

# Outer Dowsing Offshore Wind

## Environmental Statement

### Chapter 11 Marine Mammals

#### Volume 3 Appendices

#### Appendix 11.2

Date: March 2024

Pursuant to APFP Regulation: 5(2)(a)

Document Reference: 6.3.11.2

Rev: 1.0

| Company:  | <b>Outer Dowsing Offshore Wind</b>        | Asset:  | <b>Whole Asset</b> |            |                         |             |
|---|---|---|--------------------|------------|-------------------------|-------------|
| Project:  | <b>Whole Wind Farm</b>                    | Sub Project/Package:                          | Whole Asset        |            |                         |             |
| Document Title or Description:  | Appendix 11.2 Underwater Noise Assessment |   |                    |            |                         |             |
| Internal Document Number:   | PP1-ODOW-DEV-CS-REP-0170                  | 3 <sup>rd</sup> Party Doc No (If applicable): | N/A                |            |                         |             |
| <i>Outer Dowsing Offshore Wind accepts no liability for the accuracy or completeness of the information in this document nor for any loss or damage arising from the use of such information.</i> |   |   |                    |            |                         |             |
| Rev No.   | Date                                      | Status / Reason for Issue                     | Author             | Checked by | Reviewed by             | Approved by |
| V1.0  | March 2024                                | Final   | GoBe               | GoBe       | Shepherd and Wedderburn | ODOW        |

---

# Outer Dowsing Offshore Wind: Underwater Noise Assessment

Richard Barham, Tim Mason

28 February 2024

**Subacoustech Environmental Report No.  
P295R0108**

---



| <i>Document No.</i> | <i>Date</i> | <i>Written</i> | <i>Approved</i> | <i>Distribution</i>      |
|---------------------|-------------|----------------|-----------------|--------------------------|
| P295R0101           | 29/11/2022  | R Barham       | DRAFT           | P New (GoBe Consultants) |
| P295R0102           | 19/01/2023  | R Barham       | T Mason         | P New (GoBe Consultants) |
| P295R0103           | 30/03/2023  | R Barham       | T Mason         | P New (GoBe Consultants) |
| P295R0104           | 11/10/2023  | R Barham       | T Mason         | P New (GoBe Consultants) |
| P295R0105           | 03/11/2023  | R Barham       | T Mason         | P New (GoBe Consultants) |
| P295R0106           | 24/01/2024  | R Barham       | T Mason         | P New (GoBe Consultants) |
| P295R0107           | 13/02/2024  | R Barham       | T Mason         | P New (GoBe Consultants) |
| P295R0108           | 28/02/2024  | R Barham       | T Mason         | P New (GoBe Consultants) |

*This report is a controlled document. The report documentation page lists the version number, record of changes, referencing information, abstract and other documentation details.*

## List of contents

|     |   |    |
|-----|---|----|
| 1   | Introduction.....   | 1  |
| 2   | Background to underwater noise metrics.....                 | 2  |
| 2.1 | Underwater noise .....                                      | 2  |
| 2.2 | Analysis of environmental effects.....                      | 4  |
| 3   | Modelling methodology .....                                 | 10 |
| 3.1 | Modelling confidence .....                                  | 11 |
| 3.2 | Modelling parameters.....                                   | 13 |
| 3.3 | Cumulative SELs and fleeing receptors.....                  | 16 |
| 4   | Modelling results .....                                     | 20 |
| 4.1 | Predicted noise levels at 750 m from the noise source ..... | 21 |
| 4.2 | Array locations.....  | 22 |
| 4.3 | ORCP locations.....   | 34 |
| 4.4 | ANS locations.....  | 42 |
| 4.5 | Multiple location modelling .....                           | 49 |
| 5   | Other noise sources .....                                   | 56 |
| 5.1 | Noise making activities.....                                | 57 |
| 5.2 | Operational WTG noise.....                                  | 61 |
| 5.3 | UXO clearance.....  | 63 |
| 6   | Summary and conclusions .....                               | 66 |
|     | References .....  | 68 |
|     | Report documentation page.....                              | 81 |

## List of Figures

|            |  |    |
|------------|--|----|
| Figure 1-1 | Overview map showing the Order Limits, cable corridor, ORCP and ANS areas and the surrounding bathymetry and coastline .....   | 1  |
| Figure 2-1 | Auditory weighting functions for low-frequency cetaceans (LF), high-frequency cetaceans (HF), very high-frequency cetaceans (VHF), and phocid carnivores in water (PCW) (from Southall et al., 2019) .....                           | 5  |
| Figure 3-1 | Comparison between example unweighted $SPL_{peak}$ measured impact piling data (blue points) and modelled data using INSPIRE version 5.1 (orange points) .....   | 12 |
| Figure 3-2 | Comparison between example unweighted $SEL_{ss}$ measured impact piling data (blue points) and modelled data using INSPIRE version 5.1 (orange points) .....   | 13 |
| Figure 3-3 | Approximate positions of the modelling locations at the Project .....  | 14 |
| Figure 3-4 | Received single-strike noise levels ( $SEL_{ss}$ ) for receptors during the monopile foundation parameters at the NE location, assuming both a stationary and fleeing receptor starting at a location 1 m from the noise source..... | 18 |

Figure 3-5 Cumulative received noise levels ( $SEL_{cum}$ ) for receptors during monopile foundation parameters at the NE location, assuming both a stationary and fleeing receptor starting at a location 1 m from the noise source..... 18

Figure 3-6 Plot showing a fleeing animal  $SEL_{cum}$  criteria contour and the areas where the cumulative noise exposure will exceed the impact criteria..... 19

Figure 4-1 Contour plot showing the interaction between two noise sources when occurring simultaneously (TTS in fish, 186 dB  $SEL_{cum}$ , fleeing animal)..... 50

Figure 4-2 Contour plots showing the in-combination impacts of simultaneous installation of monopile foundations at the SW and NE modelling locations for marine mammals using the impulsive Southall et al. (2019) criteria assuming a fleeing animal ..... 51

Figure 4-3 Contour plots showing the in-combination impacts of simultaneous installation of monopile foundations at the SW and NE modelling locations for fish using the Popper et al. (2014) impact piling criteria assuming both a fleeing and stationary animal ..... 52

Figure 4-4 Contour plots showing the in-combination impacts of simultaneous installation of jacket pile foundations at the SW and NE modelling locations for marine mammals using the impulsive Southall et al. (2019) criteria assuming a fleeing animal ..... 54

Figure 4-5 Contour plots showing the in-combination impacts of simultaneous installation of jacket pile foundations at the SW and NE modelling locations for fish using the Popper et al. (2014) impact piling criteria assuming both a fleeing and stationary animal ..... 55

Figure 5-1 Summary of the 1/3<sup>rd</sup> octave frequency bands to which the Southall et al. (2019) weightings were applied in the simple modelling. .... 59

Figure 5-2 Predicted unweighted  $SPL_{RMS}$  from operational WTGs at the Project using the calculation from Tougaard et al. (2020) ..... 62

Figure A 1 Contour plots showing the in-combination impacts of simultaneous installation of monopile foundations at the SW and NE modelling locations for marine mammals using the non-impulsive Southall et al. (2019) criteria assuming a fleeing animal ..... 78

Figure A 2 Contour plots showing the in-combination impacts of simultaneous installation of jacket pile foundations at the SW and NE modelling locations for marine mammals using the non-impulsive Southall et al. (2019) criteria assuming a fleeing animal ..... 79

## List of Tables

Table 2-1 Marine mammal hearing groups (from Southall et al., 2019) ..... 5

Table 2-2 Single strike  $SPL_{peak}$  criteria for PTS and TTS in marine mammals (Southall et al., 2019) ... 6

Table 2-3 Impulsive and non-impulsive  $SEL_{cum}$  criteria for PTS and TTS in marine mammals (Southall et al., 2019) ..... 6

Table 2-4 Criteria for mortality and potential mortal injury, recoverable injury, and TTS in species of fish from impact piling noise (Popper et al., 2014) ..... 7

Table 2-5 Criteria for recoverable injury and TTS in species of fish from continuous noise sources (Popper et al., 2014) ..... 7

Table 2-6 Criteria for potential mortal injury in species of fish from explosions (Popper et al., 2014).... 8

|  |    |
|--|----|
| Table 2-7 Summary of the qualitative effects on species of fish from impact piling noise (Popper et al., 2014) (N = Near-field; I = Intermediate-field; F = Far-field).....  | 8  |
| Table 2-8 Summary of the qualitative effects on fish from continuous noise from Popper et al. (2014) (N = Near-field; I = Intermediate-field; F = Far-field).....  | 8  |
| Table 2-9 Summary of the qualitative effects on species of fish from explosions (Popper et al., 2014) (N = Near-field; I = Intermediate-field; F = Far-field).....   | 9  |
| Table 3-1 Summary of the underwater noise modelling locations used for this study. ....  | 14 |
| Table 3-2 Summary of the soft start and ramp up scenario used for the monopile foundation modelling at the Array and ORCP locations.....   | 15 |
| Table 3-3 Summary of the soft start and ramp up scenario used for the monopile foundation modelling at the ANS locations.....  | 15 |
| Table 3-4 Summary of the soft start and ramp up scenario used for the jacket pile foundation modelling at the Array, ORCP, and ANS locations. ....   | 15 |
| Table 3-5 Summary of the unweighted apparent source levels used for modelling. ....  | 16 |
| Table 4-1 Summary of the impact piling modelling results tables presented in this section .....  | 20 |
| Table 4-2 Summary of the maximum predicted unweighted SPL <sub>peak</sub> and SEL <sub>ss</sub> noise levels at a range of 750 m from the noise source when considering maximum hammer blow energy .....   | 22 |
| Table 4-3 Summary of the unweighted SPL <sub>peak</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the SW location .....                                      | 23 |
| Table 4-4 Summary of the weighted SEL <sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the SW location assuming a fleeing animal.....                | 23 |
| Table 4-5 Summary of the unweighted SPL <sub>RMS</sub> impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the monopile foundation modelling at the SW location .....  | 23 |
| Table 4-6 Summary of the unweighted SPL <sub>peak</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the SW location .....   | 23 |
| Table 4-7 Summary of the unweighted SEL <sub>cum</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the SW location assuming both a fleeing and stationary animal .....  | 24 |
| Table 4-8 Summary of the unweighted SPL <sub>peak</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the NW location .....                                      | 24 |
| Table 4-9 Summary of the weighted SEL <sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the NW location assuming a fleeing animal.....                | 25 |
| Table 4-10 Summary of the unweighted SPL <sub>RMS</sub> impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the monopile foundation modelling at the NW location .....   | 25 |
| Table 4-11 Summary of the unweighted SPL <sub>peak</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the NW location .....  | 25 |
| Table 4-12 Summary of the unweighted SEL <sub>cum</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the NW location assuming both a fleeing and stationary animal ..... | 26 |

Table 4-13 Summary of the unweighted SPL<sub>peak</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the NE location ..... 26

Table 4-14 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the NE location assuming a fleeing animal..... 27

Table 4-15 Summary of the unweighted SPL<sub>RMS</sub> impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the monopile foundation modelling at the NE location ..... 27

Table 4-16 Summary of the unweighted SPL<sub>peak</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the NE location ..... 27

Table 4-17 Summary of the unweighted SEL<sub>cum</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the NE location assuming both a fleeing and stationary animal ..... 28

Table 4-18 Summary of the unweighted SPL<sub>peak</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the SW location ..... 28

Table 4-19 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the SW location assuming a fleeing animal ..... 29

Table 4-20 Summary of the unweighted SPL<sub>RMS</sub> impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the jacket pile foundation modelling at the SW location ..... 29

Table 4-21 Summary of the unweighted SPL<sub>peak</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the SW location ..... 29

Table 4-22 Summary of the unweighted SEL<sub>cum</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the SW location assuming both a fleeing and stationary animal ..... 30

Table 4-23 Summary of the unweighted SPL<sub>peak</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the NW location ..... 30

Table 4-24 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the NW location assuming a fleeing animal ..... 31

Table 4-25 Summary of the unweighted SPL<sub>RMS</sub> impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the jacket pile foundation modelling at the NW location ..... 31

Table 4-26 Summary of the unweighted SPL<sub>peak</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the NW location ..... 31

Table 4-27 Summary of the unweighted SEL<sub>cum</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the NW location assuming both a fleeing and stationary animal ..... 32

Table 4-28 Summary of the unweighted SPL<sub>peak</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the NE location ..... 32

Table 4-29 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the NE location assuming a fleeing animal ..... 33

Table 4-30 Summary of the unweighted SPL<sub>RMS</sub> impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the jacket pile foundation modelling at the NE location ..... 33

|   |    |
|---|----|
| Table 4-31 Summary of the unweighted SPL <sub>peak</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the NE location .....  | 33 |
| Table 4-32 Summary of the unweighted SEL <sub>cum</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the NE location assuming both a fleeing and stationary animal .....     | 34 |
| Table 4-33 Summary of the unweighted SPL <sub>peak</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the ORCP-N location .....  | 35 |
| Table 4-34 Summary of the weighted SEL <sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the ORCP-N location assuming a fleeing animal .....                 | 35 |
| Table 4-35 Summary of the unweighted SPL <sub>RMS</sub> impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the monopile foundation modelling at the ORCP-N location .....  | 35 |
| Table 4-36 Summary of the unweighted SPL <sub>peak</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the ORCP-N location .....   | 35 |
| Table 4-37 Summary of the unweighted SEL <sub>cum</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the ORCP-N location assuming both a fleeing and stationary animal .....    | 36 |
| Table 4-38 Summary of the unweighted SPL <sub>peak</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the ORCP-S location .....  | 36 |
| Table 4-39 Summary of the weighted SEL <sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the ORCP-S location assuming a fleeing animal .....                 | 37 |
| Table 4-40 Summary of the unweighted SPL <sub>RMS</sub> impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the monopile foundation modelling at the ORCP-S location .....  | 37 |
| Table 4-41 Summary of the unweighted SPL <sub>peak</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the ORCP-S location .....   | 37 |
| Table 4-42 Summary of the unweighted SEL <sub>cum</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the ORCP-S location assuming both a fleeing and stationary animal .....    | 38 |
| Table 4-43 Summary of the unweighted SPL <sub>peak</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the ORCP-N location .....                                     | 38 |
| Table 4-44 Summary of the weighted SEL <sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the ORCP-N location assuming a fleeing animal .....              | 39 |
| Table 4-45 Summary of the unweighted SPL <sub>RMS</sub> impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the jacket pile foundation modelling at the ORCP-N location .....   | 39 |
| Table 4-46 Summary of the unweighted SPL <sub>peak</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the ORCP-N location .....  | 39 |
| Table 4-47 Summary of the unweighted SEL <sub>cum</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the ORCP-N location assuming both a fleeing and stationary animal ..... | 40 |
| Table 4-48 Summary of the unweighted SPL <sub>peak</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the ORCP-S location .....                                     | 40 |



Table 4-49 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the ORCP-S location assuming a fleeing animal ..... 41

Table 4-50 Summary of the unweighted  $SPL_{RMS}$  impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the jacket pile foundation modelling at the ORCP-S location ..... 41

Table 4-51 Summary of the unweighted  $SPL_{peak}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the ORCP-S location..... 41

Table 4-52 Summary of the unweighted  $SEL_{cum}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the ORCP-S location assuming both a fleeing and stationary animal ..... 42

Table 4-53 Summary of the unweighted  $SPL_{peak}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the ANS-NW location ..... 43

Table 4-54 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the ANS-NW location assuming a fleeing animal ..... 43

Table 4-55 Summary of the unweighted  $SPL_{RMS}$  impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the monopile foundation modelling at the ANS-NW location ..... 43

Table 4-56 Summary of the unweighted  $SPL_{peak}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the ANS-NW location..... 43

Table 4-57 Summary of the unweighted  $SEL_{cum}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the ANS-NW location assuming both a fleeing and stationary animal ..... 44

Table 4-58 Summary of the unweighted  $SPL_{peak}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the ANS-SE location..... 44

Table 4-59 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the ANS-SE location assuming a fleeing animal ..... 44

Table 4-60 Summary of the unweighted  $SPL_{RMS}$  impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the monopile foundation modelling at the ANS-SE location ..... 44

Table 4-61 Summary of the unweighted  $SPL_{peak}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the ANS-SE location..... 45

Table 4-62 Summary of the unweighted  $SEL_{cum}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the ANS-SE location assuming both a fleeing and stationary animal ..... 45

Table 4-63 Summary of the unweighted  $SPL_{peak}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the ANS-NW location ..... 45

Table 4-64 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the ANS-NW location assuming a fleeing animal ..... 46

Table 4-65 Summary of the unweighted  $SPL_{RMS}$  impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the jacket pile foundation modelling at the ANS-NW location ..... 46

Table 4-66 Summary of the unweighted  $SPL_{peak}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the ANS-NW location ..... 46

Table 4-67 Summary of the unweighted SEL<sub>cum</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the ANS-NW location assuming both a fleeing and stationary animal ..... 47

Table 4-68 Summary of the unweighted SPL<sub>peak</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the ANS-SE location ..... 47

Table 4-69 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the ANS-SE location assuming a fleeing animal ..... 48

Table 4-70 Summary of the unweighted SPL<sub>RMS</sub> impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the jacket pile foundation modelling at the ANS-SE location ..... 48

Table 4-71 Summary of the unweighted SPL<sub>peak</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the ANS-SE location ..... 48

Table 4-72 Summary of the unweighted SEL<sub>cum</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the ANS-SE location assuming both a fleeing and stationary animal ..... 49

Table 4-73 Summary of the impact areas for the installation of monopile foundations at the SW and NE modelling locations for marine mammals using the impulsive Southall et al. (2019) SEL<sub>cum</sub> criteria assuming a fleeing animal..... 53

Table 4-74 Summary of the impact areas for the installation of monopile foundations at the SW and NE modelling locations for fish using the Popper et al. (2014) SEL<sub>cum</sub> impact piling criteria assuming both a fleeing and stationary animal ..... 53

Table 4-75 Summary of the impact areas for the installation of jacket pile foundations at the SW and NE modelling locations for marine mammals using the impulsive Southall et al. (2019) SEL<sub>cum</sub> criteria assuming a fleeing animal..... 56

Table 4-76 Summary of the impact areas for the installation of jacket pile foundations at the SW and NE modelling locations for fish using the Popper et al. (2014) SEL<sub>cum</sub> impact piling criteria assuming both a fleeing and stationary animal ..... 56

Table 5-1 Summary of the possible noise making activities at the Project other than impact piling .... 57

Table 5-2 Summary of the estimated unweighted source levels and transmission losses for the different considered noise sources related to construction..... 58

Table 5-3 Reductions in source level for the different construction noise sources considered when the Southall et al. (2019) weightings are applied. .... 59

Table 5-4 Summary of the impact ranges for the different noise sources related to construction using the non-impulsive criteria from Southall et al. (2019) for marine mammals assuming a fleeing animal ..... 60

Table 5-5 Summary of the impact ranges for the different noise sources related to construction using the non-impulsive criteria from Southall et al. (2019) for marine mammals assuming a stationary animal ..... 60

Table 5-6 Summary of the impact ranges for the different noise sources related to construction using the continuous noise criteria from Popper et al. (2014) for fish (swim bladder involved in hearing) .... 61

Table 5-7 Summary of the operational WTG noise impact ranges using the non-impulsive noise criteria from Southall et al. (2019) for marine mammals assuming a fleeing receptor ..... 62

Table 5-8 Summary of the operational WTG noise impact ranges using the non-impulsive noise criteria from Southall et al. (2019) for marine mammals assuming a stationary receptor ..... 62

Table 5-9 Summary of the operational WTG noise impact ranges using the continuous noise criteria from Popper et al. (2014) for fish (swim bladder involved in hearing) ..... 62

Table 5-10 Summary of the unweighted SPL<sub>peak</sub> and SEL<sub>ss</sub> source levels used for UXO clearance modelling ..... 65

Table 5-11 Summary of the PTS and TTS impact ranges for UXO detonation using the impulsive, unweighted SPL<sub>peak</sub> noise criteria from Southall et al. (2019) for marine mammals ..... 65

Table 5-12 Summary of the PTS and TTS impact ranges for UXO detonation using the impulsive, weighted SEL<sub>ss</sub> noise criteria from Southall et al. (2019) for marine mammals. .... 65

Table 5-13 Summary of the PTS and TTS impact ranges for UXO detonation using the non-impulsive, weighted SEL<sub>ss</sub> noise criteria from Southall et al. (2019) for marine mammals. .... 66

Table 5-14 Summary of the impact ranges for UXO detonation using the unweighted SPL<sub>peak</sub> explosion noise criteria from Popper et al. (2014) for species of fish ..... 66

Table A 1 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at the SW location assuming a fleeing animal ..... 71

Table A 2 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at the NW location assuming a fleeing animal ..... 71

Table A 3 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at the NE location assuming a fleeing animal ..... 72

Table A 4 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the jacket pile foundation modelling at the SW location assuming a fleeing animal ..... 72

Table A 5 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the jacket pile foundation modelling at the NW location assuming a fleeing animal ..... 73

Table A 6 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the jacket pile foundation modelling at the NE location assuming a fleeing animal ..... 73

Table A 7 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at the ORCP-N location assuming a fleeing animal ..... 74

Table A 8 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at the ORCP-S location assuming a fleeing animal ..... 74

Table A 9 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the jacket pile foundation modelling at the ORCP-N location assuming a fleeing animal ..... 75

Table A 10 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the jacket pile foundation modelling at the ORCP-S location assuming a fleeing animal..... 75

Table A 11 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at the ANS-NW location assuming a fleeing animal..... 76

Table A 12 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at the ANS-SE location assuming a fleeing animal ..... 76

Table A 13 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the jacket pile foundation modelling at the ANS-NW location assuming a fleeing animal..... 76

Table A 14 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the jacket pile foundation modelling at the ANS-SE location assuming a fleeing animal..... 77

Table A 15 Summary of the impact areas for the installation of monopile foundations at the SW and NE modelling locations for marine mammals using the non-impulsive Southall et al. (2019) SEL<sub>cum</sub> criteria assuming a fleeing animal..... 80

Table A 16 Summary of the impact areas for the installation of jacket pile foundations at the SW and NE modelling locations for marine mammals using the non-impulsive Southall et al. (2019) SEL<sub>cum</sub> criteria assuming a fleeing animal..... 80

## Acronyms

| Acronym                     | Definition  |
|-----------------------------|---|
| ADD                         | Acoustic Deterrent Device   |
| ANS                         | Artificial Nesting Structure  |
| BGS                         | British Geological Survey   |
| ECC                         | Export Cable Corridor   |
| EIA                         | Environmental Impact Assessment   |
| EMODnet                     | European Marine Observation and Data Network  |
| FPSO                        | Floating Production Storage and Offloading  |
| GIS                         | Geographic Information System   |
| HF                          | High-Frequency Cetaceans<br>(Marine mammal hearing group from Southall <i>et al.</i> , 2019)                                      |
| INSPIRE                     | Impulse Noise Sound Propagation and Range Estimator (Subacoustech Environmental's noise model for estimating impact piling noise) |
| LF                          | Low-Frequency Cetaceans<br>(Marine mammal hearing group from Southall <i>et al.</i> , 2019)                                       |
| MTD                         | Marine Technology Directorate   |
| NMFS                        | National Marine Fisheries Service   |
| NOAA                        | National Oceanic and Atmospheric Administration   |
| NPL                         | National Physical Laboratory  |
| ODOW                        | Outer Dowsing Offshore Wind   |
| ORCP                        | Offshore Reactive Compensation Platform   |
| OWF                         | Offshore Windfarm   |
| PCW                         | Phocid Carnivores in Water<br>(Marine mammal hearing group from Southall <i>et al.</i> , 2019)                                    |
| PPV                         | Peak Particle Velocity  |
| PTS                         | Permanent Threshold Shift   |
| RMS                         | Root Mean Square  |
| SE                          | Sound Exposure  |
| SEL                         | Sound Exposure Level  |
| SEL <sub>cum</sub>          | Cumulative Sound Exposure Level   |
| SEL <sub>ss</sub>           | Single Strike Sound Exposure Level  |
| SPL                         | Sound Pressure Level  |
| SPL <sub>peak</sub>         | Peak Sound Pressure Level   |
| SPL <sub>peak-to-peak</sub> | Peak-to-peak Sound Pressure Level   |
| SPL <sub>RMS</sub>          | Root Mean Square Sound Pressure Level   |
| TNT                         | Trinitrotoluene (explosive)   |
| TTS                         | Temporary Threshold Shift   |
| UXO                         | Unexploded Ordnance   |
| VHF                         | Very High-Frequency Cetaceans<br>(Marine mammal hearing group from Southall <i>et al.</i> , 2019)                                 |
| WTG                         | Wind Turbine Generator  |

## Technical Glossary

| Term   | Definition   |
|--|--|
| Decibel (dB)   | A customary scale commonly used (in various ways) for reporting levels of sound. A difference of 10 dB corresponds to a factor of 10 in sound power. The actual sound measurement is compared to a fixed reference level and the “decibel” value is defined to be $10 \log_{10}(\text{actual}/\text{reference})$ where ( <i>actual/reference</i> ) is a power ratio. Because sound power is usually proportional to sound pressure squared, the decibel value for sound pressure is $20 \log_{10}(\text{actual pressure}/\text{reference pressure})$ . The standard reference for underwater sound is 1 micro pascal ( $\mu\text{Pa}$ ). The dB symbol is followed by a second symbol identifying the specific reference value (e.g., re 1 $\mu\text{Pa}$ ). |
| Peak pressure  | The highest pressure above or below ambient that is associated with a sound wave.  |
| Peak-to-peak pressure                                    | The sum of the highest positive and negative pressures that are associated with a sound wave.  |
| Permanent Threshold Shift (PTS)                          | A permanent total or partial loss of hearing caused by acoustic trauma. PTS results in irreversible damage to the sensory hair cells of the ear, and thus a permanent reduction of hearing acuity.   |
| Root Mean Square (RMS)                                   | The square root of the arithmetic average of a set of squared instantaneous values. Used for presentation of an average sound pressure level.  |
| Sound Exposure Level (SEL)                               | The constant sound level acting for one second, which has the same amount of acoustic energy, as indicated by the square of the sound pressure, as the original sound. It is the time-integrated, sound-pressure-squared level. SEL is typically used to compare transient sound events having different time durations, pressure levels, and temporal characteristics.  |
| Sound Exposure Level, cumulative (SEL <sub>cum</sub> )   | Single value for the collected, combined total of sound exposure over a specified time or multiple instances of a noise source.  |
| Sound Exposure Level, single strike (SEL <sub>ss</sub> ) | Calculation of the sound exposure level representative of a single noise impulse, typically a pile strike.   |
| Sound Pressure Level (SPL)                               | The sound pressure level is an expression of sound pressure using the decibel (dB) scale; the standard frequency pressures of which are 1 $\mu\text{Pa}$ for water and 20 $\mu\text{Pa}$ for air.  |
| Sound Pressure Level Peak (SPL <sub>peak</sub> )         | The highest (zero-peak) positive or negative sound pressure, in decibels.  |
| Temporary Threshold Shift (TTS)                          | Temporary reduction of hearing acuity because of exposure to sound over time. Exposure to high levels of sound over relatively short time periods could cause the same level of TTS as exposure to lower levels of sound over longer time periods. The mechanisms underlying TTS are not well understood, but there may be some temporary damage to the sensory cells. The duration of TTS varies depending on the nature of the stimulus.   |
| Unweighted sound level                                   | Sound levels which are “raw” or have not been adjusted in any way, for example to account for the hearing ability of a species.  |
| Weighted sound level                                     | A sound level which has been adjusted with respect to a “weighting envelope” in the frequency domain, typically to make an unweighted level relevant to a particular species. Examples of this are the dB(A), where the overall sound level has been adjusted to account for the hearing ability of humans in air, or the filters used by Southall <i>et al.</i> (2019) for marine mammals.  |

## Units

| Unit              | Definition                                 |
|-------------------|--|
| dB                | Decibel (sound pressure)                   |
| GW                | Gigawatt (power)                           |
| Hz                | Hertz (frequency)                          |
| kg                | Kilogram (mass)                            |
| kJ                | Kilojoule (energy)                         |
| kHz               | Kilohertz (frequency)                      |
| km                | Kilometre (distance)                       |
| km <sup>2</sup>   | Square kilometres (area)                   |
| m                 | Metre (distance)                           |
| mm/s              | Millimetres per second (particle velocity) |
| m/s               | Metres per second (speed)                  |
| MW                | Megawatt (power)                           |
| Pa                | Pascal (pressure)                          |
| Pa <sup>2</sup> s | Pascal squared seconds (acoustic energy)   |
| μPa               | Micropascal (pressure)                     |

# 1 Introduction

Outer Dowsing Offshore Wind (“the Project”) is a proposed offshore windfarm in the southern North Sea. As part of the Environmental Impact Assessment (EIA) process, Subacoustech Environmental Ltd. has undertaken detailed modelling and analysis in relation to the effect of underwater noise on marine mammals and fish at the Project.

The Project covers an area of 436 km<sup>2</sup>, it is situated approximately 54 km from the Lincolnshire coast and has a proposed capacity of 1.5 GW. The location of the Project is shown in Figure 1-1.

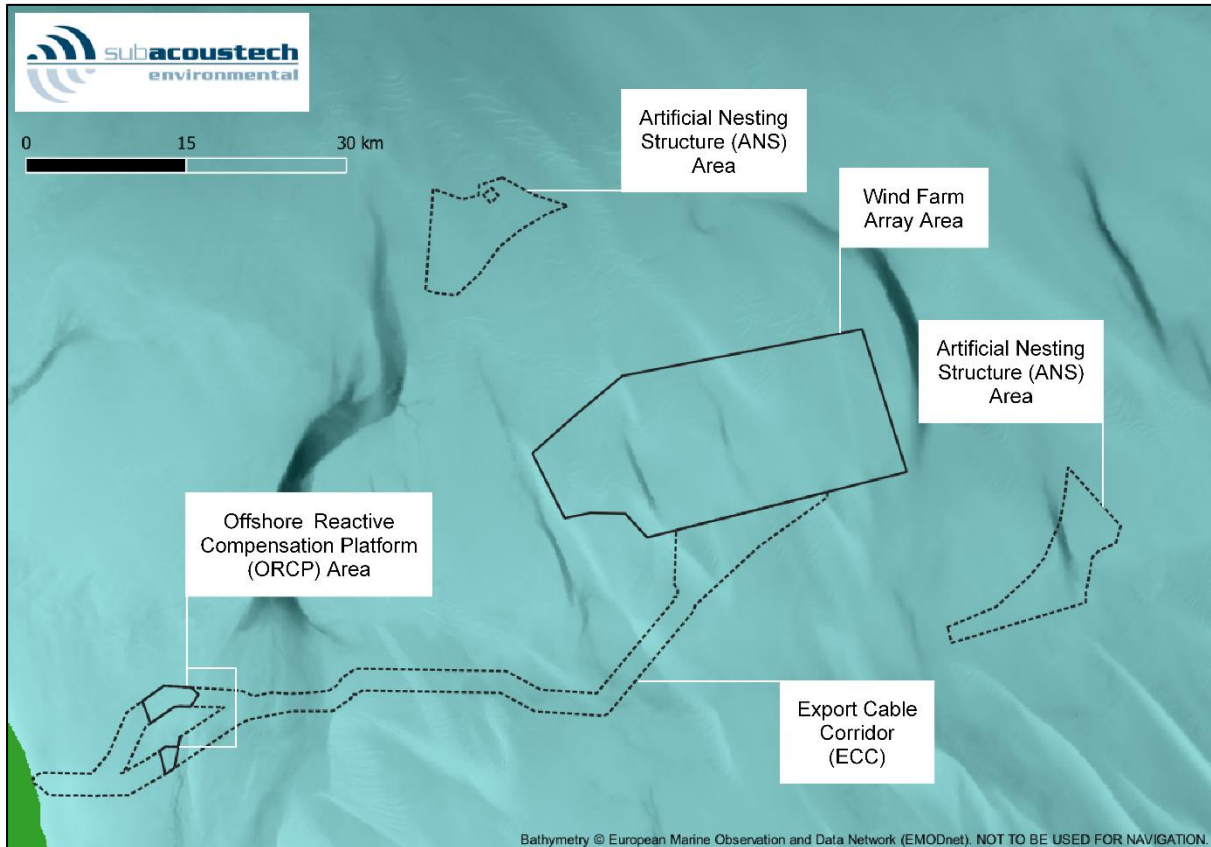


Figure 1-1 Overview map showing the Order Limits, cable corridor, ORCP and ANS areas and the surrounding bathymetry and coastline

This report presents a detailed assessment of the potential underwater noise during construction and operation of the Project, and includes the following:

- Background information covering the units used for measuring and assessing underwater noise and a review of the underwater noise metrics and criteria used to assess the possible environmental effects in marine receptors (section 2);
- Discussion of the approach, input parameters and assumptions for the detailed noise modelling undertaken (section 3);
- Presentation and interpretation of the detailed subsea noise modelling for impact piling with regards to its effect on marine mammals and fish (section 4);
- Noise modelling of other noise sources expected around the construction and operation of the Project including cable laying, dredging, drilling, rock placement, vessel movements,



operational wind turbine generator (WTG) noise, and unexploded ordnance (UXO) clearance (section 5); and

- Summary and conclusions (section 6).

Further modelling results are presented in Appendix A.

## 2 Background to underwater noise metrics

### 2.1 Underwater noise

Sound travels much faster in water (approximately 1500 m/s) than in air (340 m/s). Since water is a relatively incompressible, dense medium, the pressure associated with underwater sound tends to be much higher than in air.

It should be noted that stated underwater noise levels should not be confused with noise levels in air, which use a different scale.

#### 2.1.1 *Units of measurement*

Sound measurements underwater are usually expressed using the decibel (dB) scale, which is a logarithmic measure of sound. A logarithmic scale is used because, rather than equal increments of sound having an equal increase in effect, typically each doubling of sound level will cause a roughly equal increase of “loudness.”

Any quantity expressed in this scale is termed a “level.” If the unit is sound pressure, expressed on the dB scale, it will be termed a “sound pressure level.”

The fundamental definition of the dB scale is given by:

$$Level = 10 \times \log_{10} \left( \frac{Q}{Q_{ref}} \right)$$

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

The dB scale represents a ratio. It is therefore used with a reference unit, which expresses the base from which the ratio is expressed. The reference quantity is conventionally smaller than the smallest value to be expressed on the scale so that any level quoted is positive. For example, a reference quantity of 20  $\mu\text{Pa}$  is used for sound in air since that is the lower threshold of human hearing.

When used with sound pressure, the pressure value is squared. So that variations in the units agree, the sound pressure must be specified as units of Root Mean Square (RMS) pressure squared. This is equivalent to expressing the sound as:

$$Sound\ pressure\ level = 20 \times \log_{10} \left( \frac{P_{RMS}}{P_{ref}} \right)$$

For underwater sound, a unit of 1  $\mu\text{Pa}$  is typically used as the reference unit ( $P_{ref}$ ); a Pascal is equal to the pressure exerted by one Newton over one square metre, one micropascal equals one millionth of this.

#### 2.1.2 *Sound Pressure Level (SPL)*

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

Where SPL is used to characterise transient pressure waves, such as that from impact piling, seismic airgun or underwater blasting, it is critical that the period over which the RMS level is calculated is quoted. For instance, in the case of a pile strike lasting a tenth of a second, the mean taken over a tenth of a second will be ten times higher than the mean averaged over one second. Often, transient sounds such as these are quantified using “peak” SPLs or Sound Exposure Levels (SELs).

Unless otherwise defined, all SPL noise levels in this report are referenced to 1 µPa.

### 2.1.3 Peak Sound Pressure Level ( $SPL_{peak}$ )

Peak SPLs are often used to characterise transient sound from impulsive sources, such as percussive impact piling.  $SPL_{peak}$  is calculated using the maximum variation of the pressure from positive to zero within the wave. This represents the maximum change in positive pressure (differential pressure from positive to zero) as the transient pressure wave propagates.

A further variation of this is the peak-to-peak SPL ( $SPL_{peak-to-peak}$ ) where the maximum variation of the pressure from positive to negative is considered. Where the wave is symmetrically distributed in positive and negative pressure, the peak-to-peak pressure will be twice the peak level, or 6 dB higher (see section 2.1.1).

### 2.1.4 Sound Exposure Level (SEL)

When considering the noise from transient sources, the issue of the duration of the pressure wave is often addressed by measuring the total acoustic energy (energy flux density) of the wave. This form of analysis was used by Bebb and Wright (1953, 1954a, 1954b, 1955), and later by Rawlins (1987), to explain the apparent discrepancies in the biological effect of short and long-range blast waves on human divers. More recently, this form of analysis has been used to develop criteria for assessing injury ranges for fish and marine mammals from various noise sources (Popper *et al.*, 2014; Southall *et al.*, 2019).

