

Appendix C-3 Addendum

NAS Comparison Technical Note - Marine Mammals, Megafauna and Fish





ORIEL WIND FARM PROJECT

Natura Impact Statement Addendum

Appendix C-3 Addendum: NAS Comparison Technical Note – Marine Mammals, Megafauna and Fish

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Acronyms

Term	Meaning
ADD	Acoustic Deterrent Device
CGNS	Celtic and Greater North Seas
CIS	Celtic and Irish Sea
DBBC	Double Big Bubble Curtain
HF	High Frequency
LF	Low Frequency
MU	Management Unit
NAS	Noise Abatement System
N/E	Not Exceeded
NMFS	National Marine Fisheries Service
PCW	Phocid Carnivore in Water
PTS	Permanent Threshold Shift
RFI	Request for Further Information
RMS (rms throughout)	Root Mean Square
SCANS	Small Cetacean in European Atlantic Waters and the North Sea
SEL	Sound Exposure Level
SPL	Sound Pressure Level
TTS	Temporary Threshold Shift
VHF	Very High Frequency

Units

Unit	Description
m	Metre (distance)
km	Kilometre (distance)
km ²	Kilometres squared (area)
dB	Decibel
µPa	Micropascal
µPa ² s	Micropascals squared per second
s	Second
%	Percentage

1 INTRODUCTION

This Technical Report has been prepared in response to a Request for Further Information (RFI) from An Coimisiún Pleanála (formerly An Bord Pleanála) regarding the planning application (case reference ABP-319799-24) for the Oriel Wind Farm Project (hereafter referred to as “the Project”). The report sets out an overview of the Noise Abatement Systems (NAS) scenarios modelled (section 2) (also see appendix C-2 Addendum: NAS Modelling Report); the NAS modelling results for marine mammals (section 3.1) and for fish and shellfish (section 3.2); and overall conclusions (section 4).

This technical report provides a response to RFI 9.A.iii Marine Mammals & Megafauna – Underwater Noise – Mitigation & Noise Abatement, which requested “*Revised noise modelling and mapping which provides detailed consideration of the noise abatement strategy selected in response to (ii) above and include:*

- a. *The modelled peak sound pressure level (SPL_{pk}) and Sound Exposure Level (SEL_{cum}) Permanent Threshold Shift (PTS) and Temporary Threshold Shift (TTS) contours for each functional hearing group potentially present, emanating from the existing locations proposed in the application at the periphery of the proposed development to demonstrate the full potential spatial extent of underwater noise propagation. Modelling must also show the noise level (SPL_{pk} , SEL_{ss}) at 750 m from the locations of each of the piling activities selected.*
- b. *The modelled SEL_{ss} contours for 120-180 dB re 1 μ Pa²s at 5 dB increments at the locations in (a) above. Mapping provided must show the relevant noise contours in the context of implementing the abatement technologies/ measures identified at (i) above and should be displayed alongside the noise contours in the absence of any such noise abatement measures being implemented.*
- c. *Revised details showing the change in total impacted individuals of each species before and after consideration of noise abatement technologies.*
- d. *Modelling must be performed for monopiles and pin piles, as both are under consideration within the project design envelope.*
- e. *Any additional abatement and/or mitigation measures should also be considered where practicable in terms of their potential for reduction of cumulative effects with other projects in terms of underwater noise.”*

The modelled SPL_{pk} and SEL_{cum} PTS and TTS contours/ranges (request ‘a’) are presented for marine mammals in section 3.1.1, and mortality, recoverable injury, and TTS ranges for fish and shellfish are presented in section 3.2.1.

The noise levels (SPL_{pk} , SEL_{ss}) at 750 m from the locations of each of the piling activities selected (also request for further information ‘a’ above) are presented in appendix C-2 Addendum: NAS Modelling Report, for scenarios with and without mitigation, and are not repeated in this report.

The modelled SEL_{ss} contours for 120-180 dB re 1 μ Pa²s at 5 dB increments (request or further information ‘b’ above) are presented for marine mammals in section 3.1.2, alongside modelled SPL_{pk} contours for 150-200 dB re 1 μ Pa at 5 dB increments which are presented for fish in section 3.2.2.

Revised details showing the change in total impacted individuals of each species before and after consideration of noise abatement technologies (request ‘c’) are presented in respective sections for marine mammals (sections 3.1).

Modelling has been performed for monopiles only (request ‘d’) for a range of NAS scenarios (request ‘e’) - it should be noted that pin piles are not proposed for the Project and therefore have not been considered.

It is also noted that any reduction in underwater noise impacts by the application of NAS will have inherent reductions on potential cumulative effects with other projects, but this has not been considered quantitatively in this report (beyond the consideration of a range of NAS scenarios).

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RFI 9.A.ii referred to in 9.A.iii requested:

- “The applicant must also consider and draw on the best available technology and thresholds, including as applied in other EU jurisdictions (e.g. Germany; Belgium; Netherlands; Denmark), to identify and provide for suitable noise abatement to reduce the level and extent of potential noise impacts arising from the proposed development. Examples include the German 160 dB re 1 $\mu\text{Pa}^2\text{s}$ SEL_{ss} and 190 dB re 1 μPa SPL_{pk} thresholds that must not be exceeded at a distance of 750m from a piling site; or the frequency weighted SEL_{cum} PTS thresholds (e.g. harbour porpoise 155 dB re 1 $\mu\text{Pa}2\text{s}$) that must not be exceeded for a fleeing animal with a starting distance of 200m in Denmark.”

RFI 10.F.vi for fish and shellfish receptors is also addressed in this report, which requested:

- “Given the extensive distance of TTS on fish with a swim bladder used in hearing, the location of sensitive Atlantic spawning herring grounds within the boundary of the site, and the sensitivities of the species in terms of their spawning habitat in the region, the applicant is requested to assess the possibility for the use of NAS to reduce the spatial impact of underwater noise associated with impact piling beyond the soft start procedures.”

2 SCENARIOS MODELLED

The impact piling scenarios are modelled as a single impact pile unmitigated and with noise abatement at the east piling location. Two mitigation methods were considered against the unmitigated base scenario; the PULSE¹ in-line hammer noise reduction unit and a double big bubble curtain (DBBC²). These scenarios are outlined in Table 2-1.

The swim speeds used in the estimation of cumulative sound exposure (SEL_{cum}) for the species likely to be present in the vicinity of the Project are the same as those used in appendix F: Marine Mammals and Megafauna Supporting Information.

Table 2-1: Summary of modelling scenarios.

Scenario	Description
Unmitigated	Unmitigated scenario of piling of monopile at the east of the offshore wind farm area.
PULSE	Mitigated piling with use of in-line hammer noise reduction unit (PULSE) at the east of the offshore wind farm area.
DBBC	Mitigated piling with use of DBBC at the east of the offshore wind farm area.

2.1 Marine mammals

Auditory injury (PTS) and TTS from impact piling of monopiles was modelled using a dual metric approach (SEL and SPL_{pk}) at the east location for scenarios with and without NAS, with results in terms of both injury/TTS ranges and the numbers of animals potentially impacted presented in section 3.1.1. The unmitigated scenario is based upon the revised updated underwater noise modelling (see appendix C-1 Addendum: Updated Subsea Noise Modelling Report).

For disturbance, SEL_{ss} contours in 120-180 dB re 1 μ Pa²s at 5 dB increments were also modelled both with and without NAS. Results are presented in section 3.1.2, demonstrating the changes in total impacted numbers of animals per species with the inclusion of NAS.

2.2 Fish and shellfish

Impact piling of monopiles was modelled at the east location for scenarios with and without NAS, with results for mortality, recoverable injury, TTS presented in section 3.2.1 and behavioural disturbance presented in section 3.2.2. Modelling was conducted for all fish groups (defined in Popper *et al.* (2014) as four groups of fish with increasing sensitivity to underwater sound based on physiological adaptations) for all scenarios. Modelling was conducted for the unmitigated, PULSE mitigated, and DBBC mitigated scenarios using the dB re 1 μ Pa²s SEL_{cum} metric for impact thresholds for mortality, injury, and TTS. For an assessment of behavioural disturbance an SPL_{pk} metric (dB re 1 μ Pa) was applied as contours in 5 dB increments for all fish groups. The conservative 160 dB re 1 μ Pa SPL_{pk} behavioural disturbance threshold was applied to assess areas of overlap with herring nursery grounds, as the highest sensitivity fish species (group 4 herring *Clupea harengus*). This species was identified as an important ecological feature within appendix E: Fish and Shellfish Ecology Supporting Information.

For ease of presentation of approach to noise modelling, note that basking shark and sea turtle have been included in the fish and shellfish sections as opposed to the marine mammal section (as presented in appendix F: Marine Mammals and Megafauna Supporting Information).

¹ PULSE mitigation comprises an add-on to existing hammer technologies that consists of two plungers with a fluid layer in-between, the use of which can reduce the SEL of conventional hammers by 6-9 dB and the SPL by up to 9-12 dB (<https://iqip.com/pulse/>)

² Two layers of air bubble production hoses deployed surrounding the installation activity to absorb the sound from piling produced and reduce the noise entering the wider environment.

2.3 Project bespoke system

As outlined in section 2 of the NIS Addendum and appendix C-2 Addendum: NAS Modelling Report, the Applicant proposes to use a system (known as the MODIGA), which will be fitted with an internal air bubble ring to provide underwater noise reduction during piling (see appendix E Addendum: Fish and Shellfish Ecology Supporting Information and appendix F Addendum: Marine Mammals and Megafauna Supporting Information).

While the assessment of injury and/or disturbance to marine megafauna from underwater noise and fish during pile driving in the NIS concluded no significant impact, in an abundance of caution, the Project is committed to the use of noise abatement measures for the purpose of reducing sound levels from construction piling and will use a MODIGA with internal air bubble ring as its noise abatement system to provide reduction in underwater noise during impact piling.

It was not possible to model the precise level of reduction of noise levels at this stage as this system will be bespoke to the Project, however, a noise modelling study was undertaken for a range of NAS options to demonstrate the efficacy of applying commercially available NAS technology during piling at the Project, and it is anticipated the MODIGA will result in a noise abatement (compared to an unmitigated piling scenario) similar to other casing systems.

