
# Hornsea Project Four: Environmental Statement (ES)

## PINS Document Reference: A4.4.5
## APFP Regulation: 5(2)(a)

# Volume A4, Annex 4.5: Subsea Noise Technical Report Part 2

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**Checked** GoBe Consultants Ltd. June 2021
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Doc. no. A4.4.5
Version B

# 5 Impact Piling Noise Modelling Outputs

## 5.1 Unweighted subsea noise modelling

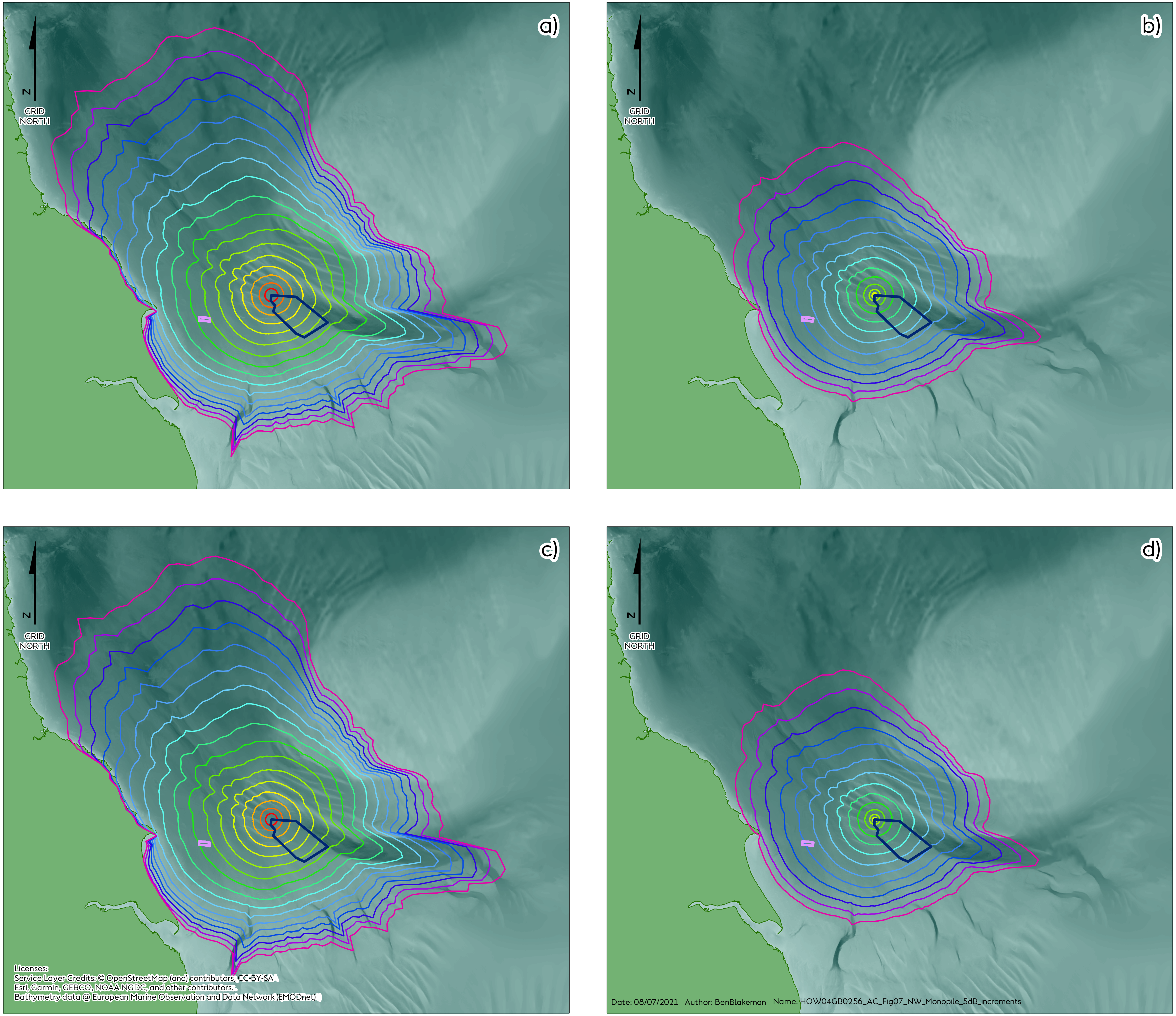
5.1.1.1 This section presents the unweighted noise level results (i.e. in the absence of any frequency weighting applied for hearing sensitivity) from the modelling undertaken for impact piling operations using the parameters detailed in **Section 2.2.2**.

5.1.1.2 The following figures present unweighted $SPL_{peak}$ and $SEL_{ss}$ noise levels from impact piling operations at the modelling locations at Hornsea Four illustrated in **Figure 6**. **Figure 7** to **Figure 14** show the unweighted $SPL_{peak}$ and $SEL_{ss}$ for monopiles and pin piles for the maximum design and most-likely installation scenarios discussed in **Section 4.3**.

5.1.1.3 Comparing these plots shows that, in general, the increased noise levels are expected to occur in deeper water, for example the Outer Silver Pit to the east of the Hornsea Four array area (as shown in **Figure 4**). The effect of the differing water depths on noise transmission is also shown at greater distances to the north west of the site, where more "jagged" contours occur over the shallow areas and deeper channels.

5.1.1.4 Due to the transient nature of impact piling noise, the impulsive noise introduced to the water will return to background levels within seconds of the impulse passing. The $SPL_{peak}$ and $SEL_{ss}$ outputs shown on these plots should not be confused with background or ambient noise levels, which are typically described in terms of $SPL_{RMS}$. The different metrics are not directly comparable.

5.1.1.5 Level vs range plots are presented in **Figure 15** showing the noise levels from a deep water transect for both monopiles and pin piles giving the highest noise levels at range. These are 316° from the NW modelling location using the maximum design parameters.




