The Sizewell C Project

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Underwater noise effect assessment for the Sizewell C revised marine freight options

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Executive summary

EDF Energy plans to build a new coastal nuclear power station (Sizewell C, SZC), adjacent to the operational Sizewell B (SZB) and decommissioned Sizewell A (SZA) sites in Suffolk. As part of the application for the construction and operation of the new station, EDF Energy submitted an assessment of the effects of underwater noise on the marine environment. Since the submission of the DCO Application in May 2020, SZC Co. have investigated plans to enhance the capacity for sustainable freight transport. A proposed change is to increase the import of materials to the site by sea.

The changes to the DCO Application relevant to underwater noise consist of:

- An enhancement to the design of the permanent beach landing facility (BLF) and addition of seabed structures to facilitate more regular deliveries of abnormal indivisible loads (AILs) by sea without the requirement for additional maintenance works and reduced dredging requirements.
- Installation of a temporary BLF to reduce the amount of construction material, such as aggregate and backfill soils, that would otherwise be delivered by land.

These changes necessitated additional underwater noise assessments for the activities arising from the installation and usage of an enhanced permanent BLF, and the installation, usage, and removal of a temporary BLF as well as increased vessel traffic.

The enhanced permanent BLF would be approximately 30m longer than that specified in the DCO Application allowing the incoming barges to align more efficiently with the BLF platform. The BLF would consist of 24 piles (12 below mean high water springs, MHWS) and four mooring dolphins or fenders. Piles would be approximately 1m in diameter and mooring dolphins would be approximately 2.5m in diameter. During installation, up to two piles would be installed in a day followed by two laying of the platform, this cycle would be repeated every three days. Two mooring dolphins may be installed per day. Impact piling to install piles is anticipated to require 120kJ hammer energies. Installation of mooring dolphins is anticipated to require 280kJ hammer energies.

The temporary BLF would be approximately 505m in length and extend 440m seawards of MHWS. The temporary BLF would consist of a trestle pier, fitted with an aggregate conveyor, with an unloading platform at the seaward terminus. The trestle pier would require 80 piles, 68 of which would be below MHWS. Piles would be approximately 1.2m in diameter. The unloading platform that would consist of 30 piles. Four mooring dolphins with a diameter of 2.5m would be installed at the seaward of the unloading platform. During installation of the trestle up to two piles may be installed per day, whereas three piles may be installed per day during the installation of the unloading platform. A maximum of two mooring dolphins would be installed per day.

This report presents the results of the underwater noise modelling to assess the potential effects of underwater noise arising from the construction and usage of the revised marine freight options for the proposed new nuclear build (NNB) at Sizewell on marine mammal and fish receptors. Noise generating activities include impact piling for the installation of the enhanced permanent BLF and temporary BLF and vessel noise during the use of the BLFs. Decommissioning of the temporary BLF during the construction phase is also considered.

A validated underwater sound propagation model and receptor specific noise exposure criteria (or thresholds) were applied to map auditory effect zones over which certain responses are predicted for marine mammals and fish. Auditory 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. Each activity was assessed for both instantaneous and cumulative noise exposure (over a 24-hour period), meaning that the results are scalable to various alternative scenarios.

This report details the results of auditory effect zones providing the evidence for the impacts associated with the proposed development. The results from underwater noise assessments presented within this report, along with the conservation objectives of relevant sites and designated species have been used to inform Ecological Impact Assessments (EcIA) within the Environmental Statement (ES) Addendum (NNB Generation Company (SZC) Ltd., 2021a [AS-181]) and shadow Habitats Regulations Assessment (sHRA) Addendum (NNB Generation Company (SZC) Ltd., 2021b [AS-173]).

Measures for securing mitigation of marine mammals is provided by Condition 40 (2) (a) of the deemed Marine Licence [REP2-015]) which has an obligation to submit a Marine Mammal Mitigation Protocol (MMMP) to be approved by the MMO. A draft MMMP for impact piling activities was prepared for the DCO Application (BEEMS Technical Report TR509 submitted as Volume 2, Chapter 22, Appendix 22N [APP-331]). This has been updated to reflect the revised marine freight options (BEEMS Technical Report TR509 v5 [REP3-019]).

In addition to the assessments presented in the ES Addendum for the revised marine freight Addendum (NNB Generation Company (SZC) Ltd, 2021a [AS-181]), this report provides the model results for the alternative decommissioning option of removing piles from the temporary BLF with mechanical cutting methods. Further context is also provided on the potential exposure of migratory fish to underwater noise impacts in Section 7.2.3 and an explanation of why the cumulative effects assessment captures the worst-case combined piling scenario is provided in Sections 2.1.1.3 and 6.5, at the request of the MMO in their Deadline 2 submission to the Planning Inspectorate (MMO, 2021 [REP2-140]).

Potential Marine Mammal Auditory Effect Zones

The largest instantaneous auditory effect range predicted was from impact piling activities with no mitigation during the installation of the mooring dolphins for the temporary BLF. Permanent hearing damage (PTS) was predicted to extend to 93m for harbour porpoise. Seals are less sensitive and the auditory effect range for PTS was predicted to be 16m. No instantaneous PTS is predicted beyond the standard 500m mitigation zone effective through implementation of the Marine Mammal Mitigation Protocol (MMMP). Temporary auditory damage (TTS) may occur at a range of 169m for harbour porpoise and 30m for seals. **Instantaneous underwater noise effects on marine mammals can be mitigated with the conditions in the MMMP**.

Cumulative (24-hour) exposure assessments incorporated fleeing behaviours, which assume that marine mammals would flee from the source location at the onset of piling. Cumulative sound exposure was predicted for pile driving two consecutive piles within 24-hours using 120kJ and 280kJ hammer energy for piles and mooring dolphins, respectively. No cumulative (24h) auditory effect zones were predicted for seal species. For harbour porpoise no PTS was predicted and the largest TTS effect zones (associated with the mooring dolphins) were predicted to occur within 5,230ha for the enhanced permanent BLF and 3,734ha for the temporary BLF.

An additional scenario was modelled whereby piling occurs at both BLFs on a given day representing the maximum number of piles installed in a 24-hour period (four piles, two from each for the temporary and enhanced BLFs). The results of the fleeing model show that there would be no PTS for harbour porpoise or seals. The largest TTS effect zones were predicted to occur within 669ha for harbour porpoise. Piling at both BLFs would only occur with piles (not mooring dolphins). Therefore, the auditory effect zones in the simultaneous piling scenario are smaller than in the case of the mooring dolphins for the individual BLF scenarios which require a larger hammer energy. **There is no PTS predicted in the cumulative assessment for marine mammals in response to piling.**

Mitigation in the form of using a hydrohammer reduces all the piling effect zones for marine mammals between approximately 30 and 80%. Therefore, instantaneous and cumulative underwater noise effects on marine mammals can be reduced further with the use of a hydrohammer. The application of the hydrohammer has been included as part of the MMMP (BEEMS Technical Report TR509 v5 [REP3-019]).

At the terminus of the enhanced permanent BLF a concrete mattress would be laid and secured in place by 25 small bore piles to facilitate barge delivery. In accordance with the deemed Marine Licence (Condition

24(1) NNB Generation Company (SZC) Ltd., 2021c [REP2-015]) the intention is to avoid installing the small-bore piles with percussive methods. The small bore piles are likely be helical screws. The effects on marine mammals from the installation of helical screws to secure the concrete mattress for the enhanced permanent BLF are likely to be similar or less than the effects for the decommissioning of the temporary BLF (vibropiling) and drilling for the cooling water intake/outfall shafts (assessed in the ES, NNB Generation Company (SZC) Ltd., 2020a [APP-317]). In which case, cumulative auditory effect zones for marine mammals are predicted to be limited to 10s of meters for TTS from the source with no PTS predicted using these methods.

A precautionary vessel traffic assessment was undertaken to simulate noise effects from vessel traffic during the use of the BLFs. The assessment considered vessels moored at each of the BLFs constantly generating the same level of noise as if they were steaming for a period of 24 hours. Vessel traffic modelling did not incorporate fleeing behaviours into the estimation of the auditory effect zones. The results of the vessel traffic modelling for the temporary BLF predict negligible PTS zones for harbour porpoise and seals. TTS was predicted over an area of 251ha and 3ha for harbour porpoise and seals, respectively assuming stationary animals.

At the end of the construction phase the temporary BLF would be decommissioned. Removal of the temporary BLF piles would require a limited number of hammer blows to loosen the piles prior to extraction. As such, instantaneous TTS and PTS ranges are the same during decommissioning as for installation of the temporary BLF. The maximum effect range is predicted for harbour porpoises for instantaneous TTS at 66m, no PTS is predicted. Following limited impact piling, vibropiling would be applied to remove the piles. Cumulative auditory effects were predicted to be negligible (0ha) for porpoise and seals as fleeing behaviours would limit exposure of this low noise impact activity.

In cases where the proposed method of pile extraction was unfeasible, an alternative mechanical cutting technique would be employed, of which the high pressure water jets would result in the highest source terms. Cumulative auditory effects were predicted to be negligible (0ha) for porpoise PTS and approximately 2ha for TTS and as fleeing behaviours would limit exposure of the low noise impact activity. In the case of seals neither PTS or TTS is predicted in the cumulative assessment.

Potential Fish Effect Zones

Underwater noise modelling utilised the Popper criteria (Popper *et al.*, 2014) applicable to piling, for fish belonging to three hearing categories. The Popper criteria provide quantitative thresholds for mortality, recoverably injury, and Temporary Threshold Shift (TTS) in fish in response to pile driving.

In the case of impact piling, for the most sensitive hearing specialists such as herring and sprat, instantaneous mortality and recoverable injury effects were restricted to small areas within 46m of the sound source for the enhanced permanent BLF and 52m for the temporary BLF.

Although fish are not expected to remain stationary during the noise-generating activities direct empirical evidence to support fleeing behaviour in fish is not currently available. Therefore, the assessment approaches for cumulative auditory effects for fish do not include assumptions of fleeing behaviour and are as such precautionary, particularly in a tidally dominated environment. For hearing specialists, mortality effect zones for cumulative (24-hour) piling activities for the enhanced permanent BLF are predicted to occur for fish remaining within 3ha for the installation of the mooring dolphins. Mortality effect zones for cumulative (24-hour) piling activities in the absence of mitigation for the temporary BLF are predicted for fish remaining within 11ha for the installation of the mooring dolphins for the duration of piling. However, areas of mortal injury are precautionary given the model does not include fleeing behaviours and in the tidally dominated environment fish would have to remain in close proximity for the duration of piling to incur mortal injury. Recoverable injury effect zones for cumulative piling activities are predicted to be 6ha for the enhanced permanent BLF and 30ha for the temporary BLF. TTS for hearing specialists is predicted to be 154ha and 580ha for worst cases associated with the enhanced permanent BLF and temporary BLF, respectively. For the scenario whereby piling occurs for both BLFs in a given day, cumulative auditory effect zones are predicted to be 1ha for mortality, and 1ha and 56ha for recoverable injury and TTS, respectively.

For less sensitive fish species including those species with a swim bladder that is not involved with hearing (e.g., European eel, whiting and seabass) mortality effect zones for the cumulative (24-hour) piling activities are predicted to be restricted to 1ha for the enhanced permanent BLF and 5ha for the temporary BLF. For the least sensitive fish species with no swim bladder, recoverable injury and mortality cumulative effect zones were restricted to <1ha. TTS thresholds for the less sensitive fish species are consistent with the hearing specialists.

Behavioural response thresholds have not been formally assigned for fish receptors and assessment thresholds to inform impact assessments have been based on behavioural responses to instantaneous noise sources reported in the literature. As such they are subject to a lower degree of confidence than established criteria for injury and predicted mortality, recoverable injury and TTS assessments and are used as a precautionary measure to determine the potential changes in prey availability. The potential for instantaneous behavioural responses was based on 135dB re 1µPa^{2}s single strike sound exposure level (SEL) contour, which has previously been shown to cause schooling sprat to disperse or change depth on 50% of presentations during daylight hours (Hawkins and Popper, 2014). For the enhanced permanent BLF, the contour extends to a maximum area of 2,009ha and for the temporary BLF the contour covers an area of 2,673ha. For decommissioning of the temporary BLF (using the water jet cutting method) the contour covers an area 1,580ha.

Proposed mitigation in the form of using a hydrohammer reduces piling effect zones for fish by approximately 30-50%. Therefore, instantaneous and cumulative underwater noise effects on fish can be mitigated further with use of hydrohammer.

The effects on fish from the installation of the helical screws required to secure the concrete mattress for the enhanced permanent BLF are likely to be similar or less than the effects for the decommissioning of the temporary BLF (vibropiling) and drilling for the cooling water intake/outfall shafts. Cumulative predicted mortality, recoverable injury and TTS effects of vibropiling is minimal. Cumulative auditory effect zones and behavioural response ranges for drilling in all fish species were predicted to be less than 25m.

The results of the vessel traffic modelling for the temporary BLF predict negligible PTS zones even for stationary fish. TTS was predicted as 31ha, equating to approximately 0.4km.

Decommissioning of the temporary BLF would require a limited number of hammer blows to loosen the piles prior to removal. The most sensitive species, those with a swim bladder, or eggs and larvae would be susceptible to mortality or recoverable injury to a range of 15m from the sound source during removal of the piles due to the initial impact piling. Following limited impact piling, vibropiling would be applied to remove the piles. Cumulative predicted mortality, recoverable injury and TTS effects of the combined impact piling and vibropiling is minimal. Effect areas for mortality or recoverable injury are negligible (0ha). TTS is predicted for all fish species remaining within 11ha of the sound source for the duration of the activity. If this method were to be unfeasible, an alternative mechanical cutting technique would be employed, of which the worst case would be using high pressure water jets. Cumulative predicted mortality, recoverable injury and TTS effects of the water jet cutting decommissioning method is minimal. Effect areas for mortality or recoverable injury are negligible. TTS is predicted for all fish species remaining within 92ha of the sound source for the duration of the activity.

1 Introduction

EDF Energy plans to build a new coastal nuclear power station (Sizewell C, SZC), adjacent to the operational Sizewell B (SZB) and decommissioned Sizewell A (SZA) sites in Suffolk. As part of the application for the construction and operation of the new station, EDF Energy is required to evaluate the effects of activities that generate underwater noise on the marine environment. As part of the original DCO Application an evidence report (BEEMS Technical Report TR312; Appendix 22L of Volume 2, Chapter 22) was provided detailing the underwater noise and auditory effect zones for marine mammal and fish receptors Since the submission of the DCO Application, SZC Co. have investigated plans to enhance the capacity for sustainable freight transport. A proposed change is to increase the import of materials to the site by sea.

The changes to the DCO Application consist of:

- An enhancement to the design of the permanent beach landing facility (BLF) and addition of seabed structures to facilitate more regular deliveries of abnormal indivisible loads (AILs) by sea without the requirement for additional maintenance works and reduced dredging requirements.
- Installation of a temporary BLF to reduce the amount of construction material, such as aggregate and backfill soils, that would otherwise be delivered by land.

These changes necessitated additional underwater noise assessments for the activities arising from the installation and usage of an enhanced permanent BLF, and the installation, usage, and removal of a temporary BLF as well as increased vessel traffic.

For each noise generating activity this report presents:

- Instantaneous auditory effects – To account for exposure to a single strike. Permanent Threshold Shift (PTS) and Temporary Threshold Shift (TTS) thresholds are formulated using the peak sound pressure level (SPL_{peak}) and presented in linear distance.
- Cumulative (24-hour) auditory effects – To account for accumulated exposure, over the duration of the activity within a 24-hour period. PTS and TTS thresholds are formulated using the weighted cumulative sound exposure level (SEL_{cum}) and presented in area (linear distance is also provided for context).

For activities with the potential to occur simultaneously (i.e., piling for both BLFs on a given day and associated vessel traffic) this report presents:

- Combined effects - PTS and TTS thresholds which are formulated using the weighted cumulative sound exposure level (SEL_{cum}) and presented as an area of effect (linear distance cannot be provided as there are two source locations).

This report provides the evidence base for underwater noise to support the Environmental Statement (ES) Addendum (NNB Generation Company [SZC] Ltd., 2021a), sHRA (NNB Generation Company (SZC) Ltd., 2021b), and SIP for the Southern North Sea SAC (NNB Generation Company (SZC) Ltd., 2021e). Results of underwater noise modelling for marine mammal and fish receptors are presented herein, however, assessments of the ecological significance of these effects and effects in relation to conservation objectives are described in the specific DCO documents.

In addition to the assessments presented in the ES Addendum for the revised marine freight Addendum (NNB Generation Company (SZC) Ltd, 2021a [AS-181]), this report provides the model results for the alternative decommissioning option of removing piles from the temporary BLF with mechanical cutting methods. Further context is also provided on the potential exposure of migratory fish to underwater noise impacts in Section 7.2.3 and an explanation of why the cumulative effects assessment captures the worst-case combined piling scenario is provided in Sections 2.1.1.3 and 6.5, at the request of the MMO in their Deadline 2 submission to the Planning Inspectorate (MMO, 2021 [REP2-140]).piling

To determine the effects of the proposed development in the context of the wider anthropogenic soundscape, a cumulative effects assessment (CEA) for underwater noise was completed as part of the ES Addendum. The CEA considers the effects of underwater noise arising from installation of the BLFs on the three key marine mammal species of importance at Sizewell; harbour porpoise (*Phocoena phocoena*), grey seal (*Halichoerus grypus*) and, harbour seal (*Phoca vitulina*) (NNB Generation Company (SZC) Ltd., 2021d). The effects of piling activities are described in terms of animals disturbed rather than injurious effects and are contextualised against the relevant Management Units (MUs) for each species to provide a population level assessment of the proposed development acting cumulatively with other third-party projects. The shadow Habitats Regulations Assessment (sHRA) (NNB Generation Company (SZC) Ltd., 2021b) relates the CEA to the conservation objectives of the relevant designated site(s) and specific projects for the Southern North Sea Special Area of Conservation (SAC) are considered in the Site Integrity Plan (SIP) (NNB Generation Company (SZC) Ltd., 2021e).

2 Background to the enhanced marine freight options

2.1 Potential noise generating activities associated with the Sizewell C revised marine freight options

2.1.1 Piling

2.1.1.1 Enhanced permanent BLF

The enhanced permanent BLF would be located on the coast at the northern end of the sea defences, in the same position as the DCO Application (NNB Generation Company (SZC) Ltd., 2020a). Installation of the permanent BLF would begin in year 1 (provisionally 2022). The enhanced permanent BLF would support construction of the power station by enabling delivery of AILs by sea. The permanent BLF would also be used infrequently during the operational phase of the power station, approximately every 5-10 years for a few weeks at a time.

The enhanced permanent BLF would be approximately 30m longer (approximately 100m in total) than that specified in the DCO Application allowing the incoming barges to align more efficiently with the BLF platform. The BLF would consist of 24 piles (12 below mean high water springs, MHWS) and four mooring dolphins or fenders. Piles would be 1m in diameter and embedded to a depth of 29m into the seabed. Mooring dolphins would be 2.5m in diameter and embedded 22m into the seabed.

At the terminus of the enhanced permanent BLF a concern mattress would be laid and secured in place by 25 small bore piles to facilitate barge delivery.. The number of piles will be confirmed during detailed design. Current assumptions are that 25 helical screw piles up to 600mm diameter will be installed by drilling or vibropiling methods, in line with Condition 24(1) in Part 4 the Deemed Marine Licence (DML) which states that drill or vibropiling must be used as standard, with percussive piling only used if required to drive a pile to its design depth (NNB Generation Company (SZC) Ltd., 2021c).

2.1.1.1.1 Piling parameters

Installation of the permanent BLF would commence from the beach and progress out to sea using a Cantitravel method. The Cantitravel method means a maximum of two piles would be installed per day followed by laying the next span. A typical cycle would include one span every three days (installation of two piles per 3-day cycle). A jack-up barge would install the grillage and mooring dolphins.

To install piles for the BLF the following sequence would occur:

- piles are lifted by crane and inserted into the guide;
- piles are laid to the seabed;
- a hydraulic hammer is used to install the piles.

The piling parameters used for modelling instantaneous and cumulative (24-hour) auditory effects are presented in Table 2.1.

The acoustic conversion efficiency factor (i.e., the proportion of the hammer energy converted to acoustic energy) was taken as 1.0% for larger diameter piles (>2m) (precautionary) and 0.5% for smaller diameter piles (<2m). This was based upon evidence from a review paper by Dahl *et al*. (2015) which suggested that ~0.5 % of the hammer energy is transmitted as acoustic energy that ultimately transfers into the water column. An acoustic conversion efficiency factor of 0.5% is therefore considered appropriately conservative for small diameter (ca.1m) piling activities in the shallow subtidal environment at Sizewell and has been previously applied by Cefas for offshore windfarm EIAs. Mooring dolphins and fenders with a diameter of 2.5m were modelled with a hammer energy conversion efficiency of 1% (Table 2.1).

Table 2.1: Piling parameters for the enhanced permanent BLF

Parameter	Piles	Mooring dolphins.
Number (below MHWS).	12	4
Pile diameter.	1m	2.5m
Modelled depth of deepest pile (depth includes +1.4m chart datum to encompass a range of tidal conditions i.e., precautionary assessment).	5.1m	5.1m
Hammer energy.	120kJ	280kJ
Strike rate.	44 blows / minute.	44 blows / minute.
Piling duration.	45 minutes (+ 20-minute ramp-up).	45 minutes (+ 20-minute ramp-up).
Acoustic conversion efficiency.	0.5%	1%
Maximum piles installed in 24-hour period.	2	2
Minimum piling interval (worst-case).	15 minutes.	15 minutes.
Mitigation see Section 2.1.1.5.	- Pre-start marine mammal searches. - 20-minute linear ramp-up in hammer strike rate from 1 blow per minute to full strike rate. - Additional mitigation including a 'hydrohammer' to dampen sound exposure level (SEL) and sound pressure level (SPL).	

The key changes to the enhanced permanent BLF and additional assessments required in the ES Addendum are detailed in Table 2.2.

Table 2.2: Key changes to the enhanced permanent BLF relevant to underwater noise

Parameter	DCO Application BLF.	Enhanced permanent BLF.	Change
Marine piles installed below MHWS.	The BLF consisted of ten pile pairs in total (20 piles) each 1m in diameter. Four pairs (8 piles) would be installed below MHWS.	The enhanced BLF would consist of twelve pile pairs (24 piles) of 1m diameter. Six pairs (12 piles) installed in the marine environment.	Additional 4 piles below MHWS would be installed. Combined effects assessments consider the combined effects of the additional piles.
Dolphins / fenders.	Four (4) dolphin / fenders would be installed for mooring. Each 1.5m in diameter.	Four (4) dolphins piles would be installed for mooring. Each 2.5m in diameter.	Same number of dolphins, but diameter increases to 2.5m. Modified piling parameters are assessed.
Piling parameters.	Assessments considered 90kJ and 200kJ options for piles and dolphins.	Piles would be installed with a 120kJ hammer. Dolphins to be installed with 280kJ hammer.	Piles are within the envelope of the original 200kJ assessment. Installation of dolphins falls beyond the envelope of the original assessment due to increased hammer energy and larger

Parameter	DCO Application BLF.	Enhanced permanent BLF.	Change
	Piling duration 33 minutes. A hammer energy to acoustic energy conversion efficiency of 0.5% was applied, for small diameter piles in shallow water.	Piling duration 45 minutes.	diameter. Larger diameter piles and increased hammer energy means a 1% hammer energy to acoustic energy conversion efficiency is applied. The value of 0.5% still applies for the small diameter piles in shallow water (see Section 2.1.1.1.1). Piling effects are reassessed to consider the updated piling parameters detailed in Table 2.1.
Maximum piling rate per 24-h period.	Cumulative acoustic assessments assumed five (5) piles and/or dolphins per day. Equating to 3 days of piling.	Maximum installation rate of two (2) piles or two (2) dolphins per day. Equating to 2 days of piling to install dolphins and 6 days of piling to install piles.	Cumulative (24-hour) auditory effects are reduced due to installation sequencing allowing a maximum of two piles per day. However, the duration of piling events increases. Combined effects arising from piling for the temporary BLF are also assessed.

2.1.1.2 Temporary BLF

The temporary BLF would be constructed approximately 165m south of the enhanced permanent BLF. The temporary BLF would be in place for approximately eight years.

The temporary BLF would consist of a trestle pier with an aggregate conveyor and an enlarged unloading platform with a single berth. The unloading platform would provide space to handle cargo, maintain equipment and to allow the mooring of vessels parallel to the beach.

The temporary BLF would be approximately 505m in length and extend approximately 440m seawards of MHWS. The trestle pier would require 80 piles, 68 of which would be below MHWS. Piles would be approximately 1.2m in diameter. The trestle would terminate at the seawards end in an unloading platform that would consist of 30 piles. Four mooring dolphins with a diameter of 2.5m would be installed at the seaward end of the temporary BLF.

Installation of the temporary BLF would commence from the beach and progress out to sea using a Cantitravel method. The Cantitravel method means a maximum of two piles would be installed per day for the trestle pier followed by laying the next span. A typical cycle for the trestle would include one span every three days. Up to three piles per day could be installed for the unloading platform (installation of three piles per 3-day cycle). A jack-up barge would install the mooring dolphins, a maximum of two dolphins could be installed per day.

The primary role of the temporary BLF would be to receive aggregate deliveries and building materials from self-unloading vessels. The temporary BLF would extend seaward of the outer longshore sand bar. As such, there are no requirements for dredging and vessels could berth alongside with sufficient under keel clearance.

The piling parameters are similar to the enhanced permanent BLF and the assumptions used for modelling instantaneous and cumulative (24-hour) auditory effects are presented in Table 2.3.

Table 2.3: Piling parameters for the temporary BLF

Parameter	Piles	Mooring dolphins.
Number (seaward of MHWS).	98 (30 unloading platform piles) (68 trestle piles).	4
Pile diameter.	1.2m	2.5m
Modelled water depth of deepest pile. (depth includes +1.4m chart datum to encompass a range of tidal conditions i.e., precautionary assessment).	8.5m at the unloading platform at the seaward end. 5.3m within the outer longshore sand bar (trestle pier).	8.5m
Hammer energy.	120kJ	280kJ
Strike rate.	44 blows / minute.	44 blows / minute.
Piling duration.	45 minutes (+ 20-minute ramp-up).	45 minutes (+ 20-minute ramp-up).
Acoustic conversion efficiency.	0.5%	1%
Maximum piles installed in 24-hour period.	2 for trestle - (34 days of piling). 3 for unloading platform - (10 days of piling).	2 (2 days of piling).
Minimum piling interval (worst-case).	15 minutes.	15 minutes.
Mitigation see Section 2.1.1.5.	- Pre-start marine mammal searches. - 20-minute linear ramp-up in hammer strike rate from 1 blow per minute to full strike rate. - Additional mitigation including a ‘hydrohammer’ to dampen SEL and SPL.	

2.1.1.3 Installation sequence

Installation of the enhanced permanent BLF is anticipated to last six months. Installation of the temporary BLF is anticipated to last nine months. For assessment purposes including for cumulative effects assessments (CEA) with other plans, projects and proposals, year 1 is assumed to be 2022.

Installation would start in August year 1 for both BLFs and piling would be completed by April of year 2 (i.e., 2023) of the construction phase. No piling would occur in the months of May, June or July to minimise the potential for effects on designated breeding birds (Little tern *Sterna albifrons*, Common tern *Sterna hirundo*, Sandwich tern *Sterna sandvicensis* and Lesser black-backed gull *Larus fuscus*). Assuming no temporal overlap of piling activities, a total of 54 days piling would occur during this period. If piling for the piers for the enhanced permanent BLF and temporary BLF occurred concurrently a total of 48 days of piling would be required. No consecutive piling would occur when the mooring dolphins are installed.

It is anticipated that the temporary BLF would not progress seaward beyond the outer longshore sand bar before the enhanced permanent BLF was completed. The typical installation sequence for each BLF involves installation of two piles (ca. 2 hours of piling including ramp-ups) every three days due to the time taken to lay each subsequent trestle span. Therefore, the worst case for the combined effects assessment in terms of the number of piles is when two piles are installed for each BLF on the same day (i.e. four piles in a 24-hour period). For the purpose of underwater noise combined effects assessment, the location of the deepest piles at the relevant position for each BLF were incorporated into the model to allow a precautionary assessment.

However, the scenario of four piles installed in a 24-hour period during the combined installation of both BLFs does not represent the worst-case for cumulative underwater noise effects. This was noted in the combined effects assessment in Table 2.62 of the ES Addendum [AS-181]. The MMO in their Deadline 2 submission (MMO, 2021 [REP2-140]) questioned why this was not the case. The worst case in terms of cumulative auditory effect zones in the scenario whereby 2 dolphins are installed in a 24-hour period. This is due to the larger diameter of the piles and higher hammer energies required. The higher hammer energies also result in a greater acoustic conversion efficiency (Table 2.1 and Table 2.3). Hence, the cumulative auditory effects of installing two dolphins is greater than for the installing four piles in a given 24 hour period. During piling for dolphins only two would be installed in a 24-hour period. The results of both scenarios are provided in Section 6.

2.1.1.4 Decommissioning of the temporary BLF

The temporary BLF would be dismantled after eight years. The full superstructure would be dismantled from seaward working back toward land.

Piles would be removed by a combination of very short duration impact piling to loosen the pile, followed by vibropiling. In a similar fashion to installation, two piles would be removed per day followed by two days to dismantle the span. The sequence for removing piles is provided in Table 2.4.

Piles and dolphins that are not possible to be removed by vibropiling would be cut off below the seabed, different options are available and include internal mechanical cutting or the use of a water abrasive system using high-pressure water jets. To reflect the potential worst-case modelling applies source terms of high-pressure water jet techniques of 189.3 dB re 1 µPa rms @ 1 m.

Table 2.4: Parameters for removing piles during dismantling of the temporary BLF

Parameter	Piles
Impact piling duration.	10 minutes / 50 blows.
Hammer energy.	120kJ
Vibropiling duration.	30 minutes.
Maximum piles removed in 24-hour period.	2 for trestle.
Minimum piling interval (worst-case).	15 minutes.
Maximum water jet interval	1 hour per pile

2.1.1.5 Mitigation

Tertiary mitigation will include implementation of *'JNCC Statutory nature conservation agency protocol for minimising the risk of injury to marine mammals from piling noise'* (JNCC, 2010). Mitigation includes:

- The implementation of a 30-minute pre-piling search to ensure no marine mammals enter a 500m mitigation zone by qualified marine mammal observers. Where appropriate, deployment of Passive Acoustic Monitoring Systems (PAMS) will be considered, however, PAMS has low effectiveness in shallow subtidal environments.
- Implementation of ramp-up procedures whereby hammer strike rates are ramped up progressively over a period of 20 minutes.

A draft Marine Mammal Mitigation Protocol (MMMP) for impact piling activities was prepared for the DCO Application (BEEMS Technical Report TR509 submitted as Volume 2, Chapter 22, Appendix 22N [APP-

331]). This has been updated to reflect the revised marine freight options (BEEMS Technical Report TR509 v5 [REP3-019]).

To mitigate the potential for impacts on breeding birds no piling would occur in May to July inclusive.

In addition, further mitigation is proposed to minimise the effects of underwater noise that includes the use of a hydrohammer. This can be considered as reducing the amount of noise pollution (noise abatement), through mitigation measures (Merchant and Robinson, 2020). The hydrohammer is positioned between the piling hammer and the sleeve, two hydraulic plungers filled with water are designed to dampen the impact and reduce the source noise associated with impact piling. Hydrohammers have been suggested to reduce sound exposure levels (SEL) by 3 to 6dB and peak sound pressure levels (SPL) by 9 to 12dB (IHC IQIP, 2020).

A precautionary 3dB reduction in SEL and 9dB reduction in peak SPL has been applied in underwater noise modelling. Results are presented with and without the use of a hydrohammer to illustrate the potential effectiveness of the mitigation measure.

The application of hydrohammer mitigation has been incorporated into the MMMP (BEEMS Technical Report TR509, [REP3-019]).

2.1.2 Vessel traffic

2.1.2.1 Enhanced permanent BLF

The enhanced design would allow the permanent BLF to facilitate more regular deliveries of AIL during the construction phase. Barges that serve the permanent BLF would be loaded with large deliveries at a transhipment port. Barges would be towed to the shore and held in position by two tugboats until the barge is grounded as the tide drops. The AILs would then be transported to site along the BLF access road.