3 RESULTS

3.1 Marine mammals

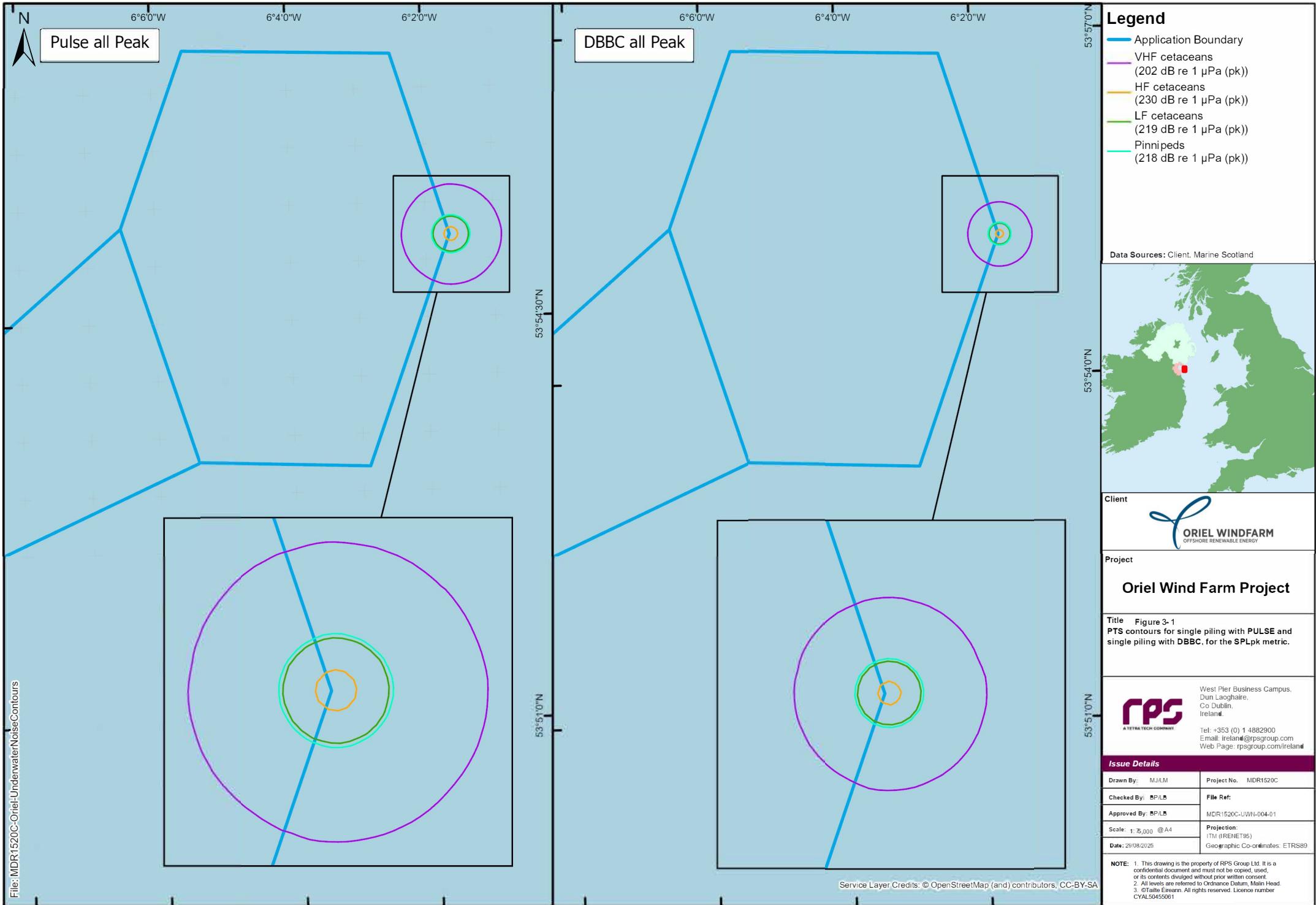
3.1.1 Auditory Injury (PTS) and TTS

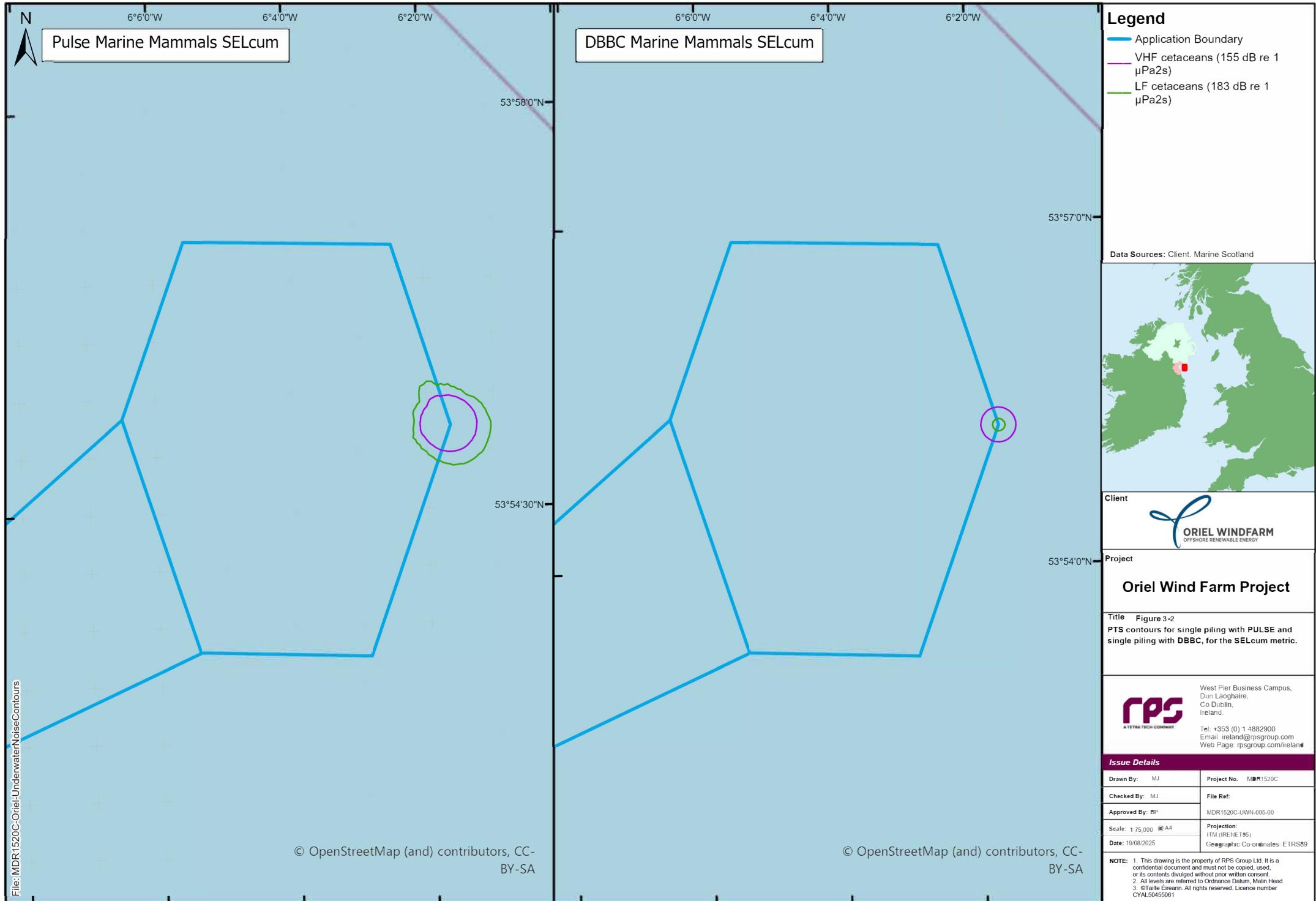
All impact piling ranges for auditory injury (PTS) and TTS are based on a comparison to the relevant impulsive sound thresholds from Southall *et al.* (2019). The injury ranges for SEL_{cum} and SPL_{pk} are both modelled for PTS and TTS (Figure 3-1 to Figure 3-4). Impact ranges for mammals for SEL_{cum} without an Acoustic Deterrent Device (ADD) and with 15 minutes of ADD are presented in Table 3-1 and Table 3-2 respectively. Impact ranges for mammals for SPL_{pk} for the first hammer strike and maximum hammer energy are presented in Table 3-3.

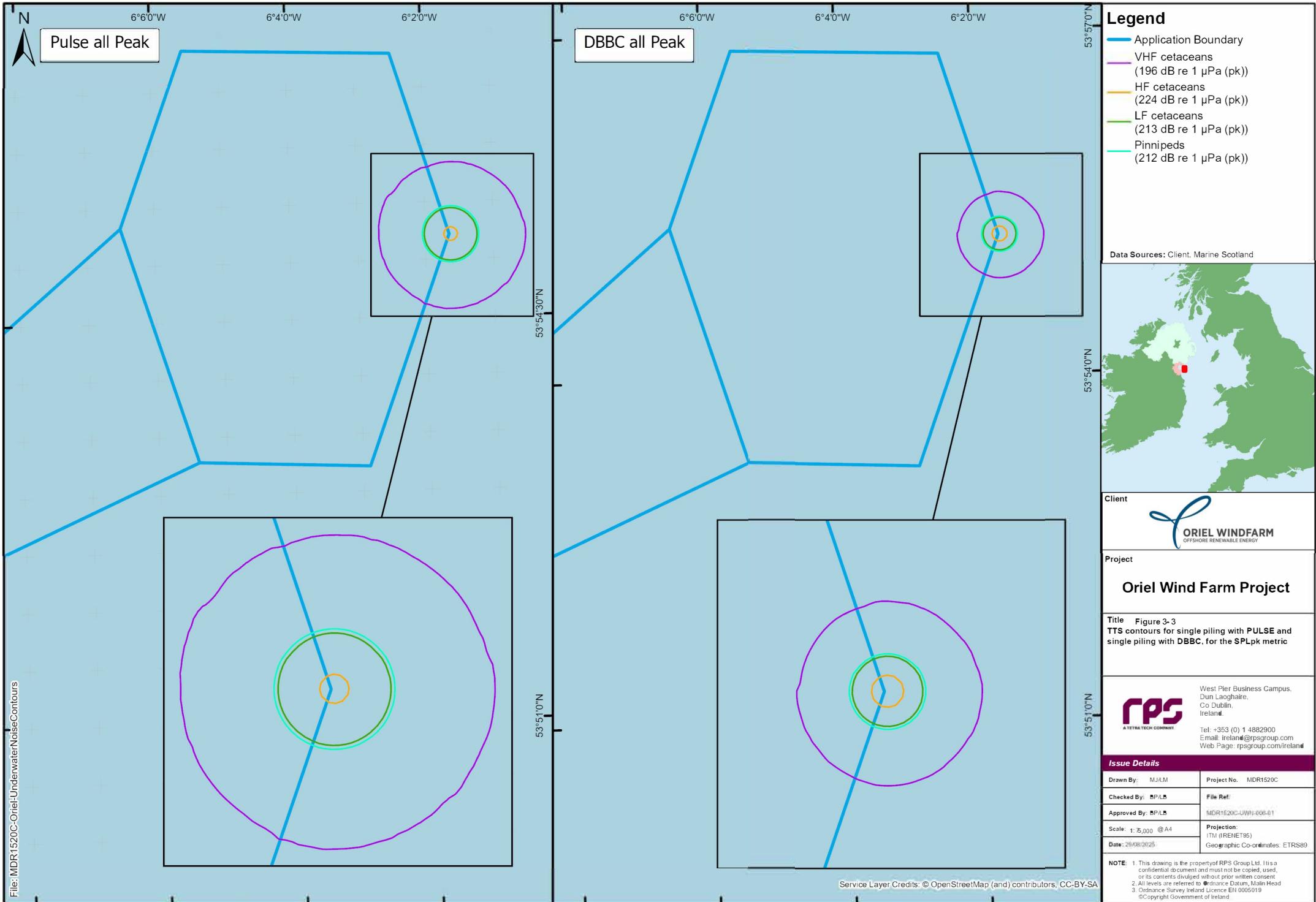
Table 3-1: Potential auditory injury (PTS) and TTS ranges for marine mammals from installation of a single pile based on the SEL_{cum} metric, without ADD.