# Hornsea Four

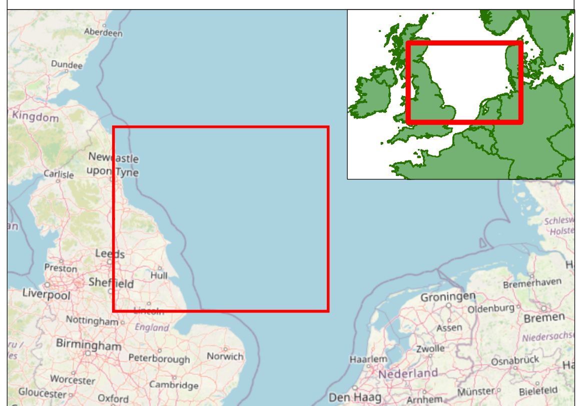
## Figure 7

Contour plot showing the unweighted noise levels in 5 dB increments for the maximum design (a: SPLpeak and b: SELss) and most-likely (c: SPLpeak and d: SELss) monopile parameters at the NW modelling location

Array Area
HVAC Booster Station Works Area

Water Depth (m below CD)
0
100

Noise Level (dB)
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195
200



Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:2,250,000

0 40 80 Kilometres
0 20 40 Nautical Miles

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Figure 7
Contour Plot
Document no: HOW04GB0256
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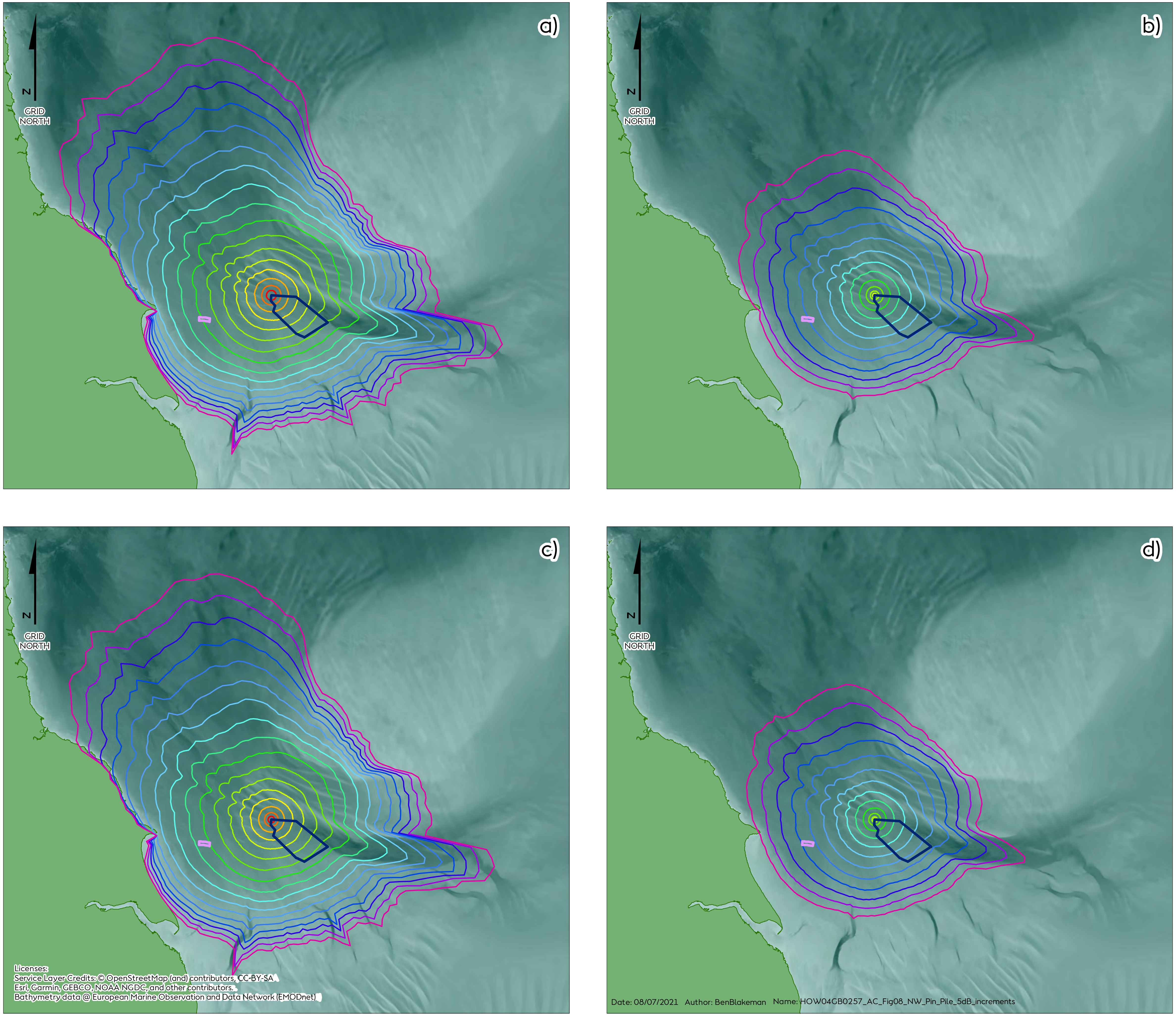
Approved by: LK

# Hornsea Four

Figure 8

Contour plot showing the unweighted noise levels in 5 dB increments for the maximum design (a: SPLpeak and b: SELss) and most-likely (c: SPLpeak and d: SELss) pin pile parameters at the NW modelling location




Array Area

HVAC Booster Station Works Area

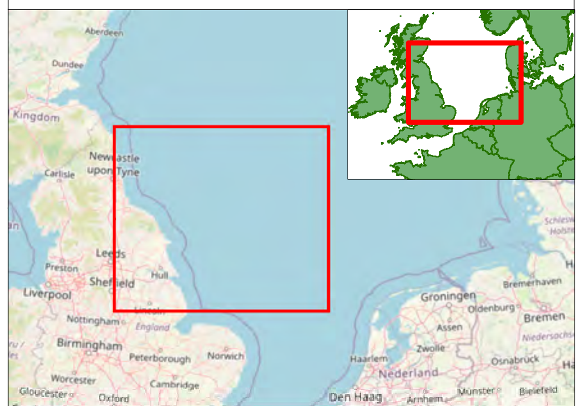
Water Depth (m below CD)

