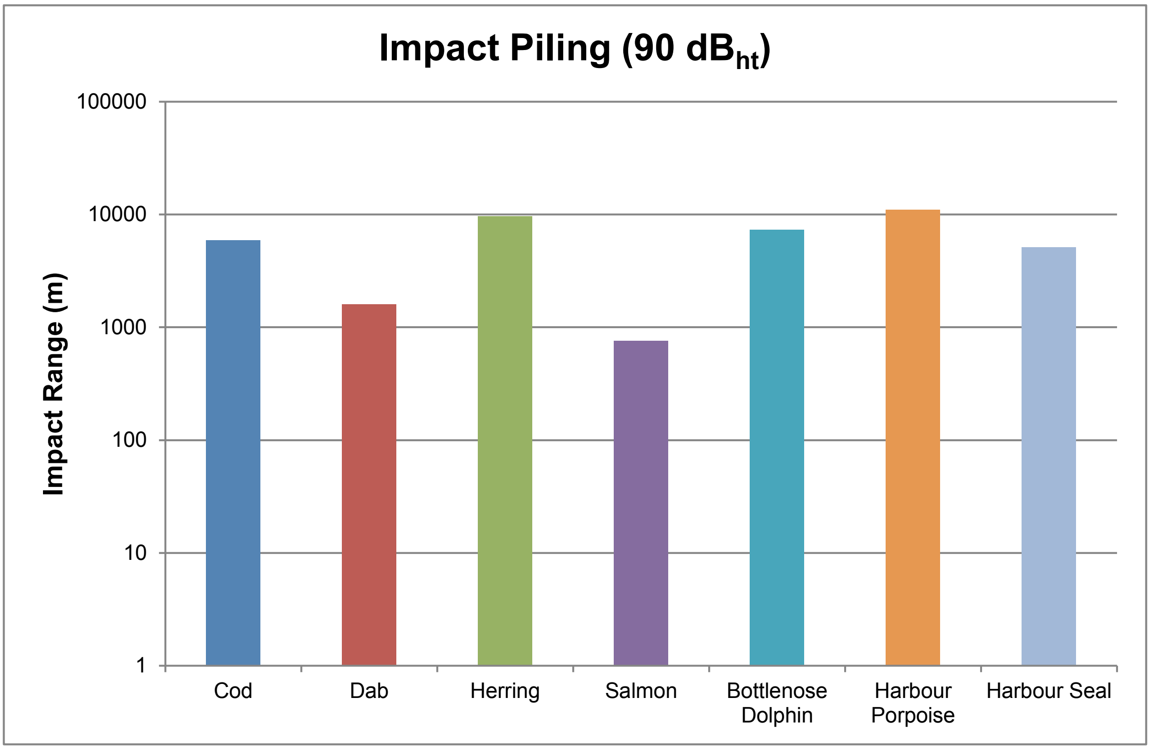


Figure A-17. Spatial extent of impact of impact piling a 2.5m diameter pile, on various species of importance

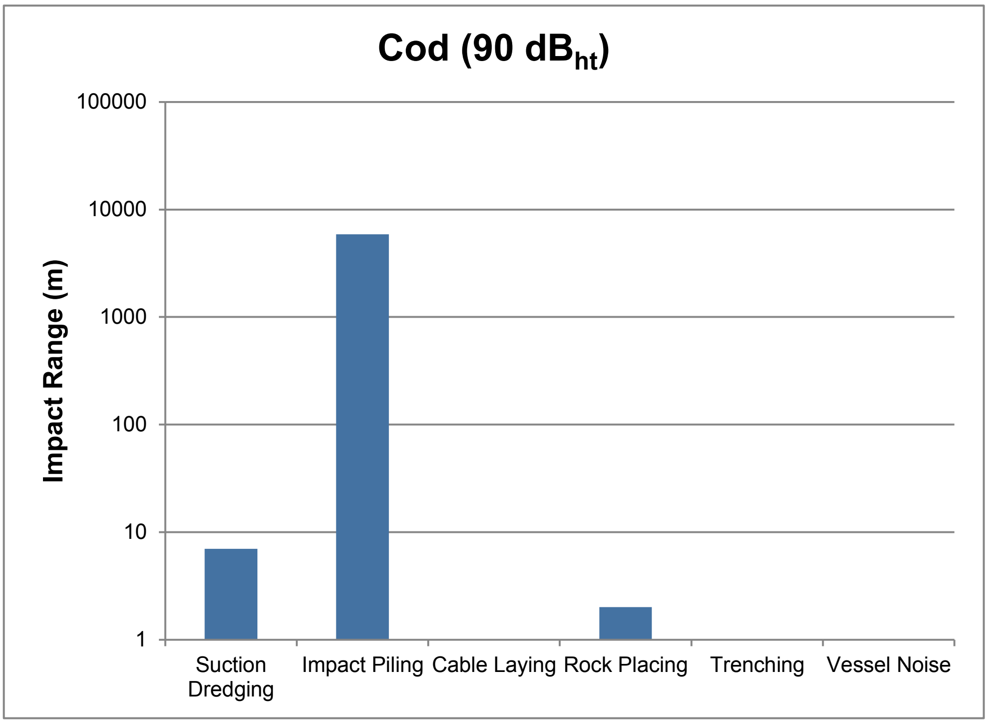


Figure A-18a. Spatial extent of impact of various activities, on cod

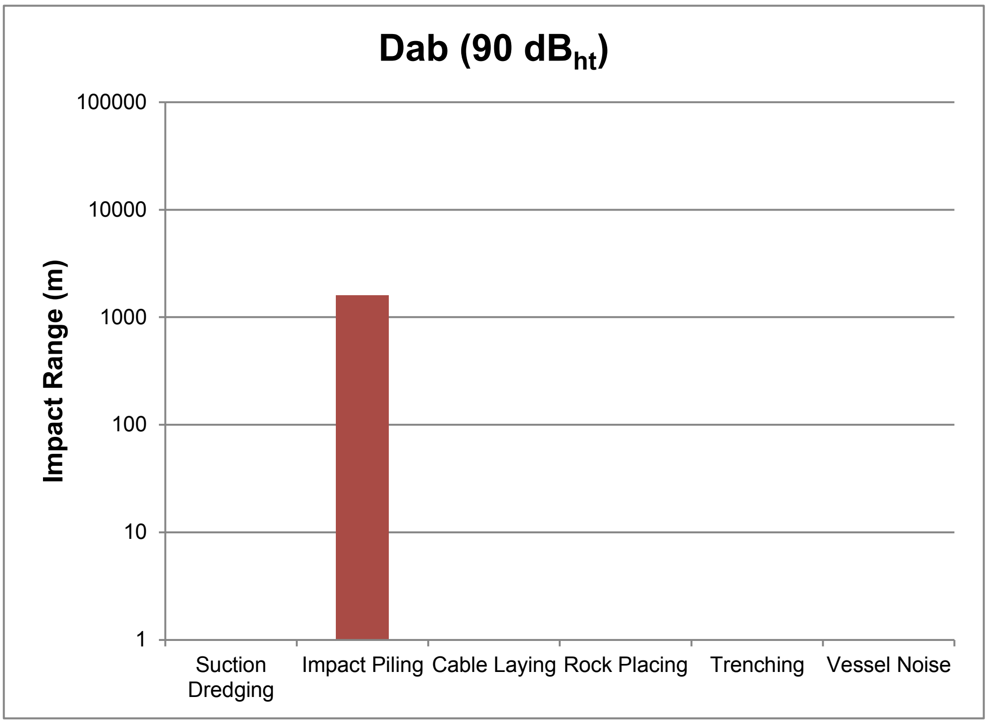


Figure A-18b. Spatial extent of impact of various activities, on dab

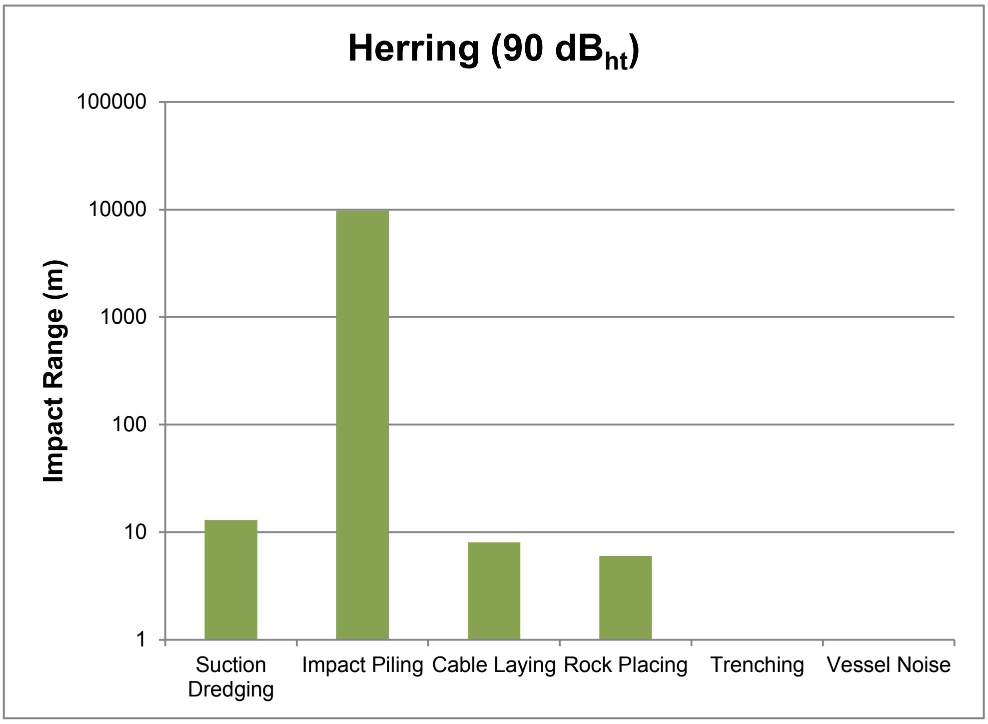


Figure A-18c. Spatial extent of impact of various activities, on herring

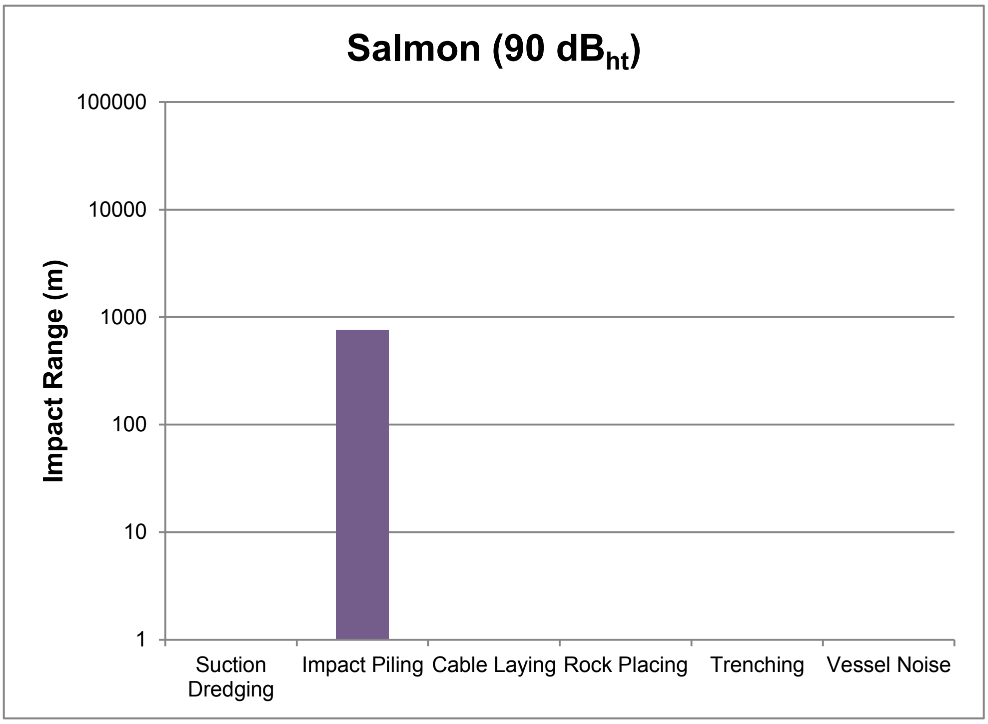


Figure A-18d. Spatial extent of impact of various activities, on salmon

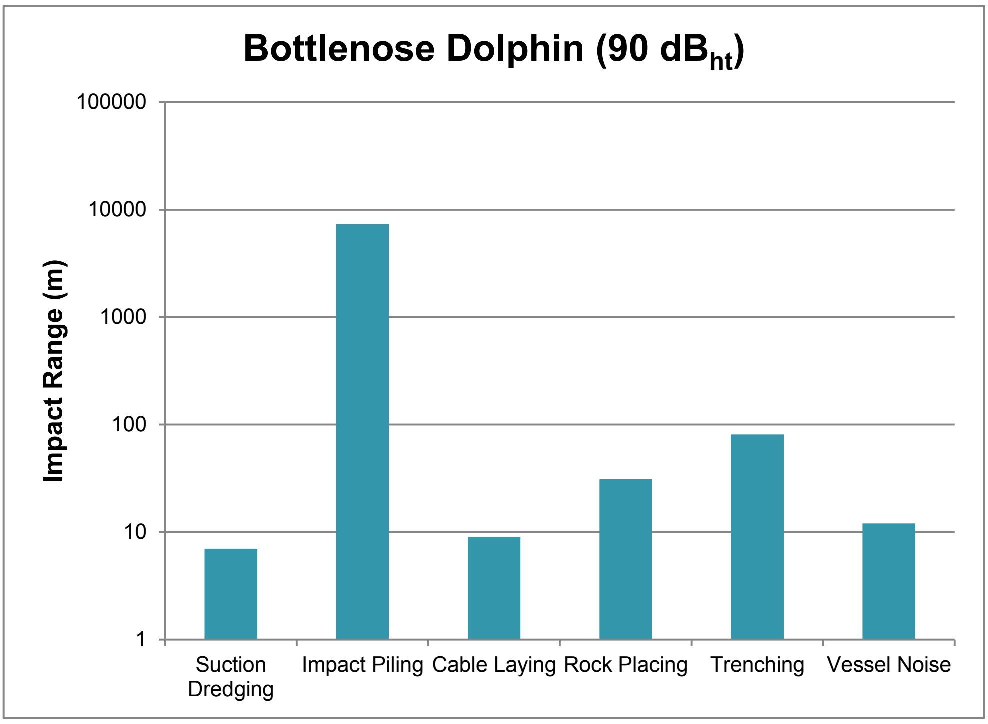


Figure A-18e. Spatial extent of impact of various activities, on bottlenose dolphin

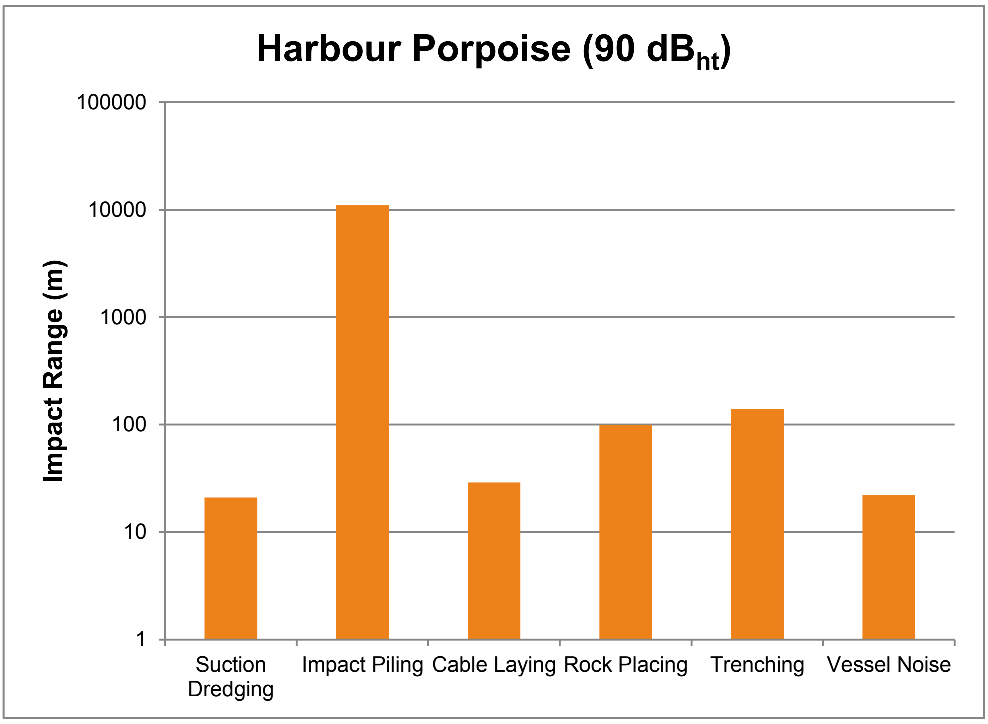


Figure A-18f. Spatial extent of impact of various activities, on harbour porpoise

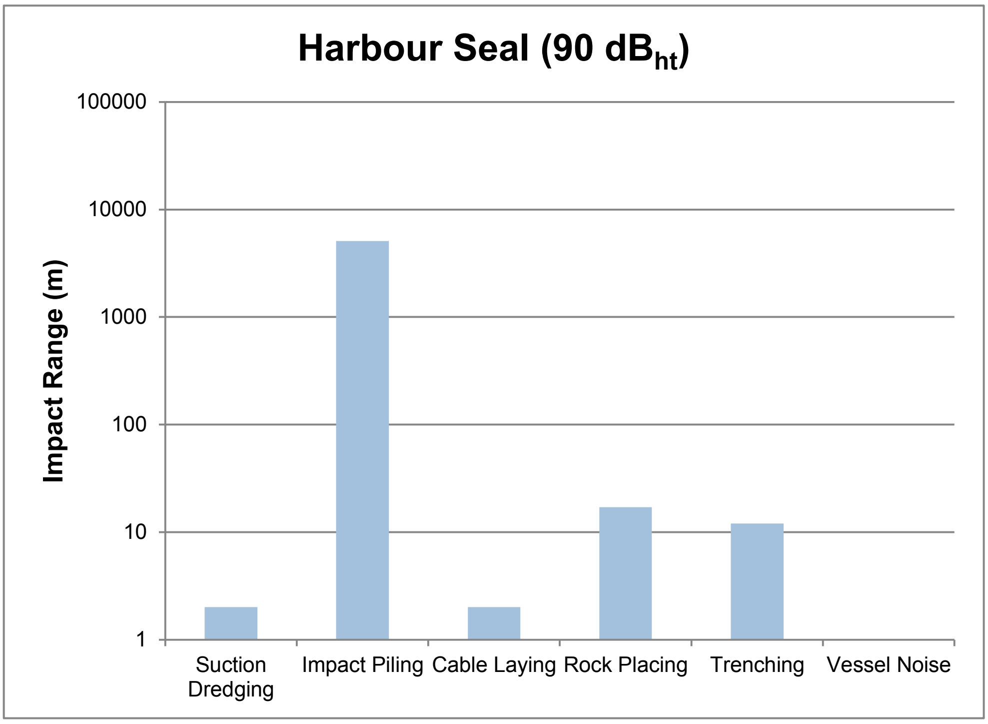


Figure A-18g. Spatial extent of impact of various activities, on harbour seal

9. Predicted impacts – Phase 2: Impact Piling

9.1 Piles being driven at a single location

9.1.1 Details of cases modelled

The INSPIRE model has been used to make predictions for two broad categories of conditions.

- Predictions of ranges, *from a single pile*, at which specified noise criteria are met. One criterion is the dB_{ht}(*Species*) value. The second is the M-weighted SEL value, for low-, mid- and high-frequency cetaceans, and pinnipeds in water. For the SEL calculations there are two cases: the 'stationary animal' case, where the programme calculates the distance at which the criterion value is reached, and the 'fleeing animal' case, where the programme calculates the distance from the pile at which the animal must start to flee such that, at the cessation of the piling operation, its noise dose will just reach but not exceed the criterion value.
- Predictions of ranges, *for a number of piles being driven simultaneously*, to allow an estimation of the envelope of the area within which specified criteria are exceeded. Again, the criteria are the dB_{ht}(*Species*) value and the four M-weighted SEL values, and the latter includes stationary and fleeing animal cases as described above.

The estimated ranges for the unweighted levels of 240 and 220 dB re. 1µPa, at which lethality and physical injury respectively could occur, due to piling a 2.5 m pile using the maximum blow energy of 1200 kJ, are given in Table A-11. It should be noted that impact ranges shown in Table A-11 for which these levels could potentially occur are extremely small and mitigation measures to be used, for example soft start and ramp up of blow energy, should ensure that no fatality or physical injury will occur.

Table A-11. Ranges to which lethality and physical injury could occur.

Unweighted Level	Range (m)
240 dB re. 1µPa (Lethality)	2
220 dB re. 1µPa (Physical injury)	38

Figure A-19 is a sketch map of the Moray Firth area where the three proposed wind farms (MORL) and BOWL are located. Modelling has been undertaken at BOWL to consider the potential cumulative effects associated with concurrent piling at both of these sites. It shows the boundaries of the Moray Firth Windfarm site, and the locations of the piles for which modelling has been done. A summary of the cases considered is given in Tables A-12 to A-16.

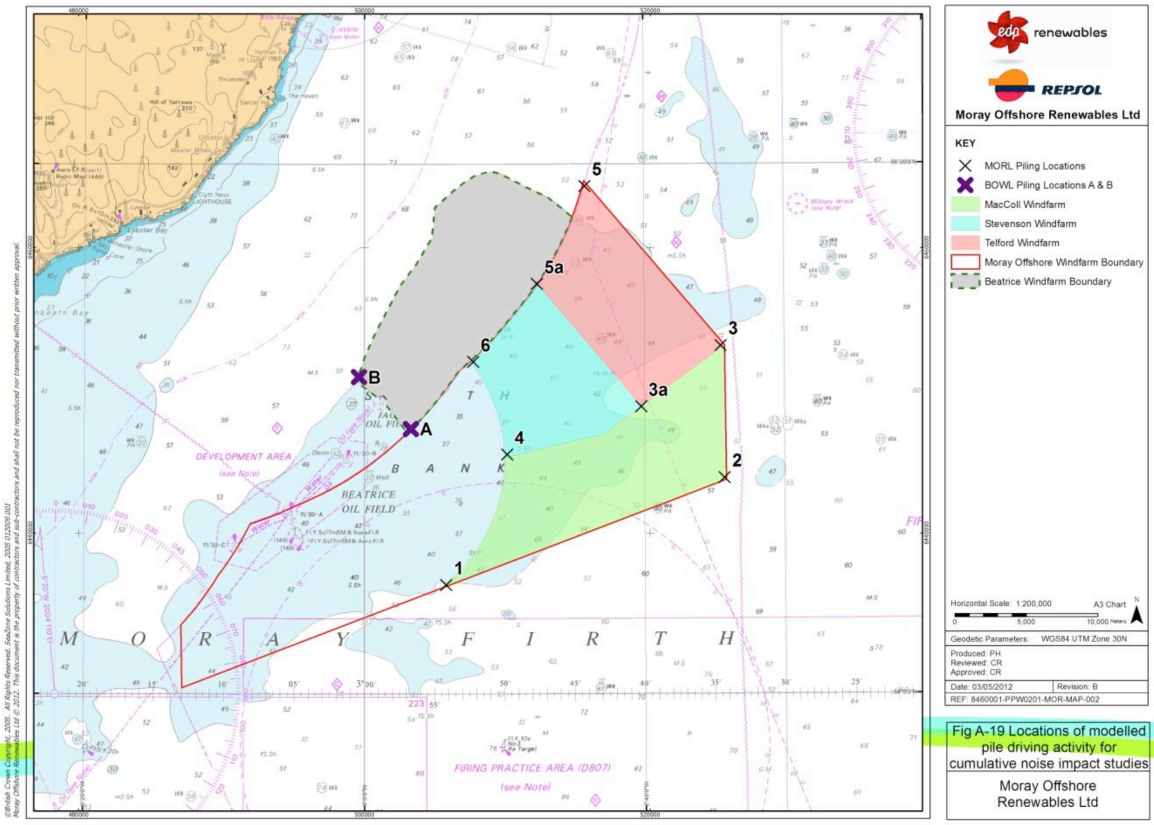


Figure A-19. Sketch map, showing locations of the piles whose driving has been modelled.

For the four fish and four marine mammal species considered, calculations were made for a single pile being driven at location 1. For the low-, mid- and high-frequency cetacean and pinniped in water cases considered, calculations were made for two piles being driven sequentially at this location, and in each case the worst case blow energies, upper bound soils in Province 3, have been used, a summary of the cases is given in Table A-12.

Table A-12. Summary of conditions modelled for piles driven at a single location

Pile diameter (m)	Number of piles / location	Hammer capacity (kJ)	Species	Results shown	Figure
2.5	Location 1	1200	Cod	90 dB_{ht} and 75 dB_{ht} contours	A-20
2.5	Location 1	1200	Herring	90 dB_{ht} and 75 dB_{ht} contours	A-21
2.5	Location 1	1200	Plaice	90 dB_{ht} and 75 dB_{ht} contours	A-22
2.5	Location 1	1200	Salmon	90 dB_{ht} and 75 dB_{ht} contours	A-23
2.5	Location 1	1200	Bottlenose dolphin	90 dB_{ht} and 75 dB_{ht} contours	A-24
2.5	Location 1	1200	Harbour porpoise	90 dB_{ht} and 75 dB_{ht} contours	A-25
2.5	Location 1	1200	Harbour seal	90 dB_{ht} and 75 dB_{ht} contours	A-26
2.5	Location 1	1200	Minke whale	90 dB_{ht} and 75 dB_{ht} contours	A-27

Pile diameter (m)	Number of piles / location	Hammer capacity (kJ)	Species	Results shown	Figure
2.5	2 piles at location 1	1200	Low frequency cetacean	Contours between 200 and 186 dB re 1 μPa².s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-28
2.5	2 piles sequentially at location 1	1200	Low frequency cetacean	Contours between 200 and 186 dB re 1 μPa².s (M_{lf}) in 2 dB increments for a stationary animal	A-29
2.5	piles sequentially at location 1	1200	Mid frequency cetacean	Contours between 200 and 186 dB re 1 μPa².s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-30
2.5	piles sequentially at location 1	1200	Mid frequency cetacean	Contours between 200 and 186 dB re 1 μPa².s (M_{lf}) in 2 dB increments for a stationary animal	A-31
2.5	piles sequentially at location 1	1200	High frequency cetacean	Contours between 200 and 186 dB re 1 μPa².s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-32
2.5	piles sequentially at location 1	1200	High frequency cetacean	Contours between 200 and 186 dB re 1 μPa².s (M_{lf}) in 2 dB increments for a stationary animal	A-33
2.5	piles sequentially at location 1	1200	Pinniped (in water)	Contours between 200 and 186 dB re 1 μPa².s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-34
2.5	piles sequentially at location 1	1200	Pinniped (in water)	Contours between 200 and 186 dB re 1 μPa².s (M_{lf}) in 2 dB increments for a stationary animal	A-35
2.5	Location 1a	1200	Cod	90 dB_{ht} and 75 dB_{ht} contours	A-36
2.5	Location 1a	1200	Herring	90 dB_{ht} and 75 dB_{ht} contours	A-37
2.5	Location 1a	1200	Plaice	90 dB_{ht} and 75 dB_{ht} contours	A-38
2.5	Location 1a	1200	Salmon	90 dB_{ht} and 75 dB_{ht} contours	A-39
2.5	Location 1a	1200	Bottlenose dolphin	90 dB_{ht} and 75 dB_{ht} contours	A-40
2.5	Location 1a	1200	Harbour porpoise	90 dB_{ht} and 75 dB_{ht} contours	A-41
2.5	Location 1a	1200	Harbour seal	90 dB_{ht} and 75 dB_{ht} contours	A-42
2.5	Location 1a	1200	Minke whale	90 dB_{ht} and 75 dB_{ht} contours	A-43
2.5	2 piles sequentially at location 1a	1200	Low frequency cetacean	Contours between 200 and 186 dB re 1 μPa².s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-44
2.5	2 piles sequentially at location 1a	1200	Low frequency cetacean	Contours between 200 and 186 dB re 1 μPa².s (M_{lf}) in 2 dB increments for a stationary animal	A-45
2.5	2 piles sequentially at location 1a	1200	Mid frequency cetacean	Contours between 200 and 186 dB re 1 μPa².s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-46

Pile diameter (m)	Number of piles / location	Hammer capacity (kJ)	Species	Results shown	Figure
2.5	2 piles sequentially at location 1a	1200	Mid frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-47
2.5	2 piles sequentially at location 1a	1200	High frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-48
2.5	2 piles sequentially at location 1a	1200	High frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-49
2.5	2 piles sequentially at location 1a	1200	Pinniped (in water)	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-50
2.5	2 piles sequentially at location 1a	1200	Pinniped (in water)	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-51
2.5	Location 4	1200	Cod	90 dB_{ht} and 75 dB_{ht} contours	A-52
2.5	Location 4	1200	Herring	90 dB_{ht} and 75 dB_{ht} contours	A-53
2.5	Location 4	1200	Plaice	90 dB_{ht} and 75 dB_{ht} contours	A-54
2.5	Location 4	1200	Salmon	90 dB_{ht} and 75 dB_{ht} contours	A-55
2.5	Location 4	1200	Bottlenose dolphin	90 dB_{ht} and 75 dB_{ht} contours	A-56
2.5	Location 4	1200	Harbour porpoise	90 dB_{ht} and 75 dB_{ht} contours	A-57
2.5	Location 4	1200	Harbour seal	90 dB_{ht} and 75 dB_{ht} contours	A-58
2.5	Location 4	1200	Minke whale	90 dB_{ht} and 75 dB_{ht} contours	A-59
2.5	2 piles sequentially at location 4	1200	Low frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-60
2.5	2 piles sequentially at location 4	1200	Low frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-61
2.5	2 piles sequentially at location 4	1200	Mid frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-62
2.5	2 piles sequentially at location 4	1200	Mid frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-63
2.5	2 piles sequentially at location 4	1200	High frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-64
2.5	2 piles sequentially at location 4	1200	High frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-65

Pile diameter (m)	Number of piles / location	Hammer capacity (kJ)	Species	Results shown	Figure
2.5	2 piles sequentially at location 4	1200	Pinniped (in water)	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-66
2.5	2 piles sequentially at location 4	1200	Pinniped (in water)	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-67
2.5	Location 3a	1200	Cod	90 dB_{ht} and 75 dB_{ht} contours	A-68
2.5	Location 3a	1200	Herring	90 dB_{ht} and 75 dB_{ht} contours	A-69
2.5	Location 3a	1200	Plaice	90 dB_{ht} and 75 dB_{ht} contours	A-70
2.5	Location 3a	1200	Salmon	90 dB_{ht} and 75 dB_{ht} contours	A-71
2.5	Location 3a	1200	Bottlenose dolphin	90 dB_{ht} and 75 dB_{ht} contours	A-72
2.5	Location 3a	1200	Harbour porpoise	90 dB_{ht} and 75 dB_{ht} contours	A-73
2.5	Location 3a	1200	Harbour seal	90 dB_{ht} and 75 dB_{ht} contours	A-74
2.5	Location 3a	1200	Minke whale	90 dB_{ht} and 75 dB_{ht} contours	A-75
2.5	2 piles sequentially at location 3a	1200	Low frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-76
2.5	2 piles sequentially at location 3a	1200	Low frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-77
2.5	2 piles sequentially at location 3a	1200	Mid frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-78
2.5	2 piles sequentially at location 3a	1200	Mid frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-79
2.5	2 piles sequentially at location 3a	1200	High frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-80
2.5	2 piles sequentially at location 3a	1200	High frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-81
2.5	2 piles sequentially at location 3a	1200	Pinniped (in water)	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-82
2.5	2 piles sequentially at location 3a	1200	Pinniped (in water)	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-83
3	Location 2	1800	Cod	90 dB_{ht} and 75 dB_{ht} contours	A-84
3	Location 2	1800	Herring	90 dB_{ht} and 75 dB_{ht} contours	A-85
3	Location 2	1800	Plaice	90 dB_{ht} and 75 dB_{ht} contours	A-86
3	Location 2	1800	Salmon	90 dB_{ht} and 75 dB_{ht} contours	A-87

Pile diameter (m)	Number of piles / location	Hammer capacity (kJ)	Species	Results shown	Figure
3	Location 2	1800	Bottlenose dolphin	90 dB_{ht} and 75 dB_{ht} contours	A-88
3	Location 2	1800	Harbour porpoise	90 dB_{ht} and 75 dB_{ht} contours	A-89
3	Location 2	1800	Harbour seal	90 dB_{ht} and 75 dB_{ht} contours	A-90
3	Location 2	1800	Minke whale	90 dB_{ht} and 75 dB_{ht} contours	A-91
3	2 piles sequentially at location 2	1800	Low frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-92
3	2 piles sequentially at location 2	1800	Low frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for a stationary animal	A-93
3	2 piles sequentially at location 2	1800	Mid frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-94
3	2 piles sequentially at location 2	1800	Mid frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for a stationary animal	A-95
3	2 piles sequentially at location 2	1800	High frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-96
3	2 piles sequentially at location 2	1800	High frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for a stationary animal	A-97
3	2 piles sequentially at location 2	1800	Pinniped (in water)	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-98
3	2 piles sequentially at location 2	1800	Pinniped (in water)	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for a stationary animal	A-99

The pile driving is envisaged to use a 'soft start' procedure, in which the strike energy is increased in steps as the pile is driven. Table A-13 sets out the assumptions which have been made in the modelling to account for this process.

Table A-13. Details of 'soft start' procedure assumed for the piling

2.5m piles at MORL (three proposed wind farms)	
Total hammer capacity	**1200 kJ**
'Ramp up' steps	260 strikes @ 170 kJ
	2400 strikes @ 450 kJ
	1000 strikes @ 890 kJ
	7000 strikes @ 1080 kJ
3m piles at MORL (for OfTI study)	
Total hammer capacity	**1800 kJ**

'Ramp up' steps	222 strikes @ 280 kJ 2200 strikes @ 750 kJ 1900 strikes @ 1600 kJ 3700 strikes @ 1800 kJ
2.4m piles at BOWL	
Total hammer capacity	**2300 kJ (2.4m pile) BOWL**
'Ramp up' steps	1200 strikes @ 460 kJ 3700 strikes @ 920 kJ 3700 strikes @ 1380 kJ 3700 strikes @ 1840 kJ 3700 strikes @ 2300 kJ

9.1.2 Results of INSPIRE modelling for piles being driven at 1 location at MORL

The results of the calculations for the single pile cases are presented in Figures A-20 to A-35 below. Location 1 was selected as the location closest to the most ecologically sensitive areas to the south-west of the site.

Figures A-36 to A-51 show contours for piling at position 1a, in the MacColl site, Figures A-52 to A-67 show contours for piling at position 4, in the Stevenson site, Figures A-68 to A-83 show contours for piling at position 3a in the Telford site, and Figures A-84 to A-99 show contours for the piling at position 2 using a 3 m pile for the OfTI study.

9.1.2.1 Results for 2 piles being driven sequentially at 1 location on MORL

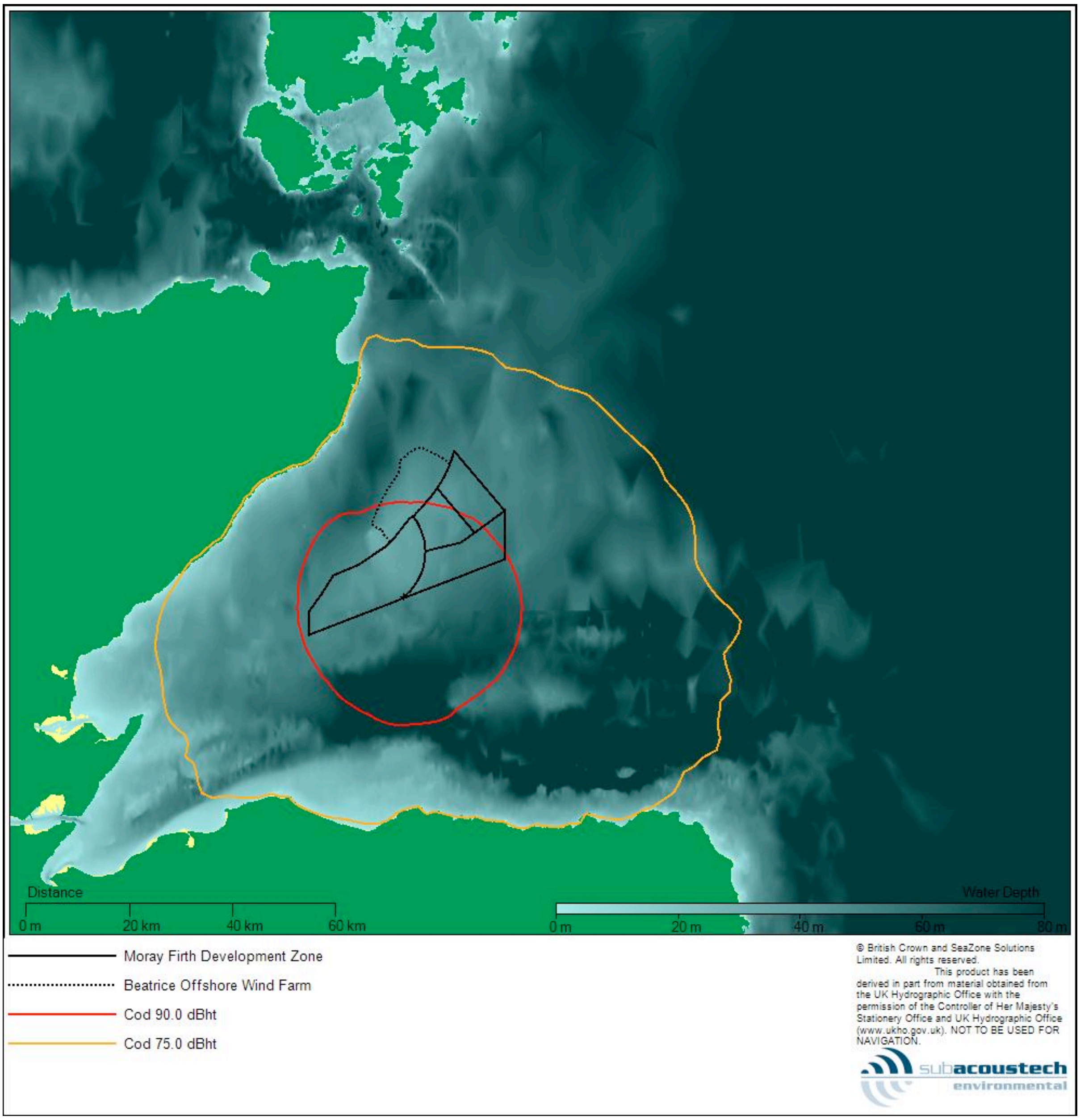


Figure A-20. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for cod; 2.5 m diameter pile being driven at location 1.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1
Pile driving energy (kJ)	1200
Species	Cod

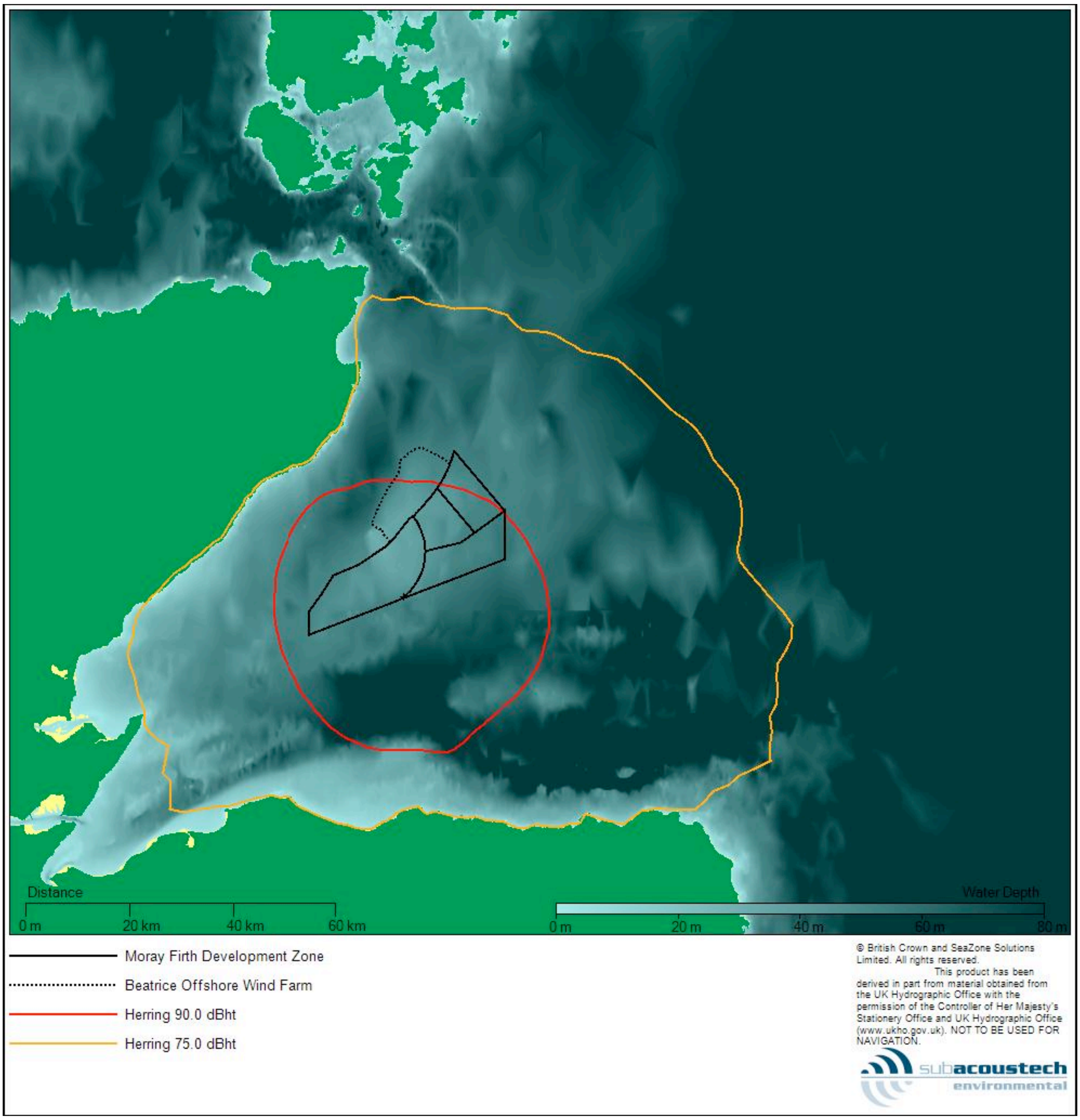


Figure A-21. 90 dB_{ht} and 75 dB_{ht} contours for herring; 2.5 m diameter pile being driven at location 1.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1
Pile driving energy (kJ)	1200
Species	Herring

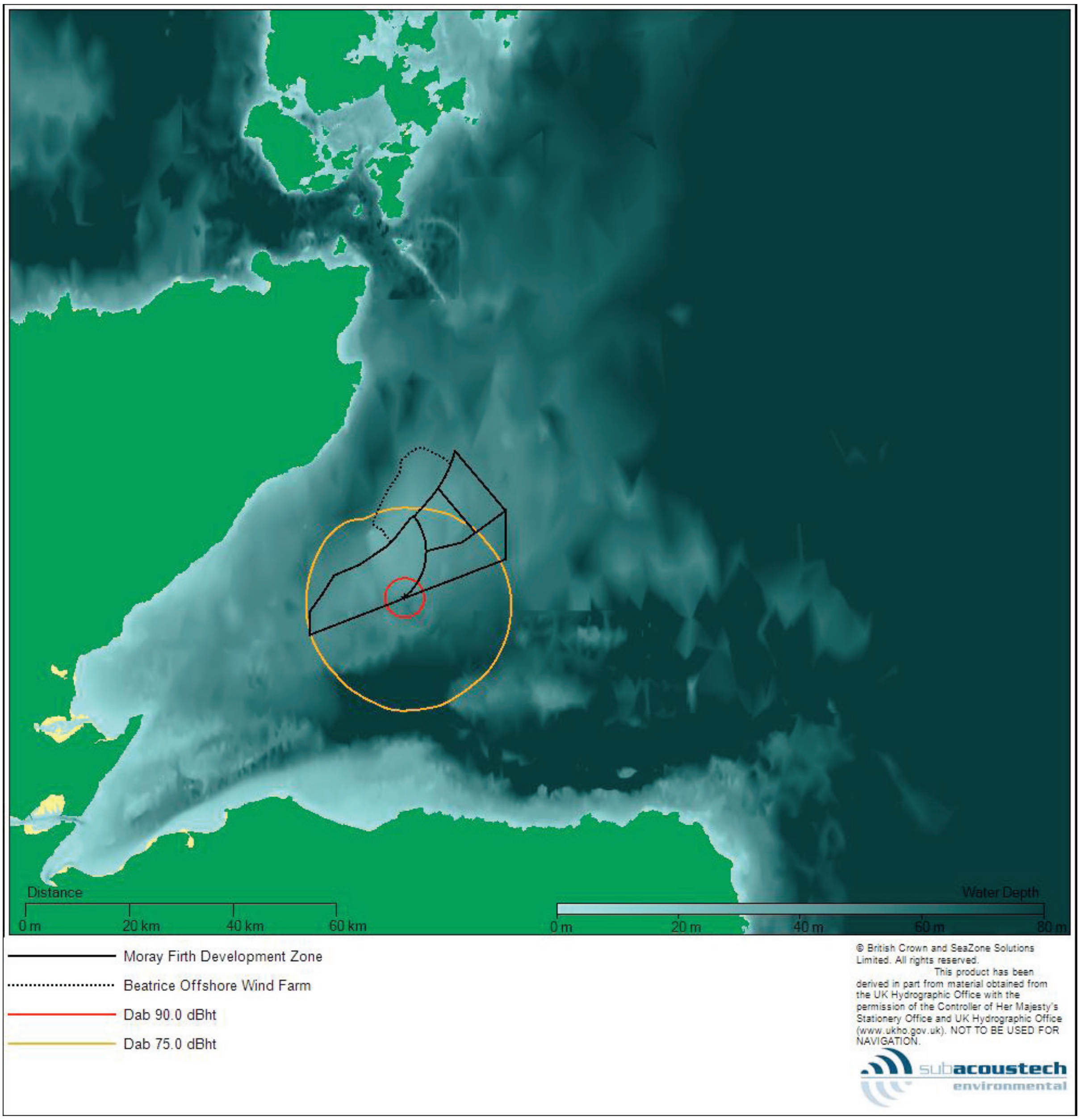


Figure A-22. 90 dB_{ht} and 75 dB_{ht} contours for plaice (dab used as surrogate); 2.5 m diameter pile being driven at location 1.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1
Pile driving energy (kJ)	1200
Species	Plaice

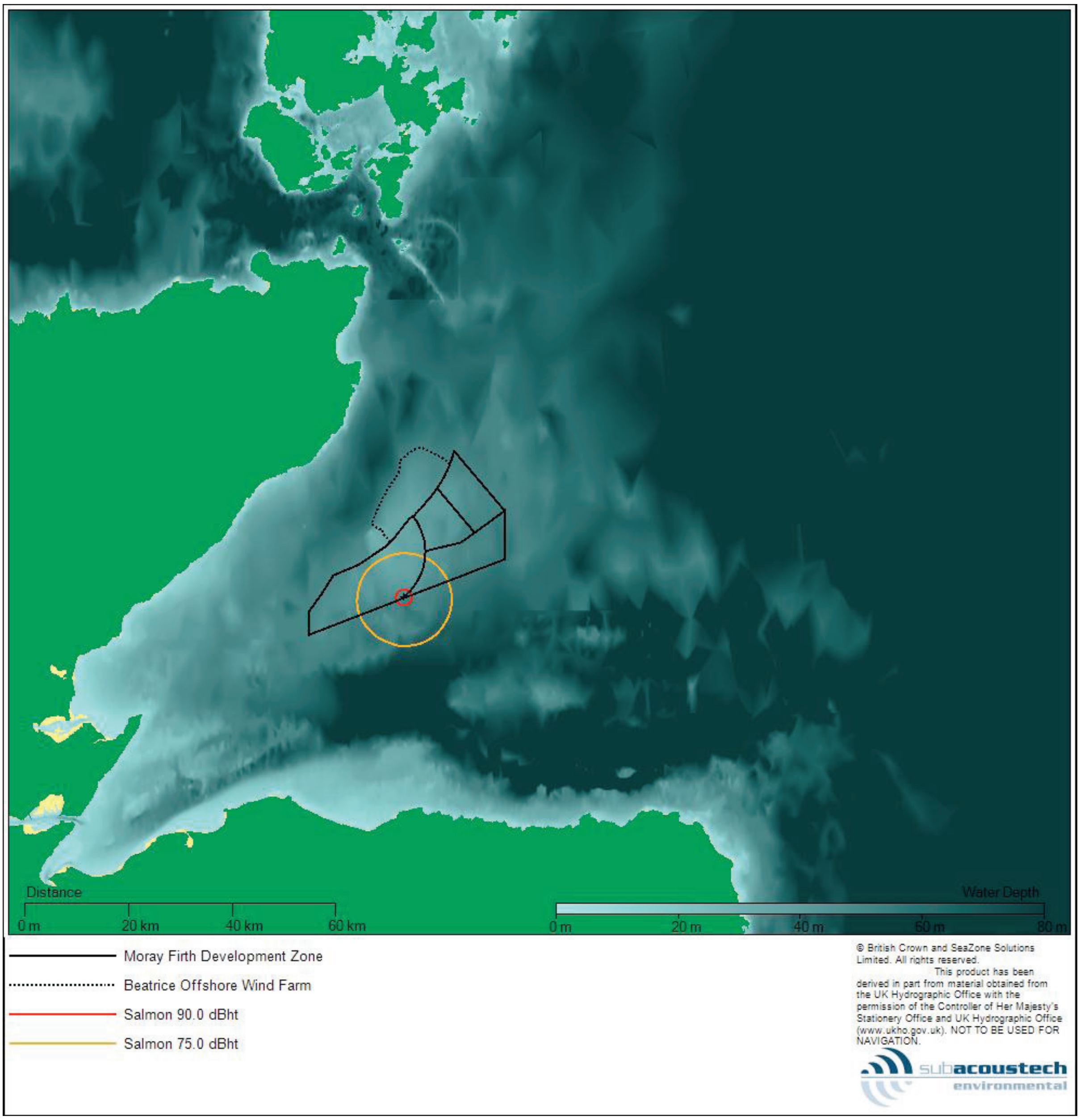


Figure A-23. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for salmon; 2.5 m diameter pile being driven at location 1.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1
Pile driving energy (kJ)	1200
Species	Salmon

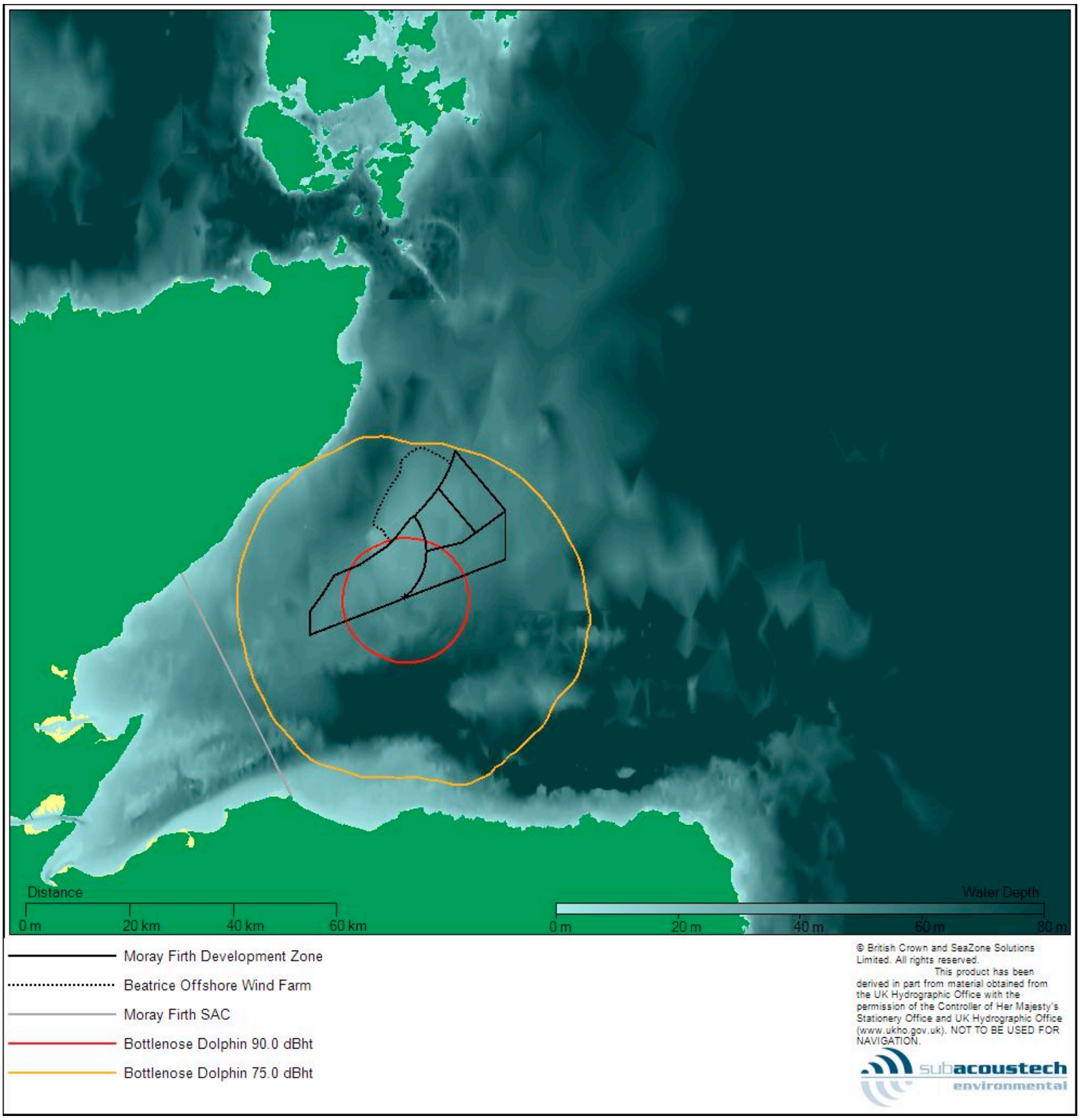


Figure A-24. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for bottlenose dolphin; 2.5 m diameter pile being driven at location 1.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1
Pile driving energy (kJ)	1200
Species	Bottlenose Dolphin

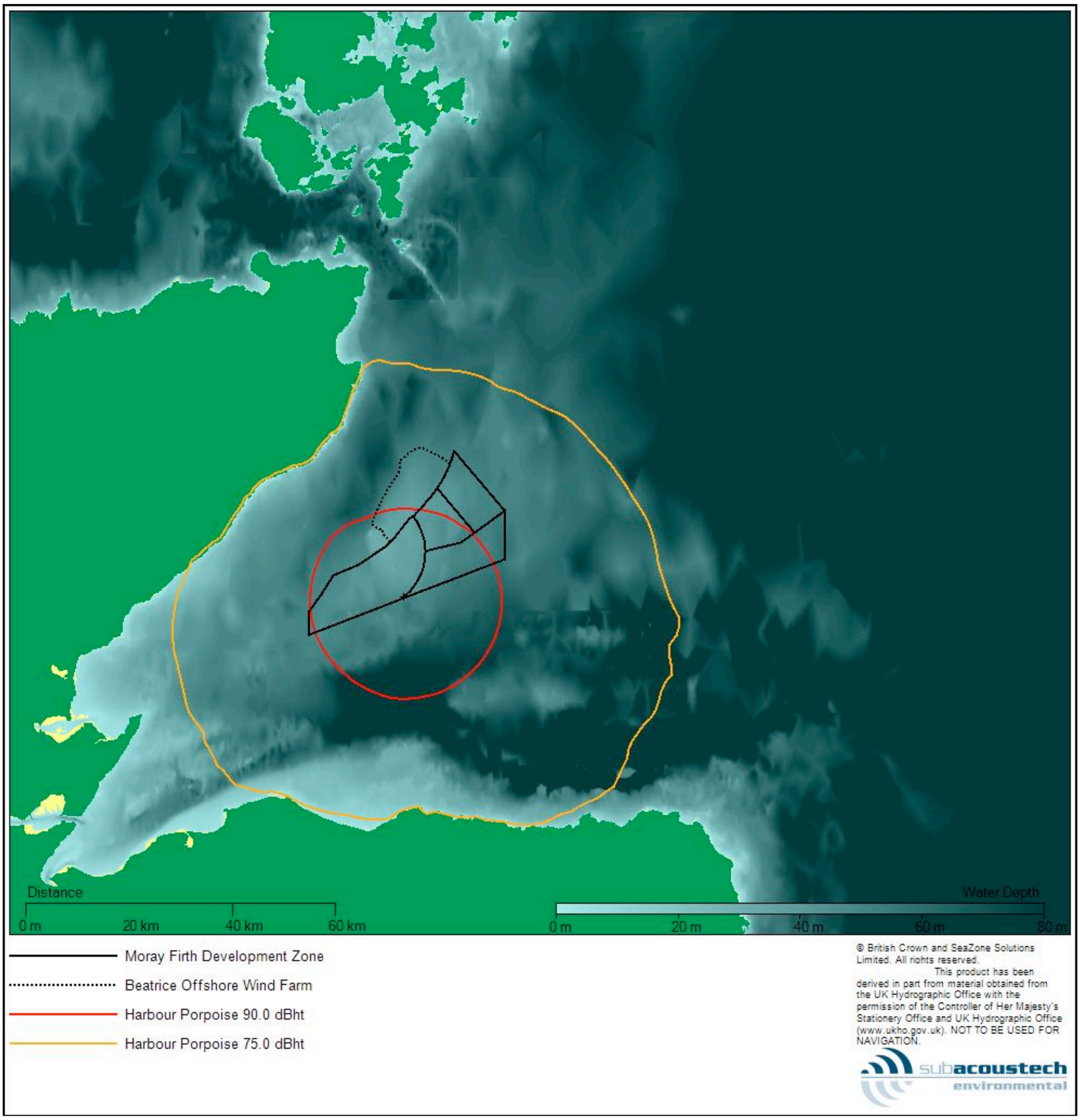


Figure A-25. 90 dB_{ht} and 75 dB_{ht} contours for harbour porpoise; 2.5 m diameter pile being driven at location 1.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1
Pile driving energy (kJ)	1200
Species	Harbour Porpoise

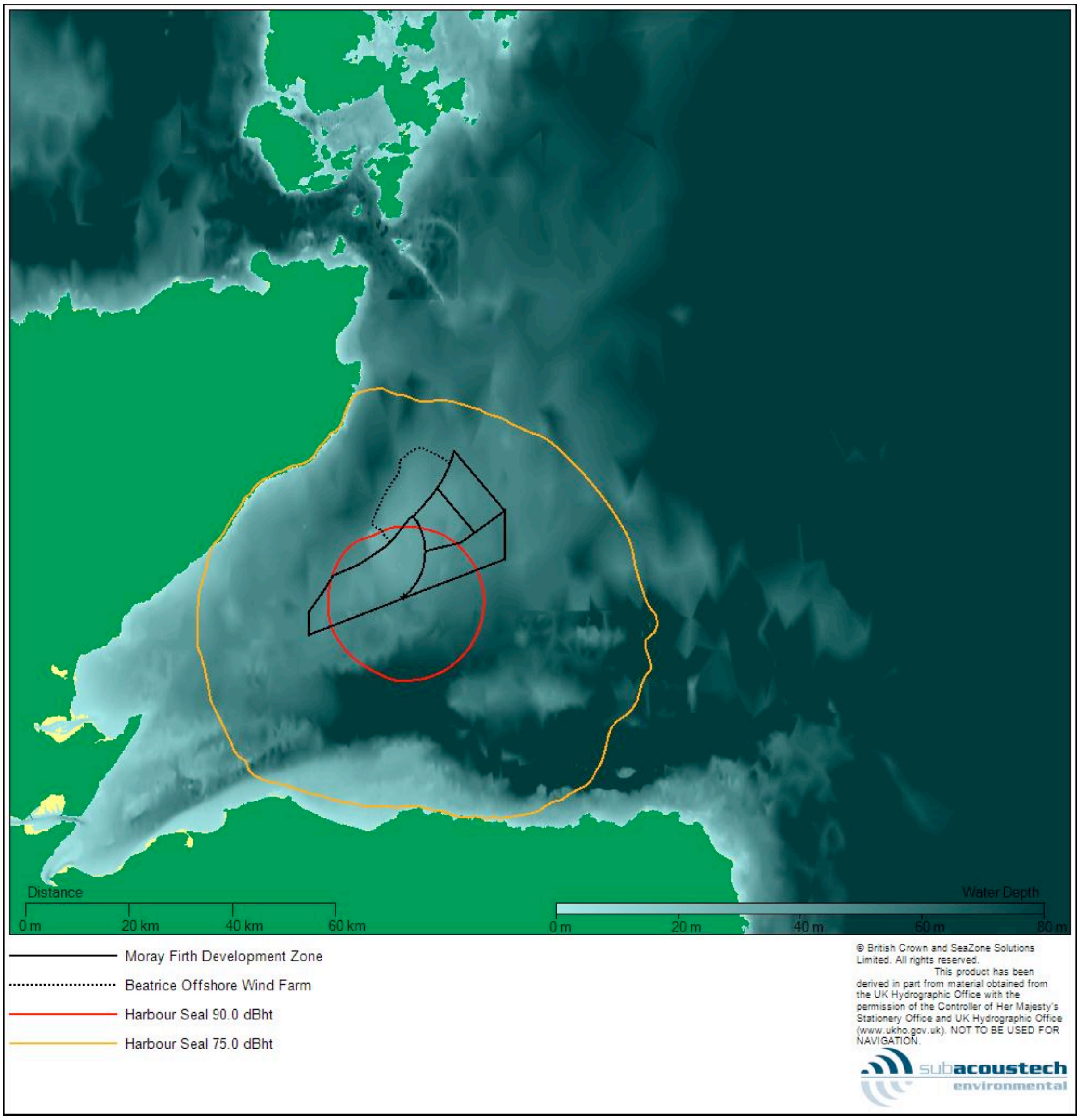


Figure A-26. 90 dB_{ht} and 75 dB_{ht} contours for harbour seal; 2.5 m diameter pile being driven at location 1.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1
Pile driving energy (kJ)	1200
Species	Harbour Seal

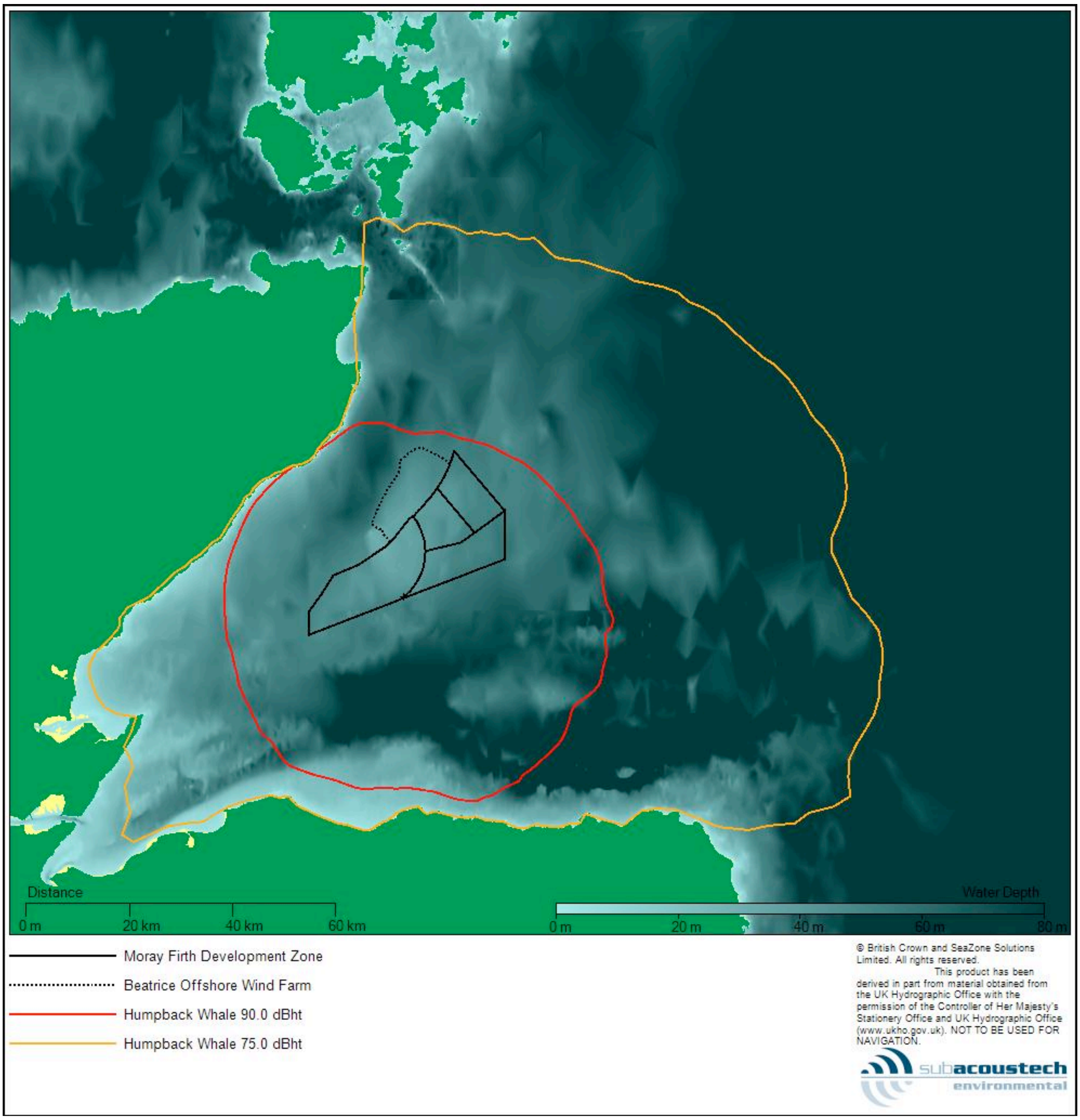


Figure A-27. 90 dB_{ht} and 75 dB_{ht} contours for minke whale (humpback whale used as surrogate); 2.5 m diameter pile being driven at location 1.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1
Pile driving energy (kJ)	1200
Species	Minke Whale

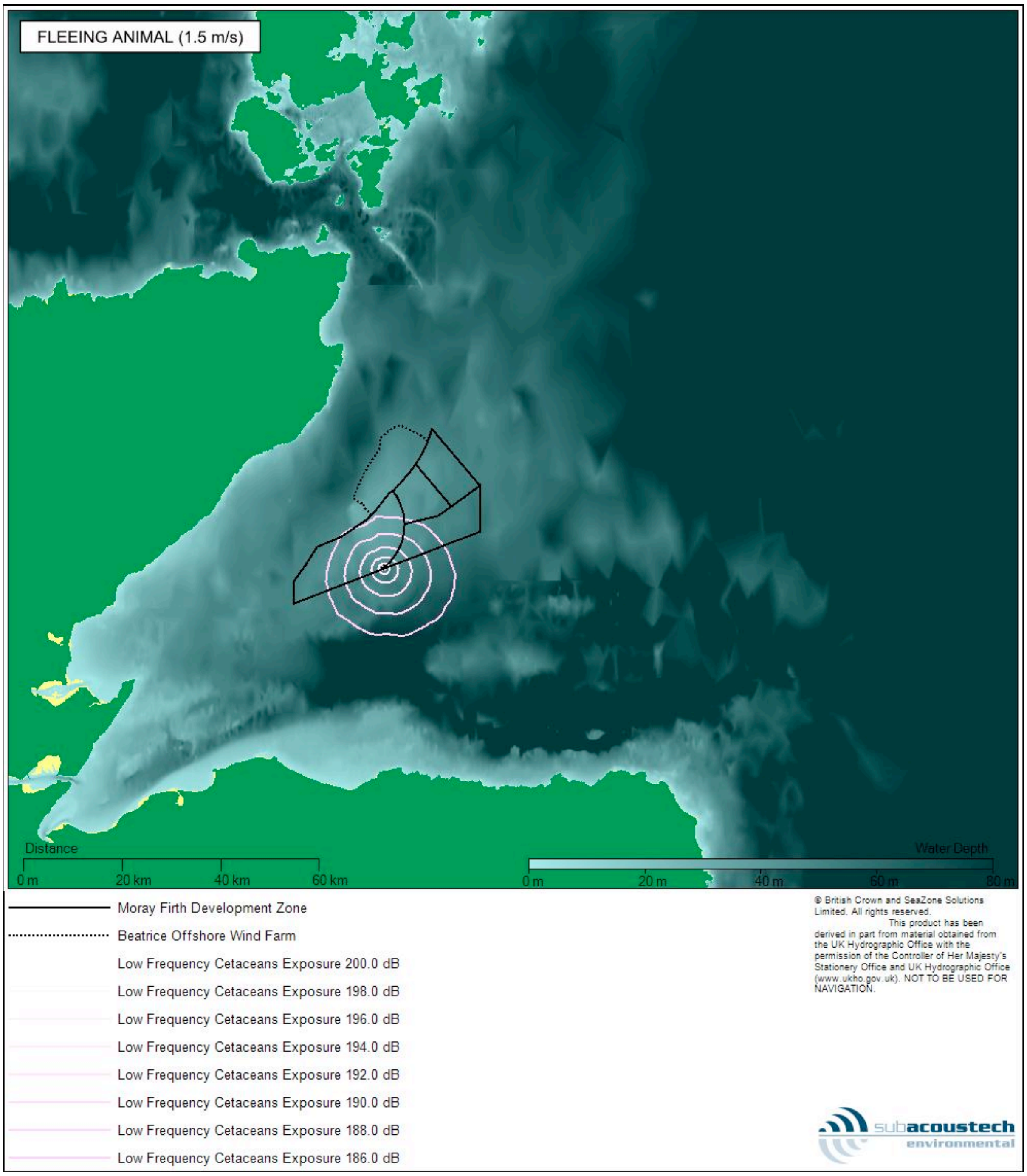


Figure A-28. Starting loci for fleeing Low Frequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 1.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1
Pile driving energy (kJ)	1200
Species	Low Frequency Cetaceans (Fleeing 1.5m/s)

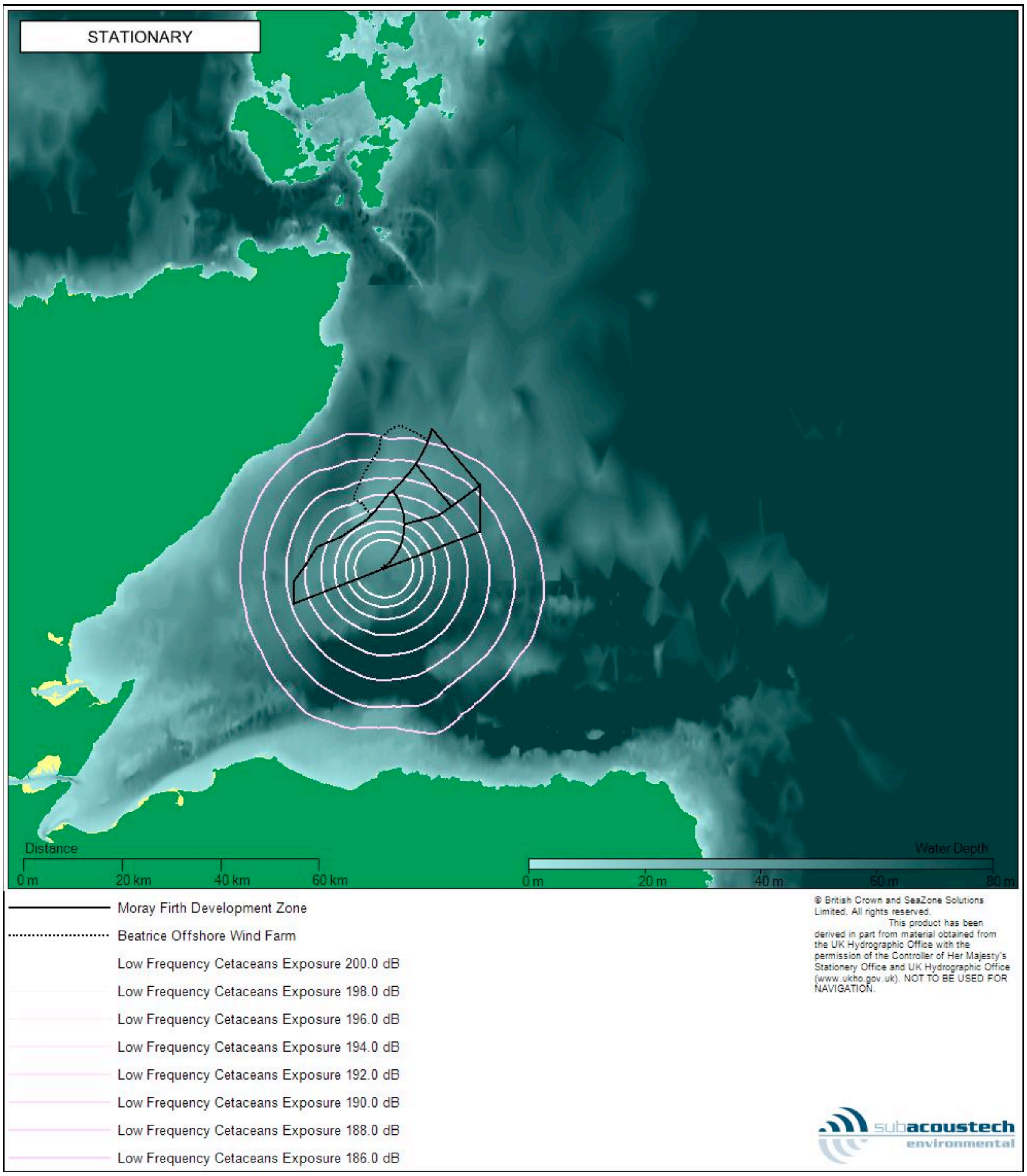


Figure A-29. Contours for stationary Low Frequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 1.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1
Pile driving energy (kJ)	1200
Species	Low Frequency Cetaceans (Stationary)

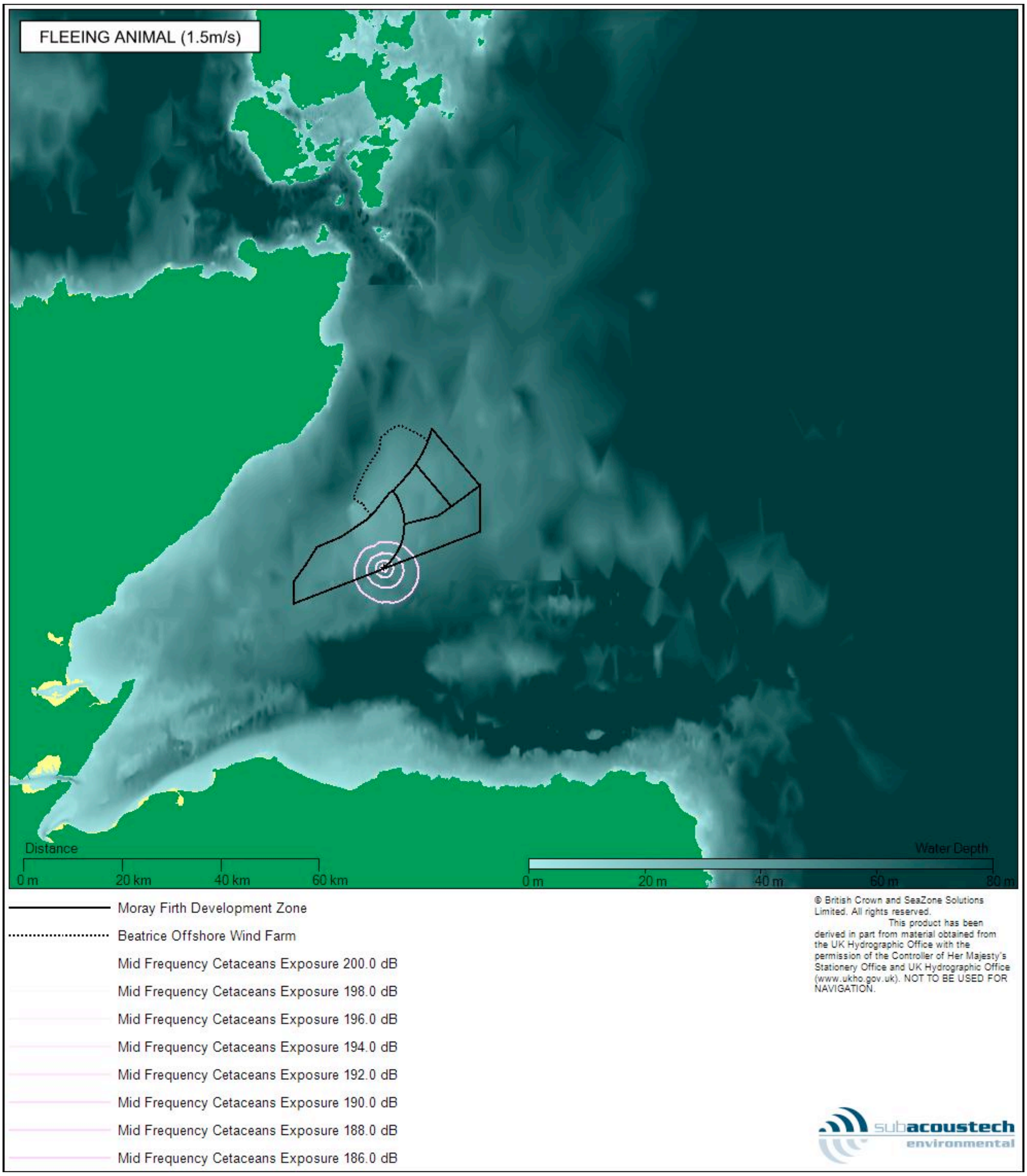


Figure A-30. Starting loci for fleeing Mid Frequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 1.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1
Pile driving energy (kJ)	1200
Species	Mid Frequency Cetaceans (Fleeing 1.5m/s)

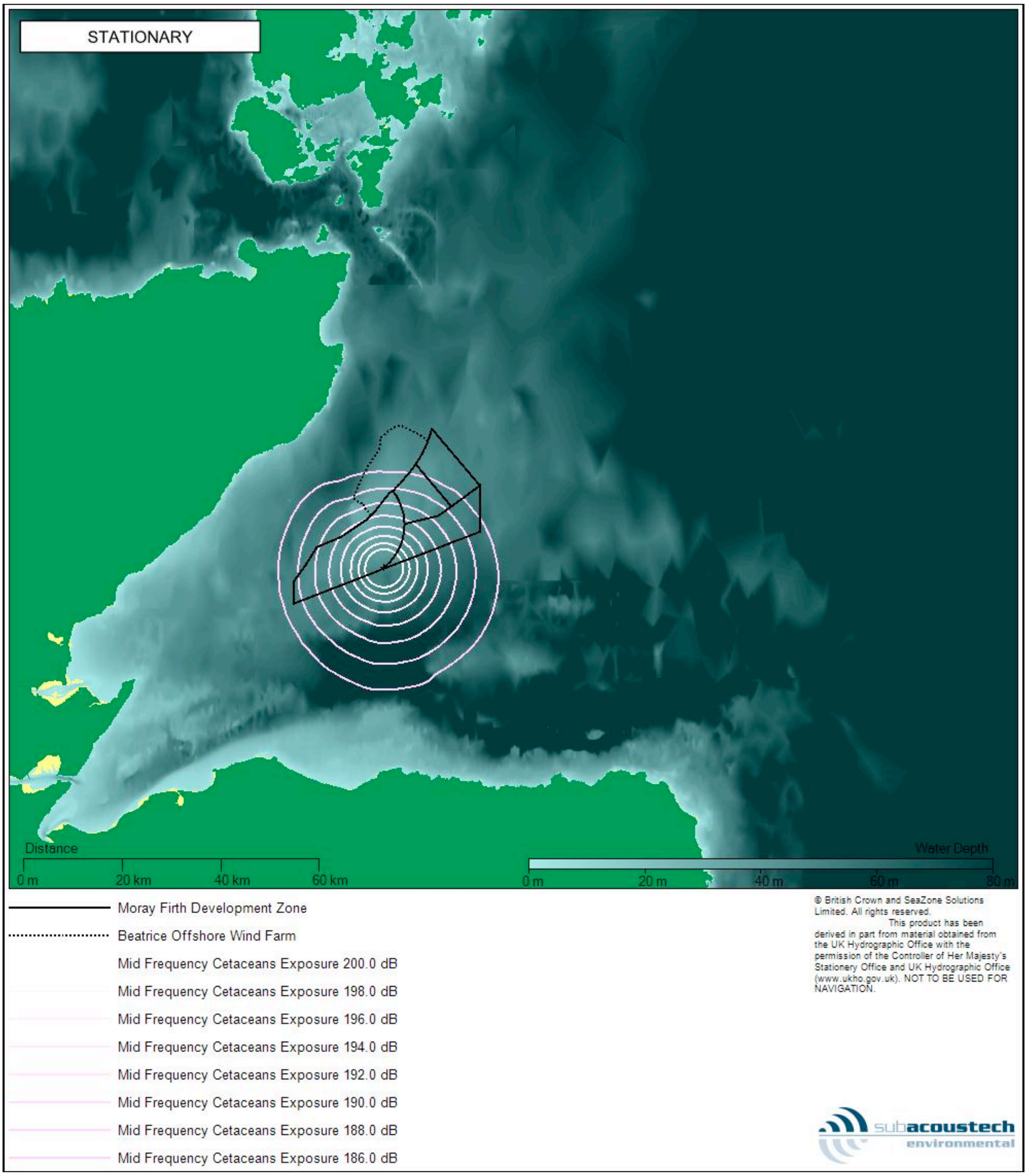


Figure A-31. Contours for stationary Mid Frequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 1.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1
Pile driving energy (kJ)	1200
Species	Mid Frequency Cetaceans (Stationary)

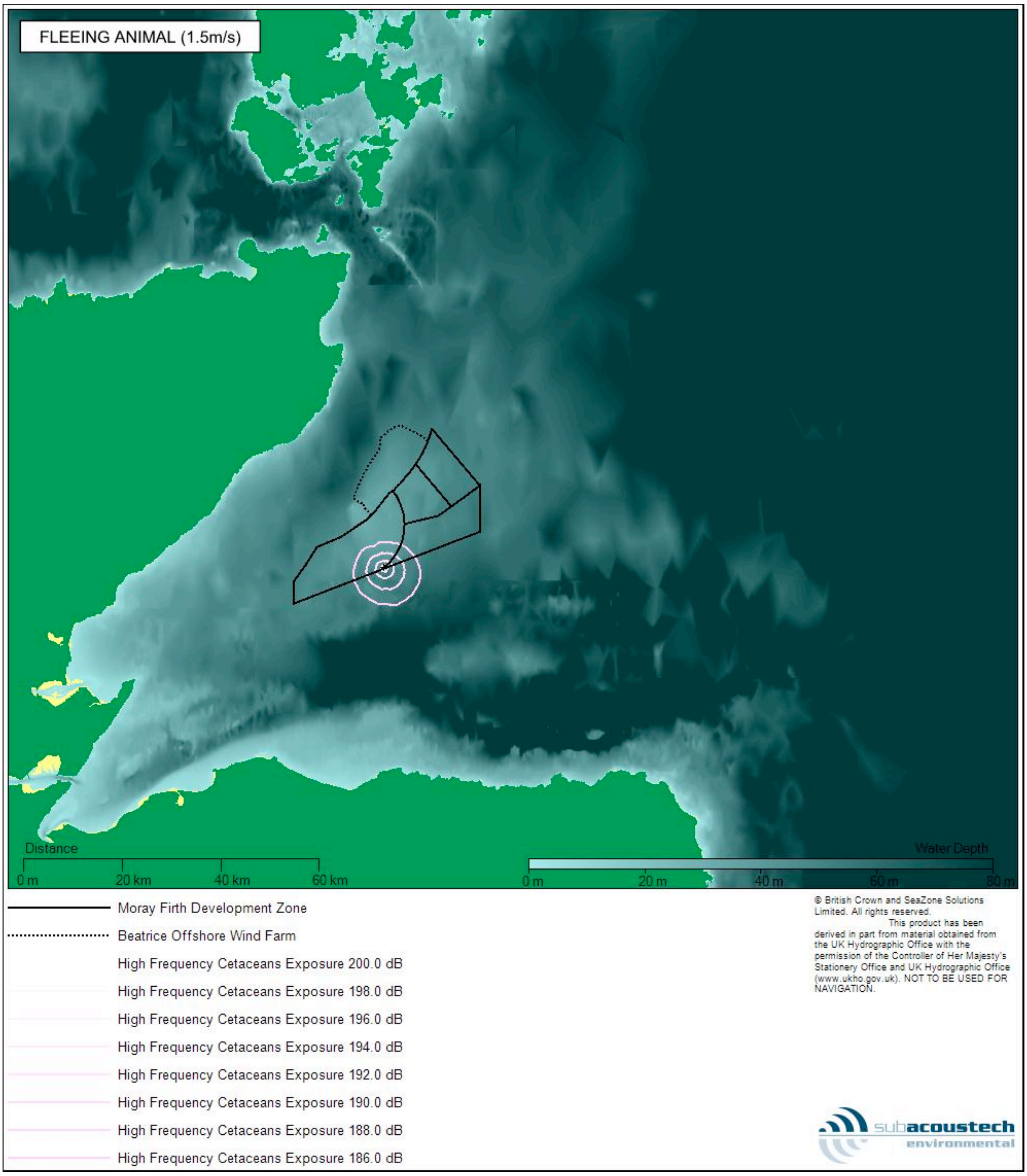


Figure A-32. Starting loci for fleeing High Frequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 1.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1
Pile driving energy (kJ)	1200
Species	High Frequency Cetaceans (Fleeing 1.5m/s)

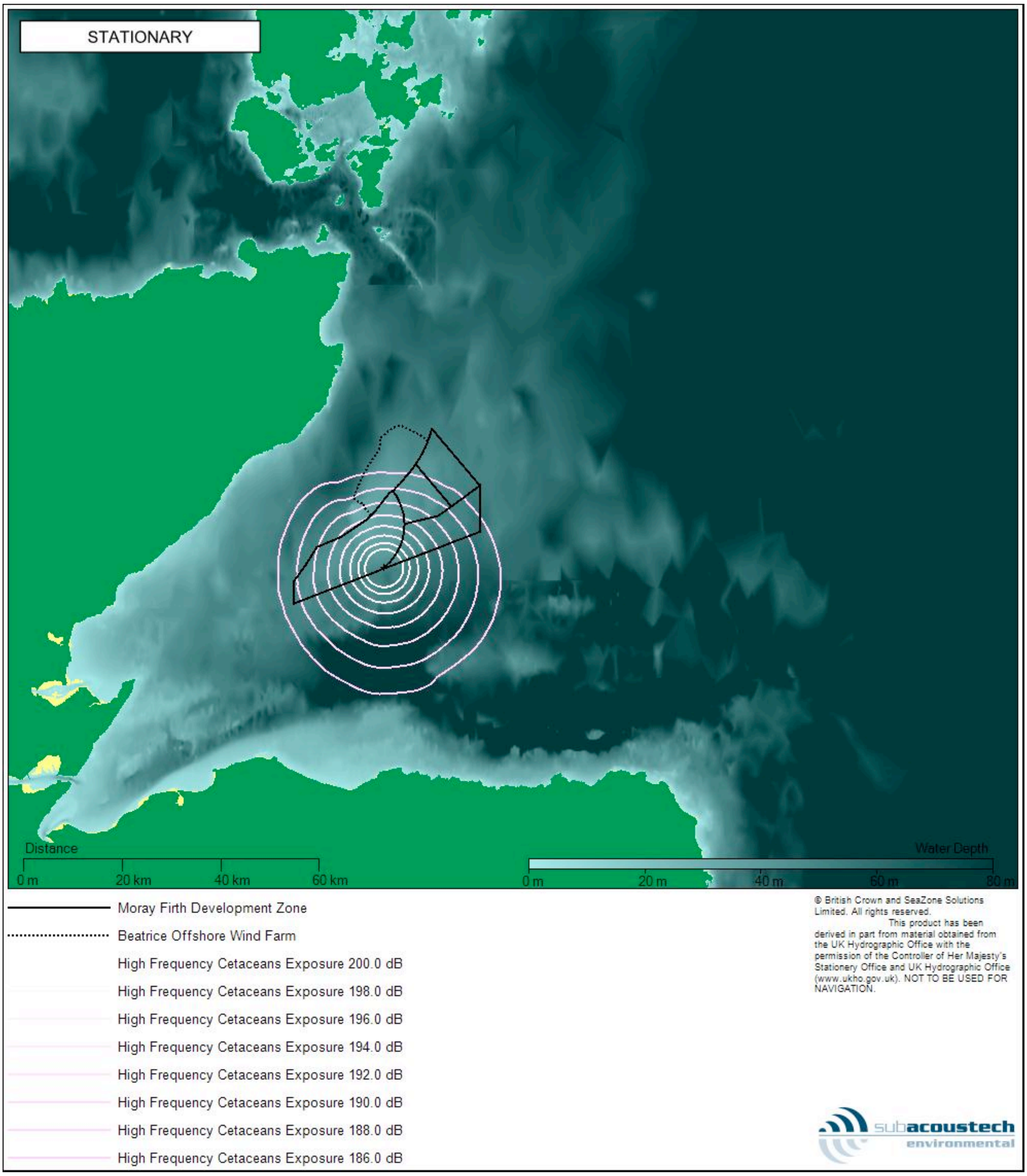


Figure A-33. Contours for stationary HighFrequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 1.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1
Pile driving energy (kJ)	1200
Species	High Frequency Cetaceans (Stationary)

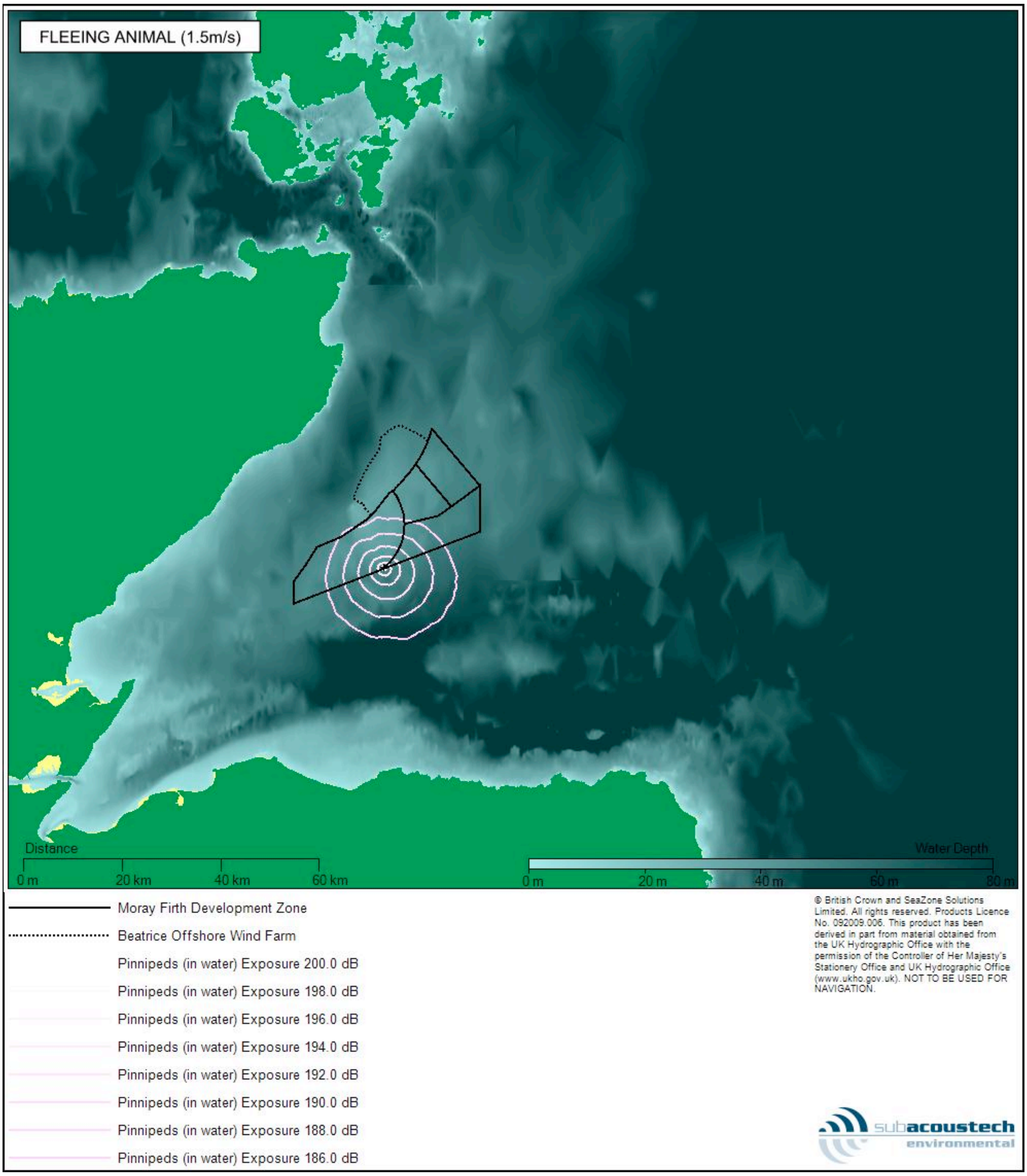


Figure A-34. Starting loci for fleeing Pinnipeds (in water); two 2.5 m diameter pin piles being driven sequentially at location 1.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1
Pile driving energy (kJ)	1200
Species	Pinnipeds (in water) (Fleeing 1.5m/s)

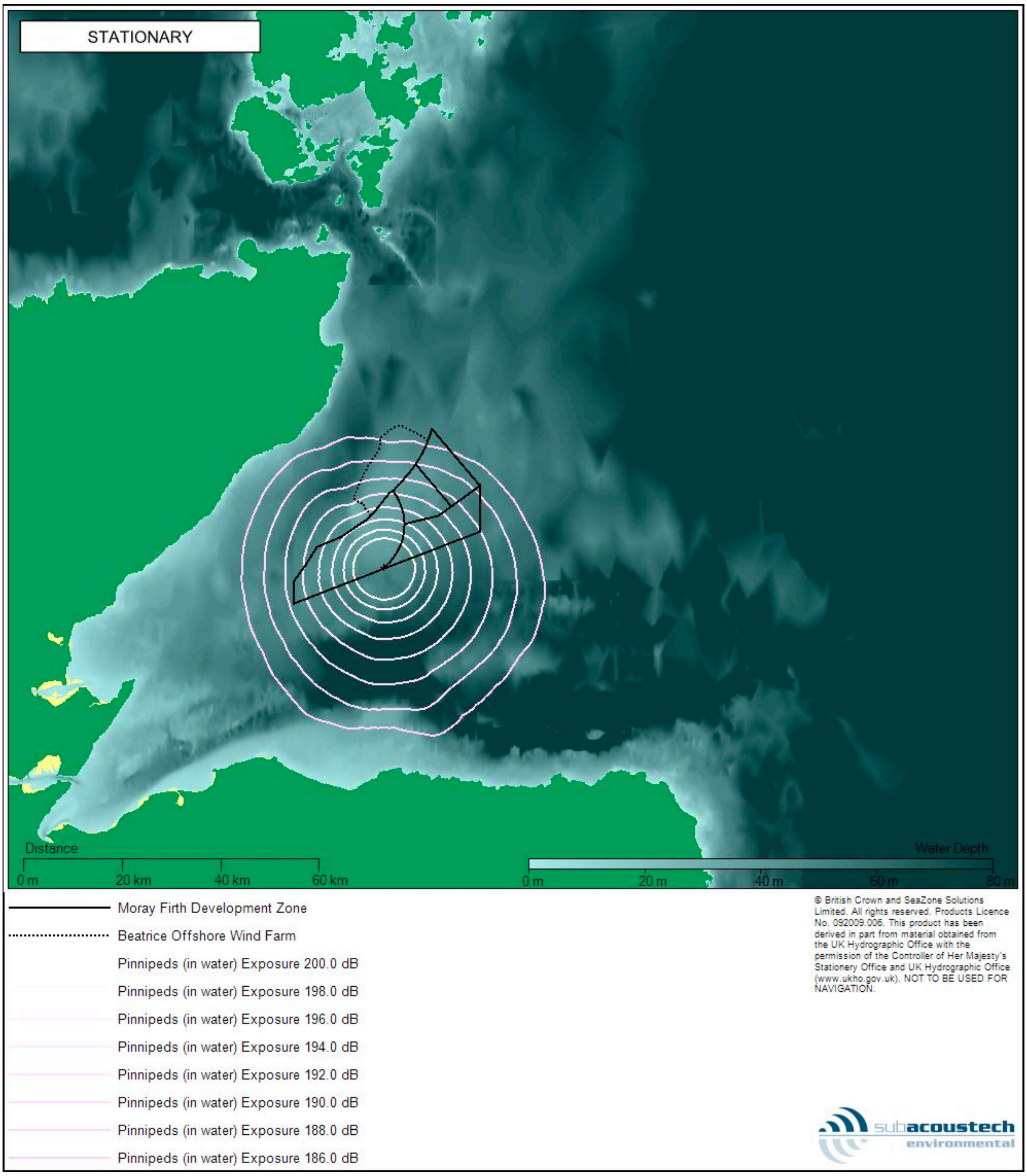


Figure A-35. Contours for stationary Pinnipeds (in water); two 2.5 m diameter pin piles being driven sequentially at location 1.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1
Pile driving energy (kJ)	1200
Species	Pinnipeds (in water) (Stationary)

9.1.2.2 Results for 2 pin piles being driven sequentially at 1 location on the MacColl site

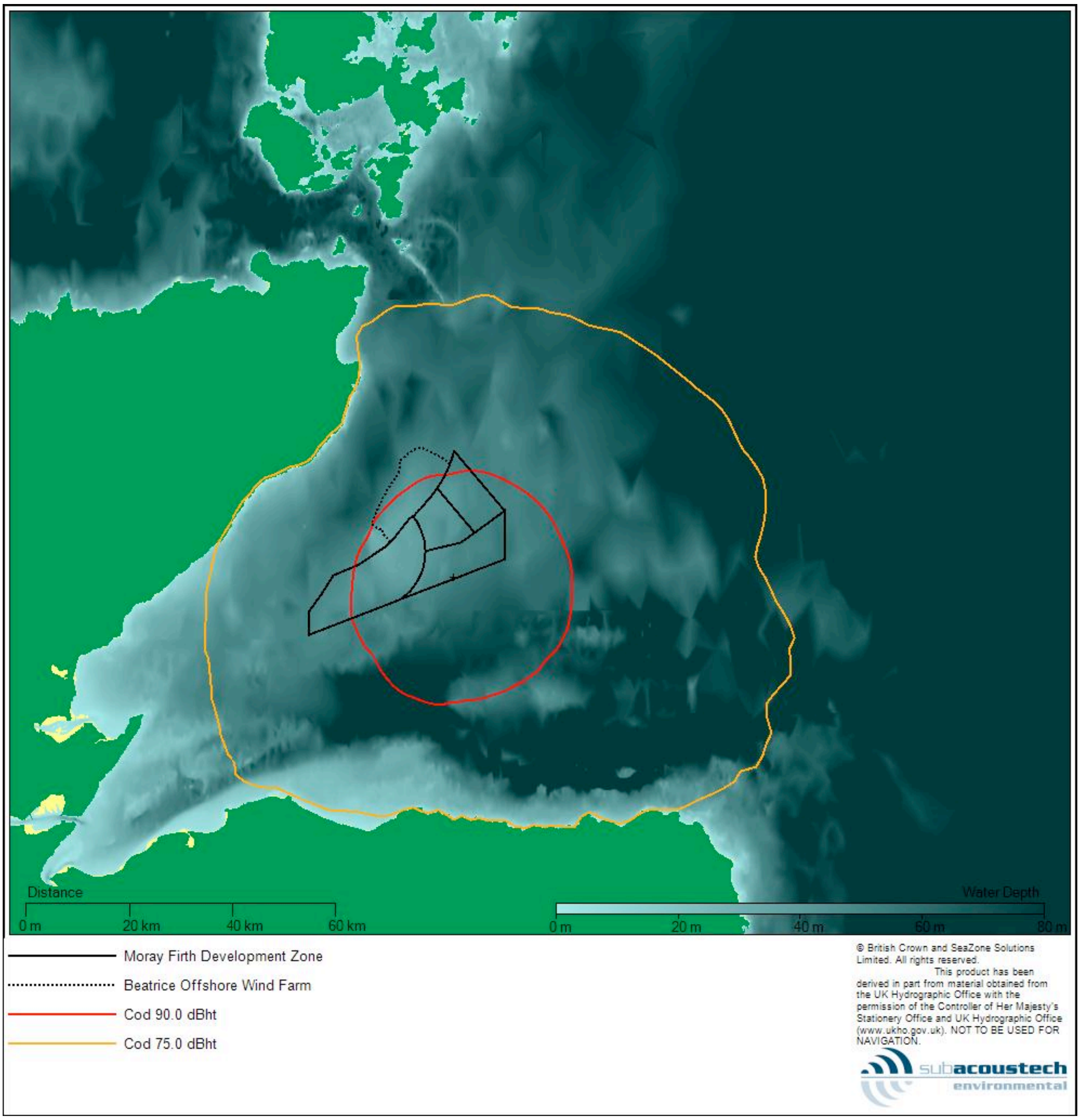


Figure A-36. 90 dB_{ht} and 75 dB_{ht} contours for cod; 2.5 m diameter pile being driven at location 1a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1a
Pile driving energy (kJ)	1200
Species	Cod

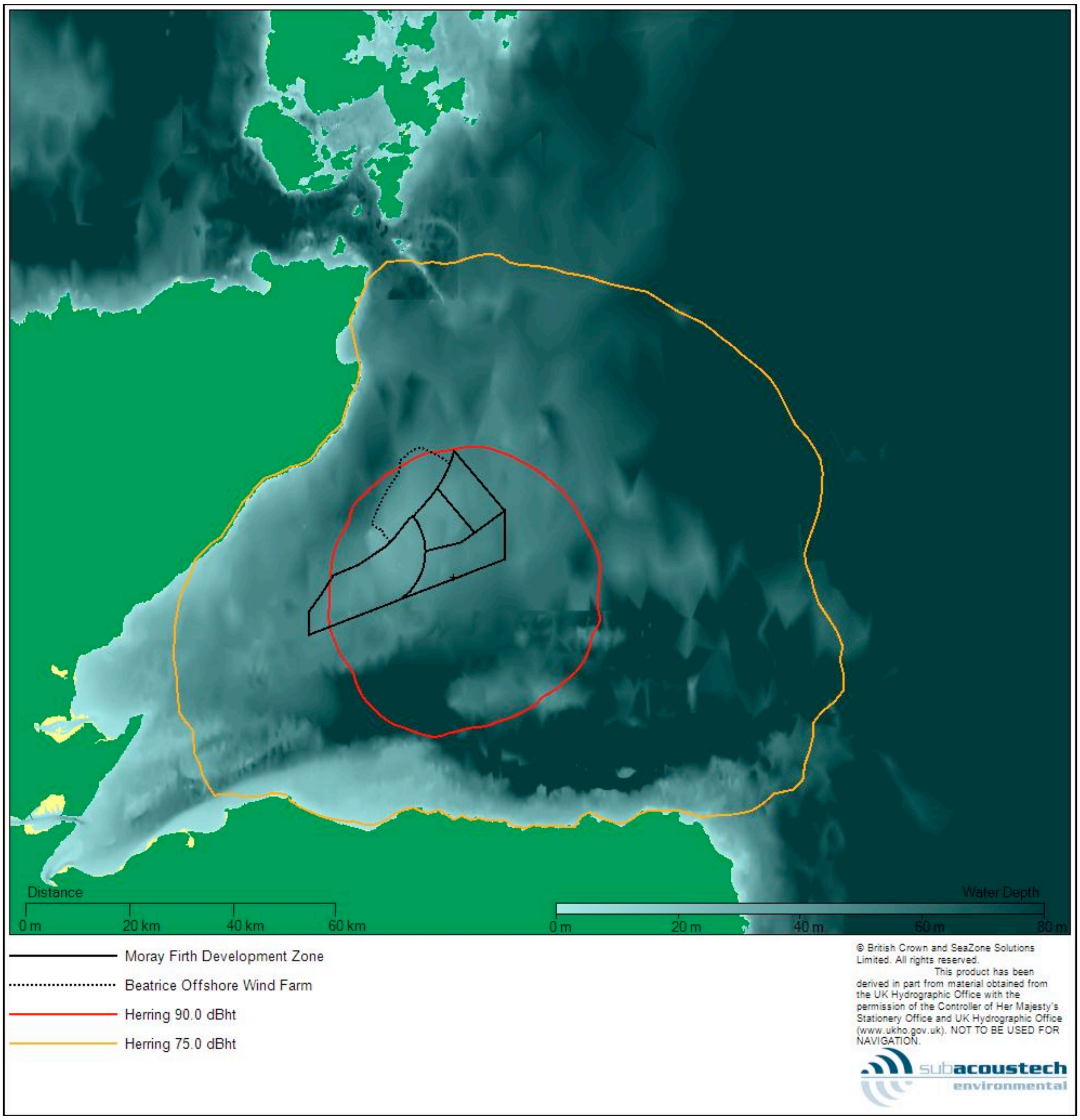


Figure A-37. 90 dB_{ht} and 75 dB_{ht} contours for herring; 2.5 m diameter pile being driven at location 1a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1a
Pile driving energy (kJ)	1200
Species	Herring

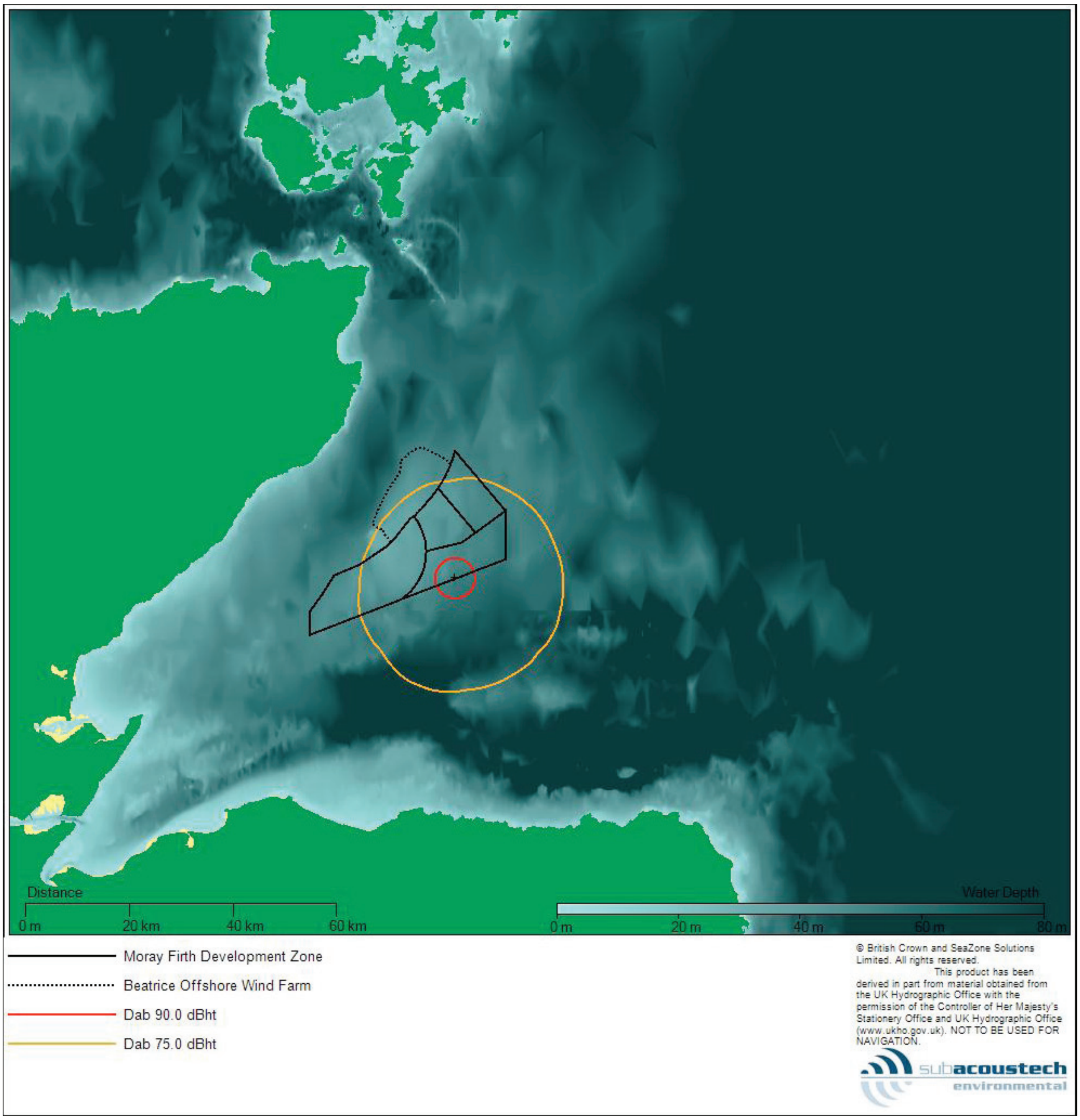


Figure A-38. 90 dB_{ht} and 75 dB_{ht} contours for plaice (dab used as surrogate); 2.5 m diameter pile being driven at location 1a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1a
Pile driving energy (kJ)	1200
Species	Plaice