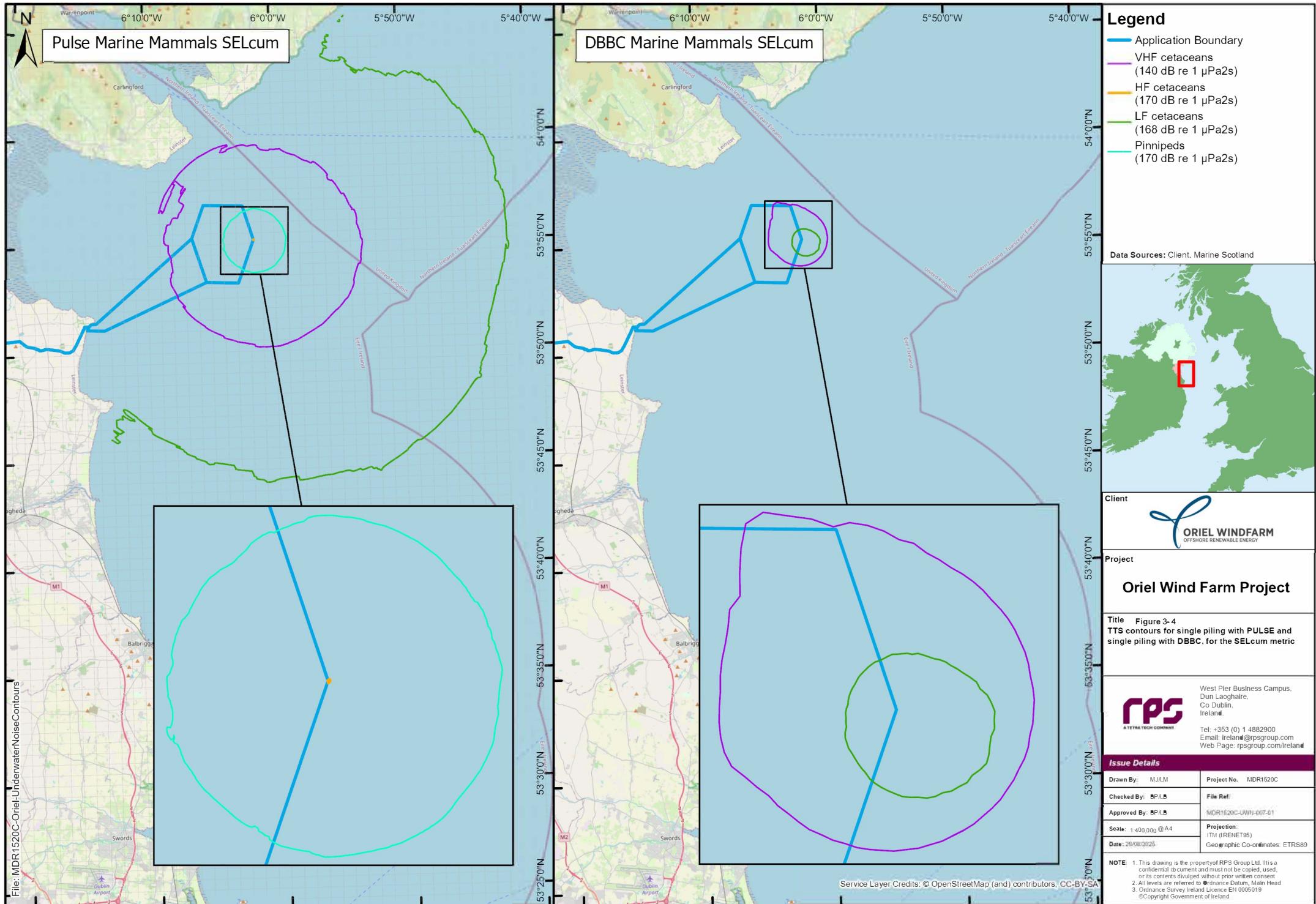
Species / Group	Threshold, SEL _{cum} (dB re 1 μ Pa ² s)	Range (m)		
		Unmitigated	PULSE	DBBC
Low Frequency (LF)	PTS – 183 dB re 1 μ Pa ² s	1,135	635	98
	TTS – 168 dB re 1 μ Pa ² s	21,500	16,500	1,145
High Frequency (HF)	PTS – 185 dB re 1 μ Pa ² s	N/E	N/E	N/E
	TTS – 170 dB re 1 μ Pa ² s	21	19	<curtain
Very High Frequency (VHF)	PTS – 155 dB re 1 μ Pa ² s	815	454	280
	TTS – 140 dB re 1 μ Pa ² s	14,500	7,720	2,050
Phocid Carnivore in Water (PCW)	PTS – 185 dB re 1 μ Pa ² s	11	N/E	<curtain
	TTS – 170 dB re 1 μ Pa ² s	5,520	2,470	<curtain

N/E = threshold not exceeded, < curtain = injury range contained within DBBC.









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Table 3-2: Potential auditory injury (PTS) and TTS ranges for marine mammals from installation of a single pile based on the SEL_{cum} metric, with 15 minutes ADD.

Species / Group	Threshold, SEL (dB re 1 μ Pa ² s)	Range (m)		
		Unmitigated	PULSE	DBBC
LF	PTS – 183 dB re 1 μ Pa ² s	N/E	N/E	N/E
	TTS – 168 dB re 1 μ Pa ² s	19,500	15,000	<curtain
HF	PTS – 185 dB re 1 μ Pa ² s	N/E	N/E	N/E
	TTS – 170 dB re 1 μ Pa ² s	N/E	N/E	N/E
VHF	PTS – 155 dB re 1 μ Pa ² s	N/E	N/E	N/E
	TTS – 140 dB re 1 μ Pa ² s	13,000	6,280	725
PCW	PTS – 185 dB re 1 μ Pa ² s	N/E	N/E	N/E
	TTS – 170 dB re 1 μ Pa ² s	3,890	910	<curtain

N/E = threshold not exceeded, < curtain = injury range contained within DBBC.

Table 3-3: Potential auditory injury (PTS) and TTS ranges for marine mammals from installation of a single pile based on the SPL_{pk} metric, for the first hammer strike and highest energy hammer strike.

Species / Group	Threshold, L _{p,0-pk} , dB re 1 μ Pa	Range (m)					
		Unmitigated		PULSE		DBBC	
		First Strike	Max Energy	First Strike	Max Energy	First Strike	Max Energy
LF	PTS – 219 dB re 1 μ Pa (pk)	169	425	144	285	< curtain	147
	TTS – 213 dB re 1 μ Pa (pk)	273	684	241	424	106	208
HF	PTS – 230 dB re 1 μ Pa (pk)	71	177	56	120	< curtain	77
	TTS – 224 dB re 1 μ Pa (pk)	114	286	93	180	< curtain	110
VHF	PTS – 202 dB re 1 μ Pa (pk)	653	1,638	624	804	201	395
	TTS – 196 dB re 1 μ Pa (pk)	1,051	2,638	1,048	1,178	285	559
PCW	PTS – 218 dB re 1 μ Pa (pk)	183	460	157	307	< curtain	156
	TTS – 212 dB re 1 μ Pa (pk)	295	741	263	454	112	221

< curtain = injury range contained within DBBC.

The numbers of animals potentially impacted and the proportion of the relevant species-specific reference populations was calculated for both auditory injury (PTS) and TTS. Only the maximum density estimate per species, and corresponding Management Unit (MU) (Table 3-4) were applied in this report in order to take a precautionary approach.

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Table 3-4: Density estimates and MUs applied.

Species	Maximum density estimate (animals/km ²)	Source	MU population	Source
Harbour porpoise <i>Phocoena phocoena</i>	1.33	Maximum density estimate, derived from monthly peak, Oriel site-specific surveys	62,517	Celtic and Irish Sea (CIS) MU (IAMMWG, 2022)
Bottlenose dolphin <i>Tursiops truncatus</i>	0.235	Maximum density estimate, derived from the Small Cetacean in European Atlantic Waters and the North Sea (SCANS)-IV Block CS-D (Gilles et al., 2023)	8,326	SCANS-IV Irish Sea Abundance Estimate from Block CS-D and Block CS-E (Gilles et al., 2023)
Common dolphin <i>Delphinus delphis</i>	0.027*	Density estimate derived from SCANS-IV Block CS-D (Gilles et al., 2023)	102,656	Celtic and Greater North Seas (CGNS) MU (IAMMWG, 2022)
Minke whale <i>Balaenoptera acutorostrata</i>	0.26	Maximum density estimate, derived from monthly peak, Oriel site-specific surveys	20,118	CGNS MU (IAMMWG, 2022)
Grey seal <i>Halichoerus grypus</i>	0.372*	Density estimate derived from Carter et al. (2022)	5,882	Grey Seal Reference Population (Oriel Windfarm Ltd, 2024)
Harbour seal <i>Phoca vitulina</i>	0.28*	Density estimate derived from Carter et al. (2022)	1,635	Harbour Seal Reference Population (Oriel Windfarm Ltd, 2024)

* A single density estimate was identified for the NIS appendix F: Marine Mammals and Megafauna (rather than a minimum and maximum density estimate)

PTS

The numbers of animals predicted to experience PTS and equivalent proportion of the reference population based on the SEL_{cum} metric is presented in Table 3-5 without ADD and with 15 minutes ADD. N/E indicates where thresholds were not exceeded, whilst '< curtain' indicates that the threshold was not exceeded beyond the limits of the DBBC.