The SEL sums the acoustic energy over a measurement period, and effectively takes account of both the SPL of the sound and the duration it is present in the acoustic environment. Sound Exposure (SE) is defined by the equation:

$$SE = \int_0^T p^2(t) dt$$

where  $p$  is the acoustic pressure in Pascals,  $T$  is the total duration of sound in seconds, and  $t$  is time in seconds. The SE is a measurement of acoustic energy and has units of Pascal squared seconds ( $Pa^2s$ ).

To press the SE on a logarithmic scale by means of a dB, it must be compared with a reference acoustic energy ( $p_{ref}^2$ ) and a reference time ( $T_{ref}$ ). The SEL is then defined by:

$$SEL = 10 \times \log_{10} \left( \frac{\int_0^T p^2(t) dt}{p_{ref}^2 T_{ref}} \right)$$

By using a common reference pressure ( $p_{ref}$ ) of 1 µPa for assessments of underwater noise, the SEL and SPL can be compared using the expression:

$$SEL = SPL + 10 \times \log_{10} T$$

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

This means that, for continuous sounds of less than one second, the SEL will be lower than the SPL. For periods greater than one second, the SEL will be numerically greater than the SPL (i.e., for a

continuous sound of 10 seconds duration, the SEL will be 10 dB higher than the SPL; for a sound of 100 seconds duration the SEL will be 20 dB higher than the SPL, and so on).

Where a single impulse noise such as the soundwave from a pile strike is considered in isolation, this can be represented by a “single strike” SEL or SEL<sub>ss</sub>. A cumulative SEL, or SEL<sub>cum</sub>, accounts for the exposure from multiple impulses or pile strikes over time, where the number of impulses replaces the *T* in the equation above, leading to:

$$SEL_{cum} = SEL + 10 \times \log_{10} X$$

Where SEL is the sound exposure level of one impulse and *X* is the total number of impulses or strikes. Unless otherwise defined, all SEL noise levels in this report are referenced to 1 μPa<sup>2</sup>s.

## 2.2 Analysis of environmental effects

Over the last 20 years it has become increasingly evident that noise from human activities in and around underwater environments can have an impact on the marine species in the area. The extent to which intense underwater sound might cause adverse impacts in species is dependent upon the incident sound level, source frequency, duration of exposure, and/or repetition rate of an impulsive sound (see, for example, Hastings and Popper, 2005). As a result, scientific interest in the hearing abilities of aquatic species has increased. Studies are primarily based on evidence from high level sources of underwater noise such as blasting or impact piling, as these sources are likely to have the greatest immediate environmental impact and therefore the clearest observable effects, although interest in chronic noise exposure is increasing.

The impacts of underwater sound on marine species can be broadly summarised as follows:

- Physical traumatic injury and fatality;
- Auditory injury (either permanent or temporary); and
- Disturbance.

The following sections discuss the underwater noise criteria used in this study with respect to species of marine mammals and fish that may be present around the Project.

The main metrics and criteria that have been used in this study to aid assessment of environmental effects come from three papers covering underwater noise and its effects:

- Southall *et al.* (2019) marine mammal exposure criteria;
- National Oceanic and Atmospheric Administration (NOAA) (2005) covering disturbance in marine mammals; and
- Popper *et al.* (2014) sound exposure guidelines for fishes and sea turtles.

At the time of writing these include relevant and authoritative criteria for assessing environmental effects for use in impact assessments.

### 2.2.1 Marine mammals

The Southall *et al.* (2019) paper is effectively an update of the previous Southall *et al.* (2007) paper and provides identical thresholds to those from the National Marine Fisheries Service (NMFS) (2018) guidance for marine mammals (although it names marine mammal categories slightly differently).

The Southall *et al.* (2019) guidance groups marine mammals into groups of similar species and applies filters to the unweighted noise to approximate the hearing sensitivities of the receptor in question. The hearing groups given by Southall *et al.* (2019) are summarised in Table 2-1 and Figure 2-1. Further

groups for sirenians and other marine carnivores in water are given, but these have not been included in this study as those species are not commonly found in the North Sea.

Table 2-1 Marine mammal hearing groups (from Southall *et al.*, 2019)

| Hearing group                       | Generalised hearing range | Example species   |
|-------------------------------------|---------------------------|---|
| Low-frequency cetaceans (LF)        | 7 Hz to 35 kHz            | Baleen whales   |
| High-frequency cetaceans (HF)       | 150 Hz to 160 kHz         | Dolphins, toothed whales, beaked whales, bottlenose whales (including bottlenose dolphin) |
| Very high-frequency cetaceans (VHF) | 275 Hz to 160 kHz         | True porpoises (including harbour porpoise)   |
| Phocid carnivores in water (PCW)    | 50 Hz to 86 kHz           | True seals (including harbour seals)  |

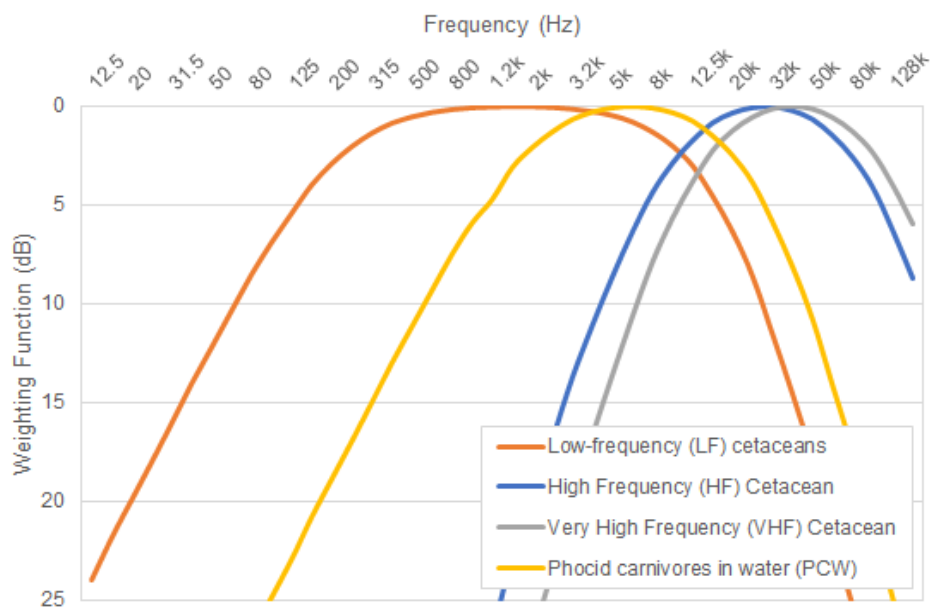


Figure 2-1 Auditory weighting functions for low-frequency cetaceans (LF), high-frequency cetaceans (HF), very high-frequency cetaceans (VHF), and phocid carnivores in water (PCW) (from Southall *et al.*, 2019)

Southall *et al.* (2019) also gives individual criteria based on whether the noise source is considered impulsive or non-impulsive. Southall *et al.* (2019) categorises impulsive noises as having high peak sound pressure, short duration, fast rise-time and broad frequency content at source, and non-impulsive sources as steady-state noise. Explosives, impact piling and seismic airguns are considered impulsive noise sources and sonars, vibro-piling, drilling and other low-level continuous noises are considered non-impulsive. A non-impulsive noise does not necessarily have to have a long duration.

Southall *et al.* (2019) presents single strike, unweighted peak criteria ( $SPL_{peak}$ ) and cumulative weighted sound exposure criteria ( $SEL_{cum}$ , i.e., can include the accumulated exposure of multiple pulses) for both permanent threshold shift (PTS), where unrecoverable (but incremental) hearing damage may occur, and temporary threshold shift (TTS), where a temporary reduction in hearing sensitivity may occur in individual receptors. These dual criteria ( $SPL_{peak}$  and  $SEL_{cum}$ ) are only used for impulsive noise: the criteria set giving the greatest calculated range is typically used as the relevant impact range.

As sound pulses propagate through the environment and dissipate, they also lose their most injurious characteristics (e.g., rapid pulse rise time and high peak sound pressure) and become more like a “non-

pulse” at greater distances; Southall *et al.* (2019) briefly discusses this. Active research is currently underway into the identification of the distance at which the pulse can be considered effectively non-impulsive, and Hastie *et al.* (2019) have analysed a series of impulsive data to investigate it. Although the situation is complex, the paper reported that most of the signals crossed their threshold for rapid rise time and high peak sound pressure characteristics associated with impulsive noise at around 3.5 km from the source. Southall (2021) discusses this further and suggests that the impulsive characteristics can correspond with significant energy content of the pulse above 10 kHz. This will naturally change depending on the noise source and the environment over which it travels.

Research by Martin *et al.* (2020) casts doubt on these findings, showing that noise in this category should be considered impulsive as long as it is above effective quiet, or a noise sufficiently low volume enough that it does not contribute significantly to any auditory impairment or injury. To provide as much detail as possible, both impulsive and non-impulsive criteria from Southall *et al.* (2019) have been included in this study.

Although the use of impact ranges derived using the impulsive criteria are recommended for all but the clearly non-impulsive sources (such as drilling), it should be recognised that where calculated ranges are beyond 3.5 km, they would be expected to become increasingly less impulsive and harmful, and the impact range is therefore likely to be somewhere between the modelled impulsive and non-impulsive impact range. Where the impulsive impact range is significantly greater than 3.5 km, the non-impulsive range should be considered.

Table 2-2 and Table 2-3 present the unweighted SPL<sub>peak</sub> and weighted SEL<sub>cum</sub> criteria for marine mammals from Southall *et al.* (2019) covering both impulsive and non-impulsive noise.

*Table 2-2 Single strike SPL<sub>peak</sub> criteria for PTS and TTS in marine mammals (Southall et al., 2019)*

| Southall <i>et al.</i><br>(2019)    | Unweighted SPL <sub>peak</sub> (dB re 1 µPa) |     |
|-------------------------------------|--|-----|
|                                     | Impulsive                                    |     |
|                                     | PTS  | TTS |
| Low-frequency cetaceans (LF)        | 219  | 213 |
| High-frequency cetaceans (HF)       | 230  | 224 |
| Very high-frequency cetaceans (VHF) | 202  | 196 |
| Phocid carnivores in water (PCW)    | 218  | 212 |

*Table 2-3 Impulsive and non-impulsive SEL<sub>cum</sub> criteria for PTS and TTS in marine mammals (Southall et al., 2019)*

| Southall <i>et al.</i><br>(2019)    | Weighted SEL <sub>cum</sub> (dB re 1 µPa <sup>2</sup> s) |     |               |     |
|-------------------------------------|--|-----|---------------|-----|
|                                     | Impulsive  |     | Non-impulsive |     |
|                                     | PTS  | TTS | PTS           | TTS |
| Low-frequency cetaceans (LF)        | 183  | 168 | 199           | 179 |
| High-frequency cetaceans (HF)       | 185  | 170 | 198           | 178 |
| Very high-frequency cetaceans (VHF) | 155  | 140 | 173           | 153 |
| Phocid carnivores in water (PCW)    | 185  | 170 | 201           | 181 |

Where SEL<sub>cum</sub> thresholds are required, a fleeing animal model has been used for marine mammals. This assumes that a receptor, when exposed to high noise levels, will swim away from the noise source. A constant fleeing speed of 3.25 m/s has been assumed for the low-frequency cetaceans (LF) group

(Blix and Folkow, 1995), based on data for minke whale, and for other receptors, a constant rate of 1.5 m/s has been assumed for flee speed, which is a cruising speed (i.e., sustainable long-term) for a harbour porpoise (Otani *et al.*, 2000). These are considered worst-case assumptions as marine mammals are expected to be able to swim much faster under stress conditions (Kastelein *et al.* 2018), especially at the start of any noisy process when the receptor will be closest to the noise source.

Limited data is available for behavioural disturbance on species of marine mammal. To take this into account, the NOAA (2005) Level B (behavioural disturbance) harassment criterion for impulsive noise on marine mammals has been included to cover disturbance effects. This criterion is 160 dB unweighted SPL<sub>RMS</sub>.

### 2.2.2 *Fish*

The large number of, and variation in, fish species leads to a greater challenge in production of a generic noise criterion, or range of criteria, for the assessment of noise impacts. Whereas other studies have applied broad criteria based on limited studies of fish that are not present in UK waters (e.g., McCauley *et al.*, 2000) or measurement data not intended to be used as criteria (Hawkins *et al.*, 2014), the publication of Popper *et al.* (2014) provides an authoritative summary of the most appropriate research and guidelines for fish exposure to sound and uses categories for fish that are representative of the species present in UK waters.

The Popper *et al.* (2014) study groups species of fish by whether they possess a swim bladder, and whether it is involved in its hearing; groups for sea turtles and fish eggs and larvae are also included. The guidance also gives specific criteria (as both unweighted SPL<sub>peak</sub> and unweighted SEL<sub>cum</sub> values) for a variety of noise sources. (It is recognised that these are related to sound pressure, whereas more recent documents (e.g., Popper and Hawkins, 2019) clearly state that many fish species are most sensitive to particle motion. This is discussed in section 2.2.2.1.)

*For this study, criteria for impact piling, continuous noise sources, and explosions have been considered; these are summarised in Table 2-4 to*

Table 2-6.

*Table 2-4 Criteria for mortality and potential mortal injury, recoverable injury, and TTS in species of fish from impact piling noise (Popper *et al.*, 2014)*

| Type of animal                                | Mortality and potential mortal injury                       | Impairment  |                              |
|---|---|---|------------------------------|
|   |   | Recoverable injury  | TTS                          |
| Fish: no swim bladder                         | > 219 dB SEL <sub>cum</sub><br>> 213 dB SPL <sub>peak</sub> | > 216 dB SEL <sub>cum</sub><br>> 213 dB SPL <sub>peak</sub> | >> 186 dB SEL <sub>cum</sub> |
| Fish: swim bladder is not involved in hearing | 210 dB SEL <sub>cum</sub><br>> 207 dB SPL <sub>peak</sub>   | 203 dB SEL <sub>cum</sub><br>> 207 dB SPL <sub>peak</sub>   | > 186 dB SEL <sub>cum</sub>  |
| Fish: swim bladder involved in hearing        | 207 dB SEL <sub>cum</sub><br>> 207 dB SPL <sub>peak</sub>   | 203 dB SEL <sub>cum</sub><br>> 207 dB SPL <sub>peak</sub>   | 186 dB SEL <sub>cum</sub>    |
| Sea turtles                                   | > 210 dB SEL <sub>cum</sub><br>> 207 dB SPL <sub>peak</sub> | See Table 2-7   |                              |
| Eggs and larvae                               | > 210 dB SEL <sub>cum</sub><br>> 207 dB SPL <sub>peak</sub> |   |                              |

*Table 2-5 Criteria for recoverable injury and TTS in species of fish from continuous noise sources (Popper *et al.*, 2014)*

| Type of animal                         | Impairment                           |  |
|--|--------------------------------------|--|
|  | Recoverable injury                   | TTS                                    |
| Fish: swim bladder involved in hearing | 170 dB SPL <sub>RMS</sub> for 48 hrs | 158 dB SPL <sub>RMS</sub> for 12 hours |

*Table 2-6 Criteria for potential mortal injury in species of fish from explosions (Popper et al., 2014)*

| Type of animal                                | Mortality and potential mortal injury |
|---|---------------------------------------|
| Fish: no swim bladder                         | 229 – 234 dB SPL <sub>peak</sub>      |
| Fish: swim bladder is not involved in hearing | 229 – 234 dB SPL <sub>peak</sub>      |
| Fish: swim bladder involved in hearing        | 229 – 234 dB SPL <sub>peak</sub>      |
| Sea turtles                                   | 229 – 234 dB SPL <sub>peak</sub>      |
| Eggs and larvae                               | > 13 mm/s peak velocity               |

Where insufficient data are available, Popper *et al.* (2014) also gives qualitative criteria that summarise the effect of the noise as having either a high, moderate, or low effect on an individual in either the near-field (tens of metres), intermediate-field (hundreds of metres), or far-field (thousands of metres). These qualitative effects are reproduced in Table 2-7 to Table 2-9.

*Table 2-7 Summary of the qualitative effects on species of fish from impact piling noise (Popper et al., 2014) (N = Near-field; I = Intermediate-field; F = Far-field)*

| Type of animal                                | Impairment                         |                                    |                                      | Behaviour                            |
|---|------------------------------------|------------------------------------|--------------------------------------|--------------------------------------|
|   | Recoverable injury                 | TTS                                | Masking                              |                                      |
| Fish: no swim bladder                         | See Table 2-4                      |                                    | (N) Moderate<br>(I) Low<br>(F) Low   | (N) High<br>(I) Moderate<br>(F) Low  |
| Fish: swim bladder is not involved in hearing |                                    |                                    | (N) Moderate<br>(I) Low<br>(F) Low   | (N) High<br>(I) Moderate<br>(F) Low  |
| Fish: swim bladder involved in hearing        |                                    |                                    | (N) High<br>(I) High<br>(F) Moderate | (N) High<br>(I) High<br>(F) Moderate |
| Sea turtles                                   | (N) High<br>(I) Low<br>(F) Low     | (N) High<br>(I) Low<br>(F) Low     | (N) High<br>(I) Moderate<br>(F) Low  | (N) High<br>(I) Moderate<br>(F) Low  |
| Eggs and larvae                               | (N) Moderate<br>(I) Low<br>(F) Low | (N) Moderate<br>(I) Low<br>(F) Low | (N) Moderate<br>(I) Low<br>(F) Low   | (N) Moderate<br>(I) Low<br>(F) Low   |

*Table 2-8 Summary of the qualitative effects on fish from continuous noise from Popper et al. (2014) (N = Near-field; I = Intermediate-field; F = Far-field)*

| Type of animal                                | Mortality and potential mortal injury | Impairment                    |                                    |                                      | Behaviour                               |
|---|---------------------------------------|-------------------------------|------------------------------------|--------------------------------------|---|
|   |                                       | Recoverable injury            | TTS                                | Masking                              |   |
| Fish: no swim bladder                         | (N) Low<br>(I) Low<br>(F) Low         | (N) Low<br>(I) Low<br>(F) Low | (N) Moderate<br>(I) Low<br>(F) Low | (N) High<br>(I) High<br>(F) Moderate | (N) Moderate<br>(I) Moderate<br>(F) Low |
| Fish: swim bladder is not involved in hearing | (N) Low<br>(I) Low<br>(F) Low         | (N) Low<br>(I) Low<br>(F) Low | (N) Moderate<br>(I) Low<br>(F) Low | (N) High<br>(I) High<br>(F) Moderate | (N) Moderate<br>(I) Moderate<br>(F) Low |
| Fish: swim bladder involved in hearing        | (N) Low<br>(I) Low<br>(F) Low         | See Table 2-5                 |                                    | (N) High<br>(I) High<br>(F) High     | (N) High<br>(I) Moderate<br>(F) Low     |
| Sea turtles                                   | (N) Low<br>(I) Low<br>(F) Low         | (N) Low<br>(I) Low<br>(F) Low | (N) Moderate<br>(I) Low<br>(F) Low | (N) High<br>(I) High<br>(F) Moderate | (N) High<br>(I) Moderate<br>(F) Low     |

| Type of animal  | Mortality and potential mortal injury | Impairment                    |                               |                                     | Behaviour                               |
|-----------------|---------------------------------------|-------------------------------|-------------------------------|-------------------------------------|---|
|                 |                                       | Recoverable injury            | TTS                           | Masking                             |   |
| Eggs and larvae | (N) Low<br>(I) Low<br>(F) Low         | (N) Low<br>(I) Low<br>(F) Low | (N) Low<br>(I) Low<br>(F) Low | (N) High<br>(I) Moderate<br>(F) Low | (N) Moderate<br>(I) Moderate<br>(F) Low |

Table 2-9 Summary of the qualitative effects on species of fish from explosions (Popper *et al.*, 2014) (N = Near-field; I = Intermediate-field; F = Far-field)

| Type of animal                                | Impairment                      |                                     |         | Behaviour                           |
|---|---------------------------------|-------------------------------------|---------|-------------------------------------|
|   | Recoverable injury              | TTS                                 | Masking |                                     |
| Fish: no swim bladder                         | (N) High<br>(I) Low<br>(F) Low  | (N) High<br>(I) Moderate<br>(F) Low | N/A     | (N) High<br>(I) Moderate<br>(F) Low |
| Fish: swim bladder is not involved in hearing | (N) High<br>(I) High<br>(F) Low | (N) High<br>(I) Moderate<br>(F) Low | N/A     | (N) High<br>(I) High<br>(F) Low     |
| Fish: swim bladder involved in hearing        | (N) High<br>(I) High<br>(F) Low | (N) High<br>(I) High<br>(F) Low     | N/A     | (N) High<br>(I) High<br>(F) Low     |
| Sea turtles                                   | (N) High<br>(I) High<br>(F) Low | (N) High<br>(I) High<br>(F) Low     | N/A     | (N) High<br>(I) High<br>(F) Low     |
| Eggs and larvae                               | (N) High<br>(I) Low<br>(F) Low  | (N) High<br>(I) Low<br>(F) Low      | N/A     | (N) High<br>(I) Low<br>(F) Low      |

Both fleeing animal and stationary animal models have been used to cover the SEL<sub>cum</sub> criteria for fish. It is recognised that there is limited evidence for fish fleeing from high level noise sources in the wild, and it would reasonably be expected that the reaction would differ between species. Most species are likely to move away from a sound that is loud enough to cause harm (Dahl *et al.*, 2015; Popper *et al.*, 2014), some may seek protection in the sediment and others may dive deeper in the water column. For those species that flee, the speed chosen for this study of 1.5 m/s is relatively slow in relation to data from Hirata (1999) and thus is considered somewhat conservative.

Although it is feasible that some species will not flee, those that are likely to remain are thought more likely to be benthic species or species without a swim bladder; these are the least sensitive species. For example, from Popper *et al.* (2014): “There is evidence (e.g., Goertner *et al.*, 1994; Stephenson *et al.*, 2010; Halvorsen *et al.*, 2012) that little or no damage occurs to fish without a swim bladder except at very short ranges from an in-water explosive event. Goertner (1978) showed that the range from an explosive event over which damage may occur to a non-swim bladder fish is in the order of 100 times less than that for swim bladder fish.”

Stationary animal modelling has been included in this study, acknowledging the limited evidence for fish fleeing behaviour as a result of noise exposure, and other modelling for similar EIA projects. However, basing the modelling on a stationary (zero flee speed) receptor is likely to greatly overestimate the potential risk to fish species, assuming that an individual would remain in the high noise level region of the water column for the whole duration of piling, especially when considering the precautionary nature of the parameters already built into the cumulative exposure calculations.



### 2.2.2.1 *Particle motion*

The criteria defined in the above section define the noise impacts on fishes in terms of sound pressure or sound pressure-associated functions (i.e., SEL). It has been identified by researchers (e.g., Popper and Hawkins, 2019; Nedelec *et al.*, 2016; Radford *et al.*, 2012) that many species of fish, as well as invertebrates, actually detect particle motion rather than acoustic pressure. Particle motion describes the back-and-forth movement of a tiny theoretical ‘element’ of water, substrate or other media as a sound wave passes, rather than the pressure caused by the action of the force created by this movement. Particle motion is usually defined in reference to the velocity of the particle (often a peak particle velocity, PPV), but sometimes the related acceleration or displacement of the particle is used. Note that species in the “Fish: swim bladder involved in hearing” category, the species most sensitive to noise, are sensitive to sound pressure.

Popper and Hawkins (2018) state that in derivation of the sound pressure-based criteria in Popper *et al.* (2014) it may be the unmeasured particle motion detected by the fish, to which the fish were responding: there is a relationship between particle motion and sound pressure in a medium. This relationship is very difficult to define where the sound field is complex, such as close to the noise source or where there are multiple reflections of the sound wave in shallow water. Even these terms “shallow” and “close” do not have simple definitions.

The primary reason for the continuing use of sound pressure as the criteria, despite particle motion appearing to be the physical measure to which so many fish react or sense, is a lack of data (Popper and Hawkins, 2018) both in respect of predictions of the particle motion level as a consequence of a noise source such as piling, and a lack of knowledge of the sensitivity of a fish, or a wider category of fish, to a particle motion value. There continue to be calls for additional research on the levels of and effects with respect to levels of particle motion. Until sufficient data are available to enable revised thresholds based on the particle motion metric, Popper and Hawkins (2019) state that “since there is an immediate need for updated criteria and guidelines on potential effects of anthropogenic sound on fishes, we recommend, as do our colleagues in Sweden (Andersson *et al.*, 2017), that the criteria proposed by Popper *et al.* (2014) should be used.”

## 3 Modelling methodology

To estimate the underwater noise levels likely to arise during the construction and operation of the Project, predictive noise modelling has been undertaken. The methods described in this section, and used within this report, meet the requirements set by the National Physical Laboratory (NPL) Good Practice Guide 133 for underwater noise measurement (Robinson *et al.*, 2014).

Of those considered, the noise source most important to consider is impact piling due to the noise level and duration it will be present (Bailey *et al.*, 2014). As such, the noise related to impact piling activities is the primary focus of this study.

The modelling of impact piling has been undertaken using the Impulse Noise Sound Propagation and Range Estimator (INSPIRE) underwater noise model. The INSPIRE model (currently version 5.1) is a semi-empirical underwater noise propagation model based around a combination of numerical modelling, based around a combined geometric and energy flow/hysteresis loss method, and actual measured data. It is designed to calculate the propagation of noise in shallow, mixed water, typical of the conditions around the UK and very well suited to the region around the Project. The model has been tuned for accuracy using over 80 datasets of underwater noise propagation from monitoring around offshore piling activities.

The model provides estimates of unweighted SPL<sub>peak</sub>, SEL<sub>ss</sub>, and SEL<sub>cum</sub> noise levels, as well as various other weighted noise metrics. Calculations are made along 180 equally spaced radial transects (one

every two degrees). For each modelling run a criterion level can be specified allowing a contour to be drawn, within which a given effect may occur. These results can then be plotted over digital bathymetry data so that impact ranges can be clearly visualised, as necessary. INSPIRE also produces these contours as Geographic Information System (GIS) shapefiles.

INSPIRE considers a wide array of input parameters, including variations in bathymetry and source frequency to ensure accurate results are produced specific to the location and nature of the piling operation. It should also be noted that the results should be considered conservative as maximum design parameters and worst-case assumptions have been selected for:

- Piling hammer blow energies;
- Soft start, ramp up profile, and strike rate;
- Total duration of piling; and
- Receptor swim speeds.

A simpler modelling approach has been used for noise sources other than piling that may be present during construction and operation of the Project, and these are discussed in section 5.

### 3.1 Modelling confidence

INSPIRE is semi-empirical and thus a validation process is inherently built into the development process. Whenever a new set of good, reliable, impact piling measurement data is gathered through offshore surveys it is compared against the outputted levels from INSPIRE and, if necessary, the model can be adjusted accordingly. Currently over 80 separate impact piling noise datasets from all around the UK have been used as part of the development for the latest version of INSPIRE, and in each case, an average fit is used.

In addition, INSPIRE is also validated by comparing the noise levels outputted from the model with measurements and modelling undertaken by third parties, as well as in Thompson *et al.* (2013).

The current version of INSPIRE (version 5.1) is the product of re-analysing all the impact piling noise measurements in Subacoustech Environmental's measurement database and cross-referencing it with blow energy data from piling logs. This gave a database of single strike noise levels referenced to a specific blow energy at a specific range. This analysis showed that, based on the most up to date measurement data for large piles at high blow energies, the previous versions of INSPIRE tended to overestimate the predicted noise levels at these blow energies.

Previous iterations of the INSPIRE model have endeavoured to give a worst-case estimate of underwater noise levels produced by various permutations of impact piling parameters. There is always some natural variability with underwater noise measurements, even when considering measurements of pile strikes under the same conditions, i.e., at the same blow energy, taken at the same range. For example, there can be variations in noise level of up to five or even 10 dB, as seen in Bailey *et al.* (2010) and the data shown in Figure 3-1. When modelling using the upper bounds of this range, in combination with other worst-case parameter selections, conservatism can be compounded and create excessively overcautious predictions, especially when calculating  $SEL_{cum}$ . With this in mind, the current version of the INSPIRE model attempts to calculate closer to the average fit of the measured noise levels at all ranges.

Figure 3-1 and Figure 3-2 present a small selection of measured impact piling noise data, in terms of unweighted  $SPL_{peak}$  and  $SEL_{ss}$ , plotted against outputs from INSPIRE. The plots show data points from measured data (in blue) plotted alongside modelled data (in orange) using INSPIRE version 5.1, matching the pile size, blow energy and range from the measured data. These show the fit to the data, with the INSPIRE model data points sitting, more or less, in the middle of the measured noise levels at

each range. When combined with the worst-case assumptions in parameter selection, modelled results will remain precautionary.

The greatest deviations from the model tend to be at the greatest distances, where the influence on the  $SEL_{cum}$  will be minimal.

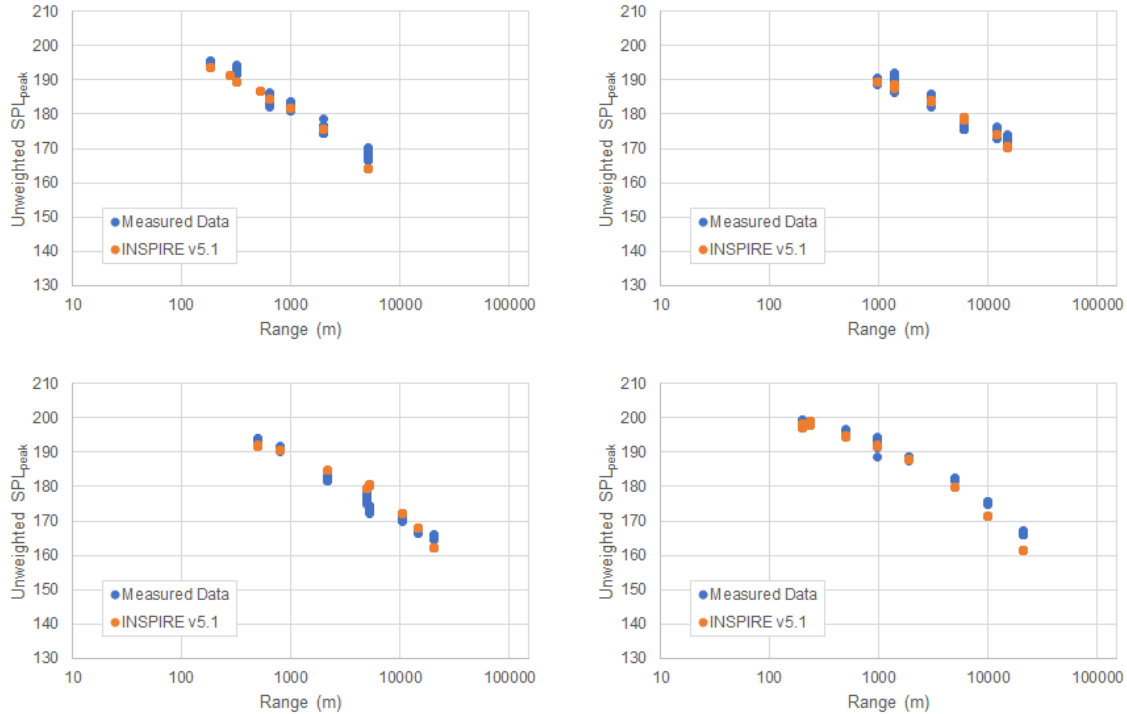


Figure 3-1 Comparison between example unweighted  $SPL_{peak}$  measured impact piling data (blue points) and modelled data using INSPIRE version 5.1 (orange points)<sup>1</sup>

<sup>1</sup> Top Left: 1.8 m pile, 260 kJ max energy, Irish Sea, 2010; Top Right: 9.5 m pile, 1,600 kJ max energy, North Sea, 2020; Bottom Left: 6.1 m pile, 1,100 kJ max energy, Southern North Sea, 2009; Bottom Right: 6 m pile, 1,000 kJ max energy, Southern North Sea, 2009.

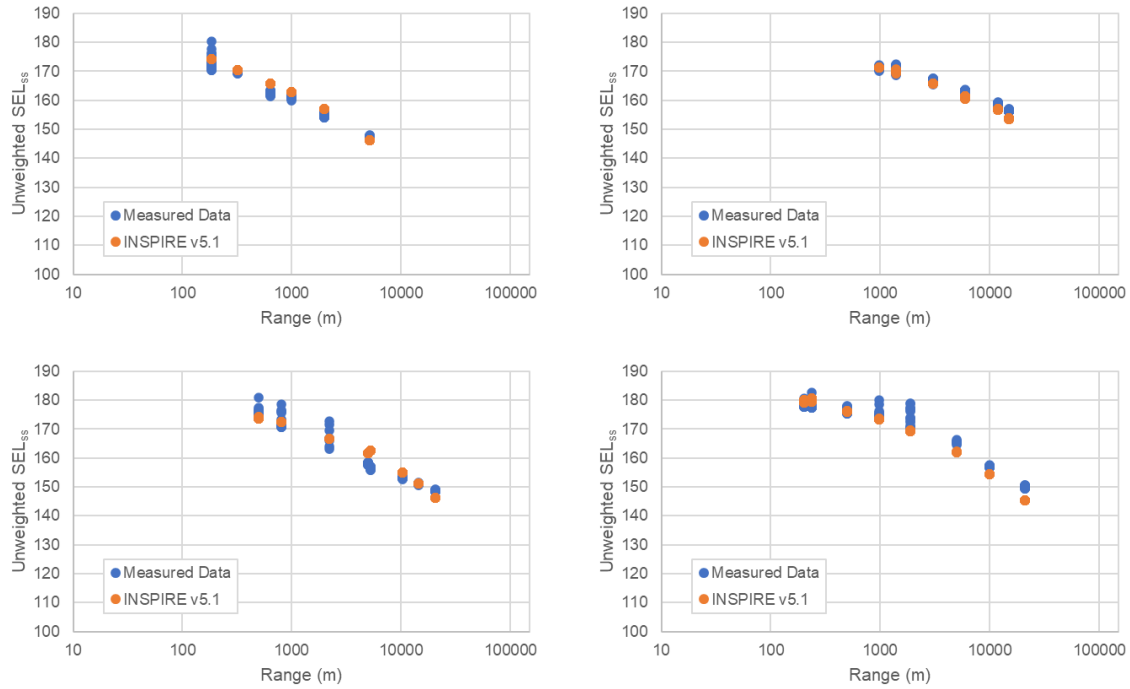


Figure 3-2 Comparison between example unweighted  $SEL_{ss}$  measured impact piling data (blue points) and modelled data using INSPIRE version 5.1 (orange points)<sup>2</sup>

It is recognised that the comparisons presented here use smaller pile sizes and blow energies than the largest potential parameters predicted for the foundations at this windfarm. At this time, no empirical data exists for these parameters, and so this method of direct validation is not possible. INSPIRE utilises extrapolations based on trends in empirical evidence for the piling parameters and has done so reliably for over ten years: plans for future offshore windfarm (OWF) developments invariably include new and novel designs. Currently, INSPIRE emphasises pile diameter, hammer energy and water depth as the primary factors that affect underwater noise levels and propagation, and this has been effective in the prediction of underwater noise to date. The predictions for the apparent source level follow the trends in noise production from pile sizes and hammer energies seen to date and extrapolate them up to the scale of piling anticipated here.