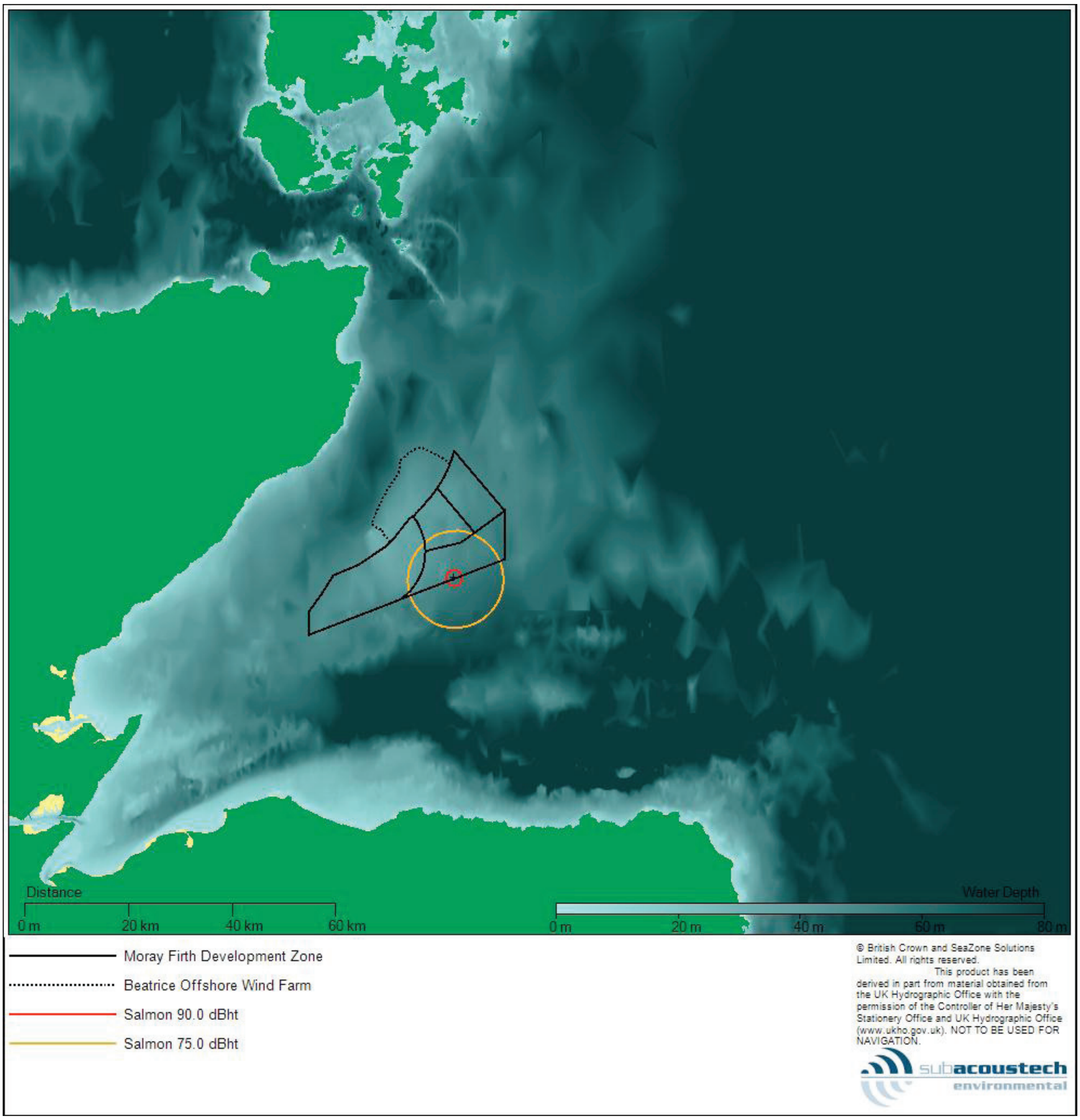


Figure A-39. 90 dB_{ht} and 75 dB_{ht} contours for salmon; 2.5 m diameter pile being driven at location 1a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1a
Pile driving energy (kJ)	1200
Species	Salmon

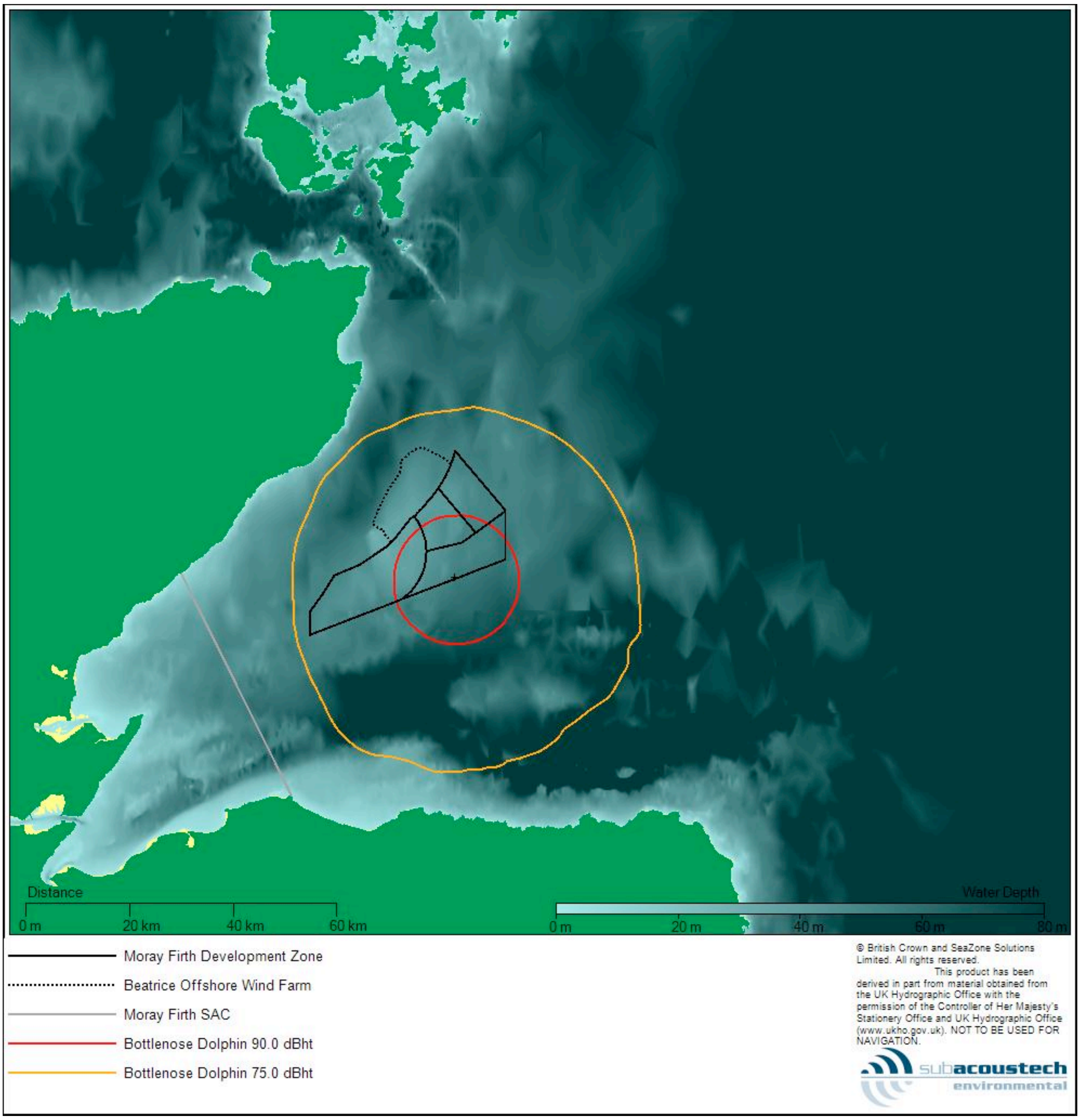


Figure A-40. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for bottlenose dolphin; 2.5 m diameter pile being driven at location 1a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1a
Pile driving energy (kJ)	1200
Species	Bottlenose Dolphin

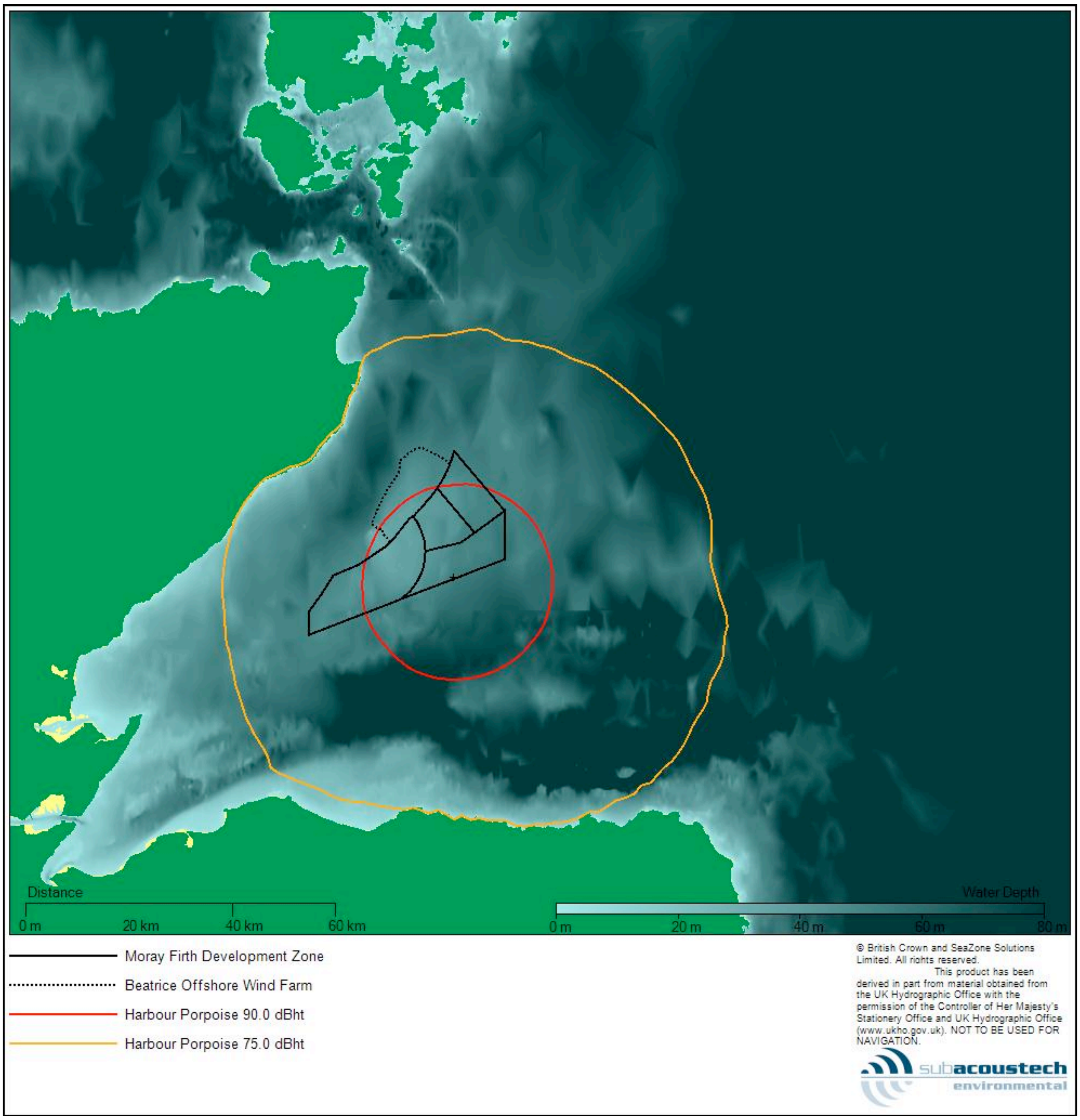


Figure A-41. 90 dB_{ht} and 75 dB_{ht} contours for harbour porpoise; 2.5 m diameter pile being driven at location 1a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1a
Pile driving energy (kJ)	1200
Species	Harbour Porpoise

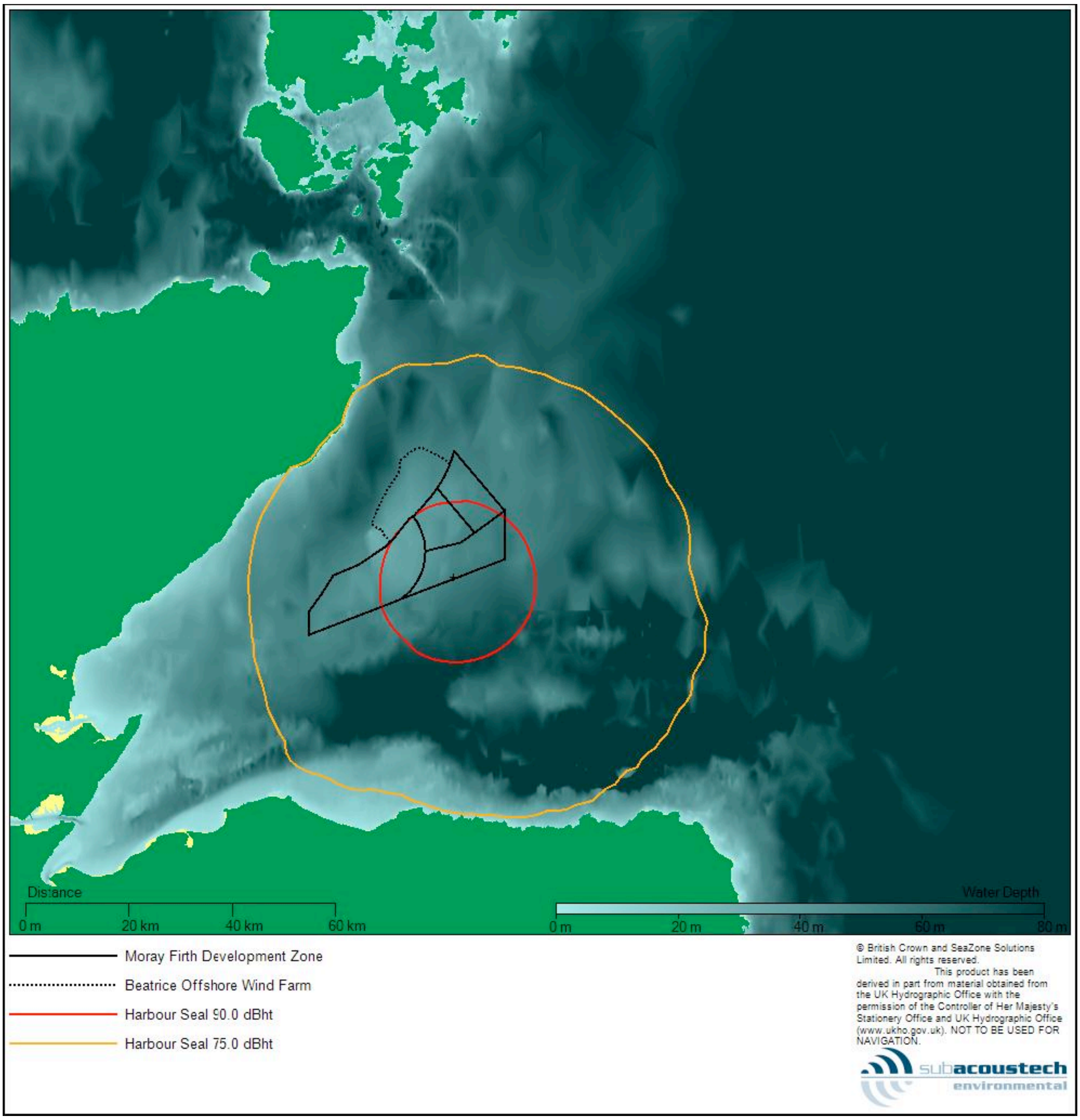


Figure A-42. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for harbour seal; 2.5 m diameter pile being driven at location 1a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1a
Pile driving energy (kJ)	1200
Species	Harbour Seal

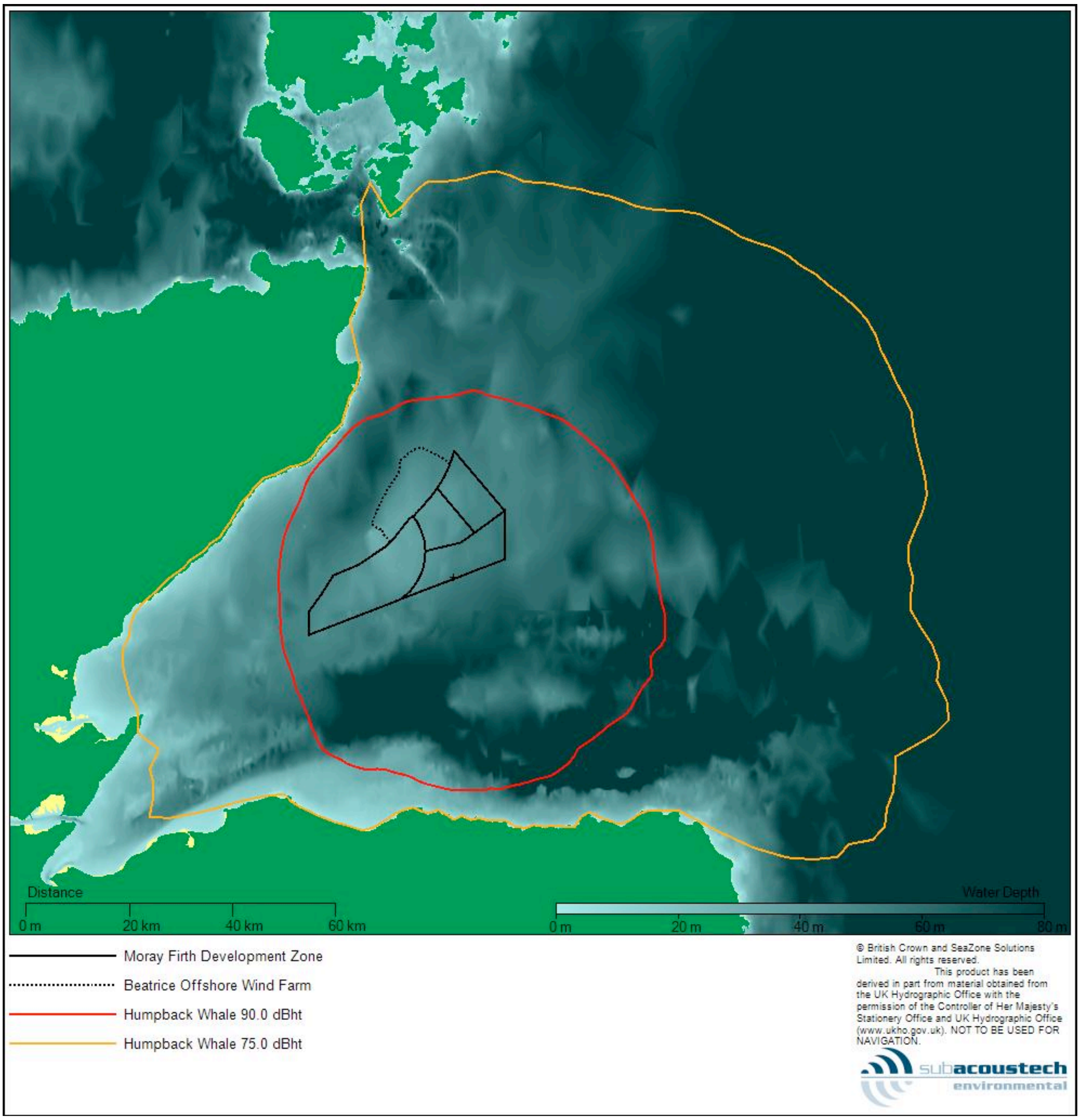


Figure A-43. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for minke whale (humpback whale used as surrogate); 2.5 m diameter pile being driven at location 1a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1a
Pile driving energy (kJ)	1200
Species	Minke Whale

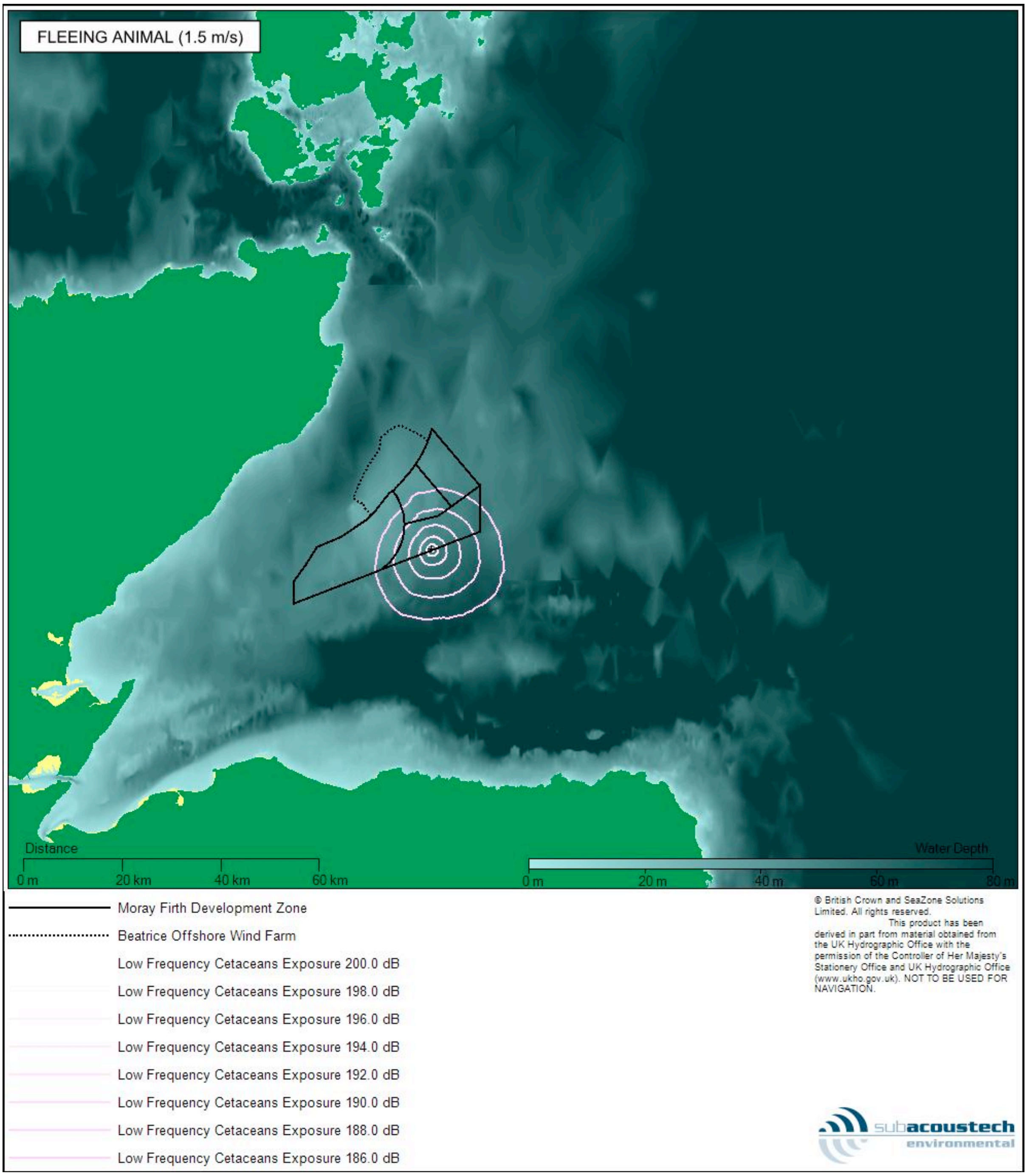


Figure A-44. Starting loci for fleeing Low Frequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 1a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1a
Pile driving energy (kJ)	1200
Species	Low Frequency Cetaceans (Fleeing 1.5m/s)

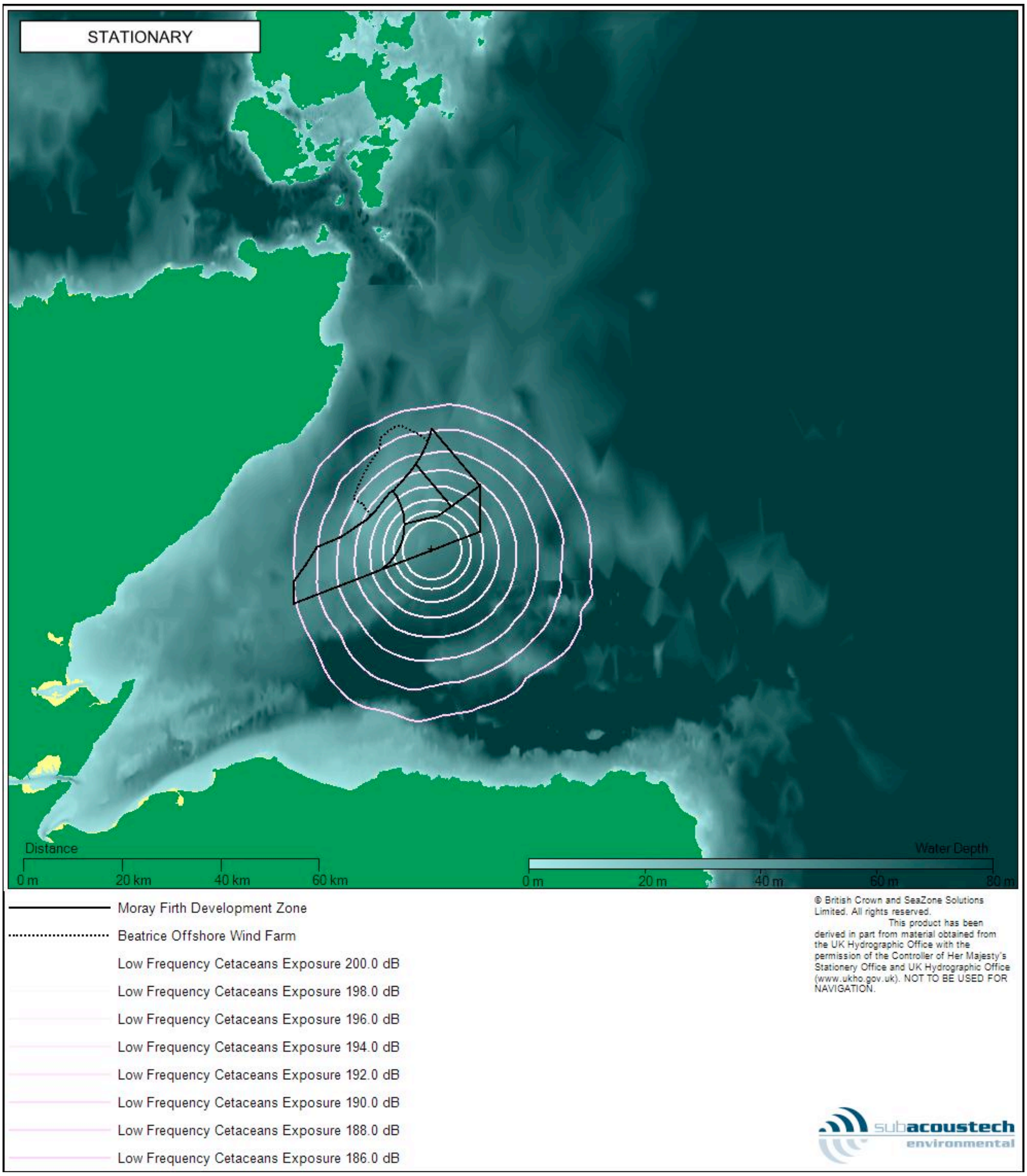


Figure A-45. Contours for stationary Low Frequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 1a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1a
Pile driving energy (kJ)	1200
Species	Low Frequency Cetaceans (Stationary)

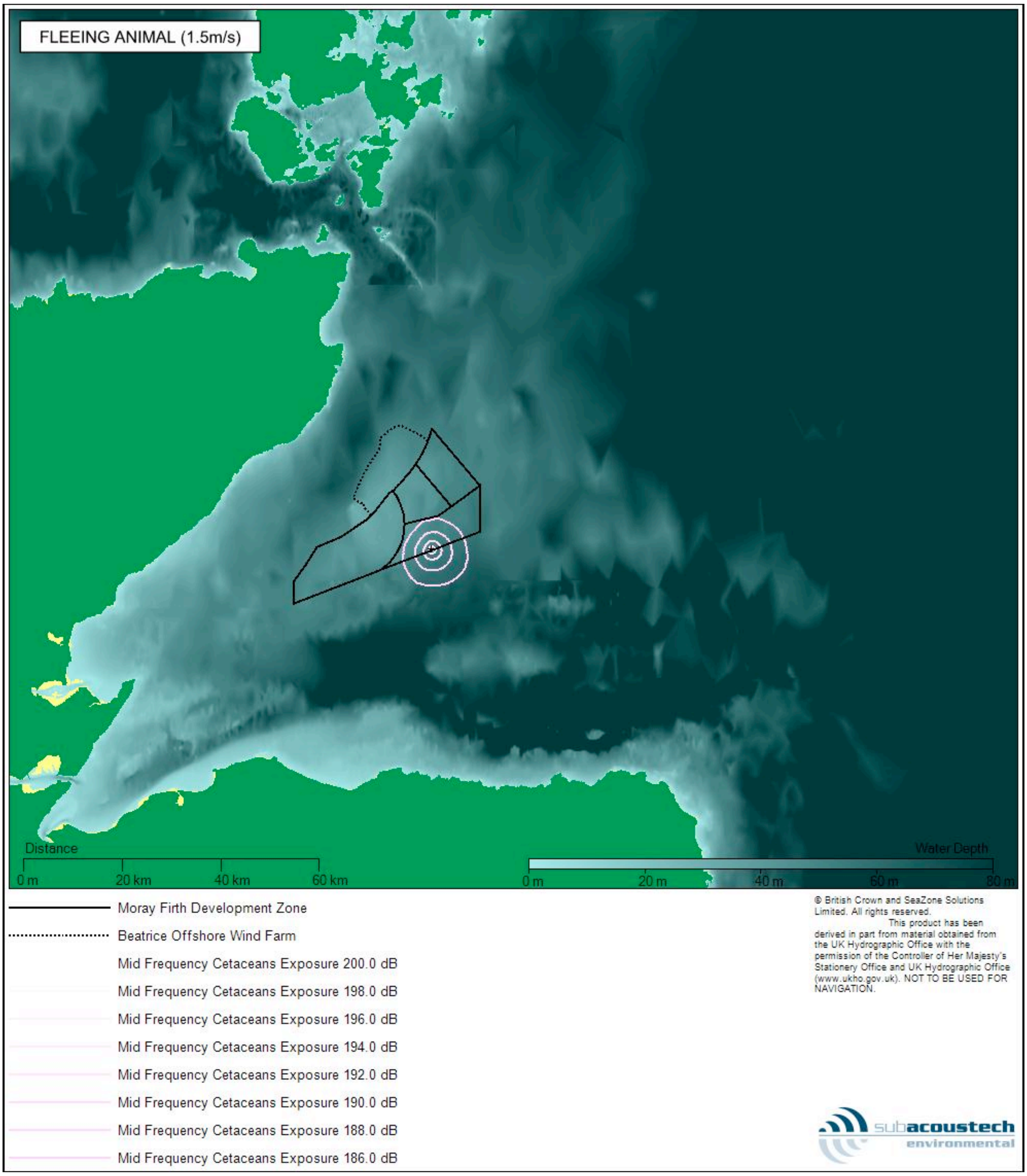


Figure A-46. Starting loci for fleeing Mid Frequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 1a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1a
Pile driving energy (kJ)	1200
Species	Mid Frequency Cetaceans (Fleeing 1.5m/s)

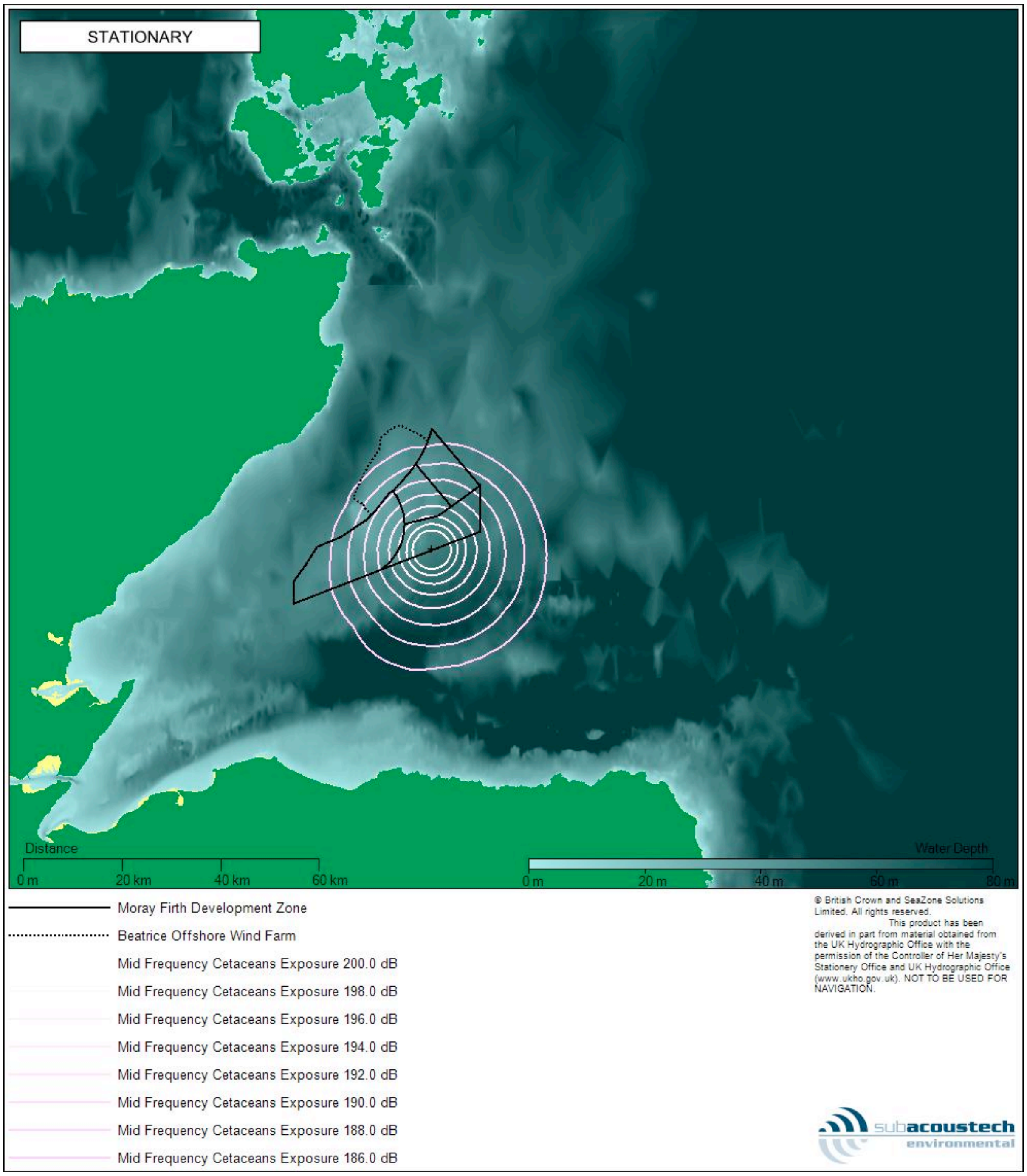


Figure A-47. Contours for stationary Mid Frequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 1a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1a
Pile driving energy (kJ)	1200
Species	Mid Frequency Cetaceans (Stationary)

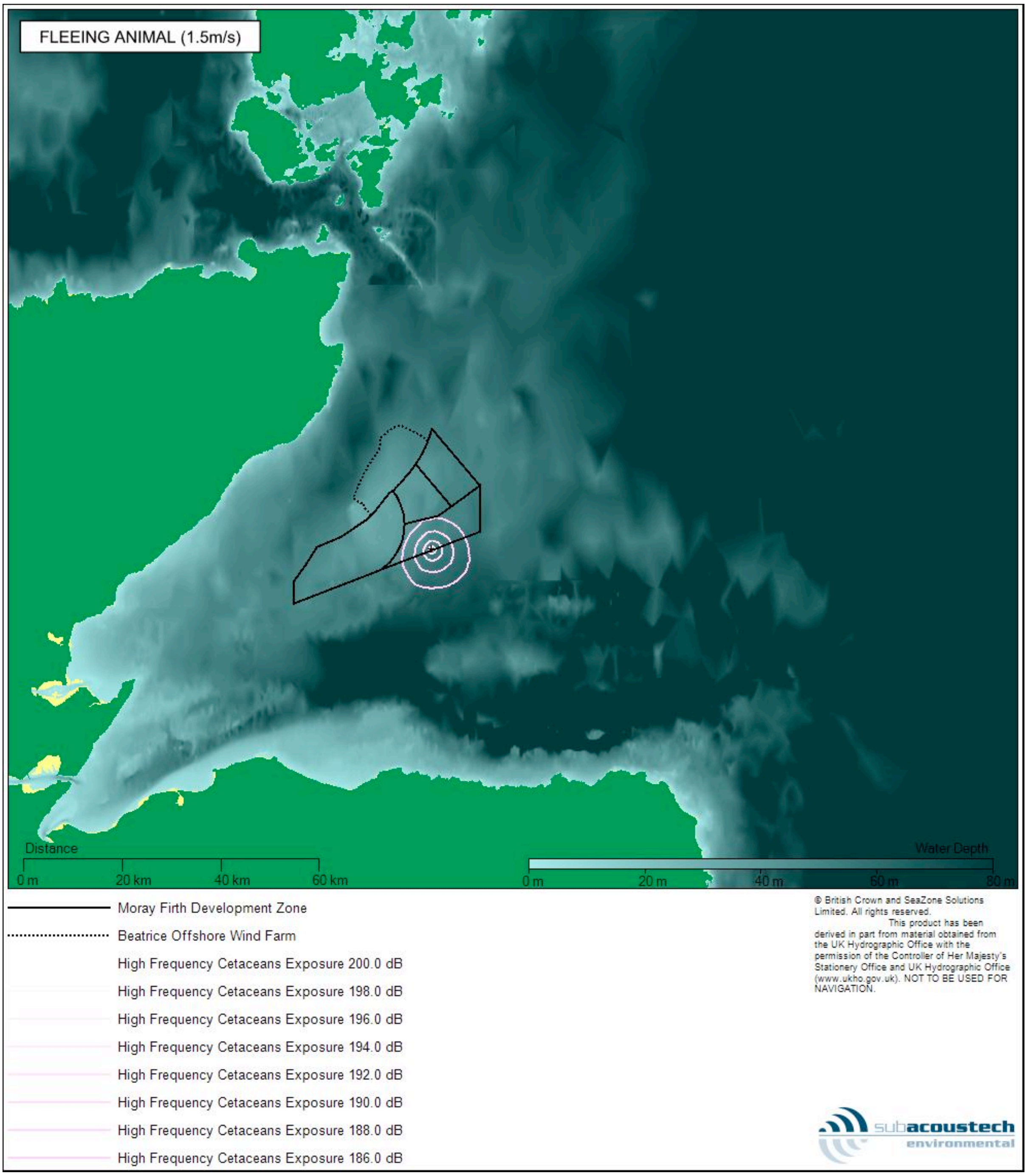


Figure A-48. Starting loci for fleeing High Frequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 1a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1a
Pile driving energy (kJ)	1200
Species	High Frequency Cetaceans (Fleeing 1.5m/s)

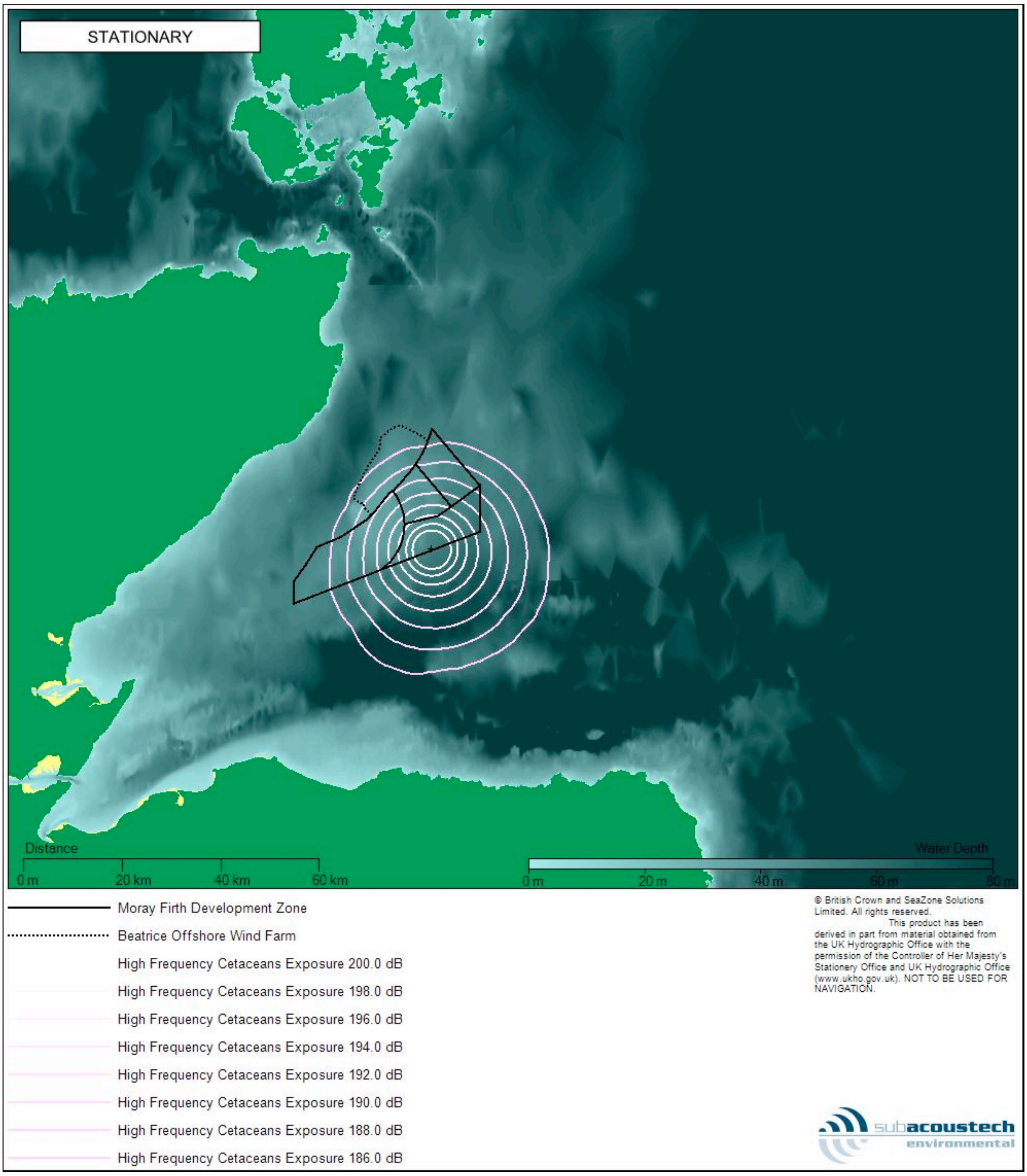


Figure A-49. Contours for stationary HighFrequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 1a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1a
Pile driving energy (kJ)	1200
Species	High Frequency Cetaceans (Stationary)

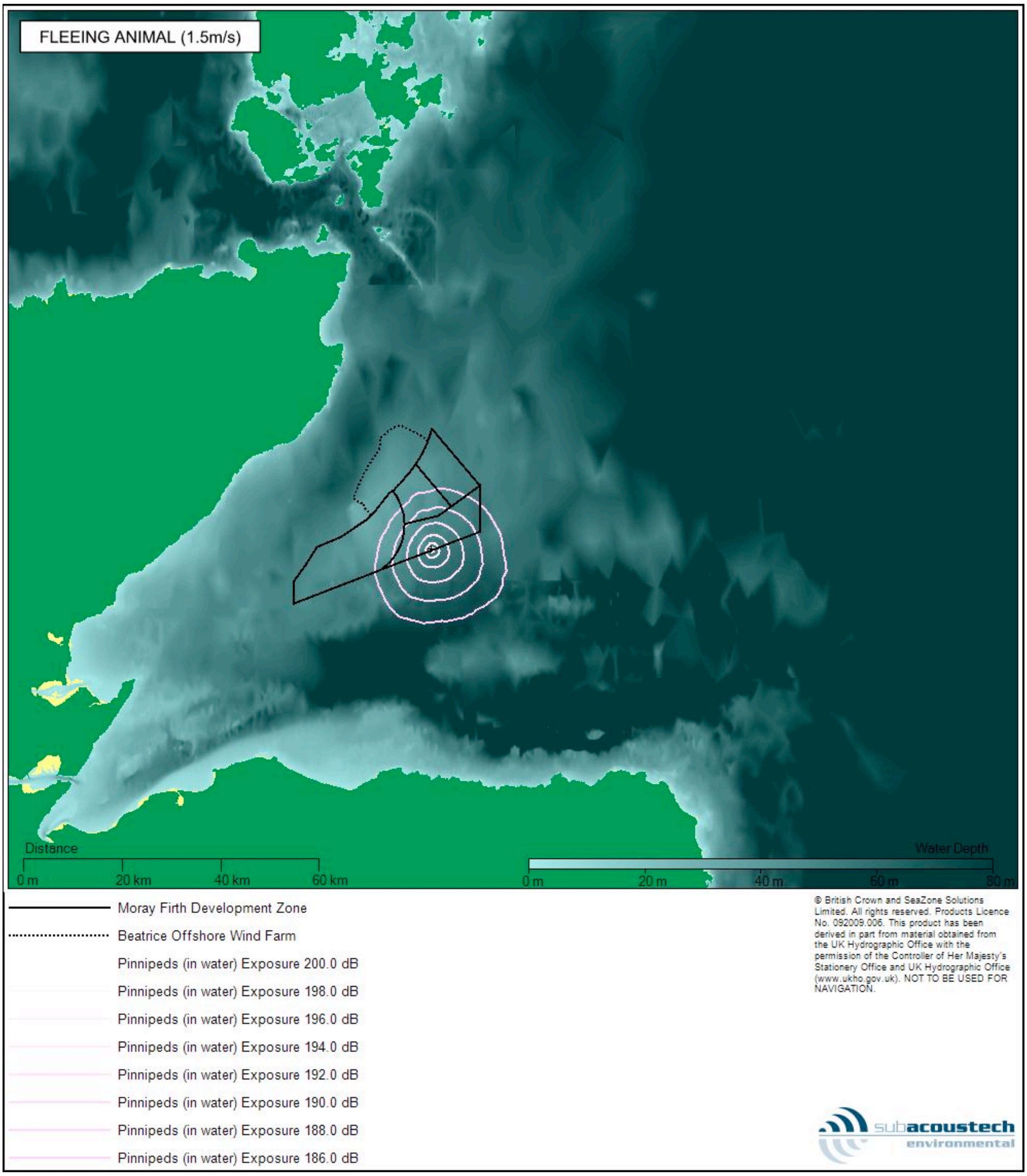


Figure A-50. Starting loci for fleeing Pinnipeds (in water); two 2.5 m diameter pin piles being driven sequentially at location 1a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1a
Pile driving energy (kJ)	1200
Species	Pinnipeds (in water) (Fleeing 1.5m/s)

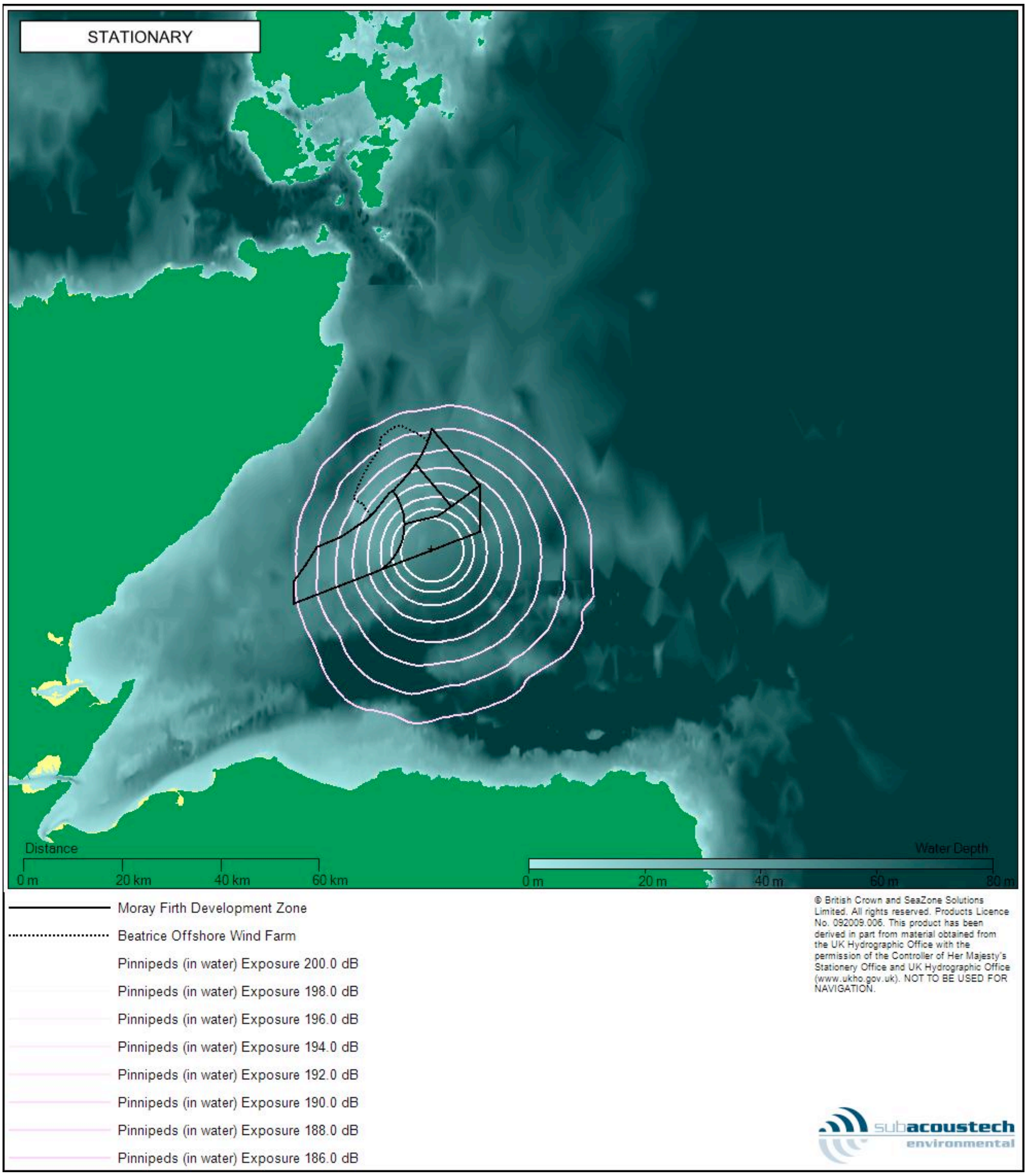


Figure A-51. Contours for stationary Pinnipeds (in water); two 2.5 m diameter pin piles being driven sequentially at location 1a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	1a
Pile driving energy (kJ)	1200
Species	Pinnipeds (in water) (Stationary)

9.1.2.3 Results for 2 pin piles being driven sequentially at 1 location on the Stevenson site

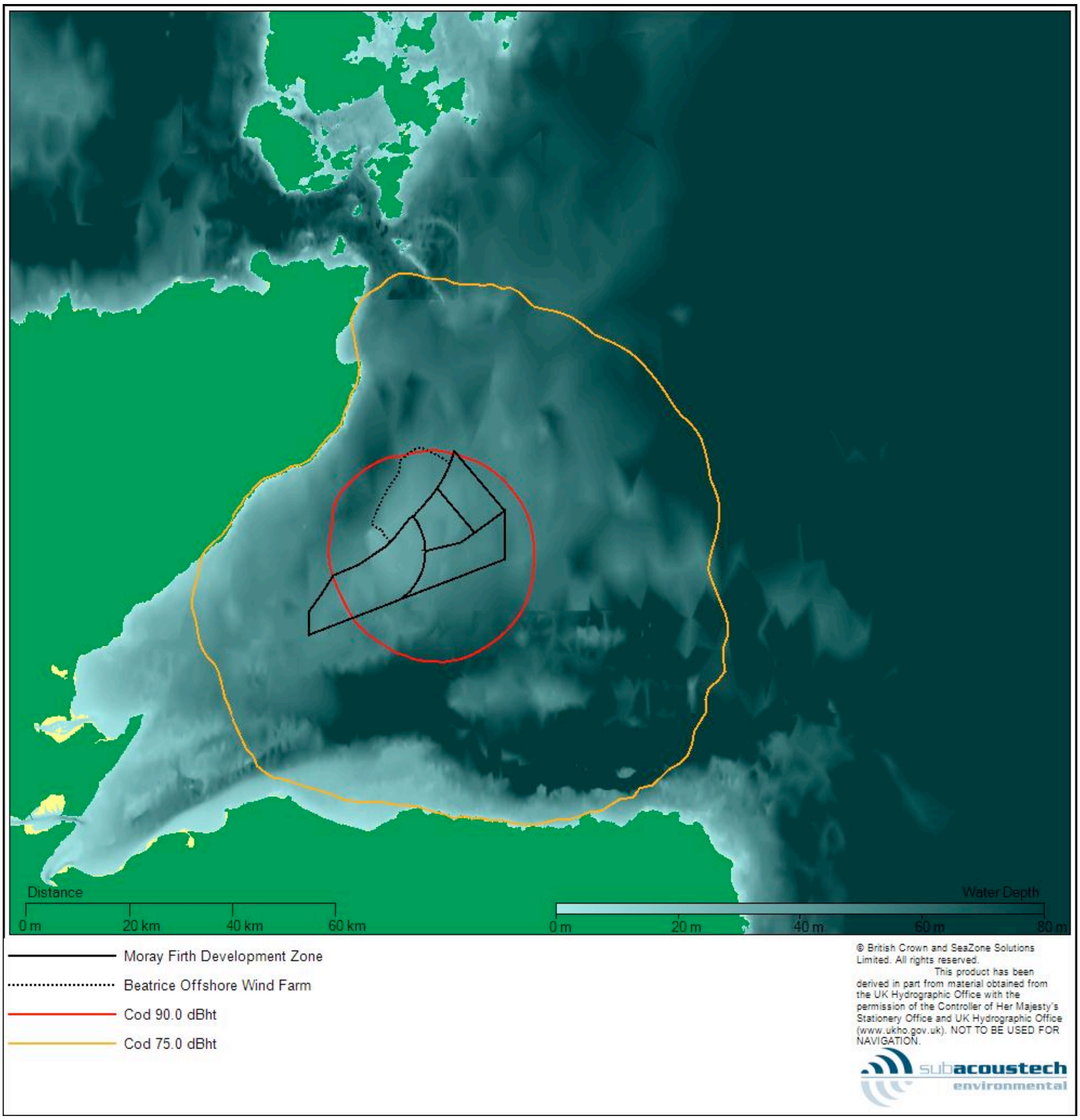


Figure A-52. 90 dB_{ht} and 75 dB_{ht} contours for cod; 2.5 m diameter pile being driven at location 4.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	4
Pile driving energy (kJ)	1200
Species	Cod

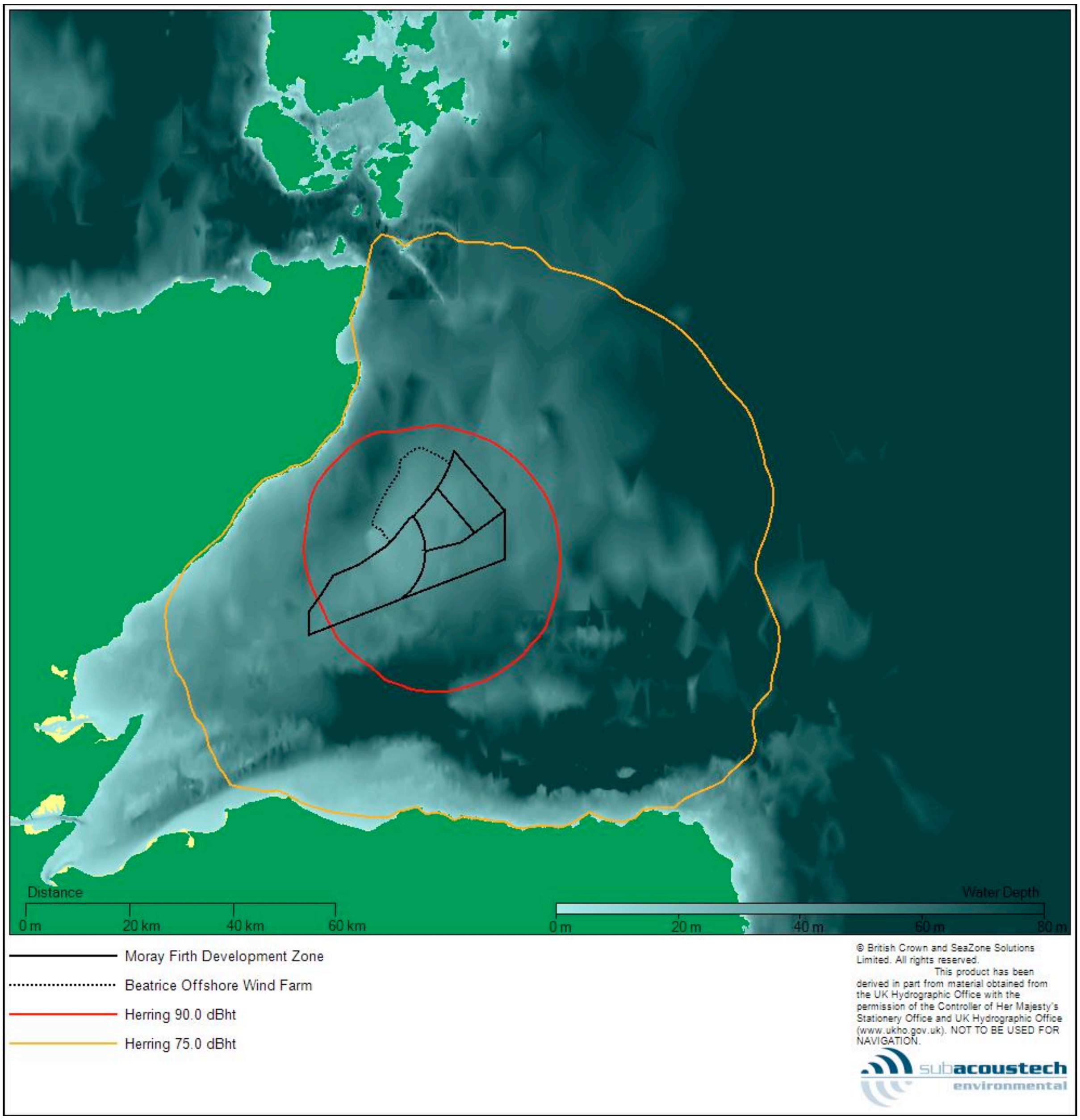


Figure A-53. 90 dB_{ht} and 75 dB_{ht} contours for herring; 2.5 m diameter pile being driven at location 4.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	4
Pile driving energy (kJ)	1200
Species	Herring

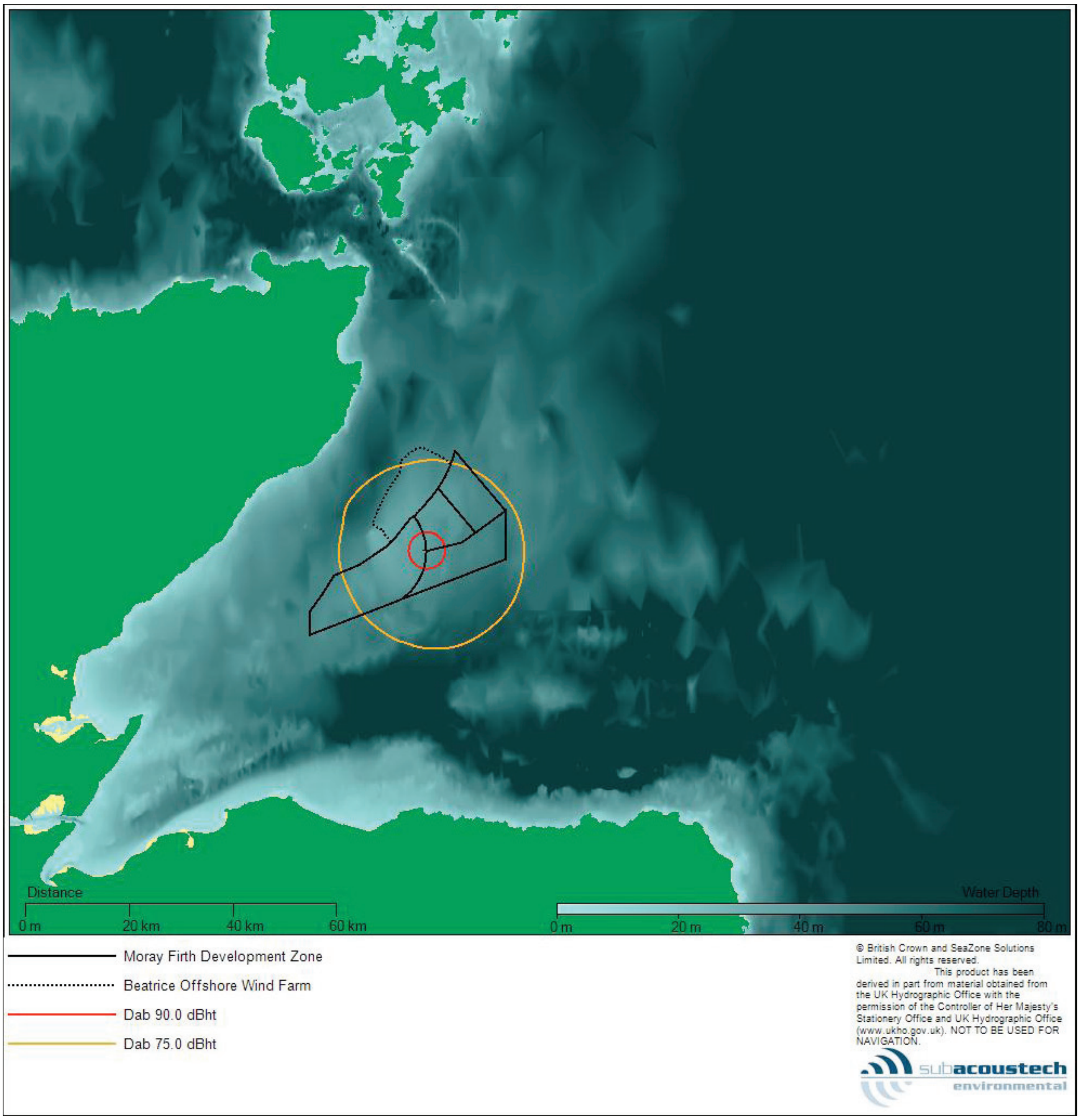


Figure A-54. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for plaice (dab used as surrogate); 2.5 m diameter pile being driven at location 4.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	4
Pile driving energy (kJ)	1200
Species	Plaice

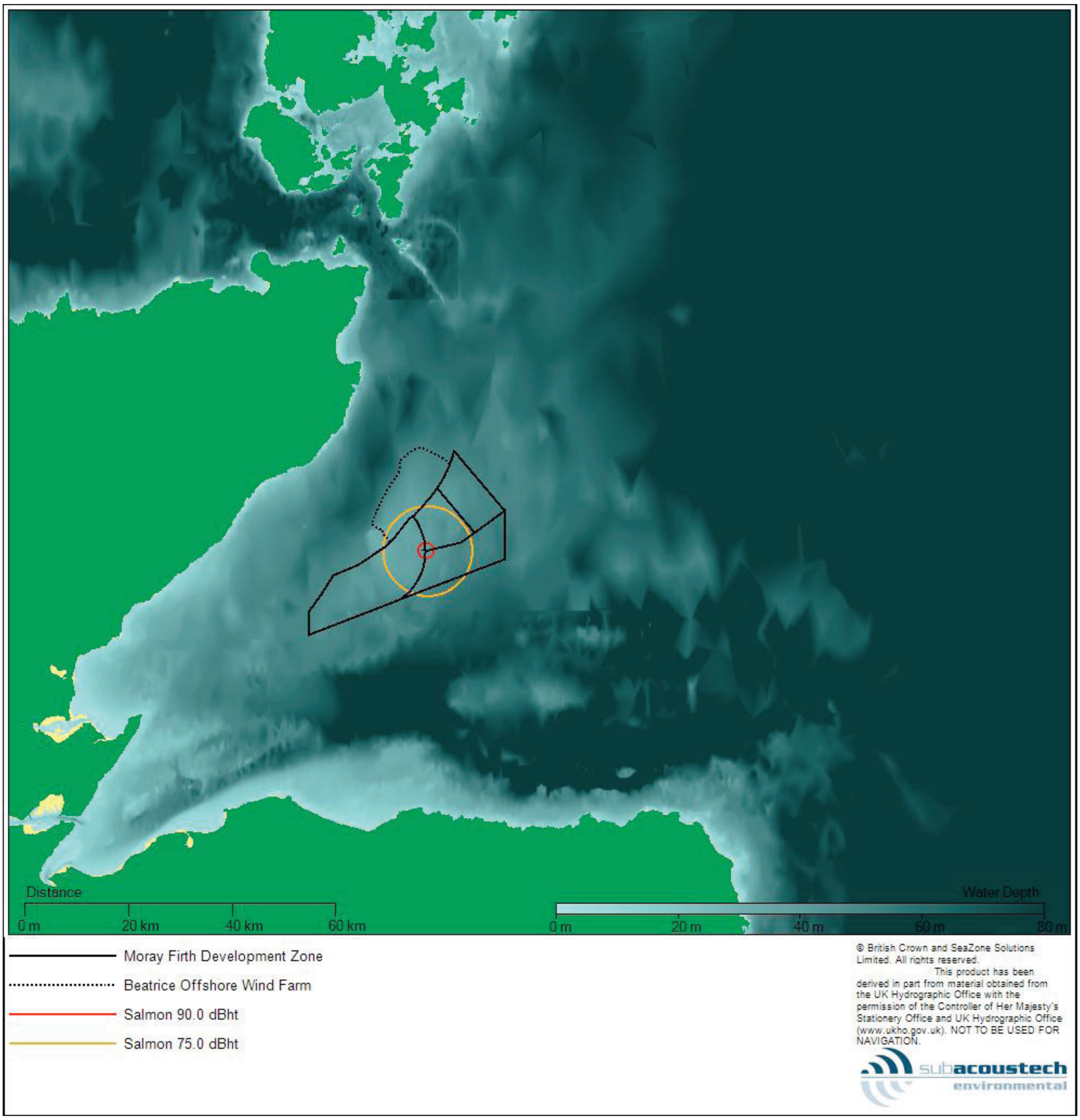


Figure A-55. 90 dB_{ht} and 75 dB_{ht} contours for salmon; 2.5 m diameter pile being driven at location 4.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	4
Pile driving energy (kJ)	1200
Species	Salmon

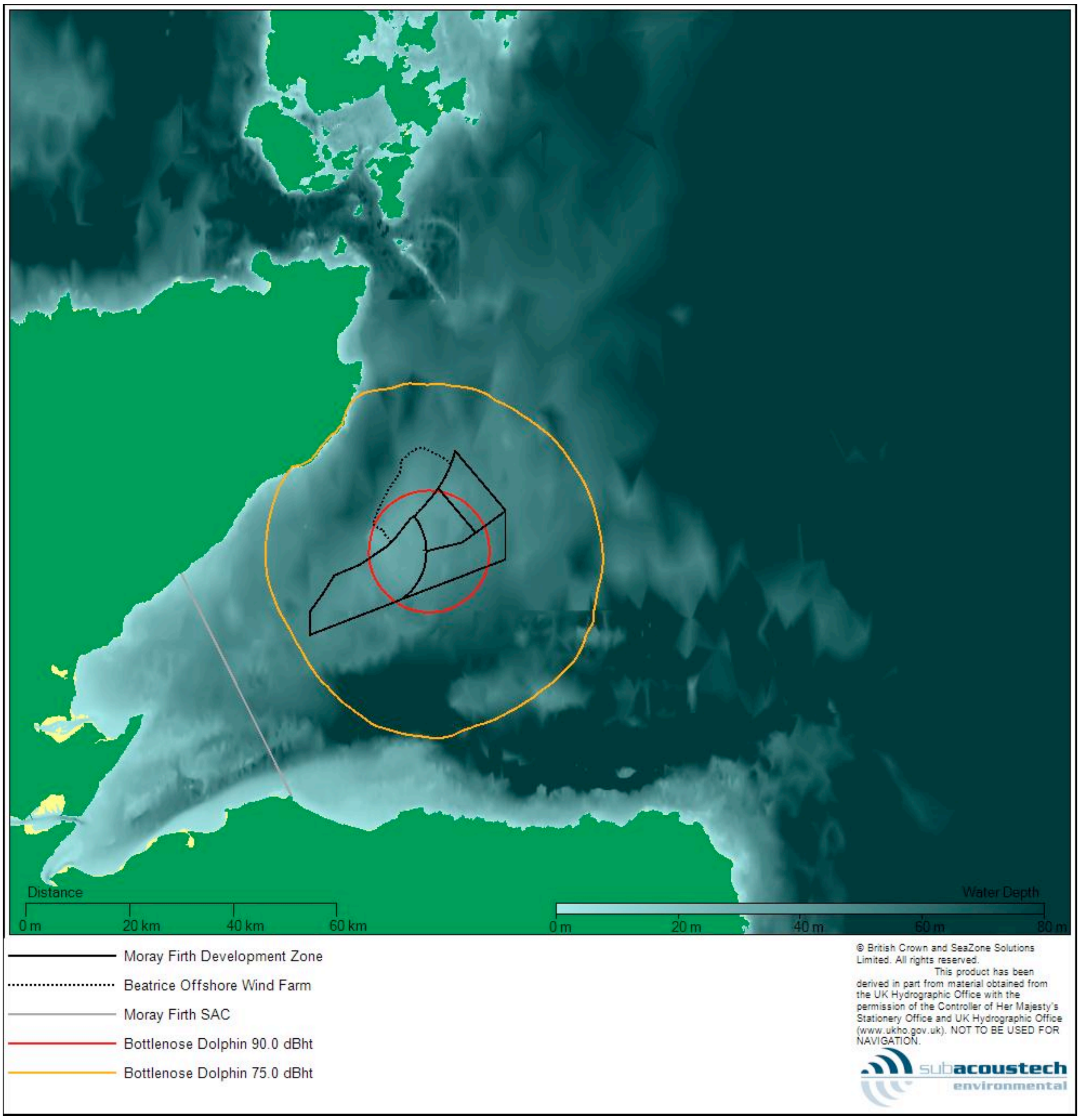


Figure A-56. 90 dB_{ht} and 75 dB_{ht} contours for bottlenose dolphin; 2.5 m diameter pile being driven at location 4.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	4
Pile driving energy (kJ)	1200
Species	Bottlenose Dolphin

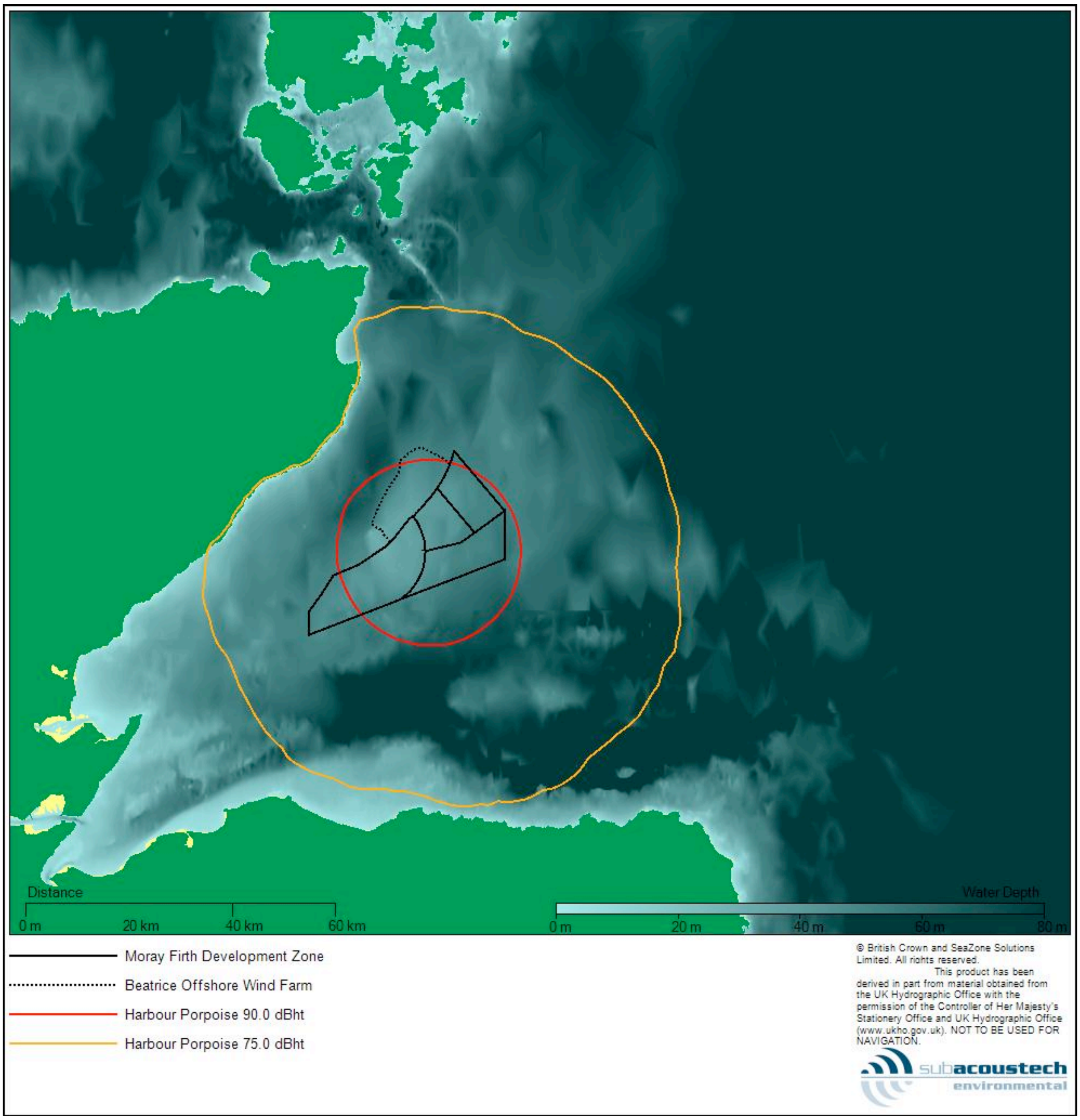


Figure A-57. 90 dB_{ht} and 75 dB_{ht} contours for harbour porpoise; 2.5 m diameter pile being driven at location 4.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	4
Pile driving energy (kJ)	1200
Species	Harbour Porpoise

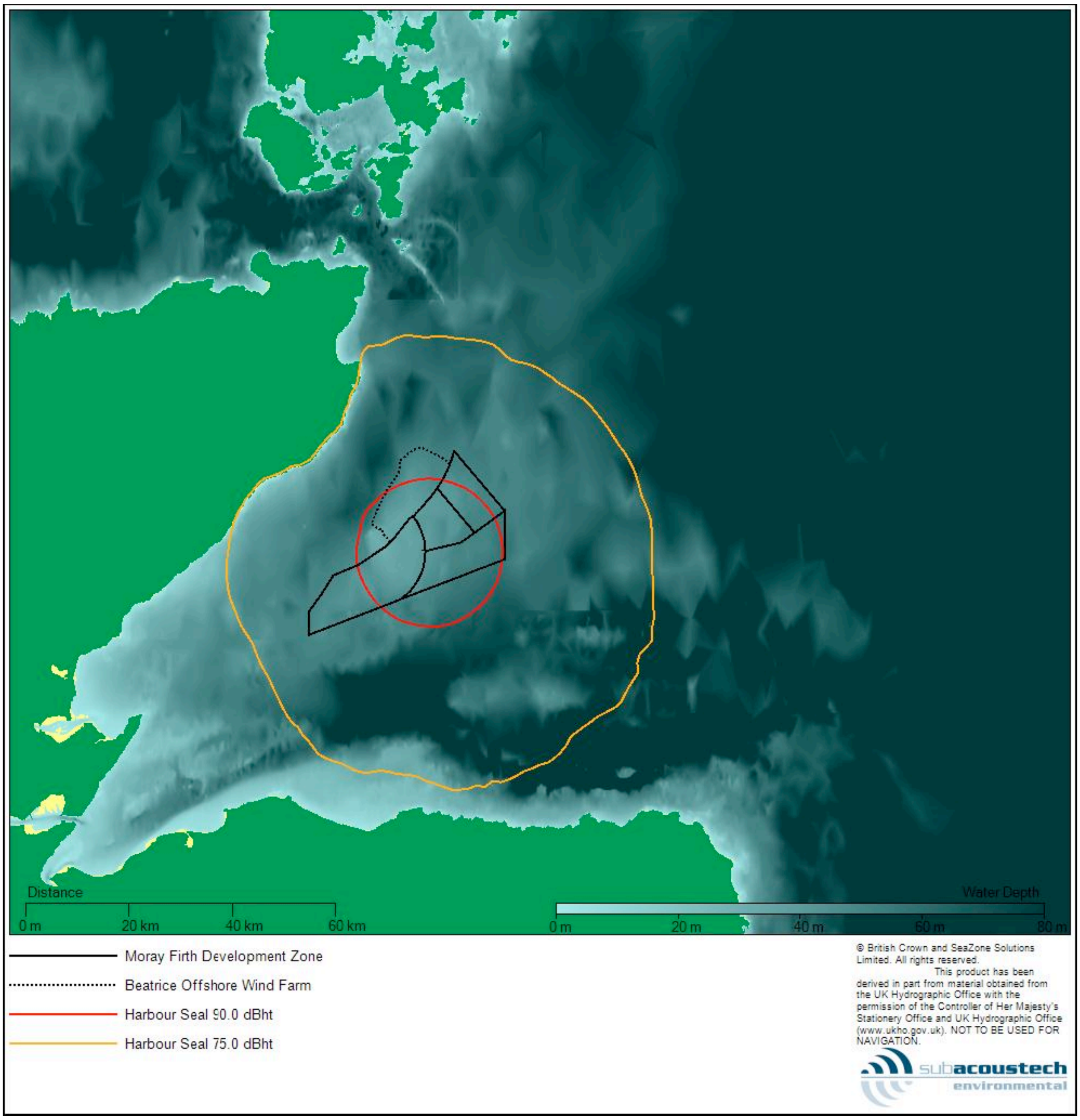


Figure A-58. 90 dB_{ht} and 75 dB_{ht} contours for harbour seal; 2.5 m diameter pile being driven at location 4.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	4
Pile driving energy (kJ)	1200
Species	Harbour Seal

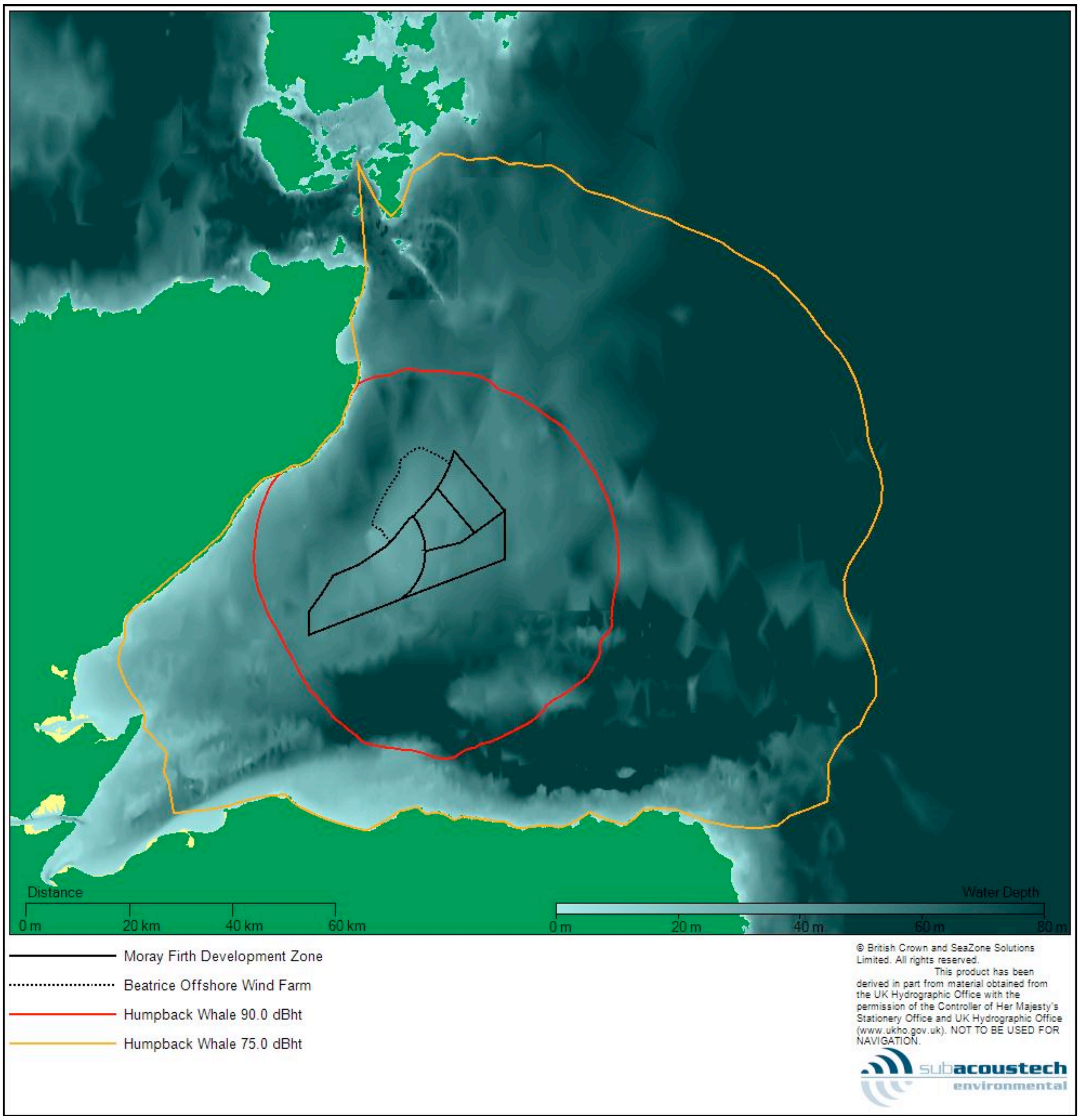


Figure A-59. 90 dB_{ht} and 75 dB_{ht} contours for minke whale (humpback whale used as surrogate); 2.5 m diameter pile being driven at location 4.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	4
Pile driving energy (kJ)	1200
Species	Minke Whale

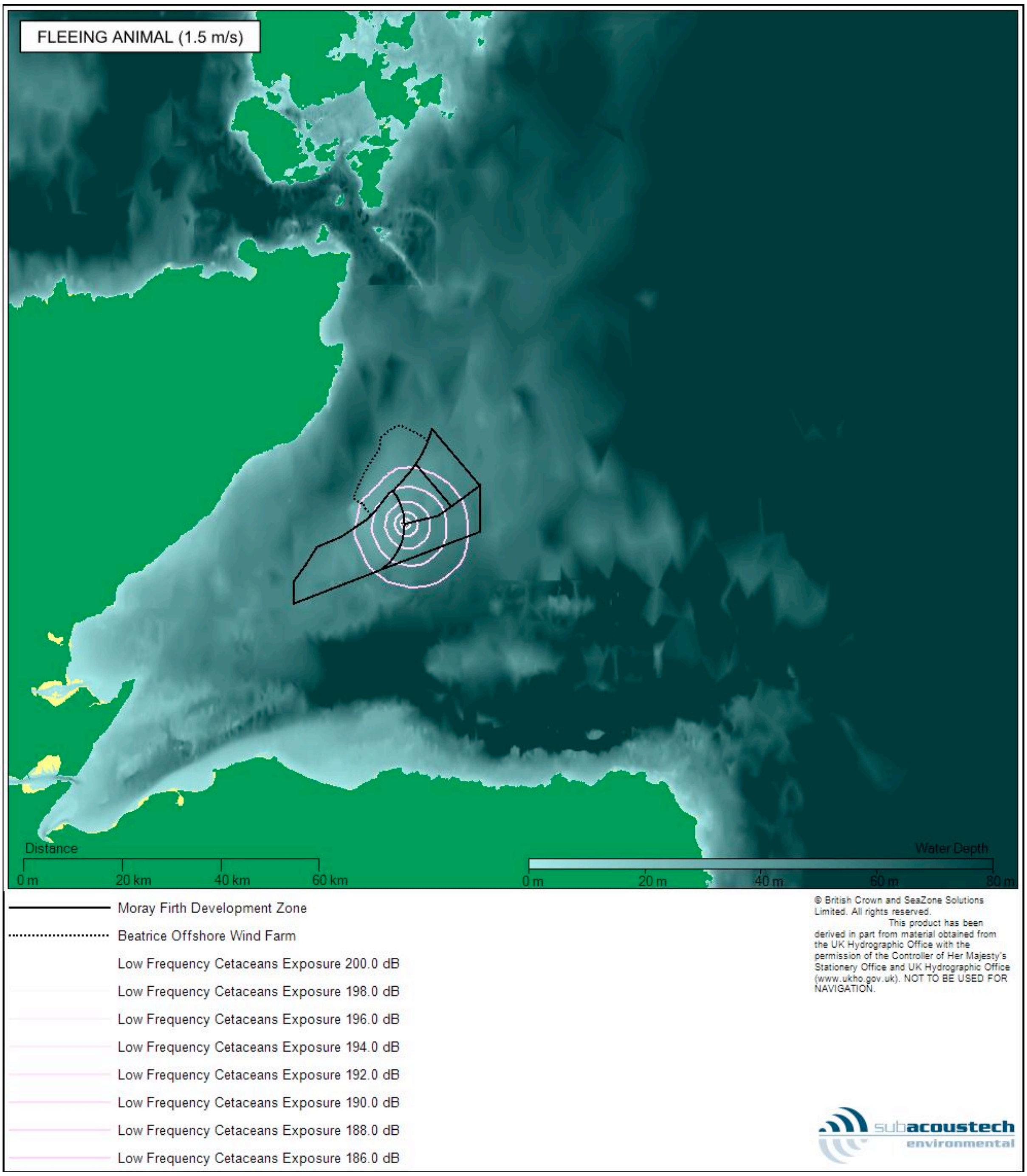


Figure A-60. Starting loci for fleeing Low Frequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 4.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	4
Pile driving energy (kJ)	1200
Species	Low Frequency Cetaceans (Fleeing 1.5m/s)

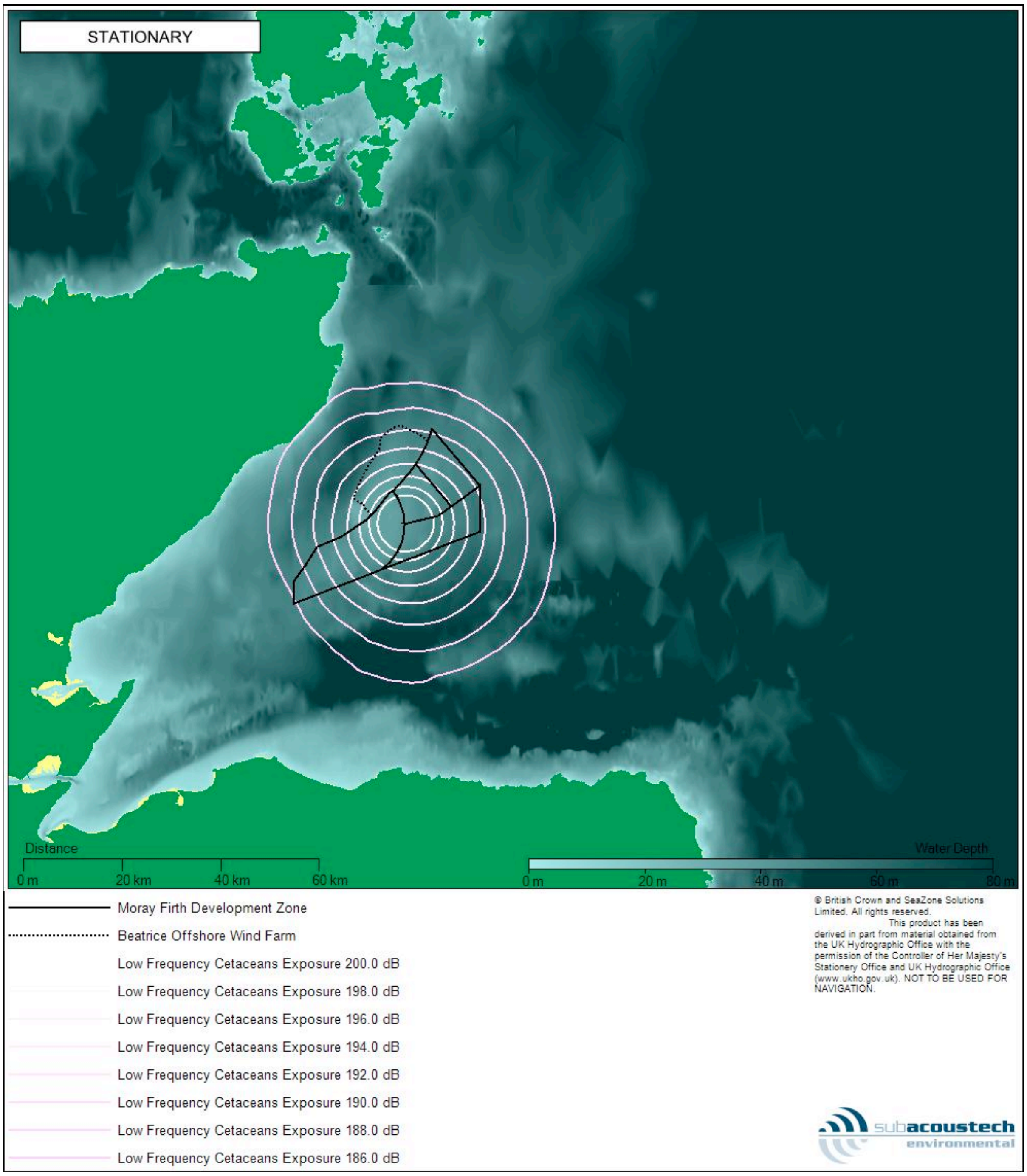


Figure A-61. Contours for stationary Low Frequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 4.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	4
Pile driving energy (kJ)	1200
Species	Low Frequency Cetaceans (Stationary)

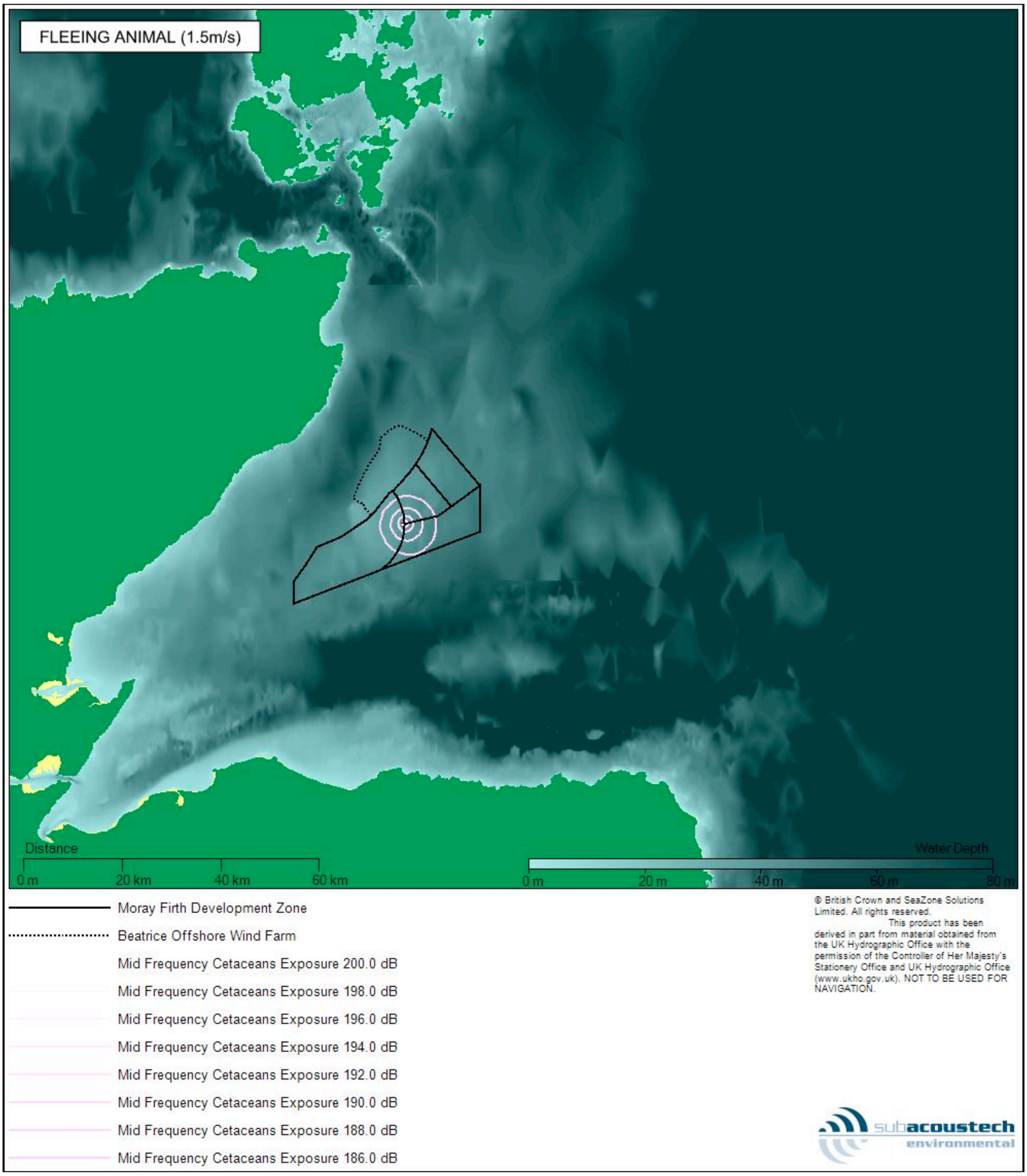


Figure A-62. Starting loci for fleeing Mid Frequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 4.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	4
Pile driving energy (kJ)	1200
Species	Mid Frequency Cetaceans (Fleeing 1.5m/s)

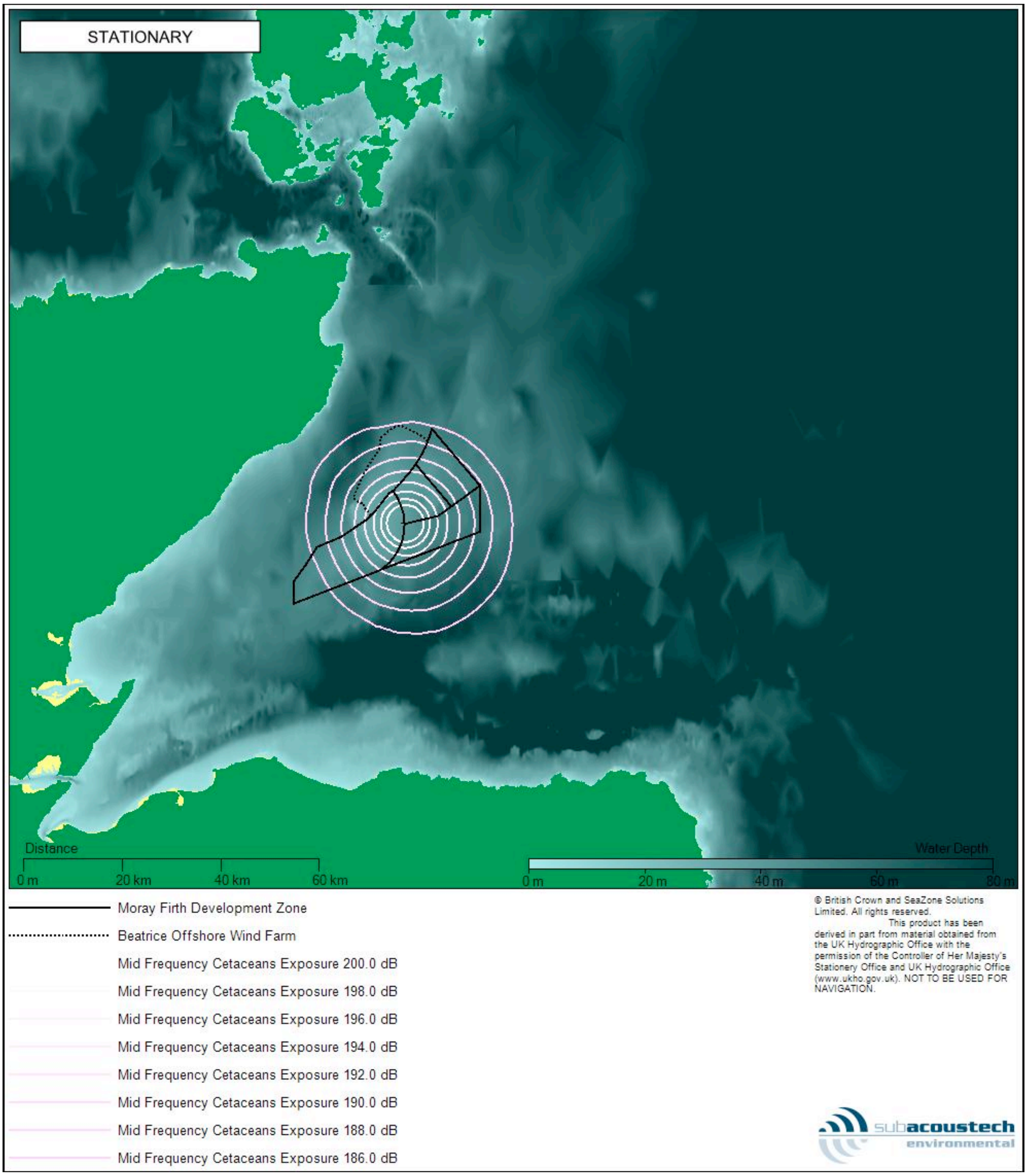


Figure A-63. Contours for stationary Mid Frequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 4.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	4
Pile driving energy (kJ)	1200
Species	Mid Frequency Cetaceans (Stationary)

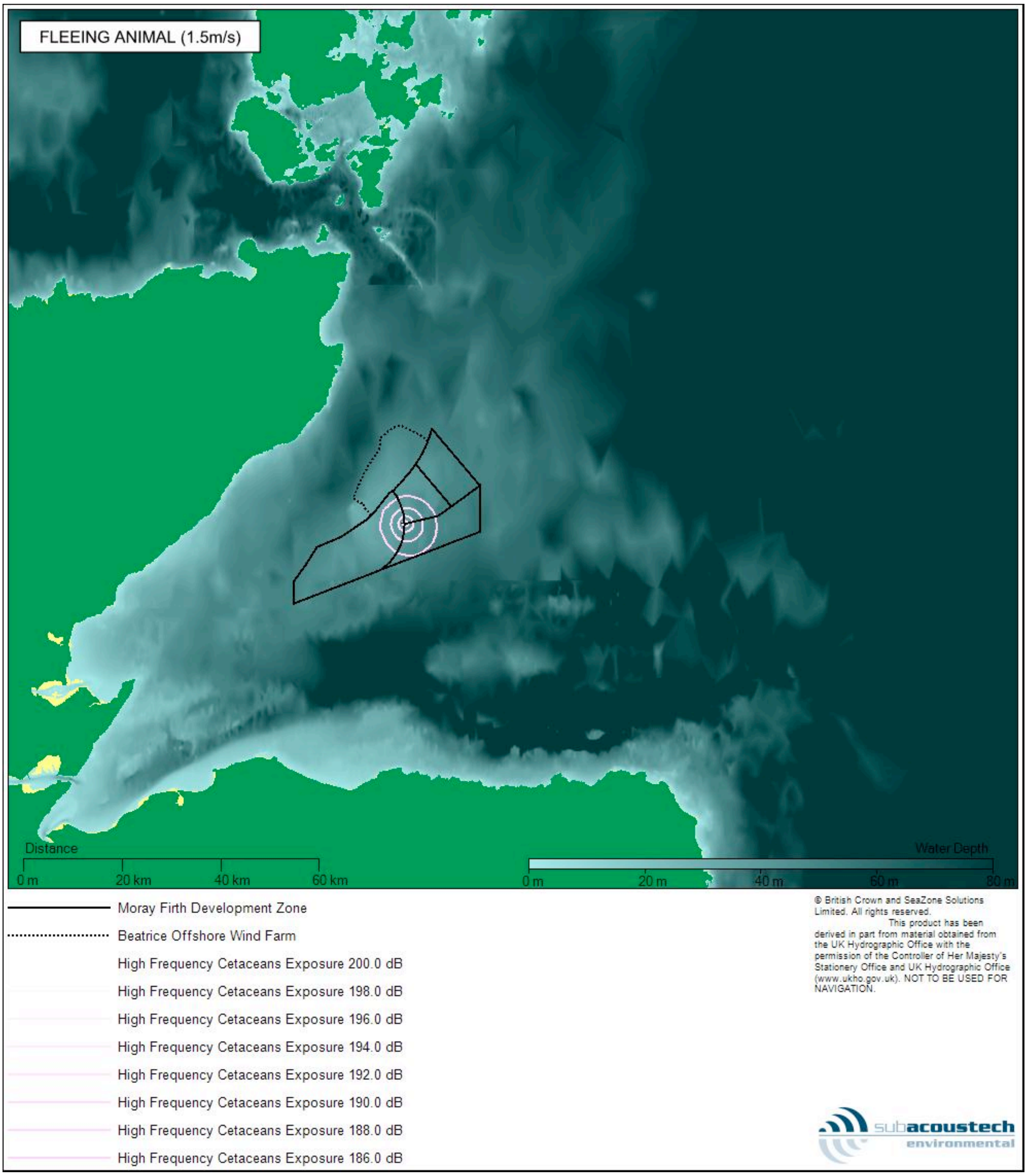


Figure A-64. Starting loci for fleeing High Frequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 4.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	4
Pile driving energy (kJ)	1200
Species	High Frequency Cetaceans (Fleeing 1.5m/s)

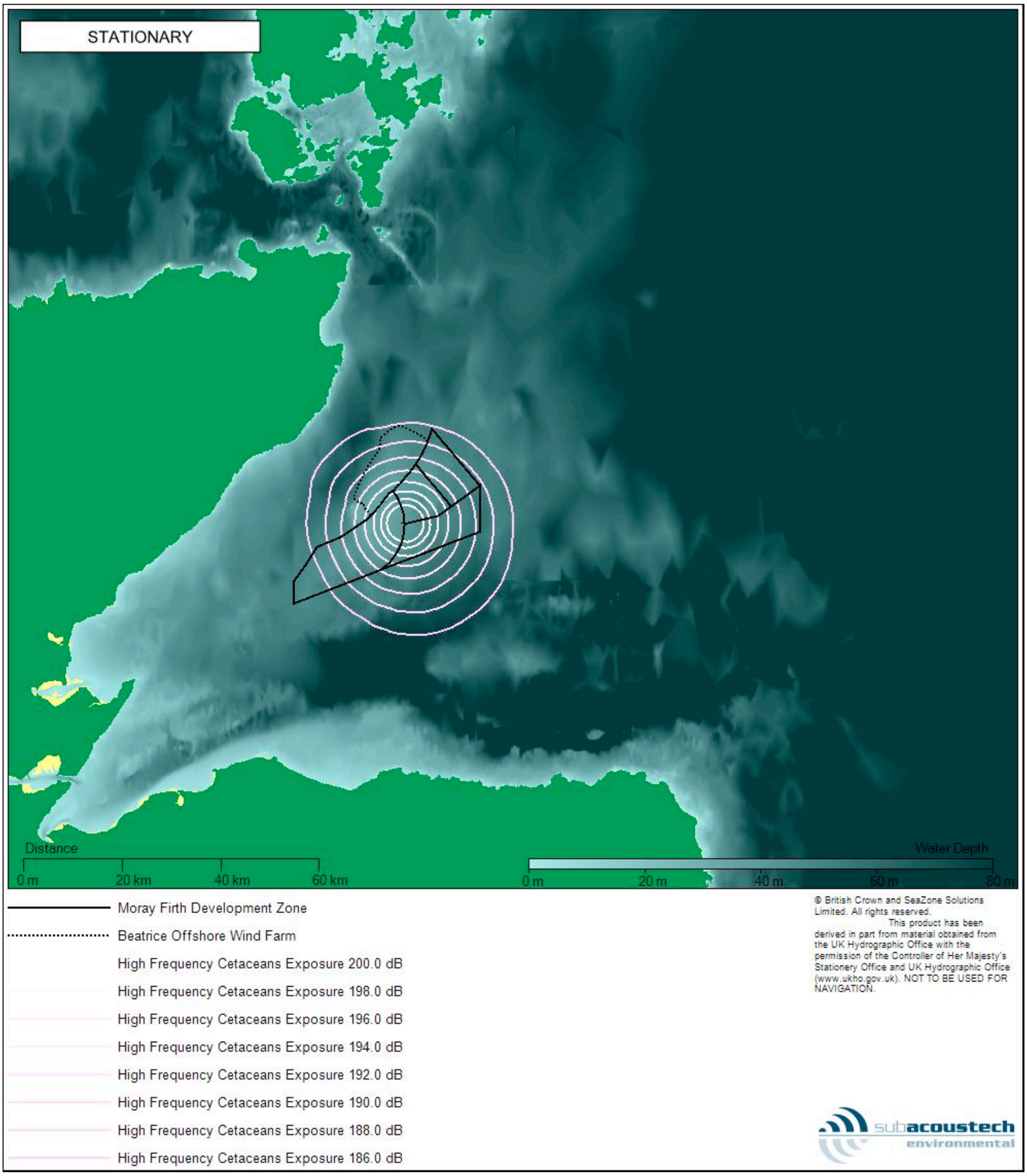


Figure A-65. Contours for stationary HighFrequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 4.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	4
Pile driving energy (kJ)	1200
Species	High Frequency Cetaceans (Stationary)

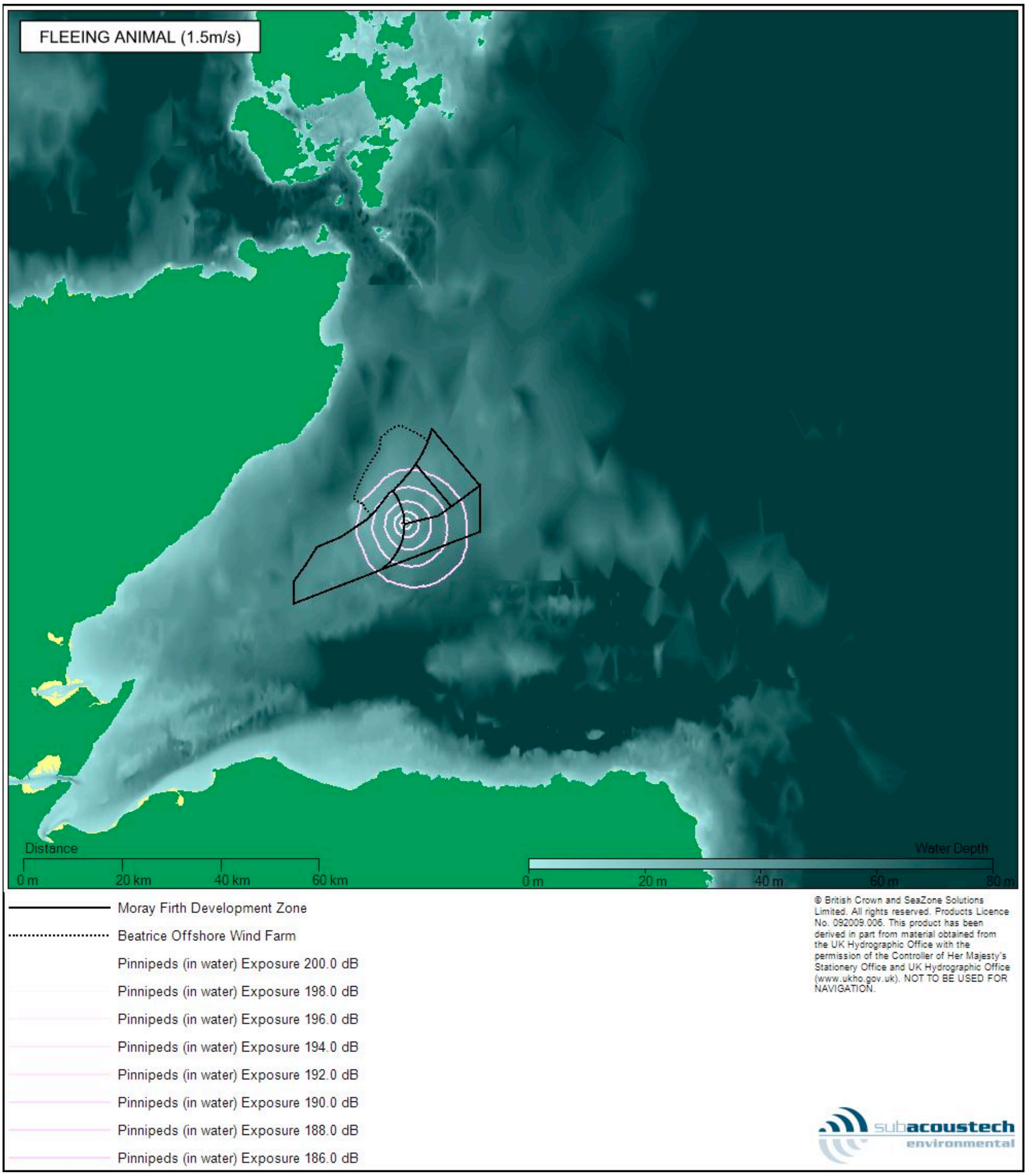


Figure A-66. Starting loci for fleeing Pinnipeds (in water); two 2.5 m diameter pin piles being driven sequentially at location 4.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	4
Pile driving energy (kJ)	1200
Species	Pinnipeds (in water) (Fleeing 1.5m/s)

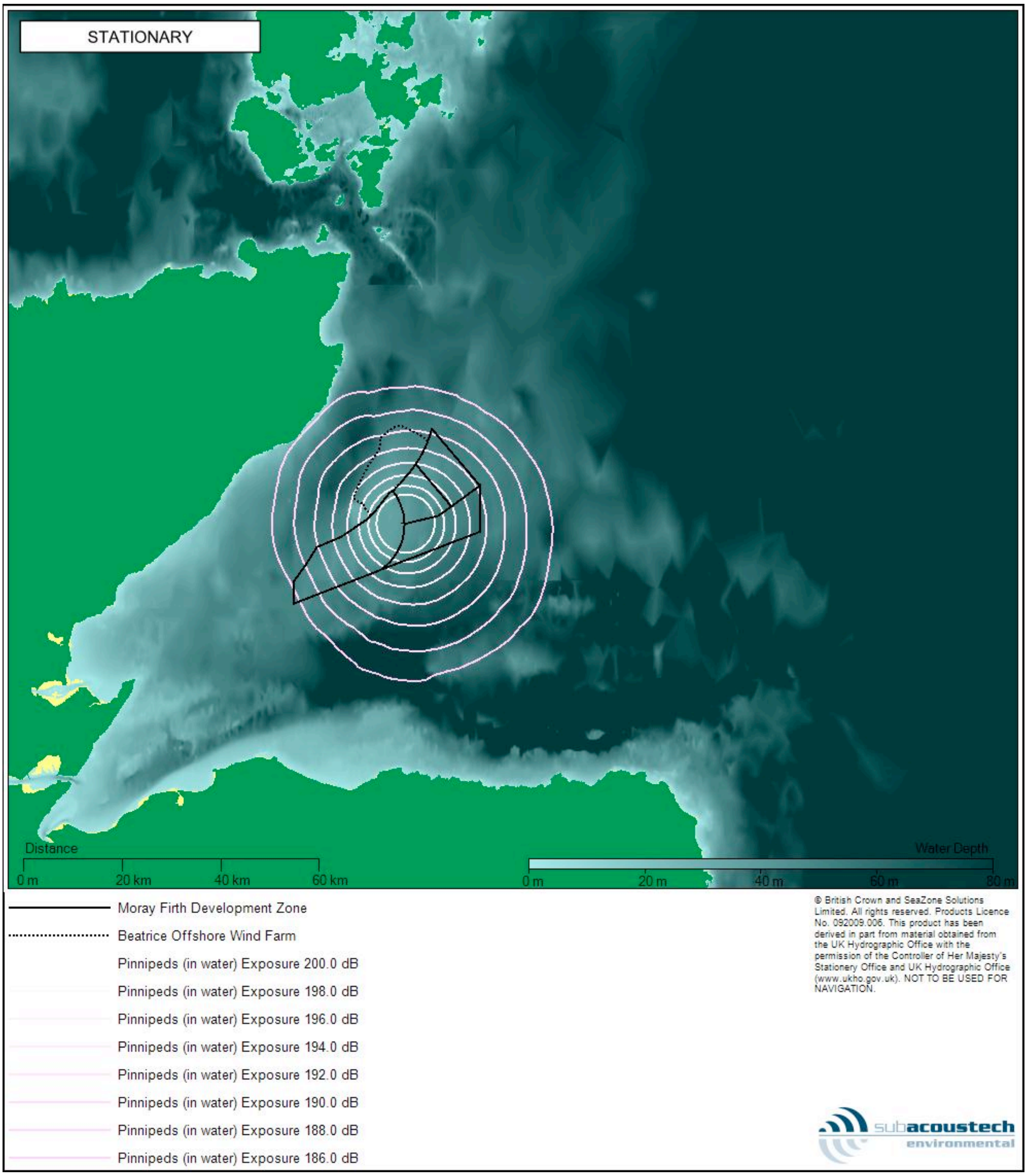


Figure A-67. Contours for stationary Pinnipeds (in water); two 2.5 m diameter pin piles being driven sequentially at location 4.