For auditory injury (PTS), for both the scenarios without ADD and with 15 minutes of ADD, the modelled impacted ranges (based on SEL_{cum}) reduce with the use of PULSE compared to the unmitigated range and further reduce with the use of DBBC. For example, without ADD use, for harbour porpoise, the unmitigated range is 815 m, which reduces to 454 m for the PULSE scenario and 280 m for the DBBC scenario. This leads to a reduction in the number of animals predicted to experience PTS also. For harbour porpoise, without ADD use, this leads to up to three harbour porpoise (0.004% of the CIS MU) were predicted to experience PTS in the unmitigated scenario, which reduces to less than one in both the PULSE and DBBC scenarios (both 0.001% of the CIS MU).

For minke whale, the unmitigated range is 1,135 m, which reduces to 635 m for the PULSE scenario and 98 m for the DBBC scenario. This leads to a reduction in the number of animals predicted to experience PTS also; up to two minke whale (0.005% of the CIS MU) were predicted to experience PTS in the unmitigated scenario, which reduces to less than one animal in the PULSE and DBBC scenarios (0.002% and 0.00004% of the CIS MU respectively).

With the use of 15 minute ADD ranges are further reduced, and for all species for all three scenarios (based on SEL_{cum}) PTS thresholds were not exceeded (and therefore no table of ranges is presented) and therefore no animals were predicted to experience PTS.

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The numbers of animals predicted to experience PTS and equivalent proportion of the reference population based on the SPL_{pk} metric is presented in Table 3-6. The modelled impacted ranges (based on SPL_{pk}) reduce with the use of PULSE compared to the unmitigated range and further reduce with the use of DBBC. For example, for harbour porpoise, the unmitigated range is 1,638 m at maximum strike hammer energy, which reduces to 804 m for the PULSE scenario and 395 m for the DBBC scenario. This leads to reduction in the number of animals predicted to experience PTS also; up to 12 harbour porpoise (0.018% of the CIS MU) were predicted to experience PTS in the unmitigated scenario which reduces to, up to three (0.004% of the CIS MU) for the PULSE scenario, and less than one for the DBBC scenario (0.001% of the CIS MU). For soft start ranges a similar pattern of reduction can be seen in Table 3-6, with the greatest reduction presented for the DBBC scenario; for all species other than harbour porpoise, thresholds were not exceeded beyond the DBBC, and for harbour porpoise the range reduces from 653 m (unmitigated) to 624 m (PULSE) to 201 m (DBBC). The equivalent number of animals predicted to be affected reduces from, up to 2 harbour porpoise (up to 0.0003% of the CIS MU) (unmitigated and PULSE) to less than one harbour porpoise (up to 0.003% of the CIS MU) (DBBC).

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Table 3-5: Number of animals potentially affected by auditory injury (PTS) from impact piling at a single monopile location at the east of the offshore wind farm area based on SEL_{cum} injury ranges without ADD (N/E = threshold not exceeded), for unmitigated, PULSE and DBBC scenarios.

Species	Threshold (Unweighted Peak)	Range (m)	Number animals within impact zone			Percentage of MU population (%)					
			Unmitigated	PULSE	DBBC	Unmitigated	PULSE	DBBC	Unmitigated	PULSE	DBBC
Harbour porpoise	PTS - 155 dB re 1 μ Pa ² s	815	454	280	3	<1	<1	<1	0.004	0.001	0.0001
Bottlenose dolphin	PTS - 185 dB re 1 μ Pa ² s	N/E	N/E	N/E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Common dolphin	PTS - 185 dB re 1 μ Pa ² s	N/E	N/E	N/E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Minke whale	PTS - 183 dB re 1 μ Pa ² s	1,135	635	98	2	<1	<1	<1	0.0005	0.002	0.00004
Grey seal	PTS - 185 dB re 1 μ Pa ² s	11	N/E	<curtain	<1	N/A	N/A	N/A	N/A	N/A	N/A
Harbour seal	PTS - 185 dB re 1 μ Pa ² s	11	N/E	<curtain	<1	N/A	N/A	N/A	N/A	N/A	N/A

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Table 3-6: Number of animals potentially affected by auditory injury (PTS) from impact piling at a single monopile location at the east of the offshore wind farm area based on SPL_{pk} injury ranges for the first strike and maximum hammer energy (N/E = threshold not exceeded, < curtain = contained within DBBC), for unmitigated, PULSE and DBBC scenarios.

Species	Threshold, Lp,0-pk, dB re 1 μ Pa	Strike	Range (m)	Number of animals within impact zone				Percentage of MU population (%)		
				Unmitigated	PULSE	DBBC	Unmitigated	PULSE	DBBC	Unmitigated
Harbour porpoise	PTS – 202 dB re 1 μ Pa (pk)	First strike	653	624	201	2	2	<1	0.003%	0.003%
		Max energy	1,638	804	395	12	3	<1	0.018%	0.00%
Bottlenose dolphin	PTS – 230 dB re 1 μ Pa (pk)	First strike	71	56	< curtain	<1	<1	N/A	0.00004%	0.00003%
		Max energy	177	120	77	<1	<1	<1	0.0003%	0.0001%
Common dolphin	PTS – 230 dB re 1 μ Pa (pk)	First strike	71	56	< curtain	<1	<1	N/A	0.000004%	0.000003%
		Max energy	177	120	77	<1	<1	<1	0.000003%	0.000001%
Minke whale	PTS – 219 dB re 1 μ Pa (pk)	First strike	169	144	< curtain	<1	<1	N/A	0.0001%	0.0001%
		Max energy	425	285	147	<1	<1	<1	0.0007%	0.0003%
Grey seal	PTS – 218 dB re 1 μ Pa (pk)	First strike	183	157	< curtain	<1	<1	N/A	0.0007%	0.0005%
		Max energy	460	307	156	<1	<1	<1	0.004%	0.002%
Harbour seal	PTS – 218 dB re 1 μ Pa (pk)	First strike	183	157	< curtain	<1	<1	N/A	0.002%	0.001%
		Max energy	460	307	156	<1	<1	<1	0.011%	0.005%

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TTS

The numbers of animals with the potential to experience TTS and proportion of the reference population (based on the SEL_{cum} metric) is presented in Table 3-7 without ADD and Table 3-8 with 15 minutes ADD. For TTS, for both the scenarios without ADD and with 15 minutes of ADD, the modelled impacted ranges reduce with the use of PULSE compared to the unmitigated range and further reduce with the use of DBBC. Without ADD, but with the use of DBBC harbour porpoise and minke whale were the only species for which the threshold was exceeded beyond the DBBC.

For example, without ADD use, for harbour porpoise, the unmitigated range is 14,500 m, which reduces to 7,720 m with the use of PULSE and 2,050 m with the use of DBBC. This leads to a reduction in the number of animals potentially impacted; up to 879 harbour porpoise (1.41% of the CIS MU) have the potential to experience TTS in the unmitigated scenario, which reduces to up to 250 harbour porpoise in the PULSE scenario (0.40% of the CIS MU) and up to 18 in the DBBC scenario (0.03% of the CIS MU).

With use of 15 minute ADD TTS ranges are further reduced. For harbour porpoise the unmitigated range is 13,000 m, which reduces to 6,280 m with the use of PULSE and 725 m with the use of DBBC. This leads to reduction in the number of animals with the potential to experience TTS; up to 707 harbour porpoise (1.13% of the CIS MU) in the unmitigated scenario, which reduces to up to 165 harbour porpoise in the PULSE scenario (0.26% of the MU) and up to three harbour porpoise in the DBBC scenario (0.004% of the CIS MU).

For minke whale, without ADD use the unmitigated range is 21,500 m, which reduces to 16,500 m with the use of PULSE and 1,145 m with the use of DBBC. This leads to a reduction in the number of animals potentially impacted; up to 378 minke whale (1.88% of the CGNS MU) have the potential to experience TTS in the unmitigated scenario, which reduces to up to 223 minke whale in the PULSE scenario (1.11% of the CGNS MU) and up two in the DBBC scenario (0.01% of the CGNS MU).

With use of 15 minute ADD TTS ranges are further reduced. For minke whale the unmitigated range is 19,500 m, which reduces to 15,000 m with the use of PULSE and to within the curtain with the use of DBBC. This leads to reduction in the number of animals with the potential to experience TTS; up to 311 minke whale (1.54% of the CGNS MU) in the unmitigated scenario, which reduces to up to 184 minke whale in the PULSE scenario (0.91% of the CGNS MU) and no minke whale in the DBBC scenario.

The numbers of animals with the potential to experience TTS and equivalent proportion of the reference population (based on the SPL_{pk} metric) is presented in Table 3-9. The modelled impacted ranges reduce with the use of PULSE compared to the unmitigated range and further reduce with the use of DBBC. For example, for harbour porpoise, the unmitigated range is 2,638 m at maximum strike hammer energy, which reduces to 1,178 m with the use of PULSE and 559 m with the use of DBBC. This leads to reduction in the number of animals with the potential to experience TTS; up to 30 harbour porpoise (0.047% of the CIS MU) in the unmitigated scenario, which reduces to up to six (0.009% of the CIS MU) in the PULSE scenario, and up to two in the DBBC scenario (0.002% of the CIS MU).

For soft start ranges a similar pattern of reduction can be seen in Table 3-9, with the greatest reduction presented for the DBBC scenario. For bottlenose dolphin and common dolphin thresholds were not exceeded beyond the DBBC. For harbour porpoise the range reduces from 1,051 m (unmitigated) to 1,048 m (PULSE) to 285 m (DBBC). The equivalent number of animals predicted to be affected reduces from up to five harbour porpoise (up to 0.007 % of the CIS MU) (unmitigated and PULSE) to less than one harbour porpoise (up to 0.0005% of the CIS MU) (DBBC). For minke whale the range reduces from 273 m (unmitigated) to 241 m (PULSE) to 106 m (DBBC). The equivalent number of animals predicted to be affected reduces was less than one minke whale for unmitigated, PULSE and DBBC scenarios.

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Table 3-7: Number of animals potentially affected by TTS from impact piling at a single monopile location at the east of the offshore wind farm area based on SEL injury ranges without ADD (N/E = threshold not exceeded, < curtain = contained within DBBC), for unmitigated, PULSE and DBBC scenarios.

