The Sizewell C Project

6.3 Volume 2 Main Development Site

Chapter 22 Marine Ecology and Fisheries

Appendix 22L - Underwater Noise Effects Assessment for Sizewell C: Edition 2

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Underwater noise effects assessment for Sizewell C: Edition 2

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Please note that the red line boundary was amended after this document was finalised, therefore figures in this document do not reflect the boundaries in respect of which development consent has been sought in this application. However, amendments to the red line boundary does not have any impact on the findings set out in this document and all other information remains correct.

Executive summary

The duration, spatial extent and magnitude of potential underwater noise impacts are dependent upon the engineering designs of specific Sizewell C coastal infrastructure. Edition 2 of this report reflects the most concurrent engineering design options, which include substantially updated designs as of September 2018 including a beach landing facility (BLF) replacing the marine offshore landing facility (MOLF). Additionally, the current edition incorporates the latest guidance for the assessment of noise impacts on marine mammals. Edition 2 version 2 incorporates comments and recommendations from regulatory consultees on version 1 of this report. Amendments also reflect discussions with regulatory bodies following the presentation of underwater noise impacts at the Marine Technical Forum on 1st May 2019 in Norwich.

Amendments in Edition 2 Revision 2 of this report include:

- Hammer energy conversions efficiency have been revised based on the latest available evidence and in line with industry standard practices for pilling activities.
- The incorporation of fleeing models for marine mammals in response to piling and dredging activities. For full transparency, results are presented for static (non-fleeing) and fleeing scenarios.
- Unexploded ordinance (UXO) have not been confirmed at the site, however, hypothetical detonation scenarios have been considered and impact ranges for fish and marine mammals modelled.
- At the request of the MTF, a method to determine the noise levels associated with potential increases in vessel traffic associated with deliveries to the BLF during the construction period has been considered.

The first edition of this report (in 2015) was based on the preliminary engineering designs, and on superseded noise exposure criteria, as such Edition 1 is now outdated and not relevant.

This report assesses the potential impacts of underwater noise arising from the construction and operation of the proposed new nuclear build (NNB) at Sizewell on marine mammal and fish species in the area. Construction of the proposed development would involve a number of anthropogenic activities in the marine environment. Noise generating activities include impact pilling for the installation of the BLF piles, dredging activities associated with the BLF access channel and placement of offshore infrastructure, and drilling the vertical connection shafts for the cooling water systems. Furthermore, in the case of UXOs being identified at the site and detonation is considered the most appropriate course of action, there is the potential for UXO clearance works.

A validated underwater sound propagation model and receptor specific noise exposure thresholds were applied to map auditory effect zones over which certain responses are predicted for marine mammals and fish. Effect zones are activity and receptor specific but may include mortality in the worst instance, permanent auditory damage (permanent threshold shift; PTS), temporary hearing impairment (temporary threshold shift; TTS) or behavioural changes. Noise mapping using a validated underwater sound propagation model and appropriate, peer-reviewed noise exposure thresholds have been applied to predict the areas within which such impacts may occur for different activities.

Each activity was assessed for both instantaneous and cumulative noise exposure, meaning that the results are scalable to various alternative scenarios. For marine mammals and fish, impact piling generated larger instantaneous and cumulative auditory effect zones than dredging or drilling.

The results from underwater noise assessments presented within this report, along with the conservation objectives of relevant sites and designated species will be used to inform Ecological Impact Assessments (EcIA) within the Environmental Statement (ES) and Habitats Regulations Assessment (HRA). It should be noted that this report details the results of auditory effect zones. Potential auditory effect zones will inform the ‘Impact Magnitude’ in an EIA context, the ES will consider the presence of marine mammal and fish, behaviour, physiology and ecology to determine the sensitivity (resistance and resilience) of receptors and

thereby the potential for adverse effects. Such effects may be a consequence of auditory damage or displacement and consideration will be paid to recovery following auditory damage or the duration of time it takes to return to an area following displacement.

A draft Marine Mammal Mitigation Protocol (MMMP) for impact pilling activities has been prepared for the DCO application with mitigation measures detailed (BEEMS Technical Report TR509, available as Appendix 22N of Volume 2). Underwater noise and MMMP conditions are likely to be a requirement on the deemed Marine Licence (DML).

Potential Marine Mammal Auditory Effect Zones

A total of 12 piles would have to be installed in the marine environment below mean high water springs (MHWS) for the BLF by impact pilling. The low energy[1] impact piling (worst-case 200 kJ hammer energy) associated with the BLF resulted in no instantaneous TTS for harbour porpoise of seals outside the standard 500 m marine mammal mitigation zone at the onset of piling. As such instantaneous impacts from piling are considered minimal.

The predicted cumulative auditory impact zones extended over wider areas. The PTS zone for stationary harbour porpoise extended up to 2.1 km offshore, while the stationary TTS zone exceeded 12 km offshore from the impact piling activity. The corresponding PTS and TTS ranges for stationary seals were smaller, at 0.3 km and 3.1 km, respectively. This indicates a risk of disturbance to marine mammals in the area if impact piling is carried out for extended periods. This cumulative assessment is precautionary in that it does not assume fleeing behaviour, and for effects to occur, the animal must remain within the effect zone for the duration of the piling activities (5 piles within a 24-hour period). When fleeing behaviour is incorporated into the model impact zones diminish. With fleeing included in the assessments, no auditory effect zones were predicted for the seal species. For harbour porpoise fleeing behaviours result in no predicted cumulative PTS. The largest TTS effect zone extended to 4.8 km (2179 ha) from the BLF piling location.

Dredging results in continuous noise sources and has lower impact ranges than piling. Construction dredging at the BLF is anticipated to take 2.1 days to complete and resulted in the largest dredging effect zones due to the precautionary 24-hour nature of the modelled activities. Despite the precautionary nature of the assessments PTS ranges were modest for highly mobile species. Dredging activities at the locations of the BLF resulted in PTS for stationary harbour porpoise extending to 1.7 km (394 ha) following 24 hours of continuous dredging. The corresponding PTS range for stationary seals was restricted to 110 m (5 ha) from the vessel. Cumulative TTS effect zones were 11,331 ha for stationary harbour porpoise and 969 ha for stationary seals. When fleeing was included in the dredging assessments, no auditory effect zones were predicted for seal. For harbour porpoise fleeing behaviours result in no cumulative PTS. The largest TTS range was within 1.4 km (241 ha) from the BLF dredging location, following 24 hours of continuous dredging.

A hypothetical in-combination dredge scenario was also considered. This involved the simultaneous dredging at the BLF and the cooling water intake, the two dredge locations with the largest individual effect ranges. The cumulative PTS effect zone increased by approximately 20% of the sum of the dredge activities individually but remained relatively small for highly mobile species; 620 ha for stationary harbour porpoise and 5 ha for stationary seals. TTS effect zones were smaller than the sum of the individual dredge activities due to spatial overlap; 14,359 ha for stationary harbour porpoise and 1,411 ha for stationary seals. When fleeing was included in the assessment of the in-combination dredge scenario, no PTS was predicted and only a TTS effect zone of 1,040 ha was predicted for harbour porpoise. No auditory effect zones were predicted for seal species.

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[1] 90kJ is the most likely required energy while 200kJ hammer energy is considered as a worst-case scenario, this is considered low energy in comparison to other marine activities. For example, impact piling for offshore wind farm installations may apply up to 5,000kJ maximum hammer energy.

Drilling will be required for the vertical connection shafts between the subterranean cooling water tunnels and the intake/outfall headworks. Drilling may also be required to install piles on the cooling water infrastructure to ensure seismic qualification of the headworks to the seabed. Drilling is a continuous (i.e. non-impulse) noise source and drilling activities are not predicted to present a risk to marine mammals. The predicted effect zones arising from drilling activities were negligible for seals (0.25 ha stationary TTS effect zone). For stationary harbour porpoise no PTS was predicted beyond 25 m and cumulative TTS was predicted to be restricted to within 1.3 km of the sound source (422 ha). Fleeing models were not considered further due to the limited extent of the potential auditory effect ranges.

Worst-case marine mammal auditory effect zone areas (ha) and maximum ranges (m) for each activity.		**Instantaneous**		**Stationary Cumulative (24 hour)**		**Fleeing Cumulative (24 hour)**	
		Harbour porpoise	Phocid seals	Harbour porpoise	Phocid seal	Harbour porpoise	Phocid seal
Impact piling (BLF): 90 kJ	PTS	27 m	6 m	1,297 m 190 ha	206 m 10 ha	No Effect	No Effect
	TTS	45 m	10 m	6,624 m 4,994 ha	1,882 m 430 ha	2,765 m 768 ha	No Effect
Impact piling (BLF): 200 kJ	PTS	41 m	9 m	2,081 m; 561 ha	303 m; 20 ha	No Effect	No Effect
	TTS	67 m	16 m	12,450 m; 10,223 ha	3,104 m; 1,064 ha	4,795 m 2,179 ha	No Effect
Drilling (cooling water intakes and outfalls)	PTS	No Effect	No Effect	<25 m; <0.25 ha	<25 m; <0.25 ha	No Effect	No Effect
	TTS	No Effect	No Effect	1,307 m; 399 ha	25 m; 0.25 ha	No Effect	No Effect
Construction Dredging for the BLF	PTS	No Effect	No Effect	1,657 m 394 ha	111 m 5 ha	No Effect	No Effect
	TTS	No Effect	No Effect	11,576 m 11,331 ha	2,975 m 969 ha	1,377 m; 241 ha	No Effect

Potential Fish Auditory Effect Zones

Injury and auditory impairment in fish were only substantive for impact piling and dredging.

The instantaneous impact zones for impact piling were small (the largest area for mortality and recoverable injury in hearing specialists had a radius of 27 m for the higher 200 kJ hammer energy scenario). In the cumulative assessment for piling activities, the auditory effect zones extended to around 800 m for TTS, 160 m for recoverable injury and 110 m for mortality. Any fish remaining in the vicinity of impact piling activities for the duration of the noise exposure, would be at risk of mortality or recoverable injury. Fish would have to remain within these distances from the source for a continuous period of 24 hours to sustain effects.

A risk of mortality, recoverable injury, and TTS is also predicted for dredging activities. Dredging at the BLF is predicted to have the longest daily duration, and as such the greatest potential for cumulative impacts. The largest ranges for mortality, recoverable injury, and TTS are 70 m, 160 m, and 1.85 km, respectively, for 24 hours of dredging activity at the BLF.

Due to the proximity of the proposed development in relation to designated Natura 2000 sites, including the Southern North Sea SAC (designated for harbour porpoise), and SPA sites designated for marine birds, the potential for noise to effect fish as a prey species was considered. Behavioural responses or displacement due to underwater noise has the potential to temporarily influence prey availability for designated species or influence the behaviour of migratory fish species. Behavioural response thresholds have not been formally assigned for assessment purposes and behavioural response ranges calculated here are based on literature observations of responses in sprat and herring to instantaneous sound sources (Hawkins and Popper, 2014). As such, behavioural assessments are subject to a lower degree of confidence than injury and auditory impairment where criteria are well defined.

The potential for behavioural responses was investigated by applying indicative response contours for instantaneous noise in sprat (a hearing specialist). In the 90 kJ hammer energy impact piling scenario the predicted response contour extends to an area of 525 ha, whilst in the 200 kJ hammer energy scenario the contour covers an area of 968 ha.

Behavioural responses to continuous noise sources are less well established and the assessment applied the same contours as for instantaneous sources. This is considered to be precautionary. Contours for drilling covered a negligible spatial area (<25 m), whilst dredging for the BLF caused the greatest continuous noise source area and extended to 2,352 m (682 ha).

The onset of behavioural responses is likely to be strongly influenced by behavioural context. Observations of startle responses in a hearing specialist species does not necesitate displacement from the area. This is particularly the case for species with lower auditory sensitivities or in response to continous noise sources. Behavioural response zones should therefore be treated as potential areas over which behavioural responses may occur rather than will occur.

Worst-case fish auditory impact zone areas (ha) and maximum ranges (m) for each activity.		**Instantaneous**	**Cumulative (24 hour)**
Impact piling (BLF): 90 kJ	Mortality	17 m	70 m 1 ha
	Recoverable Injury	17 m	111 m 3 ha
	[2]TTS	Not applicable	556 m 46 ha
	[1]Behaviour	2,111 m 525 ha	Not applicable
Impact piling (BLF): 200 kJ	Mortality	27 m	111 m; 2 ha
	Recoverable Injury	27 m	158 m; 4 ha
	[2]TTS	Not applicable	821 m; 88 ha
	[1]Behaviour	2,856 m 968 ha	Not applicable
Drilling (cooling water intakes and outfalls)	Mortality	No Effect	<25 m; <0.25 ha
	Recoverable injury	No Effect	<25 m; <0.25
	[2]TTS	Not applicable	<25 m; <0.25 ha
	[3]*Behaviour*	*< 25 m*	Not applicable
Dredging for the BLF	Mortality	No Effect	2 ha
	Recoverable injury	No Effect	6 ha
	[2]TTS	Not applicable	1,843 m 435 ha
	[3]*Behaviour*	*2,352 m* *682 ha*	Not applicable

Note:

1. Behavioural response is assumed to be triggered by instantaneous noise exposure (135 dB re 1 $\mu Pa^2 \cdot s$) and not cumulative exposure. Therefore, no assessments have been made for behavioural response to cumulative noise exposure (grey shaded boxes).
2. TTS is not defined for instantaneous noise exposure for fish (grey shaded box).
3. Behavioural response criteria for continuous sound sources are applied from instantaneous effect observations.

Hypothetical UXO Detonation Auditory Impact Zones

At the time of writing, no confirmed UXOs have been reported in the vicinity of the site. In the case UXOs were identified on site, and alternative disposal methods or relocation are not possible, underwater detonations may be required. Appropriate management actions and mitigation measured would be implemented to minimise impacts and secured through relevant condition(s) in the DML. Such measures would be highly dependent on the location and size of the UXO and would require review on a case-by-case basis. The results presented in this report should therefore be considered as indicative, worst-case scenarios for unmitigated impact ranges. Should UXOs be identified the most appropriate mitigation measures would be discussed with regulators and described within a dedicated MMMP.

Noise propagation modelling has considered three hypothetical explosive charges: 250 lb, 500 lb and 1,500 lb of TNT equivalent.

UXO detonations generate markedly larger instantaneous auditory effect zones than all other activities.

Harbour porpoise are the most sensitive species with the range for instantaneous permanent hearing damage (PTS) extending to 14 km in the case of an unmitigated 1,500 lb charge, 9.7 km in the case of a 500 lb charge, and 7.7 km for a 250 lb charge. Temporary auditory damage (TTS) may occur at a range of up to 25.6 km for harbour porpoise for the 1,500 lb change, reducing to 17.9 km and 14.2 km for the 500 lb and 250 lb charges, respectively.

Seal species are less sensitive, the largest effect range for PTS in seals was predicted to extend to 2.8 km for the largest 1,500 lb charge with TTS predicted to 5.1 km. The 500 lb 1.9 km from the source, for the 500 lb charge, and to 1.5 km for the 250 lb charge. Predicted TTS and PTS impact ranges for harbour and grey seals were 3,514 m and 1,907 m, respectively, for the 500 lb charge mass. For the 250 lb charge mass, the predicted impact ranges were 2,789 for TTS and 1,514 m for PTS

Potential auditory effect ranges for fish are substantially smaller than for marine mammals. The explosive charge mass of an unmitigated 1,500 lb had the largest effect ranges with maximum instantaneous mortality and potential mortal injury estimated to 897 m. For the smaller charge mass of 500 lb and 250 lb, the predicted mortality and potential injury range was 622 m and 493 m, respectively.

Increases in ambient noise

The potential increase in ambient noise levels associated with the BLF deliveries vessel traffic during the construction period is likely to be very modest and well within the typical variability at the site.

The expected additional operational noise generated with both power stations in operation represents only a small increase in the background noise levels at the site, which has sustained an operational nuclear power station for several decades (since 1966). It is therefore anticipated that the additional impact of the operational noise from Sizewell C will be minimal and adaptation will be rapid.

1 Introduction

EDF Energy proposes to construct a new nuclear power station, Sizewell C, adjacent to the existing operational station, Sizewell B, on the Suffolk coast. Cefas is tasked with completing the marine ecology Environmental Statement (ES) as part of the wider Environmental Impact Assessment for the proposed development. The results from underwater noise assessments presented within this report, along with the conservation objectives of relevant sites and designated species will be used to inform Ecological Impact Assessments (EcIA) within the marine ecology Environmental Statement (ES) and Habitats Regulations Assessment (HRA). Potential auditory effect zones will inform the 'Impact Magnitude' in an EIA context, the ES will consider the presence of marine mammal and fish, behaviour, physiology and ecology to determine the sensitivity (resistance and resilience) of receptors and thereby the potential for adverse effects.

This report assesses the potential effects of underwater noise from proposed activities at Sizewell on key marine mammal and fish species in the area. *Auditory effect zones* indicating modelled areas over which certain responses are predicted for different taxa (e.g. permanent auditor damage (permanent threshold shift; PTS), and temporary hearing impairment (temporary threshold shift; TTS)). Potential auditory effect zones are based on noise mapping using the validated Cefas model (see BEEMS Technical Report TR336) and appropriate, peer-reviewed noise exposure thresholds (NMFS, 2016, 2018). Guidance is also given on the adequacy of standard marine mammal mitigation measures (JNCC, 2010) for the possible piling activities at Sizewell C.

The report is structured as follows:

- Section 2: Provides background information on the proposed noise-generating activities, the assumed activity scenarios for cumulative assessment, and the known effects of noise on key species at Sizewell.
- Section 3: Describes the ambient noise levels observed during long-term monitoring at the site;
- Section 4: Summarises the sound propagation field survey and subsequent validation and optimisation of the Cefas noise model (presented in greater detail in BEEMS Technical Report TR336); describes the specific methodologies for modelling UXO detonations and vessel traffic noise.
- Section 5: Presents the predicted instantaneous noise levels resulting from each activity scenario.
- Section 6: The exposure thresholds for animal responses to underwater noise are detailed.
- Section 7: Presents the resulting maps of auditory effect zones from marine mammals and fish.
- Section 8: The implications of these auditory effect zones for mitigation measures and impact assessment are discussed.

The current Edition 2 of this report reflects the infrastructure engineering designs as of September 2018, which were substantially updated since the first edition of this document (dated 2015), especially regarding the details of piling and dredging activities. Additionally, the current edition incorporates the latest NOAA technical guidance (NMFS, 2018) for the assessment of noise impacts on marine mammals. The first edition of this report was based on the preliminary engineering designs, and on superseded noise exposure criteria (NMFS, 2013), and as such is outdated and not relevant.

The current revision of this report (Edition 2 Revision 2) incorporates comments and recommendations from regulatory consultees. Amendments also reflect discussions with regulatory bodies following the presentation of underwater noise impacts at the Marine Technical Forum on 1st May 2019 in Norwich.

Amendments in this report include:

- Hammer energy conversions efficiency have been revised based on the latest available evidence and in line with industry standard practices for pilling activities.

- The incorporation of fleeing models for marine mammals in response to piling and dredging activities. For full transparency, results are presented for static (non-fleeing) and fleeing animals.
- Unexploded ordinance (UXO) have not been confirmed at the site, however, hypothetical detonation scenarios have been considered and impact ranges for fish and marine mammals modelled.
- At the request of the MTF, a method to determine the noise levels associated with potential increases in vessel traffic associated with deliveries to the BLF during the construction period has been considered.

2 Background

2.1 Potential noise-generating activities at Sizewell C

During the construction and operation of the proposed development there are a number of activities that are expected to generate underwater noise levels which may require an impact assessment. These activities are summarised in Table 1.

Table 1 Summary of activities, noise sources and noise types for proposed activities at Sizewell C.

Activity	Possible methods	Noise type
UXO clearance	Detonation	Impulsive
Construction and installation of cooling water intake and outfall headworks including seismic qualification and drilling vertical connecting shafts.	Wet Drilled and dredging	Continuous
Construction of Beach Landing Facility (BLF) including piled deck and navigational channel	Dredging	Continuous
	Impact Pilling	Impulsive
Construction of auxiliary infrastructure including the Fish Recovery and Return (FRR) systems and the Combined Drainage Outfall (CDO)	Dredging	Continuous
Construction vessel traffic primarily associated with BLF deliveries.	N/A	Continuous
Operation	N/A	Continuous

The following sections provide a brief summary of each of these noise sources and the associated noise levels to be used in the assessment. As the final engineering designs have not been confirmed, a range of scenarios are defined in order to envelope the potential effects. In each instance, the instantaneous noise levels are described as well as the construction scenarios to be used to estimate the cumulative noise exposure per 24 hours.

2.1.1 UXO detonations

If UXOs are discovered at the site and alternative disposal methods or relocation are not possible, underwater detonations may be required. Underwater explosions generate some of the highest peak sound pressures of all anthropogenic underwater sound sources (von Benda-Beckman *et al.,* 2015), and are considered a high energy, impulsive sound source.

At the time of writing, no confirmed UXOs have been reported in the vicinity of the site, thus specific details are not available. The noise propagation modelling has therefore been conducted for three hypothetical explosive charges: 250 lb, 500 lb and 1,500 lb of TNT equivalent.

2.1.2 Impact Piling

Piles are driven into the seabed by means of a hydraulic hammer. The sounds from pile driving enters the water column directly because the impact of the hammer strike will create waves in the pile wall, which combine with the surrounding fluid (water) (Popper and Hastings, 2009). Furthermore, the pulse propagating down the pile may combine to the substrate at the bottom, causing waves to propagate outward through the seabed sediment (Popper and Hastings, 2009). Acoustic energy can radiate back into the water column from the seabed at some distance away from the pile (Erbe, 2009). The propagation of pile driving noise varies according to the seabed type (Hildebrand, 2009), pile characteristics (size, shape, length and material), the size and energy of the hammer, water depth, bathymetry, temperature and salinity (Erbe, 2009). Pile driving activities are of particular concern as they generate loud, impulsive sounds, at low frequencies and high source levels (Hildebrand, 2009).

The source level estimate for pile driving was calculated using an energy conversion model (De Jong and Ainslie, 2008), whereby a proportion of the expected hammer energy is converted to acoustic energy:

$$\boldsymbol{SL_E = 120 + 10log_{10}\left(\frac{Ec_0\rho}{4\pi}\right)} \tag{2.1}$$

where SL_E is the source level energy, E is the converted hammer energy in joules, c_0 is the speed of sound in seawater in m s^{-1}, and ρ is the density of seawater in kg m^{-3}.

This yields an estimate of the source level in units of Sound Exposure Level (SEL: dB re 1 µPa^2 s). This energy is then distributed across the frequency spectrum based on previous measurements of impact piling (Ainslie *et al.*, 2012), as shown in Figure 1.

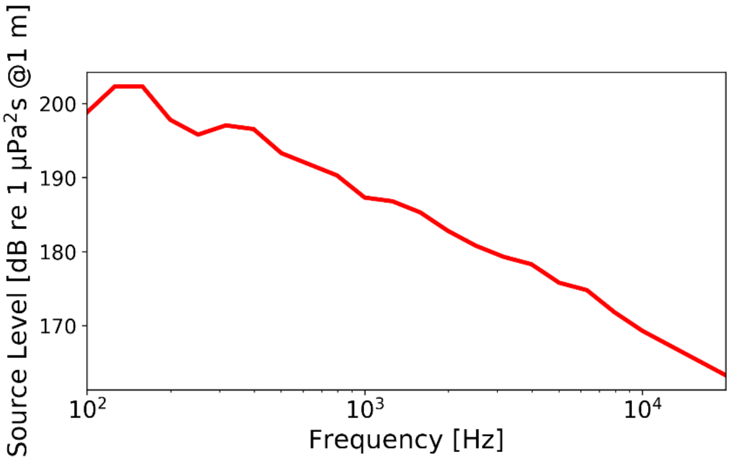

Figure 1 Source level spectrum of impact piling, derived from Ainslie *et al*., (2012).

The proposed Sizewell C development includes a beach landing facility (BLF), with piled deck that would require impact piling to install the piles. The BLF would be used to import rock armour, abnormal indivisible loads and marine freight during the construction phase as well as occasional deliveries during the operational phase. The BLF deck would require installation of four pairs of approximately 1 m diameter piles, two 1.5 m fenders and two 1.5 m mooring dolphins seaward of MHWS. Therefore, a total of twelve piles are within the marine environment below MHWS (BEEMS Technical Report TR311).

The expected piling parameters are 90 kJ for the hammer strike energy and 1500 strikes per pile. A maximum of 5 piles may be installed in a 24-hour period. It is assumed that piling will not occur concurrently, i.e. piles will be installed one at a time. To allow for engineering flexibility, a worst-case scenario is also considered, with a hammer strike energy assumption of 200 kJ.

The acoustic conversion efficiency factor (i.e. the proportion of the hammer energy converted to acoustic energy) was taken as 0.5%, as reported in review paper of Dahl *et al.* (2015) which cites several observational (Robinson et al., 2007; Dahl and Reinhall, 2013) and numerical (Zampolli et al., 2013) studies. It should be also noted that the more recent paper of Dahl and Dall'Osto (2017), which assessed new observations of the underwater sound filed arising from the installation of a 0.76 m diameter pile, in shallow water of 7.5 depth and using hammer strikes of 198 kJ, indicate a conversion factor of the hammer strike energy into water acoustic energy of approximately 0.1% - 0.15%. An acoustic conversion efficiency factor of 0.5% is therefore considered appropriately conservative for small diameter pilling activities in the shallow subtidal environment at Sizewell, and has been previously applied by Cefas for offshore windfarm EIAs.

The source levels in terms of single-pulse SEL are then 197.4 and 200.9 dB re 1 µPa^2 s, for the hammer strike energies of 90 kJ and 200 kJ, respectively.

2.1.2.1 BLF construction

The construction scenario assessed for the 24-hour cumulative exposure consisted of 5 piles per day being installed. As a precautionary assumption, the piling noise source was modelled at the position of the deepest seaward dolphin pile (264457.3 N, 647789.1 E) as this is the most favourable for sound propagation. A conservative estimate of water level has been applied in all model scenarios. The modeled water depth represents the average of Highest Astronomical Tide (HAT) and Mean High Water Spring (MHWS), which corresponds to 1.39 m ODN (1.26 m above the mean sea level at Sizewell). The seaward dolphin pile is situated in water depths of -3.38 m ODN. Therefore, cumulative assessments assume all piles are a water depth of 4.77 m (deepest pile + 1.39 m). This represents a highly precautionary stance that envelopes all piling scenarios.

2.1.3 Drilling

Drilling is a continuous (i.e. non-impulse) noise source. Very few studies have been published on the underwater noise emitted during drilling operations or on the potential effects of drilling noise, and these have mostly been from drillships (e.g. Greene, 1987; Kyhn *et al*., 2014). According to Kyhn *et al.,* (2014), drillships can be assumed to be the noisiest method of drilling in water. This is mainly due to the hull having good coupling with the water, leading to greater underwater sound radiation. Other methods, e.g. semi-submersible rigs and jack-ups (the method anticipated to be used at Sizewell), have most machinery well above the waterline so less underwater noise is generated.

Drilling at Sizewell is expected to be via a jack-up rig. Given that the drilling machinery will therefore be out of the water, noise levels are likely to be similar to those generated by a drilling platform. Source levels from an acoustic study of a drilling platform (Hannay *et al.*, 2007), were used for the assessment. The broadband source level was approximately 160 dB re µPa at 1 m in the range 10 Hz to 20 kHz. The source level spectrum is presented in Figure 2.

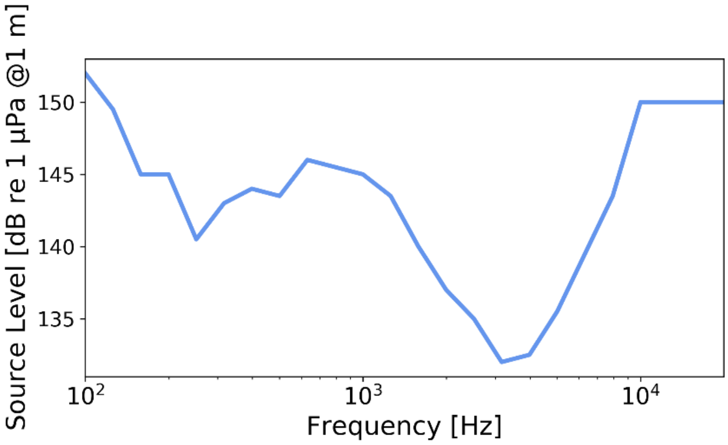

Figure 2 Source level spectrum of drilling, derived from Hannay *et al*., (2007).

2.1.3.1 Cooling water intakes/outfalls

Drilling will be required for the vertical connection shafts between the subterranean cooling water tunnels and the intake/outfall headworks. Depending on the ground conditions and geotechnical calculations, seismic qualification may be required and would be achieved through the installation of piles into the bedrock by drilling. Seismic qualification would only be required for the offshore cooling water infrastructure to secure the headworks to the seabed. Each headwork would have at least four piles, of approximately 16.6m in length and 2.1m in diameter. We asses three distinct scenarios, corresponding to drilling at the furthest offshore positions, for the northern intake, the outfall and the southern intake shafts, respectively. In all three cases, 24 hours of continuous drilling per day from 1 rig is assumed.

2.1.4 Dredging

Few data and few published characterisations of dredging-induced sound levels exist (e.g. Greene, 1987; CEDA, 2011). Overall, dredging activities emit sounds that are continuous in nature and comparatively low in frequency and intensity, although occasionally higher frequencies are emitted (CEDA, 2011).

Source levels of dredging were taken from a study by Robinson *et al.,* (2012), which measured noise levels generated by a large trailing suction hopper dredger (THSD) at a distance of 100 m. Broadband source levels were back-propagated under the assumption of spherical sound spreading, yielding a level of 187.5 dB re 1 µPa in the range 0.1-20 kHz, with acoustic energy evenly distributed below 2 kHz and peaking slightly at 125 and 400 Hz (see Figure 3). At Sizewell C, dredging at the location of the BLF is anticipated to be by plough dredger with cutter suction dredging anticipated at the locations of the infrastructure installations (FRRs, CDO, and cooling water infrastructure (BEEMS Technical Report TR480)). The assessment assumes source terms from a large THSD for all dredging activities.

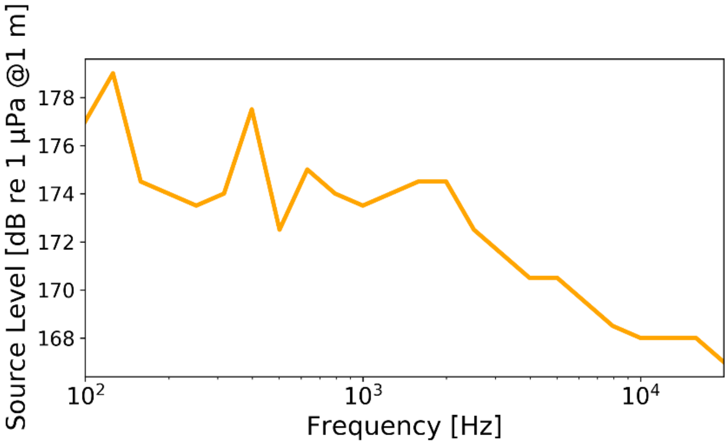

Figure 3 Source level spectrum of dredging, derived from Robinson *et al*., (2012).

2.1.4.1 Auxiliary infrastructure construction, cooling water intakes/outfalls, beach landing facility

Removal of surficial sediments is required prior to the installation of offshore infrastructure. Dredging activities for the construction of the auxiliary infrastructure, namely the two Fish Recovery and Return systems (FRR1 and FRR2), and the Combined Drainage Outfall (CDO) are anticipated to take 9.5 hours to complete in each case (with 12 cycles of 19 minutes of dredging, followed by a 30 minutes interval for repositioning). A conservative estimate of dredging near the south and north cooling water intake headworks is anticipated to take 8.5 hours (9 cycles of 30 minutes with 30 minutes intervals for repositioning), based on the largest intake headwork design. Dredging near the cooling water outfall structure will take 7 hours (9 cycles of 20 minutes with 30 minutes intervals for repositioning (BEEMS Technical Report TR480).

Dredging near the BLF is required to allow a navigable access channel and planar surface for delivery barges to come aground. Dredging is anticipated to take 2.1 days to complete, with 742 cycles of 1 minute of dredging, followed by 3 minutes of transit. Additionally, monthly dredging may be required for the maintenance of this navigable channel near BLF, with the same duty cycle parameters, but for a duration of 74 cycles or 5 hours in total.

Due to the site bathymetry and different durations for each dredging activity, seven different dredging scenarios were assessed assuming that within a 24-hour period, dredging activities take place at a single distinct location (FRR1, FRR2, CSD, south intake, north intake, outfall, and BLF). Additionally, as a precautionary assumption the in-combination effects of simultaneous dredging at the BLF and at the south intake was assessed as these were assumed to represent the worst-case scenarios for underwater noise.

In all cases continuous noise generation during the dredging activities was assumed (including during the repositioning interval). In the case of the BLF location, the noise was assumed the be continuous for 24 hours (the full length of the assessment period) and as such, provides a precautionary assessment.

2.1.5 Construction phase vessel traffic noise

At the request of the Sizewell Marine Technical Forum, Cefas developed a method to determine the noise levels associated with potential increases in vessel traffic associated with deliveries to the BLF during the construction period. The proposed routes for deliveries to Sizewell include transhipment from the UK ports of Great Yarmouth and Harwich, and from the Netherlands ports of Rotterdam and Vlissingen. The methodology for assessing the shipping noise levels is described in Section 4.3 and the results of the assessment are presented in Section 5.4.

2.1.6 Operational noise

Ambient noise recordings from Sizewell show that the existing nuclear power station at Sizewell B generates tonal noise that is 20 to 30 dB above background levels (results presented in Figure 13 and Figure 14 in Section 3.1). The most prominent tonal is at 50 Hz (the frequency of alternating current (AC) transmission in the UK) and there are also several harmonics and sub-harmonics at multiples of this frequency. It is therefore reasonable to expect that the new nuclear build at Sizewell C will also emit operational noise into the marine environment. However, the complexity of the noise generating mechanisms and propagation paths through the substrate and into the water column preclude predictive modelling of operational noise. Considerations on the additional noise generated with both power stations in operation, as seen in the context of the ambient noise at the site, are presented in Section 5.5.

2.2 Marine Mammal species of interest at Sizewell

Three marine mammal species are known to occur off Sizewell, these include the harbour porpoise, harbour seal and grey seal (BEEMS Technical Report TR324). The southern North Sea SAC adjacent to the proposed development is designated for harbour porpoise.

2.2.1 Harbour Porpoise

2.2.1.1 Hearing sensitivity of harbour porpoise

The harbour porpoise (*Phocoena phocoena*) has a wide frequency range of hearing: 250 Hz to 120 kHz (Kastelein and Jennings, 2012). Several audiograms for harbour porpoise derived from behavioural studies are shown below in Figure 4. These plots show the threshold of sound detection for specific frequencies.

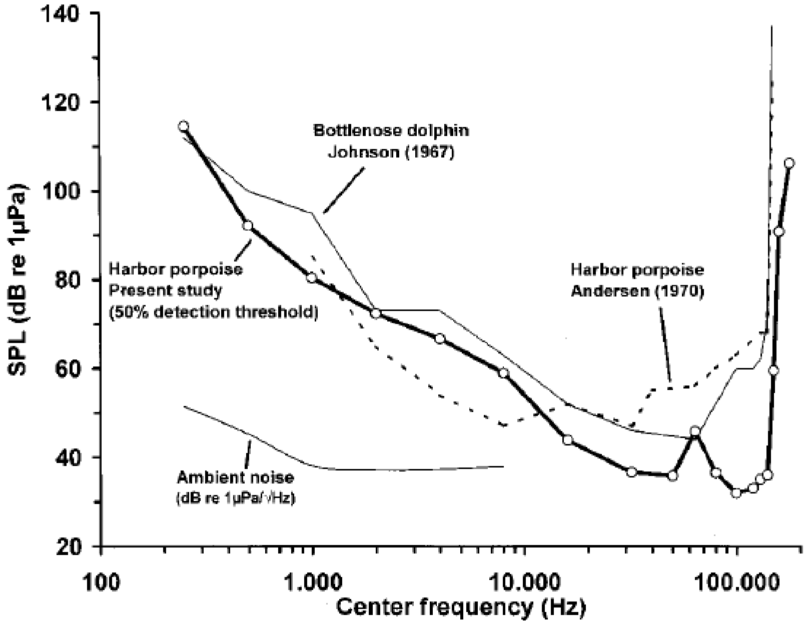

Figure 4 Audiograms of harbour porpoise from two separate studies (Kastelein *et al.*, 2002), with bottlenose dolphin audiogram from a third.

2.2.1.2 Known effects of noise on harbour porpoise

Controlled exposure experiments with captive harbour porpoises have demonstrated temporary hearing impairment (known as temporary threshold shift, TTS) using several fatiguing stimuli. Lucke *et al.,* (2009) studied TTS in response to a seismic airgun using an auditory brainstem response (ABR) technique, whereby the electrical signal sent from the ear to the brain is used to determine whether a sound has been detected. TTS was observed at peak-to-peak sound pressure levels (SPL_{p-p}) of 199.7 dB re 1 µPa, corresponding to a sound exposure level (SEL) of 164.3 dB re 1 µPa s. Aversive behavioural responses were observed at lower exposures: an SPL_{p-p} of 174 dB re 1 µPa and SEL of 145 dB re 1 µPa s. Kastelein *et al.,* (2012b) measured TTS in response to filtered white noise centred at 4 kHz, showing significant TTS at SELs in the range 151-190 dB re 1 µPa s, with recovery times (the time taken for normal hearing ability to return after exposure) of 4-96 minutes. Kastelein *et al*., (2013b) observed TTS induced by a tone at 1.5 kHz, resulting in modest TTS of 11-14 dB for a SEL of 190 dB re 1 µPa s and a recovery time of 96 min. This study also demonstrated that hearing abilities at the higher frequencies used for echolocation (around 125 kHz) were unaffected by the low-frequency (1.5 kHz) noise exposure.

Field studies have also demonstrated behavioural responses of harbour porpoises to anthropogenic noise. A number of studies have shown avoidance of pile driving activities during offshore wind farm construction (Brandt *et al.*, 2011; Carstensen *et al.*, 2006; Dähne *et al.*, 2013), with the range of measurable responses extending to at least 21 km in some cases (Tougaard *et al.*, 2009). Seismic surveys have also elicited avoidance behaviour in harbour porpoises, albeit short-term (Thompson *et al.*, 2013), and monitoring of echolocation activity suggests possible negative effects on foraging activity in the vicinity of seismic operations (Pirotta *et al.*, 2014).

2.2.2 Seals

2.2.2.1 Hearing sensitivity of harbour seal and grey seal

The audiograms of two harbour seals are shown below (Figure 5). Hearing abilities of the grey seal are likely to be similar.

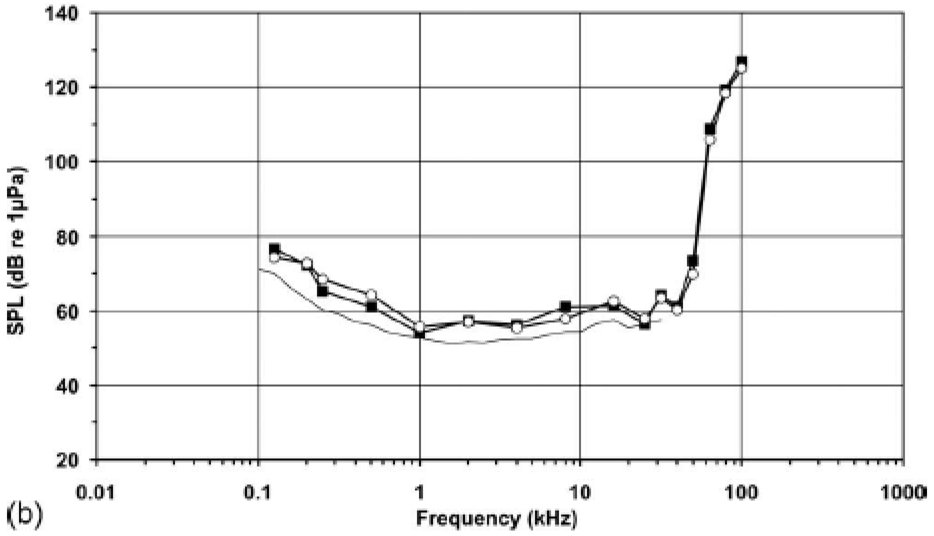

Figure 5 Audiograms based on 50% detection thresholds for pure tone and narrowband frequency-modulated (900 ms) signals obtained for two harbour seals (Kastelein *et al*., 2009).

2.2.2.2 Known effects of noise on harbour seal and grey seal

Several studies report TTS induced in captive harbour seals using filtered white noise (Kastak *et al.*, 1999, 2005; Kastelein *et al.*, 2012a), demonstrating the potential for auditory impairment from exposure to anthropogenic noise. For example, filtered white noise at 4 kHz with SELs of 170-190 dB re 1 µPa s resulted in up to 10 dB of threshold shift and a recovery time within around 60 minutes (Kastelein *et al.*, 2012a). In one study, a harbour seal was exposed to a much higher SEL of 199 dB re 1 µPa s, which resulted in 44 dB of TTS and recovery period of 4 days (Kastelein *et al.*, 2013a). This study also compared susceptibility to TTS between harbour porpoises and harbour seals, finding that harbour porpoises are more susceptible to temporary hearing impairment for white noise exposure at 4 kHz, even though hearing thresholds at this frequency are similar between the species. To our knowledge, no controlled exposure experiments have published TTS data for grey seals.

Few studies have documented responses of seals to underwater noise in the field. Koschinski *et al.,* (2003) conducted a playback experiment on harbour seals in which the recorded sound of an operational wind turbine was projected via a loudspeaker, resulting in modest displacement of seals from the source (median distance was 284 vs 239 m during control trials). Two further studies of ringed seals (*Phoca hispida*), which are closely related to both harbour and grey seals, have observed behaviour in response to anthropogenic noise: Harris *et al.,* (2001) reported animals swimming away and avoidance within ~150 m of a seismic survey, while Moulton *et al.,* (2003) found no discernible difference in seal densities in response to construction and drilling for an oil pipeline.

2.2.3 Potential effects of underwater noise from UXO clearance works on marine mammals

Von Benda-Beckmann *et al.* (2015) consider the primary potential effects of underwater explosions on individual harbour porpoise (although these will also be applicable to other species) to be:

1. Trauma (from direct or indirect blast wave effect injury) such as crushing, fracturing, haemorrhages, and rupture of body tissues caused by the blast wave, resulting in immediate or eventual mortality;
2. Auditory impairment (from exposure to the acoustic wave) either temporary or permanent; or
3. Behavioural change (i.e. disturbance to critical life functions such as feeding, mating, breeding, and resting).

Nevertheless, very few studies have demonstrated the effects of underwater noise from UXO clearance works on individual animals. Von Benda-Beckmann *et al.* (2015) modelled the impacts of underwater explosions on harbour porpoise at the population level. They estimated that the number of explosions that occurred in the Dutch Continental Shelf in 1 year, very likely caused 1,280 permanent hearing loss events (and possibly up to 5,450 events).

2.3 Fish species of interest at Sizewell

This report considers the effects of underwater noise on representative fish species at Sizewell. In selection of the fish species for assessment attention was paid to species sensitive to underwater noise, migratory species and species that form important prey items for designated birds with a marine component in their diet.

Herring (*Clupea harengus*), sprat (*Sprattus sprattus*) and anchovy (*Engraulis encrasicolus*) are abundant at Sizewell (BEEMS Technical Report TR345) and belong to the order Clupeiformes, which are considered to be particularly sensitive to sound. Specializations to enhance hearing vary widely among fish species (Webb *et al.,* 2008). The Clupeid fishes have an ancillary bubble of air in contact with, or near to, the ear and a pair of elongated gas ducts that extend from the swim bladder into the skull, enabling sound pressure to be transduced from the swim bladder to the ear. Hearing sensitivity is further increased by the presence of a compressible gas bubble in close proximity to the inner ear (Webb *et al.,* 2008). These species are selected based on there sensitivity to underwater noise and will provide a precautionary assessment for the wider fish community.

The proposed development is in proximity to the Alde-Ore Estuary SPA and Ramsar site, the Benacre to Easton Bavents SPA, the Minsmere-to-Walberswick SPA and Ramsar site and the Outer Thames Estuary SPA. No other relevant designated sites with associated marine prey species have been screened into the Sizewell shadow HRA for the Main Development Site. Designated bird species with a marine prey component to their diet include the breeding populations of sandwich tern (*Thalasseus sandvicensis*), little tern (*Sterna albifrons*), common tern (*Sterna hirundo*), lesser black-backed gull (*Larus fuscus*), and wintering populations of red-throated diver (*Gavia stellata*). Sprat, herring, anchovy, seabass (*Dicentrarchus labrax*) and whiting (*Merlangius merlangus*) form an important components of the diet of these species (BEEMS Technical Report TR431). Sprat, herring and anchovy are hearing specialists as described above. Seabass and whiting have lower hearing sensitivities (Section 6.2).

European eel has different auditory sensitivity and hearing apparatus to the hearing specialist species mentioned above. Eel may migrate past Sizewell, therefore the potential for mortality, hearing injury or behavioural effects. Such effects have the potential to disturb migration behaviour and is an important consideration for the ES. Other migratory species include shads (*Alosa alosa* and *Alosa fallax*), smelt (*Osmerus eperlanus*), as well as sea lamprey (*Petromyzon marinus*) and river lamprey (*Lampetra fluviatilis*), which do not possess a swim bladder. The criteria for assessing effects of underwater noise on these species is detailed in Section 6.2.

The hearing capabilities of selected species and known effects to underwater noise is briefly reviewed in the following sections.

2.3.1.1 Herring (*Clupea harengus*)

Table 2 Classification information for Atlantic herring.

Species	Class	Order	Family	Swim bladder present/absent
Atlantic herring (*Clupea harengus*)	Actinopterygii	Clupeiformes	Clupeidae	Swim bladder present

2.3.1.2 Hearing sensitivity of herring

Herring has a frequency range of hearing from 30 Hz to 4 kHz, with a hearing threshold of 75 dB re 1 µPa at 100 Hz (Enger, 1967; see Figure 6).

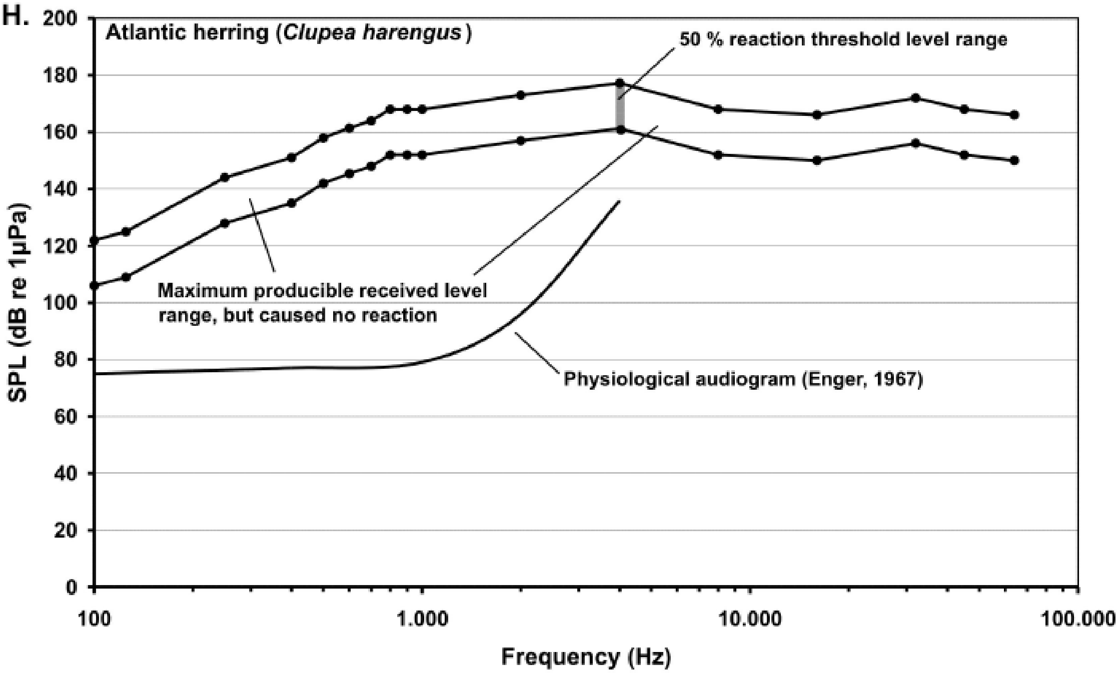

Figure 6 Audiogram of the Atlantic herring (Enger, 1967), as presented by Kastelein *et al.,* (2008). Also shown are received sound levels during a startle response study with Atlantic herring, where the only observable response in a school of 4 fish was at 4 kHz (Kastelein *et al.*, 2008).

2.3.1.3 Known effects of noise on herring

Kastelein *et al.,* (2008) investigated the behavioural reaction threshold levels for eight fish species from the North Sea, to tones of 0.1 – 64 kHz. For herring, the 50% reaction threshold occurred for signals at around 4 kHz (Figure 6). Blaxter and Hoss (1981) also exposed herring to 0.07-0.2 kHz signals and found startle responses at received levels between 122-138 dB re 1 µPa. The responses depended on the size of the fish. Furthermore, Olsen (1971) observed a noticeable behavioural response of herring to 0.1 kHz when the signal was 20 – 25 dB above ambient noise level.

Overall, herring have been shown to react directionally to sound stimuli (Kastelein *et al.*, 2008). Blaxter *et al.,* (1981) found that 2-40 ms signals were sufficient for herring to detect stimuli and localize sound sources. Thus, as observed by Kastelein *et al.,* (2008), the 900 ms stimuli were sufficiently long to cause a startle response in herring. Nonetheless, there remains a lot of uncertainty regarding the auditory capabilities of herring as well as the stimuli and circumstances that cause this species to react to sounds (Wilson and Dill, 2002; Doksæter *et al.*, 2012)

Doksæter *et al.* (2009) investigated the behavioural effect of mid-frequency sonar (1-2 kHz and 6-7 kHz) on free ranging over-wintering herring. No significant escape reactions were detected. It was concluded that the operation of sonar systems above 1 kHz and 209 dB re 1 µPa at 1 m (RMS) will not have any large-scale detrimental impact on overwintering herring populations. Doksæter *et al.,* highlight the need for further studies to demonstrate how herring may react to military sonars in different life history stages, as herring are known to change their behaviour in relation to their physiological, functional and motivational states. Similarly, later work by Doksæter *et al.,* (2012) revealed that netted herring did not significantly react to naval sonar signals (1.0 – 1.6 kHz and 168 dB re 1 µPa), and this lack of response is consistent for all phases of the yearly cycle. However, boat noise and fence strikes with a much lower SPL (most of the energy was <200 Hz) elicited both alarm and avoidance reactions in herring. This is probably due to the sudden onset, low-frequency and near field components of the sounds (Doksæter *et al.,* 2012). Furthermore, findings by Maes *et al. (*2004) showed that an acoustic deterrent system producing low frequency sound (20 – 600 Hz) had a significant effect on reducing herring from entering a power plant cooling intake. Average intake rates for herring decreased by 94.7%.

Also of interest, Sand *et al.,* (2008) comment on a previous publication by Ona *et al.,* (2007) which compares the avoidance reactions by herring to a silent “stealth” survey vessel and a traditional (non-quiet) research vessel. Surprisingly, findings revealed that avoidance reactions were stronger and more prolonged towards the “stealth” vessel. The otolith organs in the inner ears of fish are very sensitive to infrasonic particle acceleration. Thus, the herring may have responded to the near-field infrasonic particle motion which is generated by the moving hull of the ship. Sand *et al.,* (2008) recommend that possible effects of near-field particle motions associated with the local flow field generated by a moving vessel should be considered in future. The directionality of avoidance responses particularly should be compared and correlated to the directionality of such flow fields.

2.3.1.4 Sprat (Sprattus sprattus)

Table 3 Classification information for European sprat.

Species	Class	Order	Family	Swim bladder present/absent
European sprat (*Sprattus sprattus*)	Actinopterygii	Clupeiformes	Clupeidae	Swim bladder present

2.3.1.5 Hearing sensitivity of sprat

The sprat audiogram is likely to be similar to that of herring (Hawkins and Popper, 2014), shown in Figure 6.

2.3.1.6 Known effects of noise on sprat

Hawkins and Popper (2014) exposed schooling sprat to short sequences of repeated impulsive playback sounds at different sound pressure levels, to resemble that of a percussive pile driver. Observed behavioural responses included the break up of fish schools. The incidence of responses increased with increasing sound levels. The sound pressure levels to which the fish schools responded on 50% of the presentations were 163.2 and 163 dB re 1 µPa (peak-to-peak). The estimated single strike sound exposure level was 135 dB re 1 µPa^2 ·s. It is noted that such levels correspond to those recorded at tens of kilometres from an operating pile driver. Interestingly, sprat were particularly sensitive to sounds during the day, when they were aggregated into schools. At night however, when the schools had dispersed, the individual sprat no longer responded to the playback sounds. Hawkins and Popper (2014) question whether the break-up of sprat schools, in this instance, will result in lasting damage to their populations. Maes *et al. (*2004) showed that an acoustic deterrent system producing low frequency sound (20-600 Hz) had a significant effect on reducing sprat from entering a power plant cooling intake. Average intake rates for sprat decreased by 87.9%.

2.3.1.7 Anchovy (Engraulis encrasicolus)

Table 4 Classification information for European anchovy.

Species	Class	Order	Family	Swim bladder present/absent
European anchovy (*Engraulis encrasicolus*)	Actinopterygii	Clupeiformes	Engraulidae	Swim bladder present

2.3.1.8 Hearing sensitivity of anchovy

Anchovy showed a locomotor reaction to sound oscillations at frequencies from 6 – 36 kHz (Lebedev *et al.*, 1965, 1966, as cited in Kasumyan, 2005). No audiogram was available for *E. encrasicolus*. However, Figure 7 shows audiograms for a number of clupeid fishes, including the Bay anchovy (*Anchoa mitchilli*) which belongs to the same family as *E. encrasicolus*. The bay anchovy detected sounds at frequencies up to around 4 kHz (Mann *et al.*, 2001).