Deliveries to the permanent BLF are tidally restricted and no night-time deliveries are anticipated.

The anticipated routes for deliveries to the proposed development include transhipment options from the UK ports of Great Yarmouth, and Harwich or the Isle of Grain for aggregates. The Netherlands ports of Rotterdam and Vlissingen are also transhipment options. Vessels would follow shipping lanes before heading into the proposed development.

The highest frequency of expected deliveries would occur during the annual campaign period of April to October inclusive. The anticipated number of AIL deliveries to the permanent BLF is 100 per campaign (see Table 2.5).

Consideration of changes in vessel traffic noise relative to current baseline conditions along the shipping routes to and from the proposed development was considered using precautionary assumptions in BEEMS Technical Report TR312 (Appendix 22L of the ES [APP-329]). The assessments herein, represent additional information at the site level for the use of both BLFs.

2.1.2.2 Temporary BLF

The temporary BLF would operate both during the day and at night. The highest frequency of expected deliveries would occur during the annual campaign period of April to October inclusive. However, with suitable weather conditions deliveries may occur outside this period.

The greatest volume of bulk aggregate deliveries is anticipated in year 3 and year 4 of the construction phase. Vessels would be self-unloading vessels typically delivering up to approximately 4,500 tonnes of cargo per delivery. For assessment purposes up to 600 deliveries per year is assumed, with 400 anticipated during the campaign period (see Table 2.5).

Table 2.5: Summary of vessel activity associated with the BLFs

Parameter	Permanent enhanced BLF.	Temporary BLF.
Campaign period.	1st April to 31st October (outside this period if weather is suitable)	
Day / night operation.	Daylight only.	Day and night.
Annual vessel deliveries.	Up to 100 deliveries in the campaign period.	400 deliveries in the campaign period, up to 600 per annum.
Vessel type.	Barges	Self-unloading vessels.
Accompanying vessels.	Two tugs.	None.
Estimated mean monthly vessel activity during the campaign period.	12-13 AIL deliveries per month during the campaign period (<1 every two days).	Approx. 44 deliveries per month during the campaign period.
BLF length.	101m	505m

2.1.2.3 Vessel noise

Baseline modelling of the shipping lanes in the southern North Sea and Channel indicated median sound levels exceed 115dB over much of the domain, due to intense shipping traffic, with levels above 130dB in many hotspots (BEEMS Technical Report TR312). A vessel noise assessment was completed as part of the Environmental Statement within the DCO Application (NNB Generation Company (SZC) Ltd., 2020a). The vessel noise assessment was based on the maximum theoretical number of deliveries per month to the BLF from the UK ports of Great Yarmouth and Harwich. Assessments considered a total of 59 barge deliveries to the permanent BLF in a given month. The assessment considered barges only, rather than accompanying tugs. However, every available tide was assumed available for deliveries with no weather or operational constraints. The additional shipping noise was added to the existing ambient noise baseline to determine increases in noise associated with deliveries.

Ambient noise levels at Sizewell have been established by deploying long-term passive acoustic recorders adjacent to Sizewell B over a two-year period (September 2011 and September 2013) providing 481 days of ambient noise recordings. The ambient soundscape is characterised by operational noise from Sizewell B, surf noise, and noise from passing vessels.

The tonal noise from Sizewell B has a frequency of 50Hz with harmonics (and sub-harmonics) at multiples of this frequency. Representative ambient noise levels for the site were derived from the recordings in 1/3-octave bands and give a broader indication of the spread of ambient noise across the frequency spectrum. The median 1/3-octave spectrum corresponds to a broadband (0.1-1kHz) Sound Pressure Level (SPL) of 101dB re 1µPa, (BEEMS Technical Report TR312). A transect of increasing ambient noise further from the shore for both the median (P50) and P90 (90^{th} percentile) models has been predicted. The observed 7-month (February-September) median sound levels at the recording site 700m offshore were 101dB re 1µPa at a water depth of 5m. The P50 model predictions 200m offshore were 92dB and 104dB 1.5km offshore, gradually increasing to 111dB at 3km offshore, 114dB at 5km offshore and 117dB at 10km offshore. The corresponding P90 model predictions are about 5-10dB higher (BEEMS Technical Report TR312).

Simulated vessel traffic from transhipment ports of Great Yarmouth or Harwich, resulted in increases in median sound levels of approximately 1dB or less locally at Sizewell and along the shipping track. The corresponding increases in the P90 (90^{th} percentile) sound levels are about 5dB or less, but over an area much narrower around the shipping track than the median increases. The P90 statistics local to Sizewell were lower, within 3dB above ambient levels (BEEMS Technical Report TR312).

The monthly maximum model outputs assessed in the Environmental Statement (NNB Generation Company (SZC) Ltd., 2020a), predicted that the potential increase in ambient noise levels associated with the BLF deliveries from vessel traffic during the construction phase is likely to be modest and within the natural variability at the site. The increase in vessel traffic due to the enhanced permanent BLF is within the envelope of the original assessment.

Increases in vessel traffic associated with the enhanced permanent BLF and temporary BLF are unlikely to result in meaningful changes in background noise conditions in the shipping lanes and associated ports. For example, the port of Harwich situated 37km south of the proposed development received 13,752 vessels or 37 vessels per day in 2017 (Harwich Haven Authority, 2017). Great Yarmouth situated some 40km north registered 7,232 commercial vessel movements in the financial year 2018-2019 (Great Yarmouth Port Authority, 2019). Focus on increases in vessel traffic from the changes to the marine freight options in this report is therefore directed at the inshore waters off Sizewell.

The vessel noise assessment assumes sound source levels for an average oceangoing vessel whilst steaming, located at the unloading platform of the temporary BLF for a full 24 hour duration. By assuming 24-hour vessel noise the assessment is precautionary in terms of the total exposure for cumulative auditory effects. Source levels across the frequency spectrum are illustrated in Figure 2.1 and are consistent with the vessel assessment submitted in (BEEMS Technical Report TR312). Vessels on approach to the proposed development would operate at lower speeds, as such the source terms are precautionary. For example, the Code of Construction Practice (CoCP) (NNB Generation Company (SZC) Ltd., 2020b) recommends site speed restrictions of <10 knots to minimise disturbance effects.

The vessel noise assessment has also included a scenario for 24-hour utilisation of the enhanced permanent BLF and the temporary BLF for the combined effects assessment.

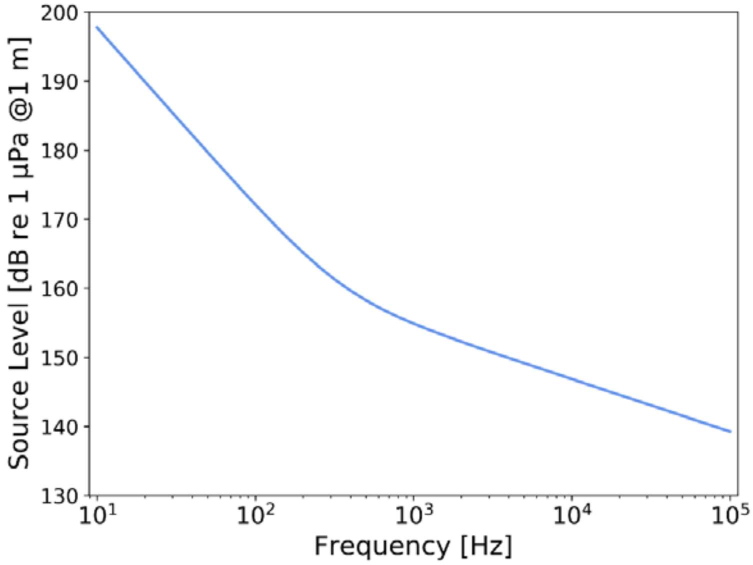

Figure 2.1: Ensemble ship source level spectrum

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 submitted as Volume 2, Chapter 22, Appendix 22E, NNB Generation Company (SZC) Ltd., 2020a). The southern North Sea Special Area of Conservation (SAC) is adjacent to the proposed development and is designated for harbour porpoise.

The hearing sensitivity and known effects of noise on these species is provided in BEEMS Technical Report TR312.

2.3 Fish species of interest at Sizewell

This report considers the effects of underwater noise from the revised marine freight options on representative fish species at Sizewell. In selecting 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. These are summarised below:

- Herring (*Clupea harengus*), sprat (*Sprattus sprattus*) and anchovy (*Engraulis encrasicolus*) are abundant at Sizewell (BEEMS Technical Report TR345 submitted as Volume 2, Chapter 22, Appendix 22D, NNB Generation Company (SZC) Ltd., 2020a) and belong to the order Clupeiformes, which are considered to be particularly sensitive to sound.
- Sprat, herring, anchovy, seabass (*Dicentrarchus labrax*) and whiting (*Merlangius merlangus*) form an important component of the diet of relevant designated bird species at Sizewell (BEEMS Technical Report TR431).
- European eel (*Anguilla anguilla*) has different auditory sensitivity and hearing apparatus to the hearing specialist species mentioned above.

The hearing capabilities of the selected species and known effects to underwater noise is briefly reviewed in BEEMS Technical Report TR312.

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 BEEMS Technical Report TR312). 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.

BEEMS Technical Report TR312 demonstrates that using the root mean square (RMS) level (mean calculated prior to decibel conversion) would lead to 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 (50^{th} 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 3.1; this corresponds to an ambient broadband noise level of **SPL of 101dB re 1µPa** (0.1-1kHz).

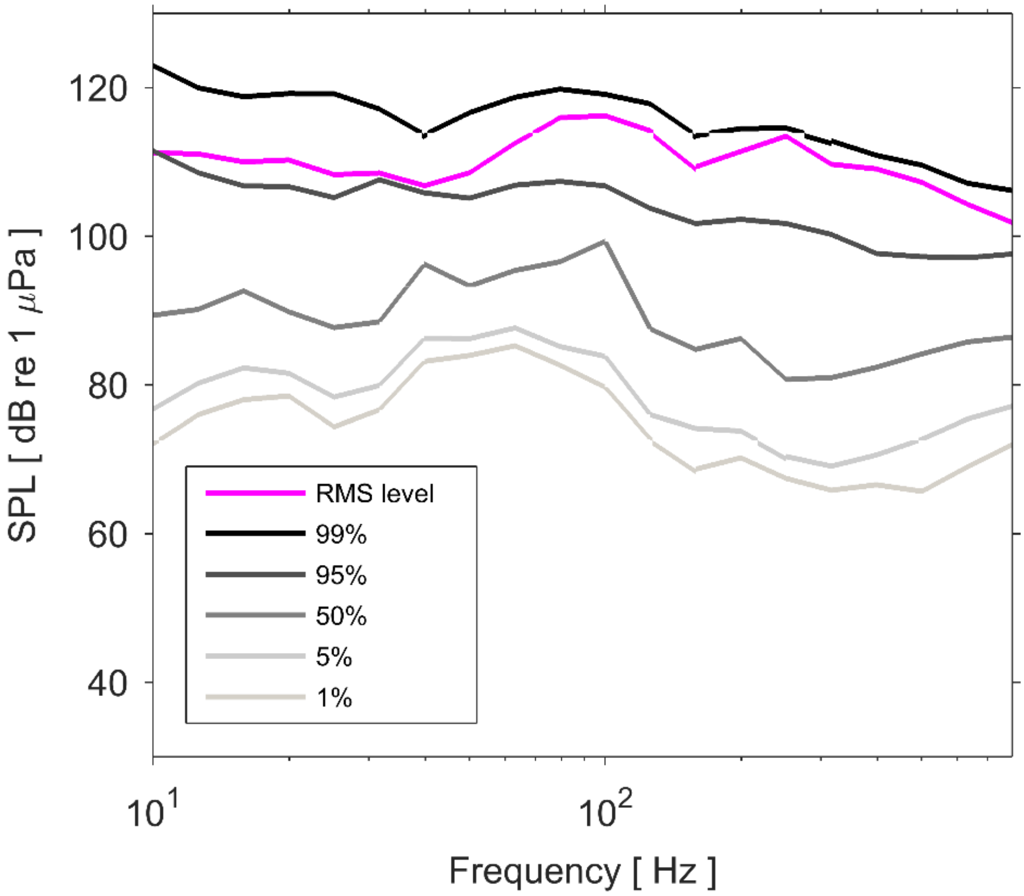

Figure 3.1: Distribution of 1/3-octave levels during 2013 recordings at Sizewell. The median level (50%) was used as a representative ambient noise level for the purposes of noise modelling.

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. The field survey and validation results are provided in BEEMS Technical Report TR312.

5 Criteria for noise effects on key species at Sizewell

5.1 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 TR312. This assessment applies criteria published by the U.S. National Marine Fisheries Service (NMFS) (part of the National Oceanic and Atmospheric Administration (NOAA)) (here termed the NOAA criteria) for all marine mammal species (harbour porpoise, harbour seals and grey seals), as this represents the most recent and relevant set of criteria. Note that the NOAA (NMFS, 2018) criteria use the same thresholds and auditory weightings as the new Southall *et al*. (2019) criteria. The NOAA criteria provide acoustic thresholds for the onset of Permanent Threshold Shift (PTS) and Temporary Threshold Shift (TTS) for marine mammals exposed to acute anthropogenic noise (NMFS, 2018).

The NOAA PTS and TTS thresholds are 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 mammal with regard to hearing ability). The criteria require the application of an auditory weighting to account for the frequency sensitivity of hearing for each functional hearing group. The applicable noise exposure thresholds for marine mammals are summarised in Table 5.1.

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.

Table 5.1: Noise exposure thresholds to be applied to the assessment of underwater noise at Sizewell C

Species	Sound type.	PTS		TTS	
		Peak SPL (dB re 1µPa).	SEL_{cum} (dB re 1µPa^{2}s).	Peak SPL (dB re 1µPa).	SEL_{cum} (dB re 1µPa^{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), 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, the accumulation period accounts only for 24 hours of continuous activity.

For any given activity and receptor, the accumulated exposure depends not only on the spatial distribution of the noise 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 21km in some cases (Tougaard *et al.*, 2009).

5.1.1 Marine mammal behaviour

Published noise criteria are for injurious effects and there are no established thresholds for behavioural responses. The ES provides an assessment based on a review of the available literature for disturbance from piling/vessel noise. However, it is common practice to account for the movement of marine mammals in models used to assess cumulative sound exposure. Fleeing behaviour is considered in such models, namely the receptor is assumed to move away from the noise source, thus in general reducing its sound exposure. 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. Assumptions related to animal behavioural responses are likely to be site-specific (Graham *et al.*, 2017). On the other hand, assuming that an animal remains stationary within the area for 24 hours (or the actual duration of activity if less than 24 hours) produces overly conservative predictions of the auditory effect zone extents (Faulkner *et al.*, 2018).

Here, the cumulative sound exposure levels for piling activities associated with the enhanced permanent BLF, temporary BLF, and decommissioning activities associated with the removal of the temporary BLF, is assessed using the fleeing assumptions detailed below.

When assessing the cumulative sound exposure for vessel activity at the BLF, a stationary receptor is assumed as fleeing behaviours from vessels are less well documented and existing model parameterisations do not currently exist. As such, injurious effect zones are only applicable to animals that remain within the effect zone for 24 hours.

5.1.1.1 Marine mammal fleeing behaviour for cumulative sound exposure estimation

For the assessment of piling and decommissioning activities, 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 25km (after which they were assumed to remain stationary at that distance). The maximum fleeing distance has no bearing on the results, as all predicted auditory effect ranges are restricted to within 9km (see Section 6).

Table 5.2: Fleeing speeds assumed for each marine mammal species/taxon

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 animal agent in each grid cell of the domain (i.e., every 90m by 90m) 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 (5 minutes) and the cumulated exposure over each time interval is calculated (e.g., for a piling scenario according to the number of strikes and the hammer energies used within the interval), as well as the agent positions at the beginning and the end of 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 is mapped back to their starting positions on the grid.

In the case of single location activity, the model assumes that the animal agents are fleeing at constant speeds (Table 5.2), along straight lines away from the pile location, as long as the local water depth exceeds a minimum value (Table 5.2). When an animal agent arrives in shallower water than the allowed minimum depth whilst moving along the straight line from the pile location, then a change in direction is calculated and effected. Directional changes are instigated, in the order of preference, being +/- 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 5.2, these rules do not apply to the seal agents, which are allowed to move in any depths of water and even move to the shore (within the 25km maximum distance from the pile location), thus stopping their sound exposure.

In the case of dual location activity, the model still assumes that the animal agents are fleeing 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 sources. Specifically, at a given time the fleeing direction is calculated by summing the two vectors originating at the current animal agent position, pointing straight away from the two sources, and having their magnitude proportionally allocated to the specific dose responses of the animal for the current single strike SEL from the two sources, respectively. The same minimum depth constrains and shallow water avoidance rules as in the single location activity described above apply also in the case of dual location activity.

5.2 Fish noise criteria

The rationale and proposed approach for assessing the potential effects of noise on fish species at Sizewell was described in BEEMS Technical Report TR312.

5.2.1 Mortality, injury, and Temporary Threshold Shift (TTS)

Underwater noise modelling utilised the Popper criteria (Popper *et al*., 2014) applicable to piling, for fish belonging to three hearing categories are summarised in Table 5.3 (BEEMS Technical Report TR312). The Popper criteria provide quantitative thresholds for mortality, recoverably injury, and Temporary Threshold Shift (TTS) in fish in response to pile driving. The thresholds are formulated using the peak sound pressure (dB peak) and the cumulative sound exposure level (SELcum).

The Popper criteria do not provide quantitative thresholds for continuous sources of noise (e.g., vessel noise) (note: only thresholds for recoverable injury and TTS in fish with swim bladder involved in hearing are available, based on the RMS metric). 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 have been applied in the assessment of sound exposure from continuous sources (vessel noise) as a precautionary approach.

The noise exposure criteria used to assess all key fish species at Sizewell are summarised in Table 5.3.

Although fish are not expected to remain stationary during the noise-generating activities direct empirical evidence to support fleeing behaviour in fish is not currently available. Therefore, the assessment approaches for fish do not include assumptions of fleeing behaviour and are as such precautionary.

Table 5.3: Fish noise exposure criteria to be applied in noise effects assessment of all key fish species at Sizewell. “dB peak” denotes peak-to-peak sound pressure levels in units of dB re 1µPa. “dB SEL” denotes sound exposure levels (SEL) in units of dB re 1µPa^{2}s

Category	Species	Mortality /potential mortal injury.	Recoverable injury.	TTS
(1) Fish with swim bladder or other air cavities to aid hearing.	**Anchovy (*Engraulis encrasicolus*)** (Webb *et al*., 2008).	207dB SEL_{cum} or >207dB peak.	203dB SEL_{cum} or > 207dB peak.	186dB SEL_{cum}.

	Herring (*Clupea harengus*) (Mann *et al*., 1997; Webb *et al*., 2008). **Sprat (*Sprattus sprattus*** (Webb *et al*., 2008).			
(2) Fish with swim bladder that does not aid hearing. Fish eggs and larvae.	**European eel (*Anguilla anguilla*)** (Jerkø *et al*., 1989; Popper and Coombs, 1982). **Whiting (*Merlangius merlangus*)** (Webb *et al*., 2008). **Seabass (*Dicentrarchus labrax*)** (Kastelein *et al*., 2008; Neo *et al*., 2014).	210dB SEL$_{cum}$ or >207dB peak.	203dB SEL$_{cum}$ or >207dB peak.	>186dB SEL$_{cum.}$
(3) Fish without a swim bladder.	Species without a swim bladder (e.g. mackerel and elasmobranchs).	>219dB SEL$_{cum}$ or >213dB peak.	>216dB SEL$_{cum}$ or > 213dB peak.	>>186dB SEL$_{cum.}$

5.2.2 Behavioural responses

Quantitative thresholds for behavioural responses to noise are not currently available. 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). Therefore, quantitative assessments for behavioural responses in the same manner as the mortality and auditory injury criteria in Table 5.3 are not feasible.

Instead, unweighted sound level contours are provided. 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) to the playback of impulsive piling noise at a single-pulse sound exposure level of **135dB re 1μPa^{2}s** and **142dB re 1μPa^{2}s** for mackerel shoals (mackerel have no swim bladder). Schools of sprat were observed to disperse or change depth on 50% of presentations during daylight hours. These single-pulse sound exposure levels are applied to estimate potential instantaneous behavioural response ranges.

Behavioural assessments are subject to a lower degree of confidence than injury and auditory damage assessments that are based on established criteria. This is particularly the case where instantaneous behavioural response thresholds are applied to continuous sound sources such as vessel noise. 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 potential of behavioural responses and displacement to be used in the context of the availability of fish as a prey item. Behavioural response zones should be treated as indicative 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 i.e.., herring and anchovy. Whiting, European eel and seabass do not exhibit the hearing specialisations as clupeids. As such the 135dB re 1μPa^{2}s threshold is likely to be conservative for these species, although this does not exclude a distinct behavioural response induced through particle motion instead of sound pressure level detection. It should be noted that a behavioural response does not necessitate displacement from the ensonified area.

6 Predicted noise effects on key species

Noise levels modelled (Section 4) were assessed with respect to noise exposure criteria (Section 5) to produce predictive auditory effect ranges and maps illustrating areas within which marine mammals and fish may be exposed to potentially harmful noise levels (auditory effect zones) for each activity. The effect distances for underwater noise assessments are based on the outputs from the acoustic sound propagation model. The effect areas are computed within the sound propagation model but outputs reported herein are from the relevant acoustic contours mapped in GIS. The additional GIS step allows a higher spatial resolution and the ability to overlay noise contours with receptors of interest within the GIS, such as foraging ranges in the context of HRA designated species (see Appendix C for the intersect areas with SPA bird mean and predicted [maximum] foraging ranges). The higher spatial resolution and subtle differences in the shape of the coastline result in minor differences in calculated areas reported herein and within the ES Addendum (sound propagation model output). However, such differences are minor and do not influence the outcome of the assessments.

6.1 Impact piling

6.1.1 Enhanced permanent BLF

6.1.1.1 Marine mammals

The low energy impact piling associated with the enhanced permanent BLF resulted in no instantaneous Permanent Threshold Shift (PTS) or Temporary Threshold Shift (TTS) outside the standard 500m marine mammal mitigation zone at the onset of piling (Table 6.1 and Figure 6.1). More specifically, the maximum instantaneous TTS effect zone was estimated to be 106m for harbour porpoise during piling of mooring dolphins. The PTS for the same scenario was restricted to 69m. The estimated ranges for instantaneous TTS and PTS for harbour porpoise during pile installation was 53m and 32m, respectively.

Seal auditory effects zones were considerably smaller, with maximum instantaneous ranges during piling for mooring dolphins of 16m and 30m for PTS and TTS, respectively (Table 6.1). The range for instantaneous auditory effects during installation of piles would be restricted to 5m and 10m for PTS and TTS, respectively.

Assessments of fleeing behaviour assumed that marine mammals would flee from the source location at the onset of activity. Cumulative sound exposure was predicted for pile driving two consecutive piles within 24-hours using 120kJ and 280kJ hammer energy for piles and mooring dolphins, respectively. The cumulative auditory PTS effect zone for harbour porpoise was predicted as less than 10ha for both piles and mooring dolphins. The cumulative TTS was predicted as 491ha and 5,230ha for piles and mooring dolphins, respectively (Table 6.1 and Figure 6.1).

The corresponding TTS and PTS zones for cumulative noise exposure were predicted to be smaller for seals than for harbour porpoise. These differences are a consequence of the differing auditory weighting (which is markedly different at low frequencies) and exposure threshold for seals. In all cases, predicted cumulative PTS and TTS effect zones were less than 25m (Table 6.1 and Figure 6.1).

Table 6.1: Marine mammal auditory effect zones for piling activities associated with the enhanced permanent BLF

Pile type.	Threshold	Instantaneous		Cumulative (24-hour): fleeing.	
		Harbour porpoise.	Phocid seals.	Harbour porpoise.	Phocid seals.
Pile	PTS	32m	5m	0ha (<25m).	0ha (<25m).
	TTS	53m	10m	491ha (2,363m).	0ha (<25m).
Mooring dolphin.	PTS	69m	16m	0ha (25m).	0ha (<25m).
	TTS	106m	30m	5,230ha (8,657m).	0ha (<25m).

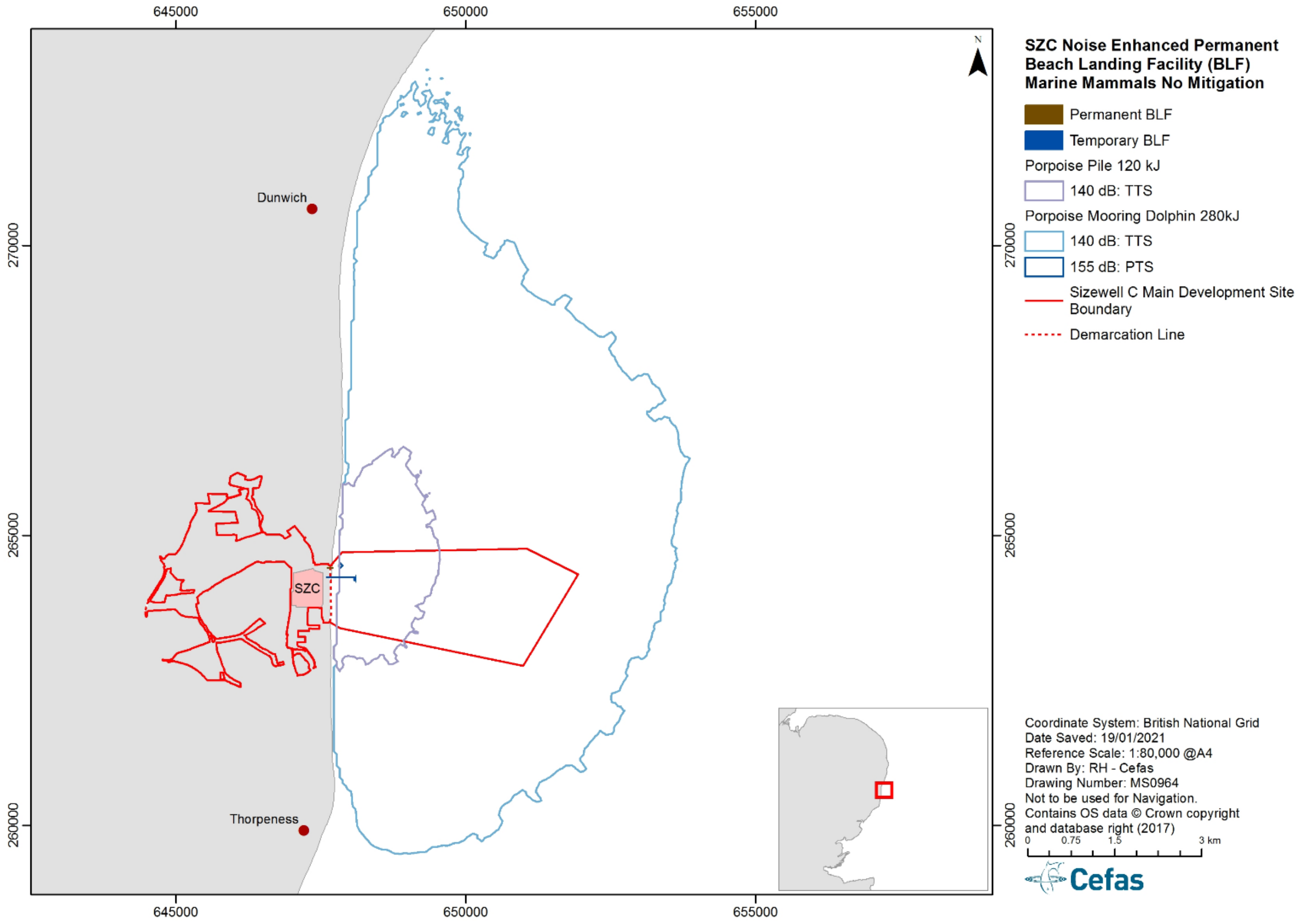

Figure 6.1: Marine mammal auditory effect zones (seal auditory effect zones are not shown as <25m from source) for piling activities associated with the enhanced permanent BLF.

6.1.1.2 Fish

The instantaneous and cumulative predicted mortality, recoverable injury and TTS effects of piling for the enhanced permanent BLF have been assessed based on the piling parameters detailed in Table 2.1.

During the installation of piles, instantaneous effect zones are predicted to be spatially limited for all species assessed. Fish with a swim bladder, and eggs and larvae would be susceptible to mortality or recoverable injury to a range of 18m from the sound source. It should be noted that there is uncertainty in the exact distance of auditory effects in very close proximity of the sound source of <50m.

In terms of potential cumulative effects, mortality is not predicted for any species. Recoverable injury is predicted for fish remaining within 50m of the sound source for the duration of piling activities, whilst TTS ranges extend to 18ha for all species (Table 6.2 and Figure 7.2 in Appendix A.2).

During the installation of the dolphins, fish with a swim bladder, and eggs and larvae would be susceptible to instantaneous mortality or recoverable injury to a range of 46m from the sound source. Fish without a swim bladder have smaller ranges of effects; mortality or recoverable injury is restricted to within 27m of the sound source. For the cumulative assessment, mortality is predicted for hearing specialists (i.e., those that use a swim bladder for hearing), of up to 3ha if they remain within the area for the duration of the piling. Recoverable injury is predicted for fish with a swim bladder remaining within 6ha of the sound source for the duration of the daily piling, whilst TTS ranges extend to 154ha for all species (Table 6.2 and Figure 6.2).

Table 6.2: Predicted mortality, recoverable injury and TTS effect zone for fish, for piling activities associated with the enhanced permanent BLF

Pile type.	Hearing category.	Threshold	Instantaneous	Cumulative *(no fleeing).*
Piles	**(1) Fish with swim bladder to aid hearing.**	**Mortality**	**18m**	**0ha (<50m).**
		Recoverable injury.	**18m**	**0ha (50m).**
		TTS		**18ha (363m).**
	(2) Fish with swim bladder that does not aid hearing.	Mortality	18m	0ha (<50m).
		Recoverable injury.	18m	0ha (50m).
		TTS		18ha (363m).
	(3) Fish without a swim bladder.	Mortality	8m	0ha (<50m).
		Recoverable injury.	8m	0ha (50m).
		TTS		18ha (363m).
Mooring dolphins.	**(1) Fish with swim bladder to aid hearing.**	**Mortality**	**46m**	**3ha (111m).**
		Recoverable injury.	**46m**	**6ha (206m).**
		TTS		**154ha (1,245m).**
	(2) Fish with swim bladder that does not aid hearing.	Mortality	46m	1ha (111m).
		Recoverable injury.	46m	6ha (206m).
		TTS		154ha (1,245m).
	(3) Fish without a swim bladder.	Mortality	27m	0ha (<25m).
		Recoverable injury.	27m	0ha (<25m).
		TTS		154ha (1,245m).