Species	Threshold (Unweighted Peak)	Range (m)	Number animals within impact zone			Percentage of MU population (%)				
			Unmitigated	PULSE	DBBC	Unmitigated	PULSE	DBBC	Unmitigated	PULSE
Harbour porpoise	TTs - 140 dB re 1 μ Pa ² s	14,500	7,720	2,050	879	250	18	1.41%	0.40%	0.03
Bottlenose dolphin	TTs - 170 dB re 1 μ Pa ² s	21	19	<curtain	<1	<1	N/A	4.0×10^{-6} %	3.0×10^{-6} %	N/A
Common dolphin	TTs - 170 dB re 1 μ Pa ² s	21	19	<curtain	<1	<1	N/A	4.0×10^{-8} %	3.0×10^{-8} %	N/A
Minke whale	TTs - 168 dB re 1 μ Pa ² s	21,500	16,500	1,145	378	223	2	1.88%	1.11%	0.01
Grey seal	TTs - 170 dB re 1 μ Pa ² s	5,520	2,470	<curtain	36	8	N/A	0.61%	0.12%	N/A
Harbour seal	TTs - 170 dB re 1 μ Pa ² s	5,520	2,470	<curtain	27	6	N/A	1.64%	0.33%	N/A

Table 3-8: Number of animals potentially affected by TTS from impact piling at a single monopile location at the east of the offshore wind farm area based on SEL injury ranges with ADD (N/E = threshold not exceeded, < curtain = contained within DBBC), for unmitigated, PULSE and DBBC scenarios.

Species	Threshold (Unweighted Peak)	Range (m)	Number animals within impact zone			Percentage of MU population (%)				
			Unmitigated	PULSE	DBBC	Unmitigated	PULSE	DBBC	Unmitigated	PULSE
Harbour porpoise	TTs - 140 dB re 1 μ Pa ² s	13,000	6,280	725	707	165	3	1.13%	0.26%	0.004%
Bottlenose dolphin	TTs - 170 dB re 1 μ Pa ² s	N/E	N/E	N/E	N/A	N/A	N/A	N/A	N/A	N/A
Common dolphin	TTs - 170 dB re 1 μ Pa ² s	N/E	N/E	N/E	N/A	N/A	N/A	N/A	N/A	N/A
Minke whale	TTs - 168 dB re 1 μ Pa ² s	19,500	15,000	<curtain	311	184	N/A	1.54%	0.91%	N/A
Grey seal	TTs - 170 dB re 1 μ Pa ² s	3,890	910	<curtain	18	< 1	N/A	0.30%	0.02%	N/A
Harbour seal	TTs - 170 dB re 1 μ Pa ² s	3,890	910	<curtain	14	< 1	N/A	0.81%	0.05%	N/A

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Table 3-9: Number of animals potentially affected by TTS from impact piling at a single monopile location at the east of the offshore wind farm area based on SPL_{pk} injury ranges for both first strike and maximum hammer energy (N/E = threshold not exceeded, < curtain = contained within DBBC), for unmitigated, PULSE and DBBC scenarios

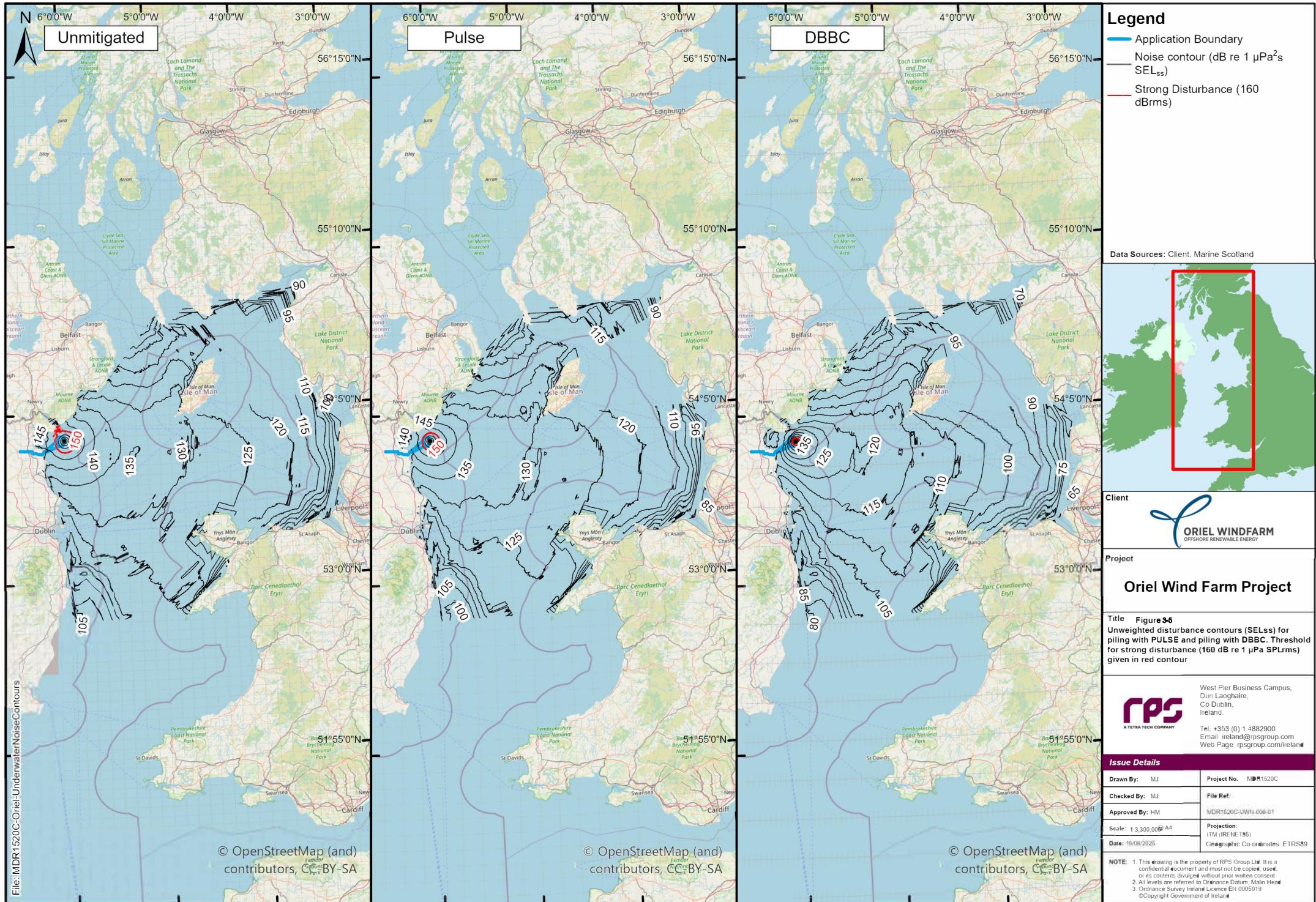
Species / Group	Threshold, $L_{p,0-pk}$, dB re 1 μPa	Strike Range (m)	Number of animals within impact zone				Percentage of MU population (%)				
			Unmitigated	PULSE	DBBC	Unmitigated	PULSE	DBBC	Unmitigated	PULSE	DBBC
Harbour porpoise	TTS – 196 dB re 1 μPa (pk)	<i>First strike</i>	1,051	1,048	285	5	5	< 1	0.007%	0.007%	0.0005%
			2,638	1,178	559	30	6	2	0.047%	0.009%	0.002%
Bottlenose dolphin	TTS – 224 dB re 1 μPa (pk)	<i>First strike</i>	114	93	< curtain	< 1	< 1	N/A	0.0001%	0.00008%	N/A%
			286	180	110	< 1	< 1	< 1	0.0001%	0.0003%	0.0001%
Common dolphin	TTS – 224 dB re 1 μPa (pk)	<i>First strike</i>	114	93	< curtain	< 1	< 1	N/A	0.000001%	0.0000007%	N/A%
			286	180	110	< 1	< 1	< 1	0.000007%	0.000003%	0.000001%
Minke whale	TTS – 213 dB re 1 μPa (pk)	<i>First strike</i>	273	241	106	< 1	< 1	< 1	0.0003%	0.0002%	0.00005%
			684	424	208	< 1	< 1	< 1	0.002%	0.0007%	0.0002%
Grey seal	PTS – 218 dB re 1 μPa (pk)	<i>First strike</i>	295	263	112	< 1	< 1	< 1	0.002%	0.001%	0.0002%
			741	454	221	< 1	< 1	< 1	0.011%	0.004%	0.001%
Harbour seal	PTS – 218 dB re 1 μPa (pk)	<i>First strike</i>	295	263	112	< 1	< 1	< 1	0.005%	0.004%	0.0002%
			741	454	221	< 1	< 1	< 1	0.030%	0.011%	0.003%