Pile diameter (m)	2.5
Pile location (see map, Figure A.13)	4
Pile driving energy (kJ)	1200
Species	Pinnipeds (in water) (Stationary)

9.1.2.4 Results for 2 pin piles being driven sequentially at 1 location on the Telford site

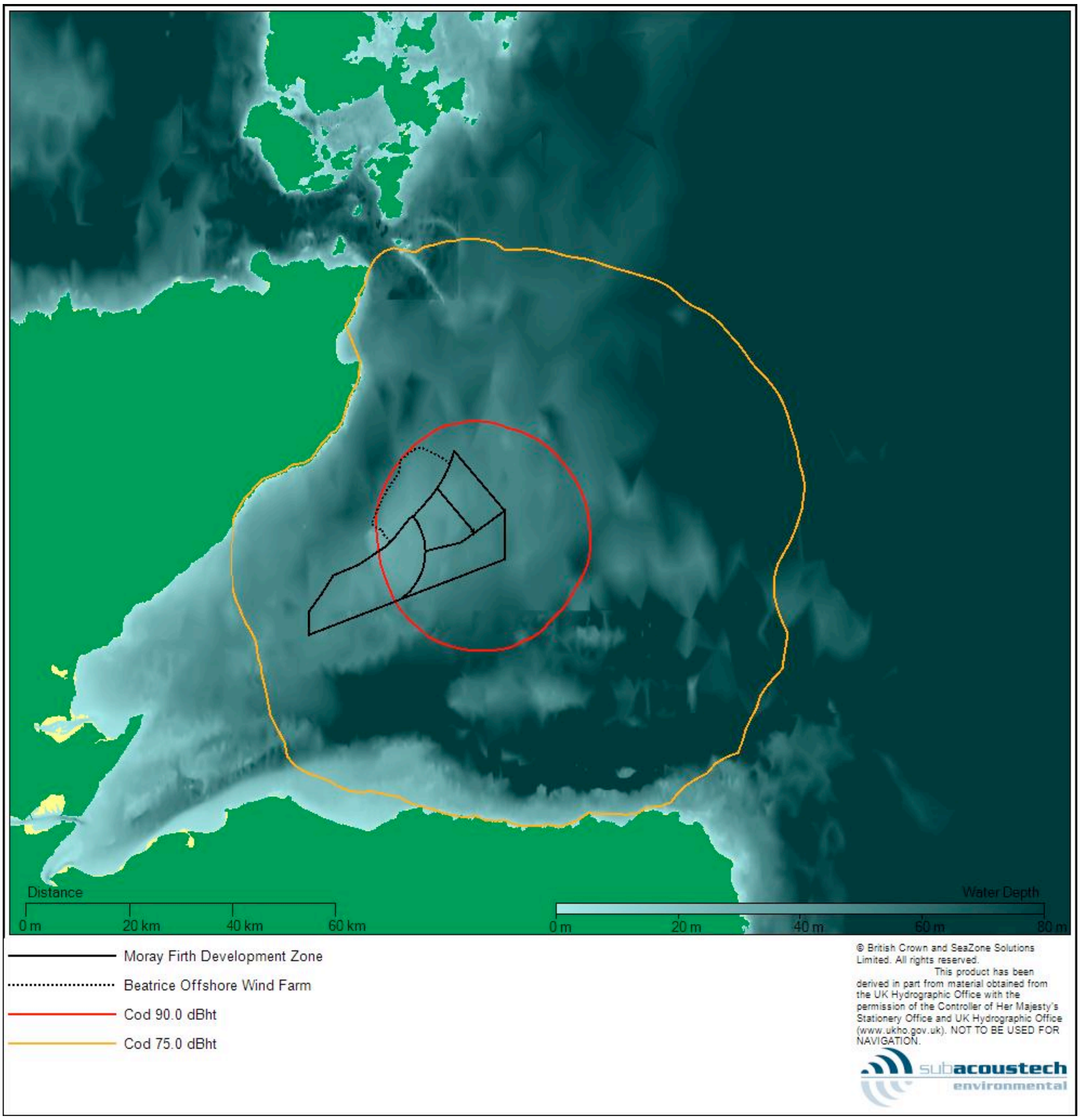


Figure A-68. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for cod; 2.5 m diameter pile being driven at location 3a.

Pile diameter (m)	2.5
Pile location (see map, Figure A.13)	3a
Pile driving energy (kJ)	1200
Species	Cod

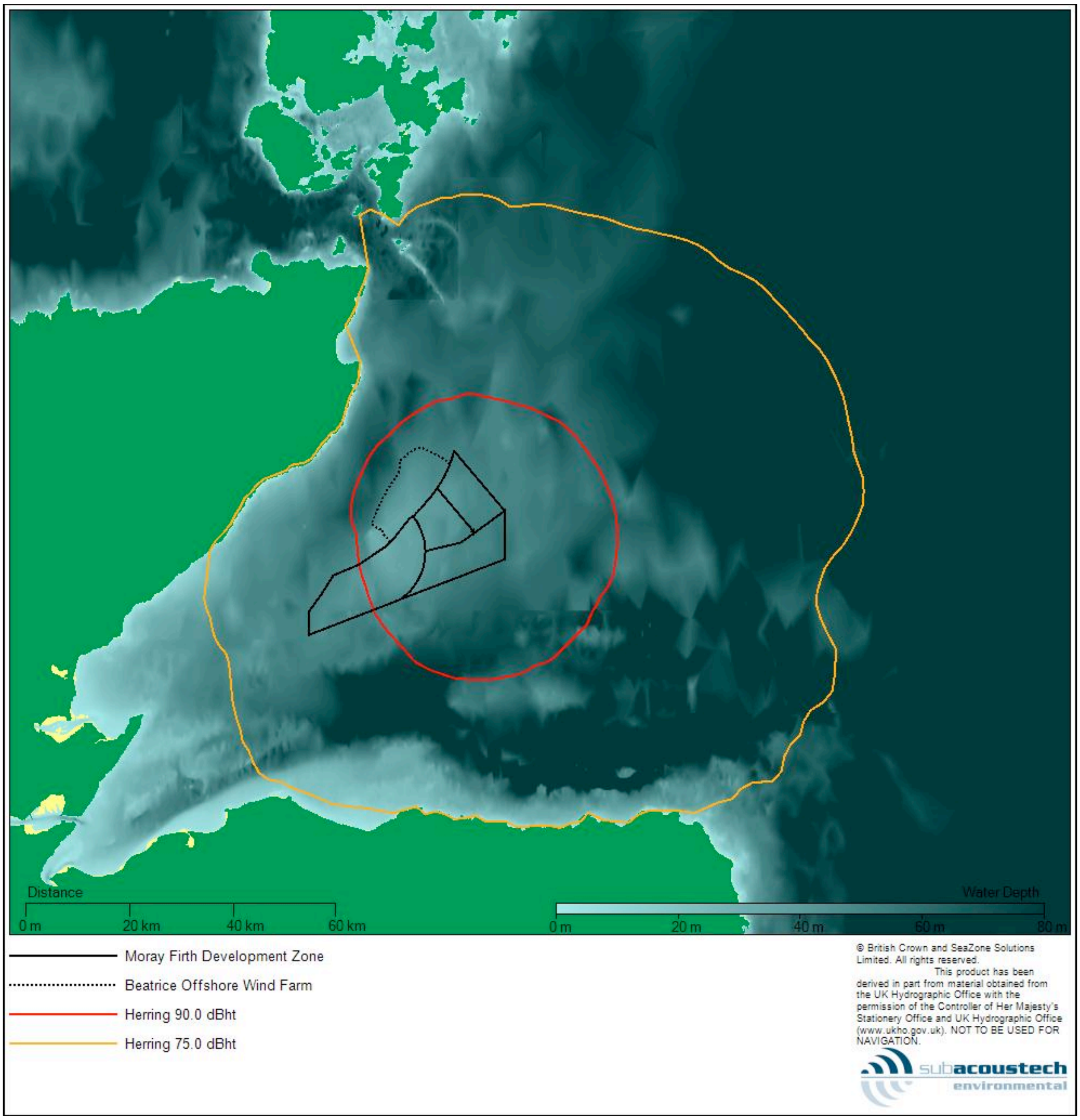


Figure A-69. 90 dB_{ht} and 75 dB_{ht} contours for herring; 2.5 m diameter pile being driven at location 3a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	3a
Pile driving energy (kJ)	1200
Species	Herring

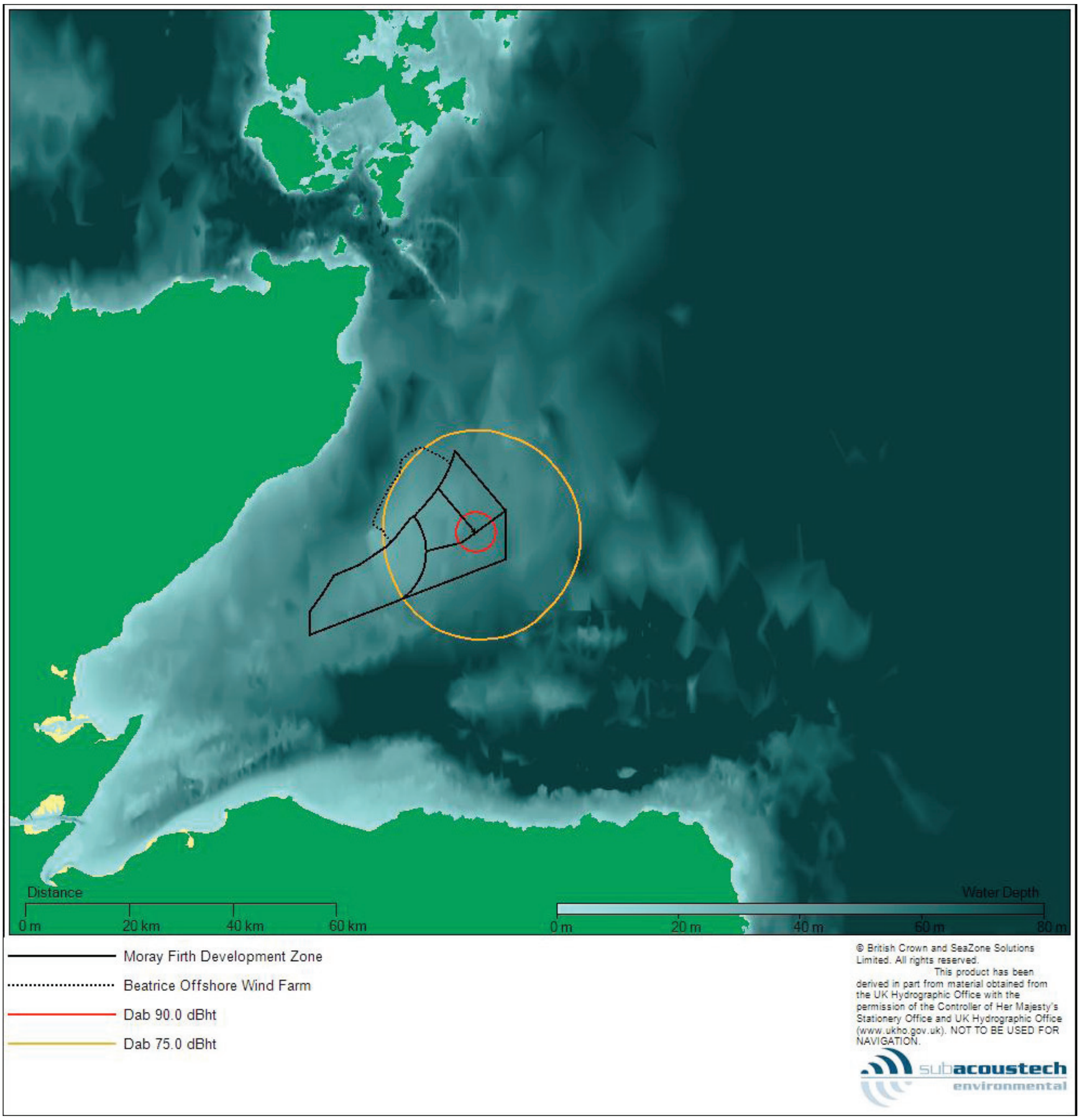


Figure A-70. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for plaice (dab used as surrogate); 2.5 m diameter pile being driven at location 3a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	3a
Pile driving energy (kJ)	1200
Species	Plaice

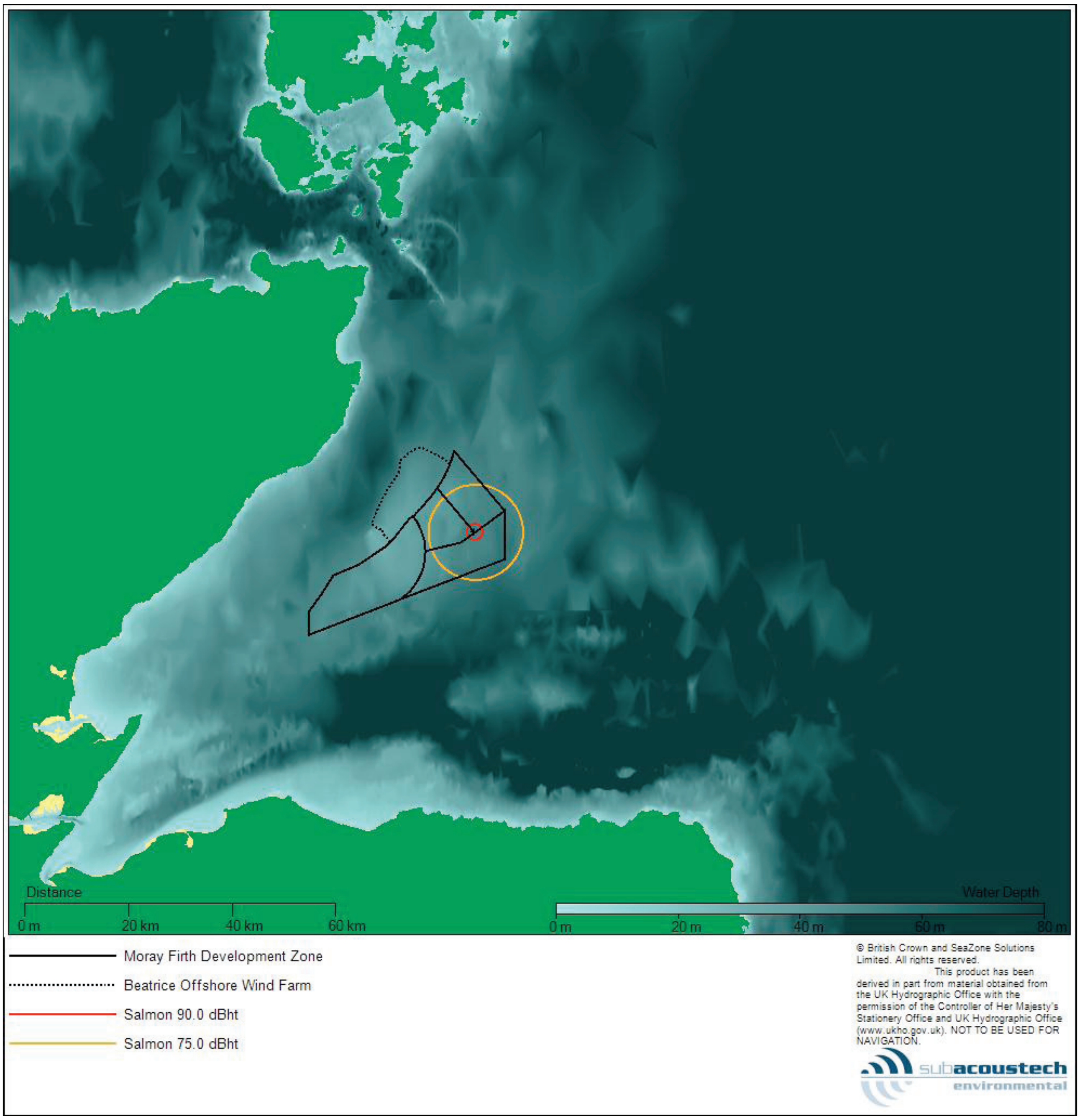


Figure A-71. 90 dB_{ht} and 75 dB_{ht} contours for salmon; 2.5 m diameter pile being driven at location 3a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	3a
Pile driving energy (kJ)	1200
Species	Salmon

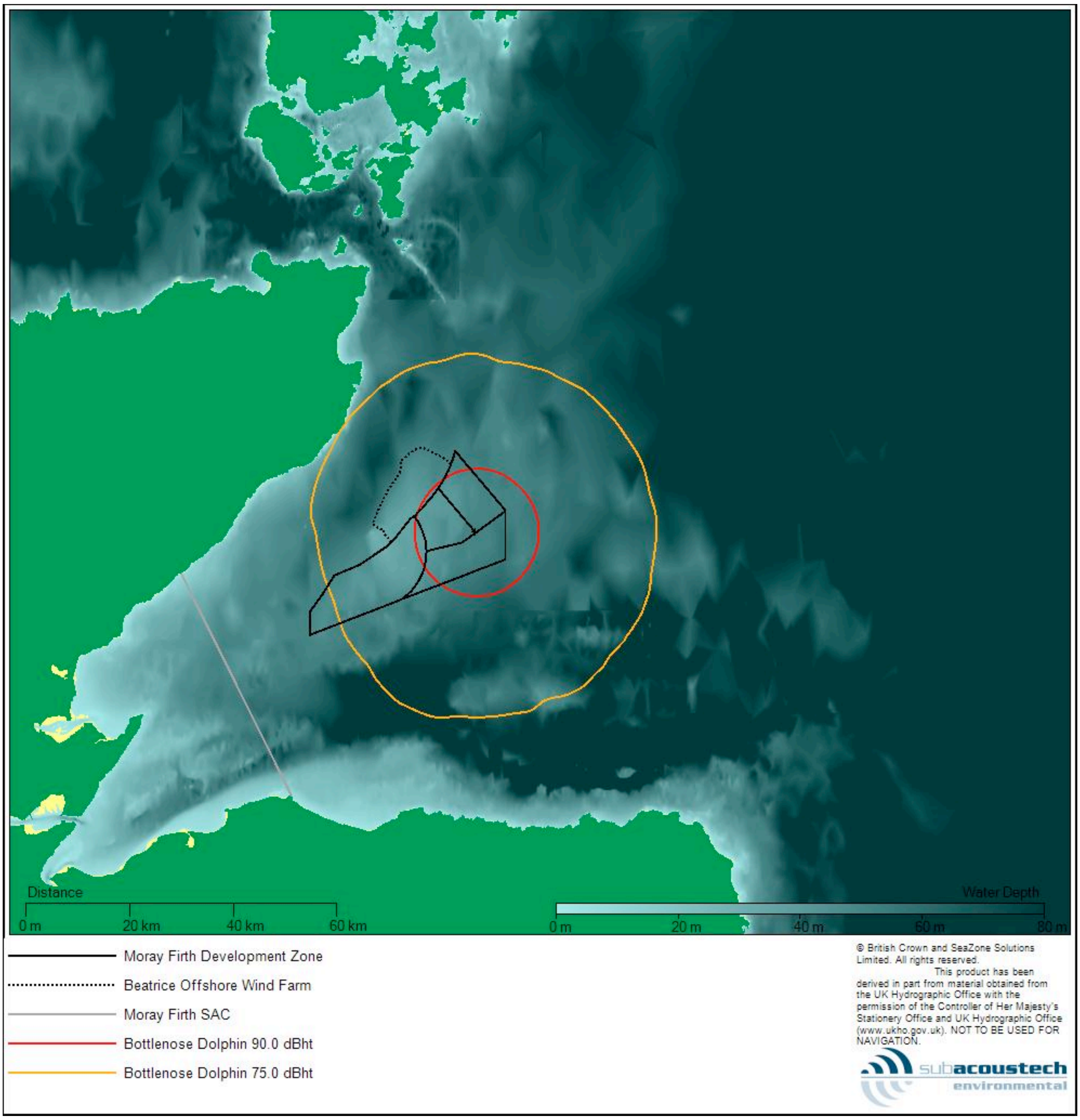


Figure A-72. 90 dB_{ht} and 75 dB_{ht} contours for bottlenose dolphin; 2.5 m diameter pile being driven at location 3a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	3a
Pile driving energy (kJ)	1200
Species	Bottlenose Dolphin

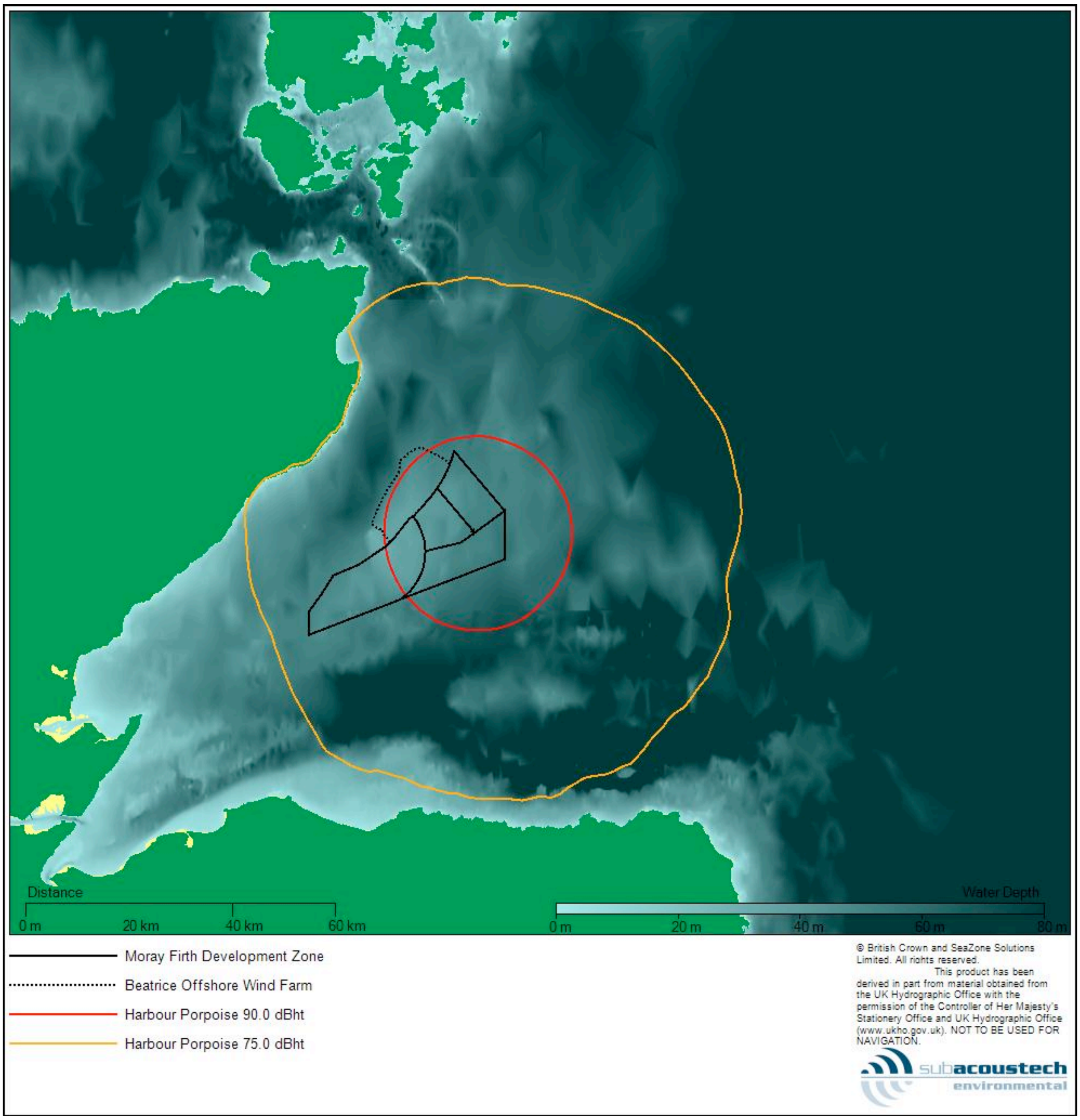


Figure A-73. 90 dB_{ht} and 75 dB_{ht} contours for harbour porpoise; 2.5 m diameter pile being driven at location 3a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	3a
Pile driving energy (kJ)	1200
Species	Harbour Porpoise

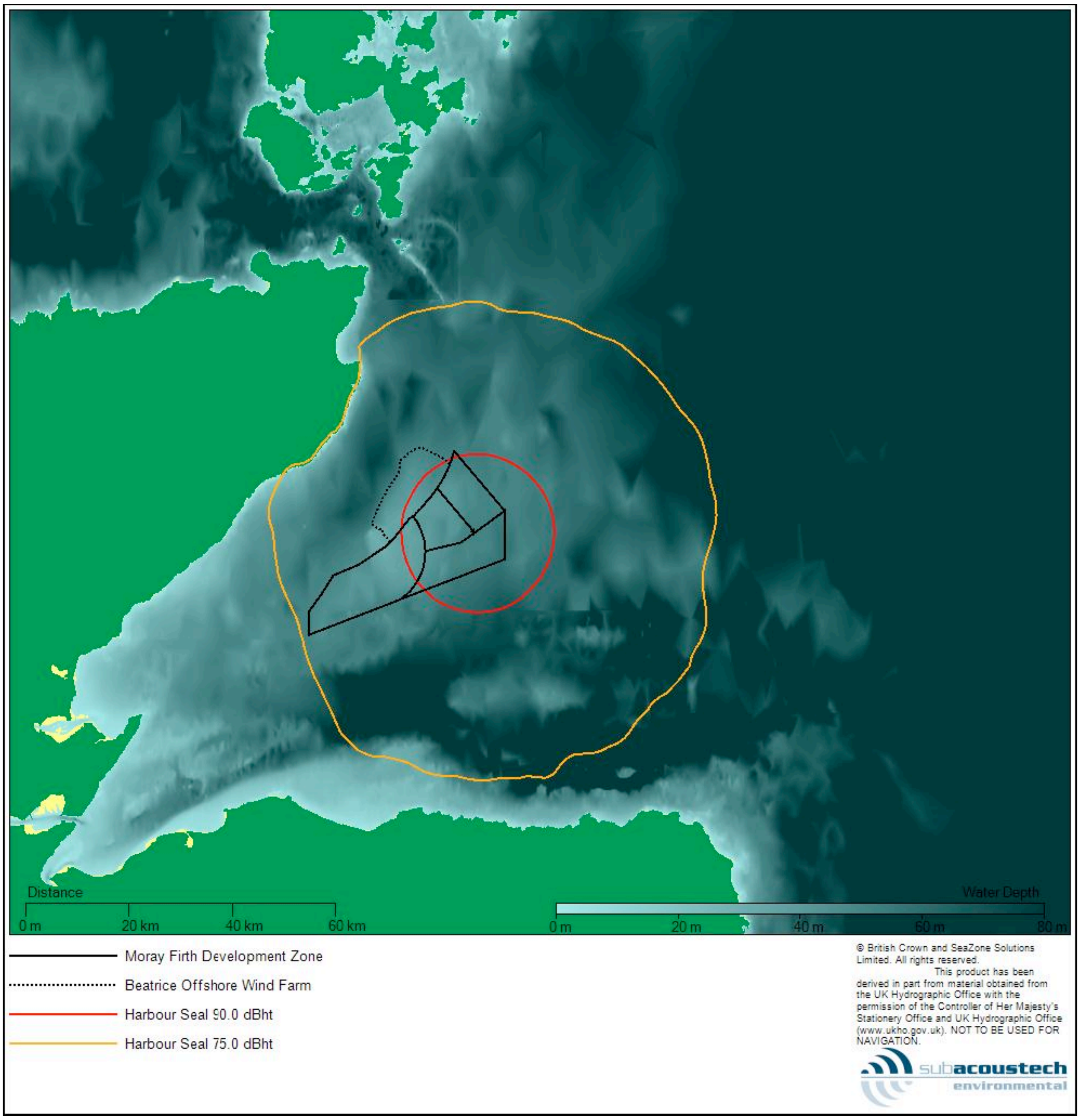


Figure A-74. 90 dB_{ht} and 75 dB_{ht} contours for harbour seal; 2.5 m diameter pile being driven at location 3a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	3a
Pile driving energy (kJ)	1200
Species	Harbour Seal

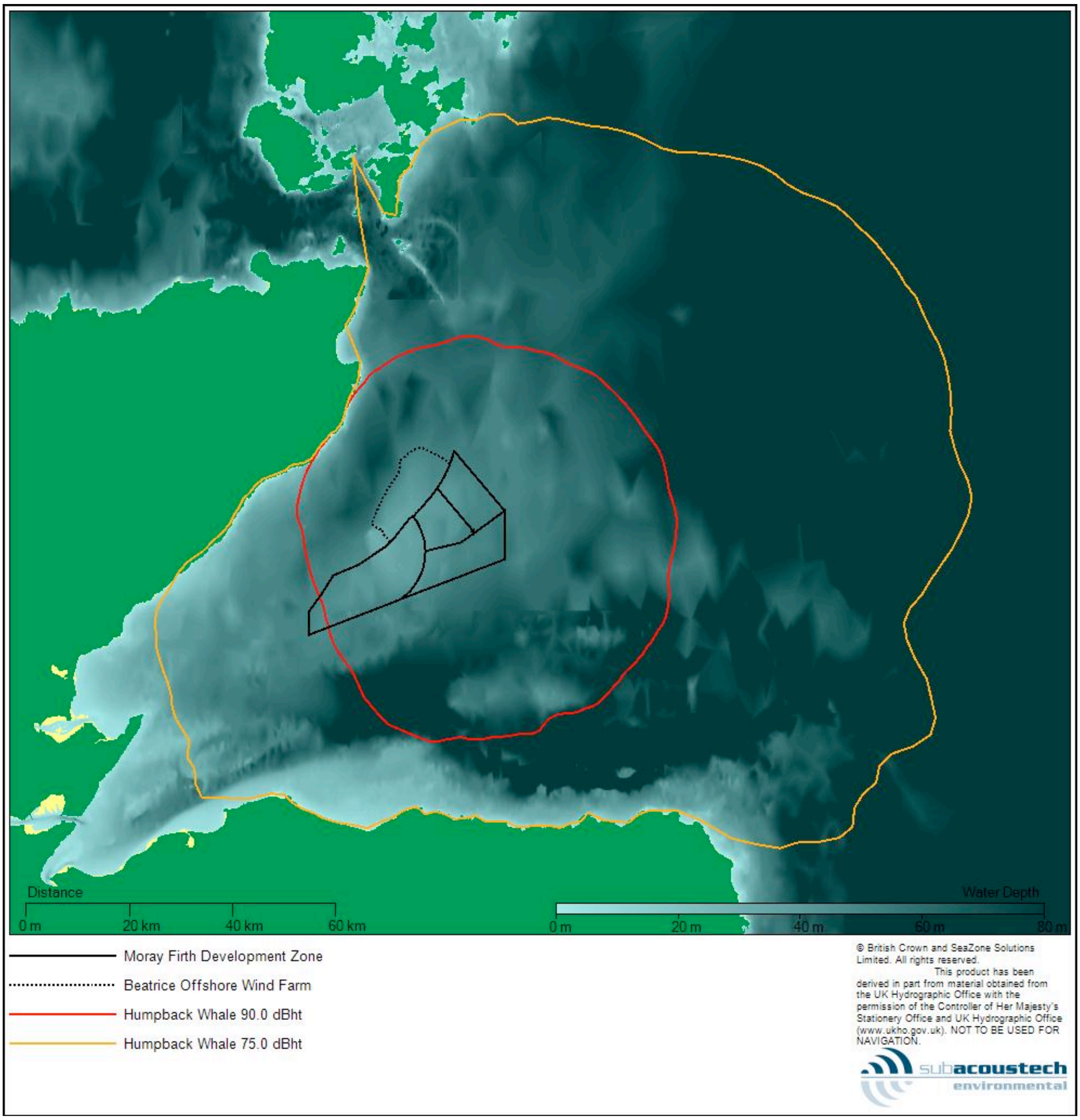


Figure A-75. 90 dB_{ht} and 75 dB_{ht} contours for minke whale (humpback whale used as surrogate); 2.5 m diameter pile being driven at location 3a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	3a
Pile driving energy (kJ)	1200
Species	Minke Whale

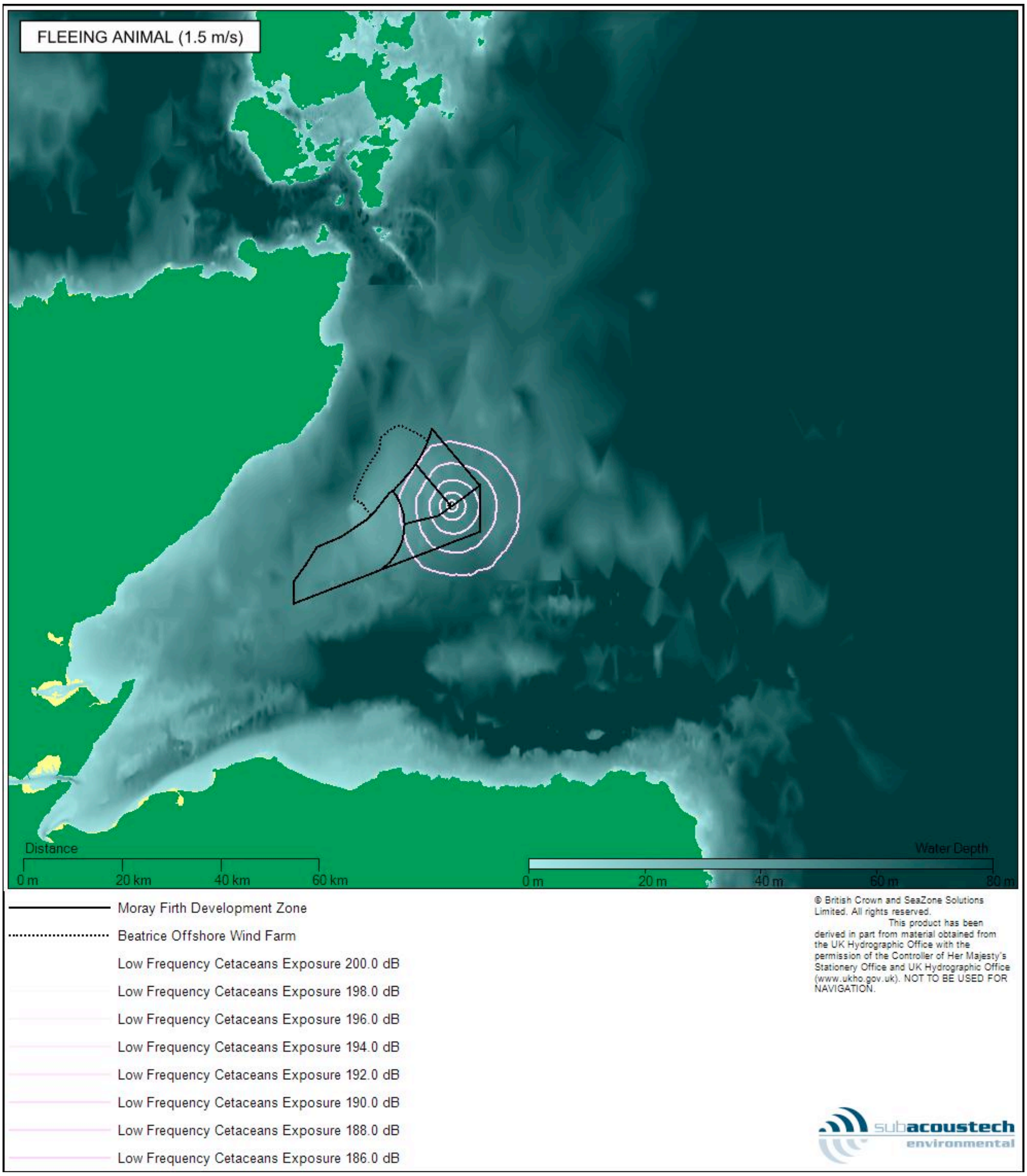


Figure A-76. Starting loci for fleeing Low Frequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 3a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	3a
Pile driving energy (kJ)	1200
Species	Low Frequency Cetaceans (Fleeing 1.5m/s)

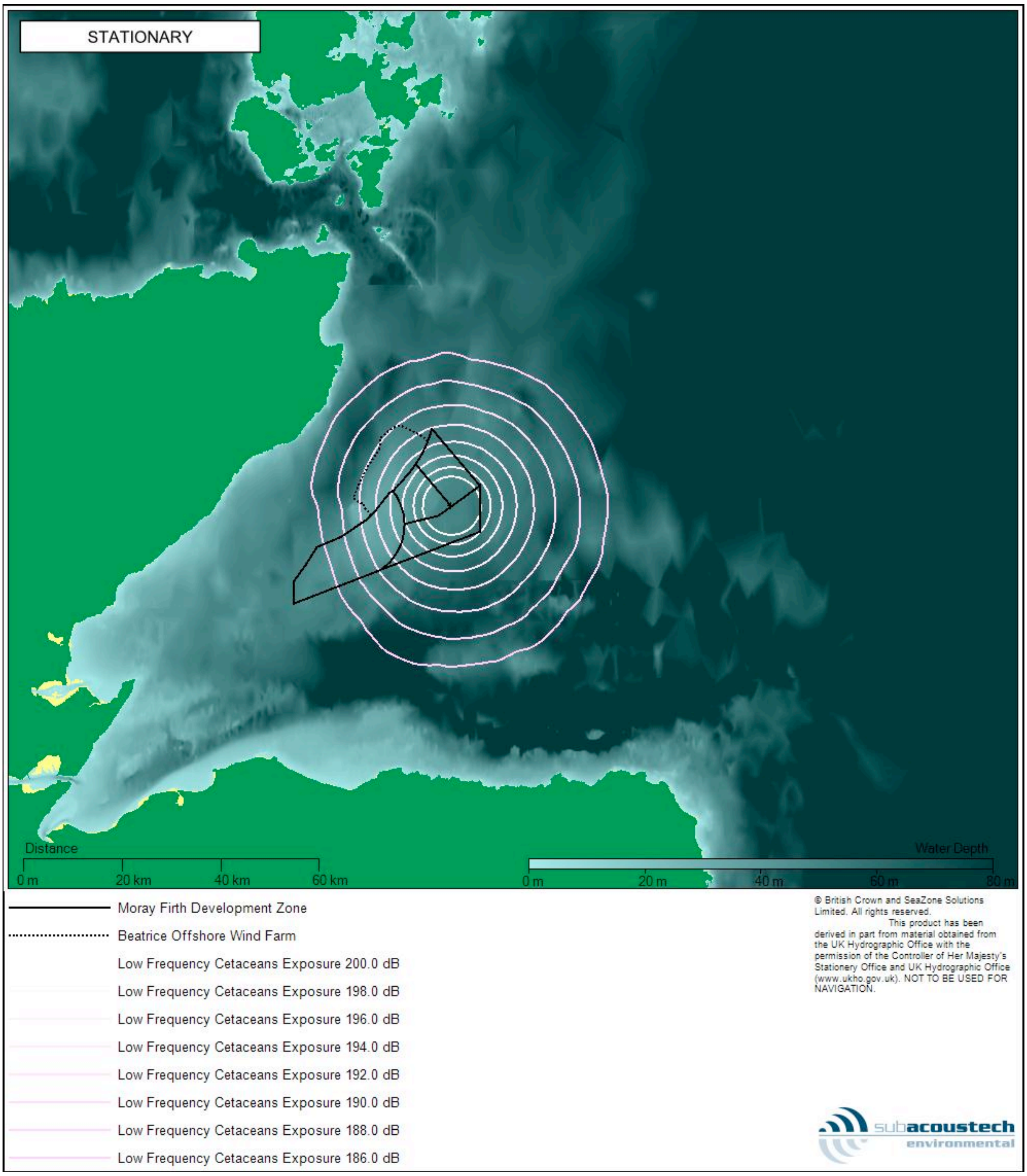


Figure A-77. Contours for stationary Low Frequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 3a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	3a
Pile driving energy (kJ)	1200
Species	Low Frequency Cetaceans (Stationary)

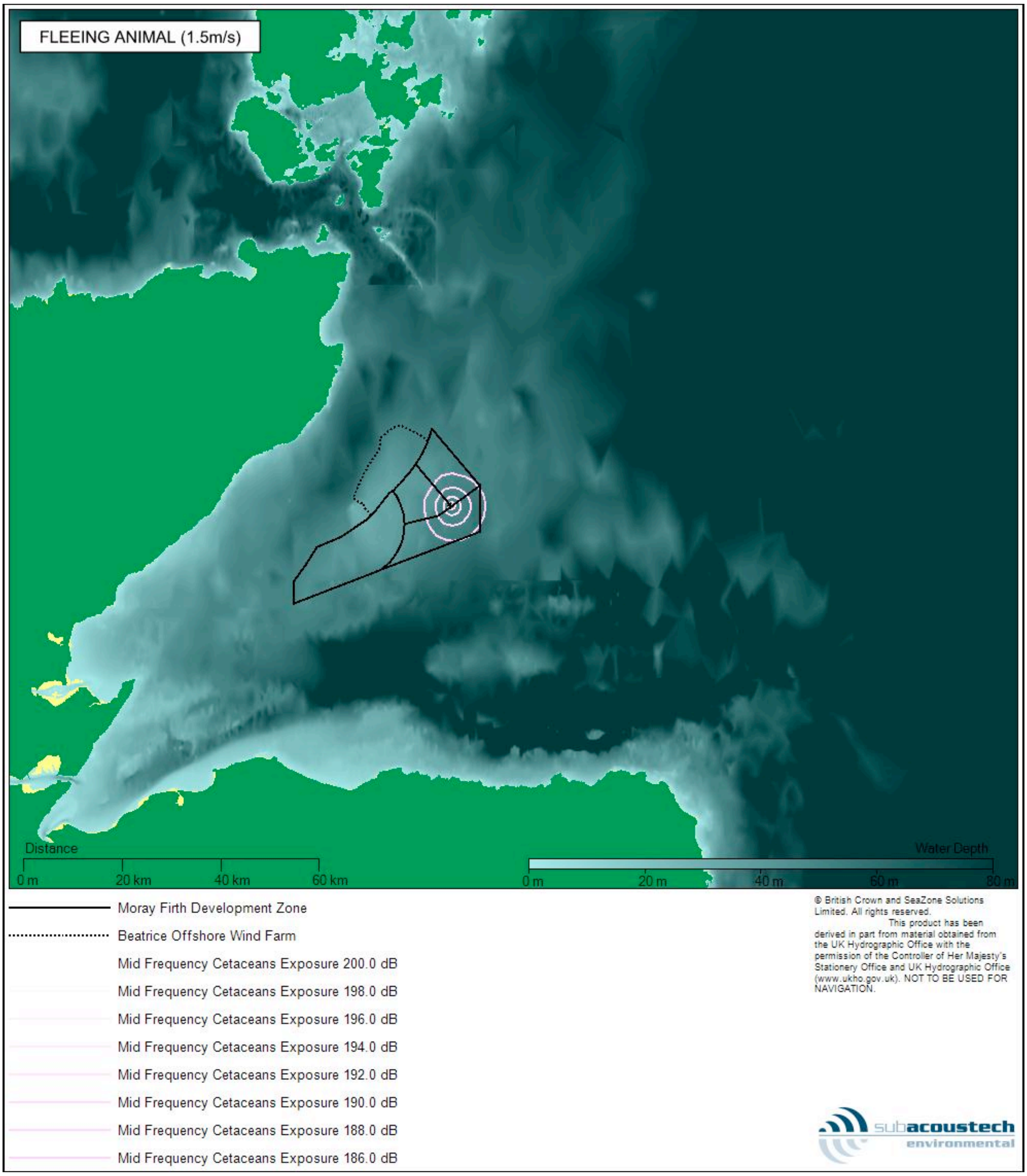


Figure A-78. Starting loci for fleeing Mid Frequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 3a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	3a
Pile driving energy (kJ)	1200
Species	Mid Frequency Cetaceans (Fleeing 1.5m/s)

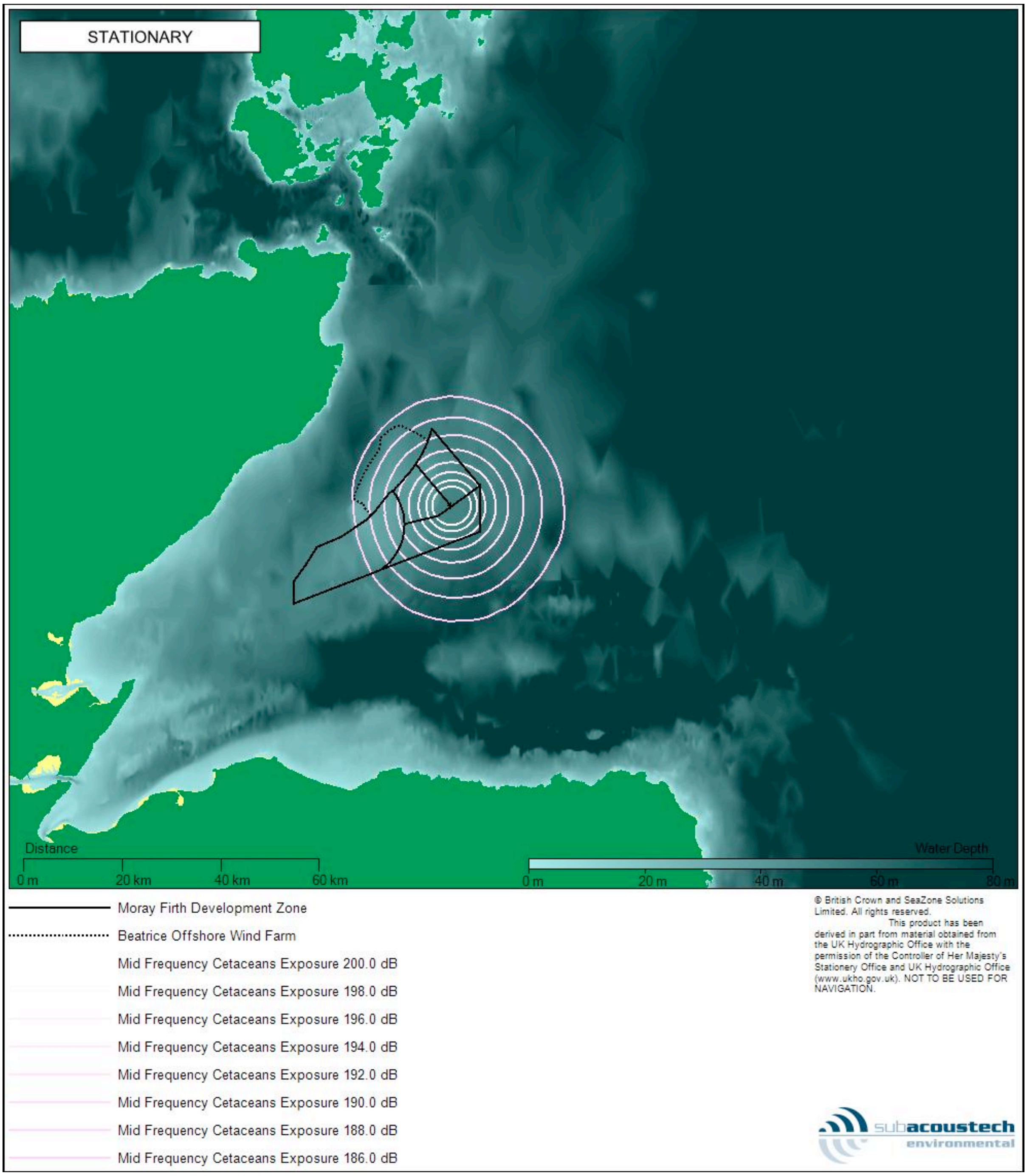


Figure A-79. Contours for stationary Mid Frequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 3a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	3a
Pile driving energy (kJ)	1200
Species	Mid Frequency Cetaceans (Stationary)

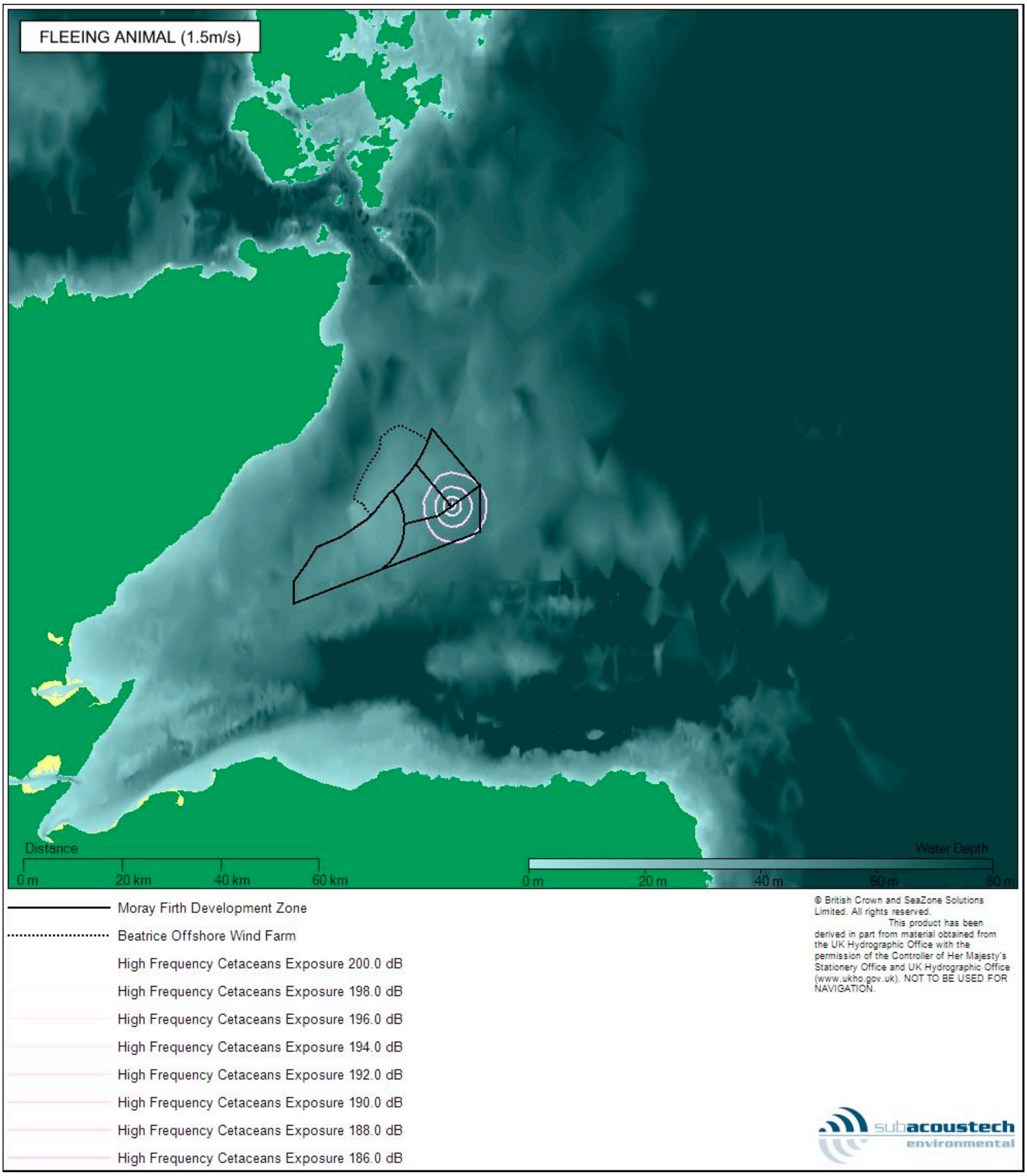


Figure A-80. Starting loci for fleeing High Frequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 3a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	3a
Pile driving energy (kJ)	1200
Species	High Frequency Cetaceans (Fleeing 1.5m/s)

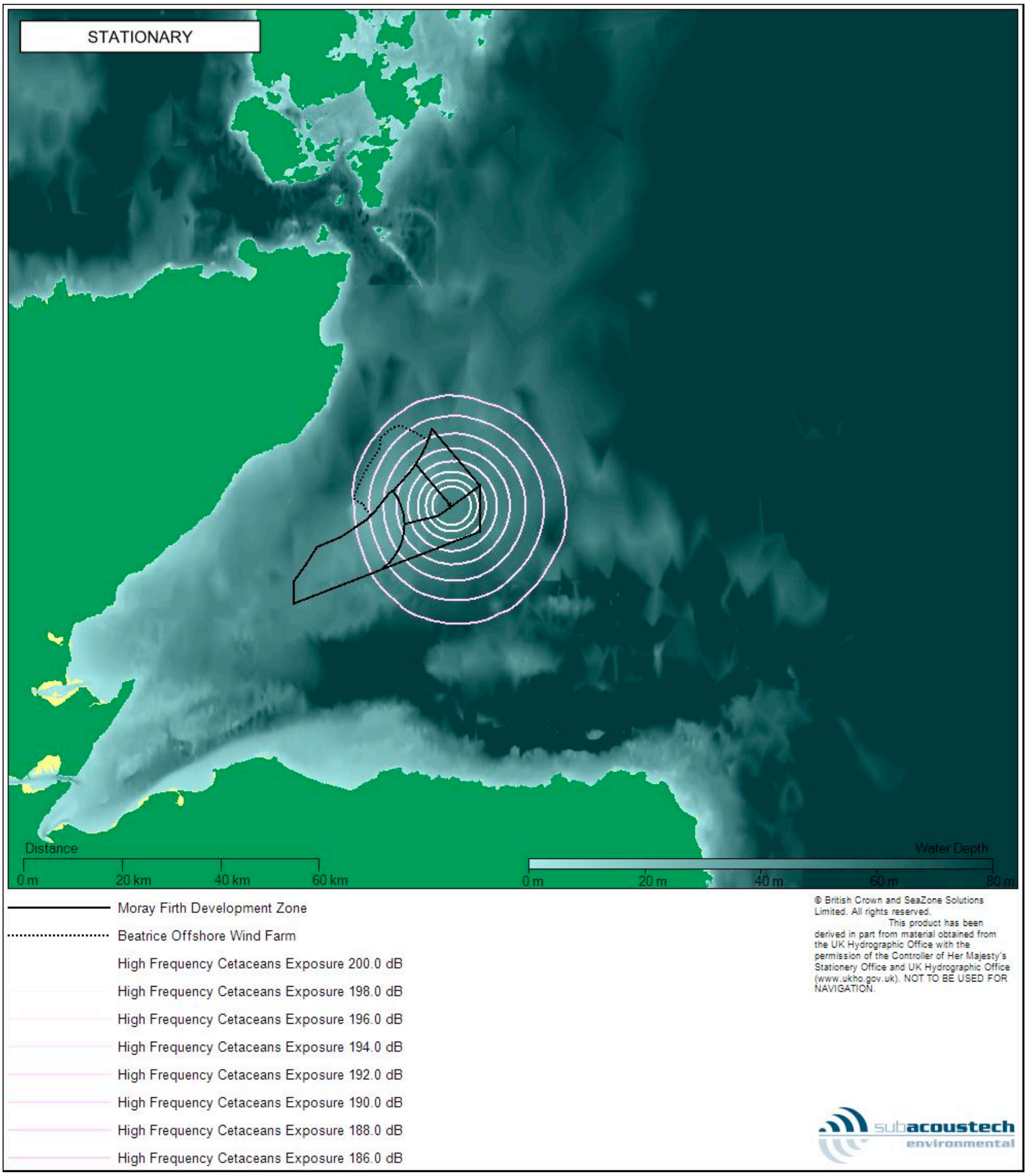


Figure A-81. Contours for stationary HighFrequency Cetaceans; two 2.5 m diameter pin piles being driven sequentially at location 3a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	3a
Pile driving energy (kJ)	1200
Species	High Frequency Cetaceans (Stationary)

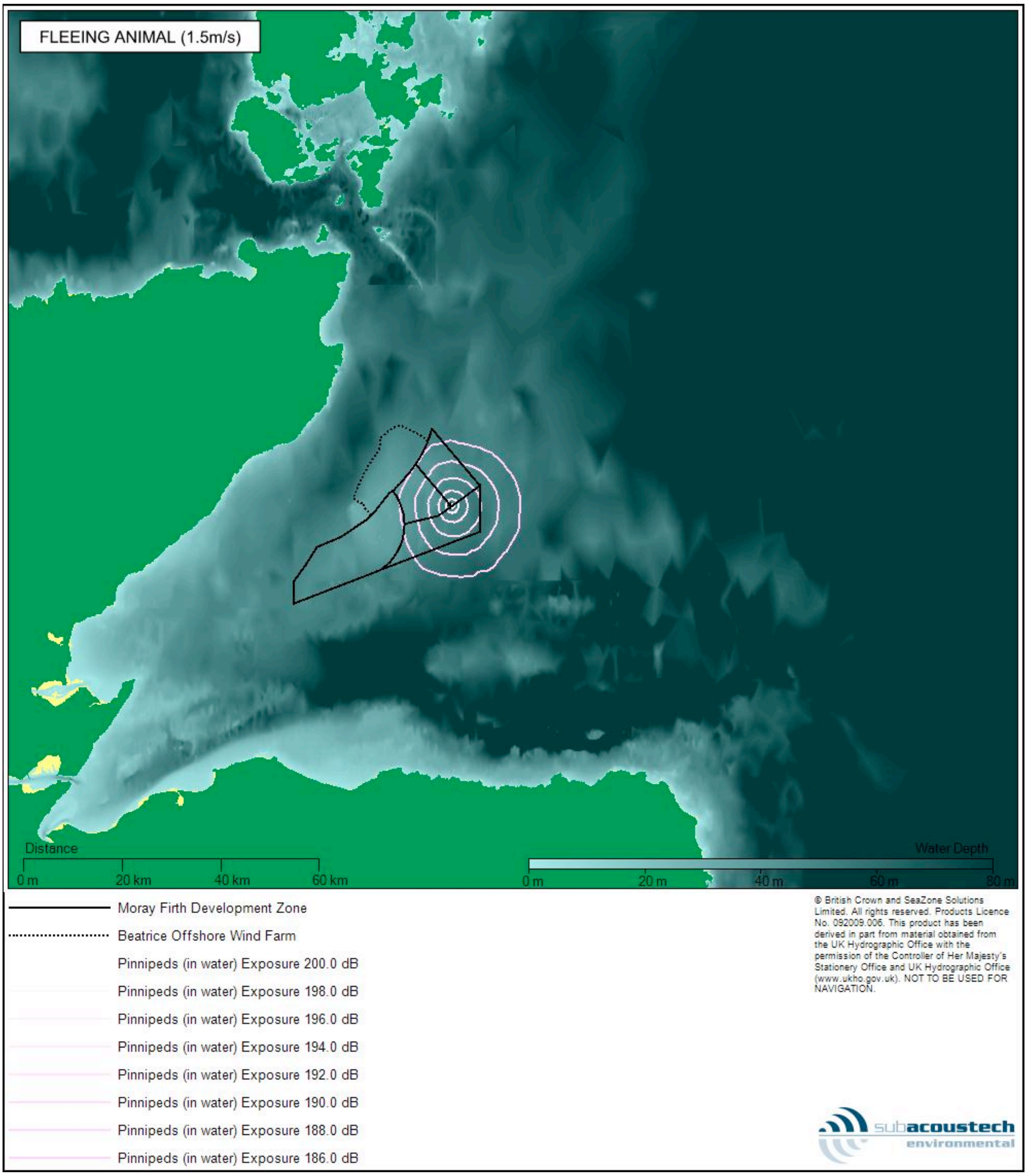


Figure A-82. Starting loci for fleeing Pinnipeds (in water); two 2.5 m diameter pin piles being driven sequentially at location 3a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	3a
Pile driving energy (kJ)	1200
Species	Pinnipeds (in water) (Fleeing 1.5m/s)

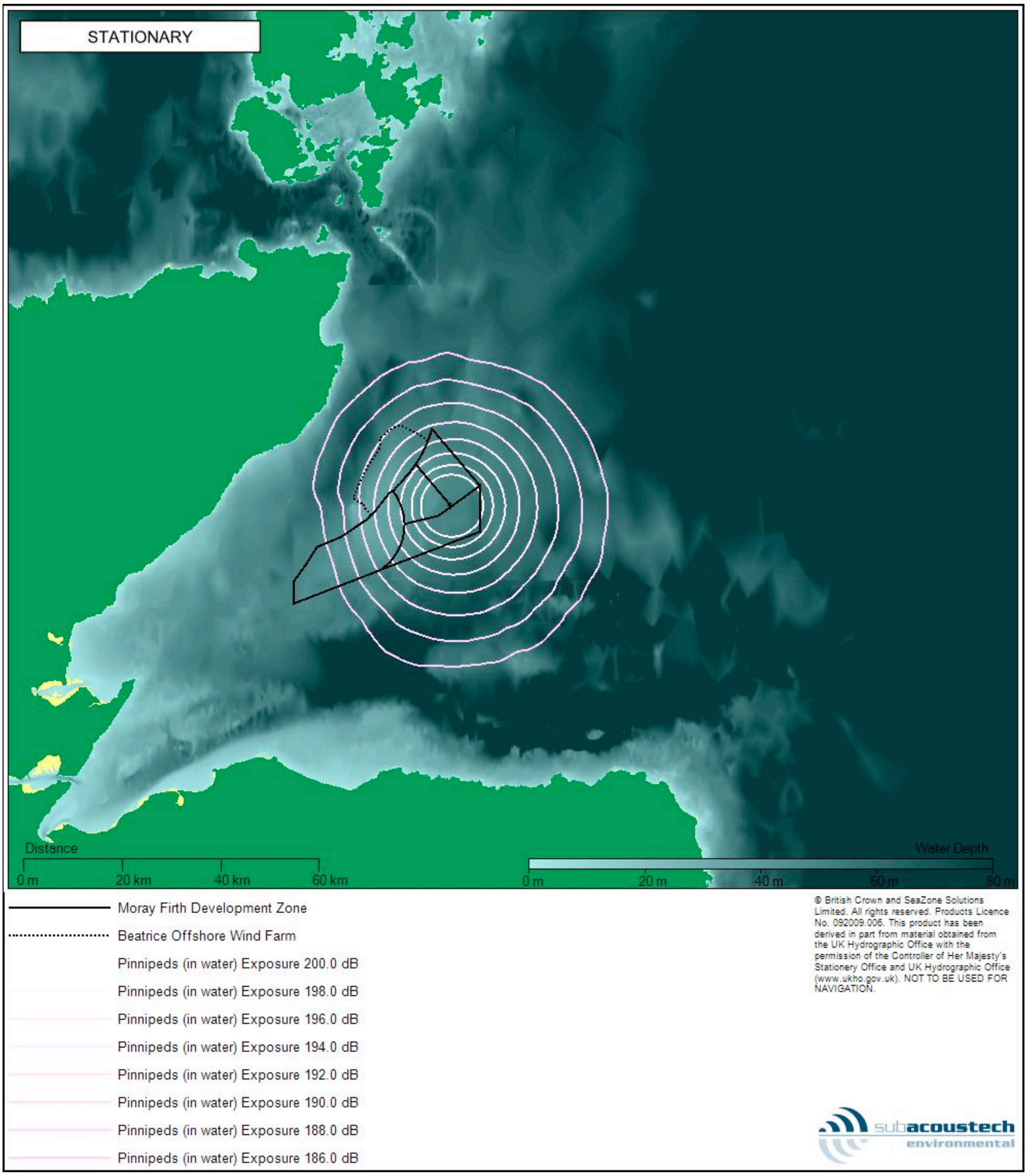


Figure A-83. Contours for stationary Pinnipeds (in water); two 2.5 m diameter pin piles being driven sequentially at location 3a.

Pile diameter (m)	2.5
Pile location (see map, Figure A-13)	3a
Pile driving energy (kJ)	1200
Species	Pinnipeds (in water) (Stationary)

9.1.2.5 Results for 2 pin piles being driven sequentially at 1 location in the South Eastern corner of MORL for OfTI

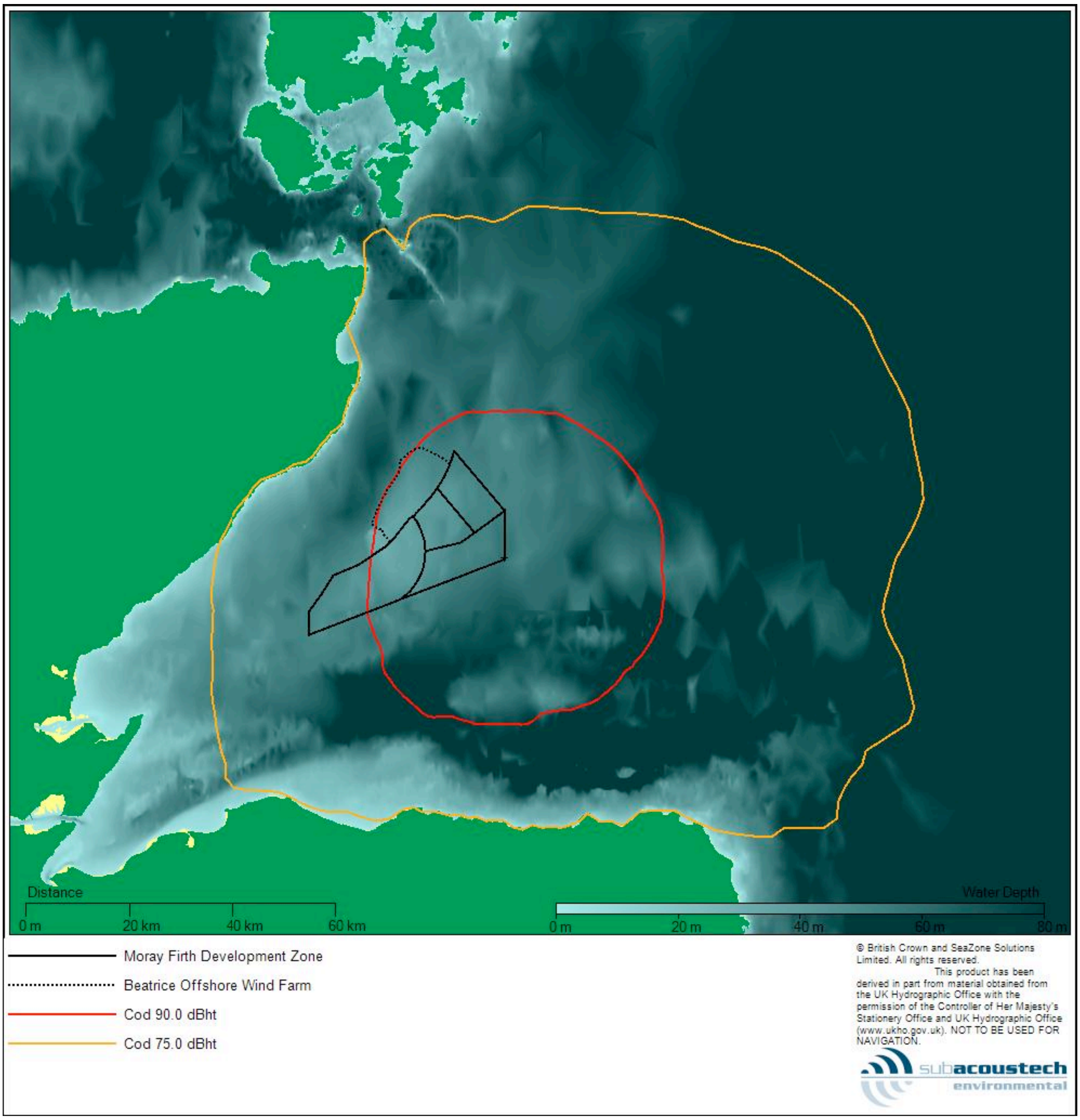


Figure A-84. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for cod; 3 m diameter pile being driven at location 2.

Pile diameter (m)	3
Pile location (see map, Figure A-13)	2
Pile driving energy (kJ)	1800
Species	Cod

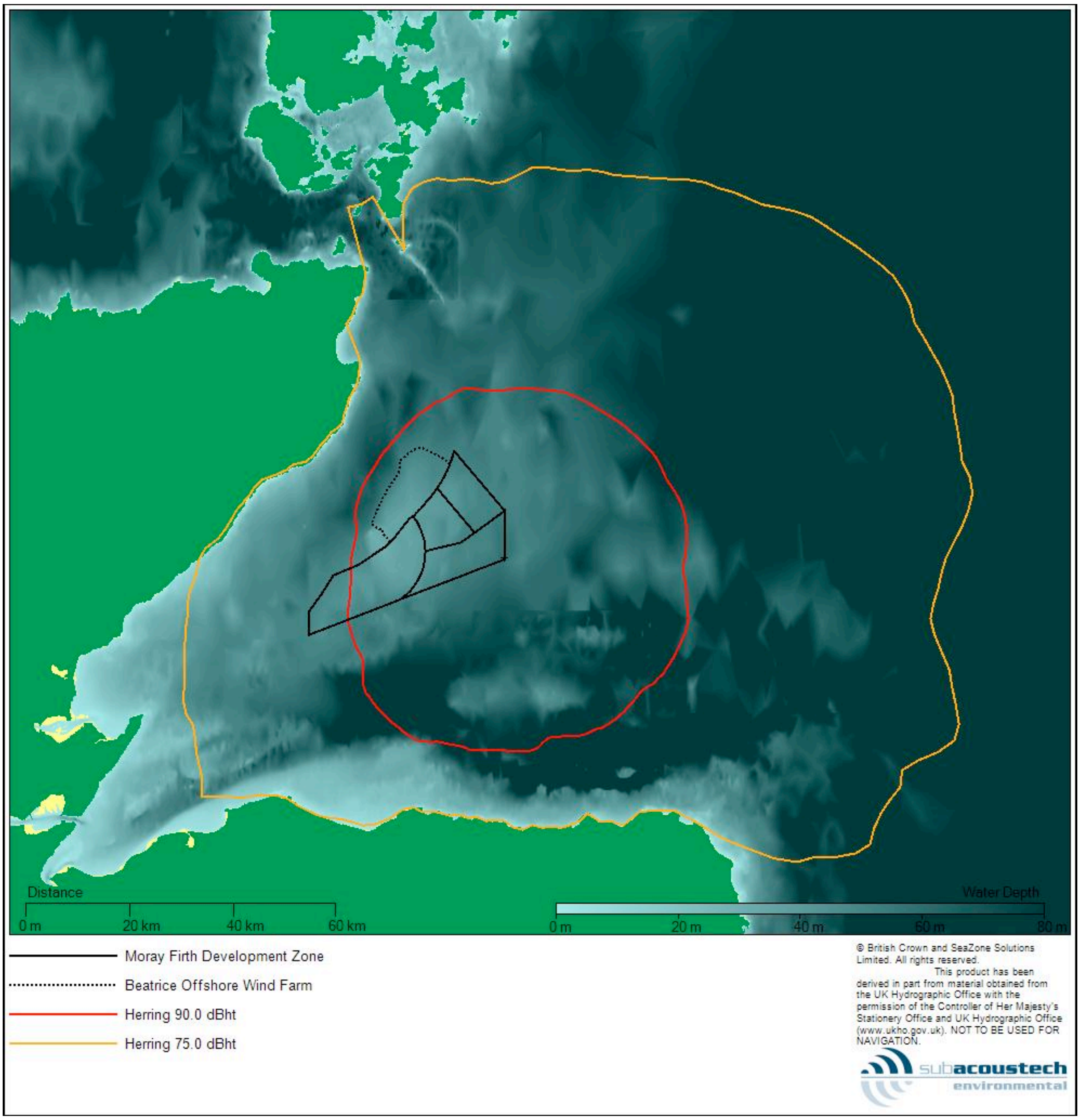


Figure A-85. 90 dB_{ht} and 75 dB_{ht} contours for herring; 3 m diameter pile being driven at location 2.

Pile diameter (m)	3
Pile location (see map, Figure A-13)	2
Pile driving energy (kJ)	1800
Species	Herring

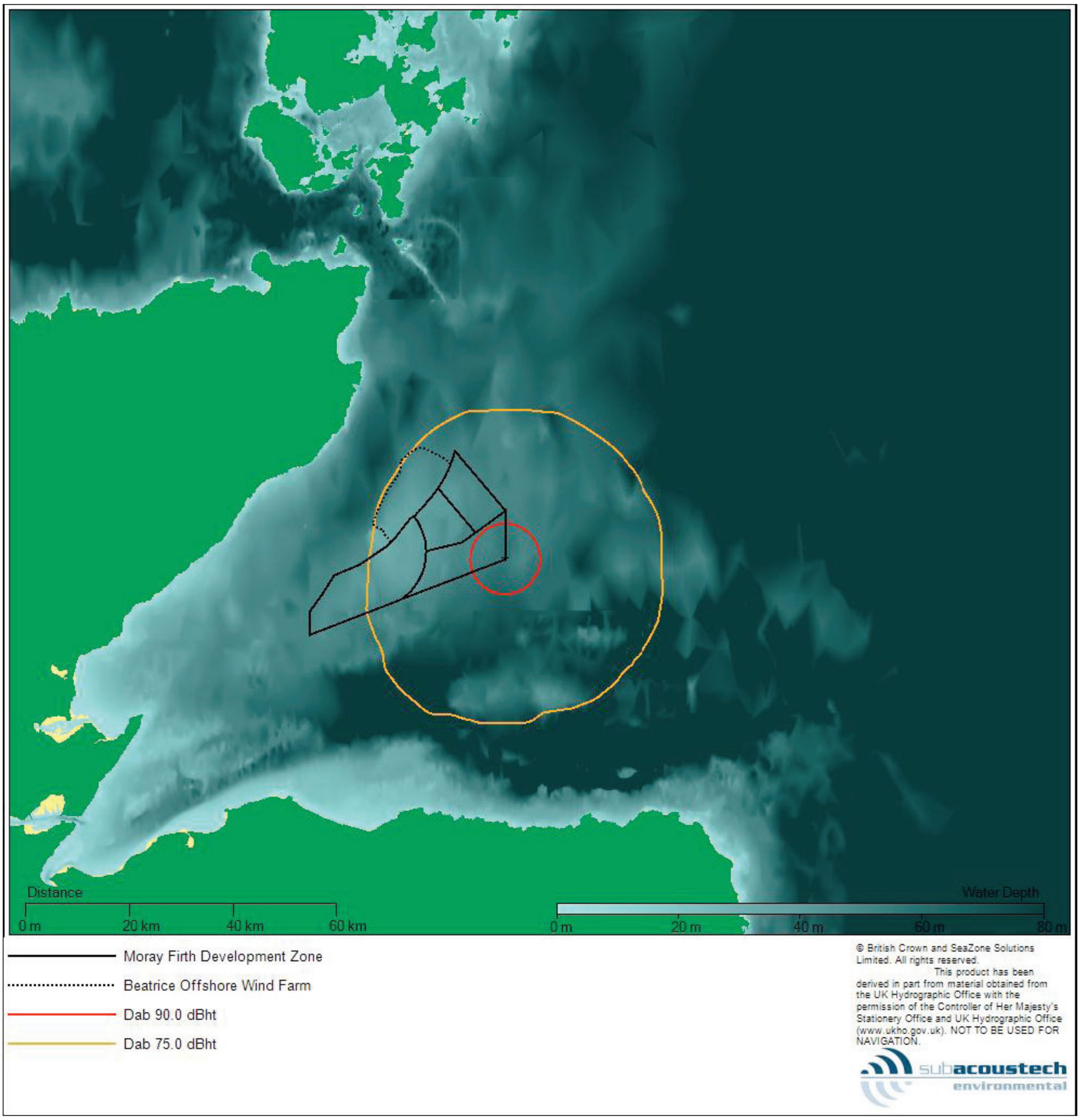


Figure A-86. 90 dB_{ht} and 75 dB_{ht} contours for plaice (dab used as surrogate); 3 m diameter pile being driven at location 2.

Pile diameter (m)	3
Pile location (see map, Figure A-13)	2
Pile driving energy (kJ)	1800
Species	Plaice

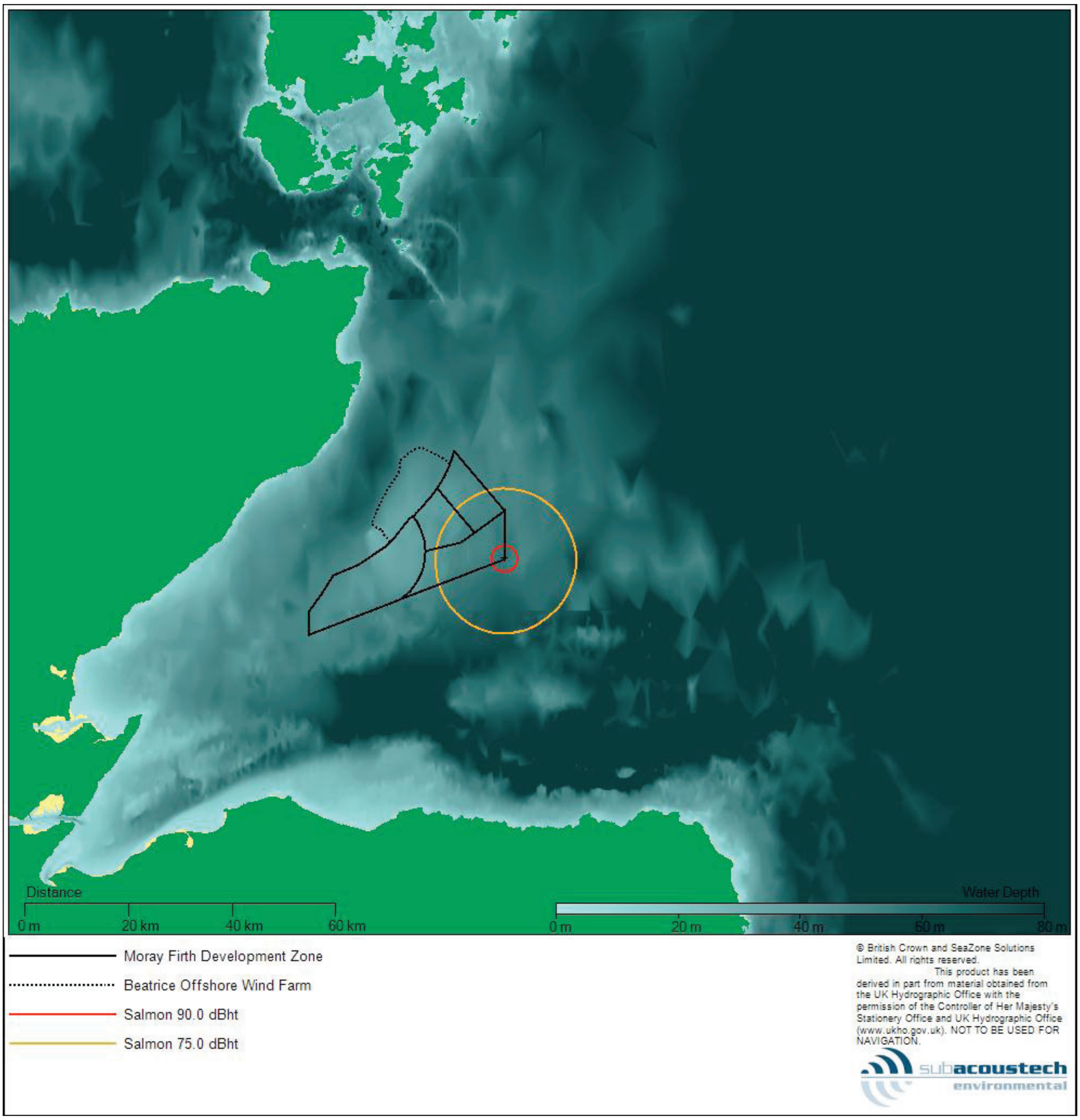


Figure A-87. 90 dB_{ht} and 75 dB_{ht} contours for salmon; 3 m diameter pile being driven at location 2.

Pile diameter (m)	3
Pile location (see map, Figure A-13)	2
Pile driving energy (kJ)	1800
Species	Salmon

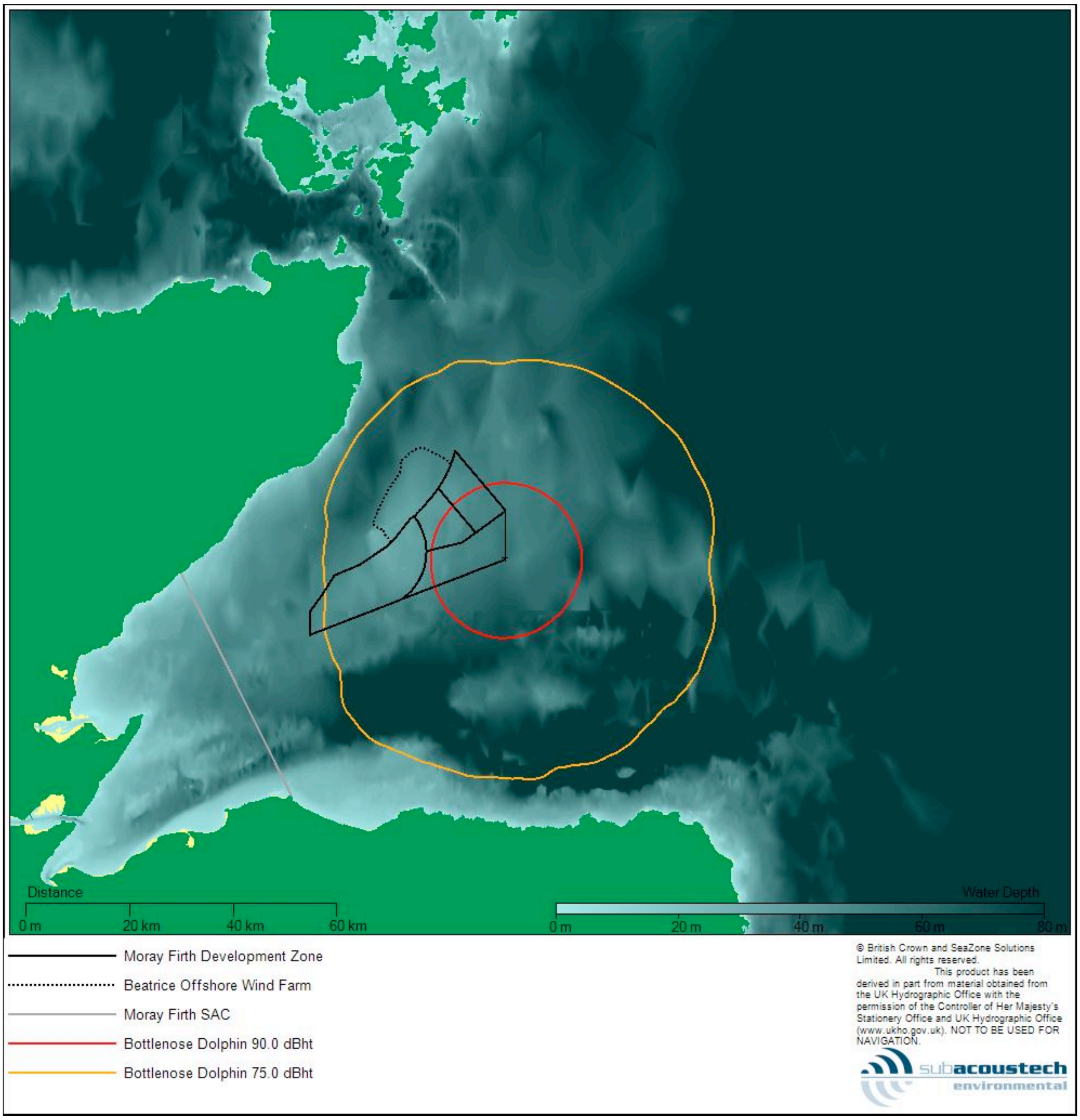


Figure A-88. 90 dB_{ht} and 75 dB_{ht} contours for bottlenose dolphin; 3 m diameter pile being driven at location 2.

Pile diameter (m)	3
Pile location (see map, Figure A-13)	2
Pile driving energy (kJ)	1800
Species	Bottlenose Dolphin

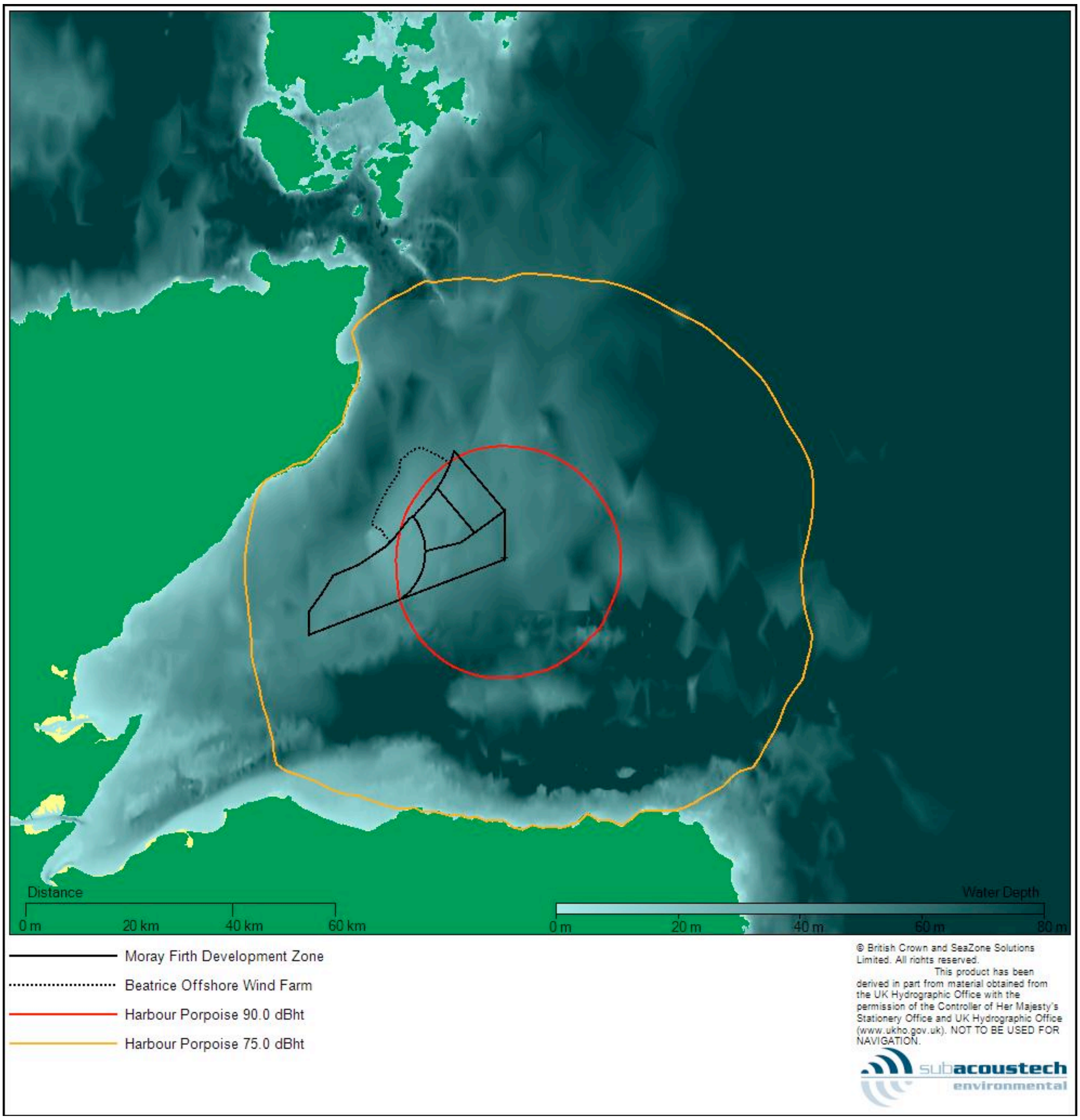


Figure A-89. 90 dB_{ht} and 75 dB_{ht} contours for harbour porpoise; 3 m diameter pile being driven at location 2.

Pile diameter (m)	3
Pile location (see map, Figure A-13)	2
Pile driving energy (kJ)	1800
Species	Harbour Porpoise

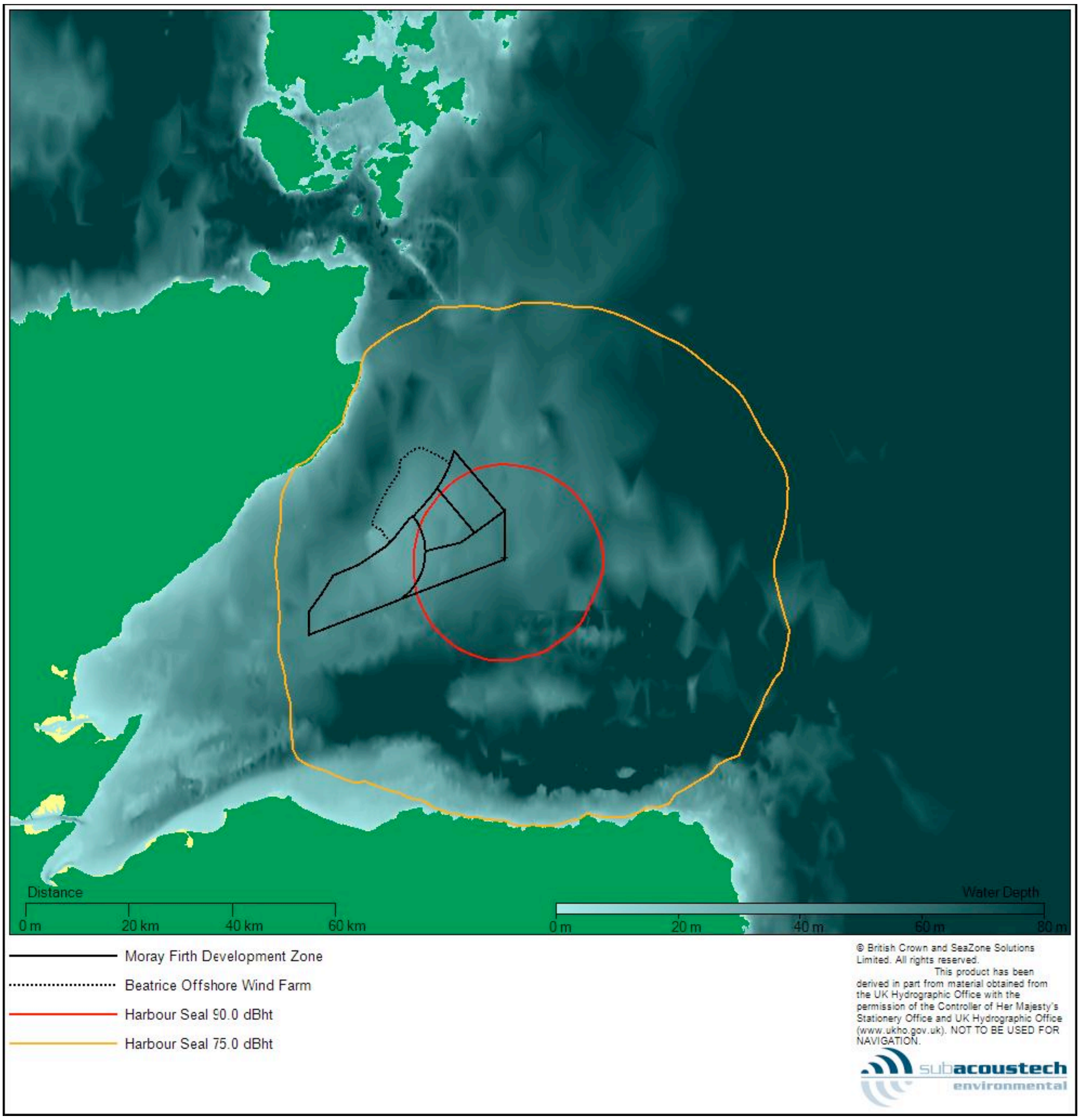


Figure A-90. 90 dB_{ht} and 75 dB_{ht} contours for harbour seal; 3 m diameter pile being driven at location 2.

Pile diameter (m)	3
Pile location (see map, Figure A-13)	2
Pile driving energy (kJ)	1800
Species	Harbour Seal

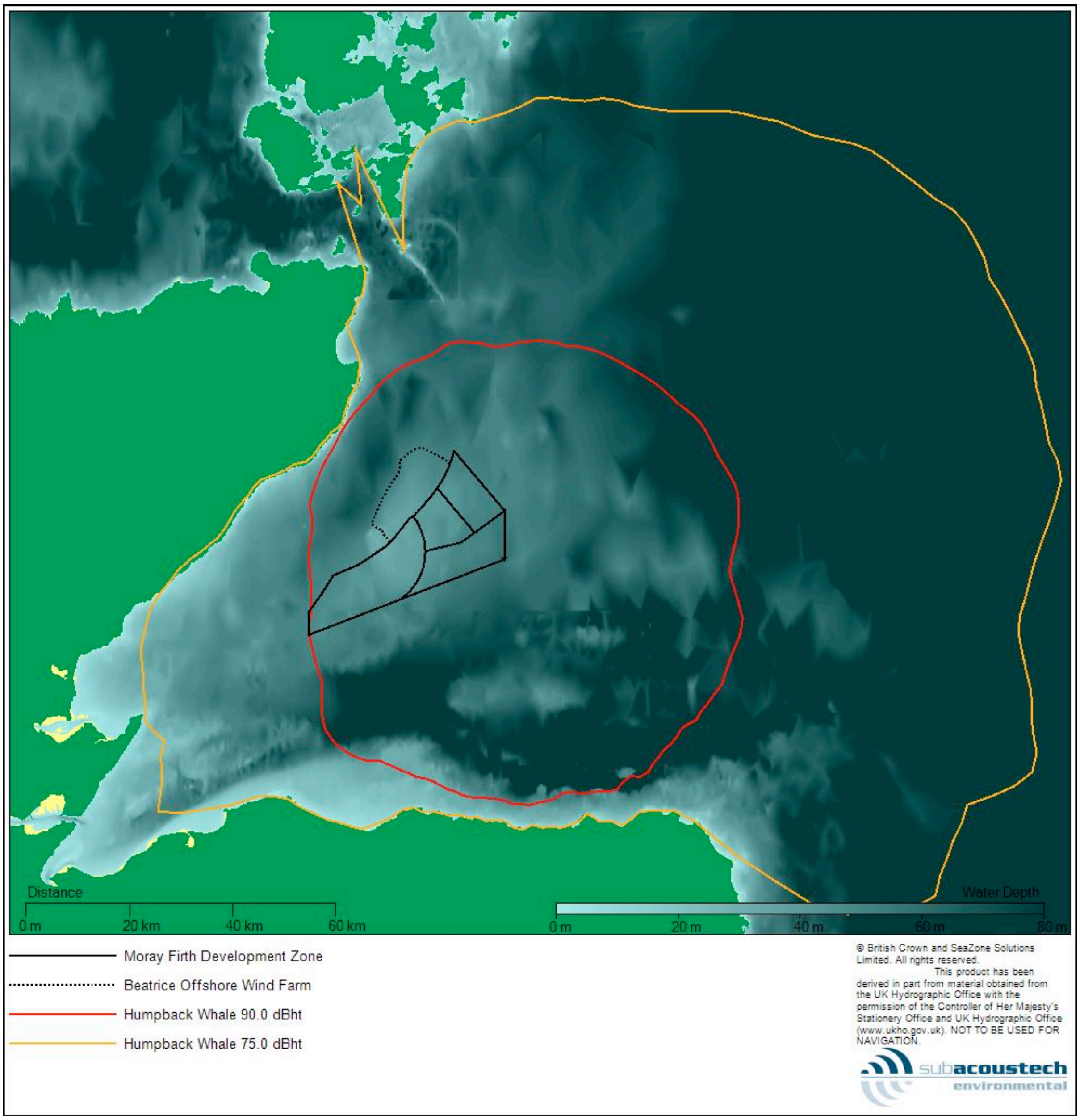


Figure A-91. 90 dB_{ht} and 75 dB_{ht} contours for minke whale (humpback whale used as surrogate); 3 m diameter pile being driven at location 2.

Pile diameter (m)	4
Pile location (see map, Figure A-13)	2
Pile driving energy (kJ)	1800
Species	Minke Whale

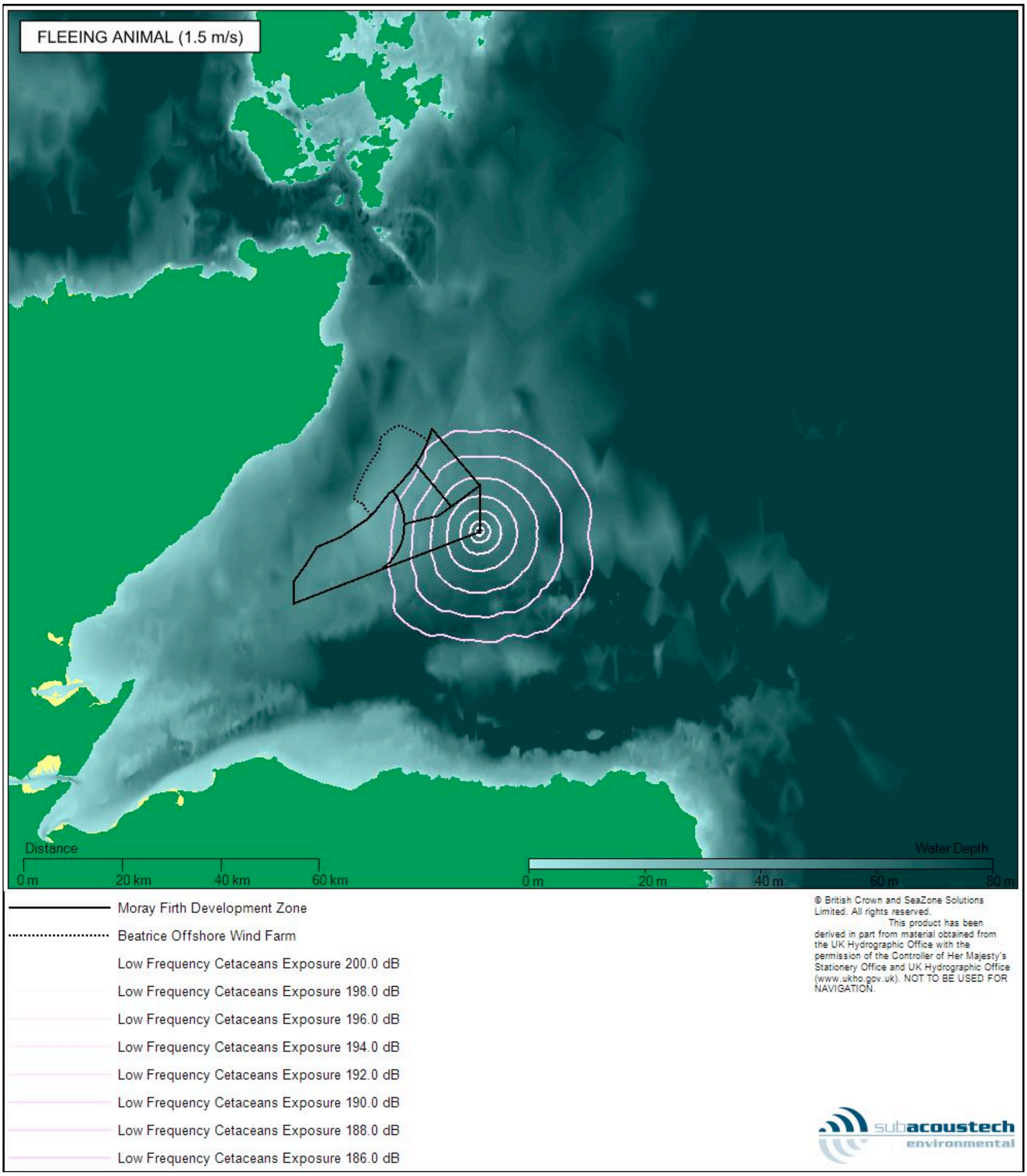


Figure A-92. Starting loci for fleeing Low Frequency Cetaceans; two 3 m diameter pin piles being driven sequentially at location 2.

Pile diameter (m)	3
Pile location (see map, Figure A-13)	2
Pile driving energy (kJ)	1800
Species	Low Frequency Cetaceans (Fleeing 1.5m/s)

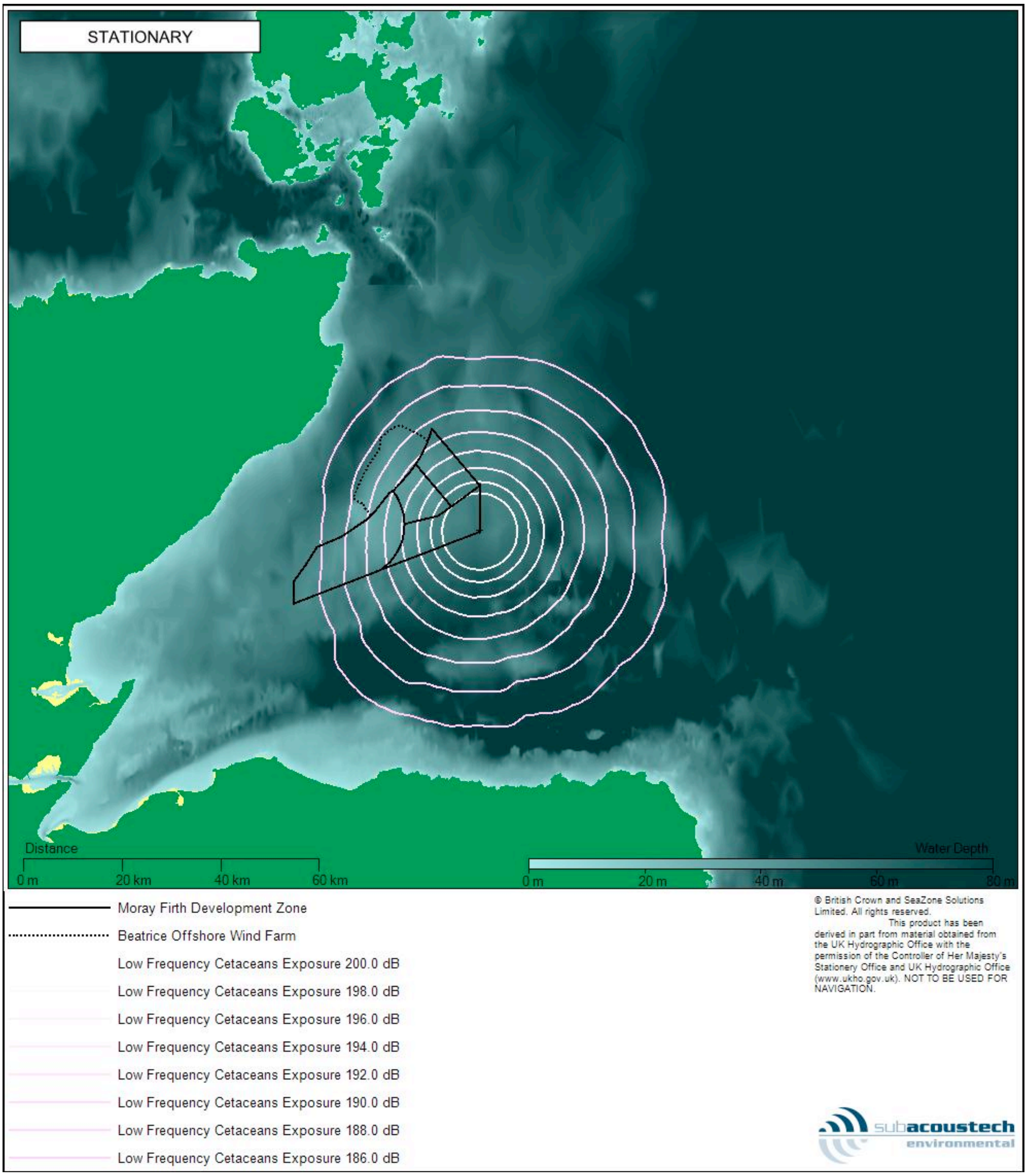


Figure A-93. Contours for stationary Low Frequency Cetaceans; two 3 m diameter pin piles being driven sequentially at location 2.

Pile diameter (m)	3
Pile location (see map, Figure A-13)	2
Pile driving energy (kJ)	1800
Species	Low Frequency Cetaceans (Stationary)

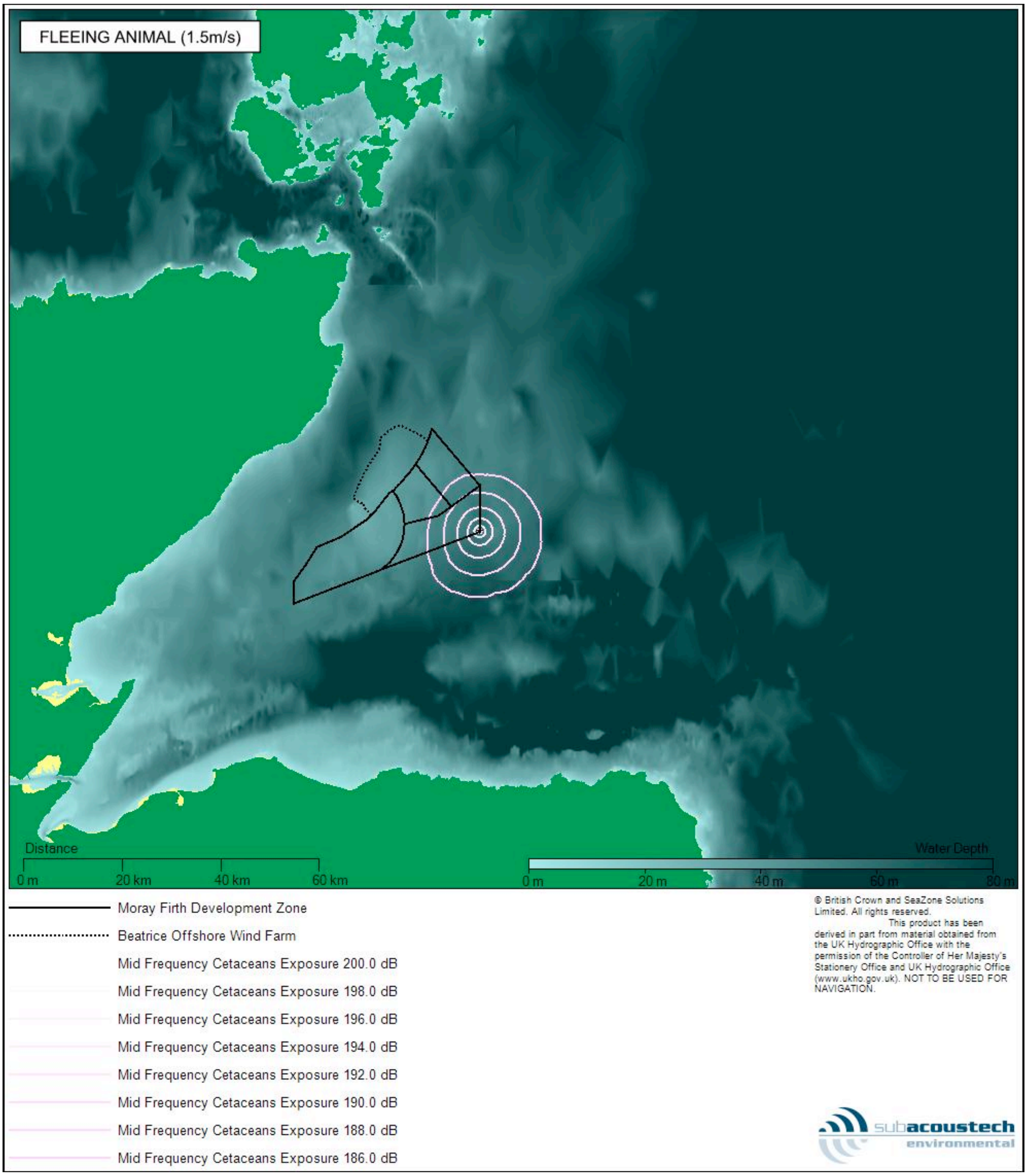


Figure A-94. Starting loci for fleeing Mid Frequency Cetaceans; two 3 m diameter pin piles being driven sequentially at location 2.

Pile diameter (m)	4
Pile location (see map, Figure A-13)	2
Pile driving energy (kJ)	1800
Species	Mid Frequency Cetaceans (Fleeing 1.5m/s)

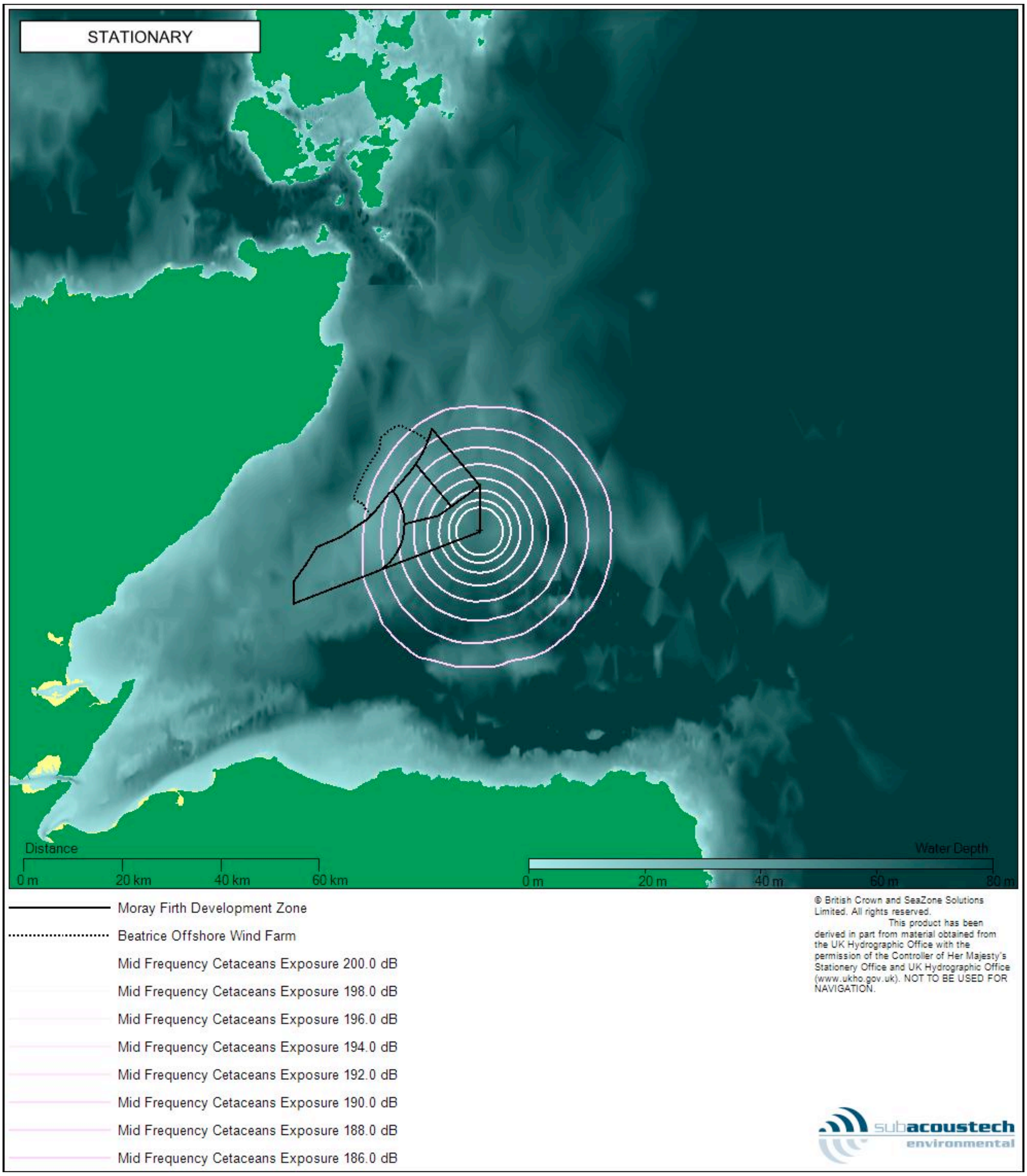


Figure A-95. Contours for stationary Mid Frequency Cetaceans; two 3 m diameter pin piles being driven sequentially at location 2.