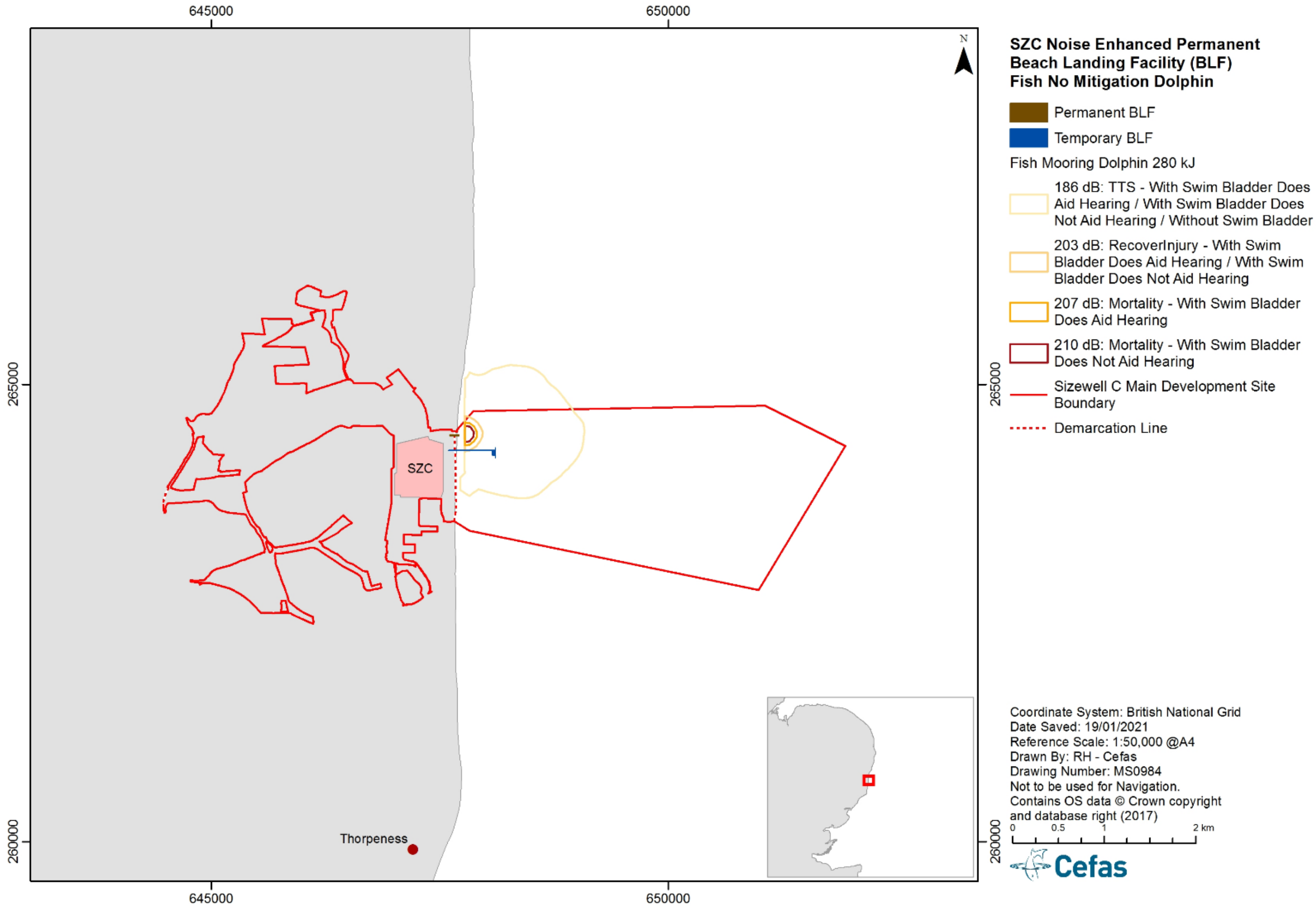

Figure 6.2: Predicted mortality, recoverable injury and TTS effect zones for fish, for piling of mooring dolphins (worst-case) associated with the enhanced permanent BLF

6.1.1.2.1 Fish behaviour

Behavioural response thresholds have not been formally assigned and assessment thresholds are based on behavioural responses to instantaneous noise sources reported in the literature. As such they are subject to a lower degree of confidence than established criteria for injury and predicted mortality, recoverable injury and TTS assessments. The applied threshold for behavioural effects are based on observations of a startle response in sprat (135dB re 1µPa^{2}s) and in mackerel (142dB re 1µPa^{2}s) (Hawkins and Popper, 2014) (see Section 5.2.2).

TTS areas would be the same as for the assessments described in Table 6.3; Figure 6.3; Figure 7.5 in Appendix A.3.

Table 6.3: Behavioural effect zones for impact piling for the enhanced permanent BLF, based on startle response observations in sprat and mackerel

Pile type.	Threshold	Indicative hearing groups.	Behavioural range.
Piles (120kJ).	135dB re 1µPa^{2}s.	Sprat: hearing specialists.	450ha (1,991m).
	142dB re 1µPa^{2}s.	Mackerel: hearing generalists.	80ha (787m).

Pile type.	Threshold	Indicative hearing groups.	Behavioural range.
Mooring Dolphins (280kJ).	135dB re 1µPa^{2}s.	Sprat: hearing specialists.	2,009ha (4,184m).
	142dB re 1µPa^{2}s.	Mackerel: hearing generalists.	626ha (2,283m).

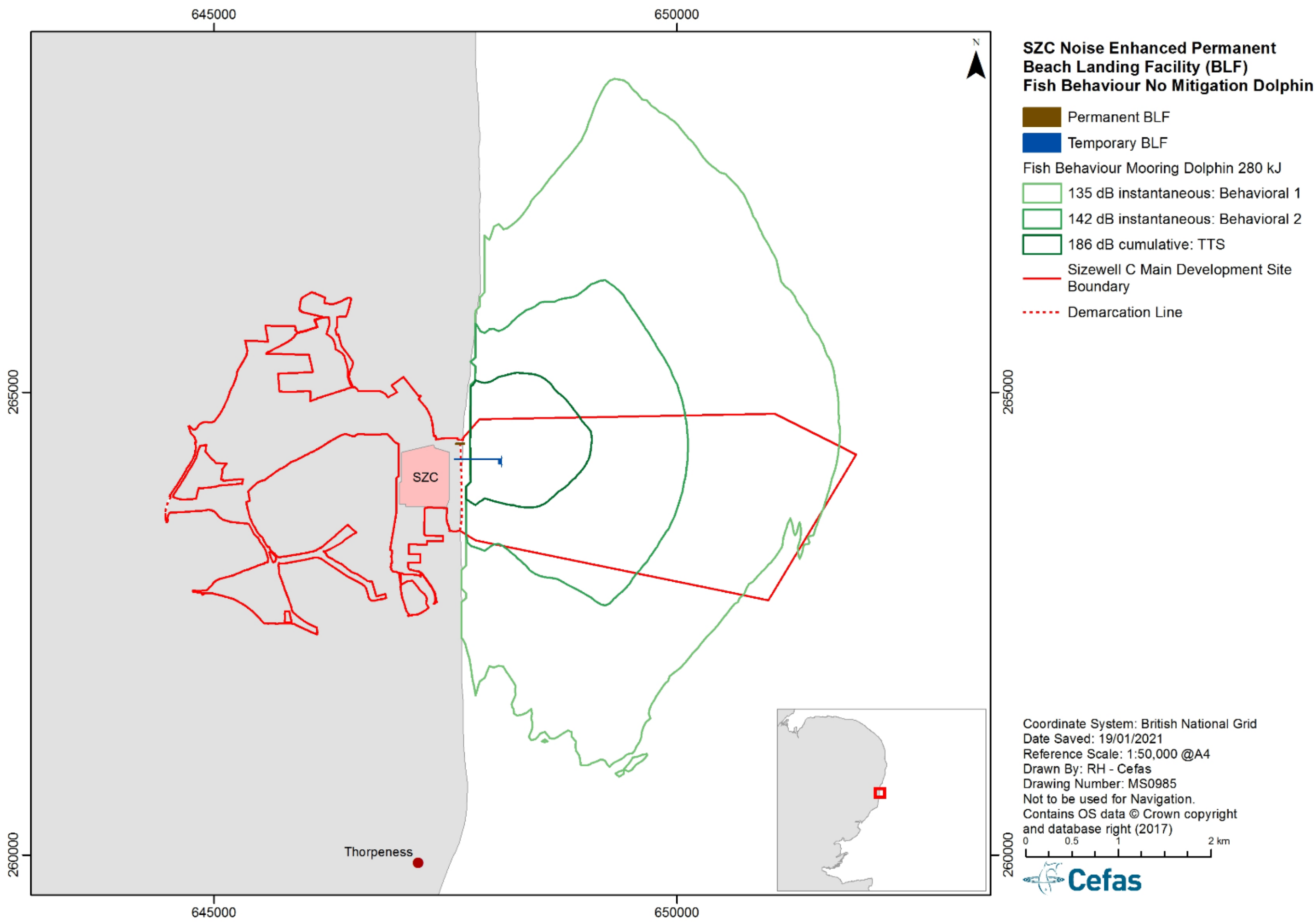

Figure 6.3: Behavioural effect zones for piling of mooring dolphins (worst-case) for the enhanced permanent BLF, based on startle response observations in sprat and mackerel

6.1.2 Temporary BLF

6.1.2.1 Marine mammals

The low energy impact piling associated with the temporary BLF resulted in no instantaneous PTS or TTS outside the standard 500m marine mammal mitigation zone at the onset of piling (Table 6.4 and Figure 6.4). The maximum instantaneous TTS and PTS effect ranges of 169m and 93m, respectively were predicted for harbour porpoise during piling of mooring dolphins. The estimated ranges for instantaneous TTS and PTS for harbour porpoise during piling for the unloading platform piles was 66m and 30m, respectively.

Seal auditory effect zones were considerably smaller with instantaneous ranges not exceeding 10m in any of the assessment scenarios (Table 6.4 and Figure 6.4).

Cumulative sound exposure was predicted for pile driving a maximum three consecutive piles within 24-hours using 120kJ hammer energy for the unloading platform and two mooring dolphins with a 280kJ hammer energy. The cumulative auditory PTS effect zones for harbour porpoise was predicted to be 25m (<1ha) for both piles and mooring dolphins. The cumulative TTS was predicted as 431ha and 3,734ha for unloading platform piles and mooring dolphins, respectively (Table 6.4 and Figure 6.4). The corresponding TTS and PTS zones for cumulative noise exposure were predicted to be negligible for seals.

Table 6.4: Marine mammal auditory effect zones for piling activities associated with the temporary BLF

Pile type.	Threshold	Instantaneous		Cumulative (24-hour): fleeing.	
		Harbour porpoise.	Phocid seals.	Harbour porpoise.	Phocid seals.
Unloading platform piles.	PTS	30m	5m	0ha (25m).	0ha (25m).
	TTS	66m	8m	431ha (1,856m).	0ha (25m).
Mooring dolphin.	PTS	93m	2m	0ha (25m).	0ha (25m).
	TTS	169m	4m	3,734ha (7,126m).	0ha (25m).

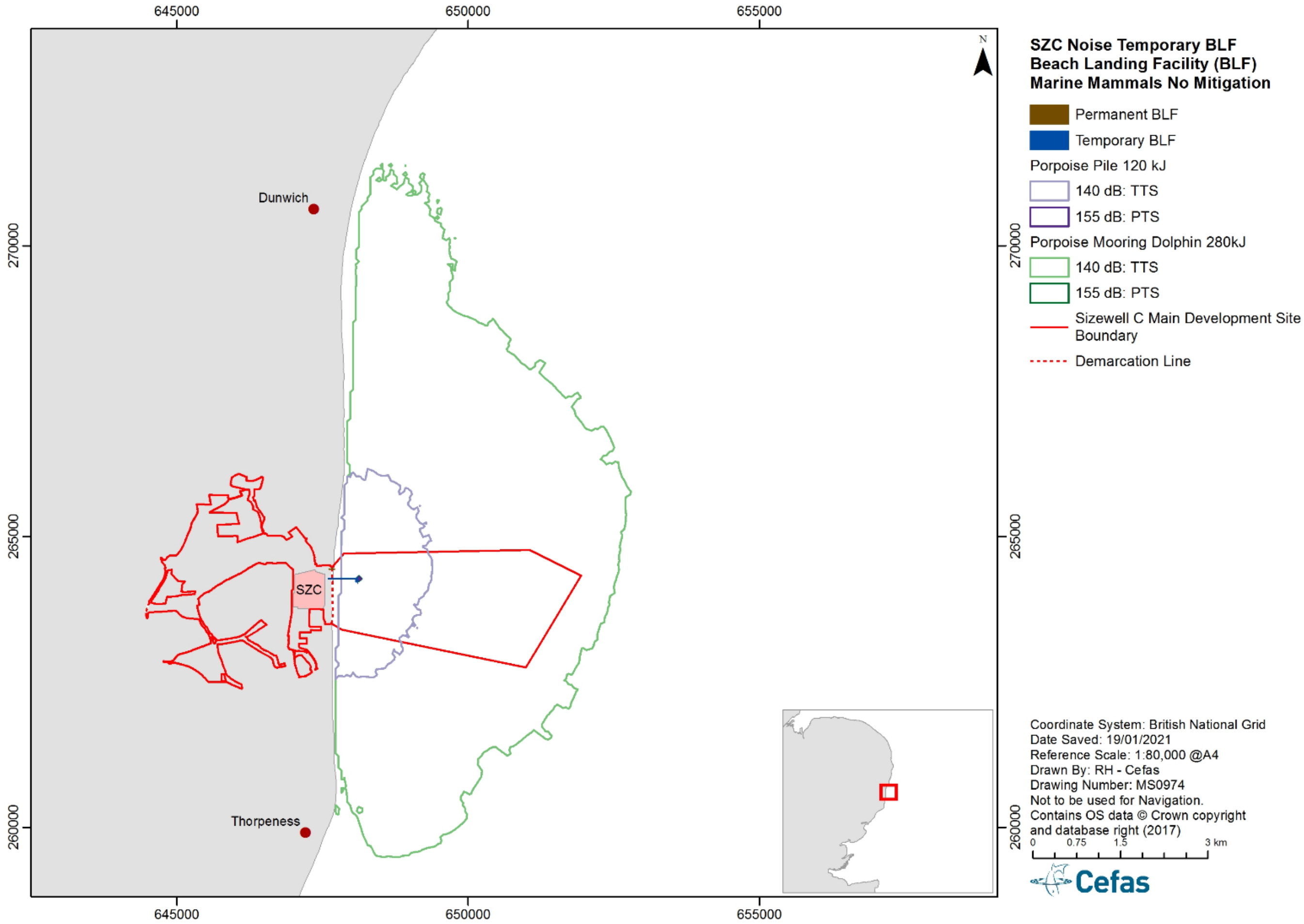

Figure 6.4: Marine mammal auditory effect zones for piling activities associated with the temporary BLF

6.1.2.2 Fish

The instantaneous and cumulative predicted mortality, recoverable injury and TTS effects of piling for the temporary BLF have been assessed based on the piling parameters detailed in Table 2.3. Cumulative sound exposure was predicted for pile driving a maximum three consecutive piles within 24-hours using 120kJ hammer energy for the unloading platform and two mooring dolphins with a 280kJ hammer energy..

Instantaneous effect ranges are predicted to be spatially limited for all species assessed. The most sensitive species groups, those with a swim bladder, and eggs and larvae would be susceptible to mortality or recoverable injury up to a range of 15m from the sound source during installation of the piles. Cumulative effects are only predicted to cause mortality for fish with a swim bladder that aids hearing if individuals remained within 2ha of the sound source during piling activities for the unloading platform (see Section 2.1.1.2). Recoverable injury is predicted for fish species with a swim bladder remaining within 8ha of the sound source for the duration of the daily piling, whilst TTS zones extend to 309ha for all species (Table 6.5 and Figure 7.11 in Appendix B.2).

During the installation of the dolphins, fish with a swim bladder, eggs and larvae would be susceptible to instantaneous mortality or recoverable injury to a range of 52m from the sound source. Fish without a swim bladder have smaller ranges of effects with mortality or recoverable injury restricted to within 24m of the sound source. Cumulative effects are predicted to cause mortality for hearing specialists, those that use a swim bladder for hearing, up to 11ha if they remain within the area for the duration of piling. Recoverable injury is predicted for fish with a swim bladder remaining within 30ha of the sound source for the duration of the daily piling, whilst TTS zones extend to 580ha for all species (Table 6.5 and Figure 6.5). If species are displaced from ensonified areas, the mobility of the species should facilitate return to the affected areas after impact piling has ceased.

Table 6.5: Predicted mortality, recoverable injury and TTS effect zones for fish, for piling activities associated with the temporary BLF

Pile type.	Hearing category.	Threshold	Instantaneous	Cumulative *(no fleeing).*
Unloading platform piles.	**(1) Fish with swim bladder to aid hearing.**	**Mortality**	**15m**	**2ha (100m).**
		Recoverable injury.	**15m**	**8ha (158m).**
		TTS		**309ha (1,385m).**
	(2) Fish with swim bladder that does not aid hearing.	Mortality	15m	0ha (<25m).
		Recoverable injury.	15m	8ha (158m).
		TTS		309ha (1,385m).
	(3) Fish without a swim bladder.	Mortality	7m	0ha (<25m).
		Recoverable injury.	7m	0ha (<25m).
		TTS		309ha (1,385m).
Mooring dolphins.	**(1) Fish with swim bladder to aid hearing.**	**Mortality**	**52m**	**11ha (180m).**
		Recoverable injury.	**52m**	**30ha (334m).**
		TTS		**580ha (1,992m).**
	(2) Fish with swim bladder that does not aid hearing.	Mortality	52m	5ha (111m).
		Recoverable injury.	52m	30ha (334m).
		TTS		580ha (1,992m).
	(3) Fish without a swim bladder.	Mortality	24m	0ha (<25m).
		Recoverable injury.	24m	0ha (<25m).
		TTS		580ha (1,992m).

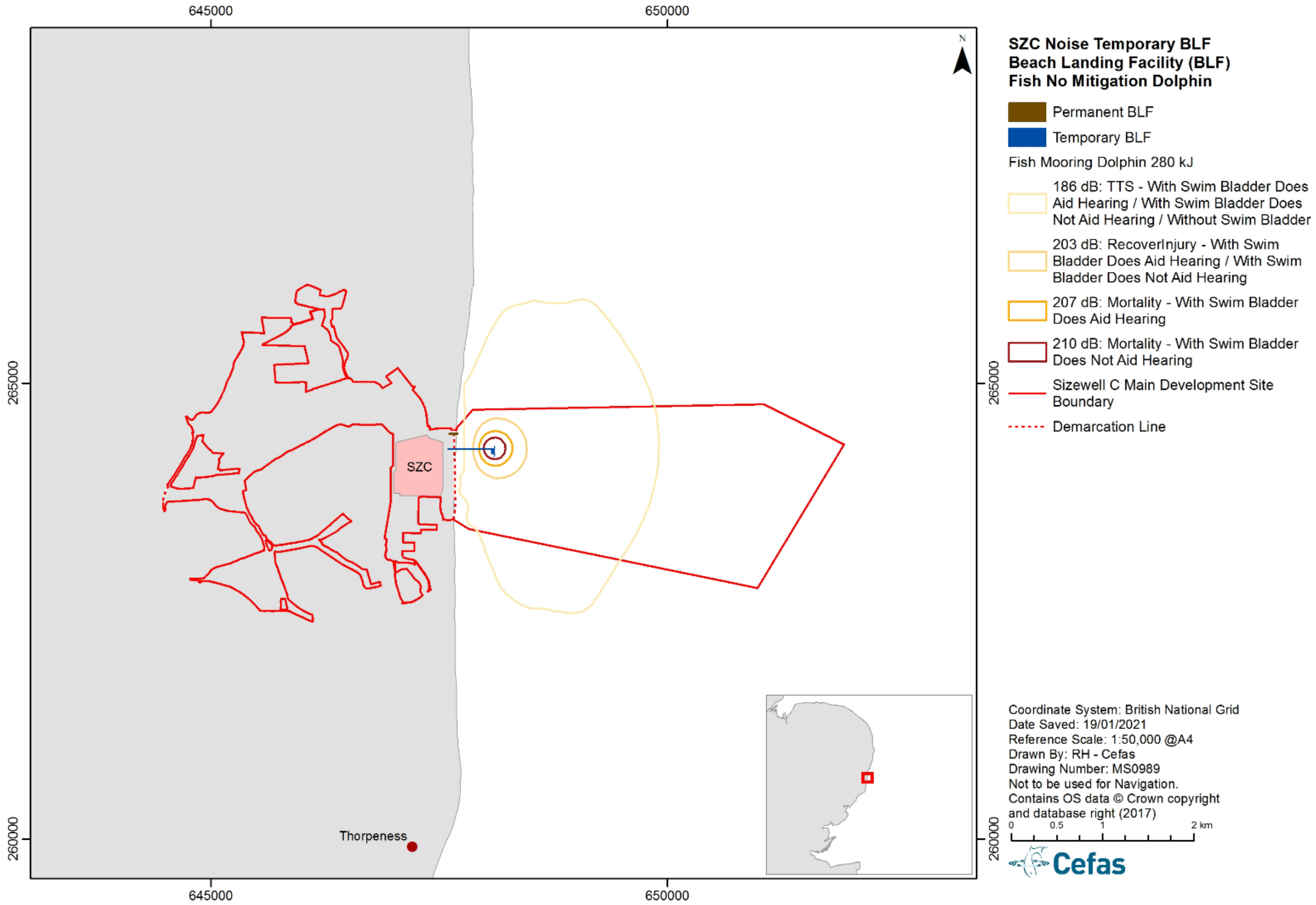

Figure 6.5: Predicted mortality, recoverable injury and TTS effect zones for fish, for piling of mooring dolphins (worst-case) associated with the temporary BLF

6.1.2.2.1 Fish behaviour

The position of the unloading platform piles approximately 440m offshore results in a larger spatial extent, in comparison to the enhanced permanent BLF, for behavioural responses in hearing specialists, such as sprat, up to 3.2km from the sound source. The larger diameter and higher energy dolphins result in the potential for behavioural responses in hearing specialists, such as sprat, up to 4.7km from the sound source (Table 6.6 and Figure 6.6).

Avoidance behaviours in mobile species in response to injurious noise levels may result in localised displacement near the sound source (Table 6.6 and Figure 7.16 in Appendix B.3). However, displacement of fish from the area within the behavioural contour is not anticipated with response being more akin to startle responses (Hawkins and Popper, 2014) or changes in swimming behaviour.

Table 6.6: Behavioural effect zones for impact piling for the temporary BLF, based on startle response observations in sprat and mackerel

Pile type.	Threshold	Indicative hearing groups.	Behavioural range.
Landing platform piles (120kJ).	135dB re 1µPa^{2}s.	Sprat: hearing specialists.	1,199ha (3,186m).

Pile type.	Threshold	Indicative hearing groups.	Behavioural range.
	142dB re 1µPa^{2}s.	Mackerel: hearing generalists.	598ha (2,053m).
Mooring Dolphins (280kJ).	135dB re 1µPa^{2}s.	Sprat: hearing specialists.	2,673ha (4,680m).
	142dB re 1µPa^{2}s.	Mackerel: hearing generalists.	1,167ha (3,111m).

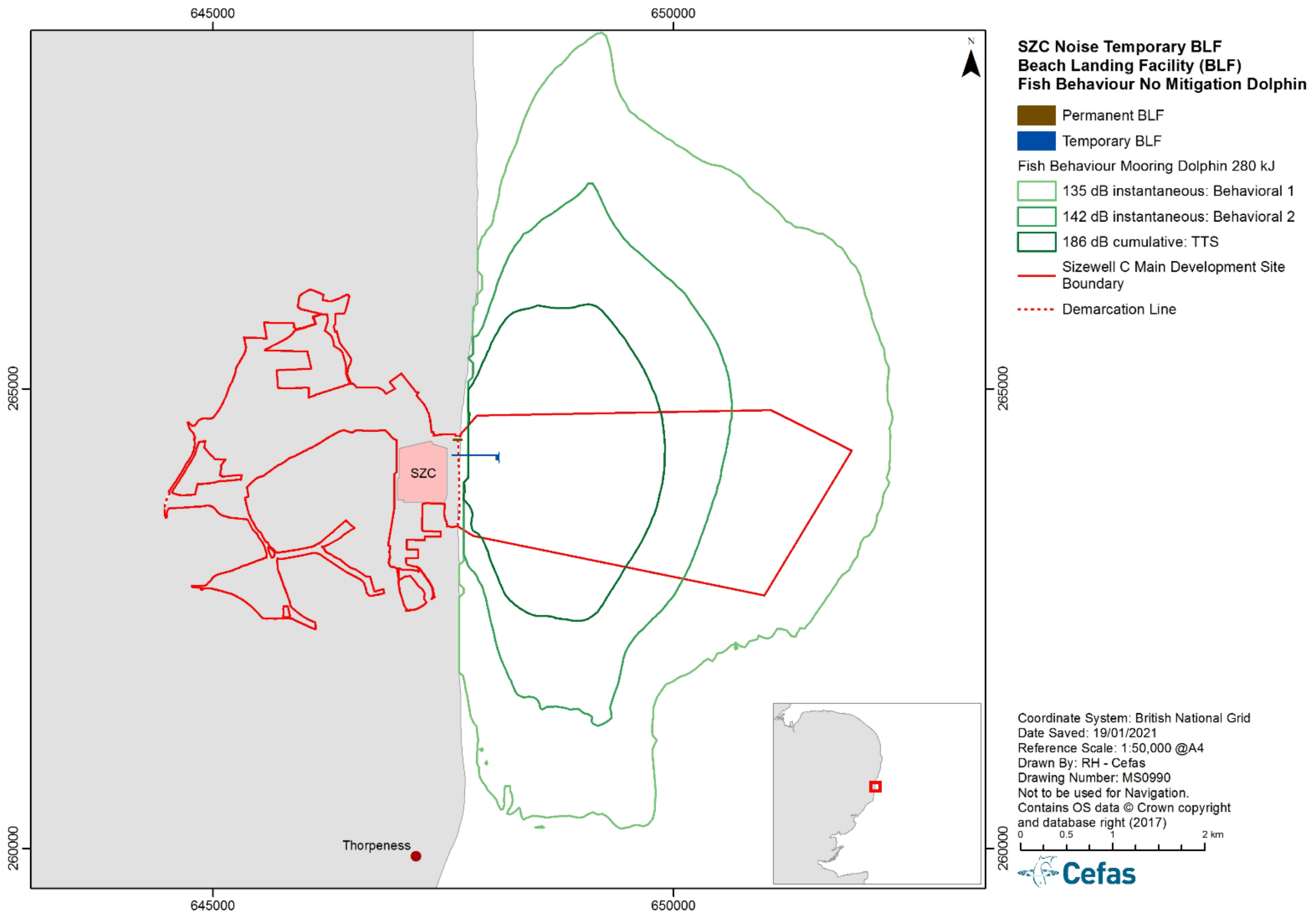

Figure 6.6: Behavioural effect zones for piling of mooring dolphins (worst-case) for the temporary BLF, based on startle response observations in sprat and mackerel

6.2 Piling with further mitigation

6.2.1 Enhanced permanent BLF

6.2.1.1 Marine mammals

The underwater noise modelling of impact piling during the installation of the enhanced permanent BLF with the further mitigation in the form of a hydrohammer showed that the acoustic effects were reduced (Table 6.7 and Figure 7.1 in Appendix A.1). Instantaneous TTS ranges were reduced from 53m to 24m (Table 6.1) and 106m to 55m (Table 6.7) for piles and mooring dolphins, respectively. Similarly, the PTS ranges reduced from 32m to 11m (Table 6.1) and 69m to 33m (Table 6.7) for piles and mooring dolphins, respectively. Instantaneous effect ranges for TTS and PTS for harbour porpoises reduced by between 50% and 65%, however, in all cases instantaneous effect ranges remained within the standard 500m mitigation zone proposed in the MMMP (BEEMS Technical Report TR509, [REP3-019]). With regard to seals, unmitigated instantaneous effect ranges did not exceed 30m (TTS range for mooring dolphins), thus reduction in the effect range with additional mitigation was not so marked. Nonetheless, the same trend of reduction in the instantaneous effect range was noted with an average reduction of 30-40% (Table 6.7).

When cumulative (fleeing) effect zones were considered, changes occurred for TTS for harbour porpoises reducing from 491ha to 95ha for piles and 5,230ha to 1,878ha for mooring dolphins (Table 6.1 and Table 6.7). This represents a reduction of the TTS effect zones of approximately 81% for piles and 64% for mooring dolphins. PTS zones for harbour porpoises and both PTS and TTS zones for seals, were negligible in all cases with or without mitigation (Table 6.7).

Table 6.7: Marine mammal auditory effect zone for piling activities associated with the enhanced permanent BLF with further mitigation measures

Pile type.	Threshold	Instantaneous		Cumulative (24-hour): fleeing.	
		Harbour porpoise.	Phocid seals.	Harbour porpoise.	Phocid seals.
Pile	PTS	11m	2m	0ha (<25m).	0ha (<25m).
	TTS	24m	4m	95ha (1,051m).	0ha (<25m).
Mooring dolphin.	PTS	33m	5m	0ha (25m).	0ha (<25m).
	TTS	55m	10m	1,878ha (4,589m).	0ha (<25m).

6.2.1.2 Fish

Instantaneous effect zones with additional mitigation are predicted to be spatially limited for all species assessed and within 5m for piles installed for the enhanced permanent BLF and 19m for mooring dolphins (Table 6.8).

Cumulative effects are not predicted to cause mortality or recoverable injury for any species during the installation of piles for the enhanced permanent BLF. TTS zones extend to 9ha for all species (Table 6.8 and Figure 7.3 in Appendix A.2). The installation of the mooring dolphins using further mitigation, would result in cumulative mortality zones of 1ha for hearing specialists and recoverable injury zones of 3ha for species with a swim bladder and ichthyoplankton (Figure 7.4 in Appendix A.2). TTS zones would extent to 81ha.

Based on conservative assumption of the effectiveness of the proposed mitigation (Section 2.1.1.5), cumulative TTS effect zones are anticipated to reduce by approximately 50% in the case of the piles and 47 in the case of the mooring dolphins. Areas of mortal injury are minimal given the model does not include fleeing and fish would have to remain within 1ha for the duration of piling to incur mortal injury, such a scenario is unlikely if fish display behavioural responses or the tidal conditions at the site are considered.

Table 6.8: Predicted mortality, recoverable injury and TTS effect zone for fish, for piling activities associated with the enhanced permanent BLF structures with further mitigation measures

Pile type.	Hearing category.	Threshold	Instantaneous	Cumulative *(no fleeing).*
Piles	**(1) Fish with swim bladder to aid hearing.**	**Mortality**	**5m**	**0ha (<50m).**
		Recoverable injury.	**5m**	**0ha (<50m).**
		TTS		**9ha (299m).**
	(2) Fish with swim bladder that does not aid hearing.	Mortality	5m	0ha (<50m).
		Recoverable injury.	5m	0ha (<50m).
		TTS		9ha (299m).
	(3) Fish without a swim bladder.	Mortality	3m	0ha (<50m).
		Recoverable injury.	3m	0ha (<50m).
		TTS		9ha (299m).
Mooring dolphins	**(1) Fish with swim bladder to aid hearing.**	**Mortality**	**19m**	**1ha (111m).**
		Recoverable injury.	**19m**	**3ha (158m).**
		TTS		**81ha (802m).**
	(2) Fish with swim bladder that does not aid hearing.	Mortality	19m	1ha (70m).
		Recoverable injury.	19m	3ha (158m).
		TTS		81ha (303m).
	(3) Fish without a swim bladder.	Mortality	8m	0ha (<25m).
		Recoverable injury.	8m	0ha (<25m).
		TTS		81ha (303m).

6.2.1.2.1 Fish behaviour

Behavioural responses extend to 1.5km for hearing specialists and 0.5km for species without specialist hearing mechanisms. The larger diameter and higher energy dolphins result in the potential for behavioural responses in hearing specialists, such as sprat, up to 3.3km from the sound source (see Table 6.9, Figure 7.6 in Appendix A.3 and Figure 7.7 in Appendix A.3), which is a reduction of approximately 40% compared to no mitigation (based on area). Linear distances represent the maximum distance at which a fish may respond from an underwater noise source, however, to represent the reduction in the contour the % in area is given.

Table 6.9: Behavioural effect zone for impact piling of the enhanced permanent BLF with further mitigation measures, based on startle response observations in sprat and mackerel

Pile type.	Threshold	Indicative hearing groups.	Behavioural range.
Piles (120kJ).	135dB re 1µPa^{2}s.	Sprat: hearing specialists.	212ha (1,464m).
	142dB re 1µPa^{2}s.	Mackerel: hearing generalists.	41ha (519m).
Mooring Dolphins (280kJ).	135dB re 1µPa^{2}s.	Sprat: hearing specialists.	1198ha (3,280m).
	142dB re 1µPa^{2}s.	Mackerel: hearing generalists.	354ha (1778m).

6.2.2 Temporary BLF

6.2.2.1 Marine mammals

The underwater noise modelling of impact piling during the installation of the temporary BLF with the further mitigation in a form of a hydrohammer showed that the acoustic effects were reduced (Table 6.10 and Figure 7.8 in Appendix B.1). TTS ranges were reduced from 66m and 169m (Table 6.4) to 20m and 68m (Table 6.10) for piles and mooring dolphins, respectively. Similarly, PTS reduced from 30m and 93m to 9m and 31m for piles and mooring dolphins, respectively. That is the reduction of the instantaneous effect ranges for TTS and PTS for harbour porpoises was predicted to be between approximately 60% and 70% lower with the inclusion of this mitigation measure. There was no material change for seals' instantaneous effect ranges considering that the unmitigated ranges were less than 10m and within the 500m mitigation zone (JNCC, 2010).