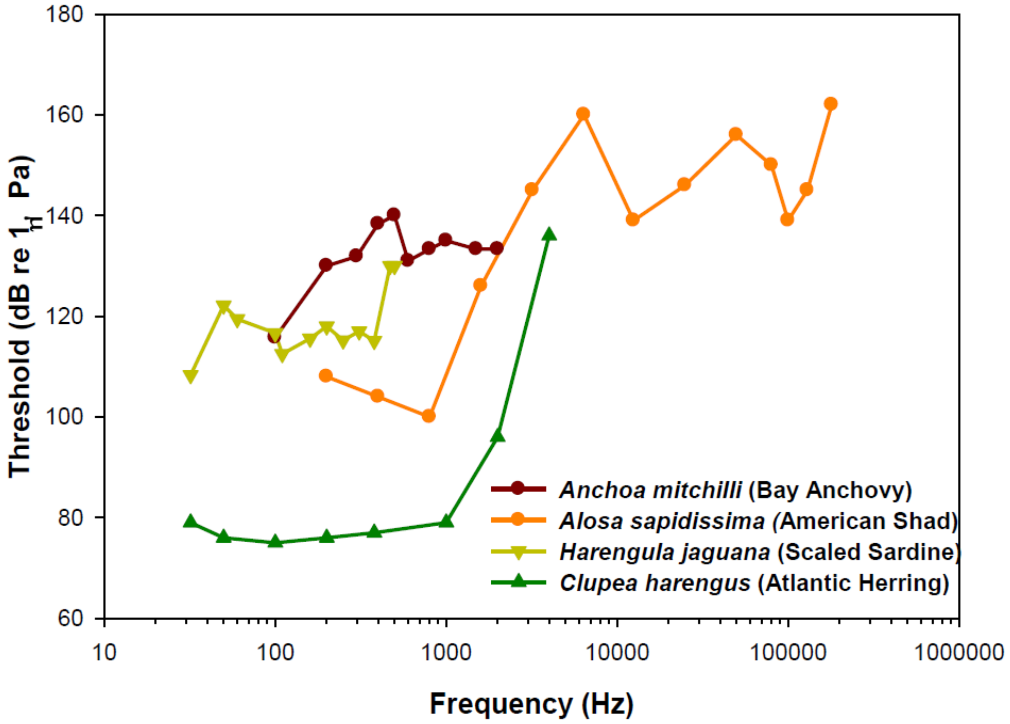

Figure 7 Audiograms of several clupeid fishes (Normandeau Associates, 2012). Thresholds for the Atlantic herring (Enger, 1967) were determined by monitoring microphonic potentials in the laboratory. Thresholds for bay anchovy (Mann *et al.*, 2001) were obtained using AEP methods, also in a quiet tank.

2.3.1.9 Known effects of noise on anchovy

To our knowledge, no effects of noise on *E.encrasicolus* have been recorded. Limited data however, are available for the northern ancovy (*Engraulis mordax*). Greenlaw *et al.,* (1988) investigated the effects of air gun seismic sources on the eggs, larvae and adult specimens of this species. The specimens were exposed to a series of air gun shots using devices of various chamber sizes, simulating realistic exposures of a seismic survey vessel. Greenlaw *et al.,* (1988) conclude that noticeable impacts on eggs and larvae of northern anchovy would result only from multiple, close exposures to seismic arrays. Histological examination revealed no evidence of gross morphological damage caused by exposure. Comparison of survival with control groups showed subtle effects in younger (2–4 days) larvae. Exposure of adults resulted in some damage to swim bladders, particularly for fish exposed at the surface where water particle motion effects are pronounced, but no significant effects on otoliths were observed.

Abbott *et al.,* (2005, cited in Popper and Hastings, 2009) found no behavioral effects of pile-driving sounds in caged northern anchovy. Similarly, no differences in mortality or pathology were observed between sound exposed and control animals. The caged fish were at a distance of 9.75 m from the source. However, the behavioural analysis was performed after the fish had been removed from test and results are thus difficult to interpret.

2.3.1.10 European seabass (*Dicentrarchus labrax*)

Table 5 Classification information for European seabass.

Species	Class	Order	Family	Swim bladder present/absent
European seabass (*Dicentrarchus labrax*)	Actinopterygii	Perciformes (perch-likes)	Moronidae (Temperate basses)	Swim bladder present

2.3.1.11 Hearing sensitivity of seabass

Seabass have no accessory hearing organs besides the swim bladder and otoliths (Neo *et al.*, 2014). A study by Lovell *et al.,* (2005) concluded that seabass have an inner ear configuration (a standard orientation pattern of hair cells in the saccule) similar to hearing generalists. This is in contrast with the sensory receptor patterns found in the hearing specialists Ostariophysi. The interaction between the otolith and hair cells in hearing generalists is initiated by particle motion and not sound pressure. With the aid of a pressure-to-displacement transducer, i.e. the swim bladder, the ear effectively becomes pressure-sensitive (Coombs and Popper, 1982).

Kastelein *et al.,* (2008) observed a behavioural response of seabass exposed to signals ranging between 0.1 and 0.7 kHz, at 0-30 dB above the hearing thresholds. The fish did not react to the maximum received levels that could be produced for the higher frequency signals (Figure 8). The study concluded that this species hears best below 700 Hz (Kastelein *et al.*, 2008).

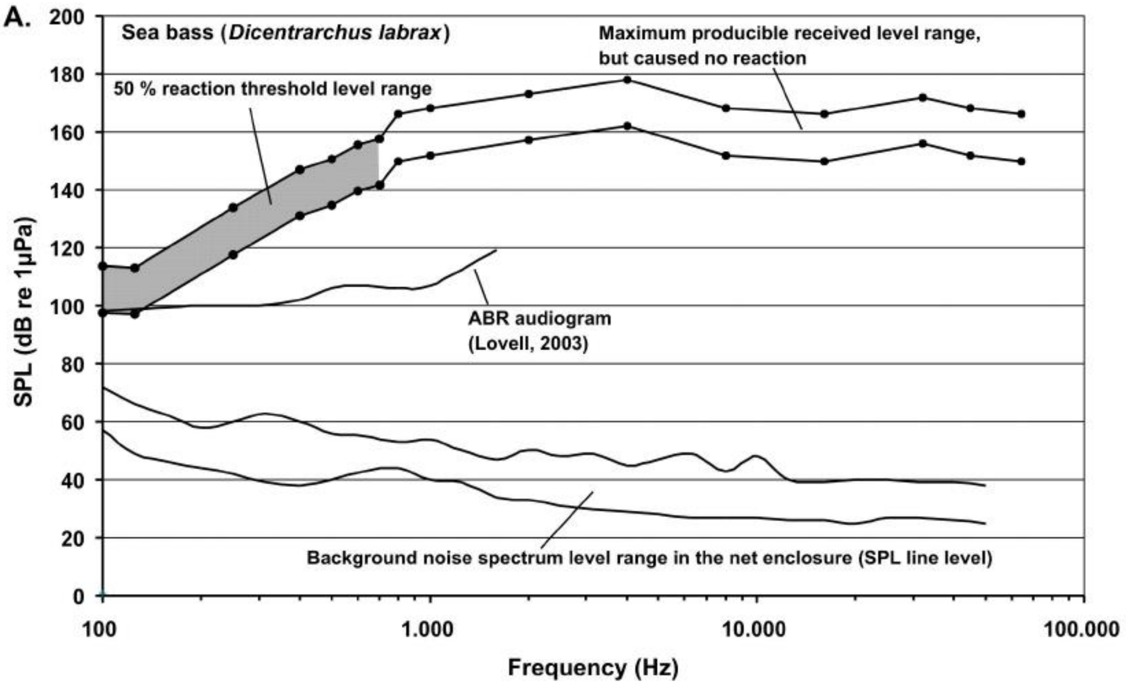

Figure 8 Seabass audiogram derived from auditory brainstem response (ABR) measurements, as reproduced in (Kastelein *et al.*, 2008). Also shown are received sound levels during a startle response study with seabass, where responses were observed at and below 700 Hz (Kastelein *et al.*, 2008).

2.3.1.12 Known effects of noise on seabass

Debusschere *et al.,* (2014) investigated the impact of piling noise on juvenile seabass. The fish were exposed to strikes with a sound exposure level (SEL) between 181 and 188 dB re 1 µPa^2.s, as close as 45 m from the actual piling activity. The cumulative SEL ranged from 215 – 222 dB re 1 µPa^2, while the peak SPL was between 210 and 211 dB re 1 µPa. No differences in mortality were observed between exposed and control (no exposure to pile driving sounds) fish groups. Further, no differences in the delayed mortality up to 14 days after exposure between the two groups were observed.

Research on acoustic stress induced by an air gun showed that blast did cause biochemical responses in seabass. The variation in cortisol, glucose, lactate, AMP, ADP, ATP and cAMP concentrations in different tissue were primary and secondary responses to the noise. The biochemical parameters (with the exception of cAMP) had returned to physiological values within 72 h after the acoustical stress exposure and no mortality was observed (Santulli *et al.*, 1999). Furthermore, Buscaino *et al.,* (2010) exposed seabass to a 0.1-1 kHz linear sweep (150 dB re 1 µPa (RMS)) to assess the noise-induced motility reaction and haematological responses. Findings revealed a significant increase in motility in addition to an increase in haematocrit and lactate levels in the fish. Buscaino *et al.,* (2010) observed a linear correlation between motility and blood parameters in seabass exposed to the noise. It was concluded that acoustic stimulus produced intense muscle activity, thus influencing the swimming activity of the fish.

Findings by Neo *et al.,* (2014) also suggest that the temporal structure of sound is highly relevant in noise impact assessments. For instance, intermittent sounds (e.g. pile driving) may have a stronger behavioural impact on fish in comparison with continuous sounds (e.g. drilling), even though continuous sounds may have higher total accumulated energy. Neo *et al.,* exposed groups of seabass to four different sound treatments, which were either intermittent or continuous. Although similar behavioural changes were observed for all sound treatments, intermittent exosure resulted in considerably slower behavioural recovery to pre-exposure levels compared to continuous exposure.

2.3.1.13 European eel (Anguilla anguilla)

Table 6 Classification information for the European eel

Species	Class	Order	Family	Swim bladder present/absent
European eel (*Anguilla anguilla*)	Actinopterygii	Anguilliformes	Anguillidae - Freshwater eels	Swim bladder present

2.3.1.14 Hearing sensitivity of the eel

The otolith hair cells in the eel have the same distribution observed in other fish species which rely on additional structures to enhance hearing ability, like connections with the swim bladder or with other gas filled vesicles in the skull (Popper and Coombs, 1982); however, this connection is not present in eels. In eels, the distance between the ear and swim bladder is very long (Jerkø *et al.*, 1989).

Information on eel hearing is limited and few studies have investigated sound detection in the eel. There is evidence that the upper audible frequency limit in the eel is around 300 Hz (Jerkø *et al.*, 1989), and there is a continuum of hearing sensitivity down into infrasound (<20 Hz) (Slabbekoorn *et al.*, 2010), as shown in Figure 9, with particle motion being more important at low frequencies and sound pressure at higher frequencies.

In addition to the ear, the lateral line organs of the eel can detect vibrations but are not activated by tones above 150 Hz (Tesch, 2003). Many fish species are able to detect sounds at very low frequency (by the otoliths in the inner ear and the neuromasts in the lateral line). Adult eels show a startle response to infrasound of 11.8 Hz and would avoid areas acoustically fenced by this sound frequency (Sand *et al.*, 2000) (see below for further detail). This sensitivity to low frequency has been explained as an adaptive response to avoid predators as the hydrodynamic sound that fish make when they swim are mostly at low frequency (Sand *et al.*, 2000; Karlsen *et al.*, 2004). The overlap in frequency response of the otolith and the lateral line covers the range 50-150 Hz (Popper and Higgs, 2009). However, the lateral line is only able to detect water vibrations at short distances (in the near field; Popper *et al.*, 2003), where there are large local variations in flow relative to the fish body. In contrast, the ear is also sensitive to sound originating further away, i.e. near-field and far-field (Hunt *et al.*, 2013).

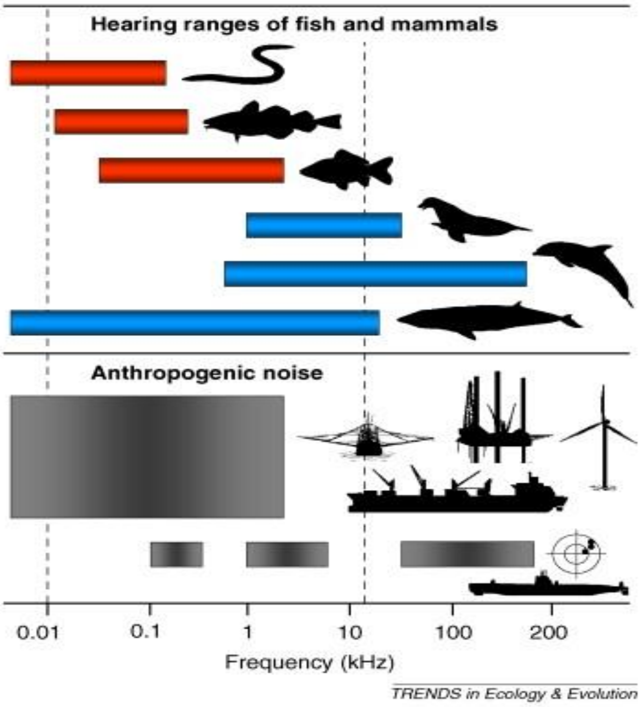

Figure 9 Hearing ranges of selected fish and mammal species, illustrating the variety among taxonomic groups (Slabbekoorn *et al.*, 2010). The vertical dashed lines demarcate the human hearing range in air. Fish species represented are (from top): European eel, Atlantic cod, and goldfish.

2.3.1.15 Known effects of noise on the European eel

There are very few studies to date concerning how exposure to anthropogenic noise might affect eels. Thus, very little is known about the impacts of noise on eels. Findings by Sand *et al.,* (2000) showed avoidance responses of European eels migrating through a river, to intense infrasound (emitted sound frequency of 11.8 Hz). This study was an attempt to develop an efficient acoustic fish fence. Such devices are used to prevent fish from entering hazardous areas, such as cooling water intakes of thermal power stations and inlets to hydroelectric power stations. Findings by Maes et al. (2004) showed that an acoustic deterrent system producing low frequency sound (20 – 600 Hz) had an insignificant effect on reducing *A. anguilla* from entering a power plant cooling intake. Eels held in observations tanks also displayed startle behaviour and prolonged stress in response to infrasound. A startle response study (Kastelein *et al.*, 2008) was unable to induce a response in a school of 10 fish using tonal sounds at the levels indicated in Figure 10.

Simpson *et al.,* (2014) investigated whether the behaviour and physiology of juvenile eels was affected by playback noise of a ship passing through a harbour, in comparison with control conditions from the same harbour without ship noise. The results demonstrated that the acoustic disturbance from a passing ship had a detrimental effect on juvenile eel antipredator behaviour with eels exposed to the noise being less likely to respond to the presence of a predator. This study also found that exposure to noise caused changes in spatial behaviour (decrease in lateralization) and in physiological state (increase in opercular beat rate and oxygen consumption).

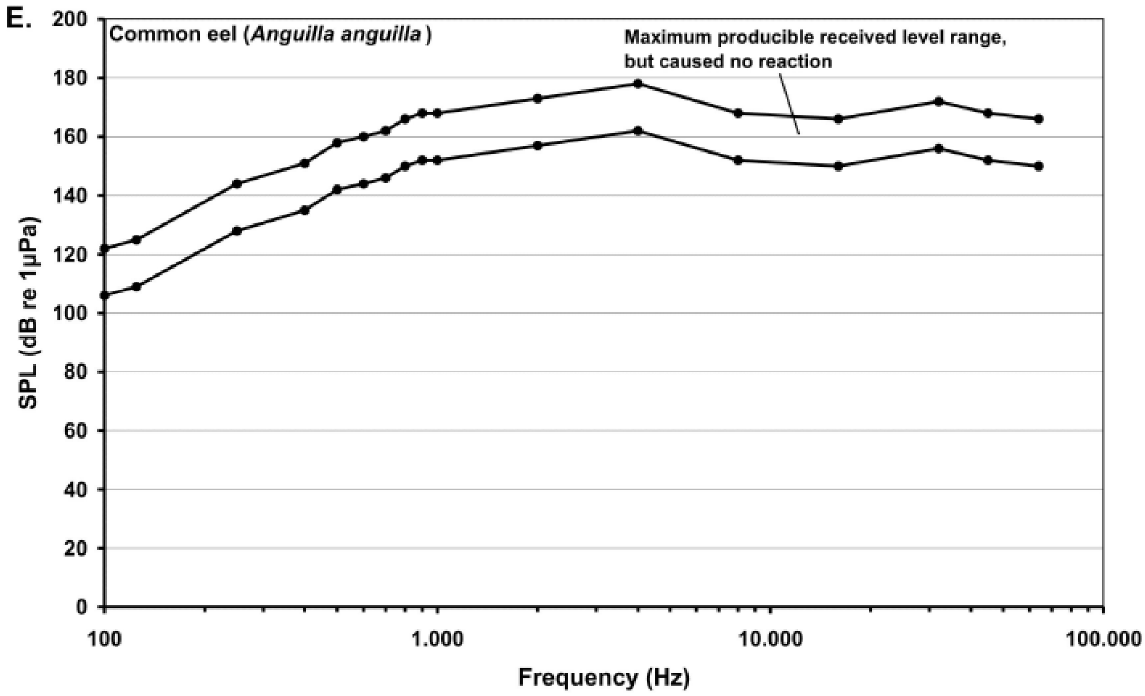

Figure 10 Maximum received levels generated during a startle response experiment with the European eel (Kastelein *et al.*, 2008). No reactions were observed in the school of 10 fish.

Other studies have looked at whether operating offshore wind farms alter the migration pattern in European eel due to noise disturbance. Operating turbines are known to produce noise below 1,000 Hz and at intensities (SPL) well above ambient noise levels (Wahlberg and Westerberg, 2005), which will be detectable by eels. Andersson *et al.*, 2012 suggest that migrating *A. Anguilla* were not notably affected by noise from a wind farm located in the Sound (between Denmark and Sweden) and did not shift their migration path before or after construction. Their swimming speed did not differ significantly between monitored areas.

3 Ambient noise baseline

To understand the variability in baseline ambient noise levels at Sizewell, long-term passive acoustic recordings were made over a two-year period adjacent to Sizewell B (see Figure 11). This extensive monitoring programme enabled a thorough characterisation of ambient noise conditions at the site, and the derivation of representative ambient noise levels for the noise effects assessment.

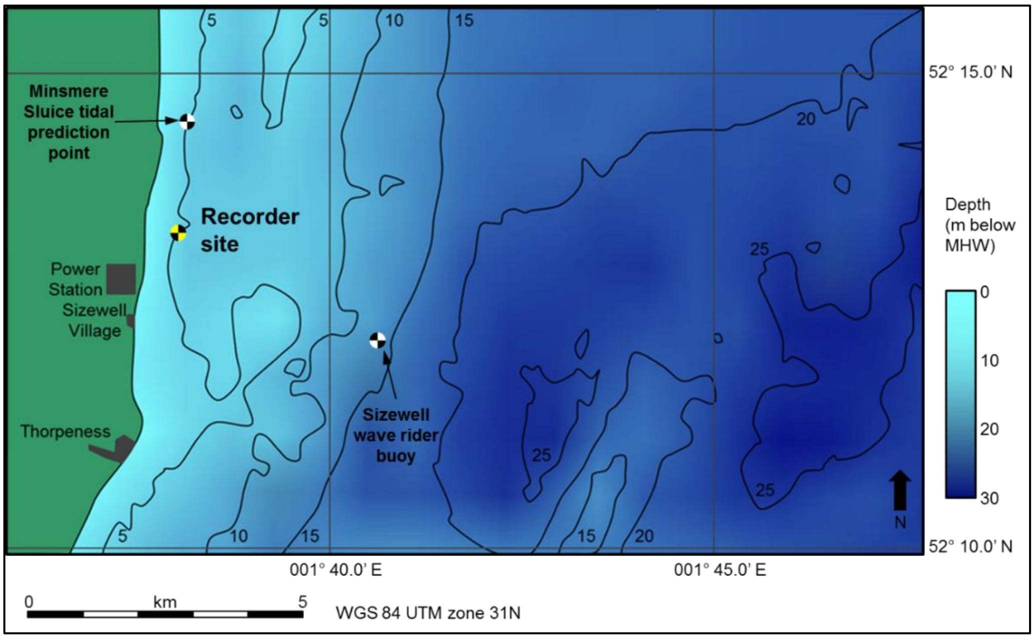

Figure 11 Location of recording site and local bathymetry (BEEMS Technical Report TR323). Recorder position: 52° 13.310'N 001° 37.965'E.

The programme gathered 481 days of continuous ambient noise recordings at Sizewell between September 2011 and September 2013 (see BEEMS Technical Report TR323 for details). Figure 12 shows the deployment periods when recordings were successfully made. The field work was carried out by a subcontractor (JASCO Applied Sciences) and the raw data provided to Cefas for subsequent analysis.

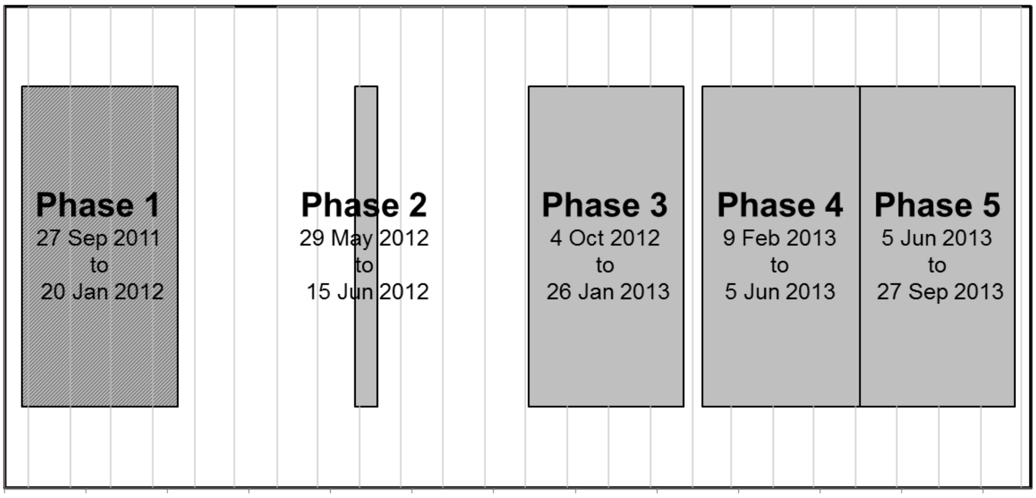

Figure 12 Ambient noise recording periods at Sizewell (BEEMS Technical Report TR323).

3.1 Analysis of long-term ambient noise monitoring at Sizewell

The long-term recordings at Sizewell revealed a baseline soundscape characterised by operational noise from the existing power station at Sizewell B, surf noise (waves breaking on the beach), and noise from passing fishing vessels (BEEMS Technical Report TR323). Figure 13 shows a long-term spectrogram of 7 months of data from 2013. The tonal noise from Sizewell B is clearly visible as a horizontal band at 50 Hz and harmonics (and sub-harmonics) at multiples of this frequency. The vertical bands at low-frequencies are pseudo-noise induced by tidal flow: this is a by-product of turbulence around the hydrophone and does not represent noise that exists in the environment (Merchant *et al.*, 2015).

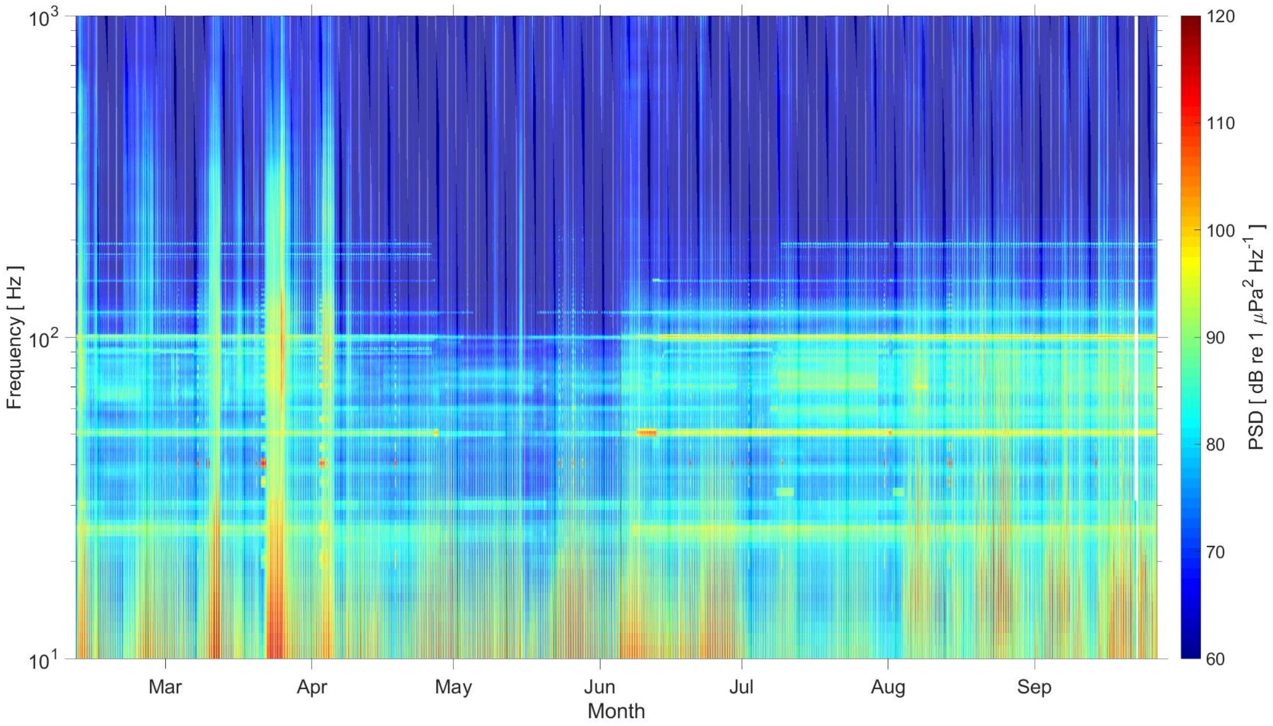

Figure 13 Example long-term ambient noise spectrogram from Sizewell: 10 Feb – 27 Sep 2013. 50-Hz tonal sounds and associated harmonics are operational noise from existing power station at Sizewell B. Vertical bands at low frequencies are pseudo-noise caused by tidal flow.

A statistical analysis of this data is presented in Figure 14, showing the percentiles, RMS level (mean level calculated prior to decibel conversion), and spectral probability density across the frequency spectrum. This analysis illustrates the variability in noise levels: there was typically a 30-40 dB spread between the first and 99th percentiles, and the mode was closely associated with the median level above ~20 Hz. The plot also demonstrates how unrepresentative the RMS level is of the overall distribution: the RMS level is the standard method of averaging underwater noise levels, but is heavily weighted towards the highest noise levels as it is computed before conversion to decibels (Merchant *et al.*, 2012). This means that the RMS level is generally a poor indicator of typical noise levels at a site (e.g. it is often above the 95th percentile in Figure 14), and other averages such as the median or mode may be more appropriate.

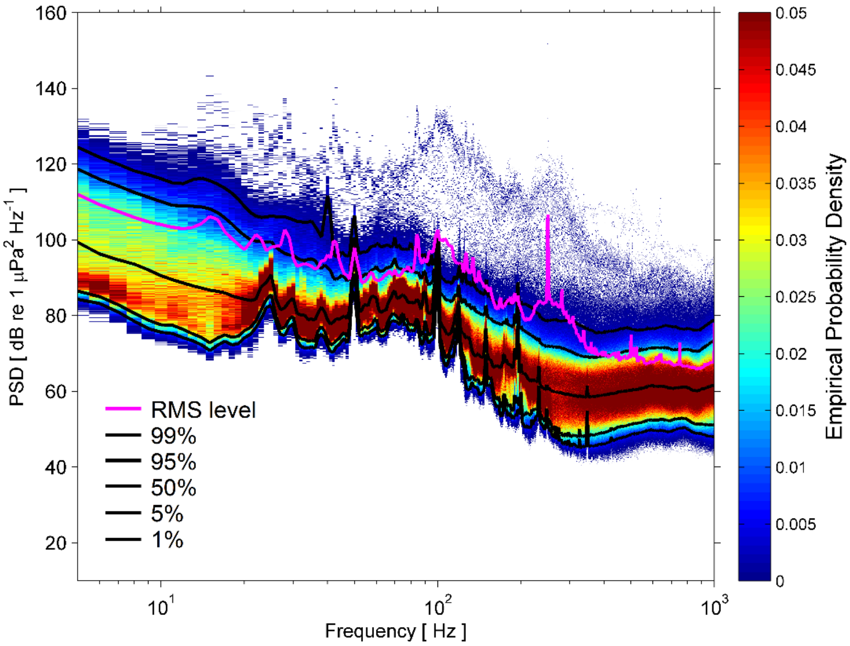

Figure 14 Example statistical analysis of ambient noise at Sizewell: 10 Feb – 27 Sep 2013. 50-Hz tonal noise and associated harmonics are operational noise from existing power station at Sizewell B. Black lines indicate percentiles; magenta line is the RMS level (mean calculated prior to decibel conversion); colour plot indicates probability density of measurements at each frequency (Merchant *et al.*, 2013).

3.2 Representative ambient noise levels for use in effects assessment

Representative ambient noise levels for the site were derived from the recordings in 1/3-octave bands (Figure 15). These bands have a lower frequency resolution than the 1-Hz bandwidth spectra presented in Figure 13 and Figure 14, and give a broader indication of the spread of ambient noise across the frequency spectrum. For the reasons outlined above, the RMS level was not deemed to be representative of ambient noise levels at the site. Using the RMS level would lead an overestimation of typical noise levels, leading to an underestimation of the area over which anthropogenic noise would be above background levels. Instead, the median level (50th percentile) was used, in keeping with recent studies of ambient noise in relation to marine mammals (Klinck *et al.*, 2012; Williams *et al.*, 2014). The median 1/3-octave spectrum is shown in Figure 15; this corresponds to a broadband (0.1-1 kHz) SPL of 101 dB re 1 µPa.

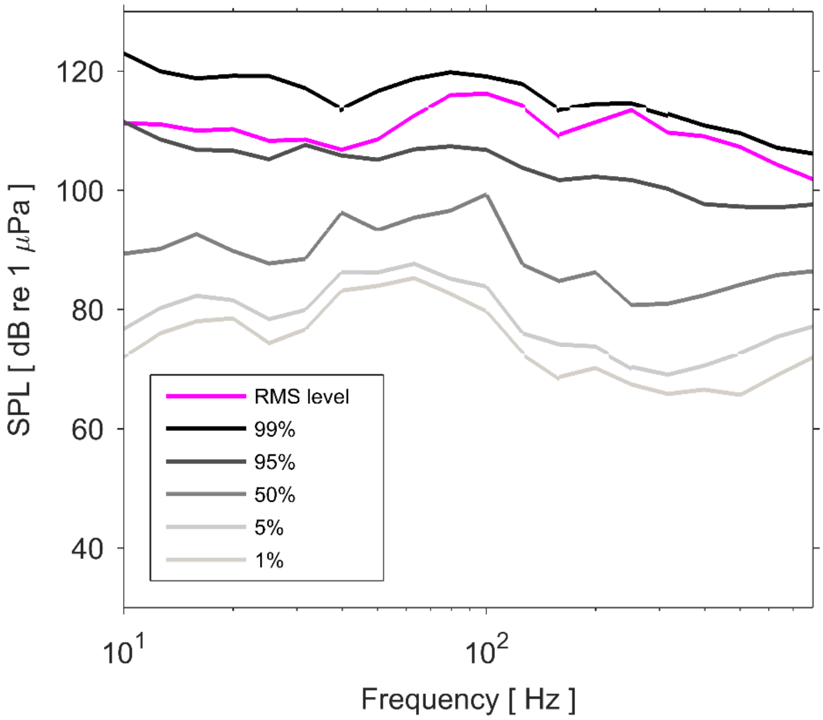

Figure 15 Distribution of 1/3-octave levels during 2013 recordings at Sizewell. The median level (50%) will be used as a representative ambient noise level for the purposes of noise modelling.

4 Noise propagation measurements and modelling

In addition to ambient noise measurements, a field survey was carried out to quantify underwater sound propagation in the vicinity of Sizewell (BEEMS Technical Report TR337). These measurements were carried out to provide validation data for the Cefas noise model, enabling noise modelling predictions at the site to be properly ground-truthed. This validation and optimisation process was detailed in BEEMS Technical Report TR336. This section briefly summarises the field survey and validation results.

4.1 Noise propagation measurements at Sizewell

To reduce uncertainty and to improve confidence in an acoustic propagation model, it is good practice to perform field measurements to test and validate model predictions of sound propagation loss. To this end, Cefas commissioned a subcontractor (Subacoustech) to carry out measurements of sound propagation at the Sizewell site. This field work is detailed in the subcontractor's report (BEEMS Technical Report TR337).

Measurements were made of the received sound level from a seismic airgun source placed at the extremity of the previously proposed marine offshore landing facility (MOLF; temporary jetty), along a series of four transects as shown in Figure 16. By comparing the received sound levels at a range of distances along each transect with the level at the source, an empirical assessment of sound propagation loss throughout the site can be made and compared with model predictions. Please note that whilst Figure 16 makes reference to MOLF, this design option is no longer proposed and has been replaced by the beach landing facility (BLF).

Raw data from the field survey were provided to Cefas by the subcontractor and were analysed to produce measurements of sound exposure level (SEL) and peak-to-peak sound pressure for each measured pulse.

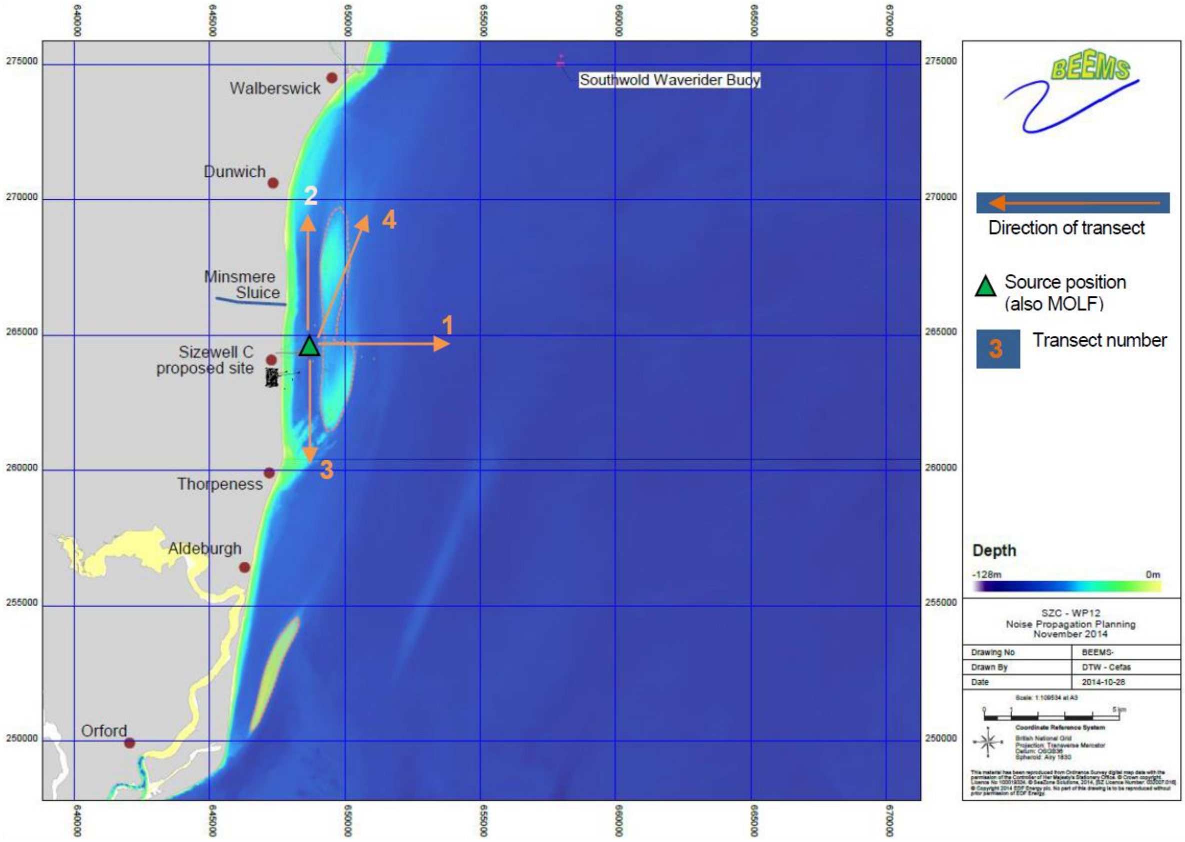

Figure 16 Transects measured during noise propagation measurements (BEEMS Technical Report TR337).

4.2 Validation of noise propagation model for Sizewell

The Cefas sound propagation model is based on a parabolic equation solution to the wave equation (Collins, 1993). Unlike many propagation models, this model takes into account the bathymetry, sediment properties, water column properties, and tidal cycle, leading to more detailed and reliable predictions of sound level.

Model predictions of sound transmission at the site were compared to the field observations for each of the four transects shown in Figure 16. The model parameters were then optimised to maximise the agreement between the model and the measurements, within the physical constraints of the best available environmental data at the site. Following optimisation, the model is able to predict propagation loss with a root-mean square error of ± 5.7%. Overall, 91% of model predictions are within a ± 10% envelope of the field measurements (see Figure 17). These results demonstrate that the validated noise model is able to make accurate predictions of sound propagation at Sizewell.

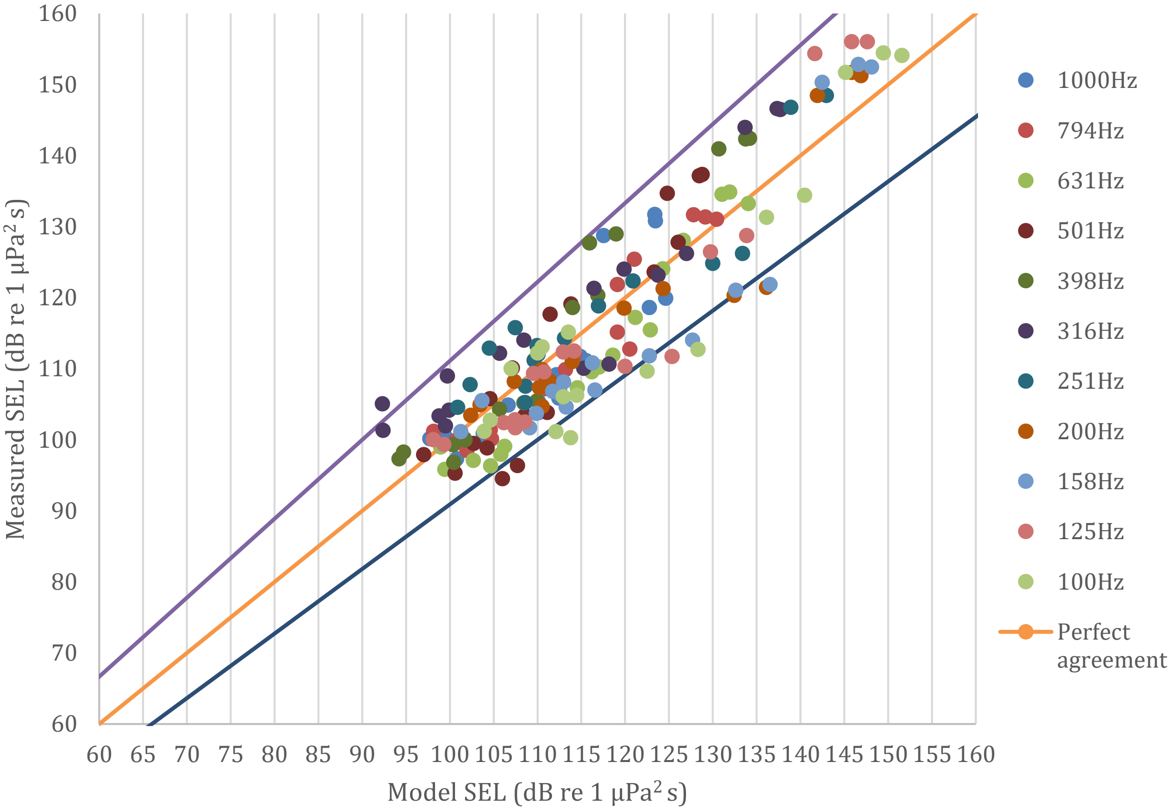

Figure 17 Modelled versus measured SEL for the measurements along the east transect, for all 1/3 octave bands in the interval 100-1000 Hz. Outer lines indicate ±10% deviation from the measured SEL (BEEMS Technical Report TR336).

4.3 Shipping noise modelling methodology

The modelling methodology used to assess potential increases in the ambient noise levels associated with the additional vessel traffic is presented in this section. Ambient noise levels can be modelled using data on the sources of noise (including their position, movements, sound level and frequency characteristics) and the acoustic propagation characteristics of the environment. The main sources of ambient noise are shipping and wind, with shipping typically dominating at low frequencies (<1 kHz). To produce ambient noise maps, each of these components is modelled separately and then combined.

4.3.1 Model domain

Proposed transhipment routes for deliveries to Sizewell include Great Yarmouth, Harwich and the Netherlands (Rotterdam and Vlissingen). In order to cover the four proposed transhipment routes, and the potential sources of ambient noise affecting the locations along these routes, we defined a model domain covering the southern North Sea region between 51°N -53.5°N latitude and 0°E - 5°E longitude (Figure 18). The noise maps are calculated for this model domain for a typical calendar month.

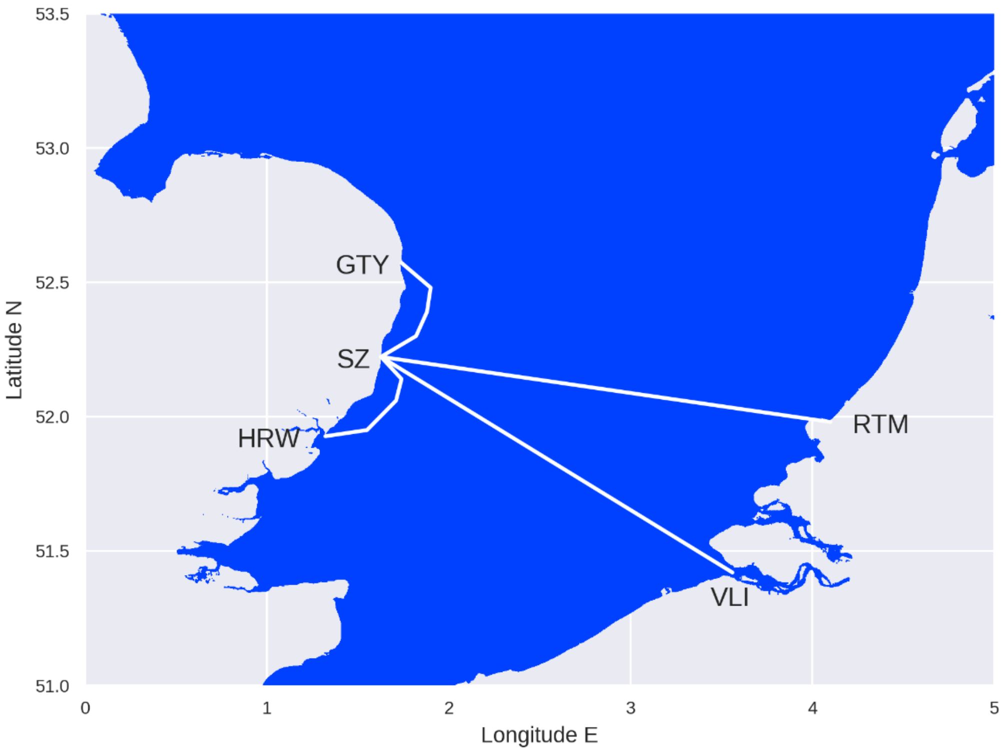

Figure 18 Shipping noise model domain with the modelled the shipping tracks.

4.3.2 Source modelling

Wind sound pressure levels are estimated from a model based on Reeder et al. (2011) using wind speed data sourced from ECMWF ERA-Interim[2] global atmospheric reanalysis, while the ship source levels are estimated using the average spectral source level model developed by Wales and Heitmeyer (2002; Figure 2) for an ensemble of merchant ships.

The vessels positioning information was based on 2017 satellite automatic identification system (AIS) dataset for the North East Atlantic area, which contained the tracking positions of approximately 120,000 ships at short but irregular intervals (5 - 30 minutes). After reprocessing and interpolation, source level estimates were calculated for all the computational grid nodes of the domain shown in Figure 18 (51°N - 53.5°N latitude and 0°E - 5°E longitude), and these were stored at each 10-minute interval, for a total of 4464 source level model “frames” for the month of July 2017. The month of July was selected as it represents the month with lowest wind energies whilst vessel noise is relatively high all year. As such differences in noise can be easily attributable to changes in vessel traffic associated with BLF deliveries.

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[2] http://www.ecmwf.int/en/forecasts/datasets/archive-datasets/reanalysis-datasets/era-interim

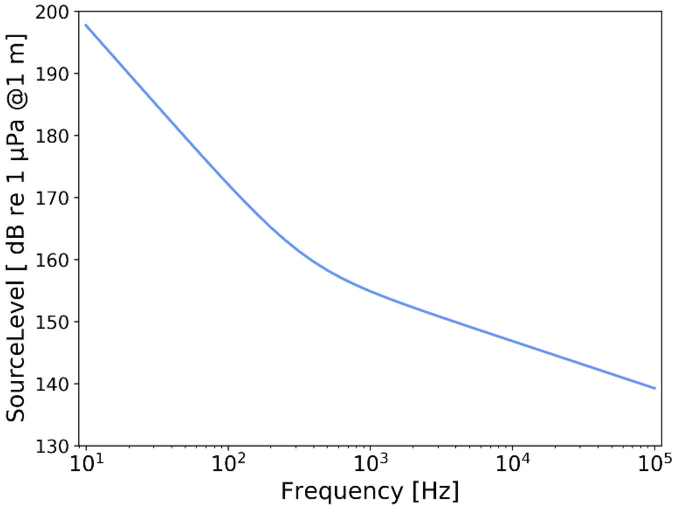

Figure 19. Ensemble ship source level spectrum (Wales and Heitmeyer, 2002).

4.3.3 Propagation modelling

The propagation loss model is based on the energy-flux method (Weston, 1971), a range-dependent model that takes into account the environmental factors such as bathymetry, water column and seabed properties, as well as the sound frequency. Data inputs for the shipping noise model included EMODNET bathymetry data with 7.5” resolution, temperature and salinity data from Copernicus[3] Atlantic European North West Shelf Ocean Physics Analysis and Forecast (0.016° x 0.016°, 33 depth levels, daily mean values) product, and acoustic seabed properties derived from the Hamilton model (Hamilton, 1987) using EMODNET seabed sediments data.

The shipping noise model uses a computational grid with latitude-longitude resolution of 0.75’ x 1.25’ (approximately 1.3 x 1.3 km).

The most computationally intensive components of the propagation loss, which depend solely on spatial variation of bathymetry (and thus are independent of the sound frequency and the water properties) were pre-computed and stored for each node of the computational grid, up to a range of 100 km. The actual values of the propagation loss, which are both time and frequency dependent are calculated at the later stage when the shipping sources are also integrated into the model, through an effective process that selects and rescales the pre-computed and stored values, thus balancing the need for both processing and memory efficiency.

4.3.4 Integration of source and propagation modelling components

Applying the source level estimates onto the pre-computed propagation loss matrices and adding the wind-driven baseline allows for the calculation of instantaneous noise maps, according to the specific spatial distribution of ships, environmental conditions as well as the desired frequency band. The noise maps match the time resolution of the source level frames (i.e. every 10 minutes) and the spatial resolution of precomputed propagation loss matrices (i.e. 1.3 x 1.3 km, as detailed above). The noise maps were calculated and stored for the month of July 2017 (with a total of 4460 10-minute frames), and for all the

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[3] http://marine.copernicus.eu/services-portfolio/access-to-products/

frequency bands in the interval 63 Hz – 20 kHz. This raw output is then frequency integrated for a broadband output, and post-processed, to produce monthly statistical outputs and graphical maps.

4.3.5 Modelling the additional traffic scenarios

We consider four modelling scenarios, corresponding to the four possible transhipment routes. At a nominal speed of 6 knots, the transit times are approximately 4.5 hours from both Great Yarmouth and Harwich, while from Rotterdam and Vlissingen transit times are approximately 15 hours and 14 hours, respectively. As the North Sea Barges can access the BLF only at high water, these durations imply a hypothetical maximum rate of 2 round trips (deliveries) per 24.8h tidal cycle from Great Yarmouth or Harwich, or 1 single trip per 24.8h tidal cycle from Rotterdam or Vlissingen. We used these maximal rates, also shown in Table 7, together with some generically defined shipping tracks, as illustrated in Figure 18, in order to define the transhipment modelling scenarios. In each case, the additional shipping traffic for the proposed development was added to the existing baseline to generate shipping noise outputs for each scenario. These scenarios were assessed against the baseline output. The increase in ambient noise provides an indicative assessment of increases in ambient noise at a regional level (southern North Sea) and at a local level relative to the site. The assessment considers barges only rather than accompanying vessels, however it assumes every available tide is available for deliveries with no weather or operational constraints. Therefore, the total number of monthly deliveries is assumed to be precautionary.

Table 7 Shipments routes used in the modelling scenarios.

Routes from and to	Transit time per leg at 6 knots	Round trips (deliveries) per month
Great Yarmouth	4.55 h	59
Harwich	4.72 h	59
Rotterdam	15.1 h	14
Vlissingen	14.1 h	14

4.4 Modelling noise levels from underwater explosions

The estimation of noise levels for each charge is performed using the methodology of Soloway and Dahl (2014), which follows the work of Arons (1954). This is a relatively simple semi-empirical calculation that was developed from theoretical considerations and experimental measurements of peak pressures from underwater explosions. Namely, the peak pressure is given as a function of scaled range as

$$P_{peak} = 52.4 \times 10^6 \left(\frac{R}{W^{\frac{1}{3}}}\right)^{-1.13} \tag{4.1}$$

where P_{peak} is the peak pressure in Pascals (Pa), R is the measurement range in metres (m), and W is the charge weight in kilograms of TNT (kg TNT). This equation assumes a freely suspended charge and does not explicitly take in account bathymetry variations of the seabed type, but was found to be in very good agreement with both the experimental measurements of Soloway and Dahl (2014) in shallow water and the previous measurements of Murata (2002), Arons (1954), and Cole (1948). It should be noted, however, that long range (beyond 2 km) propagation measurements in shallow water are currently lacking and therefore caution should be used over long range prediction of the peak pressure values. For example, Soloway and Dahl (2014) showed that the predictions compared very well with data over 4 orders of magnitude of the scaled variable $R/W^{1/3}$, but their measurements taken in shallow water of 15 m depth were at ranges from 170 m to 950 m, representing approximately 10 to 70 waveguide depths.

The peak pressure level, SPL_{peak} is defined as

$$SPL_{peak} = 20\log_{10}\left(\frac{P_{peak}}{p_0}\right) \tag{4.2}$$

where $p_0 = 1\mu\mathrm{Pa}$ is the reference pressure and the SPL_{peak} is expressed in dB re $1\mu\mathrm{Pa}$. Therefore, it follows that the peak pressure levels can be expressed as a function of charge weight and measurement range as

$$SPL_{peak} = 274.39 + 7.533\log_{10} W - 22.6\log_{10} R \tag{4.3}$$

The first two terms in Equation (4.3) represent the estimation of the source level for a charge of weight W, while the last term represent the propagation loss out to distance R. As the charge is assumed to be freely standing in mid-water, unlike a UXO which would be resting on the seabed and could potentially be buried, degraded or subject to other significant attenuation, this estimation of the source level can be considered conservative.

5 Predicted noise levels

This section presents maps of the instantaneous noise levels generated by the potential activities at Sizewell. These noise maps integrate the source level data detailed in Section 2.1 with the Cefas noise propagation model described in Section 4. The ambient noise data derived from long-term monitoring (see Section 3) are also incorporated to show the extent to which continuous noise levels generated at Sizewell would be above background levels.

For each activity, the sound exposure generated over one second is used to assess instantaneous noise levels. In all of the modelling, a conservative estimate of water level was used: sound propagates further in deeper water, so a relatively high-water level was used. This was the average of Highest Astronomical Tide (HAT) and Mean High Water Spring (MHWS), which corresponds to 1.39 m ODN (1.26 m above the mean sea level at Sizewell).

5.1 Impact Piling

The noise levels generated by impact piling during the installation of the BLF are shown in Figure 20 and Figure 21, for hammer strikes with energies of 90 kJ and 200 kJ, respectively. Note that a direct comparison of these levels (single pulse SEL) with the ambient noise level (SPL) derived from long-term monitoring would not be valid, as impact piling is an impulse source (not continuous), and so whether noise levels are above background will depend on the temporal structure of the pulse.

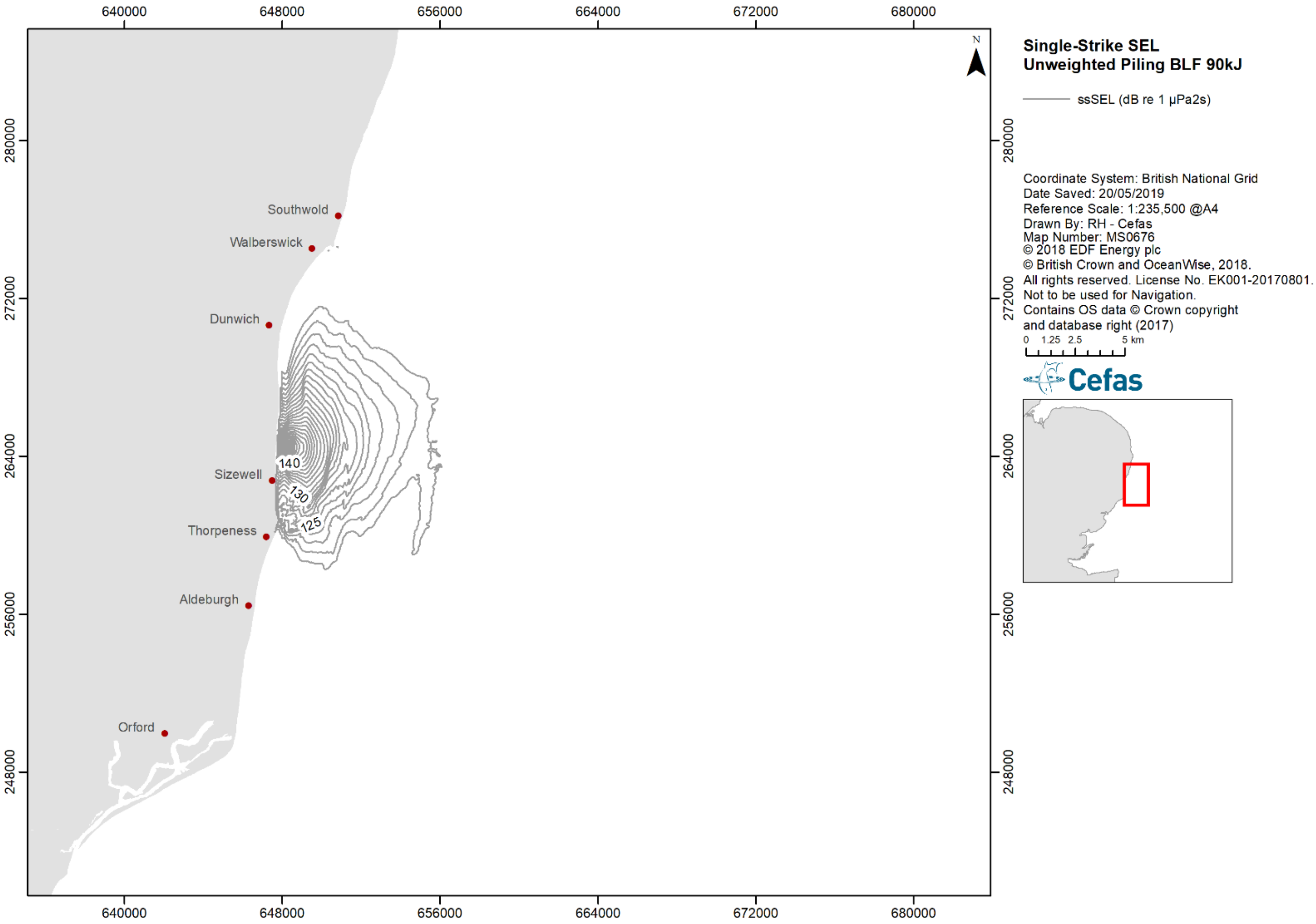

Figure 20 Impact piling noise levels (single pulse SEL) for a 90 kJ hammer strike for the installation of BLF piles, indicated by 1 dB spaced contours.