## 3.2 Modelling parameters

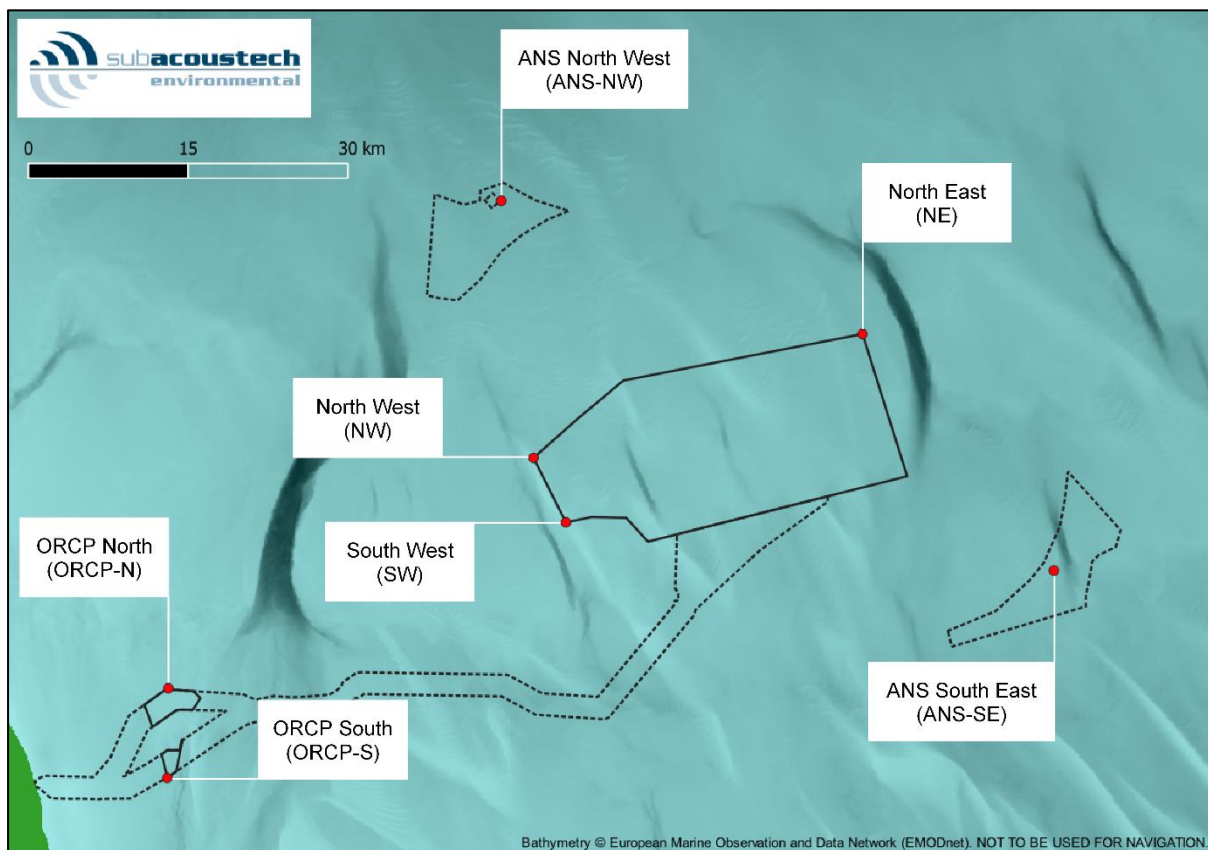
### 3.2.1 Modelling locations

Modelling for WTG foundation impact piling has been undertaken at three representative locations inside the Order Limits covering the extents, and various water depths, around the Project site. Four further positions have also been included covering two positions located in the Offshore Reactive Compensation Platform (ORCP) area of the export cable corridor (ECC) and two positions within the artificial nesting structures (ANS) areas. These locations are summarised in Table 3-1 and Figure 3-3.

<sup>2</sup> Top Left: 1.8 m pile, 260 kJ max energy, Irish Sea, 2010; Top Right: 9.5 m pile, 1,600 kJ max energy, North Sea, 2020; Bottom Left: 6.1 m pile, 1,100 kJ max energy, Southern North Sea, 2009; Bottom Right: 6 m pile, 1,000 kJ max energy, Southern North Sea, 2009.

*Table 3-1 Summary of the underwater noise modelling locations used for this study.*

| Modelling locations                | Latitude   | Longitude   | Water Depth |
|------------------------------------|------------|-------------|-------------|
| Array - South West location (SW)   | 53.48762°N | 001.06477°E | 8.6 m       |
| Array - North West location (NW)   | 53.54229°N | 001.01642°E | 14.5 m      |
| Array - North East location (NE)   | 53.65352°N | 001.47877°E | 25.1 m      |
| ORCP – North location (ORCP-N)     | 53.33835°N | 000.51091°E | 13.0 m      |
| ORCP – South location (ORCP-S)     | 53.26277°N | 000.51374°E | 14.1 m      |
| ANS – North West location (ANS-NW) | 53.75820°N | 000.96025°E | 29.7 m      |
| ANS – South East location (ANS-SE) | 53.45718°N | 001.75641°E | 20.5 m      |



*Figure 3-3 Approximate positions of the modelling locations at the Project*

### 3.2.2 *WTG foundation and impact piling parameters*

Three foundation scenarios have been considered to cover the worst cases for this study, including piled monopile and jacket foundations at the various modelling locations. These are:

- A monopile foundation scenario for the Array and ORCP, installing a 14 m diameter pile with a maximum blow energy of 6600 kJ, with up to two monopiles installed in a 24-hour period;

- A monopile foundation scenario for the ANS, installing an 8 m diameter pile with a maximum blow energy of 3500 kJ, with one pile installed in a 24-hour period; and
- A jacket pile foundation scenario for the Array, ORCP and ANS, installing a 5 m diameter pile with a maximum blow energy of 3500 kJ, with up to six piles installed in a 24-hour period for the Array and ORCP locations and up to four piles installed in a 24-hour period for the ANS locations.

For SEL<sub>cum</sub> criteria the soft start and ramp up of the blow energies along with the total duration of piling and strike rate must also be considered. The scenarios used for modelling are summarised in Table 3-2 to Table 3-4.

In a 24-hour period there may be up to two monopile foundations (excluding the ANS scenario) or six piles for a jacket foundation driven per piling rig; this is considered in the modelling as a worst case. It should be noted that, for the ANS locations a single monopile or up to four jacket piles installed in a 24-hour period has been considered; both single and multiple installed piles have been assumed where necessary for these scenarios. In addition, there is the potential for two piling rigs to install piles concurrently, which has been considered in addition to the scenarios based on a single rig.

*Table 3-2 Summary of the soft start and ramp up scenario used for the monopile foundation modelling at the Array and ORCP locations.*

| Monopile foundation   | 660 kJ       | 1650 kJ      | 3300 kJ | 4950 kJ | 6600 kJ  |
|---|--------------|--------------|---------|---------|----------|
| Number of strikes   | 100          | 450          | 900     | 1350    | 7800     |
| Duration  | 10 mins      | 15 mins      | 30 mins | 45 mins | 260 mins |
| Strike rate   | 10 blows/min | 30 blows/min |         |         |          |
| Single pile (Array and ORCP): 10600 strikes, 6 hours duration<br>2 piles (Array and ORCP): 21200 strikes, 12 hours duration |              |              |         |         |          |

*Table 3-3 Summary of the soft start and ramp up scenario used for the monopile foundation modelling at the ANS locations.*

| Monopile foundation                               | 350 kJ       | 875 kJ       | 1750 kJ | 2625 kJ | 3500 kJ  |
|---|--------------|--------------|---------|---------|----------|
| Number of strikes                                 | 100          | 450          | 900     | 900     | 4650     |
| Duration  | 10 mins      | 15 mins      | 30 mins | 30 mins | 155 mins |
| Strike rate                                       | 10 blows/min | 30 blows/min |         |         |          |
| Single pile (ANS): 7000 strikes, 4 hours duration |              |              |         |         |          |

*Table 3-4 Summary of the soft start and ramp up scenario used for the jacket pile foundation modelling at the Array, ORCP, and ANS locations.*

| Jacket pile foundation   | 350 kJ       | 875 kJ       | 1750 kJ | 2625 kJ | 3500 kJ  |
|--|--------------|--------------|---------|---------|----------|
| Number of strikes  | 100          | 450          | 900     | 900     | 4650     |
| Duration   | 10 mins      | 15 mins      | 30 mins | 30 mins | 155 mins |
| Strike rate  | 10 blows/min | 30 blows/min |         |         |          |
| Single pile: 7000 strikes, 4 hours duration<br>6 piles (Array and ORCP): 42000 strikes, 24 hours duration<br>4 piles (ANS): 28000 strikes, 16 hours duration |              |              |         |         |          |

### 3.2.3 Apparent source levels

Noise modelling requires knowledge of the source level, which is the theoretical noise level at one metre from the noise source. The INSPIRE model assumes that the noise source – that is, the hammer striking the pile – acts as an effective single point, as it will appear at long distance. The source level is estimated based on the pile diameter and the blow energy imparted on the pile by the hammer. This is adjusted depending on the water depth at the modelling location to allow for the length of pile (and effective surface area) in contact with the water, which can affect the amount of noise that is transmitted from the pile into its surroundings.

It is worth noting that the ‘source level’ technically does not exist in the context of many shallow water (< 100 m) noise sources (Heaney *et al.*, 2020). In practice, for underwater noise modelling such as this, it is effectively an ‘apparent source level’ that is used, essentially a value that can be used to produce correct noise levels at range (for a specific sound propagation model), as required in impact assessments.

The unweighted, single strike SPL<sub>peak</sub> and SEL<sub>ss</sub> apparent source levels estimated for this study are provided in Table 3-5. These figures are presented in accordance with typical requirements by regulatory authorities, although as indicated above they are not necessarily compatible or comparable with any other model or predicted source level. In each case, the differences in source level for each location are minimal.

*Table 3-5 Summary of the unweighted apparent source levels used for modelling.*

| Apparent source levels         | Location | Monopile foundation                                  |   |
|--------------------------------|----------|--|---|
|                                |          | 14 m / 6600 kJ (Array + ORCP)<br>8 m / 3500 kJ (ANS) | Jacket pile foundation<br>5 m / 3500 kJ |
| Unweighted SPL <sub>peak</sub> | SW       | 243.1 dB re 1 µPa @ 1 m                              | 241.8 dB re 1 µPa @ 1 m                 |
|                                | NW       | 243.1 dB re 1 µPa @ 1 m                              | 241.9 dB re 1 µPa @ 1 m                 |
|                                | NE       | 243.1 dB re 1 µPa @ 1 m                              | 242.0 dB re 1 µPa @ 1 m                 |
|                                | ORCP-N   | 243.1 dB re 1 µPa @ 1 m                              | 241.9 dB re 1 µPa @ 1 m                 |
|                                | ORCP-S   | 243.1 dB re 1 µPa @ 1 m                              | 241.9 dB re 1 µPa @ 1 m                 |
|                                | ANS-NW   | 242.2 dB re 1 µPa @ 1 m                              | 242.1 dB re 1 µPa @ 1 m                 |
|                                | ANS-SE   | 242.1 dB re 1 µPa @ 1 m                              | 242.0 dB re 1 µPa @ 1 m                 |
| Unweighted SEL <sub>ss</sub>   | SW       | 224.3 dB re 1 µPa <sup>2</sup> s @ 1 m               | 222.5 dB re 1 µPa <sup>2</sup> s @ 1 m  |
|                                | NW       | 224.3 dB re 1 µPa <sup>2</sup> s @ 1 m               | 222.8 dB re 1 µPa <sup>2</sup> s @ 1 m  |
|                                | NE       | 224.3 dB re 1 µPa <sup>2</sup> s @ 1 m               | 222.9 dB re 1 µPa <sup>2</sup> s @ 1 m  |
|                                | ORCP-N   | 224.3 dB re 1 µPa <sup>2</sup> s @ 1 m               | 222.7 dB re 1 µPa <sup>2</sup> s @ 1 m  |
|                                | ORCP-S   | 224.3 dB re 1 µPa <sup>2</sup> s @ 1 m               | 222.8 dB re 1 µPa <sup>2</sup> s @ 1 m  |
|                                | ANS-NW   | 223.2 dB re 1 µPa <sup>2</sup> s @ 1 m               | 223.0 dB re 1 µPa <sup>2</sup> s @ 1 m  |
|                                | ANS-SE   | 223.1 dB re 1 µPa <sup>2</sup> s @ 1 m               | 222.9 dB re 1 µPa <sup>2</sup> s @ 1 m  |

### 3.2.4 Environmental conditions

With the inclusion of measured noise propagation data for similar offshore piling operations in UK waters, the INSPIRE model intrinsically accounts for various environmental conditions. This includes the differences that can occur with the temperature and salinity of the water, as well as the sediment type surrounding the site. Data from the British Geological Survey (BGS) show that the seabed in and around the Project is generally made up of variations of gravel and sand.

Digital bathymetry from the European Marine Observation and Data Network (EMODnet) has been used for this modelling. Mean tidal depth has been used throughout.

## 3.3 Cumulative SELs and fleeing receptors

Expanding on the information in section 2.2 regarding SEL<sub>cum</sub> and the fleeing animal model used for modelling, it is important to understand the meaning of the results presented in the following sections.

When an SEL<sub>cum</sub> impact range is presented for a fleeing animal, this range can essentially be considered a starting position (at commencement of piling) for the fleeing animal receptor. For example, if a receptor began to flee in a straight line away from the noise source, starting at the position (distance from pile) denoted by a modelled PTS contour, the receptor would receive exactly the noise exposure as per the PTS criterion under consideration.

To help explain this, it is helpful to examine how the multiple pulse SEL<sub>cum</sub> ranges are calculated. As explained in Section 2.1.4, the SEL<sub>cum</sub> is a measure of the total received noise over a whole operation: in the cases of the Southall *et al.* (2019) and Popper *et al.* (2014) criteria this covers noise in a 24-hour period unless otherwise specified.

When considering a stationary receptor (i.e., one that stays at the same position throughout piling), calculating the SEL<sub>cum</sub> is straightforward: all the noise levels produced and received at a single point along a transect are aggregated to calculate the SEL<sub>cum</sub>. If this calculated level is greater than the threshold being modelled, the model steps from the noise source and the noise levels from that new location are aggregated to calculate a new SEL<sub>cum</sub>. This continues outward until the threshold is met.

For a fleeing animal, the receptor's distance from the noise source while moving away also needs to be considered. To model this, a starting point close to the source is chosen and the received noise level for each noise event (e.g., pile strike) while the receptor is fleeing is noted. For example, if a noise event occurs every six seconds and an animal is fleeing at a rate of 1.5 m/s, it is 9 m further from the source after each noise pulse, resulting in a slightly reduced noise level each time. These values are then aggregated into an SEL<sub>cum</sub> value over the entire operation. The faster an animal is fleeing the greater distance travelled between noise events. The impact range outputted by the model for this situation is the distance the receptor must be at the start of the operation to exactly meet the exposure threshold.

As an example, the graphs in Figure 3-4 and Figure 3-5 show the difference in the received SEL from a stationary receptor and a fleeing receptor travelling at a constant speed of 1.5 m/s, using the monopile foundation scenario at the NE location for a single pile installation.

The received SEL<sub>ss</sub> from the stationary receptor, as illustrated in Figure 3-4, shows the noise level gradually increasing as the blow energy increases throughout the piling operation. These step changes are also visible for the fleeing receptor, but as the receptor is further from the source by the time the levels increase, the total received exposure reduces, resulting in progressively lower received noise levels. As an example, for the first 10 minutes of the piling scenario, where the blow energy is 660 kJ, at a rate of 1.5 m/s, the fleeing receptor will have moved 0.9 km away. After the full piling installation of 6 hours, the receptor will be over 32 km from the pile.

Figure 3-5 shows the effect these different received levels have when calculating the SEL<sub>cum</sub>. It clearly shows the difference in cumulative effect of the receptor remaining still, as opposed to fleeing. To use an extreme example, starting at a range of 1 m, the first strike results in a received level of 217.2 dB re 1  $\mu\text{Pa}^2\text{s}$ . If the receptor were to remain stationary throughout the piling operation it would receive a cumulative level of 264.3 dB re 1  $\mu\text{Pa}^2\text{s}$ , whereas when fleeing at 1.5 m/s over the same scenario would result in a cumulative received level of just 221.1 dB re 1  $\mu\text{Pa}^2\text{s}$  for the receptor.



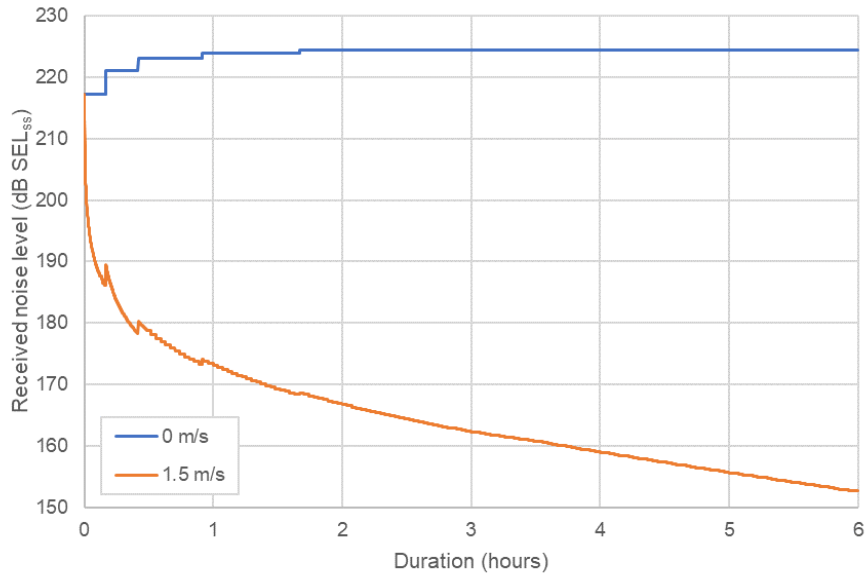


Figure 3-4 Received single-strike noise levels ( $SEL_{ss}$ ) for receptors during the monopile foundation parameters at the NE location, assuming both a stationary and fleeing receptor starting at a location 1 m from the noise source

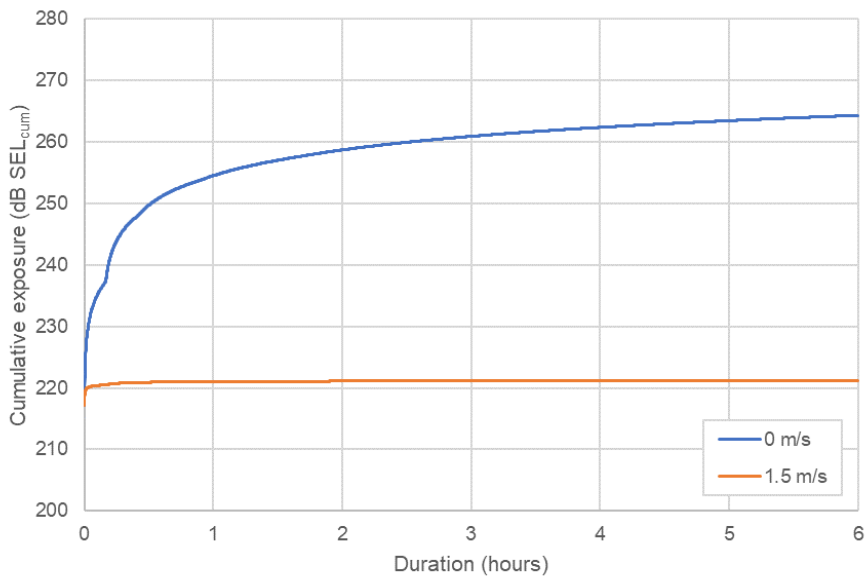


Figure 3-5 Cumulative received noise levels ( $SEL_{cum}$ ) for receptors during monopile foundation parameters at the NE location, assuming both a stationary and fleeing receptor starting at a location 1 m from the noise source

To summarise, if the receptor were to start fleeing in a straight line from the noise source starting at a range closer than the modelled value it would receive a noise exposure in excess of the criteria, and if the receptor were to start fleeing from a range further than the modelled value it would receive a noise exposure below the criteria. This is illustrated in Figure 3-6.

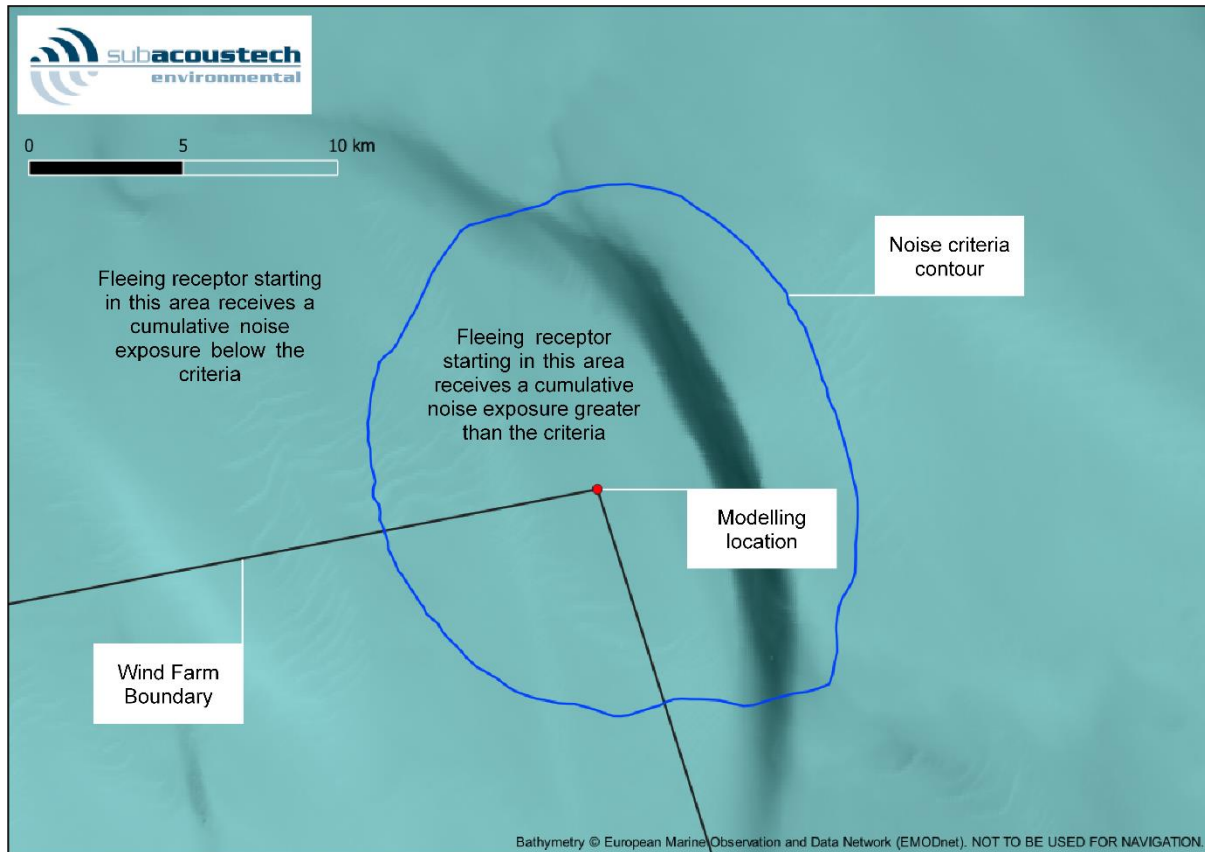


Figure 3-6 Plot showing a fleeing animal  $SEL_{cum}$  criteria contour and the areas where the cumulative noise exposure will exceed the impact criteria

Some modelling approaches include the effects of Acoustic Deterrent Devices (ADDs) that cause receptors to flee from the immediate area around the pile before activity commences. Subacoustech Environmental's modelling approach does not include this, however the effects of using an ADD can still be inferred from the results. For example, if a receptor were to flee for 20 minutes from an ADD at a rate of 1.5 m/s, it would travel 1.8 km before piling begins. If a cumulative SEL impact range from INSPIRE was calculated to be below 1.8 km, it can safely be assumed that the ADD will be effective in eliminating the risk of injury on the receptor. The noise from an ADD is of a much lower level than impact piling, and as such the overall effect on the  $SEL_{cum}$  exposure on a receptor would be minimal.

### 3.3.1 The effects of input parameters on SELs and fleeing receptors

As discussed in section 3.2.2, parameters such as bathymetry, hammer blow energies, piling ramp up, strike rate and duration all have an effect on predicted noise levels. When considering  $SEL_{cum}$  and a fleeing animal model, some of these parameters can have a greater influence than others.

Parameters like hammer blow energy can have a clear effect on impact ranges, with higher energies resulting in higher source noise levels and therefore larger impact ranges. When considering cumulative noise levels, these higher levels are compounded sometimes thousands of times due to the number of pile strikes. With this in mind, the ramp up from low blow energies to higher ones requires careful consideration for fleeing animals, as the levels while the receptors are relatively close to the noise source will have a greater effect on the overall cumulative exposure level.

Linked to the effect of the ramp up is the strike rate, as the more pile strikes that occur while the receptor is close to the noise source, the greater the exposure and the greater effect it will have on the  $SEL_{cum}$ . The faster the strike rate, the shorter the distance the receptor can flee between each pile strike, which leads to greater exposure.

## 4 Modelling results

This section presents the modelled impact ranges for impact piling noise following the parameters detailed in section 3.2, covering the Southall *et al.* (2019) and NOAA (2005) marine mammal criteria (section 2.2.1) and the Popper *et al.* (2014) fish criteria (section 2.2.2). To aid navigation, Table 4-1 contains a list of the impact range tables included in this section.

The modelling results for concurrent piling are presented in section 4.5, and the Southall *et al.* (2019) non-impulsive criteria are presented in Appendix A.

For the results presented throughout this report any predicted ranges smaller than 50 m and areas less than 0.01 km<sup>2</sup> for single strike criteria and ranges smaller than 100 m and areas less than 0.1 km<sup>2</sup> for cumulative criteria, have not been presented. At ranges this close to the noise source, the modelling processes are unable to model to a sufficient level of accuracy due to complex acoustic effects present near the pile. These ranges are given as “less than” this limit (e.g., “<100 m”).

*Table 4-1 Summary of the impact piling modelling results tables presented in this section*

| Table (page)     | Parameters (section)            |                               | Criteria                                      |   |
|------------------|---------------------------------|-------------------------------|---|---|
| Table 4-3 (p23)  | Monopile foundations (4.2.1)    | SW (4.2.1.1)                  | Southall <i>et al.</i> (2019)                 | Unweighted SPL <sub>peak</sub> (Impulsive)    |
| Table 4-4 (p23)  |                                 |                               | NOAA (2005)                                   | Weighted SEL <sub>cum</sub> (Impulsive)       |
| Table 4-5 (p23)  |                                 |                               | Popper <i>et al.</i> (2014)                   | Unweighted SPL <sub>RMS</sub> (Level B)       |
| Table 4-6 (p23)  |                                 |                               | Southall <i>et al.</i> (2019)                 | Unweighted SPL <sub>peak</sub> (Pile driving) |
| Table 4-7 (p24)  |                                 |                               | NOAA (2005)                                   | Unweighted SEL <sub>cum</sub> (Pile driving)  |
| Table 4-8 (p24)  |                                 | NW (4.2.1.2)                  | Southall <i>et al.</i> (2019)                 | Unweighted SPL <sub>peak</sub> (Impulsive)    |
| Table 4-9 (p25)  |                                 |                               | NOAA (2005)                                   | Weighted SEL <sub>cum</sub> (Impulsive)       |
| Table 4-10 (p25) |                                 |                               | Popper <i>et al.</i> (2014)                   | Unweighted SPL <sub>RMS</sub> (Level B)       |
| Table 4-11 (p25) |                                 |                               | Southall <i>et al.</i> (2019)                 | Unweighted SPL <sub>peak</sub> (Pile driving) |
| Table 4-12 (p26) |                                 |                               | NOAA (2005)                                   | Unweighted SEL <sub>cum</sub> (Pile driving)  |
| Table 4-13 (p26) |                                 | NE (4.2.1.3)                  | Southall <i>et al.</i> (2019)                 | Unweighted SPL <sub>peak</sub> (Impulsive)    |
| Table 4-14 (p27) |                                 |                               | NOAA (2005)                                   | Weighted SEL <sub>cum</sub> (Impulsive)       |
| Table 4-15 (p27) |                                 |                               | Popper <i>et al.</i> (2014)                   | Unweighted SPL <sub>RMS</sub> (Level B)       |
| Table 4-16 (p27) |                                 |                               | Southall <i>et al.</i> (2019)                 | Unweighted SPL <sub>peak</sub> (Pile driving) |
| Table 4-17 (p28) |                                 |                               | NOAA (2005)                                   | Unweighted SEL <sub>cum</sub> (Pile driving)  |
| Table 4-18 (p28) | Jacket pile foundations (4.2.2) | SW (4.2.2.1)                  | Southall <i>et al.</i> (2019)                 | Unweighted SPL <sub>peak</sub> (Impulsive)    |
| Table 4-19 (p29) |                                 |                               | NOAA (2005)                                   | Weighted SEL <sub>cum</sub> (Impulsive)       |
| Table 4-20 (p29) |                                 |                               | Popper <i>et al.</i> (2014)                   | Unweighted SPL <sub>RMS</sub> (Level B)       |
| Table 4-21 (p29) |                                 |                               | Southall <i>et al.</i> (2019)                 | Unweighted SPL <sub>peak</sub> (Pile driving) |
| Table 4-22 (p30) |                                 |                               | NOAA (2005)                                   | Unweighted SEL <sub>cum</sub> (Pile driving)  |
| Table 4-23 (p30) |                                 | NW (4.2.2.2)                  | Southall <i>et al.</i> (2019)                 | Unweighted SPL <sub>peak</sub> (Impulsive)    |
| Table 4-24 (p31) |                                 |                               | NOAA (2005)                                   | Weighted SEL <sub>cum</sub> (Impulsive)       |
| Table 4-25 (p31) |                                 |                               | Popper <i>et al.</i> (2014)                   | Unweighted SPL <sub>RMS</sub> (Level B)       |
| Table 4-26 (p31) |                                 |                               | Southall <i>et al.</i> (2019)                 | Unweighted SPL <sub>peak</sub> (Pile driving) |
| Table 4-27 (p32) |                                 |                               | NOAA (2005)                                   | Unweighted SEL <sub>cum</sub> (Pile driving)  |
| Table 4-28 (p32) |                                 | NE (4.2.2.3)                  | Southall <i>et al.</i> (2019)                 | Unweighted SPL <sub>peak</sub> (Impulsive)    |
| Table 4-29 (p33) |                                 |                               | NOAA (2005)                                   | Weighted SEL <sub>cum</sub> (Impulsive)       |
| Table 4-30 (p33) |                                 |                               | Popper <i>et al.</i> (2014)                   | Unweighted SPL <sub>RMS</sub> (Level B)       |
| Table 4-31 (p33) |                                 |                               | Southall <i>et al.</i> (2019)                 | Unweighted SPL <sub>peak</sub> (Pile driving) |
| Table 4-32 (p34) |                                 |                               | NOAA (2005)                                   | Unweighted SEL <sub>cum</sub> (Pile driving)  |
| Table 4-33 (p35) | Monopile foundations (4.3.1)    | ORCP-N (4.3.1.1)              | Southall <i>et al.</i> (2019)                 | Unweighted SPL <sub>peak</sub> (Impulsive)    |
| Table 4-34 (p35) |                                 |                               | NOAA (2005)                                   | Weighted SEL <sub>cum</sub> (Impulsive)       |
| Table 4-35 (p35) |                                 |                               | Popper <i>et al.</i> (2014)                   | Unweighted SPL <sub>RMS</sub> (Level B)       |
| Table 4-36 (p35) |                                 | Southall <i>et al.</i> (2019) | Unweighted SPL <sub>peak</sub> (Pile driving) |   |
| Table 4-37 (p36) |                                 | NOAA (2005)                   | Unweighted SEL <sub>cum</sub> (Pile driving)  |   |
| Table 4-38 (p36) |                                 | ORCP-S (4.3.1.2)              | Southall <i>et al.</i> (2019)                 | Unweighted SPL <sub>peak</sub> (Impulsive)    |
| Table 4-39 (p37) | NOAA (2005)                     |                               | Weighted SEL <sub>cum</sub> (Impulsive)       |   |

| Table (page)     | Parameters (section)            |                              | Criteria                                      |   |   |
|------------------|---------------------------------|------------------------------|---|---|---|
| Table 4-40 (p37) |                                 |                              | NOAA (2005)                                   | Unweighted SPL <sub>RMS</sub> (Level B)       |   |
| Table 4-41 (p37) |                                 |                              | Popper <i>et al.</i> (2014)                   | Unweighted SPL <sub>peak</sub> (Pile driving) |   |
| Table 4-42 (p38) |                                 |                              |   | Unweighted SEL <sub>cum</sub> (Pile driving)  |   |
| Table 4-43 (p38) | Jacket pile foundations (4.3.2) | ORCP-N (4.3.2.1)             | Southall <i>et al.</i> (2019)                 | Unweighted SPL <sub>peak</sub> (Impulsive)    |   |
| Table 4-44 (p39) |                                 |                              |   | Weighted SEL <sub>cum</sub> (Impulsive)       |   |
| Table 4-45 (p39) |                                 |                              | NOAA (2005)                                   | Unweighted SPL <sub>RMS</sub> (Level B)       |   |
| Table 4-46 (p39) |                                 |                              | Popper <i>et al.</i> (2014)                   | Unweighted SPL <sub>peak</sub> (Pile driving) |   |
| Table 4-47 (p40) |                                 |                              |   | Unweighted SEL <sub>cum</sub> (Pile driving)  |   |
| Table 4-48 (p40) |                                 |                              | ORCP-S (4.3.2.2)                              | Southall <i>et al.</i> (2019)                 | Unweighted SPL <sub>peak</sub> (Impulsive)    |
| Table 4-49 (p41) |                                 |                              |   | Weighted SEL <sub>cum</sub> (Impulsive)       |   |
| Table 4-50 (p41) |                                 | NOAA (2005)                  |   | Unweighted SPL <sub>RMS</sub> (Level B)       |   |
| Table 4-51 (p41) |                                 | Popper <i>et al.</i> (2014)  |   | Unweighted SPL <sub>peak</sub> (Pile driving) |   |
| Table 4-52 (p42) |                                 |                              |   | Unweighted SEL <sub>cum</sub> (Pile driving)  |   |
| Table 4-53 (p43) |                                 | Monopile foundations (4.4.1) |   | ANS-NW (4.4.1.1)                              | Southall <i>et al.</i> (2019)                 |
| Table 4-54 (p43) |                                 |                              |   |   | Weighted SEL <sub>cum</sub> (Impulsive)       |
| Table 4-55 (p43) | NOAA (2005)                     |                              | Unweighted SPL <sub>RMS</sub> (Level B)       |   |   |
| Table 4-56 (p43) | Popper <i>et al.</i> (2014)     |                              | Unweighted SPL <sub>peak</sub> (Pile driving) |   |   |
| Table 4-57 (p44) |                                 |                              | Unweighted SEL <sub>cum</sub> (Pile driving)  |   |   |
| Table 4-58 (p44) | ANS-SE (4.4.1.2)                |                              | Southall <i>et al.</i> (2019)                 |   | Unweighted SPL <sub>peak</sub> (Impulsive)    |
| Table 4-59 (p44) |                                 |                              |   | Weighted SEL <sub>cum</sub> (Impulsive)       |   |
| Table 4-60 (p44) |                                 |                              | NOAA (2005)                                   | Unweighted SPL <sub>RMS</sub> (Level B)       |   |
| Table 4-61 (p45) |                                 |                              | Popper <i>et al.</i> (2014)                   | Unweighted SPL <sub>peak</sub> (Pile driving) |   |
| Table 4-62 (p45) |                                 |                              |   | Unweighted SEL <sub>cum</sub> (Pile driving)  |   |
| Table 4-63 (p45) |                                 |                              | Jacket pile foundations (4.4.2)               | ANS-NW (4.4.2.1)                              | Southall <i>et al.</i> (2019)                 |
| Table 4-64 (p46) |                                 |                              |   |   | Weighted SEL <sub>cum</sub> (Impulsive)       |
| Table 4-65 (p46) | NOAA (2005)                     |                              |   |   | Unweighted SPL <sub>RMS</sub> (Level B)       |
| Table 4-66 (p46) | Popper <i>et al.</i> (2014)     |                              |   |   | Unweighted SPL <sub>peak</sub> (Pile driving) |
| Table 4-67 (p47) |                                 |                              |   |   | Unweighted SEL <sub>cum</sub> (Pile driving)  |
| Table 4-68 (p47) | ANS-SE (4.4.2.2)                |                              |   |   | Southall <i>et al.</i> (2019)                 |
| Table 4-69 (p48) |                                 |                              |   |   | Weighted SEL <sub>cum</sub> (Impulsive)       |
| Table 4-70 (p48) |                                 |                              |   | NOAA (2005)                                   | Unweighted SPL <sub>RMS</sub> (Level B)       |
| Table 4-71 (p48) |                                 | Popper <i>et al.</i> (2014)  |   | Unweighted SPL <sub>peak</sub> (Pile driving) |   |
| Table 4-72 (p49) |                                 |                              |   | Unweighted SEL <sub>cum</sub> (Pile driving)  |   |

#### 4.1 Predicted noise levels at 750 m from the noise source

In addition to the source levels given in section 3.2.3, it is useful to look at the potential noise levels at a range of 750 m from the noise source, which although not a requirement in the UK sector, is a common consideration for underwater noise studies at offshore windfarms. It has the added advantage of being comparable with other modelling or on-site measurements. A summary of the modelled unweighted levels at a range of 750 m are given in Table 4-2 considering the transect with the greatest noise transmission at each location while piling at the maximum hammer energy.