Pile diameter (m)	3
Pile location (see map, Figure A-13)	2
Pile driving energy (kJ)	1800
Species	Mid Frequency Cetaceans (Stationary)

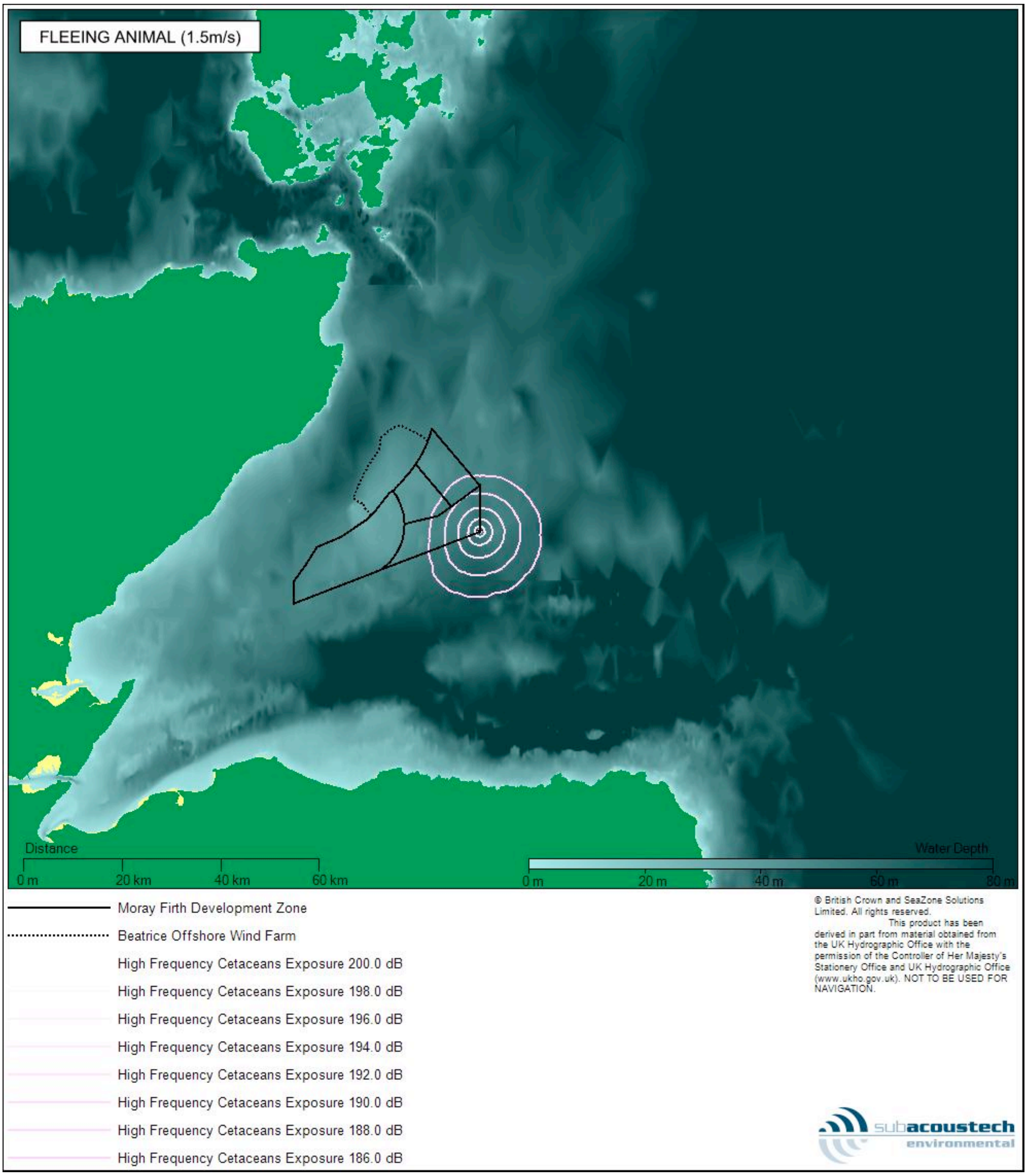


Figure A-96. Starting loci for fleeing High Frequency Cetaceans; two 3 m diameter pin piles being driven sequentially at location 2.

Pile diameter (m)	3
Pile location (see map, Figure A-13)	2
Pile driving energy (kJ)	1800
Species	High Frequency Cetaceans (Fleeing 1.5m/s)

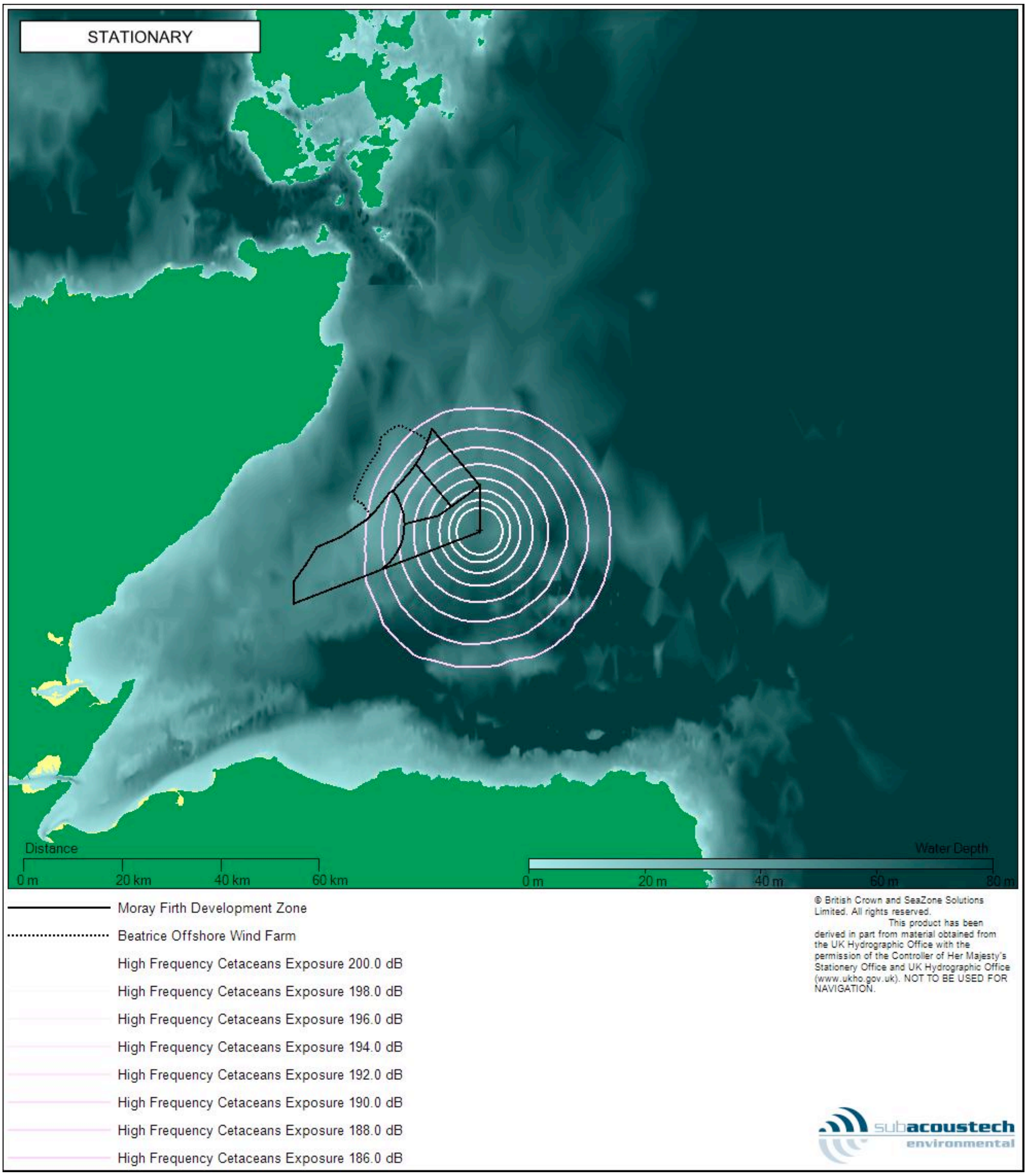


Figure A-97. Contours for stationary HighFrequency Cetaceans; two 3 m diameter pin piles being driven sequentially at location 2.

Pile diameter (m)	3
Pile location (see map, Figure A-13)	2
Pile driving energy (kJ)	1800
Species	High Frequency Cetaceans (Stationary)

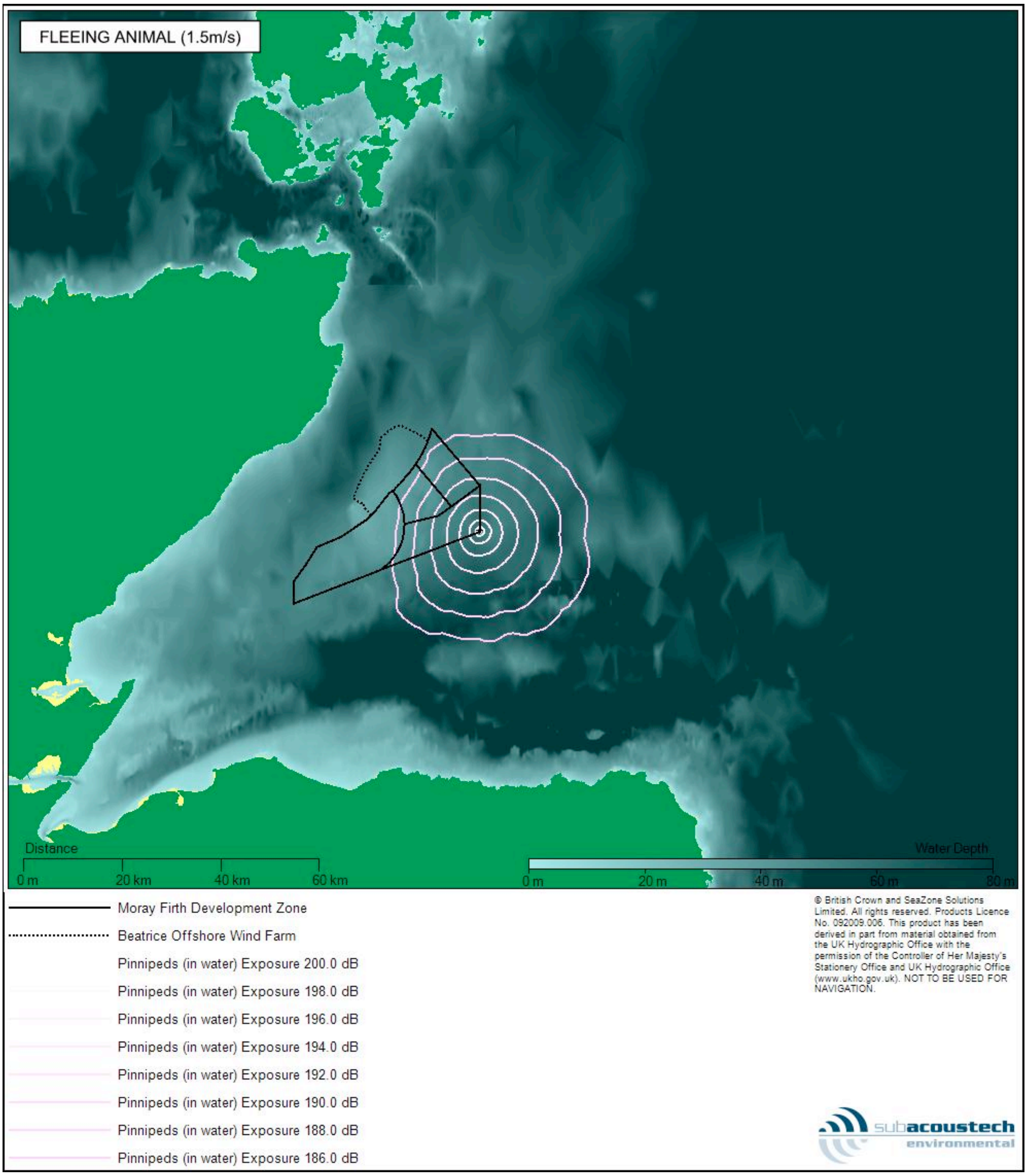


Figure A-98. Starting loci for fleeing Pinnipeds (in water); two 3 m diameter pin piles being driven sequentially at location 2.

Pile diameter (m)	3
Pile location (see map, Figure A-13)	2
Pile driving energy (kJ)	1800
Species	Pinnipeds (in water) (Fleeing 1.5m/s)

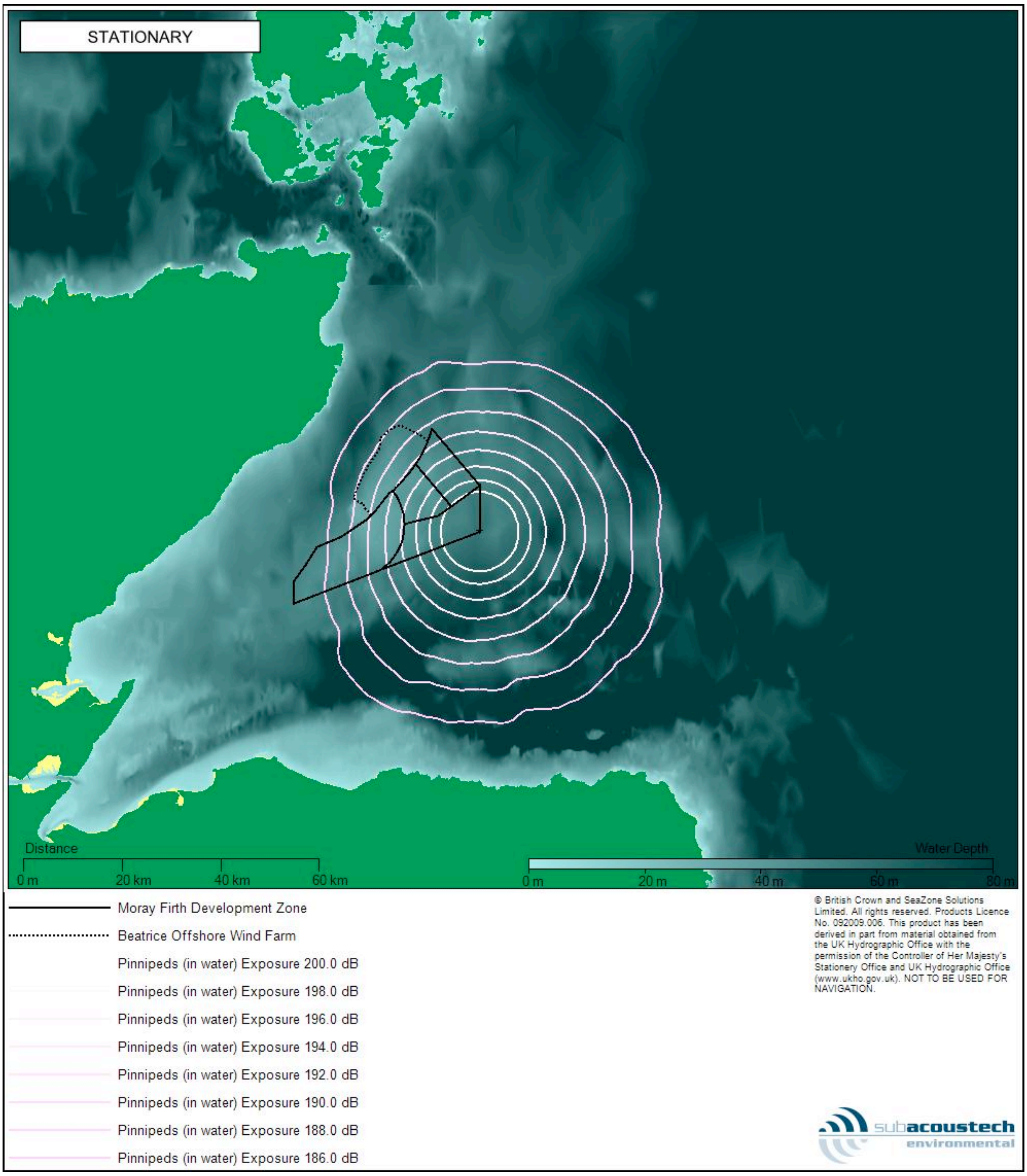


Figure A-99. Contours for stationary Pinnipeds (in water); two 3 m diameter pin piles being driven sequentially at location 2.

Pile diameter (m)	3
Pile location (see map, Figure A-13)	2
Pile driving energy (kJ)	1800
Species	Pinnipeds (in water) (Stationary)

9.1.3 Mitigation

A key element in developing a strategy for piling that has a minimised environmental impact has been the use of the INSPIRE model to understand the potential environmental effect of various piling regimes and select an optimal construction process. In addition, the model has allowed the effect of mitigation, including soft and slow start, and the use of pin piles *versus* monopoles, to be investigated. This has allowed the engineering to be further optimised. In principle it is possible to further reduce the noise generated by impact piling at source. However, while other forms of piling, such as vibropiling, drill driving and hydraulic piling, may generate much lower noise levels, and have been considered, these approaches are only suitable for much smaller piles than are required for offshore wind farms, take considerably longer than impact piling, and generally require impact piling as a final measure to drive the pile to depth. Various technologies are being developed which may be used to attenuate noise transmission from impact piling, such as cladding and bubble barriers, but currently these are either of limited efficacy or are unproven technologies.

9.1.4 Monitoring and Enhancements

In general, the INSPIRE model that has been used to estimate the noise from the piling has been shown to be accurate when tested against actual measurements of impact piling noise. However, it is considered good practice to test the model against actual results and hence in the early stage of the installation of the piles it is proposed that the noise from four piles will be measured and compared with the model.

9.1.5 Summary

The impact of introduced noise as a result of impact piling during construction of the MORL windfarm site has been calculated using the proprietary INSPIRE noise modelling software.

The range of noise emissions with reference to the different species has been calculated in respect of dB_{ht}(*Species*) and M-weighted dB SEL to assess the potential impact of the piling on marine species. This is both in terms of injury and behavioural response.

These calculated levels have been used to inform the fish and marine mammal impact assessments.

9.2 Cumulative Impacts (i.e. the results for cases of piles being driven simultaneously at multiple locations)

9.2.1 Introduction

The cumulative effects of noise may be taken to reflect the total exposure to noise that an animal has in the course of its daily existence. Consequently, this may include not only the noise from an impact piling operation, but also the way in which the additional noise dose created by the piling accumulates with noise from existing sources that the animal is exposed to, such as the noise from other piling operations, seismic exploration, vessel traffic and so on.

9.2.2 Scope of Assessment

There is little information concerning the detail of activities in coastal waters that may contribute to an animal's exposure to noise. Hence, it is difficult to define the noise field through which an animal transits during a day, and difficult or impossible to estimate the total exposure to noise of an animal during the activity that brings it into in the vicinity of the piling operation. However, as measurements of background noise levels in the Moray Firth suggest levels of the order of 130 dB re 1 μPa (unweighted) are typical, a daily exposure of this order, assuming no exposure to other high noise levels, would be reasonable. It will be noted from the analysis in Section 8.7 that impact piling, where it occurs, tends to be the dominant noise source in the area around the piling. The contributions to noise exposure offered by all other noise sources are significantly lower in significance. During the development of Round 3 sites a considerable number of piling operations may be conducted around the coastal waters of the UK, and hence a key element of cumulative noise exposure is considered to be the case where animals may encounter two or more piling operations simultaneously. Consequently, the scenario where an animal encounters two or more simultaneous piling operations has provided the main thrust of the investigation into the cumulative effects of noise.

The way in which the effects of noise accumulate depends on the effect of noise that is considered. In the worst case, impact piling operations could commence simultaneously at two sites within a few kilometres of each other. Where the animal is much closer to one operation than the other it is likely that the noise dose would be dominated by the closest piling operation, and the animal would perceive a high level of noise, likely to cause it to attempt to flee from the noise in much the same way as if the other piling operation were not happening. However, an animal trapped between the two operations would have fewer options as to how to flee from the noise, and might be expected to flee at a roughly constant distance from both. During this period the animal may therefore receive exposure to noise from both operations.

It is possible to estimate the effects of the noise in this multi-source case in a similar way to that of a single piling operation. Each of the piling operations, where conducted individually, will have a zone within which the animal will receive a noise dose sufficient to create a risk of hearing damage as it flees from the noise. Where auditory damage is considered, using for instance the SEL criterion of Southall *et al.*, and the piling operations are conducted simultaneously, the animal will receive a noise dose from both piling operations, and the zone in which the animal will receive a noise dose sufficient to create a risk of hearing damage will be larger than the sum of the individual zones for the operations conducted individually.

While this in principle creates a greater risk for the animal, it should be noted that since the duration of the exposure of the animal to noise would be less when the operations are conducted simultaneously, the reduced time may serve to mitigate the somewhat greater area in which animals may be exposed to risk of hearing damage.

The situation is somewhat different when the behavioural effects of the noise are considered. Two piling operations occurring simultaneously, at roughly similar distances, create noise impulses that are of similar level to each of the piling operations alone. It may be shown that even for piling strikes that occur at the same moment the level is similar to that of each of the impulses alone. The pulses of noise differ in shape and hence do not interfere constructively. As a consequence of this the zone in which behavioural avoidance is estimated to occur around two simultaneous piling operations is simply the union of the two zones for each piling operation conducted simultaneously. Where the zones intersect the area in which a behavioural response is expected is actually smaller than the sum of the two zones for individual piling operations.

9.2.3 Development Considered in the Assessment

The SPEAR analysis in Section 8 considered the likely potential impacts of a number of different sources on the marine species under consideration. In all cases in the analysis, the noise from impact piling was by far the dominant source with all other potential sources having a relatively insignificant noise impact, with reference to their noise output and the hearing capability of each species. Consequently, only noise from impact piling will be considered in the cumulative assessment.

There are two main sources of impact piling noise that will be considered in the cumulative assessment: multiple piling operations within the Moray Offshore Windfarm and multiple piling accounting for potentially simultaneous operations at the nearby Beatrice wind farm development.

9.2.4 Predicted Impacts for piles being driven simultaneously at two locations on MORL

9.2.4.1 Details of cases

For the four fish and four marine mammal species considered, calculations were made for a single pile being driven at each of two locations simultaneously. For the low-, mid- and high-frequency cetacean and pinniped cases considered, calculations were made for two piles being driven sequentially at each of two locations, with the piling at these locations to take place simultaneously.

A summary of the cases is given in Table A-14.

Table A-14. Detailed description of piling modelling undertaken

Pile diameter (m)	Number of piles / location	Hammer capacity (kJ)	Species	Results shown	Figure
2.5	Locations 1 and 5	1200	Cod	90 dB_{ht} and 75 dB_{ht} contours	A-100
2.5	Locations 1 and 5	1200	Herring	90 dB_{ht} and 75 dB_{ht} contours	A-101
2.5	Locations 1 and 5	1200	Plaice	90 dB_{ht} and 75 dB_{ht} contours	A-102
2.5	Locations 1 and 5	1200	Salmon	90 dB_{ht} and 75 dB_{ht} contours	A-103
2.5	Locations 1 and 5	1200	Bottlenose dolphin	90 dB_{ht} and 75 dB_{ht} contours	A-104
2.5	Locations 1 and 5	1200	Harbour porpoise	90 dB_{ht} and 75 dB_{ht} contours	A-105
2.5	Locations 1 and 5	1200	Harbour seal	90 dB_{ht} and 75 dB_{ht} contours	A-106
2.5	Locations 1 and 5	1200	Minke whale	90 dB_{ht} and 75 dB_{ht} contours	A-107
2.5	2 piles at both locations 1 and 5	1200	Low frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-108
2.5	2 piles sequentially at locations 1 and 5	1200	Low frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-109
2.5	2 piles sequentially at locations 1 and 5	1200	Mid frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-110
2.5	2 piles sequentially at locations 1 and 5	1200	Mid frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-111
2.5	2 piles sequentially at locations 1 and 5	1200	High frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-112
2.5	2 piles sequentially at locations 1 and 5	1200	High frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-113
2.5	2 piles sequentially at locations 1 and 5	1200	Pinniped (in water)	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-114
2.5	2 piles sequentially at locations 1 and 5	1200	Pinniped (in water)	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-115

Pile diameter (m)	Number of piles / location	Hammer capacity (kJ)	Species	Results shown	Figure
2.5	Locations 1 and 2	1200	Cod	90 dB_{ht} and 75 dB_{ht} contours	A-116
2.5	Locations 1 and 2	1200	Herring	90 dB_{ht} and 75 dB_{ht} contours	A-117
2.5	Locations 1 and 2	1200	Plaice	90 dB_{ht} and 75 dB_{ht} contours	A-118
2.5	Locations 1 and 2	1200	Salmon	90 dB_{ht} and 75 dB_{ht} contours	A-119
2.5	Locations 1 and 2	1200	Bottlenose dolphin	90 dB_{ht} and 75 dB_{ht} contours	A-120
2.5	Locations 1 and 2	1200	Harbour porpoise	90 dB_{ht} and 75 dB_{ht} contours	A-121
2.5	Locations 1 and 2	1200	Harbour seal	90 dB_{ht} and 75 dB_{ht} contours	A-122
2.5	Locations 1 and 2	1200	Minke whale	90 dB_{ht} and 75 dB_{ht} contours	A-123
2.5	2 piles sequentially at locations 1 and 2	1200	Low frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-124
2.5	2 piles sequentially at locations 1 and 2	1200	Low frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for a stationary animal	A-125
2.5	2 piles sequentially at locations 1 and 2	1200	Mid frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-126
2.5	2 piles sequentially at locations 1 and 2	1200	Mid frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for a stationary animal	A-127
2.5	2 piles sequentially at locations 1 and 2	1200	High frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-128
2.5	2 piles sequentially at locations 1 and 2	1200	High frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for a stationary animal	A-129
2.5	2 piles sequentially at locations 1 and 2	1200	Pinniped (in water)	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-130
2.5	2 piles sequentially at locations 1 and 2	1200	Pinniped (in water)	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for a stationary animal	A-131
2.5	Locations 4 and 6	1200	Cod	90 dB_{ht} and 75 dB_{ht} contours	A-132

Pile diameter (m)	Number of piles / location	Hammer capacity (kJ)	Species	Results shown	Figure
2.5	Locations 4 and 6	1200	Herring	90 dB_{ht} and 75 dB_{ht} contours	A-133
2.5	Locations 4 and 6	1200	Plaice	90 dB_{ht} and 75 dB_{ht} contours	A-134
2.5	Locations 4 and 6	1200	Salmon	90 dB_{ht} and 75 dB_{ht} contours	A-135
2.5	Locations 4 and 6	1200	Bottlenose dolphin	90 dB_{ht} and 75 dB_{ht} contours	A-136
2.5	Locations 4 and 6	1200	Harbour porpoise	90 dB_{ht} and 75 dB_{ht} contours	A-137
2.5	Locations 4 and 6	1200	Harbour seal	90 dB_{ht} and 75 dB_{ht} contours	A-138
2.5	Locations 4 and 6	1200	Minke whale	90 dB_{ht} and 75 dB_{ht} contours	A-139
2.5	2 piles sequentially at locations 4 and 6	1200	Low frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-140
2.5	2 piles sequentially at locations 4 and 6	1200	Low frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-141
2.5	2 piles sequentially at locations 4 and 6	1200	Mid frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-142
2.5	2 piles sequentially at locations 4 and 6	1200	Mid frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-143
2.5	2 piles sequentially at locations 4 and 6	1200	High frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-144
2.5	2 piles sequentially at locations 4 and 6	1200	High frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-145
2.5	2 piles sequentially at locations 4 and 6	1200	Pinniped (in water)	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-146
2.5	2 piles sequentially at locations 4 and 6	1200	Pinniped (in water)	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-147
2.5	Locations 3a and 5a	1200	Cod	90 dB_{ht} and 75 dB_{ht} contours	A-148
2.5	Locations 3a and 5a	1200	Herring	90 dB_{ht} and 75 dB_{ht} contours	A-149

Pile diameter (m)	Number of piles / location	Hammer capacity (kJ)	Species	Results shown	Figure
2.5	Locations 3a and 5a	1200	Plaice	90 dB_{ht} and 75 dB_{ht} contours	A-150
2.5	Locations 3a and 5a	1200	Salmon	90 dB_{ht} and 75 dB_{ht} contours	A-151
2.5	Locations 3a and 5a	1200	Bottlenose dolphin	90 dB_{ht} and 75 dB_{ht} contours	A-152
2.5	Locations 3a and 5a	1200	Harbour porpoise	90 dB_{ht} and 75 dB_{ht} contours	A-153
2.5	Locations 3a and 5a	1200	Harbour seal	90 dB_{ht} and 75 dB_{ht} contours	A-154
2.5	Locations 3a and 5a	1200	Minke whale	90 dB_{ht} and 75 dB_{ht} contours	A-155
2.5	2 piles sequentially at locations 3a and 5a	1200	Low frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-156
2.5	2 piles sequentially at locations 3a and 5a	1200	Low frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for a stationary animal	A-157
2.5	2 piles sequentially at locations 3a and 5a	1200	Mid frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-158
2.5	2 piles sequentially at locations 3a and 5a	1200	Mid frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for a stationary animal	A-159
2.5	2 piles sequentially at locations 3a and 5a	1200	High frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-160
2.5	2 piles sequentially at locations 3a and 5a	1200	High frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for a stationary animal	A-161
2.5	2 piles sequentially at locations 3a and 5a	1200	Pinniped (in water)	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-162
2.5	2 piles sequentially at locations 3a and 5a	1200	Pinniped (in water)	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for a stationary animal	A-163

9.2.4.2 Results for 2 piles being driven simultaneously at 2 locations on MORL

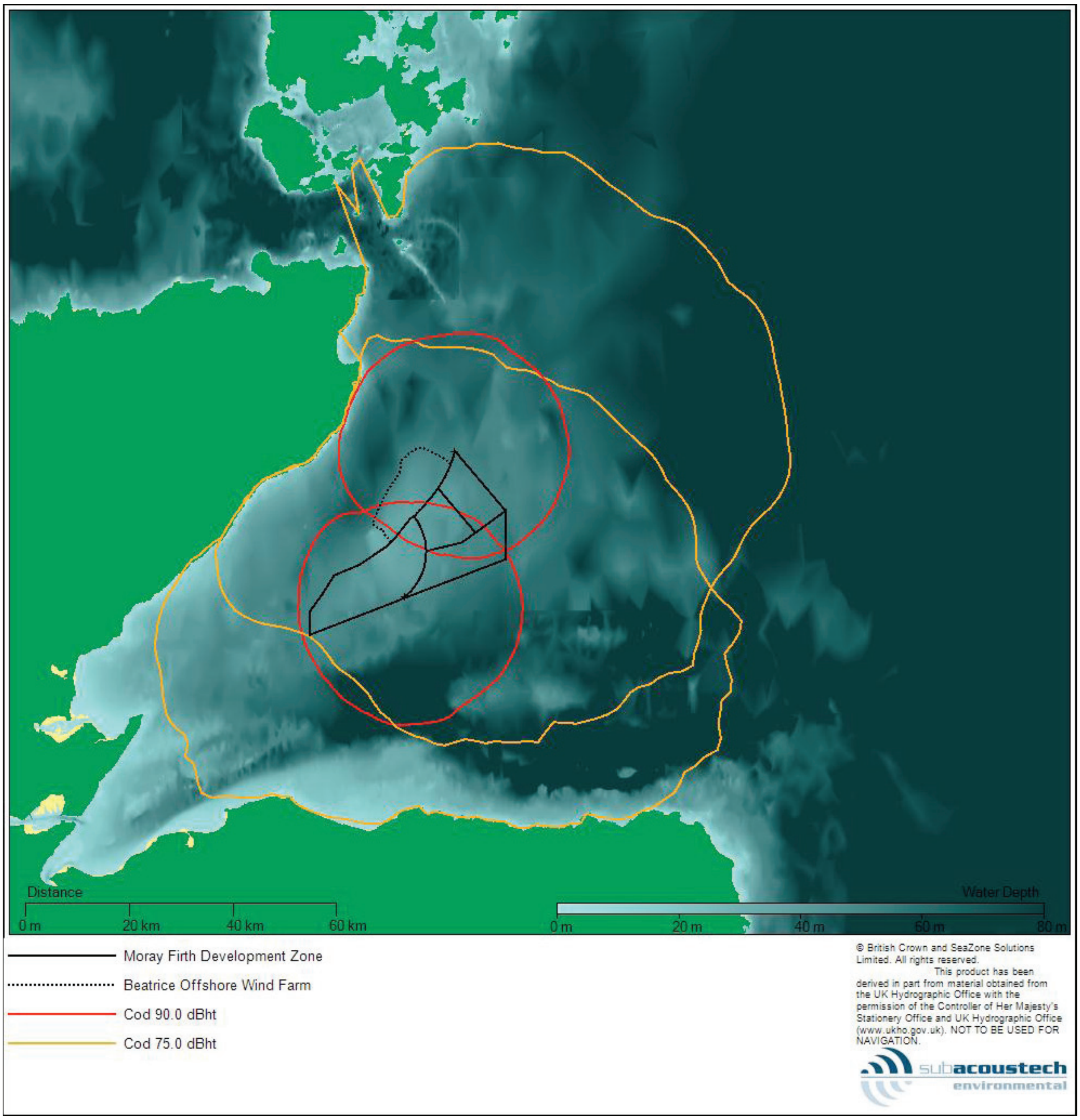


Figure A-100. 90 dB_{ht} and 75 dB_{ht} contours for cod; 2.5 m diameter piles being driven at locations 1 and 5 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 5
Pile driving energy (kJ)	1200
Species	Cod

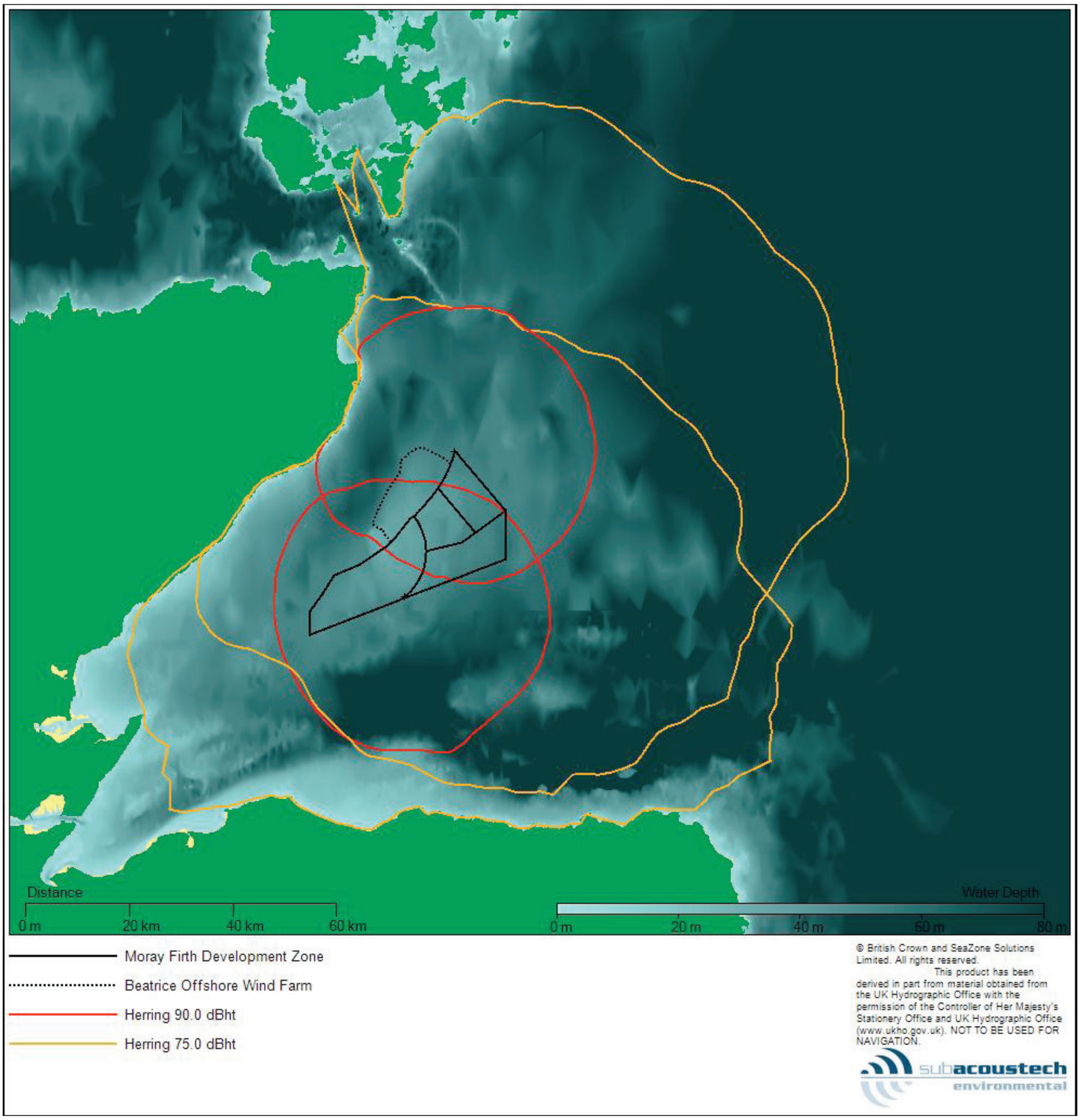


Figure A-101. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for herring; 2.5 m diameter piles being driven at locations 1 and 5 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 5
Pile driving energy (kJ)	1200
Species	Herring

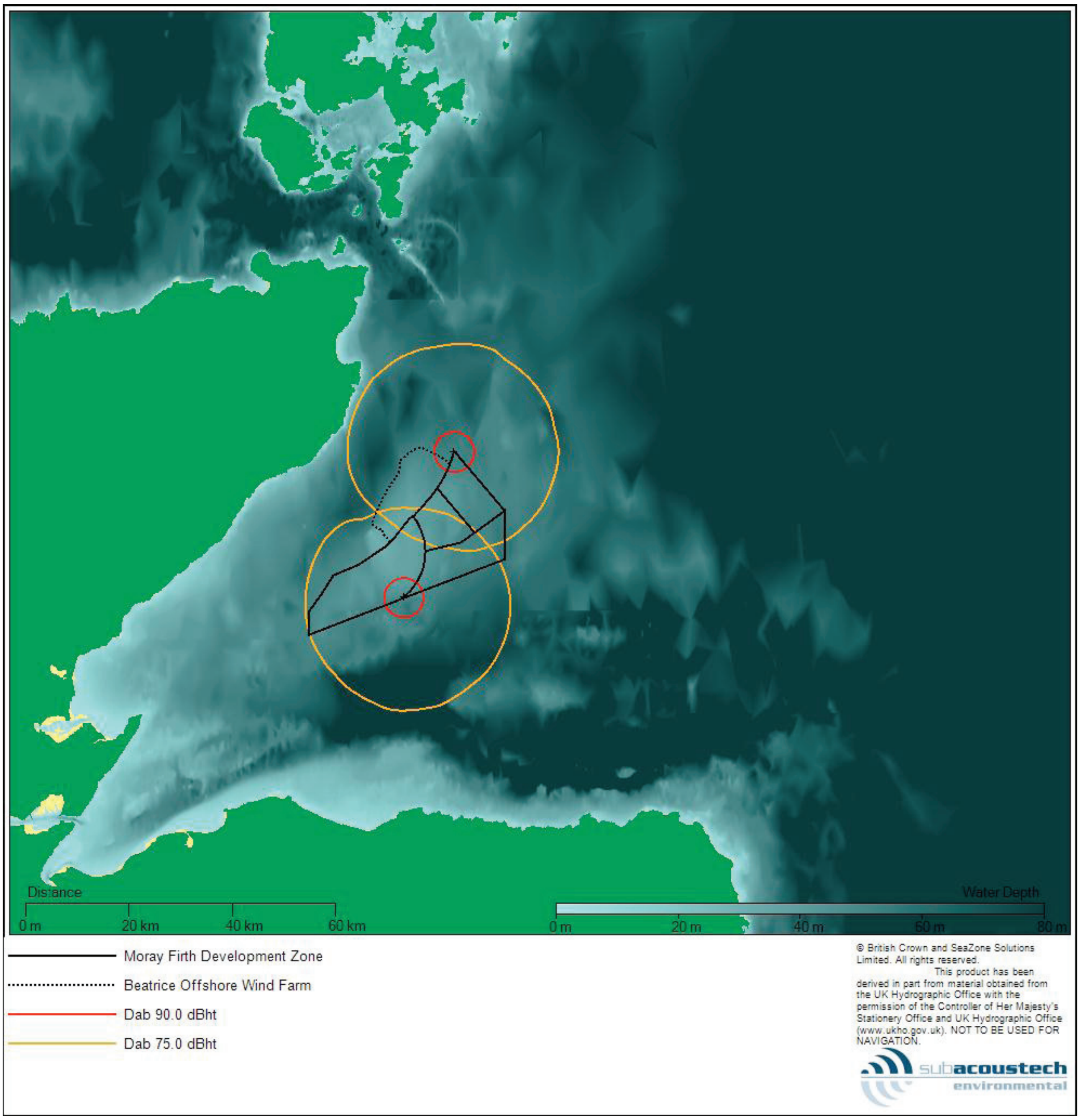


Figure A-102. 90 dB_{ht} and 75 dB_{ht} contours for plaice (dab used as surrogate); 2.5 m diameter piles being driven at locations 1 and 5 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 5
Pile driving energy (kJ)	1200
Species	Plaice

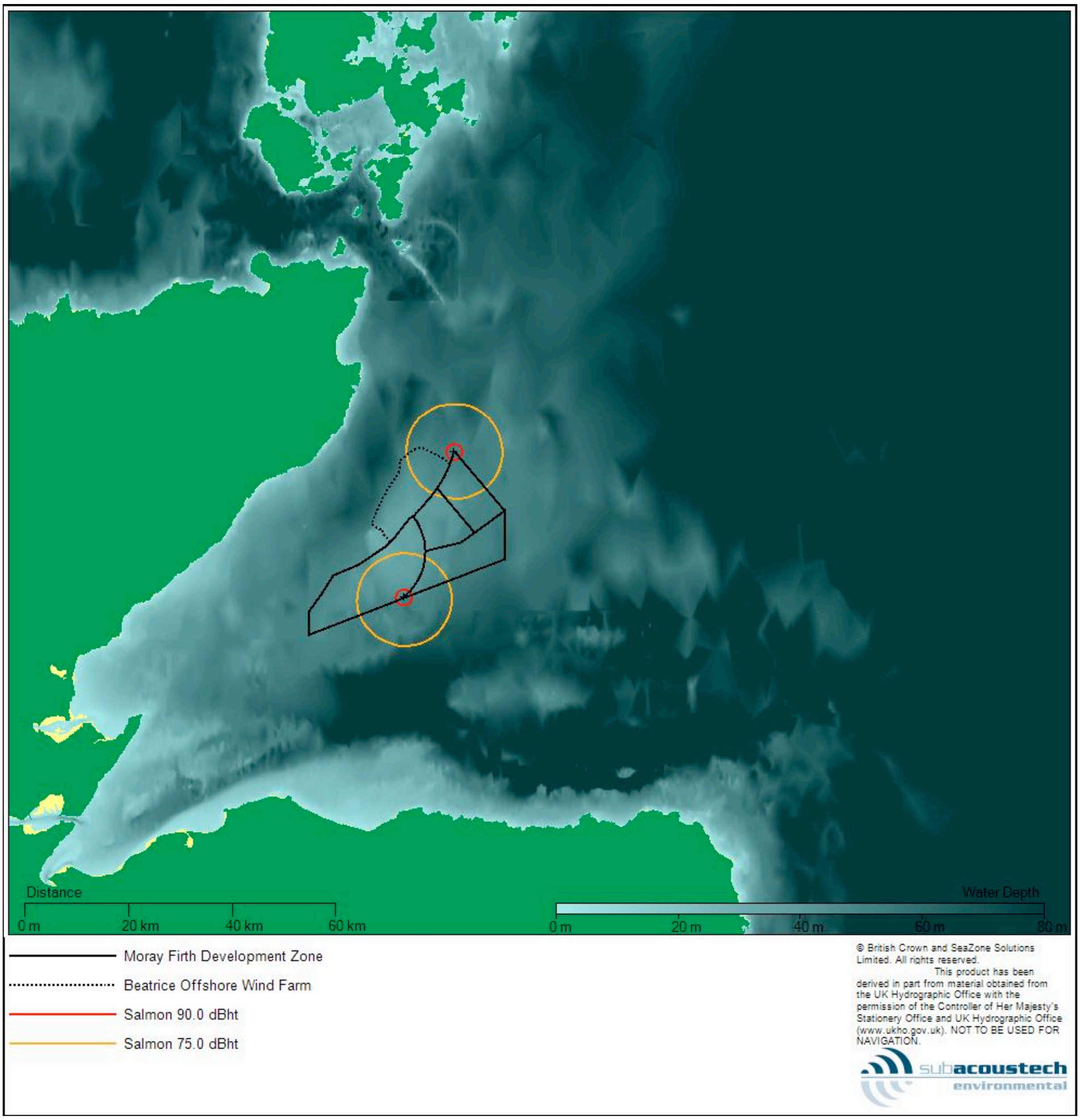


Figure A-103. 90 dB_{ht} and 75 dB_{ht} contours for salmon; 2.5 m diameter piles being driven at locations 1 and 5 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 5
Pile driving energy (kJ)	1200
Species	Salmon

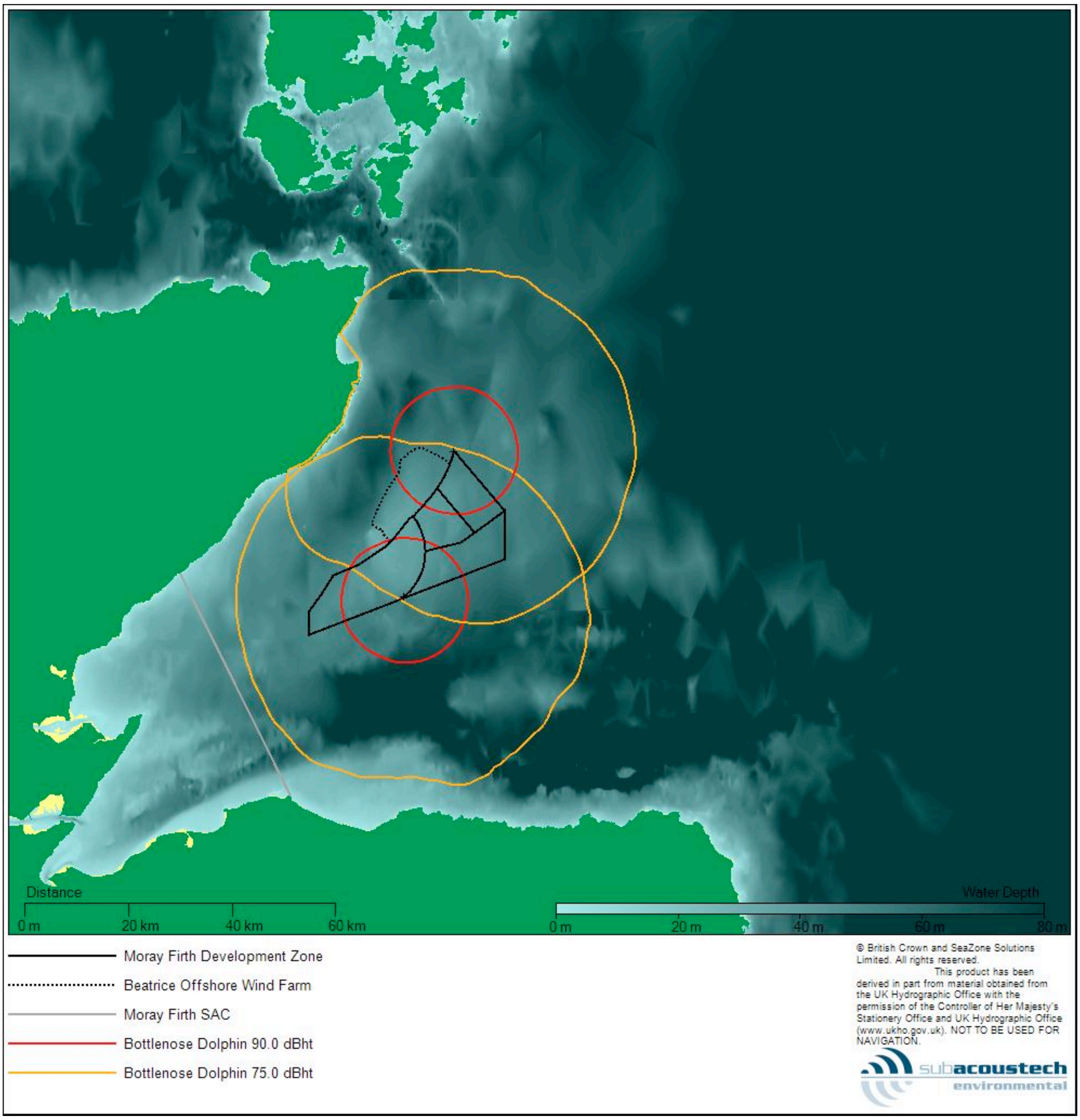


Figure A-104. 90 dB_{ht} and 75 dB_{ht} contours for bottlenose dolphin; 2.5 m diameter piles being driven at locations 1 and 5 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 5
Pile driving energy (kJ)	1200
Species	Bottlenose Dolphin

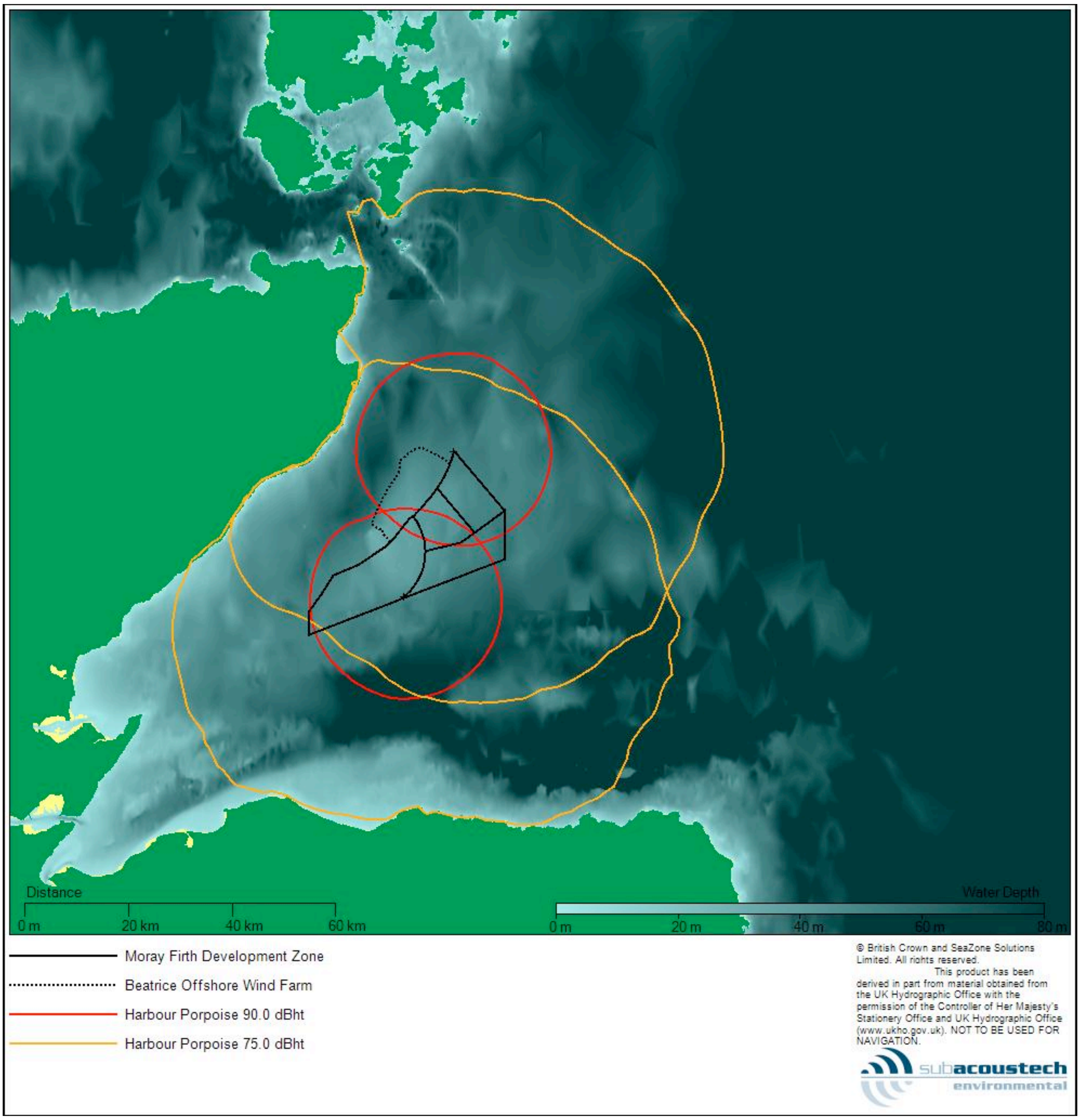


Figure A-105. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for harbour porpoise; 2.5 m diameter piles being driven at locations 1 and 5 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 5
Pile driving energy (kJ)	1200
Species	Harbour Porpoise

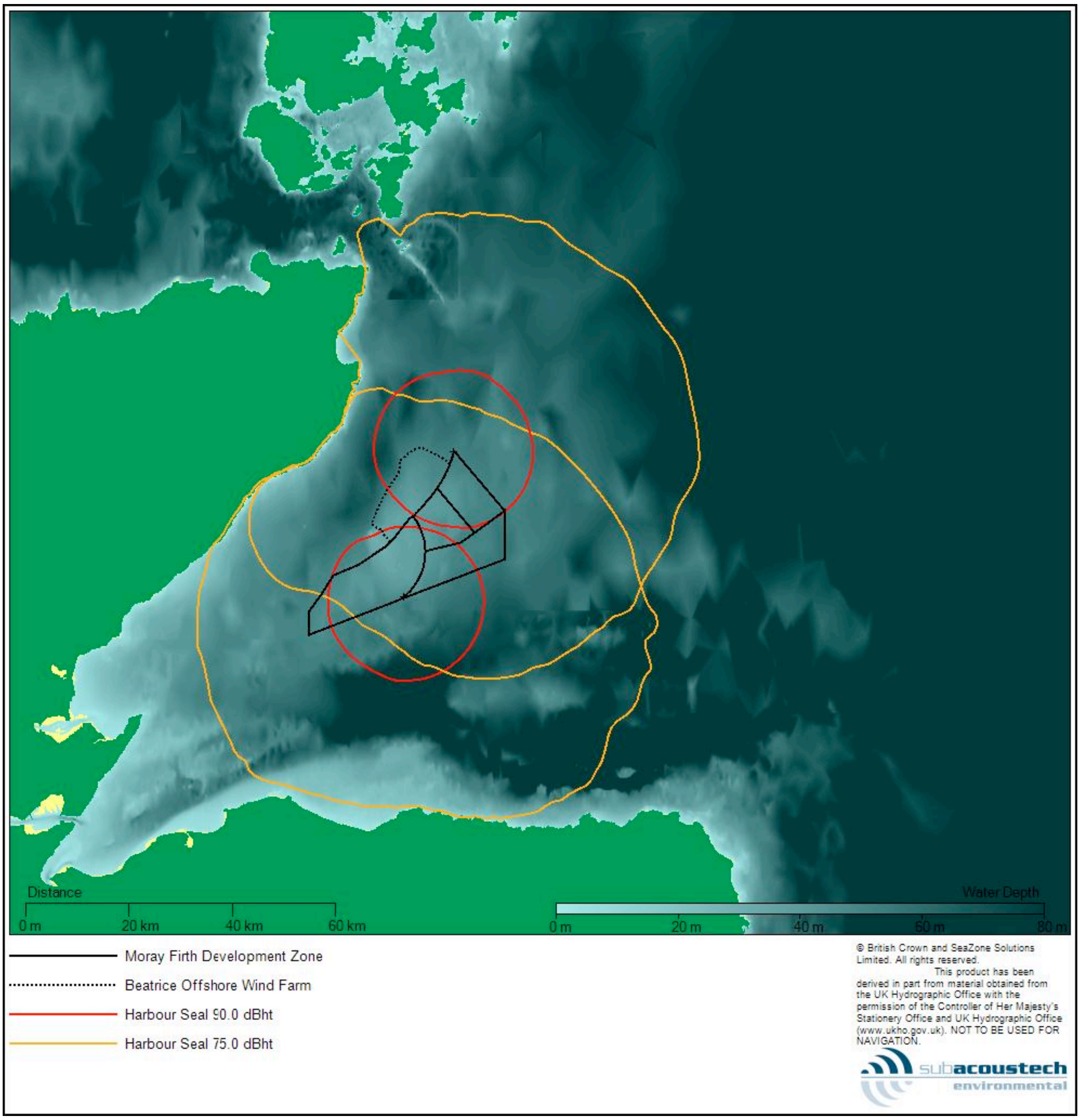


Figure A-106. 90 dB_{ht} and 75 dB_{ht} contours for harbour seal; 2.5 m diameter piles being driven at locations 1 and 5 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 5
Pile driving energy (kJ)	1200
Species	Harbour Seal

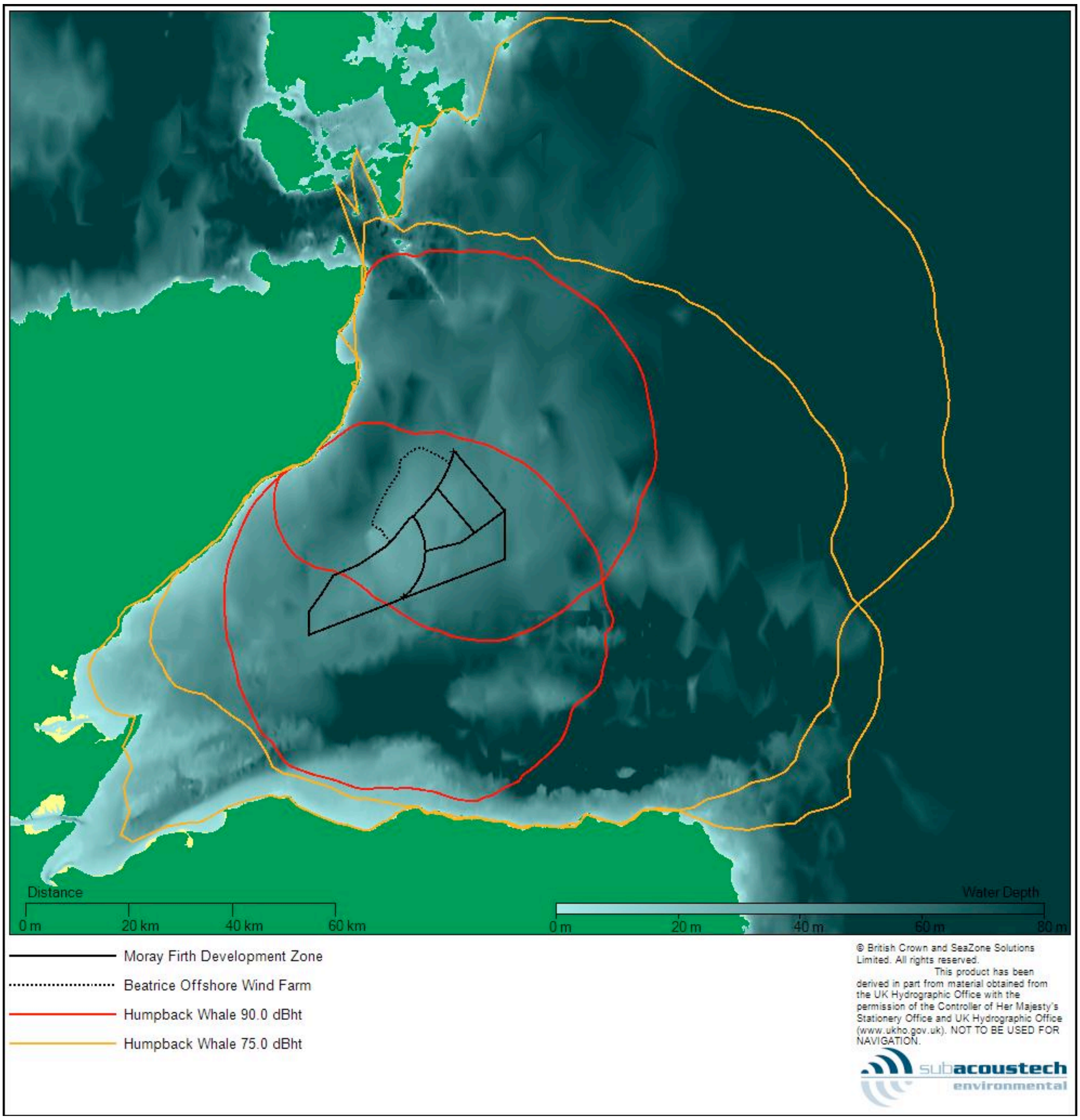


Figure A-107. 90 dB_{ht} and 75 dB_{ht} contours for minke whale (humpback whale used as surrogate); 2.5 m diameter piles being driven at locations 1 and 5 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 5
Pile driving energy (kJ)	1200
Species	Minke Whale

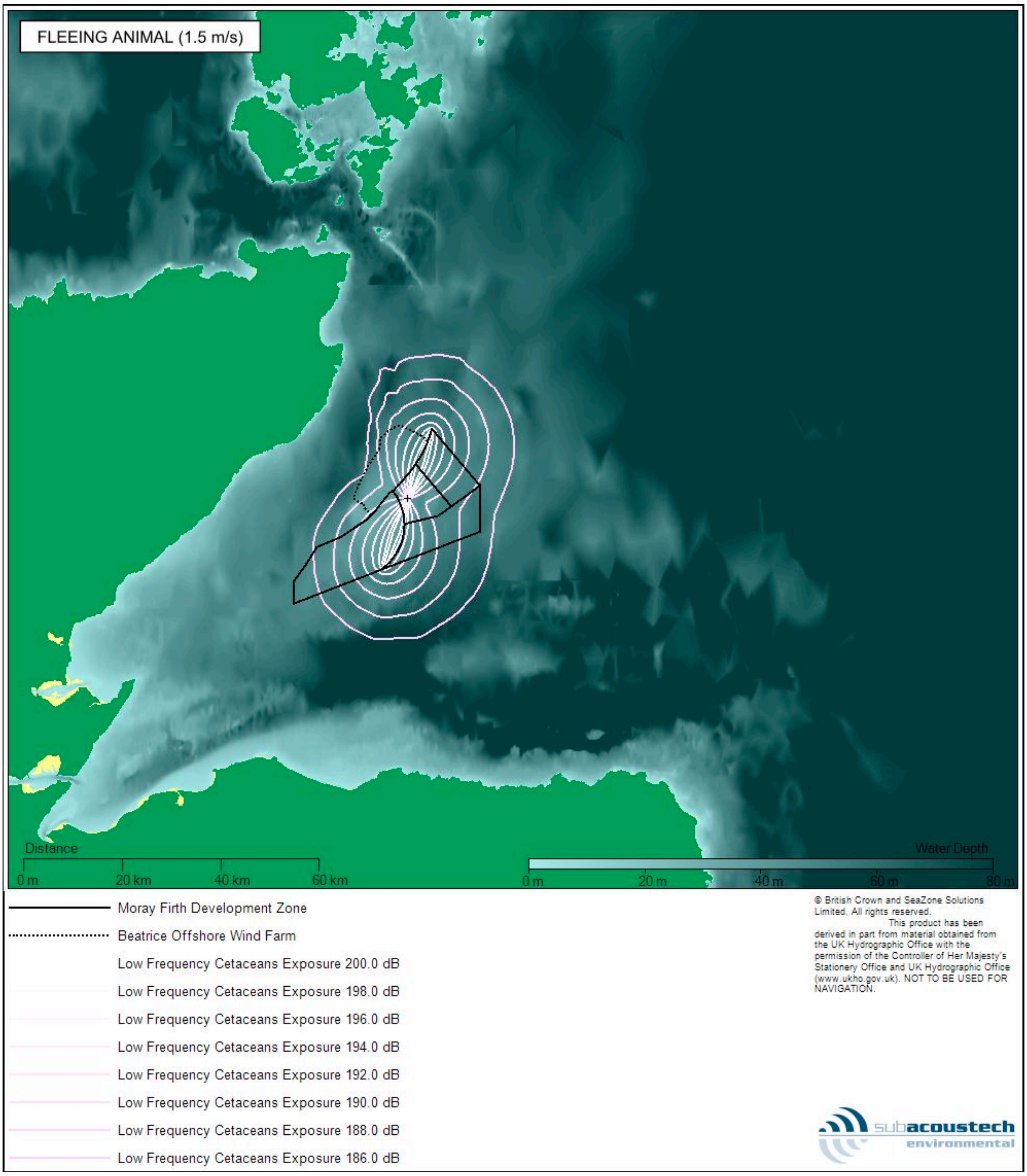


Figure A-108. Starting loci for fleeing Low Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 1 and 5 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 5
Pile driving energy (kJ)	1200
Species	Low Frequency Cetaceans (Fleeing 1.5m/s)

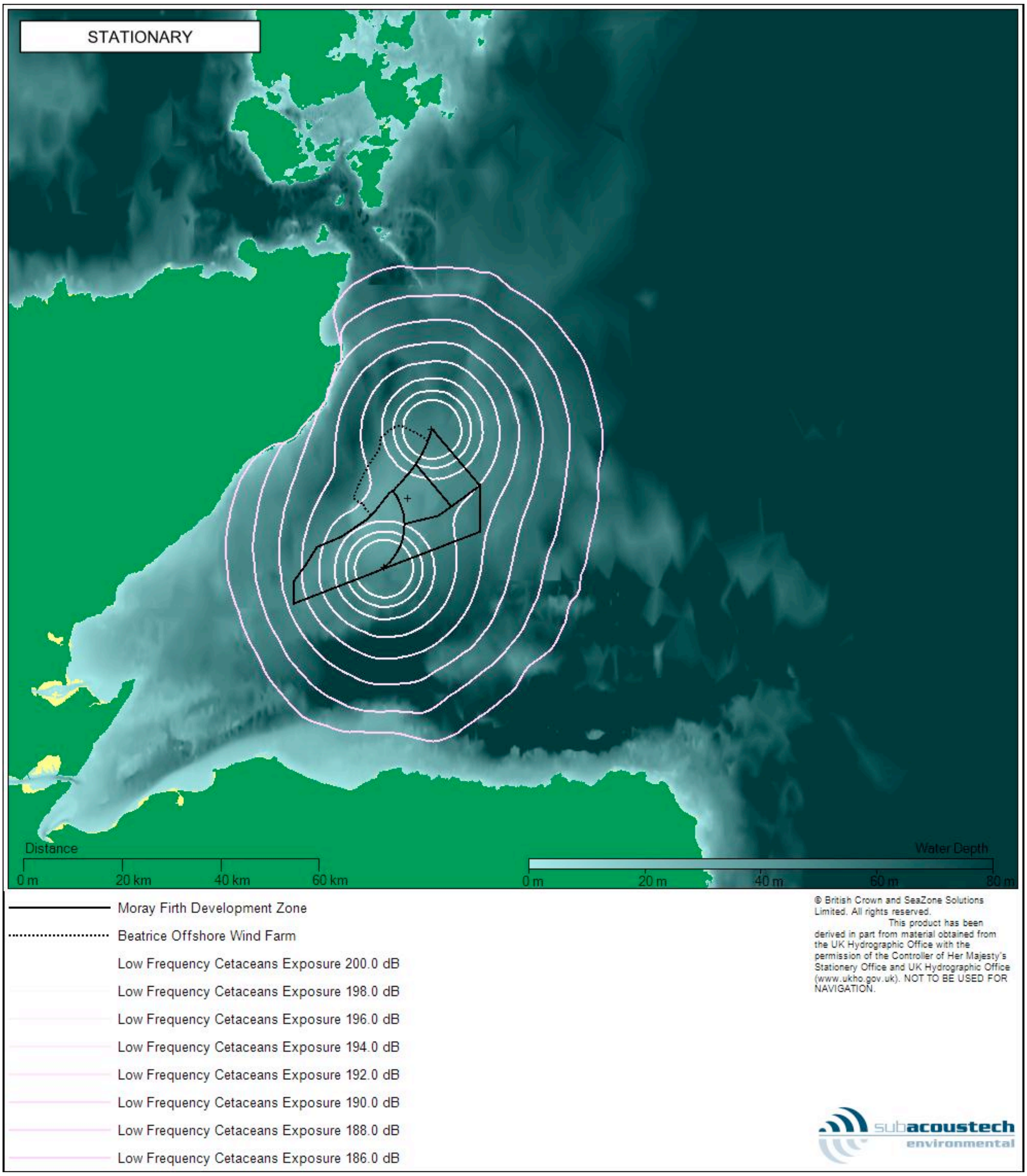


Figure A-109. Contours for stationary Low Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 1 and 5 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 5
Pile driving energy (kJ)	1200
Species	Low Frequency Cetaceans (Stationary)

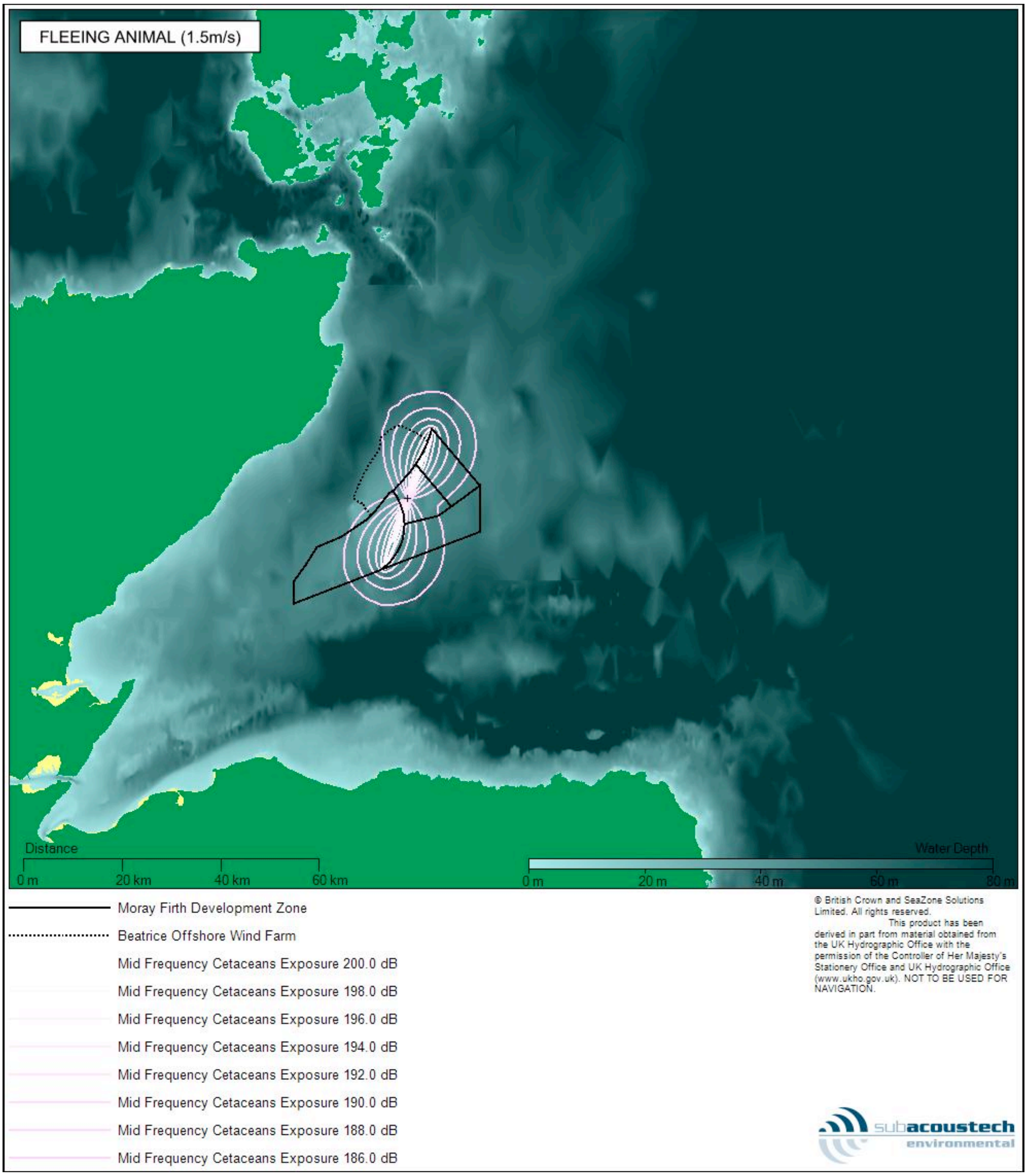


Figure A-110. Starting loci for fleeing Mid Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 1 and 5 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 5
Pile driving energy (kJ)	1200
Species	Mid Frequency Cetaceans (Fleeing 1.5m/s)

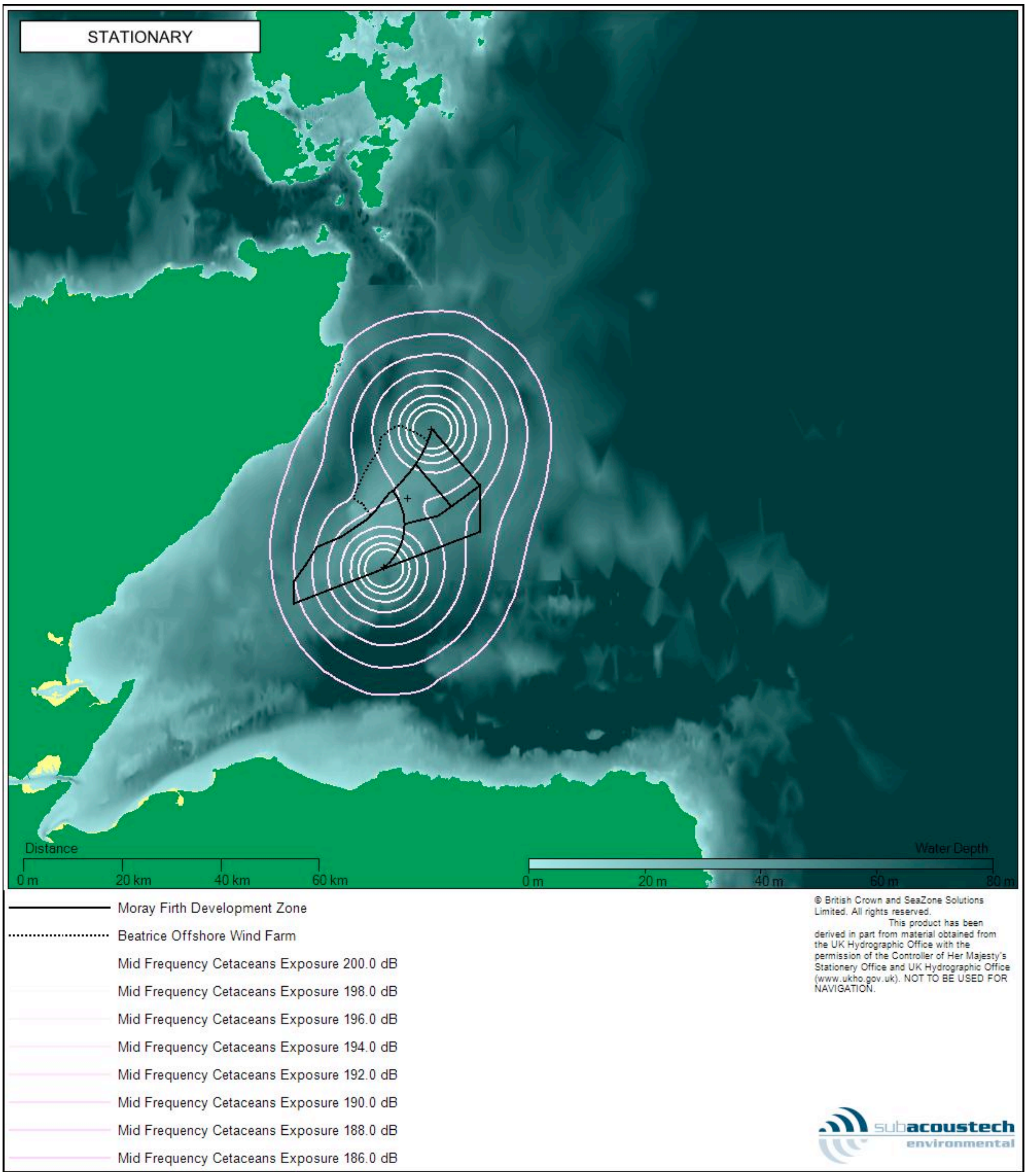


Figure A-111. Contours for stationary Mid Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 1 and 5 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 5
Pile driving energy (kJ)	1200
Species	Mid Frequency Cetaceans (Stationary)

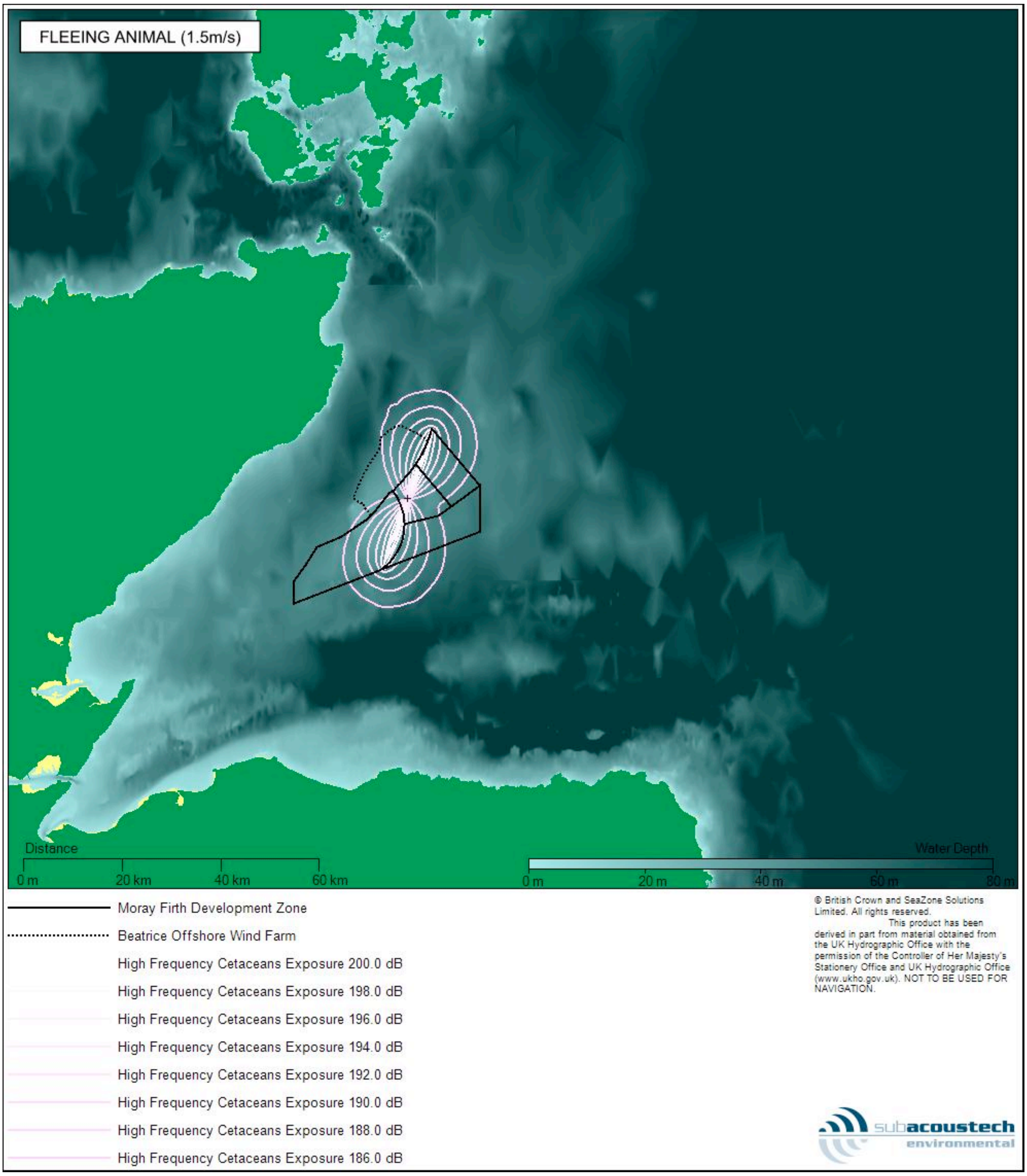


Figure A-112. Starting loci for fleeing High Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 1 and 5 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 5
Pile driving energy (kJ)	1200
Species	High Frequency Cetaceans (Fleeing 1.5m/s)

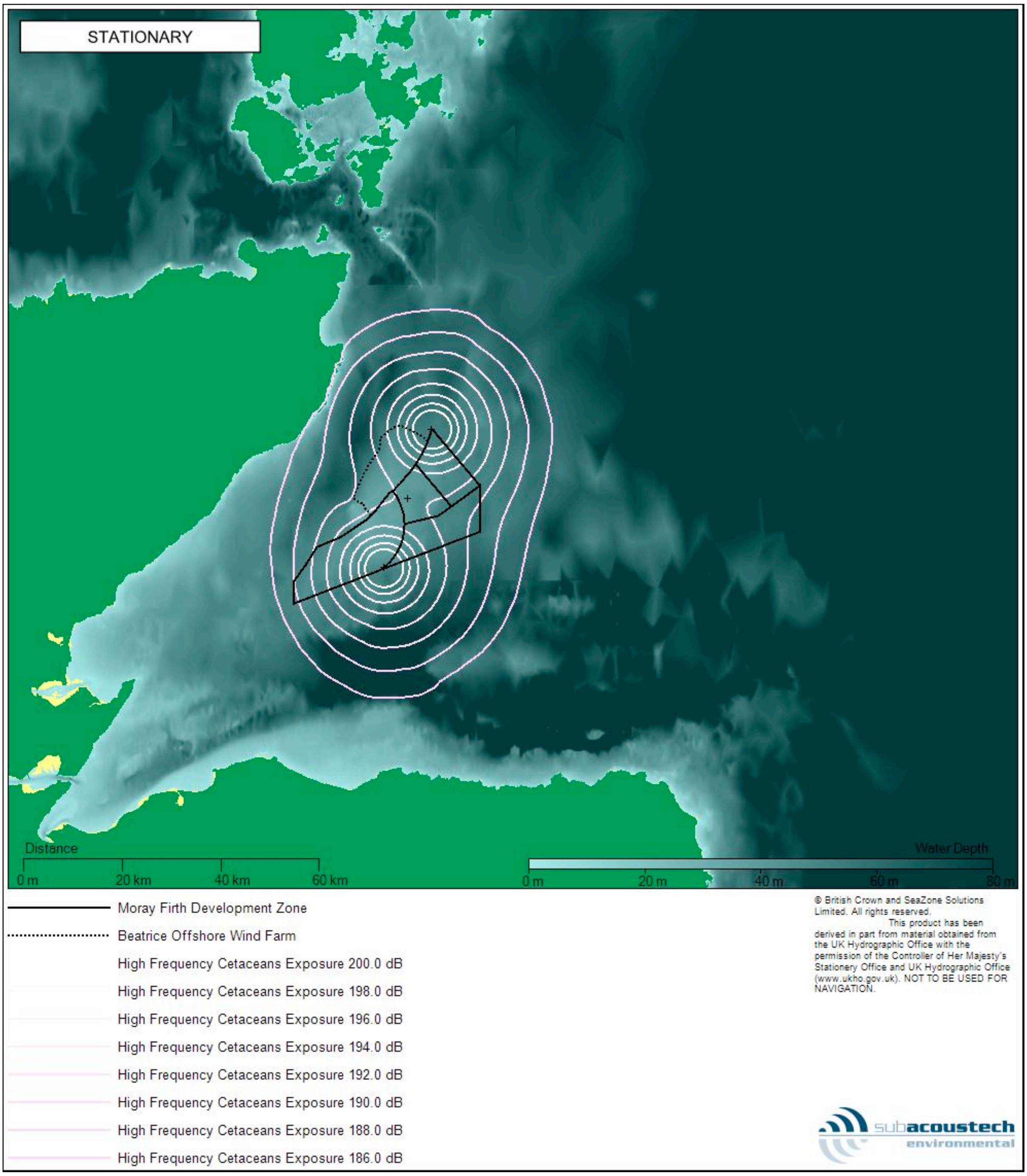


Figure A-113. Contours for stationary High Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 1 and 5 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 5
Pile driving energy (kJ)	1200
Species	High Frequency Cetaceans (Stationary)

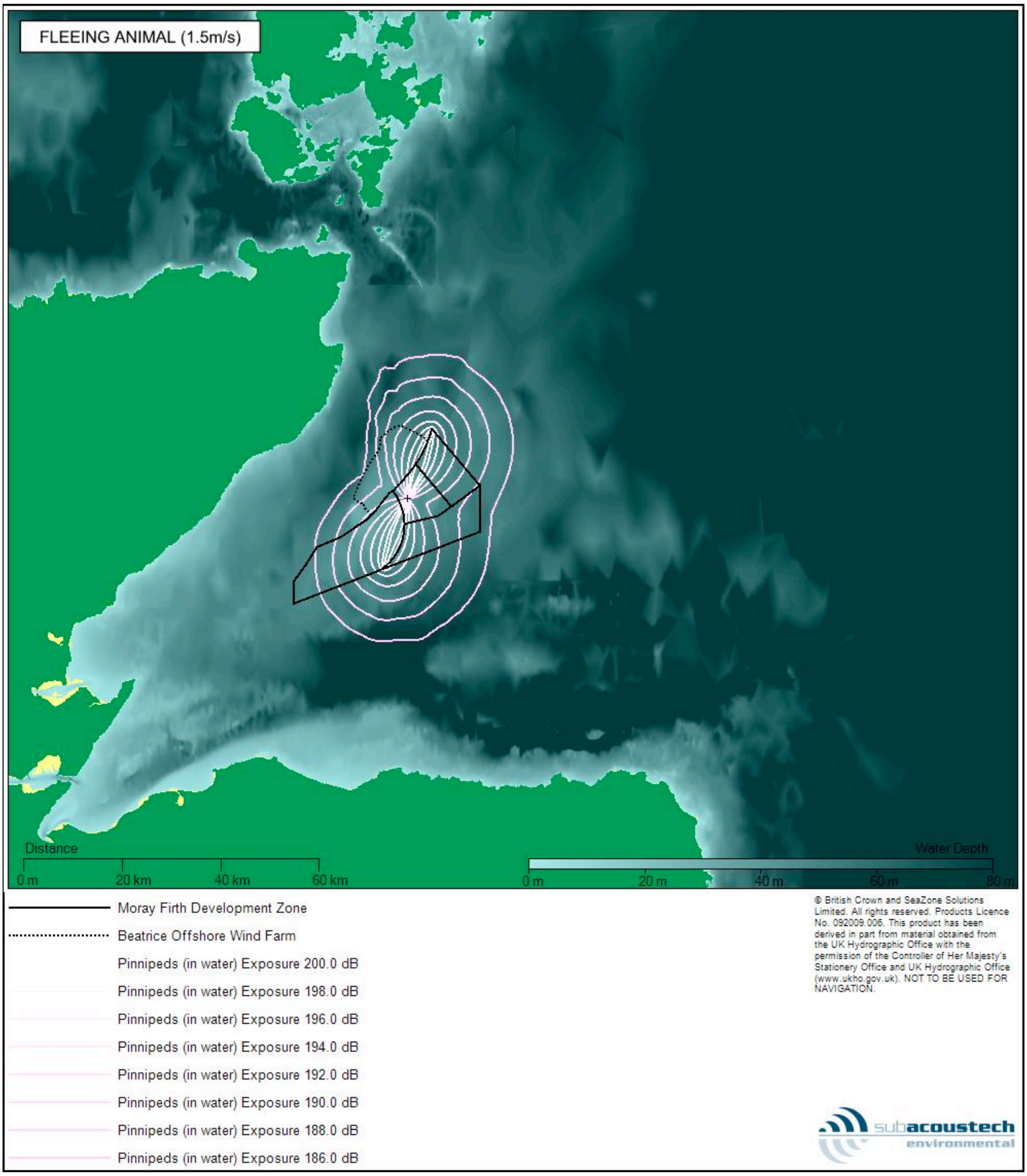


Figure A-114. Starting loci for fleeing Pinnipeds (in water); two 2.5 m diameter piles being driven sequentially at locations 1 and 5 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 5
Pile driving energy (kJ)	1200
Species	Pinnipeds (in water) (Fleeing 1.5m/s)

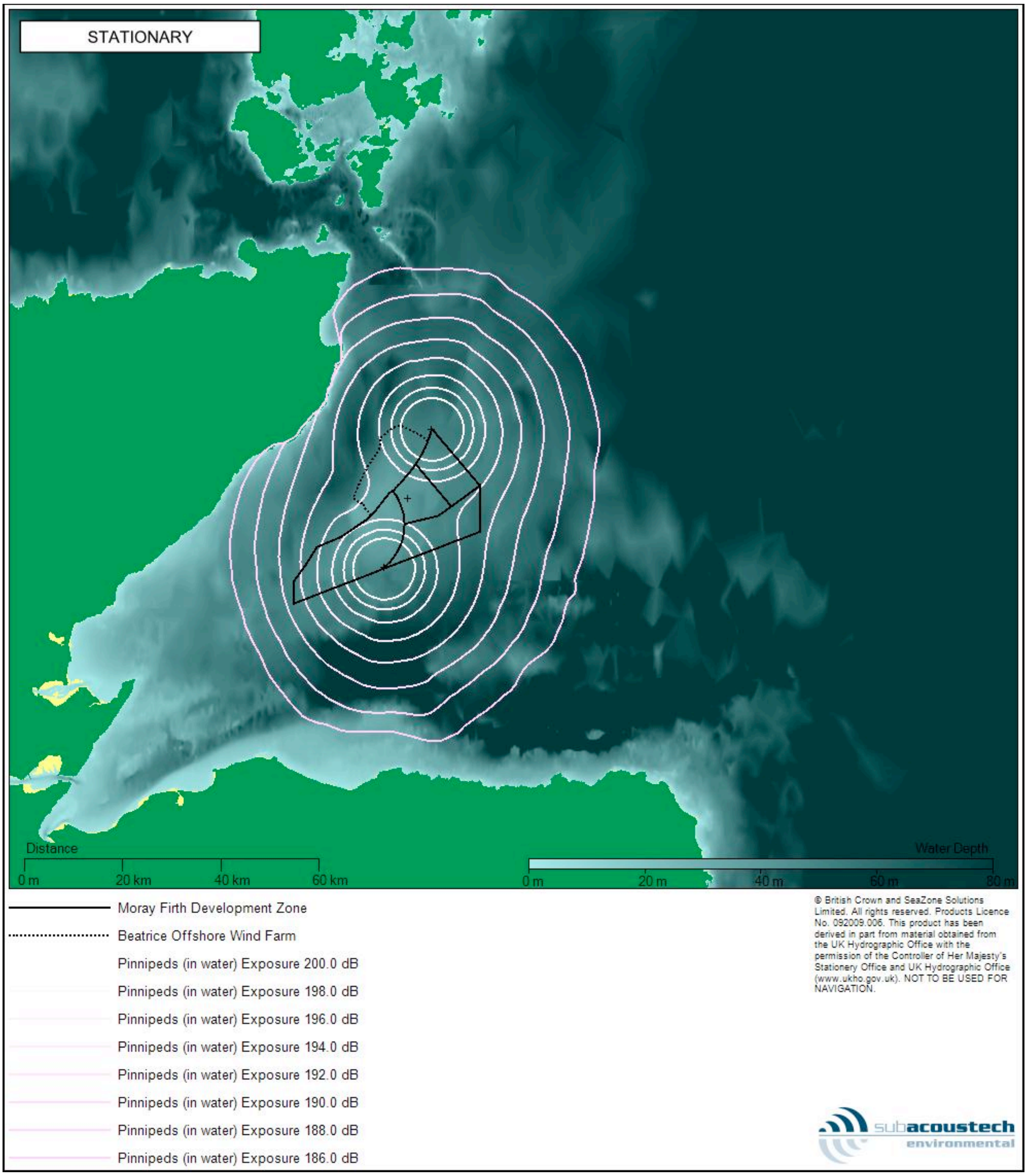


Figure A-115. Contours for stationary Pinnipeds (in water); two 2.5 m diameter piles being driven sequentially at locations 1 and 5 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 5
Pile driving energy (kJ)	1200
Species	Pinnipeds (in water) (Stationary)

9.2.4.3 Results for 2 piles being driven simultaneously at 2 locations on the MacColl site

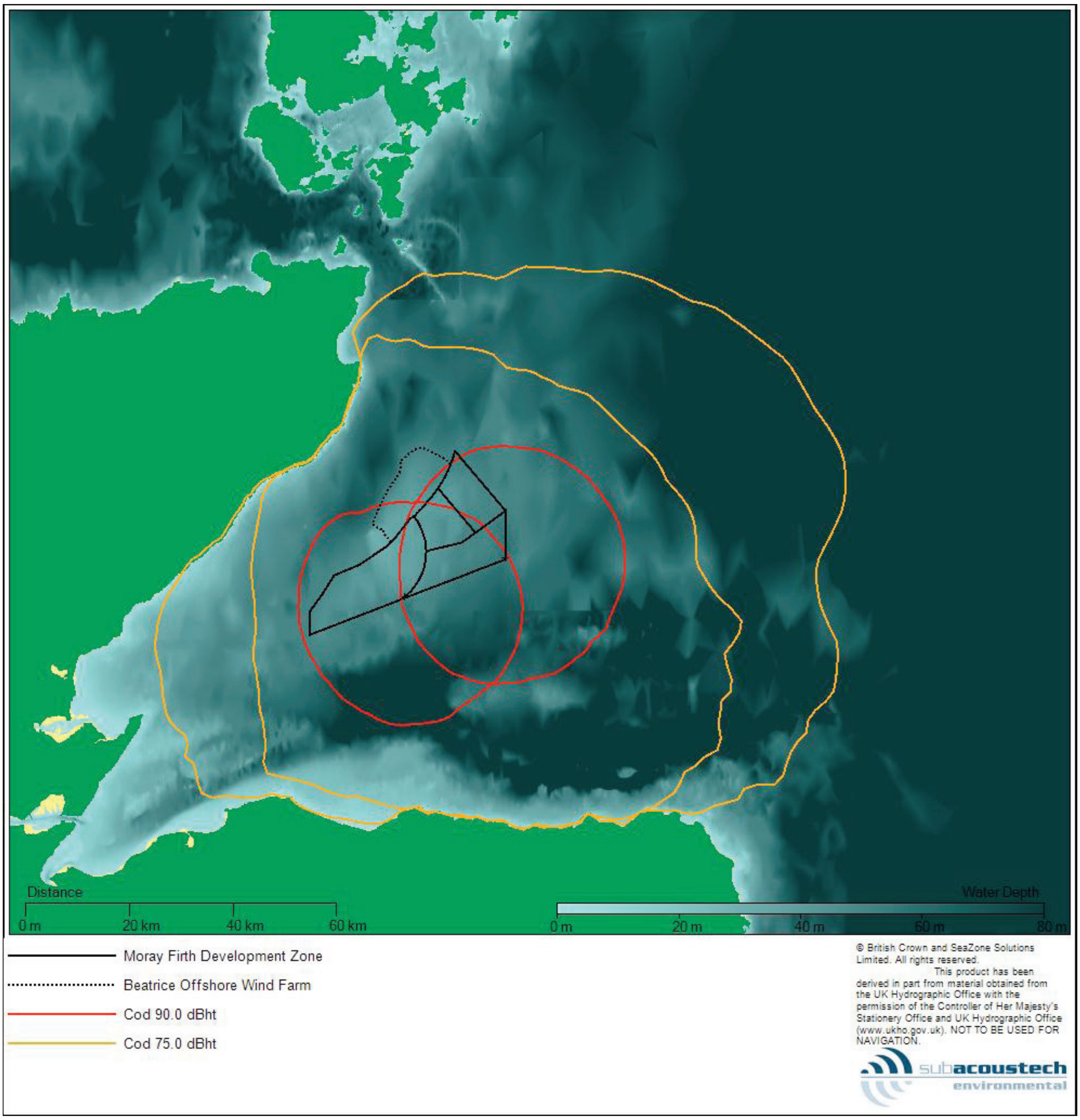


Figure A-116. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for cod; 2.5 m diameter piles being driven at locations 1 and 2 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 2
Pile driving energy (kJ)	1200
Species	Cod

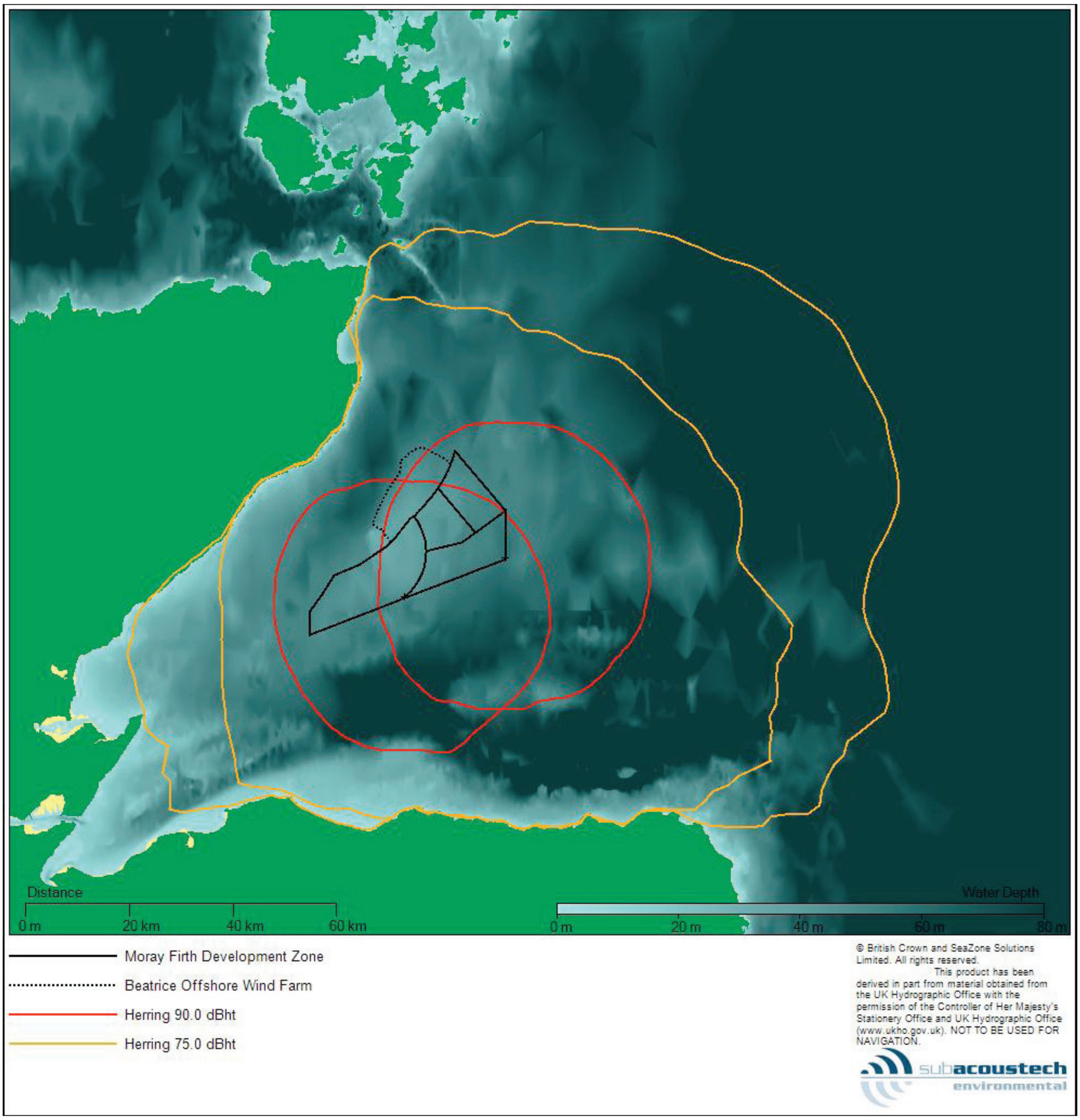


Figure A-117. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for herring; 2.5 m diameter piles being driven at locations 1 and 2 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 2
Pile driving energy (kJ)	1200
Species	Herring

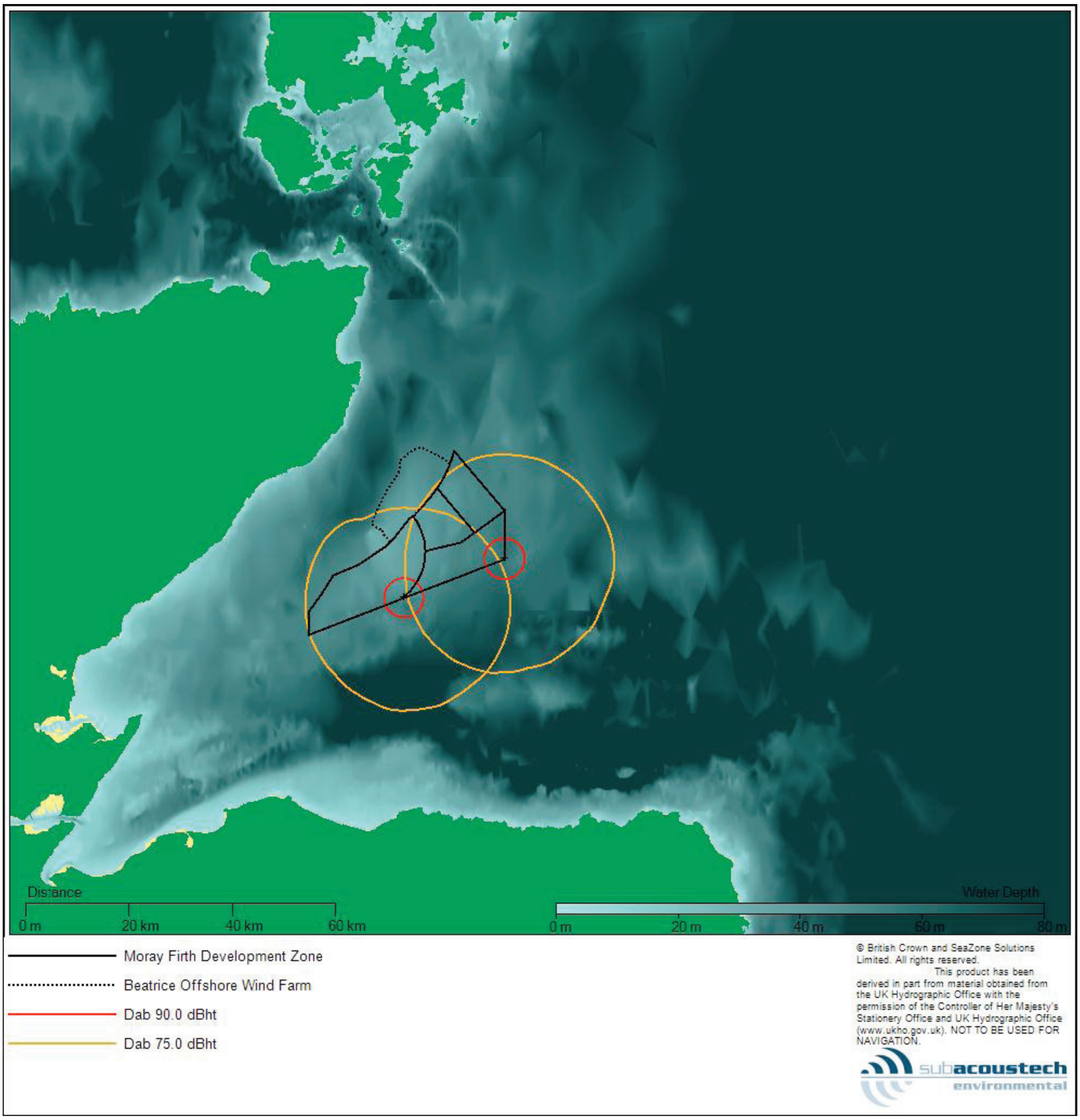


Figure A-118. 90 dB_{ht} and 75 dB_{ht} contours for plaice (dab used as surrogate); 2.5 m diameter piles being driven at locations 1 and 2 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 2
Pile driving energy (kJ)	1200
Species	Plaice

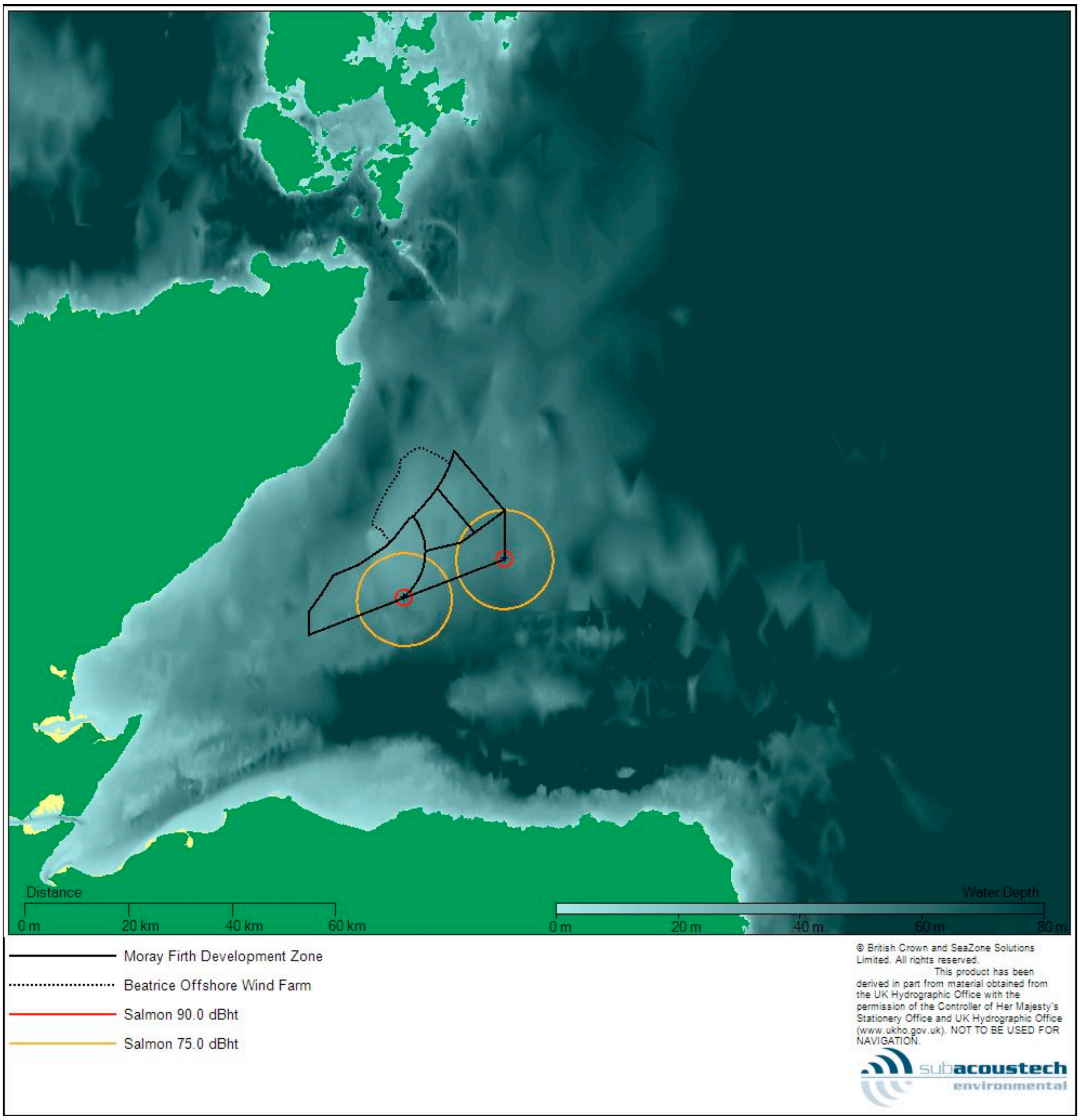


Figure A-119. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for salmon; 2.5 m diameter piles being driven at locations 1 and 2 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 2
Pile driving energy (kJ)	1200
Species	Salmon