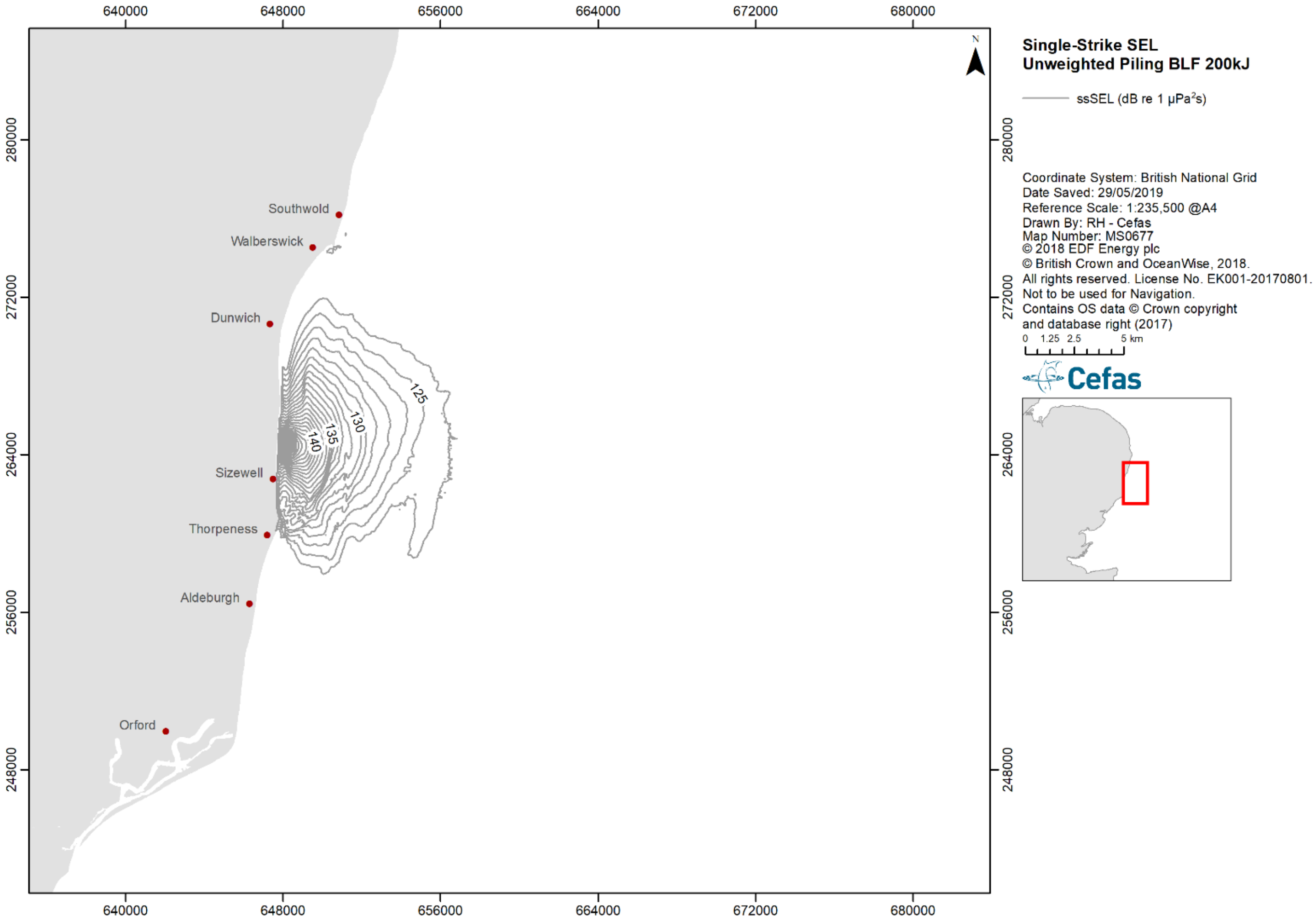

Figure 21 Impact piling noise levels (single-pulse SEL) for a 200 kJ hammer strike for the installation of BLF piles, indicated by 1 dB spaced contours.

5.2 Drilling intake/outfall shafts

Construction of the vertical shafts connecting the subterranean cooling water tunnels with the cooling water intake and outfall shafts will involve drilling activity. Predicted instantaneous noise maps resulting from this activity at each of the three locations are shown in Figure 22, Figure 23 and Figure 24, respectively. The orange line in these plots indicates the ambient noise level, and thereby the area over which noise levels are predicted above background. The plots are very similar, since the sound propagation conditions at their respective locations are similar. The plots indicate that drilling noise levels will be above background over a limited area, extending approximately 5 km from the drilling location. Note that the units here are of sound pressure level (SPL): for these continuous sources this is equivalent to the 1 second sound exposure level (SEL). Although a direct comparison with the impact piling noise levels (single pulse SEL) shown in the previous plots (Figure 20 and Figure 21) is not possible, as the piling noise levels will depend on the temporal structure (including duration) of the pulse, the impact piling noise is expected to be above background levels over a much greater area than the drilling noise.

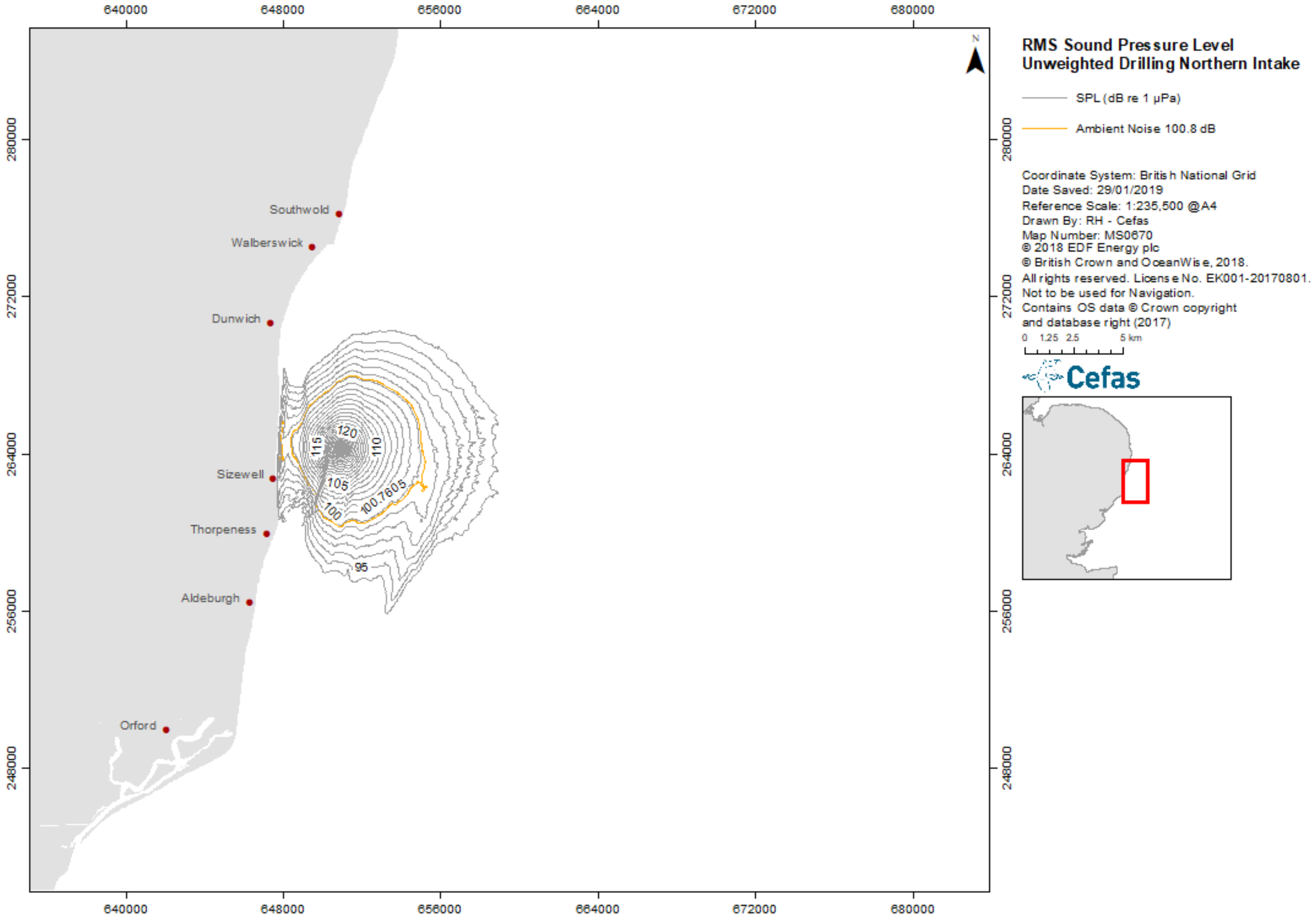

Figure 22 Instantaneous noise levels for drilling the vertical connection shaft at the northern intake. Orange line indicates the ambient noise level at the site. Note that the units here are of sound pressure level (SPL): for the continuous sources this is equivalent to the 1-s sound exposure level (SEL).

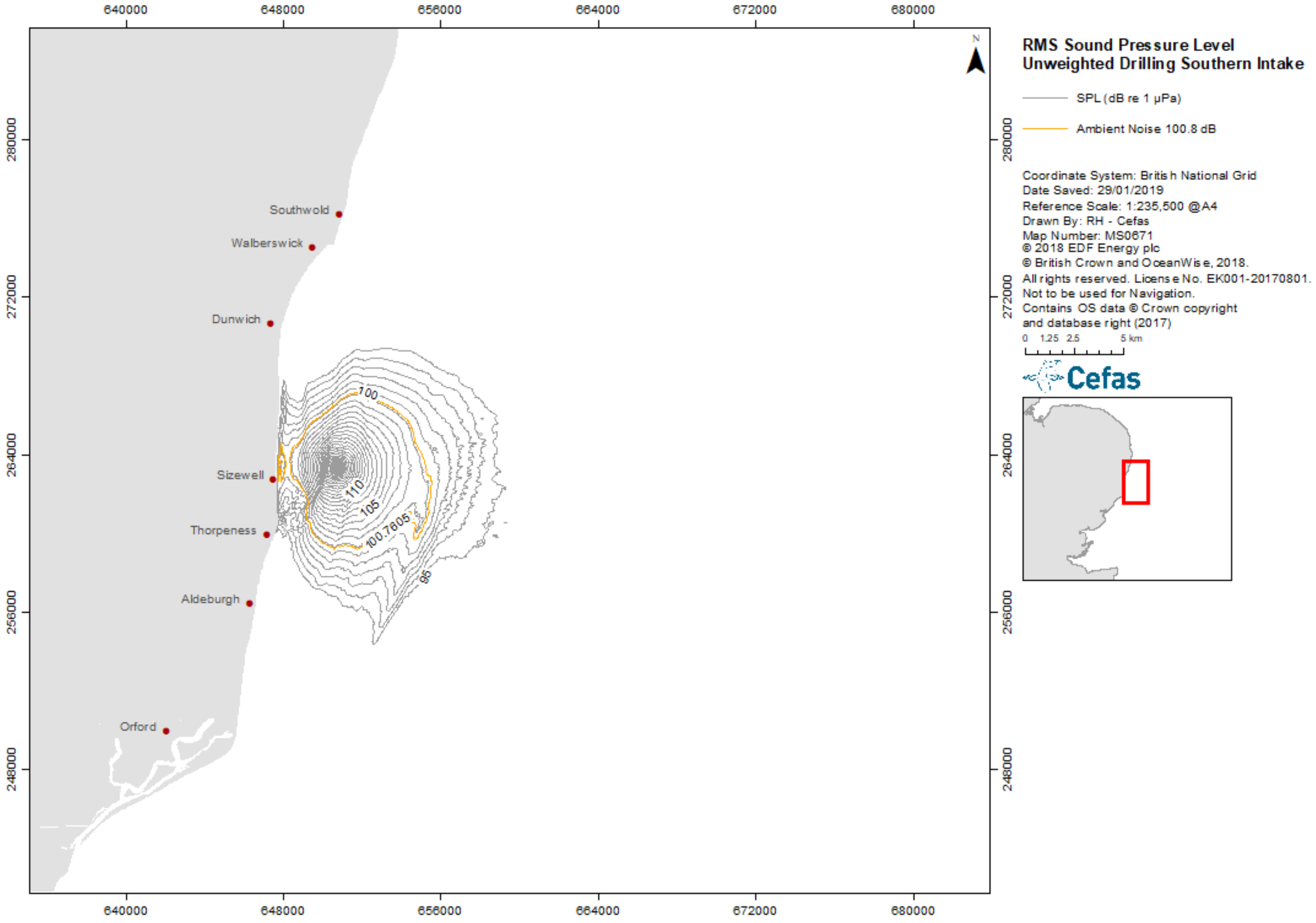

Figure 23 Instantaneous noise levels for drilling the vertical connection shaft at the southern intake. Orange line indicates the ambient noise level at the site.

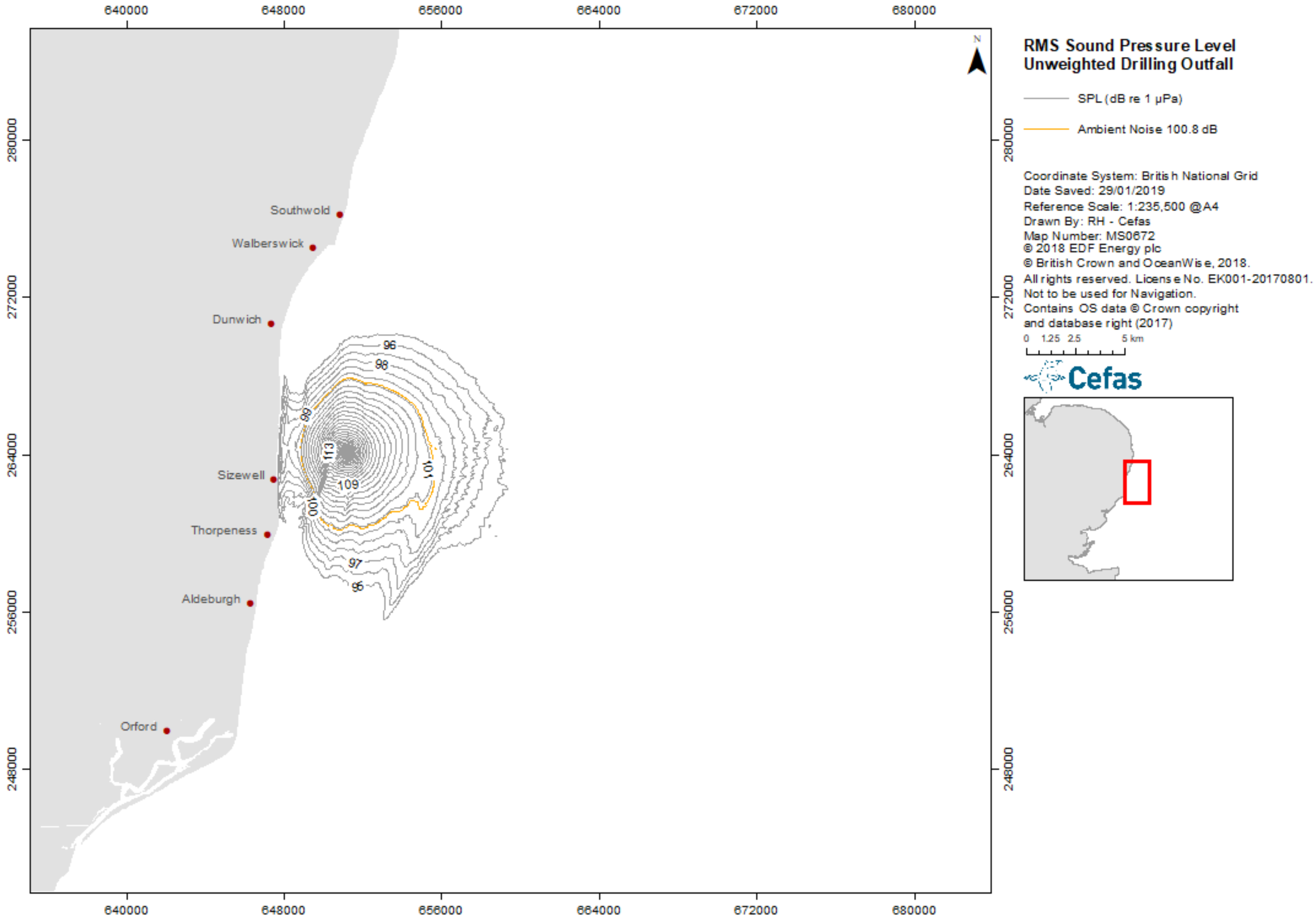

Figure 24 Instantaneous noise levels for drilling the vertical connection shaft at the outfall. Orange line indicates the ambient noise level at the site.

5.3 Dredging activities

Compared to drilling dredging source levels used for the assessment are relatively high across much of the frequency spectrum (see Figure 3, page 23). Therefore, the noise levels arising for dredging activities, shown in Figure 25 to Figure 32, are significantly higher than the drilling noise levels (shown in Figure 22 to Figure 24, in the previous section 5.2). The seven dredging locations assessed illustrate that the same acoustic source level can generate a different acoustic footprint depending on its location – with the BLF, FRR1, FRR2 and CSD displaying similar patterns. Dredging at the cooling water outfall and the intakes display a markedly different set of patterns and have higher predicted noise levels. This is due to the bathymetry at the site, with the intakes and outfall lying on the offshore side of a submarine sandbank which acts as an acoustic barrier, reducing the amount of acoustic energy that is propagated offshore from sources on its western side, as seen in Figure 25 to Figure 28. In Figure 29 to Figure 31, the converse effect can be seen: the structure of the sandbank clearly creates acoustic shadow zones on the shore side of the bank. These results demonstrate that activities at the intakes and outfall will have a larger acoustic footprint than equivalent activities at the BLF and nearby FRRs and CDO, owing to the effects of bathymetry on sound propagation. It should be noted that the dredging noise levels were above ambient noise level over the entire modelled domain (by approximately 10-15 dB near the domain edges), and therefore the ambient noise contour is not present in Figure 25 to Figure 32.

To consider in-combination effects of underwater noise the BFL and at the south intake location was modelled based on simultaneous dredging activities occurring. The noise levels resulting from simultaneous dredging are shown in Figure 32. These levels illustrate a slightly larger acoustic footprint of the combined dredging than the same activity at the two constituent single locations (see for comparison Figure 25 and Figure 30, for the dredging noise levels at BLF and south intake, respectively).

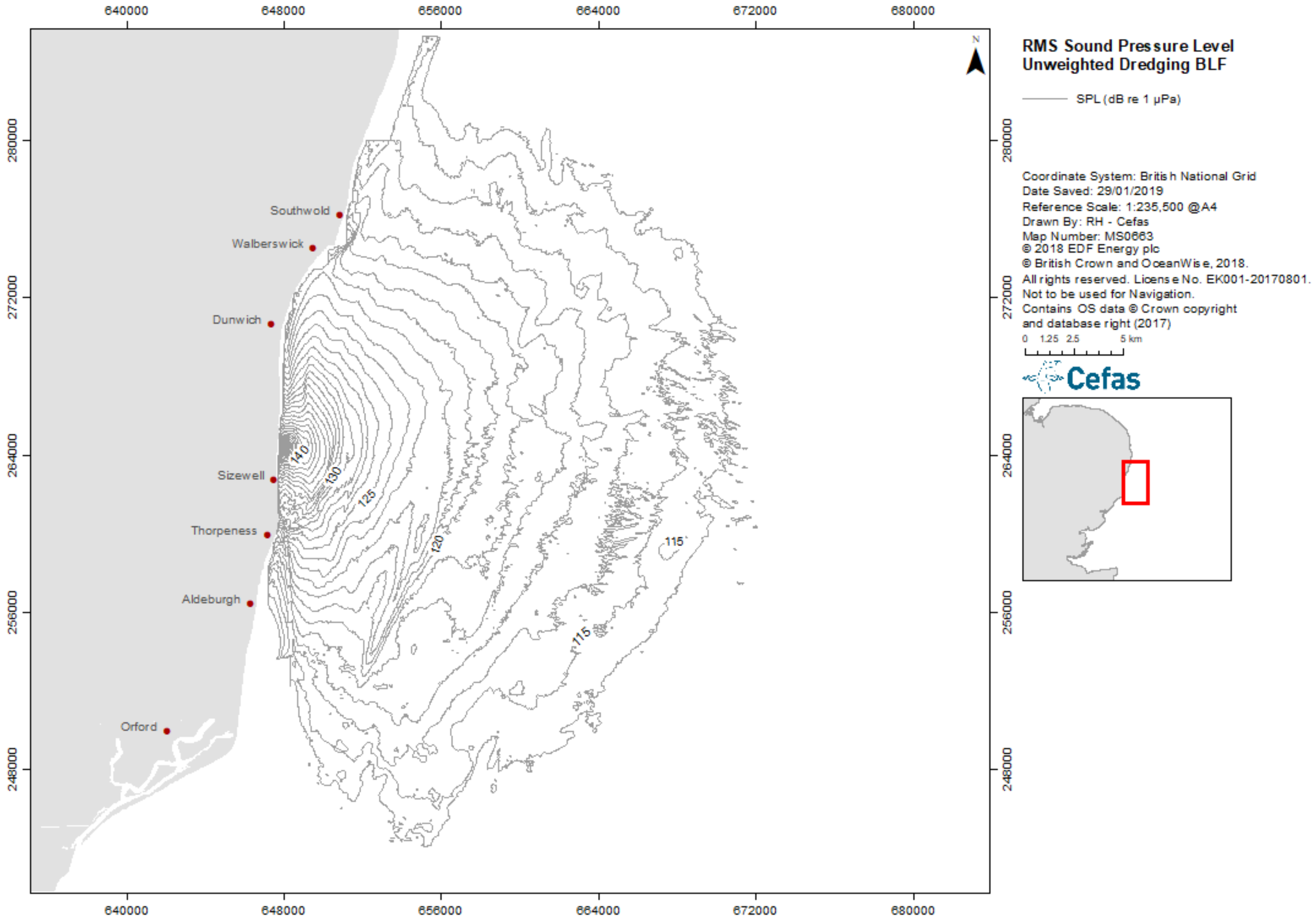

Figure 25 Instantaneous noise levels for dredging at the Beach Landing Facility location. Contours represent 1dB noise levels.

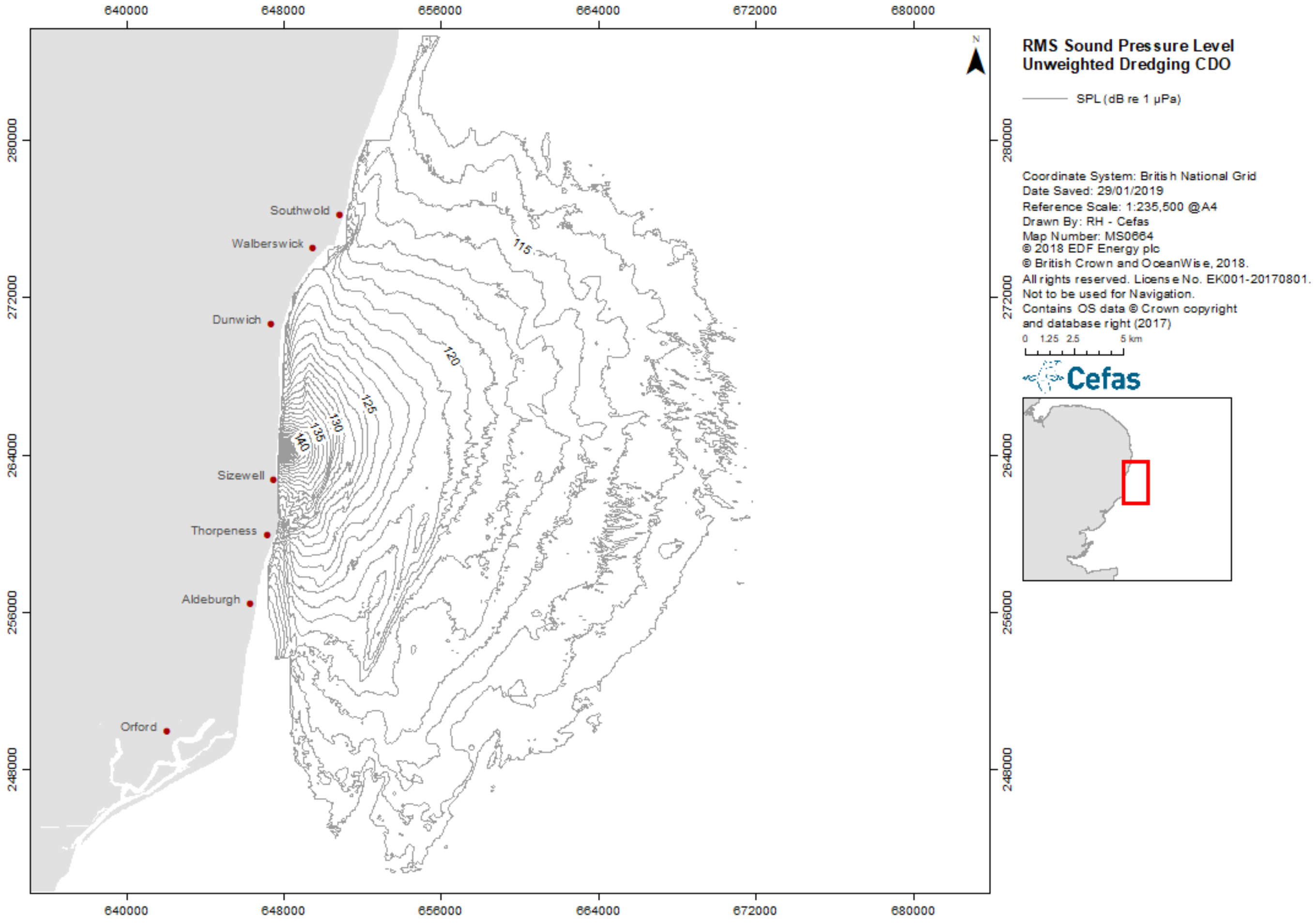

Figure 26 Instantaneous noise levels for dredging at the Combined Drainage Outfall location, indicated by 1 dB spaced contours.

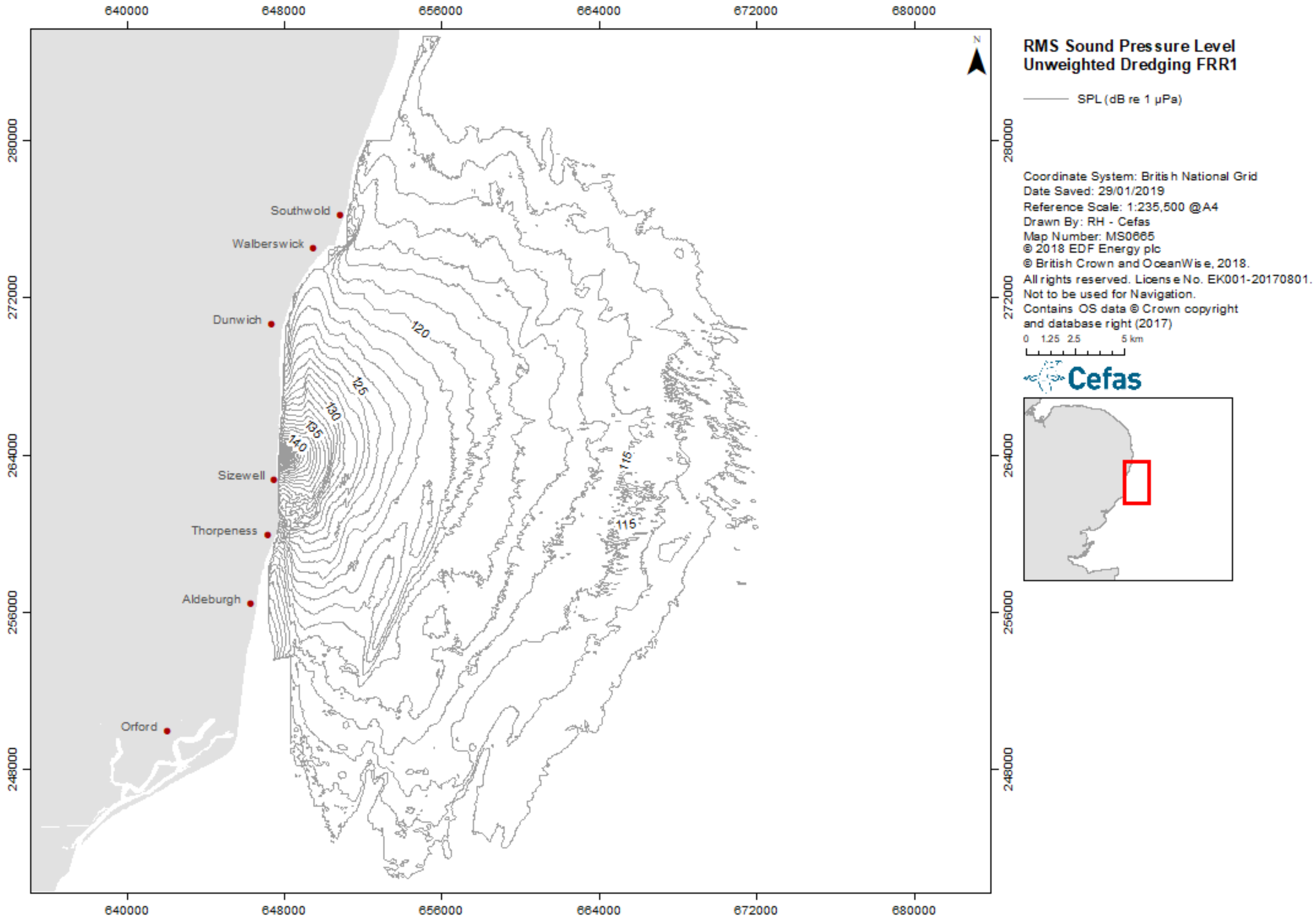

Figure 27 Instantaneous noise levels for dredging at FRR1 location, indicated by 1 dB spaced contours.

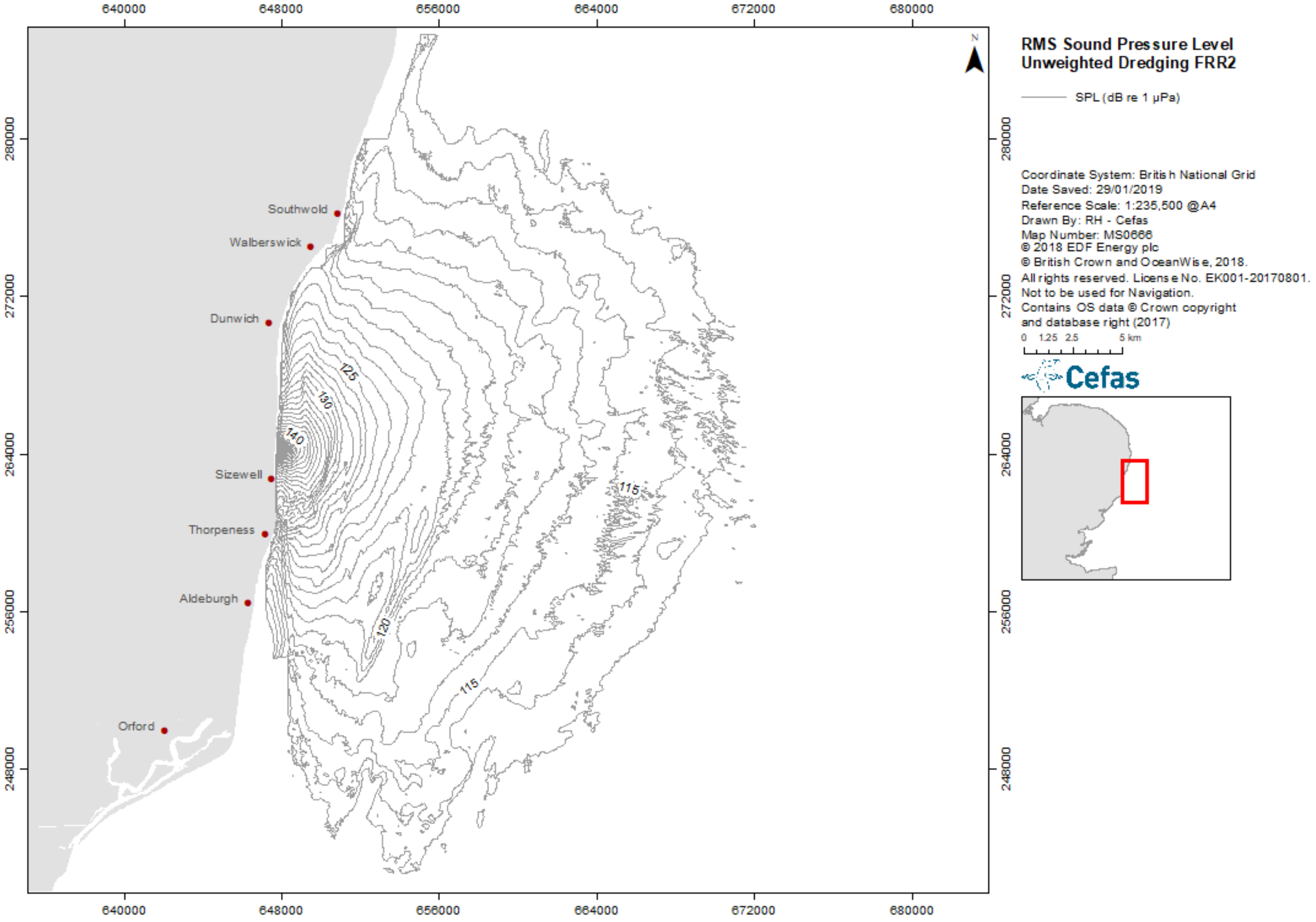

Figure 28 Instantaneous noise levels for dredging at FRR2 location, indicated by 1 dB spaced contours.

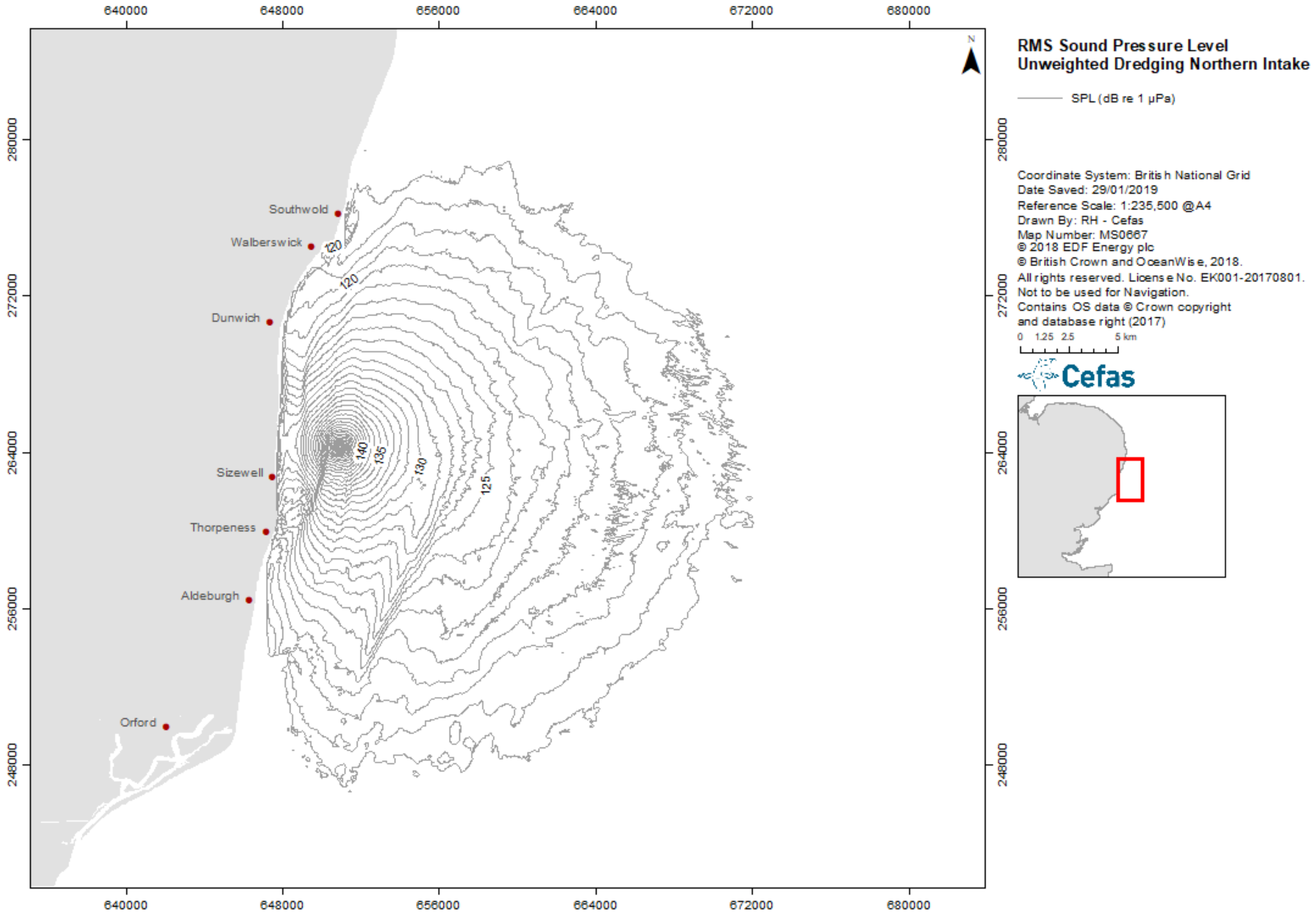

Figure 29 Instantaneous noise levels for dredging at the north intake location, indicated by 1 dB spaced contours.

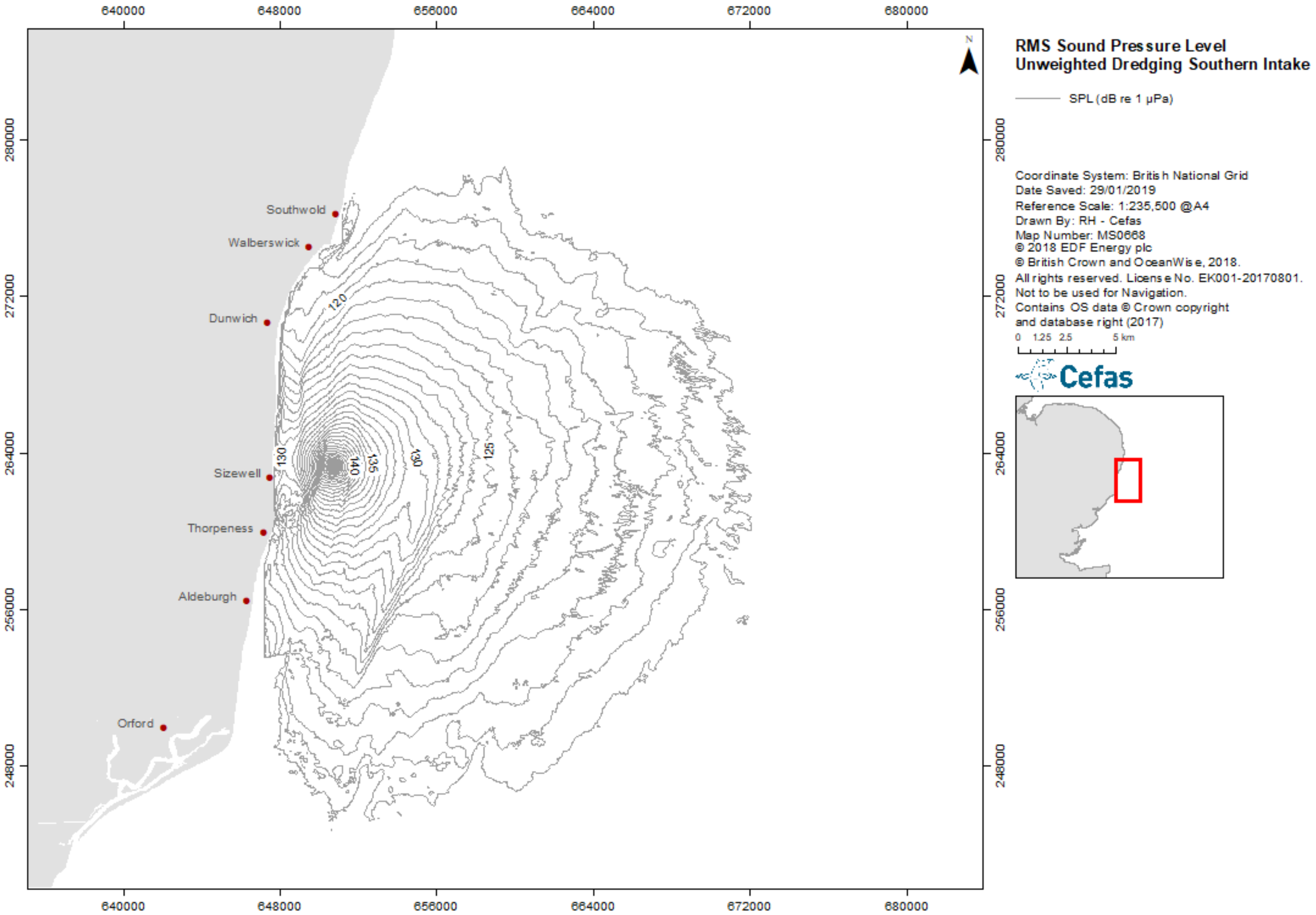

Figure 30 Instantaneous noise levels for dredging at the south intake location, indicated by 1 dB spaced contours.

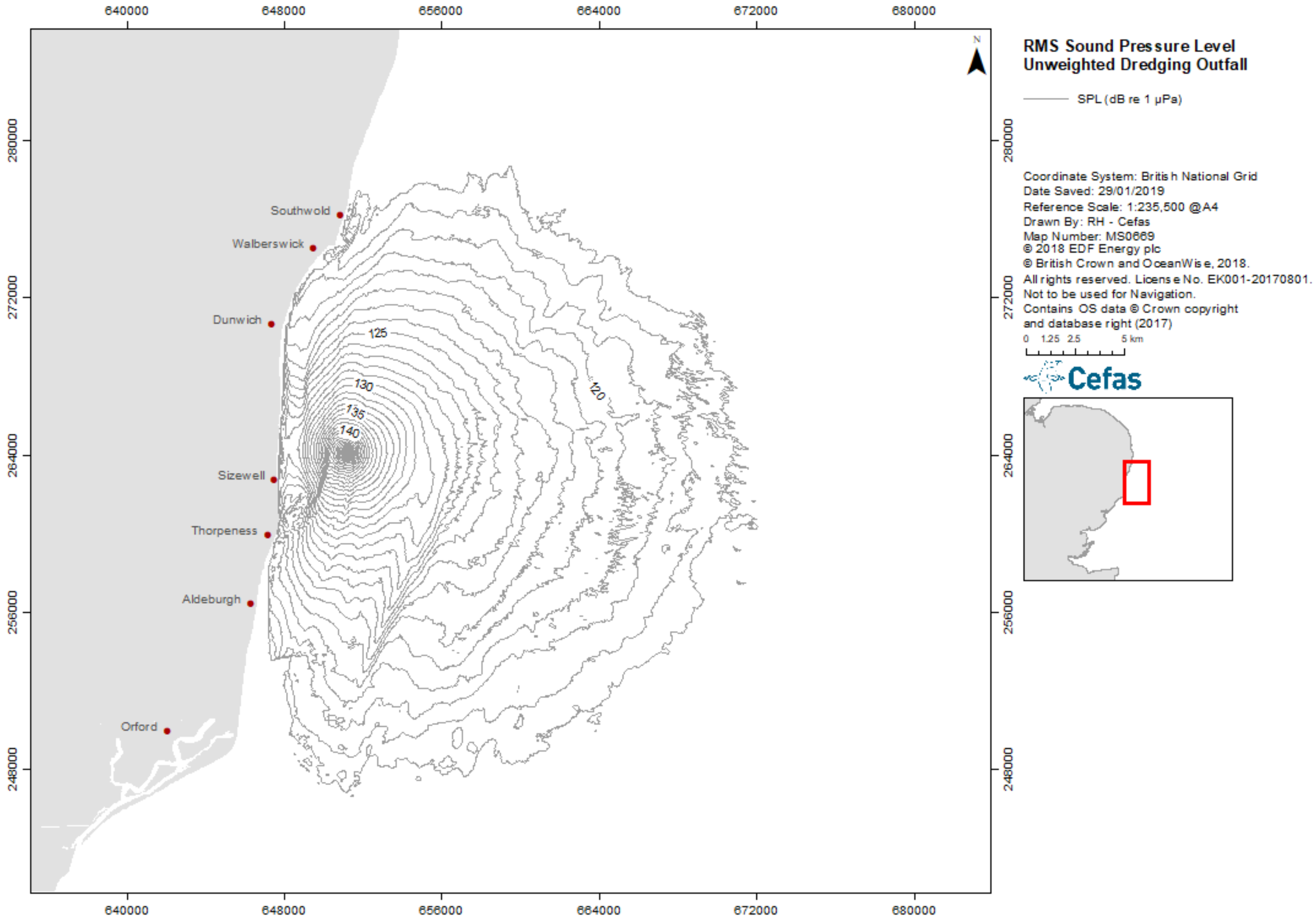

Figure 31 Instantaneous noise levels for dredging at the outfall location, indicated by 1 dB spaced contours.

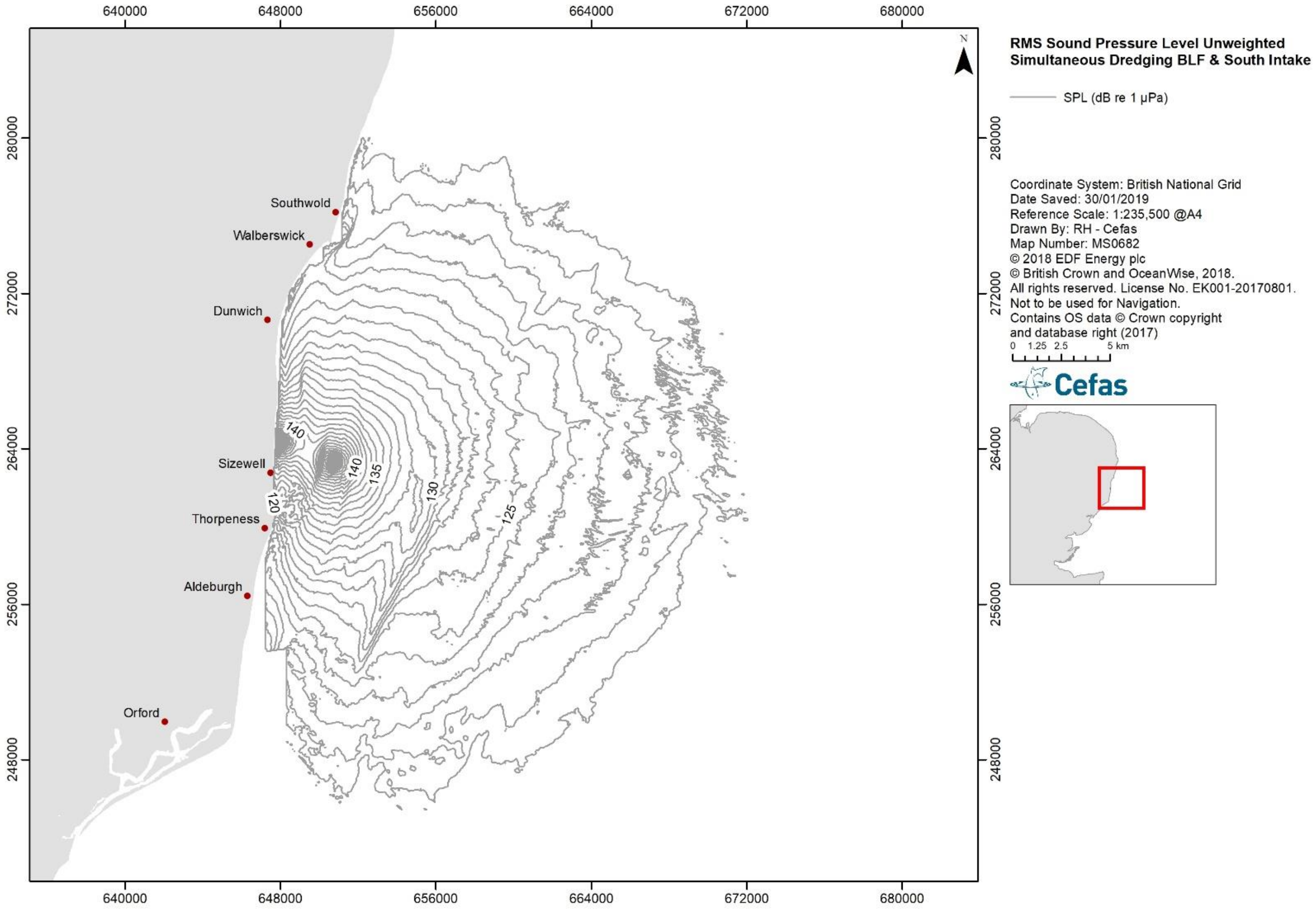

Figure 32 Instantaneous noise levels for simultaneous dredging at BLF and south intake locations, indicated by 1 dB spaced contours.

5.4 Vessel noise

In this section a modelling estimate of the ambient noise levels in the larger region around Sizewell (extending over much of the Southern North Sea) is presented as the baseline for assessing the potential increase in noise levels associated with BLF deliveries during the construction period. The baseline ambient noise map was modelled in accordance with the methodology described in Section 4.3, and includes the contribution of wind noise and shipping noise for the month of July 2017.

Statistical indicators including the median and higher percentiles are appropriate for describing the variability of the ambient noise levels (Section 3), we modelled maps of the median (the P50 or the 50th percentile) and of the P90 (the 90th percentile). These modeled maps complement the ambient noise measurements (Section 3) by providing a more comprehensive picture of the spatial distribution of the ambient noise levels. However, it should be noted that since the observational interval (February – September 2013) and modeled interval (July 2017) do not overlap and have different length (7 months and 1 month, respectively), the observational and modelled statistical indicators are not necessarily comparable, due to both seasonal and annual variability factors (e.g. shipping intensity, wind speeds, sound propagation). Nevertheless, the modelled ambient noise maps provide a reasonable baseline that we use to illustrate the potential impact of additional shipping noise.

5.4.1 Ambient noise map baseline

The median (i.e. P50) and the P90 (90th percentile) broadband sound pressure levels in the southern North Sea, as derived from the baseline model outputs for the month of July 2017, are shown in Figure 33 and Figure 34, respectively, and a close up map near Sizewell is shown in Figure 35.

The predicted median sound levels exceed 115 dB over much of domain, due to the intense shipping traffic which is typical for the Channel and southern North Sea, with levels above 130 dB in many hotspots, as seen in Figure 33. Near Sizewell, the median (P50) sound levels are lower in a narrow strip along the coast, due to less favourable propagation conditions at low frequency in very shallow water, but they increase rapidly offshore in deeper water (Figure 35a). For example, in the vicinity of the recording site, which was located approximately 700 m offshore, along the 5 m water depth contour, the P50 model predictions at the nearby model grid points are between 92 dB (at 200 m offshore) and 104 dB (1.5 km offshore), and then gradually increase to 111 dB (3 km offshore), 114 dB (5 km offshore) and 117 dB (10 km offshore). The corresponding P90 model predictions are about 5-10 dB higher. For comparison, the observed 7-months (February – September 2013) median sound levels at the recording site were 100.8 dB, which is consistent and within the July 2017 P50 model predictions at the nearby grid points, namely 92 dB and 104 dB.

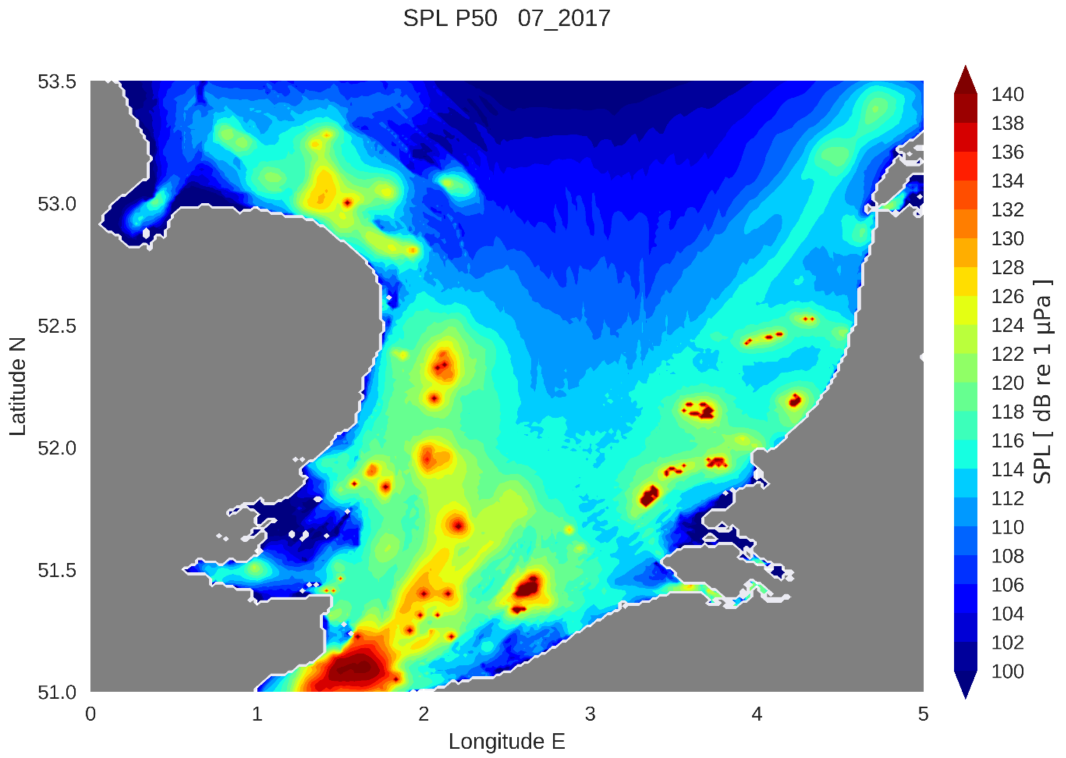

Figure 33 Southern North Sea baseline P50 (median) sound pressure levels for the month of July 2017.