*Table 4-2 Summary of the maximum predicted unweighted  $SPL_{peak}$  and  $SEL_{ss}$  noise levels at a range of 750 m from the noise source when considering maximum hammer blow energy*

| Predicted level at 750 m range | Location | Monopile foundation                                  |   |
|--------------------------------|----------|--|---|
|                                |          | 14 m / 6600 kJ (Array + ORCP)<br>8 m / 3500 kJ (ANS) | Jacket pile foundation<br>5 m / 3500 kJ |
| Unweighted $SPL_{peak}$        | SW       | 195.2 dB re 1 $\mu$ Pa                               | 193.9 dB re 1 $\mu$ Pa                  |
|                                | NW       | 199.0 dB re 1 $\mu$ Pa                               | 197.8 dB re 1 $\mu$ Pa                  |
|                                | NE       | 201.3 dB re 1 $\mu$ Pa                               | 200.2 dB re 1 $\mu$ Pa                  |
|                                | ORCP-N   | 197.5 dB re 1 $\mu$ Pa                               | 196.4 dB re 1 $\mu$ Pa                  |
|                                | ORCP-S   | 198.2 dB re 1 $\mu$ Pa                               | 197.1 dB re 1 $\mu$ Pa                  |
|                                | ANS-NW   | 200.9 dB re 1 $\mu$ Pa                               | 200.7 dB re 1 $\mu$ Pa                  |
|                                | ANS-SE   | 199.7 dB re 1 $\mu$ Pa                               | 199.5 dB re 1 $\mu$ Pa                  |
| Unweighted $SEL_{ss}$          | SW       | 177.0 dB re 1 $\mu$ Pa <sup>2</sup> s                | 175.2 dB re 1 $\mu$ Pa <sup>2</sup> s   |
|                                | NW       | 180.8 dB re 1 $\mu$ Pa <sup>2</sup> s                | 179.3 dB re 1 $\mu$ Pa <sup>2</sup> s   |
|                                | NE       | 183.1 dB re 1 $\mu$ Pa <sup>2</sup> s                | 181.7 dB re 1 $\mu$ Pa <sup>2</sup> s   |
|                                | ORCP-N   | 179.4 dB re 1 $\mu$ Pa <sup>2</sup> s                | 177.8 dB re 1 $\mu$ Pa <sup>2</sup> s   |
|                                | ORCP-S   | 180.1 dB re 1 $\mu$ Pa <sup>2</sup> s                | 178.5 dB re 1 $\mu$ Pa <sup>2</sup> s   |
|                                | ANS-NW   | 182.5 dB re 1 $\mu$ Pa <sup>2</sup> s                | 182.3 dB re 1 $\mu$ Pa <sup>2</sup> s   |
|                                | ANS-SE   | 181.2 dB re 1 $\mu$ Pa <sup>2</sup> s                | 181.0 dB re 1 $\mu$ Pa <sup>2</sup> s   |

## 4.2 Array locations

Table 4-3 to Table 4-32 present the modelling results for the various foundation modelling scenarios across the three Array modelling locations, in terms of the Southall *et al.* (2019) and NOAA (2005) marine mammal criteria (section 2.2.1), and the Popper *et al.* (2014) fish criteria (section 2.2.2).

The largest marine mammal impact ranges are predicted at the NE modelling location for the monopile scenario. Maximum PTS injury ranges are predicted for LF cetaceans using the  $SEL_{cum}$  criteria, with ranges of up to 5.3 km. For VHF cetaceans, PTS ranges are predicted up to 3.2 km for the same scenario.

For fish, the largest recoverable injury ranges (203 dB  $SEL_{cum}$  threshold) are predicted to be 9.0 km assuming a stationary receptor at the deeper NE location for the jacket pile scenario; if a fleeing animal is assumed, these ranges reduce to less than 100 m. Maximum TTS ranges (186 dB  $SEL_{cum}$  threshold) are predicted up to 25 km for a stationary animal, reducing to 9.9 km for a fleeing animal.

Also presented are the predicted impact ranges for both a single pile installation and multiple sequentially installed piles in order to show the effect on impact ranges of multiple piles being installed in a 24-hour period. The assessment is based on the understanding that up to two monopiles, or up to six pin piles (for a WTG or ORCP jacket), or four pin piles (for the ANS) could be installed in a 24-hour period.

These show that, when considering a fleeing animal, there are no noticeable differences in predicted impact ranges due to the fleeing receptor being at a great distance at the start of the second pile installation, and receiving only a very small additional sound exposure following the first pile. The effect is greater when a stationary model is under consideration.

4.2.1 *Monopile foundations*

4.2.1.1 *SW location*

Table 4-3 Summary of the unweighted  $SPL_{peak}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the SW location

| Southall et al. (2019)<br>Unweighted $SPL_{peak}$ |              | Area                   | Maximum range | Minimum range | Mean range |
|---|--------------|------------------------|---------------|---------------|------------|
| PTS   | LF (219 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | HF (230 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | VHF (202 dB) | 0.22 km <sup>2</sup>   | 270 m         | 260 m         | 270 m      |
|   | PCW (218 dB) | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
| TTS   | LF (213 dB)  | 0.01 km <sup>2</sup>   | 60 m          | 60 m          | 60 m       |
|   | HF (224 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | VHF (196 dB) | 0.97 km <sup>2</sup>   | 590 m         | 540 m         | 560 m      |
|   | PCW (212 dB) | 0.02 km <sup>2</sup>   | 70 m          | 70 m          | 70 m       |

Table 4-4 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the SW location assuming a fleeing animal

| Southall et al. (2019)<br>Weighted $SEL_{cum}$ |     | Area         | Maximum range         | Minimum range | Mean range |         |
|--|-----|--------------|-----------------------|---------------|------------|---------|
| Single pile                                    | PTS | LF (183 dB)  | < 0.1 km <sup>2</sup> | 200 m         | < 100 m    | 150 m   |
|  |     | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (155 dB) | 0.9 km <sup>2</sup>   | 650 m         | 230 m      | 510 m   |
|  |     | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (168 dB)  | 95 km <sup>2</sup>    | 6.7 km        | 1.5 km     | 5.4 km  |
|  |     | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (140 dB) | 130 km <sup>2</sup>   | 7.6 km        | 2.4 km     | 6.3 km  |
|  |     | PCW (170 dB) | 3.1 km <sup>2</sup>   | 1.3 km        | 380 m      | 970 m   |
| 2 sequential piles                             | PTS | LF (183 dB)  | < 0.1 km <sup>2</sup> | 200 m         | < 100 m    | 150 m   |
|  |     | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (155 dB) | 0.9 km <sup>2</sup>   | 650 m         | 230 m      | 510 m   |
|  |     | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (168 dB)  | 95 km <sup>2</sup>    | 6.9 km        | 1.5 km     | 5.4 km  |
|  |     | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (140 dB) | 130 km <sup>2</sup>   | 7.6 km        | 2.4 km     | 6.3 km  |
|  |     | PCW (170 dB) | 3.1 km <sup>2</sup>   | 1.3 km        | 380 m      | 970 m   |

Table 4-5 Summary of the unweighted  $SPL_{RMS}$  impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the monopile foundation modelling at the SW location

| NOAA (2005)<br>Unweighted $SPL_{RMS}$ |        | Area                | Maximum range | Minimum range | Mean range |
|---------------------------------------|--------|---------------------|---------------|---------------|------------|
| Level B                               | 160 dB | 150 km <sup>2</sup> | 7.7 km        | 3.9 km        | 6.8 km     |

Table 4-6 Summary of the unweighted  $SPL_{peak}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the SW location

| Popper et al. (2014)<br>Unweighted $SPL_{peak}$ |  | Area                 | Maximum range | Minimum range | Mean range |
|---|--|----------------------|---------------|---------------|------------|
| 213 dB  |  | 0.01 km <sup>2</sup> | 60 m          | 60 m          | 60 m       |
| 207 dB  |  | 0.06 km <sup>2</sup> | 140 m         | 140 m         | 140 m      |

Table 4-7 Summary of the unweighted  $SEL_{cum}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the SW location assuming both a fleeing and stationary animal

| Popper et al. (2014)   |                       |        | Area                  | Maximum range | Minimum range | Mean range |
|------------------------|-----------------------|--------|-----------------------|---------------|---------------|------------|
| Unweighted $SEL_{cum}$ |                       |        |                       |               |               |            |
| Single pile            | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 186 dB | 12 km <sup>2</sup>    | 2.4 km        | 650 m         | 1.9 km     |
|                        | Stationary<br>(0 m/s) | 219 dB | 0.4 km <sup>2</sup>   | 380 m         | 330 m         | 350 m      |
|                        |                       | 216 dB | 0.8 km <sup>2</sup>   | 530 m         | 480 m         | 550 m      |
|                        |                       | 210 dB | 3.2 km <sup>2</sup>   | 1.1 km        | 930 m         | 1.0 km     |
|                        |                       | 207 dB | 6.4 km <sup>2</sup>   | 1.6 km        | 1.3 km        | 1.4 km     |
|                        |                       | 203 dB | 15 km <sup>2</sup>    | 2.5 km        | 1.8 km        | 2.2 km     |
|                        |                       | 186 dB | 240 km <sup>2</sup>   | 10 km         | 4.6 km        | 8.8 km     |
| 2 sequential piles     | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 186 dB | 12 km <sup>2</sup>    | 2.4 km        | 650 m         | 1.9 km     |
|                        | Stationary<br>(0 m/s) | 219 dB | 0.8 km <sup>2</sup>   | 530 m         | 480 m         | 500 m      |
|                        |                       | 216 dB | 1.6 km <sup>2</sup>   | 750 m         | 680 m         | 720 m      |
|                        |                       | 210 dB | 6.4 km <sup>2</sup>   | 1.6 km        | 1.3 km        | 1.4 km     |
|                        |                       | 207 dB | 12 km <sup>2</sup>    | 2.2 km        | 1.7 km        | 2.0 km     |
|                        |                       | 203 dB | 28 km <sup>2</sup>    | 3.3 km        | 2.2 km        | 3.0 km     |
|                        |                       | 186 dB | 340 km <sup>2</sup>   | 12 km         | 5.1 km        | 10 km      |

4.2.1.2 *NW location*

Table 4-8 Summary of the unweighted  $SPL_{peak}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the NW location

| Southall et al. (2019)  |              |                        | Area   | Maximum range | Minimum range | Mean range |
|-------------------------|--------------|------------------------|--------|---------------|---------------|------------|
| Unweighted $SPL_{peak}$ |              |                        |        |               |               |            |
| PTS                     | LF (219 dB)  | < 0.01 km <sup>2</sup> | < 50 m | < 50 m        | < 50 m        |            |
|                         | HF (230 dB)  | < 0.01 km <sup>2</sup> | < 50 m | < 50 m        | < 50 m        |            |
|                         | VHF (202 dB) | 0.48 km <sup>2</sup>   | 420 m  | 370 m         | 390 m         |            |
|                         | PCW (218 dB) | 0.01 km <sup>2</sup>   | < 50 m | < 50 m        | < 50 m        |            |
| TTS                     | LF (213 dB)  | 0.02 km <sup>2</sup>   | 90 m   | 80 m          | 90 m          |            |
|                         | HF (224 dB)  | < 0.01 km <sup>2</sup> | < 50 m | < 50 m        | < 50 m        |            |
|                         | VHF (196 dB) | 2.3 km <sup>2</sup>    | 950 m  | 740 m         | 850 m         |            |
|                         | PCW (212 dB) | 0.03 km <sup>2</sup>   | 100 m  | 100 m         | 100 m         |            |

Table 4-9 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the NW location assuming a fleeing animal

| <b>Southall et al. (2019)</b><br>Weighted $SEL_{cum}$ |            | <b>Area</b>  | <b>Maximum range</b>  | <b>Minimum range</b> | <b>Mean range</b> |         |
|---|------------|--------------|-----------------------|----------------------|-------------------|---------|
| <b>Single pile</b>                                    | <b>PTS</b> | LF (183 dB)  | 4.6 km <sup>2</sup>   | 1.7 km               | 200 m             | 1.1 km  |
|   |            | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (155 dB) | 5.2 km <sup>2</sup>   | 1.6 km               | 480 m             | 1.3 km  |
|   |            | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   | <b>TTS</b> | LF (168 dB)  | 250 km <sup>2</sup>   | 12 km                | 3.0 km            | 8.8 km  |
|   |            | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (140 dB) | 240 km <sup>2</sup>   | 11 km                | 3.8 km            | 8.6 km  |
|   |            | PCW (170 dB) | 20 km <sup>2</sup>    | 3.1 km               | 880 m             | 2.5 km  |
| <b>2 sequential piles</b>                             | <b>PTS</b> | LF (183 dB)  | 4.6 km <sup>2</sup>   | 1.7 km               | 200 m             | 1.1 km  |
|   |            | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (155 dB) | 5.3 km <sup>2</sup>   | 1.6 km               | 480 m             | 1.3 km  |
|   |            | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   | <b>TTS</b> | LF (168 dB)  | 250 km <sup>2</sup>   | 12 km                | 3.0 km            | 8.8 km  |
|   |            | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (140 dB) | 240 km <sup>2</sup>   | 11 km                | 3.8 km            | 8.6 km  |
|   |            | PCW (170 dB) | 20 km <sup>2</sup>    | 3.1 km               | 880 m             | 2.5 km  |

Table 4-10 Summary of the unweighted  $SPL_{RMS}$  impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the monopile foundation modelling at the NW location

| <b>NOAA (2005)</b><br>Unweighted $SPL_{RMS}$ |        | <b>Area</b>         | <b>Maximum range</b> | <b>Minimum range</b> | <b>Mean range</b> |
|--|--------|---------------------|----------------------|----------------------|-------------------|
| <b>Level B</b>                               | 160 dB | 280 km <sup>2</sup> | 11 km                | 5.0 km               | 9.5 km            |

Table 4-11 Summary of the unweighted  $SPL_{peak}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the NW location

| <b>Popper et al. (2014)</b><br>Unweighted $SPL_{peak}$ |  | <b>Area</b>          | <b>Maximum range</b> | <b>Minimum range</b> | <b>Mean range</b> |
|--|--|----------------------|----------------------|----------------------|-------------------|
| 213 dB   |  | 0.02 km <sup>2</sup> | 90 m                 | 80 m                 | 90 m              |
| 207 dB   |  | 0.12 km <sup>2</sup> | 210 m                | 190 m                | 200 m             |



Table 4-12 Summary of the unweighted  $SEL_{cum}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the NW location assuming both a fleeing and stationary animal

| Popper et al. (2014)   |                       |        | Area                  | Maximum range | Minimum range | Mean range |
|------------------------|-----------------------|--------|-----------------------|---------------|---------------|------------|
| Unweighted $SEL_{cum}$ |                       |        |                       |               |               |            |
| Single pile            | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 186 dB | 52 km <sup>2</sup>    | 5.2 km        | 1.4 km        | 4.0 km     |
|                        | Stationary<br>(0 m/s) | 219 dB | 0.8 km <sup>2</sup>   | 580 m         | 480 m         | 520 m      |
|                        |                       | 216 dB | 1.8 km <sup>2</sup>   | 850 m         | 680 m         | 760 m      |
|                        |                       | 210 dB | 7.9 km <sup>2</sup>   | 1.8 km        | 1.3 km        | 1.6 km     |
|                        |                       | 207 dB | 16 km <sup>2</sup>    | 2.6 km        | 1.7 km        | 2.2 km     |
|                        |                       | 203 dB | 37 km <sup>2</sup>    | 3.9 km        | 2.3 km        | 3.4 km     |
|                        |                       | 186 dB | 440 km <sup>2</sup>   | 14 km         | 3.6 km        | 12 km      |
| 2 sequential piles     | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 186 dB | 52 km <sup>2</sup>    | 5.2 km        | 1.4 km        | 4.0 km     |
|                        | Stationary<br>(0 m/s) | 219 dB | 1.8 km <sup>2</sup>   | 850 m         | 680 m         | 760 m      |
|                        |                       | 216 dB | 3.8 km <sup>2</sup>   | 1.3 km        | 950 m         | 1.1 km     |
|                        |                       | 210 dB | 16 km <sup>2</sup>    | 2.6 km        | 1.7 km        | 2.2 km     |
|                        |                       | 207 dB | 30 km <sup>2</sup>    | 3.6 km        | 2.2 km        | 3.1 km     |
|                        |                       | 203 dB | 66 km <sup>2</sup>    | 5.2 km        | 2.9 km        | 4.6 km     |
|                        |                       | 186 dB | 600 km <sup>2</sup>   | 16 km         | 7.6 km        | 14 km      |

#### 4.2.1.3 NE location

Table 4-13 Summary of the unweighted  $SPL_{peak}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the NE location

| Southall et al. (2019)  |              |  | Area                   | Maximum range | Minimum range | Mean range |
|-------------------------|--------------|--|------------------------|---------------|---------------|------------|
| Unweighted $SPL_{peak}$ |              |  |                        |               |               |            |
| PTS                     | LF (219 dB)  |  | 0.01 km <sup>2</sup>   | < 50 m        | < 50 m        | < 50 m     |
|                         | HF (230 dB)  |  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|                         | VHF (202 dB) |  | 1.1 km <sup>2</sup>    | 580 m         | 580 m         | 580 m      |
|                         | PCW (218 dB) |  | 0.01 km <sup>2</sup>   | 50 m          | 50 m          | 50 m       |
| TTS                     | LF (213 dB)  |  | 0.04 km <sup>2</sup>   | 110 m         | 110 m         | 110 m      |
|                         | HF (224 dB)  |  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|                         | VHF (196 dB) |  | 5.5 km <sup>2</sup>    | 1.3 km        | 1.3 km        | 1.3 km     |
|                         | PCW (212 dB) |  | 0.02 km <sup>2</sup>   | 130 m         | 130 m         | 130 m      |

Table 4-14 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the NE location assuming a fleeing animal

| <b>Southall et al. (2019)</b><br>Weighted $SEL_{cum}$ |            | <b>Area</b>  | <b>Maximum range</b>  | <b>Minimum range</b> | <b>Mean range</b> |         |
|---|------------|--------------|-----------------------|----------------------|-------------------|---------|
| <b>Single pile</b>                                    | <b>PTS</b> | LF (183 dB)  | 55 km <sup>2</sup>    | 5.3 km               | 3.3 km            | 4.1 km  |
|   |            | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (155 dB) | 24 km <sup>2</sup>    | 3.2 km               | 2.4 km            | 2.8 km  |
|   |            | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   | <b>TTS</b> | LF (168 dB)  | 770 km <sup>2</sup>   | 19 km                | 12 km             | 16 km   |
|   |            | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (140 dB) | 560 km <sup>2</sup>   | 16 km                | 11 km             | 13 km   |
|   |            | PCW (170 dB) | 94 km <sup>2</sup>    | 6.6 km               | 4.6 km            | 5.5 km  |
| <b>2 sequential piles</b>                             | <b>PTS</b> | LF (183 dB)  | 55 km <sup>2</sup>    | 5.3 km               | 3.3 km            | 4.1 km  |
|   |            | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (155 dB) | 24 km <sup>2</sup>    | 3.2 km               | 2.4 km            | 2.8 km  |
|   |            | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   | <b>TTS</b> | LF (168 dB)  | 770 km <sup>2</sup>   | 19 km                | 12 km             | 16 km   |
|   |            | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (140 dB) | 560 km <sup>2</sup>   | 16 km                | 11 km             | 13 km   |
|   |            | PCW (170 dB) | 94 km <sup>2</sup>    | 6.6 km               | 4.6 km            | 5.5 km  |

Table 4-15 Summary of the unweighted  $SPL_{RMS}$  impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the monopile foundation modelling at the NE location

| <b>NOAA (2005)</b><br>Unweighted $SPL_{RMS}$ |        | <b>Area</b>         | <b>Maximum range</b> | <b>Minimum range</b> | <b>Mean range</b> |
|--|--------|---------------------|----------------------|----------------------|-------------------|
| <b>Level B</b>                               | 160 dB | 640 km <sup>2</sup> | 16 km                | 12 km                | 14 km             |

Table 4-16 Summary of the unweighted  $SPL_{peak}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the NE location

| <b>Popper et al. (2014)</b><br>Unweighted $SPL_{peak}$ |        | <b>Area</b>          | <b>Maximum range</b> | <b>Minimum range</b> | <b>Mean range</b> |
|--|--------|----------------------|----------------------|----------------------|-------------------|
|  | 213 dB | 0.04 km <sup>2</sup> | 110 m                | 110 m                | 110 m             |
|  | 207 dB | 0.24 km <sup>2</sup> | 280 m                | 280 m                | 280 m             |

Table 4-17 Summary of the unweighted  $SEL_{cum}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the NE location assuming both a fleeing and stationary animal

| Popper et al. (2014)   |                       |        | Area                  | Maximum range | Minimum range | Mean range |
|------------------------|-----------------------|--------|-----------------------|---------------|---------------|------------|
| Unweighted $SEL_{cum}$ |                       |        |                       |               |               |            |
| Single pile            | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 186 dB | 210 km <sup>2</sup>   | 9.9 km        | 6.8 km        | 8.2 km     |
|                        | Stationary<br>(0 m/s) | 219 dB | 1.9 km <sup>2</sup>   | 800 m         | 780 m         | 790 m      |
|                        |                       | 216 dB | 4.4 km <sup>2</sup>   | 1.2 km        | 1.2 km        | 1.2 km     |
|                        |                       | 210 dB | 20 km <sup>2</sup>    | 2.6 km        | 2.5 km        | 2.5 km     |
|                        |                       | 207 dB | 40 km <sup>2</sup>    | 3.7 km        | 3.5 km        | 3.6 km     |
|                        |                       | 203 dB | 94 km <sup>2</sup>    | 6.1 km        | 5.2 km        | 5.5 km     |
|                        |                       | 186 dB | 960 km <sup>2</sup>   | 20 km         | 15 km         | 17 km      |
| 2 sequential piles     | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |                       | 186 dB | 210 km <sup>2</sup>   | 9.9 km        | 6.8 km        | 8.2 km     |
|                        | Stationary<br>(0 m/s) | 219 dB | 4.4 km <sup>2</sup>   | 1.2 km        | 1.2 km        | 1.2 km     |
|                        |                       | 216 dB | 9.6 km <sup>2</sup>   | 1.8 km        | 1.8 km        | 1.8 km     |
|                        |                       | 210 dB | 40 km <sup>2</sup>    | 3.7 km        | 3.5 km        | 3.6 km     |
|                        |                       | 207 dB | 77 km <sup>2</sup>    | 5.5 km        | 4.7 km        | 5.0 km     |
|                        |                       | 203 dB | 160 km <sup>2</sup>   | 8.1 km        | 6.7 km        | 7.2 km     |
|                        |                       | 186 dB | 1,300 km <sup>2</sup> | 23 km         | 17 km         | 20 km      |

4.2.2 Jacket pile foundations

4.2.2.1 SW location

Table 4-18 Summary of the unweighted  $SPL_{peak}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the SW location

| Southall et al. (2019)  |              |                        | Area   | Maximum range | Minimum range | Mean range |
|-------------------------|--------------|------------------------|--------|---------------|---------------|------------|
| Unweighted $SPL_{peak}$ |              |                        |        |               |               |            |
| PTS                     | LF (219 dB)  | < 0.01 km <sup>2</sup> | < 50 m | < 50 m        | < 50 m        |            |
|                         | HF (230 dB)  | < 0.01 km <sup>2</sup> | < 50 m | < 50 m        | < 50 m        |            |
|                         | VHF (202 dB) | 0.16 km <sup>2</sup>   | 230 m  | 220 m         | 230 m         |            |
|                         | PCW (218 dB) | < 0.01 km <sup>2</sup> | < 50 m | < 50 m        | < 50 m        |            |
| TTS                     | LF (213 dB)  | 0.01 km <sup>2</sup>   | 50 m   | 50 m          | 50 m          |            |
|                         | HF (224 dB)  | < 0.01 km <sup>2</sup> | < 50 m | < 50 m        | < 50 m        |            |
|                         | VHF (196 dB) | 0.71 km <sup>2</sup>   | 500 m  | 470 m         | 480 m         |            |
|                         | PCW (212 dB) | 0.01 km <sup>2</sup>   | 60 m   | 60 m          | 60 m          |            |

*Table 4-19 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the SW location assuming a fleeing animal*

| <b>Southall et al. (2019)</b><br>Weighted SEL <sub>cum</sub> |            | <b>Area</b>  | <b>Maximum range</b>  | <b>Minimum range</b> | <b>Mean range</b> |         |
|--|------------|--------------|-----------------------|----------------------|-------------------|---------|
| <b>Single pile</b>   | <b>PTS</b> | LF (183 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           |         |
|  |            | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           |         |
|  |            | VHF (155 dB) | < 0.1 km <sup>2</sup> | 230 m                | < 100 m           | 160 m   |
|  |            | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|  | <b>TTS</b> | LF (168 dB)  | 55 km <sup>2</sup>    | 5.4 km               | 980 m             | 4.1 km  |
|  |            | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|  |            | VHF (140 dB) | 91 km <sup>2</sup>    | 6.5 km               | 2.0 km            | 5.3 km  |
|  |            | PCW (170 dB) | 1.2 km <sup>2</sup>   | 830 m                | 200 m             | 590 m   |
| <b>6 sequential piles</b>                                    | <b>PTS</b> | LF (183 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           |         |
|  |            | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|  |            | VHF (155 dB) | < 0.1 km <sup>2</sup> | 230 m                | < 100 m           | 160 m   |
|  |            | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|  | <b>TTS</b> | LF (168 dB)  | 55 km <sup>2</sup>    | 5.4 km               | 980 m             | 4.1 km  |
|  |            | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|  |            | VHF (140 dB) | 91 km <sup>2</sup>    | 6.5 km               | 2.0 km            | 5.3 km  |
|  |            | PCW (170 dB) | 1.2 km <sup>2</sup>   | 830 m                | 200 m             | 590 m   |

*Table 4-20 Summary of the unweighted SPL<sub>RMS</sub> impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the jacket pile foundation modelling at the SW location*

| <b>NOAA (2005)</b><br>Unweighted SPL <sub>RMS</sub> |        | <b>Area</b>         | <b>Maximum range</b> | <b>Minimum range</b> | <b>Mean range</b> |
|---|--------|---------------------|----------------------|----------------------|-------------------|
| <b>Level B</b>                                      | 160 dB | 110 km <sup>2</sup> | 6.7 km               | 3.6 km               | 6.0 km            |

*Table 4-21 Summary of the unweighted SPL<sub>peak</sub> impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the SW location*

| <b>Popper et al. (2014)</b><br>Unweighted SPL <sub>peak</sub> |        | <b>Area</b>          | <b>Maximum range</b> | <b>Minimum range</b> | <b>Mean range</b> |
|---|--------|----------------------|----------------------|----------------------|-------------------|
|   | 213 dB | 0.01 km <sup>2</sup> | 50 m                 | 50 m                 | 50 m              |
|   | 207 dB | 0.04 km <sup>2</sup> | 120 m                | 120 m                | 120 m             |

Table 4-22 Summary of the unweighted  $SEL_{cum}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the SW location assuming both a fleeing and stationary animal

| Popper et al. (2014)<br>Unweighted $SEL_{cum}$ |                       | Area   | Maximum range         | Minimum range | Mean range |                     |
|--|-----------------------|--------|-----------------------|---------------|------------|---------------------|
| Single pile                                    | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m             |
|  |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m             |
|  |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m             |
|  |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m             |
|  |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m             |
|  |                       | 186 dB | 3.4 km <sup>2</sup>   | 1.4 km        | 250 m      | 1.0 km <sup>2</sup> |
|  | Stationary<br>(0 m/s) | 219 dB | 0.2 km <sup>2</sup>   | 250 m         | 200 m      | 220 m               |
|  |                       | 216 dB | 0.3 km <sup>2</sup>   | 330 m         | 300 m      | 320 m               |
|  |                       | 210 dB | 1.3 km <sup>2</sup>   | 680 m         | 600 m      | 650 m               |
|  |                       | 207 dB | 2.6 km <sup>2</sup>   | 980 m         | 850 m      | 920 m               |
|  |                       | 203 dB | 6.6 km <sup>2</sup>   | 1.6 km        | 1.3 km     | 1.4 km              |
| 186 dB   | 150 km <sup>2</sup>   | 7.8 km | 3.9 km                | 6.8 km        |            |                     |
| 6 sequential piles                             | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m             |
|  |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m             |
|  |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m             |
|  |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m             |
|  |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m             |
|  |                       | 186 dB | 3.4 km <sup>2</sup>   | 1.4 km        | 250 m      | 1.0 km              |
|  | Stationary<br>(0 m/s) | 219 dB | 1.0 km <sup>2</sup>   | 600 m         | 530 m      | 560 m               |
|  |                       | 216 dB | 2.0 km <sup>2</sup>   | 850 m         | 750 m      | 800 m               |
|  |                       | 210 dB | 7.8 km <sup>2</sup>   | 1.8 km        | 1.4 km     | 1.6 km              |
|  |                       | 207 dB | 15 km <sup>2</sup>    | 2.4 km        | 1.8 km     | 2.2 km              |
|  |                       | 203 dB | 34 km <sup>2</sup>    | 3.6 km        | 2.4 km     | 3.3 km              |
|  |                       | 186 dB | 380 km <sup>2</sup>   | 13 km         | 5.3 km     | 11 km               |

#### 4.2.2.2 NW location

Table 4-23 Summary of the unweighted  $SPL_{peak}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the NW location

| Southall et al. (2019)<br>Unweighted $SPL_{peak}$ |              | Area                   | Maximum range | Minimum range | Mean range |
|---|--------------|------------------------|---------------|---------------|------------|
| PTS   | LF (219 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | HF (230 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | VHF (202 dB) | 0.35 km <sup>2</sup>   | 360 m         | 320 m         | 340 m      |
|   | PCW (218 dB) | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
| TTS   | LF (213 dB)  | 0.02 km <sup>2</sup>   | 70 m          | 70 m          | 70 m       |
|   | HF (224 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | VHF (196 dB) | 1.7 km <sup>2</sup>    | 820 m         | 650 m         | 740 m      |
|   | PCW (212 dB) | 0.02 km <sup>2</sup>   | 80 m          | 80 m          | 80 m       |

*Table 4-24 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the NW location assuming a fleeing animal*

| <b>Southall et al. (2019)</b><br>Weighted $SEL_{cum}$ |            | <b>Area</b>  | <b>Maximum range</b>  | <b>Minimum range</b> | <b>Mean range</b> |         |
|---|------------|--------------|-----------------------|----------------------|-------------------|---------|
| <b>Single pile</b>                                    | <b>PTS</b> | LF (183 dB)  | 0.6 km <sup>2</sup>   | 680 m                | < 100 m           | 370 m   |
|   |            | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (155 dB) | 1.5 km <sup>2</sup>   | 930 m                | 180 m             | 660 m   |
|   |            | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   | <b>TTS</b> | LF (168 dB)  | 180 km <sup>2</sup>   | 9.8 km               | 2.2 km            | 7.4 km  |
|   |            | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (140 dB) | 180 km <sup>2</sup>   | 9.4 km               | 3.1 km            | 7.5 km  |
|   |            | PCW (170 dB) | 13 km <sup>2</sup>    | 2.5 km               | 600 m             | 1.9 km  |
| <b>6 sequential piles</b>                             | <b>PTS</b> | LF (183 dB)  | 0.6 km <sup>2</sup>   | 680 m                | < 100 m           | 370 m   |
|   |            | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (155 dB) | 1.5 km <sup>2</sup>   | 930 m                | 180 m             | 660 m   |
|   |            | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   | <b>TTS</b> | LF (168 dB)  | 180 km <sup>2</sup>   | 9.8 km               | 2.2 km            | 7.4 km  |
|   |            | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (140 dB) | 180 km <sup>2</sup>   | 9.4 km               | 3.1 km            | 7.5 km  |
|   |            | PCW (170 dB) | 13 km <sup>2</sup>    | 2.5 km               | 600 m             | 2.0 km  |

*Table 4-25 Summary of the unweighted  $SPL_{RMS}$  impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the jacket pile foundation modelling at the NW location*

| <b>NOAA (2005)</b><br>Unweighted $SPL_{RMS}$ |        | <b>Area</b>         | <b>Maximum range</b> | <b>Minimum range</b> | <b>Mean range</b> |
|--|--------|---------------------|----------------------|----------------------|-------------------|
| <b>Level B</b>                               | 160 dB | 230 km <sup>2</sup> | 10 km                | 4.6 km               | 8.6 km            |

*Table 4-26 Summary of the unweighted  $SPL_{peak}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the NW location*

| <b>Popper et al. (2014)</b><br>Unweighted $SPL_{peak}$ |        | <b>Area</b>          | <b>Maximum range</b> | <b>Minimum range</b> | <b>Mean range</b> |
|--|--------|----------------------|----------------------|----------------------|-------------------|
|  | 213 dB | 0.02 km <sup>2</sup> | 70 m                 | 70 m                 | 70 m              |
|  | 207 dB | 0.09 km <sup>2</sup> | 170 m                | 170 m                | 170 m             |

Table 4-27 Summary of the unweighted  $SEL_{cum}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the NW location assuming both a fleeing and stationary animal

| Popper et al. (2014)<br>Unweighted $SEL_{cum}$ |                       | Area   | Maximum range         | Minimum range | Mean range |         |
|--|-----------------------|--------|-----------------------|---------------|------------|---------|
| Single pile                                    | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 186 dB | 28 km <sup>2</sup>    | 3.8 km        | 850 m      | 2.9 km  |
|  | Stationary<br>(0 m/s) | 219 dB | 0.3 km <sup>2</sup>   | 350 m         | 300 m      | 330 m   |
|  |                       | 216 dB | 0.7 km <sup>2</sup>   | 530 m         | 430 m      | 480 m   |
|  |                       | 210 dB | 3.3 km <sup>2</sup>   | 1.2 km        | 880 m      | 1.0 km  |
|  |                       | 207 dB | 6.8 km <sup>2</sup>   | 1.7 km        | 1.2 km     | 1.5 km  |
|  |                       | 203 dB | 17 km <sup>2</sup>    | 2.7 km        | 1.8 km     | 2.3 km  |
|  |                       | 186 dB | 300 km <sup>2</sup>   | 11 km         | 5.1 km     | 9.7 km  |
| 6 sequential piles                             | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 186 dB | 28 km <sup>2</sup>    | 3.8 km        | 850 m      | 2.9 km  |
|  | Stationary<br>(0 m/s) | 219 dB | 2.4 km <sup>2</sup>   | 980 m         | 780 m      | 880 m   |
|  |                       | 216 dB | 5.1 km <sup>2</sup>   | 1.5 km        | 1.1 km     | 1.3 km  |
|  |                       | 210 dB | 20 km <sup>2</sup>    | 2.9 km        | 1.9 km     | 2.5 km  |
|  |                       | 207 dB | 38 km <sup>2</sup>    | 4.0 km        | 2.4 km     | 3.5 km  |
|  |                       | 203 dB | 80 km <sup>2</sup>    | 5.7 km        | 3.1 km     | 5.0 km  |
|  |                       | 186 dB | 670 km <sup>2</sup>   | 17 km         | 8.1 km     | 15 km   |

#### 4.2.2.3 NE location

Table 4-28 Summary of the unweighted  $SPL_{peak}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the NE location

| Southall et al. (2019)<br>Unweighted $SPL_{peak}$ |              | Area                   | Maximum range | Minimum range | Mean range |
|---|--------------|------------------------|---------------|---------------|------------|
| PTS   | LF (219 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | HF (230 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | VHF (202 dB) | 0.78 km <sup>2</sup>   | 500 m         | 500 m         | 500 m      |
|   | PCW (218 dB) | 0.01 km <sup>2</sup>   | < 50 m        | < 50 m        | < 50 m     |
| TTS   | LF (213 dB)  | 0.03 km <sup>2</sup>   | 100 m         | 90 m          | 100 m      |
|   | HF (224 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | VHF (196 dB) | 4.2 km <sup>2</sup>    | 1.2 km        | 1.2 km        | 1.2 km     |
|   | PCW (212 dB) | 0.04 km <sup>2</sup>   | 110 m         | 110 m         | 110 m      |

*Table 4-29 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the NE location assuming a fleeing animal*

| <b>Southall et al. (2019)</b><br>Weighted $SEL_{cum}$ |            | <b>Area</b>  | <b>Maximum range</b>  | <b>Minimum range</b> | <b>Mean range</b> |         |
|---|------------|--------------|-----------------------|----------------------|-------------------|---------|
| <b>Single pile</b>                                    | <b>PTS</b> | LF (183 dB)  | 24 km <sup>2</sup>    | 3.7 km               | 2.1 km            | 2.8 km  |
|   |            | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (155 dB) | 11 km <sup>2</sup>    | 2.2 km               | 1.6 km            | 1.8 km  |
|   |            | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   | <b>TTS</b> | LF (168 dB)  | 600 km <sup>2</sup>   | 17 km                | 11 km             | 14 km   |
|   |            | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (140 dB) | 440 km <sup>2</sup>   | 14 km                | 9.7 km            | 12 km   |
|   |            | PCW (170 dB) | 71 km <sup>2</sup>    | 5.8 km               | 4.0 km            | 4.7 km  |
| <b>6 sequential piles</b>                             | <b>PTS</b> | LF (183 dB)  | 24 km <sup>2</sup>    | 3.7 km               | 2.1 km            | 2.8 km  |
|   |            | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (155 dB) | 11 km <sup>2</sup>    | 2.2 km               | 1.6 km            | 1.9 km  |
|   |            | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   | <b>TTS</b> | LF (168 dB)  | 600 km <sup>2</sup>   | 17 km                | 11 km             | 14 km   |
|   |            | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (140 dB) | 450 km <sup>2</sup>   | 14 km                | 9.7 km            | 12 km   |
|   |            | PCW (170 dB) | 72 km <sup>2</sup>    | 5.8 km               | 4.0 km            | 4.8 km  |

*Table 4-30 Summary of the unweighted  $SPL_{RMS}$  impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the jacket pile foundation modelling at the NE location*

| <b>NOAA (2005)</b><br>Unweighted $SPL_{RMS}$ |        | <b>Area</b>         | <b>Maximum range</b> | <b>Minimum range</b> | <b>Mean range</b> |
|--|--------|---------------------|----------------------|----------------------|-------------------|
| <b>Level B</b>                               | 160 dB | 540 km <sup>2</sup> | 15 km                | 12 km                | 13 km             |

*Table 4-31 Summary of the unweighted  $SPL_{peak}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the NE location*

| <b>Popper et al. (2014)</b><br>Unweighted $SPL_{peak}$ |        | <b>Area</b>          | <b>Maximum range</b> | <b>Minimum range</b> | <b>Mean range</b> |
|--|--------|----------------------|----------------------|----------------------|-------------------|
|  | 213 dB | 0.03 km <sup>2</sup> | 100 m                | 90 m                 | 100 m             |
|  | 207 dB | 0.18 km <sup>2</sup> | 240 m                | 240 m                | 240 m             |



Table 4-32 Summary of the unweighted  $SEL_{cum}$  impact ranges for fish using the Popper *et al.* (2014) pile driving criteria for the jacket pile foundation modelling at the NE location assuming both a fleeing and stationary animal

| Popper <i>et al.</i> (2014)<br>Unweighted $SEL_{cum}$ |                       | Area   | Maximum range         | Minimum range | Mean range |         |
|---|-----------------------|--------|-----------------------|---------------|------------|---------|
| Single pile   | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 186 dB | 140 km <sup>2</sup>   | 8.2 km        | 5.5 km     | 6.7 km  |
|   | Stationary<br>(0 m/s) | 219 dB | 0.7 km <sup>2</sup>   | 500 m         | 480 m      | 490 m   |
|   |                       | 216 dB | 1.7 km <sup>2</sup>   | 750 m         | 730 m      | 740 m   |
|   |                       | 210 dB | 8.5 km <sup>2</sup>   | 1.7 km        | 1.6 km     | 1.7 km  |
|   |                       | 207 dB | 18 km <sup>2</sup>    | 2.4 km        | 2.4 km     | 2.4 km  |
|   |                       | 203 dB | 45 km <sup>2</sup>    | 4.0 km        | 3.7 km     | 3.8 km  |
|   |                       | 186 dB | 970 km <sup>2</sup>   | 17 km         | 13 km      | 15 km   |
| 6 sequential piles                                    | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 186 dB | 140 km <sup>2</sup>   | 8.3 km        | 5.6 km     | 6.7 km  |
|   | Stationary<br>(0 m/s) | 219 dB | 6.2 km <sup>2</sup>   | 1.4 km        | 1.4 km     | 1.4 km  |
|   |                       | 216 dB | 13 km <sup>2</sup>    | 2.1 km        | 2.1 km     | 2.1 km  |
|   |                       | 210 dB | 54 km <sup>2</sup>    | 4.4 km        | 4.0 km     | 4.1 km  |
|   |                       | 207 dB | 100 km <sup>2</sup>   | 6.3 km        | 5.3 km     | 5.6 km  |
|   |                       | 203 dB | 200 km <sup>2</sup>   | 9.0 km        | 7.4 km     | 8.0 km  |
|   |                       | 186 dB | 1,400 km <sup>2</sup> | 25 km         | 18 km      | 21 km   |

### 4.3 ORCP locations

Table 4-33 to Table 4-52 present the modelling results for the various foundation modelling scenarios across the two ORCP modelling locations, in terms of the Southall *et al.* (2019) and NOAA (2005) marine mammal criteria (section 2.2.1) and the Popper *et al.* (2014) fish criteria (section 2.2.2). The predicted ranges are smaller than those presented in section 4.2 for the Array locations due to the shallower water at the ORCP.

