HR Wallingford
Working with water

Rampion Windfarm

Simultaneous piling assessment

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Summary

In order to support E.ON's request for the modification of seasonal restrictions on piling at the Rampion Offshore windfarm, HR Wallingford was commissioned to examine underwater noise propagation arising from a reduction in the proposed hammer energy. The results of these studies are reported in DLR5374-RT001-R03-00 (underwater noise modelling), DLR5374-RT002-R02-00 (Seasonal restrictions review) and DLR5374-RT004-R01-00 (Reduced hammer energies).

Following a review of that work by the Marine Management Organisation (MMO), E.ON asked HR Wallingford to re-analyse the previous model results for marine mammals and herring using different metrics to allow for comparison of the modelling with that described in the original EIA for the Rampion project (RSK Environmental Ltd, 2012). The results of these studies are reported on in DDM7600-RT007-R01-00 and DDM7600-RT004-R01-00.

Further modelling was also undertaken to assess the effects of simultaneous piling events at two locations (both 2no. x 2300kJ, and 1no. x 2300kJ, 1no. x 3500kJ).

Mammals

The M-weighted cumulative SEL metric for fleeing mammals (Southall *et al*, 2007) was used to assess the potential impacts of simultaneous piling on marine mammals. Model simulations for simultaneous piling showed the maximum distances for onset of PTS (Permanent Threshold Shift) for low, mid and high frequency cetaceans are 5.6km, 1.9km and 0.9 km respectively and for pinnipeds the equivalent distance is 45 km. Distances for TTS (Temporary Threshold Shift) are much larger with values in the range of 41-75 km for cetaceans and 188 km for pinnipeds. Increasing the hammer energy to 3500 kJ results in an increase in these distances, with values for low, mid and high frequency cetaceans of 8.2 km, 2.7 km and 1.5 km respectively and 50 km for pinnipeds. Maximum distances for TTS with these two hammer energies are in the range of 46-89 km for cetaceans and 212 km for pinnipeds.

It is important to note that the model results assume that no mitigation methods such as soft-start, were used. Such measures could initiate the flee response at sound levels below the PTS threshold, and therefore reduce the risk of PTS occurring. Further modelling would be required in order to assess the reduction in TTS and PTS zones due to application of a soft-start period.

Herring

This work re-examines the behavioural sound threshold for herring, following the response of the MMO to our previous studies. In this case, we have used a single strike SEL (SEL_{ss}) metric and a lower response threshold, instead of the previously used cumulative SEL (SEL_{cum}) for multiple strikes. The modelling carried out assessed the effects of simultaneous piling events at two locations (both 2no. x 2300kJ, and 1no. x 2300kJ, 1no. x 3500kJ).

For both of the simultaneous pile driving hammer energy scenarios, the combined SEL_{ss} threshold of 135 dB re 1µPa^{2}s is exceeded over the whole area of both herring spawning grounds.

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1. Introduction

The Rampion Offshore Wind Farm Order 2014 (the Order) was made by the Secretary of State in July 2014 granting E.ON Climate & Renewables Rampion Offshore Wind Limited (E.ON) permission to build an offshore wind farm off the Sussex Coast. An Environmental Impact Assessment (EIA) was undertaken for the project, which was submitted along with the application for a Development Consent Order (DCO). The EIA included an assessment of the potential underwater noise propagation that would occur from impact piling during the construction phase of the development.

The original EIA assessment (RSK Environmental Ltd, 2012) was based on an assumed hammer energy of 1500 kJ to drive a 6.5m monopile into the correct position in the seabed. Among the impacts identified, two concerned the spawning of fish, the black sea bream within the nearby Kingmere Marine Conservation Zone (MCZ) and the Downs Herring stock within the English Channel. Piling restrictions are set out within the deemed Marine Licence within the Order limiting the time of year when pile driving can take place. The conditions state that no pile driving works for installation of monopiles can take place between 15th April and 30th June each year due to potential impacts on black sea bream spawning, and pin piling cannot be undertaken during the same period within the defined black bream restriction zone. Pile driving cannot take place between 20th November and 15th January each year due to potential impacts on herring spawning in the English Channel. In the original EIA study (RSK Environmental Ltd, 2012) it was determined that an increase in hammer energy used to install the monopiles, to 2300 kJ, would not increase the environmental impacts greatly.

A geotechnical study carried out during 2014 provided additional detailed information with regards to the ground conditions at proposed turbine locations, and the results showed that hammer energies of up to 3500 kJ may be required to avoid pile refusal at a number of locations within the proposed layout. As such E.ON further commissioned HR Wallingford to carry out predictive underwater noise modelling of the higher hammer energies at two locations within the development area and to review the results of the noise modelling study in light of the most recent scientific knowledge and international guidance (DLR5374-RT002-R02-00, January 2015). This was used to carry out a review of the seasonal restrictions, with the specific aim to determine whether there was any evidence to support a reduction or removal of the piling restrictions which are currently included within the Order.

Further to the recommendations made in the seasonal restrictions review, E.ON subsequently commissioned HR Wallingford to explore the possibility of reducing the hammer energy used to drive the piles in the licenced area to reduce the underwater noise propagation (DLR5374-RT004-R01-00). The spatial coverage of noise propagation within the development area was also of interest in light of the noise modelling results. As such lower hammer energies were modelled at the two previous locations alongside a third location within the development area.

The results of the previous studies are reported in DLR5374-RT001-R03-00 (underwater noise modelling), DLR5374-RT002-R02-00 (Seasonal restrictions review) and DLR5374-RT004-R01-00 (Reduced hammer energies).

Following a review of these previous studies by the Marine Management Organisation (MMO), E.ON commissioned HR Wallingford to re-analyse the previous model results in terms of a different metric for marine mammals, namely the M-weighted cumulative SEL for fleeing individuals (Southall *et al*, 2007) so as to be more consistent with previous EIA studies (see DDM7600-RT007-R01-00). The modelling has also re-investigated the behavioural sound threshold for herring using a different metric and threshold (see

DDM7600-RT004-R01-00). A threshold for single strike SEL will be applied to the existing model results instead of the previously used cumulative SEL for multiple strikes.

The new modelling was also commissioned to assess the effects of simultaneous piling events at two locations (both 2 x 2300 kJ, and 1 x 2300 kJ, 1 x 3500 kJ), the results of which are presented in this report.

2. Overview and location

The work documented in this report consists of the modelling of simultaneous pile driving at two locations for marine mammals (Section 3.2.1) and herring (Section 3.2.2).

Figure 2.1 shows a map of the location of the Rampion Wind Farm and the wind turbine pile locations under consideration in this study. Noise fields generated during proposed pile driving at locations 1 to 3 were modelled previously (DLR5374-RT001-R03-00). The existing model data for these three noise sources will be used in the first part of the work in which revised metrics and thresholds for marine mammals and herring are applied (described in Section 3.1). The combined effects of simultaneous pile driving activity (again using the revised thresholds) will be modelled for Locations 4 and 5 (E.ON turbine locations J05 and K11) which is described in Section 3.3.