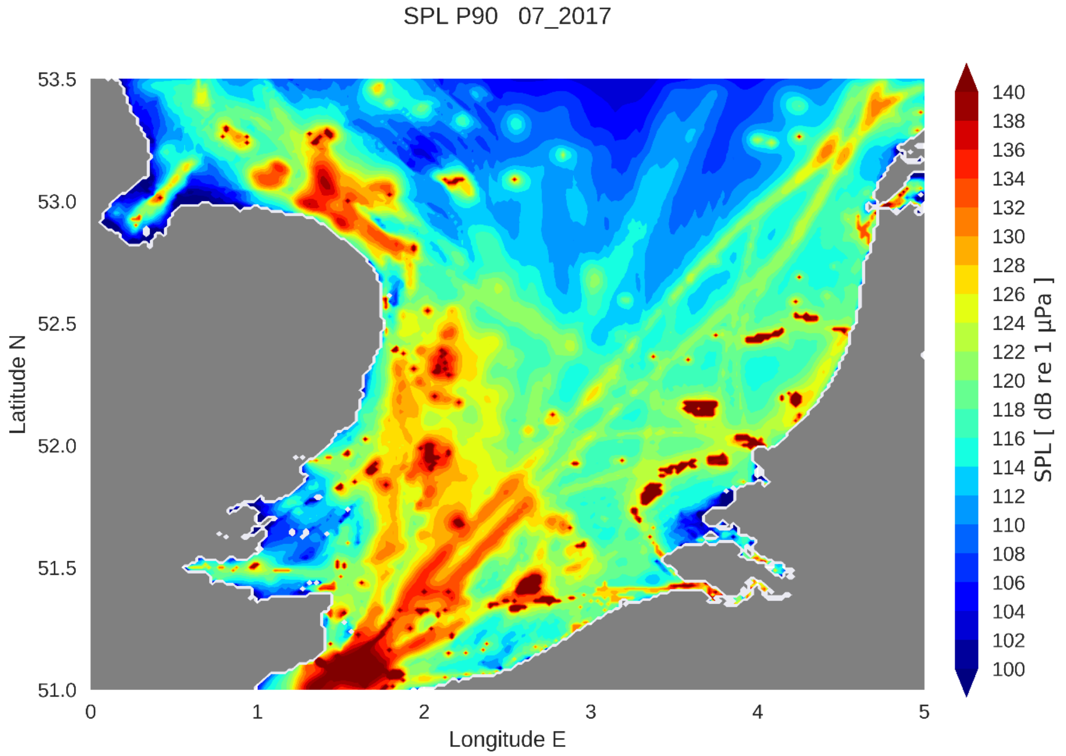

Figure 34 Southern North Sea baseline P90 sound pressure levels for the month of July 2017.

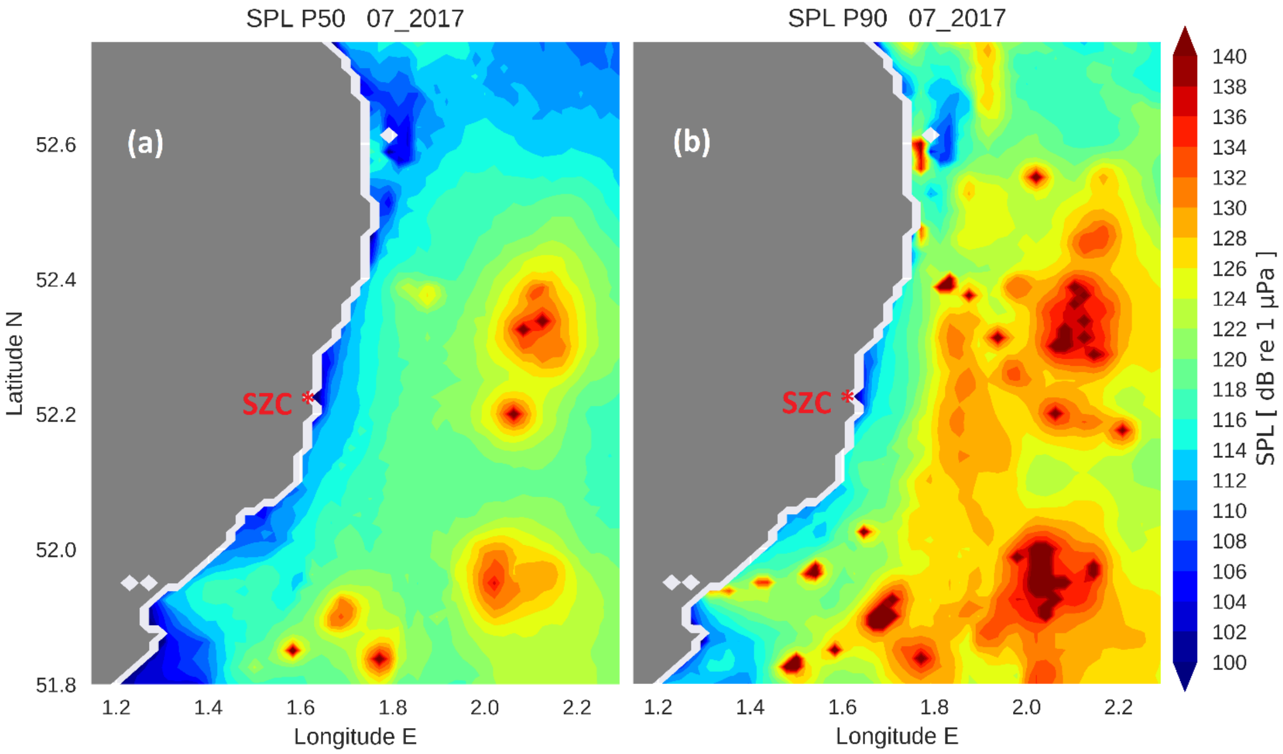

Figure 35 Baseline (a) P50 and (b) P90 sound pressure levels for the month of July 2017 near Sizewell.

5.4.2 Vessel traffic increases above the baseline

For all four transhipment scenarios, similar statistical outputs were calculated. In general, noise maps are very similar to the baseline case outputs. For example, in Figure 36 and Figure 37, which show a comparison between the baseline and the Great Yarmouth transhipment scenarios for the P50 and P90 sound pressure levels, respectively, minimal differences occur.

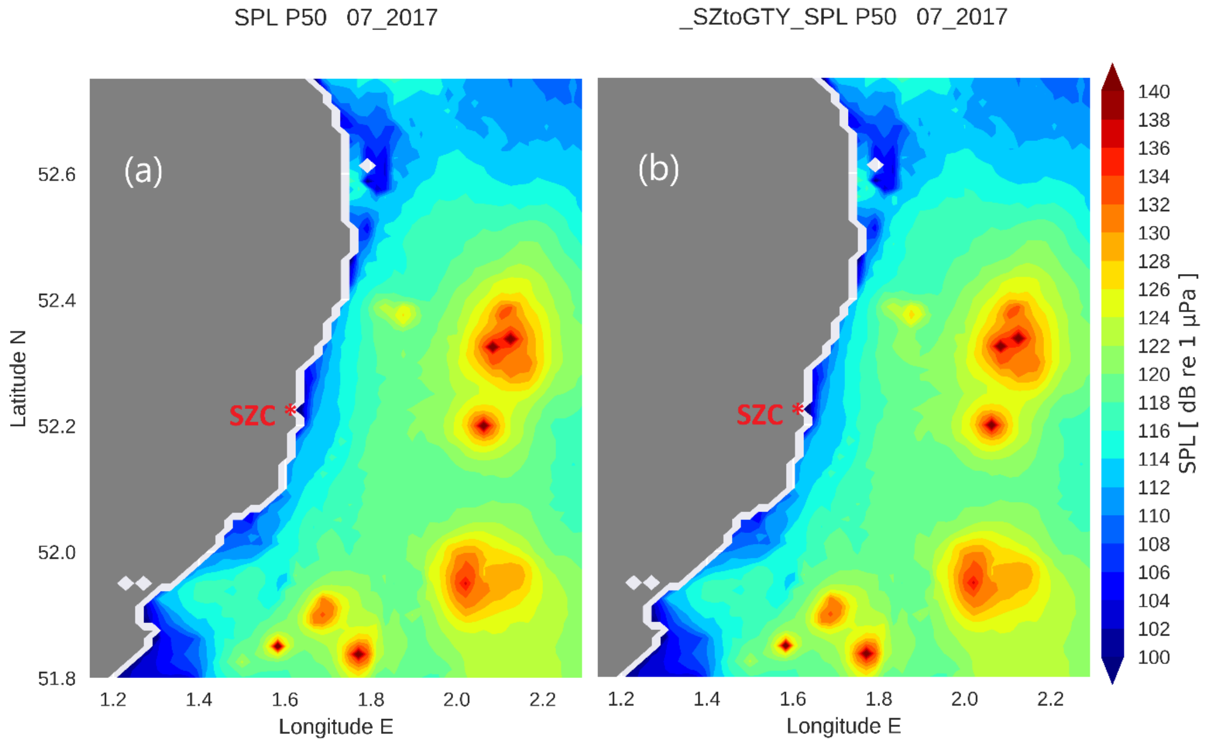

Figure 36 Comparison between (a) the baseline and (b) the Great Yarmouth transshipment scenarios P50 sound pressure levels for the month of July 2017 near Sizewell.

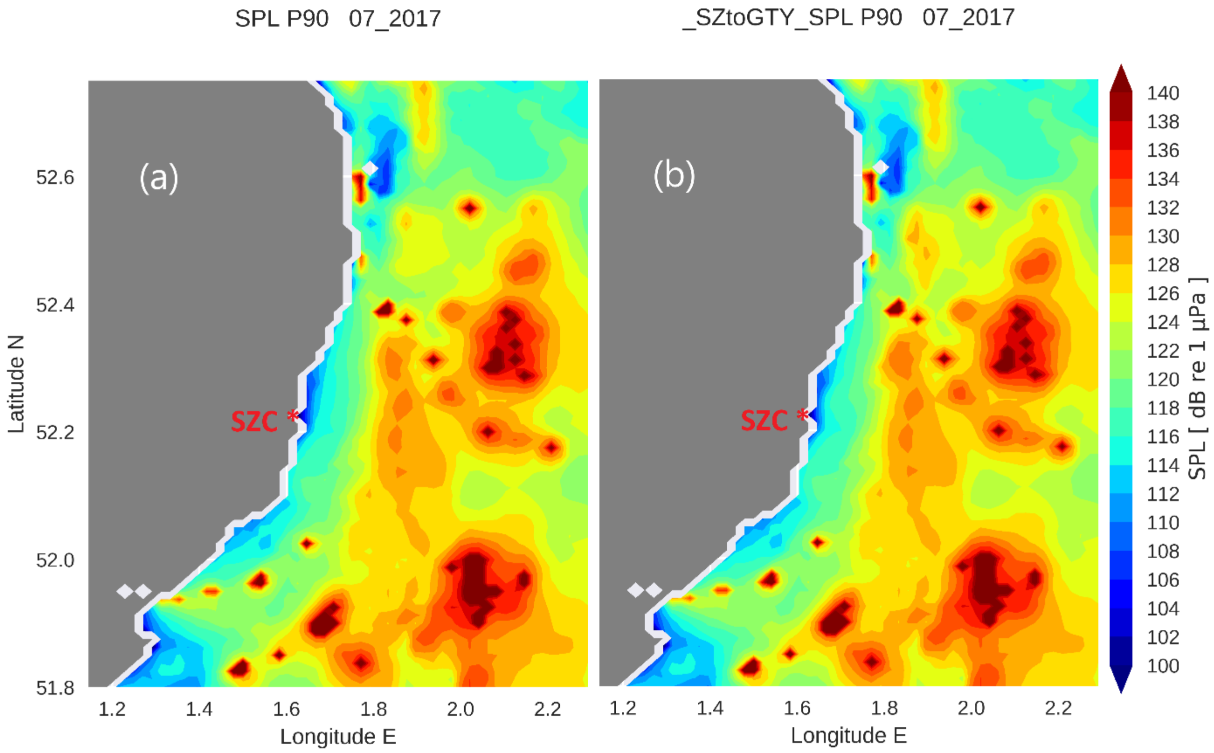

Figure 37 Comparison between (a) the baseline and (b) the Great Yarmouth transshipment scenarios P90 sound pressure levels for the month of July 2017 near Sizewell.

Since the differences between the two sets of outputs are not easily visible in a direct comparison between the maps, only the increase above the baseline for both the median (P50) and the P90 sound levels are presented for the other shipping scenarios. The increase is illustrated in Figure 38 to Figure 41 for the different transhipment scenarios. In each case increases are within 1dB of ambient for P50 and <5dB for the P90 statistics.

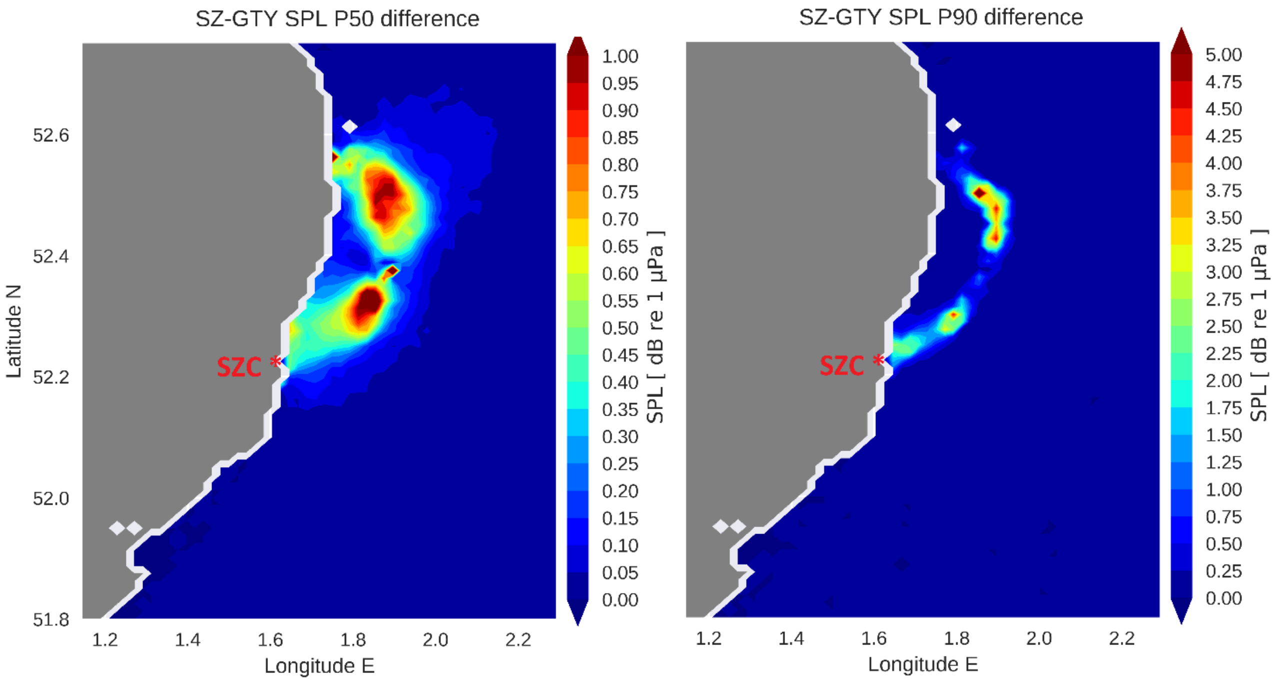

Figure 38 Increase above baseline SPL P50 and P90 near Sizewell for the transhipment from Great Yarmouth scenario. Note the different colour scales used for showing the increase in P50 (0-1 dB) and P90 (0-5 dB).

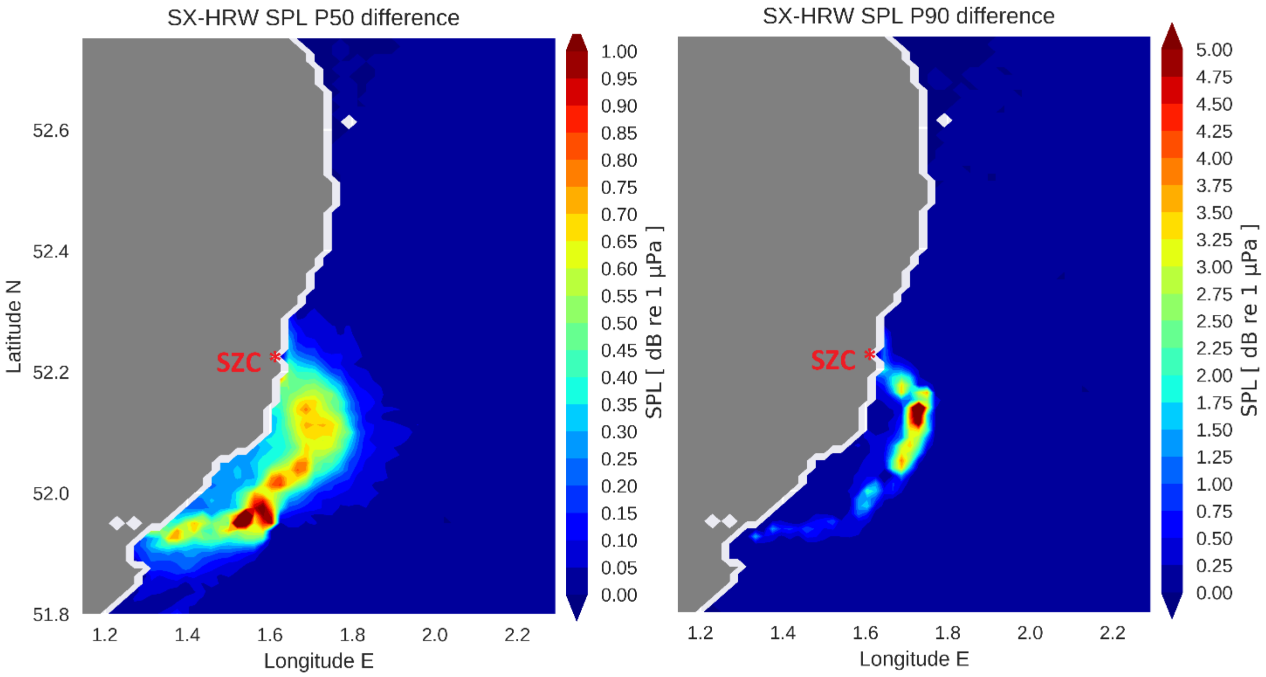

Figure 39 Increase above baseline SPL P50 and P90 near Sizewell for the transhipment from Harwich scenario. Note the different colour scales used for showing the increase in P50 (0-1 dB) and P90 (0-5 dB).

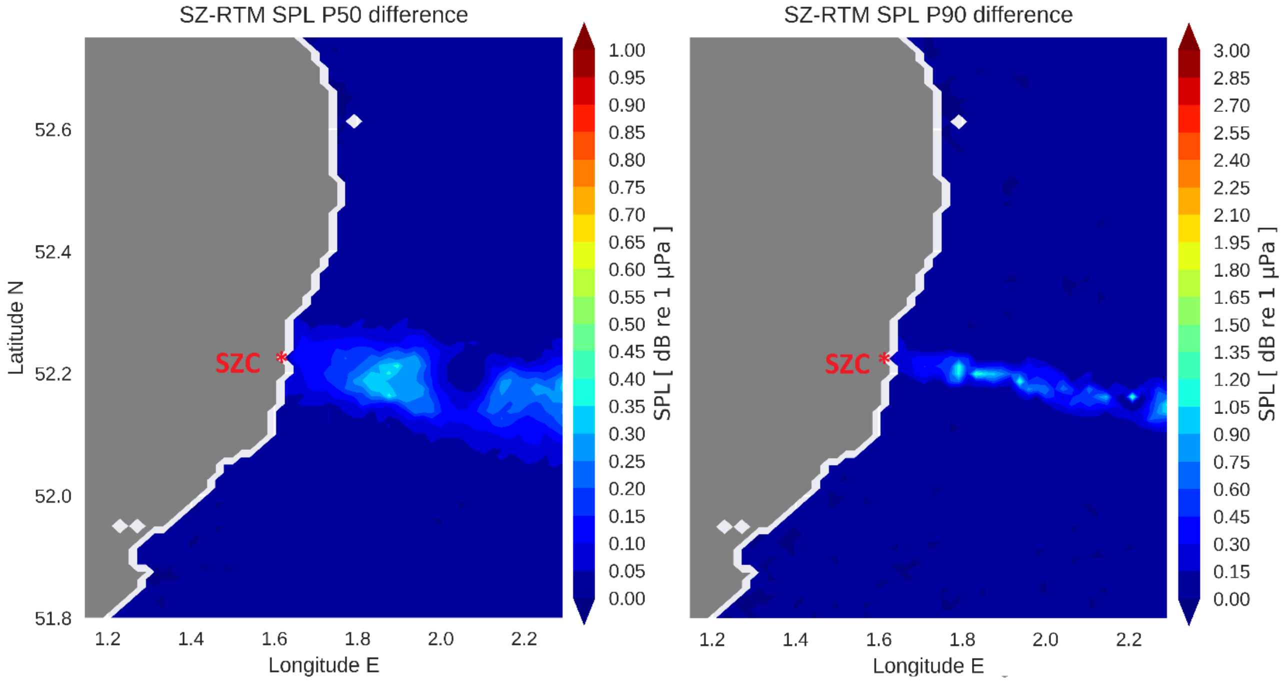

Figure 40 Increase above baseline SPL P50 and P90 near Sizewell for the transhipment from Rotterdam scenario. Note the different colour scales used for showing the increase in P50 (0-1 dB) and P90 (0-3 dB).

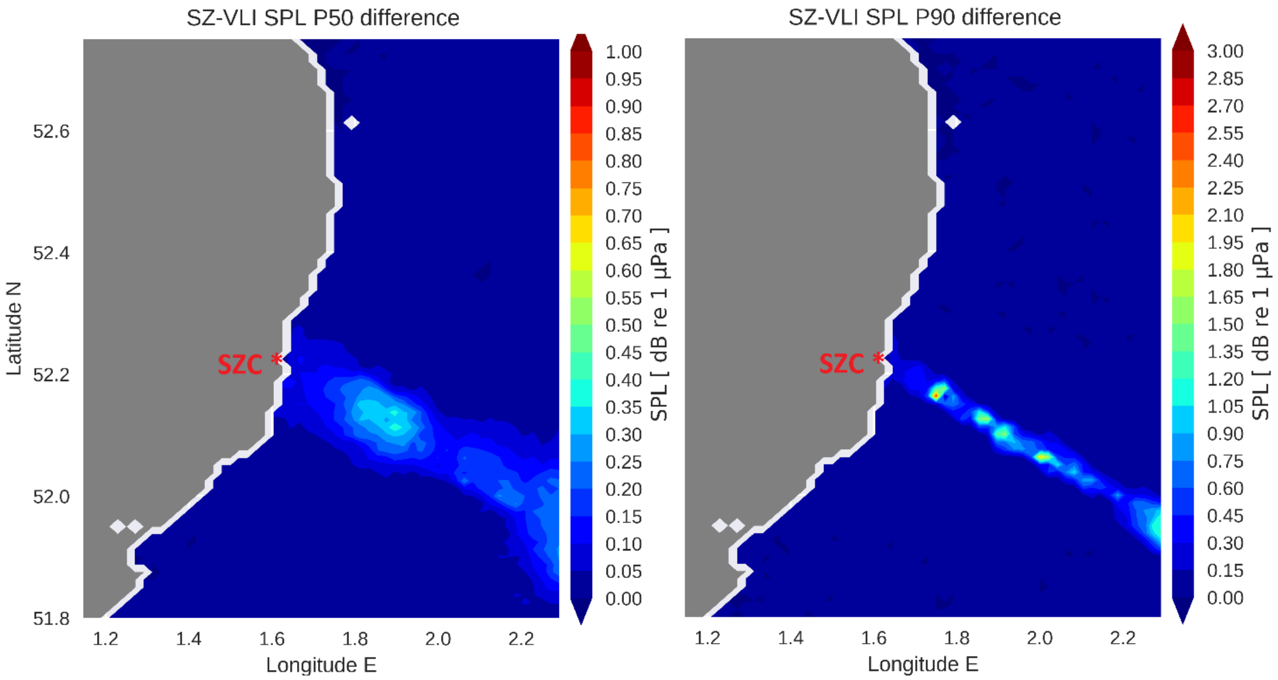

Figure 41 Increase above baseline SPL P50 and P90 near Sizewell for the transhipment from Vlissingen scenario. Note the different colour scales used for showing the increase in P50 (0-1 dB) and P90 (0-3 dB).

In the case of transhipment from Great Yarmouth or Harwich, the increase in median sound levels is about 1 dB or less locally at Sizewell and along the shipping track (Figure 38 and Figure 39). The corresponding increases in the P90 sound levels are about 5dB or less, but they cover an area much narrower around the shipping track than the median increases. The P90 statistics local to Sizewell are lower and within 3 dB above ambient. It should be noted these predictions are based on utilisation of every available high tide and are therefore conservative.

In the case of transhipment from the Netherlands ports, the sound level extends further offshore, due to the longer shipping distances compared to the UK ports, but the magnitude of these increases is much smaller. This is due to the reduced shipping frequency, which was assumed to be 4 times less (1 single trip per tidal cycle from Netherlands as opposed to 2 round trips per tidal cycle from the UK ports). The increases in the median sound levels, as seen in Figure 40 and Figure 41, are less than 0.5 dB, while the increases in the P90 sound levels are generally less than 1.5 dB.

As noted in Section 5.4.1, the baseline median sound levels in the proximity of the site are between 92 dB (200 m offshore) and 117 dB (10 km offshore), with the P90 sound levels being 5-10 dB higher than the median values. In conclusion, the potential increase in ambient noise levels associated with the BLF deliveries vessel traffic during the construction period is likely to be very modest and, as seen in Figure 36 and Figure 37, it is well within the typical variability at the site.

5.5 Operational noise

As discussed in Section 2.1.6, the complexity of the noise generating mechanisms and propagation paths through the substrate and into the water column preclude predictive modelling of operational noise. Therefore, in this section we present only estimates of the potential additional noise generated with both power stations in operation, as well as some considerations on the operational noise in the larger context of the ambient noise at the site.

Under the assumption that a similar amount of acoustic energy would be emitted into the marine environment by Sizewell C, the additional noise generated with both power stations in operation would be around 3 dB. If twice as much acoustic energy would be emitted by Sizewell C, then the additional noise would be around 4.8 dB. It should be noted that while these source level increases would translate in equal increases in the received levels of the operational noise in the field, in reality these received levels are adding up to the existing ambient noise levels in the field (e.g. due to shipping noise, wind, etc). As seen in Section 3.1, the average ambient noise levels (originating from all sources) were measured as 101 dB at approximately 700 m offshore over a 7 month period in 2013, and thus it can be inferred that the existing operational noise levels are less than 101 dB at this measurement location. In fact, as seen in Section 5.4.1, this measured value can be reasonably explain solely through the contribution of wind and shipping noise, which suggest that the contribution of operational noise to the ambient noise could be substantially less than this total measured value, even at locations that are close to shore. Furthermore, while the operational noise levels decrease further offshore, away from the source (likely by 6 dB for every doubling of the distance from the source), contribution of the shipping noise increases substantially further offshore due to greater propagation in deeper water. The modelled ambient noise levels from wind and shipping are predicted to be 104 dB at 1.5 km, 111 dB at 3 km and 114 dB at 5 km offshore, as noted in in Section 5.4.1.

In conclusion, the expected additional noise generated with both power stations in operation represents only a small increase in the background noise levels at the site, which has sustained an operational nuclear power station for several decades (since 1966). It is therefore anticipated that the additional impact of the operational noise from Sizewell C will be minimal and adaptation will be rapid.

6 Criteria for noise impacts to key species at Sizewell

Noise exposure criteria (also termed impact criteria or noise thresholds) define the sound levels at which various responses in marine animals are expected. For example, this can include temporary or permanent loss in hearing sensitivity (Temporary Threshold Shift, TTS or Permanent Threshold Shift, PTS) in marine mammals, as well as mortality or recoverable injury in fish. Noise exposure criteria are applied in environmental impact assessments (EIAs) to predict the possible extent of adverse effects of underwater noise on key species (Faulkner et al, 2018).

6.1 Marine mammal noise criteria

The rationale and proposed approach for assessing the potential effects of noise on marine mammals at Sizewell was described in BEEMS Technical Report TR335. The main findings of this report and the relevant noise exposure criteria are outlined below.

6.1.1 Southall and NOAA criteria

The first detailed marine mammal noise exposure criteria were published by Southall *et al*., in 2007, (here termed the Southall criteria), and resulted from a thorough review of marine mammal noise exposure studies (Southall *et al.*, 2007). The review sought to provide guidance on the likely severity of marine mammal responses to anthropogenic noise depending on the received sound level and sound type. The Southall criteria define sound level thresholds for permanent hearing impairment (PTS), and behavioural responses. This work has been influential and has formed the basis of many EIAs and scientific studies conducted since its publication.

Following the Southall publication, the U.S. National Marine Fisheries Service (NMFS) (part of the National Oceanic and Atmospheric Administration (NOAA)) has since issued updated criteria to reflect recent advances in the field (here termed the NOAA criteria). The NOAA criteria provide acoustic thresholds for the onset of PTS and TTS for marine mammals exposed to acute anthropogenic noise (NMFS, 2016). The NOAA criteria underwent extensive peer-review and was subject to three public (including stakeholder) consultation periods. Two previous draft versions were issued in 2013 (this version formed the basis of the original assessment from Edition 1 of this report). Recently, NOAA issued a 2018 revision to their 2016 technical guidance, following a public comment period and a Federal Interagency Consultation in 2017. The 2018 revision includes a summary and preliminary analysis of relevant scientific literature published since the 2016 guidance, although the thresholds and weightings (see below) remain unchanged.

The Southall and NOAA criteria are broadly similar and consist of thresholds formulated using two metrics: the weighted cumulative sound exposure level (SEL_{cum}), and the peak sound pressure level (SPL_{peak}). Each threshold is further categorised by (i) sound type (pulse or non-pulse sound) and (ii) functional hearing group (four broad categories of marine mammals with regard to hearing ability). Both criteria require the application of an auditory weighting (termed “M-weighting” in Southall *et al.,* 2007) to account for the frequency sensitivity of hearing for each functional hearing group.

6.1.2 Marine mammal assessment approach

This report applies the NOAA (NMFS, 2016, 2018) noise exposure criteria for all marine mammal species (harbour porpoises, harbour seals, and grey seals), as this represents the most recent and relevant set of criteria. The applicable noise exposure thresholds for marine mammals are summarised in Table 8. It should be noted that in the case of non-impulsive sound, the PTS/TTS thresholds are not explicitly defined for the peak SPL metric. However, NOAA recommends that if a non-impulsive sound has the potential of exceeding the peak SPL thresholds associated with impulsive sounds, these thresholds are recommended for consideration.

As highlighted above, the original assessment was based on the draft NOAA (NOAA, 2013) criteria. It should be noted that there are some differences and updates between the draft and finalised versions of the NOAA criteria. The thresholds for PTS and TTS for example, have been revised. The revised PTS and TTS thresholds are lower (more conservative) for harbour porpoise (for both pulsed and non-pulsed sounds) in the finalised guidance. The PTS and TTS thresholds are also lower for harbour and grey seal in the finalised guidance; the one exception being that the PTS threshold for non-pulsed sounds is higher (less precautionary).

Table 8 Noise exposure thresholds to be applied to the assessment of underwater noise at Sizewell C.

		PTS		TTS	
		Peak SPL (dB re 1 µPa)	SEL_{cum} (dB re 1 µPa^{2}s)	Peak SPL (dB re 1 µPa)	SEL_{cum} (dB re 1 µPa^{2}s)
Harbour porpoise	Pulse	202	155	196	140
	Non-pulse	N/A	173	N/A	153
Harbour seal, grey seal	Pulse	218	185	212	170
	Non-pulse	N/A	201	N/A	181

NOAA intends for the weighted SEL_{cum} metric to account for the accumulated exposure, i.e. over the duration of the activity within a 24-hour period. It should be noted that, for all sources, NOAA recommends a baseline accumulation period of 24 hours, although it acknowledges that the activities may last less than 24 hours, or they may exceed this accumulation period. If the noise generating activities occur over a shorter period within the 24-hour window (e.g. piling, most of the dredging activities) then, a receptor is at risk within the predicted auditory effect zone during the duration of activity. For the activities that may last more than 24 hours (e.g. dredging at the BLF location, drilling), the accumulation period accounts only for 24 hours of continuous activity.

For each type of noise generating activity that requires assessment of the accumulated exposure for a given receptor, the field sound pressure levels are modelled for each 1/3 octave band in the source spectrum and, following subtraction of the weighting amount as specified by the NOAA weighting curve for that receptor and frequency band, the contribution of all the 1/3 octave bands are summed resulting in weighted sound pressure levels.

For any given activity and receptor, the accumulated exposure depends not only on the spatial distribution of the sound pressure generated by the activity, but also on the position of the receptor in the field which might change over the duration of the activity within a 24-hour period. For example, field studies have demonstrated behavioural responses of harbour porpoises to anthropogenic noise. A number of studies have shown avoidance of pile driving activities during offshore wind farm construction (Brandt *et al.*, 2011; Carstensen *et al.*, 2006; Dähne *et al.*, 2013), with the range of measurable responses extending to at least 21 km in some cases (Tougaard *et al.*, 2009).

The movement of the receptor can be included in the model used to assess the cumulative sound exposure, and in particular a fleeing behaviour is often considered in such models, namely the receptor is assumed to move away from the noise source, thus in general reducing its sound exposure. However, it should be noted that the assumptions underlying such fleeing models, particularly probability of fleeing, swim speed and flight path have a critical influence on the size and extent of the predicted effect zones. These assumptions related to the animal behavioural responses are likely to be site-specific (Graham *et al*., 2017) and need to be carefully considered in order to avoid underestimating the risk (Faulkner *et al*., 2018). On the other hand, assuming that an animal remains stationary produces highly conservative predictions of the auditory effect zone extents. Static results can be interpreted as zones where the animal would be at risk of TTS/PTS cumulative noise exposure if it was to remain within the area for 24 hours (or the actual duration of activity if less than 24 hours). Static results require knowledge of the ecology of the receptor to be applied to assess the potential for effects.

Given the uncertainties related to the possible fleeing behaviour of the marine mammal receptors and the sensitivity of modelling predictions to the fleeing parameters, we assess the cumulative sound exposure levels both using stationary receptors and using a set of generic fleeing assumptions, as detailed below. It should be noted that these fleeing assumptions and the associated parameters and methodology have been previously used by Cefas for several EIAs of pilling activities associated to wind farm construction projects in East Scotland.

6.1.3 Marine mammal fleeing behaviour for cumulative sound exposure estimation

For the assessment of fleeing behaviour, it was assumed that marine mammals would flee from the source location at the onset of activity. Animals were assumed to flee out to a maximum distance of 25 km (after which they were assumed to remain stationary at that distance).

Table 9 Fleeing behaviours assumed for harbour porpoise and seals.

Species	**Harbour porpoise**	**Phocid seal**
Swimming speed (m/s)	1.4	1.8
Minimum depth Constraint (m)	3	0

The fleeing model simulates the animal displacement and their noise exposure for a given scenario by placing an ‘agent’ in each grid cell of the domain (i.e. every 50 m by 50 m) and allowing them to move on the domain grid according to a set of pre-defined rules. The position of all the agents is re-evaluated at regular short intervals (e.g. 1 to 5 minutes). The cumulated exposure over each time interval is calculated according to the positions of the agents and the energy released within the interval (e.g. for a piling scenario from the number of strikes and the hammer energies used within the interval). The duration of these time intervals was optimised in order to minimise the SPL variation due to the change in position of the agents, while maintaining a good approximation of the specified fleeing speed of the agents. At the end of the scenario activity, the total cumulated exposure of all the agents was mapped back to their starting positions on the grid. Therefore, map outputs illustrate auditory effect zones for animals starting at positions with the impact contour.

In the case of single location activity, the model assumes that the animal agents are fleeing at constant speeds (Table 9), along straight lines away from the pile location, as long as the local water depth exceeds a minimum value (Table 9). In the case of harbour porpoises fleeing, in an animal agent encounters shallower water than the allowed minimum depth a change is direction is calculated and effected. Permitted directional changes, in the order of preference, are:

- +/- 45° (forwards left or right);
- +/-90° (sideways left or right);
- +/-135° (backwards left or right) and, as a last option;
- 180° (backward, but not necessarily to the previous position, unless the previous move was straight forwards).

It should be noted that, as indicated in Table 9, these rules do not apply to the seal agents. Seals can move in any depths of water and even move to the shore (within the 25 km maximum distance from the pile location), thus stopping their sound exposure.

In the case of simultaneous noise generating activities, such as the in-combination dredge scenario, the model assumes that the animal agents flee at the same constant speeds as in the case of single location activity, but their fleeing direction is being re-evaluated at every time step according to their position relative to the location of the two sound sources. Specifically, at a given time, the fleeing direction is calculated by summing up the two vectors originating at the current animal agent position, pointing straight away from the two sources, and having their magnitude proportional with the specific dose responses of the animal for the current SPL from the two sources, respectively. The same minimum depth constrains and shallow water avoidance rules as in the single location activity described above remain consistent.

6.2 Fish noise criteria

The formulation of the Southall and NOAA criteria for marine mammals was facilitated by established precedents in human noise assessment: we share similar mammalian auditory mechanisms and so several techniques and concepts could be translated. This is not the case for fish. Fish auditory systems are dramatically different to humans, and the fundamental mode of sound detection is via the particle motion component of sound (not sound pressure, as in the mammalian ear). For these reasons, devising noise exposure assessment criteria for fish is inherently more challenging (Popper *et al.*, 2014).

6.2.1 Popper criteria

The first effort to develop generally applicable noise exposure criteria for fish was published by Popper *et al.* (2014). These criteria (here termed the Popper criteria) provide quantitative thresholds for TTS, recoverable injury, and death in fish in response to several impulse sound sources, including pile driving. The thresholds are formulated using the peak sound pressure level (dB peak) and the cumulative sound exposure level (SEL_{cum}). Fish are categorised according to the following three functional hearing groups (in decreasing order of vulnerability to noise exposure):

1. Swim bladder or other air cavities aid hearing.
2. Swim bladder does not aid hearing.
3. No swim bladder.

The representative fish species for assessment purposes at Sizewell are categorised as shown in Table 10.

Table 10 Categorisation of key fish species at Sizewell according to hearing ability.

Species	Swim bladder or air cavities aid hearing	Swim bladder does not aid hearing	No swim bladder
Anchovy (*Engraulis encrasicolus*)	Webb *et al.*, (2008)		
Atlantic herring (*Clupea harengus*)	Mann *et al.*, (1997) Webb *et al.*, (2008)		
European sprat (*Sprattus sprattus*)	Webb *et al.*, (2008)		
Seabass (*Dicentrarchus labrax*)		Neo *et al.*, (2014) Kastelein *et al.*, (2008)	
European eel (*Anguilla anguilla*)		Popper and Coombs (1982) Jerkø *et al.*, (1989)	
Whiting (*Merlangius merlangus*)		Webb *et al.*, (2008)	
Smelt (*Osmerus eperlanus*)		Webb *et al.*, (2008)	
Shad (*Alosa sp.*)	Popper (2005)		

6.2.2 Mortality, injury and TTS

The Popper criteria for impact piling are presented in Table 11. These thresholds indicate the potential for mortality, injury and TTS, according to the hearing ability of the fish species. The Popper criteria do not provide quantitative thresholds for continuous sources of noise, such as those listed in Table 1 ; e.g. dredging. Given that pulse sounds such as piling noise are likely to have a greater effect on fish than continuous sources at the same level (Neo *et al.*, 2014), the Popper thresholds for impact piling will be applied in the assessment of sound exposure from continuous sources as a precautionary approach.

Table 11 Popper criteria for piling sources. “dB peak” denotes zero-to-peak sound pressure levels in units of dB re 1 μPa. “dB SEL” denotes sound exposure levels (SEL) in units of dB re 1 μPa^2 s.

Animal type	Mortality / potential mortal injury	Recoverable injury	TTS
Fish: no swim bladder (particle motion detection)	> 219 dB SEL$_{cum}$ or > 213 dB peak	> 216 dB SEL$_{cum}$ or > 213 dB peak	>> 186 dB SEL$_{cum}$
Fish: swim bladder is not involved in hearing (particle motion detection)	210 dB SEL$_{cum}$ or > 207 dB peak	203 dB SEL$_{cum}$ or > 207 dB peak	> 186 dB SEL$_{cum}$
Fish: swim bladder involved in hearing (primarily pressure detection)	207 dB SEL$_{cum}$ or > 207 dB peak	203 dB SEL$_{cum}$ or > 207 dB peak	186 dB SEL$_{cum}$

For explosions, the Popper criteria provide only guideline quantitative thresholds for mortality and potential mortal injury, based on a study by Hubbs and Rechnitzer (1952) which showed a minimum amplitude of 40 – 70 psi (peak pressure) that resulted in mortality. This is the equivalent to 276 to 482 kPa, or 229 to 234 dB re 1 μPa. As a precautionary approach, we adopted the lower limit of this interval, namely 229 dB peak pressure, for the assessment of mortality and potential mortal injury effects from UXO detonation.

These noise exposure criteria used to asses all key fish species at Sizewell are summarised in Table 12.

Although fish are not expected to remain stationary during the noise-generating activities, we are not aware of direct empirical evidence to support fleeing behaviour in fish. Therefore, the assessment approaches for fish do not include assumptions of fleeing behaviour.

Table 12 Fish noise exposure criteria to be applied in noise effects assessment of all key fish species at Sizewell. “dB SEL” denotes sound exposure levels (SEL) in units of dB re 1 µPa^2 s.

Species	Mortality / potential mortal injury	Recoverable injury	TTS
Anchovy (*Engraulis encrasicolus*) Atlantic herring (*Clupea harengus*) European sprat (*Sprattus sprattus*) Shad (*Alosa sp.*)	207 dB peak 207 dB SEL_{cum}	207 dB peak 203 dB SEL_{cum}	186 dB SEL_{cum}
European eel (*Anguilla anguilla*) Whiting (*Merlangius merlangus*) Seabass (*Dicentrarchus labrax*)	207 dB peak 210 dB SEL_{cum}	207 dB peak 203 dB SEL_{cum}	186 dB SEL_{cum}
Species without a swim bladder (e.g. mackerel and elasmobranchs)	213 dB peak 219 dB SEL_{cum}	213 dB peak 216 dB SEL_{cum}	186 dB SEL_{cum}
All species, explosions only	236 dB peak	N/A	N/A

6.2.3 Behavioural responses

Behavioural response assessments have been undertaken to determine the potential ranges over which underwater noise may elicit fish behavioural responses. Behavioural responses or displacement due to underwater noise has the potential to temporarily effect migratory fish species or influence prey availability for designated birds and marine mammals.

The Popper criteria detailed in Table 12 do not provide quantitative thresholds for behavioural responses to noise. Indeed, the onset of behavioural responses to noise is much more difficult to quantify as reactions are likely to be strongly influenced by behavioural context (Hawkins and Popper, 2014), and the effect of a particular response is often unclear. For example, a startle or reflex response to the onset of a noise source does not necessarily lead to displacement from the ensonified area. This uncertainty is further compounded by the limitations of observing fish behavioural responses in a natural context: few studies have conducted behavioural field experiments with wild fish (Popper and Hastings, 2009), and lab-based experiments may not give a realistic measure of how fish will respond in their natural environment (Kastelein *et al.*, 2008).

For these reasons, quantitative assessments for behavioural responses in the same manner as the mortality and auditory injury criteria in Table 12 are not feasible. Instead, unweighted sound level contours are provided (Section 5). An assessment has then been made on the potential for behavioural responses, with reference to peer-reviewed literature. For example, Hawkins and Popper (2014) reported startle responses of schools of wild sprat (one of the key species at Sizewell) at a single-pulse sound exposure level of **135 dB re 1 µPa^{2}s and 142 dB re 1 µPa^{2}s for mackerel shoals** (mackerel have no swim bladder). Schools of sprat were observed to disperse or change depth on 50% of presentations.

These single-pulse sound exposure levels are applied to estimate potential behavioural response ranges. The behavioural response ranges calculated here are based on observations of responses to instantaneous noise sources in two species (sprat and mackerel). As such, assessments are subject to a lower degree of confidence than injury and auditory damage assessment that are based on established criteria. This is particularly the case where instantaneous behavioural response thresholds are applied to continuous sound sources such as drilling and dredging. Whilst the limitations of the approach must be recognised, the applied behavioural thresholds are based on the best available evidence and taken to be a conservative indicator for the risk of behavioural responses and potential displacement. Behavioural response zones should therefore be treated with lower levels of confidence when applied across species with different hearing sensitivities and auditory mechanisms, or when the fish are exposed to continuous noise for extended periods.

Sprat are a clupeid species and are likely to have similar acoustic characteristics to the other two clupeid species at Sizewell, Atlantic herring and anchovy. Whiting, smelt and European eel do not exhibit the hearing specialisations as clupeids. As such the 135 dB re 1 µPa^{2}s threshold is likely to be conservative for these species, although this does not exclude a distinct behaviour response induced through particle motion instead of sound pressure level detection. It should be noted that behavioural response do not necessitate displacement from the ensonified area.

7 Predicted noise effects on key species

Noise levels modelled in accordance with the methodology presented in Section 4 were assessed with respect to noise exposure criteria (Section 6) to produce predictive auditory effect range and/or maps illustrating areas within which marine mammals and fish may be exposed to potentially harmful noise levels (auditory effect zones) for each activity. Instantaneous and cumulative auditory effect zones were assessed for each activity (except UXO detonations, which is only assessed for the instantaneous effects).

7.1 UXO detonation

The hypothetical UXO detonations resulted in the greatest auditory effect zones for instantaneous assessments for fish and marine mammals.

7.1.1 Marine mammals

The effect ranges illustrating the distances within which marine mammals may be exposed to potentially harmful noise levels for the UXO detonation works are presented in Table 13 below.

It should be noted that the figures reported present a hypothetical worst-case scenario for unmitigated detonation. Should a UXO be identified a full assessment would be completed, subject to any relevant conditions in the DML. The location and size of the UXO in relation to site-specific factors such as proximity to existing nuclear infrastructure, sensitive habitats and geomorphic features would in part determine the suite of mitigation measures available, which as a minimum would adhere to the JNCC guidelines for minimising the risk of disturbance and injury to marine mammals whilst using explosives. Alternative disposal methods or relocation would be considered as well as appropriate mitigation measures including deployment of Marine Mammal Observers (MMOs), Acoustic Deterrent Devices (ADD), and potentially, smaller scare charges or bubble curtains where possible to minimise the potential for death or injury. The most appropriate mitigation measures for UXO would be discussed with regulators and SNCBs to maintain the integrity of the southern North Sea SAC in accordance with the conservation objectives (JNCC 2019).

Table 13 Marine mammal auditory effect ranges (expressed in metres) for UXO detonation works.

Charge mass TNT equivalent (lb)	Threshold	Harbour porpoise	Harbour/grey seal
250	PTS	7,726 m	1,514 m
	TTS	14,238 m	2,789 m
500	PTS	9,734 m	1,907 m
	TTS	17,939 m	3,514 m
1,500	PTS	14,039 m	2,750 m
	TTS	25,872 m	5,068 m

The explosive charge mass of 1,500 lb had the largest impact ranges for all species. Harbour porpoises were the most sensitive receptors and had the largest impact ranges. The maximum instantaneous impact range was estimated to be 25,872 m for TTS in harbour porpoise for the 1,500 lb whereas PTS was predicted to occur to a range of 14,039 m. For the smaller charge mass of 500 lb and 250 lb, the predicted ranges were 9,734 m and 7,726 m for PTS in harbour porpoise, respectively.

Harbour and grey seals impact ranges for a hypothetical 1,500 lb TNT equivalent explosion were predicted to be 2,750 m for PTS and 5,068 m for TTS. Predicted TTS and PTS impact ranges for harbour and grey seals were 3,514 m and 1,907 m, respectively, for the 500 lb charge mass. For the 250 lb charge mass, the predicted impact ranges were 2,789 for TTS and 1,514 m for PTS.

7.1.2 Fish

The effect ranges illustrating the distances within which fish species may be exposed to harmful noise levels potentially causing mortality or potential mortal injury for the UXO detonation works are presented in Table 14 below.

Table 14 Fish species auditory effect ranges (expressed in metres) for UXO detonation works.

Charge mass TNT equivalent (lb)	Threshold	All fish species
250	Mortality and potential mortal injury (m)	493 m
500	Mortality and potential mortal injury (m)	622 m
1,500	Mortality and potential mortal injury (m)	897 m

Potential auditory effect ranges for fish are substantially smaller than for marine mammals. The explosive charge mass of 1,500 lb had the largest effect ranges for the fish species, with the maximum instantaneous mortality and potential mortal injury estimated to 897 m. For the smaller charge mass of 500 lb and 250 lb, the predicted mortality and potential injury range was 622 m and 493 m, respectively. It should be noted that the figures reported present a hypothetical worst-case scenario for unmitigated detonation.

7.2 Impact piling

Impact piling for the installation of BLF piles resulted in the second largest (after UXO detonation) instantaneous auditory effect zones for fish and marine mammals, and the greatest auditory effect zones for the cumulative assessments.

7.2.1 Marine mammals

7.2.1.1 Instantaneous effects

The maximum instantaneous effect range during piling was estimated to be 67 m for harbour porpoise TTS with a 200 kJ hammer strike energy. PTS was restricted to 41 m of the piling activity for the 200 kJ scenario and 27 m for the 90 kJ hammer energy scenario (Table 15). Seals effects zones were considerably smaller, with maximum PTS of 9 m and TTS of 16 m for the 200 kJ scenario.

All the scenarios modelled for the peak SPL criterion for instantaneous TTS and PTS had effect ranges well within the 500 m JNCC marine mammal observation perimeter (JNCC 2010a) for both harbour porpoise and seals. Adhering to JNCC guidelines and maintaining observations within this perimeter prior to the onset of piling would be consistent with mitigating the risk of instantaneous auditory damage to these marine mammal species.

7.2.1.2 Cumulative effects

Cumulative sound exposure effects on harbour porpoise for the two impact piling scenarios; namely driving 5 consecutive piles within 24-hours using the most likely 90 kJ hammer energy and the worst-case 200 kJ hammer energy were assessed (Table 15). Sound propagation is clearly influenced by the Sizewell Dunwich Bank, a sand bank situated ~2 km offshore in a north-south orientation, which acts as an acoustic barrier limiting the easterly propagation of the sound.

The stationary receptors cumulative auditory effect zones extend furthest in the north and south directions, exceeding 12.5 km from the BLF for harbour porpoise TTS and 2.1 km for PTS (Figure 43) The lower hammer energy scenario results in TTS effect zones of 6.6 km and PTS effect zones of 1.3 km for harbour porpoise (Figure 42).

The corresponding fleeing harbour porpoise assessments resulted in no PTS effect zones, while the TTS zone extended to approximately 4.8 km for the most likely 90 kJ hammer energy scenario (Figure 44) and to approximately 2.8 km for the 200 kJ scenario (Figure 45).

The corresponding TTS and PTS zones were smaller for seals than those predicted for harbour porpoise. These differences are a consequence of the differing auditory weighting (which is markedly different at low frequencies; NOAA, (2016)) and exposure threshold for seals (see Section 6.1.1). TTS was predicted to extend to approximately 3.1 km and PTS to approximately 300 m for the seals in the 200 kJ hammer energy scenario (Figure 47). For the most likely 90 kJ hammer energy scenario, the corresponding maximum effect ranges were approximately 35 % smaller than those predicted in the worst-case scenario (Table 15).

The corresponding fleeing seals assessments resulted in no PTS or TTS effect zones.

Table 15 Marine mammal auditory effect zones areas (expressed in hectares) and/or auditory effect zone maximum ranges (expressed in metres) for impact piling activities. ‘See Figure’ indicates auditory effect zone was also large enough to appear on corresponding figure.

Activity	**Thres-hold**	**Instantaneous**		**Stationary Cumulative**		**Fleeing Cumulative**	
		Harbour porpoise	Phocid seals	Harbour porpoise	Phocid seals	Harbour porpoise	Phocid seals
Impact piling 90 kJ for BLF	PTS	27 m	16 m	1,297 m 190 ha See Figure 42	206 m 10 ha See Figure 46	No effect	No effect
	TTS	45 m	10 m	6,624 m 4,994 ha See Figure 42	1,882 m 430 ha See Figure 46	2765 m 768 ha See Figure 44	No effect
Impact piling 200 kJ for BLF (precautionary assessment)	PTS	41 m	9 m	2,081 m 561 ha See Figure 43	303 m 20 ha See Figure 47	No effect	No effect
	TTS	67 m	16 m	12,450 m 10,223 ha See Figure 43	3,104 m 1,064 ha See Figure 47	4795 m 2179 ha See Figure 45	No effect

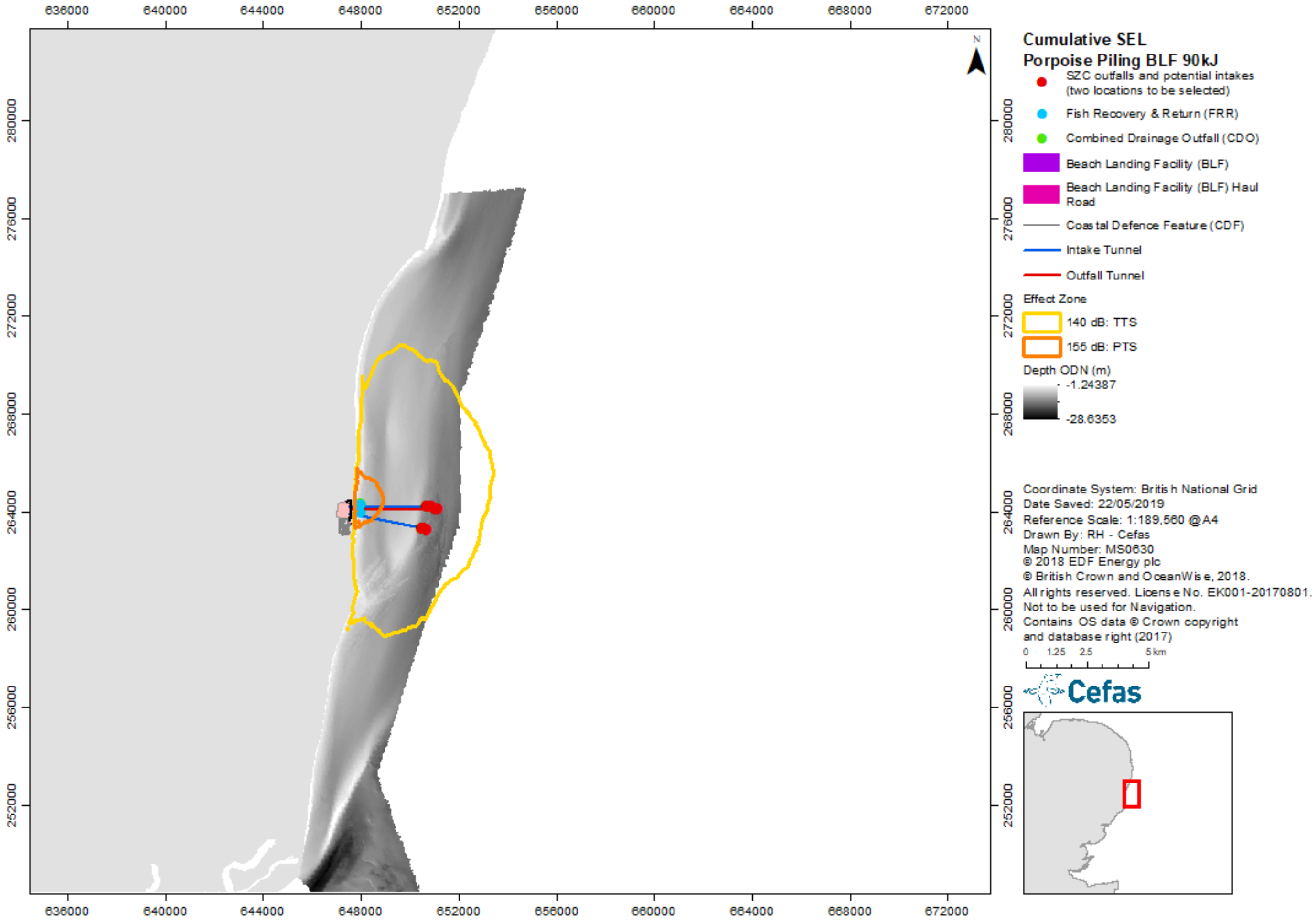

Figure 42 Predicted cumulative auditory effect zones for stationary harbour porpoise for the most likely impact piling scenario during BLF construction, assessed over 24 hours as per NOAA criteria (see Section 6.1.1). Assessment based on five consecutive piles using 1500 hammer strikes of 90 kJ energy for each pile.