0

100

Noise Level (dB)

120, 125, 130, 135, 140, 145, 150, 155, 160, 165, 170, 175, 180, 185, 190, 195, 200



Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:2,250,000

0 40 80 Kilometres

0 20 40 Nautical Miles

| REV | REMARK | DATE |
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Figure 8

Contour Plot

Document no: HOW04GB0257

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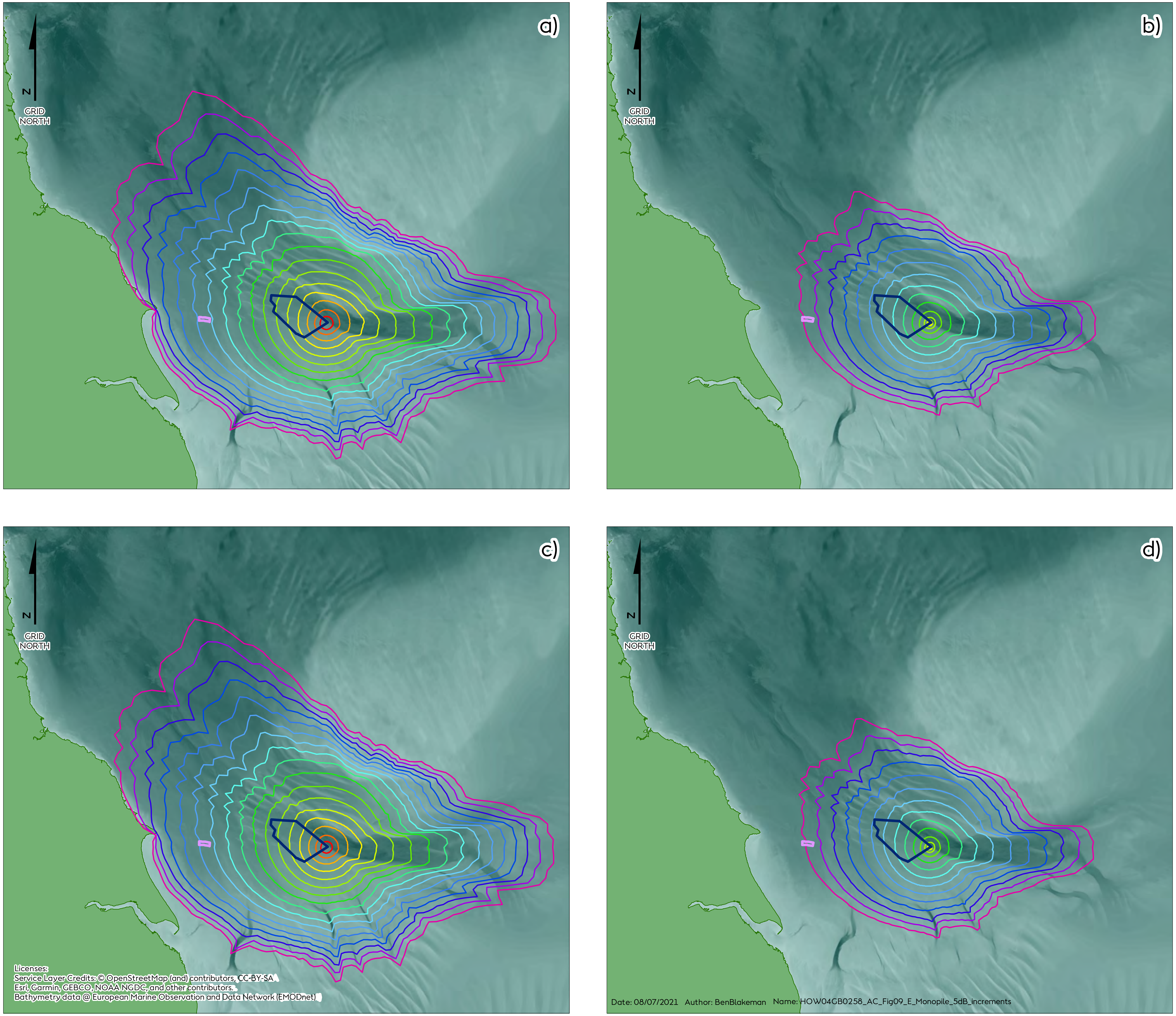
Checked by: AL

Approved by: LK




# Hornsea Four

## Figure 9

Contour plot showing the unweighted noise levels in 5 dB increments for the maximum design (a: SPLpeak and b: SELss) and most-likely (c: SPLpeak and d: SELss) monopile parameters at the E modelling location

Array Area

HVAC Booster Station Works Area

Water Depth (m below CD)

0

100

Noise Level (dB)

| | |
|---|---|
| 120 | 160 |
| 125 | 165 |
| 130 | 170 |
| 135 | 175 |
| 140 | 180 |
| 145 | 185 |
| 150 | 190 |
| 155 | 195 |
| | 200 |


Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:2,250,000

0 40 80 Kilometres

0 20 40 Nautical Miles

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Figure 9
Contour Plot
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Checked by: AL
Approved by: LK