Results of the re-analysis of marine mammals using M-weighted cumulative SEL criteria of Southall *et al* (2007) are reported in DDM7600-RT007-R01-00 and results of the re-analysis of herring thresholds using a single strike unweighted SEL are provided in DDM7600-RT004-R01-00. The simultaneous piling results are provided in Section 4.

Finally some conclusions are drawn in Section 5.

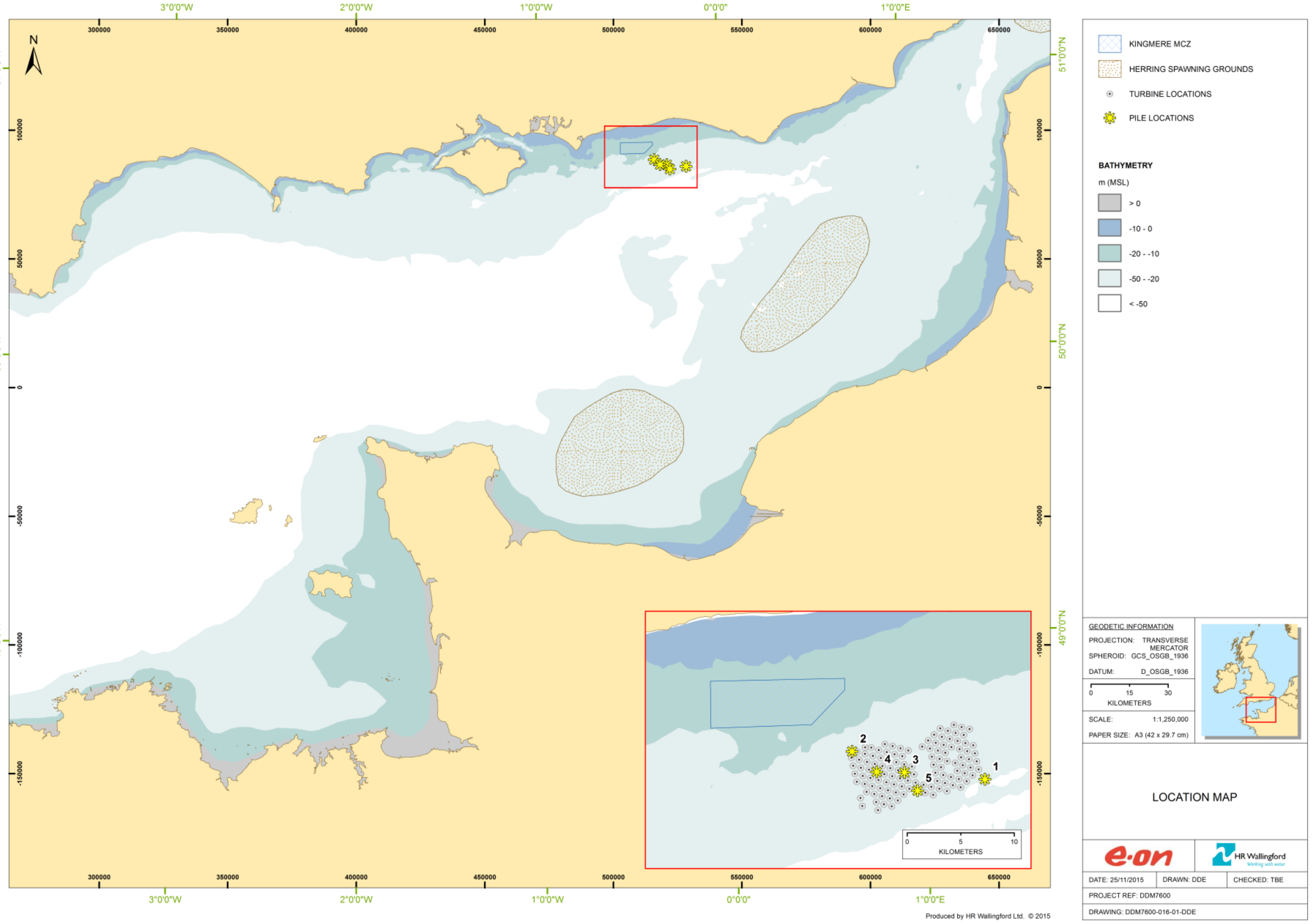

Figure 2.1: Location map showing the positions of the wind turbine piles under consideration for noise modelling

3. Methods

3.1. Source levels

Sound maps were presented in the previous noise modelling report (DLR5374-RT001-R03-00) for pile driving with a range of hammer energies. In that study, the SEL source levels for the modelled hammer energies were derived empirically by scaling up the measured broadband sound from a pile driver with a hammer energy of 800kJ. The same source levels are used in the current study for the relevant hammer energies under investigation as shown in Table 3.1.

Table 3.1: SEL source levels for each pile driver hammer energy

Hammer energy (kJ)	SEL Source level (dB re 1µPa^{2}s)
1500	218.2
2300	220.0
3500	221.9
4000	222.5

3.2. Revised sound metrics and thresholds

3.2.1. Marine mammals

GOBE are developing a Marine Mammal Mitigation Strategy for the Rampion Offshore Wind Farm. In order to complete this, they require sound maps and radii for permanent and temporary threshold shifts (PTS and TTS, respectively), based on Southall *et al.* (2007) M-weighted criteria for hearing damage in marine mammals. This requires a re-analysis of this existing underwater noise model results to calculate these contours relative to this preferred criteria.

In the main noise modelling report (DLR5374-RT001-R03-00) the noise level thresholds for behaviour and injury that were used were taken from the more recent guidelines defined by the US Marine Mammal Criteria Group within NOAA (NOAA, 2013).

To be more consistent with the previous investigations, the existing noise model results have been re-analysed using the M-weighted thresholds of Southall *et al* (2007) for a single piling event (reported in DDM7600-RT007-R01-00). These are split into similar mammal groups as defined in the NOAA criteria. The first three groups define thresholds for low, mid and high frequency cetaceans. The fourth mammal group specifies the hearing thresholds for pinnipeds in water. Note that the NOAA thresholds used in the previous noise modelling report also split the pinniped group up into two sub-groups.

The unweighted cumulative SEL thresholds defined by NOAA and the revised M-weighted cumulative SEL thresholds of Southall *et al* (2007) are given in Table 3.2. The threshold levels defined by Southall *et al* (2007) are relatively simple in definition with a PTS threshold of 198 dB re 1µPa^{2}s for all three frequencies of cetaceans and 186 dB re 1µPa^{2}s for pinnipeds in water. In all cases, the TTS thresholds are 15 dB below the corresponding PTS threshold.

It is important to note that the thresholds considered in this report are either higher, or lower, than their NOAA equivalent. It is therefore entirely to be expected that the zones of PTS/ TTS will also differ in size.