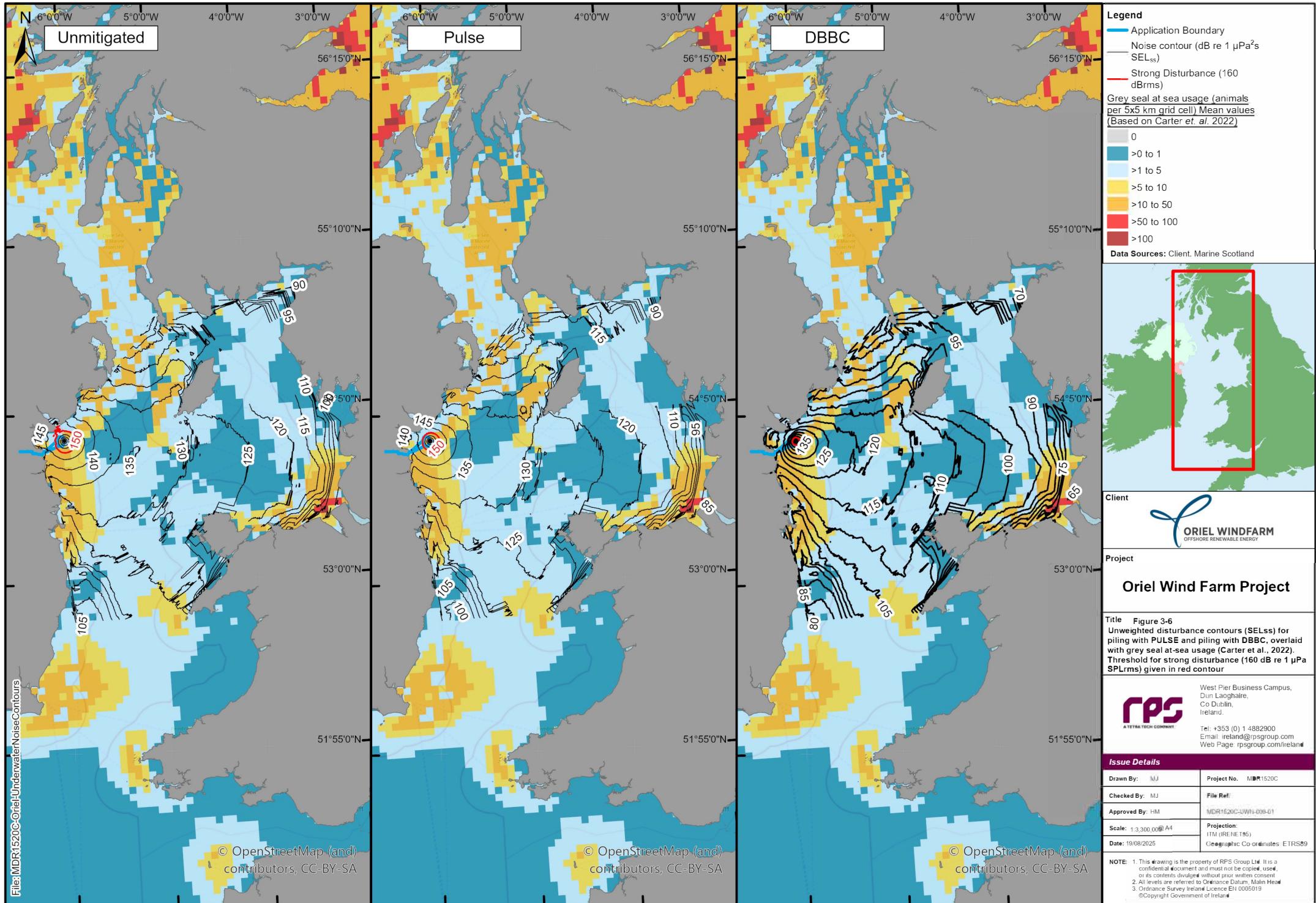
3.1.2 Behavioural Disturbance

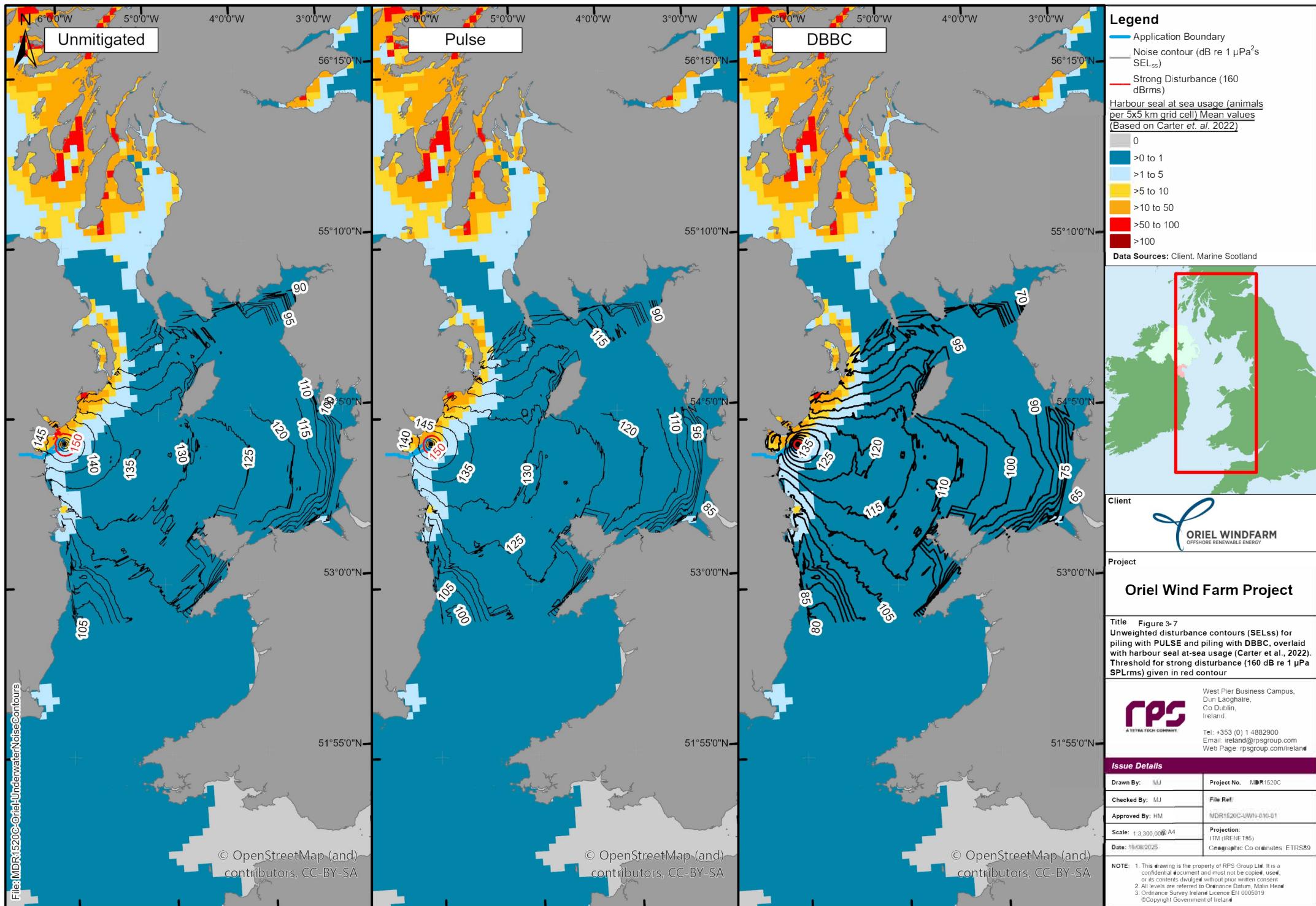
The potential number of animals predicted to be disturbed within unweighted SEL_{ss} contours (applying a dose response approach) alongside the numbers of animals predicted to experience strong and mild disturbance (using the strong and mild disturbance thresholds under National Marine Fisheries Service (NMFS) (2005)) are presented in Table 3-10. Figure 3-5 presents the unweighted disturbance contours (SEL_{ss}) for unmitigated piling, piling with PULSE and piling with DBBC all at the east piling location, with Figure 3-6 and Figure 3-7 showing contours overlaid onto the Carter *et al.* (2022) at-sea usage maps for grey seal and harbour seal respectively. The NMFS (2005) threshold for strong disturbance (160 dB re 1 μ Pa SPL root mean square (rms)) given in red contour. The predicted number of animals disturbed (Table 3-10) is based on the maximum density estimates (Table 3-4), representing the maximum numbers that could be affected in each scenario.

The numbers of animals potentially disturbed reduce for the PULSE scenario, and further reduce for the DBBC scenario for all species. Overall the greatest reduction in the number of animals predicted to be disturbed can be seen when comparing the unmitigated scenario with the DBBC scenario. This leads to a reduction in proportion of the MU population predicted to be disturbed, with the greatest proportion disturbed for the unmitigated scenario, and the least disturbed for the DBBC scenario (resulting in less than 1% of the MU disturbed for all species with the use of the DBBC). For strong disturbance (NMFS, 2005), the proportion of the MU population predicted to be disturbed is less than 1% for the PULSE and DBBC scenario. For mild disturbance (NMFS, 2005), the proportion of the MU population predicted to be disturbed is less than 1% for the DBBC scenario only.

For example, for harbour porpoise, the number of animals predicted to be disturbed using a dose response approach for the unmitigated scenario is 2,360 animals (3.77% of the CIS MU). This reduces to 1,855 (2.97% of the CIS MU) for the PULSE scenario, and further reduces to 165 for the DBBC scenario (0.26% of the CIS MU). The number of animals that fall within the strong disturbance threshold (≥ 160 dB re 1 μ Pa) reduces from 256 (0.41% of the CIS MU) in the unmitigated scenario, to 165 (0.26% of the CIS MU) for the PULSE scenario, to 29 (0.05% of the CIS MU) for the DBBC scenario.







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Table 3-10: Number of animals predicted to be disturbed within unweighted SEL_{ss} noise contours as a result of impact piling of monopiles at the east of the offshore wind farm area using a dose response approach. Also shows number of animals predicted to be disturbed, calculated within unweighted SEL_{ss} noise contours, that equate to strong and mild disturbance thresholds under NMFS (2005).

Scenario	Species	Dose response (SEL _{ss})		Strong disturbance (equivalent to ≥ 160 dB re 1 μ Pa (rms); NMFS, 2005)		Mild disturbance (equivalent to 140 – 160 dB re 1 μ Pa (rms); NMFS, 2005)	
		Number of animals	Proportion of MU population (%)	Number of animals	Proportion of MU population (%)	Number of animals	Proportion of MU population (%)
Unmitigated	Harbour porpoise	2,360	3.77%	256	0.41%	9,648	15.43%
	Bottlenose dolphin	417	5.01%	46	0.54%	1,705	20.47%
	Common dolphin	48	0.05%	6	0.01%	196	0.19%
	Minke whale	462	2.29%	51	0.25%	1,886	9.37%
	Grey seal	83	1.40%	31	0.52%	45	0.76%
	Harbour seal	71	4.30%	17	1.03%	33	1.96%
PULSE	Harbour porpoise	1,855	2.97%	165	0.26%	7,050	11.28%
	Bottlenose dolphin	328	3.94%	29	0.35%	1,246	14.97%
	Common dolphin	38	0.04%	3	0.003%	144	0.14%
	Minke whale	363	1.80%	32	0.16%	1,379	6.85%
	Grey seal	55	0.92%	20	0.34%	30	0.51%
	Harbour seal	44	2.64%	10	0.62%	21	1.28%
DBBC	Harbour porpoise	165	0.26%	29	0.05%	458	0.73%
	Bottlenose dolphin	30	0.35%	5	0.06%	81	0.97%
	Common dolphin	4	0.003%	1	0.001%	10	0.01%
	Minke whale	33	0.16%	6	0.03%	90	0.45%
	Grey seal	6	0.10%	2	0.03%	4	0.07%
	Harbour seal	6	0.37%	4	0.25%	3	0.18%

3.2 Fish and shellfish

3.2.1 Mortality, Recoverable Injury, and TTS

Table 3-11 presents indicative mortality, recoverable injury, and TTS ranges for fish modelled as moving receptors, and Table 3-12 presents these ranges for fish modelled as static receptors. The fish groups presented are based on Popper *et al.* (2014), with the three scenarios identified in section 1 presented for each fish group.