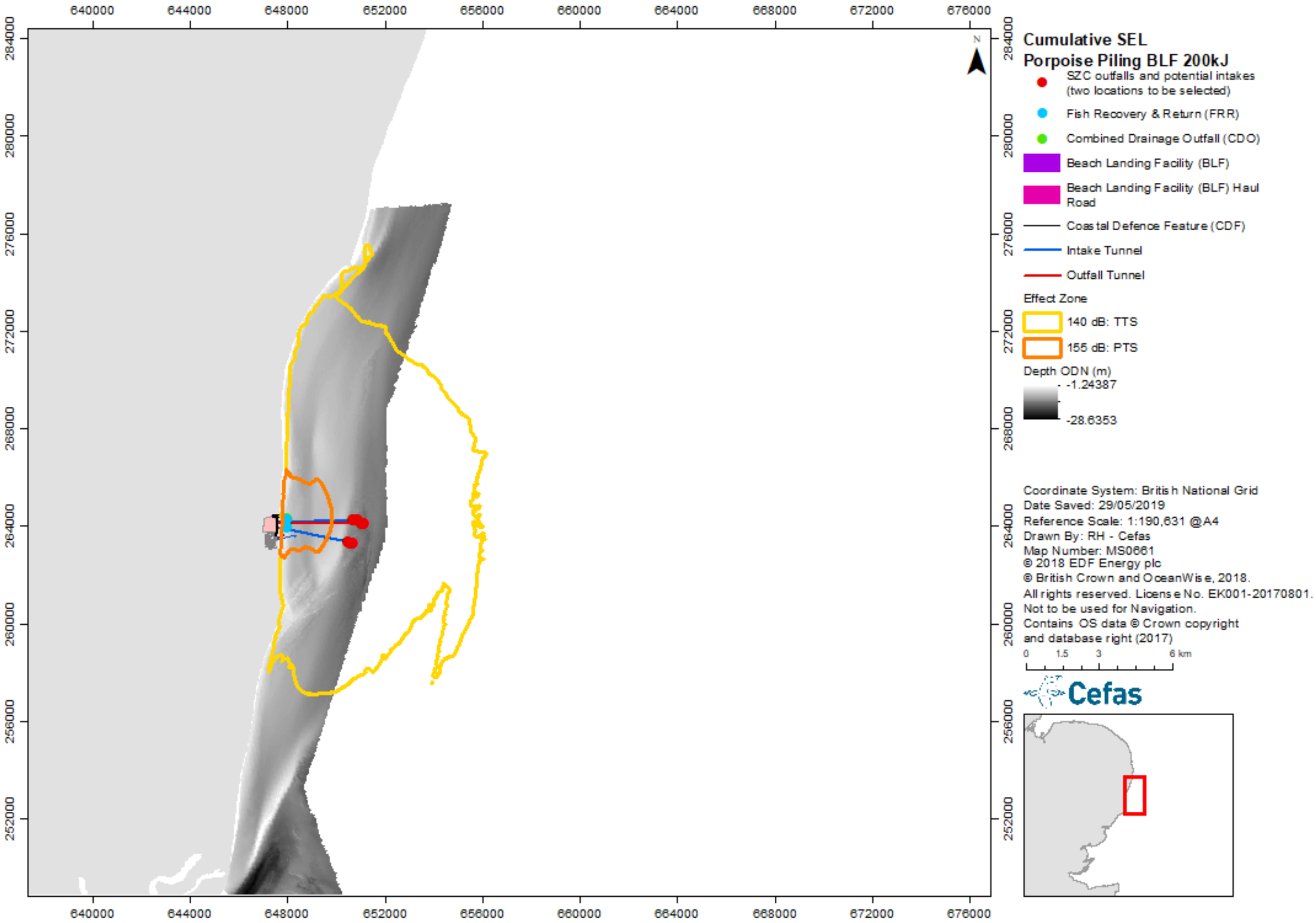

Figure 43 Predicted cumulative auditory effect zones for stationary harbour porpoise for the worst-case impact piling scenario for BLF construction, assessed over 24 hours as per NOAA criteria (see Section

6.1.1). Assessment based on five consecutive piles using 1500 hammer strikes of 200 kJ energy for each pile.

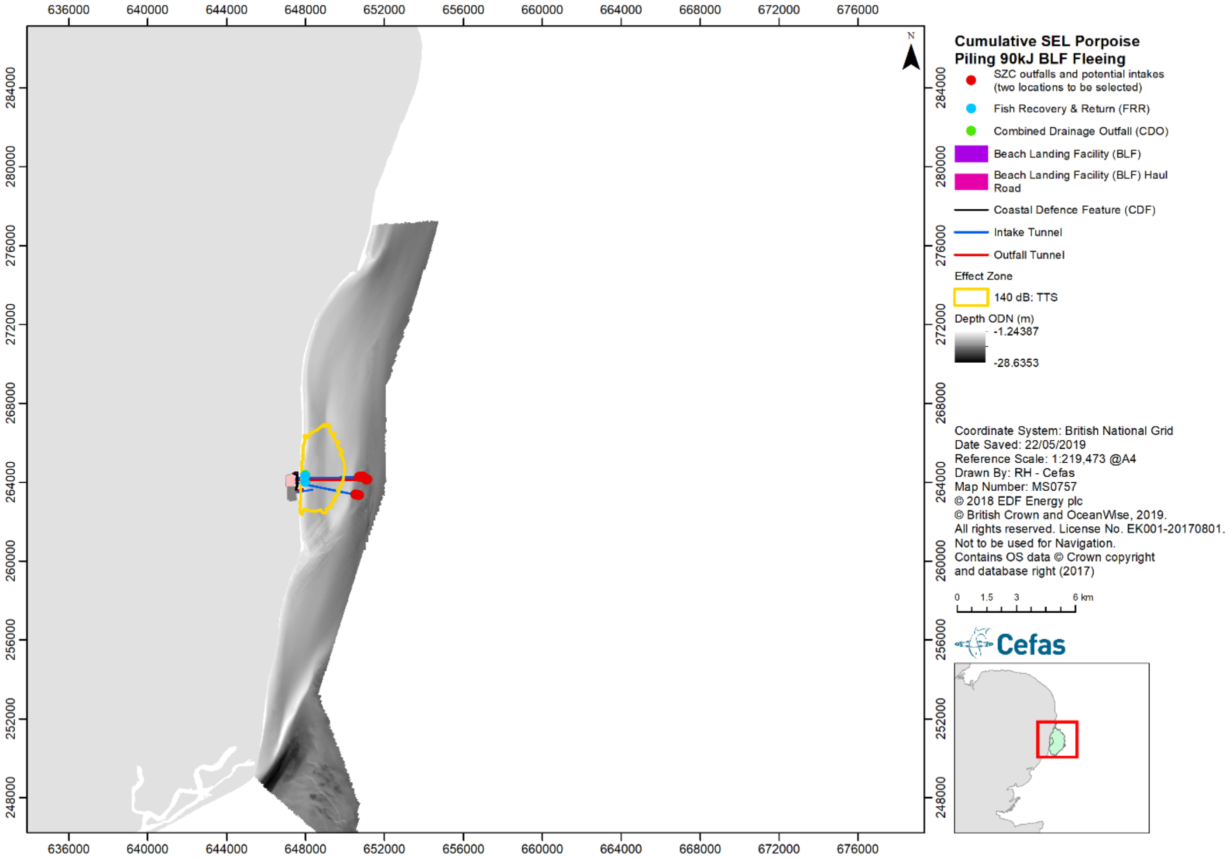

Figure 44 Predicted cumulative auditory effect zones for fleeing harbour porpoise for the most likely impact piling scenario during BLF construction, assessed over 24 hours as per NOAA criteria (see Section 6.1.1). Assessment based on five consecutive piles using 1500 hammer strikes of 90 kJ energy for each pile.

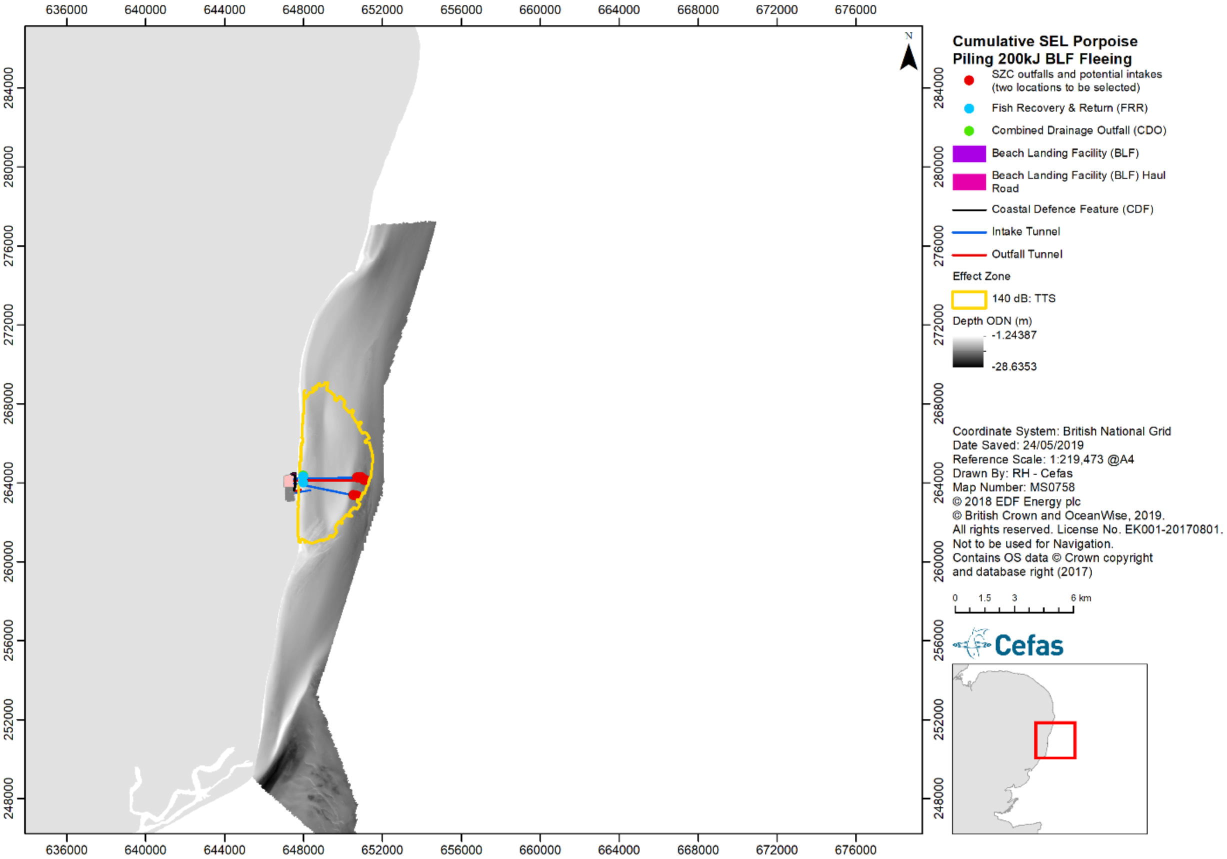

Figure 45 Predicted cumulative auditory effect zones for fleeing harbour porpoise for the worst-case impact piling scenario during BLF construction, assessed over 24 hours as per NOAA criteria (see Section 6.1.1). Assessment based on five consecutive piles using 1500 hammer strikes of 200 kJ energy for each pile.

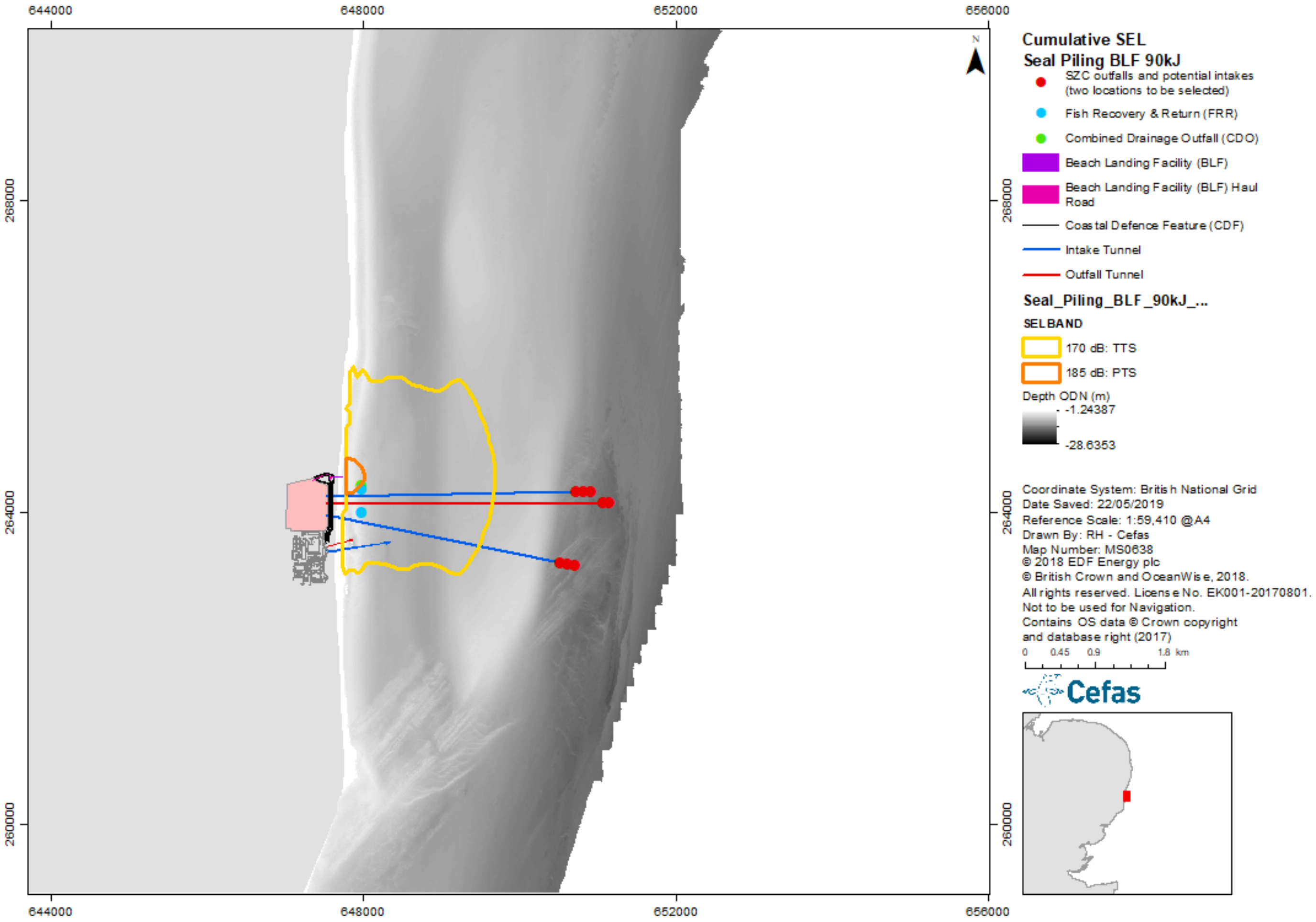

Figure 46 Predicted cumulative auditory effect zones for stationary harbour seal and grey seal for the most likely impact piling scenario for BLF construction, assessed over 24 hours as per NOAA criteria (see Section 6.1.1). Assessment based on five consecutive piles using 1500 hammer strikes of 90 kJ energy for each pile.

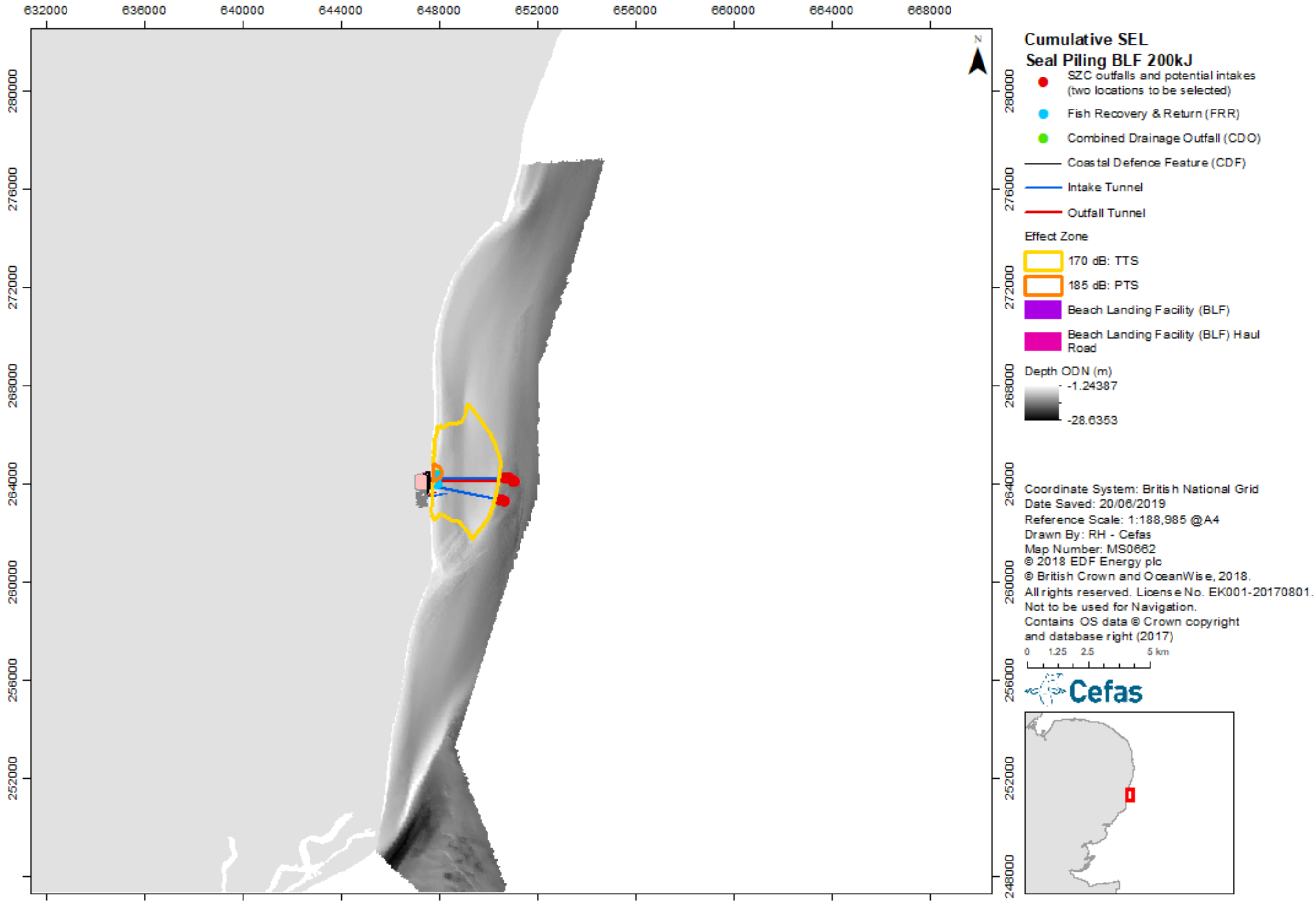

Figure 47 Predicted cumulative auditory effect zone for stationary harbour seal and grey seal for the worst-case impact piling scenario for BLF construction, assessed over 24 hours as per NOAA criteria (see Section 6.1.1). Assessment based on five consecutive piles using 1500 hammer strikes of 200 kJ energy for each pile.

7.2.2 Fish

7.2.2.1 *Instantaneous effects*

The maximum effect ranges for mortality or recoverable injury for the hearing group species with swim bladder involved in hearing (which according to the Popper criteria have the same threshold of 207 dB re 1µPa) were 17 m and 27 m, for the most likely 90 kJ hammer energy strike and the worst-case 200 kJ hammer energy strike, respectively (Table 16). For the hearing group of fish species with a swim bladder not involved in hearing (eel, whiting and smelt) the same threshold of 207 dB re 1µPa applies for mortality and recoverable injury, resulting in the same maximum auditory effect ranges as for the species with swim bladder involved in hearing (Table 17). Finally, the maximum effect ranges for mortality or recoverable injury for the hearing group without a swim bladder, which according to the Popper criteria have the same threshold of 213 dB re 1µPa, were 10 m and 15 m, for the most likely 90 kJ hammer energy strike and the worst-case 200 kJ hammer energy strike, respectively (Table 17).

7.2.2.2 *Cumulative effects*

Cumulative sound exposure effects on fish, according to the Popper criteria (see Section 6.2.1) were assessed for the two impact piling scenarios. For the hearing group most vulnerable to noise exposure (Table 16), the TTS zone extended up to 821 m from the BLF piling location for the 200 kJ hammer energy and 556 m for the 90 kJ hammer energy. Mortality and recoverable injury zones extended up to 111 m and 158 m, respectively, for the worst-case scenario (200 kJ hammer energy strikes). For the most likely 90 kJ hammer energy scenario, the corresponding maximum effect ranges reduced to 70 m for mortality, 111 m for recoverable injury (Table 16).

The mortality and recoverable injury zone extents for the other two hearing groups (fish species without swim bladder and fish with a swim bladder not involved in hearing) are shown in Table 17. Since TTS thresholds (186 dB re 1µPa) are applicable to all three fish hearing groups, and recoverable injury thresholds are the same (203 dB re 1µPa) for species with a swim bladder (irrespective if it is involved in hearing or not), the extents of the TTS and recoverable injury zones for these species is show only in Table 16 only.

The cumulative sound exposure auditory effect zones for fish species from the hearing group most vulnerable to noise exposure are illustrated in Figure 48 and Figure 49 and represent the largest effect ranges for the two impact pilling scenarios.

Table 16 Auditory effect zones areas (expressed in hectares) and/or auditory effect zone maximum ranges (expressed in metres) for the fish species with swim bladder involved in hearing, for impact pilling activities. The grey shaded boxes indicate that TTS is not defined for instantaneous noise exposure for fish; 'See Figure' indicates auditory effect zone was large enough to appear on corresponding figure.

Activity	Threshold	Instantaneous	Cumulative
Impact piling 90 kJ for BLF	Mortality	17 m	70 m; 1 ha See Figure 48
	Recoverable injury	17 m	111 m; 3 ha See Figure 48
	TTS	▨	556 m; 46 ha See Figure 48
Impact piling 200 kJ for BLF **(precautionary assessment)**	Mortality	27 m	111 m; 2 ha See Figure 49
	Recoverable injury	27 m	158 m; 4 ha See Figure 49
	TTS	▨	821 m; 88 ha See Figure 49

Table 17 Auditory effect zones areas (expressed in hectares) and/or auditory effect zone maximum ranges (expressed in metres) for the fish species without a swim bladder or with a swim bladder that is not involved in hearing, for impact pilling activities.

Activity	Threshold	Instantaneous	Cumulative
Impact piling 90 kJ for BLF	Mortality (no swim bladder)	10 m	<25 m
	Recoverable injury (no swim bladder)	10 m	<25 m
	Mortality (swim bladder not involved in hearing)	17 m	<25 m
Impact piling 200 kJ for BLF **(precautionary assessment)**	Mortality (no swim bladder)	15 m	<25 m
	Recoverable injury (no swim bladder)	15 m	<25 m
	Mortality (swim bladder not involved in hearing)	27 m	70 m; 1 ha

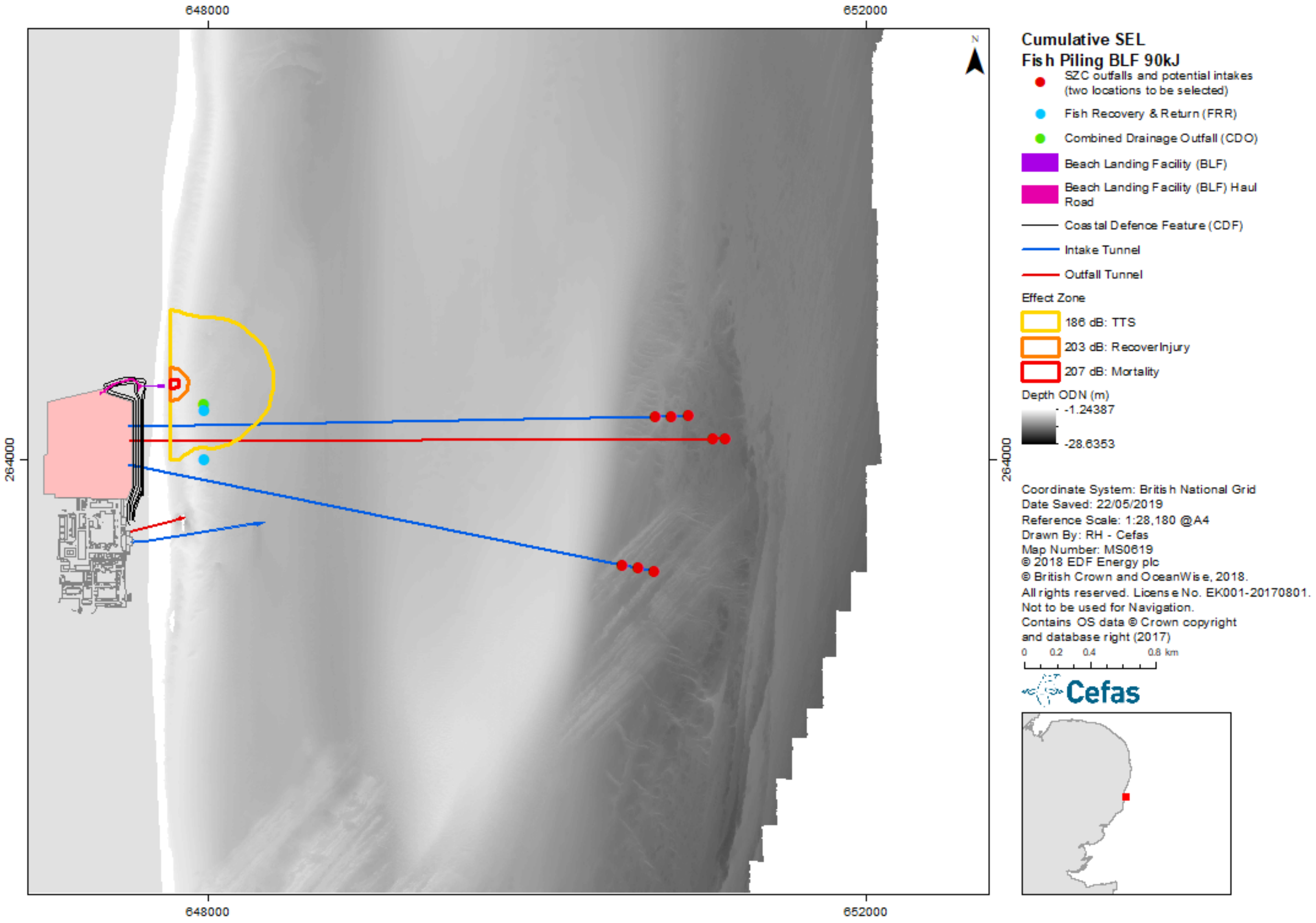

Figure 48 Predicted cumulative auditory effect zones for fish for the most likely impact piling scenario for BLF construction, assessed over 24 hours as per Popper criteria (see Section 6.2.1). Assessment based on five consecutive piles using 1500 hammer strikes of 90 kJ energy for each pile.

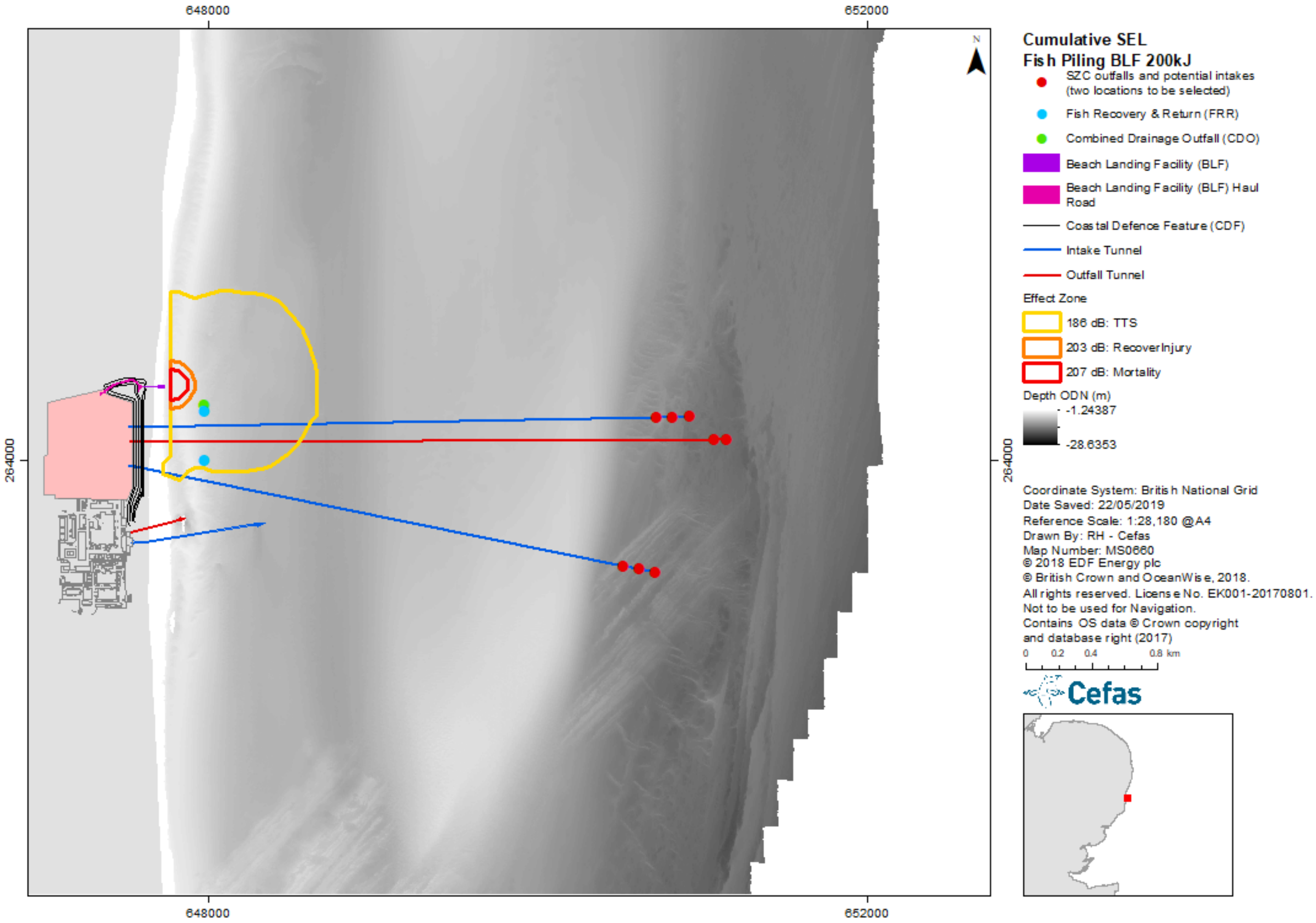

Figure 49 Predicted cumulative auditory effect zones for fish for the worst-case impact piling scenario for BLF construction, assessed over 24 hours as per Popper criteria (see Section 6.2.1). Assessment based on five consecutive piles using 1500 hammer strikes of 200 kJ energy for each pile.

7.2.2.3 Behavioural responses

Behavioural response ranges were calculated for impact piling based on the contours of the 135 db re 1 µPa^{2}s (Figure 50 and Figure 51) for hearing specialists and the 142 db re 1 µPa^{2}s for less sensitive species (based on observations with mackerel). Impact pilling using the 90 kJ hammer energy strike energy resulted in maximum behavioural response ranges of 2,111 m (525 ha) whereas the worst-case 200 kJ hammer energy hammer scenario resulted in maximum response ranges of 2,856 m (968 ha; Table 18).

Table 18. Behavioural response zones, areas (expressed in hectares) and maximum ranges (expressed in metres). Applied thresholds are based on observations of startle responses in sprat (135 db re 1 µPa²s) and mackerel (142 db re 1 µPa²s).

Activity	Applied threshold	Behavioural zone
Impact piling 90 kJ for BLF	135 dB	2,111 m 525 ha
	142 dB	1,015 m 122 ha
Impact piling 200 kJ for BLF **(precautionary assessment)**	135 dB	2,856 m 968 ha
	142 dB	1,595 m 269 ha

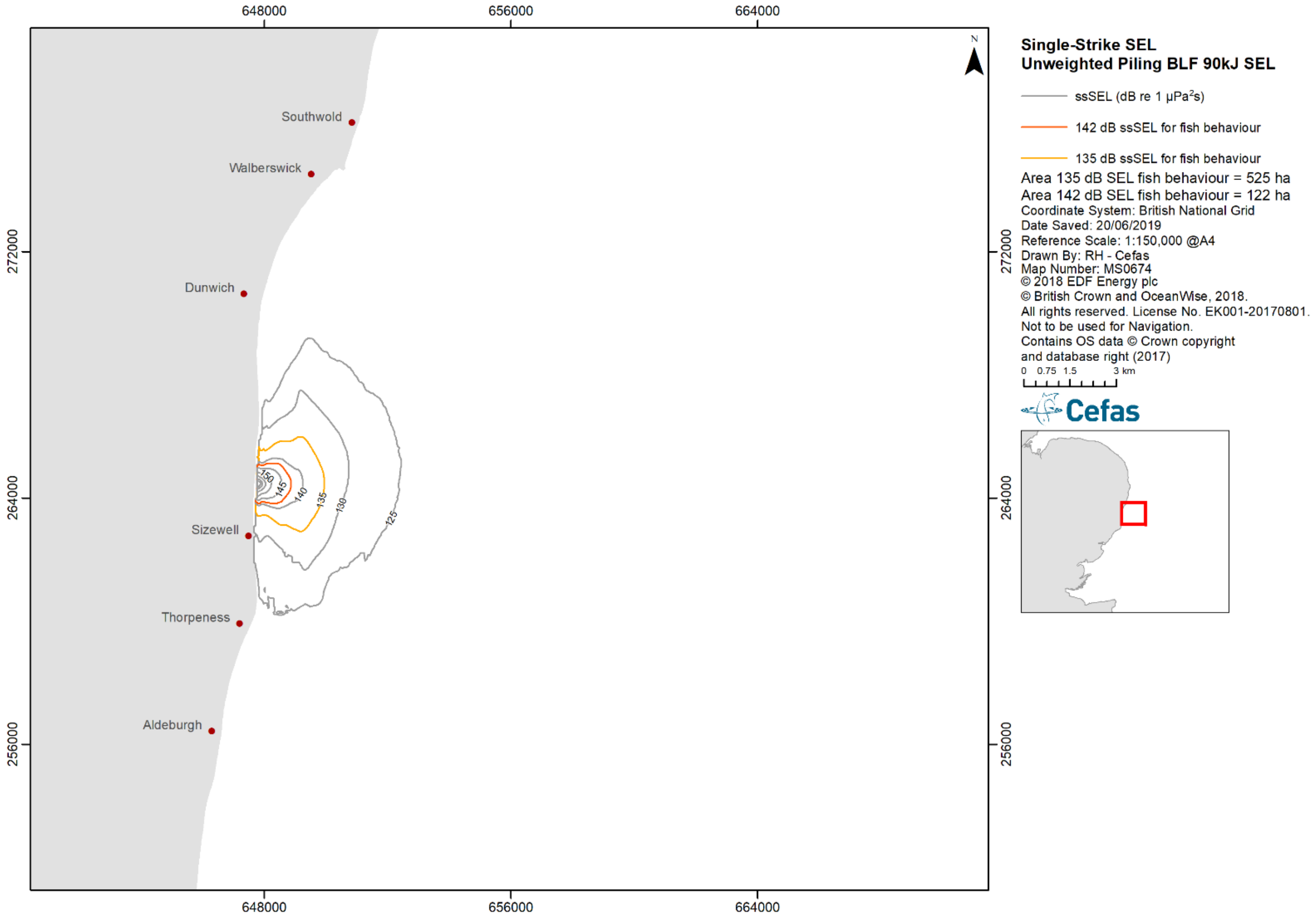

Figure 50 Impact piling noise levels (single-pulse SEL) for a 90 kJ hammer strike. The 135 and 142 db re 1 µPa²s potential behavioural effect contours are highlighed in orange and red, respectively.

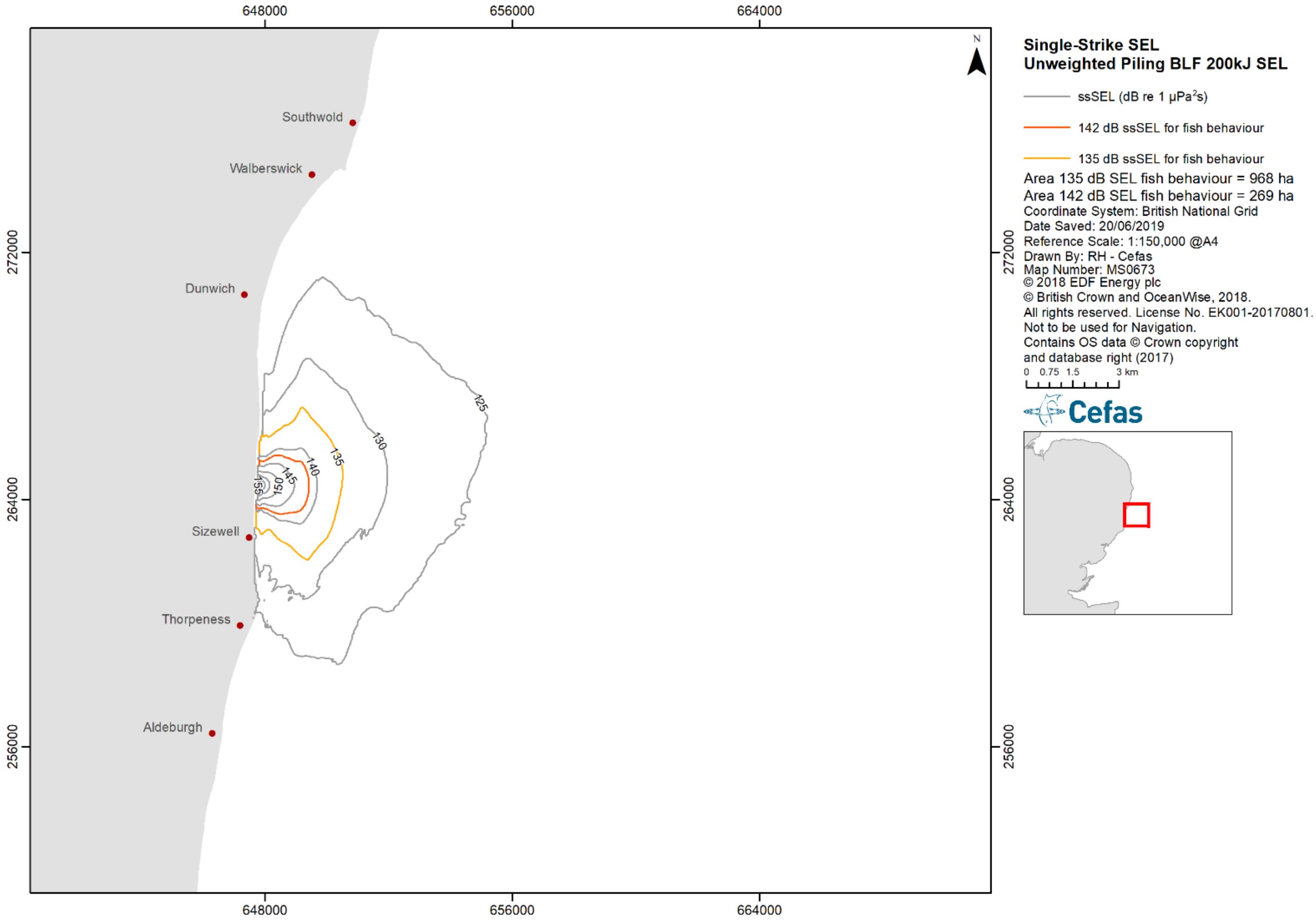

Figure 51 Impact piling noise levels (single-pulse SEL) for a 200 kJ hammer strike. The 135 and 142 db re 1 μPa²s potential behavioural effect contours are highlighted in orange and red, respectively.

7.3 Drilling cooling water intake/outfall shafts

7.3.1 Marine mammals

7.3.1.1 Instantaneous effects

Noise levels arising from drilling activities were too low to generate instantaneous auditory effect zones for marine mammals.

7.3.1.2 Cumulative effects

Cumulative auditory effect zones for harbour porpoise were spatially limited. For all drilling scenarios, the stationary PTS effect zones were predicted to extended 50 m or less from the source. Cumulative exposure for stationary harbour porpoise TTS effect zones extended to approximately1,300 m from the source (Table 19).

In all cases, the harbour seal and grey seal auditory effect zones were predicted to be less than 25 m (Table 19).

In all cases, the fleeing marine mammal assessments resulted in no PTS or TTS effect zones.

Table 19 Marine mammal auditory effect zones areas (expressed in hectares) and/or auditory effect zone maximum ranges (expressed in metres) for drilling activities. No Effect indicates source level is below relevant threshold; 'See Figure' indicates auditory effect zone was also large enough to appear on corresponding figure.

Activity	**Thres-hold**	**Instantaneous**		**Stationary Cumulative**		**Fleeing Cumulative**
		Harbour porpoise	Phocid seals	Harbour porpoise	Phocid seal	All marine mammals
Drilling north cooling water intake shaft	PTS	No Effect	No Effect	50 m; 1 ha	<25 m	No effect
	TTS	No Effect	No Effect	1,286 m; 422 ha See Figure 52	<25 m	No effect
Drilling south cooling water intake shaft	PTS	No Effect	No Effect	50 m; 1ha	<25 m	No effect
	TTS	No Effect	No Effect	1,286 m; 431 ha See Figure 53	<25 m	No effect
Drilling cooling water outfall shaft	PTS	No Effect	No Effect	25 m; 0.25 ha	<25 m	No effect
	TTS	No Effect	No Effect	1,307 m; 399 ha See Figure 54	<25 m	No effect

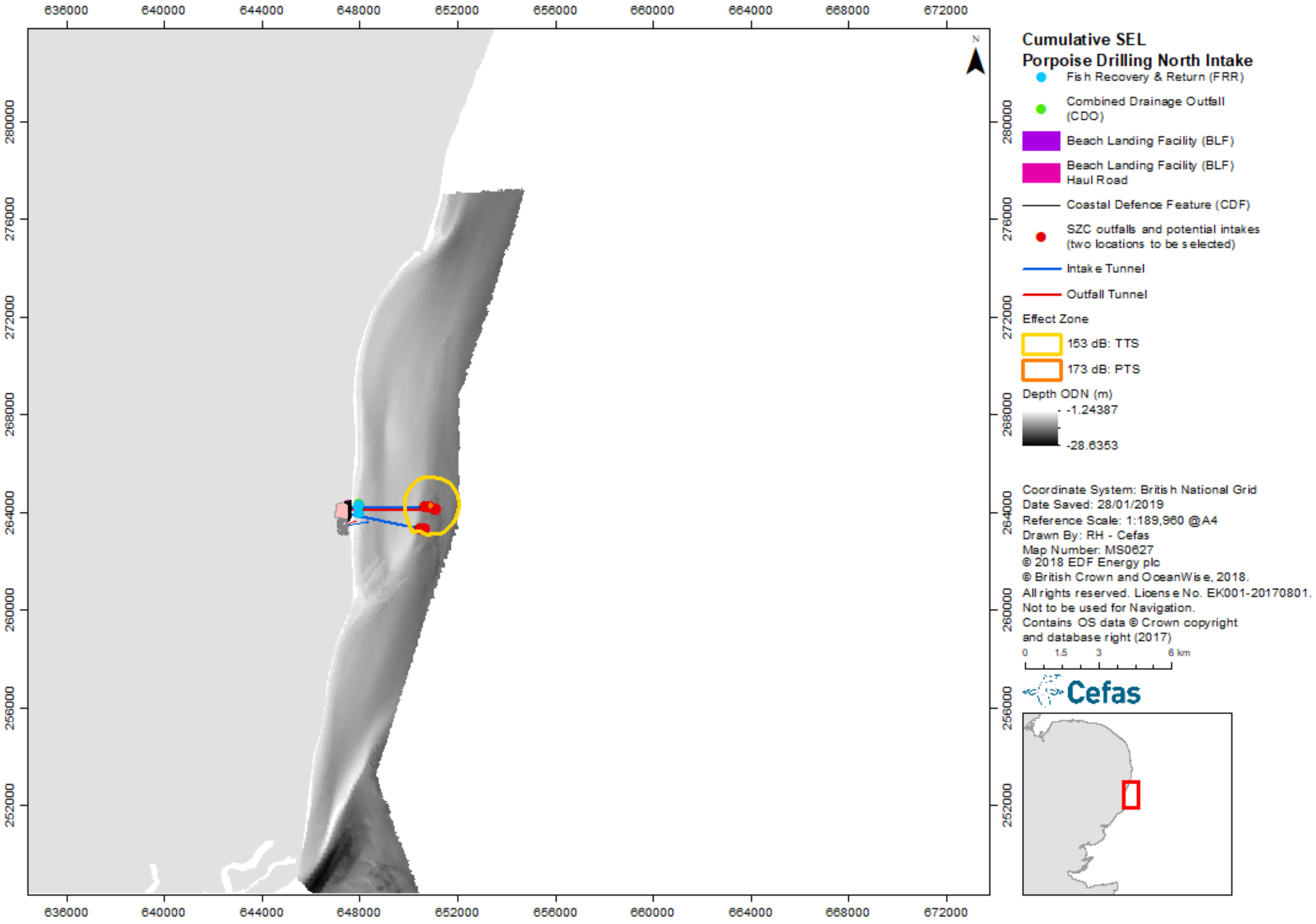

Figure 52 Predicted cumulative auditory effect zones for stationary harbour porpoise for drilling at the north cooling water intake location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on continuous drilling over 24 hours.

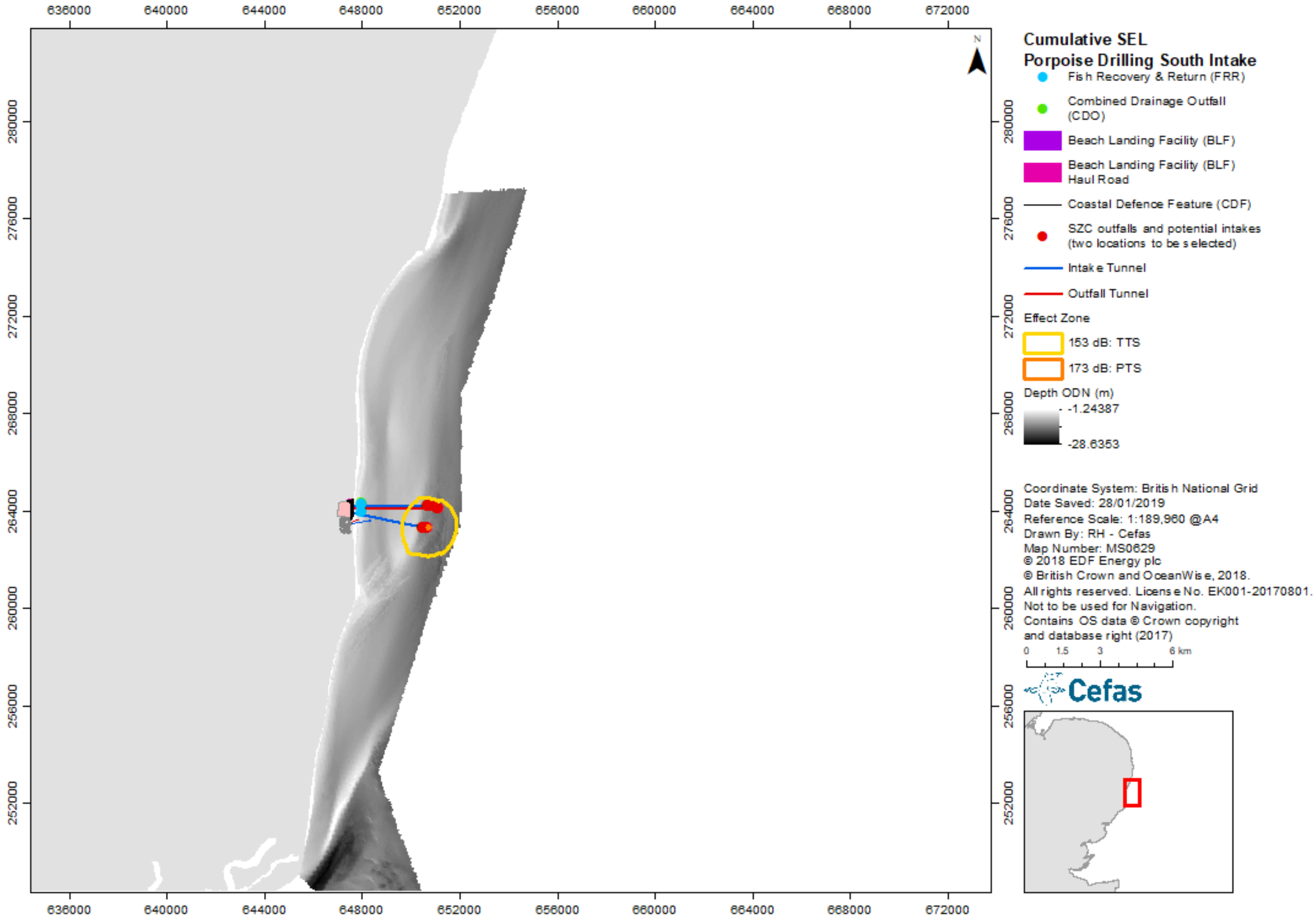

Figure 53 Predicted cumulative auditory effect zones for stationary harbour porpoise for drilling at the south cooling water intake location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on continuous drilling over 24 hours.

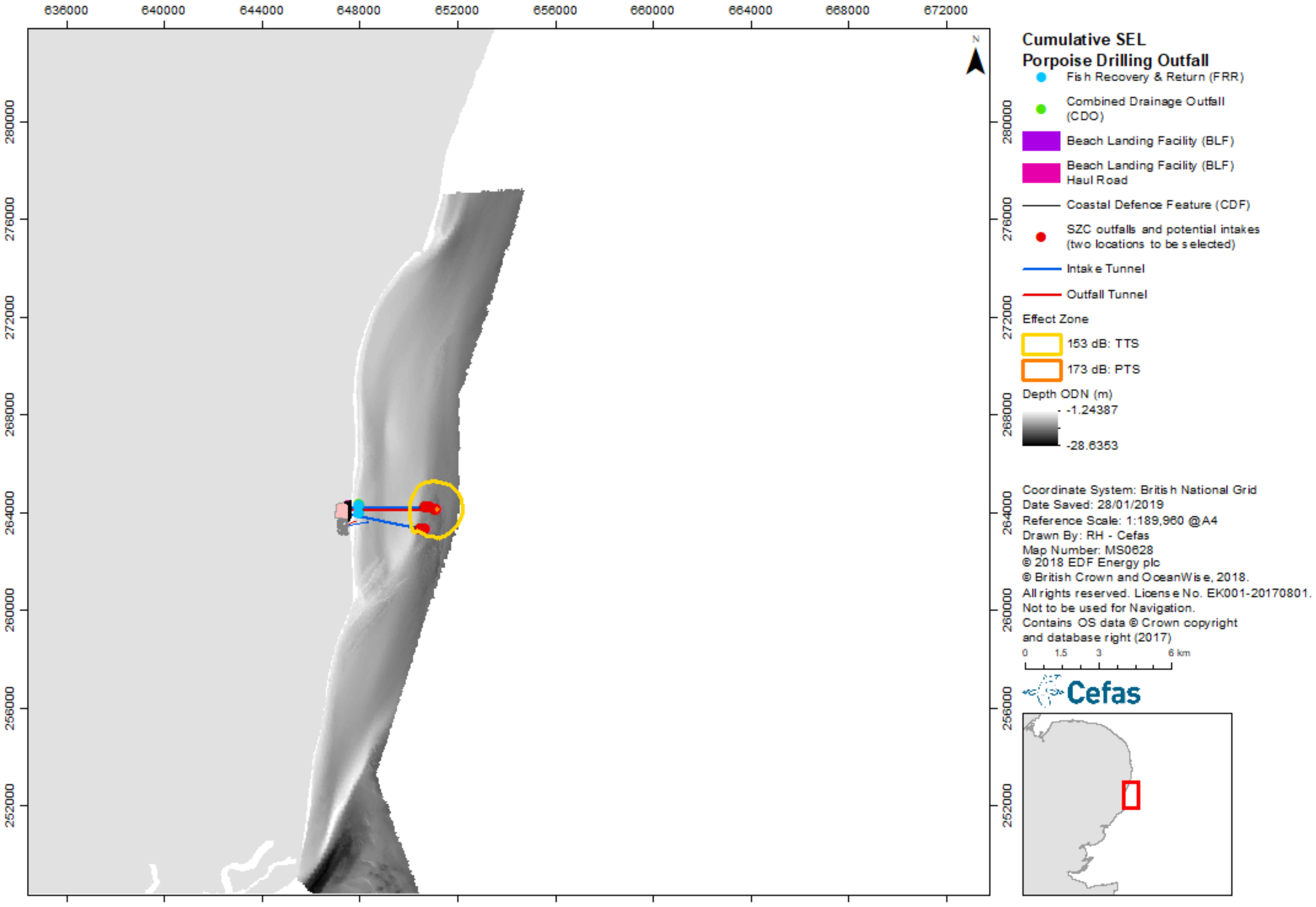

Figure 54 Predicted cumulative auditory effect zones for stationary harbour porpoise for drilling at the cooling water outfall location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on continuous drilling over 24 hours.

7.3.2 Fish

7.3.2.1 Instantaneous effects

Noise levels arising from drilling activities were too low to generate instantaneous auditory effect zones for fish.

7.3.2.2 Cumulative effects

In all cases, the 24-hour cumulative auditory effect zones for all fish species were predicted to be less than 25 m (Table 20). Drilling is therefore predicted to have negligible auditory effects on fish.

Table 20 Fish auditory effect zones areas (expressed in hectares) and/or auditory effect zone maximum ranges (expressed in metres) for drilling activities associated with the cooling water infrastructure. No Effect indicates source level is below relevant threshold.

Activity		**Instantaneous**	**Cumulative**
Drilling cooling water infrastructure (north intake, south intake, outfall)	Mortality	No Effect	<25 m; <0.25 ha
	Recoverable injury	No Effect	<25 m; <0.25 ha
	TTS	No Effect	<25 m; <0.25 ha

7.3.2.3 Behavioural responses

Behavioural response ranges calculated for drilling based on the contours of the 135 db re 1 µPa^{2}s for hearing specialists and the 142 db re 1 µPa^{2}s for less sensitive species were predicted to be less than 25 m (Table 21).