When cumulative (fleeing) effect zones were considered, the largest change occurred for TTS for harbour porpoises reducing from 431ha and 3,734ha (Table 6.4) to 90ha and 1,435ha for piles and mooring dolphins, respectively (Table 6.10). This represents a reduction of the TTS effect zones of approximately 79% for piles and 62% for mooring dolphins. There was no change when it came to PTS zones for harbour porpoises and both PTS and TTS zones for seals, which all remained negligible at or less than 25m (Table 6.10).

Table 6.10: Marine mammal auditory effect zones for piling activities associated with the temporary BLF with further mitigation measures

Pile type.	Threshold	Instantaneous		Cumulative (24-hour): fleeing.	
		Harbour porpoise.	Phocid seals.	Harbour porpoise.	Phocid seals.
Unloading platform piles.	PTS	9m	2m	0ha (25m).	0ha (25m).
	TTS	20m	4m	90ha	0ha

Pile type.	Threshold	Instantaneous		Cumulative (24-hour): fleeing.	
		Harbour porpoise.	Phocid seals.	Harbour porpoise.	Phocid seals.
				(774m).	(25m).
Mooring dolphin.	PTS	31m	5m	0ha (25m).	0ha (25m).
	TTS	68m	8m	1,435ha (4,203m).	0ha (25m).

6.2.2.2 Fish

Instantaneous effect ranges with additional mitigation are predicted to be spatially limited for all species assessed and within 6m for piles installed for the temporary BLF and 16m for mooring dolphins (Table 6.11).

Due to the deeper water depths and increased low frequency sound propagation, cumulative effect zones at the unloading platform for the temporary BLF are greater. TTS is anticipated to be confined to an area of 192ha for all species. Recoverable injury only occurs in species with a swim bladder if they remain within 3ha of the sound source. No mortality is predicted during the installation of piles.

Installation of the mooring dolphins would result in cumulative mortality zones extending to a maximum of 4ha for species with a swim bladder involved in hearing. Recoverable injury zones of 14ha are predicted for species with a swim bladder and TTS is predicted to be within an area of 401ha for all species (Table 6.11, Figure 7.12 in Appendix B.2 and Figure 7.13 in Appendix B.2).

Based on a conservative assumption of the effectiveness of the proposed mitigation (Section 2.1.1.5) cumulative TTS zones are anticipated to reduce by approximately 38% in the case of the piles and 31% in the case of the mooring dolphins. Areas of mortal injury are minimal given the model does not include fleeing and fish would have to remain within close proximity for the duration of piling to incur mortal injury, such a scenario is unlikely if fish display behavioural responses or the tidal conditions at the site are considered..

Table 6.11: Fish predicted mortality, recoverable injury and TTS effect zones for fish, for piling activities associated with the temporary BLF with further mitigation measures

Pile type.	Hearing category.	Threshold	Instantaneous	Cumulative *(no fleeing).*
Unloading platform piles.	**(1) Fish with swim bladder to aid hearing.**	**Mortality**	**6m**	**0ha (<25m).**
		Recoverable injury.	**6m**	**3ha (111m).**
		TTS		**192ha (1,074m).**
	(2) Fish with swim bladder that does not aid hearing.	Mortality	6m	0ha (<25m).
		Recoverable injury.	6m	3ha (111m).
		TTS		192ha (1,074m).
	(3) Fish without a swim bladder.	Mortality	3m	0ha (<25m).
		Recoverable injury.	3m	0ha (<25m).
		TTS		192ha (1,074m).
Mooring dolphins.	**(1) Fish with swim bladder to aid hearing.**	**Mortality**	**16m**	**4ha (111m).**
		Recoverable injury.	**16m**	**14ha (223m).**
		TTS		**401ha (1,605m).**
	(2) Fish with swim bladder that does not aid hearing.	Mortality	16m	2ha (70m).
		Recoverable injury.	16m	14ha (223m).
		TTS		401ha (1,605m).
	(3) Fish without a swim bladder.	Mortality	8m	0ha (<25m).
		Recoverable injury.	8m	0ha (<25m).
		TTS		401ha (1,605m).

6.2.2.2.1 Fish behaviour

Behavioural responses extend to 2.6km for hearing specialists for the installation of piles (Table 6.12, Figure 7.17 in Appendix B.3 and Figure 7.18 in Appendix B.3). The larger diameter and higher energy dolphins result in the potential for behavioural responses in hearing specialists up to 3.9km from the sound source (Table 6.12). The additional mitigation is anticipated to reduce the area of the behavioural contour by approximately 34% compared to the unmitigated scenarios (based on area). Linear distances represent the maximum distance at which a fish may respond from an underwater noise source however, to represent the reduction in the contour the % in area is given.

Table 6.12: Behavioural effect zones for impact piling of the temporary BLF with further mitigation measures, based on startle response observations in sprat and mackerel

Pile type.	Threshold	Indicative hearing groups.	Behavioural range.
Unloading platform piles (120kJ).	135dB re 1µPa^{2}s.	Sprat: hearing specialists.	912ha (2,632m).
	142dB re 1µPa^{2}s.	Mackerel: hearing generalists.	415ha (1,665m).
Mooring Dolphins (280kJ).	135dB re 1µPa^{2}s.	Sprat: hearing specialists.	1,763ha (3,870m).
	142dB re 1µPa^{2}s.	Mackerel: hearing generalists.	887ha (2,566m).

6.3 Helical screw piles for the enhanced permanent BLF

6.3.1 Marine mammals

6.3.1.1 Vibropiling

If the helical screws required to secure the concrete mattress for the enhanced permanent BLF are installed using vibropiling, the effects on marine mammals are likely to be similar or less than the effects described above in Section 6.6.1 for the decommissioning of the temporary BLF. Cumulative auditory effects were predicted to be negligible for porpoise and seals as fleeing behaviours would limit exposure of the low noise impact activity (Table 6.19).

6.3.1.2 Drilling

If the helical screws required to secure the concrete mattress for the enhanced permanent BLF are installed using drilling, the effects on marine mammals are likely to be similar or less than the effects described in Section 7.3.1 of BEEMS Technical Report TR312 for the drilling of the cooling water intake/outfall shafts. Noise levels arising from drilling activities were too low to generate instantaneous auditory effect zones for marine mammals. Cumulative auditory effect zones for marine mammals were spatially limited and in all cases, the fleeing marine mammal assessments resulted in no PTS or TTS effect zones.

6.3.2 Fish

6.3.2.1 Vibropiling

If the helical screws required to secure the concrete mattress for the enhanced permanent BLF are installed using vibropiling, the effects on fish are likely to be similar or less than the effects described above in Section 6.6.2 for the decommissioning of the temporary BLF. Cumulative predicted mortality, recoverable injury and TTS effects of the combined impact piling and vibropiling is minimal. Effect areas for mortality or recoverable injury are negligible. TTS is predicted for all fish species remaining within 11ha of the sound source for the duration of the activity (Table 6.20).

6.3.2.2 Drilling

If the helical screws required to secure the concrete mattress for the enhanced permanent BLF are installed using drilling, the effects on marine mammals are likely to be similar or less than the effects described in Section 7.3.2 of BEEMS Technical Report TR312 for the drilling of the cooling water intake/outfall shafts. Noise levels arising from drilling activities were too low to generate instantaneous auditory effect zones for fish. In all cases, the 24-hour cumulative auditory effect zones and behavioural response ranges for all fish species were predicted to be less than 25m. Drilling is therefore predicted to have negligible auditory effects on fish.

6.4 Vessel Traffic

6.4.1 Marine mammals

6.4.1.1 Temporary BLF

An increase in vessel traffic associated with deliveries to the temporary BLF during the construction period would occur. The anticipated vessel traffic associated with the temporary BLF is described in Section 2.1.2.2.

This increase in vessel traffic and the option for day/night deliveries to the temporary BLF would increase the baseline ambient noise levels at the site with the potential to cause auditory injury to marine mammals.

The results of the modelling (Table 6.13 and Figure 6.7) indicate negligible PTS zones for harbour porpoise and seals despite the model assuming stationary animals. TTS zones were predicted as 251ha and 3ha for harbour porpoise and seals, respectively. As such, animals would have to remain within the vicinity of the temporary BLF for 24 hours to incur TTS (Table 6.13 and Figure 6.7). Such a scenario is highly unlikely for highly mobile marine mammals. By assuming 24-hour vessel noise the assessment is precautionary in terms of the total exposure for cumulative auditory effects. The JNCC Advice on Operations (AoO) states the underwater sounds created by large ships are unlikely to cause physical trauma but could make preferred habitats less attractive as a result of disturbance (habitat displacement, area avoidance) (JNCC, 2019). The potential for disturbance due to increases in vessel activity is assessed in the ES Addendum and considered in Section 7.1.3.

Table 6.13: Stationary marine mammal cumulative auditory effect zones in the case of continuous 24-hour vessel activity at the temporary BLF

Vessel activity.	Threshold	Cumulative (24-hour): no fleeing.	
		Harbour porpoise.	Phocid seals.
Vessel noise including 24-hour utilisation of the temporary BLF.	PTS	0ha (25m).	0ha (<25m).
	TTS	251ha (1,137m).	3ha (111m).

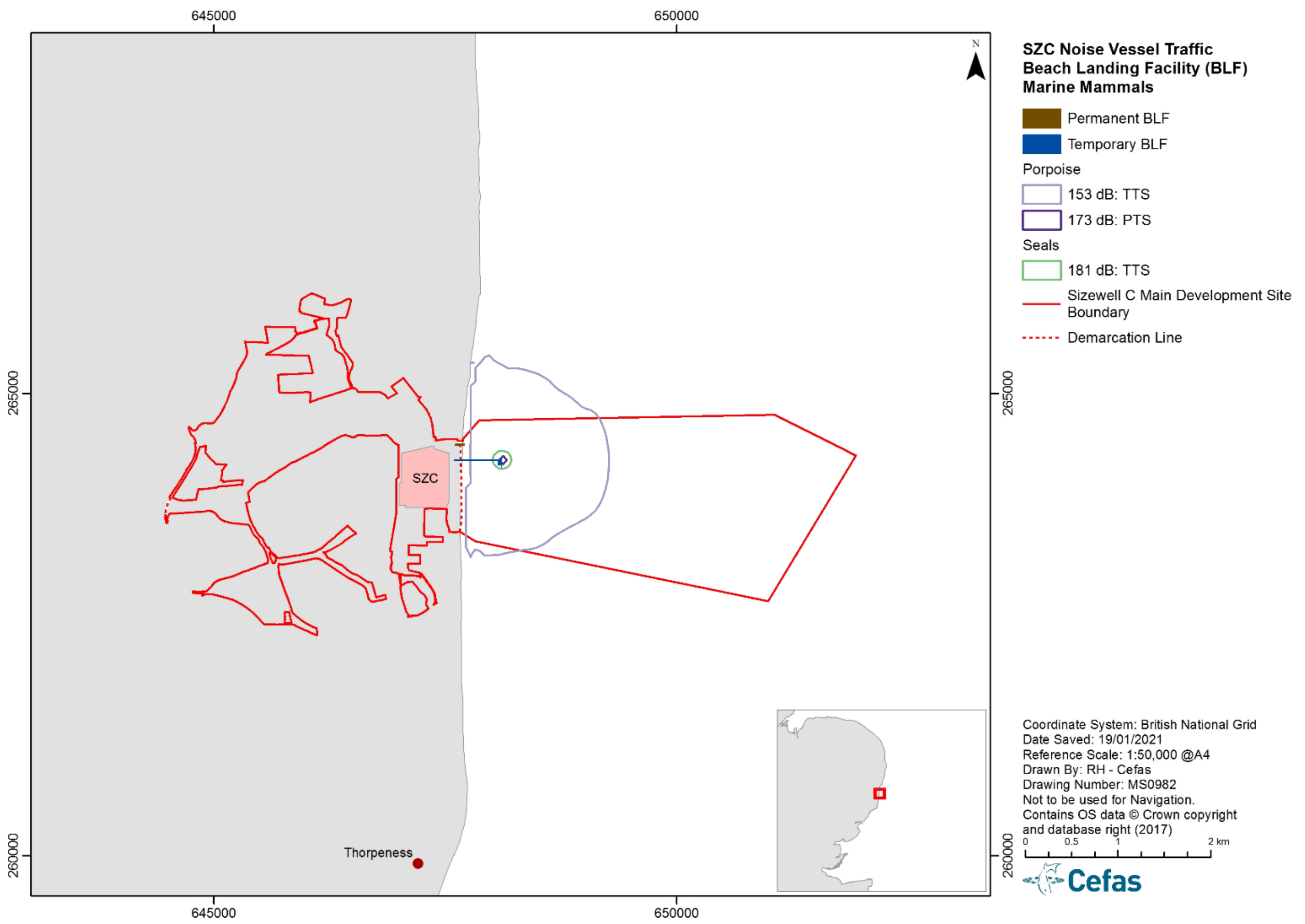

Figure 6.7: Stationary marine mammal cumulative auditory effect zones in the case of 24-hour vessel activity at the temporary BLF

6.4.2 Fish

6.4.2.1 Temporary BLF

The increase in vessel traffic due to the temporary BLF has the potential to increase the baseline ambient noise levels at the site with the potential to cause auditory injury or disturbance to fish receptors. Cumulative effects are not predicted to cause mortality or recoverable injury for fish. TTS is predicted for fish species remaining within 31ha of the sound source for 24 hours, assuming continuous vessel activity (Table 6.14 and Figure 6.8).

Behavioural responses to continuous noise sources do not have establish thresholds. Provisional noise thresholds where startle responses to impulsive noises have been observed in sprat (135dB) and mackerel (142dB) (Hawkins and Popper, 2014) indicate a limited spatial extent of the behavioural contour 45ha (429m) and 8ha (158m), respectively.

Table 6.14: Fish cumulative predicted mortality, recoverable injury and TTS effect zones in the case of continuous 24-hour vessel activity at the temporary BLF

Pile type.	Hearing category.	Threshold	Cumulative *(no fleeing).*
Vessels at the temporary BLF.	**(1) Fish with swim bladder to aid hearing.**	**Mortality**	**0ha (<25m).**
		Recoverable injury.	**0ha (<25m).**
		TTS	**31ha (352m).**
	(2) Fish with swim bladder that does not aid hearing.	Mortality	0ha (<25m).
		Recoverable injury.	0ha (<25m).
		TTS	31ha (352m).
	(3) Fish without a swim bladder.	Mortality	0ha (<25m).
		Recoverable injury.	0ha (<25m).
		TTS	31ha (352m).

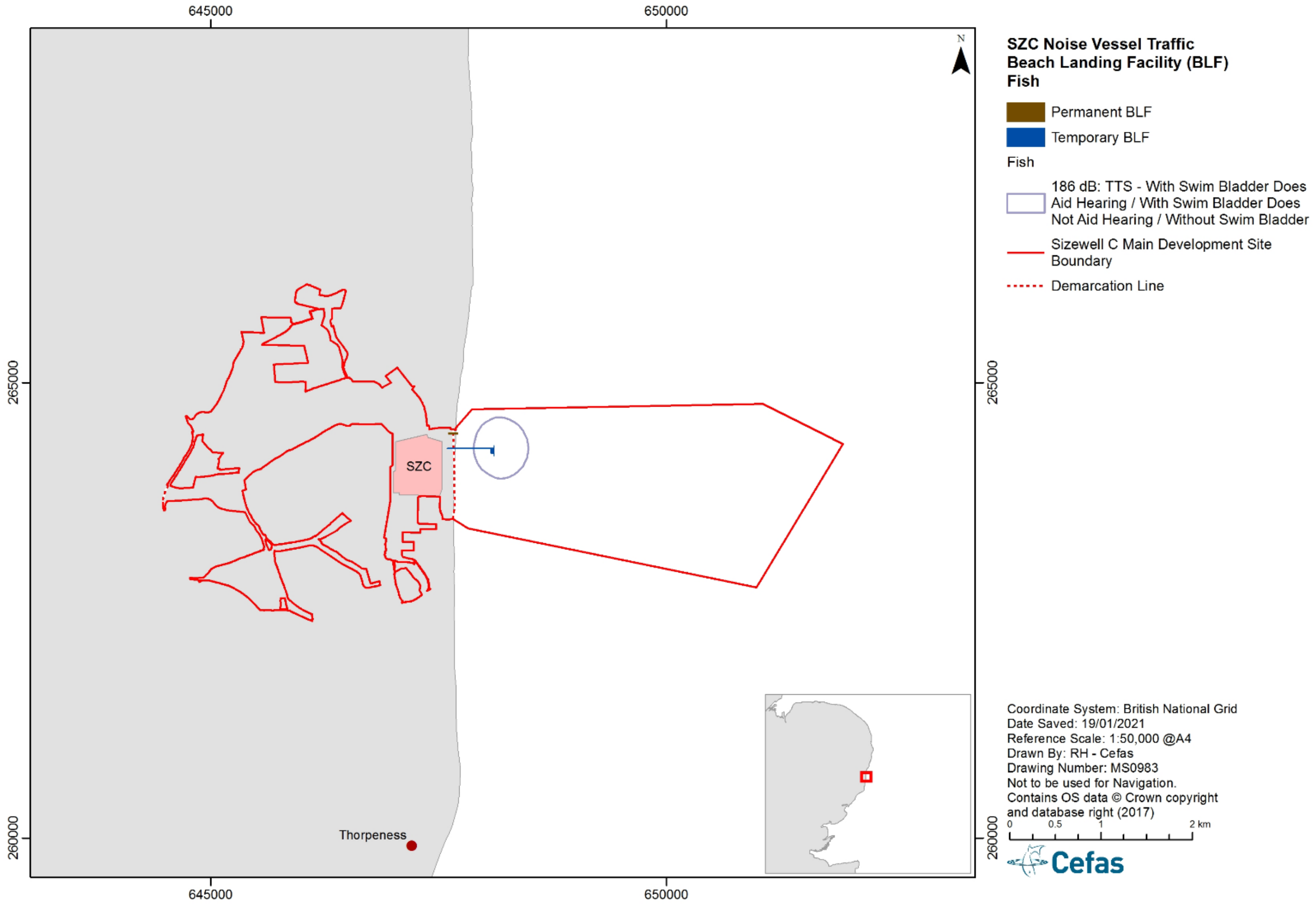

Figure 6.8: Fish cumulative TTS effect zones in the case of 24-hour vessel activity at the temporary BLF

6.5 Combined Effects

Underwater noise assessments account for the combined effects (within project effects). The combined effects considered for the revised marine freight options include noise generated during consecutive piling for the temporary BLF and enhanced permanent BLF, and vessel traffic associated with both BLFs. The typical installation sequence for each BLF involves installation of two piles (ca. 2 hours of piling including ramp-ups) every three days due to the time taken to lay each subsequent trestle span. Therefore, the maximum number of piles in a 24-hour period for the combined effects, is both BLFs installing two piles on the same day (i.e., four piles in a 24-hour period).

However, the scenario of four piles installed in a 24-hour period does not represent the worst-case for underwater noise effects. The worst case in terms of auditory effect zones is the scenario whereby two dolphins are installed in a 24-hour period (Section 6.1 and 6.2). This is due to the larger diameter of the piles and higher hammer energies required. The higher hammer energies also have a greater acoustic conversion efficiency (Table 2.1 and Table 2.3). Hence, the cumulative auditory effects of installing two dolphins is greater than installing four piles in a given 24 hour period. During piling for dolphins only two would be installed in a 24-hour period.

6.5.1 Piling

6.5.1.1 Marine Mammals

To simulate a scenario whereby piling occurs for both BLFs simultaneously, the following scenario was considered: two piles installed for the enhanced permanent BLF and two piles installed for the temporary BLF within the longshore bar. PTS and TTS thresholds are formulated using weighted cumulative sound exposure level (SELcum) and presented in terms of area. The results for the worst-case piling scenarios are presented with auditory effect zones for fleeing animals with and without further mitigation (in the form of a hydrohammer).

The results of the fleeing model (Table 6.15 and Figure 6.9) indicate that there would not be PTS for harbour porpoise or seals in scenarios with and without further mitigation. TTS would occur only for harbour porpoises within the effect zone of 669ha (Table 6.15 and Figure 6.9). This increase in the effect zone is not substantially different than the TTS for individual piling of the enhanced permanent BLF or temporary BLF without further mitigation (491ha and 431ha, respectively). Further mitigation reduced the TTS area to 128ha (Table 6.15 and Figure 6.9).

Table 6.15: Marine mammal auditory effect zone for piling activities associated with the enhanced permanent BLF and temporary BLF occurring simultaneously. Effect zones are based on fleeing animals with and without further mitigation

Pile type.	Threshold	Cumulative (24-hour): fleeing.		Cumulative (24-hour): fleeing. With additional mitigation.	
		Harbour porpoise.	Phocid seals.	Harbour porpoise.	Phocid seals.
Enhanced permanent BLF piles (2 piles) and temporary BLF piles (2 piles) within the longshore bar.	PTS	**0ha**	**0ha**	0ha	0ha
	TTS	**669ha**	**0ha**	128ha	0ha

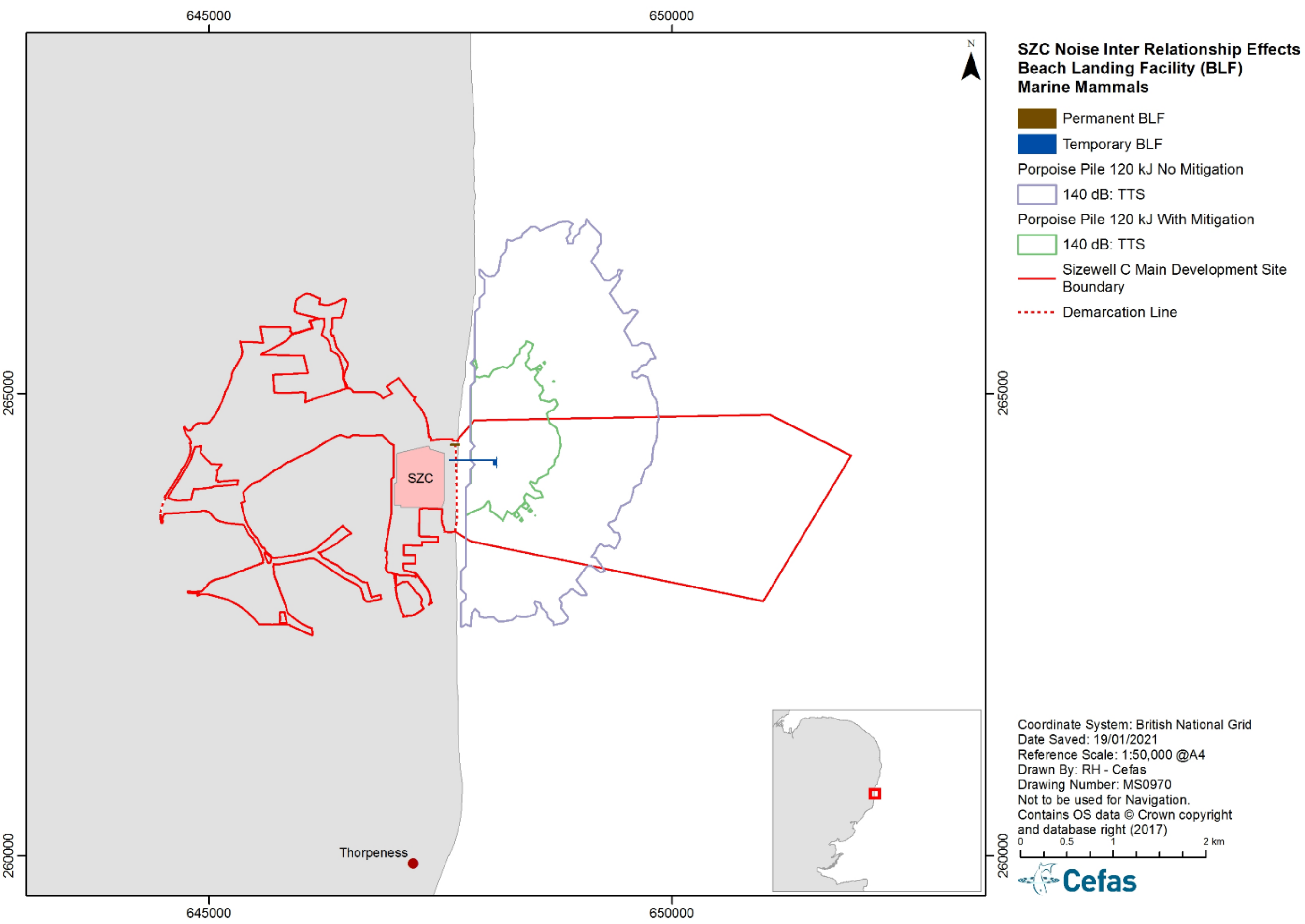

Figure 6.9: Marine mammal auditory effect zones (seal auditory effect zones are not shown as <25m from source) for piling activities associated with the enhanced permanent BLF and temporary BLF occurring simultaneously. Zones are based on fleeing animals with and without further mitigation

6.5.1.2 Fish

The cumulative predicted mortality, recoverable injury and TTS effect zones for fish receptors during impact piling for both BLFs with and without further mitigation is detailed in Table 6.16.

Table 6.16: Predicted mortality, recoverable injury and TTS effect zones for fish, for piling activities associated with the enhanced permanent BLF and temporary BLF occurring simultaneously with and without further mitigation

Pile type.	Hearing category.	Threshold	Cumulative *(no fleeing).*	Cumulative *(no fleeing).* With additional mitigation.
Enhanced permanent BLF piles (2 piles) and temporary BLF piles (2 piles) within the longshore bar.	**(1) Fish with swim bladder to aid hearing.**	**Mortality**	**1ha**	0ha
		Recoverable injury.	**1ha**	1ha
		TTS	**56ha**	32ha
	(2) Fish with swim bladder that does not aid hearing.	Mortality	0ha	0ha
		Recoverable injury.	1ha	1ha
		TTS	56ha	32ha
	(3) Fish without a swim bladder.	Mortality	0ha	0ha
		Recoverable injury.	0ha	0ha
		TTS	56ha	32ha

Cumulative auditory effects are only predicted to cause mortality for fish with a swim bladder that aids hearing if individuals remained within 1ha of the sound source during piling activities for both BLFs simultaneously. Recoverable injury is predicted for fish species with a swim bladder remaining within 1ha of the sound source for the duration of the daily piling, whilst TTS zones extend to 56ha for all species (Table 6.16 and Figure 6.10).

When further mitigation is included, the effect zones reduce. Cumulative effects are not predicted to cause mortality for fish. Recoverable injury is predicted for fish species with a swim bladder remaining within 1ha of the sound source for the duration of the daily piling, whilst TTS zones extend to 32ha for all species (Table 6.16 and Figure 6.11).

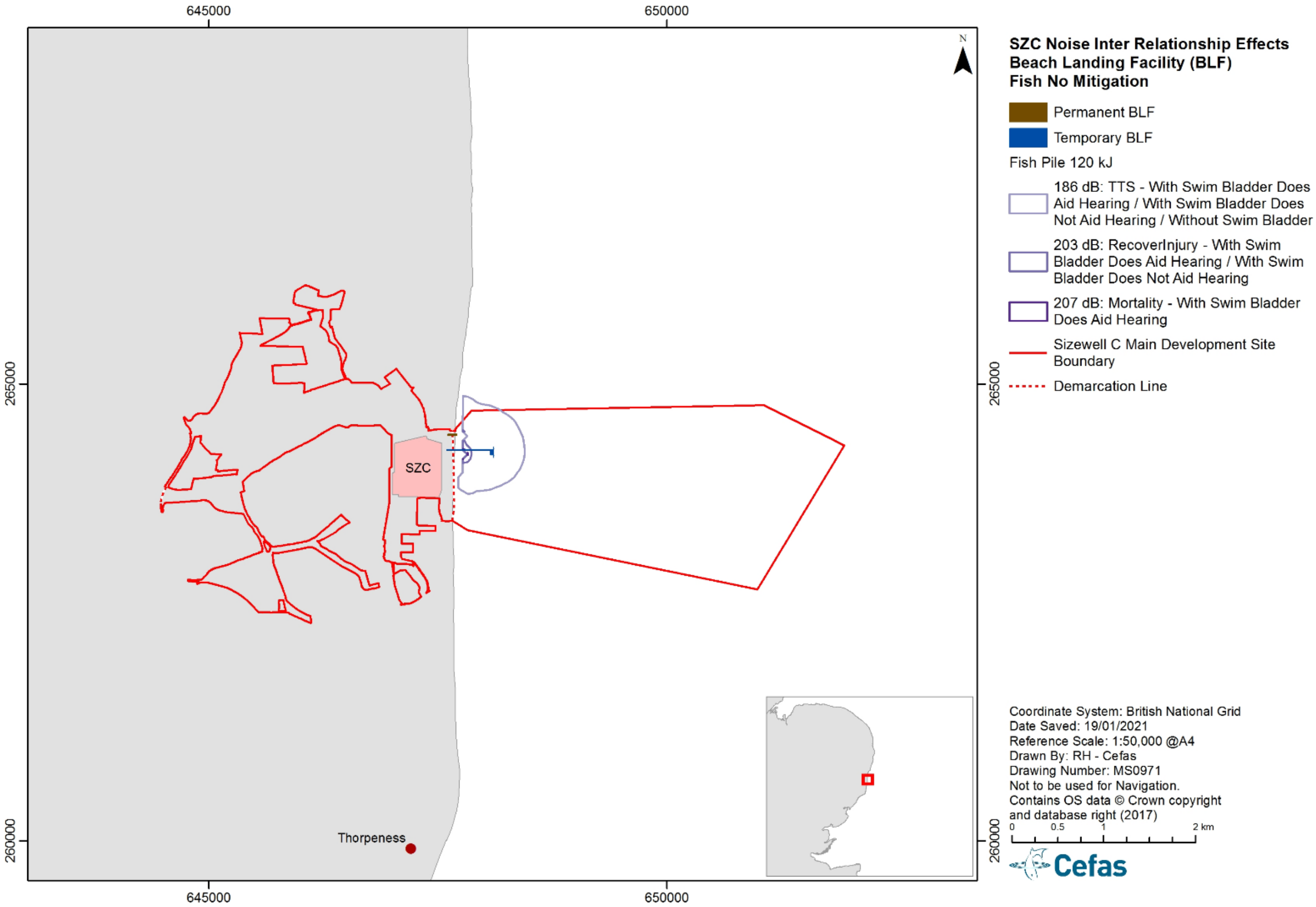

Figure 6.10: Predicted mortality, recoverable injury and TTS effect zones for fish, for piling activities associated with the enhanced permanent BLF and temporary BLF occurring simultaneously without additional mitigation measures

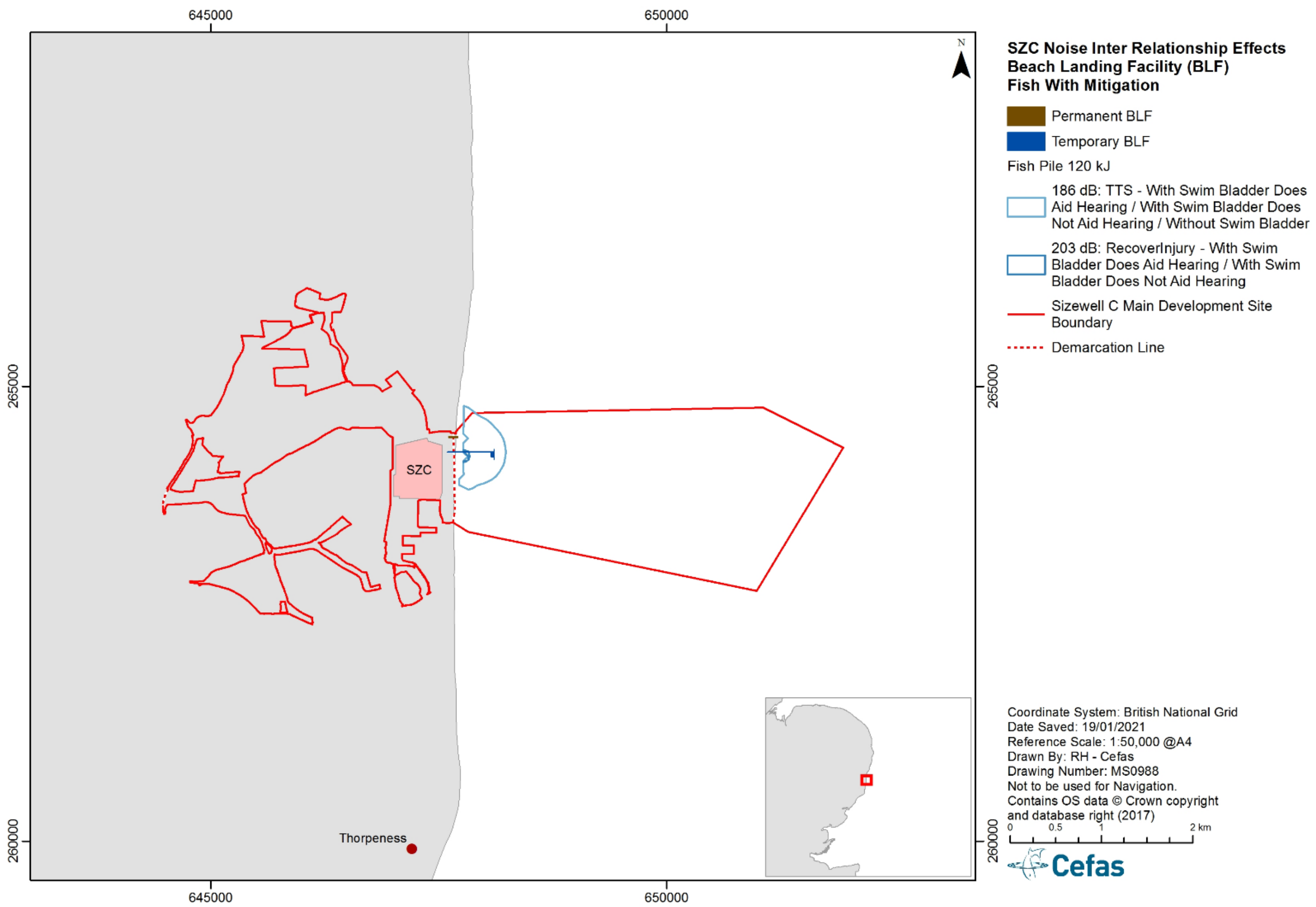

Figure 6.11: Predicted recoverable injury and TTS effect zones for fish, for piling activities associated with the enhanced permanent BLF and temporary BLF occurring simultaneously with additional mitigation measures

6.5.2 Vessel traffic

6.5.2.1 Marine Mammals

Vessel traffic in the proposed development area would increase after the installation of the two BLFs. The combined underwater noise modelling considered 24-hour utilisation of the enhanced permanent BLF and the temporary BLF consecutively. Vessels on approach to the proposed development would operate at lower speeds, as such the source terms are precautionary. The Code of Construction Practice (CoCP) (NNB Generation Company (SZC) Ltd., 2020b) recommends site speed restrictions of <10 knots to minimise disturbance effects.