The largest marine mammal impact ranges are predicted at the ORCP-S modelling location for the monopile scenario. Maximum PTS injury ranges are predicted for VHF cetaceans using the  $SEL_{cum}$  criteria, with ranges of up to 1.3 km, for LF cetaceans PTS ranges are predicted up to 1.2 km for the same scenario.

For fish, the largest recoverable injury ranges (203 dB  $SEL_{cum}$  threshold) are predicted to be 5.2 km assuming a stationary receptor at the slightly deeper ORCP-S location for the jacket pile scenario; if a fleeing animal is assumed, these ranges are reduced to less than 100 m. Maximum TTS ranges (186 dB  $SEL_{cum}$  threshold) are predicted up to 16 km for a stationary animal, reducing to 3.1 km for a fleeing animal.

4.3.1 *Monopile foundations*

4.3.1.1 *ORCP-N location*

Table 4-33 Summary of the unweighted  $SPL_{peak}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the ORCP-N location

| Southall et al. (2019)<br>Unweighted $SPL_{peak}$ |              | Area                   | Maximum range | Minimum range | Mean range |
|---|--------------|------------------------|---------------|---------------|------------|
| PTS   | LF (219 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | HF (230 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | VHF (202 dB) | 0.42 km <sup>2</sup>   | 370 m         | 360 m         | 370 m      |
|   | PCW (218 dB) | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
| TTS   | LF (213 dB)  | 0.02 km <sup>2</sup>   | 80 m          | 80 m          | 80 m       |
|   | HF (224 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | VHF (196 dB) | 1.9 km <sup>2</sup>    | 800 m         | 770 m         | 780 m      |
|   | PCW (212 dB) | 0.03 km <sup>2</sup>   | 90 m          | 90 m          | 90 m       |

Table 4-34 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the ORCP-N location assuming a fleeing animal

| Southall et al. (2019)<br>Weighted $SEL_{cum}$ |     | Area         | Maximum range         | Minimum range | Mean range |         |
|--|-----|--------------|-----------------------|---------------|------------|---------|
| Single pile                                    | PTS | LF (183 dB)  | 0.4 km <sup>2</sup>   | 480 m         | 280 m      | 360 m   |
|  |     | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (155 dB) | 1.7 km <sup>2</sup>   | 850 m         | 630 m      | 730 m   |
|  |     | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (168 dB)  | 94 km <sup>2</sup>    | 7.9 km        | 3.9 km     | 5.4 km  |
|  |     | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (140 dB) | 110 km <sup>2</sup>   | 7.9 km        | 4.7 km     | 5.9 km  |
|  |     | PCW (170 dB) | 12 km <sup>2</sup>    | 2.2 km        | 1.7 km     | 1.9 km  |
| 2 sequential piles                             | PTS | LF (183 dB)  | 0.4 km <sup>2</sup>   | 480 m         | 280 m      | 360 m   |
|  |     | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (155 dB) | 1.7 km <sup>2</sup>   | 850 m         | 630 m      | 730 m   |
|  |     | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (168 dB)  | 94 km <sup>2</sup>    | 7.9 km        | 3.9 km     | 5.4 km  |
|  |     | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (140 dB) | 110 km <sup>2</sup>   | 7.9 km        | 4.7 km     | 5.9 km  |
|  |     | PCW (170 dB) | 12 km <sup>2</sup>    | 2.2 km        | 1.7 km     | 1.9 km  |

Table 4-35 Summary of the unweighted  $SPL_{RMS}$  impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the monopile foundation modelling at the ORCP-N location

| NOAA (2005)<br>Unweighted $SPL_{RMS}$ |        | Area                | Maximum range | Minimum range | Mean range |
|---------------------------------------|--------|---------------------|---------------|---------------|------------|
| Level B                               | 160 dB | 160 km <sup>2</sup> | 7.9 km        | 6.0 km        | 7.1 km     |

Table 4-36 Summary of the unweighted  $SPL_{peak}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the ORCP-N location

| Popper et al. (2014)<br>Unweighted $SPL_{peak}$ |  | Area                 | Maximum range | Minimum range | Mean range |
|---|--|----------------------|---------------|---------------|------------|
| 213 dB  |  | 0.02 km <sup>2</sup> | 80 m          | 80 m          | 80 m       |
| 207 dB  |  | 0.11 km <sup>2</sup> | 190 m         | 190 m         | 190 m      |

Table 4-37 Summary of the unweighted  $SEL_{cum}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the ORCP-N location assuming both a fleeing and stationary animal

| Popper et al. (2014)<br>Unweighted $SEL_{cum}$ |                       | Area   | Maximum range         | Minimum range | Mean range |         |
|--|-----------------------|--------|-----------------------|---------------|------------|---------|
| Single pile                                    | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 186 dB | 17 km <sup>2</sup>    | 2.7 km        | 1.8 km     | 2.3 km  |
|  | Stationary<br>(0 m/s) | 219 dB | 0.7 km <sup>2</sup>   | 500 m         | 480 m      | 490 m   |
|  |                       | 216 dB | 1.5 km <sup>2</sup>   | 730 m         | 680 m      | 700 m   |
|  |                       | 210 dB | 6.1 km <sup>2</sup>   | 1.5 km        | 1.4 km     | 1.4 km  |
|  |                       | 207 dB | 11 km <sup>2</sup>    | 2.0 km        | 1.8 km     | 1.9 km  |
|  |                       | 203 dB | 24 km <sup>2</sup>    | 2.9 km        | 2.6 km     | 2.8 km  |
|  |                       | 186 dB | 250 km <sup>2</sup>   | 10 km         | 7.3 km     | 8.9 km  |
| 2 sequential piles                             | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 186 dB | 17 km <sup>2</sup>    | 2.7 km        | 1.8 km     | 2.3 km  |
|  | Stationary<br>(0 m/s) | 219 dB | 1.5 km <sup>2</sup>   | 730 m         | 680 m      | 700 m   |
|  |                       | 216 dB | 3.1 km <sup>2</sup>   | 1.0 km        | 980 m      | 1.0 km  |
|  |                       | 210 dB | 11 km <sup>2</sup>    | 2.0 km        | 1.8 km     | 1.9 km  |
|  |                       | 207 dB | 20 km <sup>2</sup>    | 2.7 km        | 2.4 km     | 2.5 km  |
|  |                       | 203 dB | 39 km <sup>2</sup>    | 3.8 km        | 3.3 km     | 3.5 km  |
|  |                       | 186 dB | 340 km <sup>2</sup>   | 13 km         | 8.3 km     | 10 km   |

#### 4.3.1.2 ORCP-S location

Table 4-38 Summary of the unweighted  $SPL_{peak}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the ORCP-S location

| Southall et al. (2019)<br>Unweighted $SPL_{peak}$ |              | Area                   | Maximum range | Minimum range | Mean range |
|---|--------------|------------------------|---------------|---------------|------------|
| PTS   | LF (219 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | HF (230 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | VHF (202 dB) | 0.47 km <sup>2</sup>   | 390 m         | 380 m         | 390 m      |
|   | PCW (218 dB) | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
| TTS   | LF (213 dB)  | 0.02 km <sup>2</sup>   | 80 m          | 80 m          | 80 m       |
|   | HF (224 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | VHF (196 dB) | 2.2 km <sup>2</sup>    | 850 m         | 820 m         | 840 m      |
|   | PCW (212 dB) | 0.03 km <sup>2</sup>   | 100 m         | 100 m         | 100 m      |

Table 4-39 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the ORCP-S location assuming a fleeing animal

| Southall et al. (2019) |     |              | Area                  | Maximum range | Minimum range | Mean range |
|------------------------|-----|--------------|-----------------------|---------------|---------------|------------|
| Weighted $SEL_{cum}$   |     |              |                       |               |               |            |
| Single pile            | PTS | LF (183 dB)  | 1.0 km <sup>2</sup>   | 1.2 km        | 400 m         | 550 m      |
|                        |     | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |     | VHF (155 dB) | 2.6 km <sup>2</sup>   | 1.3 km        | 780 m         | 910 m      |
|                        |     | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        | TTS | LF (168 dB)  | 110 km <sup>2</sup>   | 9.3 km        | 4.1 km        | 5.7 km     |
|                        |     | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |     | VHF (140 dB) | 120 km <sup>2</sup>   | 9.1 km        | 4.7 km        | 6.1 km     |
|                        |     | PCW (170 dB) | 9.3 km <sup>2</sup>   | 2.6 km        | 1.5 km        | 1.7 km     |
| 2 sequential piles     | PTS | LF (183 dB)  | 1.0 km <sup>2</sup>   | 1.2 km        | 400 m         | 550 m      |
|                        |     | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |     | VHF (155 dB) | 2.6 km <sup>2</sup>   | 1.3 km        | 780 m         | 910 m      |
|                        |     | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        | TTS | LF (168 dB)  | 110 km <sup>2</sup>   | 9.3 km        | 4.1 km        | 5.7 km     |
|                        |     | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m       | < 100 m    |
|                        |     | VHF (140 dB) | 120 km <sup>2</sup>   | 9.1 km        | 4.7 km        | 6.1 km     |
|                        |     | PCW (170 dB) | 9.3 km <sup>2</sup>   | 2.6 km        | 1.5 km        | 1.7 km     |

Table 4-40 Summary of the unweighted  $SPL_{RMS}$  impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the monopile foundation modelling at the ORCP-S location

| NOAA (2005)            |        |  | Area                | Maximum range | Minimum range | Mean range |
|------------------------|--------|--|---------------------|---------------|---------------|------------|
| Unweighted $SPL_{RMS}$ |        |  |                     |               |               |            |
| Level B                | 160 dB |  | 180 km <sup>2</sup> | 9.9 km        | 6.7 km        | 7.5 km     |

Table 4-41 Summary of the unweighted  $SPL_{peak}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the ORCP-S location

| Popper et al. (2014)    |        |  | Area                 | Maximum range | Minimum range | Mean range |
|-------------------------|--------|--|----------------------|---------------|---------------|------------|
| Unweighted $SPL_{peak}$ |        |  |                      |               |               |            |
|                         | 213 dB |  | 0.02 km <sup>2</sup> | 80 m          | 80 m          | 80 m       |
|                         | 207 dB |  | 0.12 km <sup>2</sup> | 200 m         | 190 m         | 200 m      |

Table 4-42 Summary of the unweighted  $SEL_{cum}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the ORCP-S location assuming both a fleeing and stationary animal

| Popper et al. (2014)<br>Unweighted $SEL_{cum}$ |                       | Area   | Maximum range         | Minimum range | Mean range |         |
|--|-----------------------|--------|-----------------------|---------------|------------|---------|
| Single pile                                    | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 186 dB | 23 km <sup>2</sup>    | 4.4 km        | 2.3 km     | 2.7 km  |
|  | Stationary<br>(0 m/s) | 219 dB | 0.8 km <sup>2</sup>   | 530 m         | 500 m      | 510 m   |
|  |                       | 216 dB | 1.8 km <sup>2</sup>   | 780 m         | 730 m      | 750 m   |
|  |                       | 210 dB | 7.4 km <sup>2</sup>   | 1.7 km        | 1.5 km     | 1.5 km  |
|  |                       | 207 dB | 14 km <sup>2</sup>    | 2.3 km        | 2.0 km     | 2.1 km  |
|  |                       | 203 dB | 29 km <sup>2</sup>    | 3.5 km        | 2.8 km     | 3.1 km  |
|  |                       | 186 dB | 270 km <sup>2</sup>   | 13 km         | 7.6 km     | 9.2 km  |
| 2 sequential piles                             | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 186 dB | 23 km <sup>2</sup>    | 4.4 km        | 2.3 km     | 2.7 km  |
|  | Stationary<br>(0 m/s) | 219 dB | 1.8 km                | 780 m         | 730 m      | 750 m   |
|  |                       | 216 dB | 3.7 km                | 1.1 km        | 1.1 km     | 1.1 km  |
|  |                       | 210 dB | 14 km <sup>2</sup>    | 2.3 km        | 2.0 km     | 2.1 km  |
|  |                       | 207 dB | 25 km <sup>2</sup>    | 3.1 km        | 2.7 km     | 2.8 km  |
|  |                       | 203 dB | 47 km <sup>2</sup>    | 4.7 km        | 3.6 km     | 3.9 km  |
|  |                       | 186 dB | 360 km <sup>2</sup>   | 15 km         | 8.1 km     | 11 km   |

4.3.2 Jacket pile foundations

4.3.2.1 ORCP-N location

Table 4-43 Summary of the unweighted  $SPL_{peak}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the ORCP-N location

| Southall et al. (2019)<br>Unweighted $SPL_{peak}$ |              | Area                   | Maximum range | Minimum range | Mean range |
|---|--------------|------------------------|---------------|---------------|------------|
| PTS   | LF (219 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | HF (230 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | VHF (202 dB) | 0.31 km <sup>2</sup>   | 320 m         | 310 m         | 310 m      |
|   | PCW (218 dB) | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
| TTS   | LF (213 dB)  | 0.01 km <sup>2</sup>   | 70 m          | 70 m          | 70 m       |
|   | HF (224 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | VHF (196 dB) | 1.4 km <sup>2</sup>    | 690 m         | 670 m         | 680 m      |
|   | PCW (212 dB) | 0.02 km <sup>2</sup>   | 80 m          | 80 m          | 80 m       |

Table 4-44 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the ORCP-N location assuming a fleeing animal

| <b>Southall et al. (2019)</b><br>Weighted $SEL_{cum}$ |            | <b>Area</b>  | <b>Maximum range</b>  | <b>Minimum range</b> | <b>Mean range</b> |         |
|---|------------|--------------|-----------------------|----------------------|-------------------|---------|
| <b>Single pile</b>                                    | <b>PTS</b> | LF (183 dB)  | 0.1 km <sup>2</sup>   | < 100 m              | < 100 m           | < 100 m |
|   |            | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (155 dB) | 0.3 km <sup>2</sup>   | 380 m                | 250 m             | 310 m   |
|   |            | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   | <b>TTS</b> | LF (168 dB)  | 58 km <sup>2</sup>    | 6.0 km               | 3.0 km            | 4.2 km  |
|   |            | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (140 dB) | 81 km <sup>2</sup>    | 6.5 km               | 3.9 km            | 5.1 km  |
|   |            | PCW (170 dB) | 3.3 km <sup>2</sup>   | 1.2 km               | 830 m             | 1.0 km  |
| <b>6 sequential piles</b>                             | <b>PTS</b> | LF (183 dB)  | < 0.1 km <sup>2</sup> | 100 m                | < 100 m           | < 100 m |
|   |            | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (155 dB) | 0.3 km <sup>2</sup>   | 380 m                | 250 m             | 310 m   |
|   |            | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   | <b>TTS</b> | LF (168 dB)  | 58 km <sup>2</sup>    | 6.0 km               | 3.0 km            | 4.2 km  |
|   |            | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (140 dB) | 81 km <sup>2</sup>    | 6.5 km               | 3.9 km            | 5.1 km  |
|   |            | PCW (170 dB) | 3.3 km <sup>2</sup>   | 1.2 km               | 830 m             | 1.0 km  |

Table 4-45 Summary of the unweighted  $SPL_{RMS}$  impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the jacket pile foundation modelling at the ORCP-N location

| <b>NOAA (2005)</b><br>Unweighted $SPL_{RMS}$ |        | <b>Area</b>         | <b>Maximum range</b> | <b>Minimum range</b> | <b>Mean range</b> |
|--|--------|---------------------|----------------------|----------------------|-------------------|
| <b>Level B</b>                               | 160 dB | 130 km <sup>2</sup> | 7.2 km               | 5.5 km               | 6.4 km            |

Table 4-46 Summary of the unweighted  $SPL_{peak}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the ORCP-N location

| <b>Popper et al. (2014)</b><br>Unweighted $SPL_{peak}$ |        | <b>Area</b>          | <b>Maximum range</b> | <b>Minimum range</b> | <b>Mean range</b> |
|--|--------|----------------------|----------------------|----------------------|-------------------|
|  | 213 dB | 0.01 km <sup>2</sup> | 70 m                 | 70 m                 | 70 m              |
|  | 207 dB | 0.08 km <sup>2</sup> | 160 m                | 160 m                | 160 m             |

Table 4-47 Summary of the unweighted  $SEL_{cum}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the ORCP-N location assuming both a fleeing and stationary animal

| <b>Popper et al. (2014)</b><br>Unweighted $SEL_{cum}$ |                              | <b>Area</b> | <b>Maximum range</b>  | <b>Minimum range</b> | <b>Mean range</b> |         |
|---|------------------------------|-------------|-----------------------|----------------------|-------------------|---------|
| <b>Single pile</b>                                    | <b>Fleeing</b><br>(1.5 m/s)  | 219 dB      | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |                              | 216 dB      | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |                              | 210 dB      | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |                              | 207 dB      | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |                              | 203 dB      | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |                              | 186 dB      | 7.1 km <sup>2</sup>   | 1.8 km               | 1.2 km            | 1.5 km  |
|   | <b>Stationary</b><br>(0 m/s) | 219 dB      | 0.3 km <sup>2</sup>   | 330 m                | 300 m             | 310 m   |
|   |                              | 216 dB      | 0.6 km <sup>2</sup>   | 450 m                | 430 m             | 440 m   |
|   |                              | 210 dB      | 2.7 km <sup>2</sup>   | 950 m                | 900 m             | 920 m   |
|   |                              | 207 dB      | 5.3 km <sup>2</sup>   | 1.3 km               | 1.3 km            | 1.3 km  |
|   |                              | 203 dB      | 12 km <sup>2</sup>    | 2.1 km               | 1.9 km            | 2.0 km  |
|   |                              | 186 dB      | 160 km <sup>2</sup>   | 8.1 km               | 6.1 km            | 7.2 km  |
| <b>6 sequential piles</b>                             | <b>Fleeing</b><br>(1.5 m/s)  | 219 dB      | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |                              | 216 dB      | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |                              | 210 dB      | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |                              | 207 dB      | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |                              | 203 dB      | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |                              | 186 dB      | 7.2 km <sup>2</sup>   | 1.8 km               | 1.2 km            | 1.5 km  |
|   | <b>Stationary</b><br>(0 m/s) | 219 dB      | 2.0 km <sup>2</sup>   | 830 m                | 780 m             | 800 m   |
|   |                              | 216 dB      | 4.0 km <sup>2</sup>   | 1.2 km               | 1.1 km            | 1.1 km  |
|   |                              | 210 dB      | 14 km <sup>2</sup>    | 2.2 km               | 2.0 km            | 2.1 km  |
|   |                              | 207 dB      | 24 km <sup>2</sup>    | 3.0 km               | 2.6 km            | 2.8 km  |
|   |                              | 203 dB      | 46 km <sup>2</sup>    | 4.2 km               | 3.5 km            | 3.9 km  |
|   |                              | 186 dB      | 380 km <sup>2</sup>   | 15 km                | 8.8 km            | 11 km   |

4.3.2.2 *ORCP-S location*

Table 4-48 Summary of the unweighted  $SPL_{peak}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the ORCP-S location

| <b>Southall et al. (2019)</b><br>Unweighted $SPL_{peak}$ |              | <b>Area</b>            | <b>Maximum range</b> | <b>Minimum range</b> | <b>Mean range</b> |
|--|--------------|------------------------|----------------------|----------------------|-------------------|
| <b>PTS</b>   | LF (219 dB)  | < 0.01 km <sup>2</sup> | < 50 m               | < 50 m               | < 50 m            |
|  | HF (230 dB)  | < 0.01 km <sup>2</sup> | < 50 m               | < 50 m               | < 50 m            |
|  | VHF (202 dB) | 0.34 km <sup>2</sup>   | 340 m                | 330 m                | 330 m             |
|  | PCW (218 dB) | < 0.01 km <sup>2</sup> | < 50 m               | < 50 m               | < 50 m            |
| <b>TTS</b>   | LF (213 dB)  | 0.02 km <sup>2</sup>   | 70 m                 | 70 m                 | 70 m              |
|  | HF (224 dB)  | < 0.01 km <sup>2</sup> | < 50 m               | < 50 m               | < 50 m            |
|  | VHF (196 dB) | 1.6 km <sup>2</sup>    | 740 m                | 710 m                | 730 m             |
|  | PCW (212 dB) | 0.02 km <sup>2</sup>   | 80 m                 | 80 m                 | 80 m              |

Table 4-49 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the ORCP-S location assuming a fleeing animal

| <b>Southall et al. (2019)</b><br>Weighted $SEL_{cum}$ |            | <b>Area</b>  | <b>Maximum range</b>  | <b>Minimum range</b> | <b>Mean range</b> |         |
|---|------------|--------------|-----------------------|----------------------|-------------------|---------|
| <b>Single pile</b>                                    | <b>PTS</b> | LF (183 dB)  | < 0.1 km <sup>2</sup> | 300 m                | 100 m             | 130 m   |
|   |            | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (155 dB) | 0.6 km <sup>2</sup>   | 650 m                | 350 m             | 440 m   |
|   |            | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   | <b>TTS</b> | LF (168 dB)  | 69 km <sup>2</sup>    | 7.8 km               | 3.4 km            | 4.6 km  |
|   |            | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (140 dB) | 89 km <sup>2</sup>    | 7.9 km               | 4.1 km            | 5.3 km  |
|   |            | PCW (170 dB) | 5.4 km <sup>2</sup>   | 2.0 km               | 1.1 km            | 1.3 km  |
| <b>6 sequential piles</b>                             | <b>PTS</b> | LF (183 dB)  | < 0.1 km <sup>2</sup> | 300 m                | 100 m             | 130 m   |
|   |            | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (155 dB) | 0.6 km <sup>2</sup>   | 650 m                | 350 m             | 440 m   |
|   |            | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   | <b>TTS</b> | LF (168 dB)  | 69 km <sup>2</sup>    | 7.8 km               | 3.4 km            | 4.6 km  |
|   |            | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (140 dB) | 89 km <sup>2</sup>    | 7.9 km               | 4.1 km            | 5.3 km  |
|   |            | PCW (170 dB) | 5.4 km <sup>2</sup>   | 2.0 km               | 1.1 km            | 1.3 km  |

Table 4-50 Summary of the unweighted  $SPL_{RMS}$  impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the jacket pile foundation modelling at the ORCP-S location

| <b>NOAA (2005)</b><br>Unweighted $SPL_{RMS}$ |        | <b>Area</b>         | <b>Maximum range</b> | <b>Minimum range</b> | <b>Mean range</b> |
|--|--------|---------------------|----------------------|----------------------|-------------------|
| <b>Level B</b>                               | 160 dB | 150 km <sup>2</sup> | 9.0 km               | 6.2 km               | 6.9 km            |

Table 4-51 Summary of the unweighted  $SPL_{peak}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the ORCP-S location

| <b>Popper et al. (2014)</b><br>Unweighted $SPL_{peak}$ |        | <b>Area</b>          | <b>Maximum range</b> | <b>Minimum range</b> | <b>Mean range</b> |
|--|--------|----------------------|----------------------|----------------------|-------------------|
|  | 213 dB | 0.02 km <sup>2</sup> | 70 m                 | 70 m                 | 70 m              |
|  | 207 dB | 0.09 km <sup>2</sup> | 170 m                | 170 m                | 170 m             |



Table 4-52 Summary of the unweighted  $SEL_{cum}$  impact ranges for fish using the Popper *et al.* (2014) pile driving criteria for the jacket pile foundation modelling at the ORCP-S location assuming both a fleeing and stationary animal

| Popper <i>et al.</i> (2014)<br>Unweighted $SEL_{cum}$ |                       | Area   | Maximum range         | Minimum range | Mean range |         |
|---|-----------------------|--------|-----------------------|---------------|------------|---------|
| Single pile   | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 186 dB | 11 km <sup>2</sup>    | 3.1 km        | 1.6 km     | 1.9 km  |
|   | Stationary<br>(0 m/s) | 219 dB | 0.3 km <sup>2</sup>   | 330 m         | 300 m      | 310 m   |
|   |                       | 216 dB | 0.7 km <sup>2</sup>   | 500 m         | 450 m      | 470 m   |
|   |                       | 210 dB | 3.2 km <sup>2</sup>   | 1.0 km        | 980 m      | 1.0 km  |
|   |                       | 207 dB | 6.4 km <sup>2</sup>   | 1.6 km        | 1.4 km     | 1.4 km  |
|   |                       | 203 dB | 15 km <sup>2</sup>    | 2.4 km        | 2.1 km     | 2.2 km  |
|   |                       | 186 dB | 180 km <sup>2</sup>   | 10 km         | 6.8 km     | 7.6 km  |
| 6 sequential piles                                    | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 186 dB | 11 km <sup>2</sup>    | 3.1 km        | 1.6 km     | 1.9 km  |
|   | Stationary<br>(0 m/s) | 219 dB | 2.3 km <sup>2</sup>   | 900 m         | 830 m      | 860 m   |
|   |                       | 216 dB | 4.8 km <sup>2</sup>   | 1.3 km        | 1.2 km     | 1.2 km  |
|   |                       | 210 dB | 18 km <sup>2</sup>    | 2.6 km        | 2.3 km     | 2.4 km  |
|   |                       | 207 dB | 30 km <sup>2</sup>    | 3.5 km        | 2.9 km     | 3.1 km  |
|   |                       | 203 dB | 56 km <sup>2</sup>    | 5.2 km        | 3.9 km     | 4.2 km  |
|   |                       | 186 dB | 400 km <sup>2</sup>   | 16 km         | 8.3 km     | 11 km   |

#### 4.4 ANS locations

Table 4-53 to Table 4-72 present the modelling results for the various foundation modelling scenarios across the two ANS modelling locations, in terms of the Southall *et al.* (2019) and NOAA (2005) marine mammal criteria (section 2.2.1) and the Popper *et al.* (2014) fish criteria (section 2.2.2).

The largest marine mammal impact ranges are predicted at the ANS-NW modelling location with similar ranges for the monopile and jacket pile foundation scenarios. Maximum PTS injury ranges are predicted for LF cetaceans using the  $SEL_{cum}$  criteria, with ranges of up to 5.0 km, for VHF cetaceans PTS ranges are predicted up to 2.6 km for the same scenario.

For fish, the largest recoverable injury ranges (203 dB  $SEL_{cum}$  threshold) are predicted to be 8.1 km assuming a stationary receptor at the deeper ANS-NW location for the jacket pile scenario; if a fleeing animal is assumed, these ranges are reduced to less than 100 m. Maximum TTS ranges (186 dB  $SEL_{cum}$  threshold) are predicted up to 28 km for a stationary animal, reducing to 11 km for a fleeing animal.

4.4.1 Monopile foundations

4.4.1.1 ANS-NW location

Table 4-53 Summary of the unweighted  $SPL_{peak}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the ANS-NW location

| Southall et al. (2019)<br>Unweighted $SPL_{peak}$ |              | Area                   | Maximum range | Minimum range | Mean range |
|---|--------------|------------------------|---------------|---------------|------------|
| PTS   | LF (219 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | HF (230 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | VHF (202 dB) | 0.94 km <sup>2</sup>   | 550 m         | 550 m         | 550 m      |
|   | PCW (218 dB) | 0.01 km <sup>2</sup>   | < 50 m        | < 50 m        | < 50 m     |
| TTS   | LF (213 dB)  | 0.03 km <sup>2</sup>   | 100 m         | 100 m         | 100 m      |
|   | HF (224 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | VHF (196 dB) | 5.2 km <sup>2</sup>    | 1.3 km        | 1.3 km        | 1.3 km     |
|   | PCW (212 dB) | 0.04 km <sup>2</sup>   | 120 m         | 1e0 m         | 120 m      |

Table 4-54 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the ANS-NW location assuming a fleeing animal

| Southall et al. (2019)<br>Weighted $SEL_{cum}$ |     | Area         | Maximum range         | Minimum range | Mean range |         |
|--|-----|--------------|-----------------------|---------------|------------|---------|
| Single pile                                    | PTS | LF (183 dB)  | 50 km <sup>2</sup>    | 5.0 km        | 3.1 km     | 4.0 km  |
|  |     | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (155 dB) | 17 km <sup>2</sup>    | 2.6 km        | 2.1 km     | 2.3 km  |
|  |     | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (168 dB)  | 1.0 km <sup>2</sup>   | 25 km         | 13 km      | 18 km   |
|  |     | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (140 dB) | 650 km <sup>2</sup>   | 18 km         | 11 km      | 14 km   |
|  |     | PCW (170 dB) | 110 km <sup>2</sup>   | 7.0 km        | 5.1 km     | 5.9 km  |

Table 4-55 Summary of the unweighted  $SPL_{RMS}$  impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the monopile foundation modelling at the ANS-NW location

| NOAA (2005)<br>Unweighted $SPL_{RMS}$ |        | Area                | Maximum range | Minimum range | Mean range |
|---------------------------------------|--------|---------------------|---------------|---------------|------------|
| Level B                               | 160 dB | 740 km <sup>2</sup> | 18 km         | 14 km         | 15 km      |

Table 4-56 Summary of the unweighted  $SPL_{peak}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the ANS-NW location

| Popper et al. (2014)<br>Unweighted $SPL_{peak}$ |  | Area                 | Maximum range | Minimum range | Mean range |
|---|--|----------------------|---------------|---------------|------------|
| 213 dB  |  | 0.03 km <sup>2</sup> | 100 m         | 100 m         | 100 m      |
| 207 dB  |  | 0.21 km <sup>2</sup> | 260 m         | 260 m         | 260 m      |

Table 4-57 Summary of the unweighted  $SEL_{cum}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the ANS-NW location assuming both a fleeing and stationary animal

| Popper et al. (2014)<br>Unweighted $SEL_{cum}$ |                       | Area   | Maximum range         | Minimum range | Mean range |         |
|--|-----------------------|--------|-----------------------|---------------|------------|---------|
| Single pile                                    | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 186 dB | 240 km <sup>2</sup>   | 11 km         | 7.0 km     | 8.6 km  |
|  | Stationary<br>(0 m/s) | 219 dB | 0.9 km <sup>2</sup>   | 550 m         | 530 m      | 540 m   |
|  |                       | 216 dB | 2.1 km <sup>2</sup>   | 830 m         | 800 m      | 810 m   |
|  |                       | 210 dB | 11 km <sup>2</sup>    | 1.9 km        | 1.9 km     | 1.9 km  |
|  |                       | 207 dB | 24 km <sup>2</sup>    | 2.8 km        | 2.7 km     | 2.7 km  |
|  |                       | 203 dB | 60 km <sup>2</sup>    | 4.5 km        | 4.3 km     | 4.4 km  |
|  |                       | 186 dB | 920 km <sup>2</sup>   | 20 km         | 15 km      | 17 km   |

#### 4.4.1.2 ANS-SE location

Table 4-58 Summary of the unweighted  $SPL_{peak}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the ANS-SE location

| Southall et al. (2019)<br>Unweighted $SPL_{peak}$ |              | Area                   | Maximum range | Minimum range | Mean range |
|---|--------------|------------------------|---------------|---------------|------------|
| PTS   | LF (219 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | HF (230 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | VHF (202 dB) | 0.63 km <sup>2</sup>   | 460 m         | 450 m         | 450 m      |
|   | PCW (218 dB) | 0.01 km <sup>2</sup>   | < 50 m        | < 50 m        | < 50 m     |
| TTS   | LF (213 dB)  | 0.02 km <sup>2</sup>   | 90 m          | 90 m          | 90 m       |
|   | HF (224 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | VHF (196 dB) | 3.4 km <sup>2</sup>    | 1.1 km        | 1.0 km        | 1.0 km     |
|   | PCW (212 dB) | 0.03 km <sup>2</sup>   | 100 m         | 100 m         | 100 m      |

Table 4-59 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the monopile foundation modelling at the ANS-SE location assuming a fleeing animal

| Southall et al. (2019)<br>Weighted $SEL_{cum}$ |     | Area         | Maximum range         | Minimum range | Mean range |         |
|--|-----|--------------|-----------------------|---------------|------------|---------|
| Single pile                                    | PTS | LF (183 dB)  | 14 km <sup>2</sup>    | 2.9 km        | 1.5 km     | 2.0 km  |
|  |     | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (155 dB) | 7.5 km <sup>2</sup>   | 1.9 km        | 1.3 km     | 1.5 km  |
|  |     | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (168 dB)  | 500 km <sup>2</sup>   | 15 km         | 11 km      | 13 km   |
|  |     | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (140 dB) | 390 km <sup>2</sup>   | 13 km         | 10 km      | 11 km   |
|  |     | PCW (170 dB) | 50 km <sup>2</sup>    | 4.9 km        | 3.4 km     | 4.0 km  |

Table 4-60 Summary of the unweighted  $SPL_{RMS}$  impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the monopile foundation modelling at the ANS-SE location

| NOAA (2005)<br>Unweighted $SPL_{RMS}$ |        | Area                | Maximum range | Minimum range | Mean range |
|---------------------------------------|--------|---------------------|---------------|---------------|------------|
| Level B                               | 160 dB | 470 km <sup>2</sup> | 14 km         | 11 km         | 12 km      |