3.2.1.1 Mortality

When comparing mortality ranges for moving fish receptors between the unmitigated, PULSE mitigated, and DBBC mitigated scenarios, impact ranges were reduced from 21 m (group 2 fish and sea turtles) and 51 m (group 3 and 4 fish) in the unmitigated scenario to 18 m and 39 m respectively in the PULSE mitigation scenario, and to below the curtain range of the DBBC for all groups in the DBBC mitigation scenario. For group 1 fish and basking shark, no thresholds were exceeded for mortality in any scenario. The mortality range for fish eggs and larvae reduced from 935 m in the unmitigated scenario to 810 m in the PULSE mitigation scenario and further reduced to 506 m in the DBBC mitigation scenario.

For static fish receptors, the mortality ranges reduced from 385 m for group 1 fish in the unmitigated scenario, to 340 m in the PULSE scenario, to 265 m in the DBBC scenario. A similar reduction was seen for group 3 and 4 fish, with mortality reducing from 1,250 m in the unmitigated scenario, to 1,075 m in the PULSE scenario, to 630 m in the DBBC scenario. The mortality range for basking shark reduced from 385 m in the unmitigated scenario to 340 m in the PULSE mitigation scenario and further reduced to 265 m in the DBBC mitigation scenario. Similarly, for sea turtles, the mortality range reduced from 935 m in the unmitigated scenario to 810 m in the PULSE mitigation scenario and further reduced to 506 m in the DBBC mitigation scenario.

3.2.1.2 Recoverable Injury

Similar to mortality, the recoverable injury ranges for moving fish reduced when mitigation was applied for all fish groups except group 1 fish and basking shark, for which no thresholds were exceeded in any scenario. For group 2, and group 3 and 4 fish, recoverable injury ranges reduced from 147 m in the unmitigated scenario to 107 m in the PULSE mitigated scenario, to below the curtain range of the DBBC.

For static fish receptors, the recoverable injury ranges were significantly larger for all fish groups, due to increased exposure to underwater sound compared to moving receptors, but a trend of recoverable injury range reduction was noted with the use of mitigation in all scenarios. For group 1 fish, the unmitigated scenario caused recoverable injury to a range of 516 m, reducing to 457 m for the PULSE mitigation scenario, and to 329 m in the DBBC mitigated scenario. For group 2, 3, and 4 fish, recoverable injury reduced from 1,860 m in the unmitigated scenario to 1,580 m in the PULSE mitigated scenario, and further to 835 m in the DBBC mitigated scenario.

3.2.1.3 TTS

When comparing TTS ranges between the three scenarios for moving fish receptors, these ranged from 5,520 m (all fish groups) and 3,200 m (basking shark) in the unmitigated scenario and reduced to 4,020 m and 2,100 m, respectively, in the PULSE mitigation scenario. This reduced further to 700 m and 382 m, respectively, in the DBBC mitigated scenario.

For static fish receptors, the TTS ranges were greater than that modelled for moving receptors, with unmitigated ranges of 9,620 m (all fish groups and basking shark), with only a slight reduction to 7,920 m noted in the PULSE mitigated scenario. This further reduced to 2,820 m in the DBBC mitigated scenario.

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Table 3-11: Potential injury ranges for moving fish from installation of a single pile based on the SEL_{cum} metric

Hearing Group	Response	Threshold, SEL (dB re 1 $\mu\text{Pa}^2\text{s}$)	Unmitigated range (m)	PULSE range (m)	DBBC range (m)
Group 1 Fish: No swim bladder	Mortality	219 dB re 1 $\mu\text{Pa}^2\text{s}$	N/E	N/E	N/E
	Recoverable Injury	216 dB re 1 $\mu\text{Pa}^2\text{s}$	N/E	N/E	N/E
	TTS	186 dB re 1 $\mu\text{Pa}^2\text{s}$	5,520	4,020	700
Group 2 Fish: Swim bladder no involved in hearing	Mortality	210 dB re 1 $\mu\text{Pa}^2\text{s}$	21	18	<curtain
	Recoverable Injury	203 dB re 1 $\mu\text{Pa}^2\text{s}$	147	107	<curtain
	TTS	186 dB re 1 $\mu\text{Pa}^2\text{s}$	5,520	4,020	700
Group 3 and 4 Fish: Swim bladder involved in hearing	Mortality	207 dB re 1 $\mu\text{Pa}^2\text{s}$	51	39	<curtain
	Recoverable Injury	203 dB re 1 $\mu\text{Pa}^2\text{s}$	147	107	<curtain
	TTS	186 dB re 1 $\mu\text{Pa}^2\text{s}$	5,520	4,020	700
Fish eggs and larvae	Mortality	210 dB re 1 $\mu\text{Pa}^2\text{s}$	935	810	506
Basking shark	Mortality	219 dB re 1 $\mu\text{Pa}^2\text{s}$	N/E	N/E	N/E
	Recoverable Injury	216 dB re 1 $\mu\text{Pa}^2\text{s}$	N/E	N/E	N/E
	TTS	186 dB re 1 $\mu\text{Pa}^2\text{s}$	3,200	2,110	382
Sea turtles	Mortality	210 dB re 1 $\mu\text{Pa}^2\text{s}$	21	18	<curtain

N/E = threshold not exceeded, < curtain = injury range contained within DBBC.

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Table 3-12: Potential injury ranges for static fish from installation of a single pile based on the SEL_{cum} metric

Hearing Group	Response	Threshold, SEL (dB re 1 $\mu\text{Pa}^2\text{s}$)	Unmitigated range (m)	PULSE range (m)	DBBC range (m)
Group 1 Fish: No swim bladder	Mortality	219 dB re 1 $\mu\text{Pa}^2\text{s}$	385	340	265
	Recoverable Injury	216 dB re 1 $\mu\text{Pa}^2\text{s}$	516	457	329
	TTS	186 dB re 1 $\mu\text{Pa}^2\text{s}$	9,620	7,920	2,820
Group 2 Fish: Swim bladder no involved in hearing	Mortality	210 dB re 1 $\mu\text{Pa}^2\text{s}$	935	810	506
	Recoverable Injury	203 dB re 1 $\mu\text{Pa}^2\text{s}$	1,860	1,580	835
	TTS	186 dB re 1 $\mu\text{Pa}^2\text{s}$	9,620	7,920	2,820
Group 3 and 4 Fish: Swim bladder involved in hearing	Mortality	207 dB re 1 $\mu\text{Pa}^2\text{s}$	1,250	1,075	630
	Recoverable Injury	203 dB re 1 $\mu\text{Pa}^2\text{s}$	1,860	1,580	835
	TTS	186 dB re 1 $\mu\text{Pa}^2\text{s}$	9,620	7,920	2,820
Fish eggs and larvae	Mortality	210 dB re 1 $\mu\text{Pa}^2\text{s}$	935	810	506
Basking shark	Mortality	219 dB re 1 $\mu\text{Pa}^2\text{s}$	385	340	265
	Recoverable Injury	216 dB re 1 $\mu\text{Pa}^2\text{s}$	516	457	329
	TTS	186 dB re 1 $\mu\text{Pa}^2\text{s}$	9,620	7,920	2,820
Sea turtles	Mortality	210 dB re 1 $\mu\text{Pa}^2\text{s}$	935	810	506

3.2.2 Behavioural Disturbance

Figure 3-8 presents underwater sound contours using the SPL_{pk} metric for a monopile for the unmitigated, PULSE mitigated, and DBBC mitigated scenarios alongside mapped herring nursery grounds derived from Coull *et al.* (1998) and Ellis *et al.* (2012). Noise levels in excess of 160 dB re 1 μPa SPL_{pk} (defined in section 1) are expected to lead to behavioural effects on fish. Whilst the underwater noise report (appendix C-2 Addendum: NAS Modelling Report) presents 150 dB re 1 μPa SPL_{rms} as an alternative behavioural threshold, this contour is expected to be a conservative threshold for behavioural effects, with a 160 dB re 1 μPa SPL_{pk} threshold providing a more realistic behavioural disturbance threshold. Herring nursery grounds have been presented, given that this species is within the highest sensitivity hearing Group 4 (Popper *et al.*, 2014), and therefore underwater noise is likely to have the greatest impact on this group, with all other groups experiencing a lesser impact.

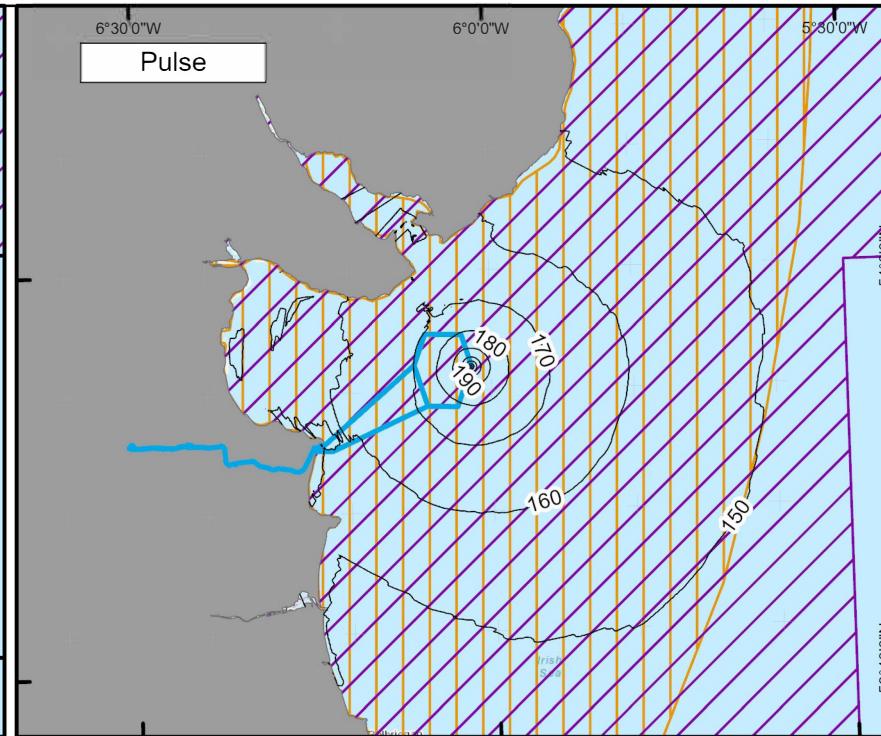
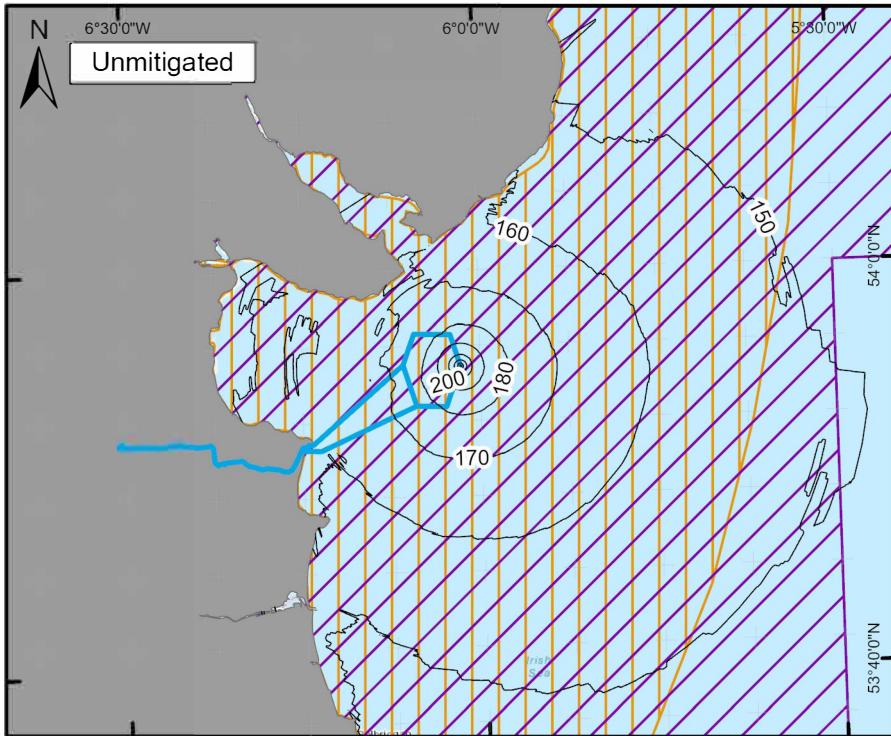
When comparing modelled contours using the SPL_{pk} metric against mapped herring nursery grounds, all piling scenarios fully overlapped with both high intensity nursery ground (Ellis *et al.*, 2012) and unspecified intensity nursery ground (Coull *et al.*, 1998), but the areas impacted showed a significant decrease with increased mitigation measures modelled (Figure 3-8).