Cumulative PTS was predicted to be 1ha and 0ha for stationary harbour porpoise and seals, respectively. The restricted spatial area and the assumption of stationary animals for a 24-hour period indicated negligible PTS. The TTS zone for harbour porpoise extended to 436ha while it was limited to 7ha for seals (Table 6.17). The combined utilisation of the two BLFs increases the spatial extent of the TTS zone by 185ha (42%) in comparison to the temporary BLF operating alone.

The spatial extent of the porpoise PTS and TTS auditory effect zones and seal TTS zone for the operation of both BLFs is illustrated in Figure 6.12.

Table 6.17: Cumulative auditory effect zones in the case of 24-hour vessel activity at the enhanced permanent BLF and temporary BLF for stationary (no fleeing) marine mammals

Vessel activity	Threshold	Cumulative (24-hour): no fleeing.	
		Harbour porpoise.	Phocid seals.
Vessel noise including 24-hour utilisation of the enhanced permanent BLF and the temporary BLF.	PTS	1ha	0ha
	TTS	436ha	7ha

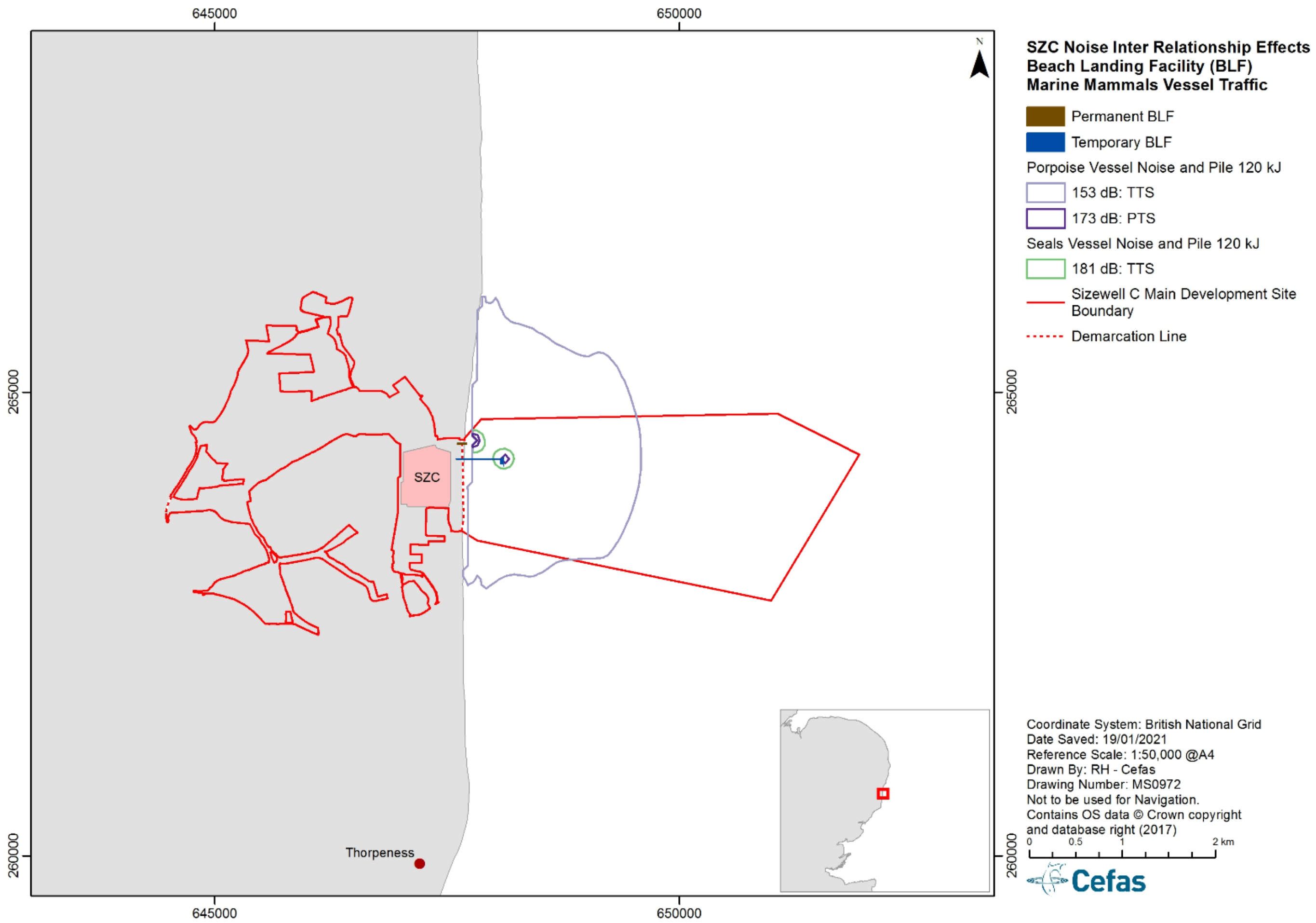

Figure 6.12: Combined effect zone of cumulative 24-hour vessel activity at both BLFs on marine mammals

6.5.2.2 Fish

Cumulative auditory effects would not cause mortality or recoverable injury for fish. TTS is predicted for fish species remaining within 39ha of the sound source for 24 hours, assuming continuous vessel activity throughout that period (Table 6.18 and Figure 6.13). The combined utilisation of the two BLFs increases the spatial extent of the TTS zone by 9ha (29%) in comparison to the temporary BLF operating alone.

Behavioural responses to continuous noise sources do not have establish thresholds. Provisional noise thresholds where startle responses to impulsive noises have been observed in sprat (135dB) and mackerel (142dB) (Hawkins and Popper, 2014) indicate a limited spatial extent of the behavioural contour 55ha and 11ha, respectively (Figure 6.14).

Table 6.18: Fish cumulative predicted mortality, recoverable injury and TTS effect zone in the case of 24-hour vessel activity at the enhanced permanent BLF and temporary BLF

Pile type.	Hearing category.	Threshold	Cumulative *(no fleeing).*
Vessel noise including 24-hour utilisation of the enhanced permanent BLF and the temporary BLF.	**(1) Fish with swim bladder to aid hearing.**	**Mortality**	**0ha**
		Recoverable injury.	**0ha**
		TTS	**39ha**
	(2) Fish with swim bladder that does not aid hearing.	Mortality	0ha
		Recoverable injury.	0ha
		TTS	39ha
	(3) Fish without a swim bladder.	Mortality	0ha
		Recoverable injury.	0ha
		TTS	39ha

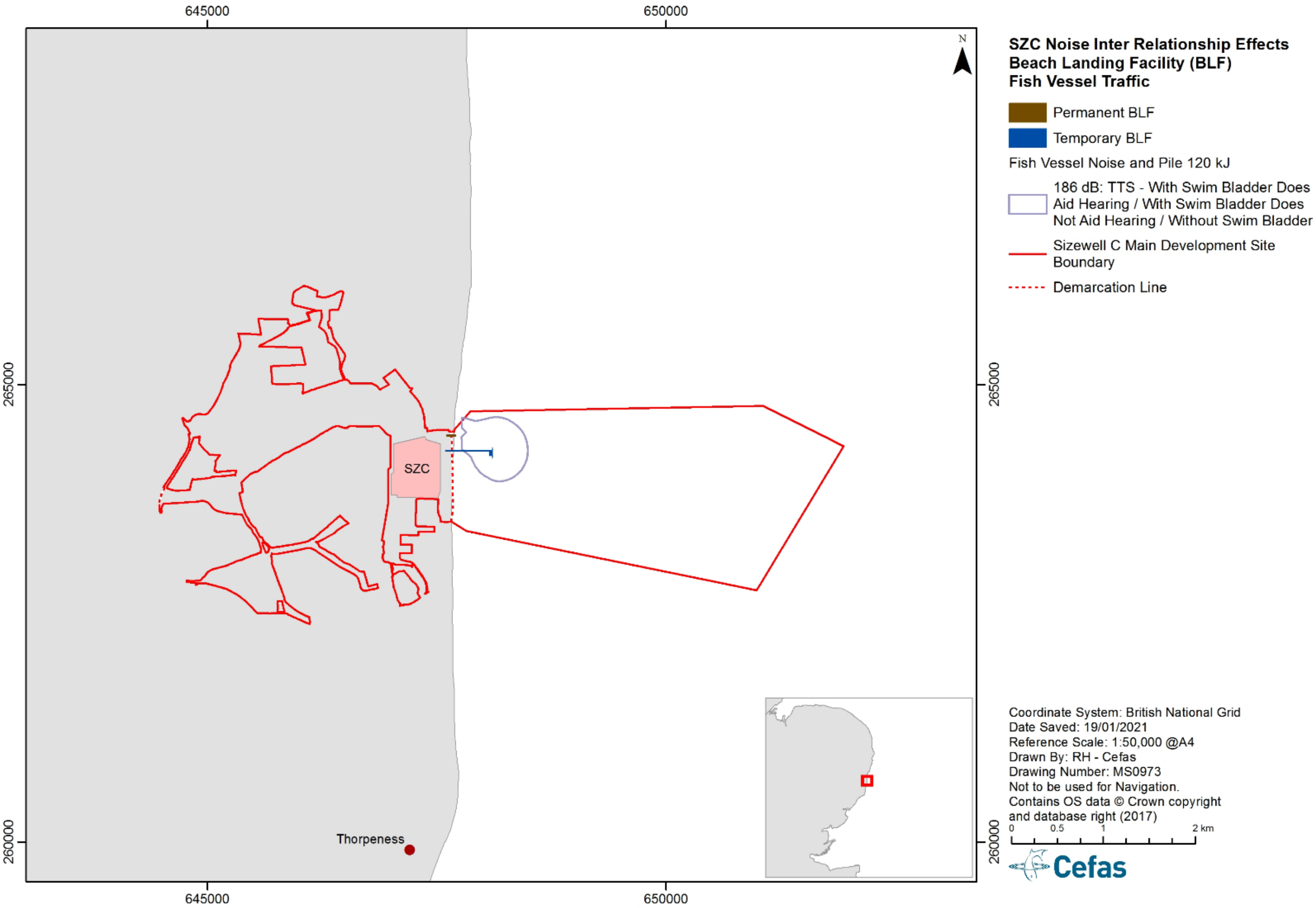

Figure 6.13: Fish cumulative TTS effect zone in the case of 24-hour vessel activity at the enhanced permanent BLF and temporary BLF

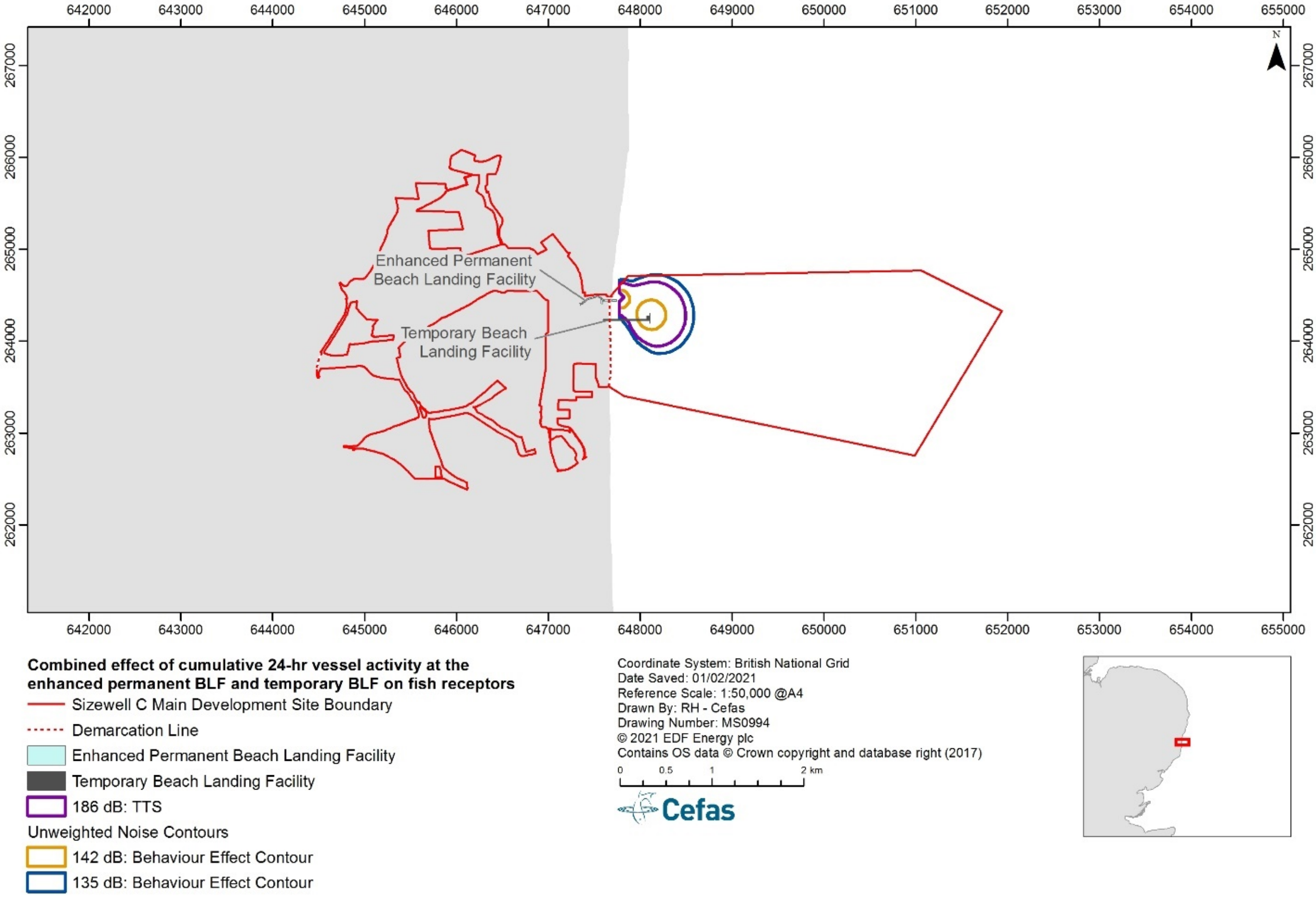

Figure 6.14: Behavioural effect contours for effect zone in the case of 24-hour vessel activity at the enhanced permanent BLF and temporary BLF, based on startle response observations in sprat and mackerel, the TTS 186dB contour is also shown for reference

6.6 Decommissioning of temporary BLF (piling)

6.6.1 Marine mammals

The preferred method for decommissioning the temporary BLF at the end of the construction phase is to use vibropiling methods for extraction. A limited number of hammer blows would be required to loosen the piles prior to removal, as such instantaneous TTS and PTS ranges are the same during decommissioning as installation of the unloading platform piles for the temporary BLF. Instantaneous effects are limited to the immediate vicinity of the piles both for seals and harbour porpoises. The maximum effect range is predicted for harbour porpoises for instantaneous TTS at 66m (Table 6.19 and Figure 7.9 in Appendix B.1).

Following limited impact piling, vibropiling would be applied to remove the piles. Cumulative auditory effects were predicted to be negligible for porpoise and seals as fleeing behaviours would limit exposure of the low noise impact activity (Table 6.19).

Table 6.19: Marine mammal auditory effect zones for activities associated with the removal of the temporary BLF (piling).

Pile type.	Threshold	Instantaneous		Cumulative (24-hour): fleeing.	
		Harbour porpoise.	Phocid seals.	Harbour porpoise.	Phocid seals.
Removal of piles (impact piling followed by vibropiling).	PTS	30m	5m	0ha (25m).	0ha (<25m).
	TTS	66m	8m	0ha (25m).	0ha (25m).

6.6.2 Fish

The most sensitive species, those with a swim bladder, and eggs and larvae would be susceptible to mortality or recoverable injury to a range of 15m from the sound source during removal of the piles due to the initial impact piling (Table 6.20 and Figure 7.14 in Appendix B.2).

Cumulative predicted mortality, recoverable injury and TTS effects of the combined impact piling and vibropiling (detailed in Section 2.1.1) is minimal. Effect areas for mortality or recoverable injury are negligible. TTS is predicted for all fish species remaining within 11ha of the sound source for the duration of the activity (Table 6.20 and Figure 7.14 in Appendix B.2).

Table 6.20: Predicted mortality, recoverable injury and TTS effect zones for fish, for pile removal activities associated with decommissioning the temporary BLF (piling)

Pile type.	Hearing category.	Threshold	Instantaneous	Cumulative *(no fleeing).*
Removal of piles (impact piling followed by vibropiling).	**(1) Fish with swim bladder to aid hearing.**	**Mortality**	**15m**	**0ha (<25m).**
		Recoverable injury.	**15m**	**0ha (<25m).**
		TTS		**11ha (206m).**
	(2) Fish with swim bladder that does not aid hearing.	Mortality	15m	0ha (<25m).
		Recoverable injury.	15m	0ha (<25m).

Pile type.	Hearing category.	Threshold	Instantaneous	Cumulative *(no fleeing).*
		TTS		11ha (206m).
	(3) Fish without a swim bladder.	Mortality	7m	0ha (<25m).
		Recoverable injury.	7m	0ha (<25m).
		TTS		11ha (206m).

6.7 Decommissioning of temporary BLF (water jet cutting)

6.7.1 Marine mammals

If the preferred vibropiling method for extracting the temporary BLF piles were to be unfeasible, an alternative mechanical cutting technique would be employed, of which the worst case would be using high pressure water jets. Noise levels from this method will be too low to generate instantaneous auditory effect zones for marine mammals.

Assessments of fleeing behaviour assumed that marine mammals would flee from the source location at the onset of activity. Cumulative sound exposure was predicted for removing two piles within 24-hours, with the maximum interval of 1 hour per pile. The cumulative auditory PTS effect zone for harbour porpoise and phocid seals was predicted as less than 1ha. The cumulative TTS was predicted as approximately 2ha and less than 1ha for harbour porpoise and phocid seals, respectively (Table 6.21 and Figure 7.10 in Appendix B.1).

Table 6.21: Marine mammal auditory effect zones for activities associated with the removal of the temporary BLF (water jet cutting).

Pile type.	Threshold	Cumulative (24-hour): fleeing.	
		Harbour porpoise.	Phocid seals.
Removal of piles (water jet cutting).	PTS	0ha (25m).	0ha (<25m).
	TTS	2ha (249m).	0ha (25m).

6.7.2 Fish

The alternative decommissioning method of using high pressure water jets has been assessed in relation to fish. Noise levels from this method will be too low to generate instantaneous auditory effect zones for fish.

Cumulative predicted mortality, recoverable injury and TTS effects of the water jet cutting decommissioning method is minimal. Effect areas for mortality or recoverable injury are negligible. TTS is predicted for all fish species remaining within 92ha of the sound source for the duration of the activity (Table 6.22 and Figure 7.15 in Appendix B.2)

Table 6.22: Predicted mortality, recoverable injury and TTS effect zones for fish, for pile removal activities associated with decommissioning the temporary BLF (water jet cutting)

Pile type.	Hearing category.	Threshold	Cumulative *(no fleeing).*
Removal of piles (water jet cutting).	**(1) Fish with swim bladder to aid hearing.**	**Mortality**	**0ha (<25m).**
		Recoverable injury.	**0ha (<25m).**
		TTS	**92ha (602m).**
	(2) Fish with swim bladder that does not aid hearing.	Mortality	0ha (<25m).
		Recoverable injury.	0ha (25m).
		TTS	92ha (602m).
	(3) Fish without a swim bladder.	Mortality	0ha (25m).
		Recoverable injury.	0ha (25m).
		TTS	92ha (602m).

6.7.2.1 Fish behaviour

Behavioural response thresholds have not been formally assigned and assessment thresholds are based on behavioural responses to instantaneous noise sources reported in the literature. As such they are subject to a lower degree of confidence than established criteria for injury and predicted mortality, recoverable injury and TTS assessments. The applied threshold for behavioural effects are based on observations of a startle response in sprat (135dB re 1µPa^{2}s) and in mackerel (142dB re 1µPa^{2}s) (Hawkins and Popper, 2014) (see Section 0).

TTS areas would be the same as for the assessments described in Table 6.22 and Figure 7.15 in Appendix B.2; Figure 7.19 in Appendix B.3.

Table 6.23: Behavioural effect zones for pile removal activities associated with decommissioning the temporary BLF (water jet cutting), based on startle response observations in sprat and mackerel

Pile type.	Threshold	Indicative hearing groups.	Behavioural range.
Removal of piles (water jet cutting).	135dB re 1µPa^{2}s.	Sprat: hearing specialists.	1,580ha (3,753m).
	142dB re 1µPa^{2}s.	Mackerel: hearing generalists.	378ha (1,515m).

7 Summary

7.1 Marine mammals

7.1.1 Instantaneous auditory effects

The largest range for permanent hearing damage (PTS) resulting from piling activities is predicted to be 93m for harbour porpoise from the installation of mooring dolphins (280kJ hammer energy) for the temporary BLF without mitigation. Seals are less sensitive and the auditory effect range for PTS was predicted to be 16m from the mooring dolphins for the enhanced permanent BLF. Temporary auditory damage (TTS) may occur at a range of 169m for harbour porpoise and 30m for seals.

JNCC guidelines for minimising the risk of injury to marine mammals from piling noise stipulate that a 500m mitigation zone is established in which a marine mammal observer (MMO) completes pre-piling searches to detect the presence of marine mammals (JNCC, 2010). All instantaneous effect ranges are well within the 500m mitigation zone. Therefore, compliance with standard mitigation procedures is predicted to be effective in negating the risk of instantaneous auditory damage in marine mammals.

Further mitigation in the form of a hydrohammer can reduce underwater noise during pile driving. The concept is based on two hydraulic plungers filled with water designed to dampen the effect and reduce the source noise associated with impact piling. Hydrohammers have been suggested to reduce sound exposure levels (SEL) by 3 to 6dB and peak sound pressure levels (SPL) by 9 to 12dB (IHC IQIP, 2020). Indeed, when this was modelled there was a reduction of the worst-case (mooring dolphins for temporary BLF) PTS instantaneous effect ranges from 93m to 31m for harbour porpoise and from 16m to 5m for seals. Furthermore, the TTS instantaneous ranges are reduced from 169m to 68m for harbour porpoise and from 30m to 10m for seals. The reduction of the instantaneous effect zones for TTS and PTS for harbour porpoises is between 50% and 70% when using a hydrohammer. There was no material change for seals' instantaneous effect zones considering that the unmitigated ranges were less than 10m.

The application of this form of additional mitigation would reduce the predicted effect zones to an area in the immediate vicinity of the pile, thereby reducing the amount of noise pollution (noise abatement), through mitigation measures (Merchant and Robinson, 2020). However, even in the absence of the mitigation the effect ranges could be effectively monitored by MMOs as per the JNCC guidelines as outlined in the MMMP (BEEMS Technical Report TR509, [REP3-019]).

7.1.2 Cumulative auditory effects

Cumulative exposure to noise sources can result in predicted mortality, recoverable injury and TTS effects extending over larger areas. Should a marine mammal remain within the effect zone for the duration of the piling activities cumulative effects may occur.

Ramp-up procedures are a requirement of the Deemed Marine Licence (DML) (NNB Generation Company (SZC) Ltd., 2021c), whereby the hammer frequency is incrementally increased to full operational strike rates over a period no longer than 20 minutes. The intention is that by initiating piling at a lower frequency, marine mammals within the area have the opportunity to move away thereby reducing the likelihood of exposure to harmful noise levels (JNCC, 2010).

Modelling considered the scenario of a maximum of two piles or two dolphins per day to be installed in a 24-hour period. Fleeing behaviour was incorporated into the model. Piling is anticipated to occur over a 9 month period with a total of approximately 54 days of piling activities.

The modelling predicts no PTS in any of the scenarios, thus irreversible loss of hearing as a result of cumulative exposure to noise is not anticipated for marine mammals.

TTS was not predicted for seals in any of the cumulative modelled scenarios. For harbour porpoise the largest TTS effect zones were predicted to occur during piling for the mooring dolphins for the enhanced permanent BLF and the temporary BLF (5,230ha and 3,734ha, respectively). The use of a hydrohammer reduced these zones by approximately 60%.

For the scenario whereby piling occurs for both BLFs simultaneously (two piles installed for the enhanced permanent BLF and two piles installed for the temporary BLF within the longshore bar), the results of the fleeing model show that there would be no PTS for harbour porpoise or seals. The largest TTS effect zones were predicted to occur within 669ha for harbour porpoise. This increase in the effect zone is not substantially different than cumulative fleeing harbour porpoise TTS for the individual piling of the enhanced permanent BLF and temporary BLF without additional mitigation (491ha and 431ha, respectively). Further mitigation (i.e., use of hydrohammer) reduced the TTS area to 128ha.

The ecological effects of TTS are not completely clear, but it is thought that the effects depend on the magnitude of the TTS, the duration of the TTS and the affected hearing frequency. Reduced hearing may reduce the efficiency with which harbour porpoises can carry out ecologically important activities such as navigation, communication, foraging, and predator avoidance, thus potentially reducing their fitness and reproductive output. However, TTS is short lived and harbour porpoises are known to recover rapidly (usually within an hour) (Kastelein *et al*., 2015). The results of modelling indicate that the spatial extent of the TTS zones is limited in comparison to daily foraging ranges of porpoises (average daily movement of the animals in the North Sea is around 20km/day (Sveegaard *et al*. 2011)). However, whilst injurious effect zones are limited, behavioural avoidance and displacement is a potential concern and is assessed in greater detail in the ES Addendum.

7.1.3 Vessel traffic

The results of the vessel traffic modelling for the temporary BLF predict negligible PTS zones for harbour porpoise and seals even though the model assumed stationary animals. TTS was predicted within 251ha and 3ha for harbour porpoise and seals, respectively. As such, animals would have to remain within the vicinity of the temporary BLF for 24 hours to incur TTS. Marine mammals demonstrate a variable level of adverse reactions towards vessel traffic. However, it has been acknowledged that the underwater sounds created by large ships are unlikely to cause physical trauma but could make preferred habitats less attractive as a result of disturbance (i.e. habitat displacement, area avoidance), especially for harbour porpoises (JNCC, 2019). The potential for vessel traffic to cause behavioural disturbance to marine mammals or displacement from the area is considered in more detail in the ES Addendum (NNB Generation Company (SZC) Ltd., 2021a [AS-181]).

7.2 Fish

7.2.1 Instantaneous effects

In the case of impact piling, for the most sensitive hearing specialists such as herring, sprat, anchovy and shad, mortality and recoverable injury was predicted to be restricted to a small area within 46m of the sound source for the enhanced permanent BLF and 52m for the temporary BLF (worst-case mooring dolphins, 280kJ hammer energy).

Further mitigation in the form of using a hydrohammer reduces the instantaneous mortality effect ranges to 19m and 16m for the enhanced permanent BLF and temporary BLF, respectively.

7.2.2 Cumulative auditory effects

The cumulative effects for fish considered the same scenarios and assumptions for piling activities and vessel noise as described in the marine mammal summary (Section 7.1.2).

7.2.2.1 Hearing specialists

Hearing specialists are those species with a swim bladder or other air cavities that aid hearing, such as clupeids that are abundant off Sizewell. For hearing specialists, the largest mortality effect zones for cumulative piling activities is 11ha for the mooring dolphins associated with the temporary BLF without mitigation and 4ha with mitigation. Recoverable injury effect zones extend to 30ha without mitigation and 14ha with further mitigation for the temporary BLF.

TTS for hearing specialists is predicted to be 154ha and 580ha for the enhanced permanent BLF and temporary BLF, respectively. The TTS effect zones with further mitigation reduce to 81ha and 401ha for the enhanced permanent BLF and temporary BLF, respectively.

For the scenario whereby piling occurs for both BLFs simultaneously, effect zones are predicted to be 1ha for mortality and 1ha and 56ha for recoverable injury and TTS, respectively. Further mitigation reduces these areas to 0ha, 1ha and 32ha for mortality, recoverable injury, and TTS, respectively.

The effect zones for mortality and recoverable injury are spatially limited. Noise levels associated with TTS in fish may create physiological and behavioural stress responses similar to those found in mammals (Smith *et al*., 2004). However, unlike marine mammals, direct empirical evidence to support fleeing behaviour in models of fish behaviour is limited so the assessment has not included fleeing. The cumulative effect zones are therefore precautionary and the behavioural responses would lessen the effect zones. TTS effects are short-term with recovery likely. If species are displaced from ensonified areas, the mobility of the species should facilitate return to the affected areas after impact piling has ceased.

7.2.2.2 Less sensitive species

For less sensitive fish species including those species with a swim bladder that is not involved with hearing (e.g., European eel, seabass and whiting) the largest mortality effect zones for cumulative piling activities are predicted to be 5ha and 2ha for the temporary BLF without and with further mitigation, respectively.

For less sensitive fish species, recoverable injury thresholds are consistent with the hearing specialists summarised in 7.2.2.1.

For the least sensitive fish species with no swim bladder, recoverable injury and mortality cumulative effect zones were restricted to 25m.

For the scenario whereby piling occurs for both BLFs simultaneously, there are no mortality effect zones predicted. Recoverable injury effect zones are predicted to be 1ha and 0ha for those species with a swim bladder that is not involved with hearing and those species with no swim bladder respectively, which reduces to 1ha and 0ha with further mitigation. TTS thresholds for this scenario are consistent with the hearing specialists summarised in 7.2.2.1.

7.2.3 Behavioural responses

Behavioural responses or displacement from ensonified areas has the potential to temporarily affect migratory fish species or influence the availability of prey species including for designated birds or marine mammals. Quantitative behavioural response thresholds do not exist for fish. The potential for instantaneous behavioural responses was based on a 135dB re 1µPa^{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). During impact piling for the enhanced permanent BLF, the contour extends to an area of 2,009ha and for the temporary BLF the contour covers an area of 2,673ha. Further mitigation in the form of using a hydrohammer reduces these areas to 1,198ha and 1,763ha for the enhanced permanent BLF and the temporary BLF, respectively.