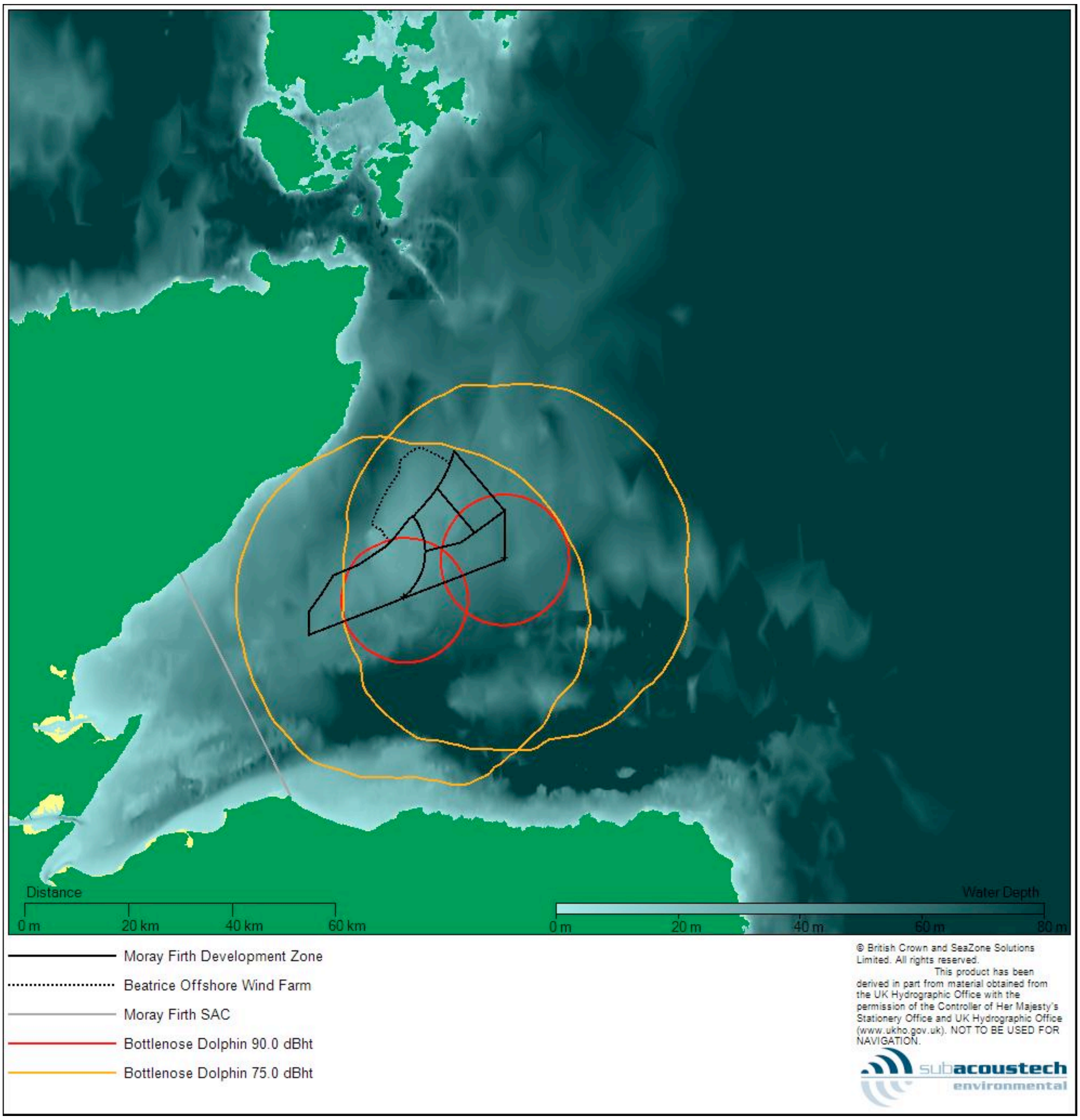


Figure A-120. 90 dB_{ht} and 75 dB_{ht} contours for bottlenose dolphin; 2.5 m diameter piles being driven at locations 1 and 2 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 2
Pile driving energy (kJ)	1200
Species	Bottlenose Dolphin

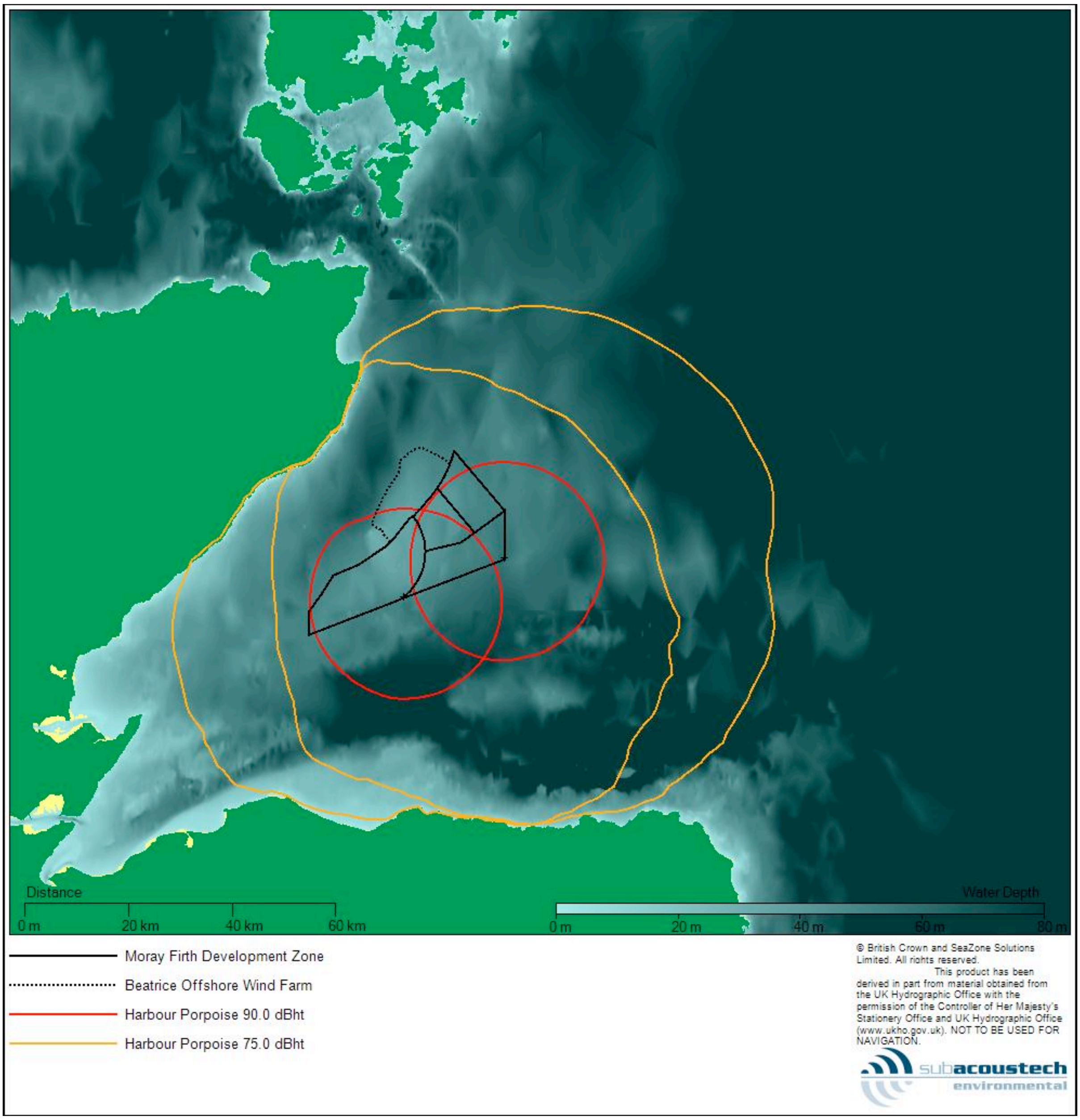


Figure A-121. 90 dB_{ht} and 75 dB_{ht} contours for harbour porpoise; 2.5 m diameter piles being driven at locations 1 and 2 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 2
Pile driving energy (kJ)	1200
Species	Harbour Porpoise

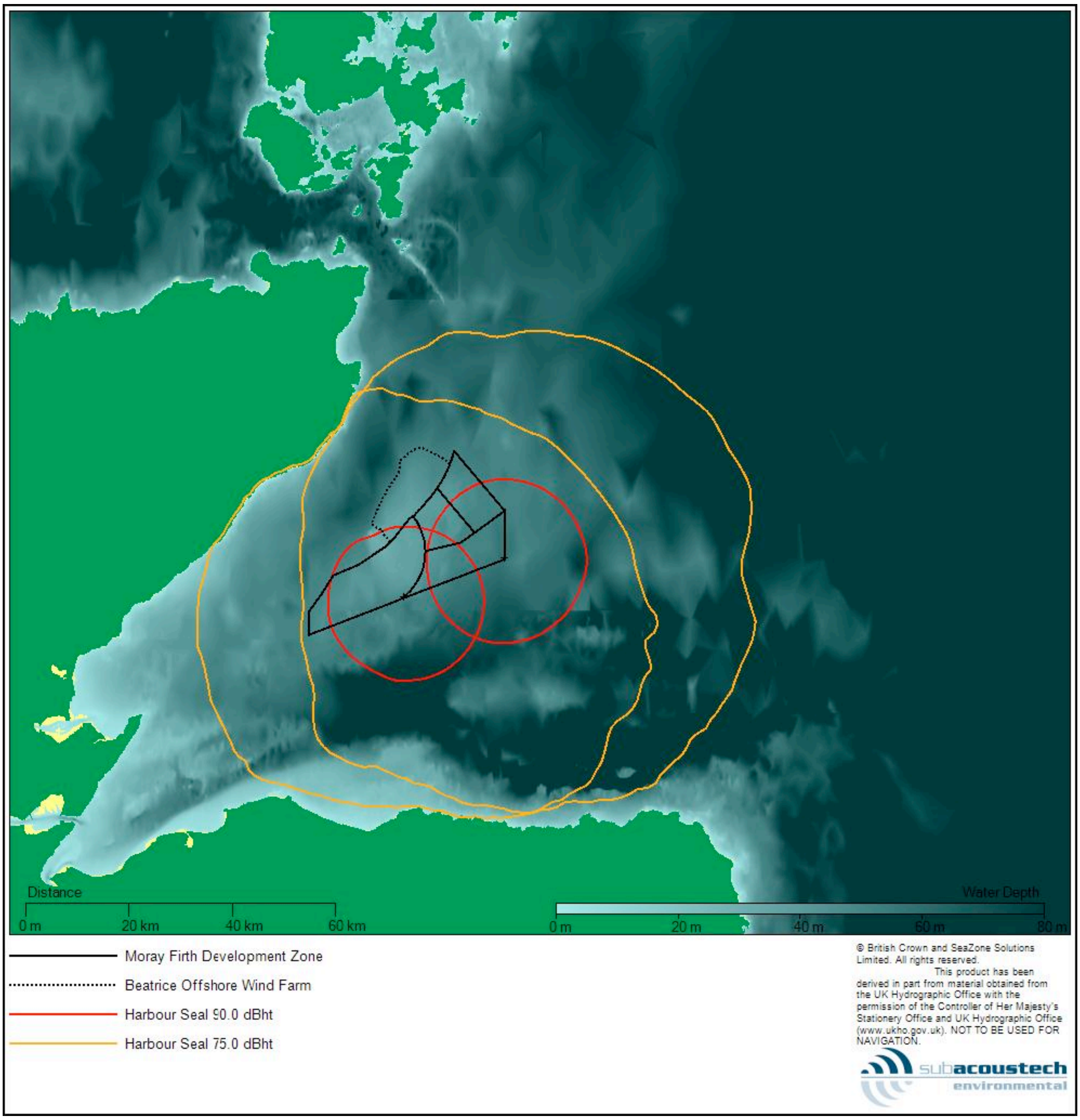


Figure A-122. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for harbour seal; 2.5 m diameter piles being driven at locations 1 and 2 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 2
Pile driving energy (kJ)	1200
Species	Harbour Seal

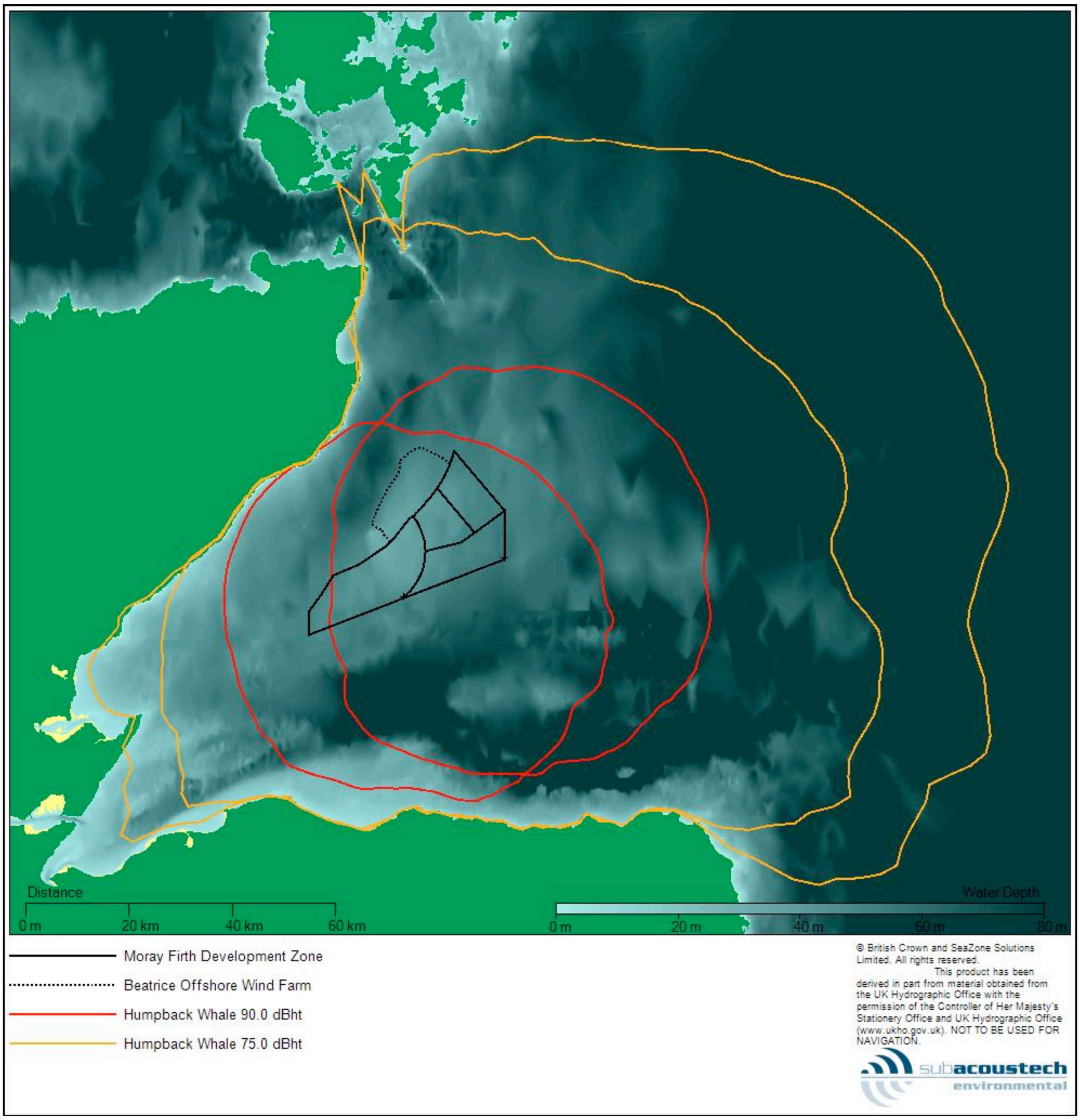


Figure A-123. 90 dB_{ht} and 75 dB_{ht} contours for minke whale (humpback whale used as surrogate); 2.5 m diameter piles being driven at locations 1 and 2 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 2
Pile driving energy (kJ)	1200
Species	Minke Whale

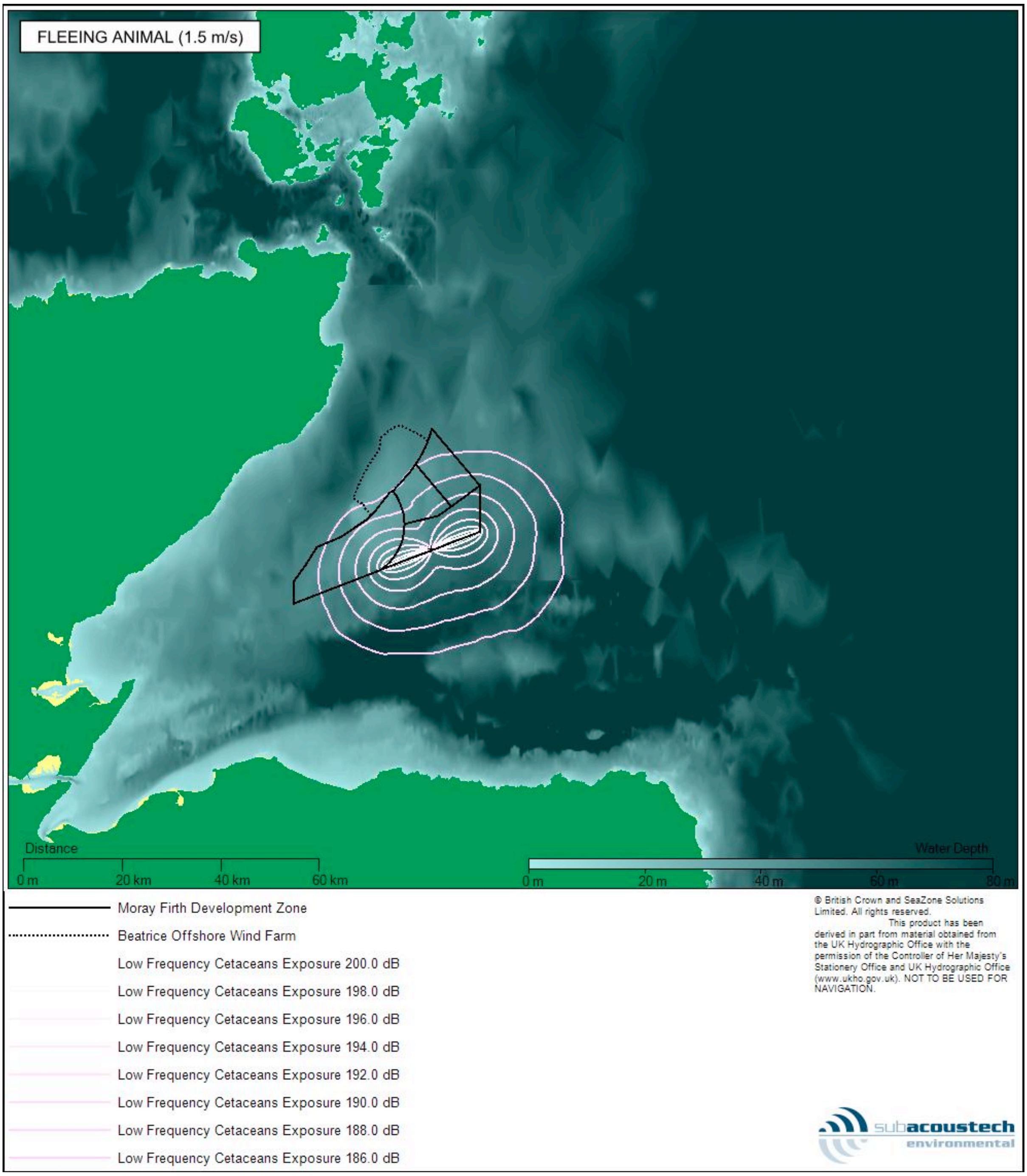


Figure A-124. Starting loci for fleeing Low Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 1 and 2 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 2
Pile driving energy (kJ)	1200
Species	Low Frequency Cetaceans (Fleeing 1.5m/s)

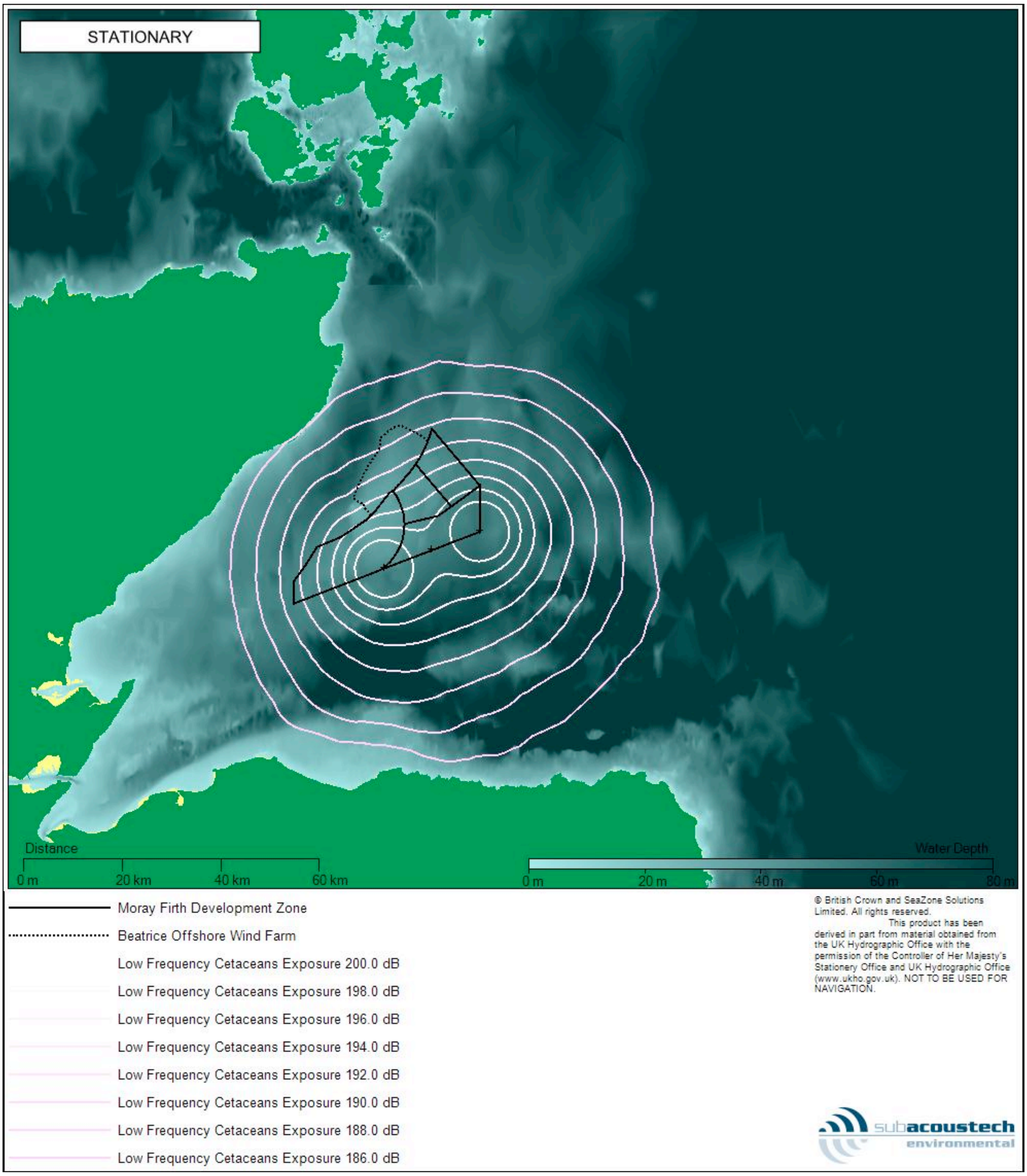


Figure A-125. Contours for stationary Low Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 1 and 2 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 2
Pile driving energy (kJ)	1200
Species	Low Frequency Cetaceans (Stationary)

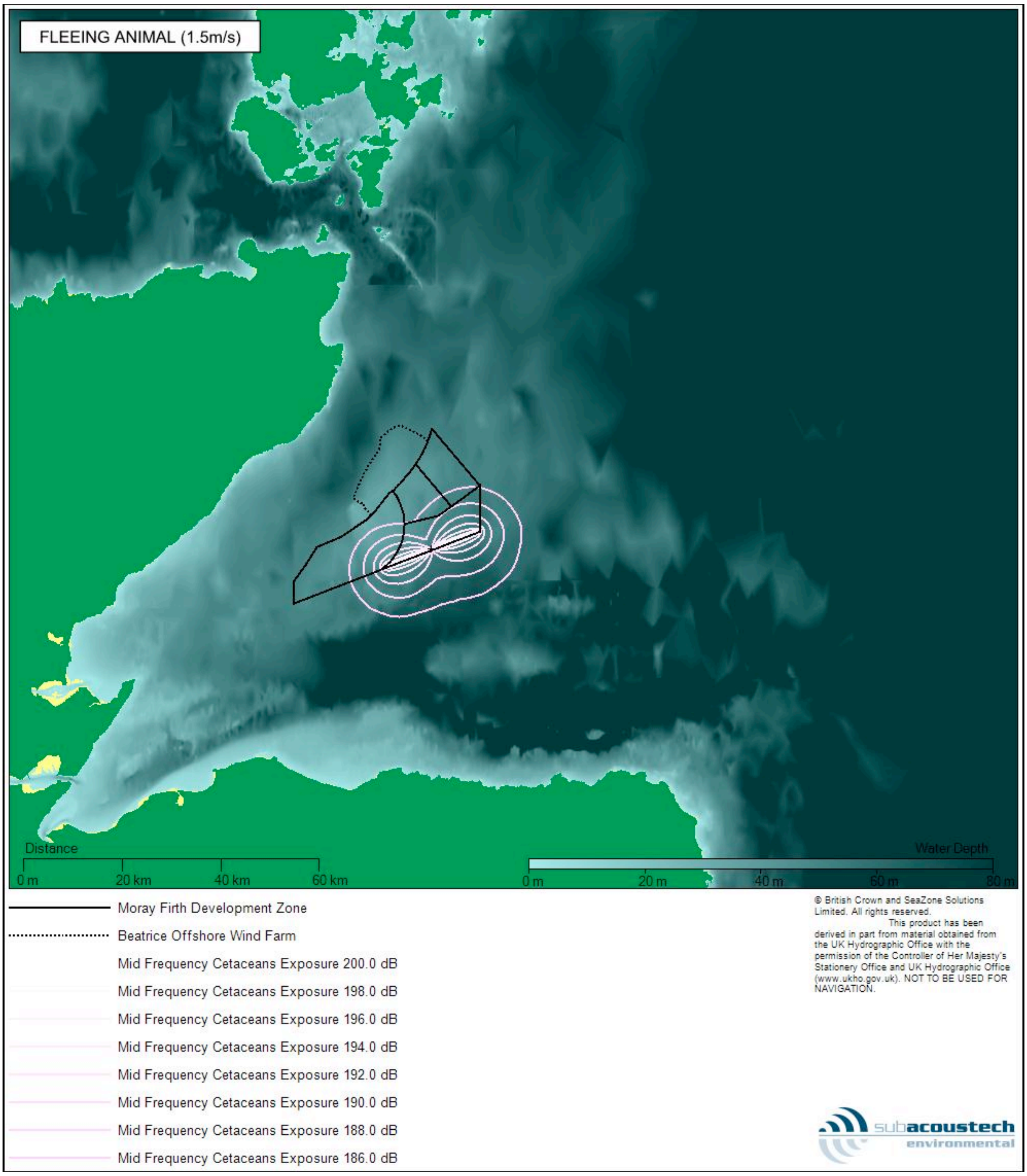


Figure A-126. Starting loci for fleeing Mid Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 1 and 2 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 2
Pile driving energy (kJ)	1200
Species	Mid Frequency Cetaceans (Fleeing 1.5m/s)

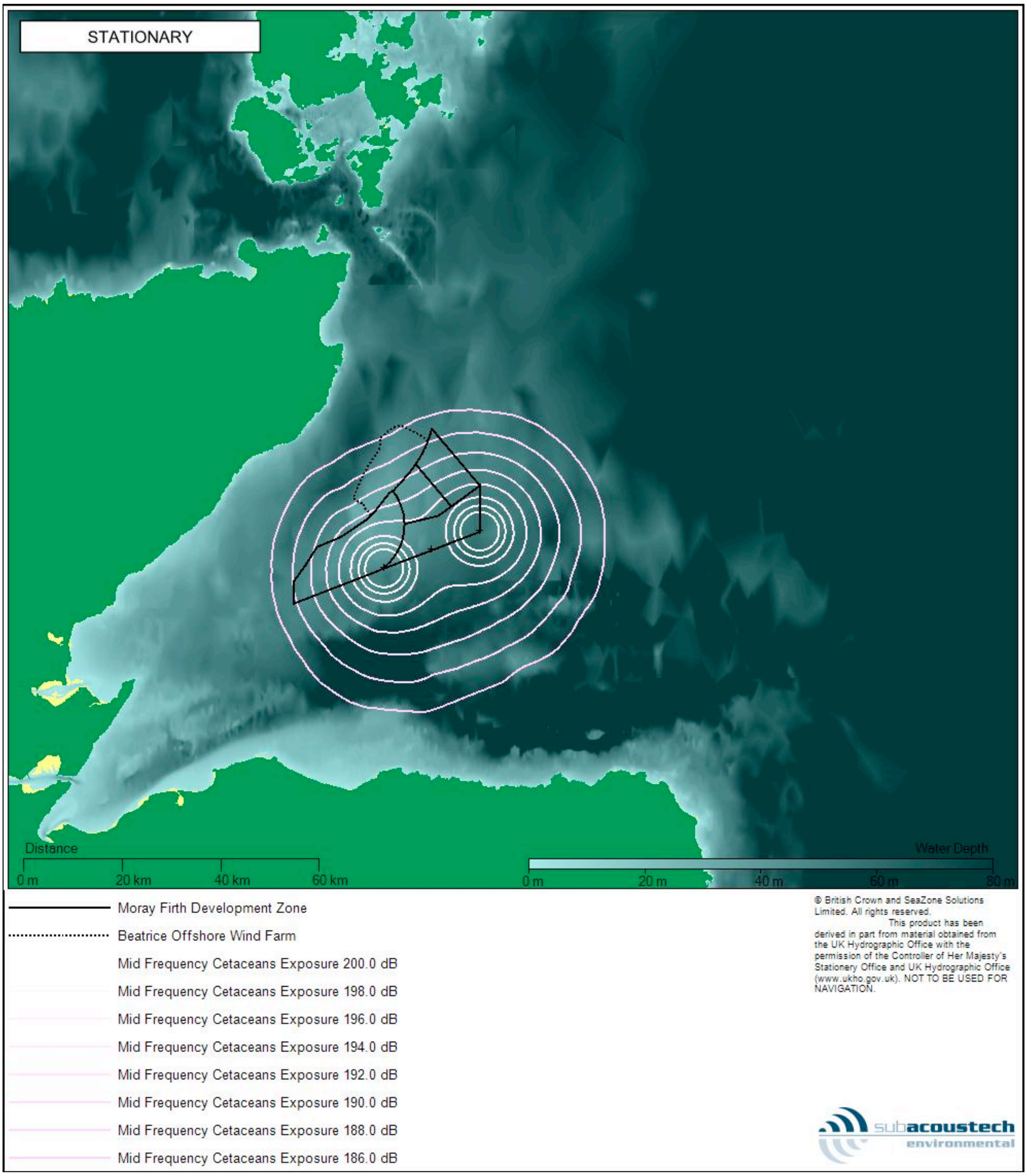


Figure A-127. Contours for stationary Mid Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 1 and 2 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 2
Pile driving energy (kJ)	1200
Species	Mid Frequency Cetaceans (Stationary)

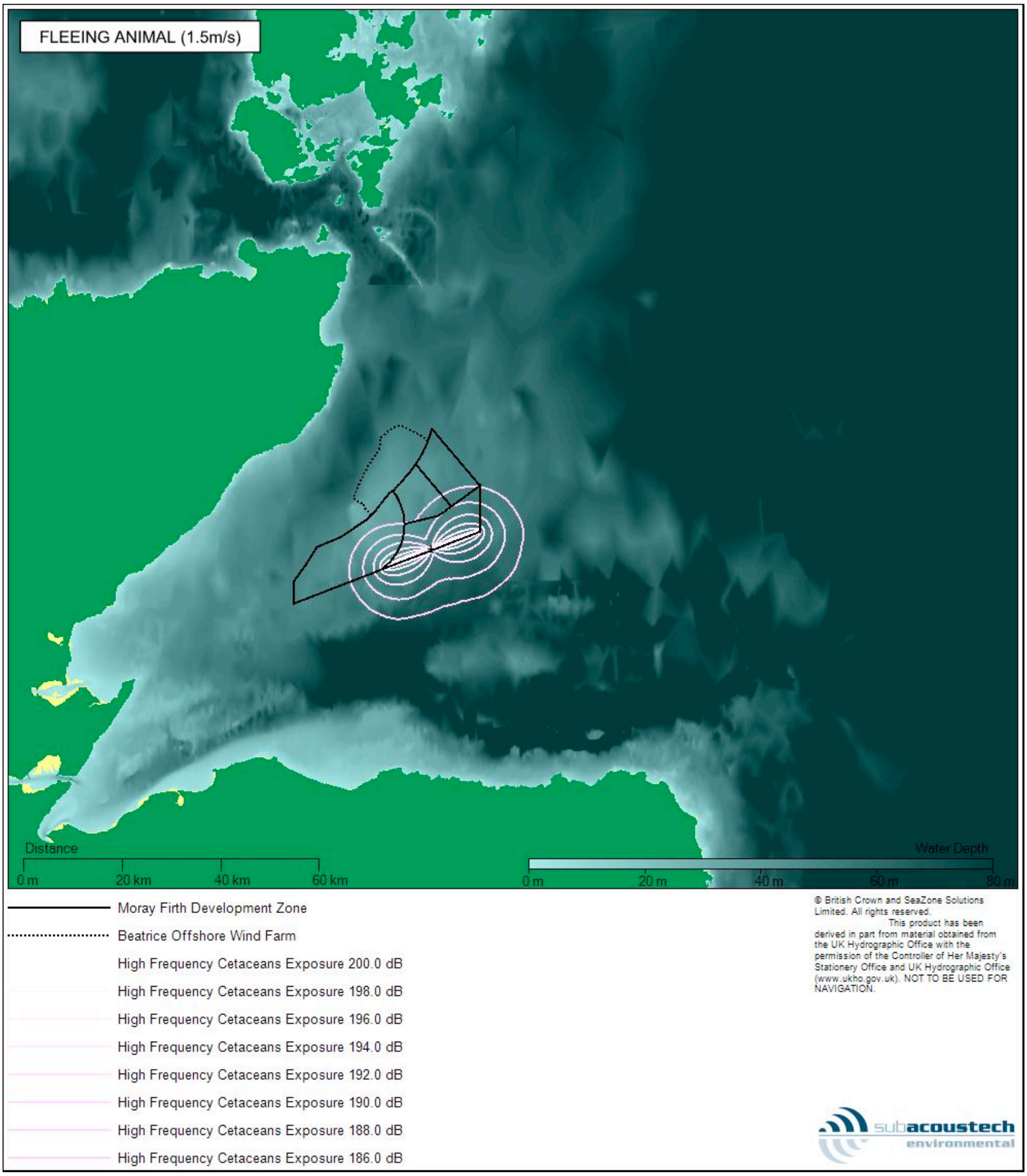


Figure A-128. Starting loci for fleeing High Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 1 and 2 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 2
Pile driving energy (kJ)	1200
Species	High Frequency Cetaceans (Fleeing 1.5m/s)

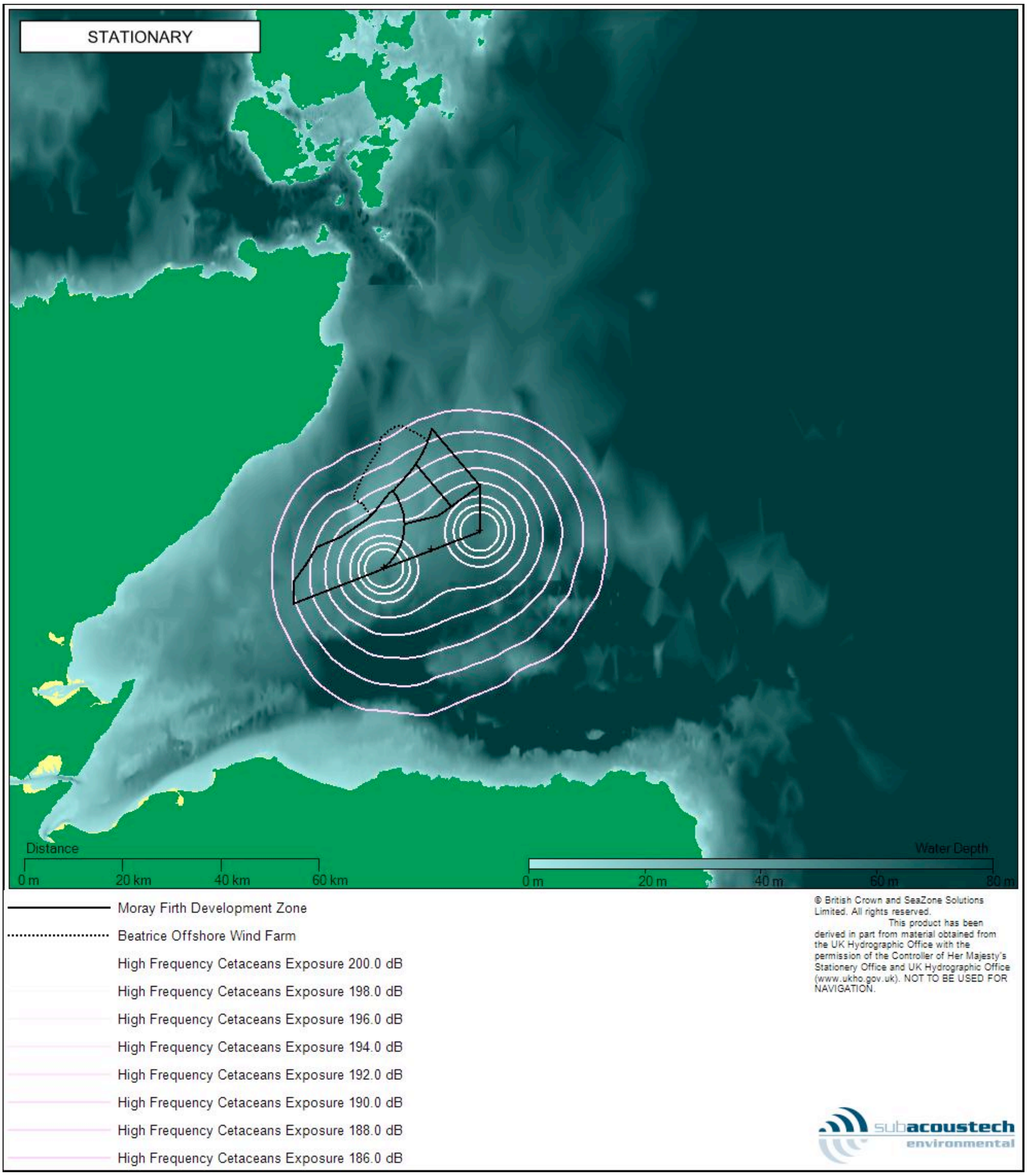


Figure A-129. Contours for stationary High Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 1 and 2 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 2
Pile driving energy (kJ)	1200
Species	High Frequency Cetaceans (Stationary)

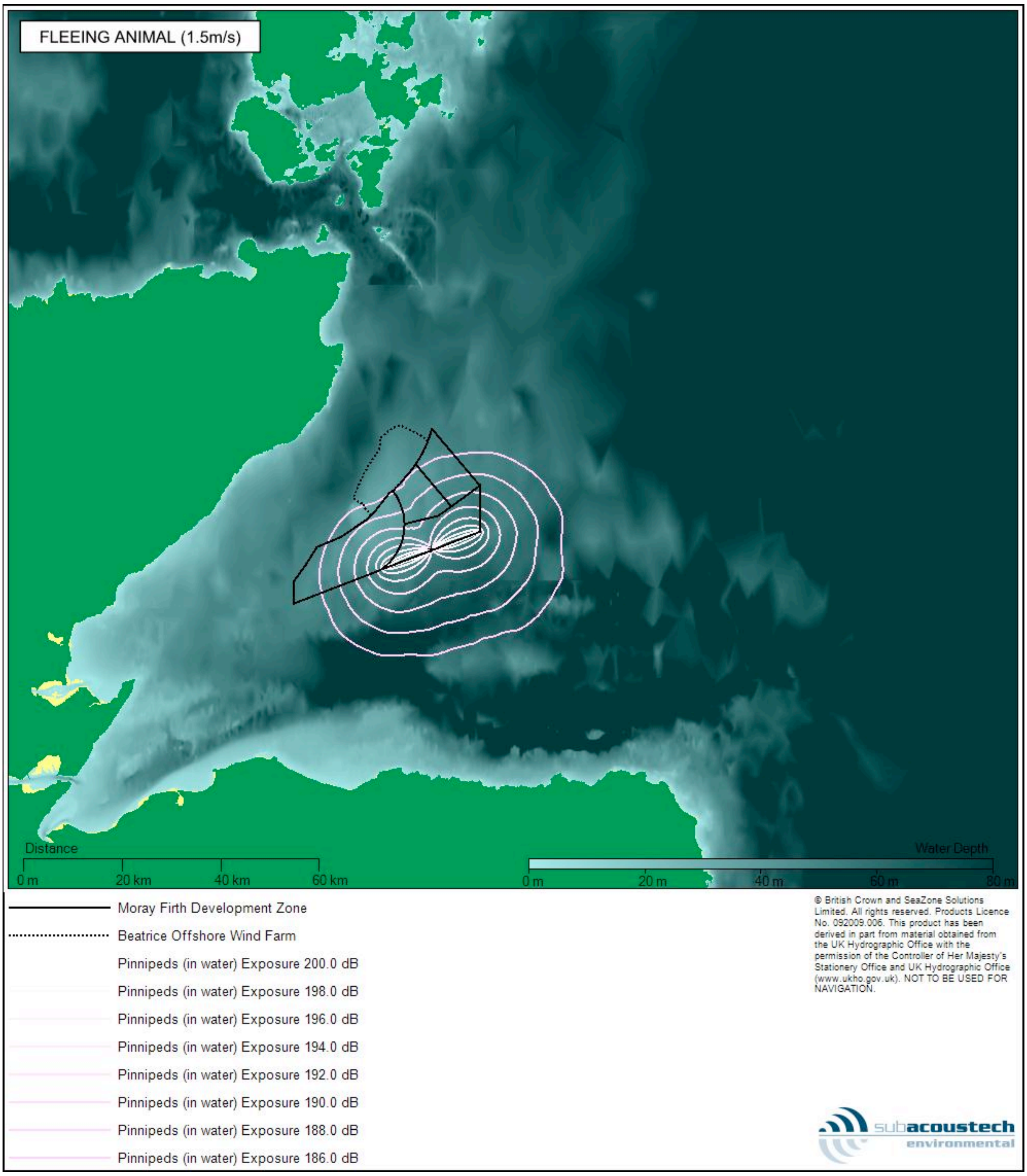


Figure A-130. Starting loci for fleeing Pinnipeds (in water); two 2.5 m diameter piles being driven sequentially at locations 1 and 2 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 2
Pile driving energy (kJ)	1200
Species	Pinnipeds (in water) (Fleeing 1.5m/s)

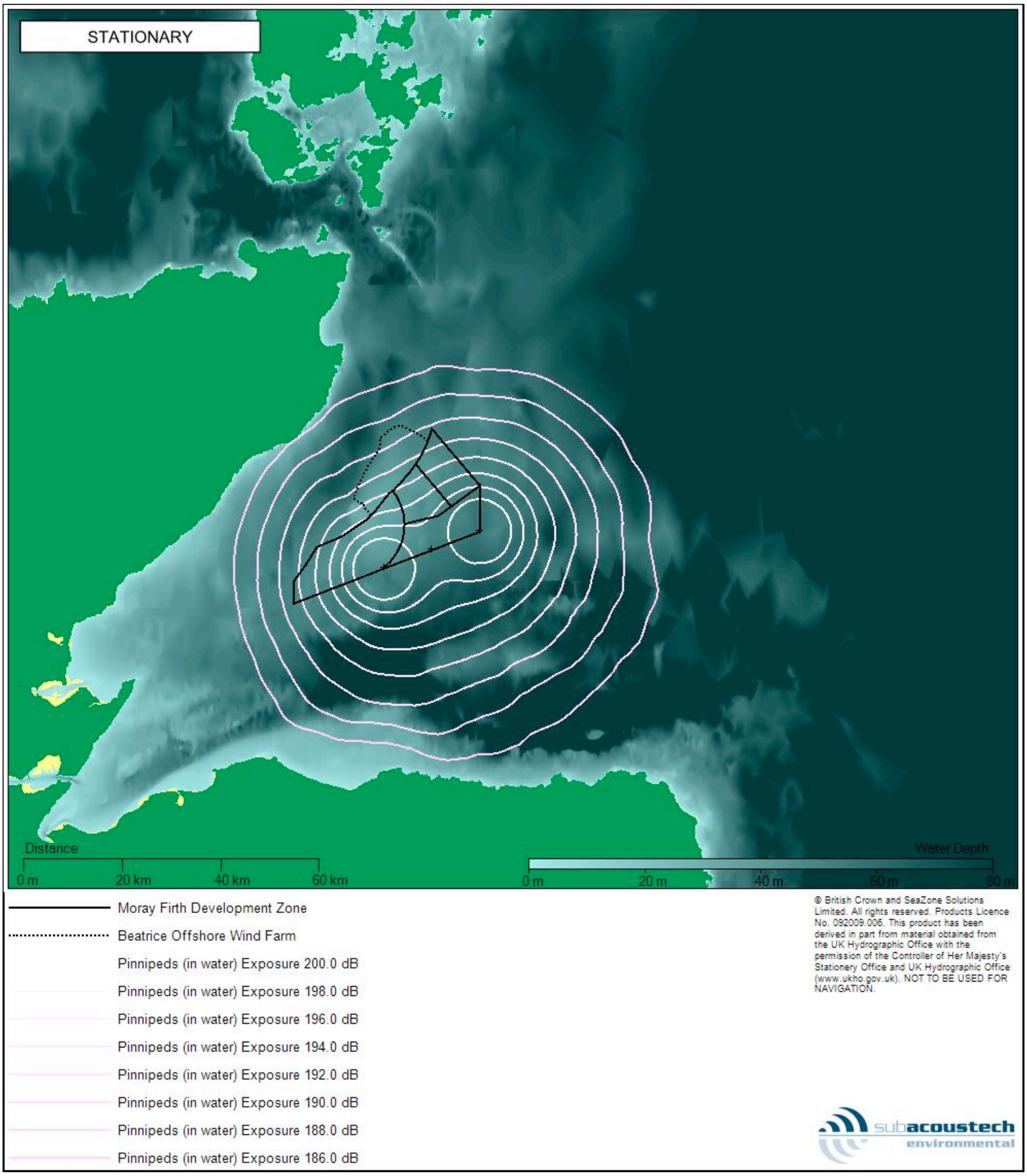


Figure A-131. Contours for stationary Pinnipeds (in water); two 2.5 m diameter piles being driven sequentially at locations 1 and 2 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1 and 2
Pile driving energy (kJ)	1200
Species	Pinnipeds (in water) (Stationary)

9.2.4.4 Results for 2 piles being driven simultaneously at 2 locations on the Stevenson site

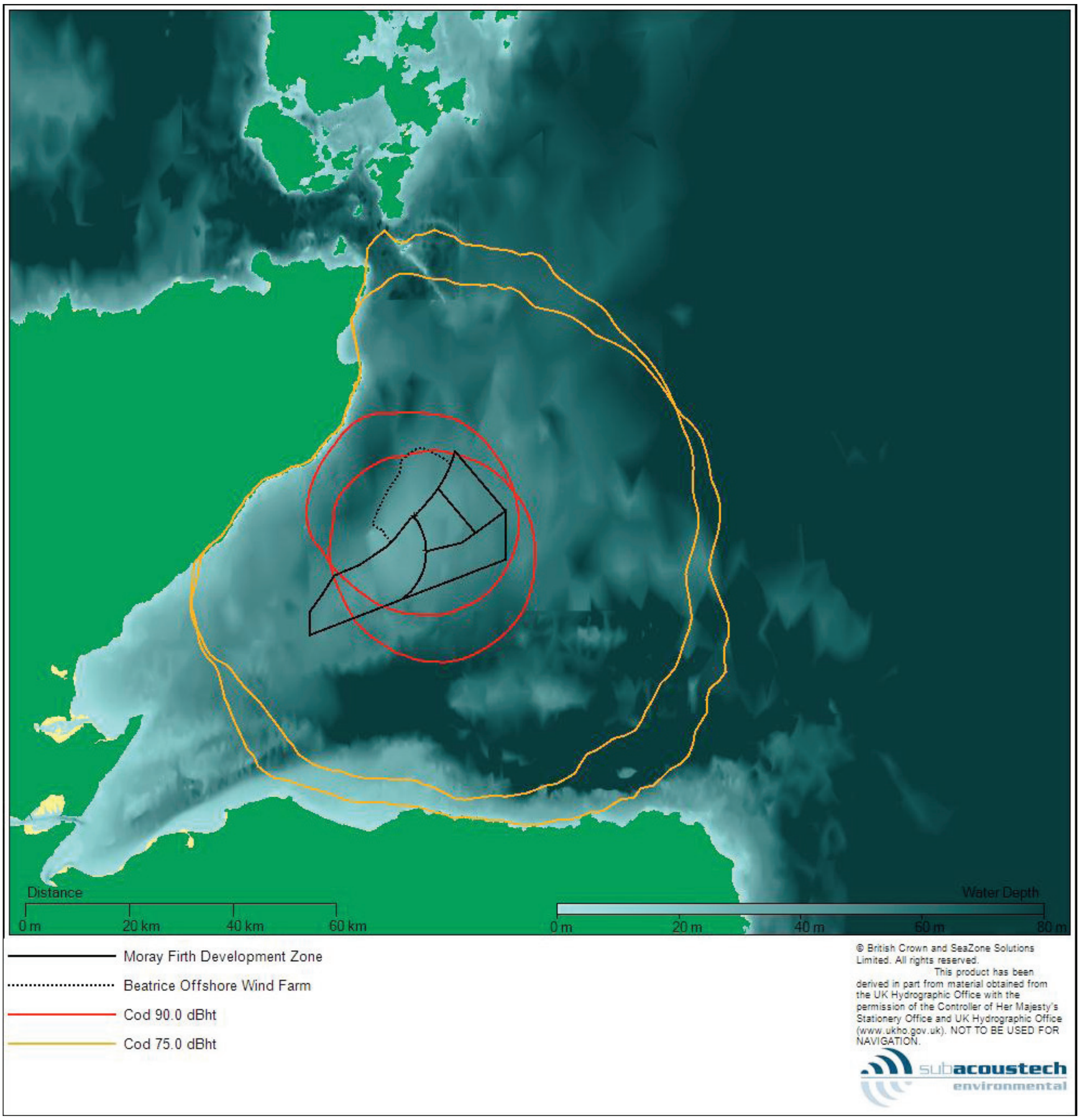


Figure A-132. 90 dB_{ht} and 75 dB_{ht} contours for cod; 2.5 m diameter piles being driven at locations 4 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	4 and 6
Pile driving energy (kJ)	1200
Species	Cod

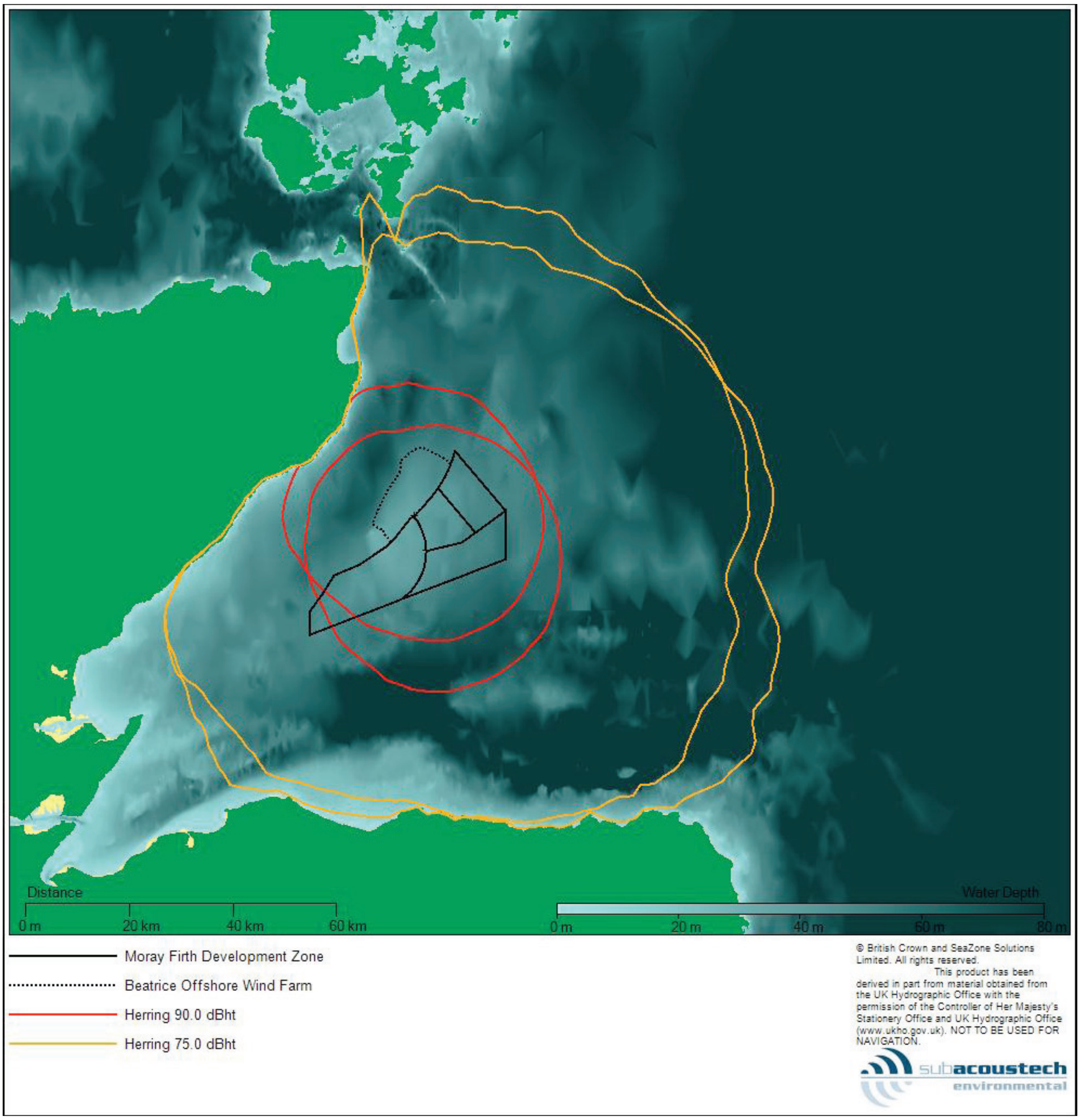


Figure A-133. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for herring; 2.5 m diameter piles being driven at locations 4 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	4 and 6
Pile driving energy (kJ)	1200
Species	Herring

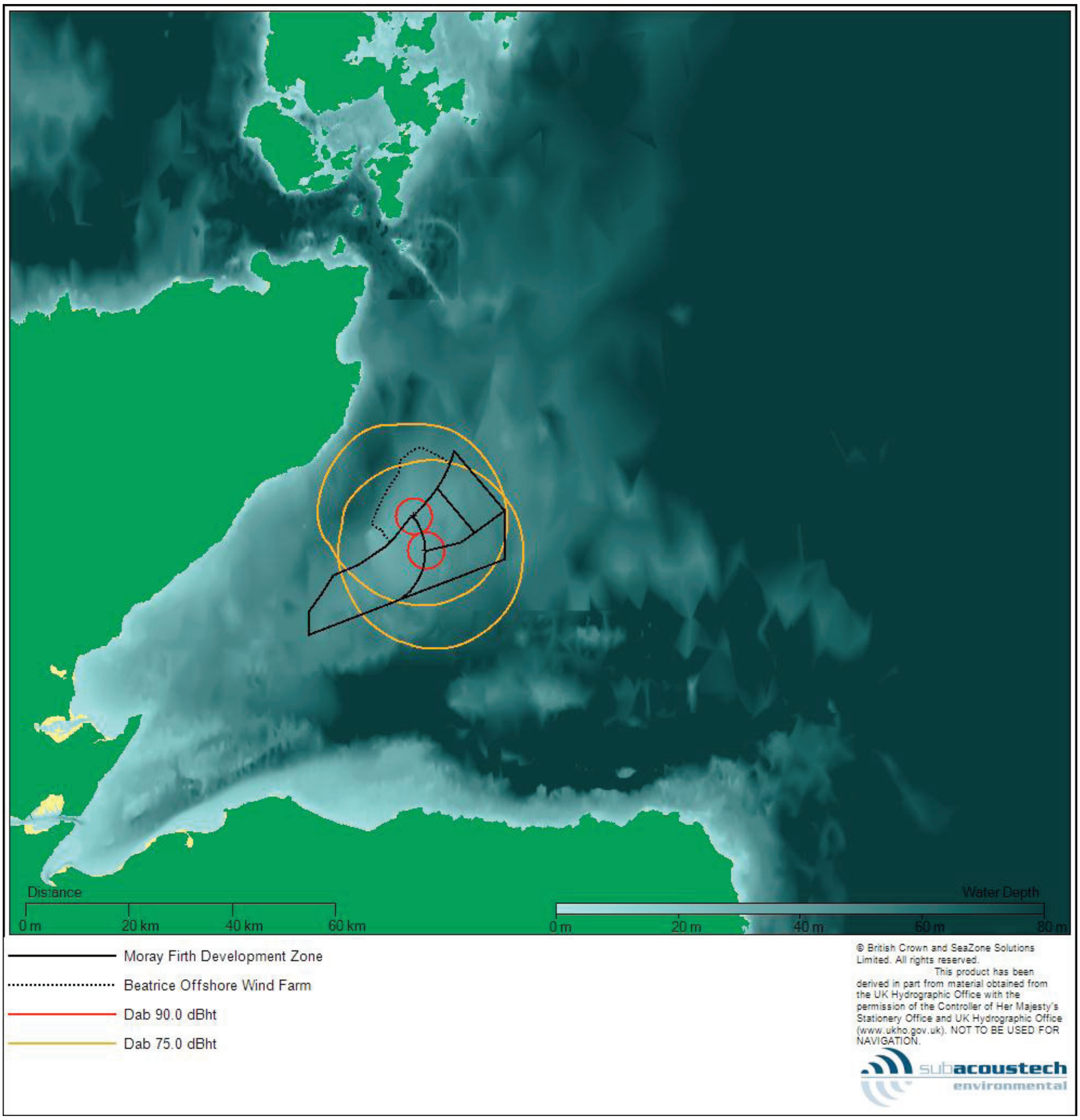


Figure A-134. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for plaice (dab used as surrogate); 2.5 m diameter piles being driven at locations 4 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	4 and 6
Pile driving energy (kJ)	1200
Species	Plaice

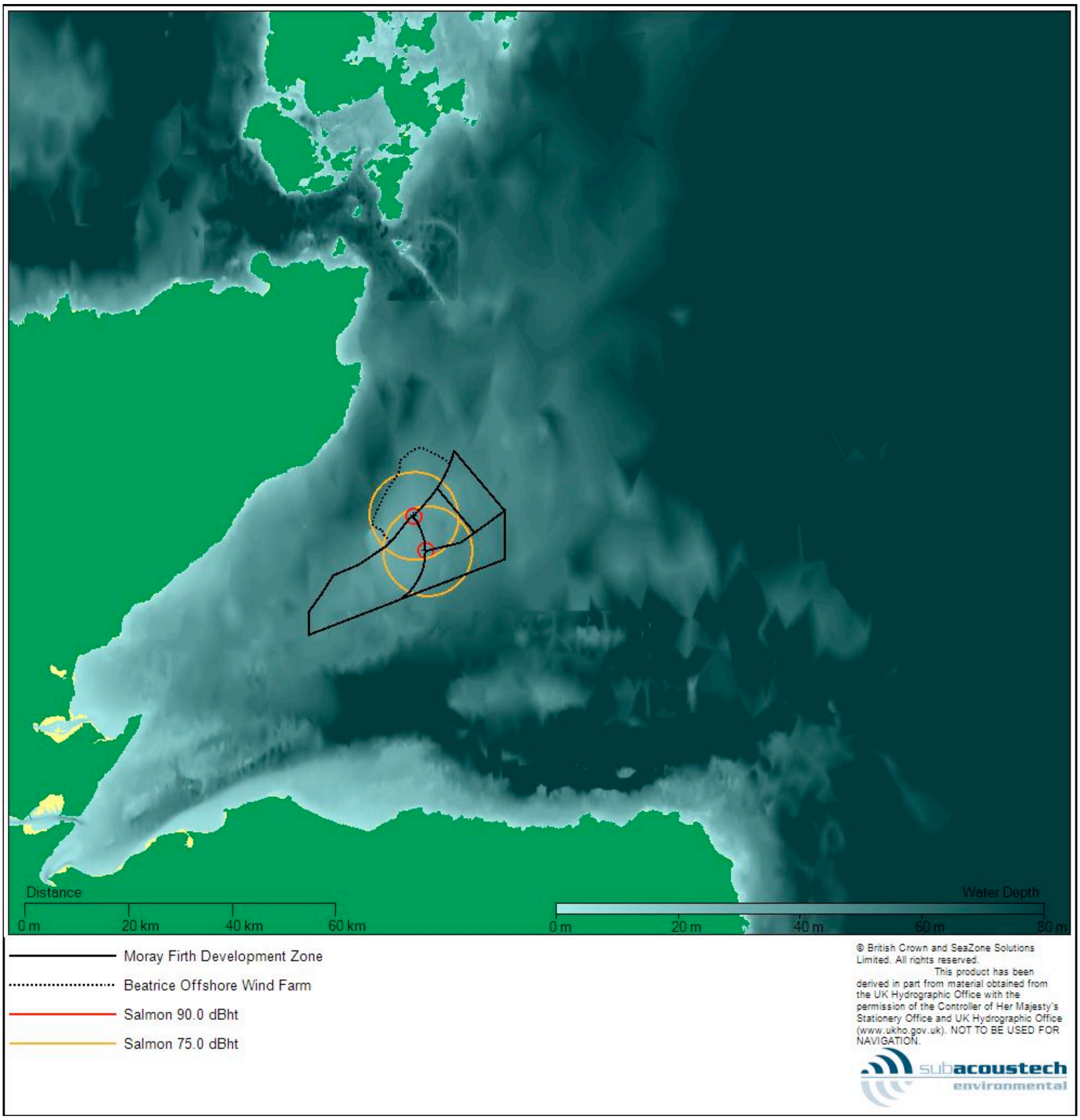


Figure A-135. 90 dB_{ht} and 75 dB_{ht} contours for salmon; 2.5 m diameter piles being driven at locations 4 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	4 and 6
Pile driving energy (kJ)	1200
Species	Salmon

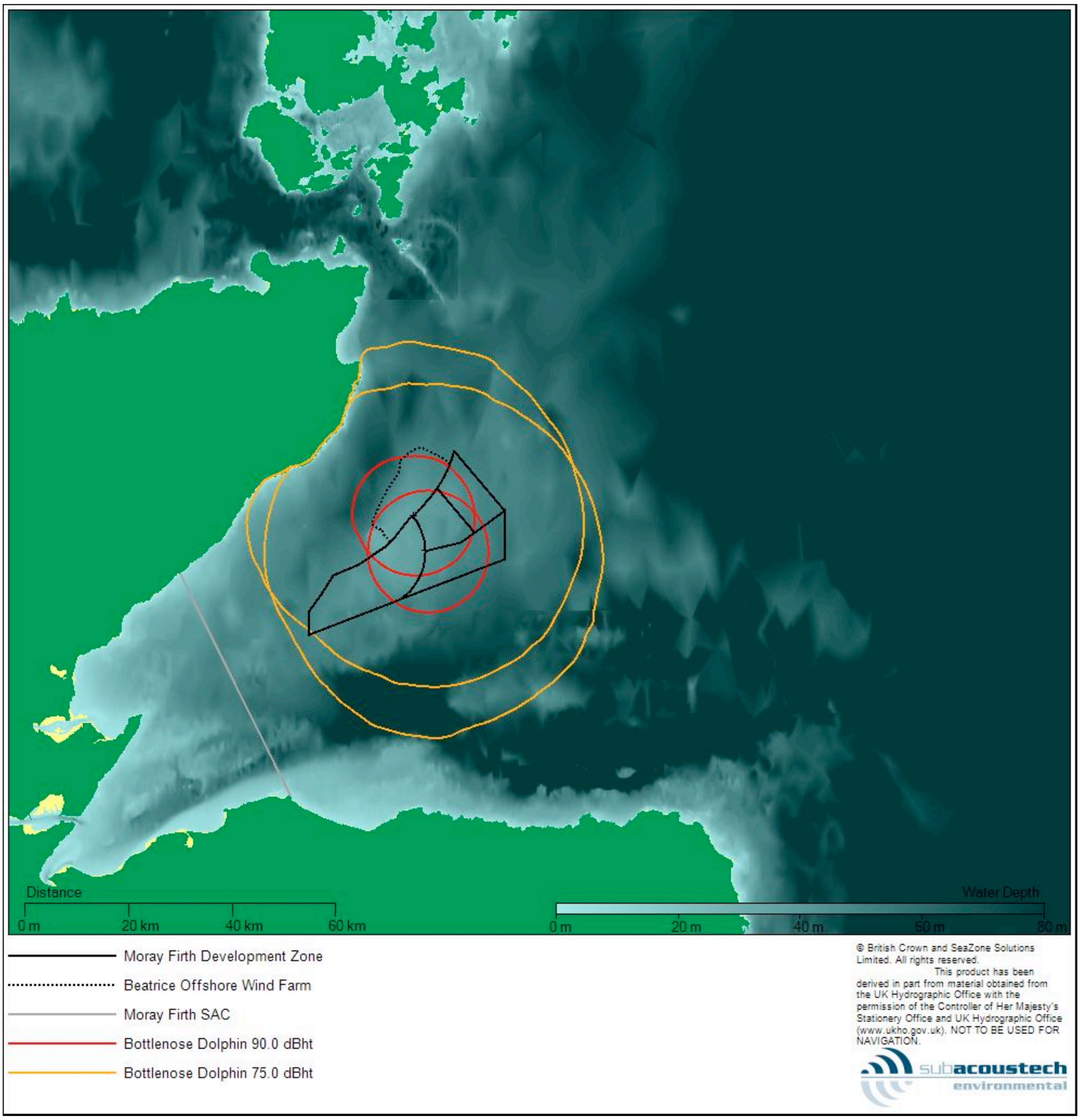


Figure A-136. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for bottlenose dolphin; 2.5 m diameter piles being driven at locations 4 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	4 and 6
Pile driving energy (kJ)	1200
Species	Bottlenose Dolphin

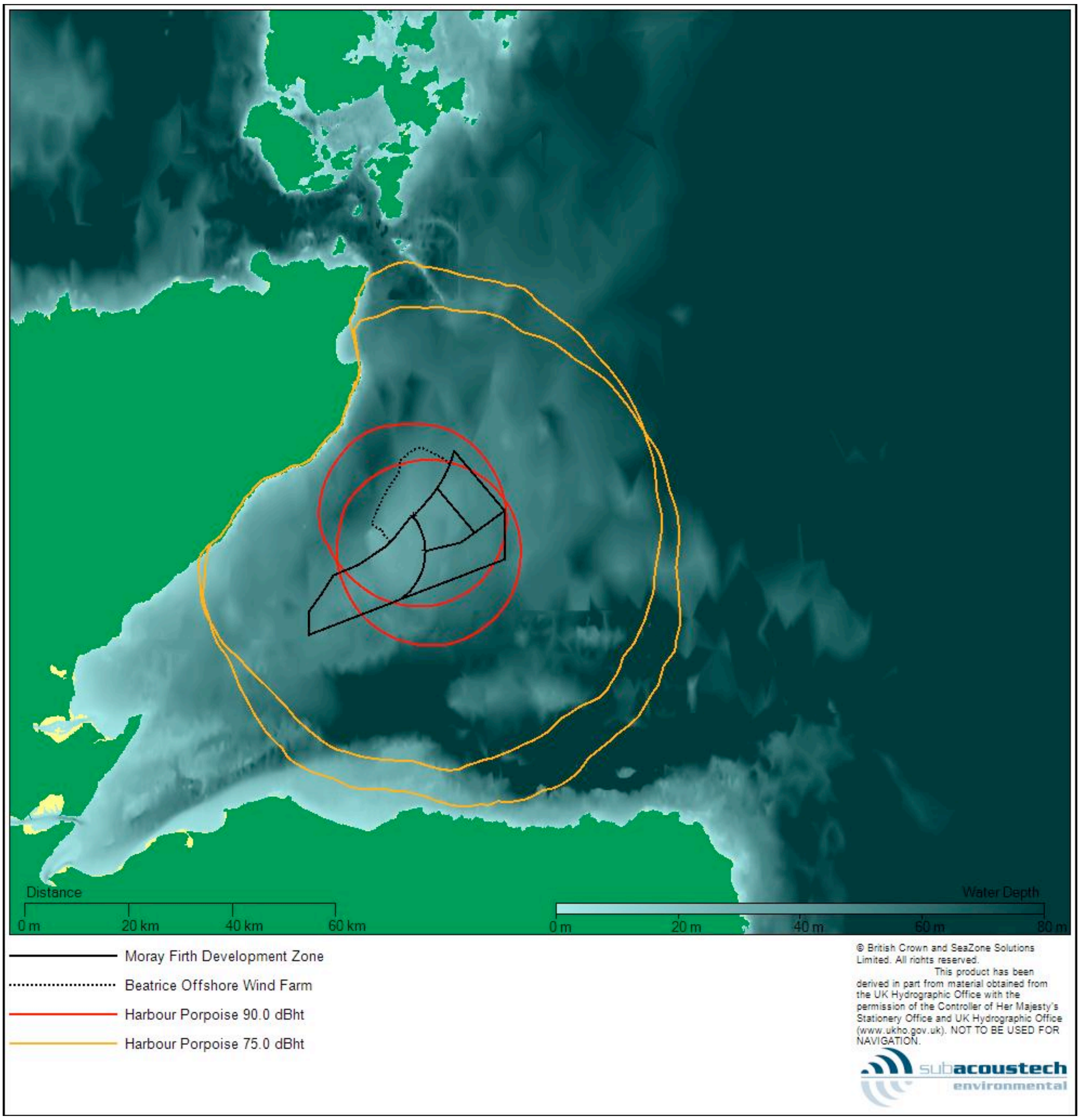


Figure A-137. 90 dB_{ht} and 75 dB_{ht} contours for harbour porpoise; 2.5 m diameter piles being driven at locations 4 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	4 and 6
Pile driving energy (kJ)	1200
Species	Harbour Porpoise

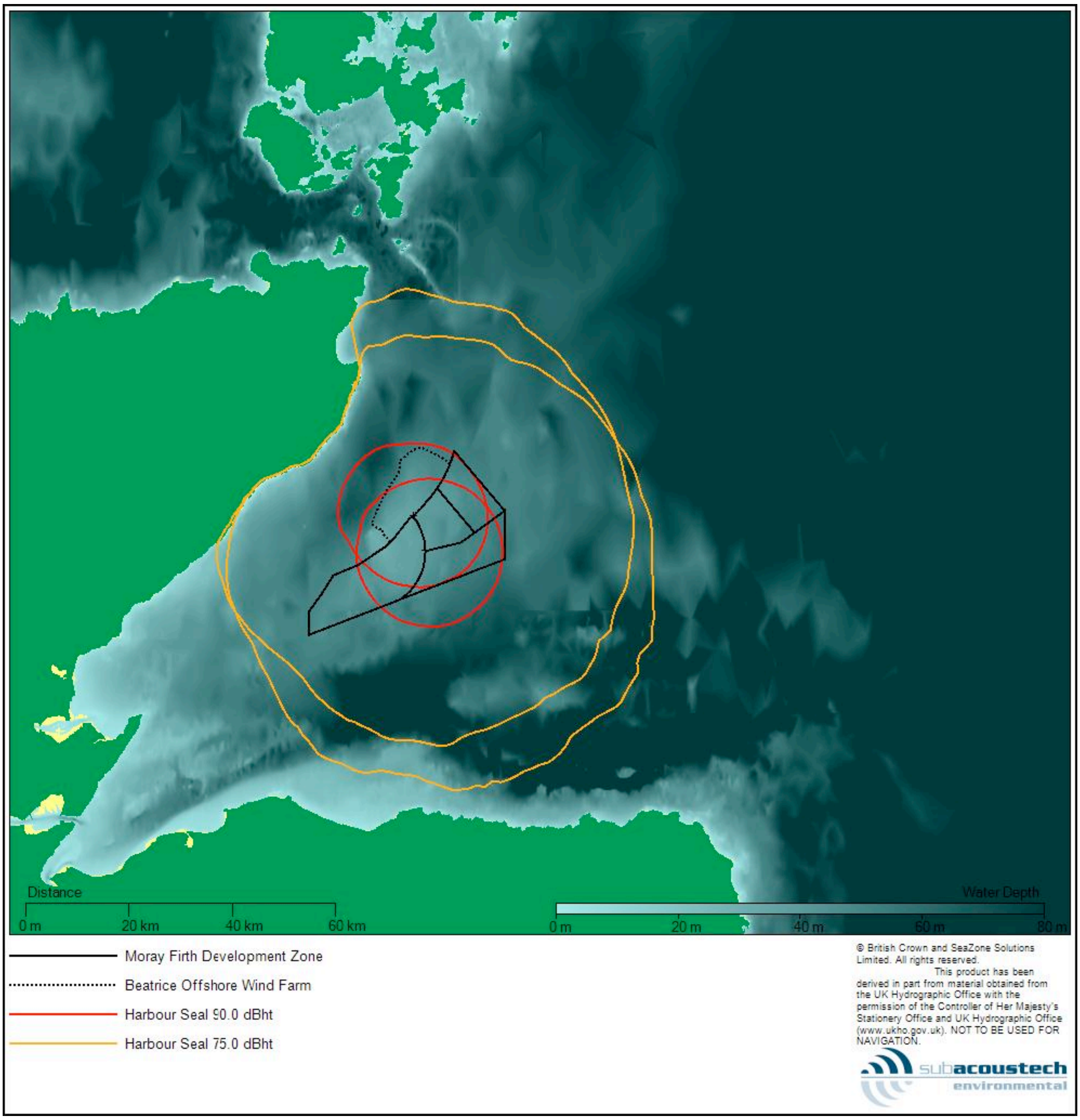


Figure A-138. 90 dB_{ht} and 75 dB_{ht} contours for harbour seal; 2.5 m diameter piles being driven at locations 4 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	4 and 6
Pile driving energy (kJ)	1200
Species	Harbour Seal

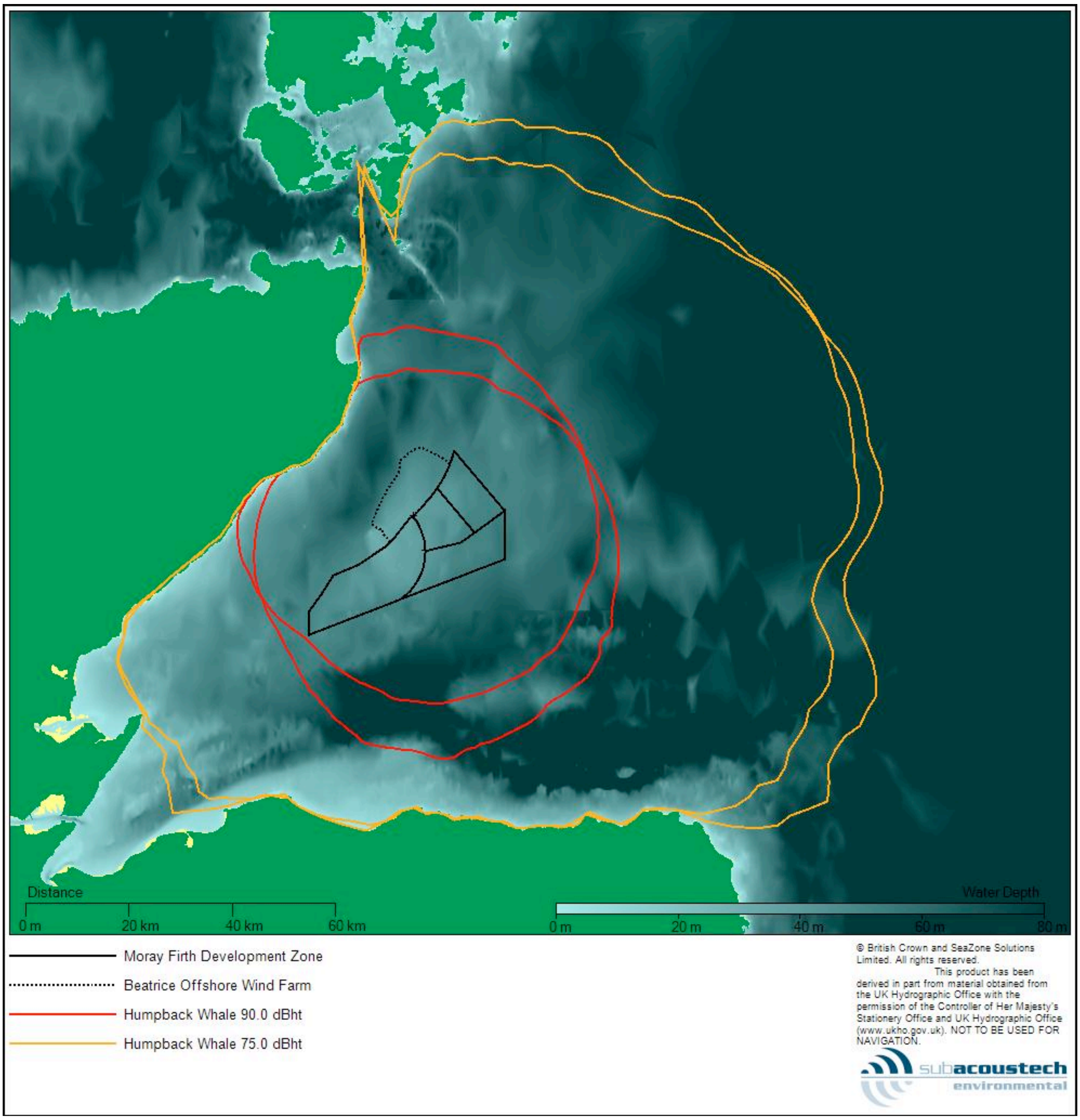


Figure A-139. 90 dB_{ht} and 75 dB_{ht} contours for minke whale (humpback whale used as surrogate); 2.5 m diameter piles being driven at locations 4 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	4 and 6
Pile driving energy (kJ)	1200
Species	Minke Whale

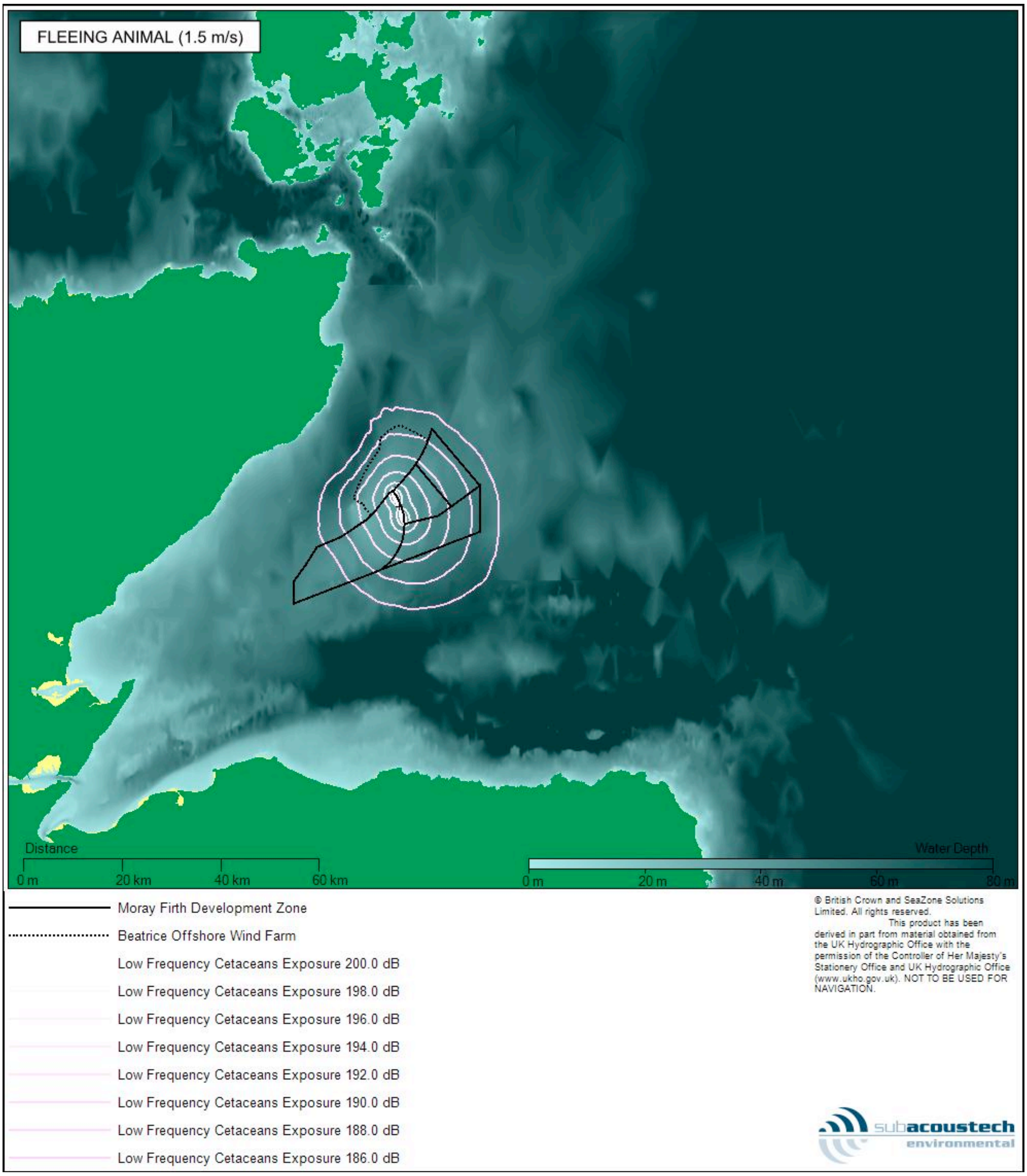


Figure A-140. Starting loci for fleeing Low Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 4 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	4 and 6
Pile driving energy (kJ)	1200
Species	Low Frequency Cetaceans (Fleeing 1.5m/s)

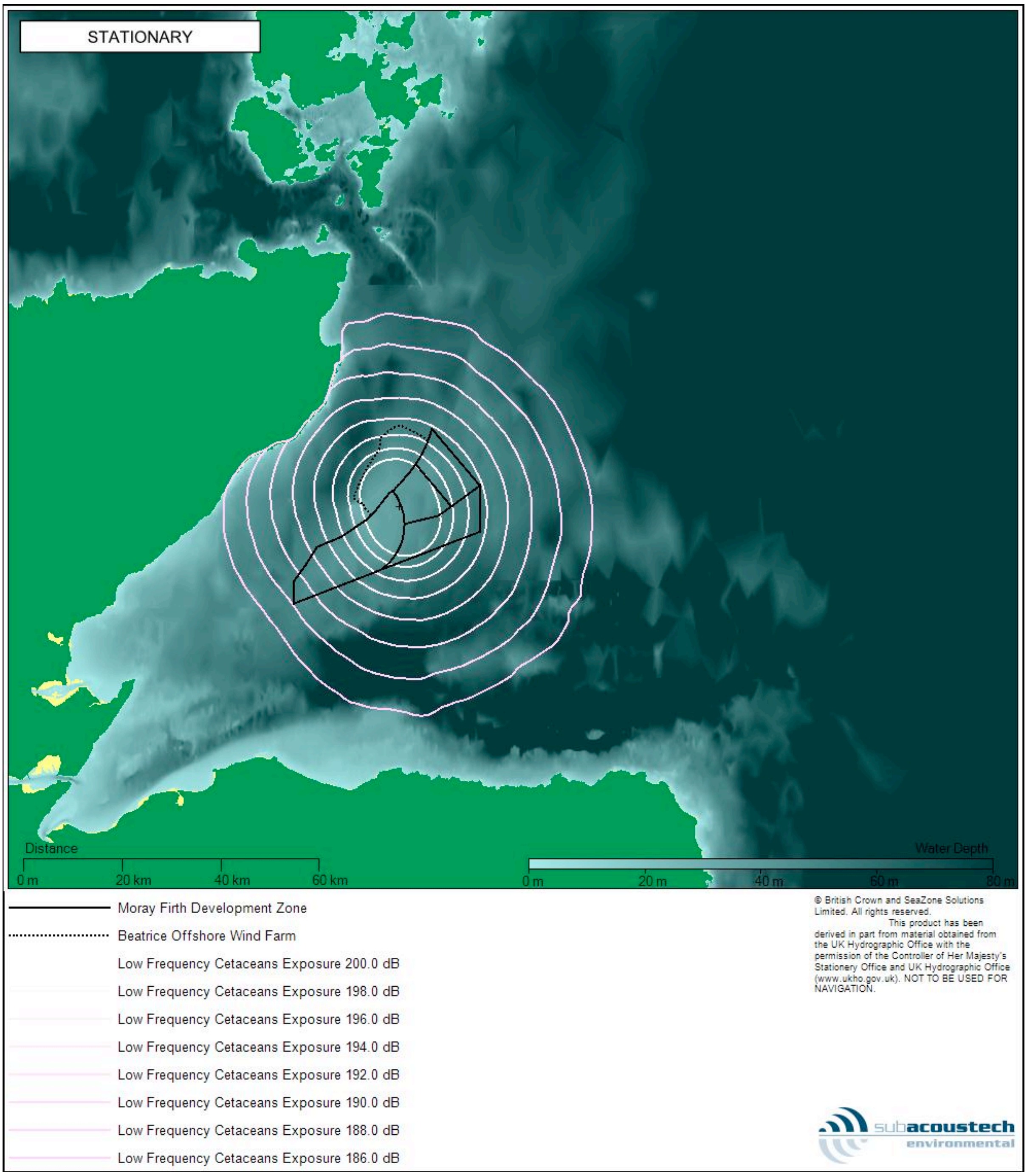


Figure A-141. Contours for stationary Low Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 4 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	4 and 6
Pile driving energy (kJ)	1200
Species	Low Frequency Cetaceans (Stationary)

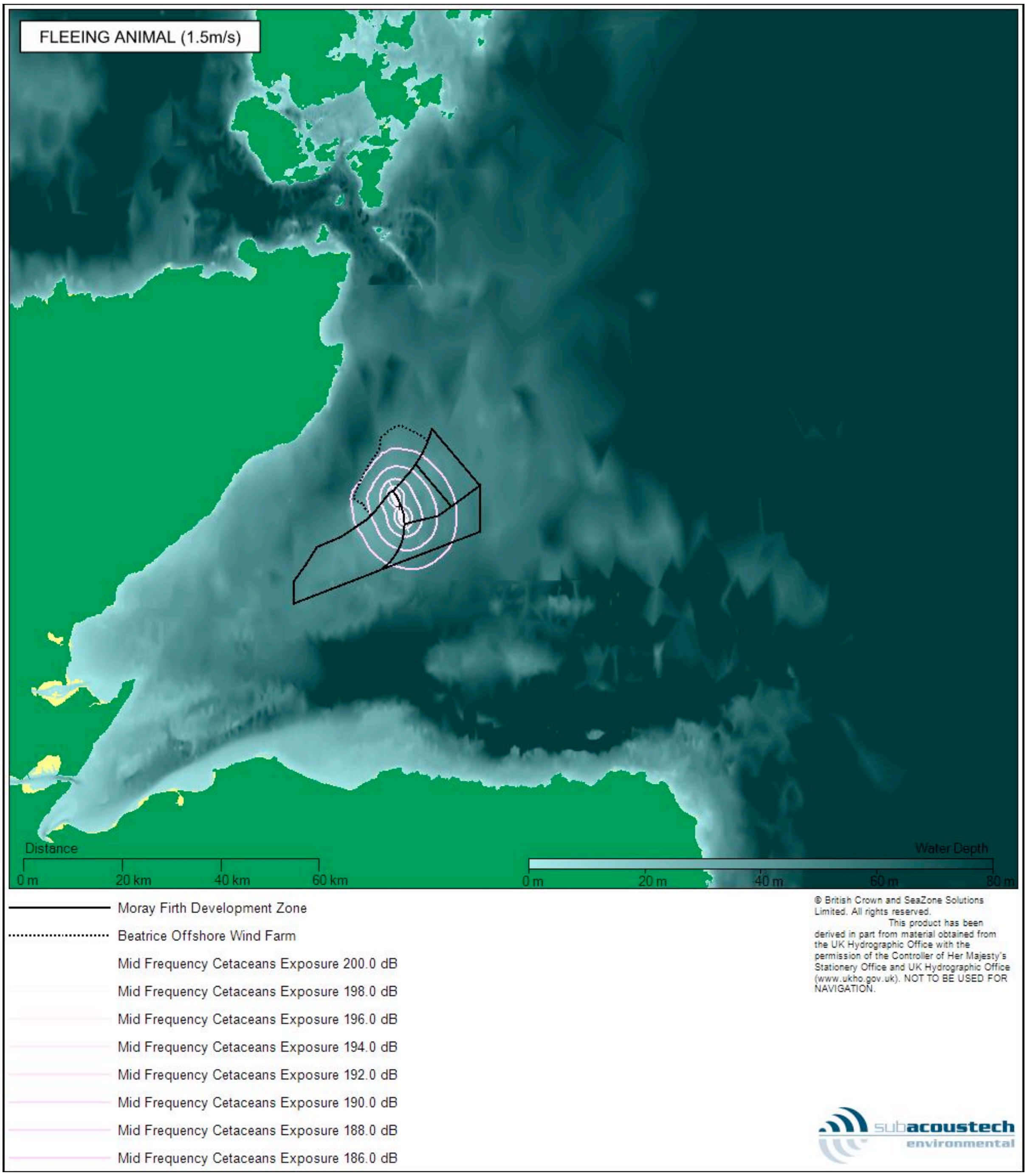


Figure A-142. Starting loci for fleeing Mid Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 4 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	4 and 6
Pile driving energy (kJ)	1200
Species	Mid Frequency Cetaceans (Fleeing 1.5m/s)

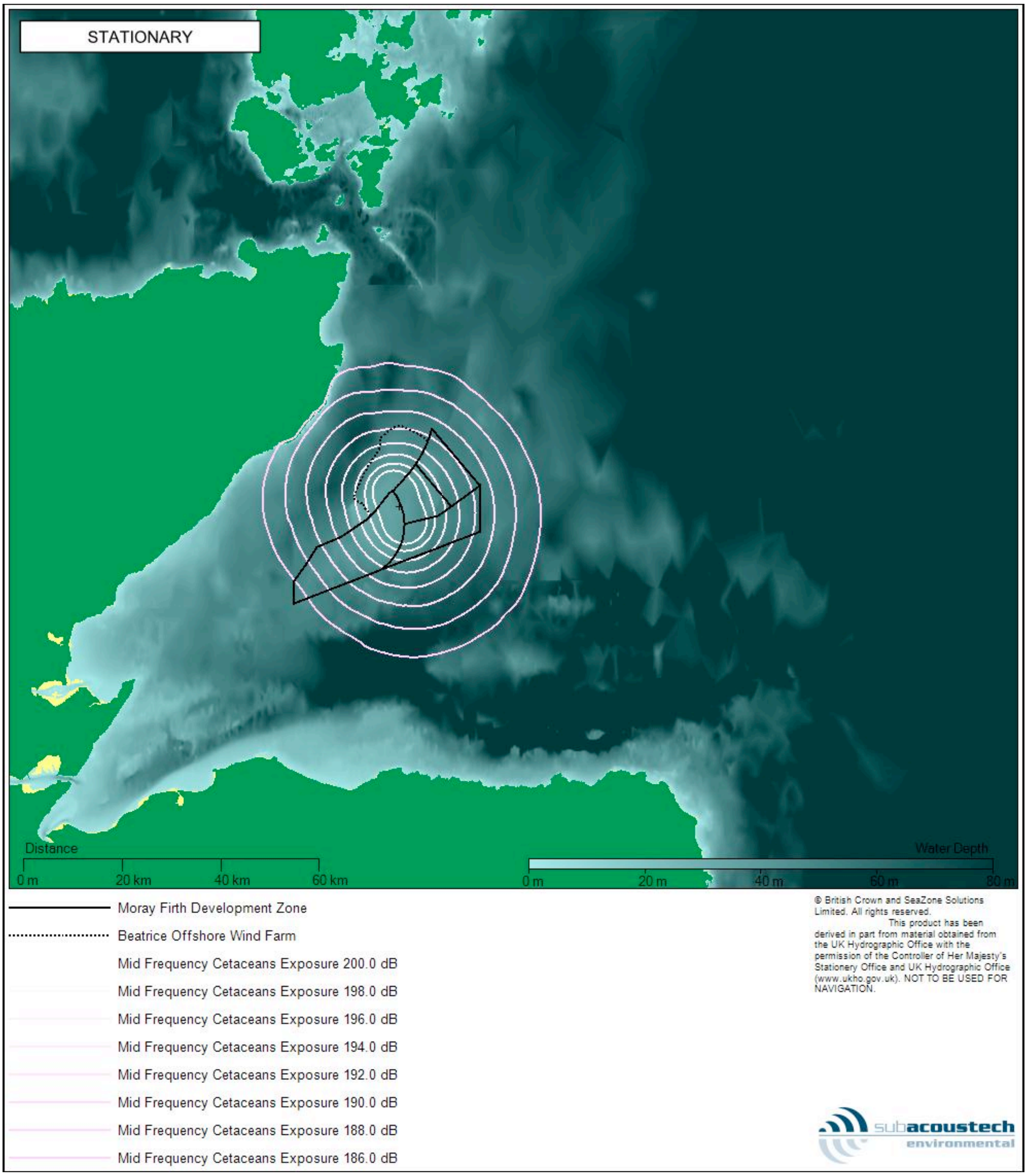


Figure A-143. Contours for stationary Mid Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 4 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	4 and 6
Pile driving energy (kJ)	1200
Species	Mid Frequency Cetaceans (Stationary)

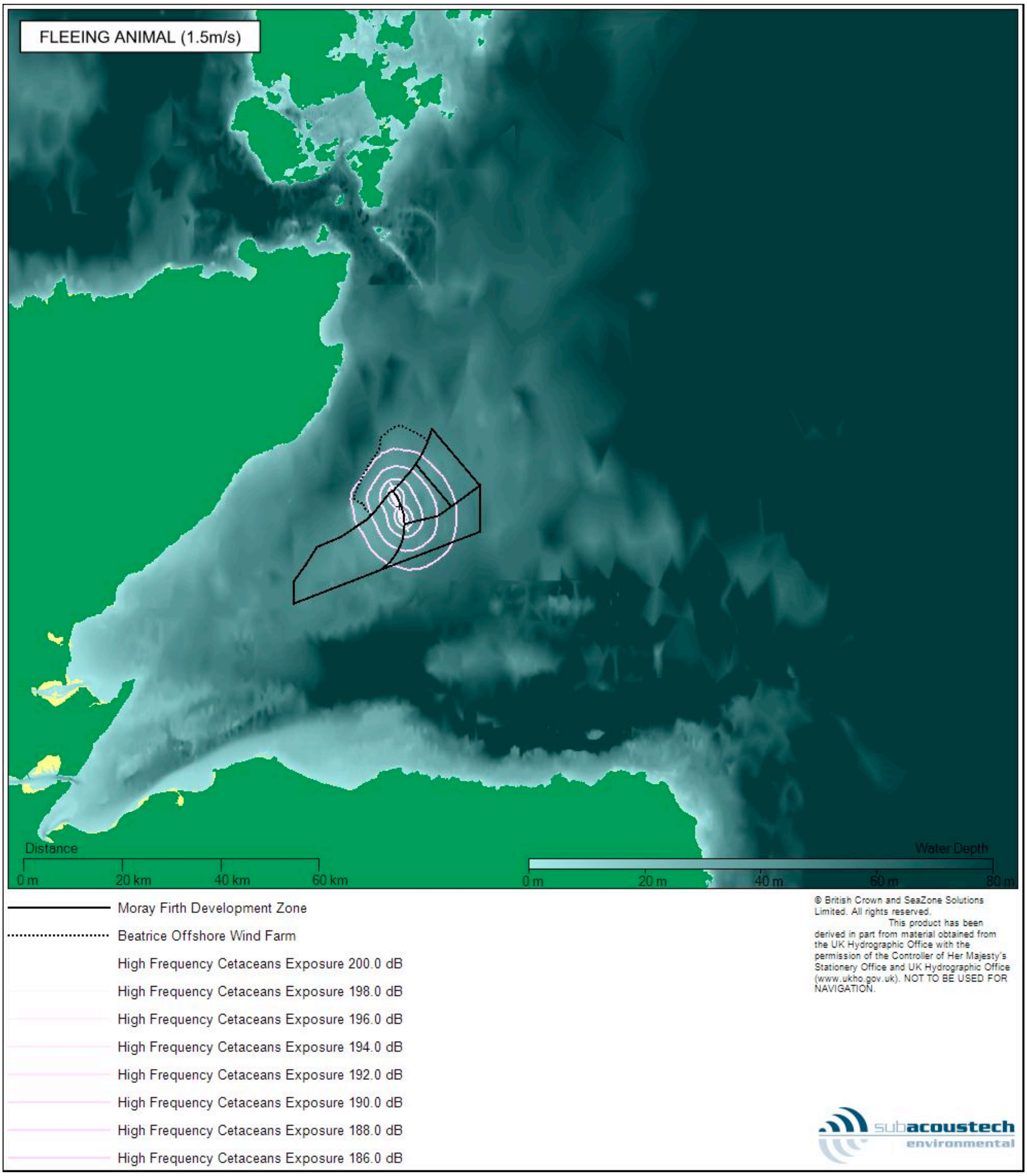


Figure A-144. Starting loci for fleeing High Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 4 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	4 and 6
Pile driving energy (kJ)	1200
Species	High Frequency Cetaceans (Fleeing 1.5m/s)

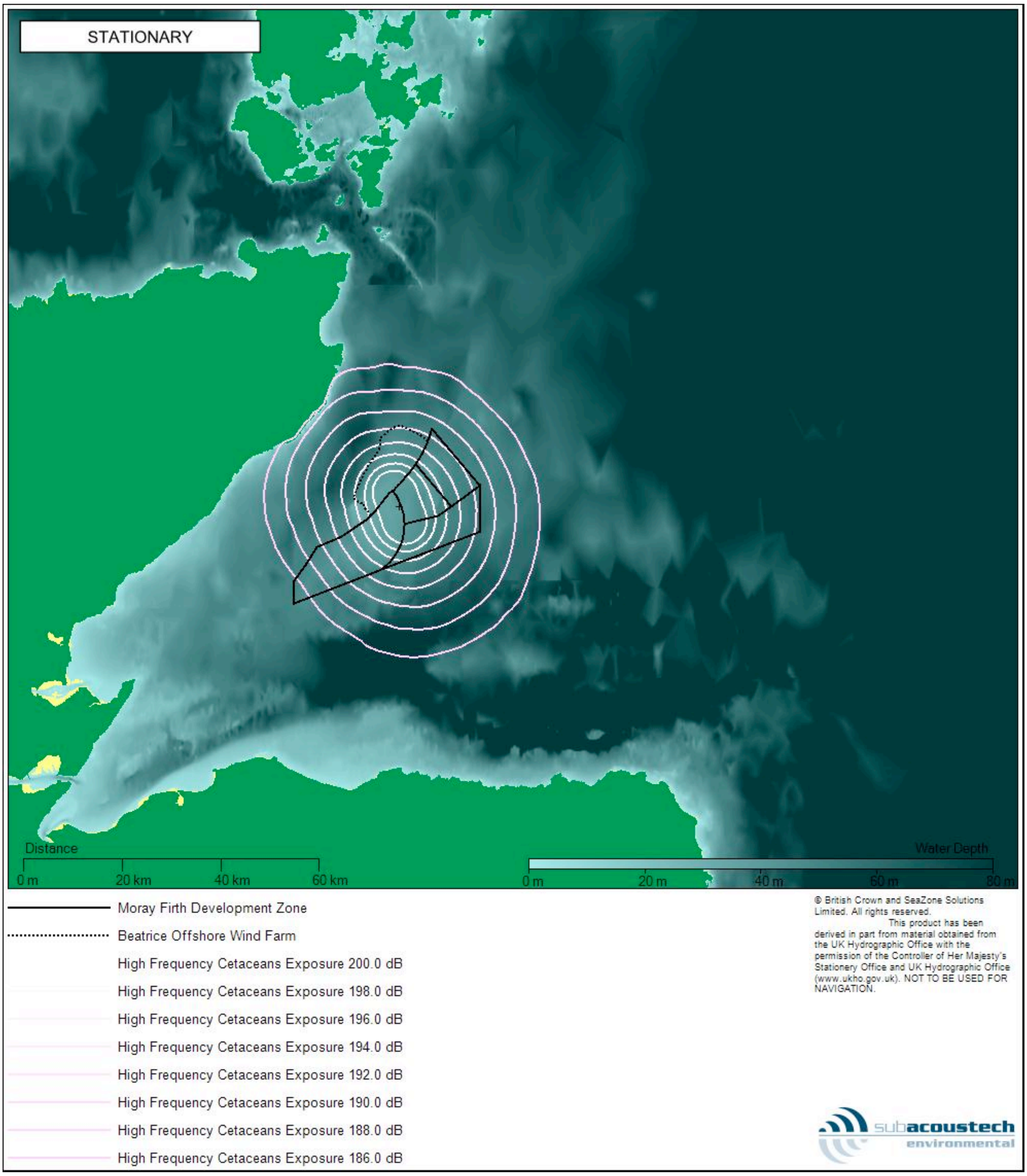


Figure A-145. Contours for stationary High Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 4 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	4 and 6
Pile driving energy (kJ)	1200
Species	High Frequency Cetaceans (Stationary)

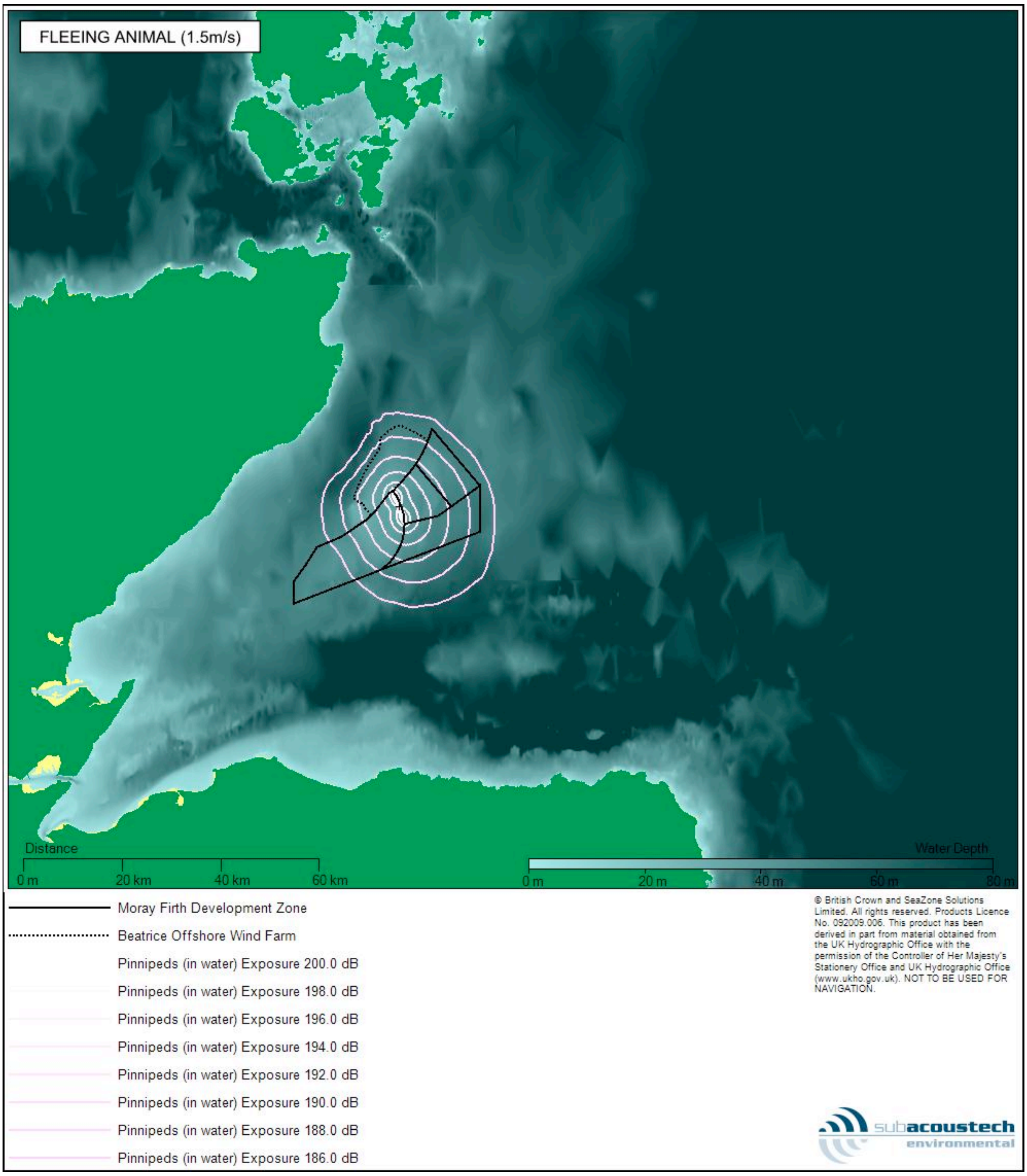


Figure A-146. Starting loci for fleeing Pinnipeds (in water); two 2.5 m diameter piles being driven sequentially at locations 4 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	4 and 6
Pile driving energy (kJ)	1200
Species	Pinnipeds (in water) (Fleeing 1.5m/s)

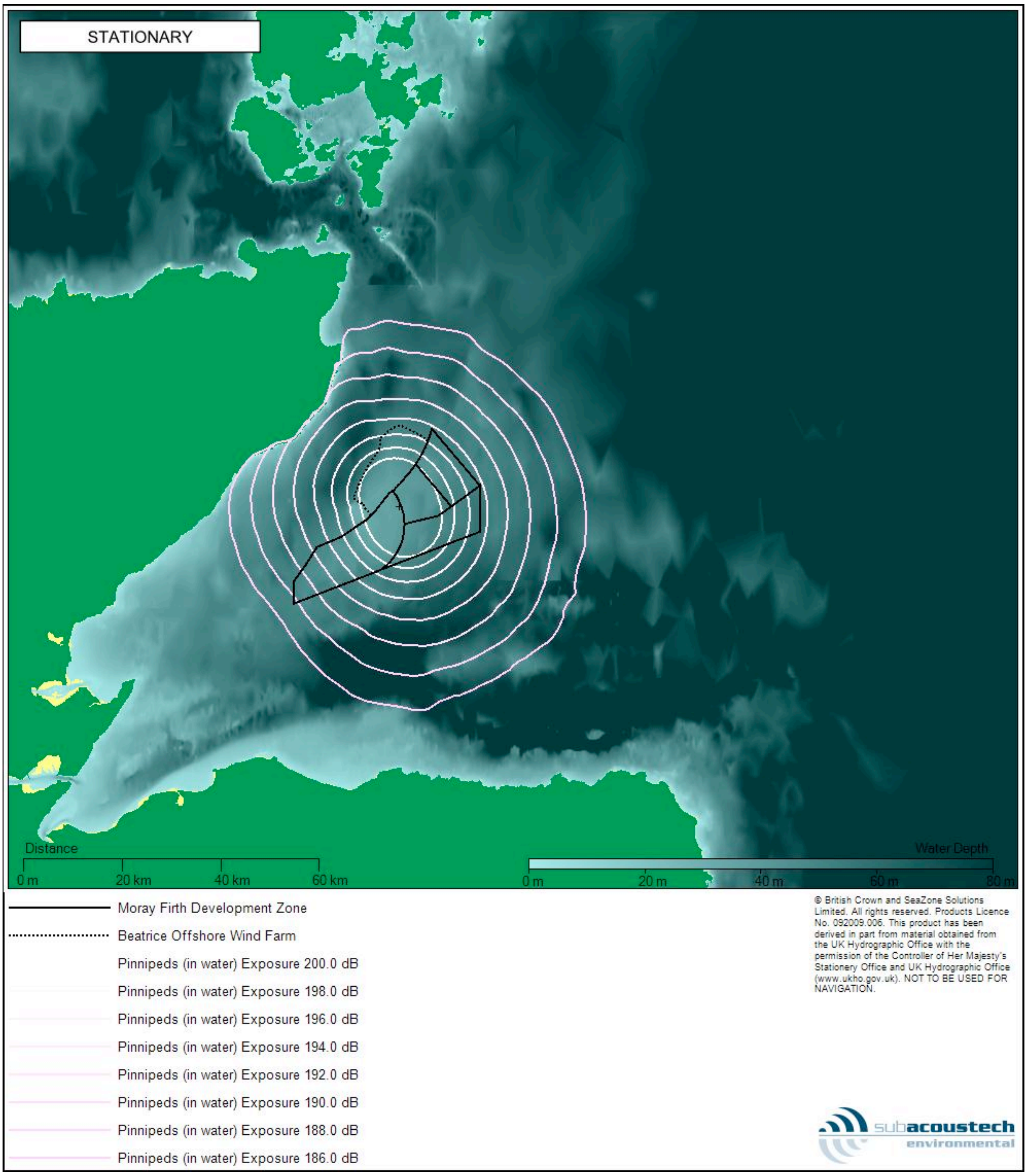


Figure A-147. Contours for stationary Pinnipeds (in water); two 2.5 m diameter piles being driven sequentially at locations 4 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	4 and 6
Pile driving energy (kJ)	1200
Species	Pinnipeds (in water) (Stationary)

9.2.4.5 Results for 2 piles being driven simultaneously at 2 locations on the Telford site

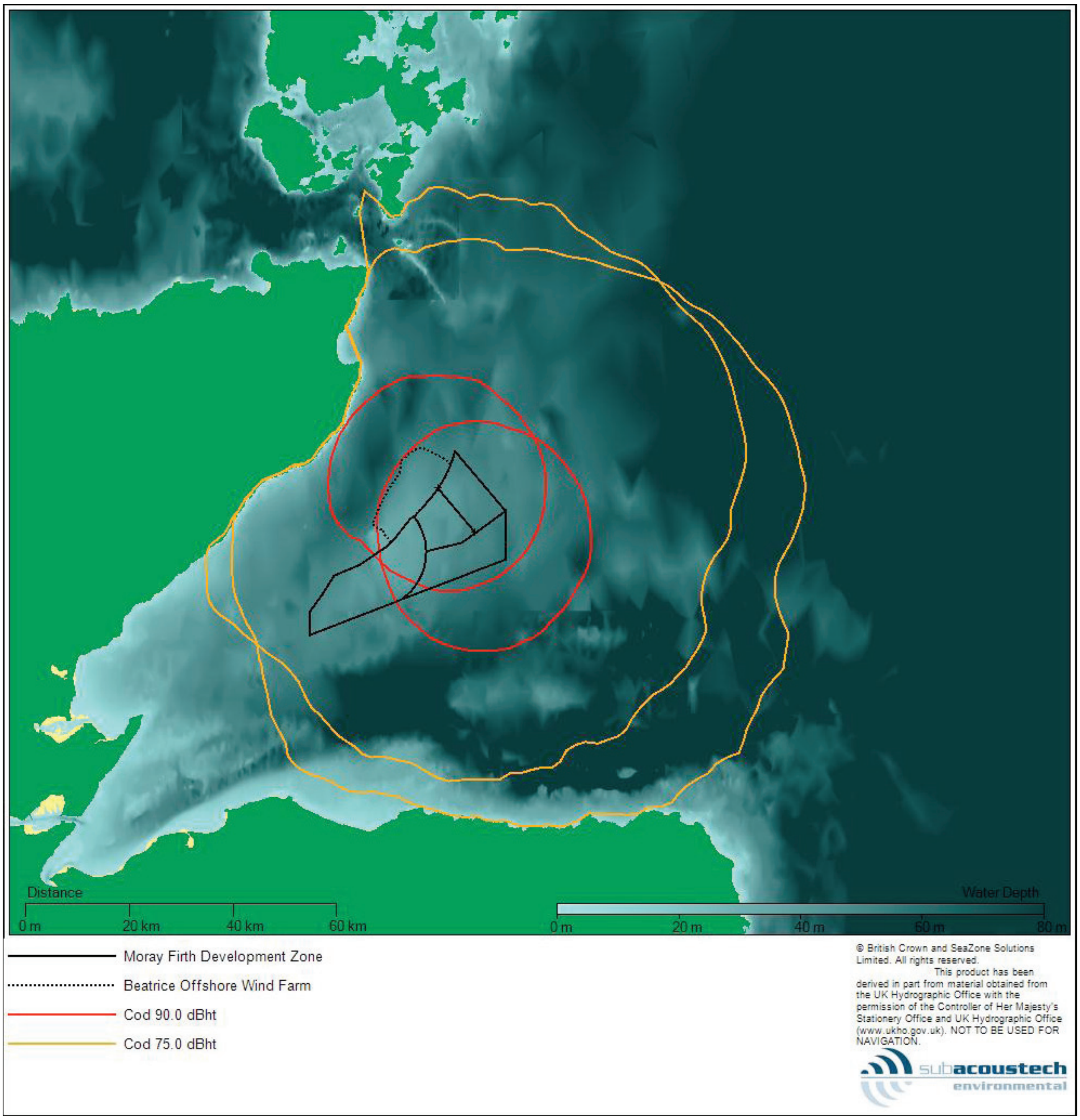


Figure A-148. 90 dB_{ht} and 75 dB_{ht} contours for cod; 2.5 m diameter piles being driven at locations 3a and 5a simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	3a and 5a
Pile driving energy (kJ)	1200
Species	Cod