Table 21 Behavioural response zones for drilling, with maximum ranges expressed in metres.

Activity	**Threshold**	**Behavioural zone**
Drilling cooling water infrastructure (north intake, south intake, outfall)	135 dB	<25 m
	142 dB	<25 m

7.4 Dredging activities

7.4.1 Marine mammals

7.4.1.1 Instantaneous effects

Noise levels from dredging were too low to generate instantaneous auditory effect zones for marine mammals.

7.4.1.2 Cumulative effects

The cumulative sound exposure effects on harbour porpoise for the 9 dredging modelled scenarios (corresponding to the 8 single dredging locations and the simultaneous dredging at BLF and south cooling water intake simultaneously) were assessed.

Although the same acoustic source level was used for all 8 single source scenarios, the extent of the PTS and TTS auditory effect zones varied markedly amongst the scenarios (see also Table 22). This variation is caused not only by the different acoustic propagation patterns associated to the specific source locations (as discussed previously in Section 5.3), but especially by the differences in dredging duration over which the noise exposure is assumed to accumulate.

Dredging associated to the BLF construction resulted in the largest stationary harbour porpoise cumulative auditory effect zones with TTS extending to ~11.6 km and PTS to ~1.7 km, where continuous exposure over 24 hours was assumed (Figure 55). The smallest stationary auditory effect zones (TTS extending to ~5.1 km and PTS to ~550 m) were predicted for dredging at the cooling water outfall where the exposure was assumed to be just 7 hours over the 24-hour assessment period (Figure 69).

The corresponding dredging assessments for fleeing harbour porpoise resulted in no PTS effect zones, with the largest TTS effect zone extending to ~1.4 km in the case of 24 hours dredging associated to the BLF construction (Figure 56;Table 22).

The hypothetical worst-case in-combination dredging scenario resulted in the largest overall auditory effect zone for stationary harbour porpoise, with the PTS zone (620 ha) covering 20% more than the sum of the PTS zones predicted for the single source BLF (394 ha) and south intake (131 ha) scenarios. However, for the TTS auditory effect zone the situation was reversed (14,359 ha, or ~20% less than the sum of 11,331 ha and 6,856 ha), due to the spatial overlap of the TTS auditory effect zone for the single source scenarios (Figure 71; Table 22). The corresponding in-combination dredging assessment for fleeing harbour porpoise resulted in no PTS effect zones, with the TTS effect zone covering 1,040 ha (Figure 72;Table 22).

The predicted cumulative sound exposure effects on stationary harbour seals and grey seals were much smaller than the corresponding predictions for stationary harbour porpoise (see Table 22), as a consequence of differences in auditory weightings and noise exposure thresholds applicable to these distinct functional hearing groups (see Section 6.1.1 for details). The largest stationary seal auditory effect zones (with TTS extending to ~3.0 km and PTS to ~110 m) were predicted for dredging at the BLF, where continuous exposure over 24 hours was assumed (Figure 73). The smallest stationary auditory effect zones (TTS extending to 870 m and PTS zone <25 m, i.e. smaller than a model grid cell) were predicted at the outfall location where the exposure was assumed to be just 7 hours over the 24-hour assessment period (Figure 79). Again, the in-combination dredging scenario resulted in the largest overall auditory effect zones, with the stationary PTS zone covering 5 ha, but only around the BLF location. The stationary TTS zone covered 1,411 ha, which represents ~15% more than the combined coverage of the TTS zones predicted for the single source BLF (969 ha) and south intake (256 ha) scenarios (Figure 80).

The corresponding dredging assessments for fleeing harbour or grey seals resulted in no PTS and no TTS effect zones. Therefore, fleeing behaviours are predicted to prevent auditory damage in these species.

Table 22 Marine mammal auditory effect zones areas (expressed in hectares) and/or auditory effect zone maximum ranges (expressed in metres) for dredging activities. N/A indicates source level is below relevant threshold.

Activity	**Thres-hold**	**Instant.**	**Stationary Cumulative**		**Fleeing cumulative**	
		All species	**Harbour porpoise**	**Phocid seals**	**Harbour porpoise**	**Phocid seals**
Dredging for BLF construction	PTS	N/A	1,657 m; 394 ha	111 m; 5 ha	No effect	No effect
	TTS	N/A	11,576 m; 11,331 ha	2,975 m; 969 ha	1,377 m; 241 ha	No effect
Dredging for BLF maintenance	PTS	N/A	665 m; 76 ha	25 m; <0.25 ha	No effect	No effect
	TTS	N/A	5,565 m; 3650 ha	903 m; 125 ha	1,308 m; 225 ha	No effect
Dredging CDO	PTS	N/A	849 m; 135 ha	25 m; <0.25 ha	No effect	No effect
	TTS	N/A	6,421 m; 4,799 ha	1,369 m; 280 ha	1,025 m; 173 ha	No effect
Dredging FRR1	PTS	N/A	822 m; 140 ha	50 m; 1 ha	No effect	No effect
	TTS	N/A	6,532 m; 4920 ha	1,426 m; 299 ha	1,097 m; 191 ha	No effect
Dredging FRR2	PTS	N/A	849 m; 135 ha	25 m; <0.25 ha	No effect	No effect
	TTS	N/A	6,433 m; 4,839 ha	1,376 m; 285 ha	1.025 m; 177 ha	No effect
Dredging north cooling water intake	PTS	N/A	668 m; 125 ha	<25 m	No effect	No effect
	TTS	N/A	5,640 m; 6,540 ha	989 m; 246 ha	797 m; 103 ha	No effect
Dredging south cooling water intake	PTS	N/A	718 m; 131 ha	<25 m	No effect	No effect
	TTS	N/A	5,922 m; 6856 ha	996 m; 256 ha	810 m; 114 ha	No effect
Dredging cooling water outfall	PTS	N/A	549 m; 90 ha	<25 m	No effect	No effect
	TTS	N/A	5,074 m; 5,663 ha	869 m; 188 ha	654 m; 88 ha	No effect
In-combination scenario Dredging BLF and south cooling water intake	PTS	N/A	620 ha	5 ha	No effect	No effect
	TTS	N/A	14,359 ha	1,411 ha	1,040 ha	No effect

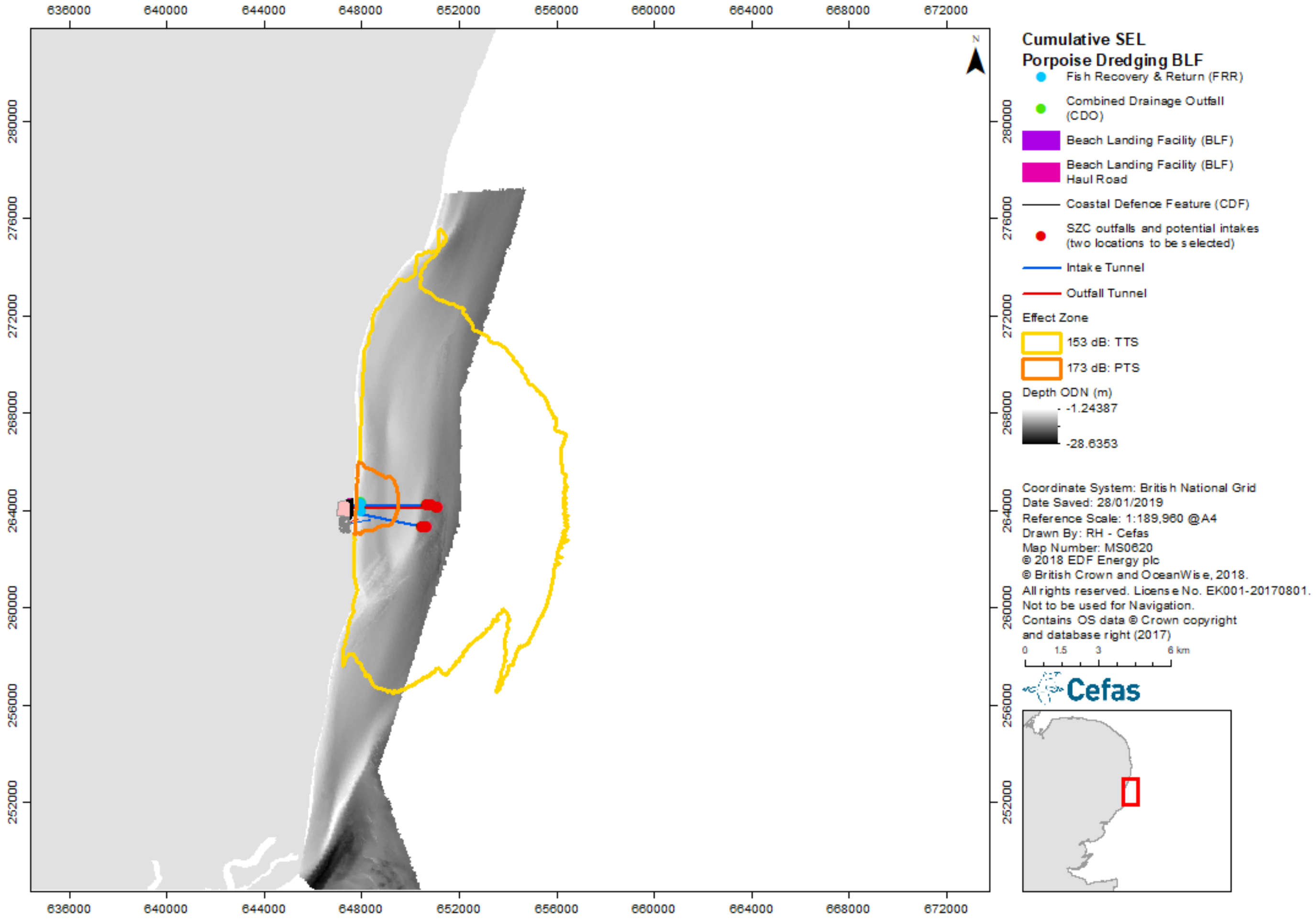

Figure 55 Predicted cumulative auditory effect on stationary harbour porpoise for construction dredging at the BLF location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on continuous dredging over the 24 hours assessment period.

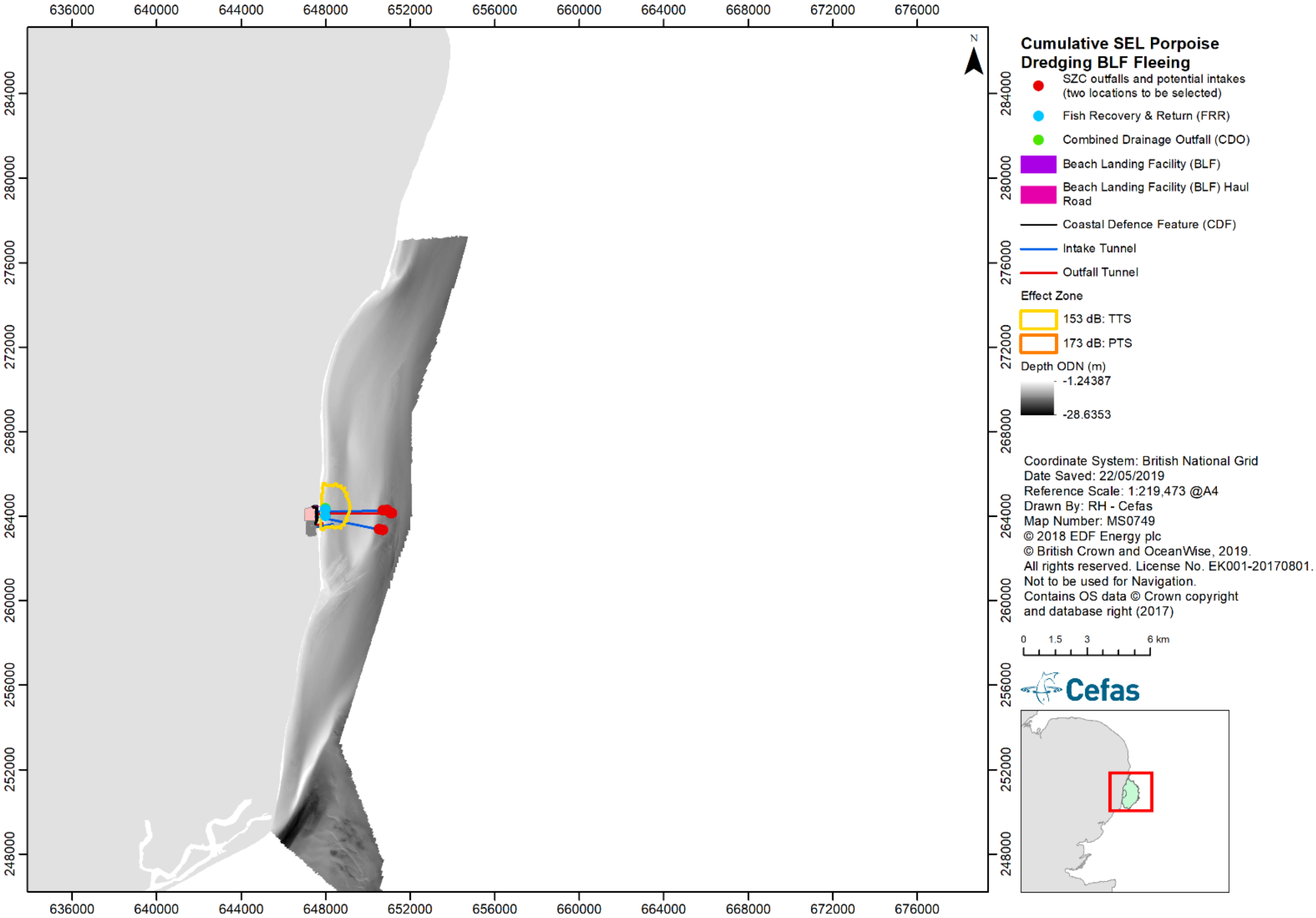

Figure 56 Predicted cumulative auditory effect on fleeing harbour porpoise for construction dredging at the BLF location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on continuous dredging over the 24 hours assessment period.

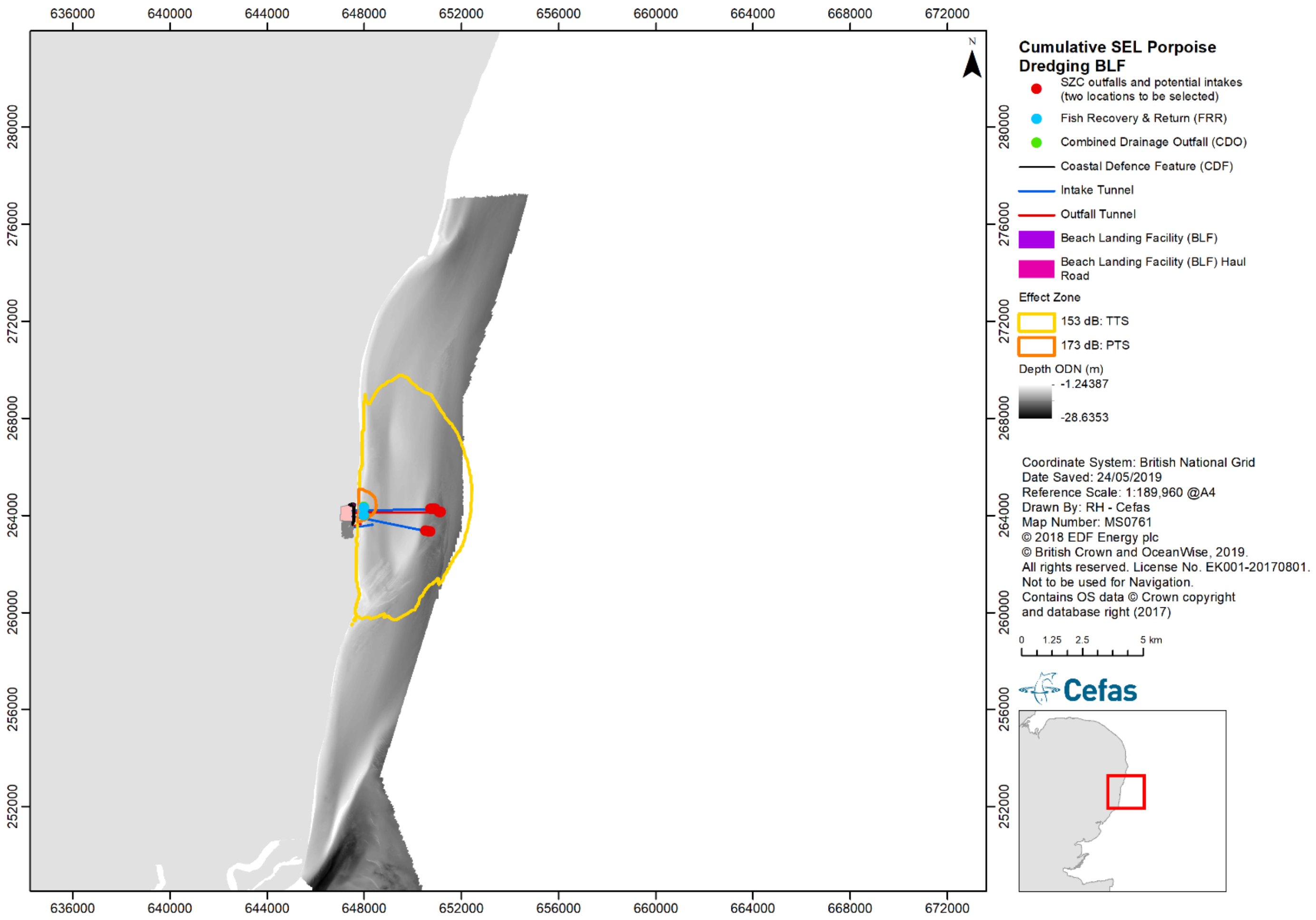

Figure 57 Predicted cumulative auditory effect on stationary harbour porpoise for maintenance dredging at the BLF location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on 5 hours of dredging over the 24 hours assessment period.

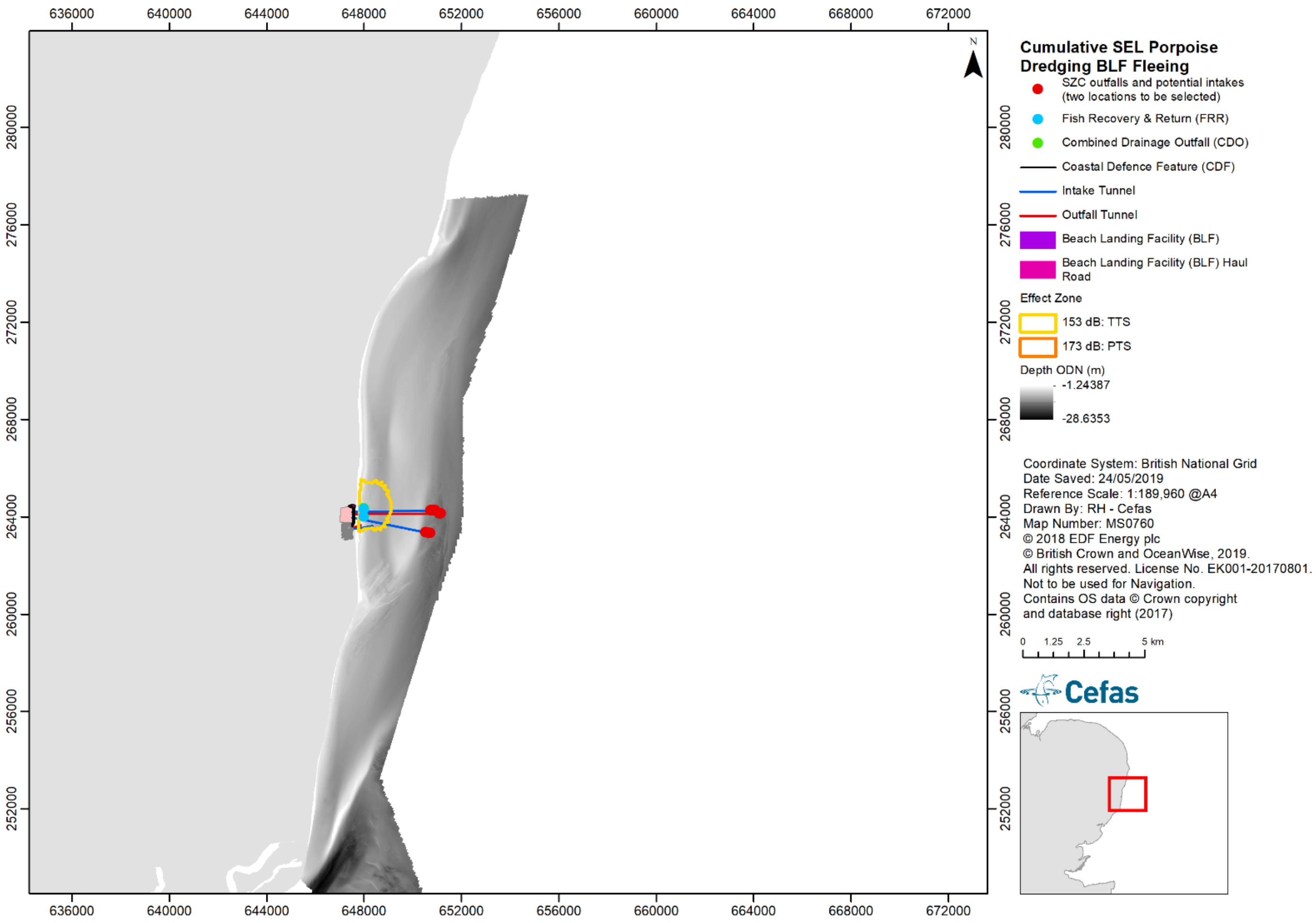

Figure 58 Predicted cumulative auditory effect on fleeing harbour porpoise for maintenance dredging at the BLF location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on 5 hours of dredging over the 24 hours assessment period.

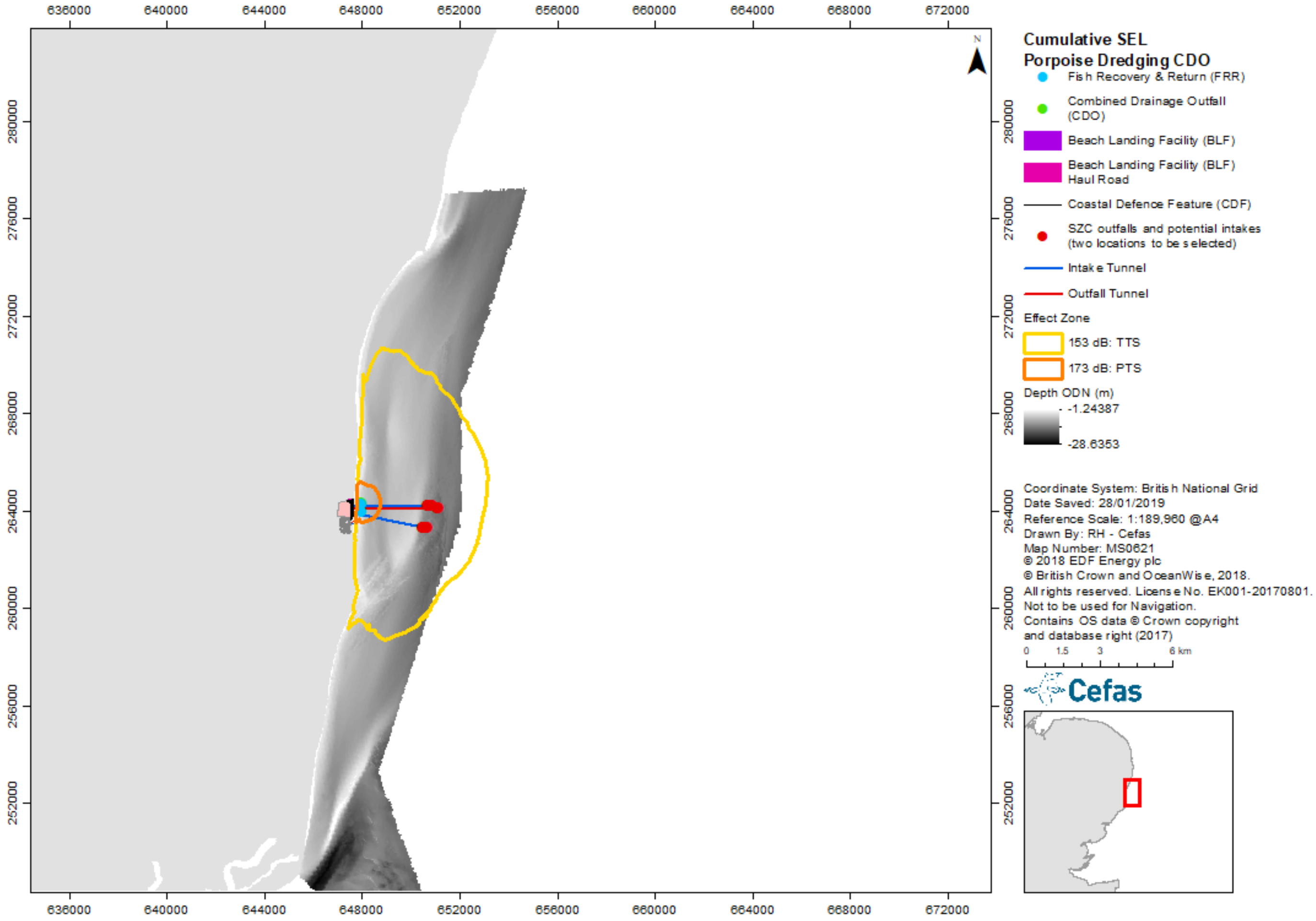

Figure 59 Predicted cumulative auditory effect on stationary harbour porpoise for dredging at the CDO location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on 9.5 hours of dredging over the 24 hours assessment period.

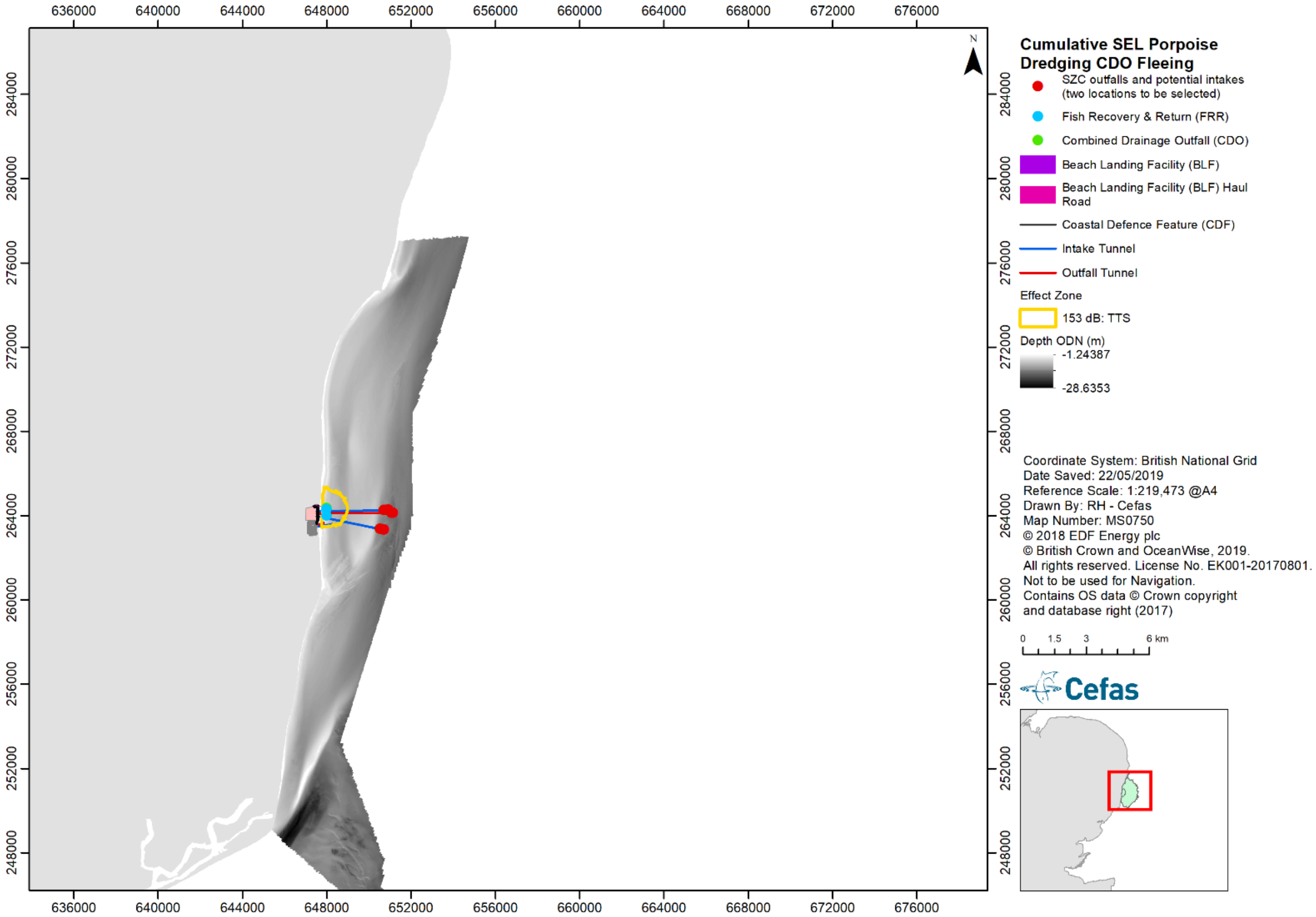

Figure 60 Predicted cumulative auditory effect on fleeing harbour porpoise for dredging at the CDO location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on 9.5 hours of dredging over the 24 hours assessment period.

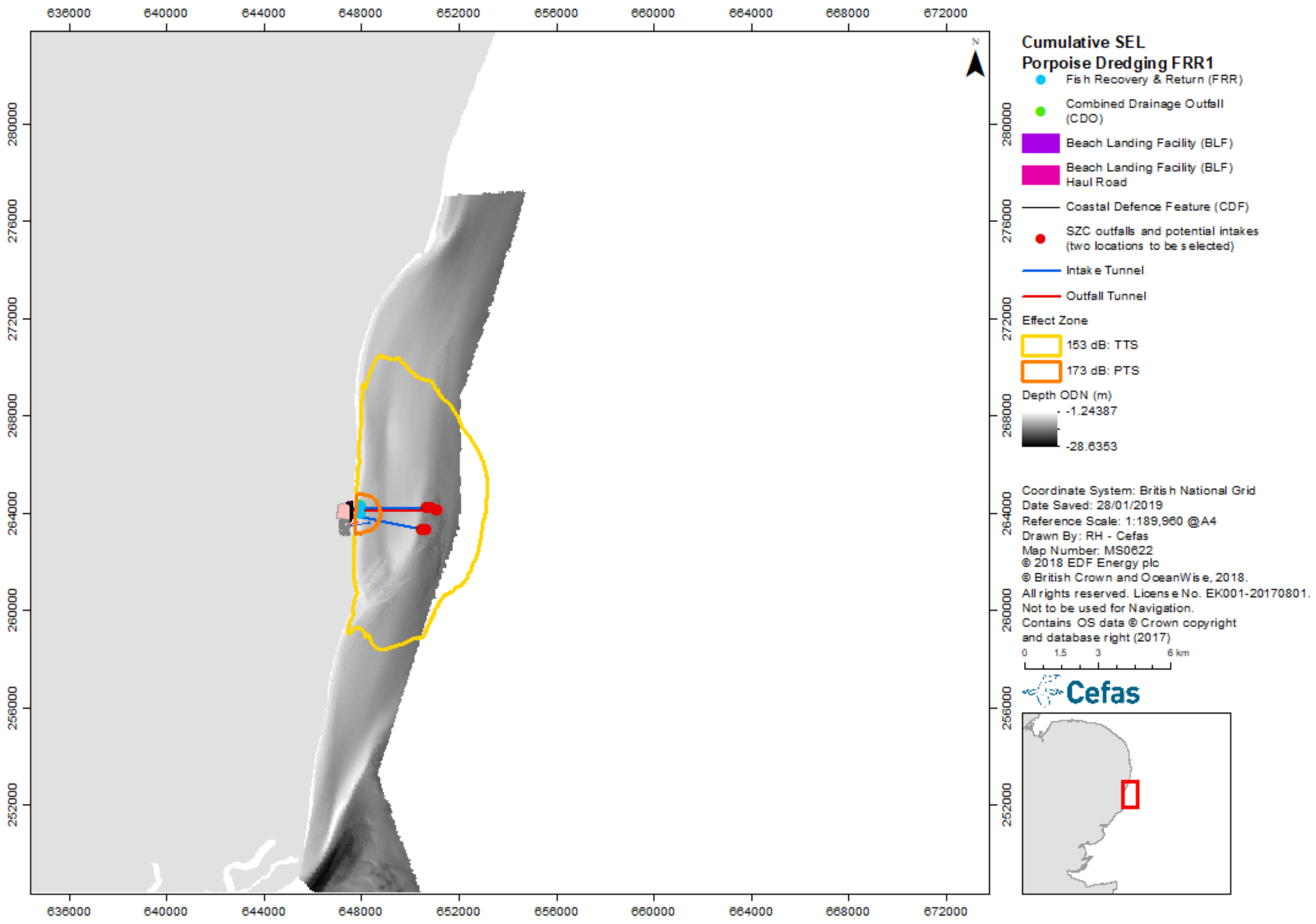

Figure 61 Predicted cumulative auditory effect on stationary harbour porpoise for dredging at the FRR1 location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on 9.5 hours of dredging over the 24 hours assessment period.

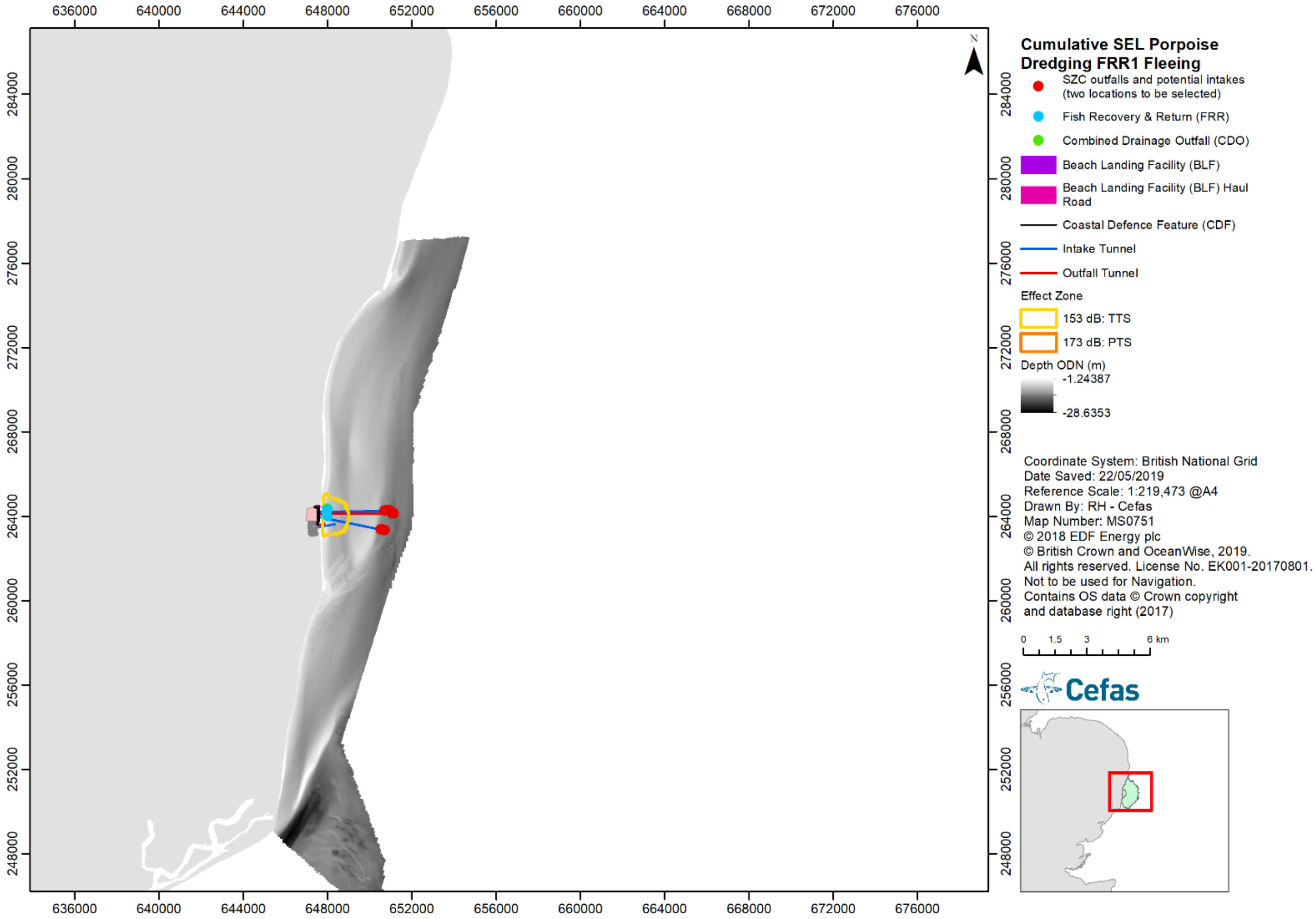

Figure 62 Predicted cumulative auditory effect on fleeing harbour porpoise for dredging at the FRR1 location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on 9.5 hours of dredging over the 24 hours assessment period.

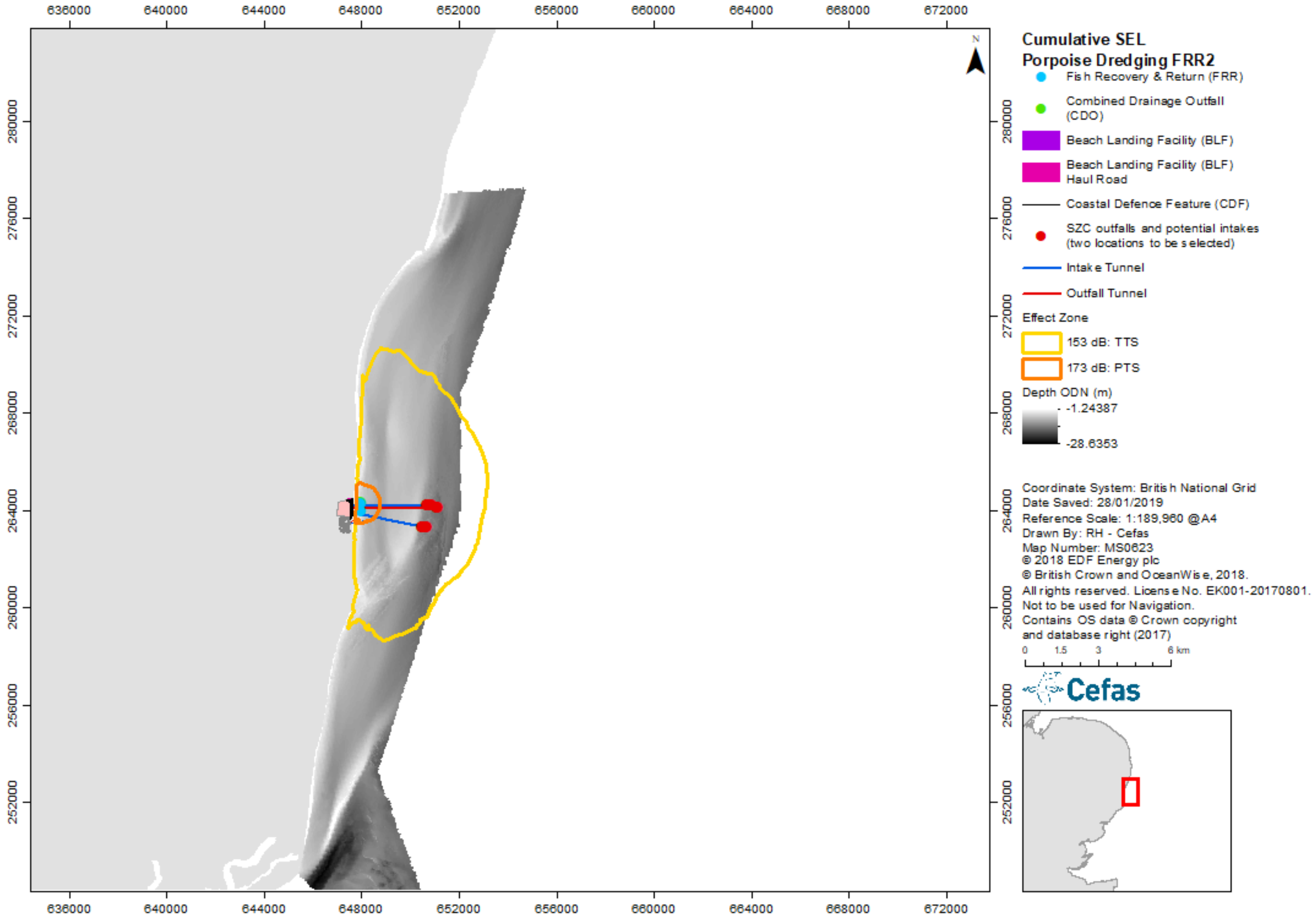

Figure 63 Predicted cumulative auditory effect on stationary harbour porpoise for dredging at the FRR2 location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on 9.5 hours of dredging over the 24 hours assessment period.

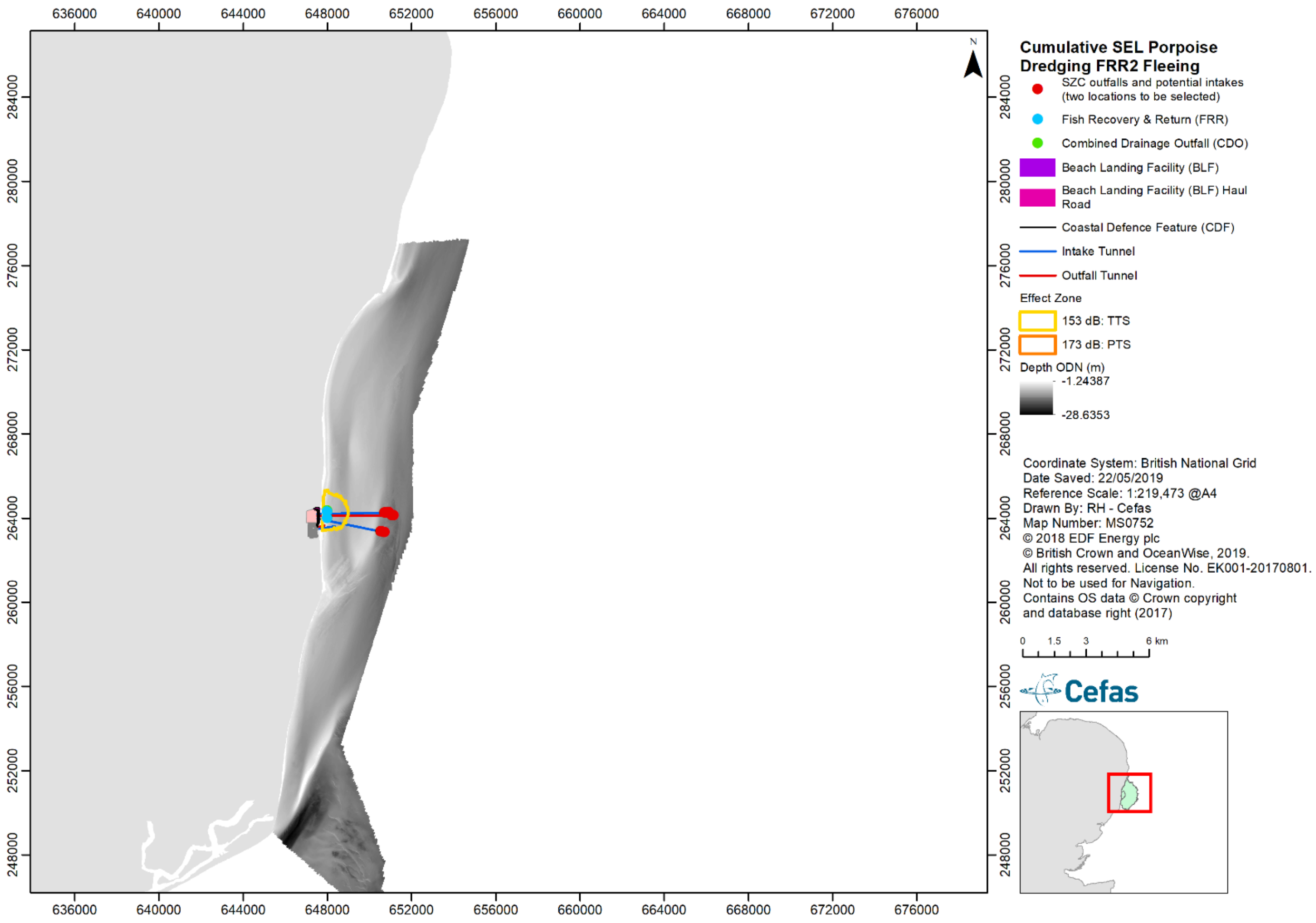

Figure 64 Predicted cumulative auditory effect on fleeing harbour porpoise for dredging at the FRR2 location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on 9.5 hours of dredging over the 24 hours assessment period.

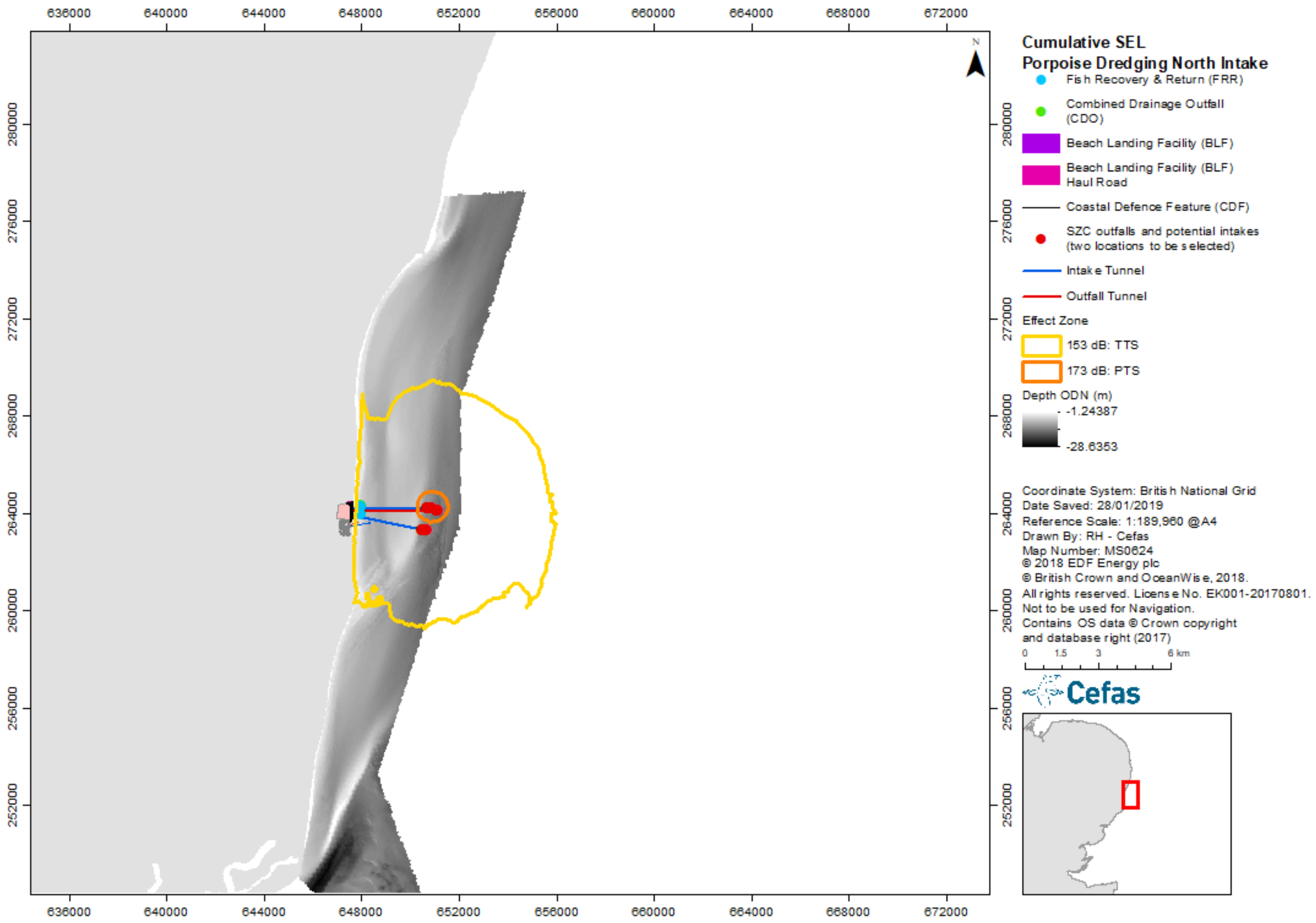

Figure 65 Predicted cumulative auditory effect on stationary harbour porpoise for dredging at the north intake location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on 8.5 hours of dredging over the 24 hours assessment period.

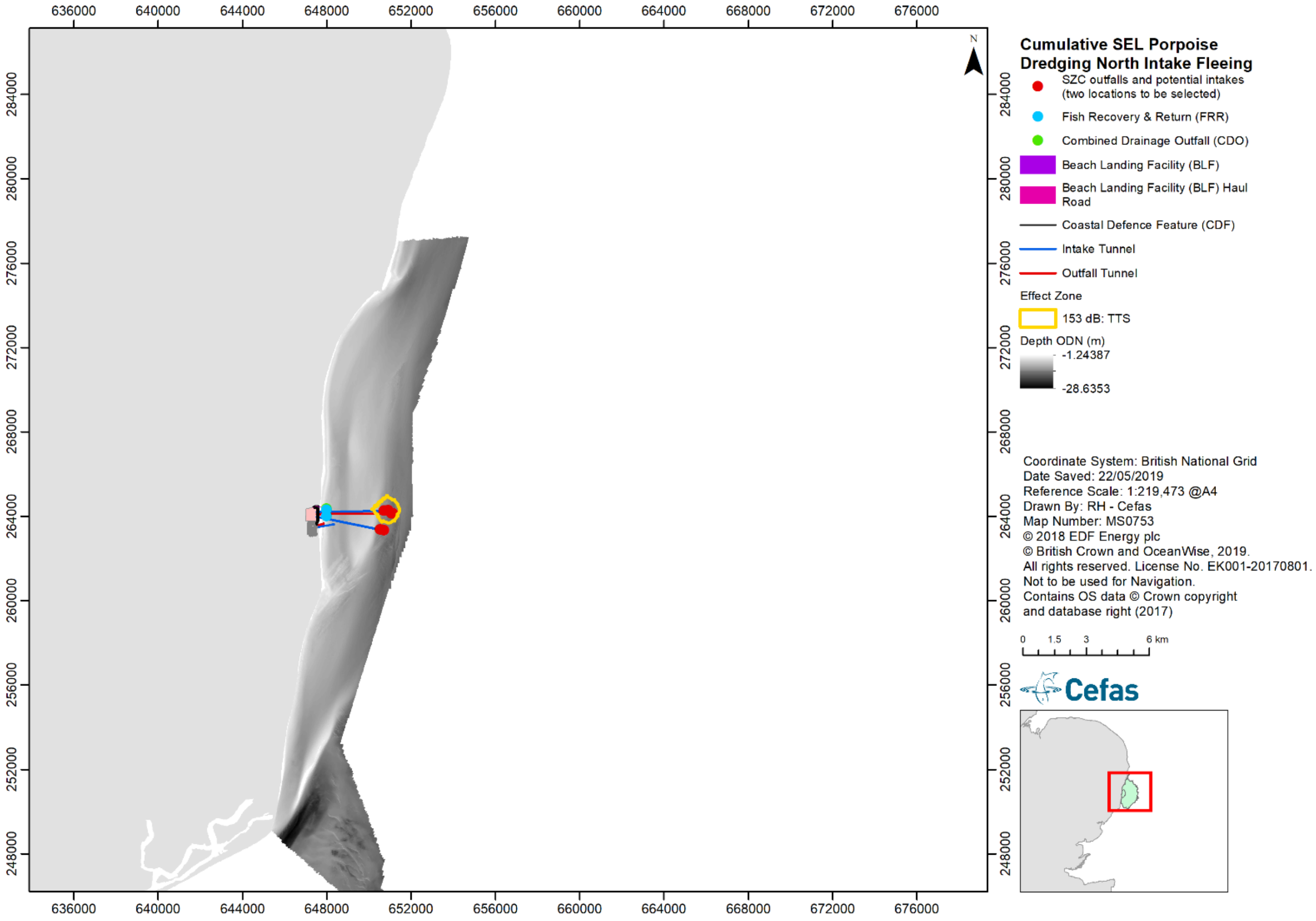

Figure 66 Predicted cumulative auditory effect on fleeing harbour porpoise for dredging at the north intake location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on 8.5 hours of dredging over the 24 hours assessment period.

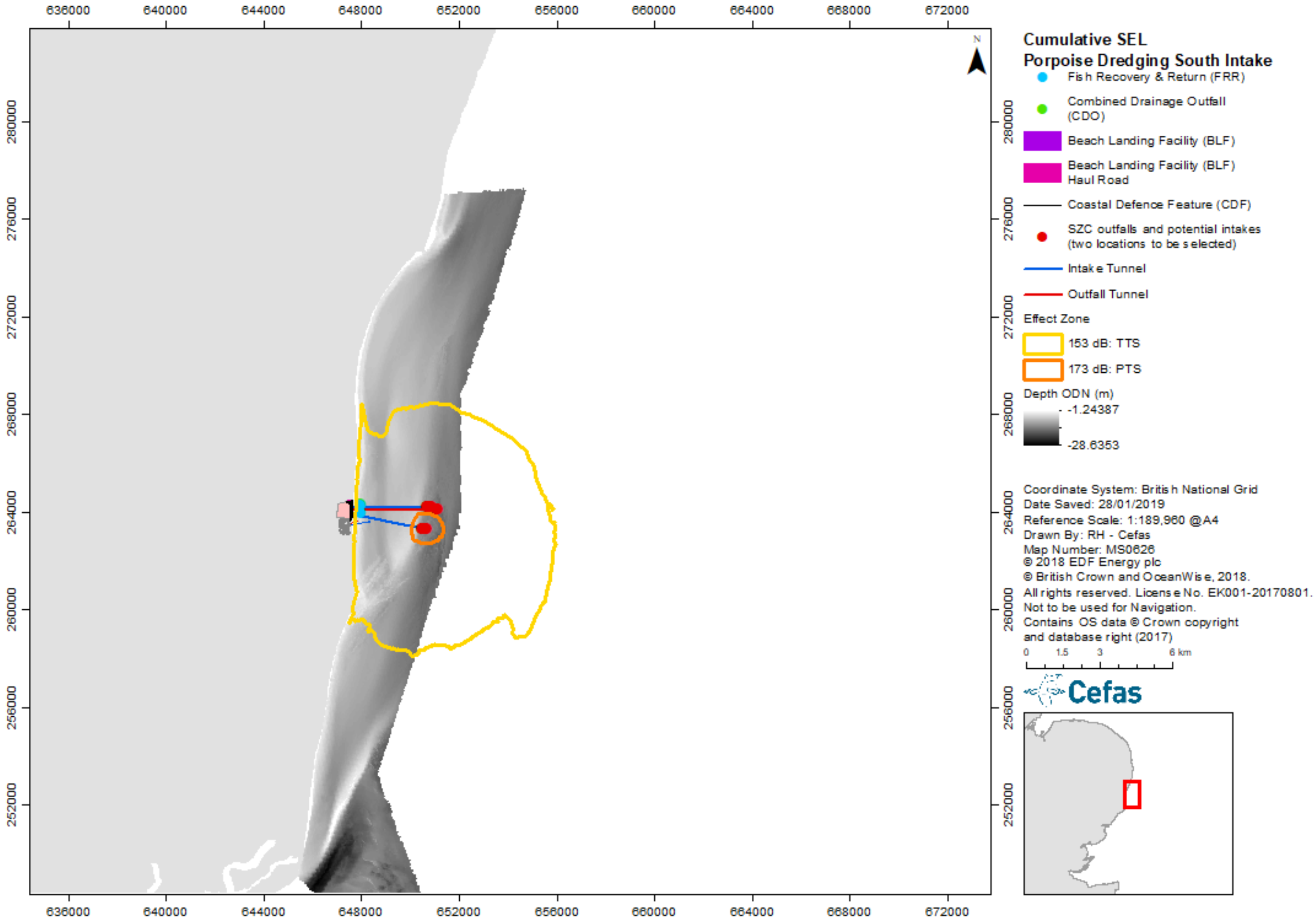

Figure 67 Predicted cumulative auditory effect on stationary harbour porpoise for dredging at the south intake location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on 8.5 hours of dredging over the 24 hours assessment period.