Table 4-61 Summary of the unweighted  $SPL_{peak}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the ANS-SE location

| Popper et al. (2014)<br>Unweighted $SPL_{peak}$ | Area                 | Maximum range | Minimum range | Mean range |
|---|----------------------|---------------|---------------|------------|
| 213 dB  | 0.02 km <sup>2</sup> | 90 m          | 90 m          | 90 m       |
| 207 dB  | 0.15 km <sup>2</sup> | 220 m         | 220 m         | 220 m      |

Table 4-62 Summary of the unweighted  $SEL_{cum}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the monopile foundation modelling at the ANS-SE location assuming both a fleeing and stationary animal

| Popper et al. (2014)<br>Unweighted $SEL_{cum}$ |                       | Area                | Maximum range         | Minimum range | Mean range |        |
|--|-----------------------|---------------------|-----------------------|---------------|------------|--------|
| Single pile                                    | Fleeing<br>(1.5 m/s)  | 219 dB              | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    |        |
|  |                       | 216 dB              | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    |        |
|  |                       | 210 dB              | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    |        |
|  |                       | 207 dB              | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    |        |
|  |                       | 203 dB              | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    |        |
|  | Stationary<br>(0 m/s) | 186 dB              | 110 km <sup>2</sup>   | 7.2 km        | 5.1 km     | 5.9 km |
|  |                       | 219 dB              | 0.6 km <sup>2</sup>   | 450 m         | 430 m      | 440 m  |
|  |                       | 216 dB              | 1.4 km <sup>2</sup>   | 700 m         | 650 m      | 670 m  |
|  |                       | 210 dB              | 7.2 km <sup>2</sup>   | 1.6 km        | 1.4 km     | 1.5 km |
|  |                       | 207 dB              | 16 km <sup>2</sup>    | 2.4 km        | 2.1 km     | 2.2 km |
|  | 203 dB                | 39 km <sup>2</sup>  | 3.8 km                | 3.3 km        | 3.5 km     |        |
|  | 186 dB                | 590 km <sup>2</sup> | 16 km                 | 13 km         | 14 km      |        |

#### 4.4.2 Jacket pile foundations

##### 4.4.2.1 ANS-NW location

Table 4-63 Summary of the unweighted  $SPL_{peak}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the ANS-NW location

| Southall et al. (2019)<br>Unweighted $SPL_{peak}$ |              | Area                   | Maximum range | Minimum range | Mean range |
|---|--------------|------------------------|---------------|---------------|------------|
| PTS   | LF (219 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | HF (230 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | VHF (202 dB) | 0.91 km <sup>2</sup>   | 540 m         | 540 m         | 540 m      |
|   | PCW (218 dB) | 0.01 km <sup>2</sup>   | < 50 m        | < 50 m        | < 50 m     |
| TTS   | LF (213 dB)  | 0.03 km <sup>2</sup>   | 100 m         | 100 m         | 100 m      |
|   | HF (224 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | VHF (196 dB) | 5.0 km <sup>2</sup>    | 1.3 km        | 1.3 km        | 1.3 km     |
|   | PCW (212 dB) | 0.04 km <sup>2</sup>   | 120 m         | 120 m         | 120 m      |

*Table 4-64 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the ANS-NW location assuming a fleeing animal*

| <b>Southall et al. (2019)</b><br>Weighted $SEL_{cum}$ |            | <b>Area</b>  | <b>Maximum range</b>  | <b>Minimum range</b> | <b>Mean range</b> |         |
|---|------------|--------------|-----------------------|----------------------|-------------------|---------|
| <b>Single pile</b>                                    | <b>PTS</b> | LF (183 dB)  | 48 km <sup>2</sup>    | 5.0 km               | 3.1 km            | 3.9 km  |
|   |            | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (155 dB) | 17 km <sup>2</sup>    | 2.6 km               | 2.1 km            | 2.3 km  |
|   |            | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   | <b>TTS</b> | LF (168 dB)  | 1000 km <sup>2</sup>  | 25 km                | 13 km             | 18 km   |
|   |            | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (140 dB) | 650 km <sup>2</sup>   | 18 km                | 11 km             | 14 km   |
|   |            | PCW (170 dB) | 110 km <sup>2</sup>   | 6.9 km               | 5.0 km            | 5.9 km  |
| <b>4 sequential piles</b>                             | <b>PTS</b> | LF (183 dB)  | 48 km <sup>2</sup>    | 5.0 km               | 3.1 km            | 3.9 km  |
|   |            | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (155 dB) | 17 km <sup>2</sup>    | 2.6 km               | 2.1 km            | 2.3 km  |
|   |            | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   | <b>TTS</b> | LF (168 dB)  | 1000 km <sup>2</sup>  | 25 km                | 13 km             | 18 km   |
|   |            | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (140 dB) | 660 km <sup>2</sup>   | 19 km                | 11 km             | 14 km   |
|   |            | PCW (170 dB) | 110 km <sup>2</sup>   | 7.1 km               | 5.1 km            | 5.9 km  |

*Table 4-65 Summary of the unweighted  $SPL_{RMS}$  impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the jacket pile foundation modelling at the ANS-NW location*

| <b>NOAA (2005)</b><br>Unweighted $SPL_{RMS}$ |        | <b>Area</b>         | <b>Maximum range</b> | <b>Minimum range</b> | <b>Mean range</b> |
|--|--------|---------------------|----------------------|----------------------|-------------------|
| <b>Level B</b>                               | 160 dB | 720 km <sup>2</sup> | 17 km                | 13 km                | 15 km             |

*Table 4-66 Summary of the unweighted  $SPL_{peak}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the ANS-NW location*

| <b>Popper et al. (2014)</b><br>Unweighted $SPL_{peak}$ |        | <b>Area</b>          | <b>Maximum range</b> | <b>Minimum range</b> | <b>Mean range</b> |
|--|--------|----------------------|----------------------|----------------------|-------------------|
|  | 213 dB | 0.03 km <sup>2</sup> | 100 m                | 100 m                | 100 m             |
|  | 207 dB | 0.2 km <sup>2</sup>  | 260 m                | 250 m                | 250 m             |

Table 4-67 Summary of the unweighted  $SEL_{cum}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the ANS-NW location assuming both a fleeing and stationary animal

| Popper et al. (2014)<br>Unweighted $SEL_{cum}$ |                       | Area   | Maximum range         | Minimum range | Mean range |         |
|--|-----------------------|--------|-----------------------|---------------|------------|---------|
| Single pile                                    | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 186 dB | 230 km <sup>2</sup>   | 10 km         | 6.9 km     | 8.5 km  |
|  | Stationary<br>(0 m/s) | 219 dB | 0.8 km <sup>2</sup>   | 530 m         | 500 m      | 510 m   |
|  |                       | 216 dB | 1.9 km <sup>2</sup>   | 800 m         | 780 m      | 790 m   |
|  |                       | 210 dB | 10 km <sup>2</sup>    | 1.9 km        | 1.8 km     | 1.8 km  |
|  |                       | 207 dB | 23 km <sup>2</sup>    | 2.7 km        | 2.7 km     | 2.7 km  |
|  |                       | 203 dB | 58 km <sup>2</sup>    | 4.4 km        | 4.2 km     | 4.3 km  |
|  |                       | 186 dB | 910 km <sup>2</sup>   | 20 km         | 15 km      | 17 km   |
| 4 sequential piles                             | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |                       | 186 dB | 230 km <sup>2</sup>   | 11 km         | 6.9 km     | 8.5 km  |
|  | Stationary<br>(0 m/s) | 219 dB | 4.6 km <sup>2</sup>   | 1.2 km        | 1.2 km     | 1.2 km  |
|  |                       | 216 dB | 11 km <sup>2</sup>    | 1.9 km        | 1.8 km     | 1.8 km  |
|  |                       | 210 dB | 46 km <sup>2</sup>    | 3.9 km        | 3.8 km     | 3.8 km  |
|  |                       | 207 dB | 88 km <sup>2</sup>    | 5.5 km        | 5.2 km     | 5.3 km  |
|  |                       | 203 dB | 190 km <sup>2</sup>   | 8.1 km        | 7.4 km     | 7.7 km  |
|  |                       | 186 dB | 1700 km <sup>2</sup>  | 28 km         | 19 km      | 23 km   |

4.4.2.2 ANS-SE location

Table 4-68 Summary of the unweighted  $SPL_{peak}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the ANS-SE location

| Southall et al. (2019)<br>Unweighted $SPL_{peak}$ |              | Area                   | Maximum range | Minimum range | Mean range |
|---|--------------|------------------------|---------------|---------------|------------|
| PTS   | LF (219 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | HF (230 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | VHF (202 dB) | 0.61 km <sup>2</sup>   | 450 m         | 440 m         | 440 m      |
|   | PCW (218 dB) | 0.01 km <sup>2</sup>   | < 50 m        | < 50 m        | < 50 m     |
| TTS   | LF (213 dB)  | 0.02 km <sup>2</sup>   | 90 m          | 90 m          | 90 m       |
|   | HF (224 dB)  | < 0.01 km <sup>2</sup> | < 50 m        | < 50 m        | < 50 m     |
|   | VHF (196 dB) | 3.3 km <sup>2</sup>    | 1.1 km        | 990 m         | 1.0 km     |
|   | PCW (212 dB) | 0.03 km <sup>2</sup>   | 100 m         | 100 m         | 100 m      |

Table 4-69 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) impulsive criteria for the jacket pile foundation modelling at the ANS-SE location assuming a fleeing animal

| <b>Southall et al. (2019)</b><br>Weighted $SEL_{cum}$ |            | <b>Area</b>  | <b>Maximum range</b>  | <b>Minimum range</b> | <b>Mean range</b> |         |
|---|------------|--------------|-----------------------|----------------------|-------------------|---------|
| <b>Single pile</b>                                    | <b>PTS</b> | LF (183 dB)  | 13 km <sup>2</sup>    | 2.8 km               | 1.5 km            | 2.0 km  |
|   |            | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (155 dB) | 7.5 km <sup>2</sup>   | 1.9 km               | 1.3 km            | 1.5 km  |
|   |            | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   | <b>TTS</b> | LF (168 dB)  | 490 km <sup>2</sup>   | 15 km                | 11 km             | 13 km   |
|   |            | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (140 dB) | 390 km <sup>2</sup>   | 13 km                | 10 km             | 11 km   |
|   |            | PCW (170 dB) | 49 km <sup>2</sup>    | 4.9 km               | 3.4 km            | 4.0 km  |
| <b>4 sequential piles</b>                             | <b>PTS</b> | LF (183 dB)  | 13 km <sup>2</sup>    | 2.8 km               | 1.5 km            | 2.0 km  |
|   |            | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (155 dB) | 7.5 km <sup>2</sup>   | 1.9 km               | 1.3 km            | 1.5 km  |
|   |            | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   | <b>TTS</b> | LF (168 dB)  | 490 km <sup>2</sup>   | 15 km                | 11 km             | 13 km   |
|   |            | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 100 m              | < 100 m           | < 100 m |
|   |            | VHF (140 dB) | 390 km <sup>2</sup>   | 13 km                | 10 km             | 11 km   |
|   |            | PCW (170 dB) | 50 km <sup>2</sup>    | 4.9 km               | 3.4 km            | 4.0 km  |

Table 4-70 Summary of the unweighted  $SPL_{RMS}$  impact ranges for marine mammals using the NOAA (2005) impulsive criteria for the jacket pile foundation modelling at the ANS-SE location

| <b>NOAA (2005)</b><br>Unweighted $SPL_{RMS}$ |        | <b>Area</b>         | <b>Maximum range</b> | <b>Minimum range</b> | <b>Mean range</b> |
|--|--------|---------------------|----------------------|----------------------|-------------------|
| <b>Level B</b>                               | 160 dB | 460 km <sup>2</sup> | 14 km                | 11 km                | 12 km             |

Table 4-71 Summary of the unweighted  $SPL_{peak}$  impact ranges for fish using the Popper et al. (2014) pile driving criteria for the jacket pile foundation modelling at the ANS-SE location

| <b>Popper et al. (2014)</b><br>Unweighted $SPL_{peak}$ |        | <b>Area</b>          | <b>Maximum range</b> | <b>Minimum range</b> | <b>Mean range</b> |
|--|--------|----------------------|----------------------|----------------------|-------------------|
|  | 213 dB | 0.02 km <sup>2</sup> | 90 m                 | 90 m                 | 90 m              |
|  | 207 dB | 0.14 km <sup>2</sup> | 210 m                | 210 m                | 210 m             |

Table 4-72 Summary of the unweighted  $SEL_{cum}$  impact ranges for fish using the Popper *et al.* (2014) pile driving criteria for the jacket pile foundation modelling at the ANS-SE location assuming both a fleeing and stationary animal

| Popper <i>et al.</i> (2014)<br>Unweighted $SEL_{cum}$ |                       | Area   | Maximum range         | Minimum range | Mean range |         |
|---|-----------------------|--------|-----------------------|---------------|------------|---------|
| Single pile   | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 186 dB | 100 km <sup>2</sup>   | 7.0 km        | 4.9 km     | 5.7 km  |
|   | Stationary<br>(0 m/s) | 219 dB | 0.6 km <sup>2</sup>   | 450 m         | 400 m      | 420 m   |
|   |                       | 216 dB | 1.3 km <sup>2</sup>   | 680 m         | 630 m      | 650 m   |
|   |                       | 210 dB | 6.7 km <sup>2</sup>   | 1.6 km        | 1.4 km     | 1.5 km  |
|   |                       | 207 dB | 15 km <sup>2</sup>    | 2.4 km        | 2.0 km     | 2.2 km  |
|   |                       | 203 dB | 37 km <sup>2</sup>    | 3.7 km        | 3.2 km     | 3.4 km  |
|   |                       | 186 dB | 580 km <sup>2</sup>   | 15 km         | 13 km      | 14 km   |
| 4 sequential piles                                    | Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 216 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 210 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 207 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 203 dB | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|   |                       | 186 dB | 100 km <sup>2</sup>   | 7.1 km        | 4.9 km     | 5.7 km  |
|   | Stationary<br>(0 m/s) | 219 dB | 3.0 km <sup>2</sup>   | 1.0 km        | 950 m      | 980 m   |
|   |                       | 216 dB | 6.8 km <sup>2</sup>   | 1.6 km        | 1.4 km     | 1.5 km  |
|   |                       | 210 dB | 30 km <sup>2</sup>    | 3.3 km        | 2.9 km     | 3.1 km  |
|   |                       | 207 dB | 56 km <sup>2</sup>    | 4.6 km        | 3.9 km     | 4.2 km  |
|   |                       | 203 dB | 120 km <sup>2</sup>   | 7.0 km        | 5.7 km     | 6.2 km  |
|   |                       | 186 dB | 1100 km <sup>2</sup>  | 21 km         | 17 km      | 19 km   |

#### 4.5 Multiple location modelling

Additional modelling has been carried out to investigate the potential impacts of two piling installations occurring simultaneously at separated foundation locations. Using the monopile and jacket pile foundation piling scenarios, separately, modelling has been carried out for simultaneous piling at the SW and NE locations, representing a maximum geographical spread of locations. All modelling in this section assumes that the two piling operations start at the same time and that the maximum number of sequential piles are installed at each location. This means for the concurrent location monopile scenario, two piles are installed at each location and a total of four piles are installed in a 24-hour period. For the concurrent location jacket pile scenario, six piles are installed at each location resulting in a total of 12 piles installed in a 24-hour period.

When considering  $SEL_{cum}$  modelling, piling from multiple sources has the ability to increase impact ranges and areas significantly as, in this case, it introduces noise from double the number of pile strikes to the water. Unlike sequential piling that was included as part of the previous sections, fleeing receptors can be closer to a source for more pile strikes resulting in higher cumulative exposures. Figure 4-1 shows the TTS contour for fish from Popper *et al.* (2014) (186 dB  $SEL_{cum}$ ) for a fleeing receptor as an example. The red contours show the impact from each modelling location individually (as covered in the previous section), and the blue contour shows the increase in impact when both sources occur simultaneously, resulting in a contour encircling the previous two. It is assumed that a fleeing animal in the model starts at both piling locations.

This modelling scenario was chosen to provide the greatest geographical spread of impact range contours. In a modelling scenario where two piles are installed immediately adjacent to one another,



there would be an expansion of the single location contour in all directions, but less than the spread seen in Figure 4-1. It is understood that for operational and safety reasons the course or route of piling rigs would be designed to ensure that they would not be positioned near to each other at any time during piling, so the immediately adjacent scenario should not occur. Thus the 'separated' scenario here represents a worst case.

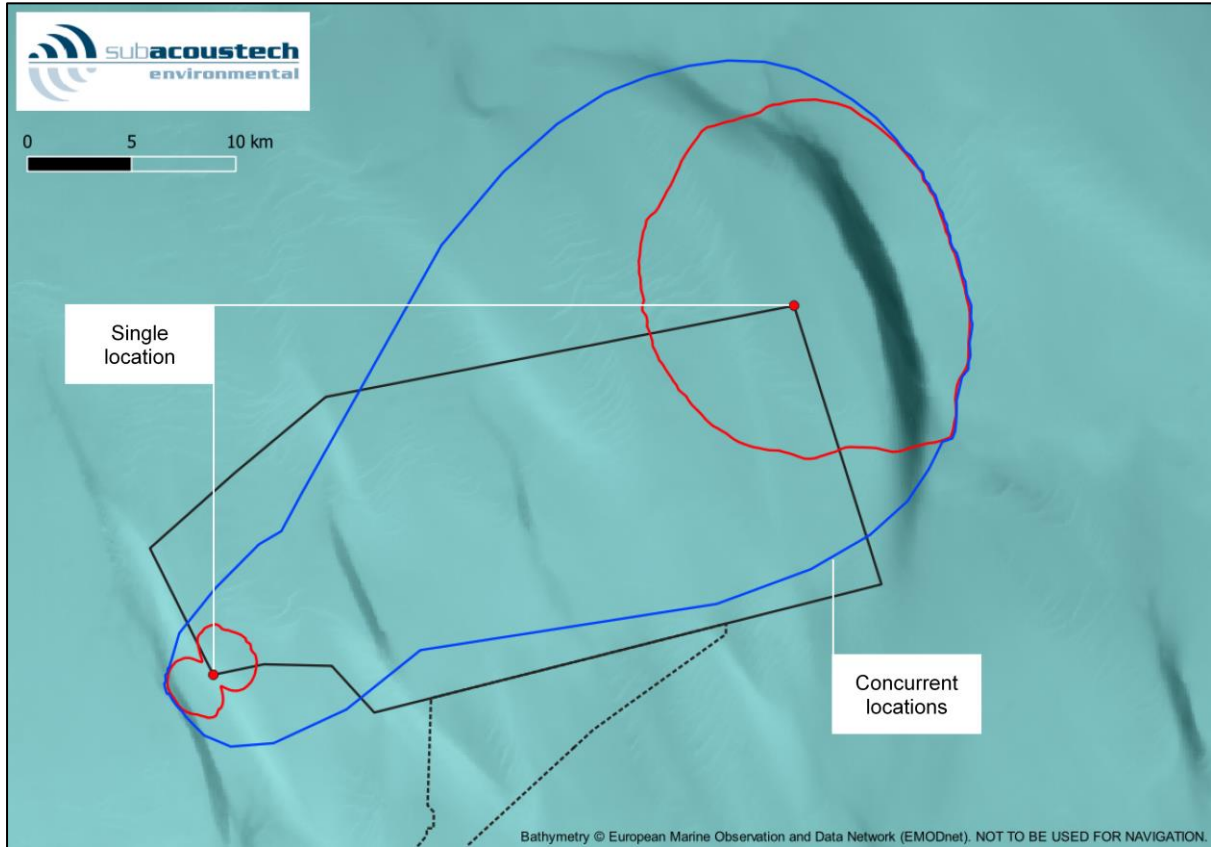


Figure 4-1 Contour plot showing the interaction between two noise sources when occurring simultaneously (TTS in fish, 186 dB SEL<sub>cum</sub>, fleeing animal)

Sections 4.5.1 and 4.5.2 present contour plots for the multiple location piling scenarios alongside tables showing the increases in overall area. Impact ranges have not been presented in this section as there are two starting points for receptors. Fields denoted with a dash “-” show where there is no in-combination effect when piling occurs at the two locations simultaneously, generally where the individual ranges are small enough that the distant site does not produce an influencing additional exposure. In the figures, contours that are too small to be seen clearly at the scale of the figures have not been included. In the impact range tables only areas are provided, as there is no individual single ‘impact range’ from multiple locations.

As with the other impact piling results, the non-impulsive criteria from Southall *et al.* (2019) have also been modelled and are presented in Appendix A.

4.5.1 *Monopile foundations*

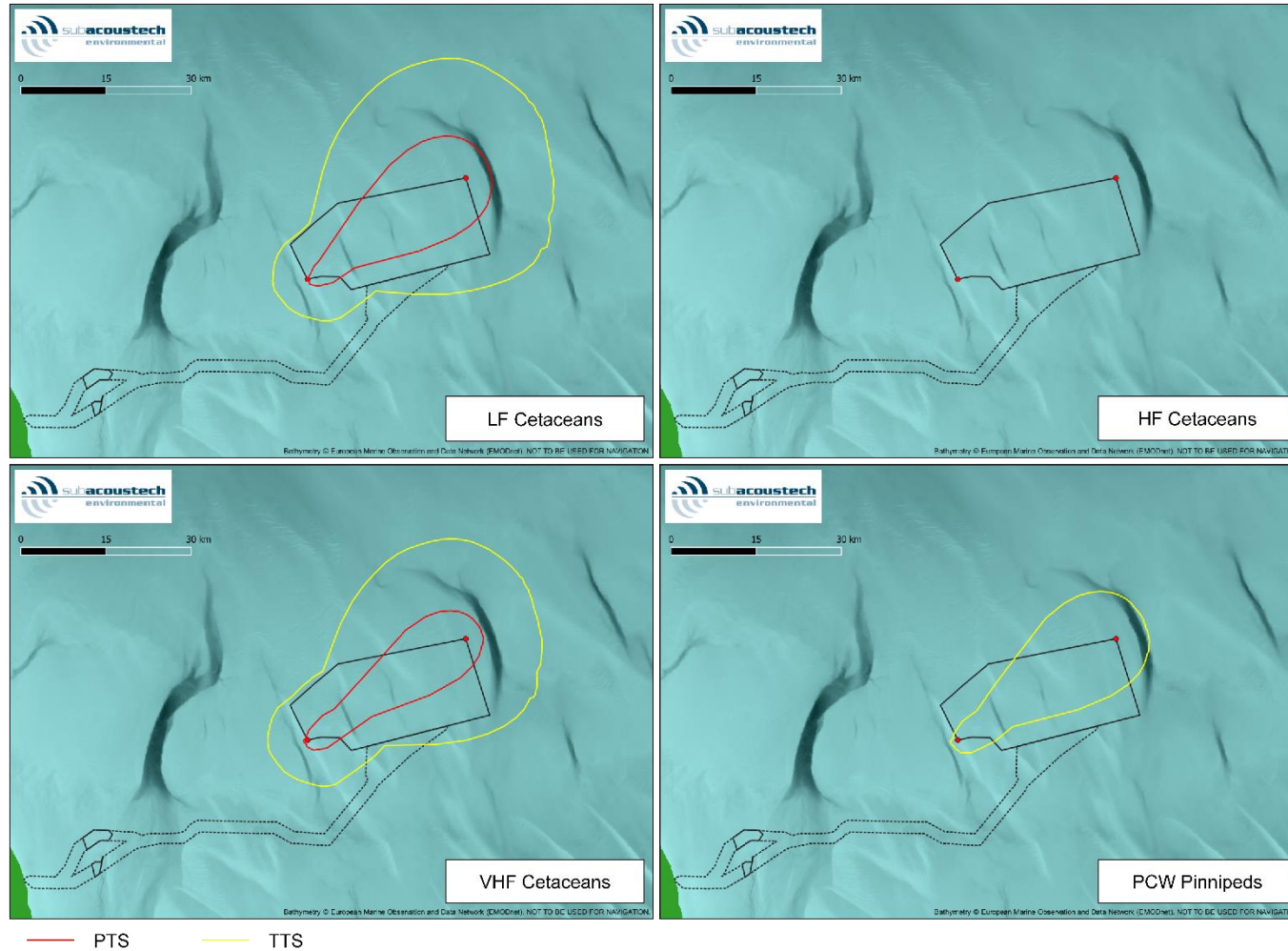


Figure 4-2 Contour plots showing the in-combination impacts of simultaneous installation of monopile foundations at the SW and NE modelling locations for marine mammals using the impulsive Southall et al. (2019) criteria assuming a fleeing animal

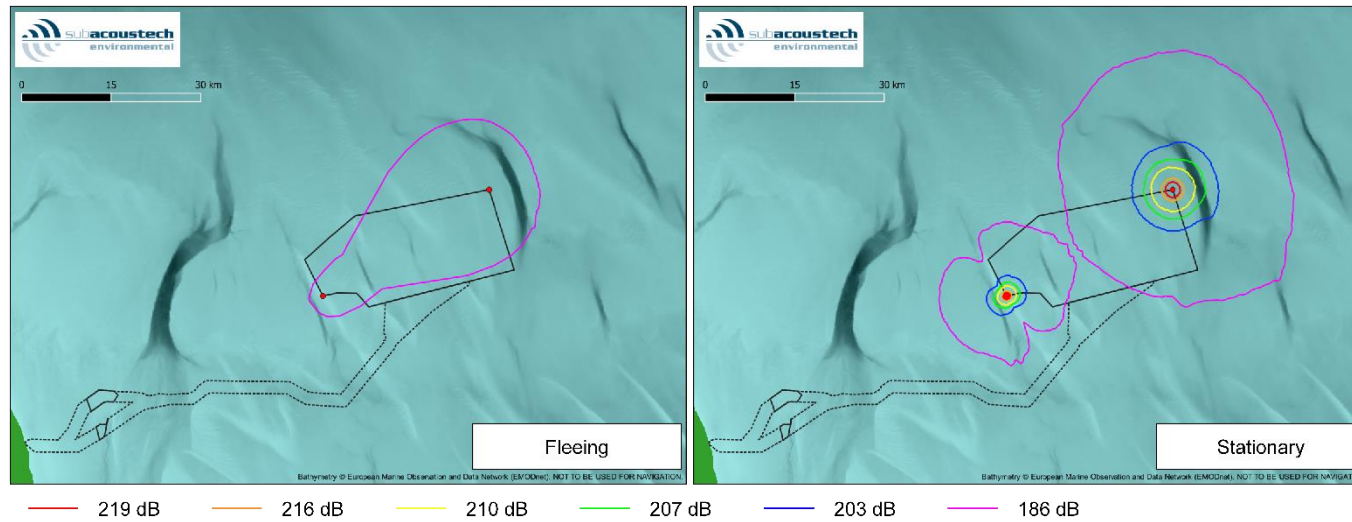


Figure 4-3 Contour plots showing the in-combination impacts of simultaneous installation of monopile foundations at the SW and NE modelling locations for fish using the Popper et al. (2014) impact piling criteria assuming both a fleeing and stationary animal

Table 4-73 Summary of the impact areas for the installation of monopile foundations at the SW and NE modelling locations for marine mammals using the impulsive Southall et al. (2019) SEL<sub>cum</sub> criteria assuming a fleeing animal

| Monopile foundation<br>Southall et al. (2019)<br>Weighted SEL <sub>cum</sub> |              | SW area               | NE area               | In-combination area   |
|--|--------------|-----------------------|-----------------------|-----------------------|
| <b>PTS</b><br>(Impulsive)  | LF (183 dB)  | < 0.1 km <sup>2</sup> | 55 km <sup>2</sup>    | 430 km <sup>2</sup>   |
|  | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                     |
|  | VHF (155 dB) | 0.9 km <sup>2</sup>   | 24 km <sup>2</sup>    | 300 km <sup>2</sup>   |
|  | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                     |
| <b>TTS</b><br>(Impulsive)  | LF (168 dB)  | 95 km <sup>2</sup>    | 770 km <sup>2</sup>   | 1,600 km <sup>2</sup> |
|  | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                     |
|  | VHF (140 dB) | 130 km <sup>2</sup>   | 560 km <sup>2</sup>   | 1,300 km <sup>2</sup> |
|  | PCW (170 dB) | 3.1 km <sup>2</sup>   | 94 km <sup>2</sup>    | 470 km <sup>2</sup>   |

Table 4-74 Summary of the impact areas for the installation of monopile foundations at the SW and NE modelling locations for fish using the Popper et al. (2014) SEL<sub>cum</sub> impact piling criteria assuming both a fleeing and stationary animal

| Monopile foundation<br>Popper et al. (2014)<br>Unweighted SEL <sub>cum</sub> |        | SW area               | NE area               | In-combination area   |
|--|--------|-----------------------|-----------------------|-----------------------|
| <b>Fleeing</b><br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                     |
|  | 216 dB | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                     |
|  | 210 dB | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                     |
|  | 207 dB | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                     |
|  | 203 dB | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                     |
|  | 186 dB | 12 km <sup>2</sup>    | 210 km <sup>2</sup>   | 710 km <sup>2</sup>   |
| <b>Stationary</b><br>(0 m/s)   | 219 dB | 0.8 km <sup>2</sup>   | 4.4 km <sup>2</sup>   | 6 km <sup>2</sup>     |
|  | 216 dB | 1.6 km <sup>2</sup>   | 9.6 km <sup>2</sup>   | 13 km <sup>2</sup>    |
|  | 210 dB | 6.4 km <sup>2</sup>   | 40 km <sup>2</sup>    | 49 km <sup>2</sup>    |
|  | 207 dB | 12 km <sup>2</sup>    | 77 km <sup>2</sup>    | 94 km <sup>2</sup>    |
|  | 203 dB | 28 km <sup>2</sup>    | 160 km <sup>2</sup>   | 200 km <sup>2</sup>   |
|  | 186 dB | 340 km <sup>2</sup>   | 1,300 km <sup>2</sup> | 1,700 km <sup>2</sup> |

4.5.2 *Jacket pile foundations*

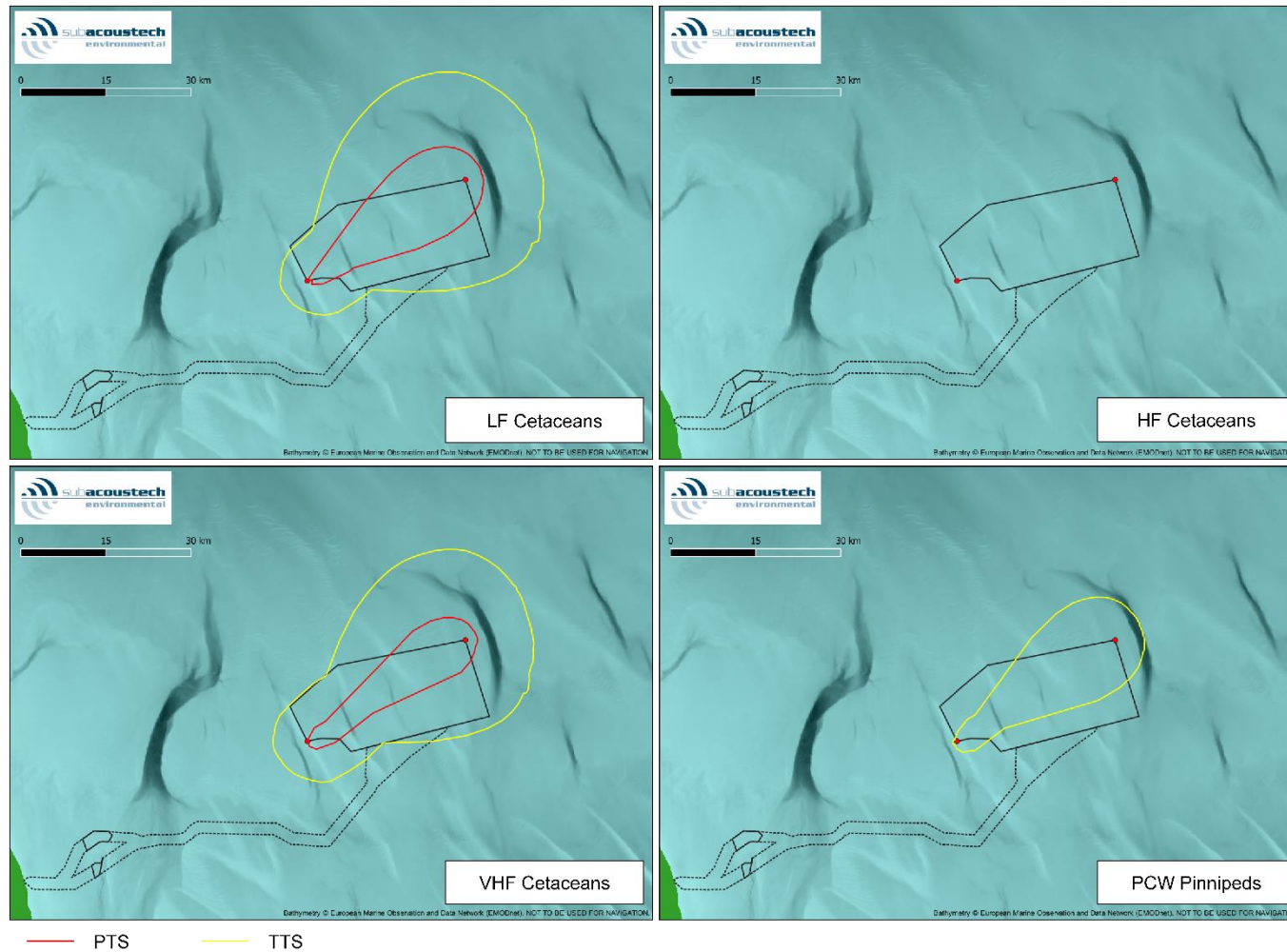


Figure 4-4 Contour plots showing the in-combination impacts of simultaneous installation of jacket pile foundations at the SW and NE modelling locations for marine mammals using the impulsive Southall et al. (2019) criteria assuming a fleeing animal

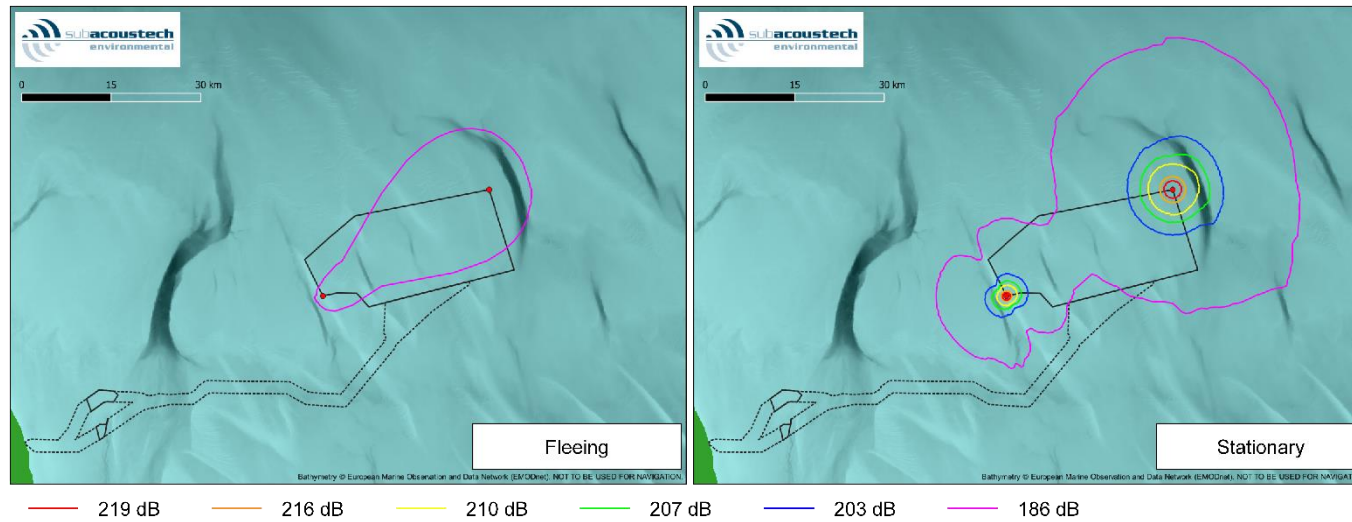


Figure 4-5 Contour plots showing the in-combination impacts of simultaneous installation of jacket pile foundations at the SW and NE modelling locations for fish using the Popper et al. (2014) impact piling criteria assuming both a fleeing and stationary animal

Table 4-75 Summary of the impact areas for the installation of jacket pile foundations at the SW and NE modelling locations for marine mammals using the impulsive Southall *et al.* (2019)  $SEL_{cum}$  criteria assuming a fleeing animal

| Jacket pile foundation<br>Southall <i>et al.</i> (2019)<br>Weighted $SEL_{cum}$ |              | SW area               | NE area               | In-combination area   |
|---|--------------|-----------------------|-----------------------|-----------------------|
| PTS<br>(Impulsive)  | LF (183 dB)  | < 0.1 km <sup>2</sup> | 24 km <sup>2</sup>    | 350 km <sup>2</sup>   |
|   | HF (185 dB)  | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                     |
|   | VHF (155 dB) | < 0.1 km <sup>2</sup> | 11 km <sup>2</sup>    | 230 km <sup>2</sup>   |
|   | PCW (185 dB) | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                     |
| TTS<br>(Impulsive)  | LF (168 dB)  | 55 km <sup>2</sup>    | 600 km <sup>2</sup>   | 1,300 km <sup>2</sup> |
|   | HF (170 dB)  | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                     |
|   | VHF (140 dB) | 92 km <sup>2</sup>    | 450 km <sup>2</sup>   | 1,100 km <sup>2</sup> |
|   | PCW (170 dB) | 1.2 km <sup>2</sup>   | 72 km <sup>2</sup>    | 430 km <sup>2</sup>   |

Table 4-76 Summary of the impact areas for the installation of jacket pile foundations at the SW and NE modelling locations for fish using the Popper *et al.* (2014)  $SEL_{cum}$  impact piling criteria assuming both a fleeing and stationary animal

| Jacket pile foundation<br>Popper <i>et al.</i> (2014)<br>Unweighted $SEL_{cum}$ |        | SW area               | NE area               | In-combination area   |
|---|--------|-----------------------|-----------------------|-----------------------|
| Fleeing<br>(1.5 m/s)  | 219 dB | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                     |
|   | 216 dB | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                     |
|   | 210 dB | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                     |
|   | 207 dB | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                     |
|   | 203 dB | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                     |
|   | 186 dB | 3.4 km <sup>2</sup>   | 140 km <sup>2</sup>   | 600 km <sup>2</sup>   |
| Stationary<br>(0 m/s)   | 219 dB | 1.0 km <sup>2</sup>   | 6.2 km <sup>2</sup>   | 7.9 km <sup>2</sup>   |
|   | 216 dB | 2.0 km <sup>2</sup>   | 13 km <sup>2</sup>    | 17 km <sup>2</sup>    |
|   | 210 dB | 7.8 km <sup>2</sup>   | 54 km <sup>2</sup>    | 65 km <sup>2</sup>    |
|   | 207 dB | 15 km <sup>2</sup>    | 100 km <sup>2</sup>   | 120 km <sup>2</sup>   |
|   | 203 dB | 34 km <sup>2</sup>    | 200 km <sup>2</sup>   | 240 km <sup>2</sup>   |
|   | 186 dB | 380 km <sup>2</sup>   | 1,400 km <sup>2</sup> | 1,900 km <sup>2</sup> |

## 5 Other noise sources

Although impact piling is expected to be the greatest overall noise source during offshore construction and development (Bailey *et al.*, 2014), several other anthropogenic noise sources may be present. Each of these has been considered, and relevant biological noise criteria presented, in this section.