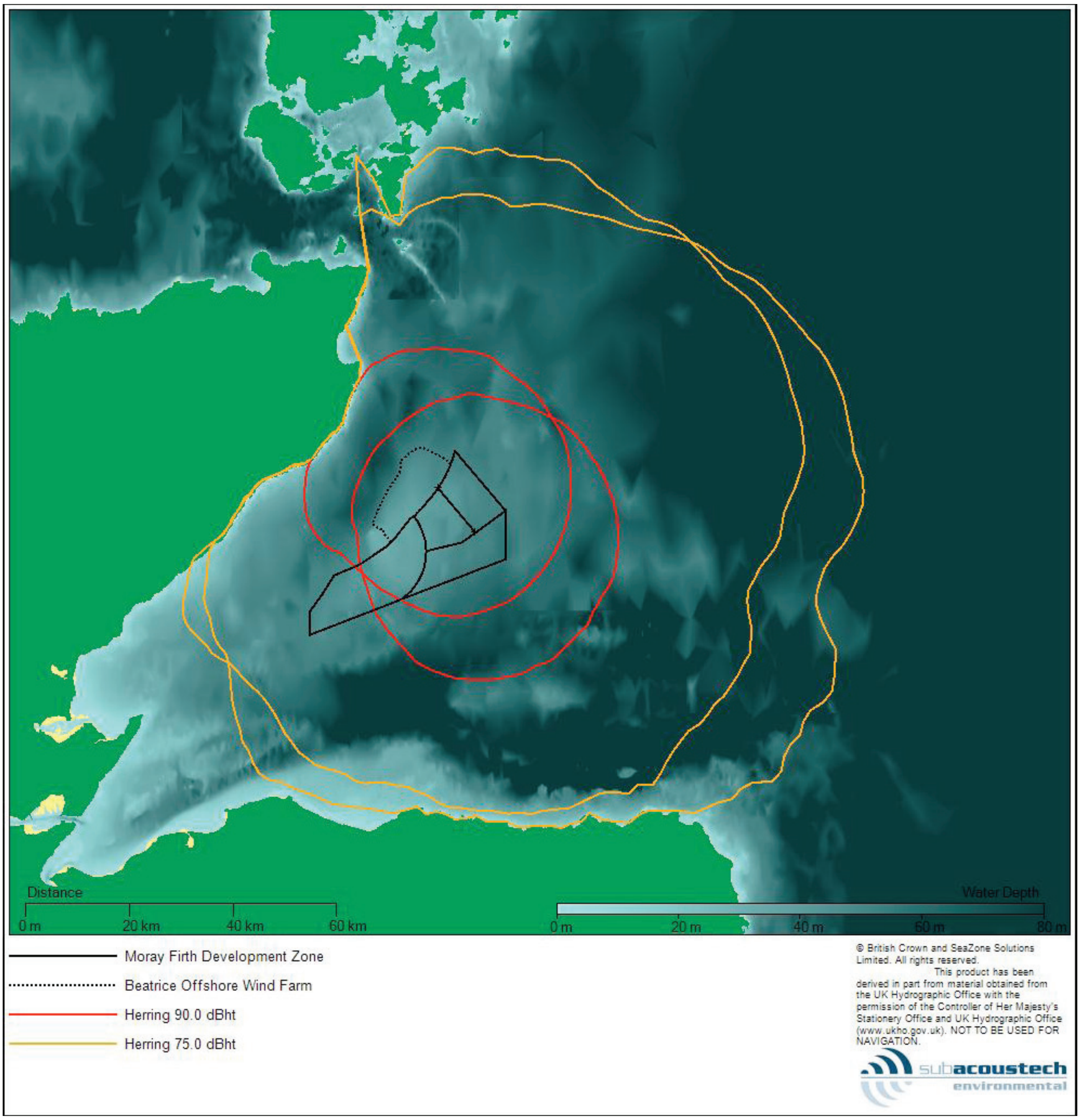


Figure A-149. 90 dB_{ht} and 75 dB_{ht} contours for herring; 2.5 m diameter piles being driven at locations 3a and 5a simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	3a and 5a
Pile driving energy (kJ)	1200
Species	Herring

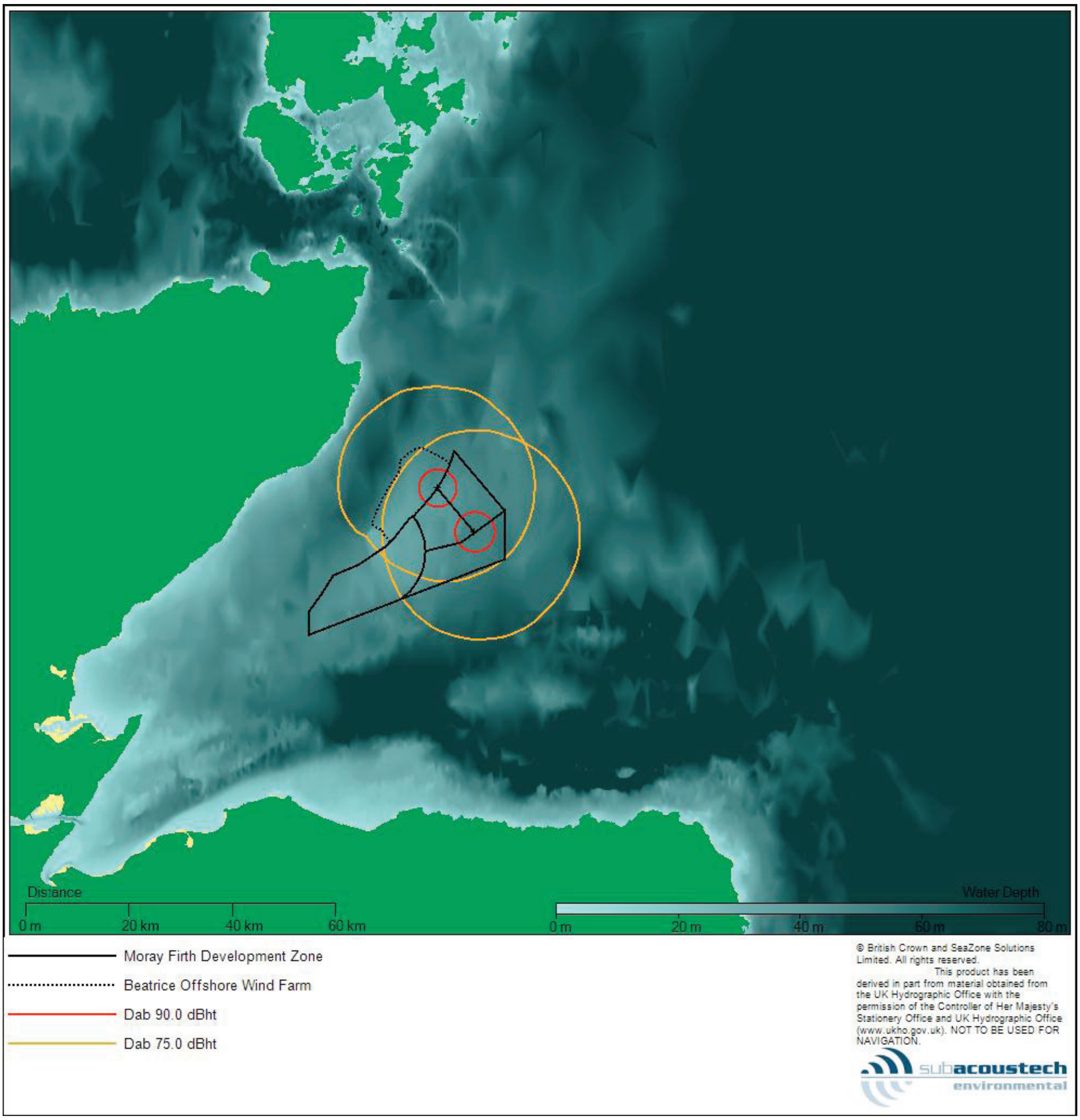


Figure A-150. 90 dB_{ht} and 75 dB_{ht} contours for plaice (dab used as surrogate); 2.5 m diameter piles being driven at locations 3a and 5a simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	3a and 5a
Pile driving energy (kJ)	1200
Species	Plaice

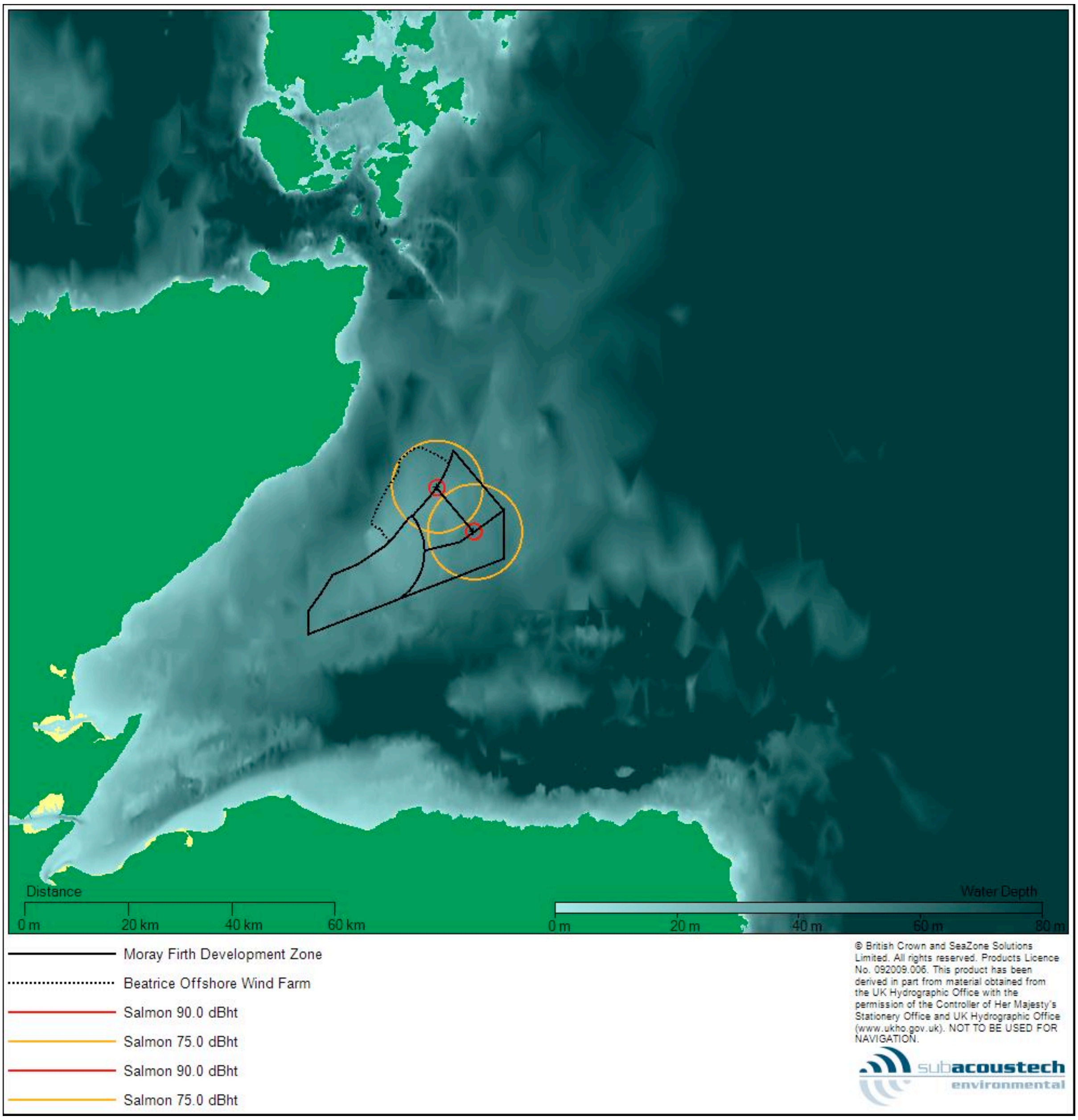


Figure A-151. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for salmon; 2.5 m diameter piles being driven at locations 3a and 5a simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	3a and 5a
Pile driving energy (kJ)	1200
Species	Salmon

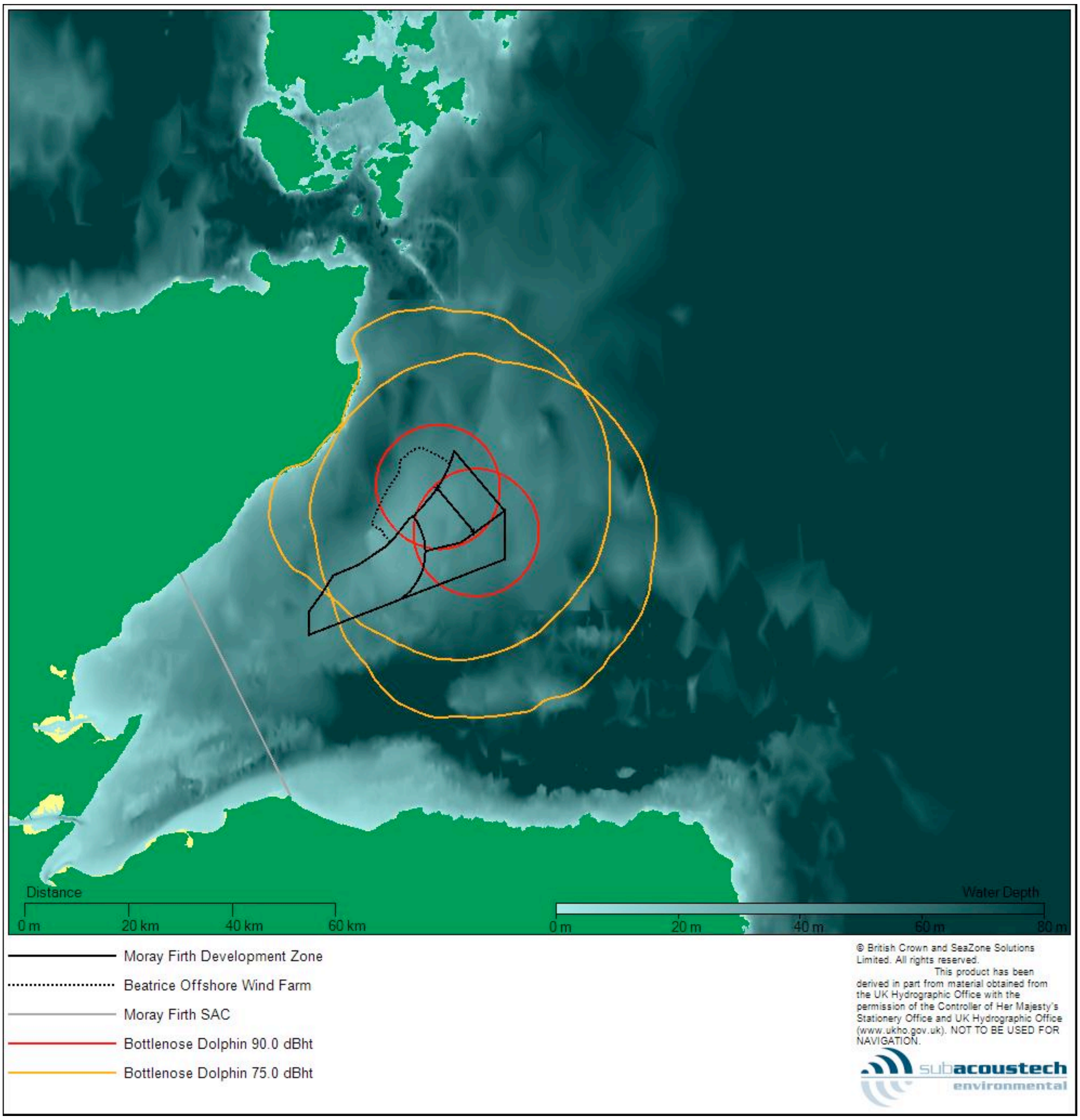


Figure A-152. 90 dB_{ht} and 75 dB_{ht} contours for bottlenose dolphin; 2.5 m diameter piles being driven at locations 3a and 5a simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	3a and 5a
Pile driving energy (kJ)	1200
Species	Bottlenose Dolphin

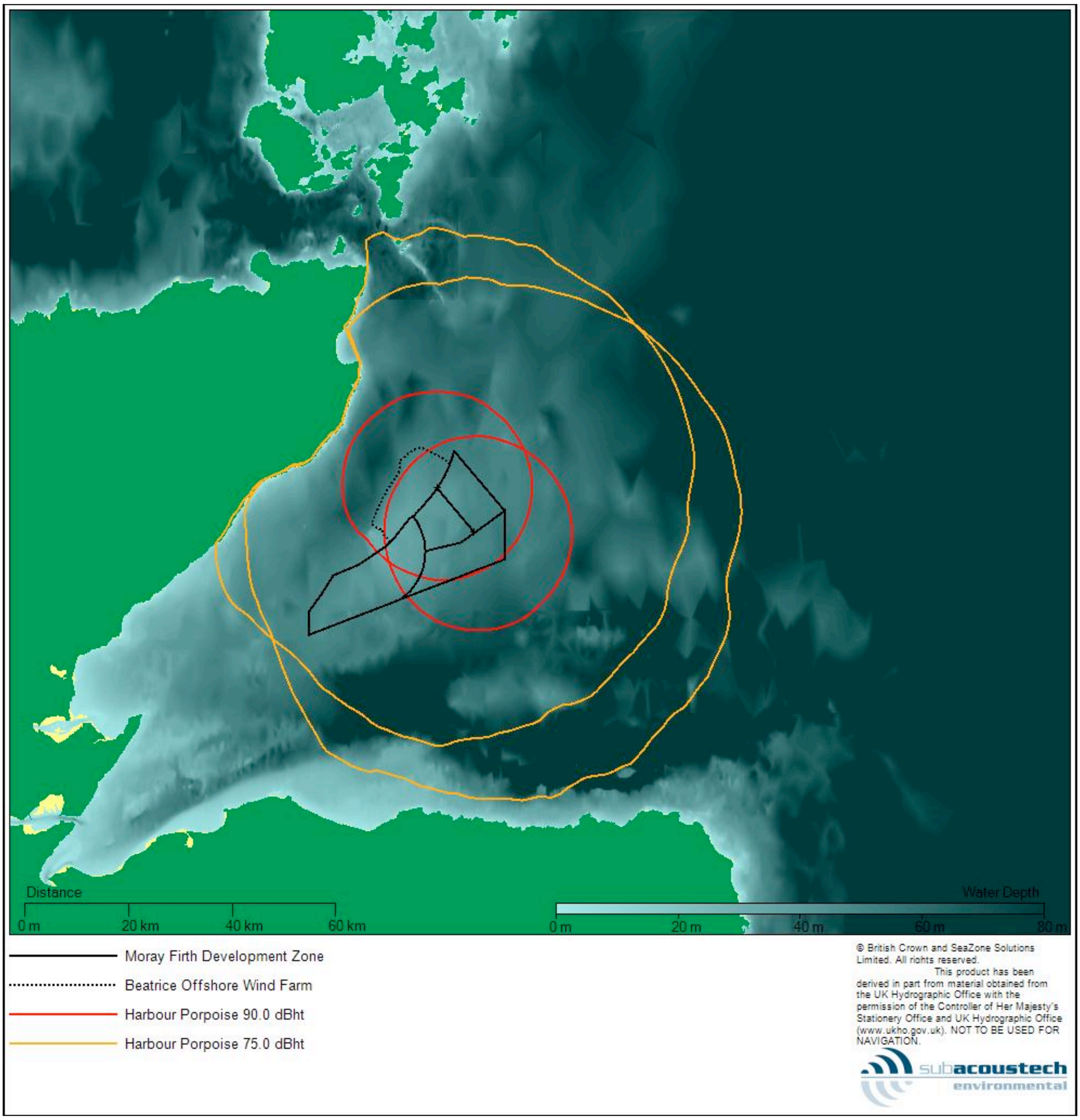


Figure A-153. 90 dB_{ht} and 75 dB_{ht} contours for harbour porpoise; 2.5 m diameter piles being driven at locations 3a and 5a simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	3a and 5a
Pile driving energy (kJ)	1200
Species	Harbour Porpoise

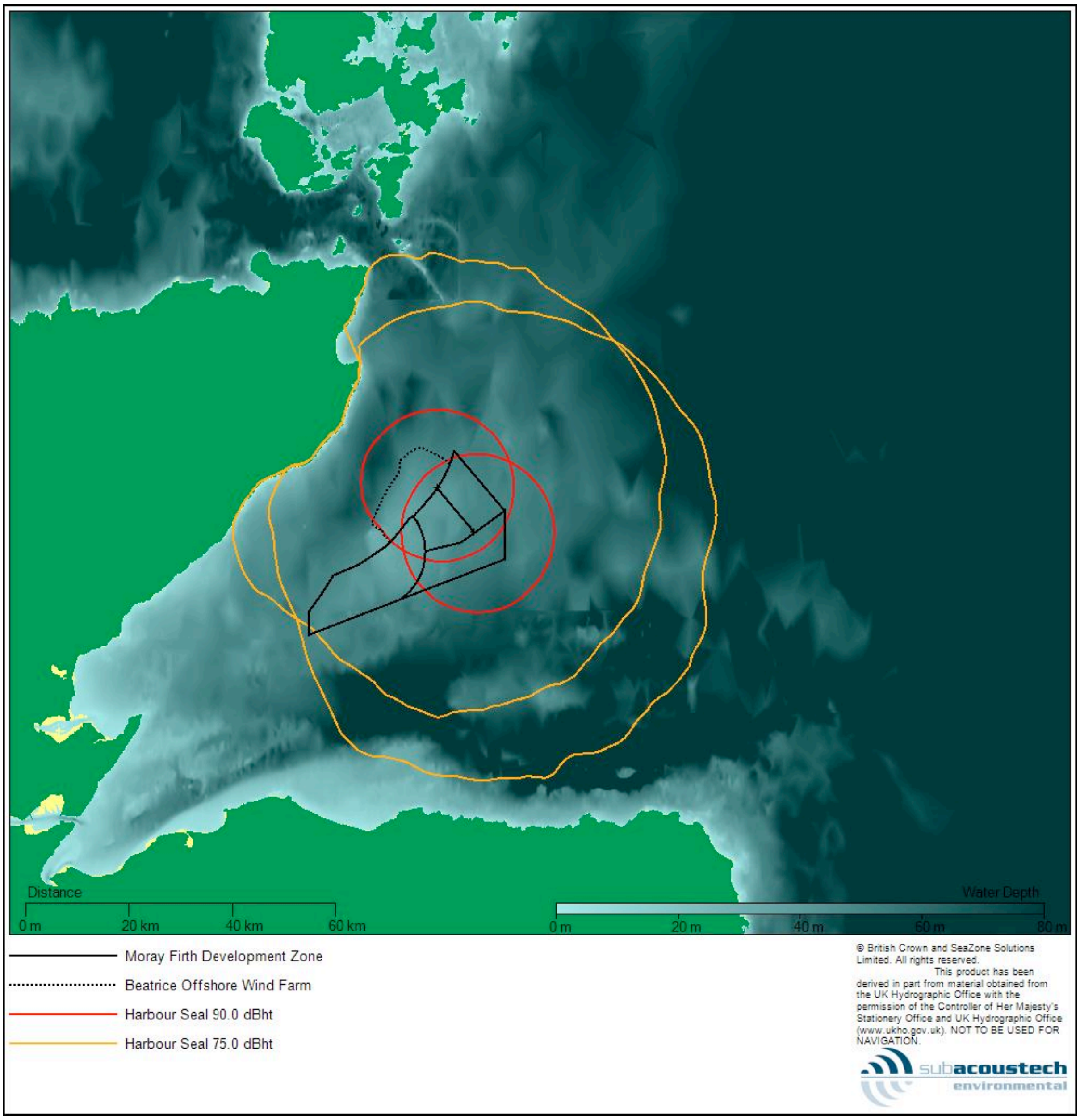


Figure A-154. 90 dB_{ht} and 75 dB_{ht} contours for harbour seal; 2.5 m diameter piles being driven at locations 3a and 5a simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	3a and 5a
Pile driving energy (kJ)	1200
Species	Harbour Seal

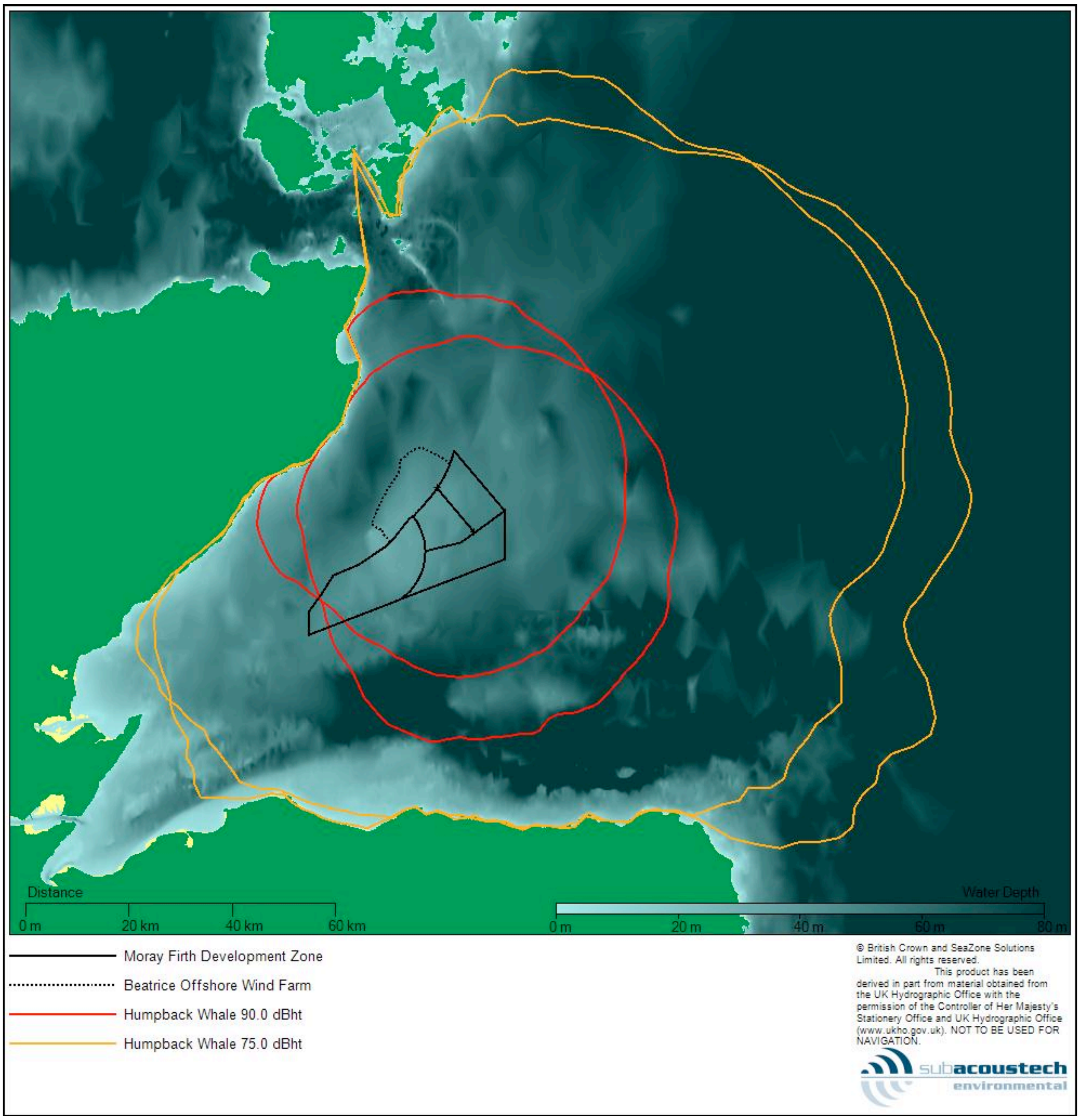


Figure A-155. 90 dB_{ht} and 75 dB_{ht} contours for minke whale (humpback whale used as surrogate); 2.5 m diameter piles being driven at locations 3a and 5a simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	3a and 5a
Pile driving energy (kJ)	1200
Species	Minke Whale

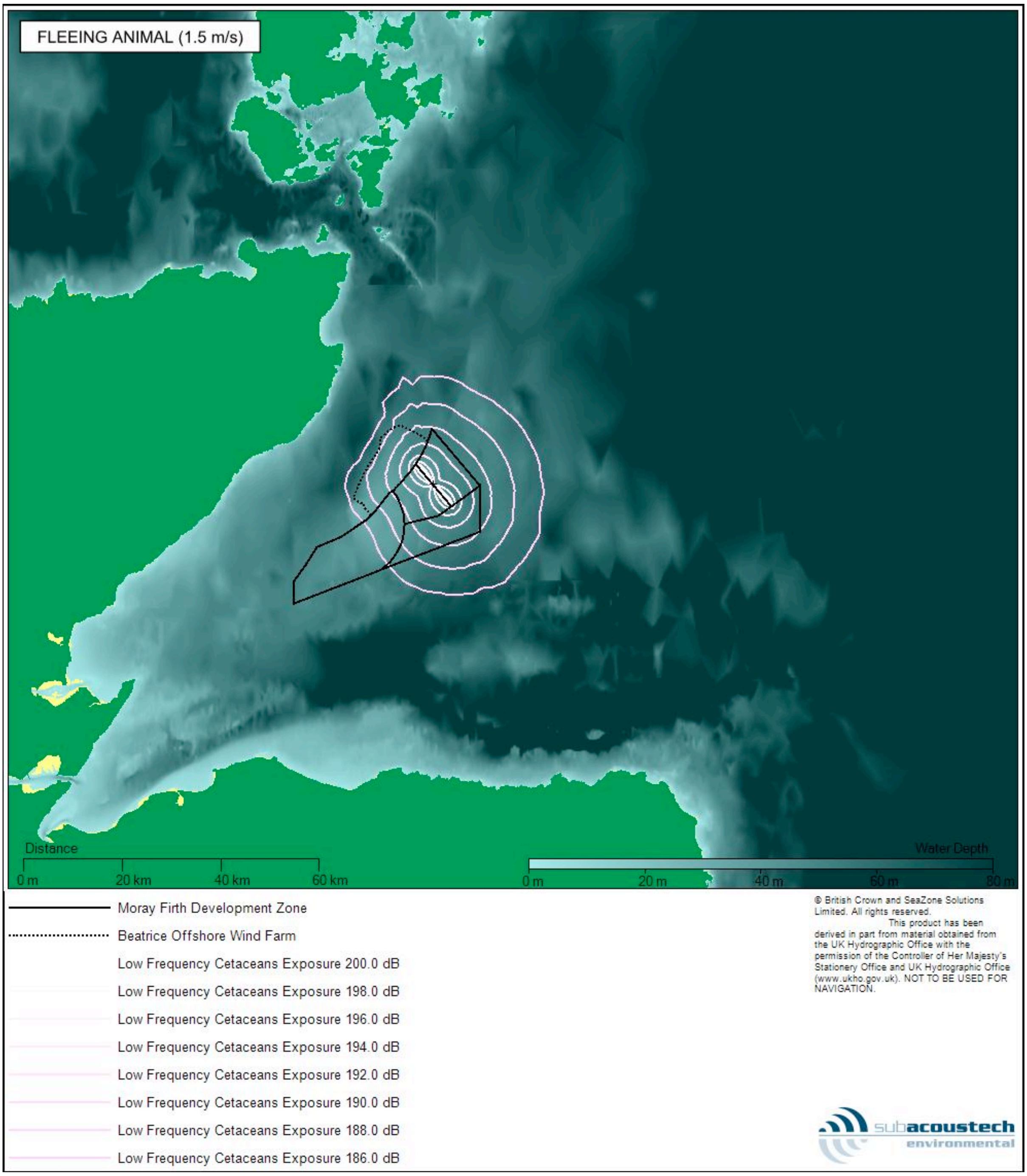


Figure A-156. Starting loci for fleeing Low Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 3a and 5a simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	3a and 5a
Pile driving energy (kJ)	1200
Species	Low Frequency Cetaceans (Fleeing 1.5m/s)

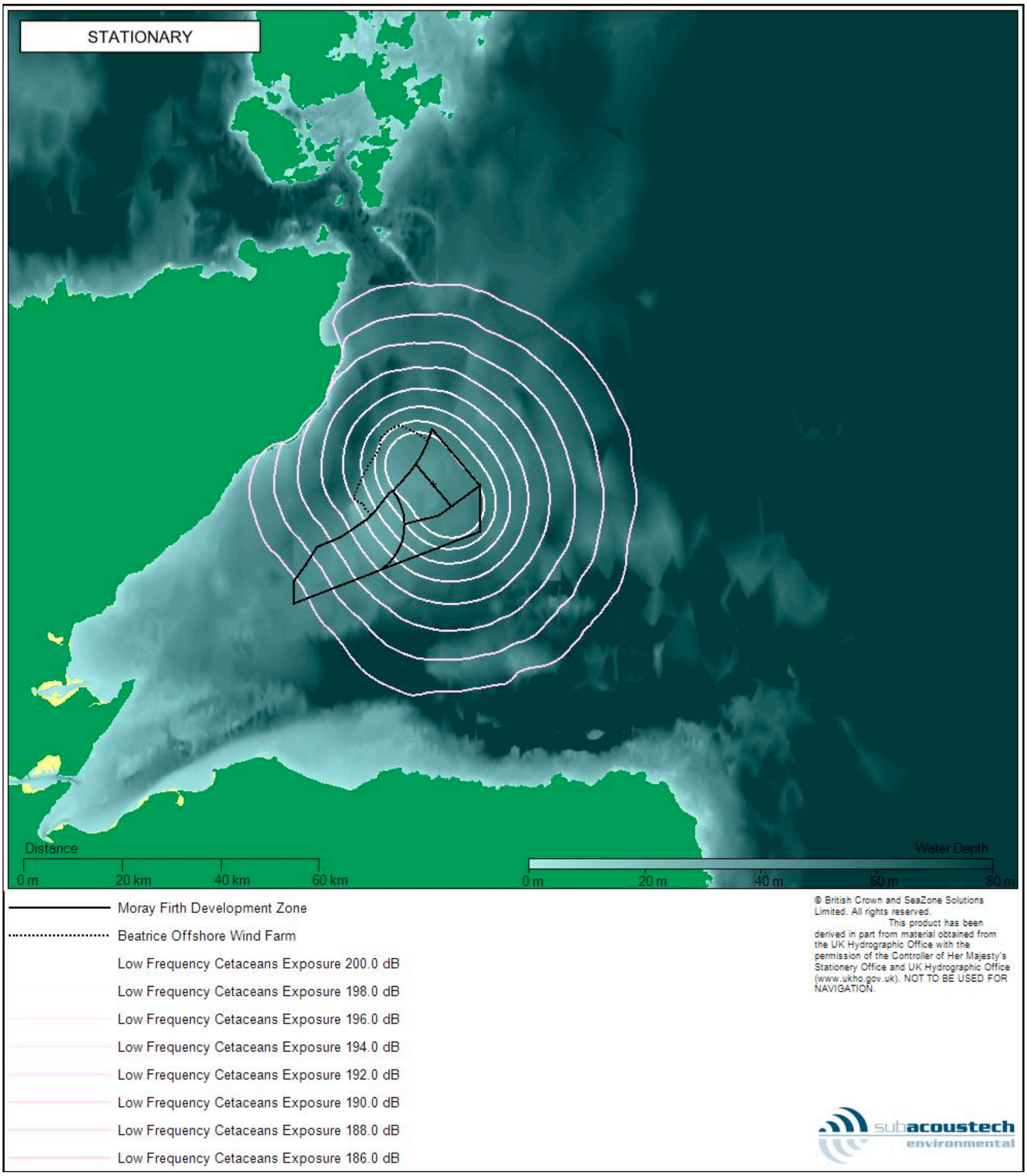


Figure A-157. Contours for stationary Low Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 3a and 5a simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	3a and 5a
Pile driving energy (kJ)	1200
Species	Low Frequency Cetaceans (Stationary)

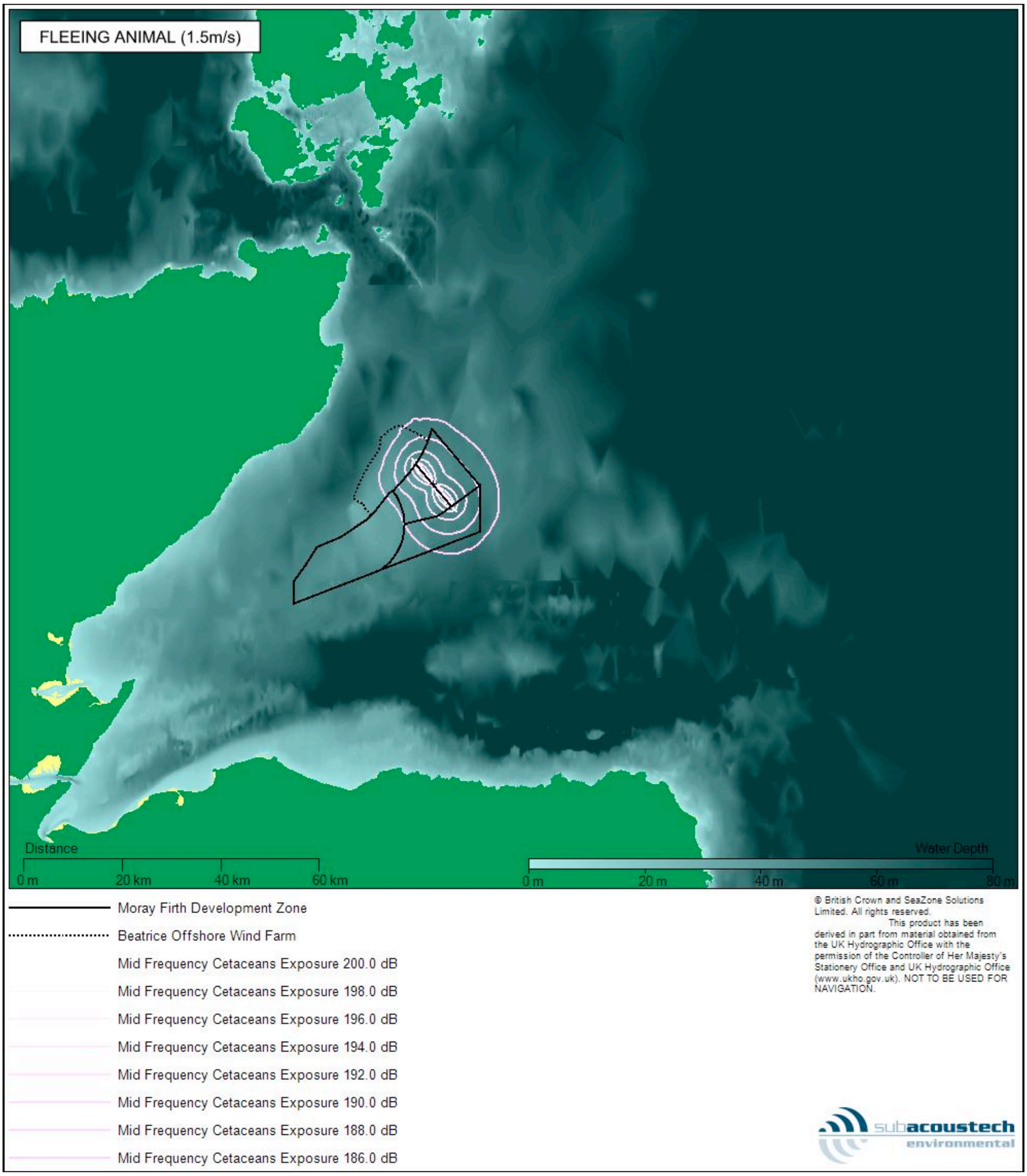


Figure A-158. Starting loci for fleeing Mid Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 3a and 5a simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	3a and 5a
Pile driving energy (kJ)	1200
Species	Mid Frequency Cetaceans (Fleeing 1.5m/s)

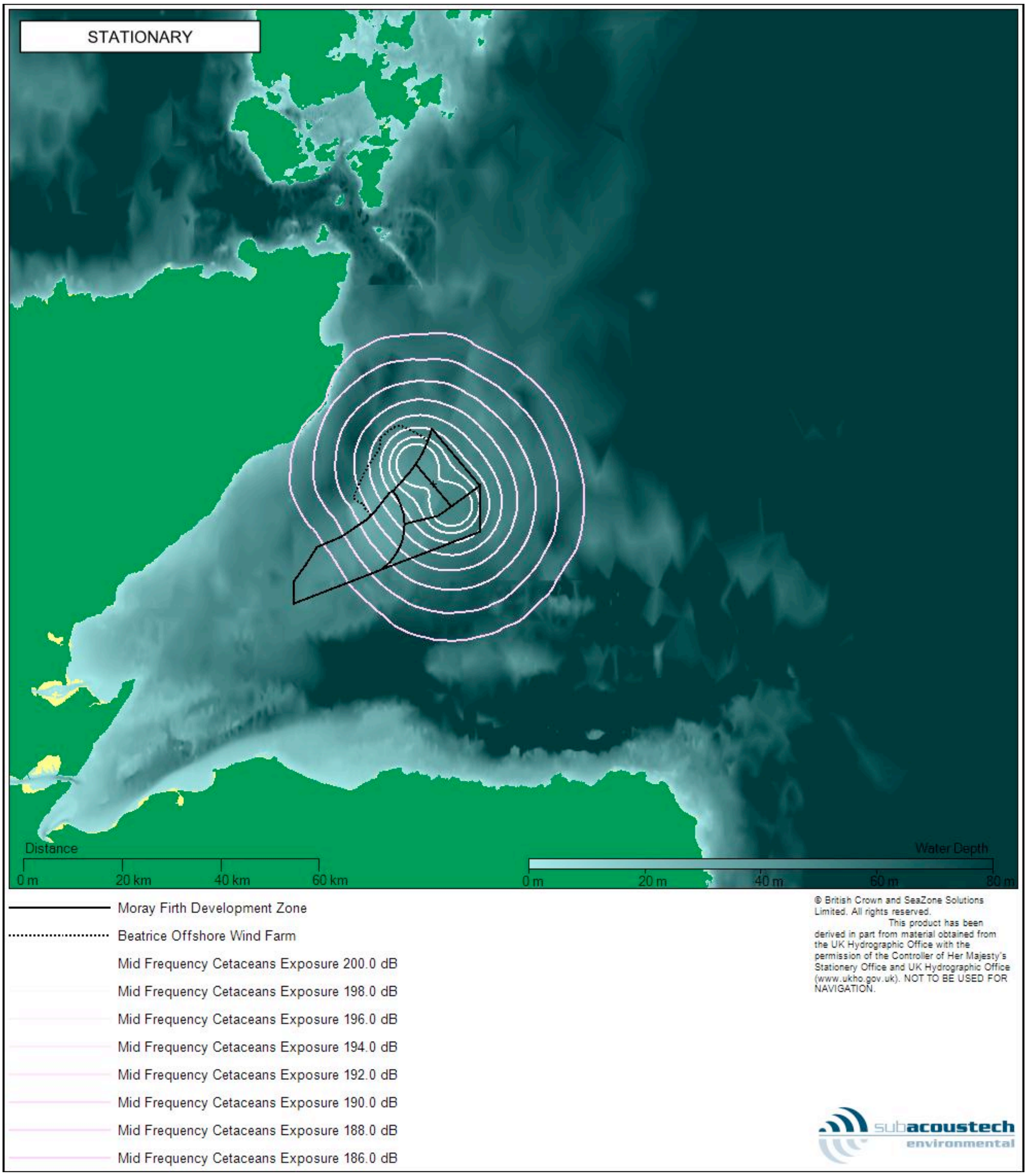


Figure A-159. Contours for stationary Mid Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 3a and 5a simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	3a and 5a
Pile driving energy (kJ)	1200
Species	Mid Frequency Cetaceans (Stationary)

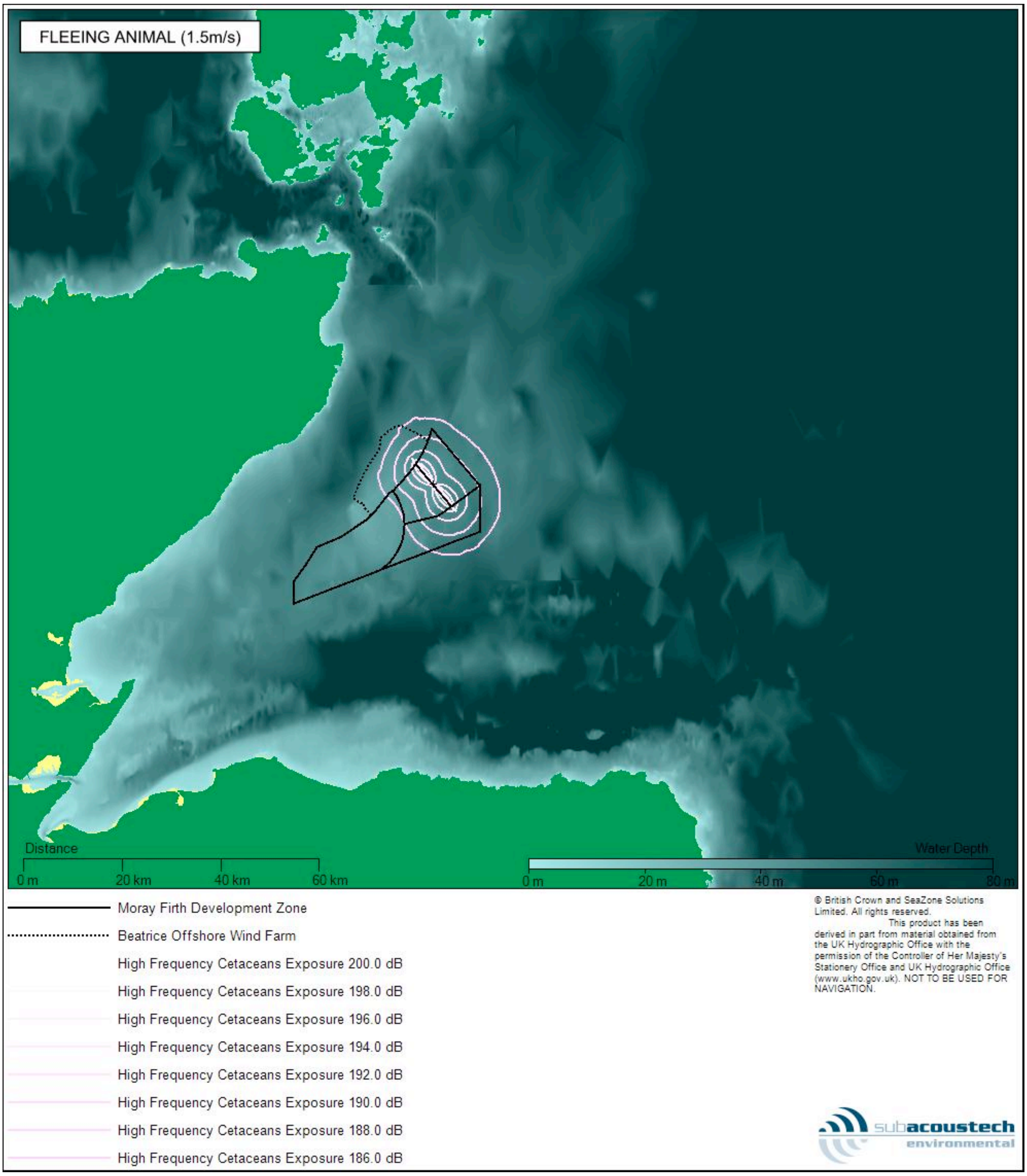


Figure A-160. Starting loci for fleeing High Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 3a and 5a simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	3a and 5a
Pile driving energy (kJ)	1200
Species	High Frequency Cetaceans (Fleeing 1.5m/s)

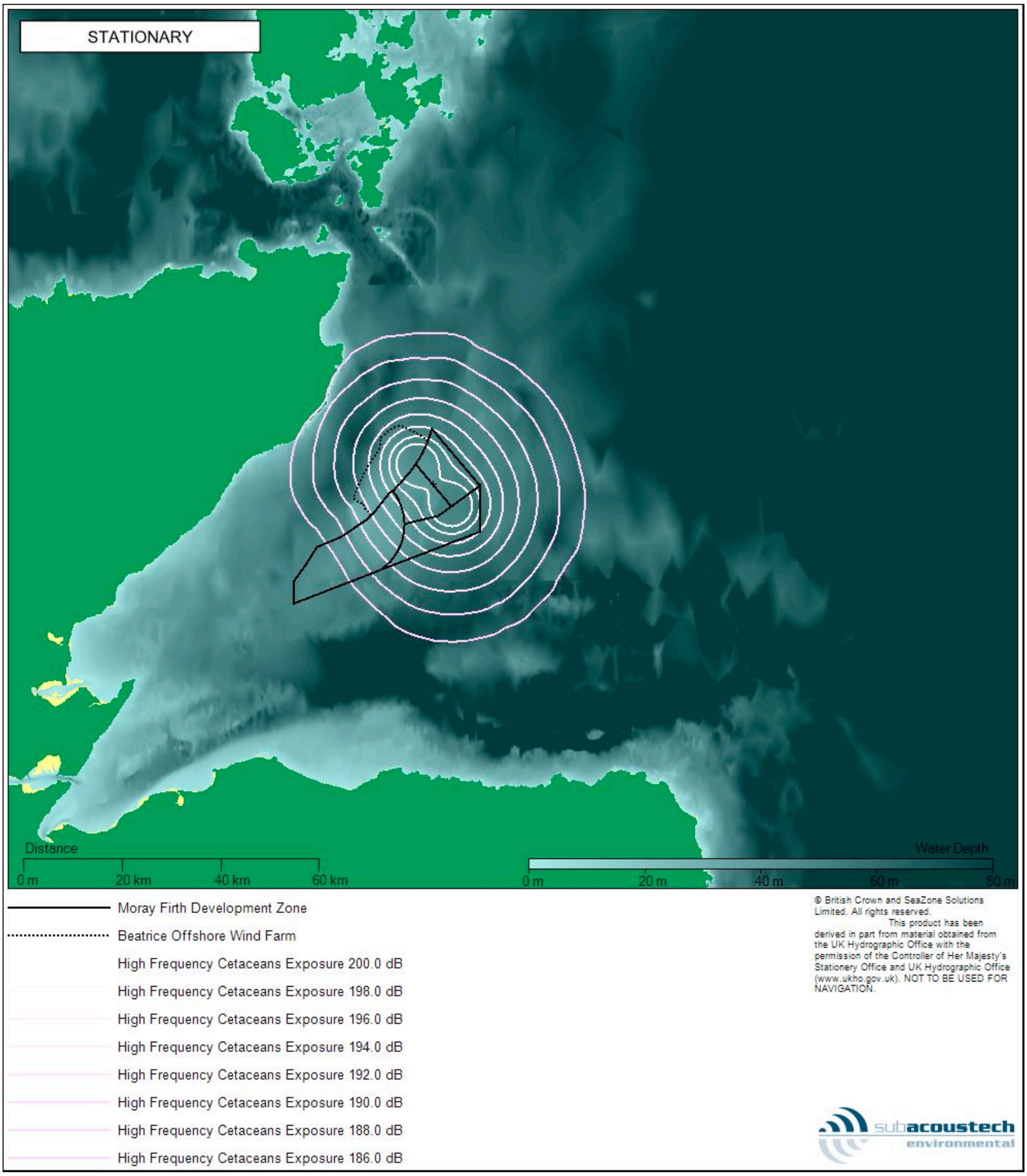


Figure A-161. Contours for stationary High Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 3a and 5a simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	3a and 5a
Pile driving energy (kJ)	1200
Species	High Frequency Cetaceans (Stationary)

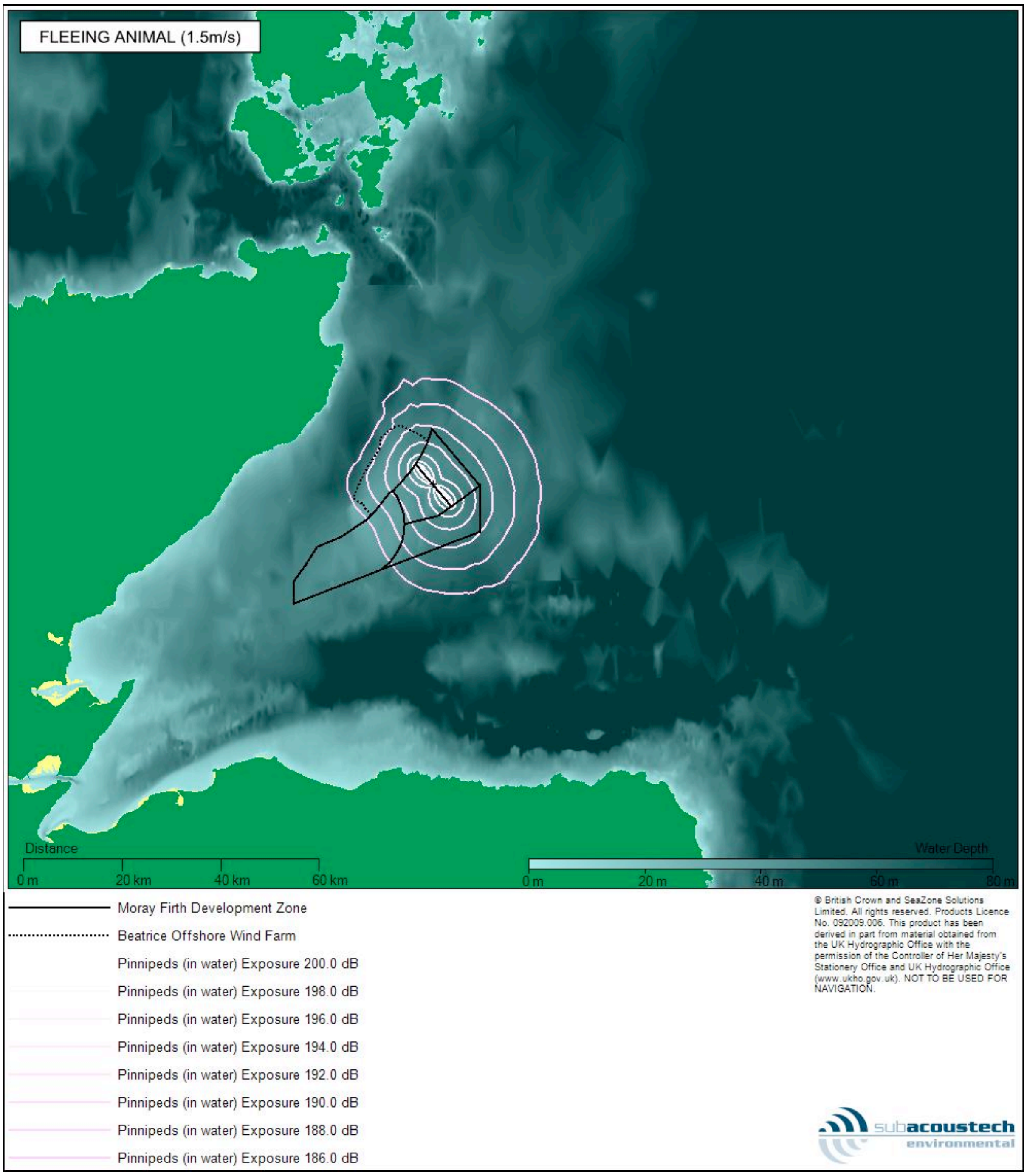


Figure A-162. Starting loci for fleeing Pinnipeds (in water); two 2.5 m diameter piles being driven sequentially at locations 3a and 5a simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	3a and 5a
Pile driving energy (kJ)	1200
Species	Pinnipeds (in water) (Fleeing 1.5m/s)

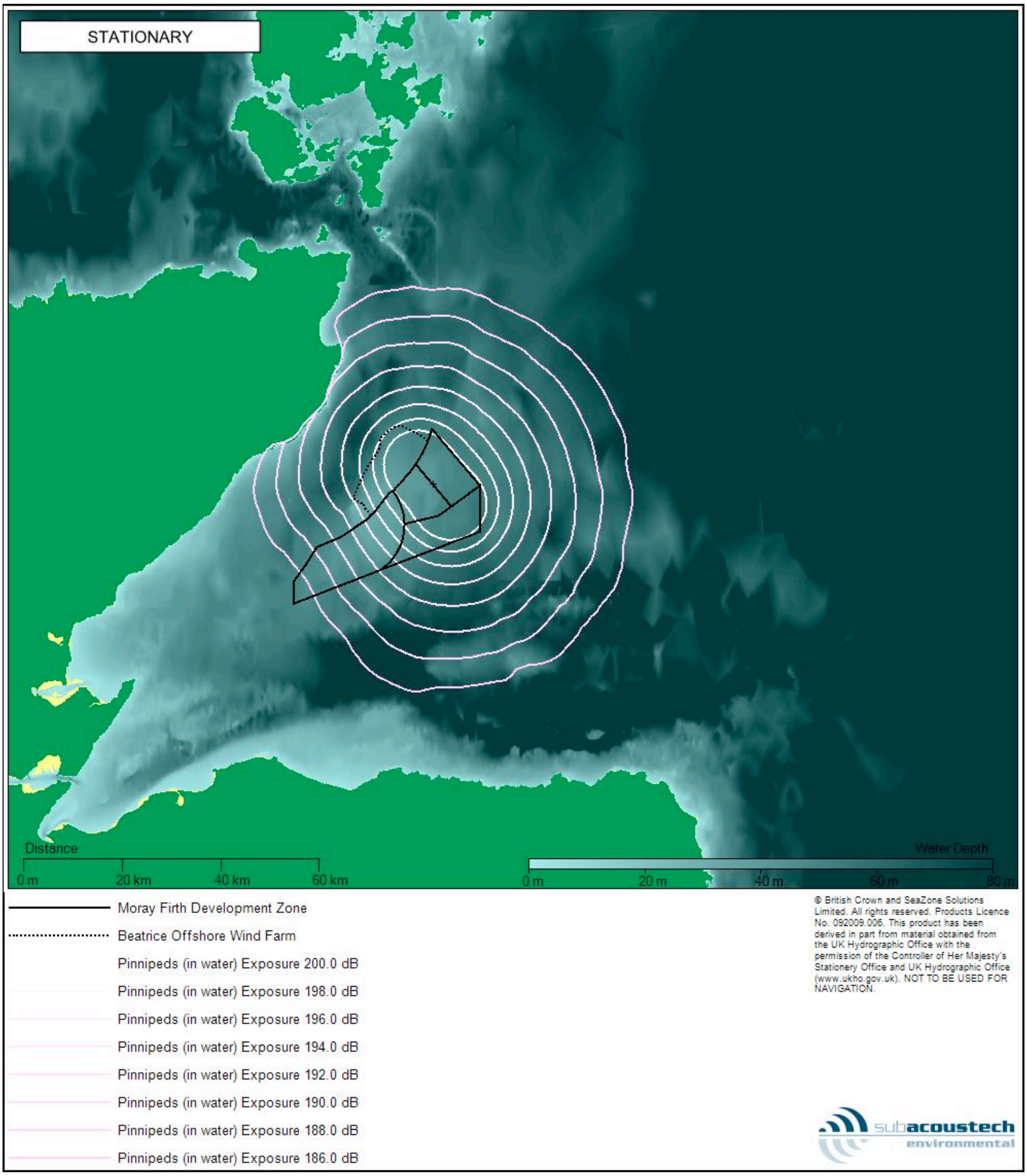


Figure A-163. Contours for stationary Pinnipeds (in water); two 2.5 m diameter piles being driven sequentially at locations 3a and 5a simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	3a and 5a
Pile driving energy (kJ)	1200
Species	Pinnipeds (in water) (Stationary)

9.2.5 Piles being driven simultaneously 6 locations

9.2.5.1 Details of cases

For the four fish and four marine mammal species considered, calculations were made for a single pile being driven at each of locations 1 to 6 simultaneously. For the low-, mid- and high-frequency cetacean and pinniped in water cases considered, calculations were made for two piles being driven sequentially at each of locations 1, 2, 3, 4, 5 and 6, with the piling at these locations to take place simultaneously

A summary of the cases is given in Table A-15.

Table A-15. Detailed description of piling modelling undertaken

Pile diameter (m)	Number of piles / location	Hammer capacity (kJ)	Species	Results shown	Figure
2.5	Locations 1, 2, 3, 4, 5 and 6	1200	Cod	90 dB_{ht} and 75 dB_{ht} contours	A-164
2.5	Locations 1, 2, 3, 4, 5 and 6	1200	Herring	90 dB_{ht} and 75 dB_{ht} contours	A-165
2.5	Locations 1, 2, 3, 4, 5 and 6	1200	Plaice	90 dB_{ht} and 75 dB_{ht} contours	A-166
2.5	Locations 1, 2, 3, 4, 5 and 6	1200	Salmon	90 dB_{ht} and 75 dB_{ht} contours	A-167
2.5	Locations 1, 2, 3, 4, 5 and 6	1200	Bottlenose dolphin	90 dB_{ht} and 75 dB_{ht} contours	A-168
2.5	Locations 1, 2, 3, 4, 5 and 6	1200	Harbour porpoise	90 dB_{ht} and 75 dB_{ht} contours	A-169
2.5	Locations 1, 2, 3, 4, 5 and 6	1200	Harbour seal	90 dB_{ht} and 75 dB_{ht} contours	A-170
2.5	Locations 1, 2, 3, 4, 5 and 6	1200	Minke whale	90 dB_{ht} and 75 dB_{ht} contours	A-171
2.5	2 piles sequentially at locations 1, 2, 3,4, 5 and 6	1200	Low frequency cetacean	Contours between 200 and 186 dB re 1 μPa².s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-172
2.5	2 piles sequentially at locations 1, 2, 3,4, 5 and 6	1200	Low frequency cetacean	Contours between 200 and 186 dB re 1 μPa².s (M_{lf}) in 2 dB increments for a stationary animal	A-173
2.5	2 piles sequentially at locations 1, 2, 3,4, 5 and 6	1200	Mid frequency cetacean	Contours between 200 and 186 dB re 1 μPa².s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-174
2.5	2 piles sequentially at locations 1, 2, 3,4, 5 and 6	1200	Mid frequency cetacean	Contours between 200 and 186 dB re 1 μPa².s (M_{lf}) in 2 dB increments for a stationary animal	A-175
2.5	2 piles sequentially at locations 1, 2, 3,4, 5 and 6	1200	High frequency cetacean	Contours between 200 and 186 dB re 1 μPa².s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-176

Pile diameter (m)	Number of piles / location	Hammer capacity (kJ)	Species	Results shown	Figure
2.5	2 piles sequentially at locations 1, 2, 3,4, 5 and 6	1200	High frequency cetacean	Contours between 200 and 186 dB re 1 µPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-177
2.5	2 piles sequentially at locations 1, 2, 3,4, 5 and 6	1200	Pinniped (in water)	Contours between 200 and 186 dB re 1 µPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-178
2.5	2 piles sequentially at locations 1, 2, 3,4, 5 and 6	1200	Pinniped (in water)	Contours between 200 and 186 dB re 1 µPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-179

9.2.5.2 Results for piles at 6 locations on MORL, driven simultaneously

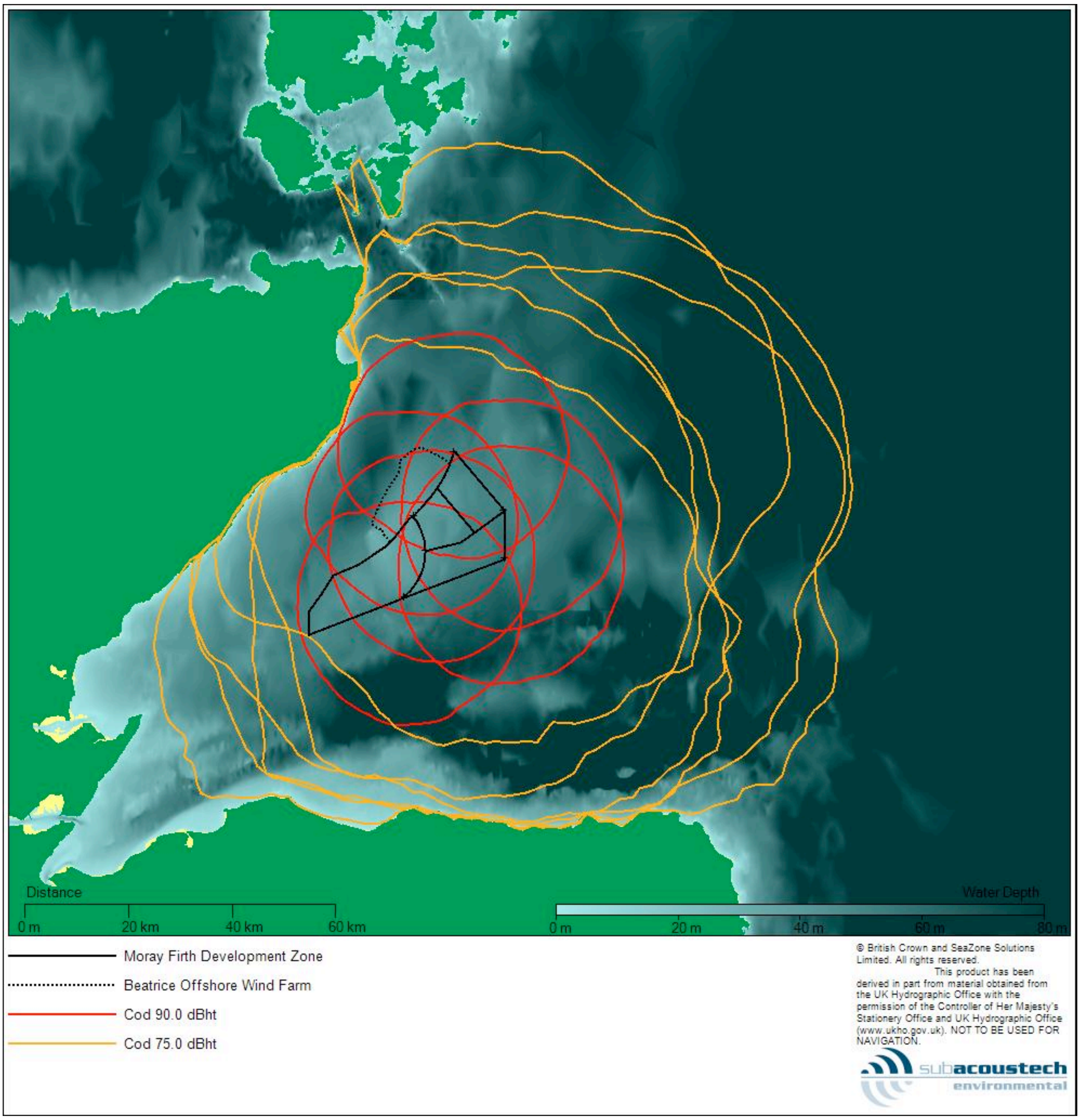


Figure A-164. 90 dB_{ht} and 75 dB_{ht} contours for cod; 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6
Pile driving energy (kJ)	1200
Species	Cod

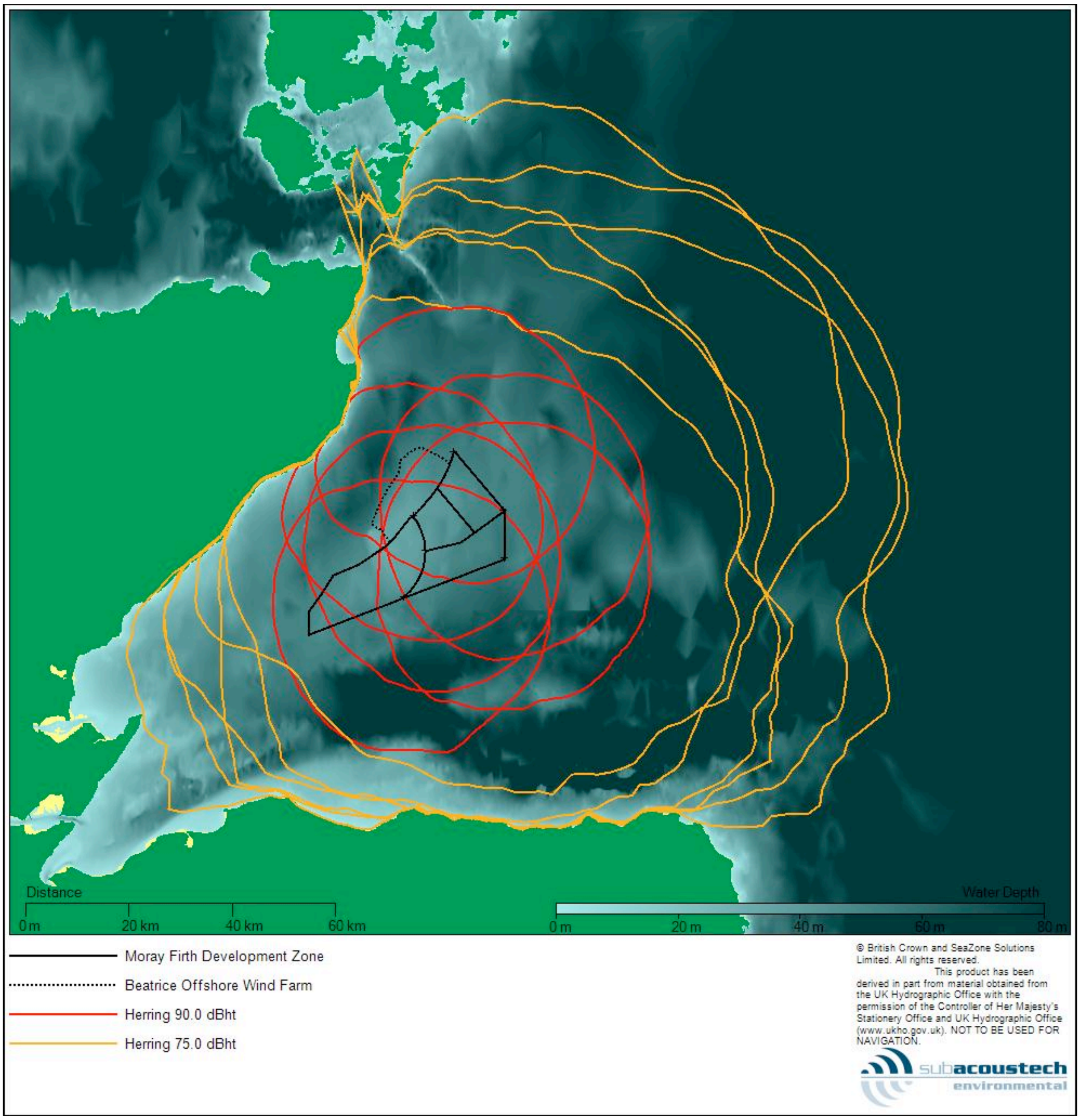


Figure A-165. 90 dB_{ht} and 75 dB_{ht} contours for herring; 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6
Pile driving energy (kJ)	1200
Species	Herring

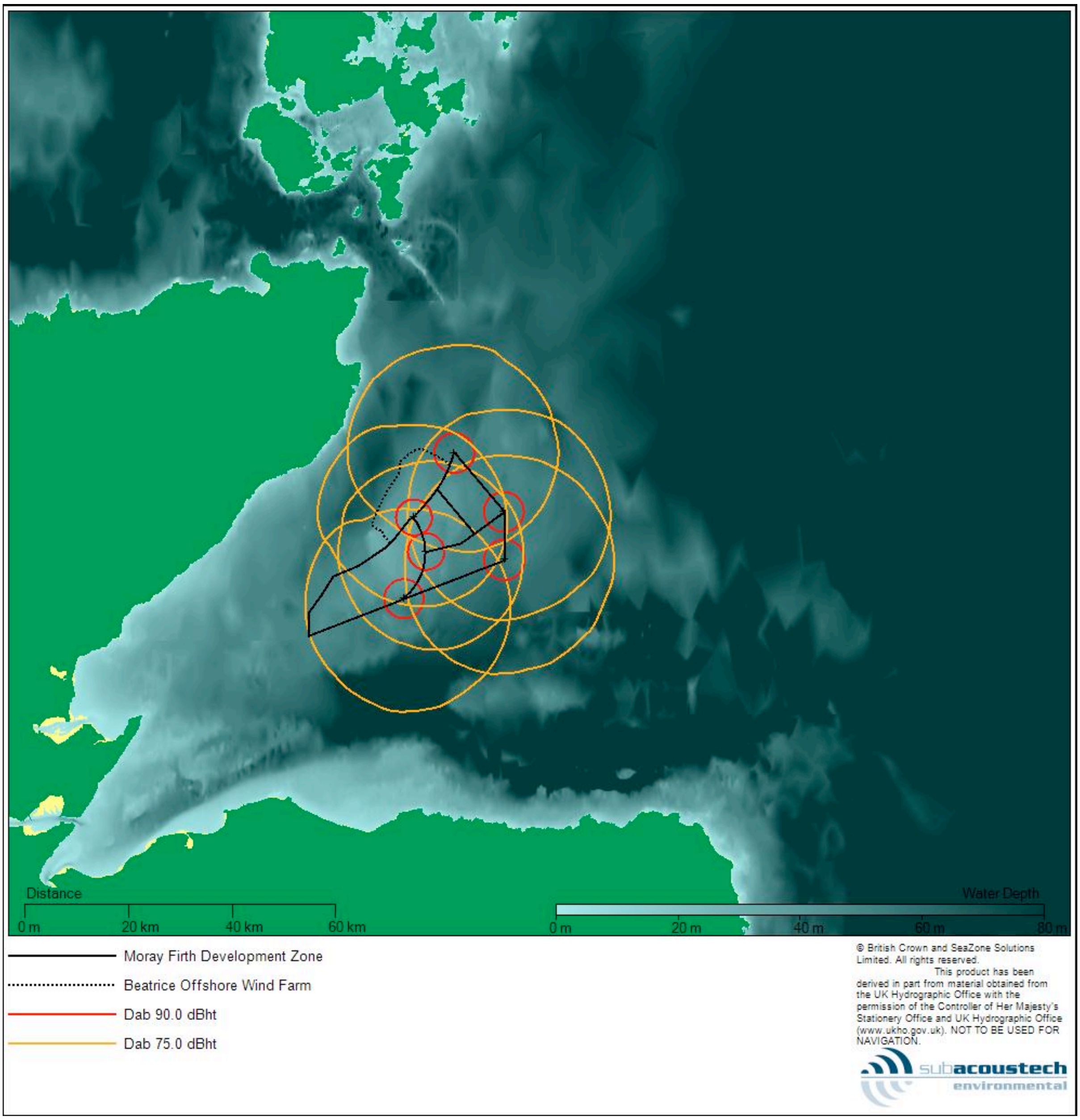


Figure A-166. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for plaice (dab used as surrogate); 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6
Pile driving energy (kJ)	1200
Species	Plaice

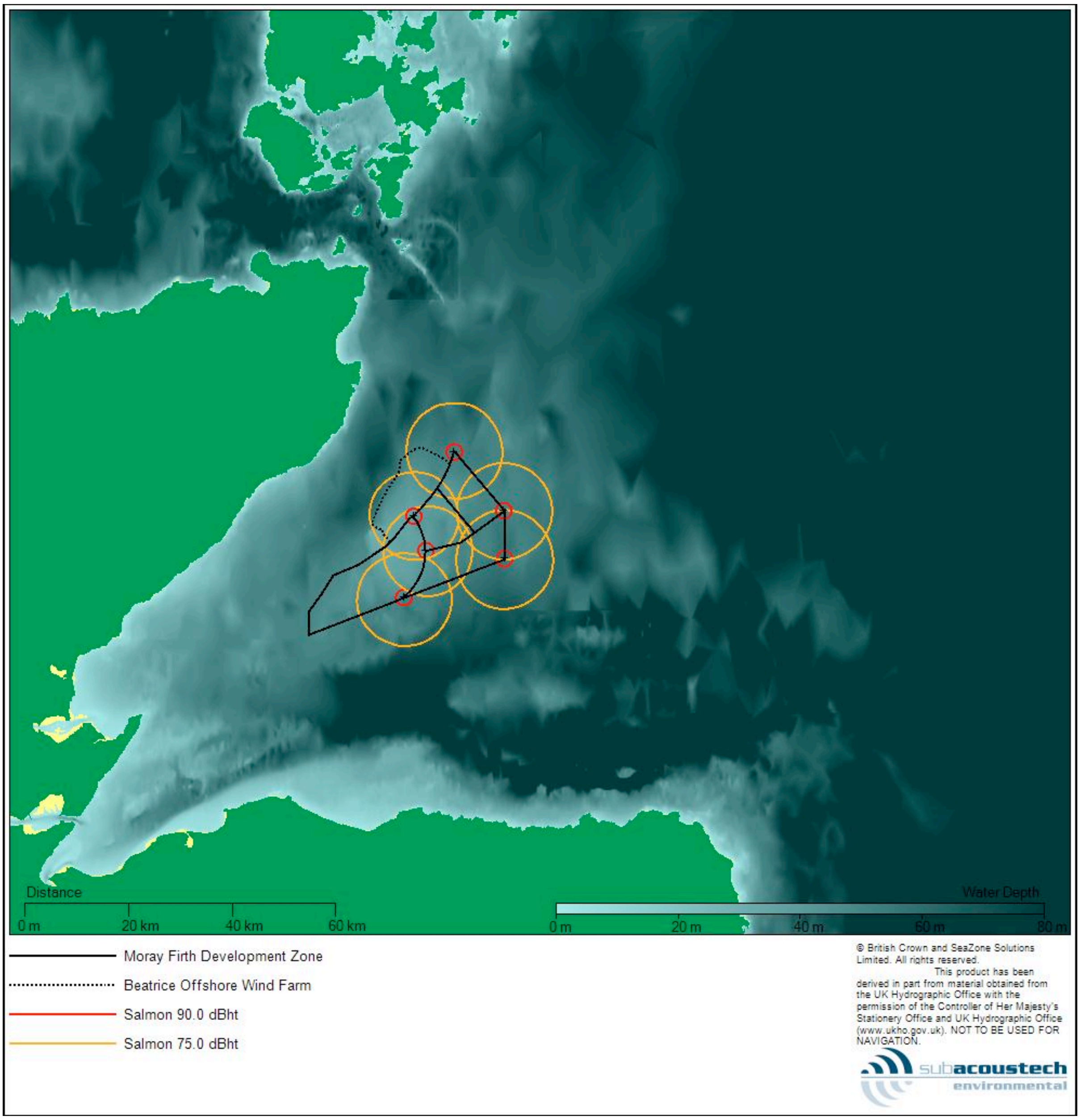


Figure A-167. 90 dB_{ht} and 75 dB_{ht} contours for salmon; 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6
Pile driving energy (kJ)	1200
Species	Salmon

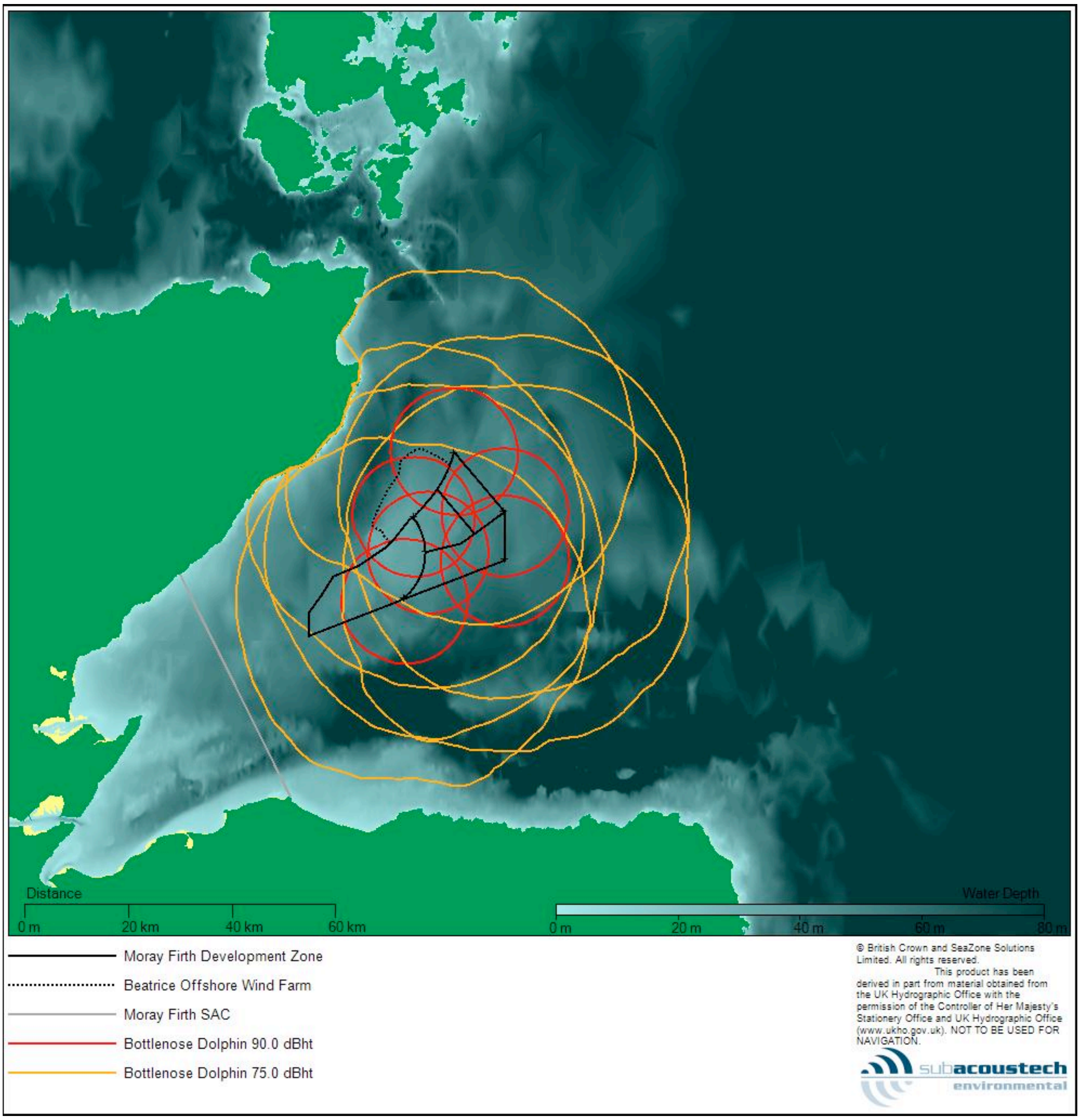


Figure A-168. 90 dB_{ht} and 75 dB_{ht} contours for bottlenose dolphin; 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6
Pile driving energy (kJ)	1200
Species	Bottlenose Dolphin

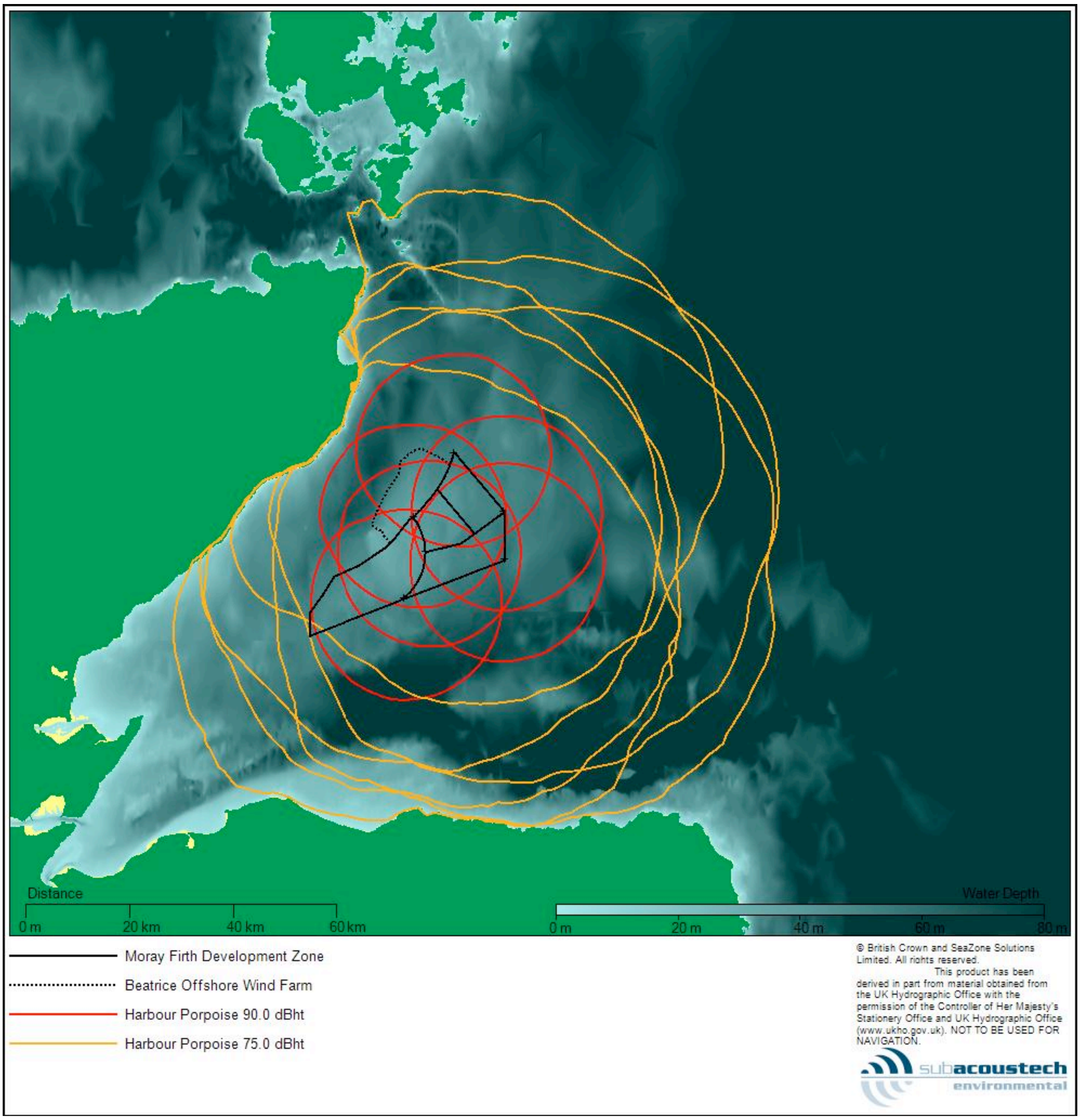


Figure A-169. 90 dB_{ht} and 75 dB_{ht} contours for harbour porpoise; 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6
Pile driving energy (kJ)	1200
Species	Harbour Porpoise

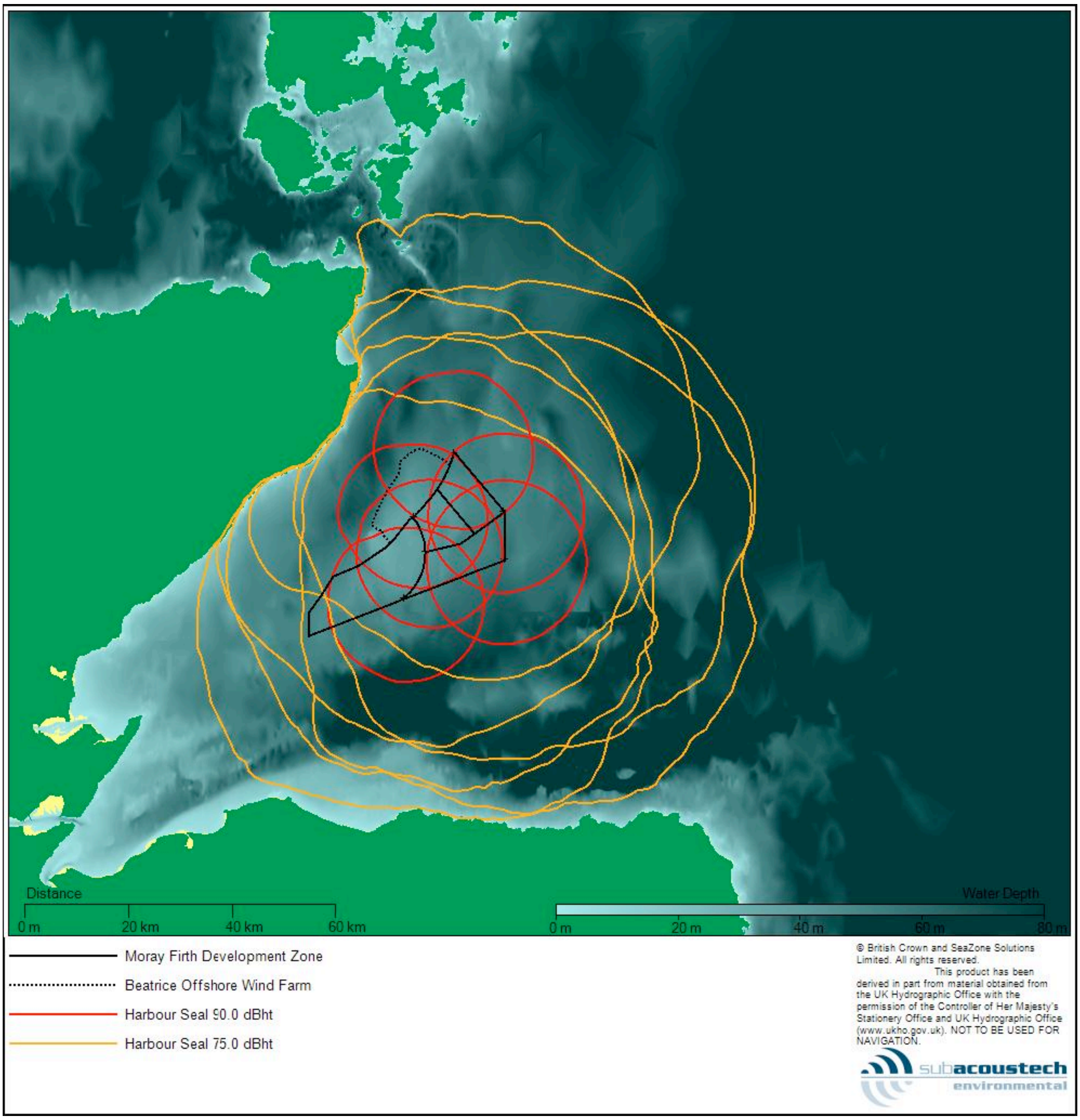


Figure A-170. 90 dB_{ht} and 75 dB_{ht} contours for harbour seal; 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6
Pile driving energy (kJ)	1200
Species	Harbour Seal

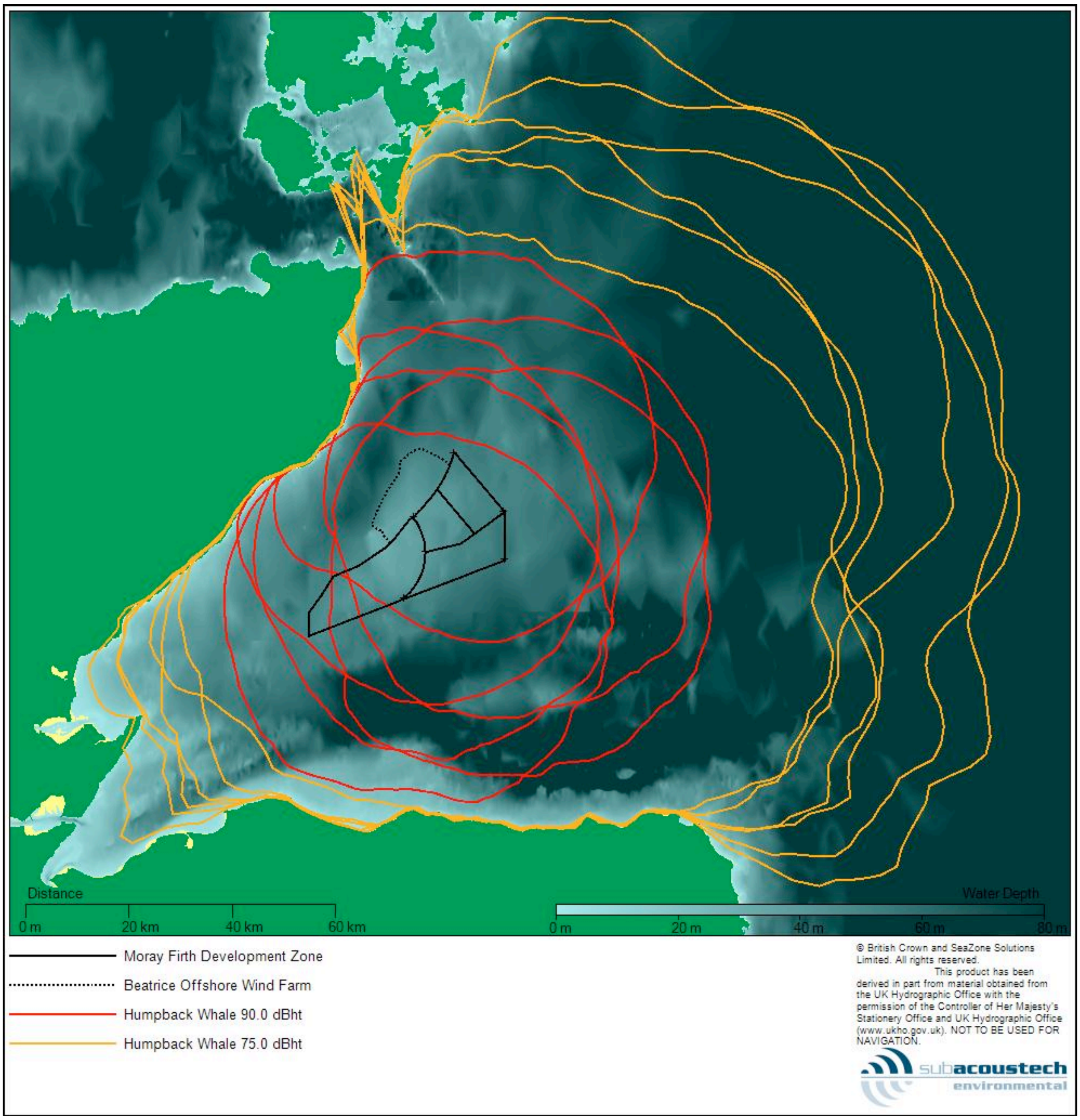


Figure A-171. 90 dB_{ht} and 75 dB_{ht} contours for minke whale (humpback whale used as surrogate); 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6
Pile driving energy (kJ)	1200
Species	Minke Whale

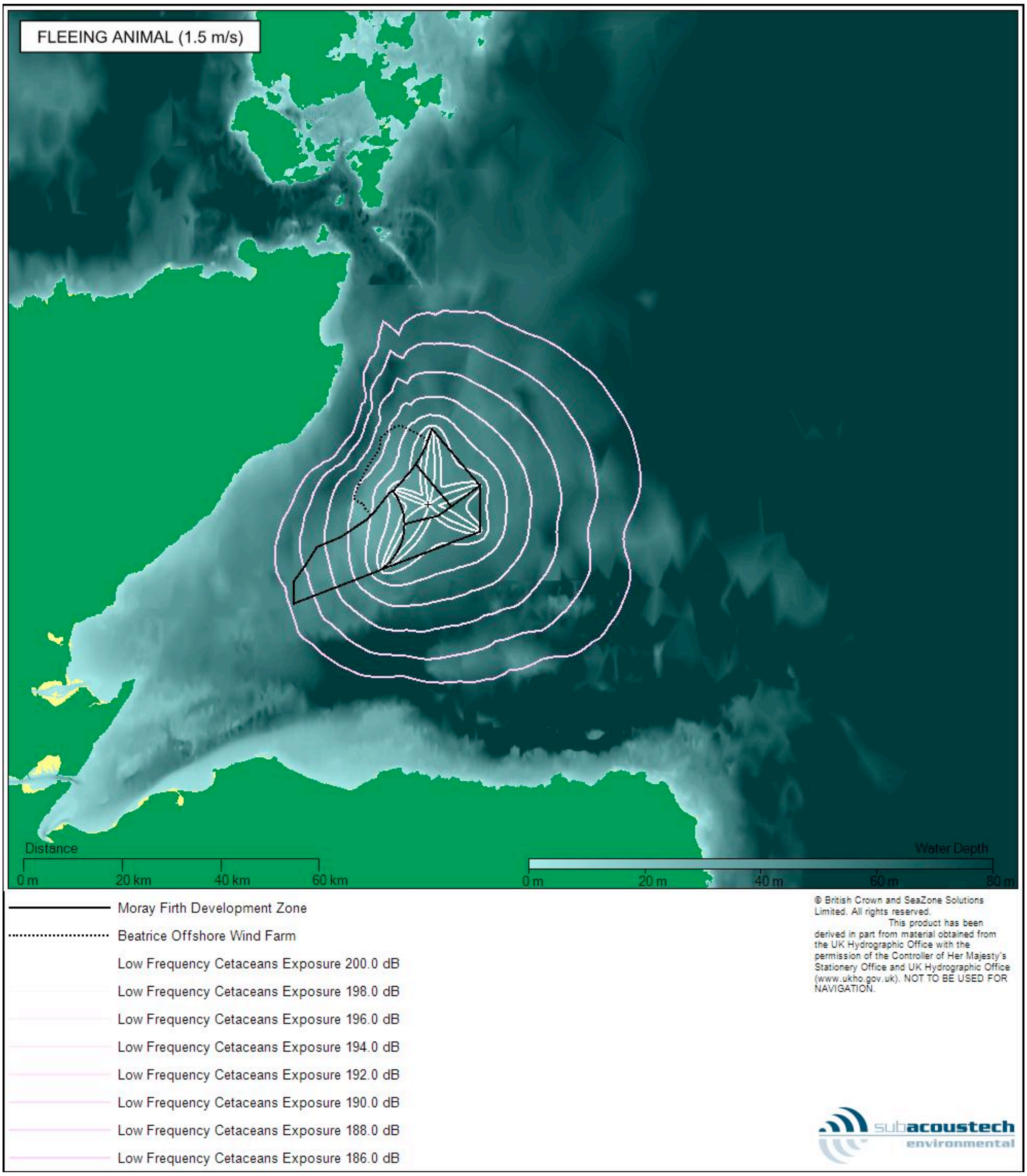


Figure A-172. Starting loci for fleeing Low Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 1, 2, 3, 4, 5 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6
Pile driving energy (kJ)	1200
Species	Low Frequency Cetaceans (Fleeing 1.5m/s)

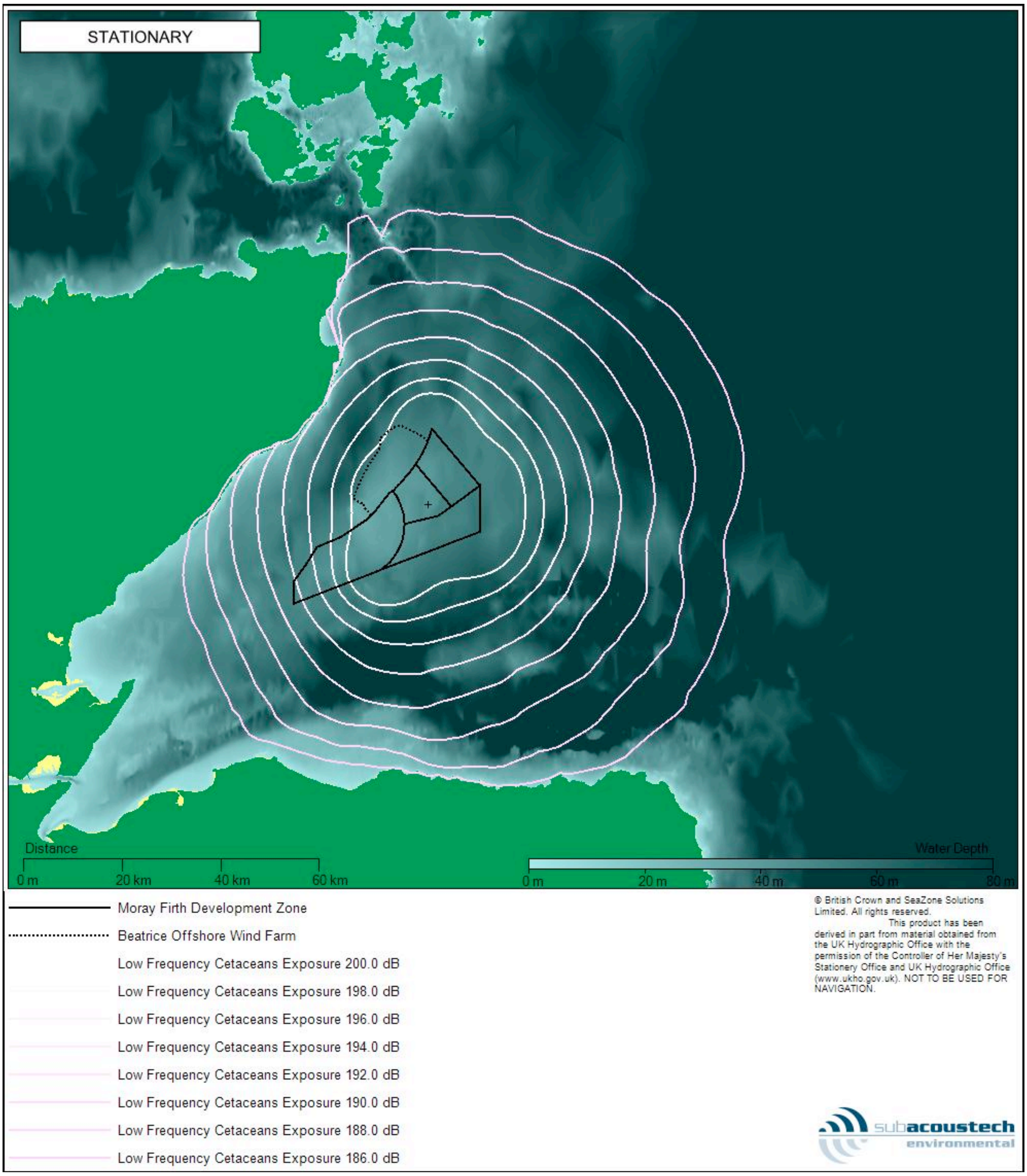


Figure A-173. Contours for stationary Low Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 1, 2, 3, 4, 5 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6
Pile driving energy (kJ)	1200
Species	Low Frequency Cetaceans (Stationary)

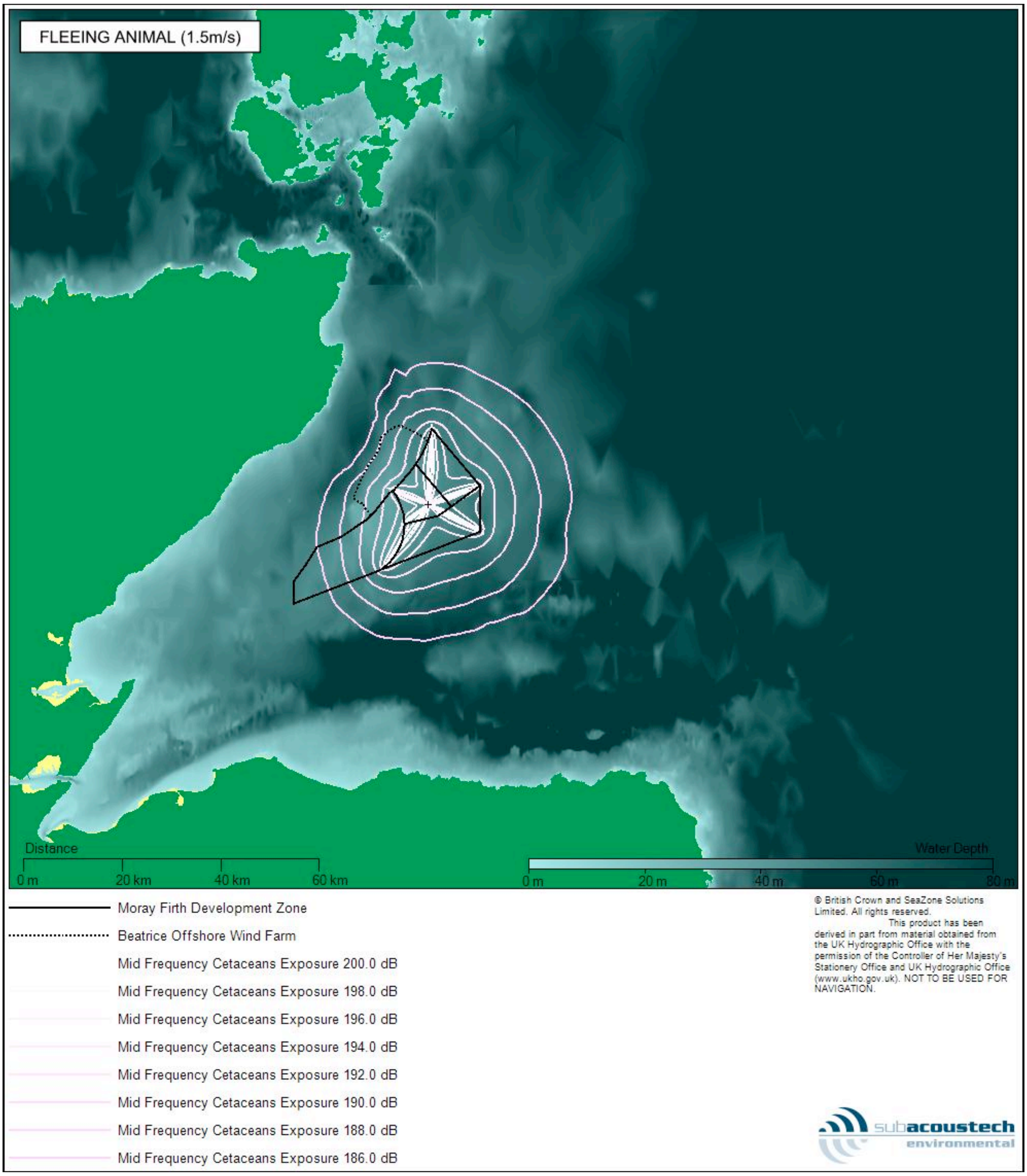


Figure A-174. Starting loci for fleeing Mid Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 1, 2, 3, 4, 5 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6
Pile driving energy (kJ)	1200
Species	Mid Frequency Cetaceans (Fleeing 1.5m/s)

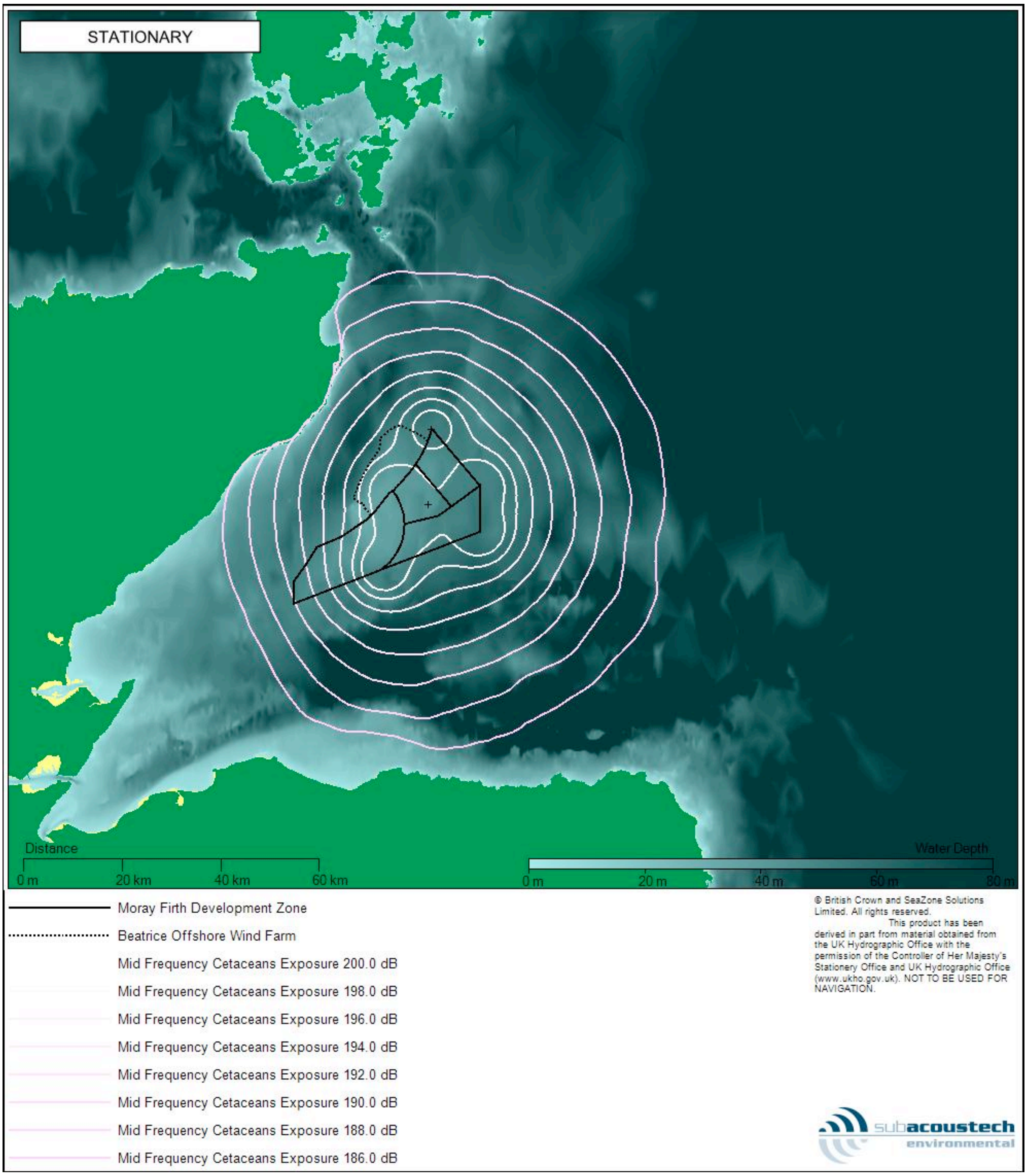


Figure A-175. Contours for stationary Mid Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 1, 2, 3, 4, 5 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6
Pile driving energy (kJ)	1200
Species	Mid Frequency Cetaceans (Stationary)

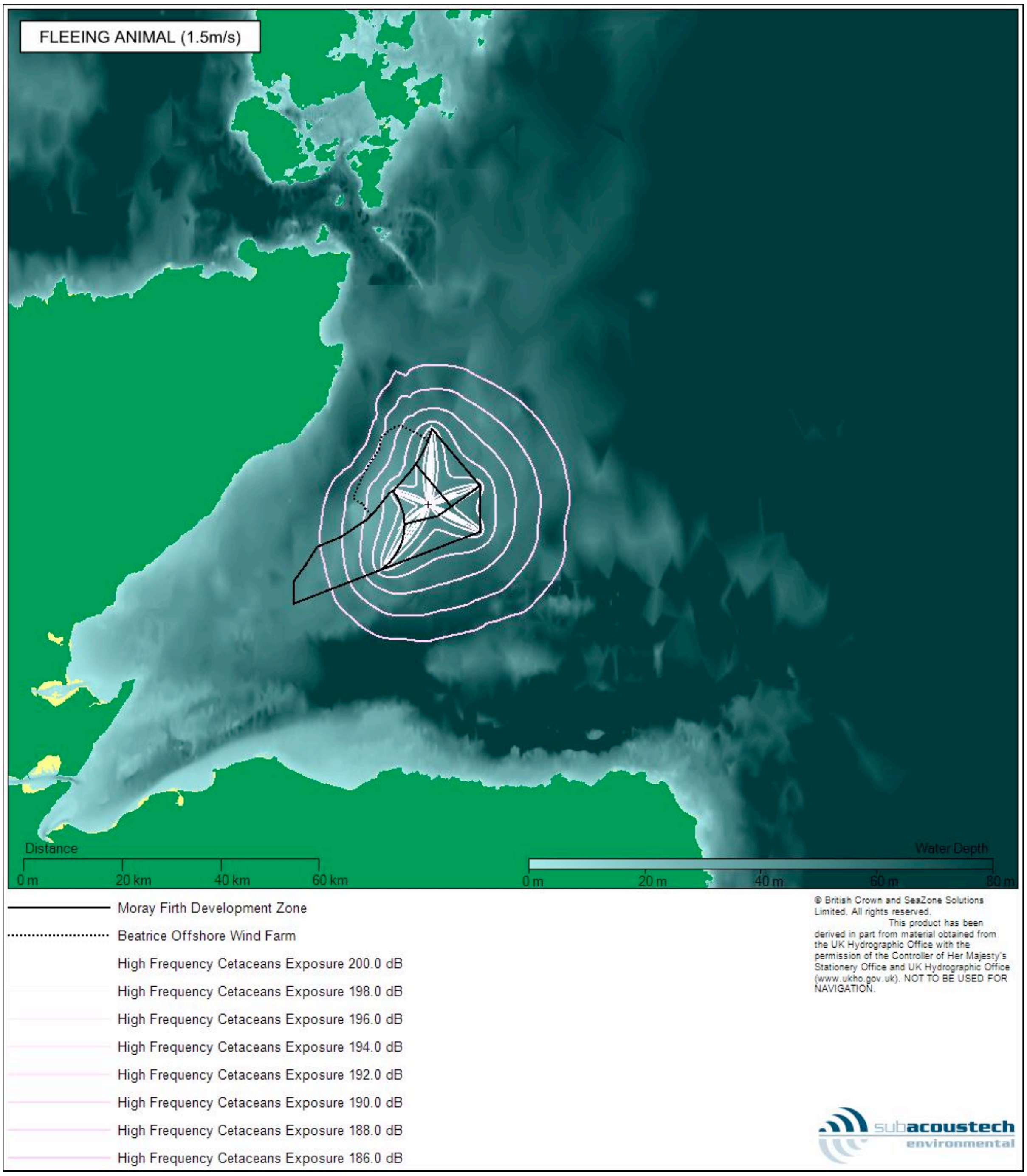


Figure A-176. Starting loci for fleeing High Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 1, 2, 3, 4, 5 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6
Pile driving energy (kJ)	1200
Species	High Frequency Cetaceans (Fleeing 1.5m/s)

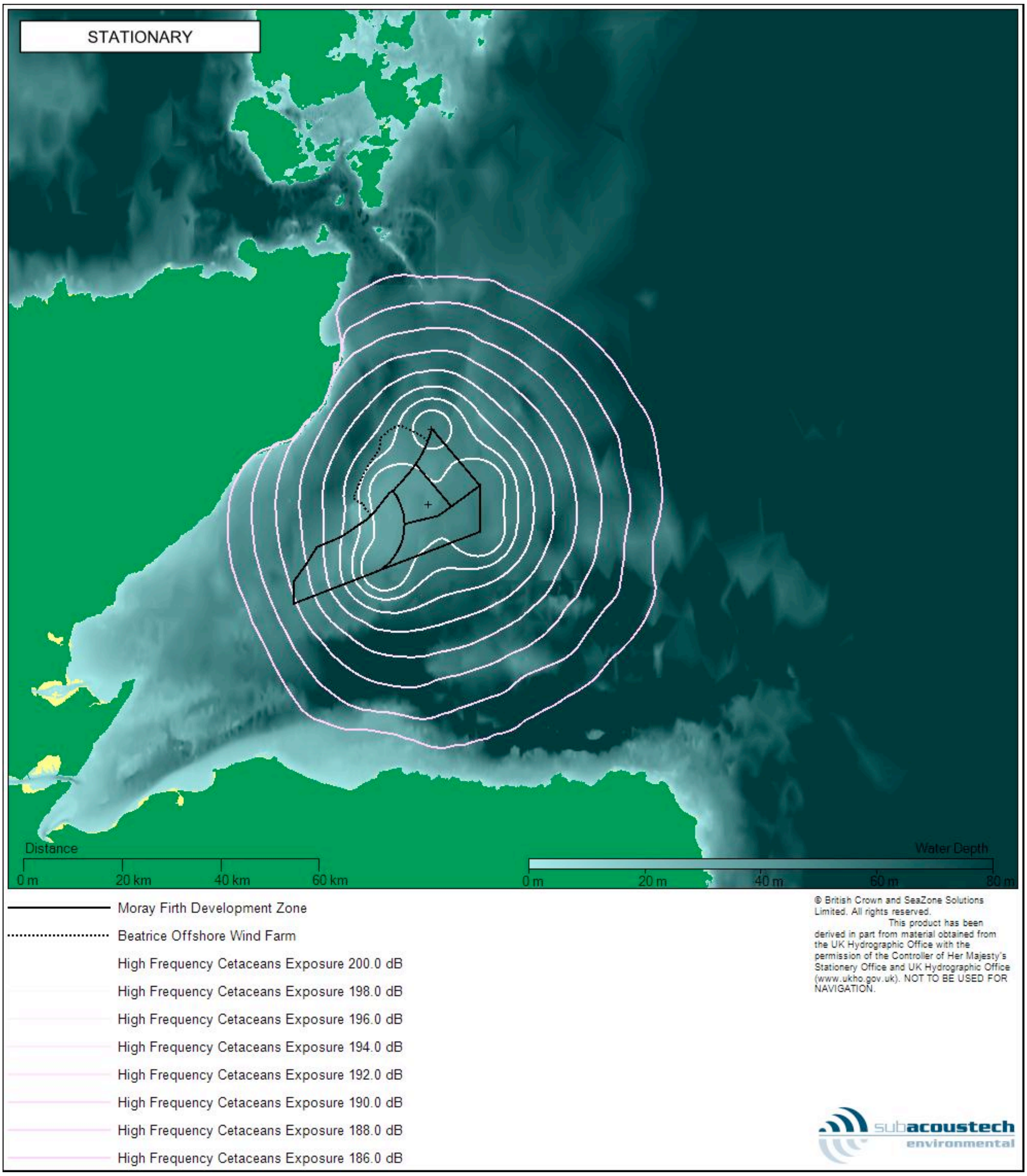


Figure A-177. Contours for stationary High Frequency Cetaceans; two 2.5 m diameter piles being driven sequentially at locations 1, 2, 3, 4, 5 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6
Pile driving energy (kJ)	1200
Species	High Frequency Cetaceans (Stationary)

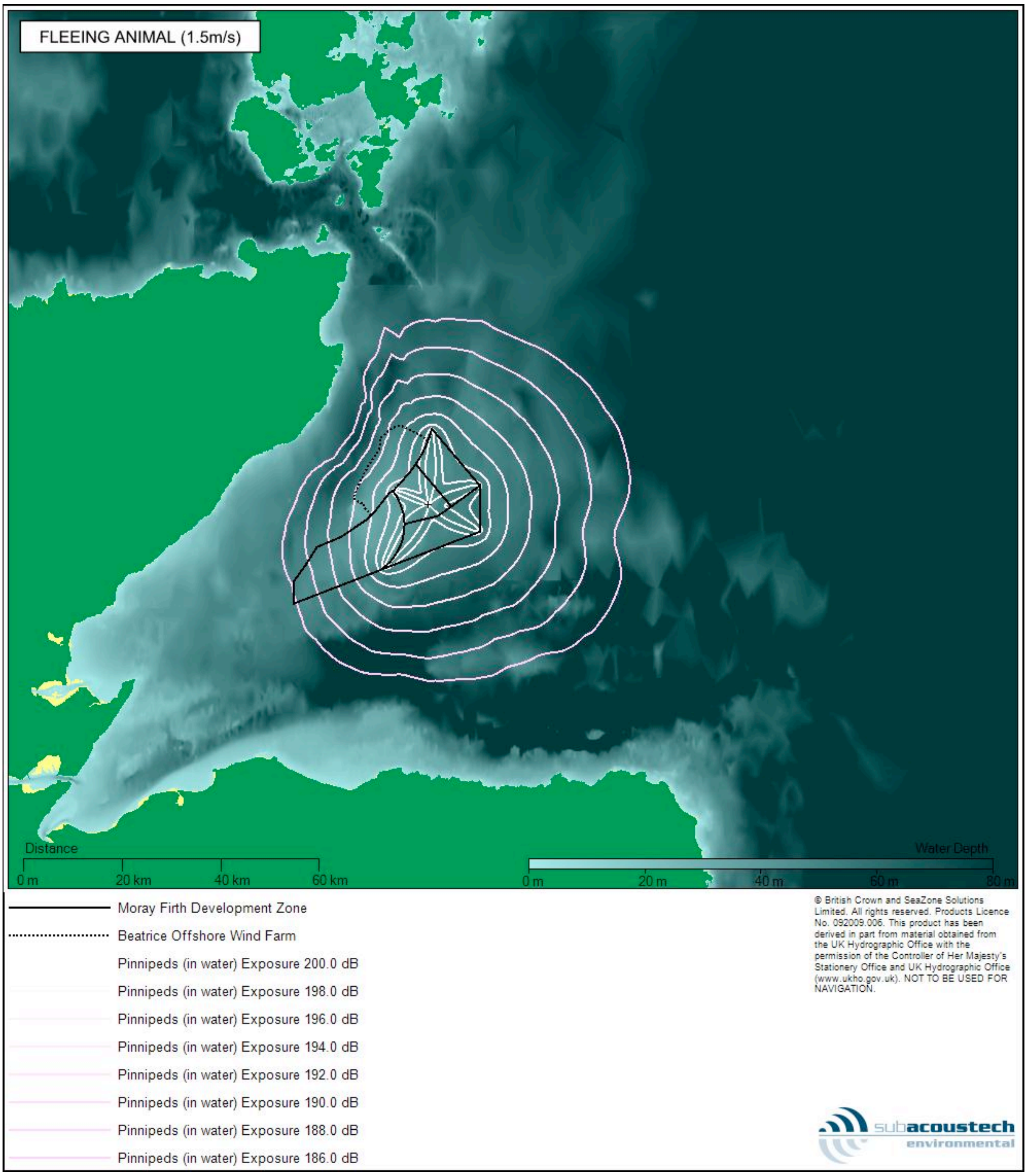


Figure A-178. Starting loci for fleeing Pinnipeds (in water); two 2.5 m diameter piles being driven sequentially at locations 1, 2, 3, 4, 5 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6
Pile driving energy (kJ)	1200
Species	Pinnipeds (in water) (Fleeing 1.5m/s)

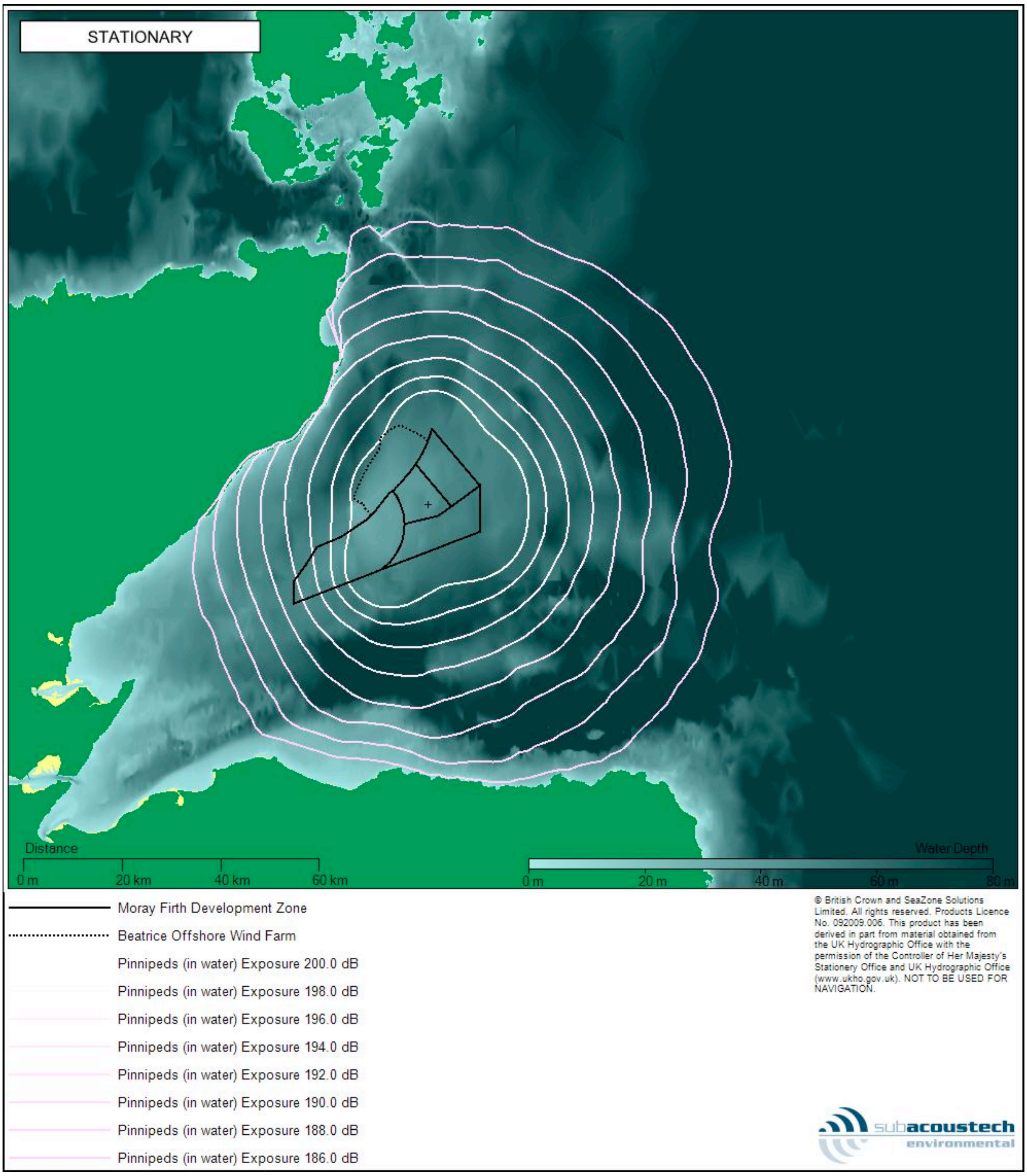


Figure A-179. Contours for stationary Pinnipeds (in water); two 2.5 m diameter piles being driven sequentially at locations 1, 2, 3, 4, 5 and 6 simultaneously.