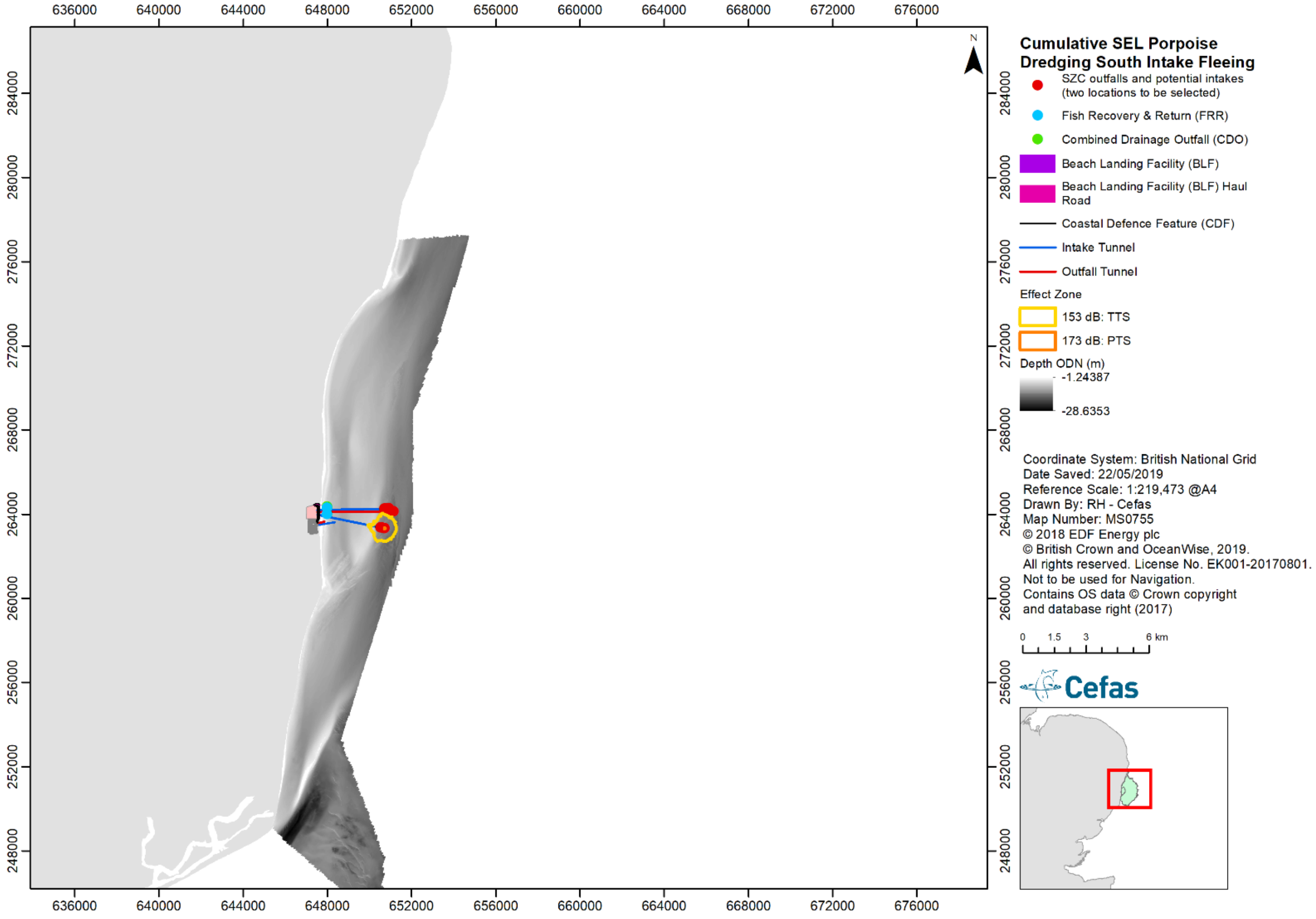

Figure 68 Predicted cumulative auditory effect on fleeing harbour porpoise for dredging at the south intake location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on 8.5 hours of dredging over the 24 hours assessment period.

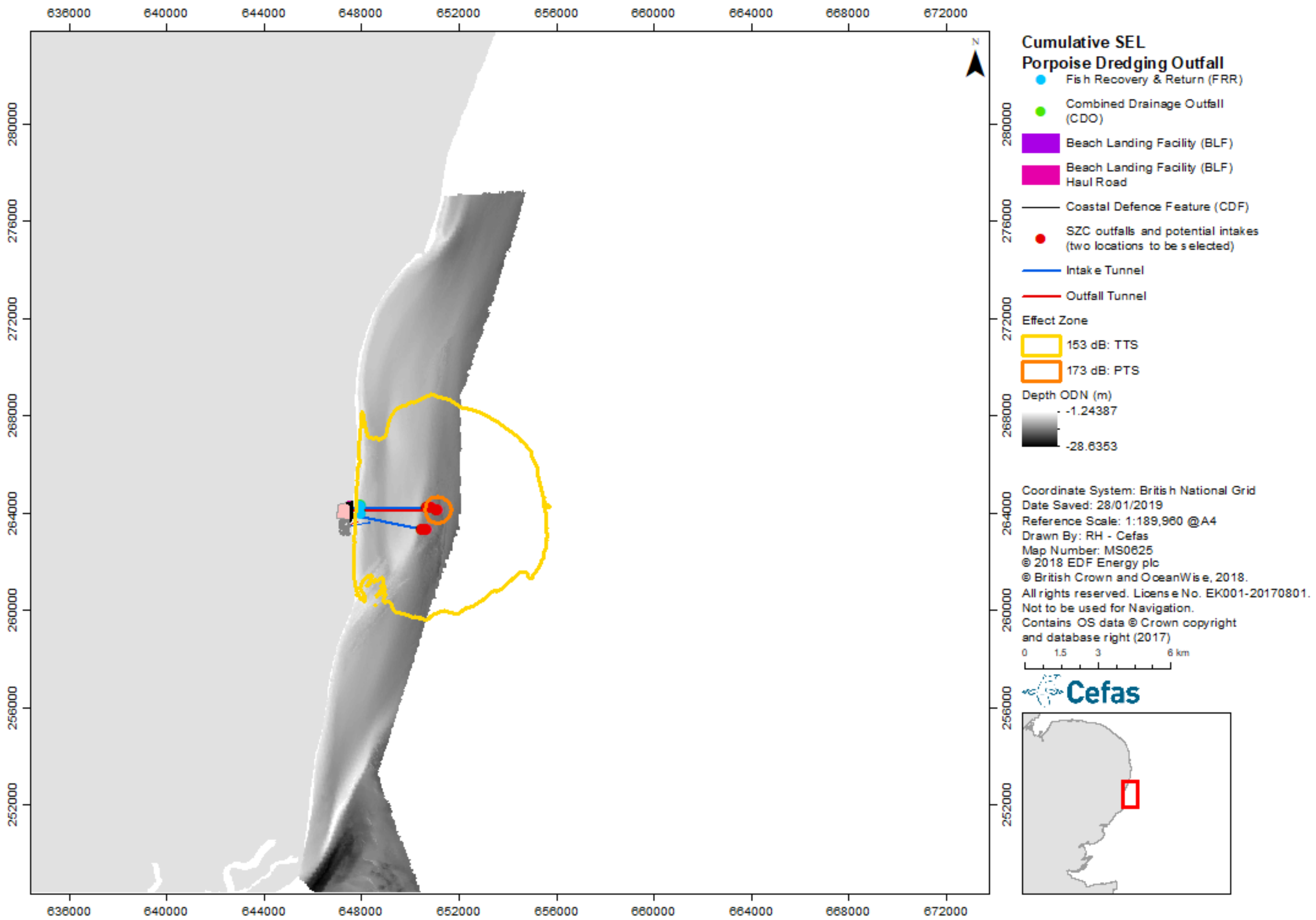

Figure 69 Predicted cumulative auditory effect on stationary harbour porpoise for dredging at the outfall location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on 7 hours of dredging over the 24 hours assessment period.

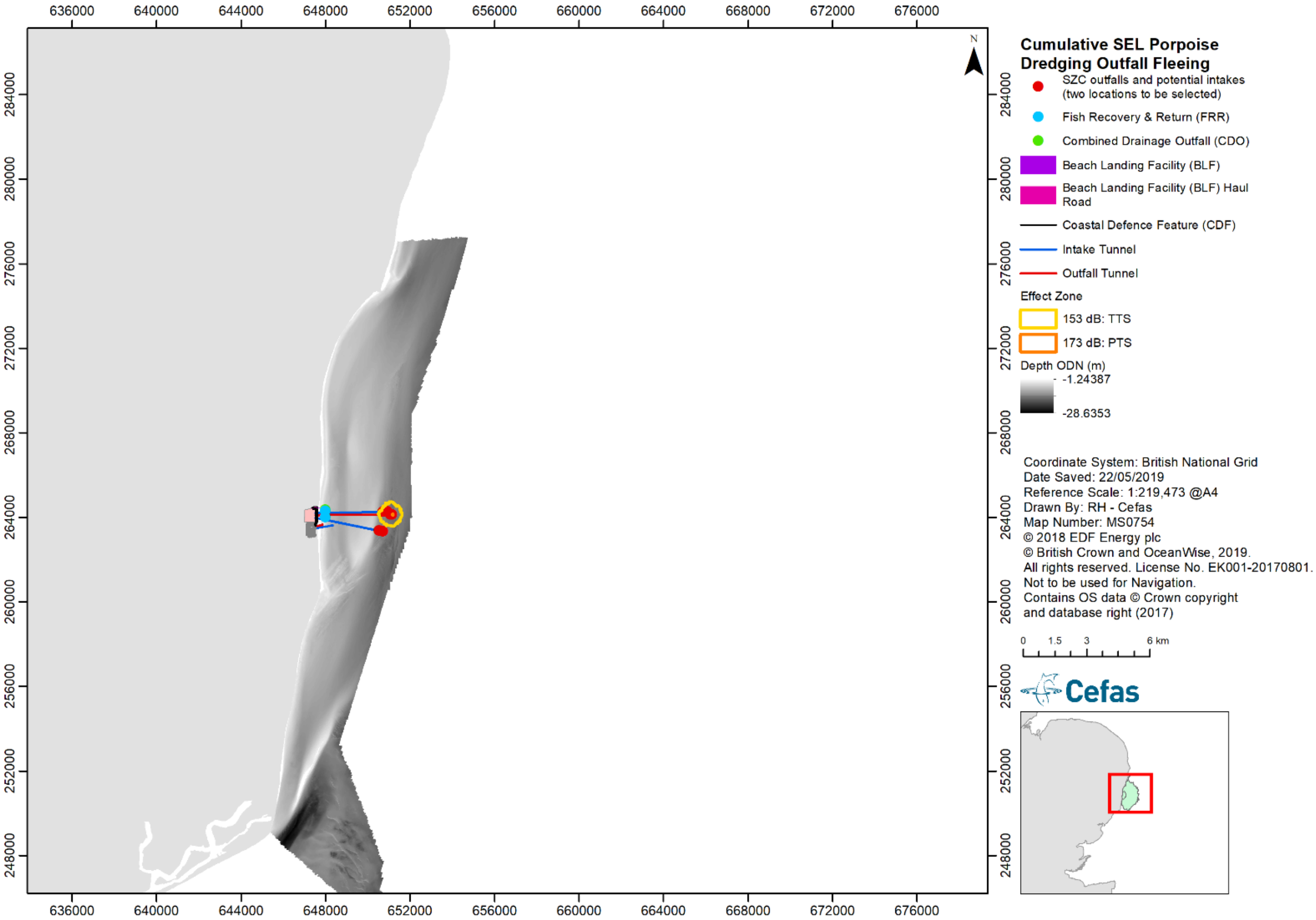

Figure 70 Predicted cumulative auditory effect on fleeing harbour porpoise for dredging at the outfall location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on 7 hours of dredging over the 24 hours assessment period.

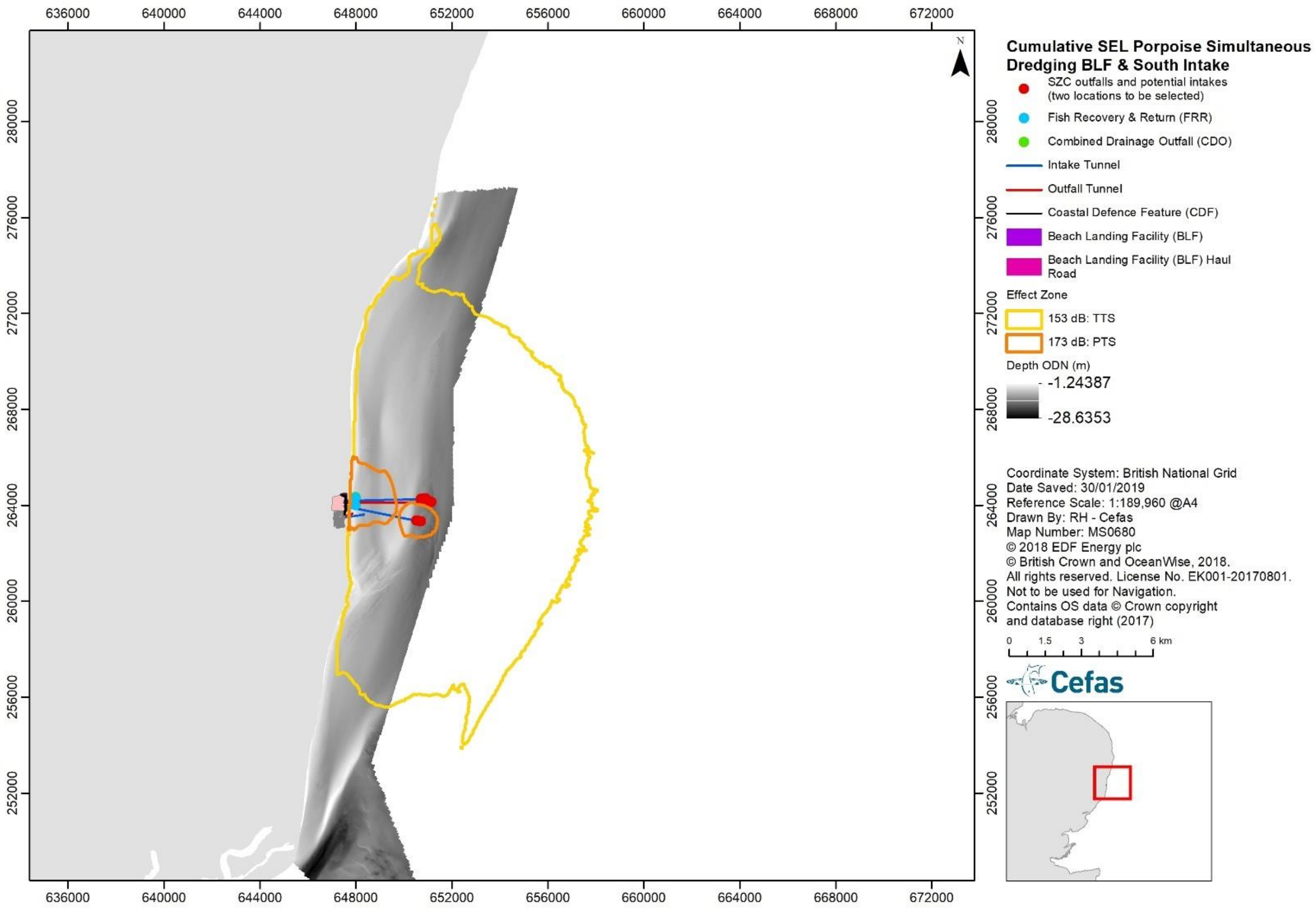

Figure 71 Predicted cumulative auditory effect on stationary harbour porpoise for simultaneous dredging at the BLF and south intake locations, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on continuous dredging at the BLF and 8.5 hours of dredging at the south intake over the 24 hours assessment period.

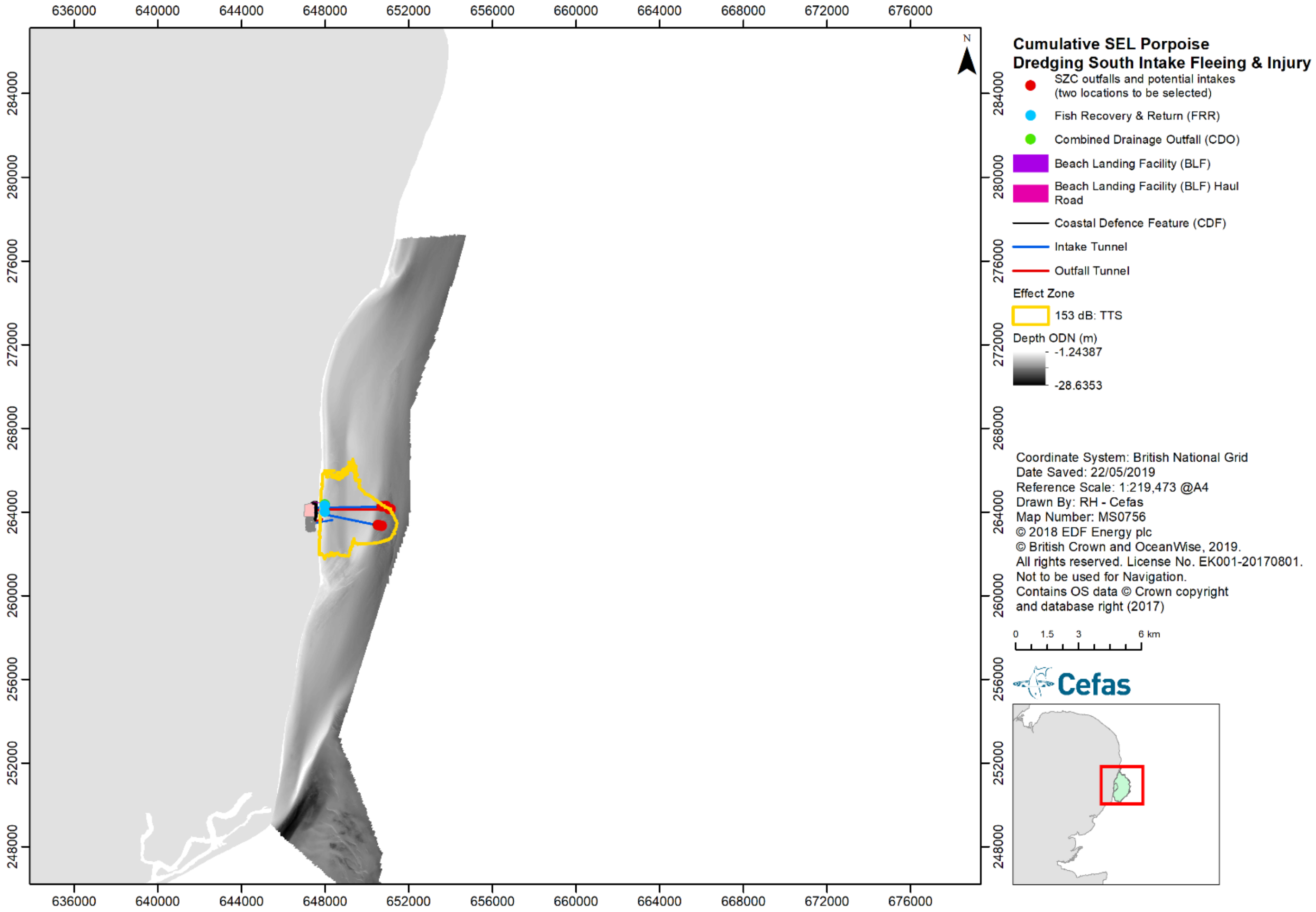

Figure 72 Predicted cumulative auditory effect on fleeing harbour porpoise for simultaneous dredging at the BLF and south intake locations, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on continuous dredging at the BLF and 8.5 hours of dredging at the south intake over the 24 hours assessment period.

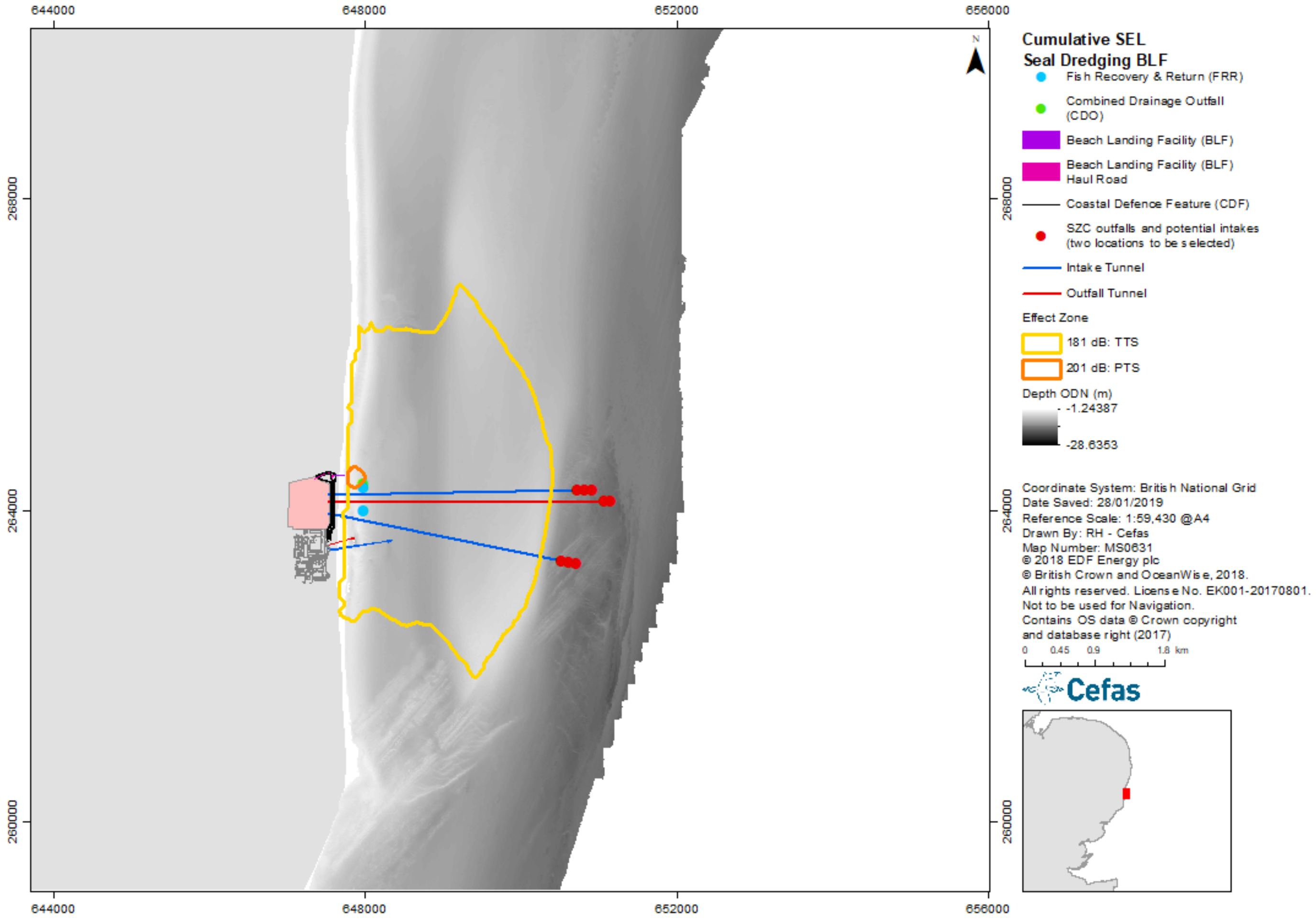

Figure 73 Predicted cumulative auditory effect on stationary harbour seal and grey seal for dredging at the BLF location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on continuous dredging over the 24 hours assessment period.

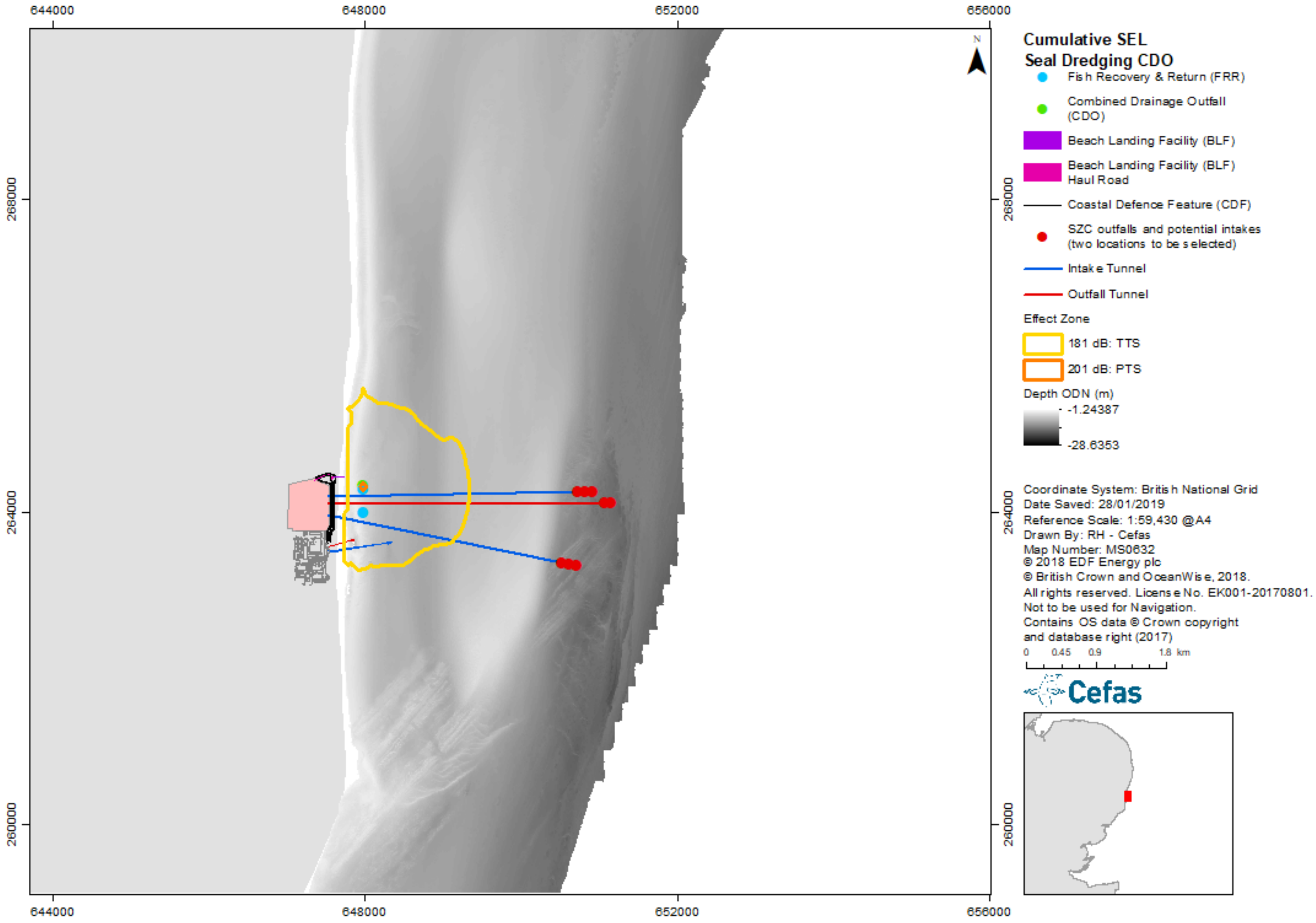

Figure 74 Predicted cumulative auditory effect on stationary harbour seal and grey seal for dredging at the CDO location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on 9.5 hours of dredging over the 24 hours assessment period.

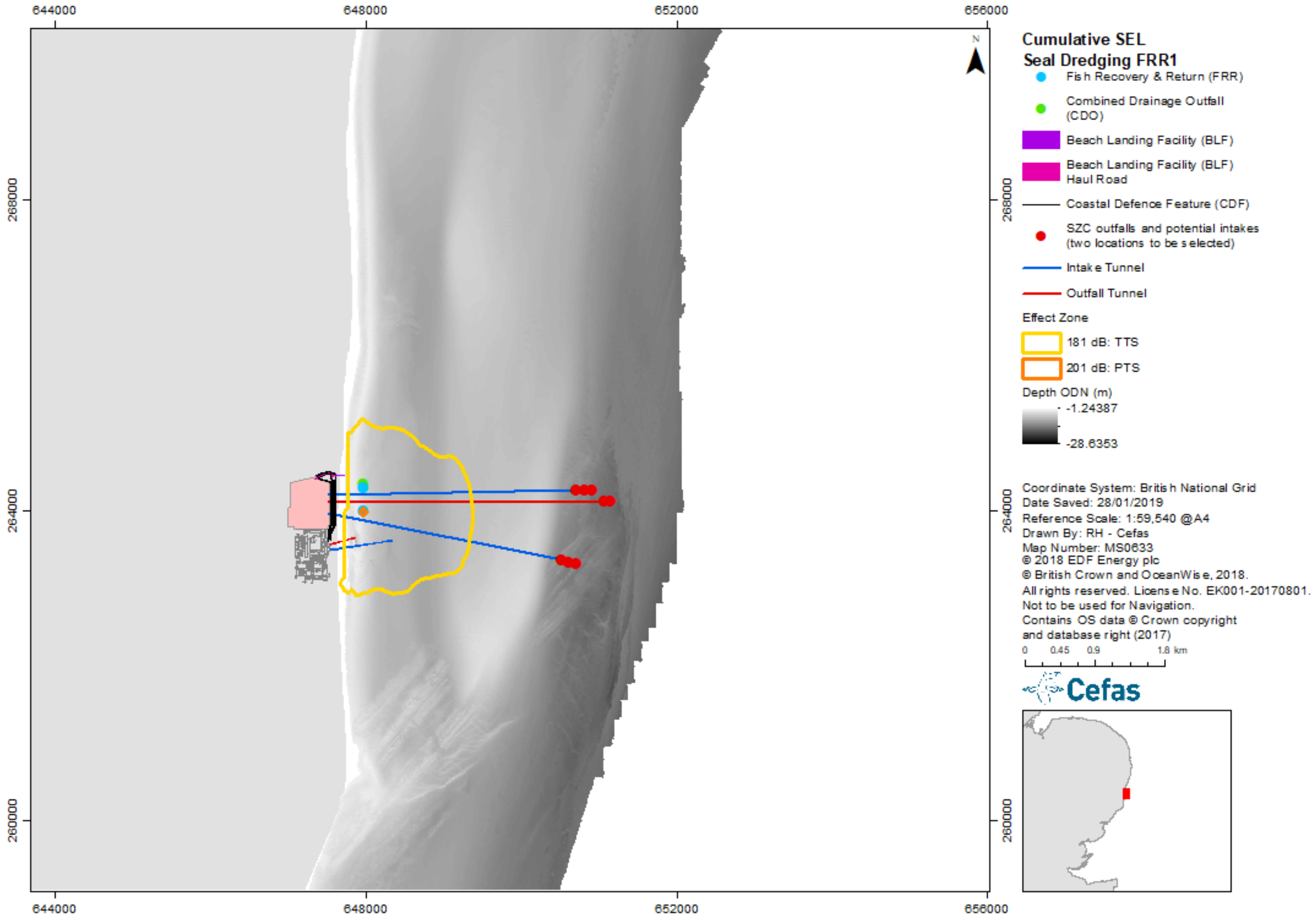

Figure 75 Predicted cumulative auditory effect on stationary harbour seal and grey seal for dredging at the FRR1 location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on 9.5 hours of dredging over the 24 hours assessment period.

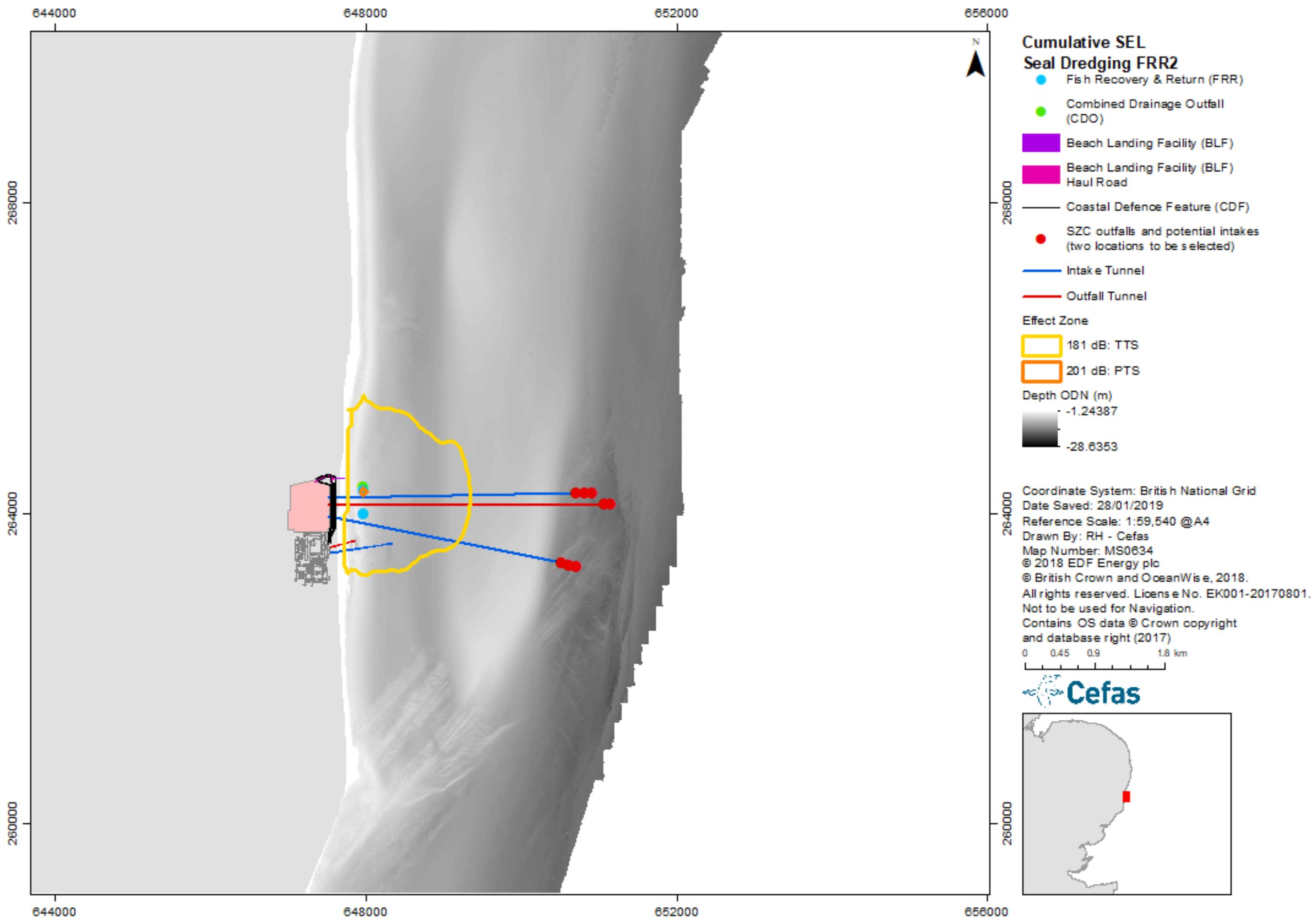

Figure 76 Predicted cumulative auditory effect on stationary harbour seal and grey seal for dredging at the FRR2 location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on 9.5 hours of dredging over the 24 hours assessment period.

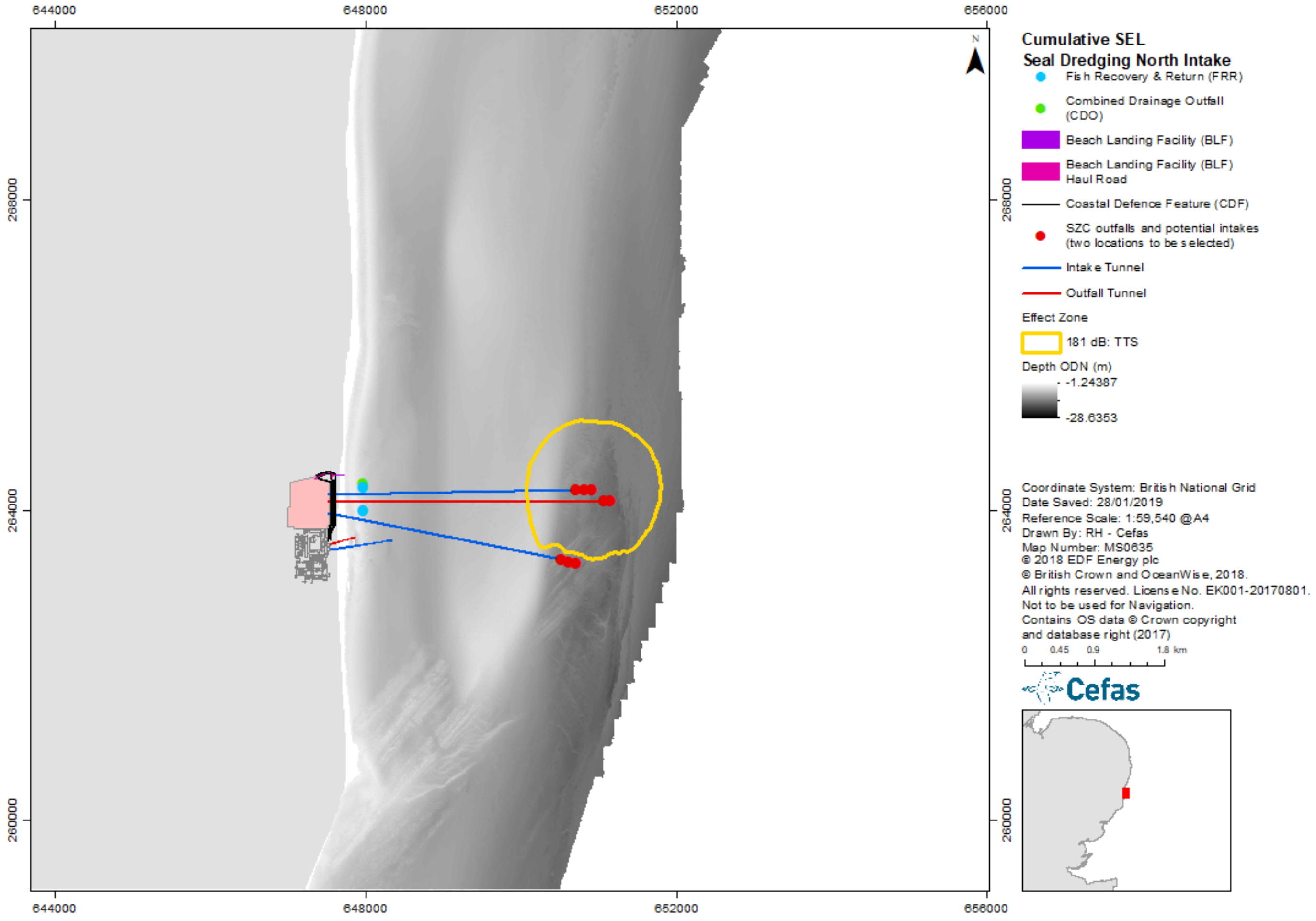

Figure 77 Predicted cumulative auditory effect on stationary harbour seal and grey seal for dredging at the north intake location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on 8.5 hours of dredging over the 24 hours assessment period.

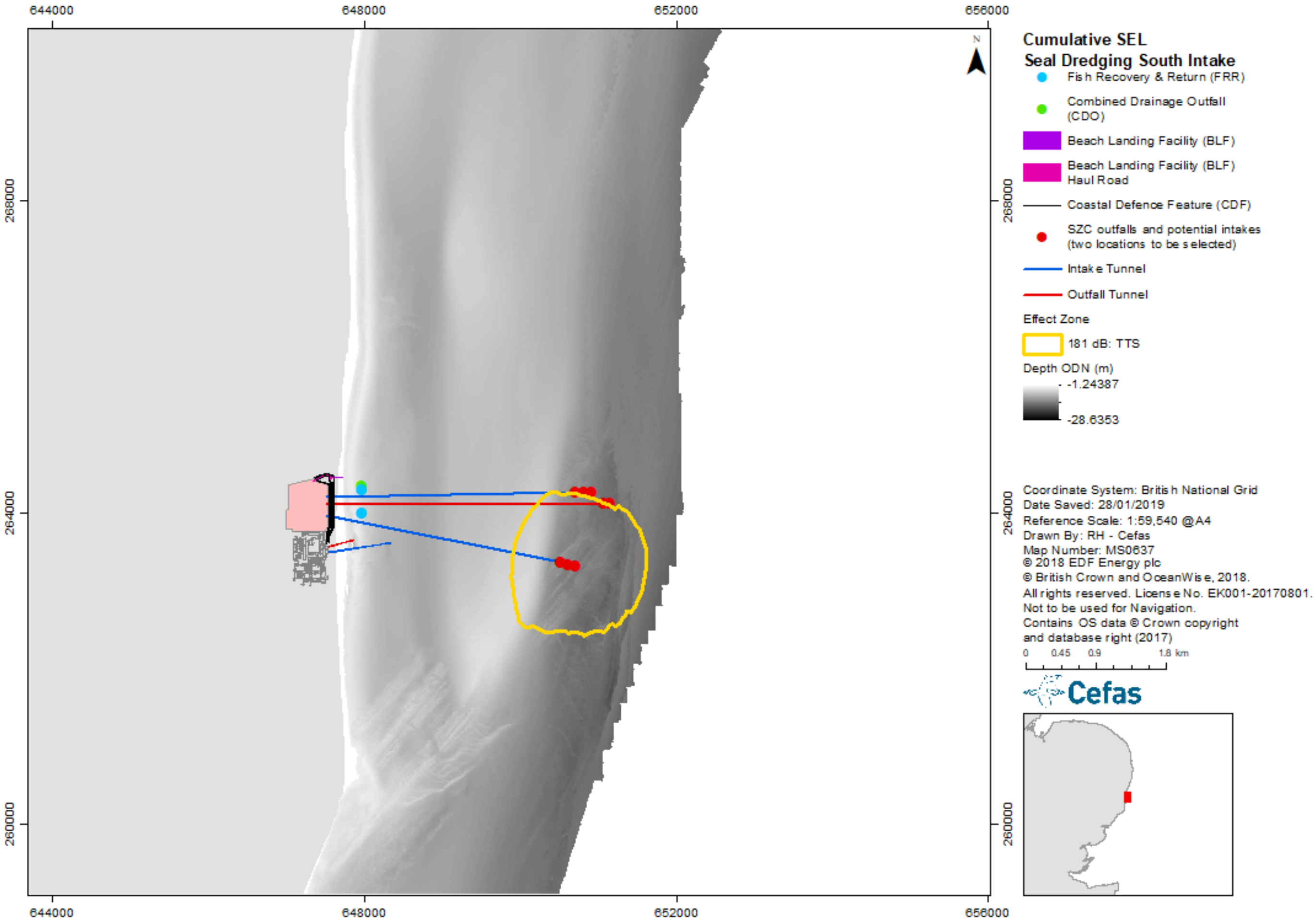

Figure 78 Predicted cumulative auditory effect on stationary harbour seal and grey seal for dredging at the south intake location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on 8.5 hours of dredging over the 24 hours assessment period.

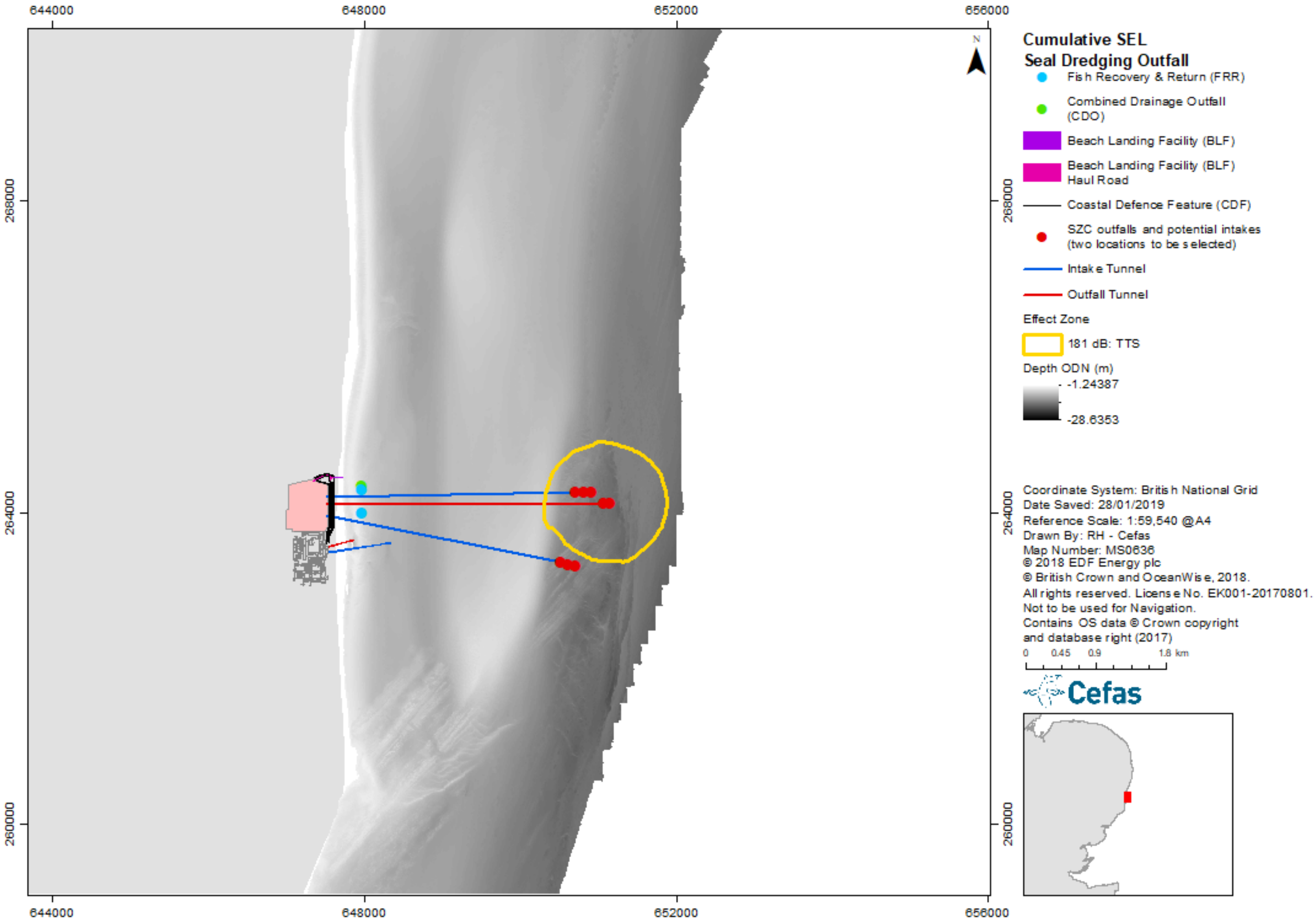

Figure 79 Predicted cumulative auditory effect on stationary harbour seal and grey seal for dredging at the outfall location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on 7 hours of dredging over the 24 hours assessment period.

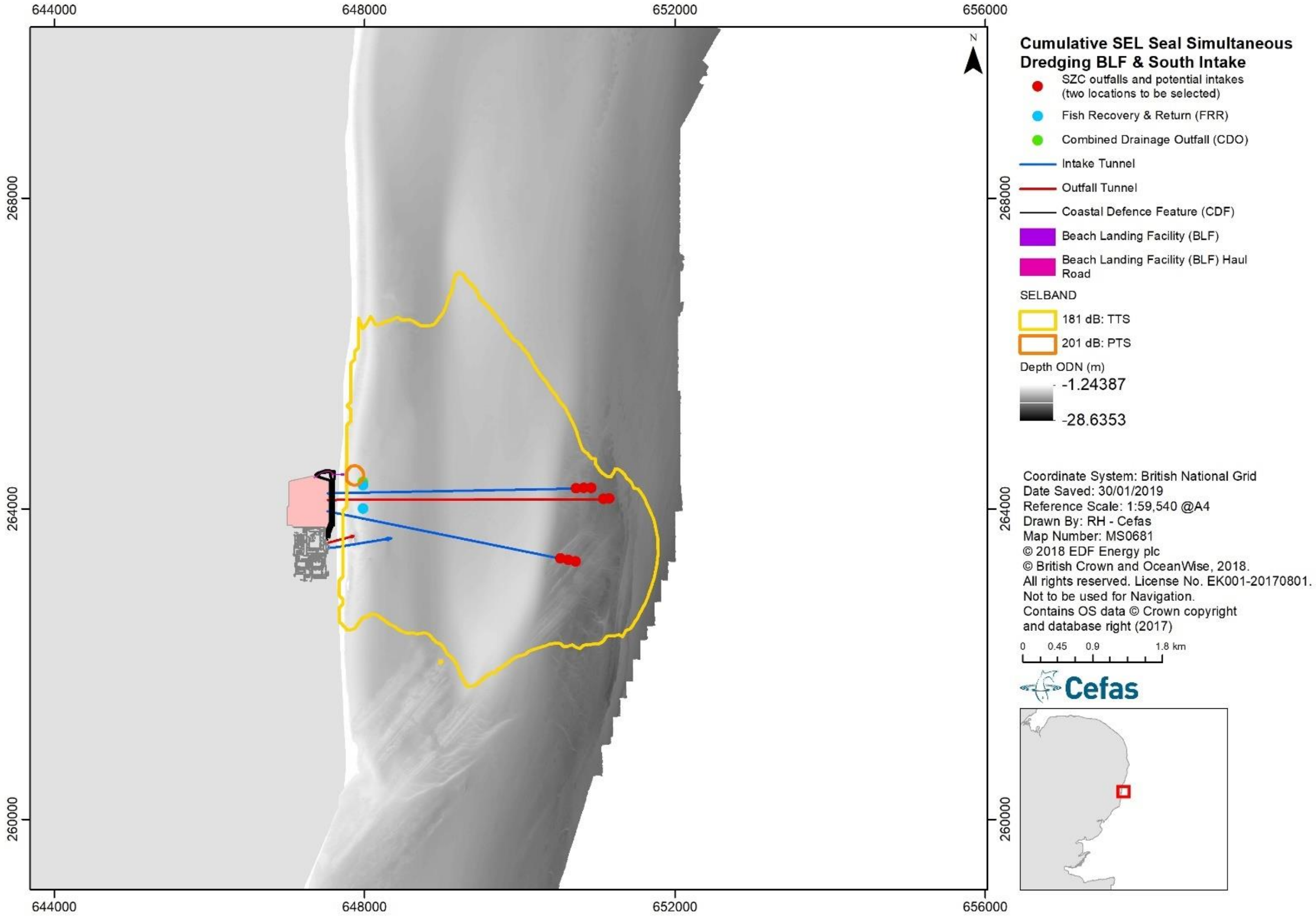

Figure 80 Predicted cumulative auditory effect on stationary harbour seal and grey seal for simultaneous dredging at the BLF and south intake location, assessed as per NOAA criteria (see Section 6.1.1). Assessment based on continuous dredging at the BLF and 8.5 hours of dredging at the south intake over the 24 hours assessment period.

7.4.2 Fish

7.4.2.1 *Instantaneous effects*

Noise levels arising from dredging activities were too low to generate instantaneous auditory effect zones for fish.

7.4.2.2 *Cumulative effects*

The cumulative sound exposure auditory effect zones for the fish species in the hearing group most vulnerable to sound exposure, from the eight dredging modelled scenarios, are illustrated in Figure 81 to Figure 89. Although the same acoustic source level was used for all seven single source scenarios, the extent of the PTS and TTS auditory effect zones varied markedly amongst the scenarios (see also Table 23). This variation is caused not only by the different acoustic propagation patterns associated to the specific source locations (as discussed previously in Section 5.3), but especially by the differences in dredging duration over which the noise exposure is assumed to accumulate. As such, the largest fish auditory effect zones (with TTS extending to ~1.8 km, recoverable injury to 158 m and mortality to 70 m) were predicted for dredging at the BLF, where continuous exposure over 24 hours was assumed (Figure 81). The smallest auditory effect zones (TTS extending to ~1.1 km, recoverable injury to 50 m and the mortality zone to <25 m, or smaller than a model grid cell) were predicted at the cooling water outfall where the exposure was assumed to be just 7 hours over the 24-hour assessment period (Figure 88).

The in-combination dredging scenario resulted in the largest overall effects, with the TTS zone (939 ha) covering ~30% more than the sum of the TTS zones predicted for the single source BLF (435 ha) and south intake (300 ha) scenarios, while recoverable injury zone (7 ha) was equal to sum of the zones predicted for the single source scenarios (6 ha and 1 ha, respectively). Finally, the fish mortality zone for the simultaneous dredging scenario was predicted to cover 2 ha around the BLF location only and was equal to the mortality zone predicted for the single source BLF scenarios (Table 23; Figure 89).

The mortality and recoverable injury zone extents for the other two hearing group (the fish species without a swim bladder or with swim bladder that is not involved in hearing) are shown in Table 24, for the two scenarios involving dredging at the BLF location. For all the other six dredging scenarios, the corresponding auditory effect zone extents were predicted to be less than 25 m and thus are not shown in Table 24. It should be noted that since the TTS threshold (186 dB re 1µPa) is applicable to all three fish hearing groups, while the recoverable injury threshold is the same (203 dB re 1µPa) for all species having a swim bladder (irrespective if it is involved in hearing or not). The extents of the TTS and recoverable injury extent zones for these species is show only in Table 23.

Table 23 Auditory effect zones areas (expressed in hectares) and/or auditory effect zone maximum ranges (expressed in metres) from dredging activities, for the fish species with swim bladder involved in hearing.N/A indicates source level is below relevant threshold; ‘See Figure’ indicates auditory effect zone was large enough to appear on corresponding figure.