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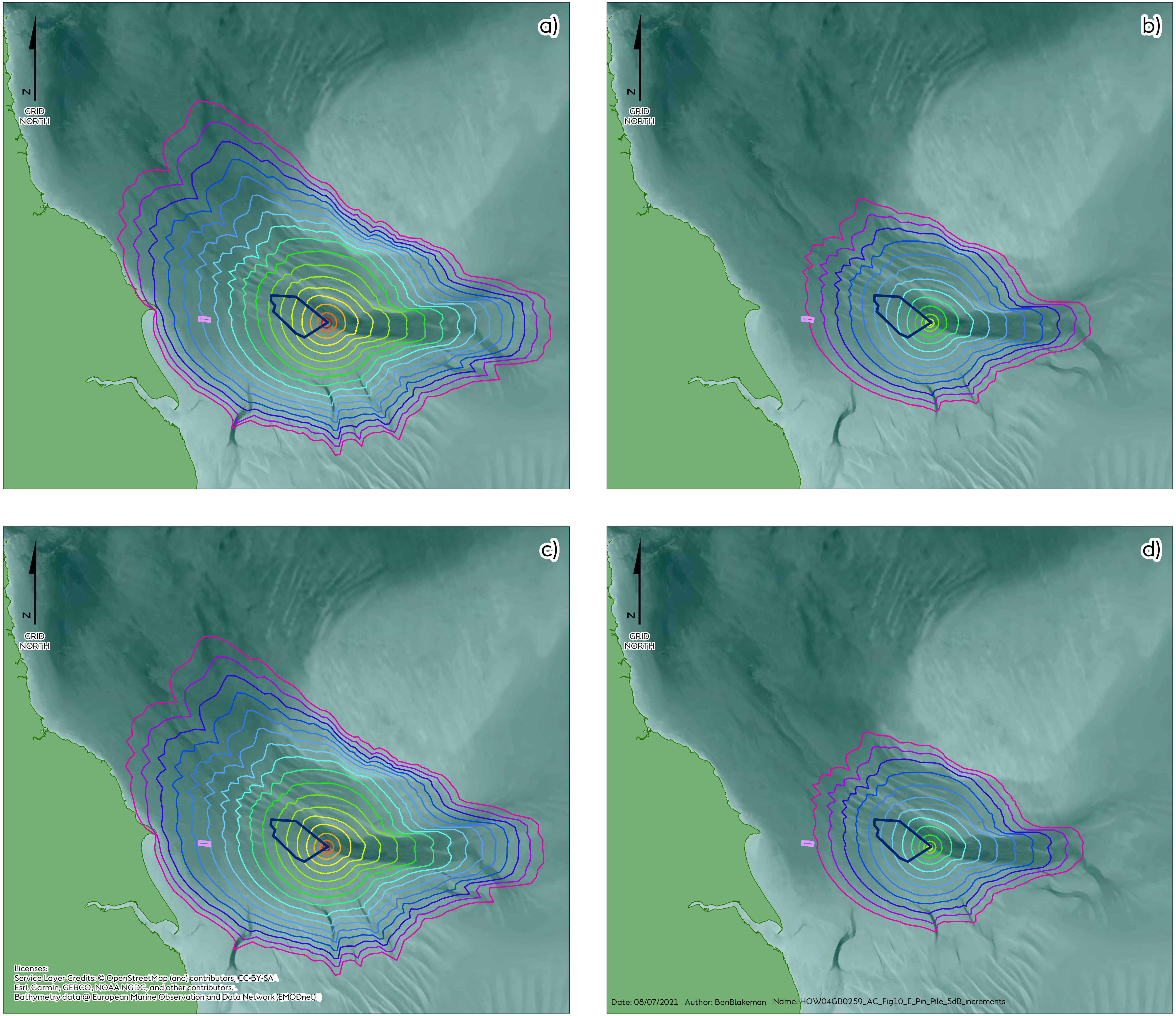





Date: 08/07/2021 Author: BenBlakeman Name: HOW04GB0259_AC_Fig10_E_Pin_Pile_5dB_increments

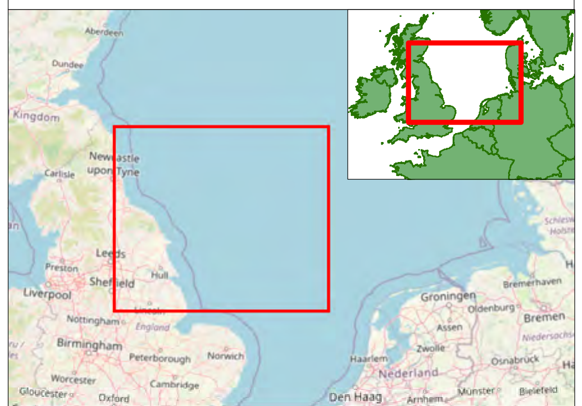
# Hornsea Four

## Figure 10

Contour plot showing the unweighted noise levels in 5 dB increments for the maximum design (a: SPLpeak and b: SELss) and most-likely (c: SPLpeak and d: SELss) pin pile parameters at the E modelling location

Array Area
HVAC Booster Station Works Area
Water Depth (m below CD)
0
100

Noise Level (dB)
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195
200



Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:2,250,000
0 40 80 Kilometres
0 20 40 Nautical Miles