7.2.3.1 Migratory fish

The 9-month installation period coincides with migrations of shad, eel, smelt and lamprey. Modest noise levels at several kilometres distance from the sound source are unlikely to alter migratory behaviour particularly in species using selective tidal stream transport as an energetically efficient method to travel. Selective tidal stream transport is when fish leave the sea bed at or shortly after slack water, swim up into mid-water and are carried downstream by the tide before returning to the bottom about six hours later. Maturing fish use one tidal stream to reach their spawning grounds; fish that have spawned use the opposing stream to return to their feeding grounds (Metcalfe and Arnold, 1997). Fish in active migration closer to the sound source may not avoid the ensonified area, in which case the mortality, recoverable injury and TTS areas would be the same as for the assessments described in Table 6.6. Fish that do incur TTS may be subject to temporary reductions in fitness. However, whilst exposure to noise may result in physiological stress responses, there remains uncertainty about whether small changes in hearing thresholds have meaningful impacts on the fitness of fish in the wild (Popper and Hawkins, 2019).

The recti-linear tidal flows off Sizewell and behavioural responses to underwater noise mean predicting 'residence' time within a given effect zone is challenging as it would vary due to the direction of migration, the state of the tide and location of the fish at the onset of piling. Cumulative effect assessments assume no behaviour in fish and does not take into account the changes in sound exposure of fish as they near a noise source, pass it and then drift further away. In most cases the tidally dominated conditions off Sizewell would reduce the exposure of fish during piling activities relative to the static assessment. Tidal currents flow south for most of the rising (flood) tide (1.14 m/s (peak) seaward of Sizewell Bank) and flow north for most of the falling (ebb) tide (1.08 m/s). Tidal currents reduce close to shore and peak at about 0.2 m/s (NNB Generation Company (SZC) Ltd., 2020a). Starting with the worst-case cumulative TTS range (conservatively assumed the radius) of 1,992m from source during the installation of the mooring dolphins associated with the temporary BLF (Table 6.5, Figure 6.5), a number of theoretical scenarios can be considered to reflect exposure of migratory fish.

In the case of a fish passively moving[1] with the peak tidal flow (approximately 1m/s) from north to south across the entire TTS effect zone, it would remain within the effect zone for approximately 1 hour, notwithstanding the potential for greater behavioural responses closer to the noise source. In such a scenario it would be exposed for less than half the total period of piling (Table 2.3), for the installation of two piles in the cumulative assessment. Equally if the fish remained within the TTS effect zone or was moving close to the shore in the slower tidal flows it could potentially be exposed to the full piling duration and incur TTS Alternatively, if the tide was running against the direction of migration at the onset of piling, species which maintain position close to the seabed awaiting the next tide could be exposed for the full duration of piling events. In such a scenario the predicted cumulative effect zones apply as behavioural avoidance is not included in the model.

Based on the predicted effect ranges, and the local hydrodynamics, the true exposure is likely to be less than currently predicted particularly where fish avoid avoidance behaviours close to the sound source occur.

7.2.3.2 Prey species

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 does not necessitate displacement from the area particularly for species with lower hearing 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 135dB re 1µPa^{2}s threshold is likely to be conservative for these species and additional 142dB re 1µPa^{2}s ranges based on mackerel (no swim bladder) response zones vary from 41ha for the piling for the enhanced permanent BLF (135dB re 1µPa^{2}s threshold) to 1,763ha (142dB re 1µPa^{2}s) for the piling of mooring dolphins for the temporary BLF (see Sections 6.1.1.2.1 and 6.1.2.2.1). These behavioural response ranges do not exclude a distinct behavioural response induced through particle motion instead of sound pressure level detection.

Behavioural response zones should therefore be treated as indicative areas over which such responses may occur. To mitigate the effects of piling on designated breeding birds, no piling would occur in the months of May, June or July. Therefore, any changes in behaviour with the potential to influence availability of fish as a prey resource should not affect breeding birds.

[1] Not accounting for swimming speed in the tidal flow which, as a rule of thumb, is ~0.6 body lengths/second.

7.2.4 Vessel traffic

The results of the vessel traffic modelling for the temporary BLF predict negligible PTS zones even for stationary fish. TTS was predicted to an area of 31ha. As such, fish would have to remain within the immediate vicinity of the temporary BLF for 24 hours to incur TTS.

Vessel movements can elicit behavioural responses in different fish species. Pelagic fish (including sardine and mackerel) schools have demonstrated avoidance reactions at ranges of between 150m to 400m (Davies *et al*., 2009). Following vessel disturbance, fish return to previously disturbed areas and this has been shown to occur rapidly for a range of species (Vabø *et al*., 2002; Mitson, 1995; Ivanova *et al*., 2020). For example, the original pattern of haddock distribution was re-established by the time the vessel was 400m away, some four or five minutes later (Davies *et al*., 2009).

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Appendix A Enhanced Permanent Beach Landing Facility Figures

A.1 Marine mammals

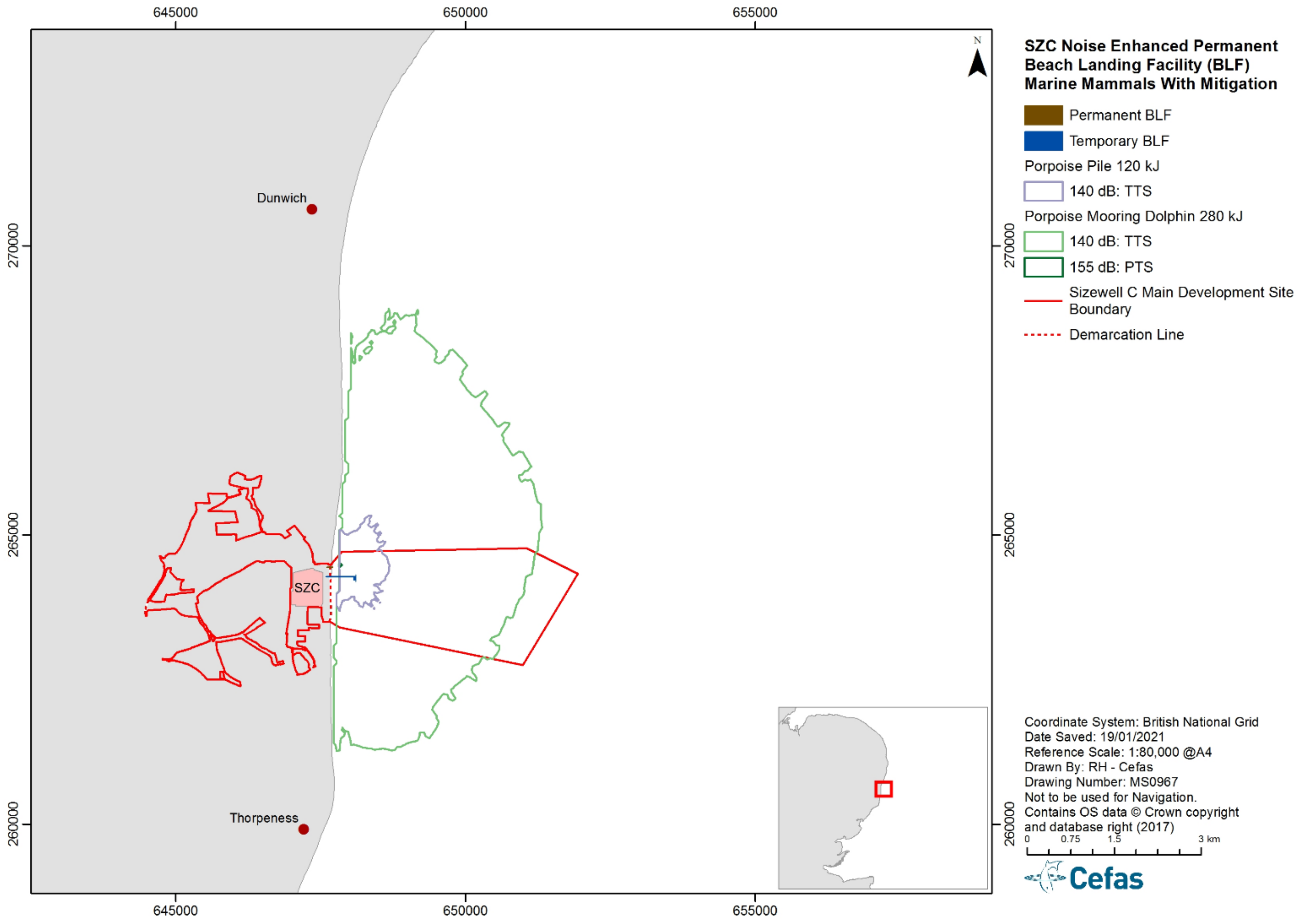

Figure A.1: Marine mammal auditory effect zones (seal auditory effect zones are not shown as <25m from source) for piling activities associated with the enhanced permanent BLF with further mitigation measures

A.2 Fish

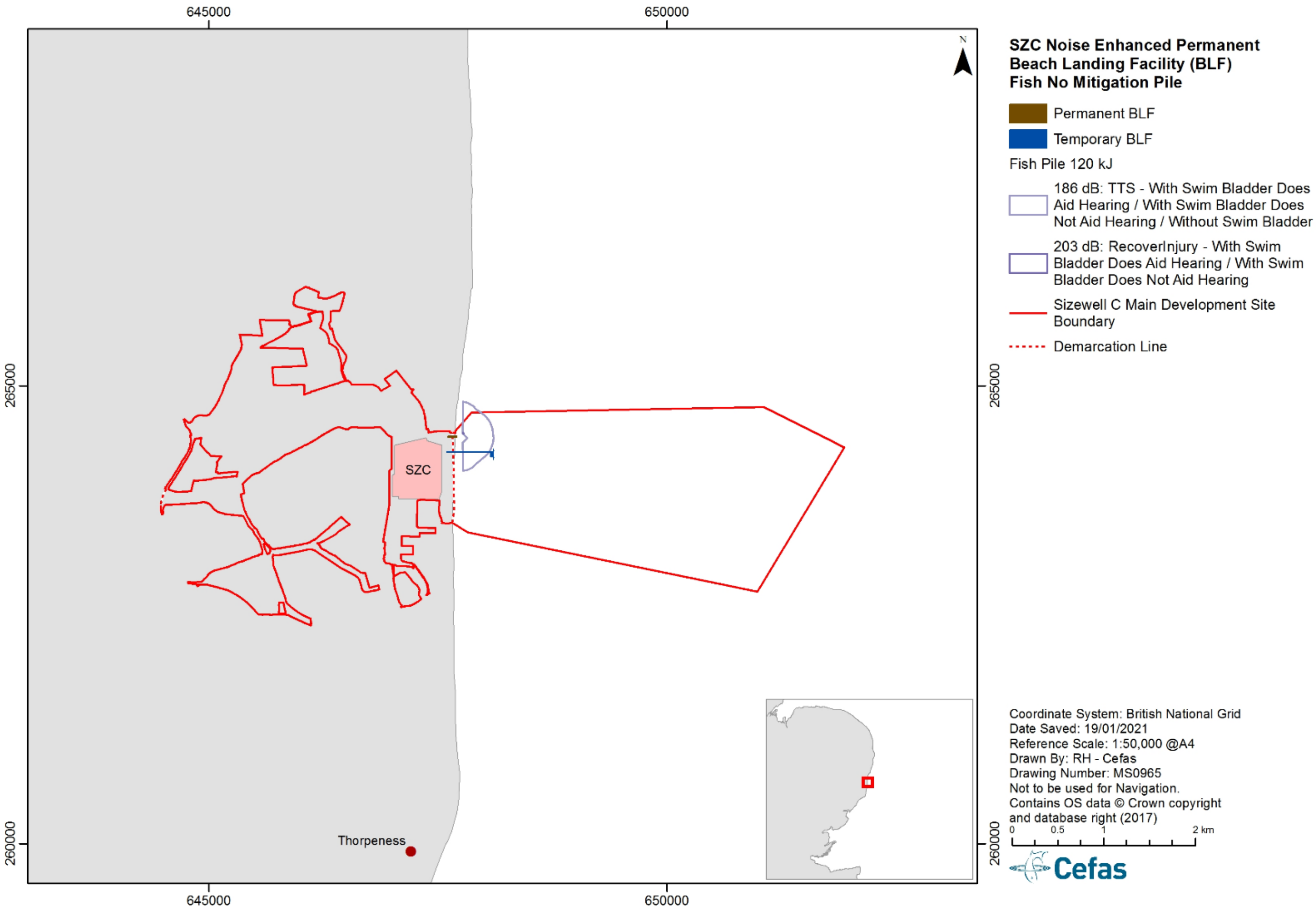

Figure A.2: Predicted recoverable injury and TTS effect zones for fish, for piling associated with the enhanced permanent BLF

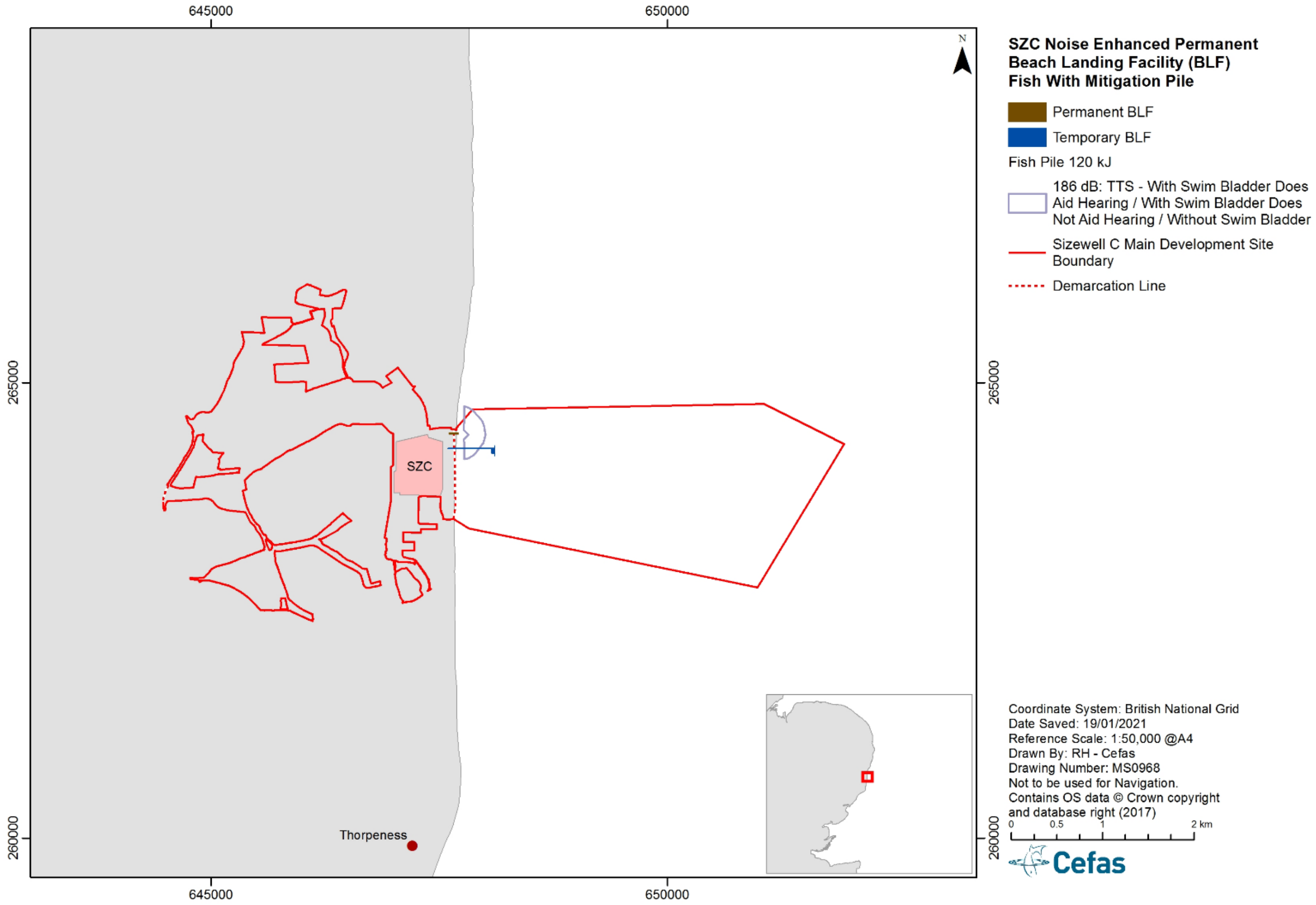

Figure A.3: Predicted TTS effect zones for fish, for piling associated with the enhanced permanent BLF with further mitigation measures

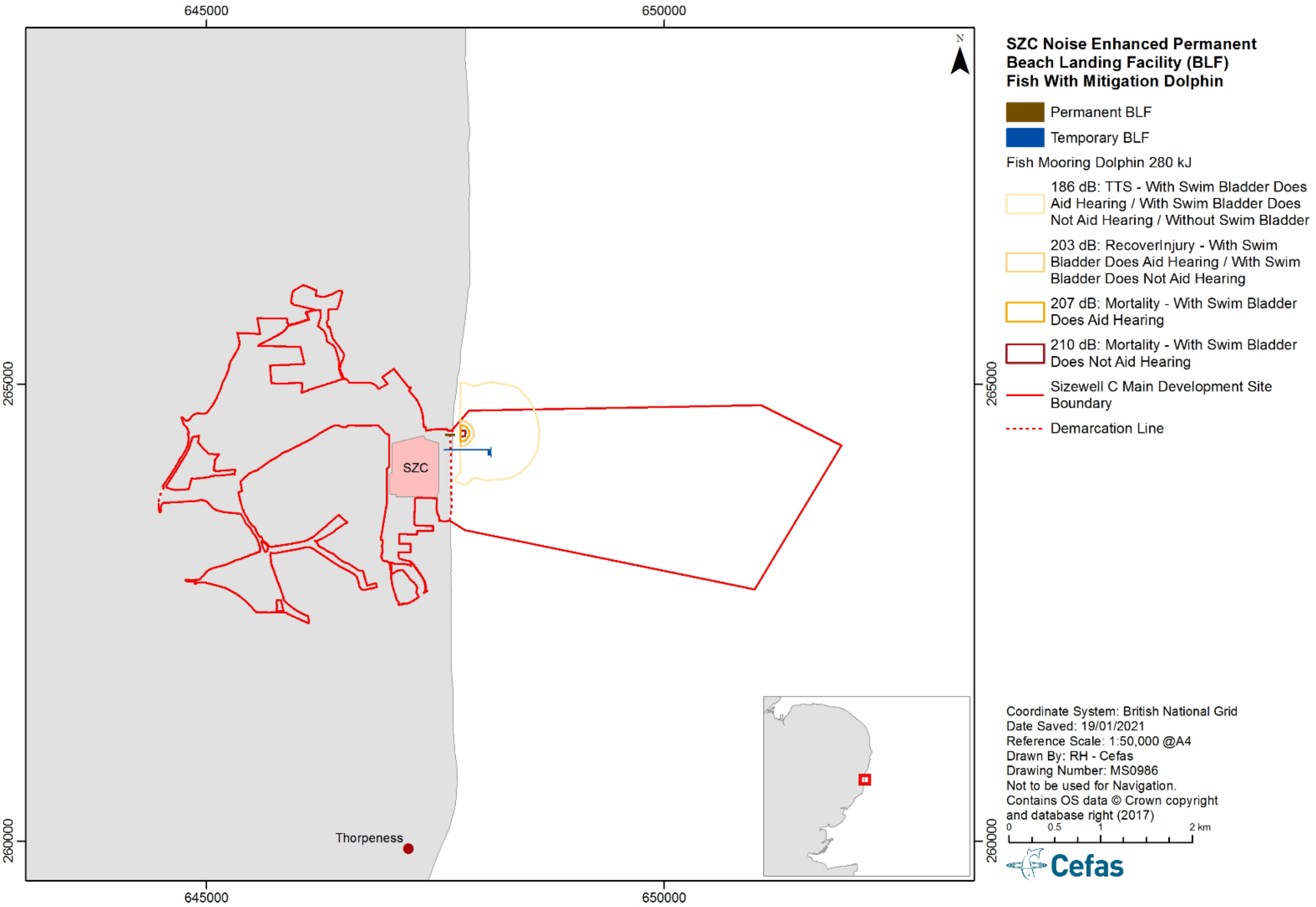

Figure A.4: Predicted mortality, recoverable injury and TTS effect zones for fish, for piling of mooring dolphins associated with the enhanced permanent BLF with further mitigation measures

A.3 Fish behaviour

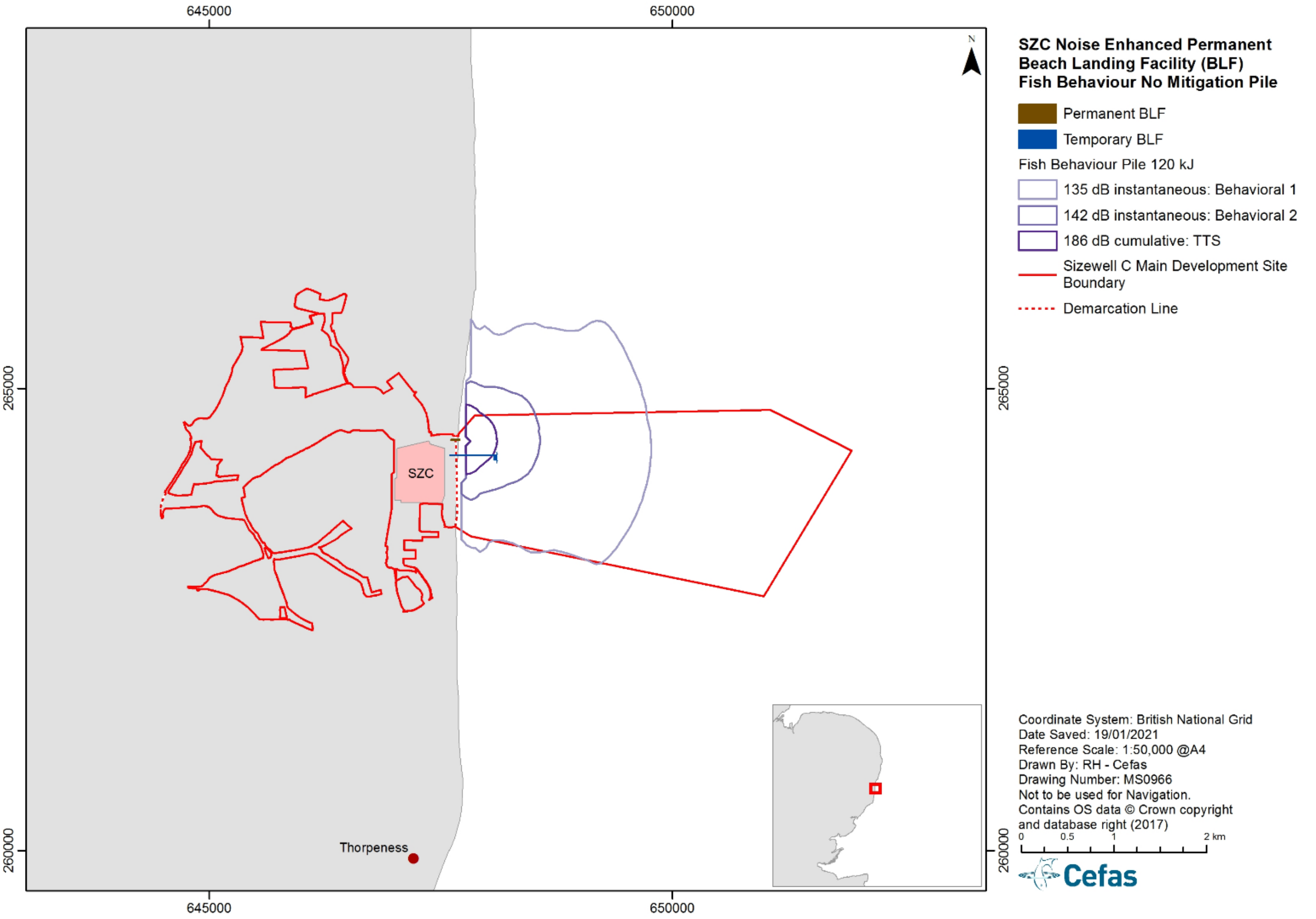

Figure A.5: Behavioural effect contours for impact piling for the enhanced permanent BLF, based on startle response observations in sprat and mackerel, the TTS 186dB contour is also shown for reference

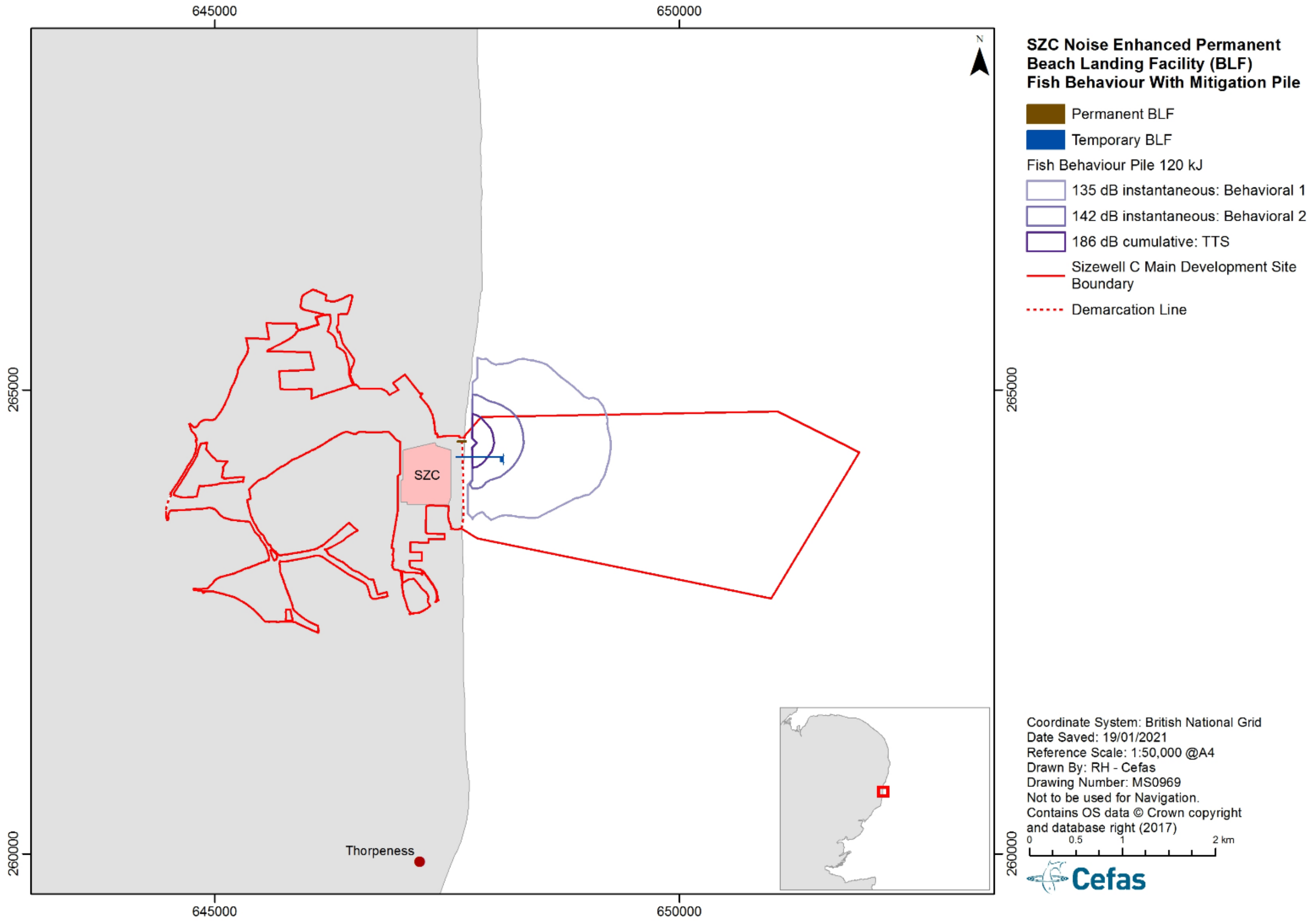

Figure A.6: Behavioural effect contours for impact piling for the enhanced permanent BLF, based on startle response observations in sprat and mackerel with further mitigation measures, the TTS 186dB contour is also shown for reference

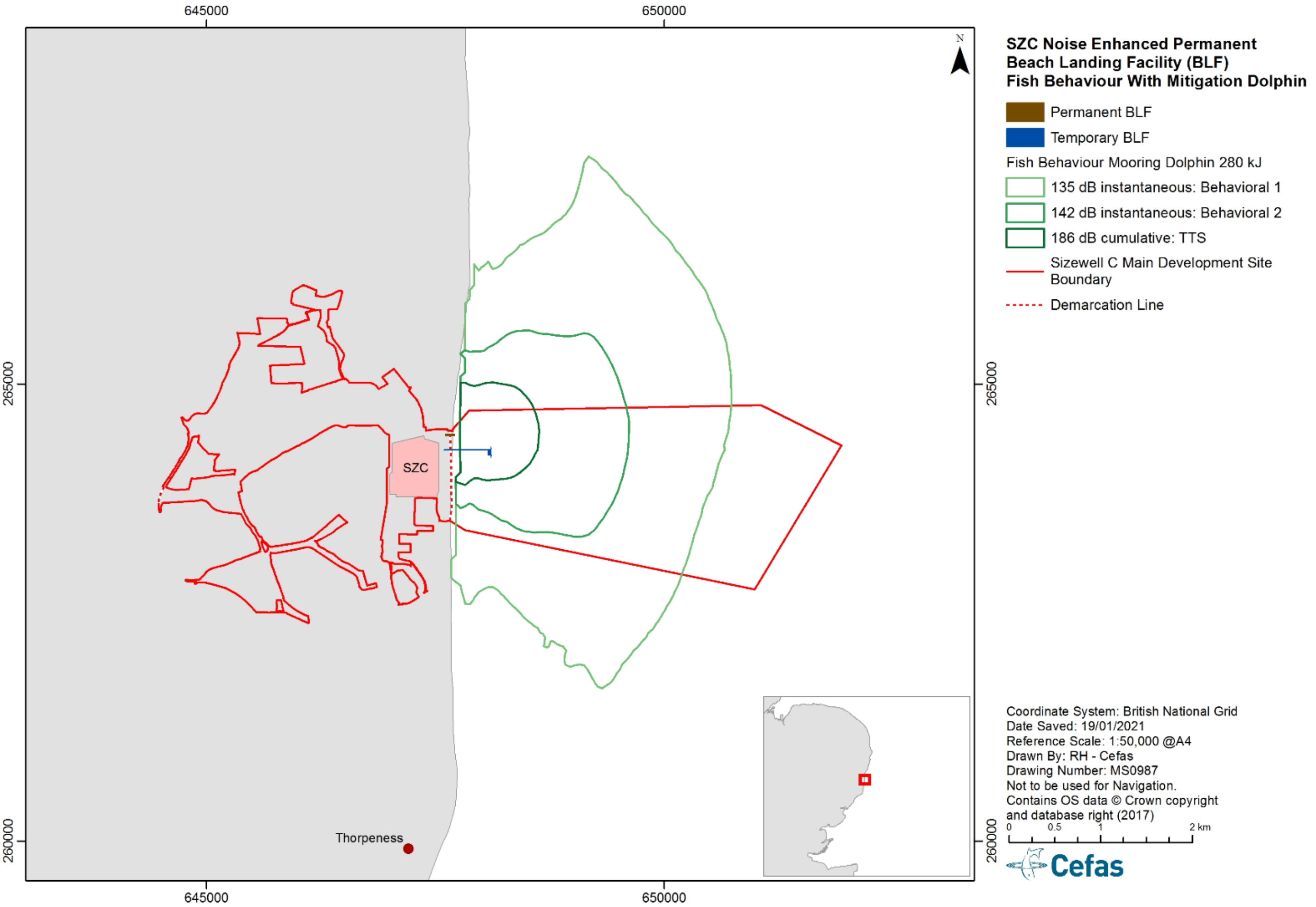

Figure A.7: Behavioural effect contours for piling of mooring dolphins for the enhanced permanent BLF, based on startle response observations in sprat and mackerel with further mitigation measures, the TTS 186dB contour is also shown for reference