Table 3.2: Thresholds for onset of PTS and TTS defined by NOAA (2013) and Southall *et al* (2007)

Mammal group	Unweighted SEL_{cum} thresholds of NOAA (2013)		M-weighted SEL_{cum} thresholds of Southall et al (2007)	
	PTS Onset	**TTS Onset**	**PTS Onset**	**TTS Onset**
Low frequency cetaceans (Mlf)	187	172	198	183
Mid frequency cetaceans (Mmf)	204	189	198	183
High frequency cetaceans (Mhf)	180	165	198	183
Pinnipeds in water (Mpw)	192 or 215**	177 or 200**	186	171

*Source: ** Pinnipeds (in water) were split into two types of seals under the NOAA guidelines*

Another factor to consider when calculating a cumulative SEL metric is that mammals have the ability to swim away from a noise source if the sound levels are not tolerable. Hence it is now common practice (Lepper *et al*, 2007) to assume that as soon as piling is initiated, the mammals affected by the noise swim in a straight line away from the source. As the individuals move away into quieter water, the single strike SEL for each consecutive pile strike generally reduces with range from the pile. The cumulative SEL for each individual is therefore considerably less than if they were assumed to remain stationary. A value of swim speeds for the mammals is usually taken to be 1.5m/s (e.g. Lepper *et al*, 2007; RSK Environmental, 2012) and this value has been assumed in this study.

3.2.2. Herring

For fish, the use of auditory weightings is not recommended (Popper *et al.*, 2014) until a better understanding of fish sound detection abilities has emerged. For herring the unweighted broadband sound exposure level is therefore used in this study as used previously (DLR5374-RT001-R03-00).

Previously an unweighted cumulative SEL (SEL_{cum}) threshold of 186 dB dB re 1µPa^{2}s, as defined by Popper *et al* (2014) for all types of fish, was used to assess the spatial extent of behavioural response for herring. Using this metric the potential impact on the herring spawning grounds to the south and southeast of the proposed Rampion wind farm was assessed (located as shown in Figure 2.1).

More recent literature by Hawkins *et al* (2014) has suggested the use of a single strike SEL (SEL_{ss}) metric with a behavioural response threshold of 135 dB re 1µPa^{2}s. In their study, the in situ measurements of the behavioural response of schools of sprat to pulsed sound was measured using sonar equipment. Sprat is a close relative of the Atlantic herring, and is thought to be especially sensitive to sounds by virtue of its specialized auditory system (Enger, 1967). The UK Centre for Ecology Fisheries and Aquaculture Science (CEFAS) also state that sprat are a clupeid fish related to herring and so sound level thresholds are likely to be similar. In the experiment by Hawkins *et al* (2014), the response of the fish was observed to mainly occur in the first sound pulse in a set of ten pulses. For this reason, a single strike SEL (SEL_{ss}) was considered to be the appropriate metric instead of cumulative SEL_{cum}. It was concluded that herring have a behavioural response above an SEL_{ss} threshold of 135 dB re 1µPa^{2}s. This metric and threshold value will be used in the current study.

Although the new behavioural response threshold of 135 dB re 1µPa^{2}s is very much lower than the previously assumed cumulative threshold of 186 dB re 1µPa^{2}s, it is emphasised that new metric is for a single strike only. It was therefore not immediately apparent as to how the extents of the zones of behavioural response would be affected without a full re-analysing of the noise model results (reported in DDM7600-RT004-R01-00).

3.3. Combined sound fields from simultaneous pile driving activity

E.ON required the assessment of simultaneous piling events at two locations within the Rampion OWF. To fulfil this, the following scenarios were modelled:

a) 2 x 2300 kJ hammer energy;

b) 1 x 2300 kJ and 1 x 3500 kJ hammer energy.

The locations of the piles to be modelled are wind turbine locations J05 and K11, which are referred to as locations 4 and 5 in Figure 2.1. This activity required the noise field to be remodelled for all frequencies and the combined broadband sound levels then mapped as described in the main noise modelling report (DLR5374-RT001-R03-00).

Given the period of time to install a single pile (approximately 2 hours) and frequent strike rate (assumed to be about 32 strikes per minute) it is probable that pile strikes from each location will occasionally occur near simultaneously, in which case the single strike sound level will be additive. If the sound waves of two simultaneous strikes were coherent and of equal energy, then the combined sound level would increase by up to 6 dB. This is however unlikely to occur very often at any given point in space or time. The sound from the two sources was therefore combined, but assuming incoherent summation in which case two pulses of equal energy would result in a combined level of up to 3 dB above the noise level for just a single pulse.

As part of the analysis, it was necessary to develop a method for calculating the cumulative SEL for the mammals fleeing from the two separate noise sources. There is some uncertainty as to how marine mammals will respond if they are at a point between the two noise sources. It is plausible to assume that individuals will swim away perpendicularly to an imaginary line drawn between the two piles. So, in the model they are made to swim directly away from this line if they start at a point that is perpendicular to it. This is shown diagrammatically in Figure 3.1.

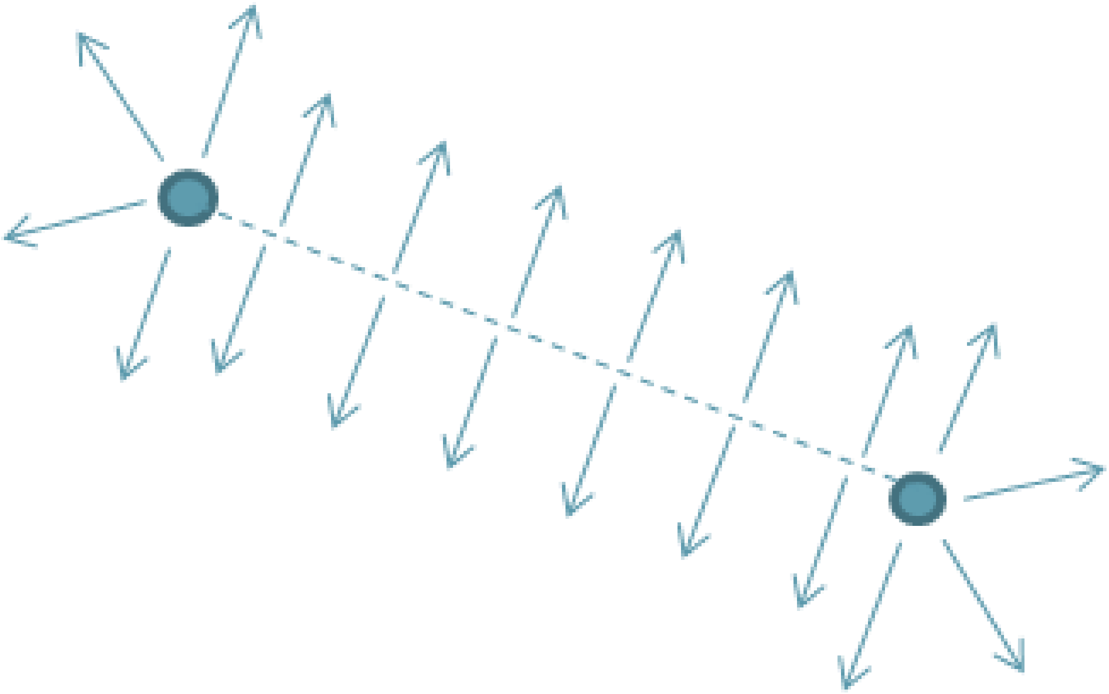

Figure 3.1: Schematisation of direction in which mammals flee during simultaneous pile driving activity

Mammals that are not positioned perpendicularly to any point along the imaginary line are assumed to swim directly away from the closest pile in a similar manner to the previous single pile simulations. As the individuals flee, they accumulate SEL from both of the pile sources (summed incoherently).