Specifically, the unmitigated piling scenario 160 dB re 1 μPa SPL_{pk} behavioural disturbance contour for group 4 fish overlapped with 812.4 km² of both high intensity and unspecified intensity herring nursery grounds. In the PULSE mitigated scenario, this area of overlap reduced by 30.90% to 561.35 km², and in the DBBC mitigated scenario the area of overlap reduced by 91.82% compared to the unmitigated scenario to 66.45 km². This indicates significant reductions with increasing levels of mitigation, even when only applying the PULSE mitigation method.

In relation to the Western Irish Sea Fish and Shellfish Ecology Study Area (defined in appendix E: Fish and Shellfish Ecology Supporting Information), the unmitigated scenario 160 dB re 1 μPa SPL_{pk} behavioural disturbance contour ensonified 5.91% of the Study Area, the PULSE mitigated scenario ensonified 4.08% of the Study Area, and the DBBC ensonified 0.48% of the Study Area, indicating a low level of impact overall even without mitigation.

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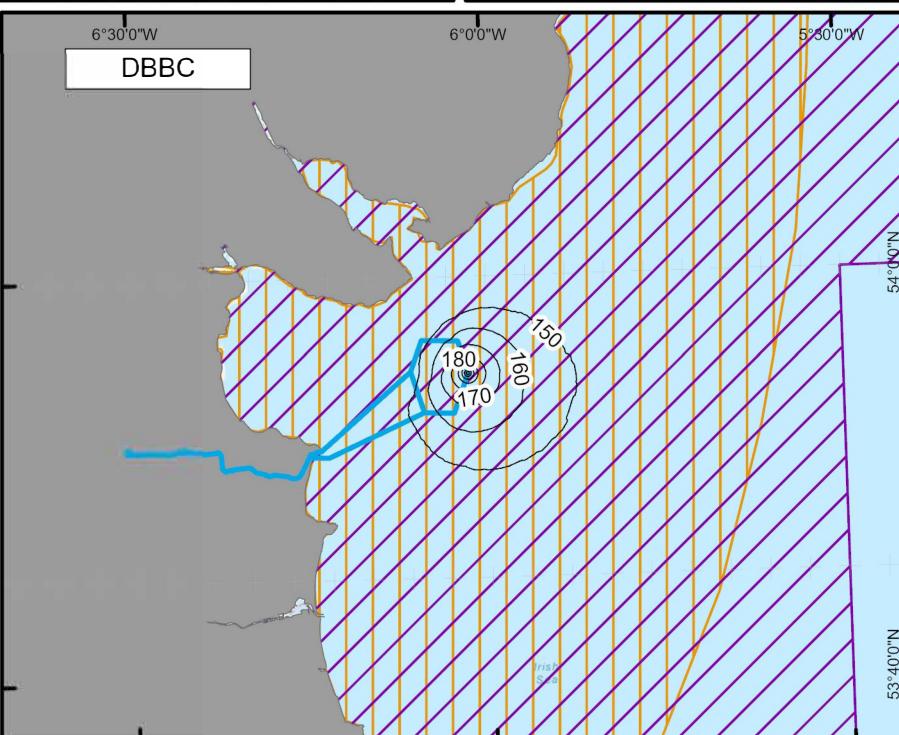
In the context of the herring nursery grounds within the Western Irish Sea Fish and Shellfish Ecology Study Area, the unmitigated scenario 160 dB re 1 μ Pa SPL_{pk} behavioural disturbance contour impacted 18.13% of high intensity nursery grounds (Ellis *et al.*, 2012) and 22.92% of unspecified intensity nursery grounds (Coull *et al.*, 1998). This reduced to 12.53% of high intensity nursery grounds and 15.83% of unspecified intensity nursery grounds in the PULSE mitigated scenario, and to 1.48% of high intensity nursery grounds and 1.87% of unspecified intensity nursery grounds in the DBBC mitigated scenario.



Legend

- Application Boundary
- Noise contours: dB re 1 μ Pa (SPLpk)
- Nursery Ground - High Intensity (Ellis et al., 2012)
- Nursery Ground - Intensity Not Specified (Coull et al., 1998)

Data Sources: Client, CEFAS



Service Layer Credits: © OpenStreetMap (and) contributors, CC-BY-SA, DoBH, OS, Esri, HERE, Garmin, USGS, NGA

Title Figure 3-8
Herring nursery grounds with subsea contours for moving fish from installation of a single pile based on the SPLpk metric

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Date:	26/08/2025	Geographic Co-ordinates:	ETRS89
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4 CONCLUSIONS

The NAS modelling clearly demonstrates the potential for measurable reductions in auditory injury, TTS and disturbance impact ranges/areas for both the scenarios modelled (PULSE and DBBC systems).

The Applicant highlights that the modelling presented in this report is just an example of suitable types of NAS, and other options are available (as detailed in the review of NAS technology, in appendix C-4 Addendum: Comprehensive Review of Relevant Mitigation (Noise Abatement)). Given the range of reductions demonstrated it is expected that application of NAS available at the time of construction will produce similar results. Furthermore, given that the impact assessment has already concluded no significant impact on marine mammals, it is considered that any application of NAS would simply further reduce the magnitude of effect on marine mammals for PTS, TTS and disturbance.

Finally, given the potential for measurable reductions in impact zones, it is considered that this will also lead to a reduction in the Project's contribution to potential underwater noise cumulative effects with other projects in the vicinity of the Project, should construction programme and piling schedules overlap.

4.1 Marine mammals

Overall modelling for impact piling of monopiles on the Project with different NAS scenarios results in reduced impact ranges and areas, for both the PULSE and DBBC scenarios when compared to unmitigated piling. The DBBC scenario modelling results in the greatest reduction in ranges and areas compared to the unmitigated scenario.

For PTS (SEL_{cum}), without ADD, thresholds for harbour porpoise and minke whale were exceeded for the unmitigated, PULSE and DBBC scenarios (though PTS ranges reduced for the PULSE scenario, and further reduced for the DBBC scenario). With the application of PULSE or DBBC, PTS ranges were below the NPWS (2014) recommended mitigation zone of 1,000 m for all species. With the inclusion of ADD, no PTS threshold was exceeded for any species, for any scenario.

For PTS (SPL_{pk}), ranges reduced with PULSE and further with DBBC, leading to a maximum of up to one animal predicted to experience PTS with DBBC for all species at max energy and less than 0.01% of the respective MUs. For all species other than harbour porpoise, the range of the PTS threshold remained within the DBBC. For harbour porpoise, the threshold was exceeded by 395 m leading to less than one animal predicted to experience PTS (0.001% of the CIS MU).

For TTS, ranges reduced with PULSE and further with DBBC, both with and without ADD. Without ADD, the threshold was exceeded with PULSE but at smaller ranges than the unmitigated scenario. For bottlenose dolphin and short-beaked common dolphin less than one animal was predicted to experience TTS under the PULSE scenario. The TTS threshold was within the DBBC curtain for bottlenose dolphin, common dolphin, grey seal and harbour seal, leading to no animals predicted to experience TTS for the DBBC scenario. With the inclusion of ADD, the TTS threshold was within the DBBC curtain for all species except for harbour porpoise. The TTS range for harbour porpoise was 725 m, within the 1,000 m mitigation zone (leading to up to three harbour porpoise predicted to experience TTS, 0.004% of the CIS MU).

For disturbance, using the dose response approach, the numbers of animals potentially disturbed reduced for the PULSE scenario and further reduced for the DBBC scenario for all species (with less than 0.5% of the respective MU's disturbed for all species for the DBBC scenario). The number of animals predicted to experience strong disturbance and mild disturbance (NMFS, 2005) also decreased for the PULSE scenario, and further reduced for the DBBC scenario. For mild and strong disturbance thresholds, the DBBC scenario was less than 1% of the MU for all species.

4.2 Fish and shellfish

For mortality, recoverable injury, TTS, and behavioural disturbance, the evidence presented in section 3 indicated that the use of NAS technology can reduce impact ranges for highly sensitive group 4 herring when modelled both as moving and static receptors. Furthermore, underwater noise modelling indicated that the use of NAS has the potential to reduce the overlap of ensonification with juvenile herring populations in high and unspecified intensity spawning grounds. The underwater noise modelling assumptions and the

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behavioural impact threshold applied for herring (160 dB re 1 μ Pa SPL_{pk}) are considered to be conservative (appendix C-1 Addendum: Updated Subsea Noise Modelling Report, section 3.1), and therefore these indicative scenarios likely represent an overestimate of the potential impact on herring nursery grounds. This NAS modelling work demonstrates the effectiveness of both PULSE and DBBC as potential NAS mitigation measures, in significantly reducing noise levels associated with piling activity, even in a highly conservative scenario.

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