Pile diameter (m)	2.5
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6
Pile driving energy (kJ)	1200
Species	Pinnipeds (in water) (Stationary)

9.2.6 Piles being driven simultaneously at MORL and BOWL

9.2.6.1 Details of cases

For the four fish and four marine mammal species considered, calculations were made for a single pile being driven at each of locations on MORL and a single pile being driven at each of locations on BOWL, all being driven simultaneously. For the low-, mid- and high-frequency cetacean and pinniped in water cases considered, calculations were made for two piles being driven sequentially at each of locations on MORL and two piles being driven sequentially at each of locations on BOWL, with the piling at these to take place simultaneously

A summary of the cases is given in Table A-16.

Table A-16. Detailed description of piling modelling undertaken

Pile diameter (m)	Number of piles / location	Hammer capacity (kJ)	Species	Results shown	Figure
2.5 (MORL) 2.4 (BOWL)	Locations 1 (MORL) and A (BOWL)	1200 (MORL) 2300 (BOWL)	Cod	90 dB_{ht} and 75 dB_{ht} contours	A-180
2.5 (MORL) 2.4 (BOWL)	Locations 1 (MORL) and A (BOWL)	1200 (MORL) 2300 (BOWL)	Herring	90 dB_{ht} and 75 dB_{ht} contours	A-181
2.5 (MORL) 2.4 (BOWL)	Locations 1 (MORL) and A (BOWL)	1200 (MORL) 2300 (BOWL)	Plaice	90 dB_{ht} and 75 dB_{ht} contours	A-182
2.5 (MORL) 2.4 (BOWL)	Locations 1 (MORL) and A (BOWL)	1200 (MORL) 2300 (BOWL)	Salmon	90 dB_{ht} and 75 dB_{ht} contours	A-183
2.5 (MORL) 2.4 (BOWL)	Locations 1 (MORL) and A (BOWL)	1200 (MORL) 2300 (BOWL)	Bottlenose dolphin	90 dB_{ht} and 75 dB_{ht} contours	A-184
2.5 (MORL) 2.4 (BOWL)	Locations 1 (MORL) and A (BOWL)	1200 (MORL) 2300 (BOWL)	Harbour porpoise	90 dB_{ht} and 75 dB_{ht} contours	A-185
2.5 (MORL) 2.4 (BOWL)	Locations 1 (MORL) and A (BOWL)	1200 (MORL) 2300 (BOWL)	Harbour seal	90 dB_{ht} and 75 dB_{ht} contours	A-186
2.5 (MORL) 2.4 (BOWL)	Locations 1 (MORL) and A (BOWL)	1200 (MORL) 2300 (BOWL)	Minke whale	90 dB_{ht} and 75 dB_{ht} contours	A-187
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1 (MORL) and A (BOWL)	1200 (MORL) 2300 (BOWL)	Low frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-188
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1 (MORL) and A (BOWL)	1200 (MORL) 2300 (BOWL)	Low frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for a stationary animal	A-189

Pile diameter (m)	Number of piles / location	Hammer capacity (kJ)	Species	Results shown	Figure
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1 (MORL) and A (BOWL)	1200 (MORL) 2300 (BOWL)	Mid frequency cetacean	Contours between 200 and 186 dB re 1 µPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-190
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1 (MORL) and A (BOWL)	1200 (MORL) 2300 (BOWL)	Mid frequency cetacean	Contours between 200 and 186 dB re 1 µPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-191
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1 (MORL) and A (BOWL)	1200 (MORL) 2300 (BOWL)	High frequency cetacean	Contours between 200 and 186 dB re 1 µPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-192
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1 (MORL) and A (BOWL)	1200 (MORL) 2300 (BOWL)	High frequency cetacean	Contours between 200 and 186 dB re 1 µPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-193
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1 (MORL) and A (BOWL)	1200 (MORL) 2300 (BOWL)	Pinniped (in water)	Contours between 200 and 186 dB re 1 µPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-194
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1 (MORL) and A (BOWL)	1200 (MORL) 2300 (BOWL)	Pinniped (in water)	Contours between 200 and 186 dB re 1 µPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-195
2.5 (MORL) 2.4 (BOWL)	Locations 1, 5 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Cod	90 dB_{ht} and 75 dB_{ht} contours	A-196
2.5 (MORL) 2.4 (BOWL)	Locations 1, 5 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Herring	90 dB_{ht} and 75 dB_{ht} contours	A-197
2.5 (MORL) 2.4 (BOWL)	Locations 1, 5 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Plaice	90 dB_{ht} and 75 dB_{ht} contours	A-198
2.5 (MORL) 2.4 (BOWL)	Locations 1, 5 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Salmon	90 dB_{ht} and 75 dB_{ht} contours	A-199
2.5 (MORL) 2.4 (BOWL)	Locations 1, 5 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Bottlenose dolphin	90 dB_{ht} and 75 dB_{ht} contours	A-200
2.5 (MORL) 2.4 (BOWL)	Locations 1, 5 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Harbour porpoise	90 dB_{ht} and 75 dB_{ht} contours	A-201
2.5 (MORL) 2.4 (BOWL)	Locations 1, 5 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Harbour seal	90 dB_{ht} and 75 dB_{ht} contours	A-202

Pile diameter (m)	Number of piles / location	Hammer capacity (kJ)	Species	Results shown	Figure
2.5 (MORL) 2.4 (BOWL)	Locations 1, 5 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Minke whale	90 dB_{ht} and 75 dB_{ht} contours	A-203
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1, 5 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Low frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-204
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1, 5 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Low frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for a stationary animal	A-205
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1, 5 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Mid frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-206
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1, 5 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Mid frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for a stationary animal	A-207
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1, 5 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	High frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-208
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1, 5 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	High frequency cetacean	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for a stationary animal	A-209
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1, 5 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Pinniped (in water)	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-210
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1, 5 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Pinniped (in water)	Contours between 200 and 186 dB re 1 $\mu Pa^2.s$ (M_{lf}) in 2 dB increments for a stationary animal	A-211
2.5 (MORL) 2.4 (BOWL)	Locations 1, 2, 3, 4, 5, 6 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Cod	90 dB_{ht} and 75 dB_{ht} contours	A-212
2.5 (MORL) 2.4 (BOWL)	Locations 1, 2, 3, 4, 5, 6 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Herring	90 dB_{ht} and 75 dB_{ht} contours	A-213

Pile diameter (m)	Number of piles / location	Hammer capacity (kJ)	Species	Results shown	Figure
2.5 (MORL) 2.4 (BOWL)	Locations 1, 2, 3, 4, 5, 6 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Plaice	90 dB_{ht} and 75 dB_{ht} contours	A-214
2.5 (MORL) 2.4 (BOWL)	Locations 1, 2, 3, 4, 5, 6 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Salmon	90 dB_{ht} and 75 dB_{ht} contours	A-215
2.5 (MORL) 2.4 (BOWL)	Locations 1, 2, 3, 4, 5, 6 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Bottlenose dolphin	90 dB_{ht} and 75 dB_{ht} contours	A-216
2.5 (MORL) 2.4 (BOWL)	Locations 1, 2, 3, 4, 5, 6 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Harbour porpoise	90 dB_{ht} and 75 dB_{ht} contours	A-217
2.5 (MORL) 2.4 (BOWL)	Locations 1, 2, 3, 4, 5, 6 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Harbour seal	90 dB_{ht} and 75 dB_{ht} contours	A-218
2.5 (MORL) 2.4 (BOWL)	Locations 1, 2, 3, 4, 5, 6 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Minke whale	90 dB_{ht} and 75 dB_{ht} contours	A-219
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1, 2, 3, 4, 5, 6 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Low frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-220
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1, 2, 3, 4, 5, 6 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Low frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-221
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1, 2, 3, 4, 5, 6 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Mid frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-222
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1, 2, 3, 4, 5, 6 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Mid frequency cetacean	Contours between 200 and 186 dB re 1 μPa^2.s (M_{lf}) in 2 dB increments for a stationary animal	A-223

Pile diameter (m)	Number of piles / location	Hammer capacity (kJ)	Species	Results shown	Figure
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1, 2, 3, 4, 5, 6 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	High frequency cetacean	Contours between 200 and 186 dB re 1 µPa^2.s (M_{hf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-224
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1, 2, 3, 4, 5, 6 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	High frequency cetacean	Contours between 200 and 186 dB re 1 µPa^2.s (M_{hf}) in 2 dB increments for a stationary animal	A-225
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1, 2, 3, 4, 5, 6 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Pinniped (in water)	Contours between 200 and 186 dB re 1 µPa^2.s (M_{hf}) in 2 dB increments for starting point locus for an animal fleeing at 1.5m/s	A-226
2.5 (MORL) 2.4 (BOWL)	2 piles sequentially at locations 1, 2, 3, 4, 5, 6 (MORL), A and B (BOWL)	1200 (MORL) 2300 (BOWL)	Pinniped (in water)	Contours between 200 and 186 dB re 1 µPa^2.s (M_{hf}) in 2 dB increments for a stationary animal	A-227

9.2.6.2 Results for piling at 1 location on MORL and 1 location on BOWL, driven simultaneously

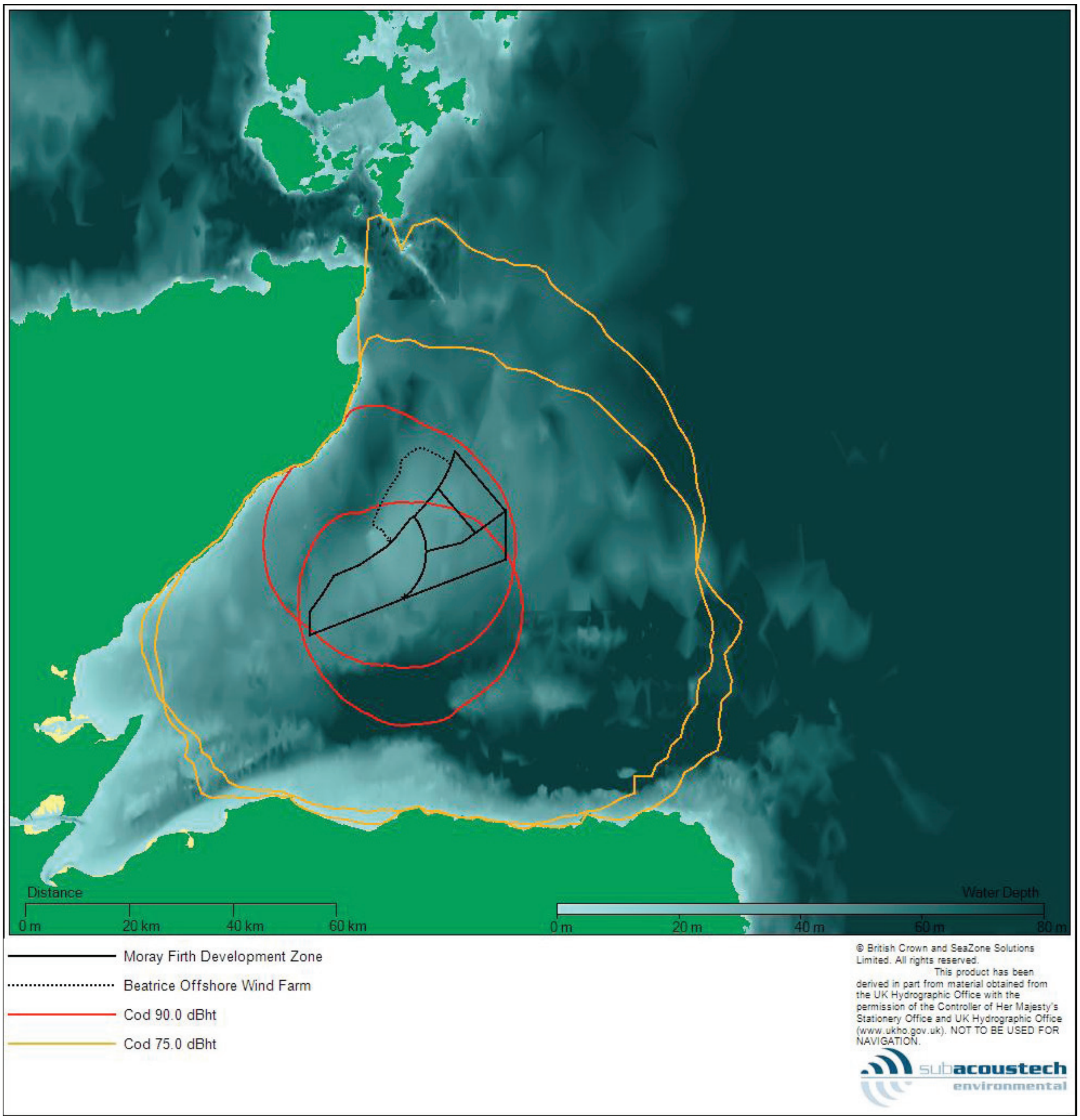


Figure A-180. 90 dB_{ht} and 75 dB_{ht} contours for cod; 2.5 m diameter piles being driven at location 1 on the MORL site and 2.4 m diameter piles being driven at location A on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and A
Pile driving energy (kJ)	1200 and 2300
Species	Cod

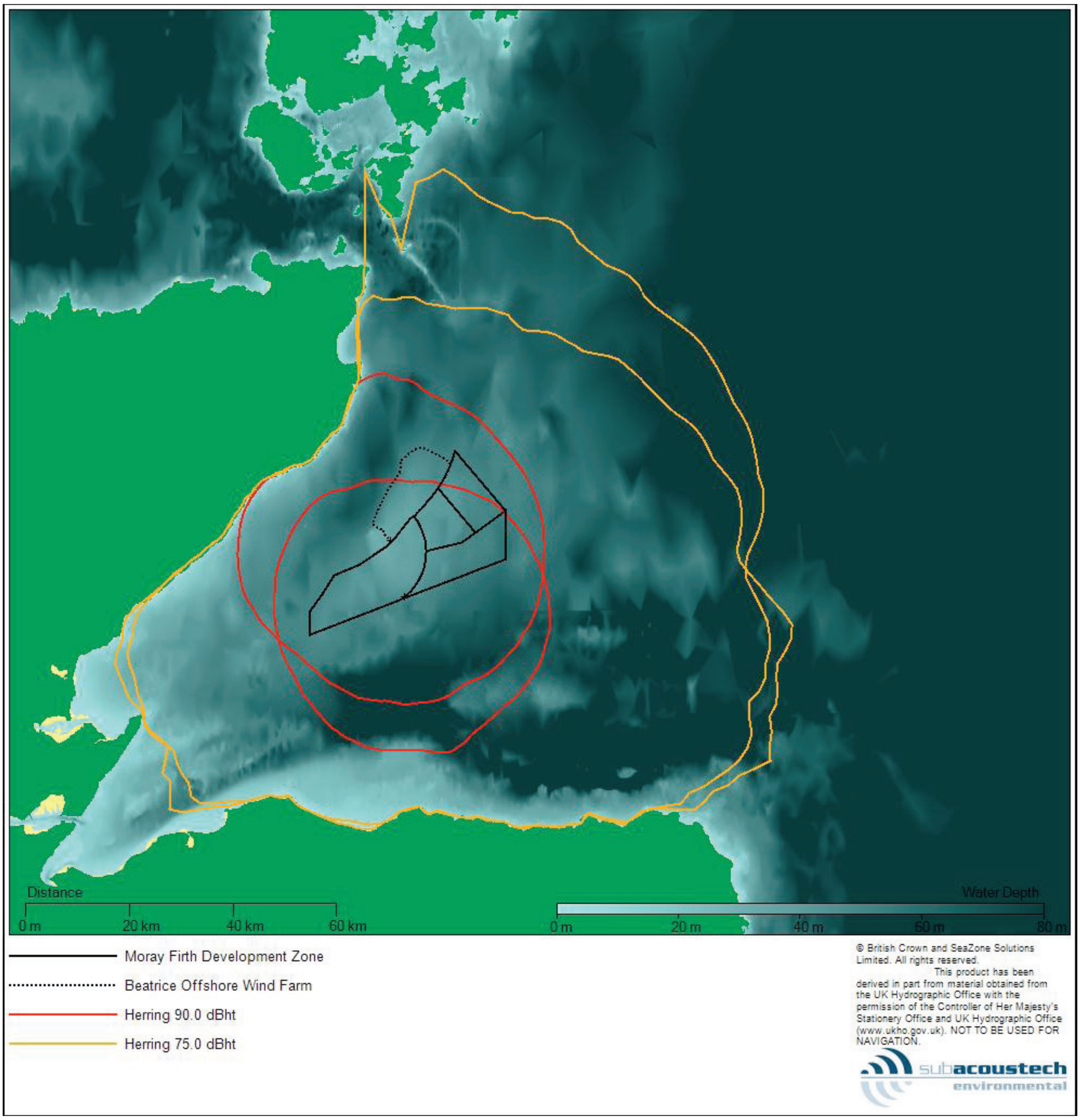


Figure A-181. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for herring; 2.5 m diameter piles being driven at location 1 on the MORL site and 2.4 m diameter piles being driven at location A on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and A
Pile driving energy (kJ)	1200 and 2300
Species	Herring

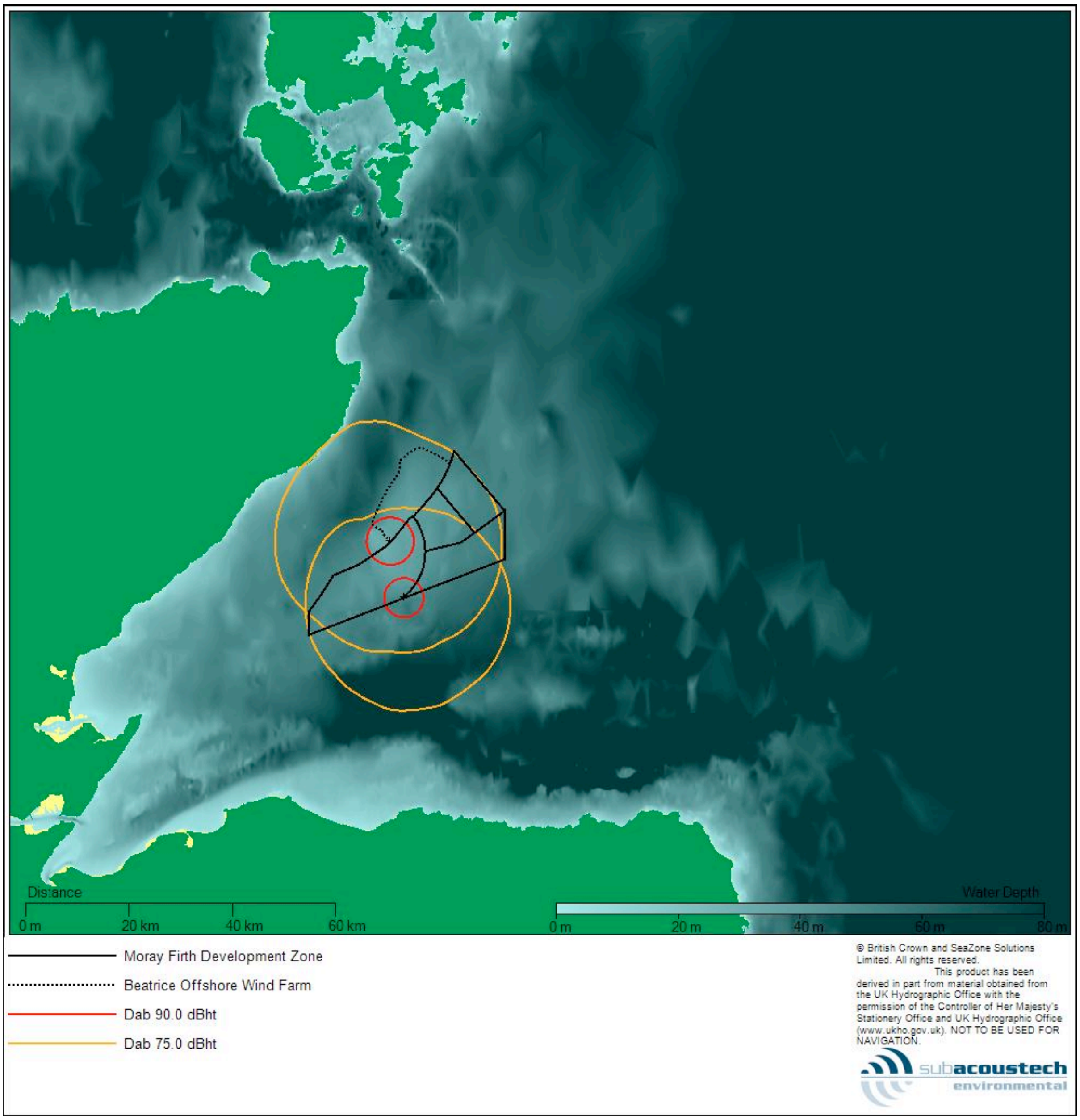


Figure A-182. 90 dB_{ht} and 75 dB_{ht} contours for plaice (dab used as surrogate); 2.5 m diameter piles being driven at location 1 on the MORL site and 2.4 m diameter piles being driven at location A on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and A
Pile driving energy (kJ)	1200 and 2300
Species	Plaice

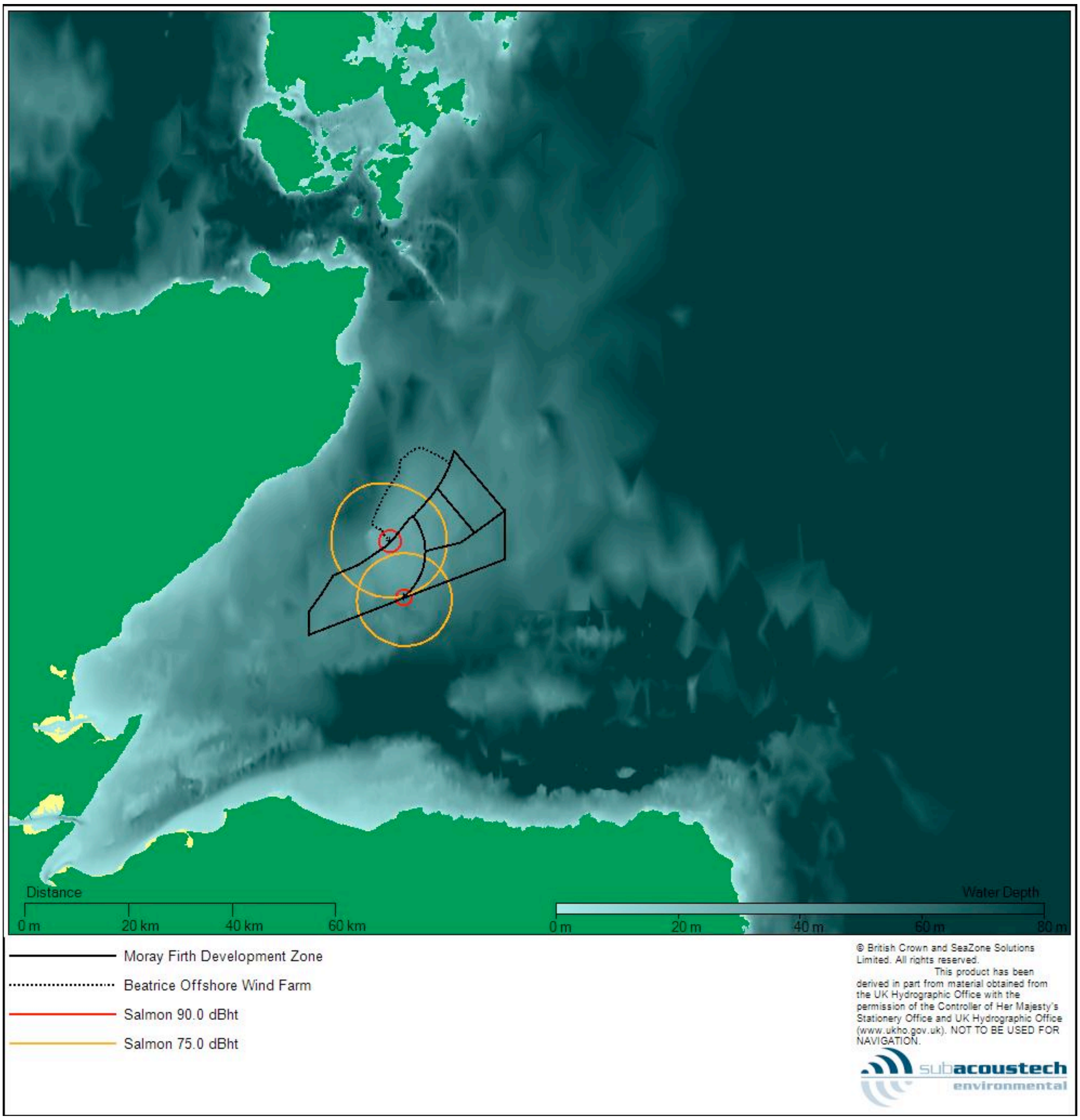


Figure A-183. 90 dB_{ht} and 75 dB_{ht} contours for salmon; 2.5 m diameter piles being driven at location 1 on the MORL site and 2.4 m diameter piles being driven at location A on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and A
Pile driving energy (kJ)	1200 and 2300
Species	Salmon

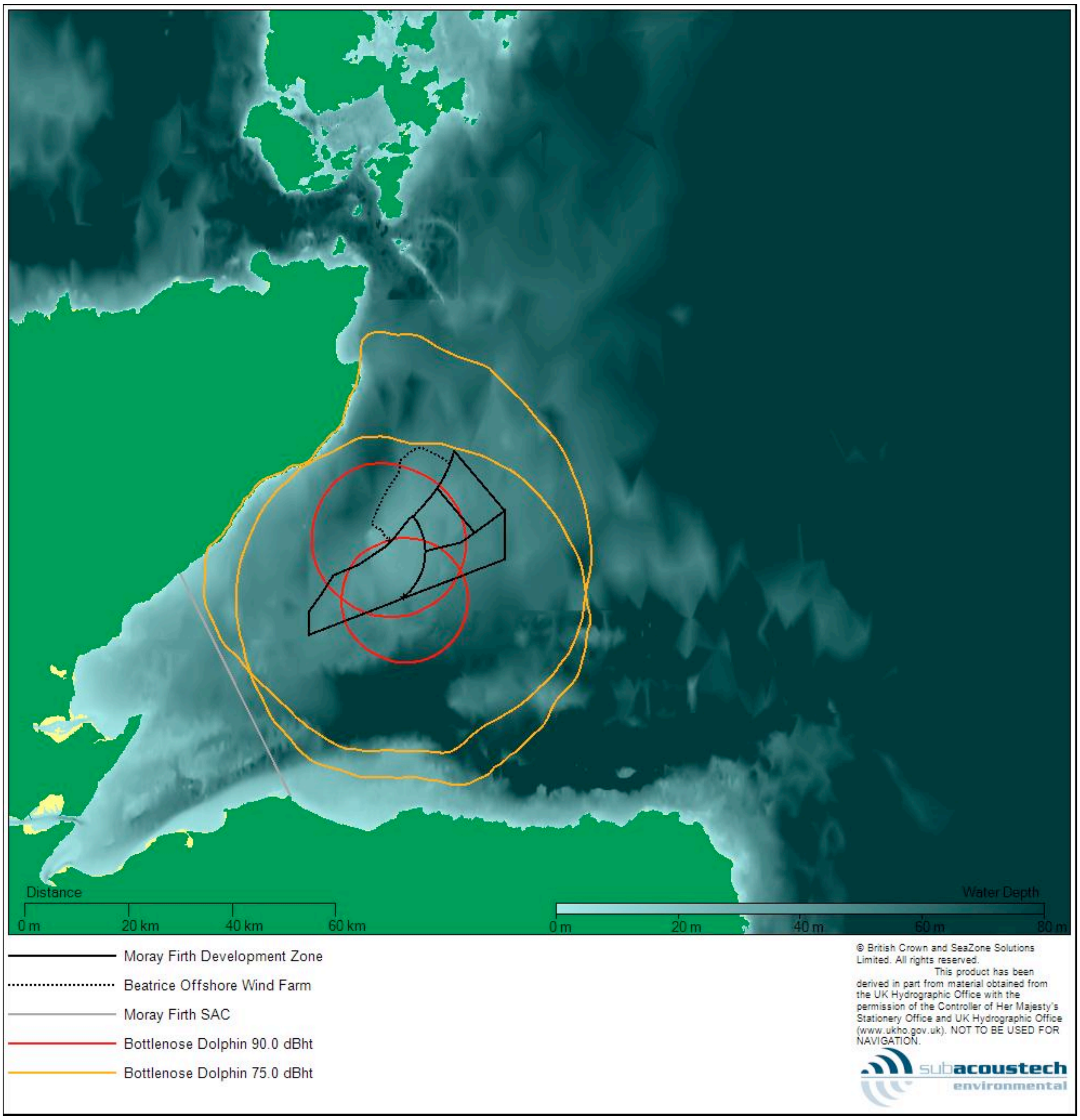


Figure A-184. 90 dB_{ht} and 75 dB_{ht} contours for bottlenose dolphin; 2.5 m diameter piles being driven at location 1 on the MORL site and 2.4 m diameter piles being driven at location A on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and A
Pile driving energy (kJ)	1200 and 2300
Species	Bottlenose Dolphin

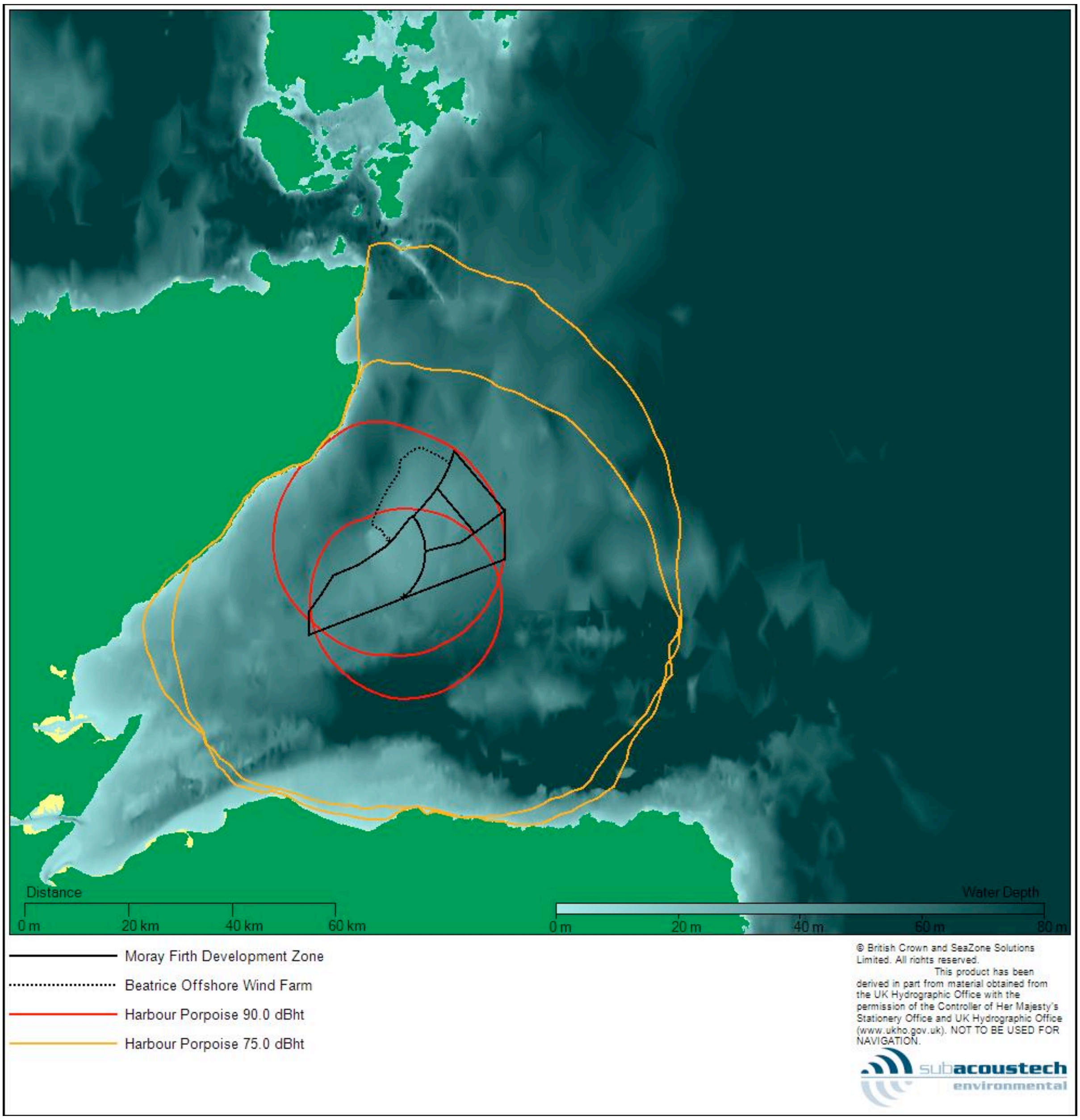


Figure A-185. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for harbour porpoise; 2.5 m diameter piles being driven at location 1 on the MORL site and 2.4 m diameter piles being driven at location A on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and A
Pile driving energy (kJ)	1200 and 2300
Species	Harbour Porpoise

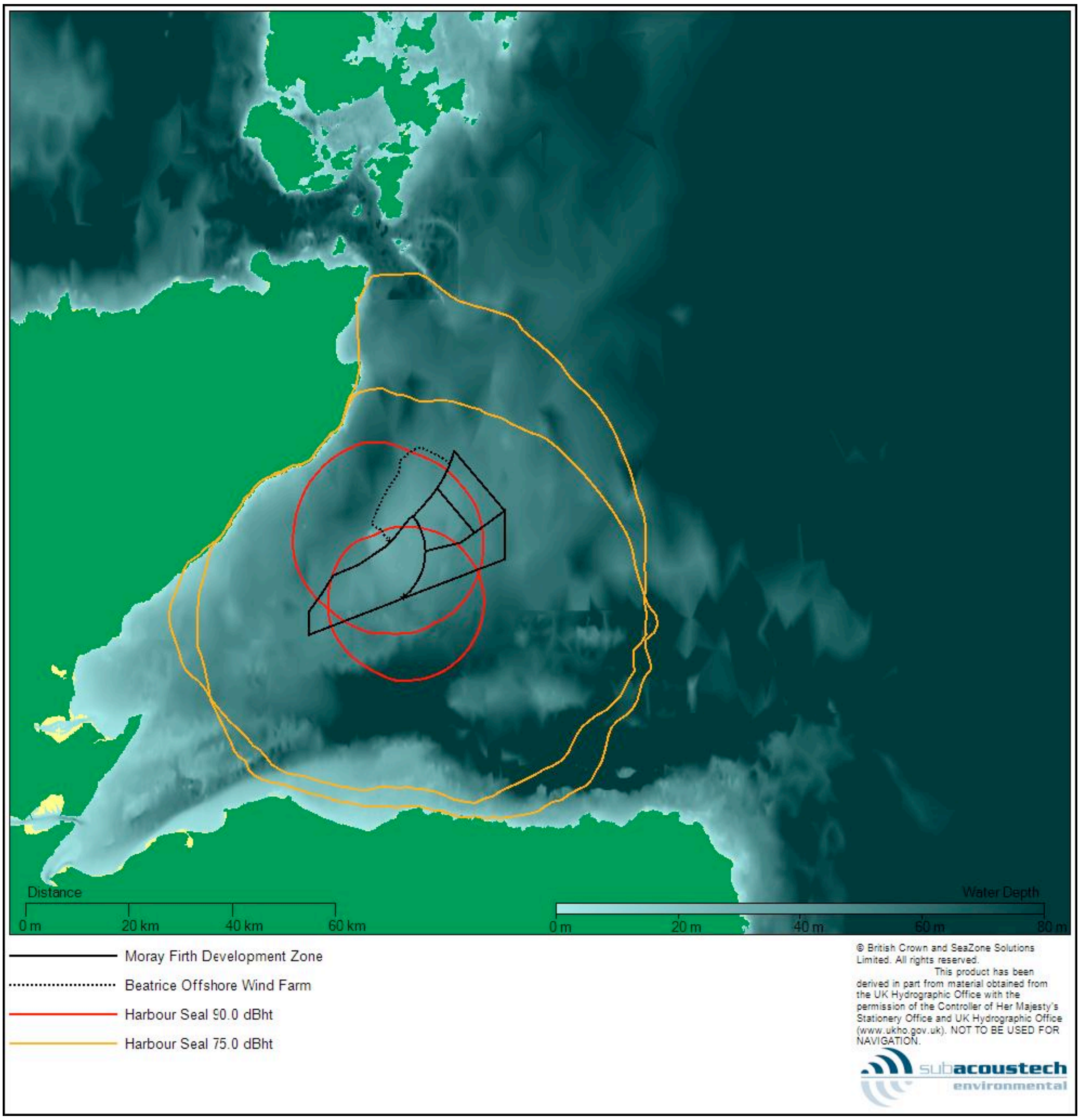


Figure A-186. 90 dB_{ht} and 75 dB_{ht} contours for harbour seal; 2.5 m diameter piles being driven at location 1 on the MORL site and 2.4 m diameter piles being driven at location A on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and A
Pile driving energy (kJ)	1200 and 2300
Species	Harbour Seal

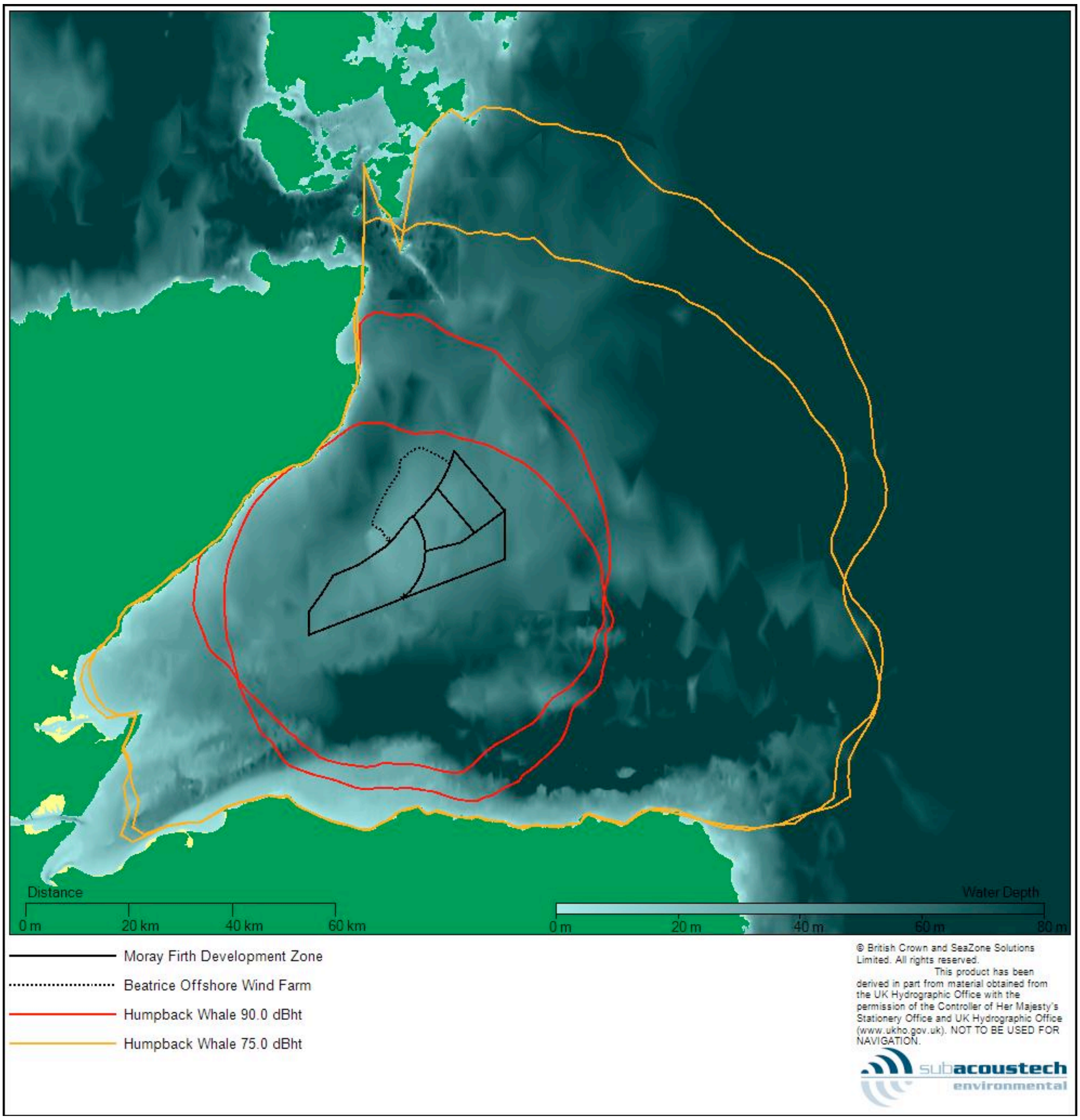


Figure A-187. 90 dB_{ht} and 75 dB_{ht} contours for minke whale (humpback whale used as surrogate); 2.5 m diameter piles being driven at location 1 on the MORL site and 2.4 m diameter piles being driven at location A on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and A
Pile driving energy (kJ)	1200 and 2300
Species	Minke Whale

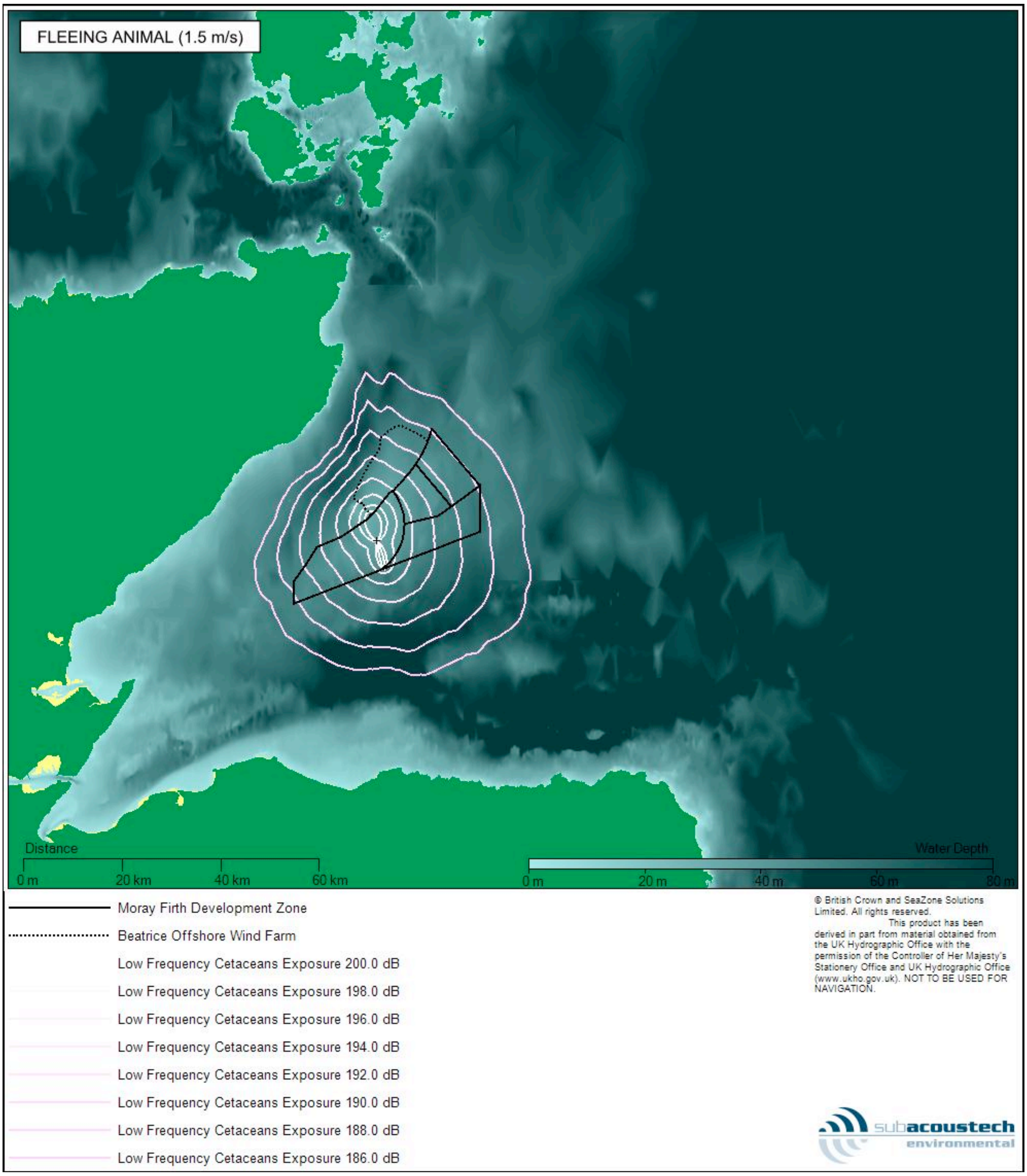


Figure A-188. Starting loci for fleeing Low Frequency Cetaceans; two 2.5 m diameter piles being driven at location 1 on the MORL site and two 2.4 m diameter piles being driven at location A on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and A
Pile driving energy (kJ)	1200 and 2300
Species	Low Frequency Cetaceans (Fleeing 1.5m/s)

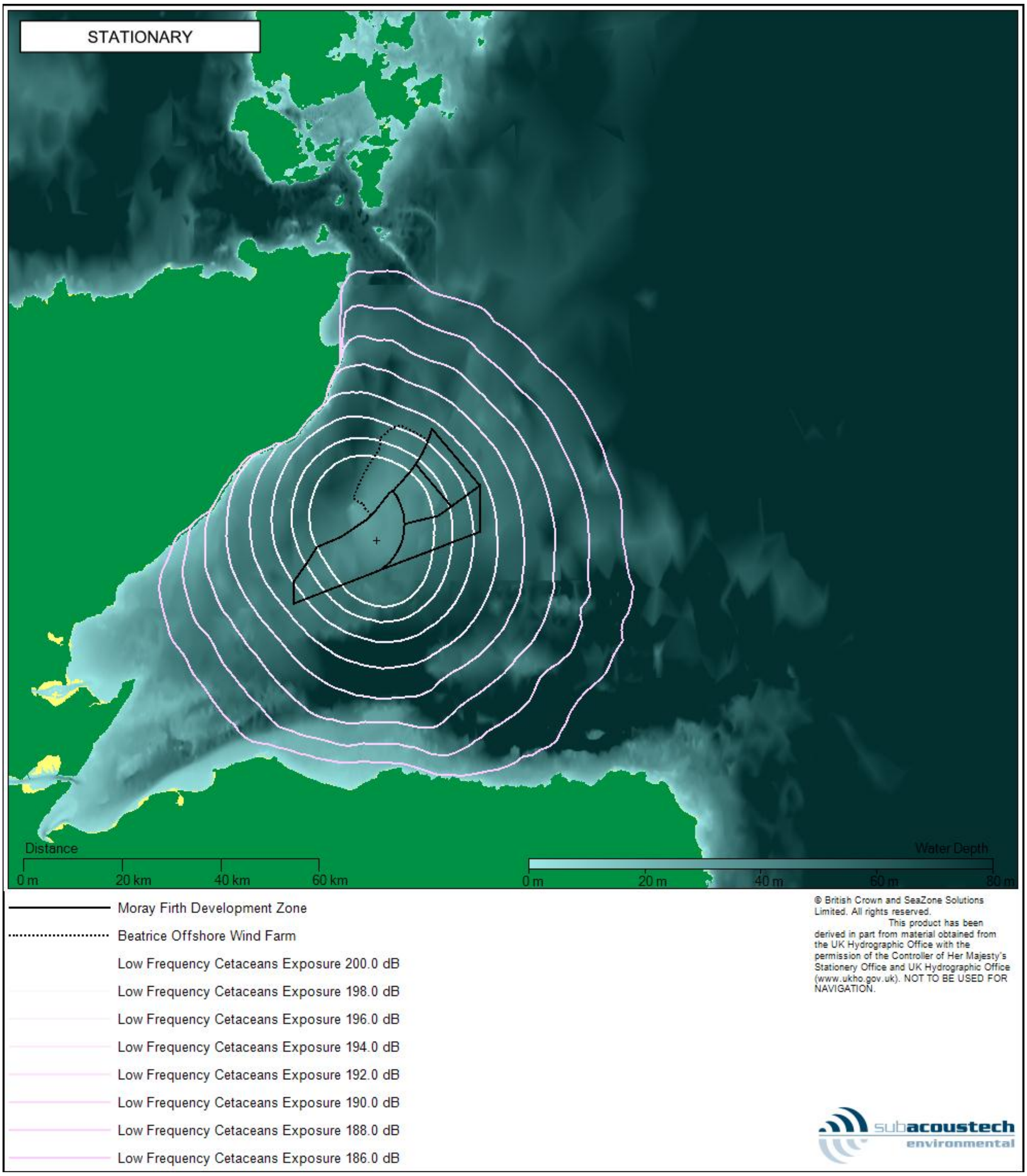


Figure A-189. Contours for stationary Low Frequency Cetaceans; two 2.5 m diameter piles being driven at location 1 on the MORL site and two 2.4 m diameter piles being driven at location A on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and A
Pile driving energy (kJ)	1200 and 2300
Species	Low Frequency Cetaceans (Stationary)

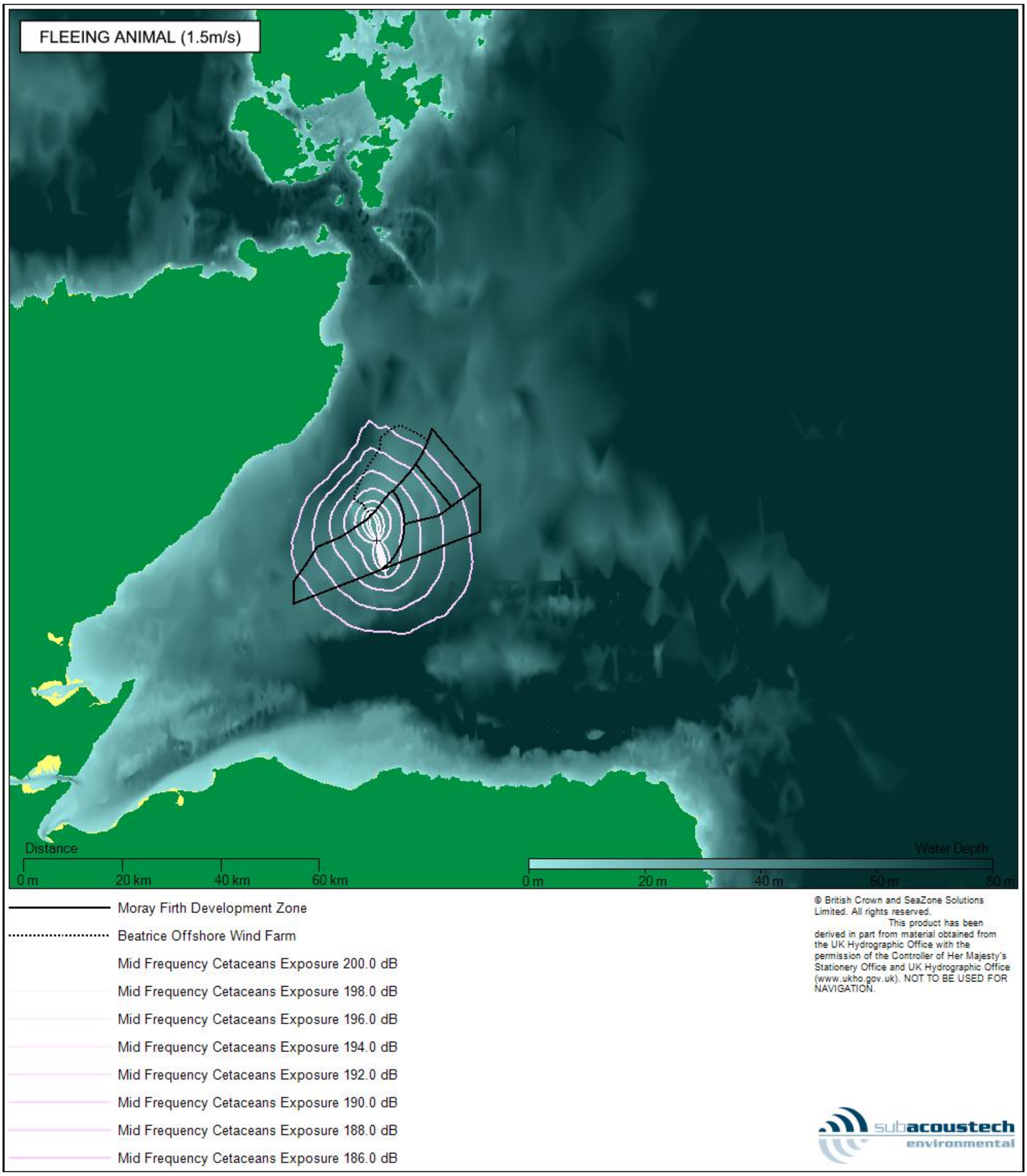


Figure A-190. Starting loci for fleeing Mid Frequency Cetaceans; two 2.5 m diameter piles being driven at location 1 on the MORL site and two 2.4 m diameter piles being driven at location A on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and A
Pile driving energy (kJ)	1200 and 2300
Species	Mid Frequency Cetaceans (Fleeing 1.5m/s)

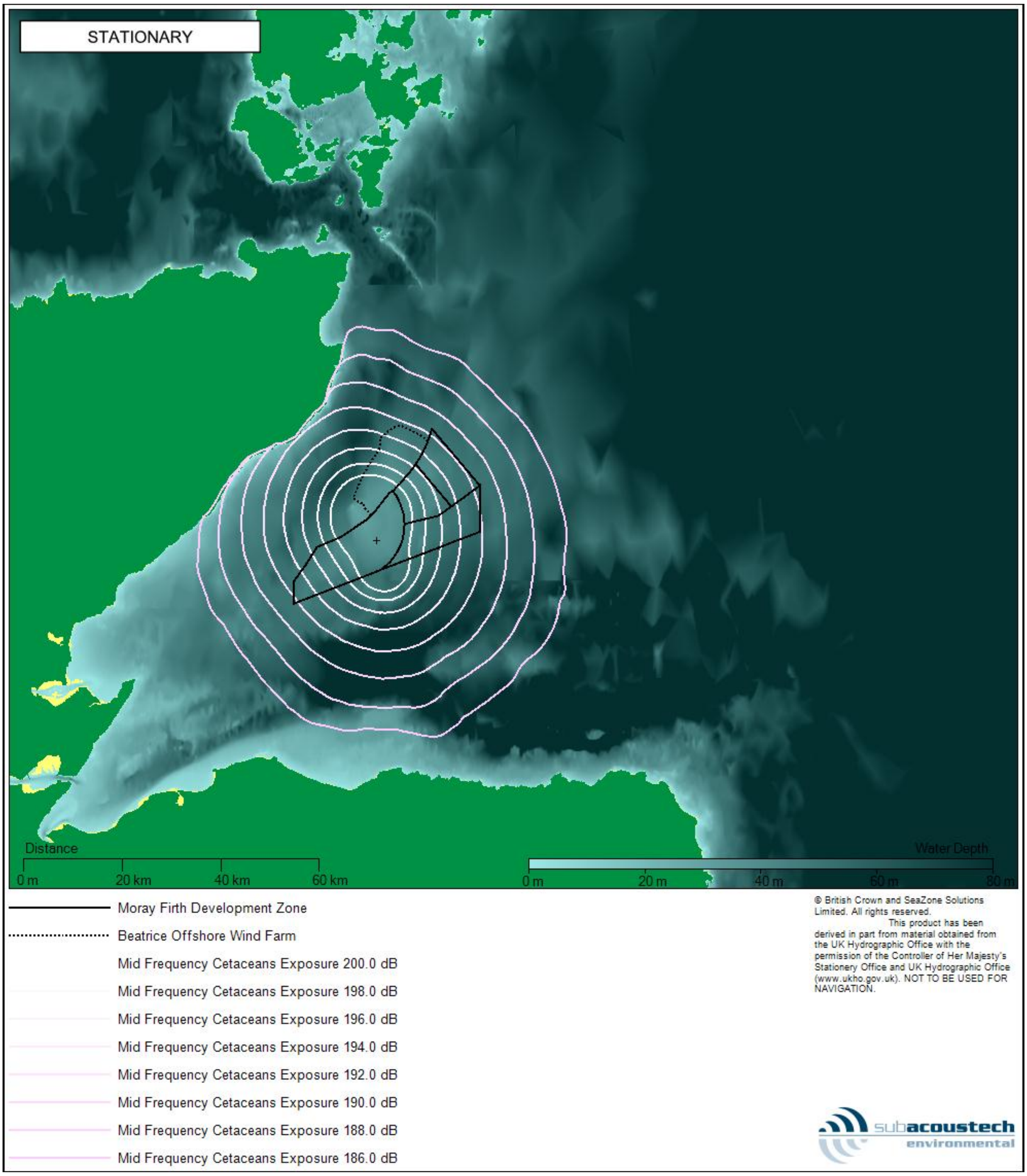


Figure A-191. Contours for stationary Mid Frequency Cetaceans; two 2.5 m diameter piles being driven at location 1 on the MORL site and two 2.4 m diameter piles being driven at location A on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and A
Pile driving energy (kJ)	1200 and 2300
Species	Mid Frequency Cetaceans (Stationary)

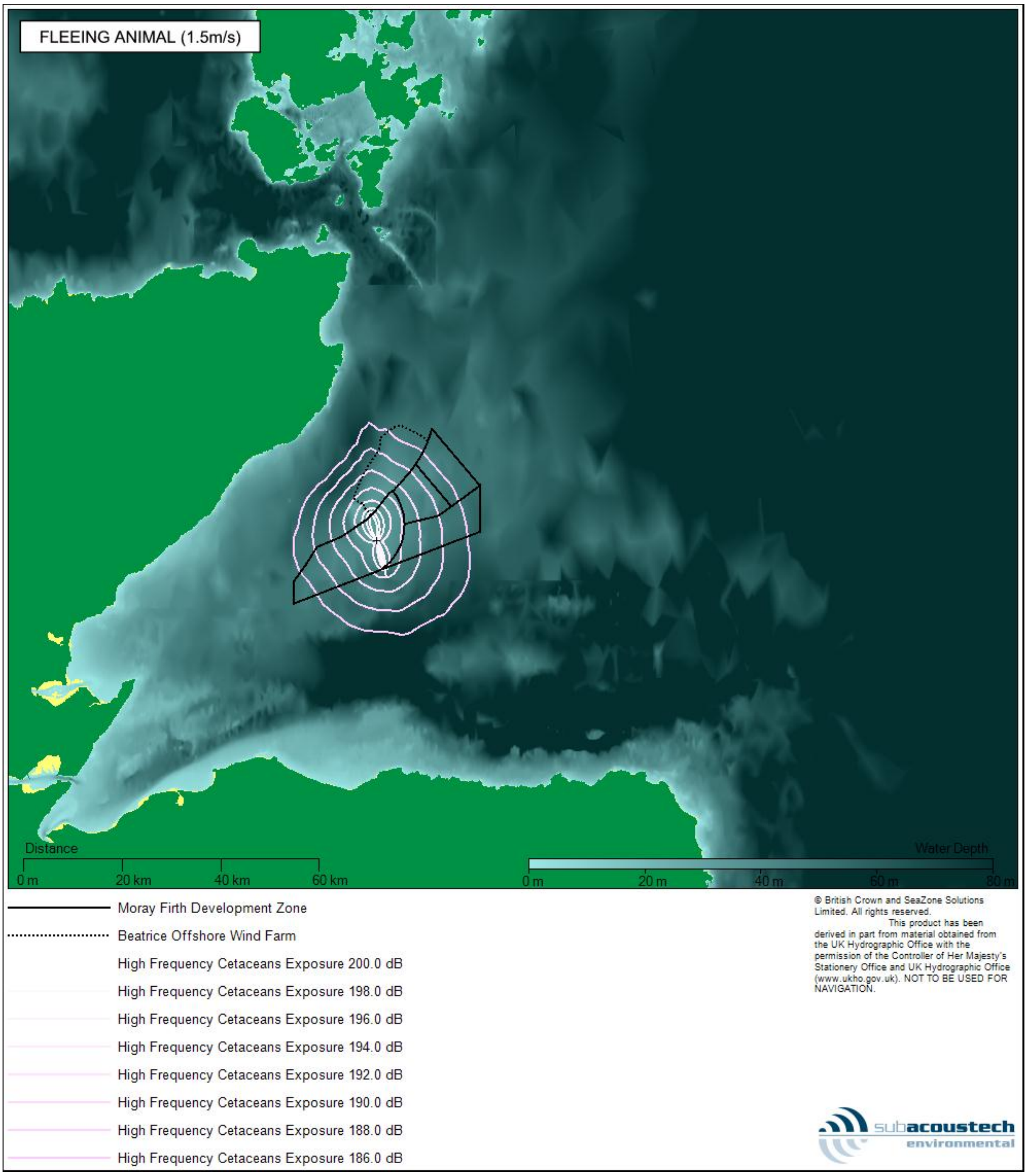


Figure A-192. Starting loci for fleeing High Frequency Cetaceans; two 2.5 m diameter piles being driven at location 1 on the MORL site and two 2.4 m diameter piles being driven at location A on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and A
Pile driving energy (kJ)	1200 and 2300
Species	High Frequency Cetaceans (Fleeing 1.5m/s)

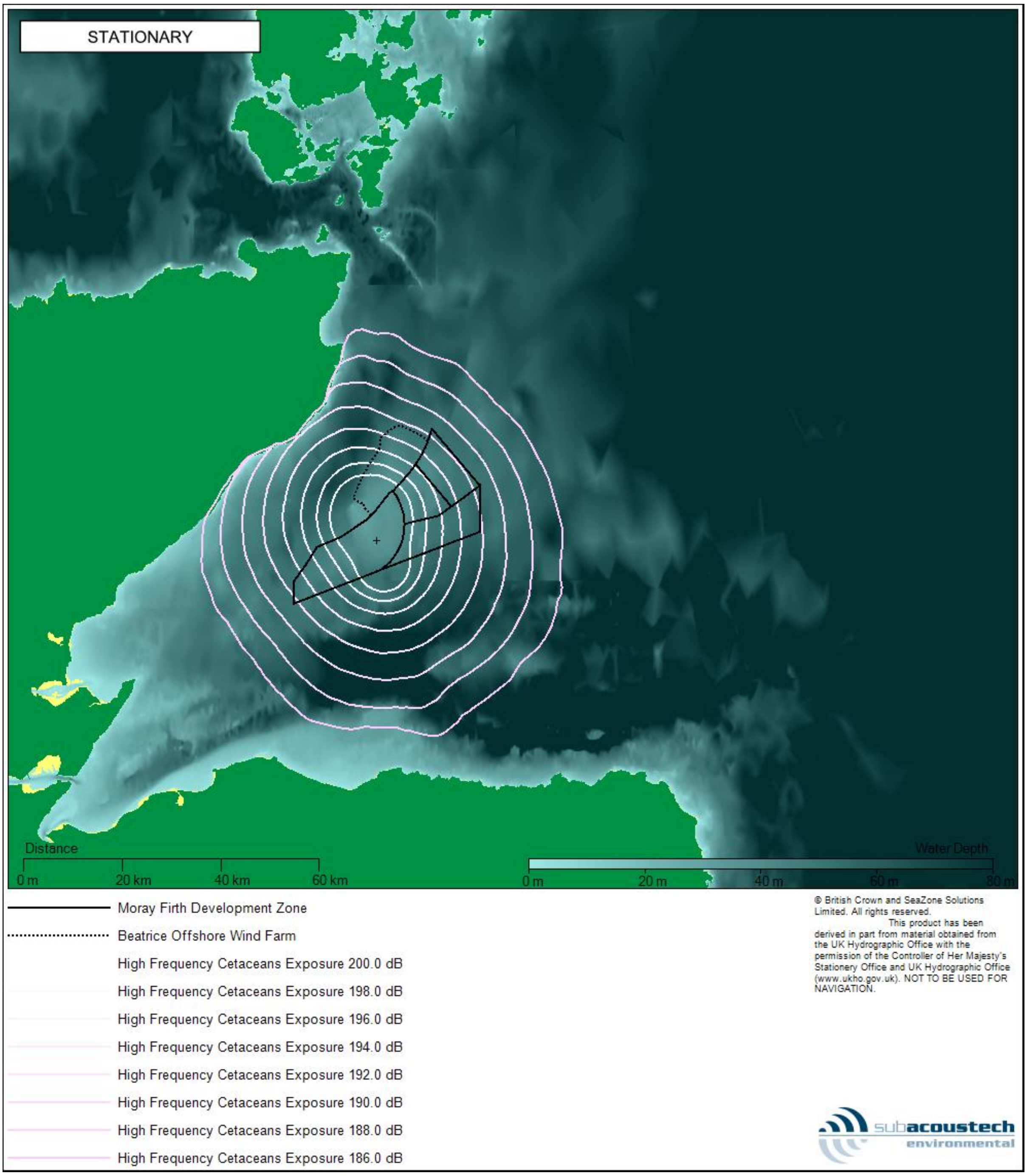


Figure A-193. Contours for stationary High Frequency Cetaceans; two 2.5 m diameter piles being driven at location 1 on the MORL site and two 2.4 m diameter piles being driven at location A on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and A
Pile driving energy (kJ)	1200 and 2300
Species	High Frequency Cetaceans (Stationary)

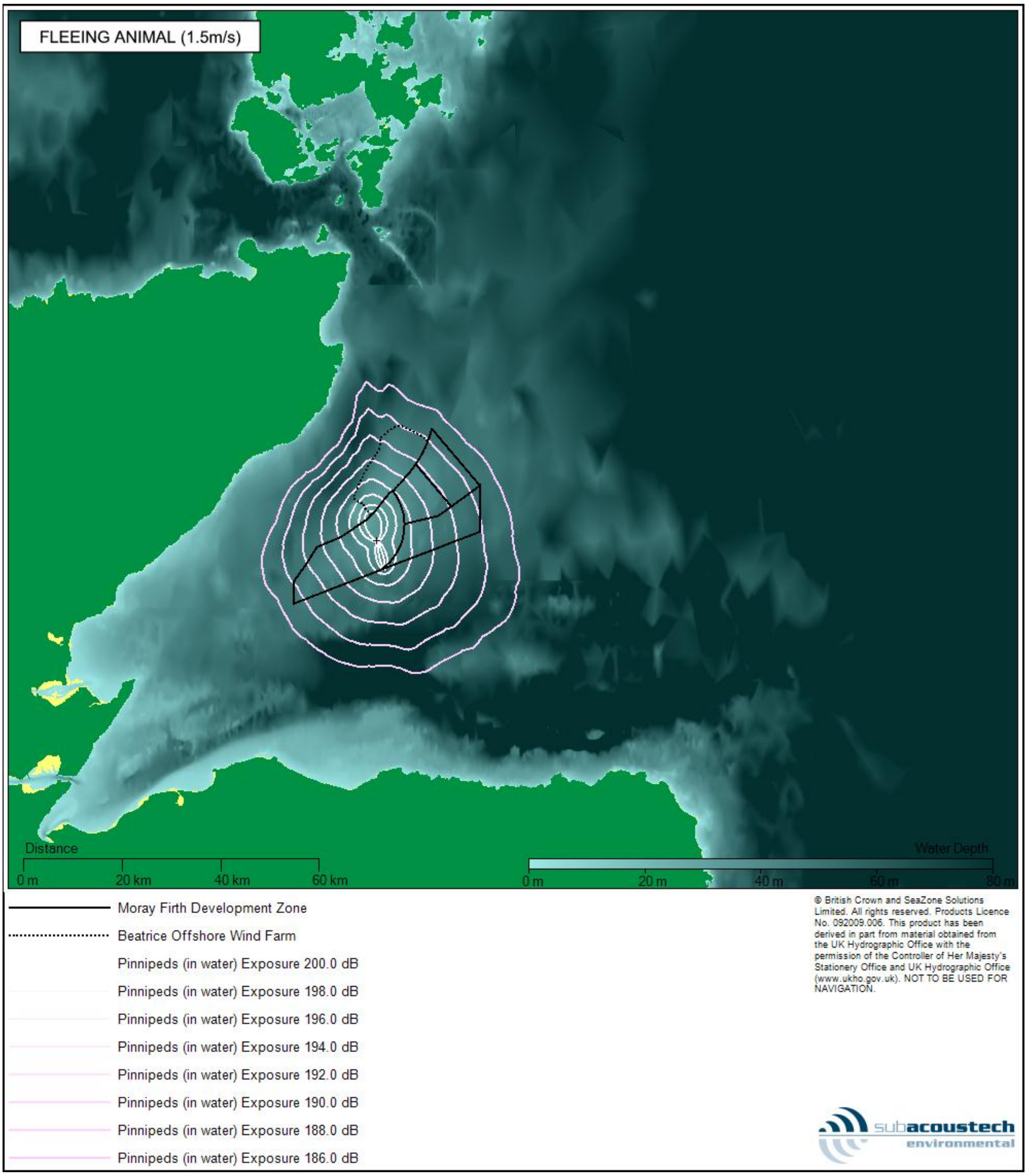


Figure A-194. Starting loci for fleeing Pinnipeds (in water); two 2.5 m diameter piles being driven at location 1 on the MORL site and two 2.4 m diameter piles being driven at location A on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and A
Pile driving energy (kJ)	1200 and 2300
Species	Pinnipeds (in water) (Fleeing 1.5m/s)

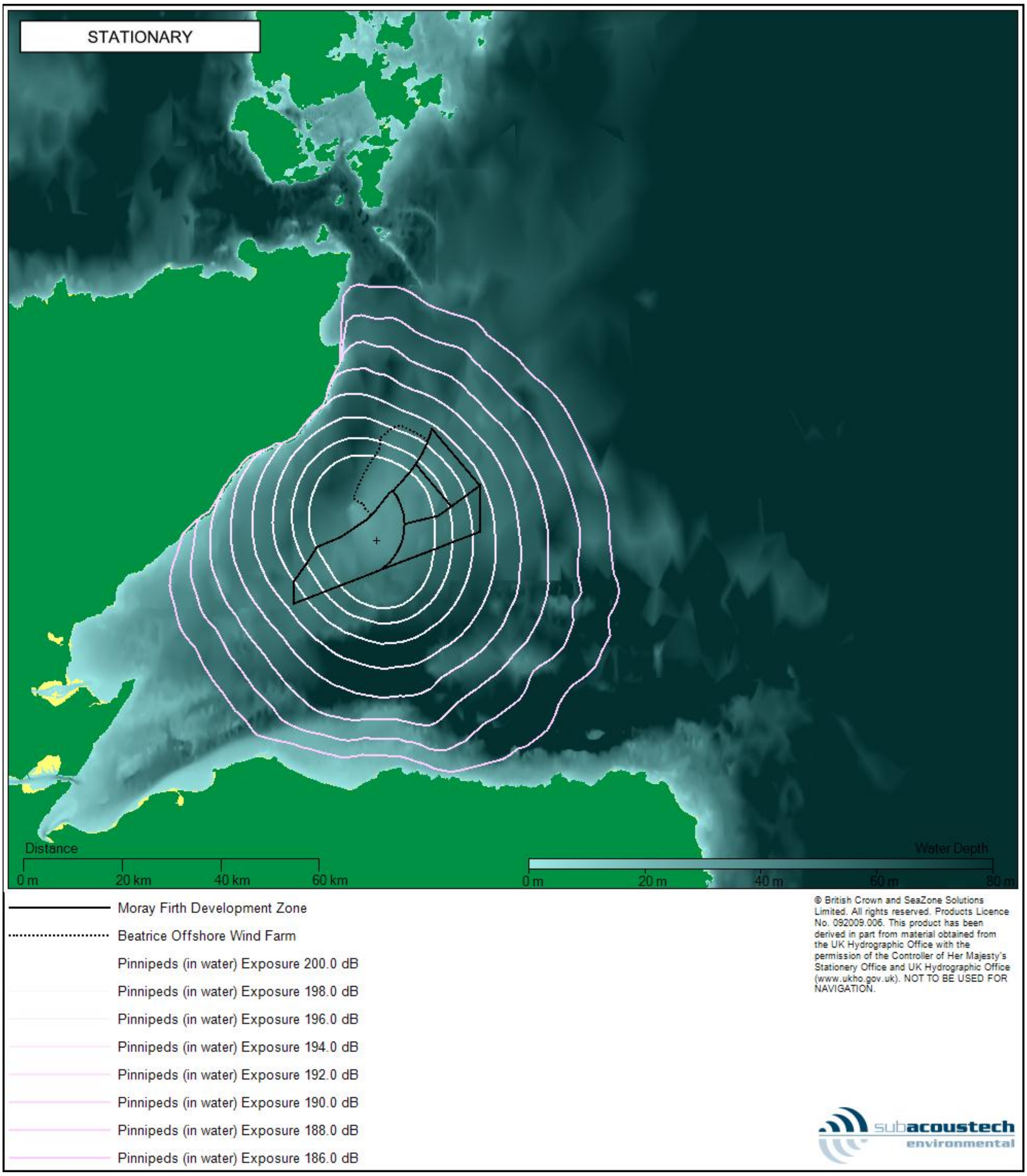


Figure A-195. Contours for stationary Pinnipeds (in water); two 2.5 m diameter piles being driven at location 1 on the MORL site and two 2.4 m diameter piles being driven at location A on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and A
Pile driving energy (kJ)	1200 and 2300
Species	Pinnipeds (in water) (Stationary)

9.2.6.3 Results for piling at 2 locations on MORL and 2 locations on BOWL, driven simultaneously

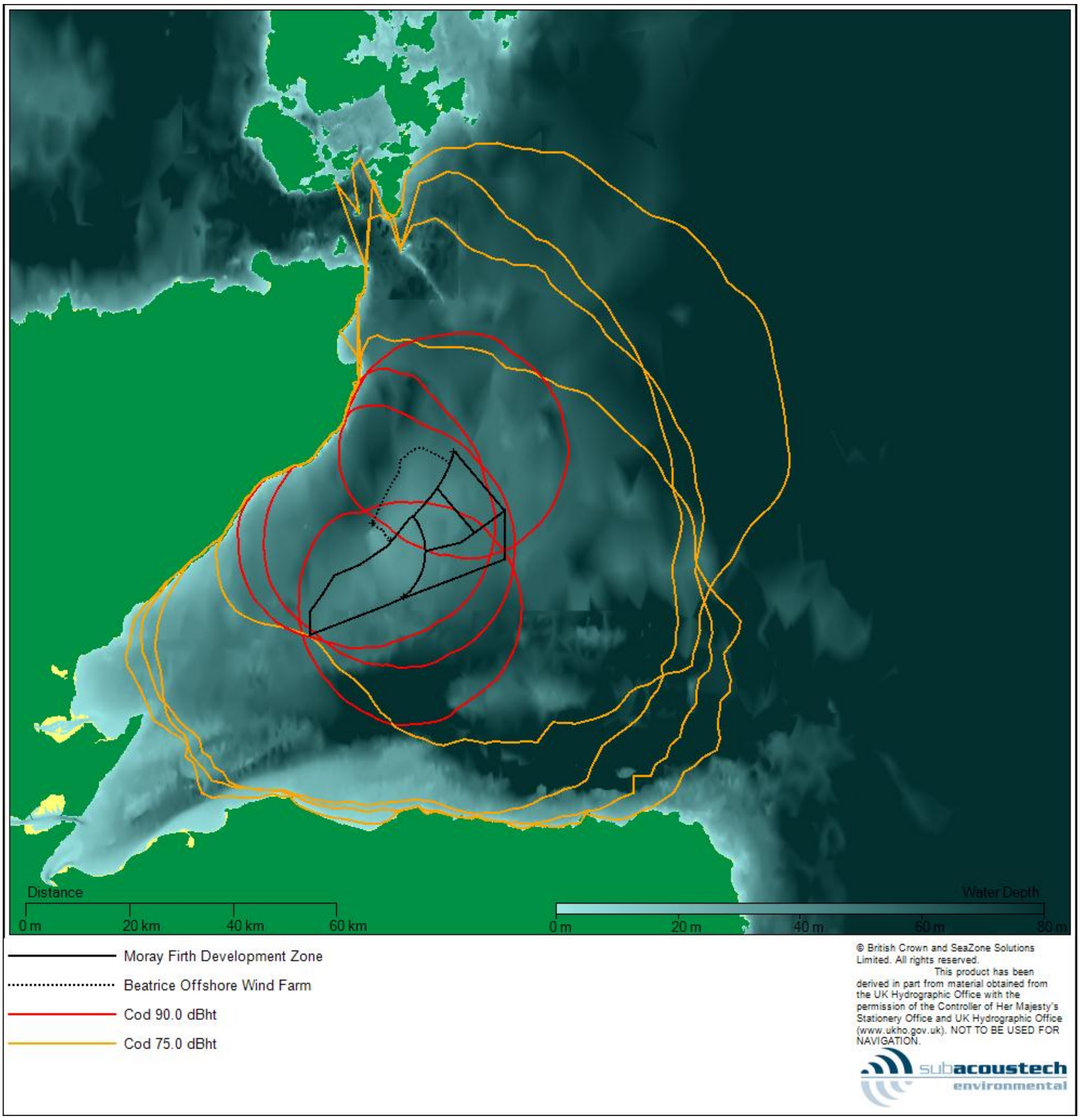


Figure A-196. 90 dB_{ht} and 75 dB_{ht} contours for cod; 2.5 m diameter piles being driven at locations 1 and 5 on the MORL site and 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and 5, A and B
Pile driving energy (kJ)	1200 and 2300
Species	Cod

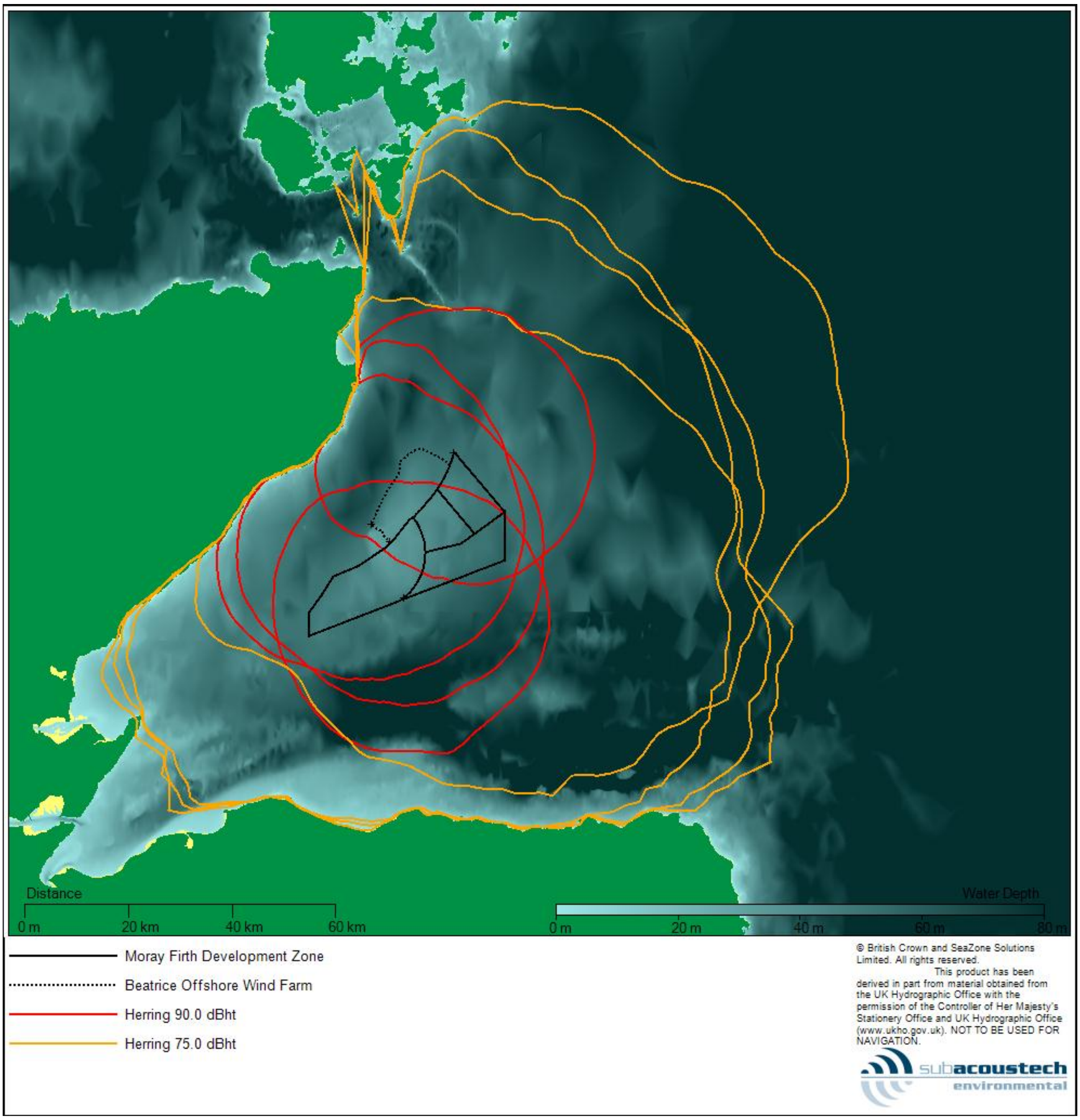


Figure A-197. 90 dB_{ht} and 75 dB_{ht} contours for herring; 2.5 m diameter piles being driven at locations 1 and 5 on the MORL site and 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and 5, A and B
Pile driving energy (kJ)	1200 and 2300
Species	Herring

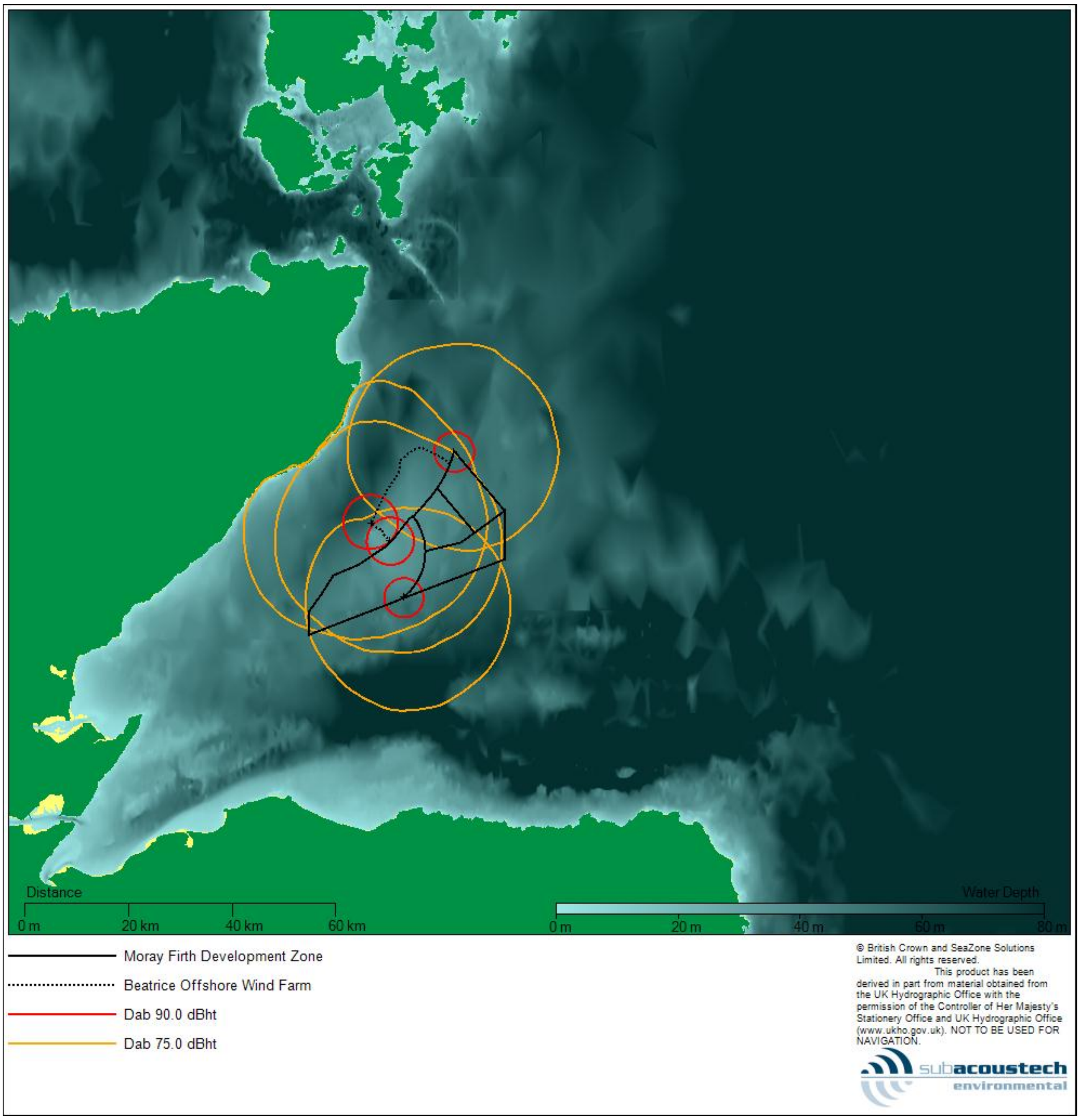


Figure A-198. 90 dB_{ht} and 75 dB_{ht} contours for plaice (dab used as surrogate); 2.5 m diameter piles being driven at locations 1 and 5 on the MORL site and 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and 5, A and B
Pile driving energy (kJ)	1200 and 2300
Species	Plaice

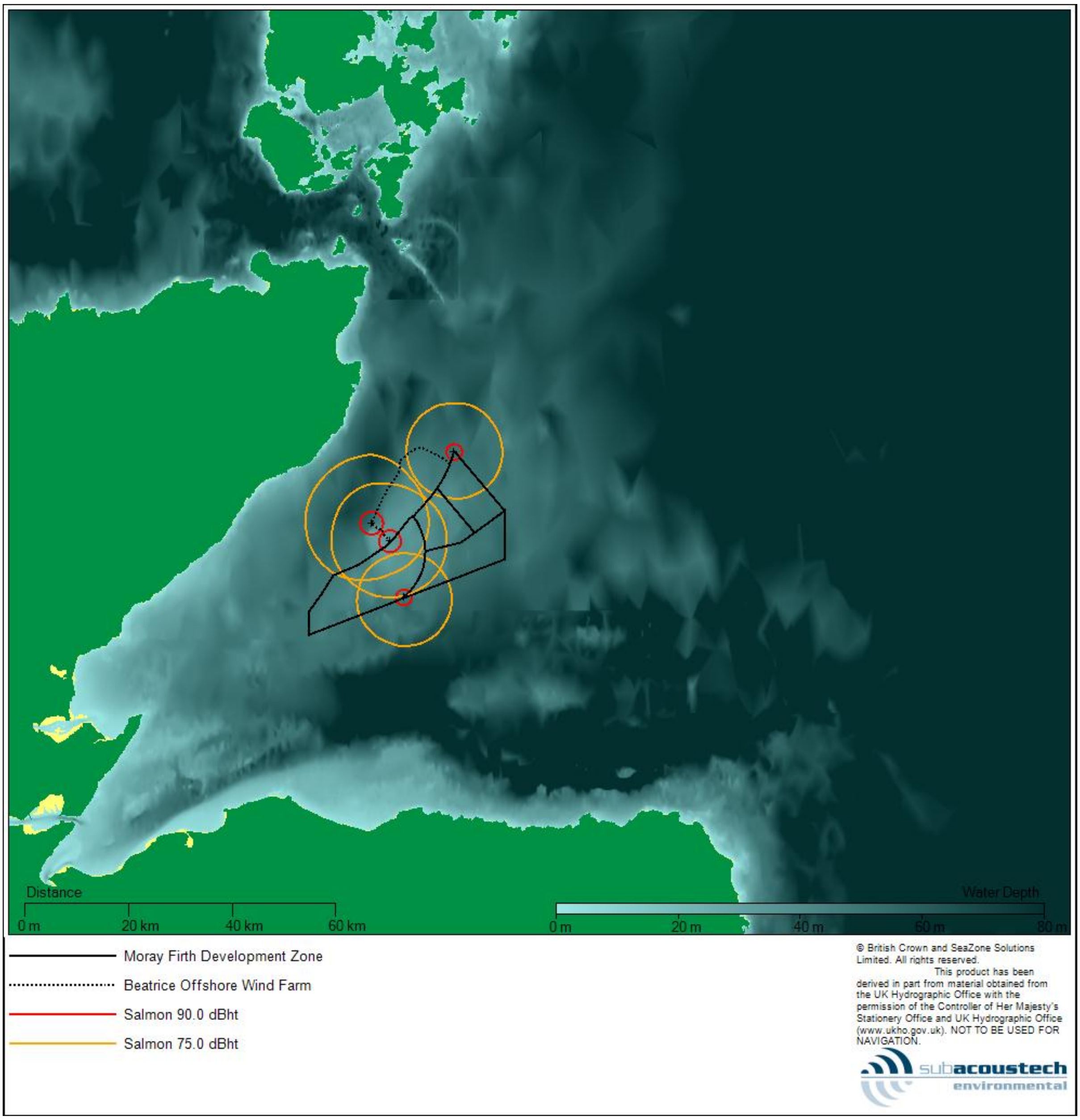


Figure A-199. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for salmon; 2.5 m diameter piles being driven at locations 1 and 5 on the MORL site and 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and 5, A and B
Pile driving energy (kJ)	1200 and 2300
Species	Salmon

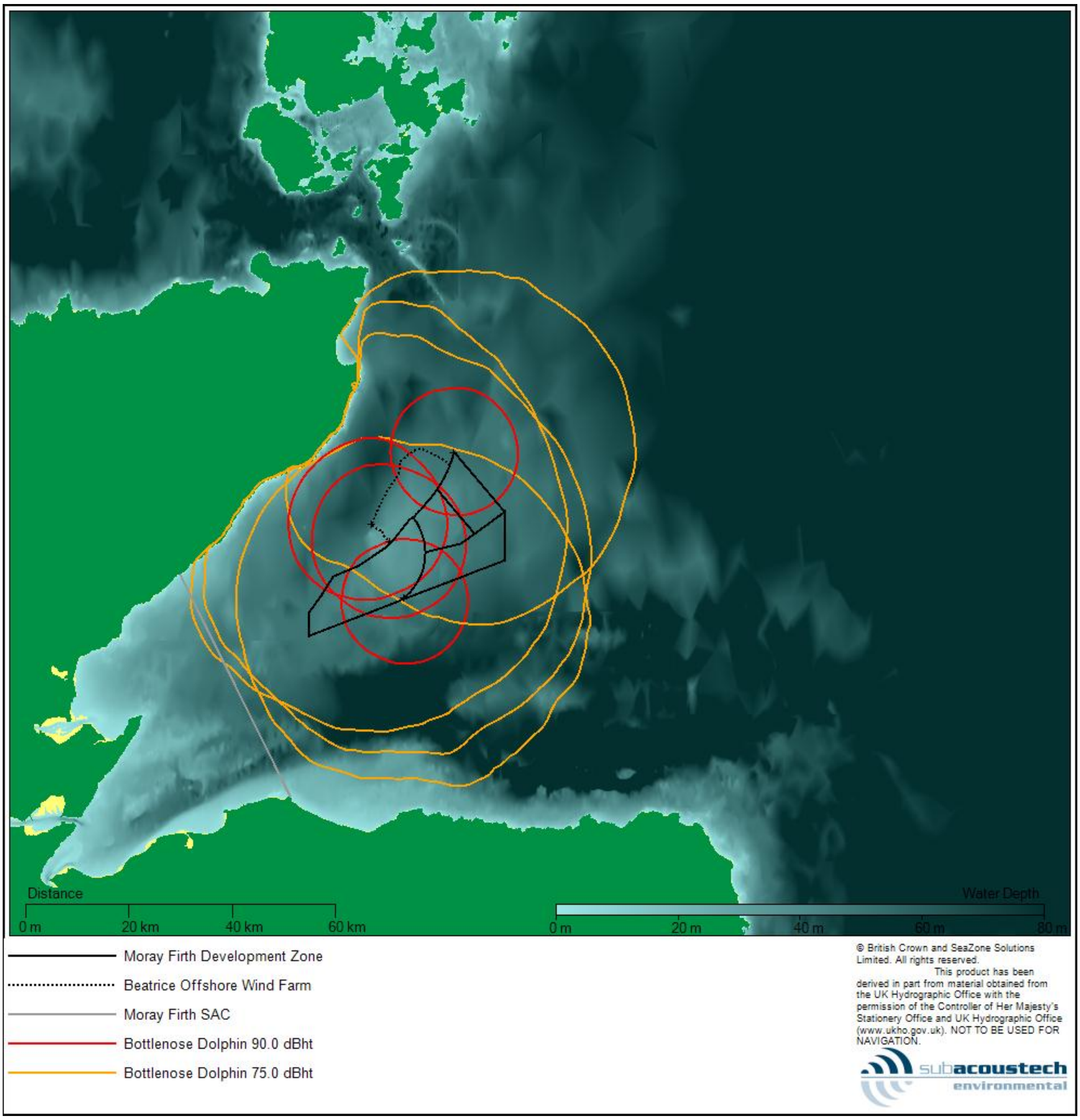


Figure A-200. 90 dB_{ht} and 75 dB_{ht} contours for bottlenose dolphin; 2.5 m diameter piles being driven at locations 1 and 5 on the MORL site and 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and 5, A and B
Pile driving energy (kJ)	1200 and 2300
Species	Bottlenose Dolphin