4. Results

4.1. Simultaneous pile driving activity at two locations

4.1.1. Mammals

Figure 4.1 shows contours for each M-weighted mammal group, for the maximum start distance from pile at which PTS occurs for fleeing mammals during simultaneous pile driving at Locations 4 and 5 (wind turbines J05 and K11). This assumes hammer energies of 2300 kJ at both locations. The maximum distance from the line between the piles to the PTS and TTS contours in these figures are given in Table 4.1.

Table 4.1: Maximum start distance from pile at which PTS and TTS occurs for fleeing mammals during simultaneous pile driving at Locations 4 and 5

	Maximum start distance from line between locations 4 & 5 for 2300 kJ & 2300 kJ hammer energies (m)		**Maximum start distance from line between locations 4 & 5 for 2300 kJ & 3500 kJ hammer energies (m)**	
Mammal group	**PTS onset**	**TTS onset**	**PTS onset**	**TTS onset**
Low frequency cetaceans (MLF)	5,660 m	74,600 m	8,170 m	88,600 m
Mid frequency cetaceans (MMF)	1,890 m	49,500 m	2,730 m	52,800 m
High frequency cetaceans (MHF)	870 m	40,900 m	1,470 m	46,200 m
Pinnipeds in water (MPW)	45,200 m	188,400 m	49,900 m	212,400 m

For the scenario of two simultaneous pile drivers with the same energy (2300 kJ) the maximum distances for onset of PTS for low, mid and high frequency cetaceans are 5.6km, 1.9km and 0.9 km respectively and for pinnipeds the equivalent distance is 45 km. Distances for TTS are much larger with values in the range of 41-75 km for cetaceans and 188 km for pinnipeds. Increasing the hammer energy at location 5 to 3500 kJ results in an increase in these distances, with values for low, mid and high frequency cetaceans of 8.2 km, 2.7 km and 1.5 km respectively and 50 km for pinnipeds. Maximum distances for TTS with these two hammer energies are in the range of 46-89 km for cetaceans and 212 km for pinnipeds.

The maximum distances described above cannot be compared directly with the previously modelled results for single piles (see DDM7600-RT007-R01-00) since the pile locations (and hence water depths) are different. This results in differences in the noise propagation. Therefore, for comparison, contours were also calculated for the J05 and K11 piles (locations 4 and 5) under the assumption that they were not piling simultaneously. For these, the maximum distances for the onset of PTS and TTS are given in Table 4.2 and Table 4.3. It is important to note that in this analysis, when considering simultaneous pile driving it is the distance to the line drawn between the piles and for a single pile it is simply the distance to the pile itself.

Table 4.2: Maximum start distance from pile at which PTS and TTS occurs for fleeing mammals for a single pile being driving at Location 4 (Wind turbine J05) at a hammer energy of 2300 kJ

	Maximum start distance from Location 4 for 2300 kJ hammer energy (m)	
Mammal group	**PTS onset**	**TTS onset**
Low frequency cetaceans (Mlf)	4,040 m	57,600 m
Mid frequency cetaceans (Mmf)	1,090 m	33,900 m
High frequency cetaceans (Mhf)	550 m	26,700 m
Pinnipeds in water (Mpw)	31,600 m	150,700 m

Table 4.3: Maximum start distance from pile at which PTS and TTS occurs for fleeing mammals for a single pile being driving at Location 5 (Wind turbine K11) at 2300 kJ and 3500 kJ hammer energies

Mammal group	Maximum start distance from Location 5 for 2300 kJ hammer energy (m)		Maximum start distance from Location 5 for 3500 kJ hammer energy (m)	
	PTS onset	**TTS onset**	**PTS onset**	**TTS onset**
Low frequency cetaceans (Mlf)	3,700 m	54,200 m	5,650 m	68,300 m
Mid frequency cetaceans (Mmf)	770 m	32,600 m	1,650 m	44,500 m
High frequency cetaceans (Mhf)	310 m	25,700 m	790 m	34,300 m
Pinnipeds in water (Mpw)	31,400 m	168,100 m	42,100 m	180,100 m

As would be expected, carrying out simultaneous piling at the two locations increases the maximum distance within which PTS and TTS are likely to occur. The increases in the distances for PTS when piling at two locations simultaneously are summarised in Table 4.4. In this table, three combinations are given for the noise increases when piling at two locations simultaneously (either at 2300 and 2300kJ or 2300 and 3500kJ) as opposed to a single location (either at 2300 kJ or 3500kJ). In general, if two piles are being installed each with the same energy hammer of 2300 kJ, when compared with one pile of the same energy the maximum distance for onset of PTS is increased by between 40-58% for cetaceans and 43% for pinnipeds. Increasing the simultaneous pile driver energy at K11 to 3500 kJ results in an increase in distance of between 102-167% for cetaceans and 58% for pinnipeds when compared to a single pile driver at 2300 kJ. If the single pile hammer energy was also 3500 kJ, then the increases in distance for cetaceans are between 19-35% and 18% for pinnipeds.

Similarly, the percentage increase in the distances for TTS are summarised in Table 4.5. For simultaneous piles being installed each with the same energy hammer of 2300 kJ, when compared with one pile of the same energy the distance for onset of TTS is increased by between 30-53% for cetaceans and 12% for pinnipeds. If the simultaneous K11 pile driver energy is increased to 3500 kJ, the increase in maximum distance for TTS onset becomes 54-73% for cetaceans and 26% for pinnipeds when compared with a single pile driver energy of 2300 kJ. If the single pile hammer energy was also 3500 kJ, then the increases in distance for cetaceans are between 45-86% and 19% for pinnipeds.

Table 4.4: Increases (as percentages) in maximum start distance for PTS to occur for simultaneous piling compared with a piling at a single location

Mammal group	Increase in maximum start distance for onset of TTS (%)		
	Simultaneous piling at 2300 & 2300 kJ, versus single pile at 2300 kJ	**Simultaneous piling at 2300 & 3500 kJ, versus single pile at 3500 kJ**	**Simultaneous piling at 2300 & 3500 kJ, versus single pile at 2300 kJ**
Low frequency cetaceans (Mlf)	40 %	45 %	102 %
Mid frequency cetaceans (Mmf)	73 %	65 %	150 %
High frequency cetaceans (Mhf)	58 %	86 %	167 %
Pinnipeds in water (Mpw)	43 %	19 %	58 %

Table 4.5: Increases (as percentages) in maximum start distance for TTS to occur for simultaneous piling compared with a piling at a single location

Mammal group	Increase in maximum start distance for onset of TTS (%)		
	Simultaneous piling at 2300 & 2300 kJ, versus single pile at 2300 kJ	Simultaneous piling at 2300 & 3500 kJ, versus single pile at 3500 kJ	Simultaneous piling at 2300 & 3500 kJ, versus single pile at 2300 kJ
Low frequency cetaceans (Mlf)	30 %	30 %	54 %
Mid frequency cetaceans (Mmf)	46 %	19 %	56 %
High frequency cetaceans (Mhf)	53 %	35 %	73 %
Pinnipeds in water (Mpw)	12 %	18 %	26 %