Appendix B Temporary Beach Landing Facility Figures

B.1 Marine mammals

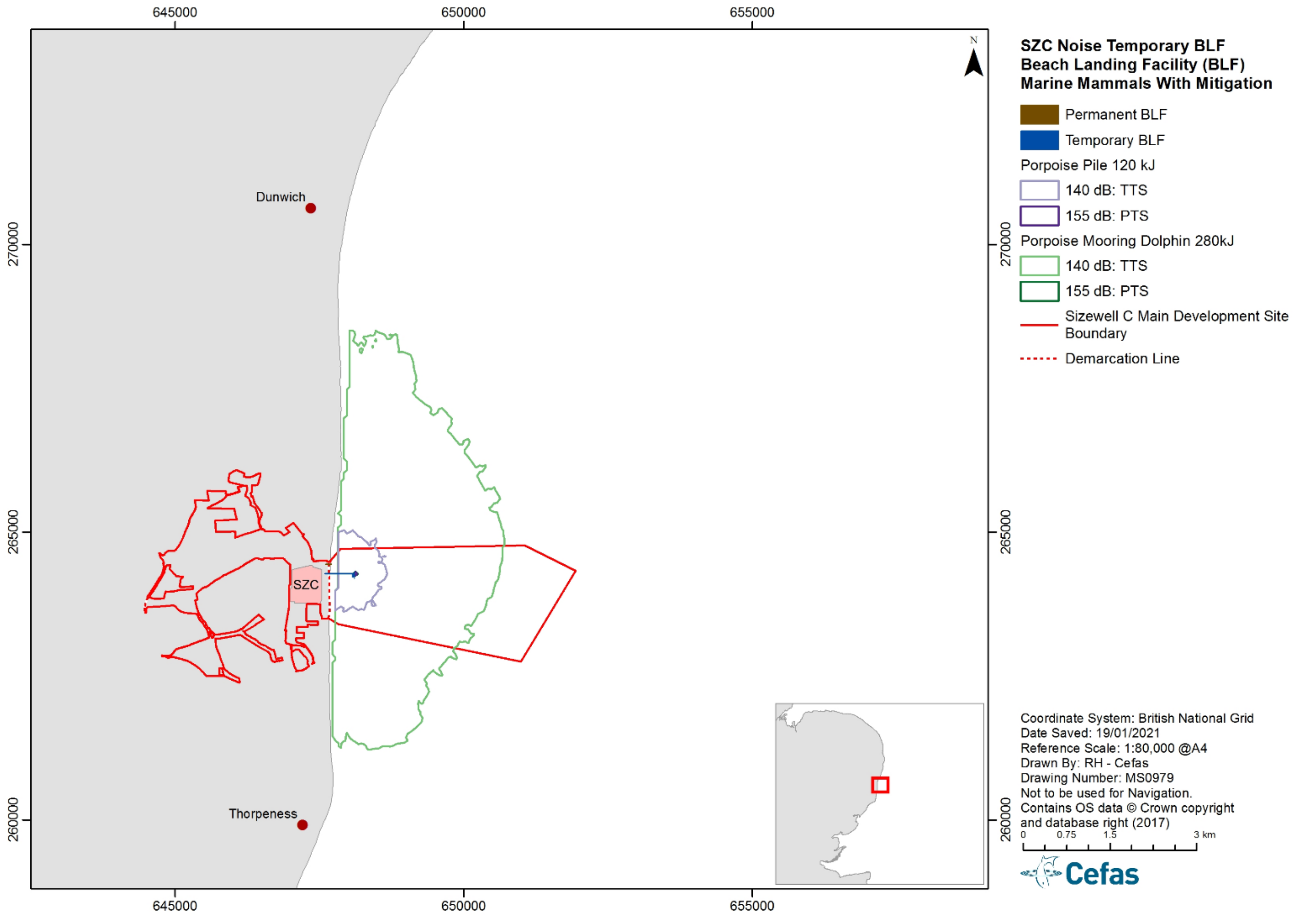

Figure B.1: Marine mammal auditory effect zones (seal auditory effect zones are not shown as <25m from source) for piling activities associated with the temporary BLF with further mitigation measures

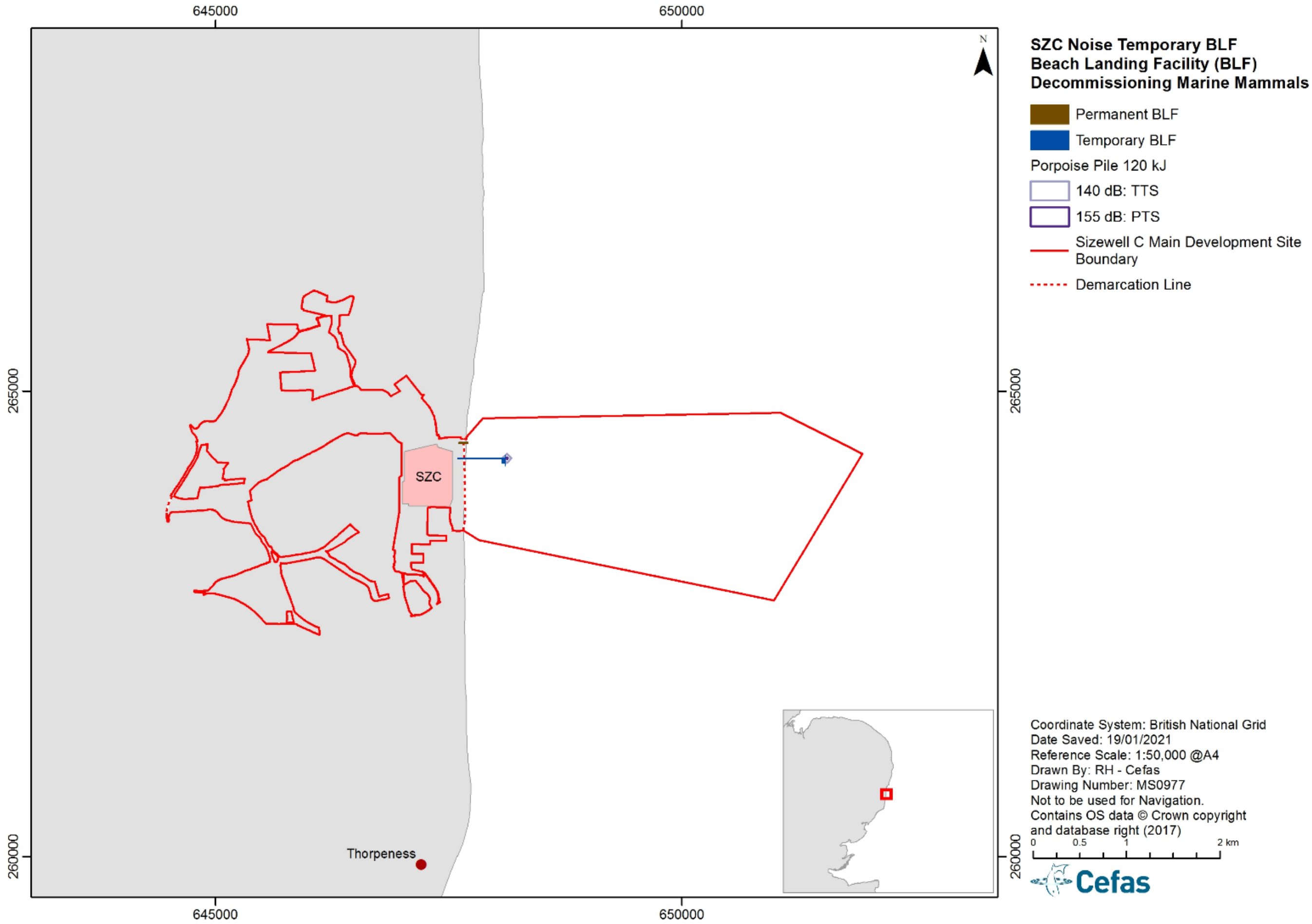

Figure B.2: Marine mammal auditory effect zones (seal auditory effect zones are not shown as <25m from source) for activities associated with the removal of the temporary BLF (piling)

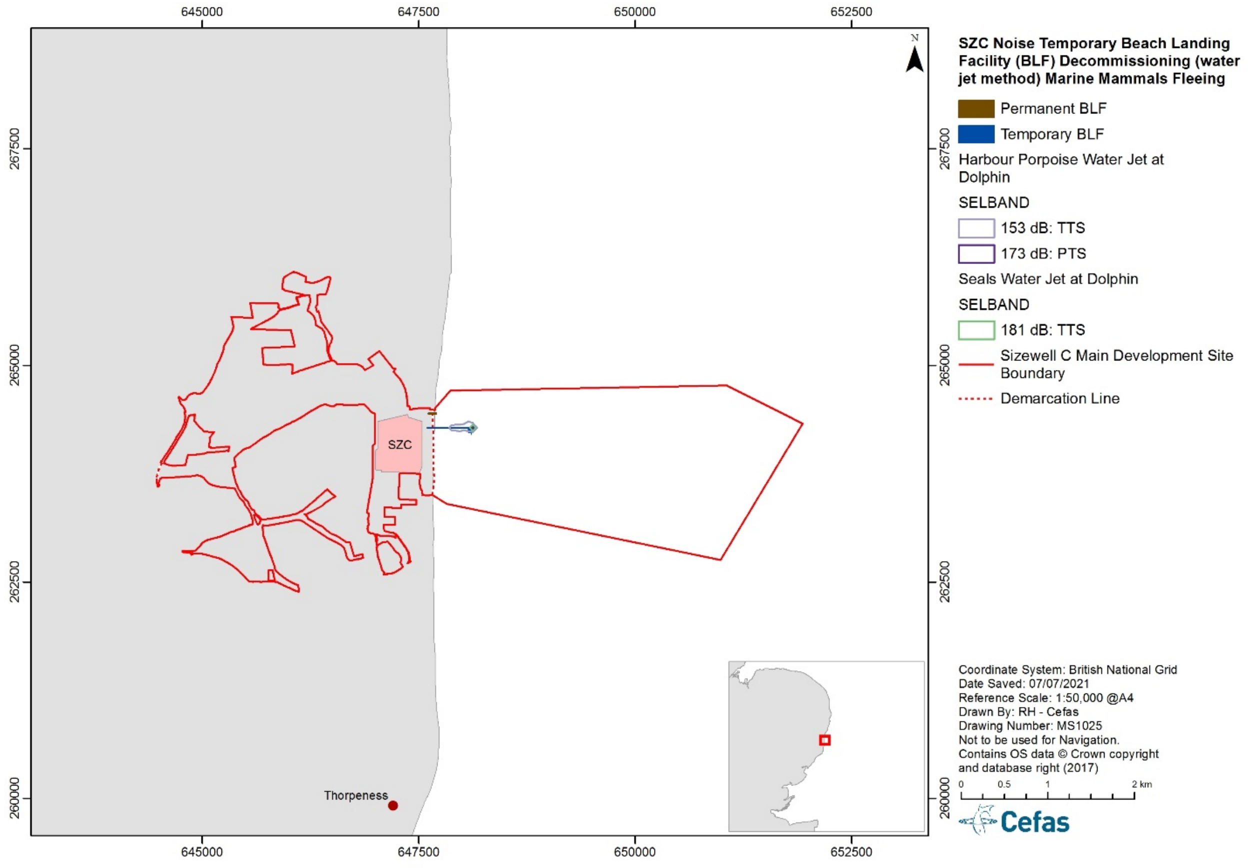

Figure B3: Marine mammal auditory effect zones for activities associated with the removal of the temporary BLF (water jet cutting)

B.2 Fish

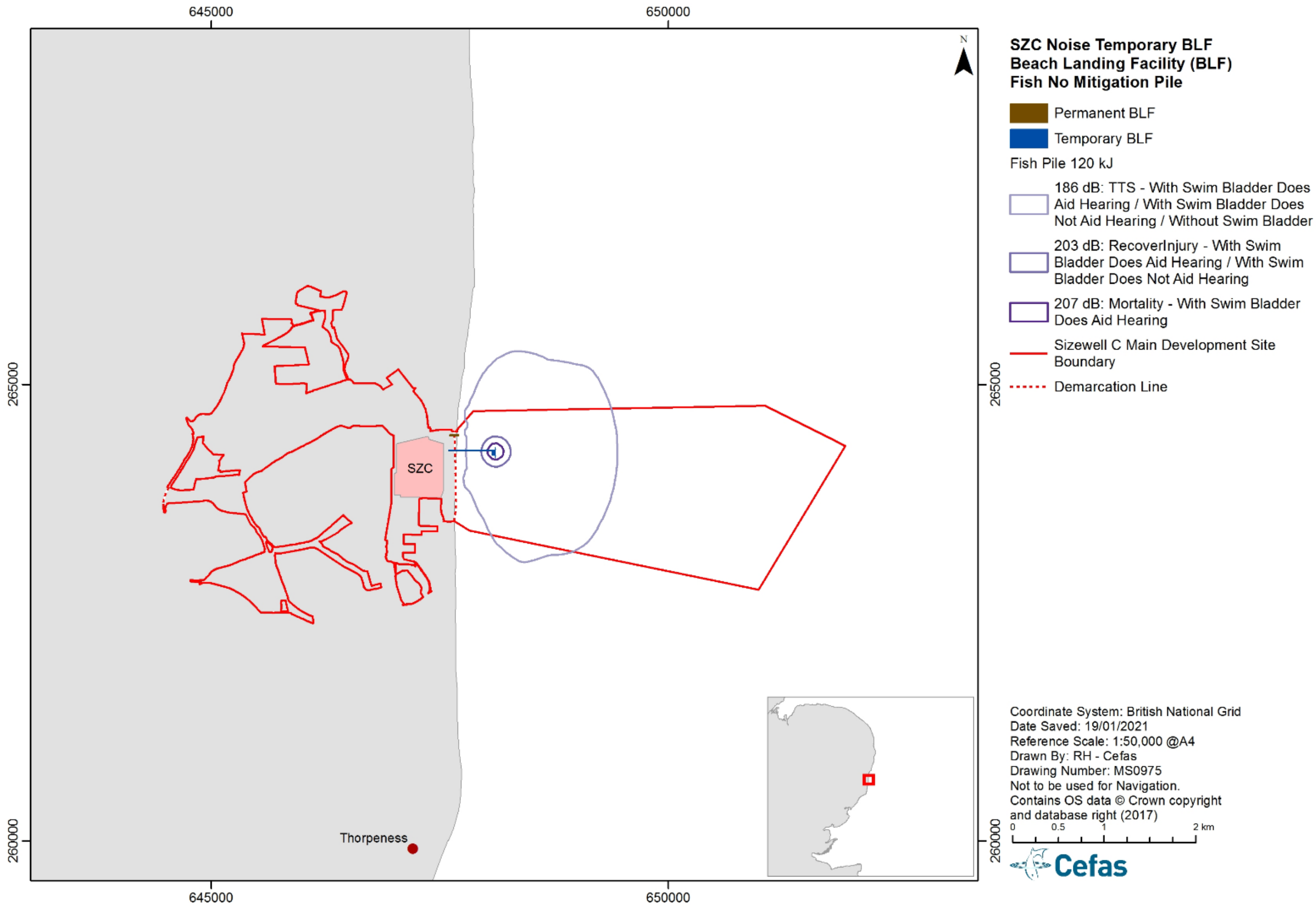

Figure B4: Predicted mortality, recoverable injury and TTS effect zones for fish, for piling activities associated with the temporary BLF

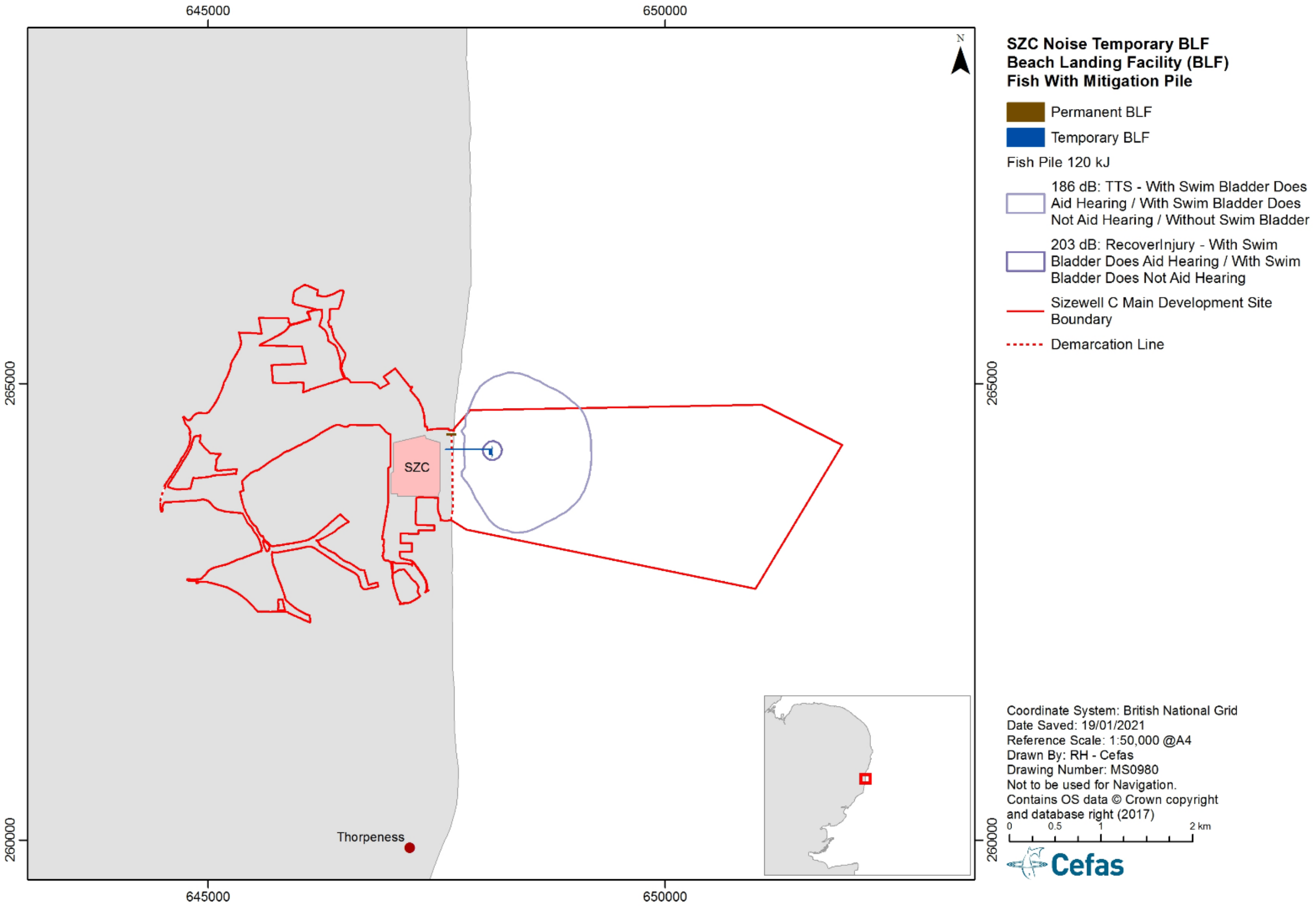

Figure B.5: Predicted recoverable injury and TTS effects zones for fish, for piling activities associated with the temporary BLF with further mitigation measures

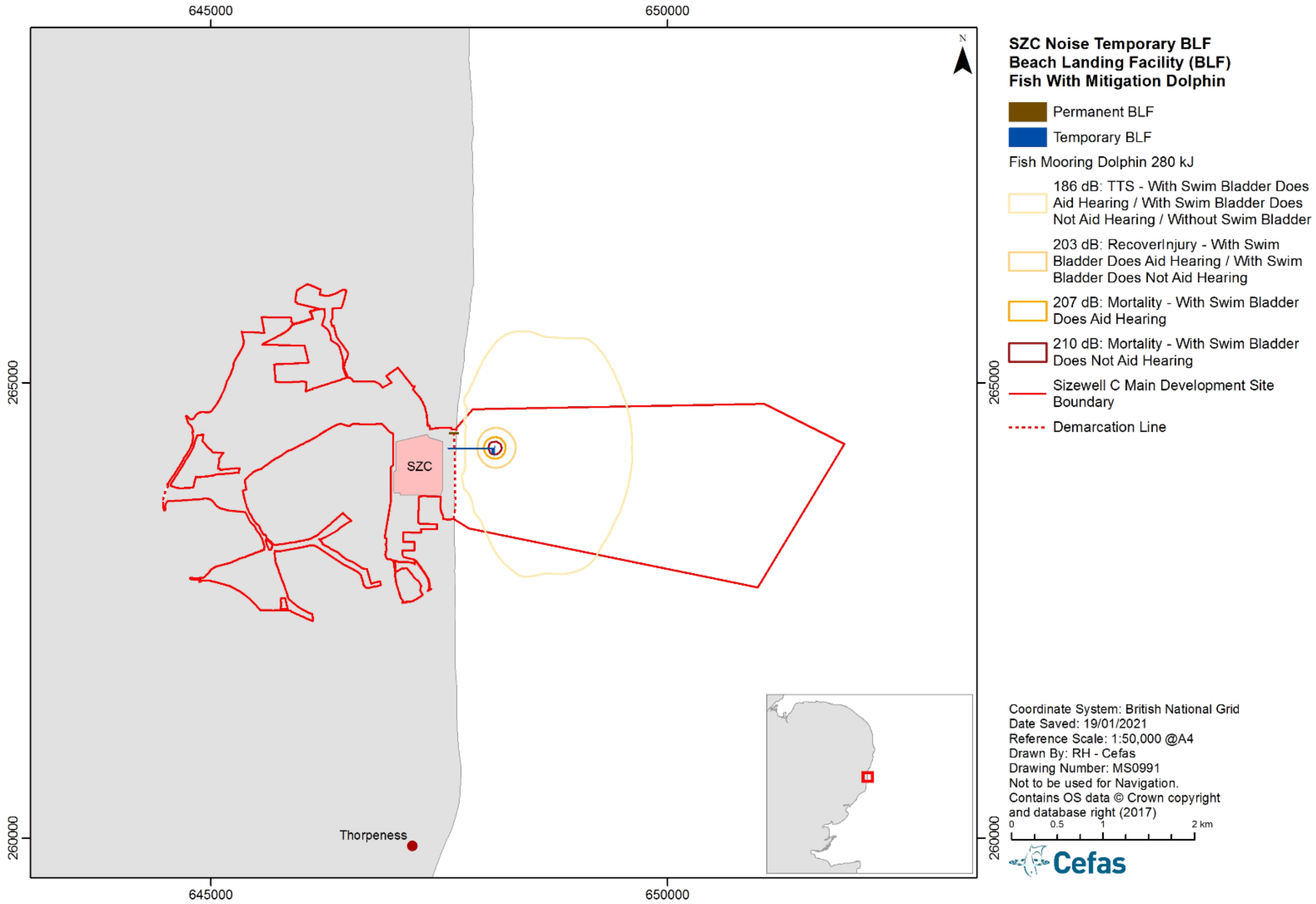

Figure B.6: Predicted mortality, recoverable injury and TTS effect zones for fish, for piling of mooring dolphins associated with the temporary BLF with further mitigation measures

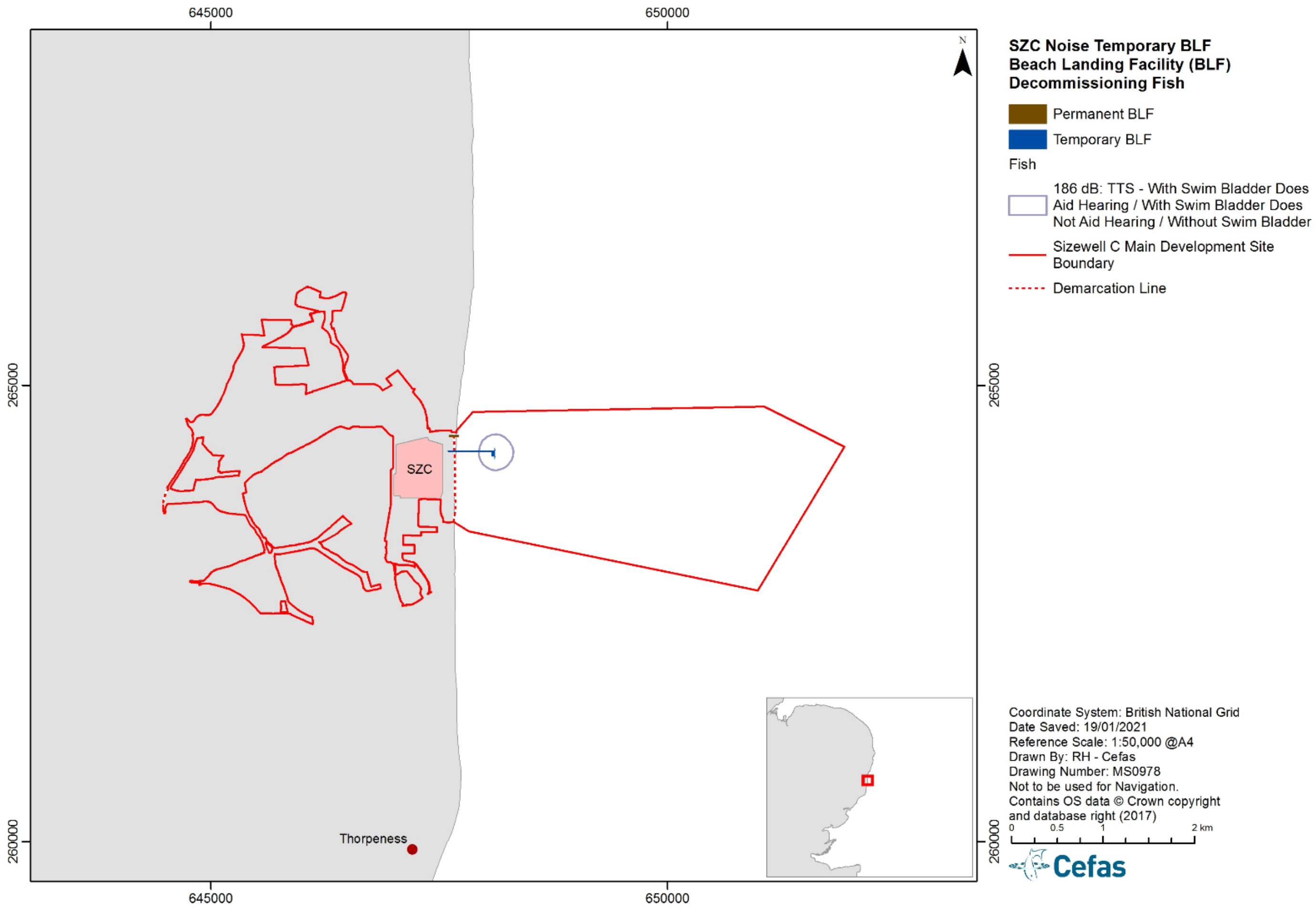

Figure B.7: Predicted TTS effects zones for fish, for pile removal activities associated with decommissioning the temporary BLF (piling)

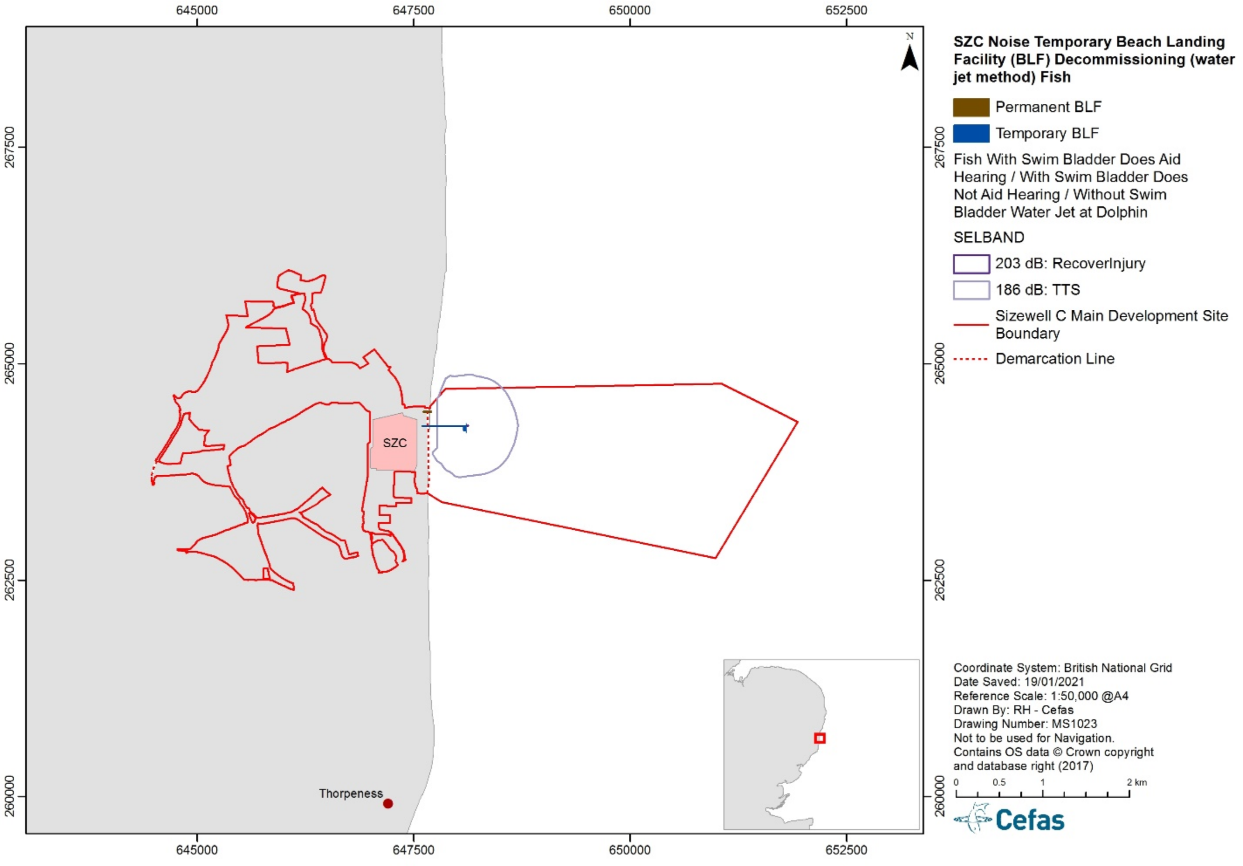

Figure B.8: Predicted Recoverable Injury and TTS effects zones for fish, for pile removal activities associated with decommissioning the temporary BLF (water jet cutting)

B.3 Fish behaviour

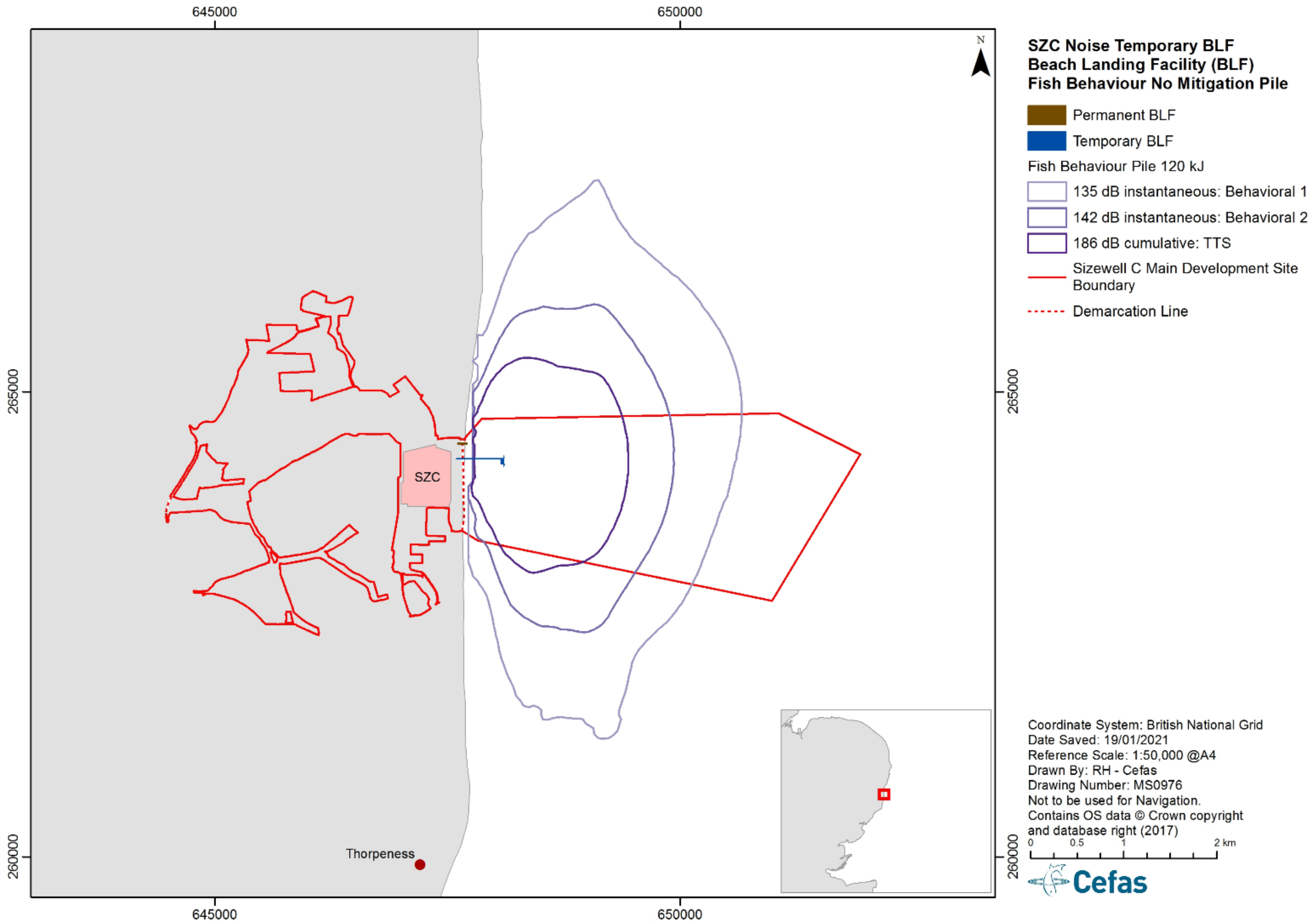

Figure B.9: Behavioural effect contours for piling activities for the temporary BLF, based on startle response observations in sprat and mackerel, the TTS 186dB contour is also shown for reference