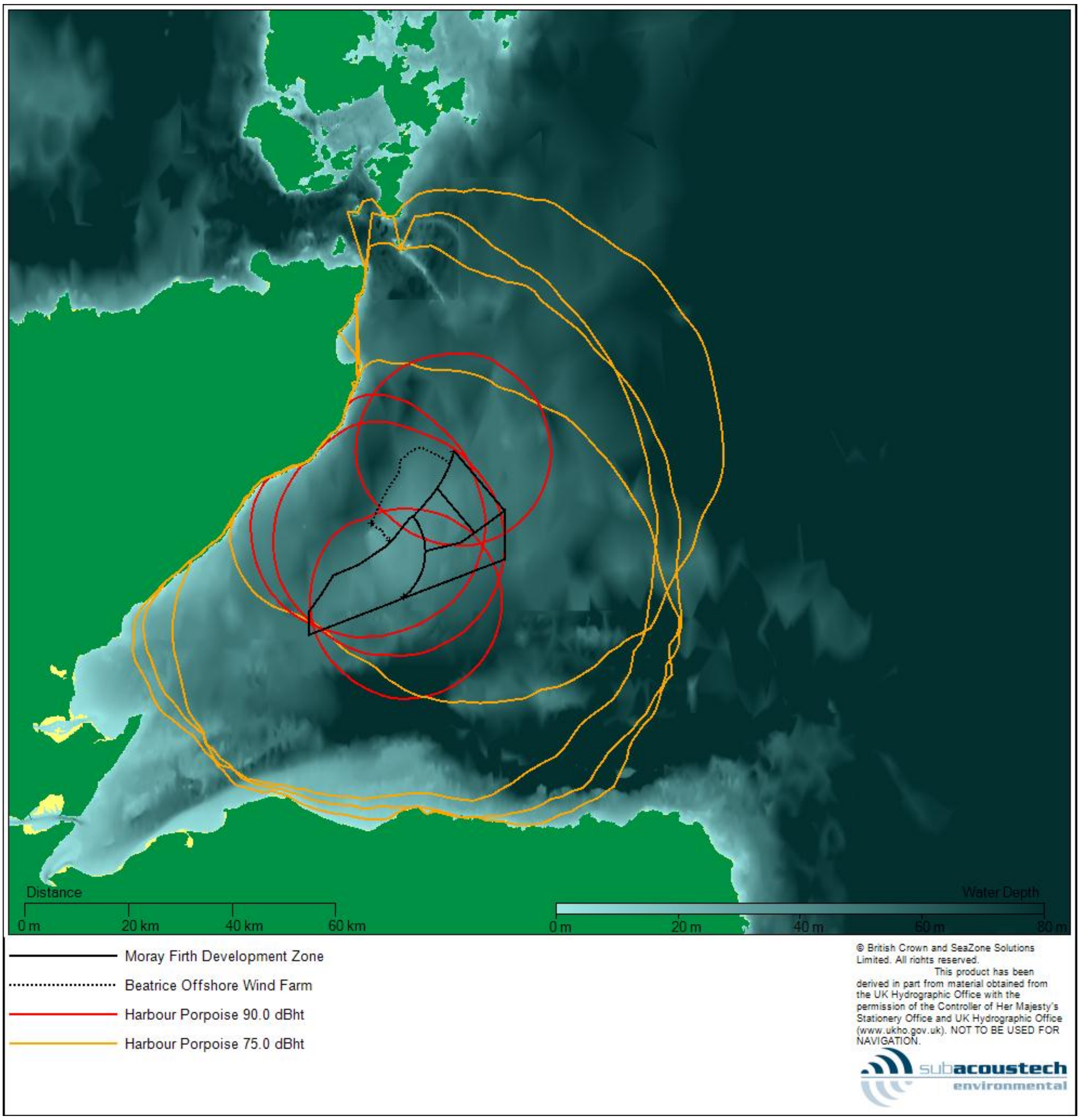


Figure A-201. 90 dB_{ht} and 75 dB_{ht} contours for harbour porpoise; 2.5 m diameter piles being driven at locations 1 and 5 on the MORL site and 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and 5, A and B
Pile driving energy (kJ)	1200 and 2300
Species	Harbour Porpoise

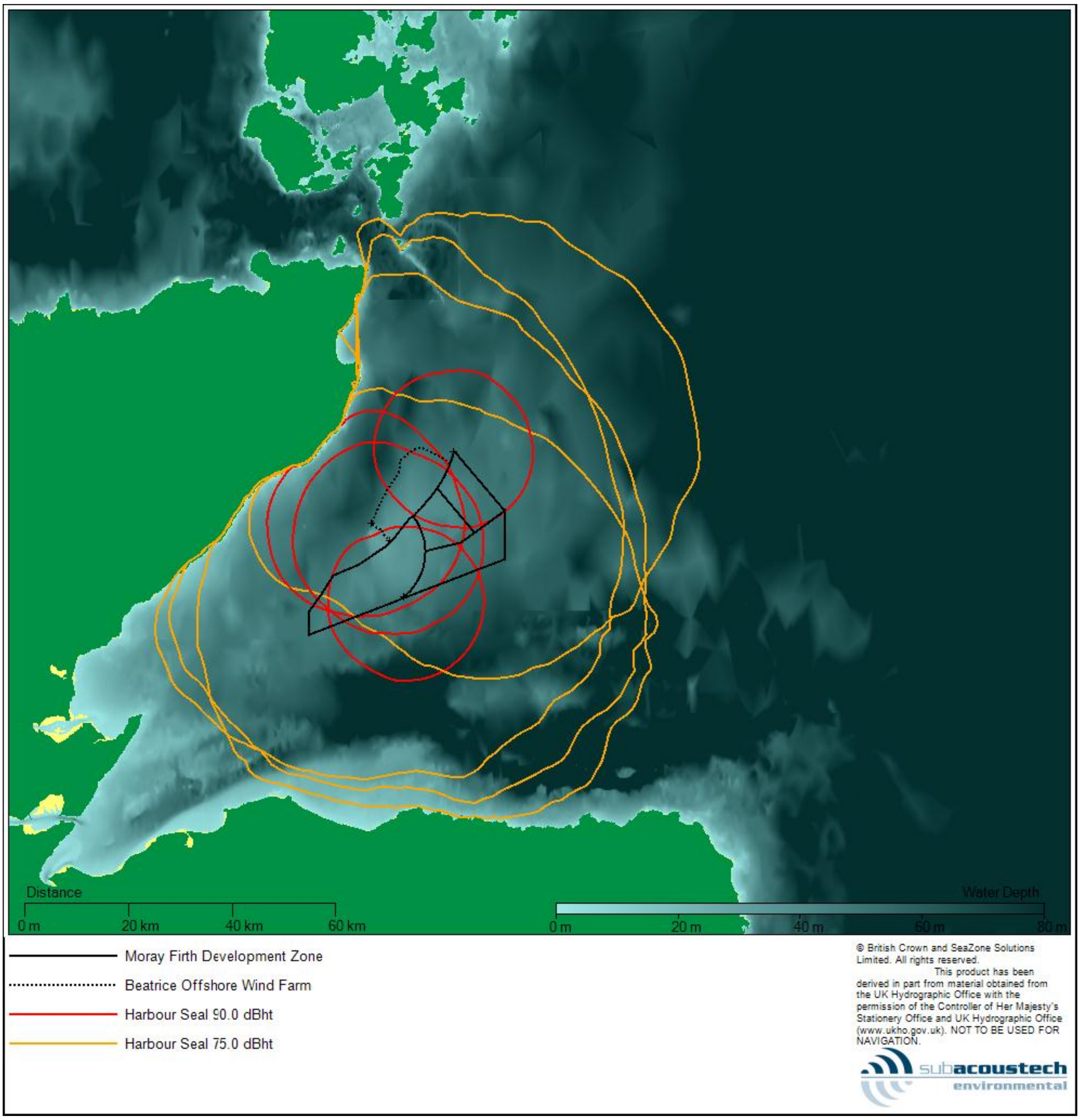


Figure A-202. 90 dB_{ht} and 75 dB_{ht} contours for harbour seal; 2.5 m diameter piles being driven at locations 1 and 5 on the MORL site and 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and 5, A and B
Pile driving energy (kJ)	1200 and 2300
Species	Harbour Seal

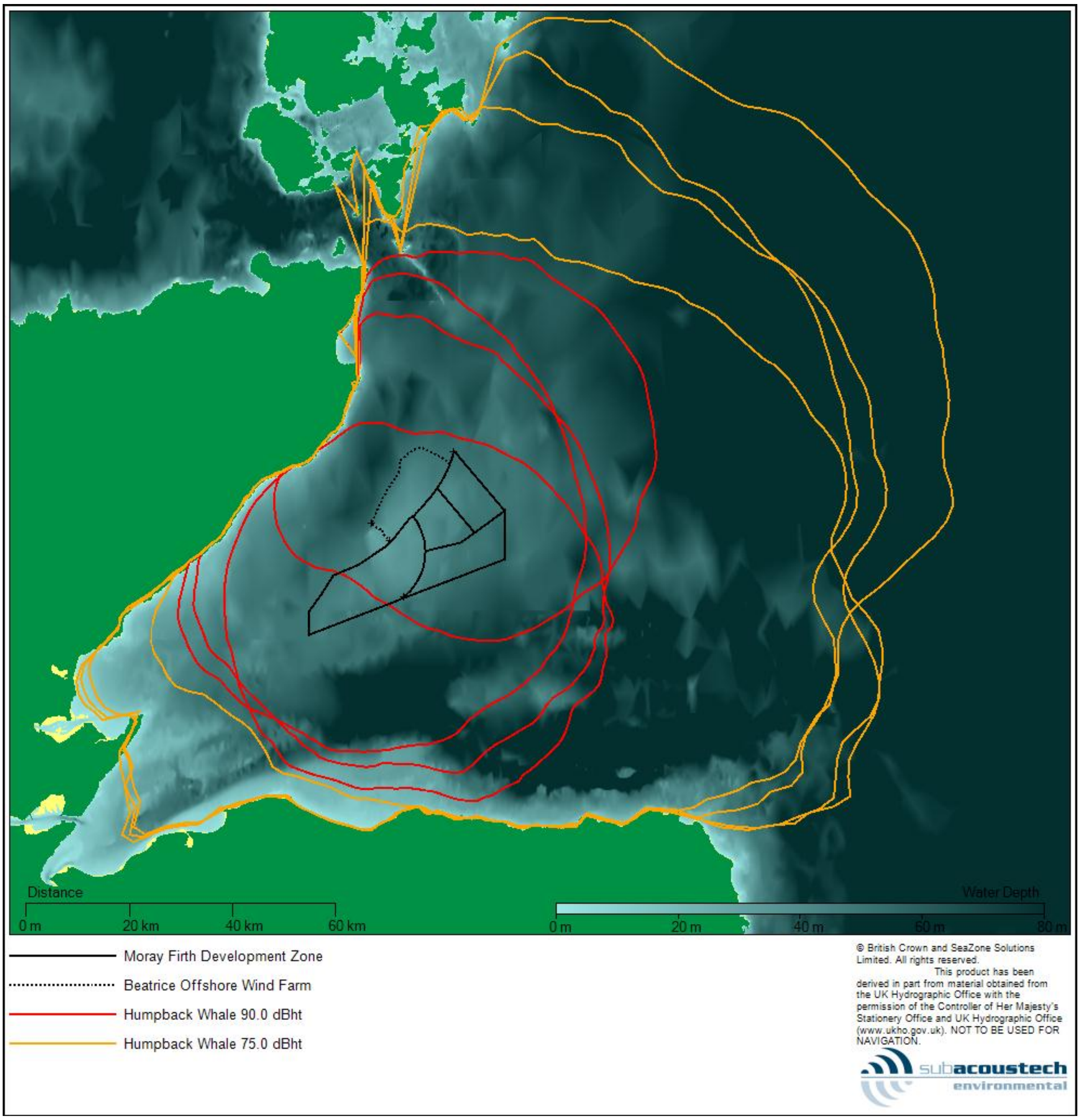


Figure A-203. 90 dB_{ht} and 75 dB_{ht} contours for minke whale (humpback whale used as surrogate); 2.5 m diameter piles being driven at locations 1 and 5 on the MORL site and 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and 5, A and B
Pile driving energy (kJ)	1200 and 2300
Species	Minke Whale

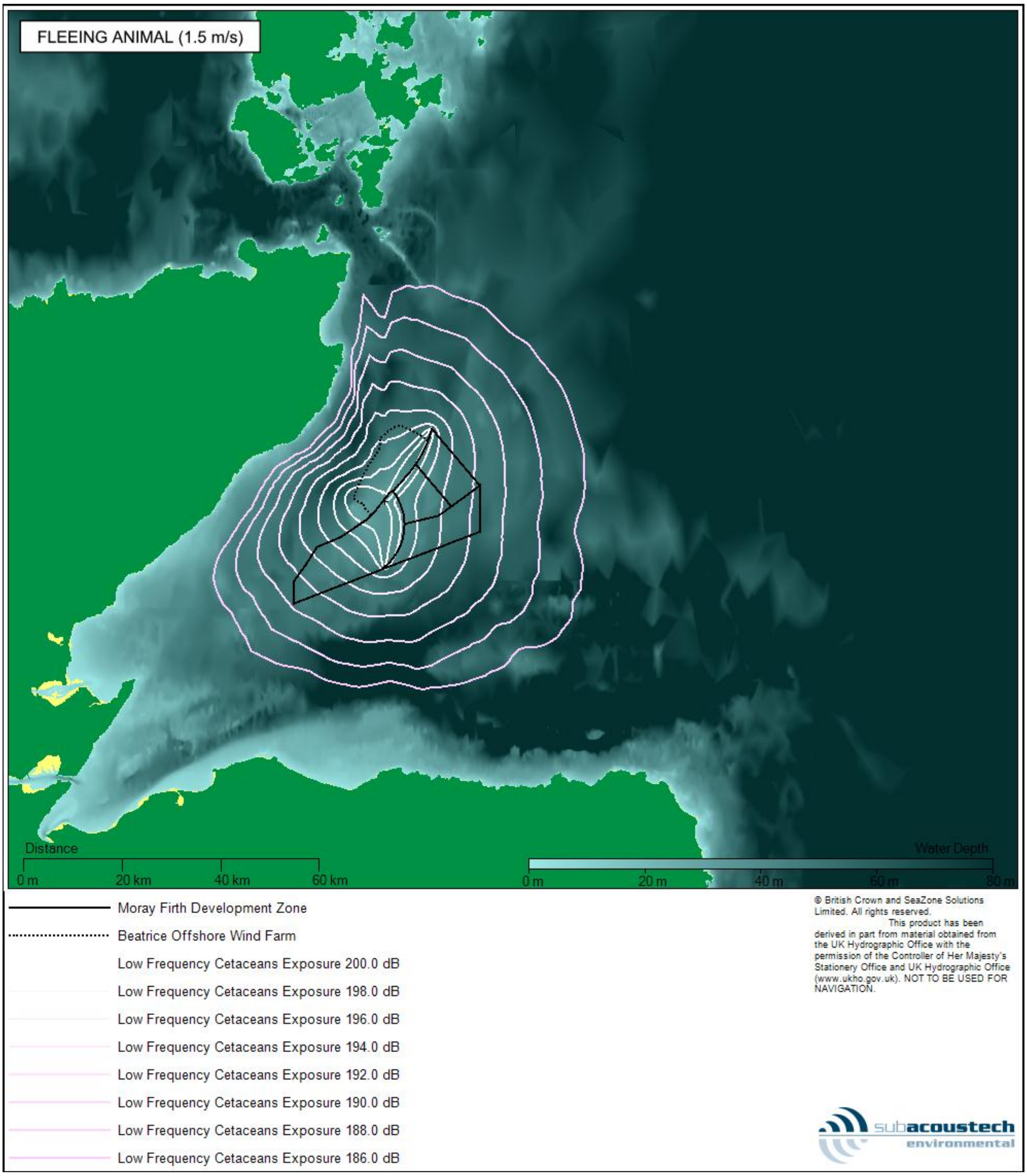


Figure A-204. Starting loci for fleeing Low Frequency Cetaceans; two 2.5 m diameter piles being driven at locations 1 and 5 on the MORL site and two 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and 5, A and B
Pile driving energy (kJ)	1200 and 2300
Species	Low Frequency Cetaceans (Fleeing 1.5m/s)

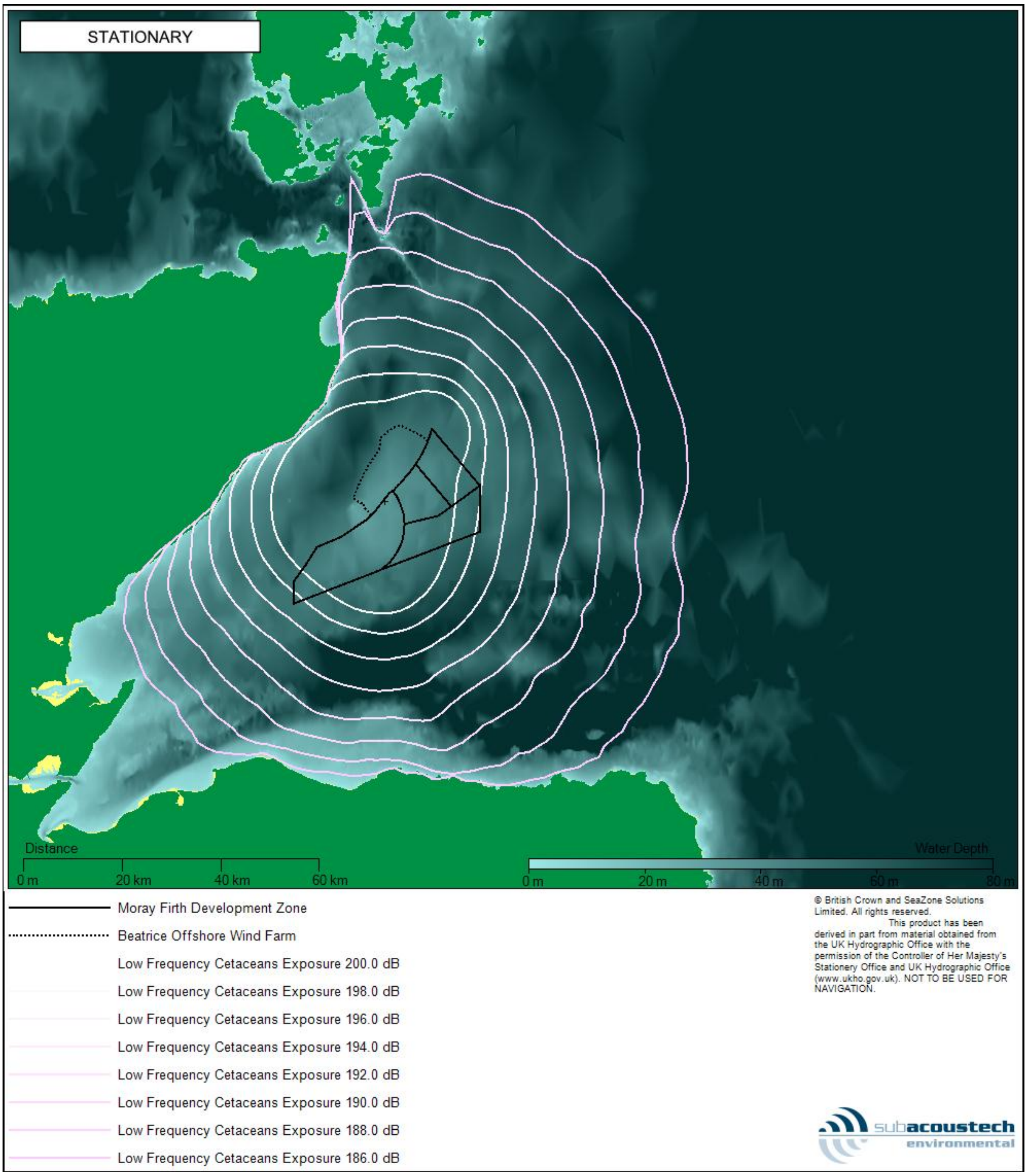


Figure A-205. Contours for stationary Low Frequency Cetaceans; two 2.5 m diameter piles being driven at locations 1 and 5 on the MORL site and two 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and 5, A and B
Pile driving energy (kJ)	1200 and 2300
Species	Low Frequency Cetaceans (Stationary)

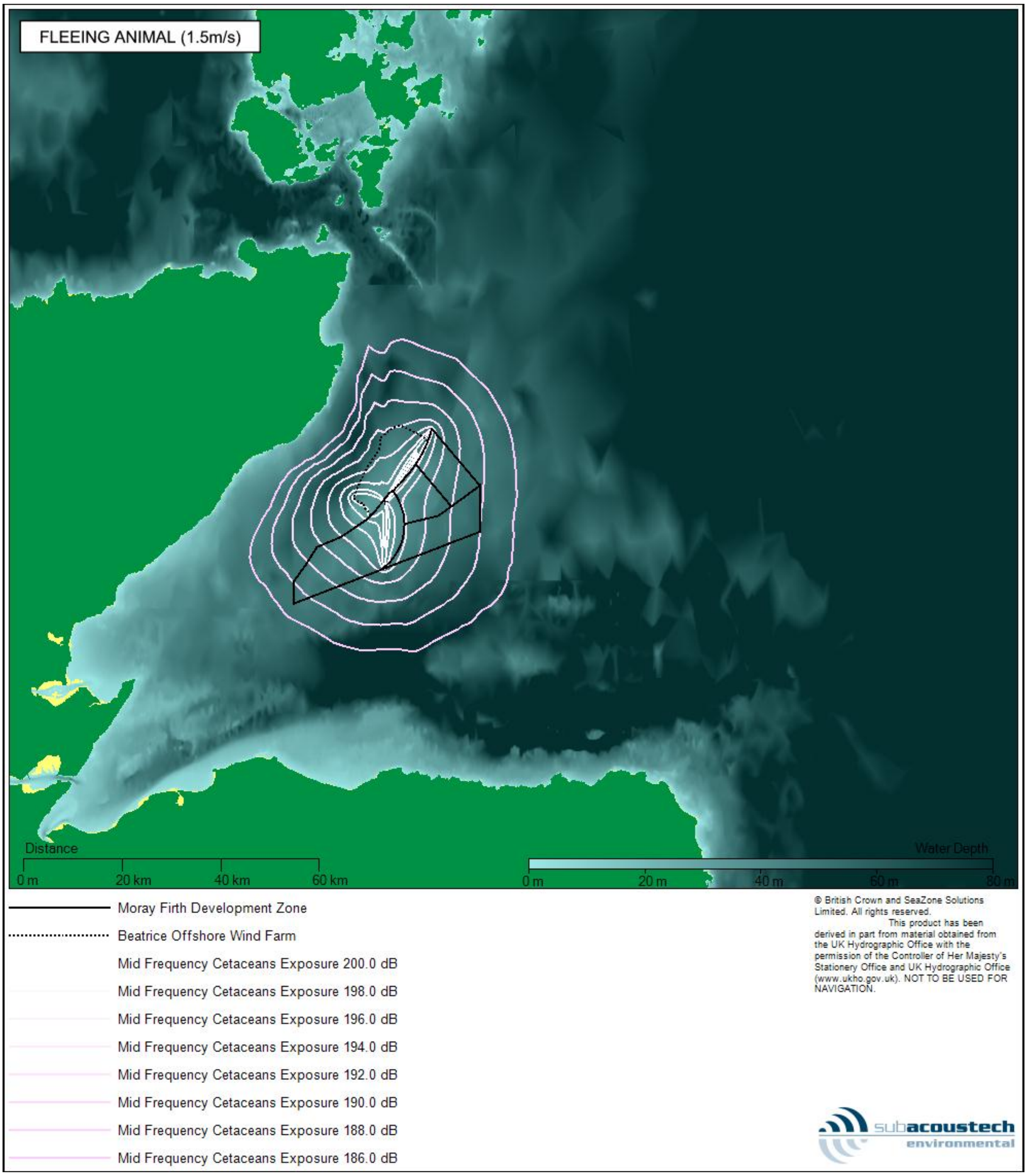


Figure A-206. Starting loci for fleeing Mid Frequency Cetaceans; two 2.5 m diameter piles being driven at locations 1 and 5 on the MORL site and two 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and 5, A and B
Pile driving energy (kJ)	1200 and 2300
Species	Mid Frequency Cetaceans (Fleeing 1.5m/s)

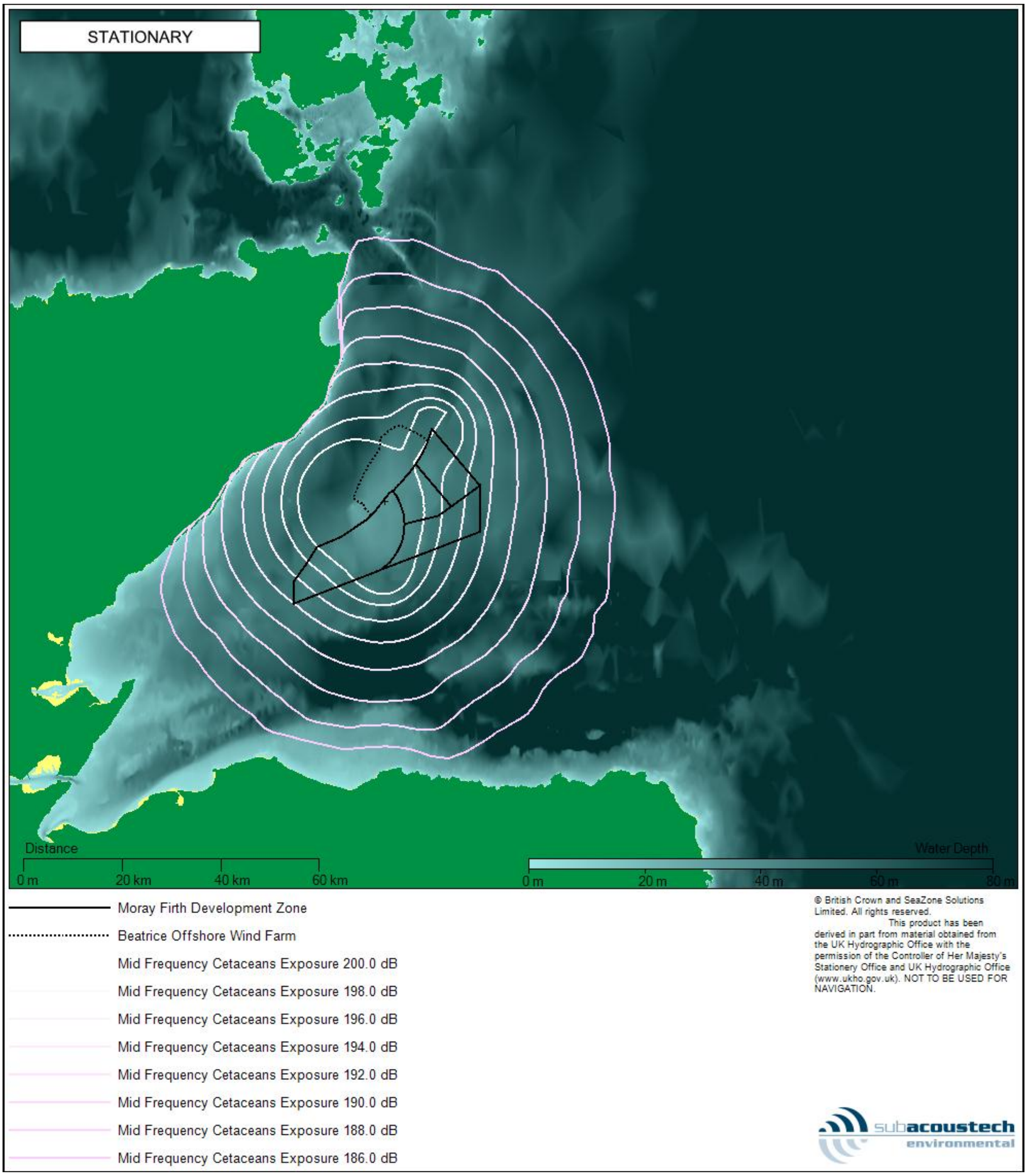


Figure A-207. Contours for stationary Mid Frequency Cetaceans; two 2.5 m diameter piles being driven at locations 1 and 5 on the MORL site and two 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and 5, A and B
Pile driving energy (kJ)	1200 and 2300
Species	Mid Frequency Cetaceans (Stationary)

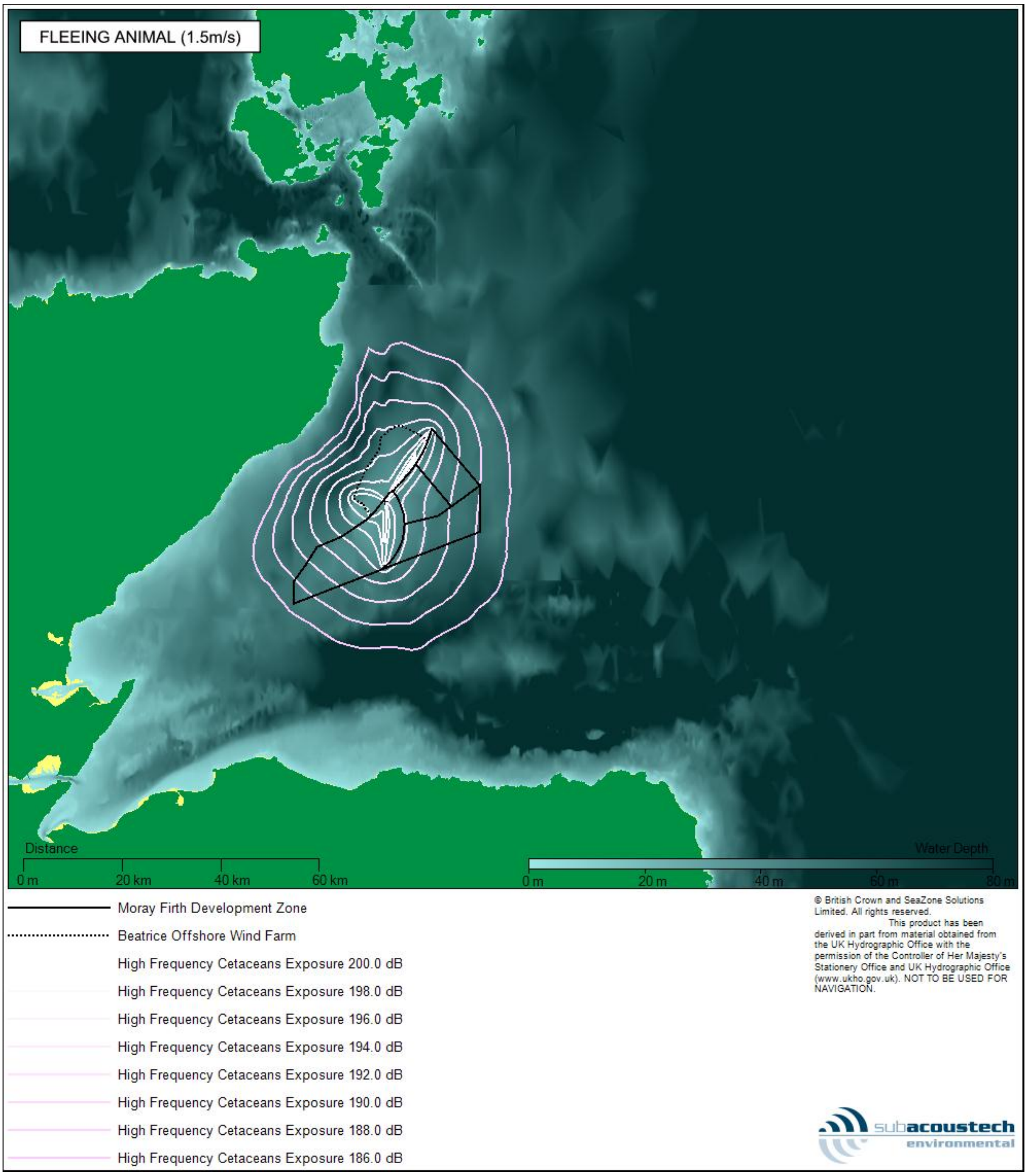


Figure A-208. Starting loci for fleeing High Frequency Cetaceans; two 2.5 m diameter piles being driven at locations 1 and 5 on the MORL site and two 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and 5, A and B
Pile driving energy (kJ)	1200 and 2300
Species	High Frequency Cetaceans (Fleeing 1.5m/s)

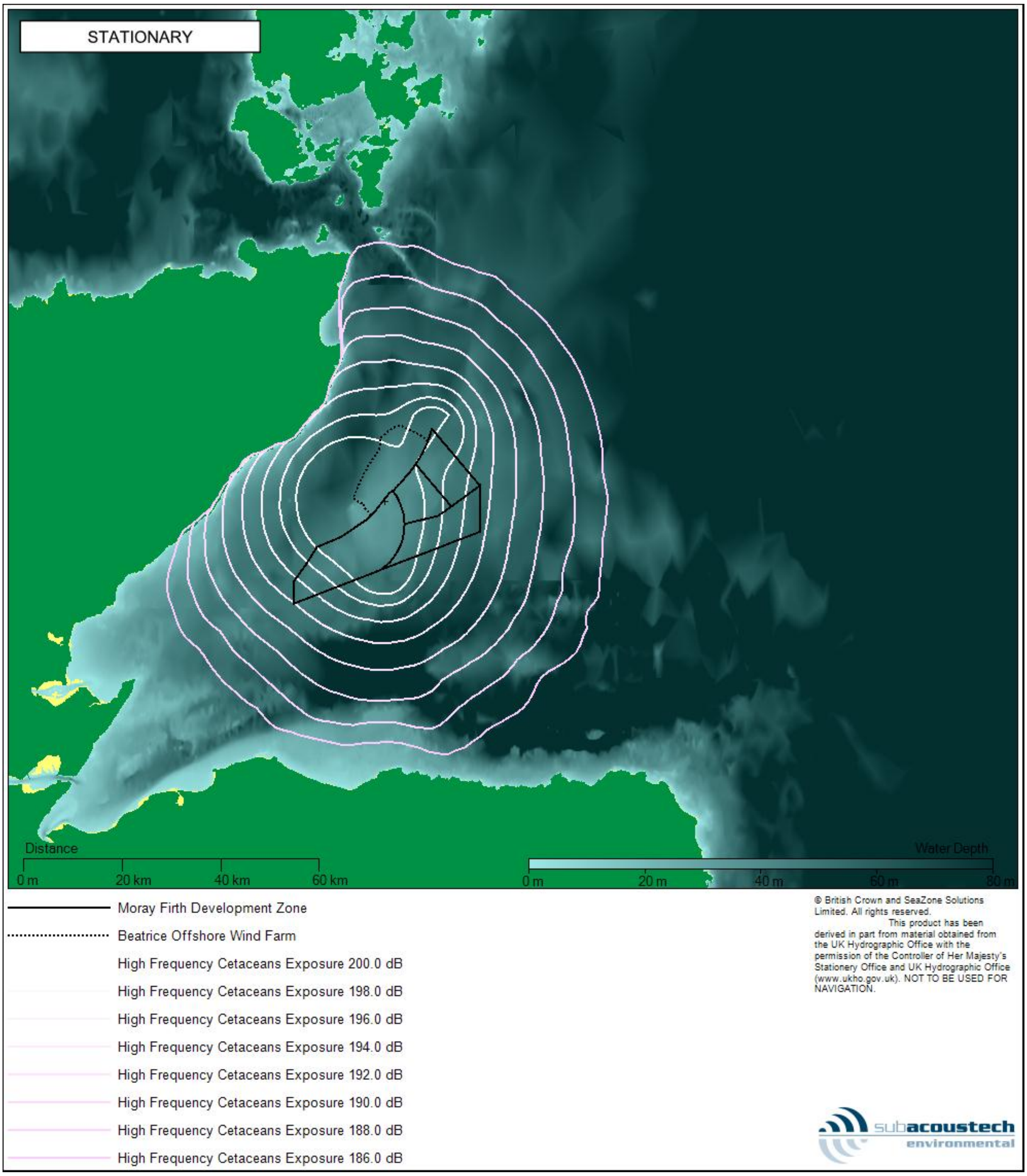


Figure A-209. Contours for stationary High Frequency Cetaceans; two 2.5 m diameter piles being driven at locations 1 and 5 on the MORL site and two 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and 5, A and B
Pile driving energy (kJ)	1200 and 2300
Species	High Frequency Cetaceans (Stationary)

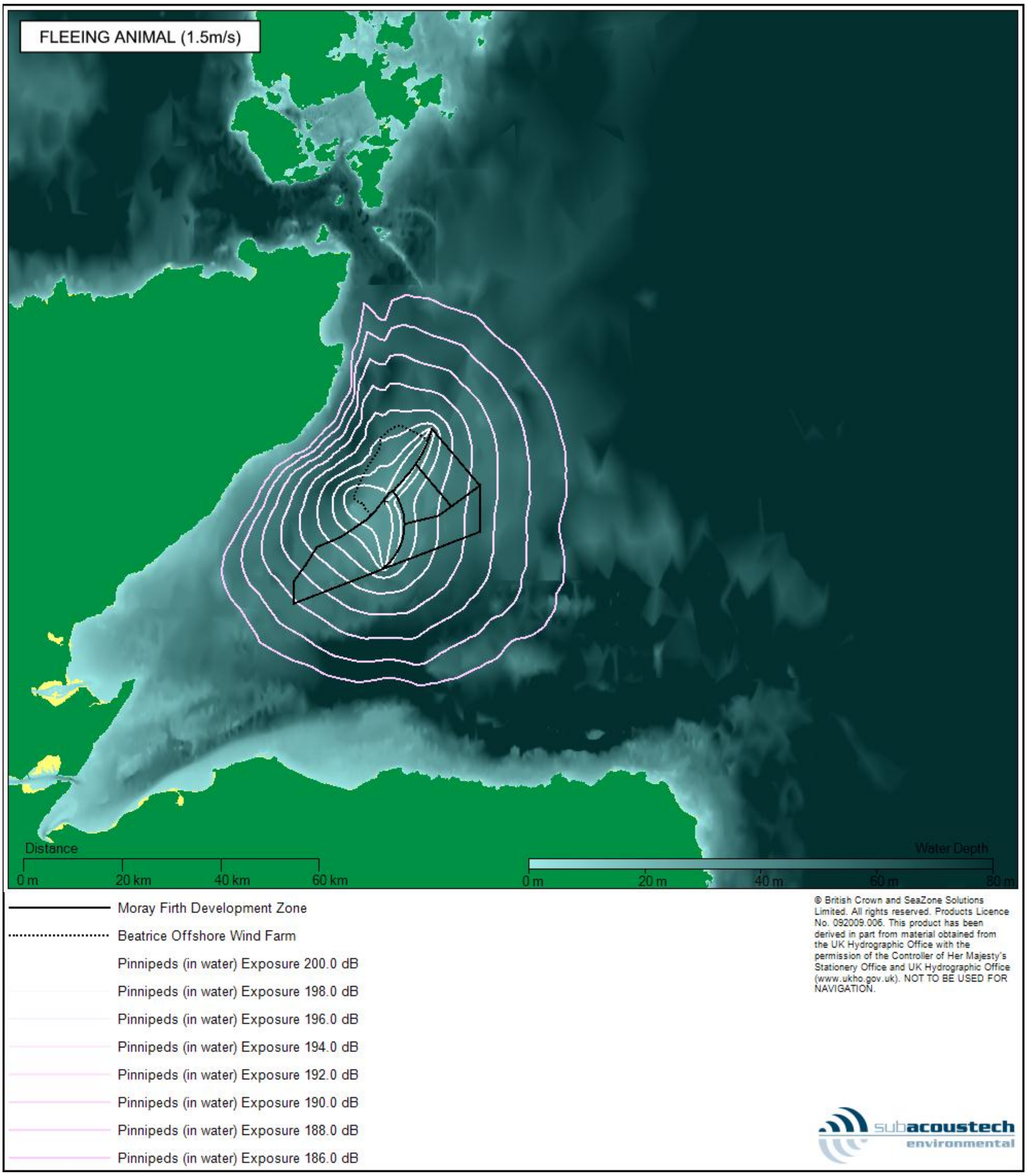


Figure A-210. Starting loci for fleeing Pinnipeds (in water); two 2.5 m diameter piles being driven at locations 1 and 5 on the MORL site and two 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and 5, A and B
Pile driving energy (kJ)	1200 and 2300
Species	Pinnipeds (in water) (Fleeing 1.5m/s)

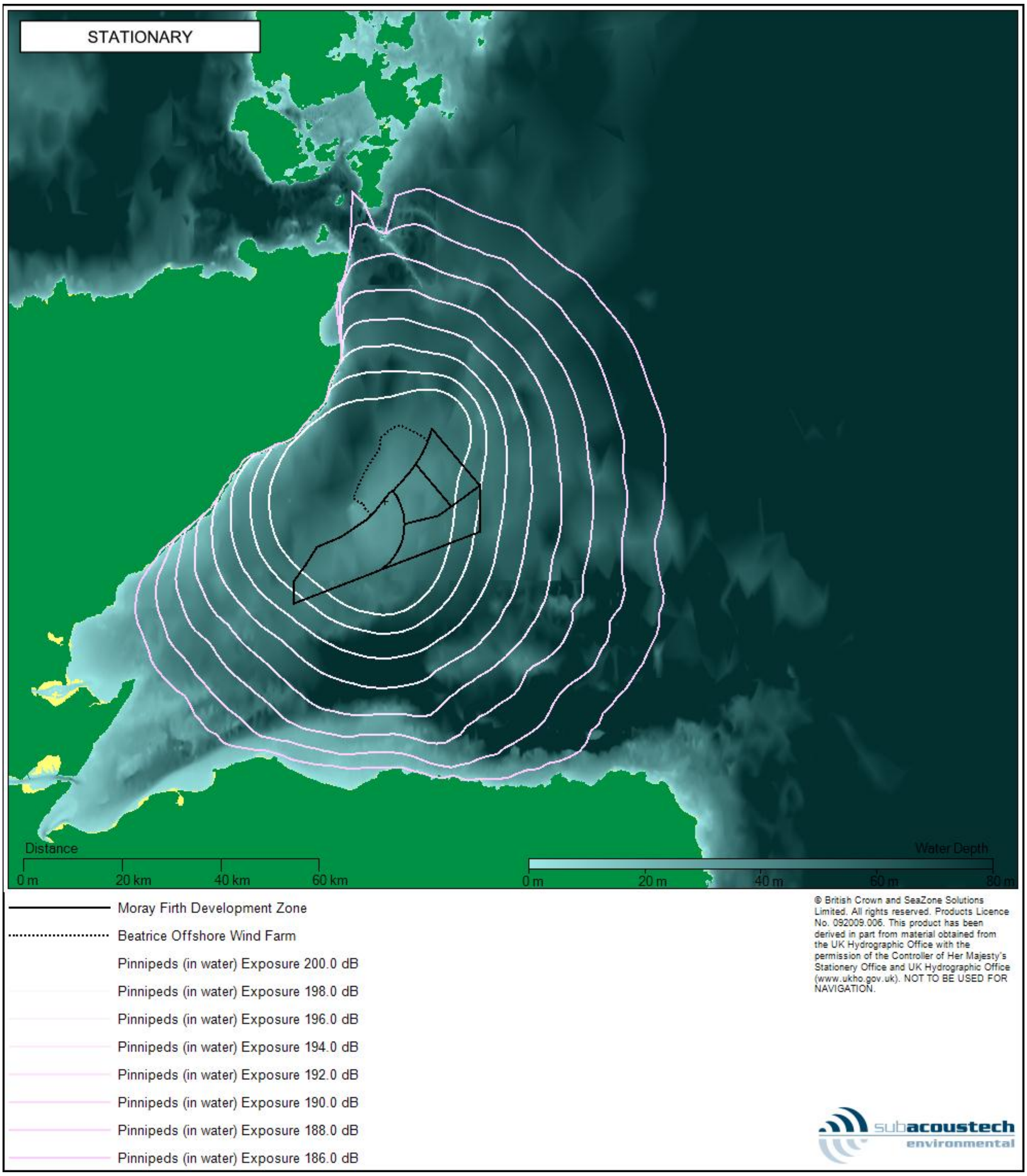


Figure A-211. Contours for stationary Pinnipeds (in water); two 2.5 m diameter piles being driven at locations 1 and 5 on the MORL site and two 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1 and 5, A and B
Pile driving energy (kJ)	1200 and 2300
Species	Pinnipeds (in water) (Stationary)

9.2.6.4 Results for piling at 6 locations on MORL and 2 locations on BOWL, driven simultaneously

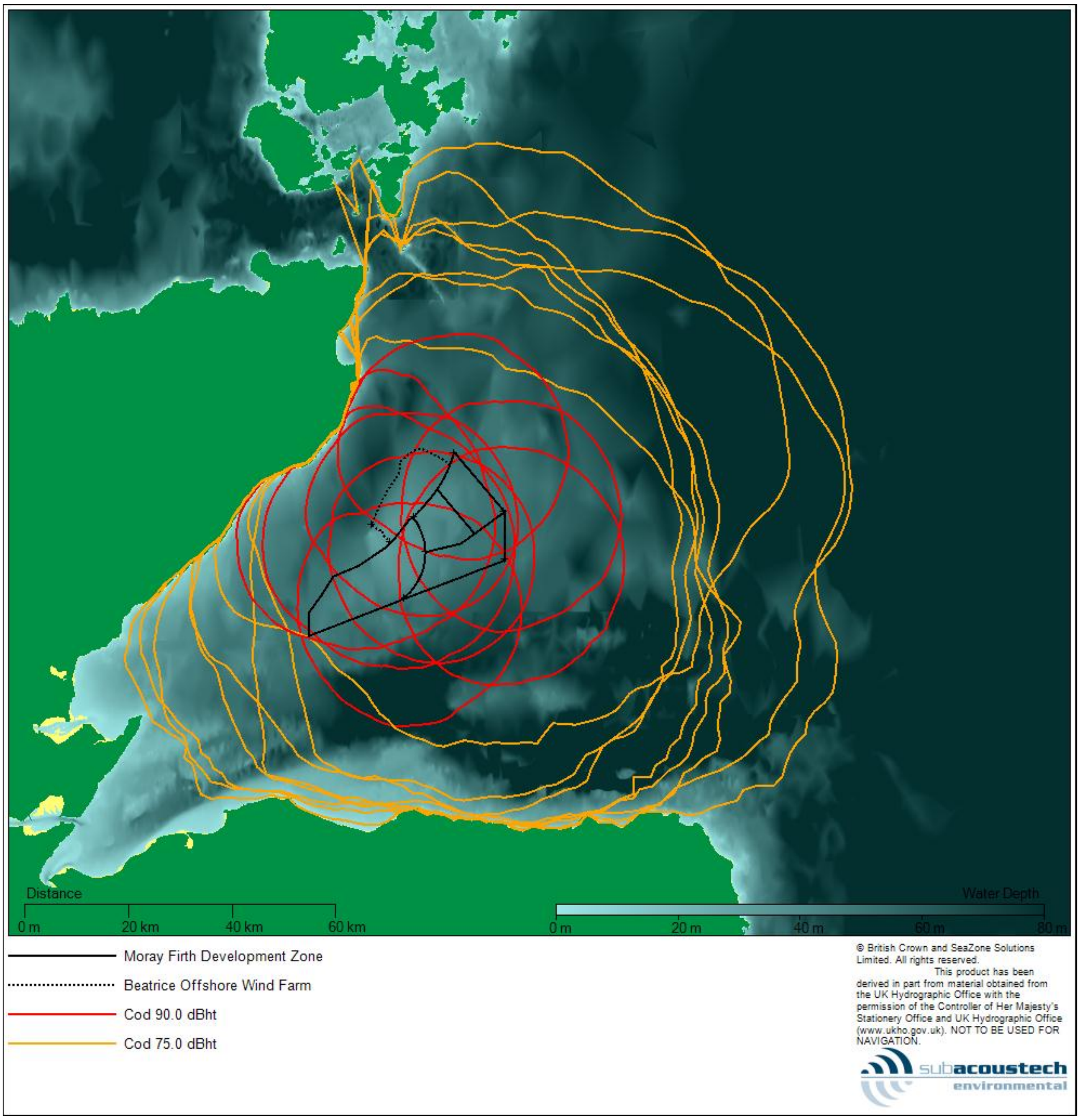


Figure A-212. 90 dB_{ht} and 75 dB_{ht} contours for cod; 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 on the MORL site and 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6 A and B
Pile driving energy (kJ)	1200 and 2300
Species	Cod

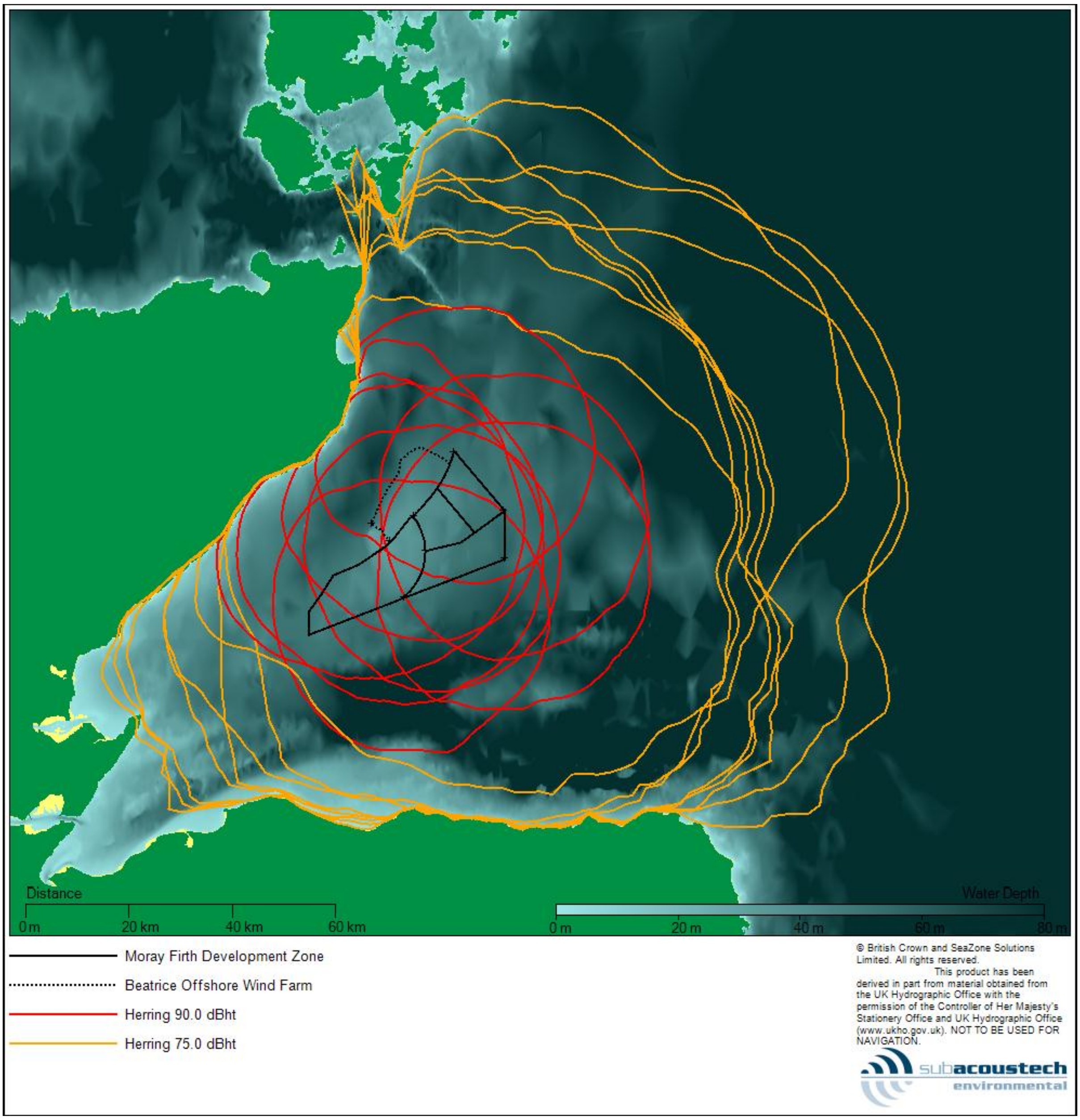


Figure A-213. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for herring; 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 on the MORL site and 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6 A and B
Pile driving energy (kJ)	1200 and 2300
Species	Herring

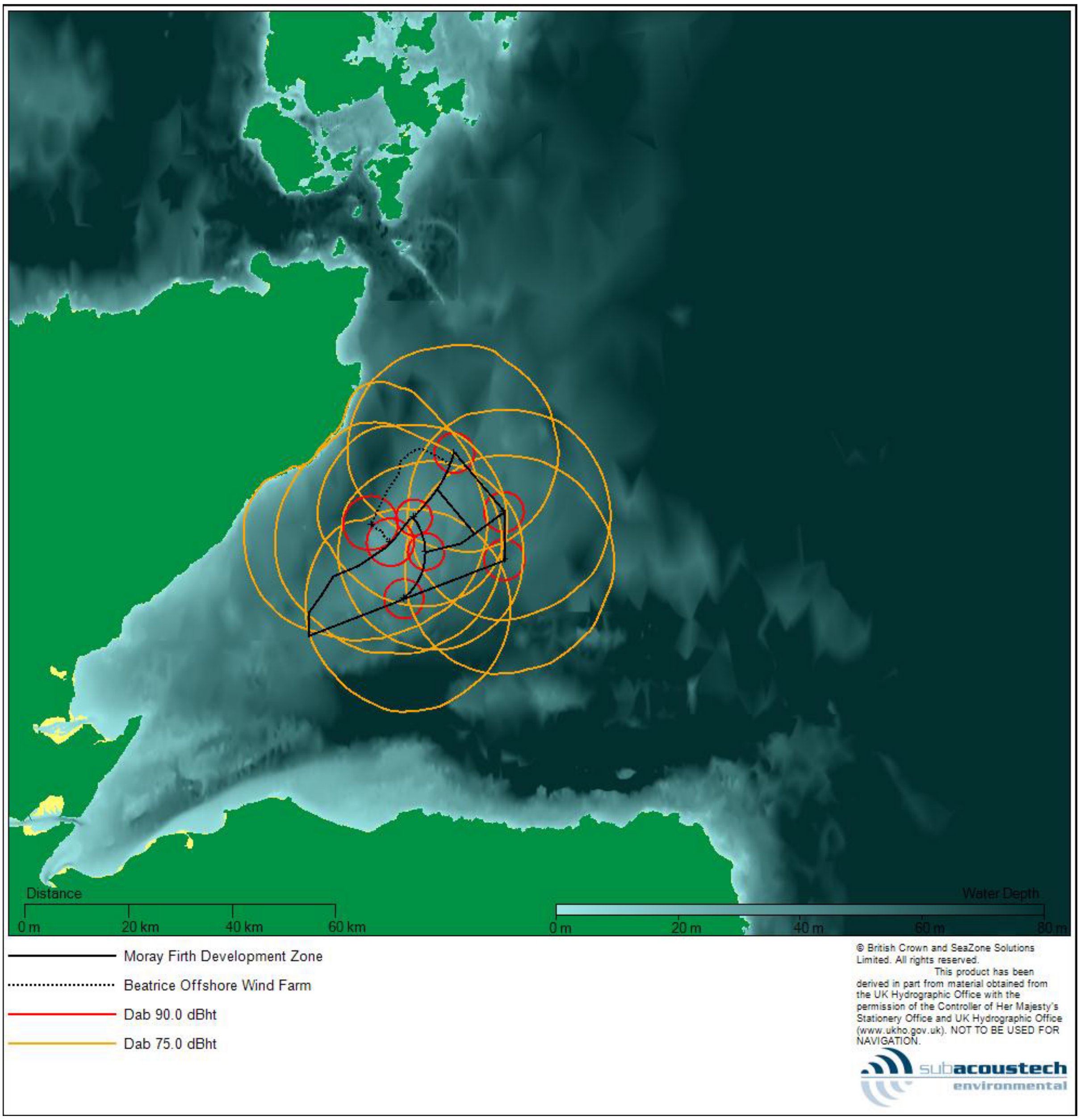


Figure A-214. 90 dB_{ht} and 75 dB_{ht} contours for plaice (dab used as surrogate); 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 on the MORL site and 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6 A and B
Pile driving energy (kJ)	1200 and 2300
Species	Plaice

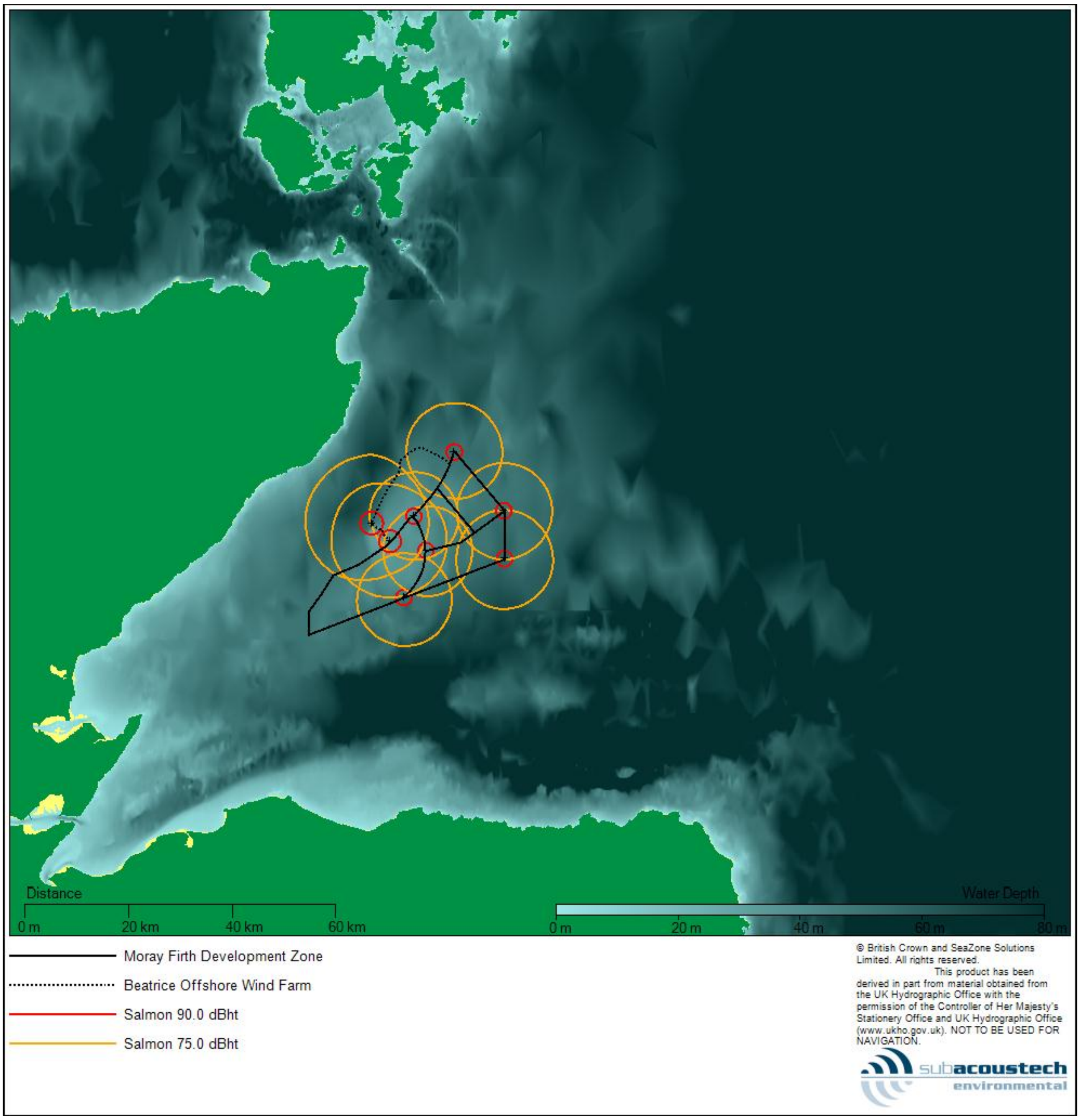


Figure A-215. 90 dB_{ht} and 75 dB_{ht} contours for salmon; 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 on the MORL site and 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6 A and B
Pile driving energy (kJ)	1200 and 2300
Species	Salmon

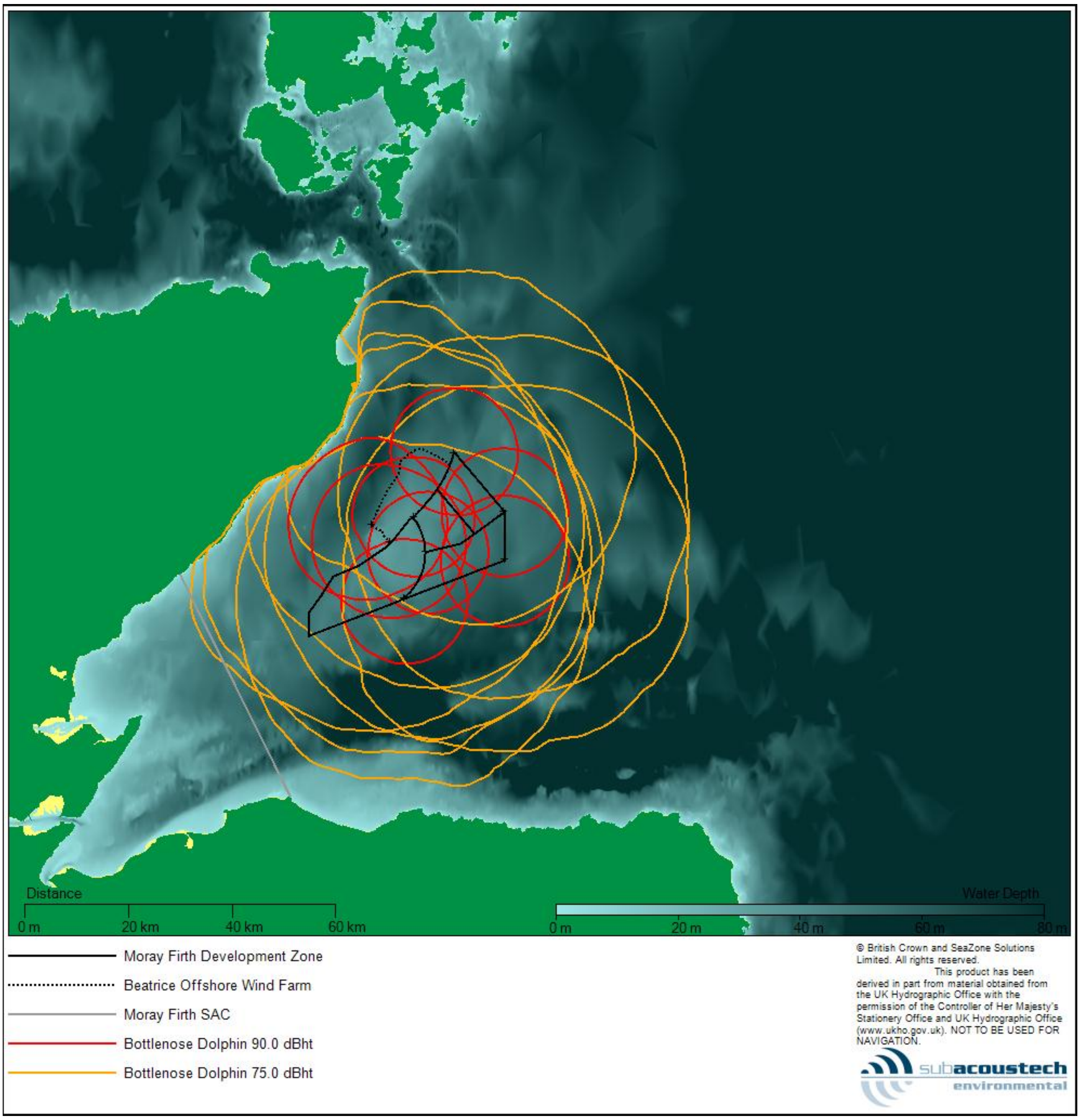


Figure A-216. 90 dB_{ht} and 75 dB_{ht} contours for bottlenose dolphin; 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 on the MORL site and 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6 A and B
Pile driving energy (kJ)	1200 and 2300
Species	Bottlenose Dolphin

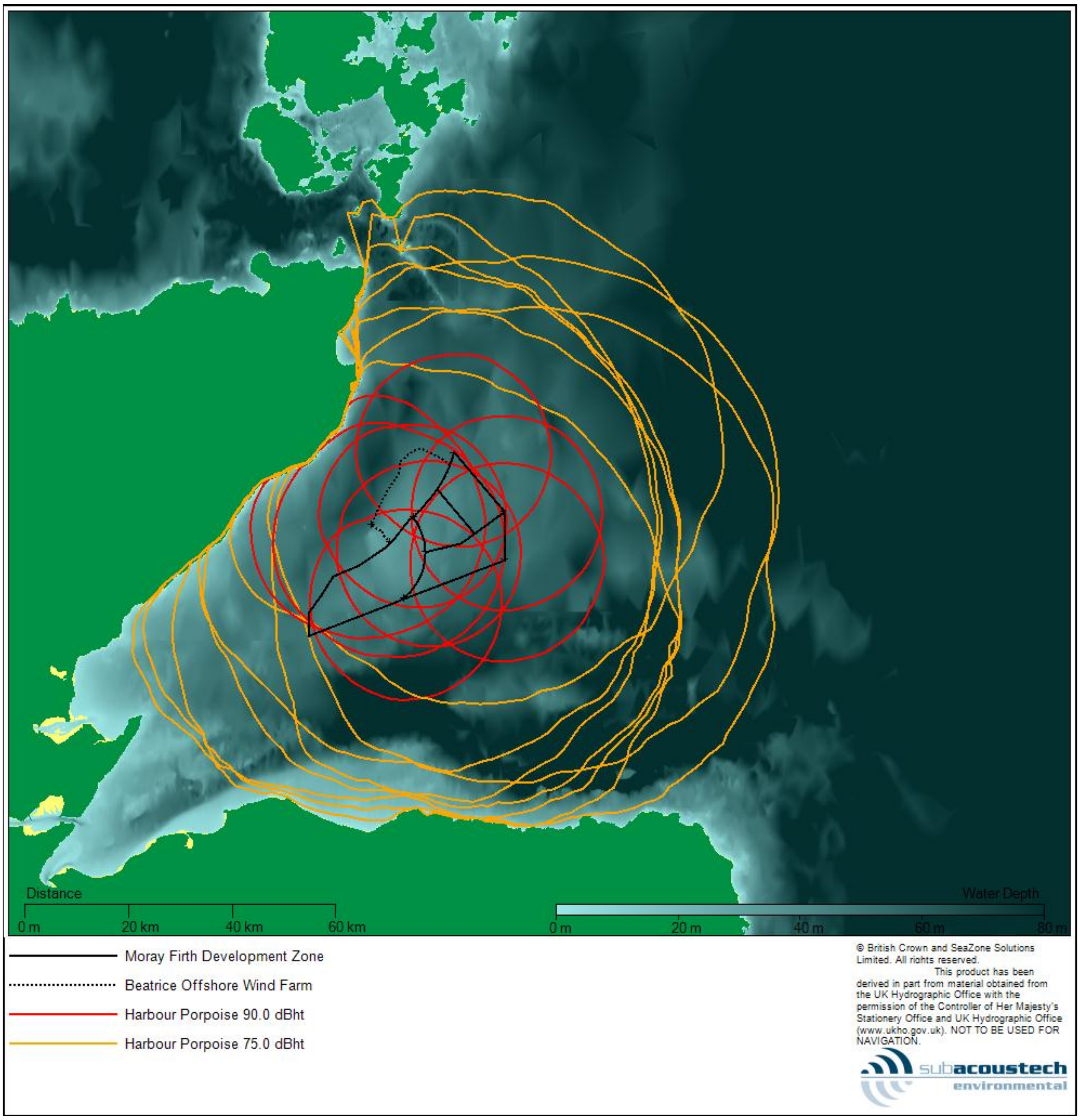


Figure A-217. 90 dB_{ht} and 75 dB_{ht} contours for harbour porpoise; 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 on the MORL site and 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6 A and B
Pile driving energy (kJ)	1200 and 2300
Species	Harbour Porpoise

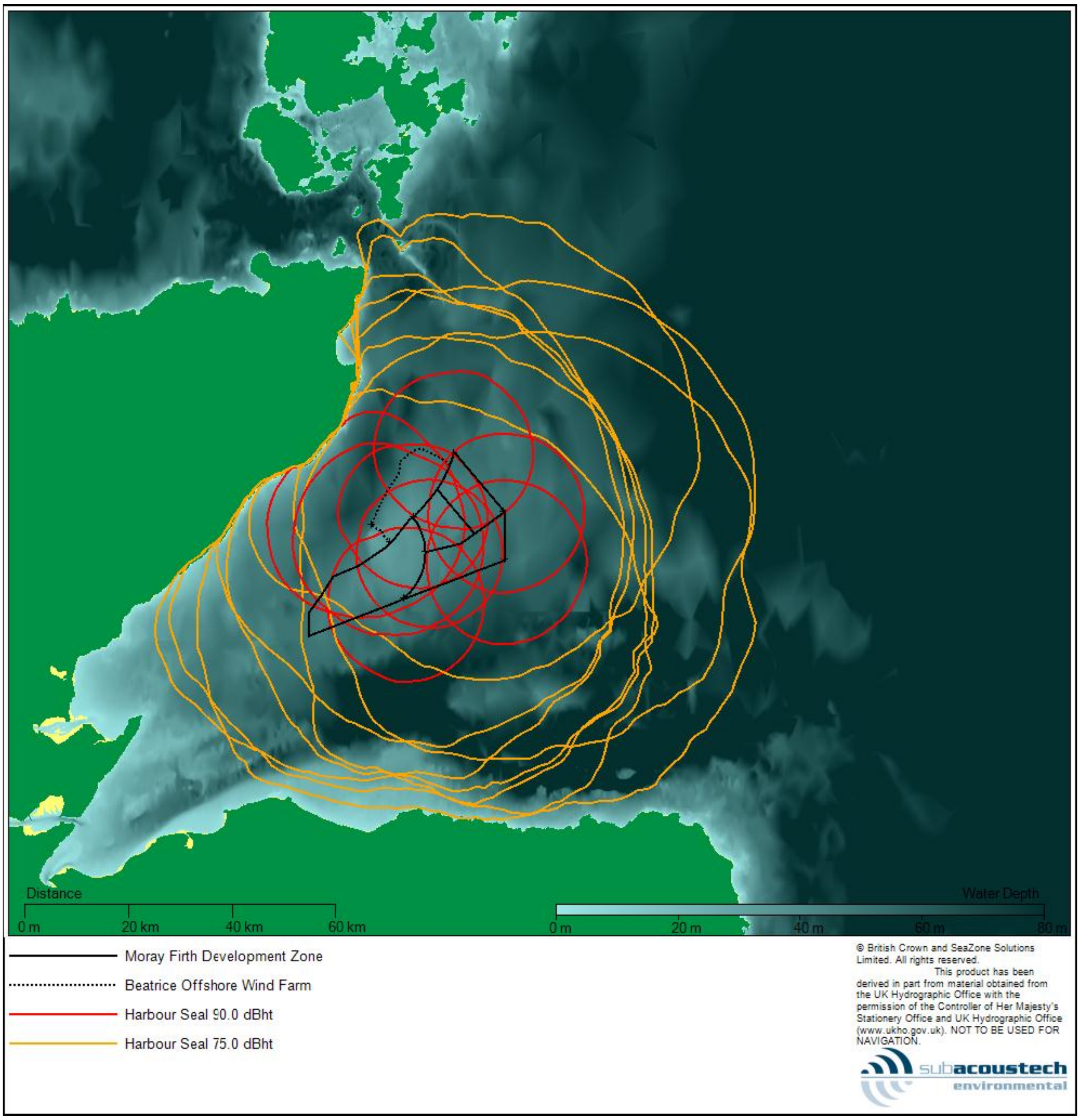


Figure A-218. 90 dB_{ht} and 75 dB_{ht} contours for harbour seal; 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 on the MORL site and 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6 A and B
Pile driving energy (kJ)	1200 and 2300
Species	Harbour Seal

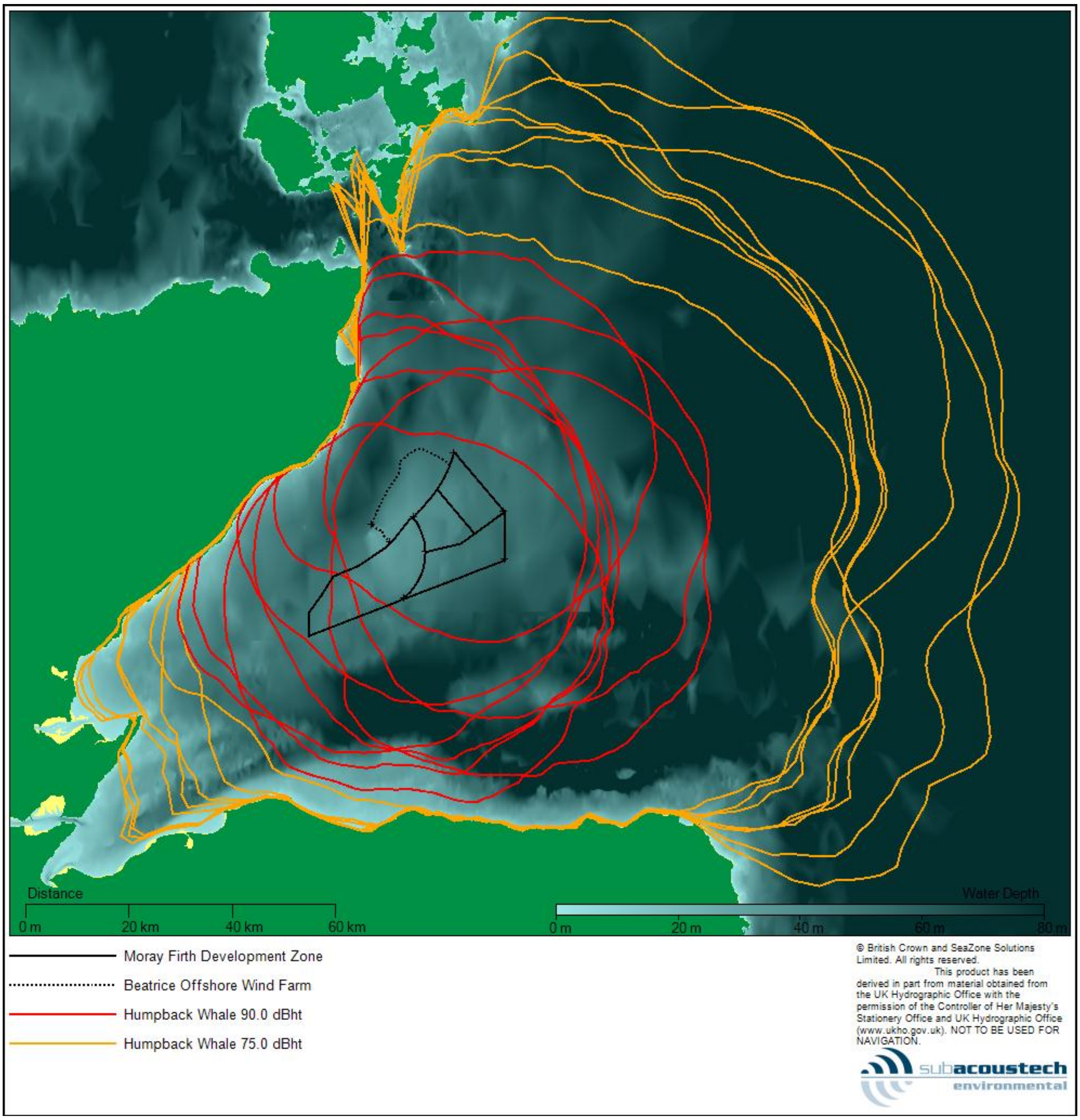


Figure A-219. 90 dB$_{ht}$ and 75 dB$_{ht}$ contours for minke whale (humpback whale used as surrogate); 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 on the MORL site and 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL) 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6 A and B
Pile driving energy (kJ)	1200 and 2300
Species	Minke Whale

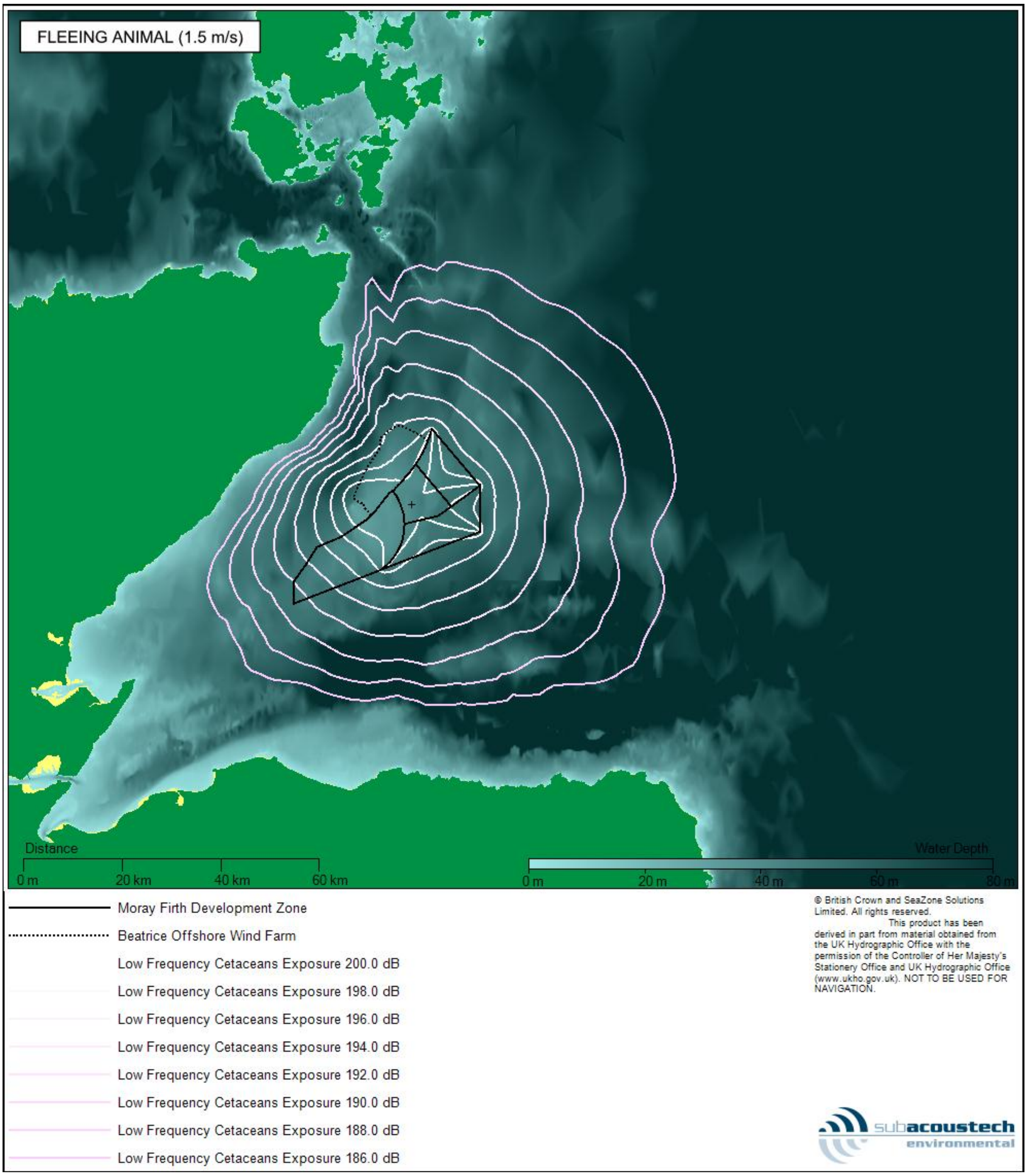


Figure A-220. Starting loci for fleeing Low Frequency Cetaceans; two 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 on the MORL site and two 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6, A and B
Pile driving energy (kJ)	1200 and 2300
Species	Low Frequency Cetaceans (Fleeing 1.5m/s)

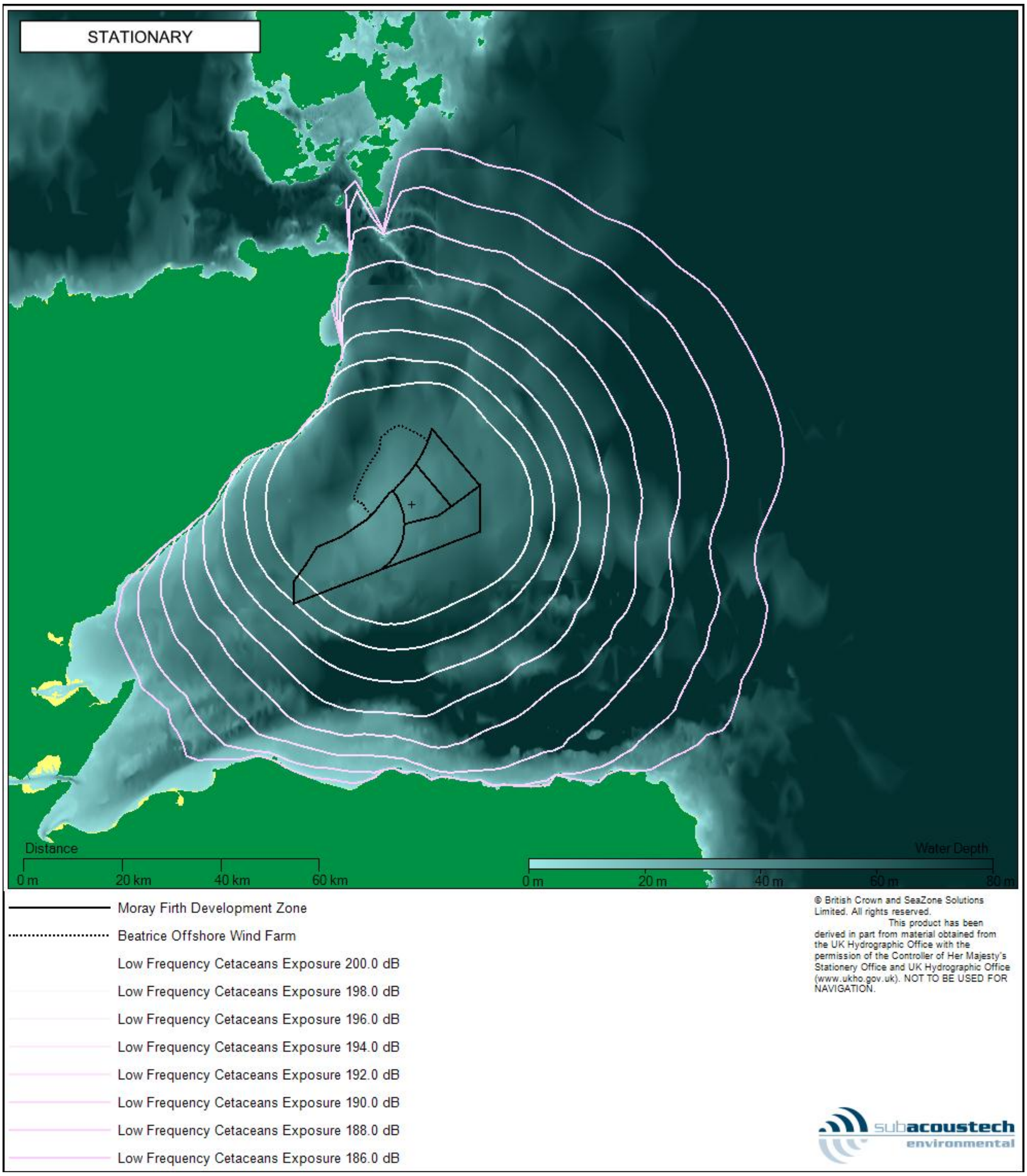


Figure A-221. Contours for stationary Low Frequency Cetaceans; two 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 on the MORL site and two 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6, A and B
Pile driving energy (kJ)	1200 and 2300
Species	Low Frequency Cetaceans (Stationary)

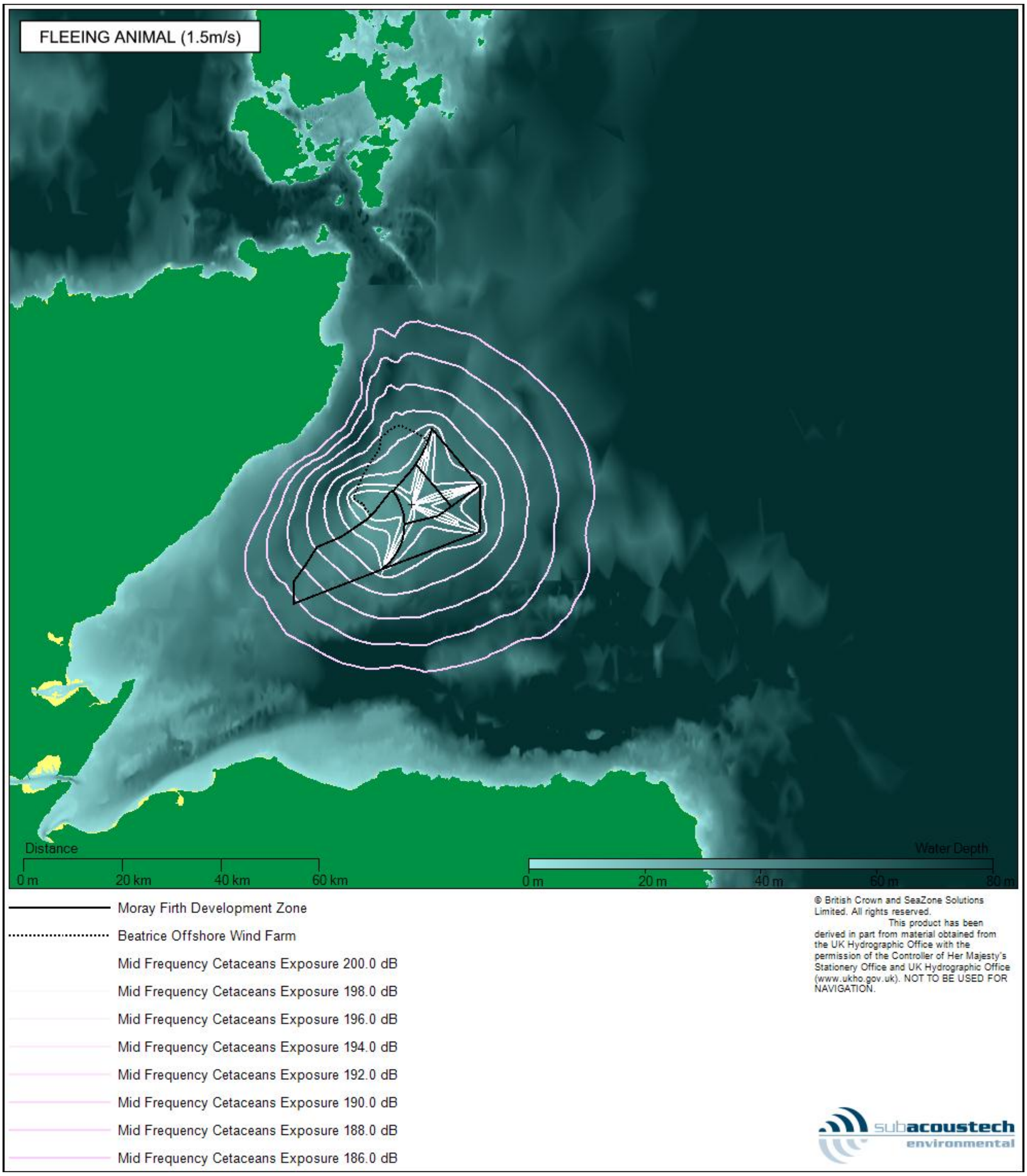


Figure A-222. Starting loci for fleeing Mid Frequency Cetaceans; two 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 on the MORL site and two 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6, A and B
Pile driving energy (kJ)	1200 and 2300
Species	Mid Frequency Cetaceans (Fleeing 1.5m/s)

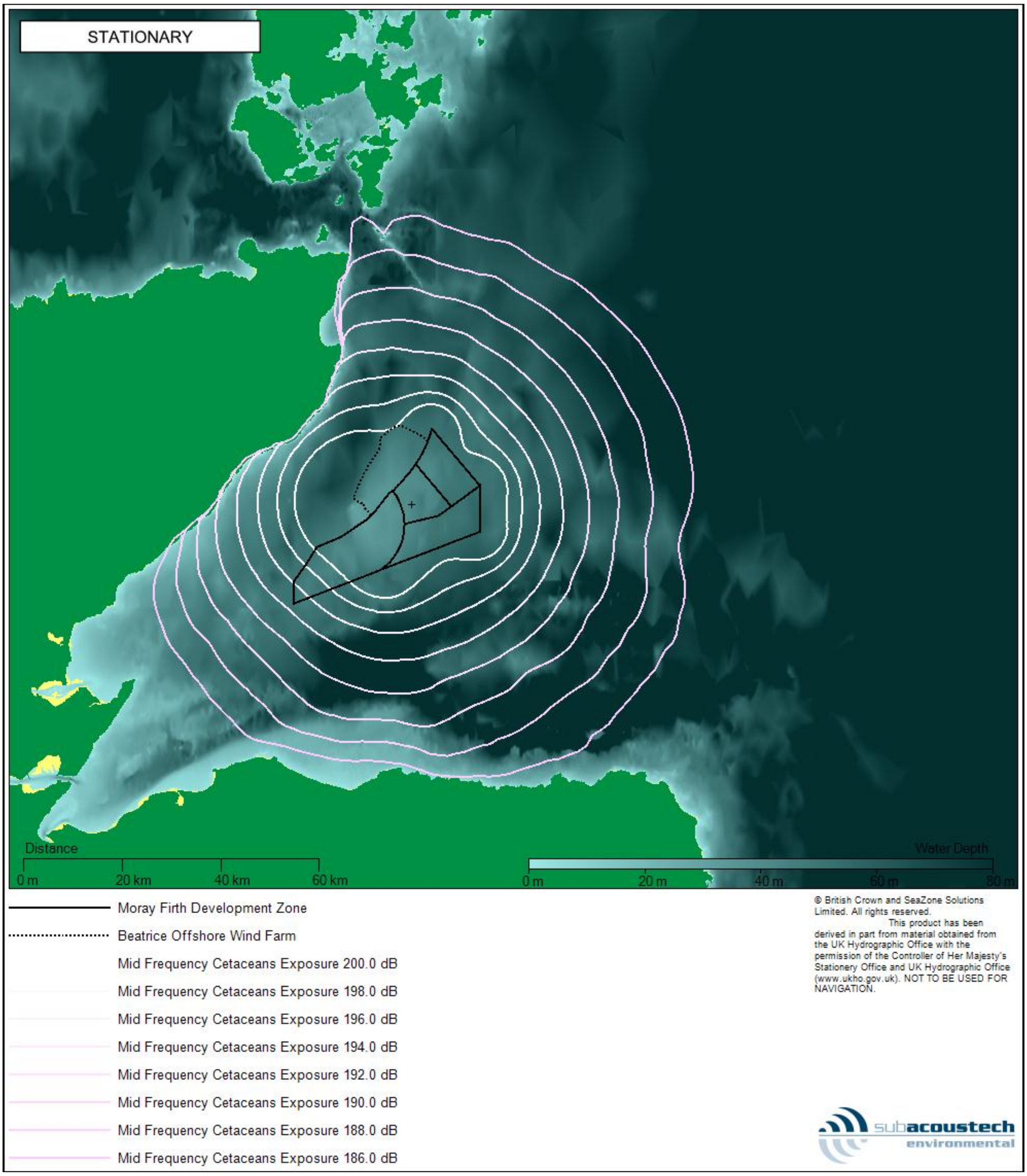


Figure A-223. Contours for stationary Mid Frequency Cetaceans; two 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 on the MORL site and two 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6, A and B
Pile driving energy (kJ)	1200 and 2300
Species	Mid Frequency Cetaceans (Stationary)

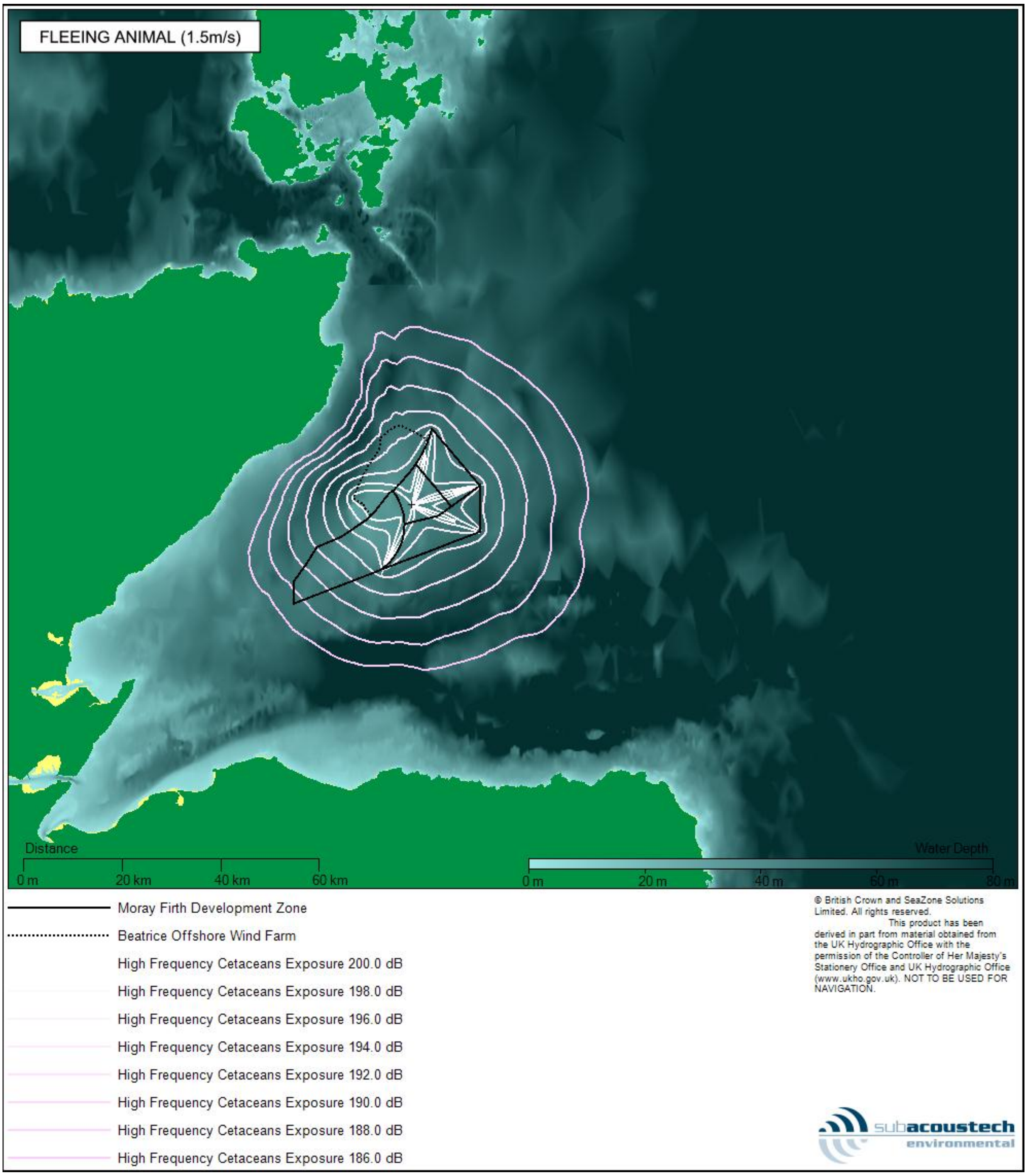


Figure A-224. Starting loci for fleeing High Frequency Cetaceans; two 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 on the MORL site and two 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6, A and B
Pile driving energy (kJ)	1200 and 2300
Species	High Frequency Cetaceans (Fleeing 1.5m/s)

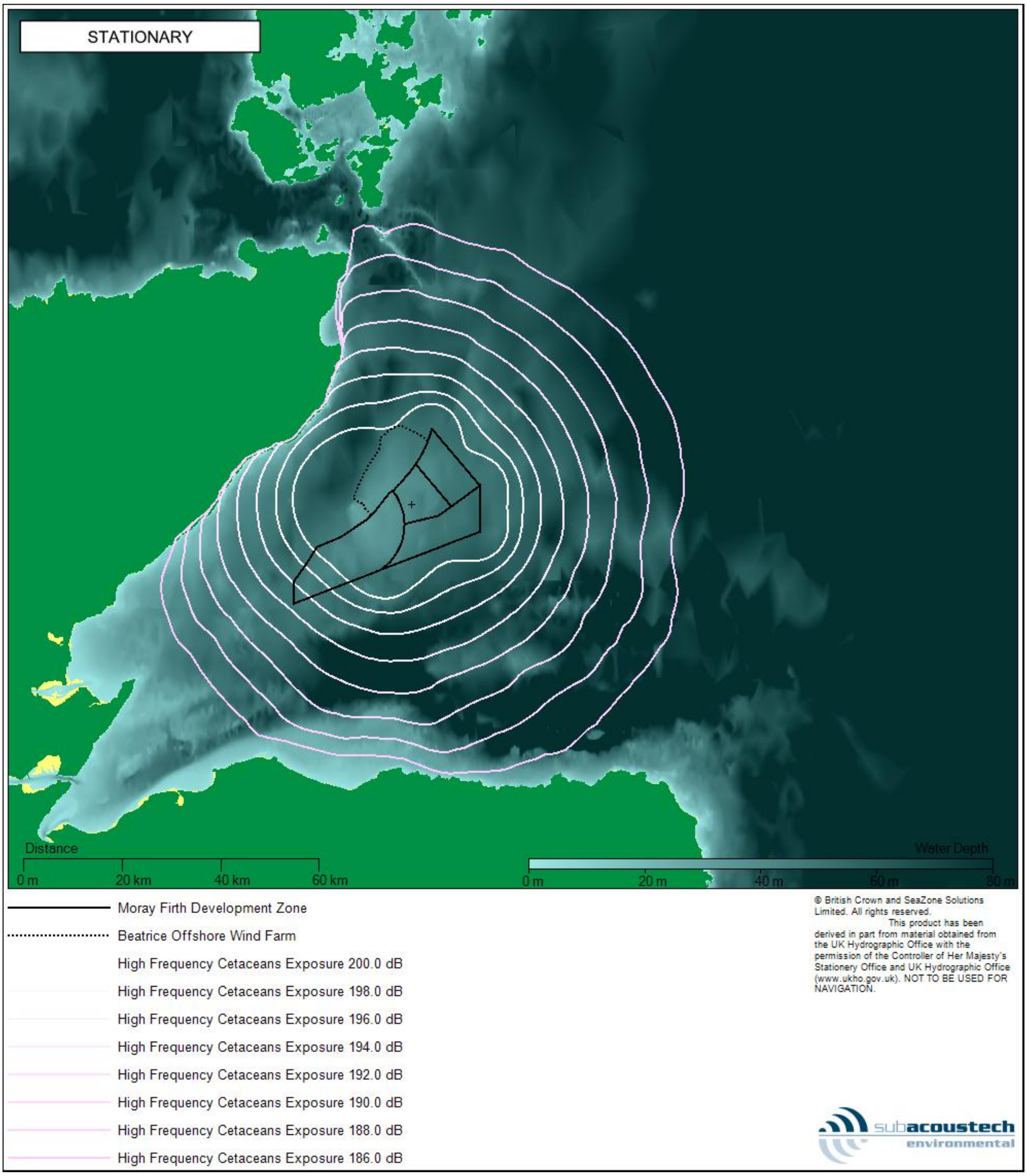


Figure A-225 Contours for stationary High Frequency Cetaceans; two 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 on the MORL site and two 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6, A and B
Pile driving energy (kJ)	1200 and 2300
Species	High Frequency Cetaceans (Stationary)

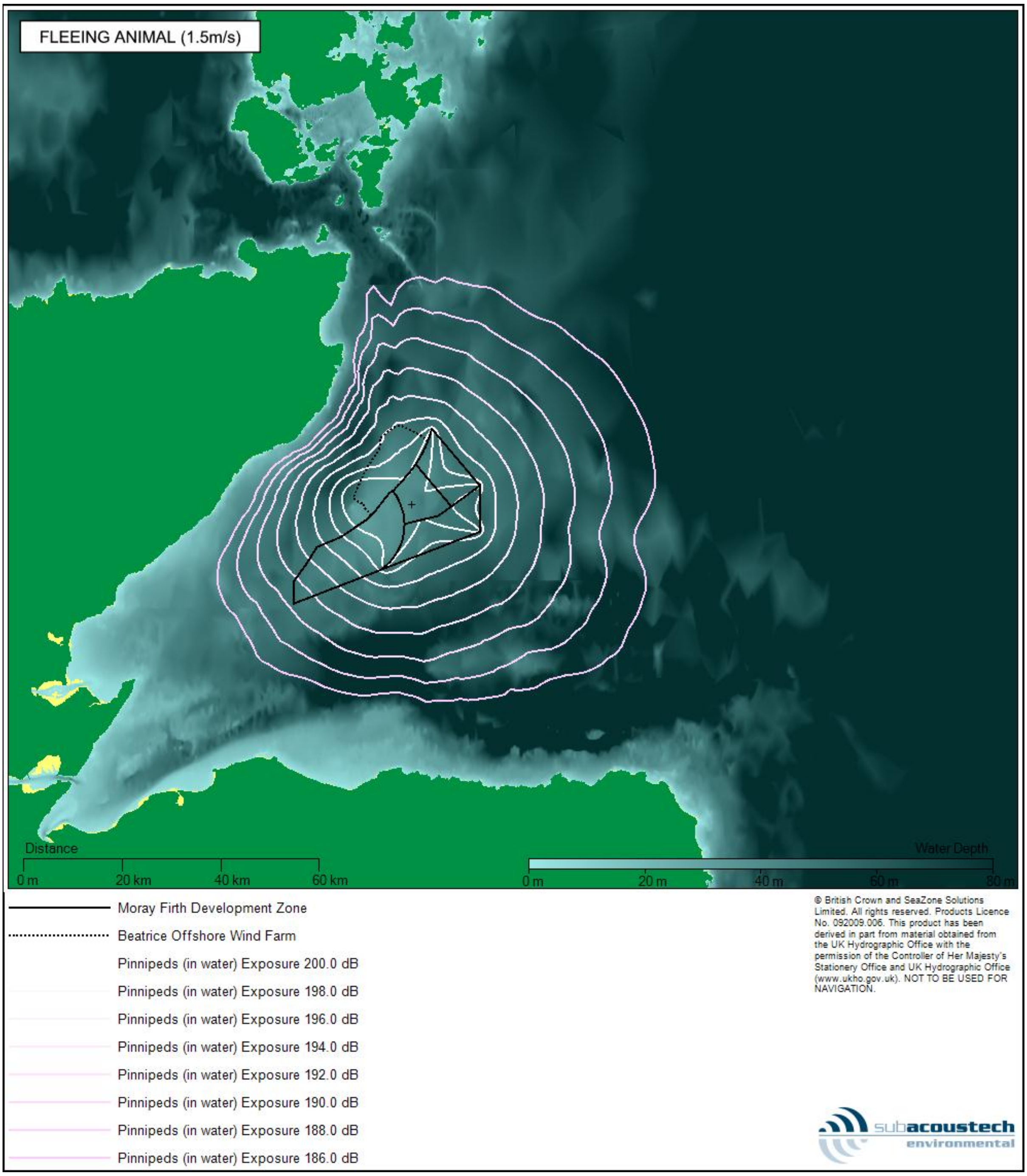


Figure A-226. Starting loci for fleeing Pinnipeds (in water); two 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 on the MORL site and two 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6, A and B
Pile driving energy (kJ)	1200 and 2300
Species	Pinnipeds (in water) (Fleeing 1.5m/s)

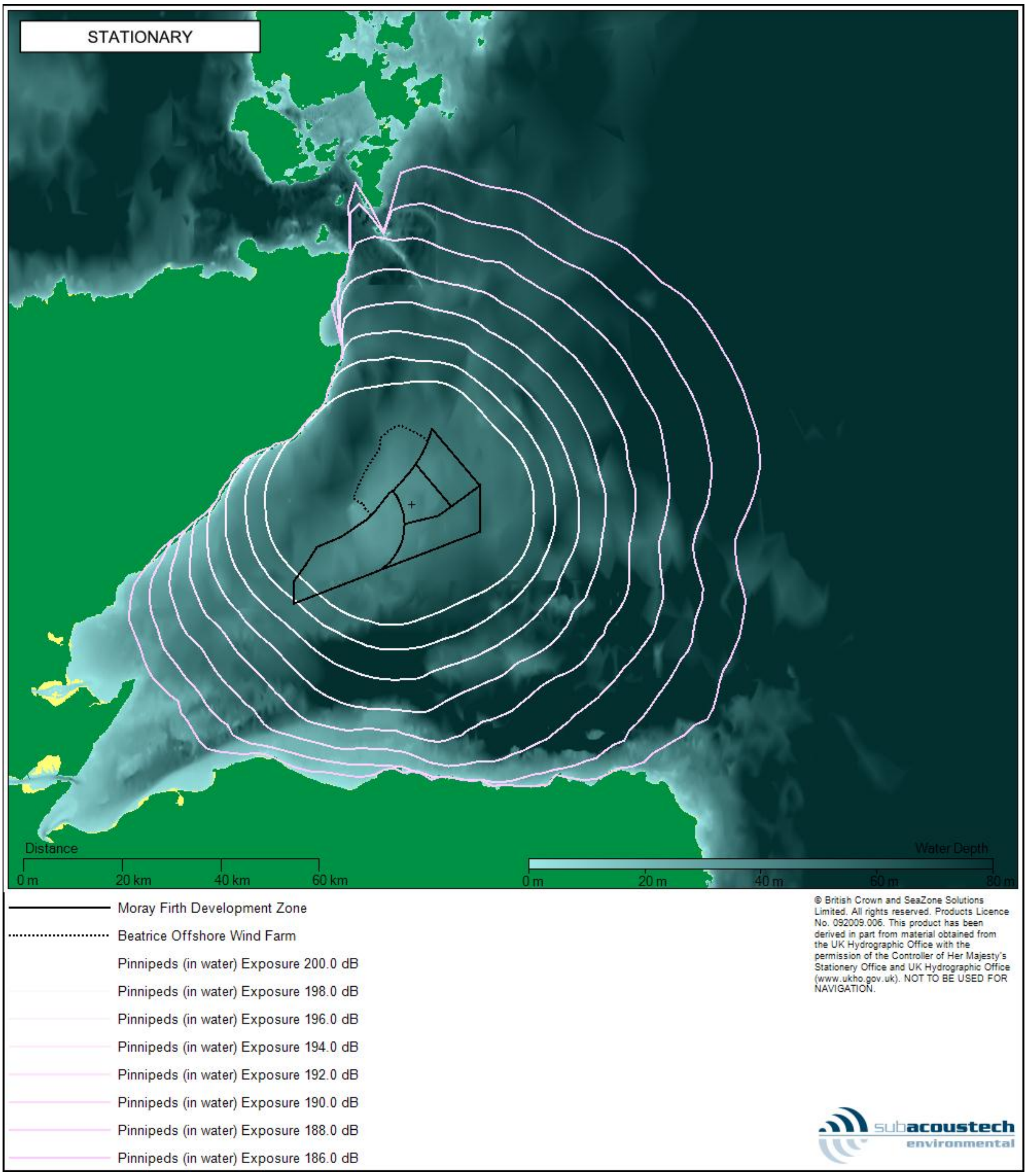


Figure A-227. Contours for stationary Pinnipeds (in water); two 2.5 m diameter piles being driven at locations 1, 2, 3, 4, 5 and 6 on the MORL site and two 2.4 m diameter piles being driven at locations A and B on the BOWL site simultaneously.

Pile diameter (m)	2.5 (MORL), 2.4 (BOWL)
Pile locations (see map, Figure A-13)	1, 2, 3, 4, 5 and 6, A and B
Pile driving energy (kJ)	1200 and 2300
Species	Pinnipeds (in water) (Stationary)

9.2.6.5 Results for meteorological mast installation impact.

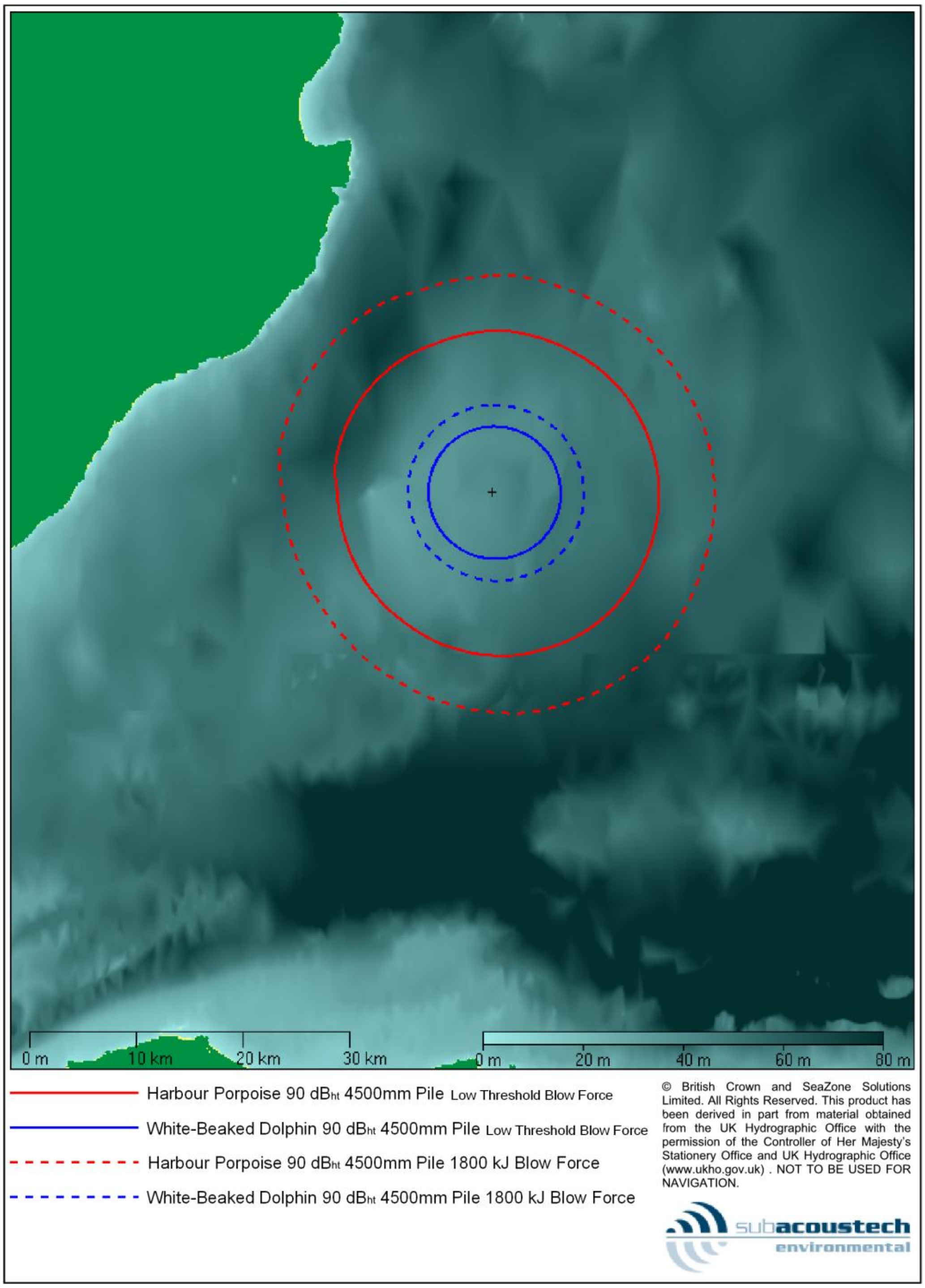


Figure A-72. Contour plot showing estimated 90 dB_{ht} behavioural impact zones for harbour porpoise and white-beaked dolphin during the installation of a 4.5 m diameter pile at both low threshold and maximum estimated blow forces for a meteorological mast.

Pile diameter (m)	4.5
Pile locations	Met mast
Pile driving energy (kJ)	720 and 1800
Species	Harbour porpoise and White-beaked dolphin

9.2.7 Summary

The impact of introduced noise as a result of impact piling in multiple locations during construction of the Telford, Stevenson and MaColl wind farms and associated OfTI has been calculated using the proprietary INSPIRE noise modelling software. In addition, the potential impact arising from the installation of a met mast has also been calculated using INSPIRE..

The range of noise emissions with reference to the different species has been calculated in respect of dB_{ht}(*Species*) and M-weighted dB SEL to assess the potential impact of the piling on marine species. This is both in terms of injury and behavioural response.

These calculated levels have been used to inform the fish and marine mammal impact assessments.

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