| REV | REMARK | DATE |
|---|---|---|
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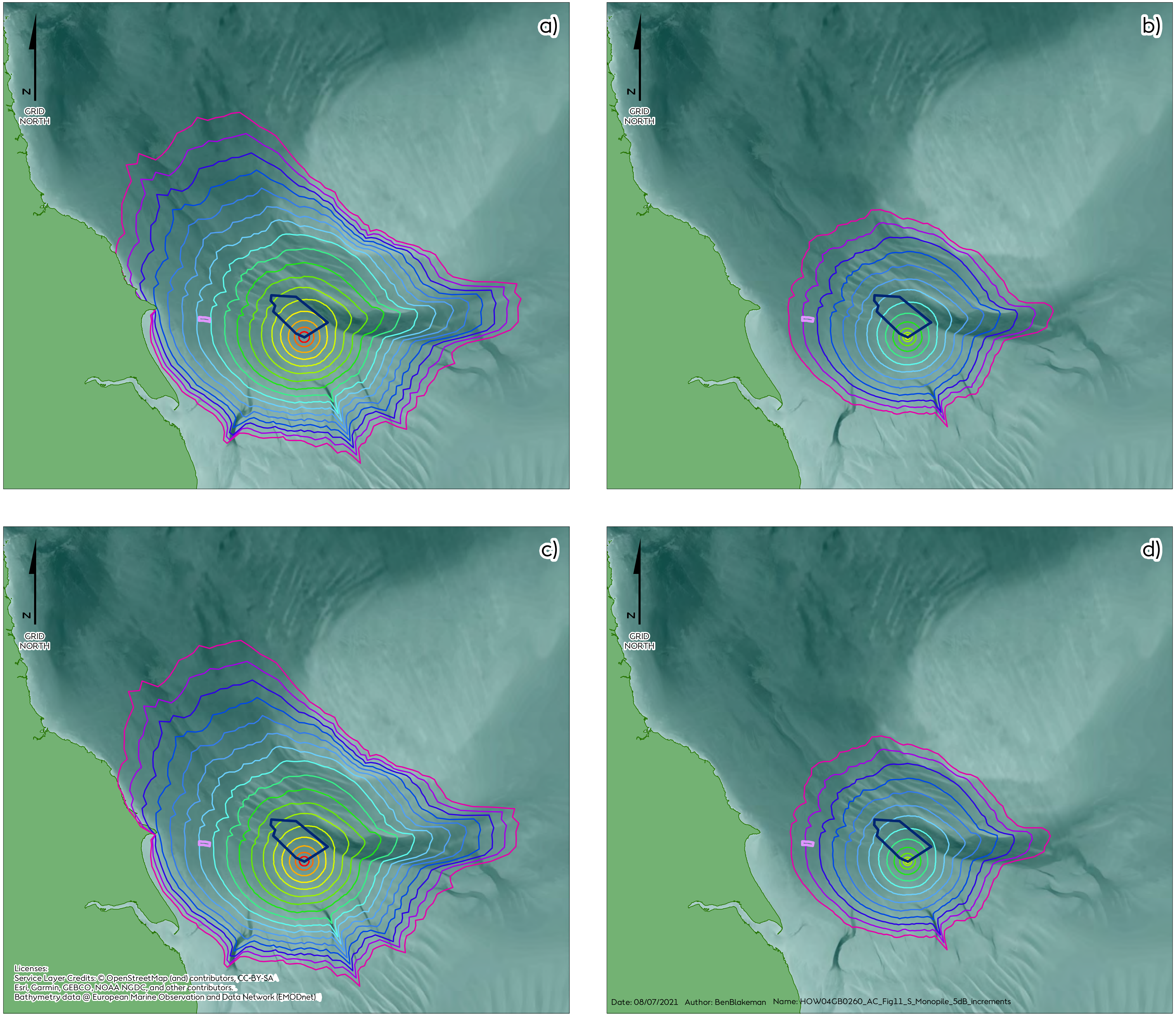
Figure 10
Contour Plot
Document no: HOW04GB0259
Created by: BPHB
Checked by: AL
Approved by: LK




# Hornsea Four

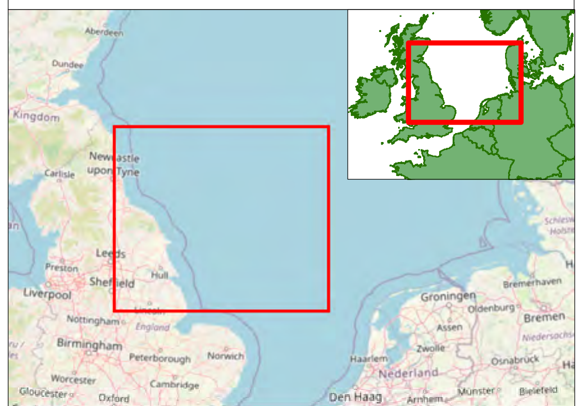
## Figure 11

Contour plot showing the unweighted noise levels in 5 dB increments for the maximum design (a: SPLpeak and b: SELss) and most-likely (c: SPLpeak and d: SELss) monopile parameters at the S modelling location

Array Area
HVAC Booster Station Works Area

Water Depth (m below CD)
0
100

Noise Level (dB)
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195
200



Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:2,250,000

0 40 80 Kilometres

0 20 40 Nautical Miles

| REV | REMARK | DATE |
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Figure 11
Contour Plot
Document no: HOW04GB0260
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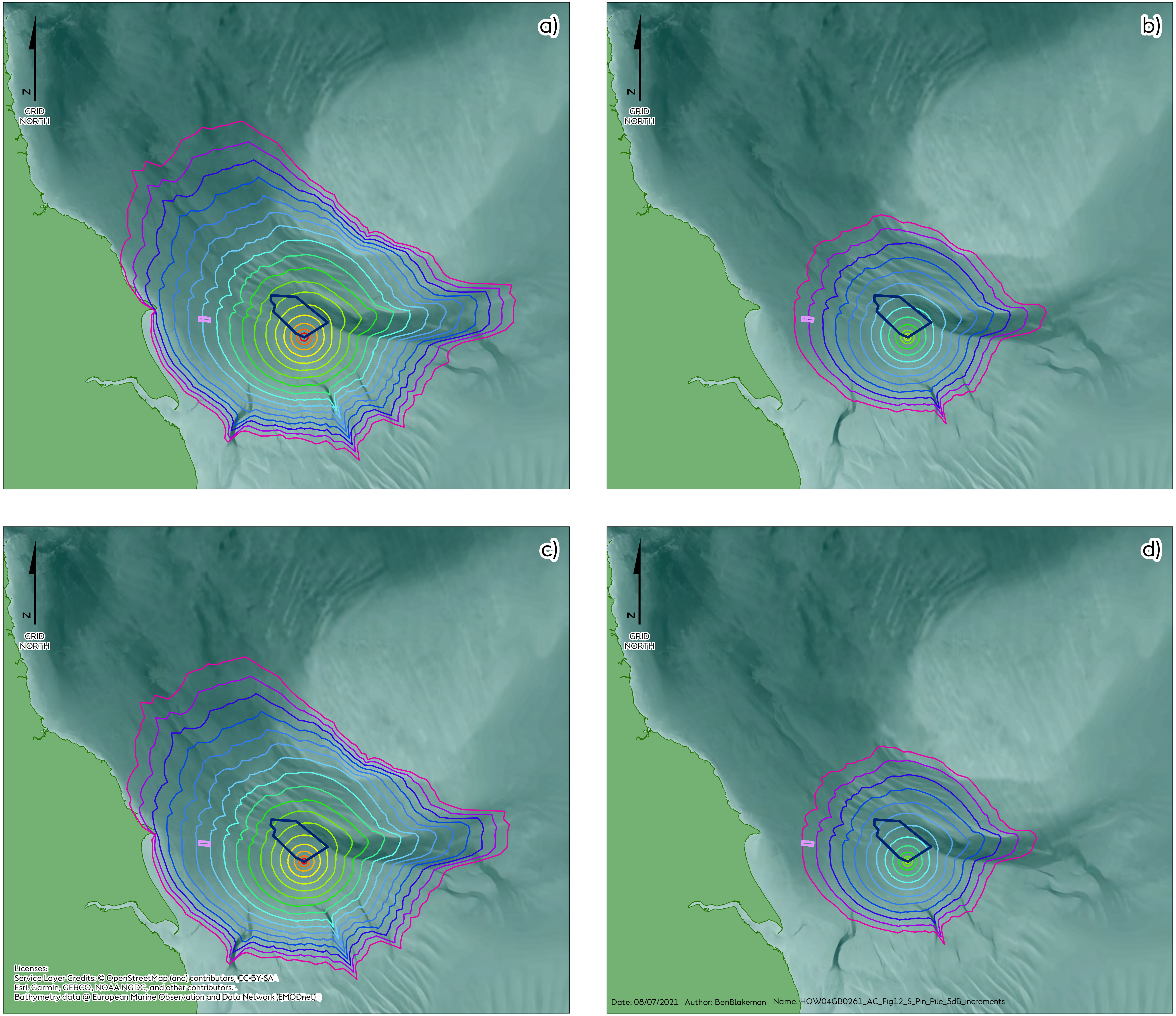
Checked by: AL
Approved by: LK