Table 5-1 provides a summary of the various noise producing sources, aside from impact piling, that are expected to be present during the construction and operation of the Project.

*Table 5-1 Summary of the possible noise making activities at the Project other than impact piling*

| Activity        | Description   |
|-----------------|---|
| Cable laying    | Noise from the cable laying vessel and any other associated noise during the offshore cable installation.   |
| Dredging        | Dredging may be required on site for seabed preparation work for certain foundation options, as well as for the export cable, array cables and interlink cable installation. Suction dredging has been assumed as a worst-case. |
| Drilling        | There is the potential for WTG foundations to be installed using drilling depending on seabed type or if a pile refuses during impact piling operations.  |
| Rock placement  | Potentially required on site for installation of offshore cables (cable crossings and cable protection) and scour protection around foundation structures.  |
| Trenching       | Plough trenching may be required during offshore cable installation.  |
| Vessel noise    | Jack-up barges for piling substructure and WTG installation. Other large and medium sized vessels to carry out other construction tasks and anchor handling. Other small vessels for crew transport and maintenance on site.    |
| Operational WTG | Noise transmitted through the water from operational WTG. A range of WTG sizes has been considered based on the Project design envelope.  |
| UXO clearance   | There is a possibility that Unexploded Ordnance (UXO) may exist within the boundaries of the Project, which would need to be cleared before construction can begin.   |

The NPL Good Practice Guide 133 for underwater noise measurements (Robinson *et al.*, 2014) indicates that under certain circumstances, a simple modelling approach may be considered acceptable. Such an approach has been used for these noise sources, which are variously either quiet compared to impact piling (e.g., cable laying and dredging), or where detailed modelling would imply unjustified accuracy (e.g., where data is limited such as with UXO detonation). The high-level overview of modelling that has been presented here is considered sufficient and there would be little benefit in using a more detailed model at this stage. The limitations of this approach are noted, including the lack of frequency or bathymetric dependence.

Most of these activities are considered in section 5.1, with operational WTG noise and UXO clearance assessed in sections 5.2 and 5.3 respectively.

## 5.1 Noise making activities

For the purposes of identifying the greatest noise levels, approximate subsea noise levels have been predicted using a simple modelling approach based on measurement data from Subacoustech Environmental's own underwater noise measurement database, scaled to relevant parameters for the site and to the specific noise sources to be used. The calculation of underwater noise transmission loss for the non-impulsive sources is based on an empirical analysis of the noise measurements taken along transects around these sources by Subacoustech Environmental. The predictions use the following principle fitted to the measured data, where  $R$  is the range from the source,  $N$  is the transmission loss, and  $\alpha$  is the absorption loss:

$$Received\ level = Source\ level\ (SL) - N \log_{10} R - \alpha R$$

Predicted source levels and propagation calculations for the construction activities are presented in Table 5-2 along with a summary of the number of datasets used in each case. As previously, all SEL<sub>cum</sub> criteria use the same assumptions as presented in section 2.2, and ranges smaller than 50 m (single strike) and 100 m (cumulative) have not been presented. It should be reiterated that this modelling approach does not take bathymetry or any other environmental conditions into account, and as such can be applied to any location at, or surrounding, the Project.



*Table 5-2 Summary of the estimated unweighted source levels and transmission losses for the different considered noise sources related to construction*

| Source                | Estimated unweighted source level | Transmission loss parameters       | Comments   |
|-----------------------|-----------------------------------|------------------------------------|--|
| Cable laying          | 171 dB re 1 $\mu$ Pa @ 1 m (RMS)  | $N: 13, \alpha: 0$ (no absorption) | Based on 11 datasets from a pipe laying vessel measuring 300 m in length; this is considered a worst-case noise source for cable laying operations.  |
| Dredging (Backhoe)    | 165 dB re 1 $\mu$ Pa @ 1 m (RMS)  | $N: 19, \alpha: 0.0009$            | Based on three datasets from backhoe dredgers.   |
| Dredging (Suction)    | 186 dB re 1 $\mu$ Pa @ 1 m (RMS)  | $N: 19, \alpha: 0.0009$            | Based on five datasets from suction and cutter suction dredgers.   |
| Drilling              | 169 dB re 1 $\mu$ Pa @ 1 m (RMS)  | $N: 16, \alpha: 0.0006$            | Based on six datasets from various drilling operations covering ground investigations and pile installation. A 200kW drill has been assumed for modelling.   |
| Rock placement        | 172 dB re 1 $\mu$ Pa @ 1 m (RMS)  | $N: 12, \alpha: 0.0005$            | Based on four datasets from rock placement vessel 'Rollingstone.'  |
| Trenching             | 172 dB re 1 $\mu$ Pa @ 1 m (RMS)  | $N: 13, \alpha: 0.0004$            | Based on three datasets of measurements from trenching vessels more than 100 m in length.  |
| Vessel noise (large)  | 168 dB re 1 $\mu$ Pa @ 1 m (RMS)  | $N: 12, \alpha: 0.0021$            | Based on five datasets of large vessels including container ships, floating production storage and offloading (FPSOs) and other vessels more than 100 m in length. Vessel speed assumed as 10 knots. |
| Vessel noise (medium) | 161 dB re 1 $\mu$ Pa @ 1 m (RMS)  | $N: 12, \alpha: 0.0021$            | Based on three datasets of moderate sized vessels less than 100 m in length. Vessel speed assumed as 10 knots.   |

All values of  $N$  and  $\alpha$  are empirically derived and will be linked to the size and shape of the machinery and the noise source on it, the transect on which the measurements are taken and the local environment at the time.

For  $SEL_{cum}$  calculations, the duration the noise is present also needs to be considered, with all sources assumed to operate constantly for 24 hours to give a worst-case assessment of the noise. Due to the low noise level of the sources considered both fleeing and stationary animals have been included for all  $SEL_{cum}$  criteria.

To account for the weightings required for modelling using the Southall *et al.* (2019) criteria (see section 2.2.1), reductions in source level have been applied to the various noise sources: Figure 5-1 shows the representative noise measurements used for this, which have been adjusted for the source levels given in Table 5-2. Details of the reductions in sources levels for each of the weightings used for modelling are given in Table 5-3.

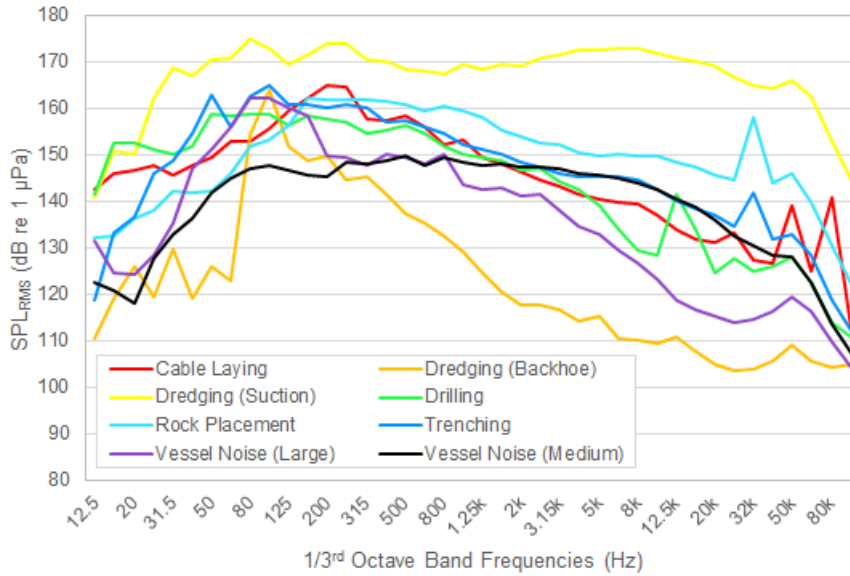


Figure 5-1 Summary of the 1/3<sup>rd</sup> octave frequency bands to which the Southall *et al.* (2019) weightings were applied in the simple modelling.

Table 5-3 Reductions in source level for the different construction noise sources considered when the Southall *et al.* (2019) weightings are applied.

| Source         | Reduction in source level from the unweighted level (Southall <i>et al.</i> , 2019) |         |         |         |
|----------------|---|---------|---------|---------|
|                | LF  | HF      | VHF     | PCW     |
| Cable laying   | 3.6 dB  | 22.9 dB | 23.9 dB | 13.2 dB |
| Dredging       | 2.5 dB  | 7.9 dB  | 9.6 dB  | 4.2 dB  |
| Drilling       | 4.0 dB  | 25.8 dB | 48.7 dB | 13.2 dB |
| Rock placement | 1.6 dB  | 11.9 dB | 12.5 dB | 8.2 dB  |
| Trenching      | 4.1 dB  | 23.0 dB | 25.0 dB | 13.7 dB |
| Vessel noise   | 5.5 dB  | 34.4 dB | 38.6 dB | 17.4 dB |

Table 5-4 to Table 5-6 summarise the predicted impact ranges for these noise sources. All the sources in this section are considered non-impulsive or continuous. As with the previous results, ranges smaller than 50 m (single strike) and 100 m (cumulative) have not been presented.

Given the modelled impact ranges, any marine mammal would have to be closer than 100 m from the continuous noise source at the start of the activity to acquire the necessary exposure to induce PTS as per Southall *et al.* (2019). The exposure calculation assumes the same receptor swim speeds as the impact piling modelling in section 4. As explained in section 3.3, this would only mean that the receptor reaches the 'onset' stage at these ranges, which is the minimum exposure that could potentially lead to the start of an effect and may only be marginal. In most hearing groups, the noise levels are low enough that there is a minimal risk.

For fish, there is a minimal risk of any injury or TTS with reference to the SPL<sub>RMS</sub> guidance for continuous noise sources in Popper *et al.* (2014).

All sources presented here result in much quieter levels than those presented for impact piling in section 4.

*Table 5-4 Summary of the impact ranges for the different noise sources related to construction using the non-impulsive criteria from Southall et al. (2019) for marine mammals assuming a fleeing animal*

| Southall et al.<br>(2019)<br>Weighted SEL <sub>cum</sub> | PTS (non-impulsive) |              |               |               | TTS (non-impulsive) |              |               |               |
|--|---------------------|--------------|---------------|---------------|---------------------|--------------|---------------|---------------|
|  | LF<br>199 dB        | HF<br>198 dB | VHF<br>173 dB | PCW<br>201 dB | LF<br>179 dB        | HF<br>178 dB | VHF<br>153 dB | PCW<br>181 dB |
| Cable laying   | < 100 m             | < 100 m      | < 100 m       | < 100 m       | < 100 m             | < 100 m      | 110 m         | < 100 m       |
| Dredging<br>(Backhoe)                                    | < 100 m             | < 100 m      | < 100 m       | < 100 m       | < 100 m             | < 100 m      | < 100 m       | < 100 m       |
| Dredging<br>(Suction)                                    | < 100 m             | < 100 m      | < 100 m       | < 100 m       | < 100 m             | < 100 m      | 230 m         | < 100 m       |
| Drilling   | < 100 m             | < 100 m      | < 100 m       | < 100 m       | < 100 m             | < 100 m      | < 100 m       | < 100 m       |
| Rock placement   | < 100 m             | < 100 m      | < 100 m       | < 100 m       | < 100 m             | < 100 m      | 990 m         | < 100 m       |
| Trenching  | < 100 m             | < 100 m      | < 100 m       | < 100 m       | < 100 m             | < 100 m      | < 100 m       | < 100 m       |
| Vessel noise<br>(large)                                  | < 100 m             | < 100 m      | < 100 m       | < 100 m       | < 100 m             | < 100 m      | < 100 m       | < 100 m       |
| Vessel noise<br>(medium)                                 | < 100 m             | < 100 m      | < 100 m       | < 100 m       | < 100 m             | < 100 m      | < 100 m       | < 100 m       |

*Table 5-5 Summary of the impact ranges for the different noise sources related to construction using the non-impulsive criteria from Southall et al. (2019) for marine mammals assuming a stationary animal*

| Southall et al.<br>(2019)<br>Weighted SEL <sub>cum</sub> | PTS (non-impulsive) |              |               |               | TTS (non-impulsive) |              |               |               |
|--|---------------------|--------------|---------------|---------------|---------------------|--------------|---------------|---------------|
|  | LF<br>199 dB        | HF<br>198 dB | VHF<br>173 dB | PCW<br>201 dB | LF<br>179 dB        | HF<br>178 dB | VHF<br>153 dB | PCW<br>181 dB |
| Cable laying   | < 100 m             | < 100 m      | < 100 m       | < 100 m       | 810 m               | < 100 m      | 2.3 km        | 110 m         |
| Dredging<br>(Backhoe)                                    | < 100 m             | < 100 m      | < 100 m       | < 100 m       | < 100 m             | < 100 m      | < 100 m       | < 100 m       |
| Dredging<br>(Suction)                                    | < 100 m             | < 100 m      | 570 m         | < 100 m       | 640 m               | 390 m        | 4.3 km        | 420 m         |
| Drilling   | < 100 m             | < 100 m      | < 100 m       | < 100 m       | 160 m               | < 100 m      | 200 m         | < 100 m       |
| Rock placement   | < 100 m             | < 100 m      | 900 m         | < 100 m       | 2.1 km              | 410 m        | 13 km         | 460 m         |
| Trenching  | < 100 m             | < 100 m      | < 100 m       | < 100 m       | 830 m               | < 100 m      | 1.9 km        | 120 m         |
| Vessel noise<br>(large)                                  | < 100 m             | < 100 m      | < 100 m       | < 100 m       | 480 m               | < 100 m      | 140 m         | < 100 m       |
| Vessel noise<br>(medium)                                 | < 100 m             | < 100 m      | < 100 m       | < 100 m       | 130 m               | < 100 m      | < 100 m       | < 100 m       |

Ranges for a stationary animal are theoretical only and are expected to be over-conservative as the assumption is for the animal to remain stationary in respect to the noise source, when the source itself is moving in most cases.

*Table 5-6 Summary of the impact ranges for the different noise sources related to construction using the continuous noise criteria from Popper et al. (2014) for fish (swim bladder involved in hearing)*

| <b>Popper et al. (2014)</b><br>Unweighted SPL <sub>RMS</sub> | <b>Recoverable injury</b><br>170 dB (48 hours) | <b>TTS</b><br>158 dB (12 hours) |
|--|--|---------------------------------|
| Cable laying   | < 50 m   | < 50 m                          |
| Dredging (Backhoe)   | < 50 m   | < 50 m                          |
| Dredging (Suction)   | < 50 m   | < 50 m                          |
| Drilling   | < 50 m   | < 50 m                          |
| Rock placement   | < 50 m   | < 50 m                          |
| Trenching  | < 50 m   | < 50 m                          |
| Vessel noise (large)   | < 50 m   | < 50 m                          |
| Vessel noise (medium)  | < 50 m   | < 50 m                          |

## 5.2 Operational WTG noise

The main source of underwater noise from operational WTGs will be mechanically generated vibration from the rotating machinery in the WTGs, which is transmitted into the sea through the structure of the WTG tower and foundations (Nedwell *et al.*, 2003; Tougaard *et al.*, 2020). Noise levels generated above the water surface are low enough that no significant airborne sound will pass from the air to the water.

Tougaard *et al.* (2020) published a study investigating underwater noise data from 17 operational WTGs in Europe and the United States, from 0.2 MW to 6.15 MW nominal power output. The paper identified the nominal power output and wind speed as the two primary driving factors for underwater noise generation. Although the datasets were acquired under different conditions, the authors devised a formula based on the published data for the operational windfarms, allowing a broadband noise level to be estimated based on the application of wind speed, turbine size (by nominal power output) and distance from the turbine:

$$L_{eq} = C + \alpha \log_{10} \left( \frac{\text{distance}}{100 \text{ m}} \right) + \beta \log_{10} \left( \frac{\text{wind speed}}{10 \text{ m s}^{-1}} \right) + \gamma \log_{10} \left( \frac{\text{turbine size}}{1 \text{ MW}} \right)$$

where  $C$  is a fixed constant and the coefficients  $\alpha$ ,  $\beta$ , and  $\gamma$  are derived from the empirical data for the 17 datasets.

Estimated power ratings based on the range of WTGs being considered in the Project design envelope have been used for modelled in this study.

The maximum turbine sizes considered at the Project are much larger than those used for the estimation above, so caution must be used when considering the results presented in this section; no empirical data is available for large wind turbines close to the specifications proposed here. Figure 5-2 presents a level against range plot for the proposed turbine sizes using the Tougaard *et al.* (2020) calculation, assuming an average 6 m/s wind speed. Although wind speeds (and thus operational noise levels) may be greater than this, this will not represent the typical condition. It is also worth noting that the background noise level will also naturally increase, somewhat offsetting any additional impact this may have.

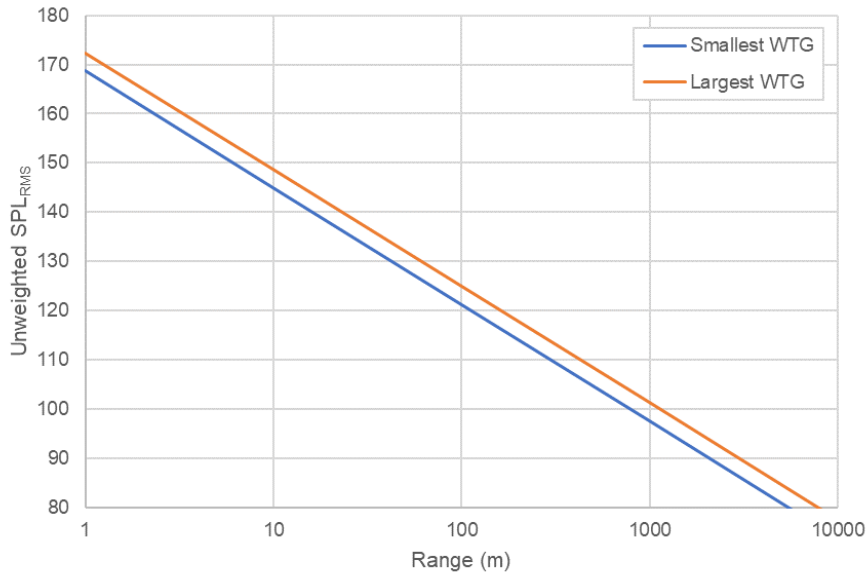


Figure 5-2 Predicted unweighted SPL<sub>RMS</sub> from operational WTGs at the Project using the calculation from Tougaard et al. (2020)

Using this data, a summary of the predicted impact ranges has been produced, shown in Table 5-7 to Table 5-9. All SEL<sub>cum</sub> criteria use the same assumptions as presented in section 2.2, and ranges smaller than 50 m (single strike) and 100 m (cumulative) have not been presented. Operational WTG noise is considered a non-impulsive, or continuous, source.

For SEL<sub>cum</sub> calculations, it has been assumed that the operational WTG noise is present 24 hours a day, and similarly to the noise sources in section 5.1, both fleeing and stationary animals have been included for all SEL<sub>cum</sub> criteria due to the low noise levels considered.

Table 5-7 Summary of the operational WTG noise impact ranges using the non-impulsive noise criteria from Southall et al. (2019) for marine mammals assuming a fleeing receptor

| Southall et al. (2019)      | PTS (non-impulsive) |         |         |         | TTS (non-impulsive) |         |         |         |
|-----------------------------|---------------------|---------|---------|---------|---------------------|---------|---------|---------|
|                             | LF                  | HF      | VHF     | PCW     | LF                  | HF      | VHF     | PCW     |
| Weighted SEL <sub>cum</sub> | 199 dB              | 198 dB  | 173 dB  | 201 dB  | 179 dB              | 178 dB  | 153 dB  | 181 dB  |
| Smallest WTG                | < 100 m             | < 100 m | < 100 m | < 100 m | < 100 m             | < 100 m | < 100 m | < 100 m |
| Largest WTG                 | < 100 m             | < 100 m | < 100 m | < 100 m | < 100 m             | < 100 m | < 100 m | < 100 m |

Table 5-8 Summary of the operational WTG noise impact ranges using the non-impulsive noise criteria from Southall et al. (2019) for marine mammals assuming a stationary receptor

| Southall et al. (2019)      | PTS (non-impulsive) |         |         |         | TTS (non-impulsive) |         |         |         |
|-----------------------------|---------------------|---------|---------|---------|---------------------|---------|---------|---------|
|                             | LF                  | HF      | VHF     | PCW     | LF                  | HF      | VHF     | PCW     |
| Weighted SEL <sub>cum</sub> | 199 dB              | 198 dB  | 173 dB  | 201 dB  | 179 dB              | 178 dB  | 153 dB  | 181 dB  |
| Smallest WTG                | < 100 m             | < 100 m | < 100 m | < 100 m | < 100 m             | < 100 m | < 100 m | < 100 m |
| Largest WTG                 | < 100 m             | < 100 m | < 100 m | < 100 m | < 100 m             | < 100 m | < 100 m | < 100 m |

Table 5-9 Summary of the operational WTG noise impact ranges using the continuous noise criteria from Popper et al. (2014) for fish (swim bladder involved in hearing)

| Popper et al. (2014)          | Recoverable injury | TTS               |
|-------------------------------|--------------------|-------------------|
| Unweighted SPL <sub>RMS</sub> | 170 dB (48 hours)  | 158 dB (12 hours) |
| Smallest WTG                  | < 50 m             | < 50 m            |
| Largest WTG                   | < 50 m             | < 50 m            |

The results show that, for operational WTGs, injury risk is minimal. Increasing the wind speed does not lead to significant increases in the impact ranges.

Stöber & Thomsen (2021) produced a similar study of an operational wind turbine dataset to Tougaard *et al.* (2020) and it raises the potential for behavioural disturbance caused by larger wind turbines. While prospective turbine sizes are increasing, Stöber & Thomsen conclude that these might only have limited impacts related to behavioural response on marine mammals and fish, although there is considerable uncertainty in criteria available to assess these. However, based on the highly precautionary NOAA Level B behavioural threshold for continuous noise sources (120 dB SPL<sub>RMS</sub>, see NOAA, 2005) that the study utilises, it is estimated that the WTGs may only reach that threshold at around 200 m away. As the distance between turbines is considerably greater than 400 m, twice this distance, this would indicate that any array effect from the turbines is not expected.

### 5.3 UXO clearance

It is possible that UXO devices with a range of charge weights (or quantity of contained explosive) are present within the boundaries of the Project. These would need to be cleared before any construction can begin. When modelling potential noise from UXO clearance, a variety of explosive types need to be considered, with the potential that many have been subject to degradation and burying over time. Two otherwise identical explosive devices are likely to produce different blasts in the case where one has spent an extended period on the seabed. A selection of explosive sizes has been considered based on what might be present, and in each case, it has been assumed that the maximum explosive charge in each device is present and detonates with the clearance. Please note that this section has been provided for information only, as the Project is not seeking consent for UXO clearance at present and will apply for a separate marine licence post-consent.

#### 5.3.1 Estimation of underwater noise levels

The noise produced by the detonation of explosives is affected by several different elements, only one of which can easily be factored into a calculation: the charge weight. In this case the charge weight is based on the equivalent weight of Trinitrotoluene (TNT). Many other elements relating to its situation (e.g., its design, composition, age, position, orientation, whether it is covered by sediment) and exactly how they will affect the sound produced by detonation are usually unknown and cannot be directly considered in this type of assessment. This leads to a high degree of uncertainty in the estimation of the source noise level. A worst-case estimation has therefore been used for calculations, assuming the UXO to be detonated is not buried, degraded or subject to any other significant attenuation from its as new condition.

The consequence of this is that the noise levels produced, particularly by the larger explosives under consideration, are likely to be over-estimated as some degree of degradation would be expected.

The maximum equivalent charge weight for the potential UXO devices that could be present within the Order Limits has been estimated as 800 kg. This has been modelled alongside a range of smaller devices, at charge weights of 25, 55, 120, 240, 525 and 700 kg. In each case, an additional donor weight of 0.5 kg has been included to initiate detonation. Low-order deflagration has also been assessed, which assumes that the donor or shaped charge (charge weight of 0.5 kg) detonates fully to initiate a burnout of the explosive but without the follow-up detonation of the UXO. No mitigation has been considered for this modelling.

Estimation of the source noise level for each charge weight has been carried out in accordance with the methodology of Soloway and Dahl (2014), which follows Arons (1954) and the Marine Technical Directorate Ltd (MTD) (1996).

### 5.3.2 Estimation of underwater noise propagation

For this assessment, the attenuation of the noise from UXO detonation has been accounted for in calculations using geometric spreading and a sound absorption coefficient, primarily using the methodologies cited in Soloway and Dahl (2014), which establishes a trend based on measured data in open water. These are, for  $SPL_{peak}$ :

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

and for  $SEL_{ss}$

$$SEL = 6.14 \times \log_{10} \left( W^{1/3} \left( \frac{R}{W^{1/3}} \right)^{-2.12} \right) + 219$$

where  $W$  is the equivalent charge weight for TNT in kilograms and  $R$  is the range from the source.

These equations give a relatively simple calculation which can be used to give an indication of the range of effect. The equation does not consider variable bathymetry or seabed type, and thus calculation results will be the same regardless of where it is used. An attenuation correction can be added to the Soloway and Dahl (2014) equations for the absorption over long ranges (i.e., of the order of thousands of metres), based on measurements of high intensity noise propagation taken in the North Sea and Irish Sea. This uses standard frequency-based absorption coefficients for the seawater conditions expected in the region.

Despite this attenuation correction, the resulting noise levels still need to be considered carefully. For example,  $SPL_{peak}$  noise levels over larger distances are difficult to predict accurately (von Benda-Beckmann *et al.*, 2015). Soloway and Dahl (2014) only verify results from the equation above for small charges at ranges of less than 1 km, although the results are similar to the measurements presented by von Benda-Beckmann *et al.* (2015). At longer ranges, greater confidence is expected with the SEL calculations.

A further limitation in the Soloway and Dahl (2014) equations that must be considered are that variations in noise levels at different depths are not considered. Where animals are swimming near the surface, the acoustics can cause the noise level, and hence the exposure, to be lower (MTD, 1996). The risk to animals near the surface may therefore be lower than indicated by the impact ranges and therefore the results presented can be considered conservative in respect of the impact at different depths.

Additionally, an impulsive wave tends to be smoothed (i.e., the pulse becomes longer) over distance (Cudahy and Parvin, 2001), meaning the injurious potential of a wave at greater range can be even lower than just a reduction in the absolute noise level. An assessment in respect of SEL is considered preferential at long range as it considers the overall energy, and the degree of smoothing of the peak with increasing distance is less critical.

The selection of assessment criteria must also be considered in light of this. As discussed in section 2.2.1, the smoothing of the pulse at range means that a pulse may be considered non-impulsive with distance, suggesting that, at greater ranges, it may be more appropriate to use the non-impulsive criteria. This consideration may begin at 3.5 km (Hastie *et al.*, 2019).

A summary of the unweighted UXO clearance source levels, calculated using the equations above, are given in Table 5-10.

Table 5-10 Summary of the unweighted  $SPL_{peak}$  and  $SEL_{ss}$  source levels used for UXO clearance modelling

| Charge weight  | $SPL_{peak}$ source level<br>(dB re 1 $\mu$ Pa @ 1 m) | $SEL_{ss}$ source level<br>(dB re 1 $\mu$ Pa <sup>2</sup> s @ 1 m) |
|----------------|---|--|
| 0.5 kg         | 272.1   | 217.1  |
| 25 kg + donor  | 284.9   | 228.0  |
| 55 kg + donor  | 287.5   | 230.1  |
| 120 kg + donor | 290.0   | 232.3  |
| 240 kg + donor | 292.3   | 234.2  |
| 525 kg + donor | 294.8   | 236.4  |
| 700 kg + donor | 295.8   | 237.2  |
| 800 kg + donor | 296.2   | 237.5  |

### 5.3.3 Impact ranges

Table 5-11 to Table 5-14 present the impact ranges for UXO detonation, considering various charge weights and impact criteria. It should be noted that Popper et al. (2014) gives specific impact criteria for explosions (

Table 2-6). A UXO detonation source is defined as a single pulse, and as such the  $SEL_{cum}$  criteria from Southall et al. (2019) have been given as  $SEL_{ss}$  in the tables below. Thus, fleeing animal assumptions do not apply. As with the previous sections, ranges smaller than 50 m have not been presented.

Although the impact ranges in Table 5-11 to Table 5-14 are large, the duration the noise is present must also be considered. For the detonation of a UXO, each explosion is a single noise event, compared to the multiple pulse nature and longer durations of impact piling.

Table 5-11 Summary of the PTS and TTS impact ranges for UXO detonation using the impulsive, unweighted  $SPL_{peak}$  noise criteria from Southall et al. (2019) for marine mammals.

| Southall et al.<br>(2019)<br>Unweighted $SPL_{peak}$ | PTS (impulsive) |        |        |        | TTS (impulsive) |        |        |        |
|--|-----------------|--------|--------|--------|-----------------|--------|--------|--------|
|  | LF              | HF     | VHF    | PCW    | LF              | HF     | VHF    | PCW    |
|  | 219 dB          | 230 dB | 202 dB | 218 dB | 213 dB          | 224 dB | 196 dB | 212 dB |
| 0.5 kg   | 220 m           | 70 m   | 1.2 km | 240 m  | 410 m           | 130 m  | 2.3 km | 450 m  |
| 25 kg + donor  | 820 m           | 260 m  | 4.6 km | 910 m  | 1.5 km          | 490 m  | 8.5 km | 1.6 km |
| 55 kg + donor  | 1.0 km          | 340 m  | 6.0 km | 1.1 km | 1.9 km          | 640 m  | 11 km  | 2.1 km |
| 120 kg + donor                                       | 1.3 km          | 450 m  | 7.8 km | 1.5 km | 2.5 km          | 830 m  | 14 km  | 2.8 km |
| 240 kg + donor                                       | 1.7 km          | 560 m  | 9.8 km | 1.9 km | 3.2 km          | 1.0 km | 18 km  | 3.5 km |
| 525 kg + donor                                       | 2.2 km          | 730 m  | 12 km  | 2.5 km | 4.1 km          | 1.3 km | 23 km  | 4.6 km |
| 700 kg + donor                                       | 2.4 km          | 810 m  | 14 km  | 2.7 km | 4.5 km          | 1.4 km | 25 km  | 5.0 km |
| 800 kg + donor                                       | 2.6 km          | 840 m  | 14 km  | 2.8 km | 4.7 km          | 1.5 km | 26 km  | 5.3 km |

Table 5-12 Summary of the PTS and TTS impact ranges for UXO detonation using the impulsive, weighted  $SEL_{ss}$  noise criteria from Southall et al. (2019) for marine mammals.

| Southall et al.<br>(2019)<br>Weighted $SEL_{ss}$ | PTS (impulsive) |        |        |        | TTS (impulsive) |        |        |        |
|--|-----------------|--------|--------|--------|-----------------|--------|--------|--------|
|  | LF              | HF     | VHF    | PCW    | LF              | HF     | VHF    | PCW    |
|  | 183 dB          | 185 dB | 155 dB | 185 dB | 168 dB          | 170 dB | 140 dB | 170 dB |
| 0.5 kg   | 320 m           | < 50 m | 110 m  | 60 m   | 4.5 km          | < 50 m | 930 m  | 800 m  |
| 25 kg + donor                                    | 2.2 km          | < 50 m | 570 m  | 390 m  | 29 km           | 150 m  | 2.4 km | 5.2 km |
| 55 kg + donor                                    | 3.2 km          | < 50 m | 740 m  | 570 m  | 41 km           | 210 m  | 2.8 km | 7.5 km |
| 120 kg + donor                                   | 4.7 km          | < 50 m | 950 m  | 830 m  | 57 km           | 300 m  | 3.2 km | 10 km  |
| 240 kg + donor                                   | 6.5 km          | < 50 m | 1.1 km | 1.1 km | 76 km           | 390 m  | 3.5 km | 14 km  |
| 525 kg + donor                                   | 9.5 km          | 50 m   | 1.4 km | 1.6 km | 100 km          | 530 m  | 4.0 km | 19 km  |
| 700 kg + donor                                   | 10 km           | 60 m   | 1.5 km | 1.9 km | 110 km          | 690 m  | 4.1 km | 22 km  |
| 800 kg + donor                                   | 11 km           | 60 m   | 1.6 km | 2.0 km | 120 km          | 620 m  | 4.2 km | 23 km  |



Table 5-13 Summary of the PTS and TTS impact ranges for UXO detonation using the non-impulsive, weighted  $SEL_{ss}$  noise criteria from Southall *et al.* (2019) for marine mammals.

| Southall <i>et al.</i> (2019)<br>Weighted $SEL_{ss}$ | PTS (non-impulsive) |              |               |               | TTS (non-impulsive) |              |               |               |
|--|---------------------|--------------|---------------|---------------|---------------------|--------------|---------------|---------------|
|  | LF<br>199 dB        | HF<br>198 dB | VHF<br>173 dB | PCW<br>201 dB | LF<br>179 dB        | HF<br>178 dB | VHF<br>153 dB | PCW<br>181 dB |
| 0.5 kg   | < 50 m              | < 50 m       | < 50 m        | < 50 m        | 650 m               | < 50 m       | 150 m         | 110 m         |
| 25 kg + donor  | 130 m               | < 50 m       | < 50 m        | < 50 m        | 4.4 km              | < 50 m       | 730 m         | 790 m         |
| 55 kg + donor  | 190 m               | < 50 m       | < 50 m        | < 50 m        | 6.4 km              | 60 m         | 940 m         | 1.1 km        |
| 120 kg + donor                                       | 280 m               | < 50 m       | 70 m          | < 50 m        | 9.4 km              | 80 m         | 1.1 km        | 1.6 km        |
| 240 kg + donor                                       | 390 m               | < 50 m       | 100 m         | 70 m          | 13 km               | 110 m        | 1.4 km        | 2.3 km        |
| 525 kg + donor                                       | 570 m               | < 50 m       | 130 m         | 100 m         | 18 km               | 160 m        | 1.7 km        | 3.3 km        |
| 700 kg + donor                                       | 660 m               | < 50 m       | 150 m         | 110 m         | 21 km               | 180 m        | 1.8 km        | 3.8 km        |
| 800 kg + donor                                       | 700 m               | < 50 m       | 160 m         | 120 m         | 22 km               | 190 m        | 1.8 km        | 4.1 km        |

Table 5-14 Summary of the impact ranges for UXO detonation using the unweighted  $SPL_{peak}$  explosion noise criteria from Popper *et al.* (2014) for species of fish

| Popper <i>et al.</i> (2014)<br>Unweighted $SPL_{RMS}$ | Mortality and potential mortal injury |        |
|---|---------------------------------------|--------|
|   | 234 dB                                | 229 dB |
| 0.5 kg  | < 50 m                                | 80 m   |
| 25 kg + donor   | 170 m                                 | 290 m  |
| 55 kg + donor   | 230 m                                 | 380 m  |
| 120 kg + donor  | 300 m                                 | 490 m  |
| 240 kg + donor  | 370 m                                 | 620 m  |
| 525 kg + donor  | 490 m                                 | 810 m  |
| 700 kg + donor  | 530 m                                 | 890 m  |
| 800 kg + donor  | 560 m                                 | 930 m  |

#### 5.3.4 Summary

The maximum PTS range calculated for UXO is 14 km for the VHF cetacean category, when considering the unweighted  $SPL_{peak}$  criteria. For  $SEL_{ss}$  criteria, the largest PTS range is calculated for LF cetaceans with a predicted impact of 11 km using the impulsive noise criteria. As explained earlier, this assumes no degradation of the UXO and no smoothing of the pulse over that distance, which is very precautionary. Although an assumption of non-pulse could under-estimate the potential impact (Martin *et al.*, 2020) (the equivalent range based on LF cetacean non-pulse criteria is 700 m), it is likely that the long-range smoothing of the pulse peak would reduce its potential harm and the maximum 'impulsive' range for all species is very precautionary.