Table 4.6: Increases (as percentages) in maximum start distance for PTS to occur for simultaneous piling compared with a piling at a single location

Mammal group	Increase in maximum start distance for onset of TTS (%)		
	Simultaneous piling at 2300 & 2300 kJ, versus single pile at 2300 kJ	Simultaneous piling at 2300 & 3500 kJ, versus single pile at 3500 kJ	Simultaneous piling at 2300 & 3500 kJ, versus single pile at 2300 kJ
Low frequency cetaceans (Mlf)	40 %	45 %	102 %
Mid frequency cetaceans (Mmf)	73 %	65 %	150 %
High frequency cetaceans (Mhf)	58 %	86 %	167 %
Pinnipeds in water (Mpw)	43 %	19 %	58 %

Table 4.7: Increases (as percentages) in maximum start distance for TTS to occur for simultaneous piling compared with a piling at a single location

Mammal group	Increase in maximum start distance for onset of TTS (%)		
	Simultaneous piling at 2300 & 2300 kJ, versus single pile at 2300 kJ	Simultaneous piling at 2300 & 3500 kJ, versus single pile at 3500 kJ	Simultaneous piling at 2300 & 3500 kJ, versus single pile at 2300 kJ
Low frequency cetaceans (Mlf)	30 %	30 %	54 %
Mid frequency cetaceans (Mmf)	46 %	19 %	56 %
High frequency cetaceans (Mhf)	53 %	35 %	73 %
Pinnipeds in water (Mpw)	12 %	18 %	26 %

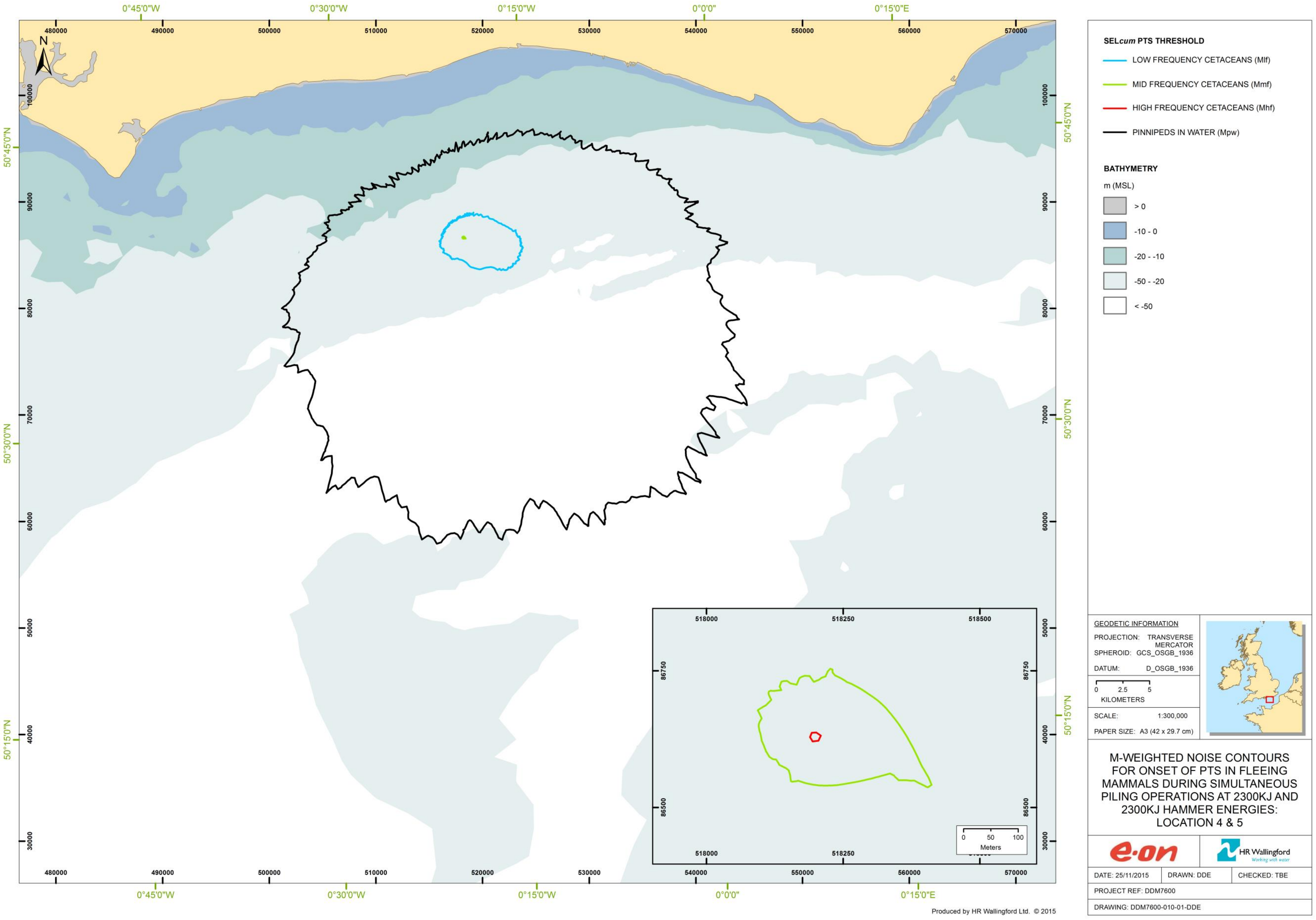

Figure 4.1: Maximum start distance from pile at which PTS occurs for fleeing mammals during simultaneous pile driving at Locations 4 and 5 with hammer energies of 2300 kJ at both locations