Activity	Threshold	Instantaneous	Cumulative
Dredging BLF construction	Mortality	N/A	70 m; 2 ha See Figure 81
	Recoverable injury	N/A	158 m; 6 ha See Figure 81
	TTS	N/A	1,843 m; 435 ha See Figure 81
Dredging BLF maintenance	Mortality	N/A	<25 m
	Recoverable injury	N/A	70 m; 1 ha See Figure 82
	TTS	N/A	629 m; 69 ha See Figure 82
Dredging CDO	Mortality	N/A	25 m; 0.25 ha See Figure 83
	Recoverable injury	N/A	70 m; 2 ha See Figure 83
	TTS	N/A	1,000 m; 162 ha See Figure 83
Dredging FRR1	Mortality	N/A	25 m; 0.25 ha See Figure 84
	Recoverable injury	N/A	100 m; 3 ha See Figure 84
	TTS	N/A	1,063 m; 173 ha See Figure 84
Dredging FRR2	Mortality	N/A	25 m; 0.25 ha See Figure 85
	Recoverable injury	N/A	100 m; 3 ha See Figure 85
	TTS	N/A	1,015 m; 163 ha See Figure 85
Dredging north intake	Mortality	N/A	<25 m
	Recoverable injury	N/A	50 m; 1 ha See Figure 86
	TTS	N/A	1,048 m; 293 ha See Figure 86
Dredging south intake	Mortality	N/A	<25 m
	Recoverable injury	N/A	50 m; 1 ha See Figure 87
	TTS	N/A	1,078 m; 300 ha See Figure 87
Dredging outfall	Mortality	N/A	<25 m
	Recoverable injury	N/A	25 m; 0.25 ha See Figure 88
	TTS	N/A	982 m; 241 ha See Figure 88
In-combination scenario Dredging BLF and south intake	Mortality	N/A	2 ha; see Figure 89
	Recoverable injury	N/A	7 ha; see Figure 89
	TTS	N/A	939 ha; see Figure 89

Table 24 Auditory effect zones areas (expressed in hectares) and/or auditory effect zone maximum ranges (expressed in metres) from dredging activities, for the fish species without swim bladder or with swim bladder not involved in hearing.

Activity	Threshold	Instantaneous	Cumulative
Dredging BLF construction and Maintenance	Mortality (no swim bladder)	N/A	<25 m
	Recoverable injury (no swim bladder)	N/A	<25 m
	Mortality (swim bladder not involved in hearing)	N/A	50 m; 1 ha
In-combination scenario Dredging BLF and south intake	Mortality (no swim bladder)	N/A	<0.25 ha
	Recoverable injury (no swim bladder)	N/A	<0.25 ha
	Mortality (swim bladder not involved in hearing)	N/A	1 ha

7.4.2.3 Behavioural responses

Behavioural response ranges were calculated for dredging based on the contours of the 135 db re 1 μPa^2s (as shown in Figure 25 to Figure 32) for hearing specialists and the 142 db re 1 μPa^2s for less sensitive species (Table 25). The in-combination dredging scenario resulted in the largest overall effects, with the maximum behavioural response areas of 2,131 ha. The inshore BLF dredging resulted in a behavioural response range of 2,352 m (682 ha) whilst dredging activities for the cooling water infrastructure, located 3 km offshore resulted in behavioural response areas of ca. 1,200 ha.

Table 25 Behavioural effect zones for dredging, with areas (expressed in hectares) and maximum ranges (expressed in metres).

Activity	Threshold	Behavioural zone
Dredging BLF construction and maintenance	135 dB	2,352 m; 682 ha
	142 dB	761 m; 98 ha
Dredging CDO	135 dB	2,213 m; 640 ha
	142 dB	778 m; 118 ha
Dredging FRR1	135 dB	2,312 m; 674 ha
	142 dB	810 m; 123 ha
Dredging FRR2	135 dB	2,203 m; 647 ha
	142 dB	788 m; 119 ha
Dredging north intake	135 dB	2,271 m; 1,156 ha
	142 dB	927 m; 237 ha
Dredging south intake	135 dB	2,324 m; 1,191 ha
	142 dB	957 m; 244 ha
Dredging outfall	135 dB	2,213 m; 1,191 ha
	142 dB	961 m; 239 ha
In-combination scenario **Dredging BLF and south intake**	135 dB	2,131 ha
	142 dB	371 ha

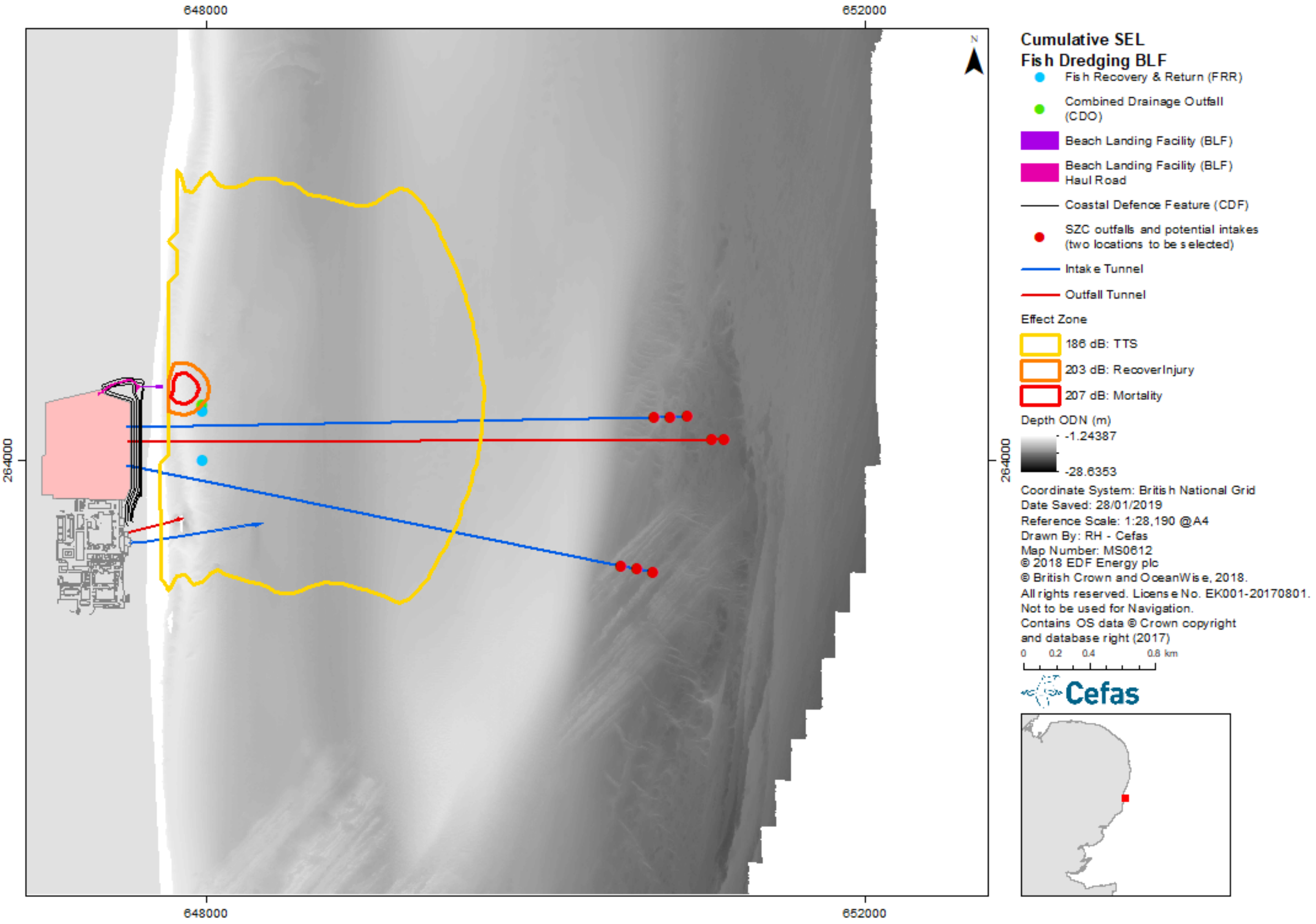

Figure 81 Predicted cumulative auditory effect zone for fish due to construction dredging at the BLF location, assessed as per Popper criteria (see Section 6.2.1). Assessment based on continuous dredging over the 24 hours assessment period.

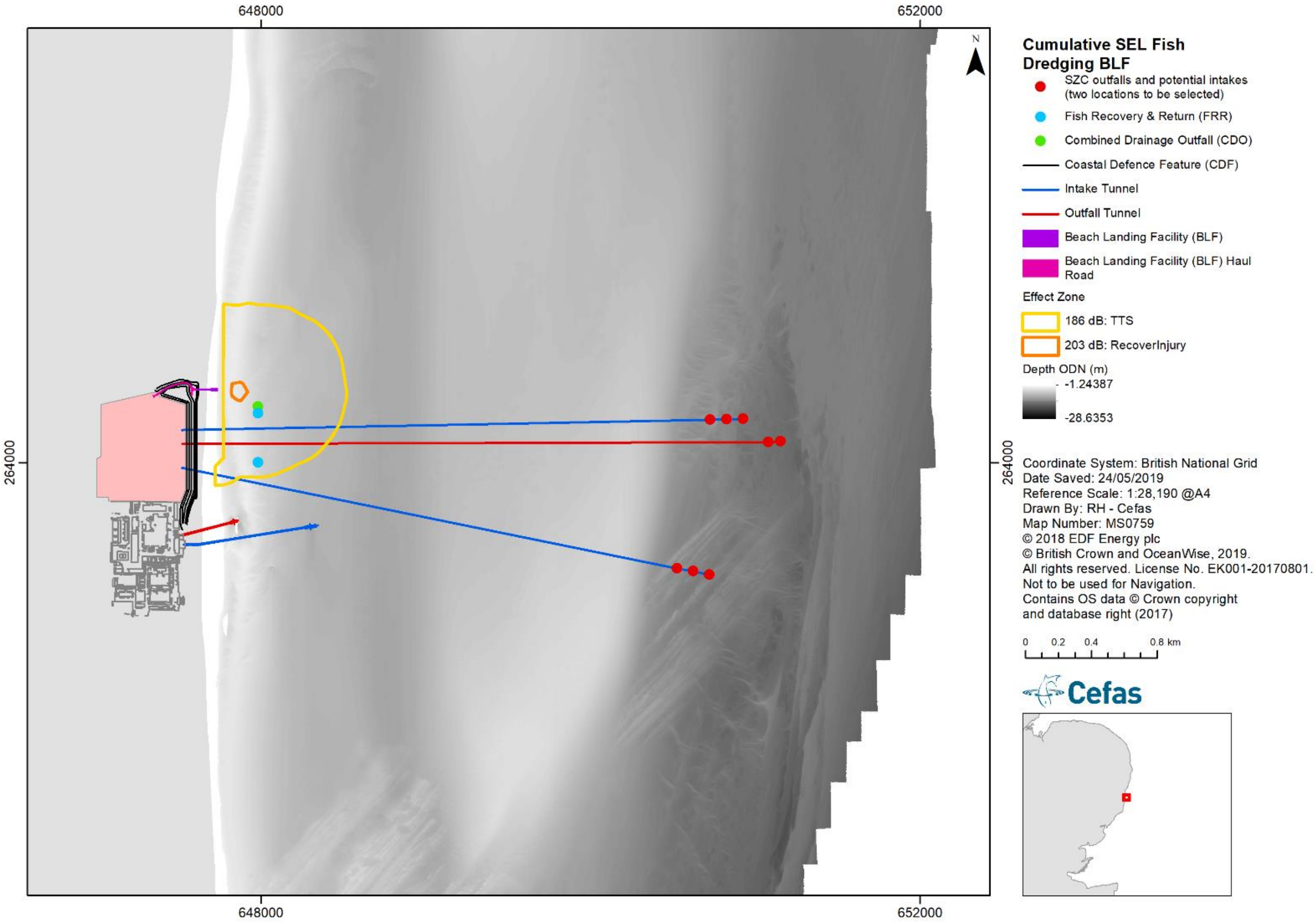

Figure 82 Predicted cumulative auditory effect zone for fish due to maintenance dredging at the BLF location, assessed as per Popper criteria (see Section 6.2.1). Assessment based on 5 hours of dredging over the 24 hours assessment period.

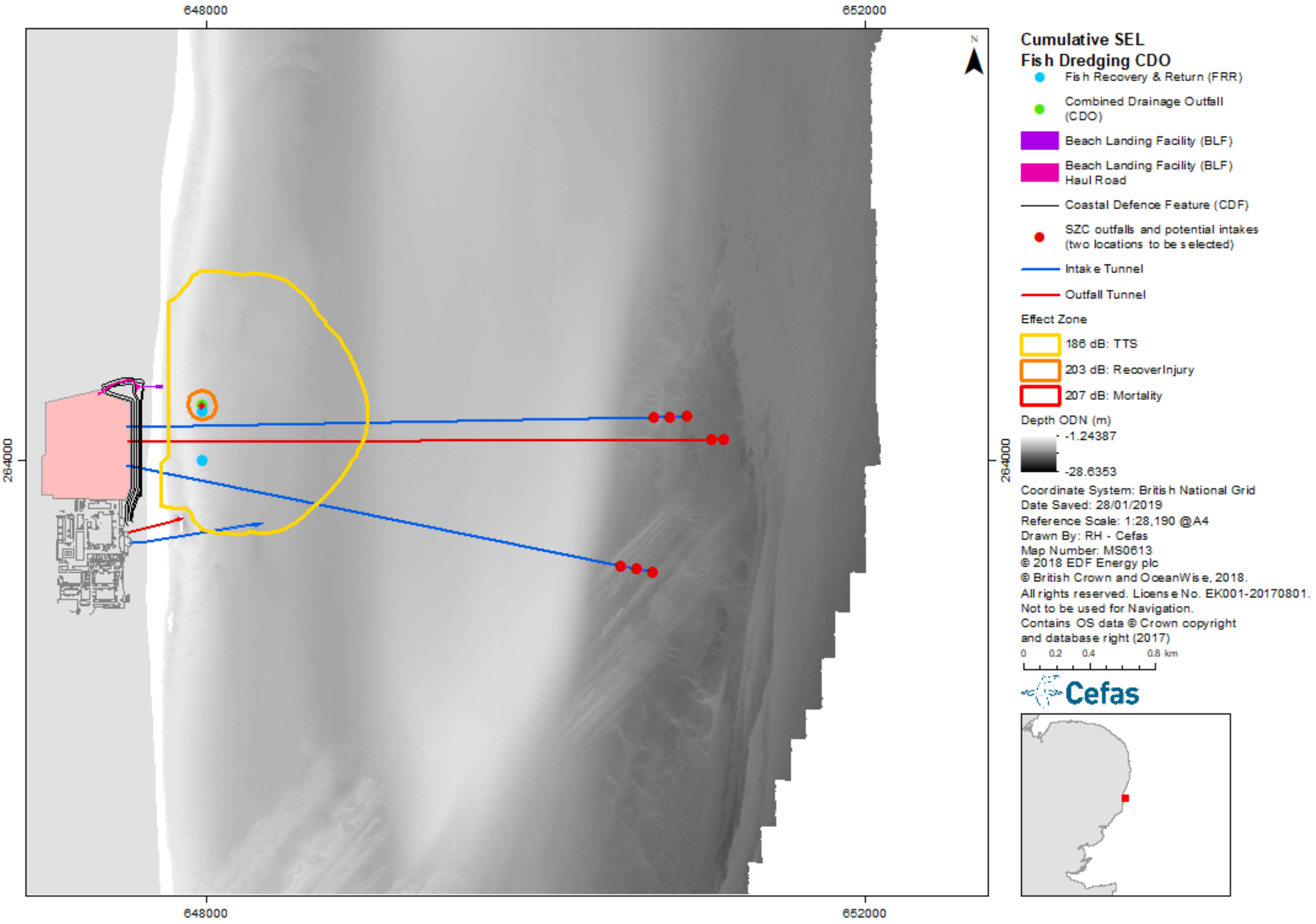

Figure 83 Predicted cumulative auditory effect zone for fish due to dredging at the CDO location, assessed as per Popper criteria (see Section 6.2.1). Assessment based on 9.5 hours of dredging over the 24 hours assessment period.

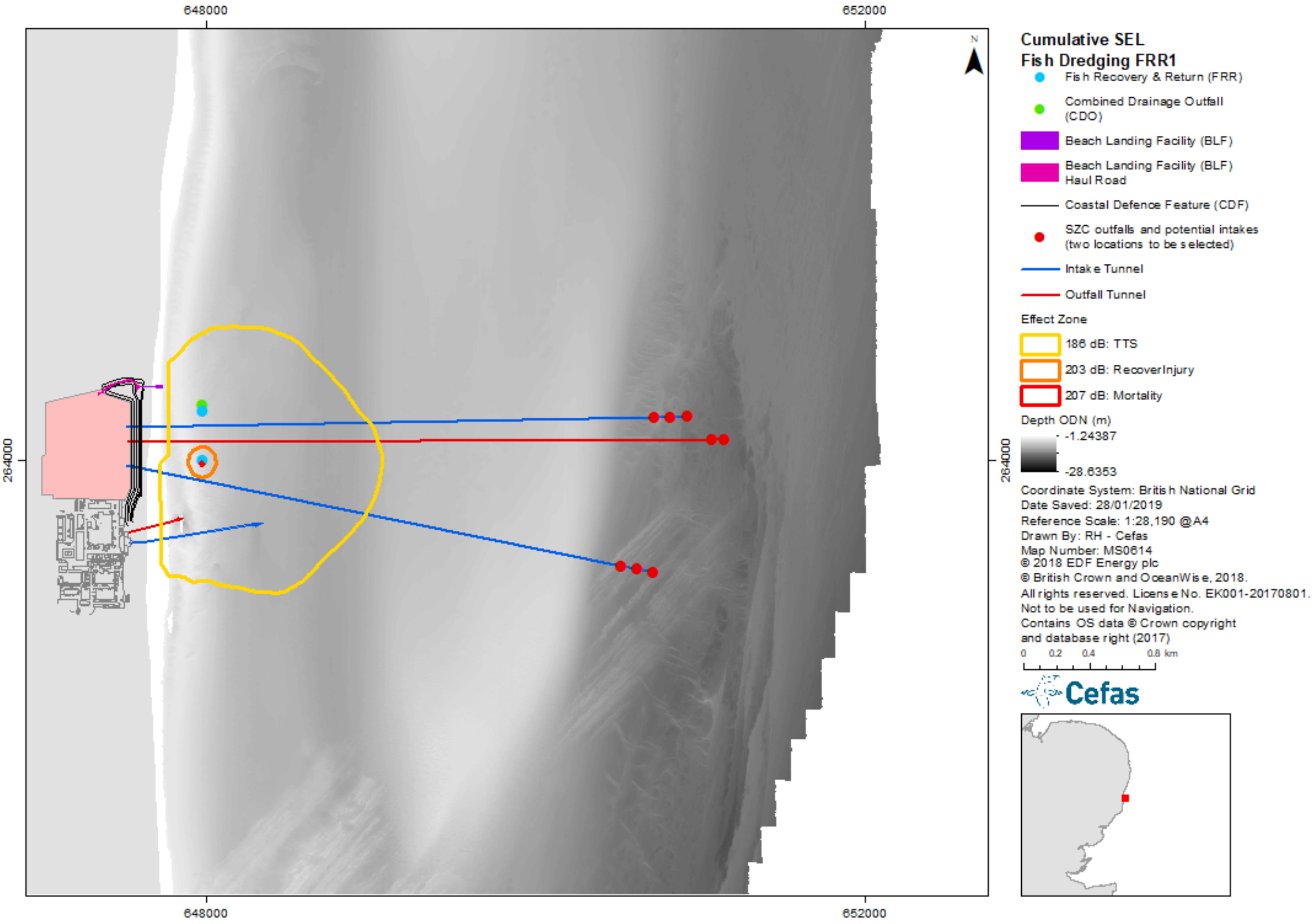

Figure 84 Predicted cumulative auditory effect zone for fish due to dredging at the FRR1 location, assessed as per Popper criteria (see Section 6.2.1). Assessment based on 9.5 hours of dredging over the 24 hours assessment period.

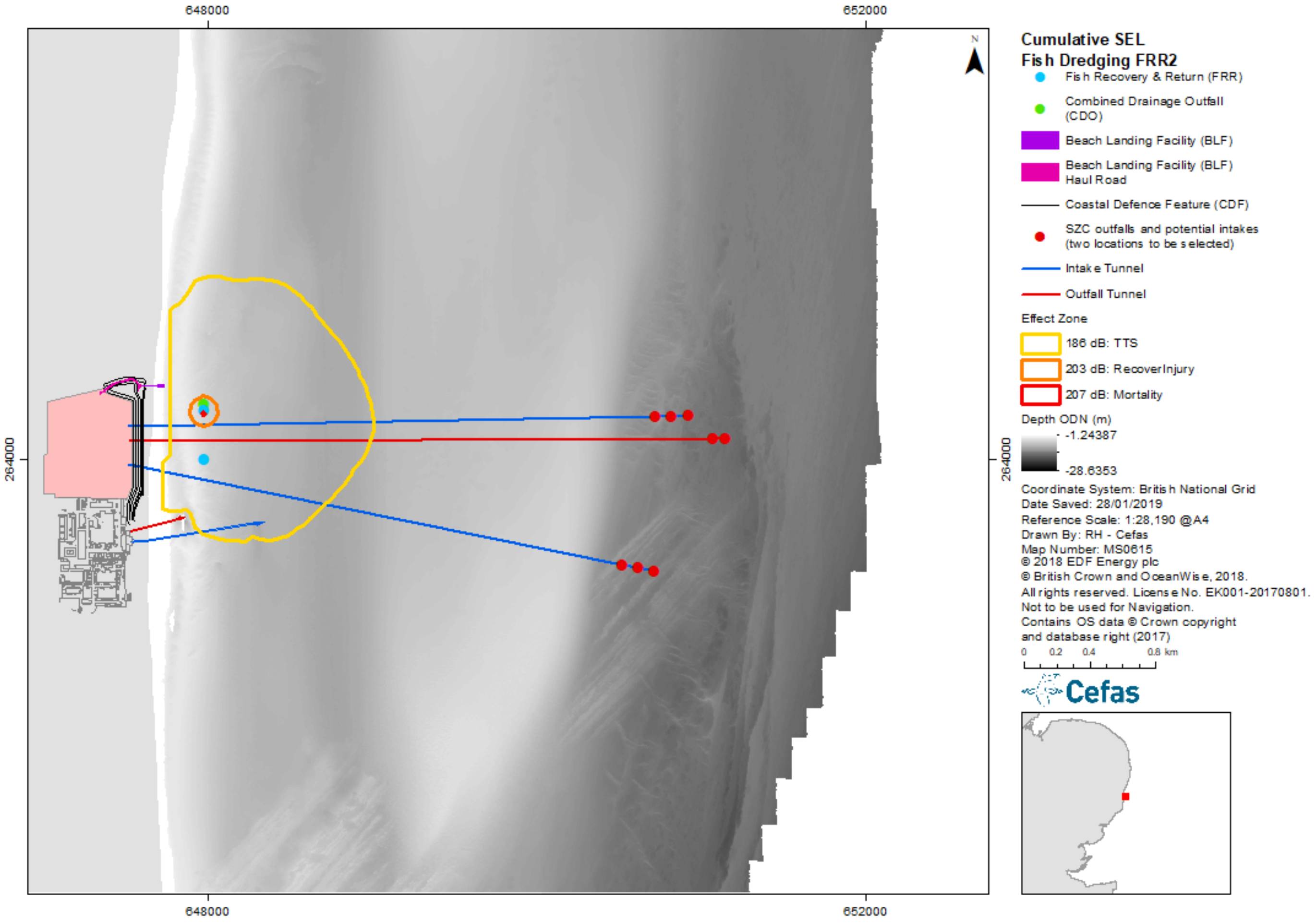

Figure 85 Predicted cumulative auditory effect zone for fish due to dredging at the FRR2 location, assessed as per Popper criteria (see Section 6.2.1). Assessment based on 9.5 hours of dredging over the 24 hours assessment period.

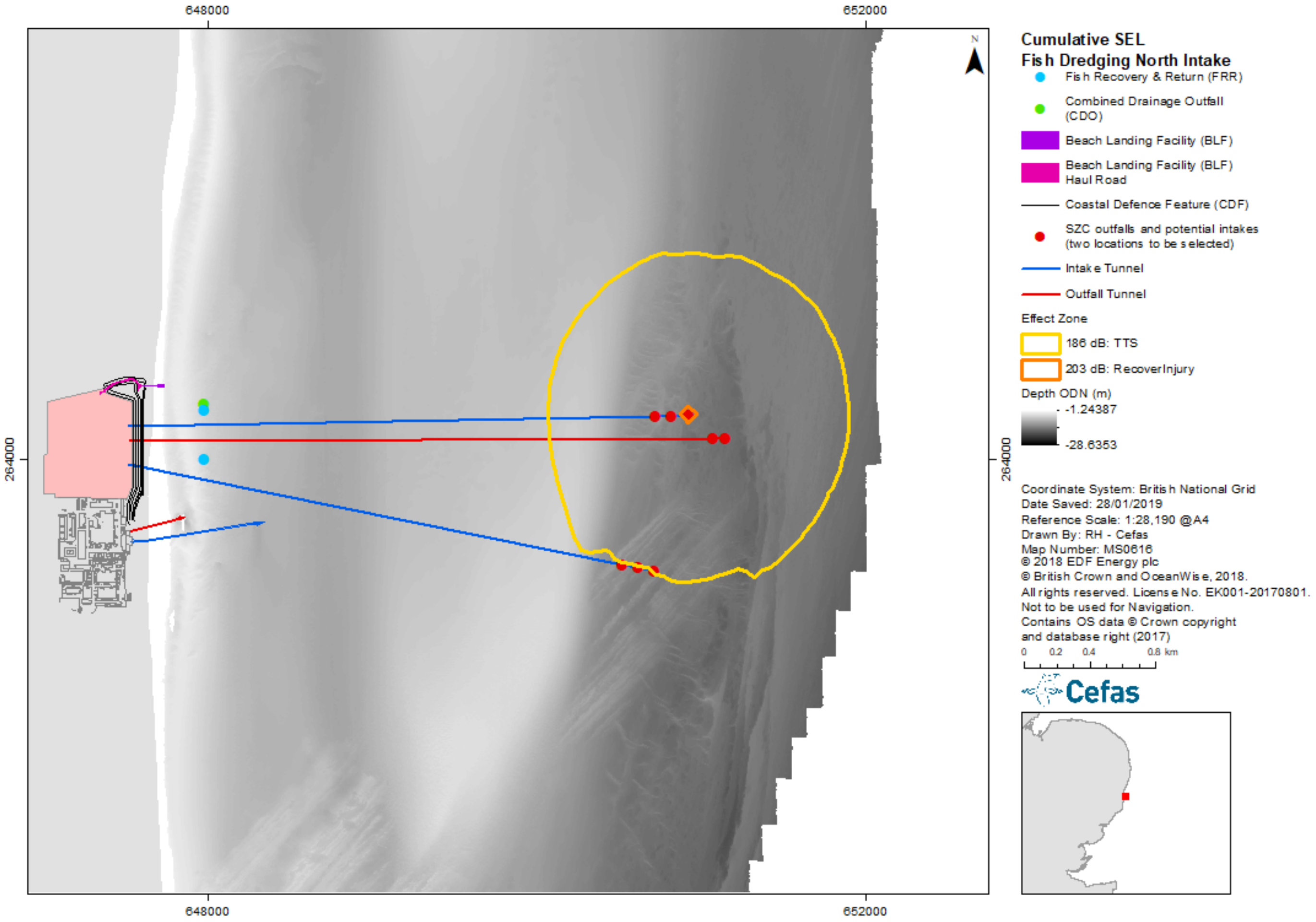

Figure 86 Predicted cumulative auditory effect zone for fish due to dredging at the north intake location, assessed as per Popper criteria (see Section 6.2.1). Assessment based on 8.5 hours of dredging over the 24 hours assessment period.

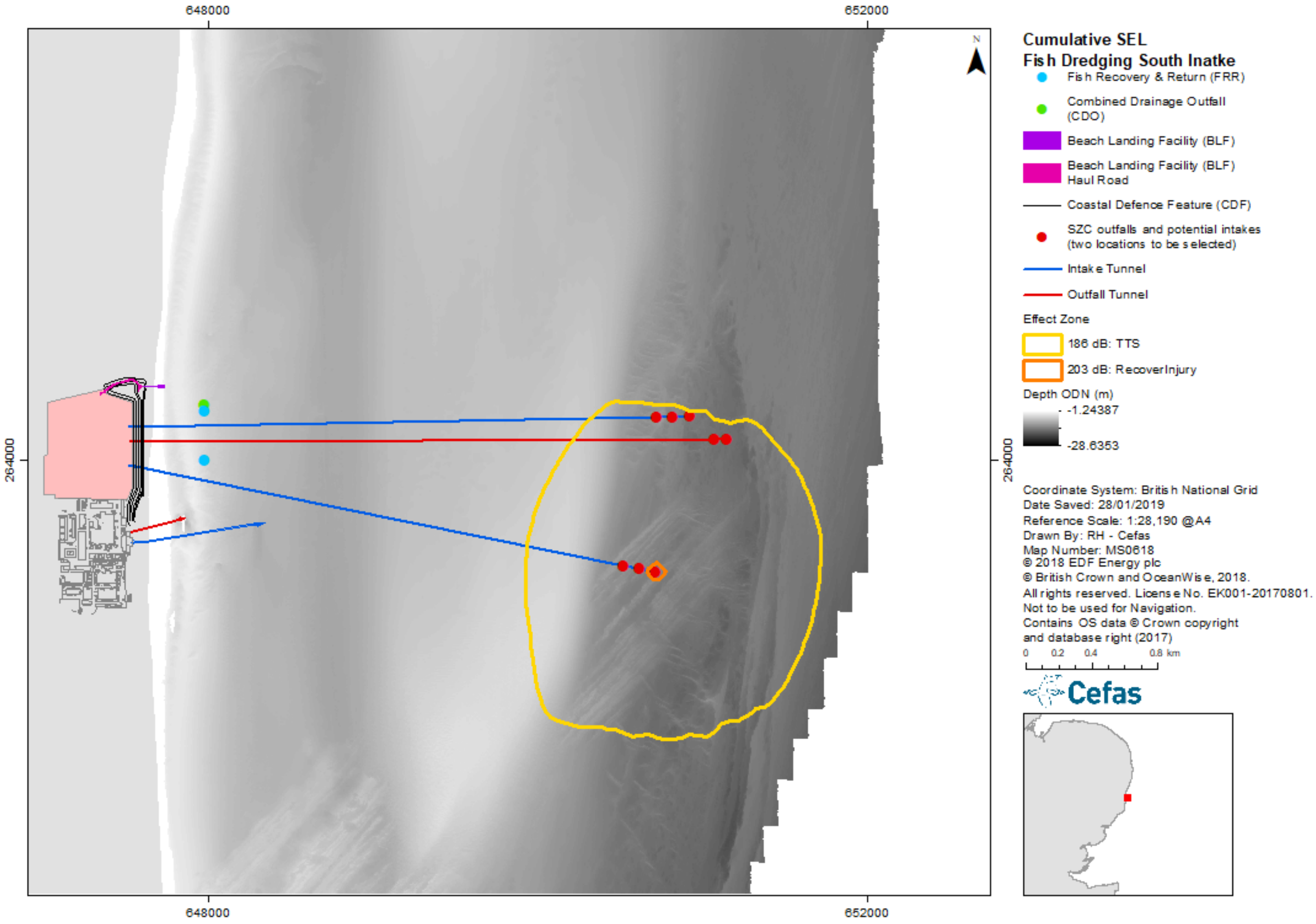

Figure 87 Predicted cumulative auditory effect zone for fish due to dredging at the south intake location, assessed as per Popper criteria (see Section 6.2.1). Assessment based on 8.5 hours of dredging over the 24 hours assessment period.

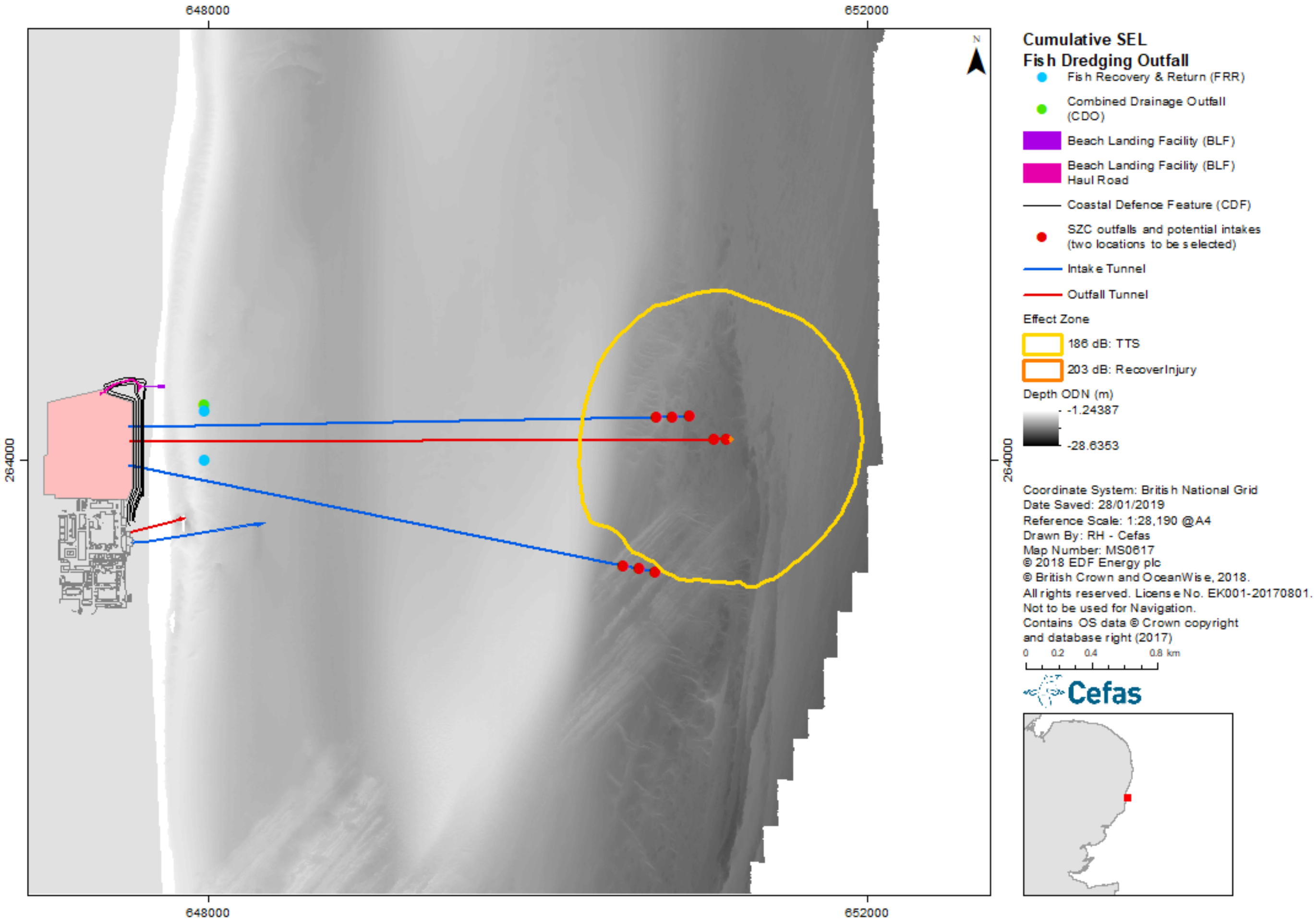

Figure 88 Predicted cumulative auditory effect zone for fish due to dredging at the outfall location, assessed as per Popper criteria (see Section 6.2.1). Assessment based on 7 hours of dredging over the 24 hours assessment period.

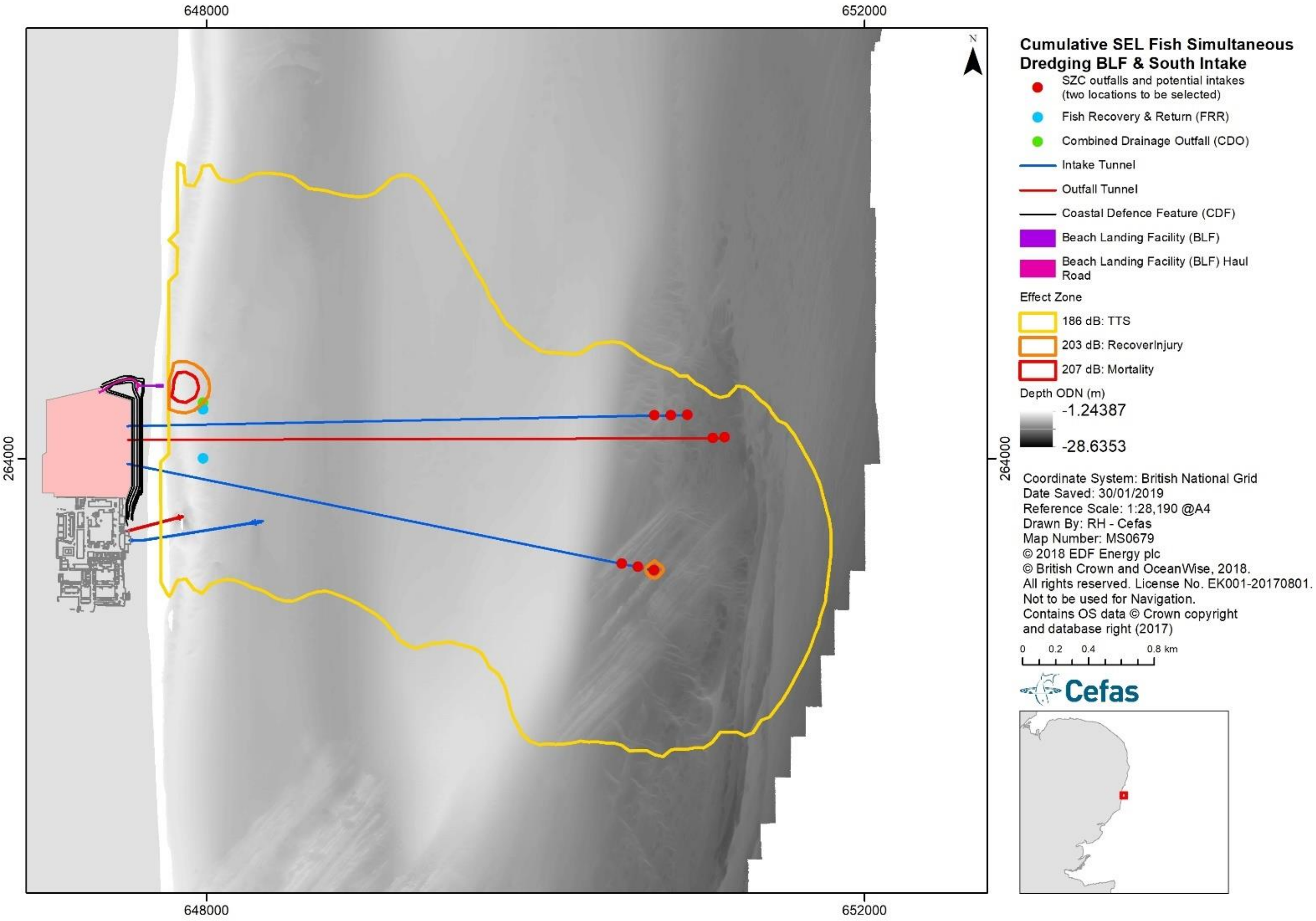

Figure 89 Predicted cumulative auditory effect zone for fish due to in-combination dredging at the BLF and south intake locations, assessed as per Popper criteria (see Section 6.2.1). Assessment based on continuous dredging at the BLF and 8.5 hours of dredging at the south intake over the 24 hours assessment period.

8 Implications for environmental impact assessment

8.1 Marine mammals

The species of concern for the Sizewell Bay area are the harbour porpoise *(Phocoena phocoena*), the grey seal (*Halichoerus grypus*) and the harbour seal (*Phoca vitulina*). Underwater noise may arise from dredging, drilling and impact piling activities. A hypothetical UXO clearance scenario was also considered. This section summarises the results of the underwater noise assessments in relation to auditory damage. This section indicates some of the implications for the ES, which will also consider behavioural effects, and where appropriate, mitigation measures are considered. The ES will consider the results presented here in relation to the conservation objectives of the species of concern. Furthermore, a draft Marine Mammal Mitigation Protocol (MMMP) for impact pilling activities has been submitted for DCO with mitigation measures detailed and any relevant conditions included in the DML.

8.1.1 Instantaneous noise

UXO detonations and impact pilling are the only activities with the potential to cause instantaneous PTS to marine mammal species at Sizewell.

Drilling and dredging activities represented no risk for instantaneous auditory injury to marine mammals.

8.1.1.1 UXO detonations

In the case UXOs were identified on site, appropriate management actions and mitigation measured would be required to minimise impacts. Such measures would be highly dependent on the location of the UXO, HSE and logistical constraints and would require review on a case-by-case basis. In addition to *in-situ* detonation, there may be other alternatives options. These include deflagration (effectively burning the charge extremely quickly instead of detonating); water jet cutting the UXO into sections; relocation of the UXO; physical barriers (mitigation materials) placed on top of the UXO to reduce noise levels; or using a static detonation chamber. Furthermore, should *in-situ* detonation be the most appropriate mitigation measures would be discussed with regulators and described within a dedicated MMMP. The MMMP would account for site-specific factors and follow the measures, where appropriate, in accordance with '*JNCC (2010) guidelines for minimising the risk of injury to marine mammals from using explosives'.*

The results presented in this report should therefore be considered as indicative, worst-case scenarios for unmitigated impact ranges.

In-situ UXO detonation has the potential to cause instantaneous PTS in marine mammal species at Sizewell over large spatial extents. As highlighted in Section 7.1.1, a worst-case charge mass of 1,500 lb, has the potential to cause PTS up to 14,039 m from the source for harbour porpoise. Seals are less sensitive. The largest potential auditory effect range for PTS in seals was predicted to be 2,750 m from the source. Temporary auditory damage (TTS) may occur at a range of 25,872 m for harbour porpoise and 5,068 m for seals.

8.1.1.2 Impact piling

The largest range for permanent hearing damage (PTS) resulting from piling activities was 41 m for harbour porpoise assuming a 200 kJ hammer energy. Seals are less sensitive and the auditory effect range for PTS was predicted to be 9 m from the sound source. Temporary auditory damage may occur at a range of 67 m for harbour porpoise and 16 m for seals.

JNCC guidelines for minimising the risk of injury to marine mammals from piling noise stipulate that a 500 m mitigation zone is established in which a marine mammal observer (MMO) completes pre-piling searches to detect the presence of marine mammals (JNCC 2010b). All instantaneous effect ranges are well within the 500 m mitigation zone, even under the worst-case assumption of using a 200 kJ hammer. Therefore, compliance with standard mitigation procedures are predicted to be effective in effectively negating the risk of instantaneous auditory damage in marine mammals. Soft-start procedures are a requirement of the DML, whereby the hammer energy is incrementally increased to fully operational power over a period no longer than 20 minutes. The intention is that by initiating piling at a lower power marine mammals within the area have the opportunity to move away thereby reducing the likelihood of exposure to harmful noise levels (JNCC 2010b). However, hammer energies during piling activities are relatively low and instantaneous effect zones are within the 500 m mitigation zone.

8.1.2 Cumulative noise

Cumulative exposure to noise sources can result in auditory effects extending over larger areas. Should a marine mammal remain within the auditory effect zone for the duration of the piling activities cumulative effects may occur. Assessments considered the scenario of a maximum of 5 piles being installed in a 24-hour assessment period. It should be noted that based on this scenario the 12 marine piles associated with the BLF would be installed in less than 3 days.

Cumulative PTS auditory effect zones of 2.1 km (561 ha) for stationary harbour porpoise and 300 m (20 ha) were predicted for harbour and grey seals for 200 kJ hammer energies. TTS was predicted up to a maximum range of 12.5 km in the stationary harbour porpoise model (10,223 ha) and 3.1 km (1,064 ha) for seals (Table 15). The risk of PTS or TTS will depend on the behaviour of the animal and whether is remains within the effect zone for the duration of the piling activities in the cumulative assessment period. Animals that remain in the area for the duration of the piling activity would be at risk of auditory damage. The auditory effect zones predictions for stationary marine mammals can be regarded as precautionary (see Section 6.1.2 for details) and need to be contextualised in relation to marine mammal behaviour and ecology to determine the potential for adverse effects. Field studies have demonstrated behavioural responses of harbour porpoises to anthropogenic noise. A number of studies have shown avoidance of pile driving activities during offshore wind farm construction (Brandt *et al.*, 2011; Carstensen *et al.*, 2006; Dähne *et al.*, 2013), with the range of measurable responses extending to at least 21 km in some cases (Tougaard *et al.*, 2009).

To account for avoidance behaviour fleeing behaviour was incorporated into the model. With fleeing included in the piling assessments, no auditory effect zones were predicted for seal species. For harbour porpoise no PTS was predicted and TTS effect zones were predicted to occur within 4.8 km (2179 ha) from the BLF piling location, for the 200 kJ hammer energy scenario.

Drilling activities are not predicted to present a risk to marine mammals. The predicted auditory effect zones arising from drilling activities were negligible for stationary seals (0.25 ha continuous TTS impact zone). For stationary harbour porpoise no PTS was predicted beyond 25 m and cumulative TTS was predicted to be restricted to within 1.3 km of the sound source (422 ha). With fleeing included in the drilling assessments, no PTS or TTS impact zones were predicted for any of the marine mammal species.

In the case of dredging, the auditory injury effect zones are larger than those predicted for the drilling operations but remain modest for permanent injury. The largest PTS range for stationary harbour porpoise was within 1.7 km (394 ha) from the BLF dredging location, for 24 hours of continuous dredging. The corresponding PTS range for seals was limited to within 110 m (Table 22). The likelihood of marine mammals remaining in this proximity to the shallow subtidal dredging activity for the full 24-hour period required to cause auditory damage is very low. TTS ranges for the BLF construction dredging were predicted to have a maximum range of 11.6 km (11,331 ha) for stationary harbour porpoise, and 3 km (969 ha) for stationary seals. The auditory effect zones for BLF dredging are precautionary as they assume continuous 24-hour operations with noise levels consistent throughout (i.e. dredging and repositioning cause equal sounds exposure). When fleeing was included in the dredging assessments, no auditory effect zones were predicted for the seal species, while for the harbour porpoise only TTS effect zones were predicted, with the largest TTS range being within 1.4 km (241 ha) from the BLF dredging location, for 24 hours of continuous dredging.

A hypothetical in-combination dredge scenario was also considered. This involved the simultaneous dredging at the BLF and the cooling water intake, the two dredge locations with the largest individual effect ranges. The cumulative PTS effect zone increased by approximately 20% of the sum of the dredge activities individually but remained relatively small for highly mobile species; 620 ha for stationary harbour porpoise and 5 ha for stationary seals. TTS effect zones were smaller than the sum of the individual dredge activities due to spatial overlap; 14,359 ha for stationary harbour porpoise and 1,411 ha for stationary seals. When fleeing was included in the assessment of the in-combination dredge scenario, no PTS was predicted. A TTS effect zone of 1,040 ha was predicted for harbour porpoise, while no auditory effect zones were predicted for the seal species.

8.2 Fish

This report considers the effects of underwater noise on representative fish species at Sizewell. Assessments are based on established criteria to determine potential mortality and auditory injury of susceptible fish species. Assessments focus on hearing specialists as these species provide the most precautionary estimates for effect zones to underwater noise sources. In addition to auditory injury, potential behavioural response ranges were estimated to determine areas where migratory species and species that form important prey items for designated birds (Section 2.3) may exhibit temporary behavioural responses.

8.2.1 Instantaneous effects

UXO detonations and, to a much smaller extent, impact piling were the only activities with the potential to cause mortality or recoverable injury in fish.

In the case of UXO detonations, the instantaneous mortality and potential mortal injury range for all fish species was estimated at 897 m, for the 1,500 lb charge, 622 m, for the 500 lb charge, and at 493 m for the smallest charge mass of 250 lb.

In the case of impact piling, for the most sensitive hearing specialists such as herring, sprat, anchovy and shad, such effects were restricted to a small area within 27 m of the sound source in the 200 kJ scenario and 17 m in the 90 kJ scenario (Table 16).

Dredging and drilling activities resulted in no instantaneous effect zones.

8.2.2 Cumulative effects

Impact piling caused the greatest cumulative effect zones for hearing specialists. Mortality and recoverable injury effect zones for cumulative piling activities (5 piles within a 24-hour period) were restricted to within ca. 110 m (2 ha) and 160 m (4 ha), respectively for the worst-case 200 kJ hammer energy scenario (Table 16). TTS extended to approximately 820 m from the sound source (88 ha).

For less sensitive fish species including those species with a swim bladder that is not involved with hearing (e.g. European eel, whiting and smelt) mortality would occur if they remained within 70 m (1 ha) of the piling activity for the cumulative assessment period (Recoverable injury and TTS thresholds are consistent with the hearing specialists summarised above). For the least sensitive fish species with no swim bladder, recoverable injury and mortality cumulative effect zones were restricted to <25 m (Table 17).

Cumulative auditory effect zones for drilling activities were all within 25 m of the sound source for mortality, recoverable injury, and TTS. The restricted extent of noise impacts from drilling activities are predicted to have negligible effects on fish within the Sizewell Bay area.

Dredging activities associated with the continuous 24-hour dredging at the BLF resulted in the largest auditory effect zones. Mortality and recoverable injury for hearing specialists were restricted to within 70 m and 158 m respectively, whilst TTS was predicted to occur over an area of 435 ha, 1.8 km from the sound source (Table 23). Species with a swim bladder that is not involved in hearing would only be predicted to incur mortality if they remained within 50 m of the sound source for the duration of the 24-hour assessment period. Mortality and injury effect zones were <25 m for species lacking a swim bladder (Table 24).

8.2.3 Behavioural responses

Quantitative behavioural response thresholds do not exist for fish. The potential for instantaneous behavioural responses was based on 135 dB re 1 µPa^{2}s single strike SEL contour, which has previously been shown to cause schooling sprat to disperse or change depth on 50% of presentations (Hawkins and Popper, 2014). In the 90 kJ hammer energy scenario the contour extends to an area of 525 ha, whilst in the 200 kJ hammer energy scenario the contour covers an area of 968 ha (Figure 50 and Figure 51).

Behavioural responses or displacement from these areas has the potential to temporarily effect migratory fish species or influence prey availability for designated birds or marine mammals. The onset of behavioural responses is likely to be strongly influenced by behavioural context (Hawkins and Popper, 2014) and observations of startle responses in a hearing specialist species to not necesitate displacement from the area particularly for species with lower auditory sensitivities. Sprat are a clupeid species and are likely to have similar acoustic characteristics to the other clupeid species at Sizewell. Whiting, smelt and European eel do not exhibit the hearing specialisations as clupeids. As such the 135 dB re 1 µPa^{2}s threshold is likely to be conservative for these species and additional 142 dB re 1 µPa^{2}s ranges based on mackerel (no swim bladder) response ranges are provided (Section 7). These behavioural response ranges do not exclude a distinct behaviour response induced through particle motion instead of sound pressure level detection. Behavioural response zones should therefore be treated as indicative areas over which behavioural responses may occur. The duration of piling is anticipated to be short-term (12 piles in total below MHWS).

Applied instantaneous behavioural thresholds were also used as an indicative assessment for behavioural effects of continuous sound sources. Behavioural response ranges were restricted to within 25 m of the sound source for all drilling activities and are therefore negligible.

Dredging for the inshore BLF access channel represents the continuous noise source with the greatest potential for spatial overlap with designated breeding birds at Sizewell (for example little terns at Minsmere. The inshore BLF dredging resulted in a behavioural response range of 2,352 m (682 ha) and is anticipated to last 2.1 days. The offshore cooling water infrastructure, located 3 km offshore resulted in the largest behavioural response areas of ca. 1,200 ha but did not intersect the coast (Figure 29 to Figure 31). Dredging for the inshore FRRs and CDO are predicted to take 9.5 hours each and have behavioural response ranges of up to 2,312 m (674 ha; Table 25 Section 5.3).

8.3 Conclusions

UXO detonations generate markedly larger instantaneous auditory impact zones than all other activities. In the instance UXOs are identified and detonated on site, the clearance works have the potential to cause permanent and temporary hearing impairment to marine mammals and fish over extended areas. Harbour porpoise in particular, have the potential to be affected with the largest range for instantaneous permanent hearing damage (PTS) extending to 14.0 km for an unmitigated detonation of a 1,500 lb TNT charge. In the case of hearing specialist fish species maximum mortality ranges extend to 897 m.

If UXOs are identified on site, appropriate management actions and mitigation measured would be implemented on a case-by-case basis to minimise impacts. As a minimum mitigation would adhere to the JNCC guidelines for minimising the risk of disturbance and injury to marine mammals whilst using explosives (JNCC 2010a). Alternative disposal methods or relocation would be considered as well as case specific mitigation measures including deployment of Marine Mammal Observers (MMOs), Acoustic Deterrent Devices (ADD), and potentially, smaller scare charges or bubble curtains where possible to minimise the potential for death or injury. The most appropriate mitigation measures for UXO would be discussed with regulators and SNCBs to maintain the integrity of the southern North Sea SAC in accordance with the conservation objectives (JNCC 2019).

Impact pilling associated with the BLF represents the primary construction issue for marine mammals at Sizewell. However, with appropriate mitigation measures effects on form marine mammals from instantaneous noise is anticipated to be effectively minimised.

Cumulative effects may occur should marine mammals remain in the vicinity of the piling activity for the duration of daily operations (24-hour assessment period). Given that behavioural responses have been observed in the field (Section 2.2) it is unlikely that marine mammals would remain within the relatively small static PTS zones for a sufficient duration in incur permeant auditory damage (PTS). Incorporation of fleeing models demonstrates PTS is unlikely should marine mammals avoid the sound source.

Impact piling also had the greatest cumulative auditory effect zones for fish with TTS predicted for hearing specialist fish species remaining within 821 m of the sound source. However, direct fish mortality and recoverable injury is restricted to limited spatial areas in the vicinity of the sound source for impact piling.

Dredging has the potential to cause cumulative PTS over small areas close to the source with TTS extending over larger areas in both marine mammals and fish. Marine mammal fleeing behaviours would eliminate the incidence of PTS.

Drilling has very minor auditory effect zones and is unlikely to have negligible effects on marine mammals or fish.

Vessel noise conclusions

The potential increase in ambient noise levels associated with the BLF deliveries vessel traffic during the construction period is likely to be very modest and well within the typical variability at the site.

Operational noise conclusions

The expected additional operational noise generated with both power stations in operation represents only a small increase in the background noise levels at the site, which has sustained an operational nuclear power station for several decades (since 1966). It is therefore anticipated that the additional impact of the operational noise from Sizewell C will be minimal and adaptation will be rapid**.**

The results from underwater noise assessments presented within this report, along with the conservation objectives of relevant sites and designated species will be used to inform Ecological Impact Assessments (EcIA) within the Environmental Statement (ES) and Habitats Regulations Assessment (HRA). Such effects may be a consequence of auditory damage or displacement and consideration will be paid to recovery following auditory damage or the duration of time it takes to return to an area following displacement. The effects of underwater noise on marine mammals and fish at Sizewell will be considered in the ES both directly on the specific receptors, and in the case of fish, indirectly in a food-web context due to the potential for behaviours responses to reduce the foraging efficiency of designated birds and marine mammals. Whilst sources of underwater noise, particularly impact piling, are anticipated to be short-lived events at Sizewell, they will be considered in a Cumulative Effects Assessment (CEA) framework with other planned or proposed developments in the area. CEA will form part of the ES assessment.

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