## 6 Summary and conclusions

Subacoustech Environmental have undertaken a study on behalf of GoBe Consultants to assess the potential underwater noise and its effects during the construction and operation of the proposed Outer Dowsing Offshore Wind project, located in the North Sea.

The level of underwater noise from the installation of turbine foundations during construction has been estimated using the semi-empirical underwater noise model INSPIRE. The modelling considers a wide variety of input parameters including bathymetry, hammer blow energy, strike rate, and receptor fleeing speed.

Seven representative modelling locations were chosen to give spatial variation as well as account for changes in water depth around the Project Array, ORCP and ANS. At each location, monopile and

jacket pile foundation modelling scenarios were considered with the potential for multiple piles to be installed sequentially in a 24-hour period.

The loudest levels of noise and greatest impact ranges have been largely predicted for the monopile foundation scenario at the NE array modelling location, and the NW scenario of the ANS modelling locations. Smaller ranges are predicted at the other locations due to shallower water and the proximity to the coastline.

The modelling results were analysed in terms of relevant noise metrics and criteria to assess the effects of the impact piling on marine mammals (Southall *et al.*, 2019; NOAA, 2005) and fish (Popper *et al.*, 2014), which have been used to aid biological assessments.

For marine mammals, maximum PTS ranges were predicted for LF cetaceans, with ranges of up to 5.3 km based on the monopile foundation scenario in the Array. For fish, the largest recoverable injury ranges (203 dB SEL<sub>cum</sub>) in the array were predicted to be less than 100 m for a fleeing receptor, increasing to a maximum of 9.0 km for a stationary receptor.

Noise sources other than piling were considered using a high-level, simple modelling approach, including cable laying, dredging, drilling, rock placement, vessel movements, and operational WTG noise. The predicted noise levels for the other construction noise sources and during WTG operation are well below those predicted for impact piling noise. The risk of any potentially injurious effects to fish or marine mammals from these sources are expected to be minimal as the noise emissions from these are close to, or below, the appropriate injury criteria even when very close to the source of the noise.

Modelling of UXO clearance has also been included at the Project site, for information only, and for the expected UXO clearance noise, there is a risk of PTS up to 14 km for the largest, 800 kg, UXO device considered, using the unweighted SPL<sub>peak</sub> criteria for VHF cetaceans. However, this is likely to be precautionary as the impact range is based on a worst-case criterion and calculation methodology that does not account for any smoothing of the pulse over long ranges, which would reduce the pulse peak and other characteristics of the sound that cause injury.

The outputs of this modelling have been used to inform analysis of the impacts of underwater noise on marine mammals and fish in their respective reports.

## References

1. Andersson, M. H., Andersson, S., Ahlsén, J., Andersson, B. L., Hammar, J., Persson, L. K. G., Pihl, J., Sigray, P. and Wilkström, A. (2017), 'A framework for regulating underwater noise during pile driving', A technical Vindval report, ISBN 978-91-620-6775-5, Swedish Environmental Protection Agency, Stockholm, Sweden.
2. Arons, A. B. (1954), 'Underwater explosion shock wave parameters at large distances from the charge', *J. Acoust. Soc. Am.* 26, 343-346.
3. Bailey, H., Senior, B., Simmons, D., Rusin, J., Picken, G. and Thompson, P. M. (2010), 'Assessing underwater noise levels during pile-driving at an offshore wind farm and its potential effects on marine mammals', *Marine Pollution Bulletin* 60 (2010), pp 888-897.
4. Bailey, H., Brookes, K. L. and Thompson, P. M. (2014), 'Assessing environmental impacts of offshore wind farms: lessons learned and recommendations for the future', *Aquatic Biosystems* 2014, 10:8.
5. Bebb, A. H. and Wright, H. C. (1953), 'Injury to animals from underwater explosions', Medical Research Council, Royal Navy Physiological Report 53/732, Underwater Blast Report 31, January 1953.
6. Bebb, A. H. and Wright, H. C. (1954a), 'Lethal conditions from underwater explosion blast', RNP Report 51/654, RNPL 3/51, National Archives Reference ADM 298/109, March 1954.
7. Bebb, A. H. and Wright, H. C. (1954b), 'Protection from underwater explosion blast: III. Animal experiments and physical measurements', RNP Report 57/792, RNPL 2/54m March 1954.
8. Bebb, A. H. and Wright, H. C. (1955), 'Underwater explosion blast data from the Royal Navy Physiological Labs 1950/1955', Medical Research Council, April 1955.
9. Blix, A. S. and Folkow, L. P. (1995), 'Daily energy expenditure in free living minke whales', *Acta Physio. Scand.*, 153: 61-66.
10. Cudahy, E. A. and Parvin, S. (2001), 'The effects of underwater blast on divers', Report 1218, Naval Submarine Medical Research Laboratory: #63706N M0099.001-5901.
11. Dahl, P. H., de Jong, C. A. and Popper, A. N. (2015), 'The underwater sound field from impact pile driving and its potential effects on marine life', *Acoustics Today*, Spring 2015, Volume 11, Issue 2.
12. Goertner, J. F. (1978), 'Dynamical model for explosion injury to fish', Naval Surface Weapons Center, White Oak Lab, Silver Spring, MD. Report No. NSWC/WOL.TR-76-155.
13. Goertner, J. F., Wiley, M. L., Young, G. A. and McDonald, W. W. (1994), 'Effects of underwater explosions on fish without swim bladders', Naval Surface Warfare Center. Report No. NSWC/TR-76-155.
14. Halvorsen, M. B., Casper, B. C., Matthew, D., Carlson, T. J. and Popper, A. N. (2012), 'Effects of exposure to pile driving sounds on the lake sturgeon, Nile tilapia, and hogchoker', *Proc. Roy. Soc. B* 279: 4705-4714.
15. Hastie, G., Merchant, N. D., Götz, T., Russell, D. J. F., Thompson, P. and Janik, V. M. (2019), 'Effects of impulsive noise on marine mammals: Investigating range-dependent risk', DOI: 10.1002/ eap.1906.
16. Hastings, M. C. and Popper, A. N. (2005), 'Effects of sound on fish', Report to the California Department of Transport, under Contract No. 43A01392005, January 2005.

17. Hawkins, A. D., Roberts, L. and Cheesman, S. (2014), 'Responses of free-living coastal pelagic fish to impulsive sounds', *J. Acoust. Soc. Am.* 135: 3101-3116.
18. Heaney, K. D., Ainslie, M. A., Halvorsen, M. B., Seger, K. D., Müller, R. A. J., Nijhof, M. J. J. and Lippert, T. (2020), 'A Parametric Analysis and Sensitivity Study of the Acoustic Propagation for Renewable Energy Sources', Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. Prepared by CSA Ocean Sciences Inc. OCS Study BOEM 2020-011, 165 p.
19. Hirata, K. (1999), 'Swimming speeds of some common fish', National Maritime Research Institute (Japan). Data sourced from Iwai T, Hisada M (1998). *Fishes – Illustrated book of Gakken* (in Japanese). Accessed on 8<sup>th</sup> November 2022 at <https://www.nmri.go.jp/archives/eng/khirata/fish/general/speed/speede.htm>
20. Kastelein, R. A., van de Voorde, S. and Jennings, N. (2018), 'Swimming speed of a harbor porpoise (*Phocoena phocoena*) during playbacks of offshore pile driving sounds', *Aquatic Mammals*. 2018, 44(1), 92-99, DOI 10.1578/AM.44.1.2018.92.
21. Marine Technical Directorate Ltd (MTD) (1996), 'Guidelines for the safe use of explosives underwater', MTD Publication 96/101. ISBN 1 870553 23 3.
22. Martin, S. B., Lucke, K. and Barclay, D. R. (2020), 'Techniques for distinguishing between impulsive and non-impulsive sound in the context of regulating sound exposure for marine mammals', *The Journal of the Acoustical Society of America* 147, 2159.
23. McCauley, E. D., Fewtrell, K., Duncan, A. J., Jenner, C., Jenner, M.-N., Penrose, J. D., Prince, R. I. T., Adhitya, A., Murdoch, J. and McCabe, K. (2000), 'Marine seismic survey – A study of environmental implications', *Appea Journal*, pp 692-708.
24. National Marine Fisheries Service (NMFS) (2018), 'Revisions to: Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing (version 2.0): Underwater thresholds for onset of permanent and temporary threshold shifts', U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OPR-59.
25. National Oceanic and Atmospheric Administration (NOAA) 2005. *Endangered fish and wildlife; Notice of intent to prepare an Environmental Impact Statement*. Federal Register 70: 1871-1875.
26. Nedelec, S. L., Campbell, J., Radford, A. N., Simpson, S. D. and Merchant, N. D. (2016), 'Particle motion: The missing link in underwater acoustic ecology', *Methods Ecol. Evol.* 7, 836 – 842.
27. Nedwell, J. R., Langworthy, J. and Howell, D. (2003), 'Assessment of subsea noise and vibration from offshore wind turbines and its impact on marine wildlife. Initial measurements of underwater noise during construction of offshore wind farms, and comparisons with background noise', Subacoustech Report No. 544R0423, published by COWRIE, May 2003.
28. Otani, S., Naito, T., Kato, A. and Kawamura, A. (2000), 'Diving behaviour and swimming speed of a free-ranging harbour porpoise (*Phocoena phocoena*)', *Marine Mammal Science*, Volume 16, Issue 4, pp 881-814, October 2000.
29. Popper, A. N., Hawkins, A. D., Fay, R. R., Mann, D. A., Bartol, S., Carlson, T. J., Coombs, S., Ellison, W. T., Gentry, R. L., Halvorsen, M. B., Løkkeborg, S., Rogers, P. H., Southall, B. L., Zeddies, D. G. and Tavolga, W. N. (2014), 'Sound exposure guidelines for Fishes and Sea Turtles', *Springer Briefs in Oceanography*, DOI 10.1007/978-3-319-06659-2.
30. Popper, A. N. and Hawkins, A. D. (2018), 'The importance of particle motion to fishes and invertebrates', *J. Acoust. Soc. Am.* 143, 470 – 486.

31. Popper, A. N. and Hawkins, A. D. (2019), 'An overview in fish bioacoustics and the impacts of anthropogenic sounds on fishes', *Journal of Fish Biology*, 1-22. DOI: 10.1111/jfp.13948.
32. Radford, C. A., Montgomery, J. C., Caiger, P. and Higgs, D. M. (2012), 'Pressure and particle motion detection thresholds in fish: a re-examination of salient auditory cues in teleosts', *Journal of Experimental Biology*, 215, 3429 – 3435.
33. Rawlins, J. S. P. (1987), 'Problems in predicting safe ranges from underwater explosions', *Journal of Naval Science*, Volume 13, No. 4, pp 235-246.
34. Robinson, S. P., Lepper, P. A. and Hazelwood, R. A. (2014), 'Good practice guide for underwater noise measurement', National Measurement Office, Marine Scotland, The Crown Estate. NPL Good Practice Guide No. 133, ISSN 1368-6550.
35. Soloway, A. G. and Dahl, P. H. (2014), 'Peak sound pressure and sound exposure level from underwater explosions in shallow water', *The Journal of the Acoustical Society of America*, 136(3), EL219 – EL223. <http://dx.doi.org/10.1121/1.4892668>.
36. Southall, B. L., Bowles, A. E., Ellison, W. T., Finneran, J. J., Gentry, R. L., Green Jr., C. R., Kastak, D., Ketten, D. R., Miller, J. H., Nachtigall, P. E., Richardson, W. J., Thomas, J. A. and Tyack, P. L. (2007), 'Marine mammal noise exposure criteria: Initial scientific recommendations', *Aquatic Mammals*, 33 (4), pp 411-509.
37. Southall, B. L., Finneran, J. J., Reichmuth, C., Nachtigall, P. E., Ketten, D. R., Bowles, A. E., Ellison, W. T., Nowacek, D. P., Tyack, P. L. (2019), 'Marine mammal noise exposure criteria: Updated scientific recommendations for residual hearing effects', *Aquatic Mammals* 2019, 45 (20, 125-232) DOI 10.1578/AM.45.2.2019.125.
38. Southall, B. L. (2021), 'Evolutions in Marine Mammal Noise Exposure Criteria', *Acoustics Today* 17(2) <https://doi.org/10.1121/AT.2021.17.2.52>.
39. Stephenson, J. R., Gingerich, A. J., Brown, R. S., Pflugrath, B. D., Deng, Z., Carlson, T. J., Langeslay, M. J., Ahmann, M. L., Johnson, R. L. and Seaburg, A. G. (2010), 'Assessing barotrauma in neutrally and negatively buoyant juvenile salmonids exposed to simulated hydro-turbine passage using a mobile aquatic barotrauma laboratory', *Fisheries Research* Volume 106, Issue 3, pp 271-278, December 2010.
40. Thompson, P. M., Hastie, G. D., Nedwell, J., Barham, R., Brookes, K. L., Cordes, L. S., Bailey, H. and McLean, N. (2013), 'Framework for assessing impacts of pile-driving noise from offshore wind farm construction on a harbour seal population', *Environmental Impact Assessment Review* 43 (2013) 73-85.
41. Tougaard, J., Hermannsen, L. and Madsen, P. T. (2020), 'How loud is the underwater noise from operating offshore wind turbines?', *J. Acoust. Soc. Am.* 148 (5). [doi.org/10.1121/10.0002453](https://doi.org/10.1121/10.0002453).
42. von Benda-Beckmann, A. M., Aarts, G., Sertlek, H. Ö., Lucke, K., Verboom, W. C., Kastelein, R. A., Ketten, D. R., van Bemmelen, R., Lamm, F.-P. A., Kirkwood, R. J. and Ainslie, M. A. (2015), 'Assessing the impact of underwater clearance of unexploded ordnance on harbour porpoises (*Phocoena phocoena*) in the southern North Sea', *Aquatic Mammals* 2015, 41(4), pp 503-523, DOI 10.1578/ AM.41.4.2015.503.

## Appendix A Additional modelling results

Following from the Southall *et al.* (2019) modelled impact piling ranges presented in Section 4 of the main report, the modelling results for non-impulsive criteria from impact piling noise at the Project, as discussed in Section 2.2.1, is presented below. The predicted ranges here fall well below the impulsive criteria presented in the main report.

### A.1 Single location modelling

Table A 1 to Table A 14 present the modelling results considering single locations for the non-impulsive Southall *et al.* (2019) criteria.

*Table A 1 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at the SW location assuming a fleeing animal*

| Southall <i>et al.</i> (2019)<br>Weighted SEL <sub>cum</sub> |     | Area         | Maximum<br>range      | Minimum<br>range | Mean<br>range |         |
|--|-----|--------------|-----------------------|------------------|---------------|---------|
| Single pile  | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  | TTS | LF (179 dB)  | 2.4 km <sup>2</sup>   | 1.2 km           | 230 m         | 820 m   |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | VHF (153 dB) | 3.1 km <sup>2</sup>   | 1.2 km           | 400 m         | 970 m   |
| 2 sequential piles   | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  | TTS | LF (179 dB)  | 2.4 km <sup>2</sup>   | 1.2 km           | 230 m         | 820 m   |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | VHF (153 dB) | 3.1 km <sup>2</sup>   | 1.2 km           | 400 m         | 970 m   |
|  |     | PCW (181 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |

*Table A 2 Summary of the weighted SEL<sub>cum</sub> impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at the NW location assuming a fleeing animal*

| Southall <i>et al.</i> (2019)<br>Weighted SEL <sub>cum</sub> |     | Area         | Maximum<br>range      | Minimum<br>range | Mean<br>range |         |
|--|-----|--------------|-----------------------|------------------|---------------|---------|
| Single pile  | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  | TTS | LF (179 dB)  | 26 km <sup>2</sup>    | 3.8 km           | 600 m         | 2.8 km  |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | VHF (153 dB) | 12 km <sup>2</sup>    | 2.4 km           | 750 m         | 2.0 km  |
| 2 sequential piles   | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  | TTS | LF (179 dB)  | 26 km <sup>2</sup>    | 3.8 km           | 600 m         | 2.8 km  |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | VHF (153 dB) | 12 km <sup>2</sup>    | 2.4 km           | 750 m         | 2.0 km  |
|  |     | PCW (181 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |

Table A 3 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at the NE location assuming a fleeing animal

| Southall et al. (2019)<br>Weighted $SEL_{cum}$ |     | Area         | Maximum<br>range      | Minimum<br>range | Mean<br>range |         |
|--|-----|--------------|-----------------------|------------------|---------------|---------|
| Single pile                                    | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  | TTS | LF (179 dB)  | 150 km <sup>2</sup>   | 8.5 km           | 5.5 km        | 6.8 km  |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | VHF (153 dB) | 46 km <sup>2</sup>    | 4.6 km           | 3.3 km        | 3.8 km  |
| 2 sequential piles                             | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  | TTS | LF (179 dB)  | 150 km <sup>2</sup>   | 8.5 km           | 5.5 km        | 6.8 km  |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | VHF (153 dB) | 46 km <sup>2</sup>    | 4.6 km           | 3.3 km        | 3.8 km  |
|  |     | PCW (181 dB) | 0.1 km <sup>2</sup>   | 250 m            | 180 m         | 210 m   |

Table A 4 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the jacket pile foundation modelling at the SW location assuming a fleeing animal

| Southall et al. (2019)<br>Weighted $SEL_{cum}$ |     | Area         | Maximum<br>range      | Minimum<br>range | Mean<br>range |         |
|--|-----|--------------|-----------------------|------------------|---------------|---------|
| Single pile                                    | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  | TTS | LF (179 dB)  | 0.2 km <sup>2</sup>   | 330 m            | < 100 m       | 210 m   |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | VHF (153 dB) | 0.7 km <sup>2</sup>   | 630 m            | 180 m         | 460 m   |
| 6 sequential piles                             | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  | TTS | LF (179 dB)  | 0.2 km <sup>2</sup>   | 330 m            | < 100 m       | 210 m   |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|  |     | VHF (153 dB) | 0.7 km <sup>2</sup>   | 630 m            | 180 m         | 460 m   |
|  |     | PCW (181 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |

Table A 5 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the jacket pile foundation modelling at the NW location assuming a fleeing animal

| Southall et al. (2019)<br>Weighted $SEL_{cum}$ |     | Area         | Maximum range         | Minimum range | Mean range |         |
|--|-----|--------------|-----------------------|---------------|------------|---------|
| Single pile                                    | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (179 dB)  | 9.6 km <sup>2</sup>   | 2.4 km        | 250 m      | 1.7 km  |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | PCW (181 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
| 6 sequential piles                             | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (179 dB)  | 9.6 km <sup>2</sup>   | 2.4 km        | 250 m      | 1.7 km  |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (153 dB) | 5.1 km <sup>2</sup>   | 1.6 km        | 400 m      | 1.2 km  |
|  |     | PCW (181 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |

Table A 6 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the jacket pile foundation modelling at the NE location assuming a fleeing animal

| Southall et al. (2019)<br>Weighted $SEL_{cum}$ |     | Area         | Maximum range         | Minimum range | Mean range |         |
|--|-----|--------------|-----------------------|---------------|------------|---------|
| Single pile                                    | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (179 dB)  | 89 km <sup>2</sup>    | 6.8 km        | 4.2 km     | 5.3 km  |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | PCW (181 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
| 6 sequential piles                             | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (179 dB)  | 89 km <sup>2</sup>    | 6.8 km        | 4.2 km     | 5.3 km  |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | PCW (181 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |



Table A 7 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at the ORCP-N location assuming a fleeing animal

| Southall et al. (2019)<br>Weighted $SEL_{cum}$ |     | Area         | Maximum range         | Minimum range | Mean range |         |
|--|-----|--------------|-----------------------|---------------|------------|---------|
| Single pile                                    | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (179 dB)  | 4.8 km <sup>2</sup>   | 1.6 km        | 880 m      | 1.2 km  |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (153 dB) | 4.4 km <sup>2</sup>   | 1.4 km        | 1.0 km     | 1.2 km  |
|  |     | PCW (181 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
| 2 sequential piles                             | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (179 dB)  | 4.8 km <sup>2</sup>   | 1.6 km        | 880 m      | 1.2 km  |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (153 dB) | 4.4 km <sup>2</sup>   | 1.4 km        | 1.0 km     | 1.2 km  |
|  |     | PCW (181 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |

Table A 8 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at the ORCP-S location assuming a fleeing animal

| Southall et al. (2019)<br>Weighted $SEL_{cum}$ |     | Area         | Maximum range         | Minimum range | Mean range |         |
|--|-----|--------------|-----------------------|---------------|------------|---------|
| Single pile                                    | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (179 dB)  | 8.1 km <sup>2</sup>   | 3.0 km        | 1.3 km     | 1.6 km  |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (153 dB) | 6.2 km <sup>2</sup>   | 2.0 km        | 1.2 km     | 1.4 km  |
|  |     | PCW (181 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
| 2 sequential piles                             | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (179 dB)  | 8.1 km <sup>2</sup>   | 3.0 km        | 1.3 km     | 1.6 km  |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (153 dB) | 6.2 km <sup>2</sup>   | 2.0 km        | 1.2 km     | 1.4 km  |
|  |     | PCW (181 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |

Table A 9 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the jacket pile foundation modelling at the ORCP-N location assuming a fleeing animal

| Southall et al. (2019)<br>Weighted $SEL_{cum}$ |     | Area         | Maximum range         | Minimum range | Mean range |         |
|--|-----|--------------|-----------------------|---------------|------------|---------|
| Single pile                                    | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (179 dB)  | 0.9 km <sup>2</sup>   | 730 m         | 350 m      | 520 m   |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (153 dB) | 1.4 km <sup>2</sup>   | 800 m         | 550 m      | 670 m   |
| 6 sequential piles                             | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (179 dB)  | 0.9 km <sup>2</sup>   | 730 m         | 350 m      | 520 m   |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (153 dB) | 1.4 km <sup>2</sup>   | 800 m         | 550 m      | 670 m   |
| 6 sequential piles                             | TTS | PCW (181 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |

Table A 10 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the jacket pile foundation modelling at the ORCP-S location assuming a fleeing animal

| Southall et al. (2019)<br>Weighted $SEL_{cum}$ |     | Area         | Maximum range         | Minimum range | Mean range |         |
|--|-----|--------------|-----------------------|---------------|------------|---------|
| Single pile                                    | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (179 dB)  | 2.1 km <sup>2</sup>   | 1.8 km        | 580 m      | 790 m   |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (153 dB) | 2.3 km <sup>2</sup>   | 1.3 km        | 730 m      | 860 m   |
| 6 sequential piles                             | PTS | PCW (181 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | LF (179 dB)  | 2.1 km <sup>2</sup>   | 1.8 km        | 580 m      | 790 m   |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
| 6 sequential piles                             | TTS | VHF (153 dB) | 2.3 km <sup>2</sup>   | 1.3 km        | 730 m      | 860 m   |
|  |     | PCW (181 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |

Table A 11 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at the ANS-NW location assuming a fleeing animal

| Southall et al. (2019)<br>Weighted $SEL_{cum}$ |     | Area         | Maximum range         | Minimum range | Mean range |         |
|--|-----|--------------|-----------------------|---------------|------------|---------|
| Single pile                                    | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (179 dB)  | 160 km <sup>2</sup>   | 9.2 km        | 5.6 km     | 7.1 km  |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (153 dB) | 37 km <sup>2</sup>    | 3.9 km        | 3.0 km     | 3.4 km  |
|  |     | PCW (181 dB) | < 0.1 km <sup>2</sup> | 130 m         | 100 m      | 110 m   |

Table A 12 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the monopile foundation modelling at the ANS-SE location assuming a fleeing animal

| Southall et al. (2019)<br>Weighted $SEL_{cum}$ |     | Area         | Maximum range         | Minimum range | Mean range |         |
|--|-----|--------------|-----------------------|---------------|------------|---------|
| Single pile                                    | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (179 dB)  | 61 km <sup>2</sup>    | 5.7 km        | 3.6 km     | 4.4 km  |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (153 dB) | 18 km <sup>2</sup>    | 3.0 km        | 2.1 km     | 2.4 km  |
|  |     | PCW (181 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |

Table A 13 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall et al. (2019) non-impulsive criteria for the jacket pile foundation modelling at the ANS-NW location assuming a fleeing animal

| Southall et al. (2019)<br>Weighted $SEL_{cum}$ |     | Area         | Maximum range         | Minimum range | Mean range |         |
|--|-----|--------------|-----------------------|---------------|------------|---------|
| Single pile                                    | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (179 dB)  | 160 km <sup>2</sup>   | 9.1 km        | 5.5 km     | 7.0 km  |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (153 dB) | 37 km <sup>2</sup>    | 3.9 km        | 3.0 km     | 3.4 km  |
|  |     | PCW (181 dB) | < 0.1 km <sup>2</sup> | 130 m         | 100 m      | 110 m   |
| 4 sequential piles                             | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  | TTS | LF (179 dB)  | 160 km <sup>2</sup>   | 9.1 km        | 5.5 km     | 7.0 km  |
|  |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m       | < 100 m    | < 100 m |
|  |     | VHF (153 dB) | 37 km <sup>2</sup>    | 4.0 km        | 3.0 km     | 3.4 km  |
|  |     | PCW (181 dB) | < 0.1 km <sup>2</sup> | 130 m         | 100 m      | 110 m   |

Table A 14 Summary of the weighted  $SEL_{cum}$  impact ranges for marine mammals using the Southall *et al.* (2019) non-impulsive criteria for the jacket pile foundation modelling at the ANS-SE location assuming a fleeing animal

| Southall <i>et al.</i> (2019)<br>Weighted $SEL_{cum}$ |     | Area         | Maximum<br>range      | Minimum<br>range | Mean<br>range |         |
|---|-----|--------------|-----------------------|------------------|---------------|---------|
| Single pile   | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|   |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|   |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|   |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|   | TTS | LF (179 dB)  | 58 km <sup>2</sup>    | 5.6 km           | 3.5 km        | 4.3 km  |
|   |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|   |     | VHF (153 dB) | 18 km <sup>2</sup>    | 3.0 km           | 2.1 km        | 2.4 km  |
|   |     | PCW (181 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
| 4 sequential piles                                    | PTS | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|   |     | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|   |     | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|   |     | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|   | TTS | LF (179 dB)  | 58 km <sup>2</sup>    | 5.6 km           | 3.5 km        | 4.3 km  |
|   |     | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |
|   |     | VHF (153 dB) | 18 km <sup>2</sup>    | 3.0 km           | 2.1 km        | 2.4 km  |
|   |     | PCW (181 dB) | < 0.1 km <sup>2</sup> | < 100 m          | < 100 m       | < 100 m |

## A.2 Multiple location modelling

Figure A 1 and Figure A 2, Table A 15 and Table A 16 expand on the results presented in section 4.5 for multiple location piling, covering the non-impulsive criteria from Southall *et al.* (2019) for marine mammals. As before, contours too small to be seen at this scale have not been included, impact ranges have not been presented as there are two starting points for fleeing receptors, and fields denoted with a dash “-” show where there is no in-combination effect when the two piles are installed simultaneously.

FINAL FOR ISSUE  
Outer Dowsing Offshore Wind: Underwater Noise Assessment



Figure A 1 Contour plots showing the in-combination impacts of simultaneous installation of monopile foundations at the SW and NE modelling locations for marine mammals using the non-impulsive Southall et al. (2019) criteria assuming a fleeing animal

FINAL FOR ISSUE  
Outer Dowsing Offshore Wind: Underwater Noise Assessment

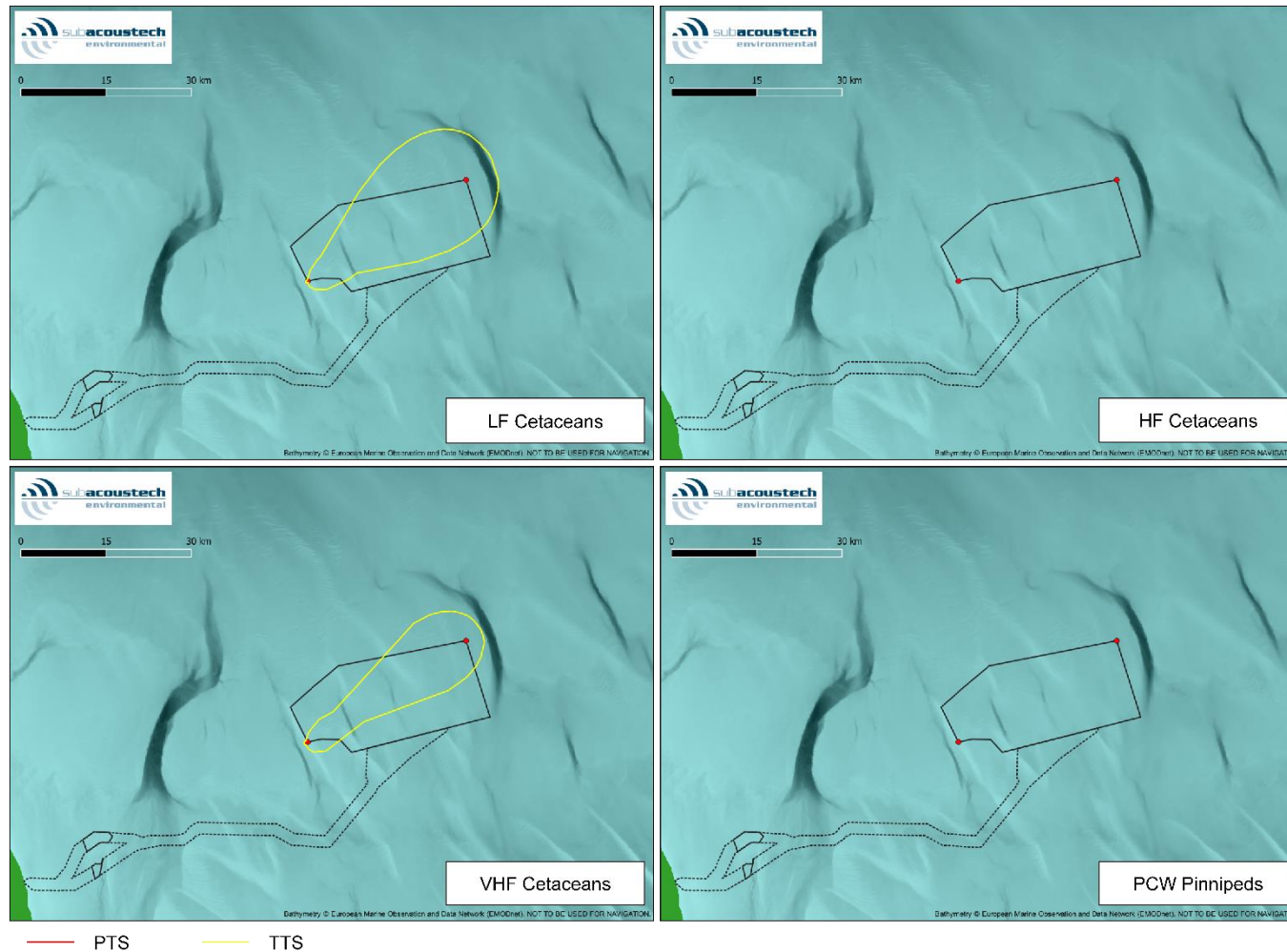


Figure A 2 Contour plots showing the in-combination impacts of simultaneous installation of jacket pile foundations at the SW and NE modelling locations for marine mammals using the non-impulsive Southall et al. (2019) criteria assuming a fleeing animal

Table A 15 Summary of the impact areas for the installation of monopile foundations at the SW and NE modelling locations for marine mammals using the non-impulsive Southall et al. (2019)  $SEL_{cum}$  criteria assuming a fleeing animal

| Monopile foundation<br>Southall et al. (2019)<br>Weighted $SEL_{cum}$ |              | SW area               | NE area               | In-combination area |
|---|--------------|-----------------------|-----------------------|---------------------|
| PTS<br>(Non-impulsive)  | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                   |
|   | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                   |
|   | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                   |
|   | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                   |
| TTS<br>(Non-impulsive)  | LF (179 dB)  | 2.4 km <sup>2</sup>   | 150 km <sup>2</sup>   | 630 km <sup>2</sup> |
|   | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                   |
|   | VHF (153 dB) | 3.1 km <sup>2</sup>   | 46 km <sup>2</sup>    | 380 km <sup>2</sup> |
|   | PCW (181 dB) | < 0.1 km <sup>2</sup> | 0.1 km <sup>2</sup>   | -                   |

Table A 16 Summary of the impact areas for the installation of jacket pile foundations at the SW and NE modelling locations for marine mammals using the non-impulsive Southall et al. (2019)  $SEL_{cum}$  criteria assuming a fleeing animal

| Jacket pile foundation<br>Southall et al. (2019)<br>Weighted $SEL_{cum}$ |              | SW area               | NE area               | In-combination area |
|--|--------------|-----------------------|-----------------------|---------------------|
| PTS<br>(Non-impulsive)   | LF (199 dB)  | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                   |
|  | HF (198 dB)  | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                   |
|  | VHF (173 dB) | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                   |
|  | PCW (201 dB) | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                   |
| TTS<br>(Non-impulsive)   | LF (179 dB)  | 0.2 km <sup>2</sup>   | 89 km <sup>2</sup>    | 530 km <sup>2</sup> |
|  | HF (178 dB)  | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                   |
|  | VHF (153 dB) | 0.7 km <sup>2</sup>   | 25 km <sup>2</sup>    | 300 km <sup>2</sup> |
|  | PCW (181 dB) | < 0.1 km <sup>2</sup> | < 0.1 km <sup>2</sup> | -                   |

## Report documentation page

- This is a controlled document.
- Additional copies should be obtained through the Subacoustech Environmental librarian.
- If copied locally, each document must be marked “Uncontrolled copy”.
- Amendment shall be by whole document replacement.
- Proposals for change to this document should be forwarded to Subacoustech Environmental.

| Document No. | Draft | Date       | Details of change  |
|--------------|-------|------------|--|
| P295R0100    | 01    | 23/10/2022 | Initial writing and internal review                                    |
| P295R0101    | 01    | 29/11/2022 | Draft issued to client   |
| P295R0102    | -     | 19/01/2023 | Amendments following client comments                                   |
| P295R0103    | 01    | 30/03/2023 | Update following new impact piling parameters                          |
| P295R0104    | -     | 11/10/2023 | Minor amendments   |
| P295R0105    | -     | 03/11/2023 | Updates following changes to ODOW Order Limits and modelling locations |
| P295R0106    | -     | 24/01/2024 | Updated figures with latest boundaries                                 |
| P295R0107    | -     | 13/02/2024 | Updates following client comments                                      |
| P295R0108    | -     | 28/02/2024 | Issue to client  |

|  |  |
|--|--|
| Originator’s current report number   | P295R0108  |
| Originator’s name and location   | R Barham; Subacoustech Environmental Ltd.                  |
| Contract number and period covered   | P295; September 2022 – February 2024                       |
| Sponsor’s name and location  | P New; GoBe Consultants                                    |
| Report classification and caveats in use   | FINAL FOR ISSUE  |
| Date written   | October 2022 – November 2023, January 2024 – February 2024 |
| Pagination   | Cover + xii + 81   |
| References   | 42   |
| Report title   | Outer Dowsing Offshore Wind: Underwater Noise Assessment   |
| Translation/Conference details (if translation, give foreign title/if part of a conference, give conference particulars) |  |
| Title classification   | Unclassified   |
| Author(s)  | Richard Barham, Tim Mason                                  |
| Descriptors/keywords   |  |
| Abstract   |  |
| Abstract classification  | Unclassified; Unlimited distribution                       |