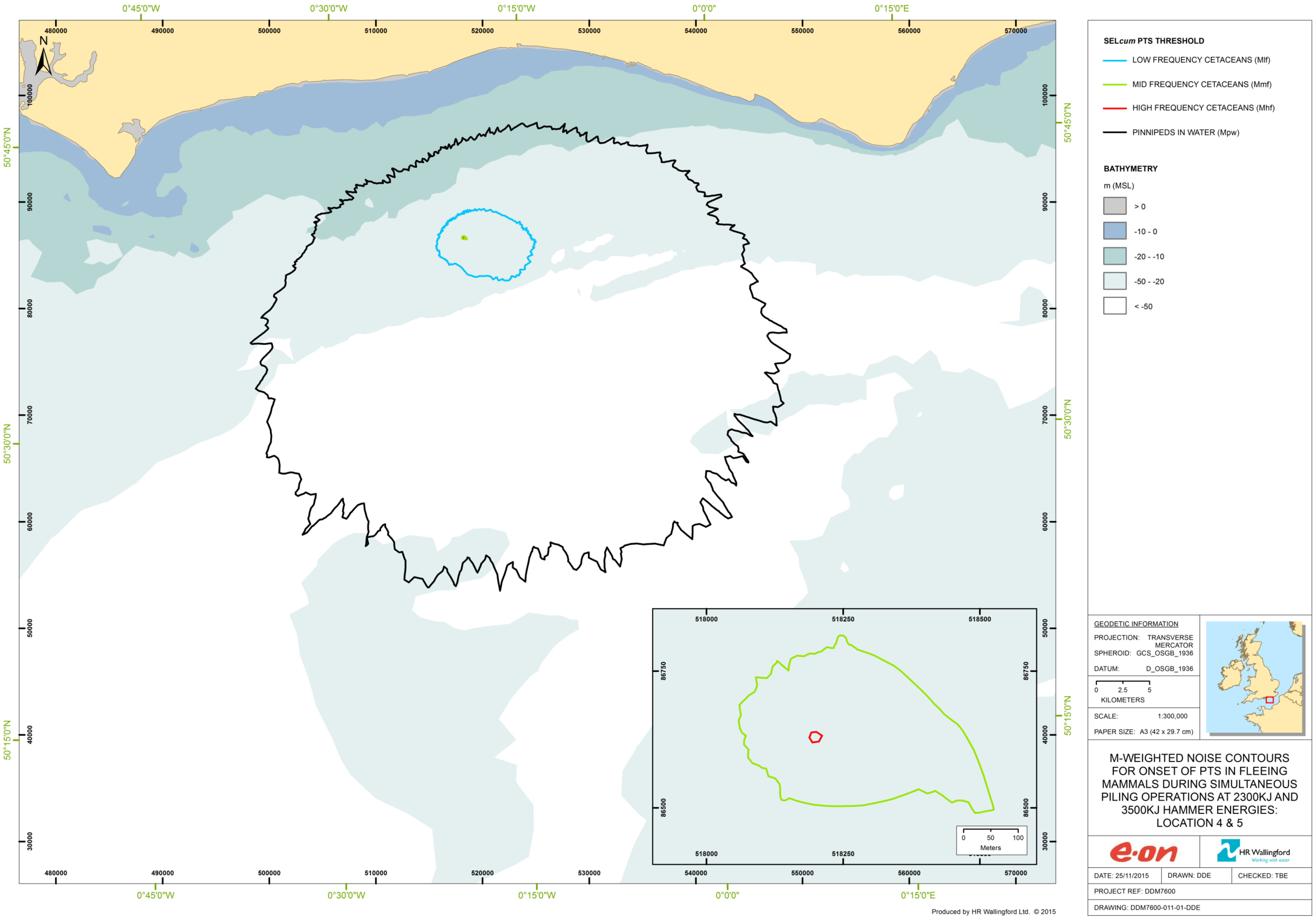

Figure 4.2: Maximum start distance from pile at which PTS occurs for fleeing mammals during simultaneous pile driving at Locations 4 and 5 with hammer energies of 2300 kJ and 3500 kJ

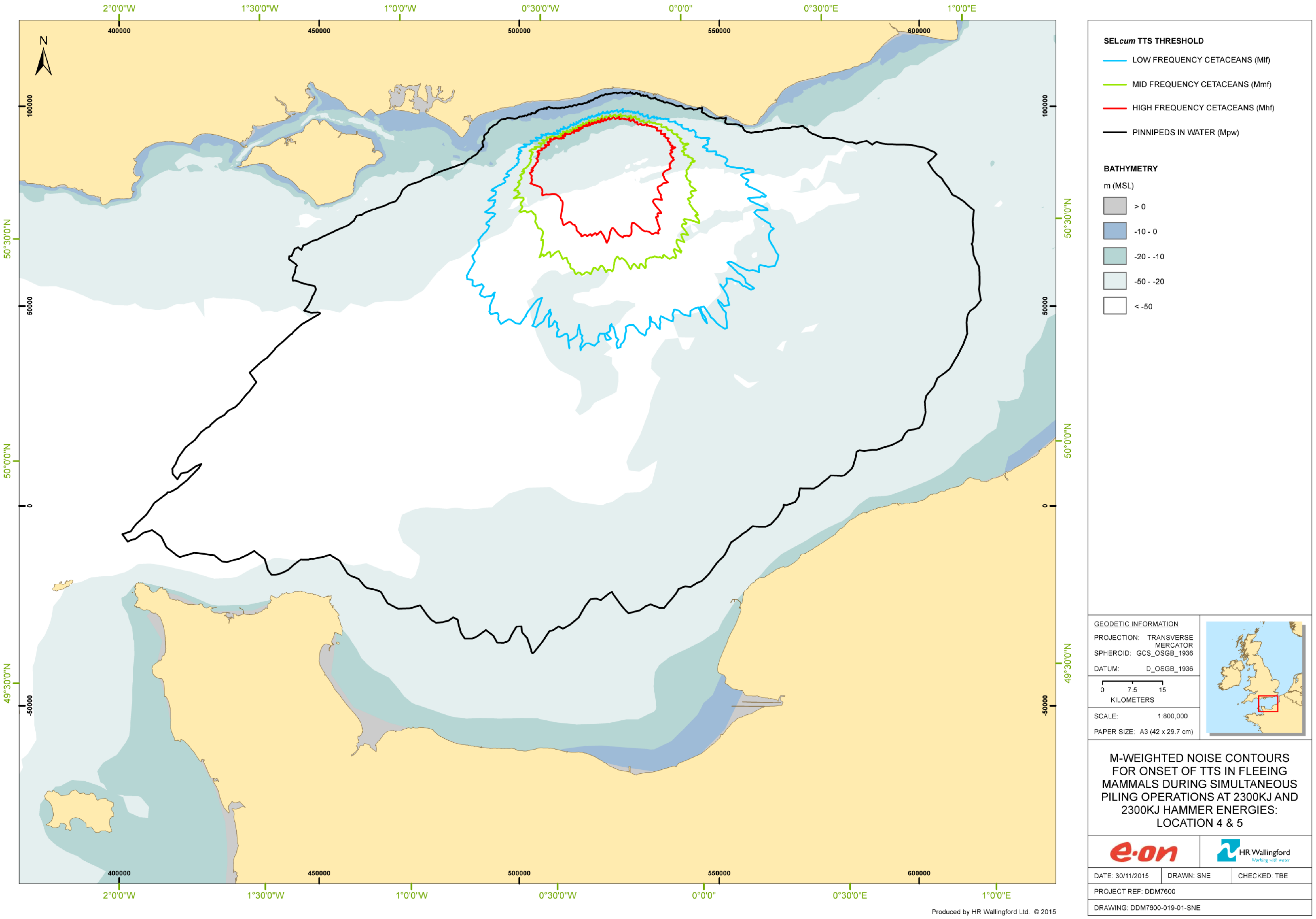

Figure 4.3: Maximum start distance from pile at which TTS occurs for fleeing mammals during simultaneous pile driving at Locations 4 and 5 with hammer energies of 2300 kJ at both locations