# Hornsea Four

## Figure 12

Contour plot showing the unweighted noise levels in 5 dB increments for the maximum design (a: SPLpeak and b: SELss) and most-likely (c: SPLpeak and d: SELss) pin pile parameters at the S modelling location

Array Area

HVAC Booster Station Works Area

Water Depth (m below CD)

0

100

Noise Level (dB)

120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195
200

Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:2,250,000

0 40 80 Kilometres

0 20 40 Nautical Miles

| REV | REMARK | DATE |
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Figure 12
Contour Plot
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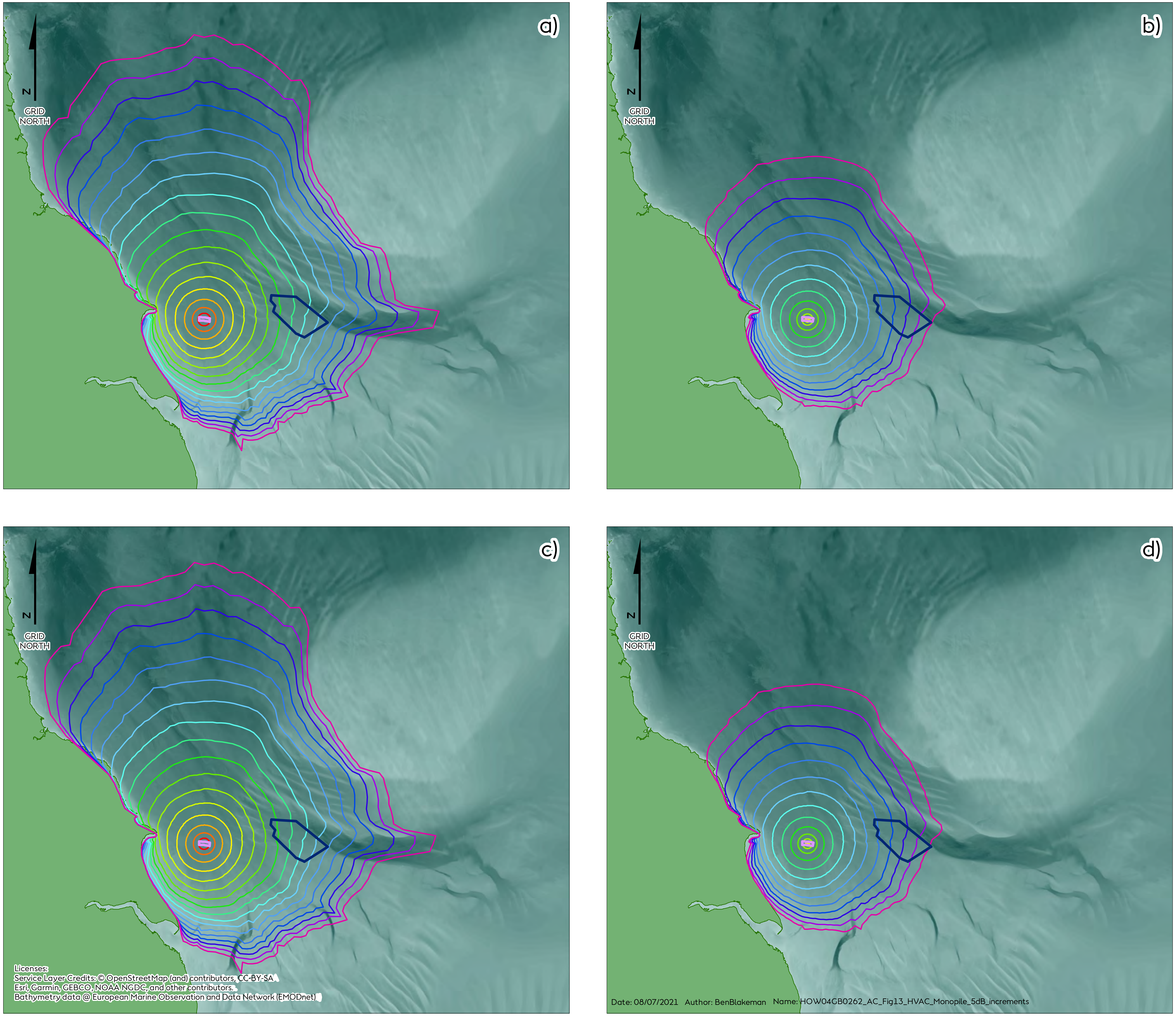
Created by: BPHB
Checked by: AL
Approved by: LK