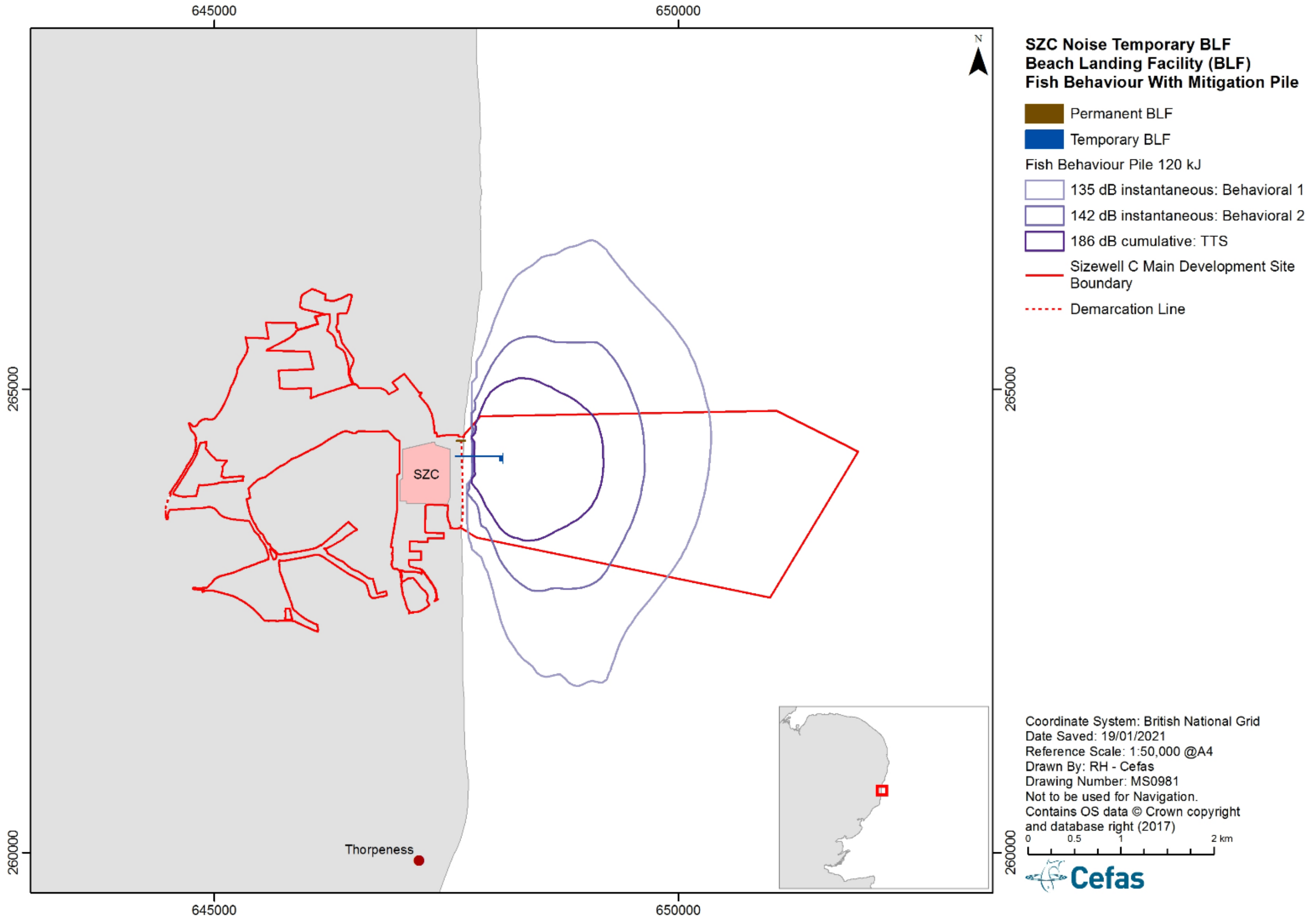

Figure B.10: Behavioural effect contours for impact piling of the temporary BLF with further mitigation measures, based on startle response observations in sprat and mackerel, the TTS 186dB contour is also shown for reference

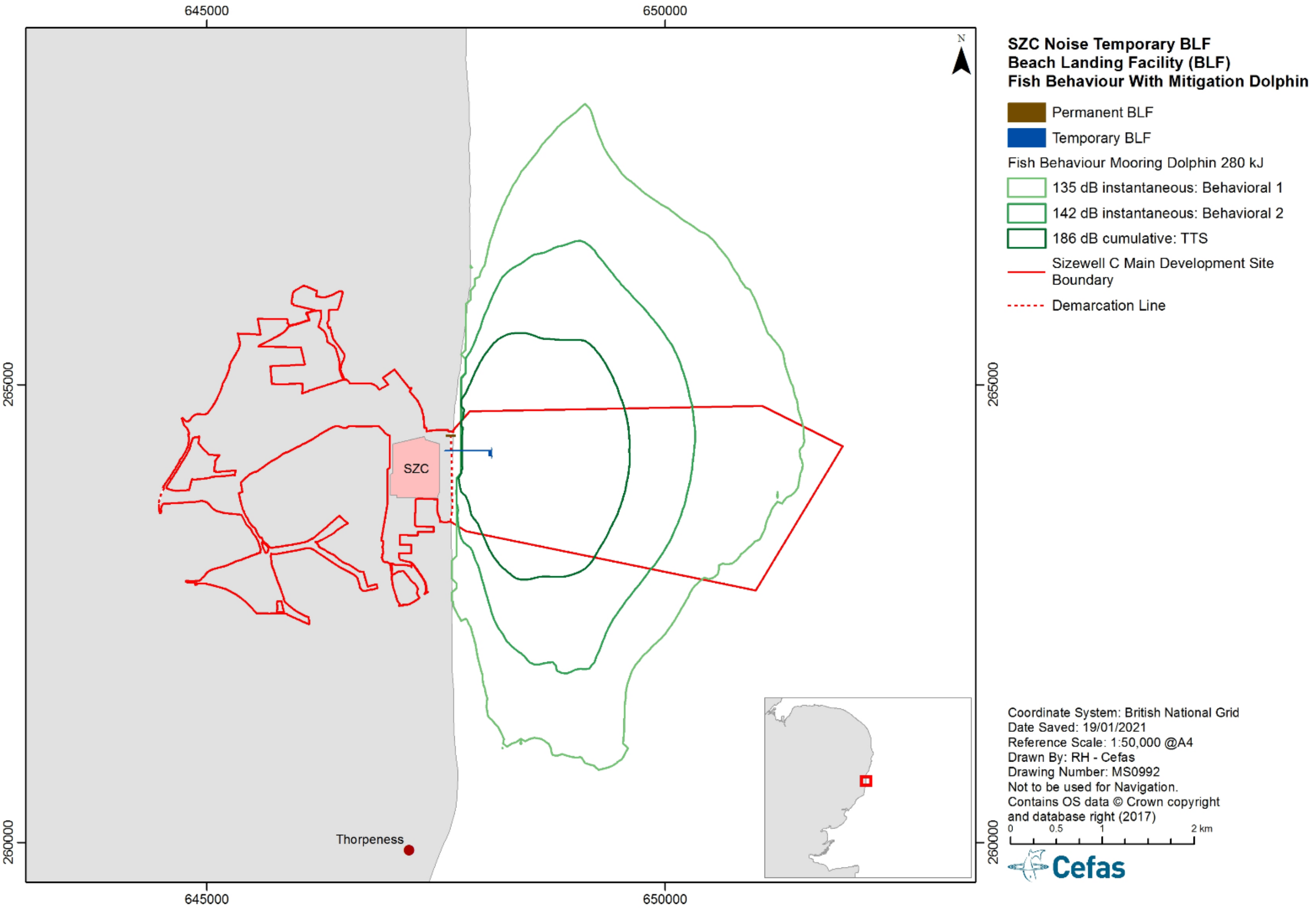

Figure B.11: Behavioural effects contours for piling of mooring dolphins for the temporary BLF with further mitigation measures, based on startle response observations in sprat and mackerel, the TTS 186dB contour is also shown for reference

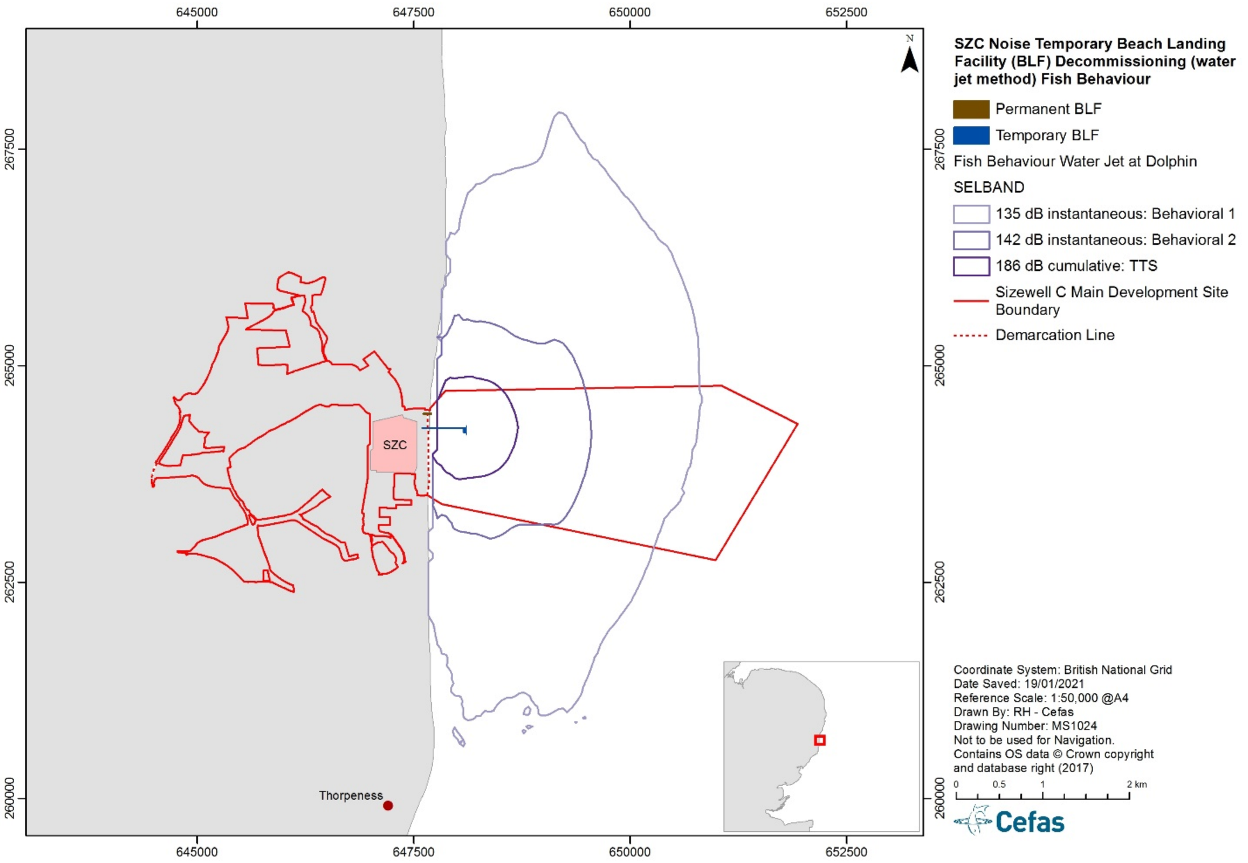

Figure B.12: Behavioural effect contours for pile removal activities associated with decommissioning the temporary BLF (by water jet cutting), based on startle response observations in sprat and mackerel with further mitigation measures, the TTS 186dB contour is also shown for reference

Appendix C Underwater noise contour intersect areas with SPA bird foraging ranges

C.1 Mean foraging areas (except for little tern where only predicted ranges apply)

Table C.1: Behavioural effect zone for vessel noise associated with the revised marine freight options, based on startle response observations in sprat and mackerel and the intersect with SPA bird mean foraging areas. No piling would occur in the months of May, June or July to minimise the potential for effects on designated breeding birds

SPA	Species	Location	Threshold	Temporary BLF Vessel noise*		Both BLFs (combined) Vessel noise*	
				Intersect area	% foraging range	Intersect area	% foraging range
Outer Thames Estuary	Breeding Common tern (*Sterna hirundo*)	Minsmere	135dB instantaneous	45.07	1.45	54.30	1.74
			142dB instantaneous	7.40	0.24	9.35	0.30
Alde-Ore Estuary	Breeding Lesser black-backed gull (*Larus fuscus*)	Orfordness	135dB instantaneous	45.07	0.00	54.30	0.01
			142dB instantaneous	7.40	0.00	9.35	0.00
Alde-Ore Estuary	Breeding Sandwich tern (*Sterna sandvicensis*)	Minsmere	135dB instantaneous	45.07	0.23	54.30	0.28
			142dB instantaneous	7.40	0.04	9.35	0.05
		Orfordness	135dB instantaneous	N/A	N/A	N/A	N/A
			142dB instantaneous	N/A	N/A	N/A	N/A
		Slaughden	135dB instantaneous	45.07	0.20	54.30	0.24
			142dB instantaneous	7.40	0.03	9.35	0.04

*Note: vessel noise is continuous whereas the inferred behavioural contour is for impulsive noise

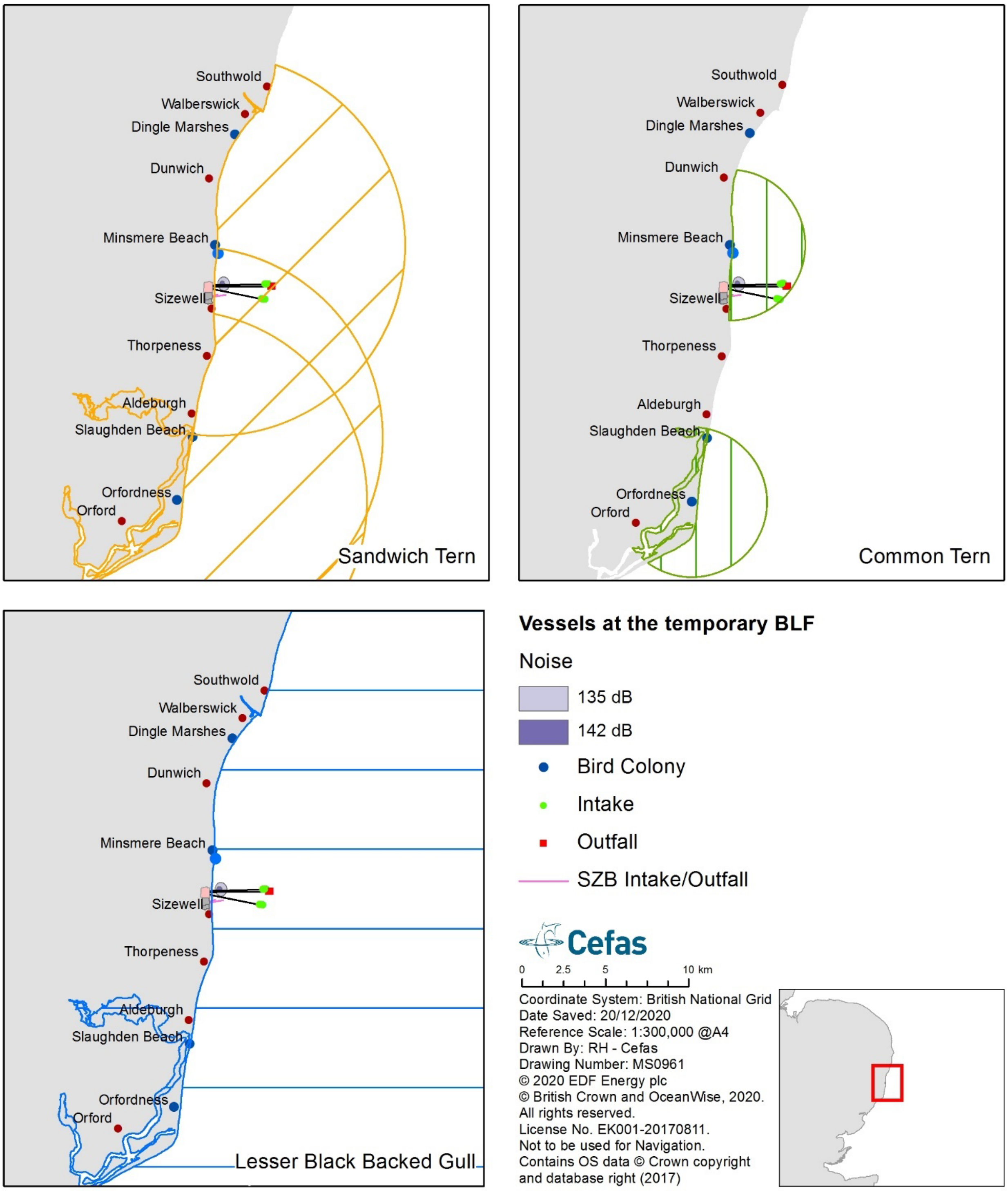

Figure C.1: Behavioural contours for the case of 24-hour vessel activity at the temporary BLF, based on startle response observations in sprat and mackerel and the intersect with SPA bird mean foraging areas

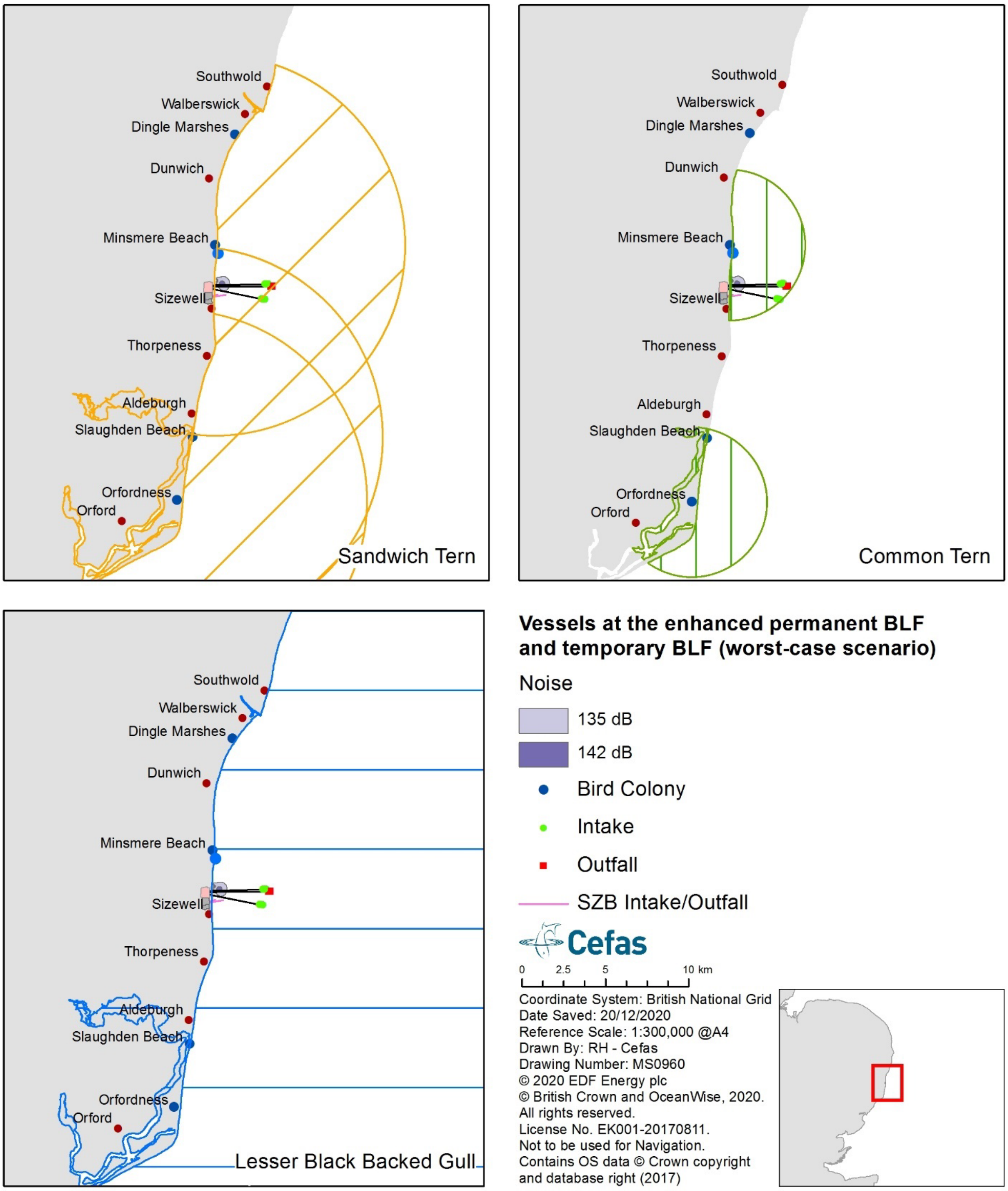

Figure C.2: Behavioural contour for the case of 24-hour vessel activity at the enhanced permanent BLF and temporary BLF, based on startle response observations in sprat and mackerel and the intersect with SPA bird mean foraging areas

C.2 Predicted (maximum) foraging areas

Table C.2: Behavioural effect zone for vessel noise associated with the revised marine freight options, based on startle response observations in sprat and mackerel and the intersect with SPA bird predicted (maximum foraging areas). No piling would occur in the months of May, June or July to minimise the potential for effects on designated breeding birds.

SPA	Species	Location	Threshold	Temporary BLF Vessel noise*		Both BLFs (combined) Vessel noise*	
				Intersect area	% foraging range	Intersect area	% foraging range
Minsmere to Walberswick	Breeding Little tern (*Sterna albifrons*)	Minsmere	135dB instantaneous	45.07	2.49	54.30	3.00
			142dB instantaneous	7.40	0.41	9.35	0.52
Outer Thames Estuary	Breeding Common tern (*Sterna hirundo*)	Minsmere	135dB instantaneous	45.07	0.09	54.30	0.11
			142dB instantaneous	7.40	0.01	9.35	0.02
		Orfordness	135dB instantaneous	45.07	0.07	54.30	0.09
			142dB instantaneous	7.40	0.01	9.35	0.01
Alde-Ore Estuary	Breeding Sandwich tern (*Sterna sandvicensis*)	Minsmere	135dB instantaneous	45.07	0.03	54.30	0.03
			142dB instantaneous	7.40	0.00	9.35	0.01
		Orfordness	135dB instantaneous	45.07	0.02	54.30	0.03
			142dB instantaneous	7.40	0.00	9.35	0.00
		Slaughden	135dB instantaneous	45.07	0.03	54.30	0.03
			142dB instantaneous	7.40	0.00	9.35	0.01
Alde-Ore Estuary	Breeding Lesser black-backed gull (*Larus fuscus*)	Orfordness	135dB instantaneous	45.07	0.00	54.30	0.00
			142dB instantaneous	7.40	0.00	9.35	0.00

* Note: vessel noise is continuous whereas the inferred behavioural contour is for impulsive noise

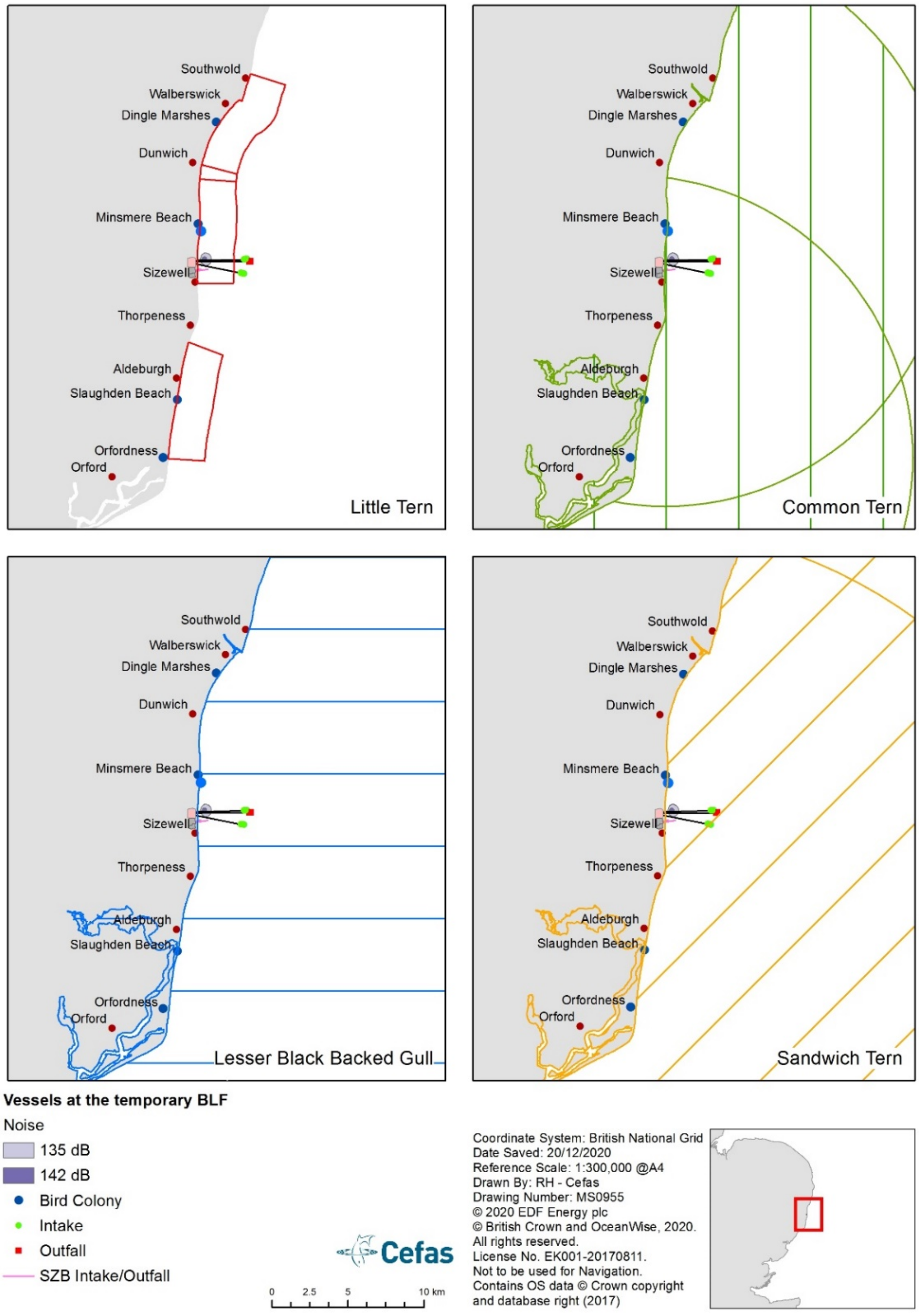

Figure C.3: Behavioural contour for the case of 24-hour vessel activity at the temporary BLF, based on startle response observations in sprat and mackerel and the intersect with SPA bird predicted (maximum) foraging areas

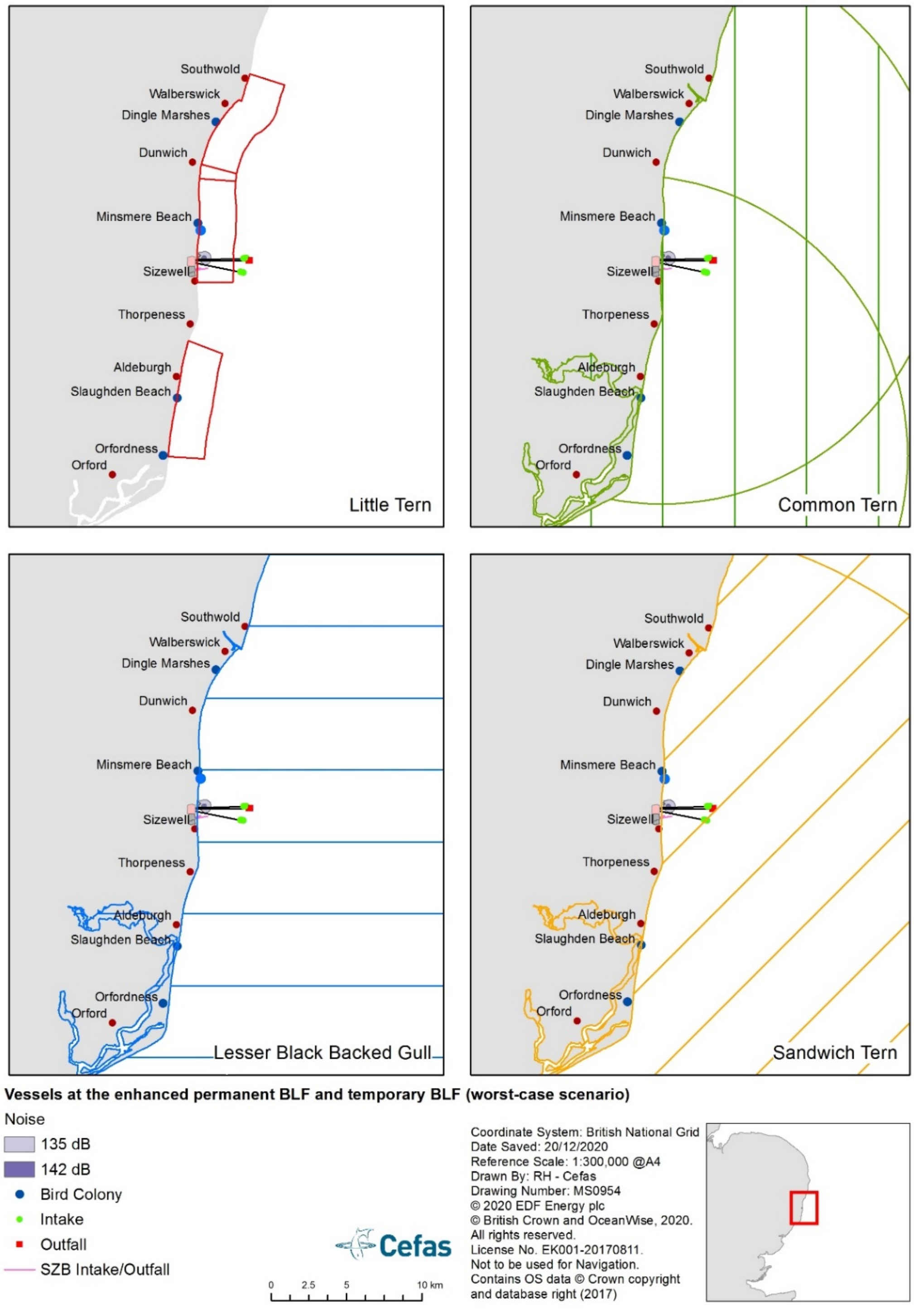

Figure C.4: Behavioural contour for the case of 24-hour vessel activity at the enhanced permanent BLF and temporary BLF, based on startle response observations in sprat and mackerel and the intersect with SPA bird mean foraging areas