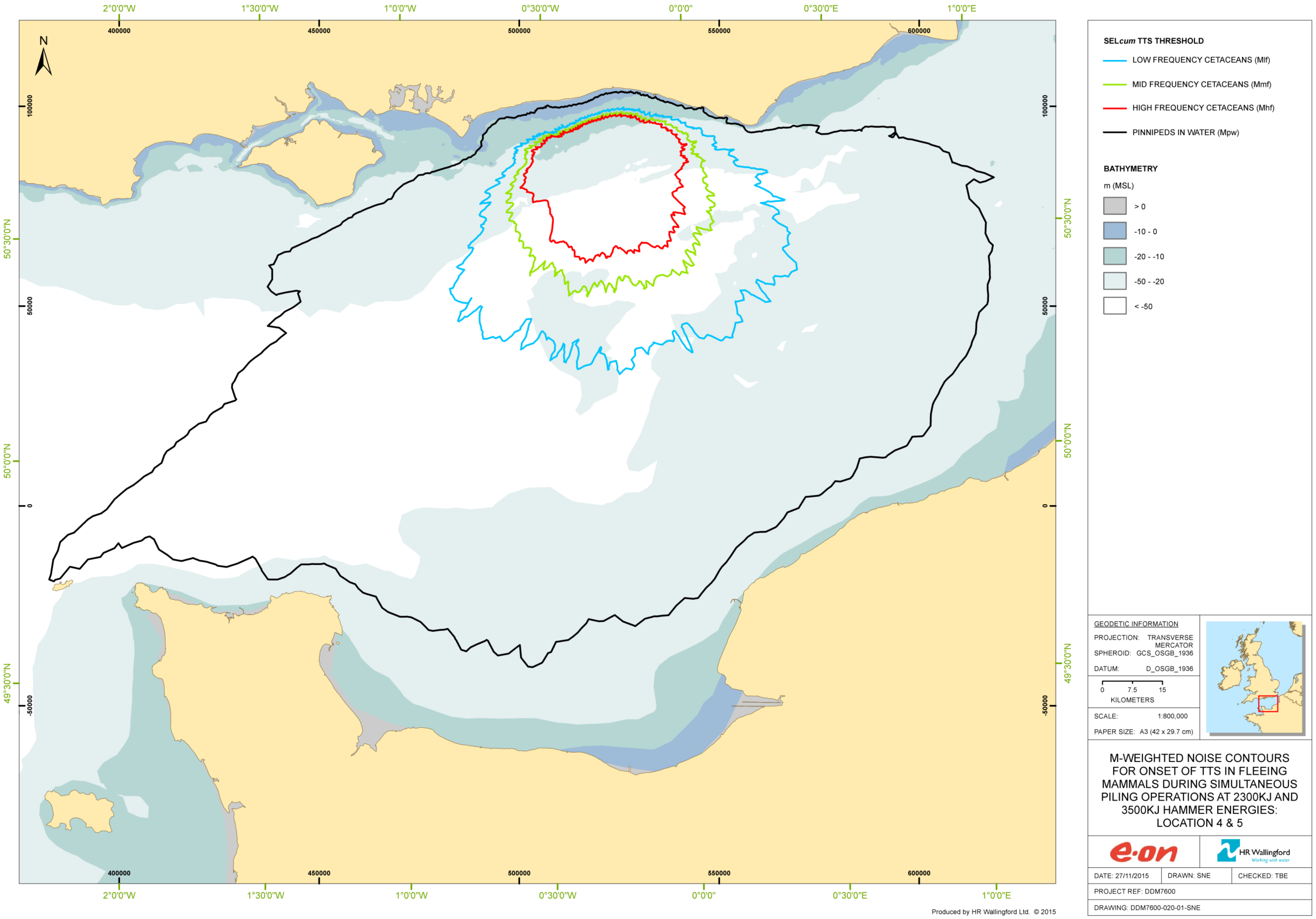

Figure 4.4: Maximum start distance from pile at which TTS occurs for fleeing mammals during simultaneous pile driving at Locations 4 and 5 with hammer energies of 2300 kJ and 3500 kJ

4.1.2. Herring

Figure 4.5 show the combined SEL_{ss} for simultaneous piling with hammer energies of 2300kJ at both location 4 and 5. Figure 4.6 shows a similar plot for the case where the hammer energy at location 5 is 3500 kJ. In both cases, the threshold level for herring of 135 dB re $1\mu Pa^2s$ is exceeded over all of both spawning grounds.

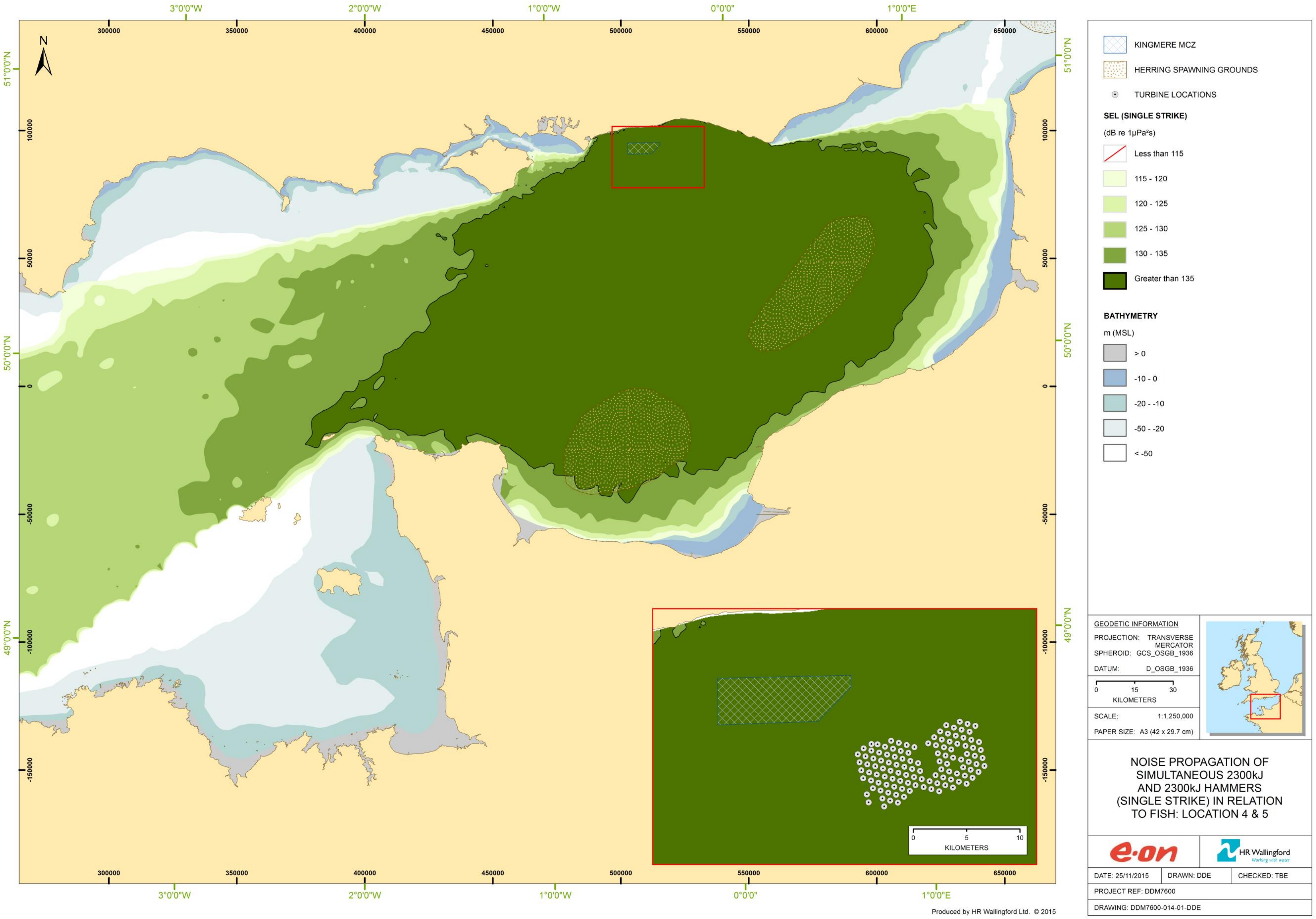

Figure 4.5: Combined single-strike SEL sound map for piling at Location 4 and 5 using a 2300 kJ hammer at both locations with a behavioural threshold contour for herring of 135 dB re 1µPa^{2}s

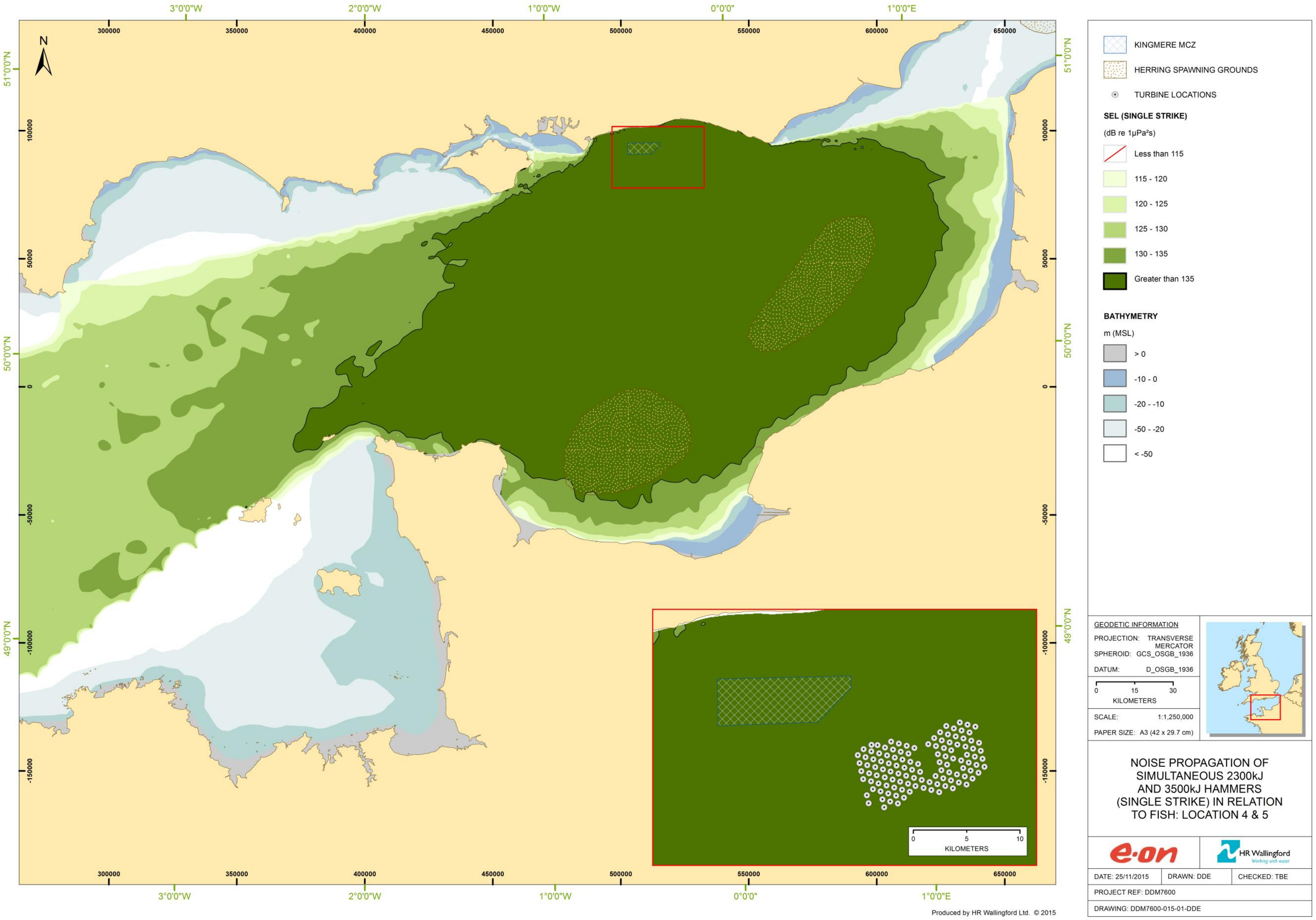

Figure 4.6: Combined single-strike SEL sound map for piling at Location 4 and 5 using a 2300 kJ and 3500 kJ hammer energy with a behavioural threshold contour for herring of 135 dB re 1µPa^{2}s

5. Conclusions

Model simulations were carried out for simultaneous piling at two new locations (Locations 4 and 5, which are wind turbines J05 and K11). Two scenarios were considered, one with two hammer energies at 2300 kJ and the second with Location 5 set to a higher hammer energy of 3500 kJ.

For mammals, an M-weighted SEL_{cum} metric was applied with the thresholds for PTS and TTS taken to be as defined by Southall *et al* (2007). In the piling scenarios described above, for mammals the maximum distances for onset of PTS for low, mid and high frequency cetaceans are 5.6km, 1.9km and 0.9 km respectively and for pinnipeds the equivalent distance is 45 km. Distances for TTS are much larger with values in the range of 41-75 km for cetaceans and 188 km for pinnipeds. Increasing the hammer energy at location 5 to 3500 kJ results in an increase in these distances, with values for low, mid and high frequency cetaceans of 8.2 km, 2.7 km and 1.5 km respectively and 50 km for pinnipeds. Maximum distances for TTS with these two hammer energies are in the range of 46-89 km for cetaceans and 212 km for pinnipeds.

It is important to note that the presented results for the maximum distances for onset of PTS and TTS in mammals were calculated assuming that no mitigation measures were used during piling and as such are considered to be ‘worst-case’. Potential mitigation measures include the use of soft-start piling whereby the hammer energy is reduced at the start of piling and then gradually ramped up to full energy over a set period of time. Soft-start measures would allow the mammals time to flee the area during the lower energy hammer strikes. Since the metric used for assessing sound exposure is cumulative (SEL_{cum}), the use of soft-start would decrease the maximum radius for PTS and TTS to occur, thus reducing the likelihood of injury to mammals. Since no details of mitigation measures were available then none were applied in the modelling described in this study. If details are supplied these could be assessed with additional modelling.

The use of a single-strike SEL metric with a threshold for behavioural response in herring of 135 dB re 1µPa^{2}s was assessed at both pile locations using the scenario for simultaneous piling of two monopiles as described. In this situation the combined SEL_{ss} threshold of 135 dB re 1µPa^{2}s is exceeded over the whole area of both spawning grounds for both of the simultaneous pile driving hammer energy scenarios.

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