# Hornsea Four

## Figure 13

Contour plot showing the unweighted noise levels in 5 dB increments for the maximum design (a: SPLpeak and b: SELss) and most-likely (c: SPLpeak and d: SELss) monopile parameters at the NVAC modelling location

Array Area

HVAC Booster Station Works Area

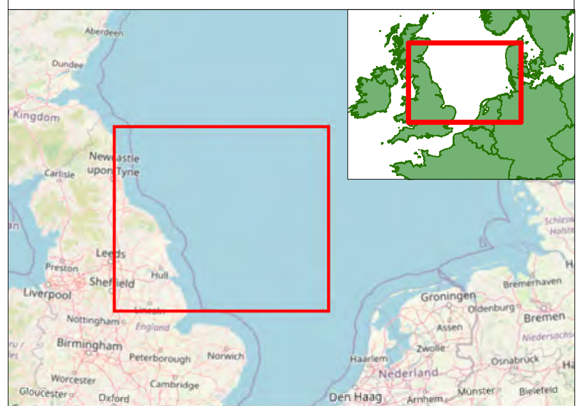
Water Depth (m below CD)

0

100

Noise Level (dB)

120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195
200



Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:2,250,000

0 40 80 Kilometres

0 20 40 Nautical Miles

| REV | REMARK | DATE |
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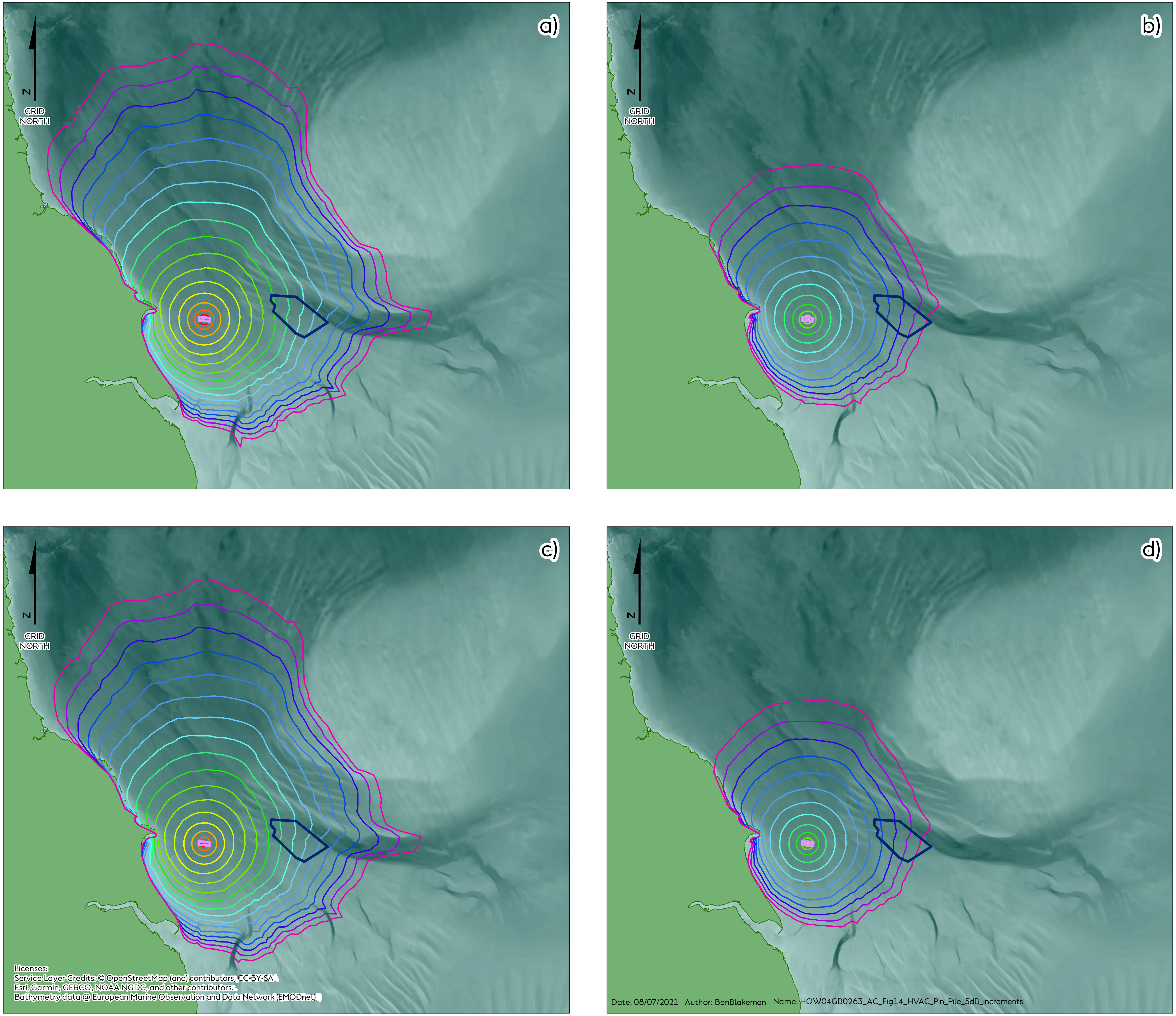
Figure 13
Contour Plot
Document no: HOW04GB0262
Created by: BPHB
Checked by: AL
Approved by: LK




# Hornsea Four

Figure 14

Contour plot showing the unweighted noise levels in 5 dB increments for the maximum design (a: SPLpeak and b: SELss) and most-likely (c: SPLpeak and d: SELss) pin pile parameters at the HVAC modelling location

Array Area

HVAC Booster Station Works Area

Water Depth (m below CD)

0

100

Noise Level (dB)

120, 125, 130, 135, 140, 145, 150, 155, 160, 165, 170, 175, 180, 185, 190, 195, 200

Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:2,250,000

0 40 80 Kilometres

0 20 40 Nautical Miles

| REV | REMARK | DATE |
|---|---|---|
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Figure 14
Contour Plot
Document no: HOW04GB0263
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Approved by: LK

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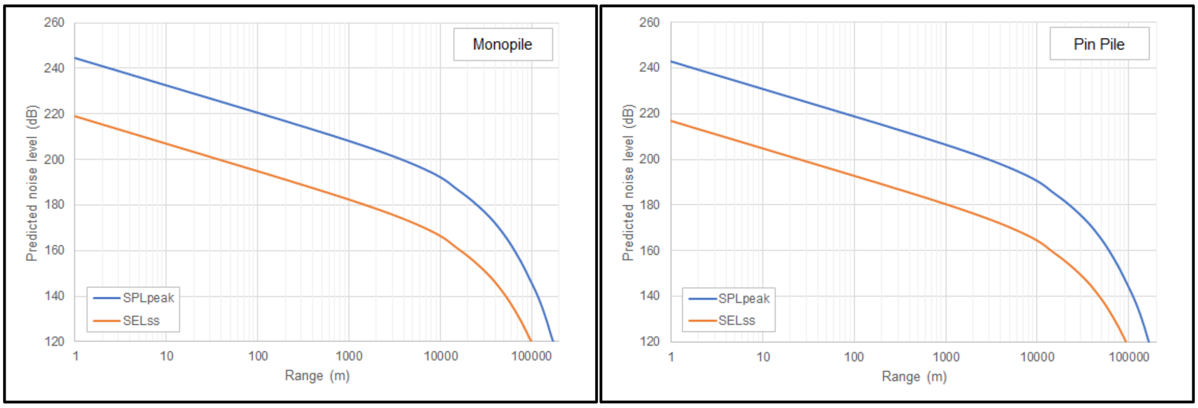



**Figure 15: Level vs. range plots showing the unweighted $SPL_{peak}$ and $SEL_{ss}$ noise levels along one of the longest predicted transects; 316° from the NW modelling location using the maximum design parameters.**

## 5.2 Noise modelling results in respect of marine mammal and fish impact criteria

### 5.2.1 Introduction

5.2.1.1 This section presents the modelling results in terms of noise metrics and criteria covered in **Section 2.2**. This discussion will guide the assessment of environmental impact from the predicted impact piling noise on marine species (see **Volume A2, Chapter 3: Fish and Shellfish Ecology** and **Volume A2, Chapter 4: Marine Mammals**). For all the results given in the following sections, ranges calculated to be less than 50 m for single strike criteria and 100 m for cumulative criteria have not been included due to the uncertainty in the accuracy of the results at such close range. In this case, the ranges are given as "< 50 m" or "< 100 m," indicating that the impact range will be within this distance.

### 5.2.2 Marine mammal criteria

5.2.2.1 This section presents the modelling results in biological terms for various species of marine mammals using the Southall et al. (2019) guidance. Interpretation of these modelling results are provided in **Volume A2, Chapter 4: Marine Mammals**. As discussed in **paragraph 2.2.2.12**, for the $SEL_{cum}$ criteria, fleeing animal speeds of 3.25 $ms^{-1}$ (Blix and Folkow 1995) for LF cetaceans and 1.5 $ms^{-1}$ (Otani et al. 2000) for other species of marine mammal have been used. It should be reiterated that the marine mammal naming terminology used by Southall et al. (2019) is different to that used by NMFS (2018) and Southall et al. (2007), in that the former MF and HF categories are now effectively presented as HF and VHF, respectively.

5.2.2.2 **Table 13** to **Table 44** present the predicted PTS and TTS impact ranges for the different marine mammal hearing groups using the Southall et al. (2019) thresholds. The criteria are given as unweighted $SPL_{peak}$ or weighted $SEL_{cum}$ based on the hearing sensitivity of the receptor. Multiple pulse ($SEL_{cum}$) includes the noise exposure to a fleeing animal receptor over the entire installation period. In addition, instantaneous $SPL_{peak}$ values for the first strike of each scenario have been given. **Volume A2, Chapter 4: Marine Mammals** provides an assessment of behavioural disturbance in marine mammals based on dose-response curves and the 5 dB increment $SEL_{ss}$ contours shown above in **Figure 7** to **Figure 14**.

5.2.2.3 Further to this, impact ranges for three pin piles installed consecutively in a single 24-hour period at the NW location are given in **Table 45** to **Table 48**. When considering a fleeing animal, the addition of two extra piling scenarios does not have a great effect on impact ranges as, following the first pile, the animal will have reached a distance where the noise is of a much lower level and thus contributes a relatively low additional exposure.

5.2.2.4 There is also the potential for piling to occur at two locations concurrently under the maximum design scenario. This modelling scenario is covered in depth and is presented in **Section 5.3**.

5.2.2.5 In line with the unweighted results shown in **Section 5.1**, the largest predicted ranges occur over the deeper water areas and transects with maximum $SEL_{cum}$ PTS ranges of 11 km for LF cetaceans for monopiles and 12 km for VHF cetaceans for pin piles. The larger impact ranges for pin piles for HF and VHF cetaceans are also caused by the frequencies filtered by the Southall et al. (2019) species group weightings (**Table 2** and **Table 3**); this is discussed further in **paragraphs 5.2.2.6** to **5.2.2.9** after the results tables.

Impact ranges – maximum design monopile

**Table 13: Summary of the $SPL_{peak}$ Southall et al. (2019) PTS impact ranges for the four modelling locations considering the maximum design monopile input parameters.**

| Southall et al. (2019) – PTS | | | Maximum design – Monopile (5,000 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Unweighted $SPL_{peak}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 219 dB | 0.06 km² | 140 m | 140 m | 140 m |
| | HF | 230 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 25 km² | 2.9 km | 2.8 km | 2.8 km |
| | PCW | 218 dB | 0.09 km² | 170 m | 170 m | 170 m |
| E | LF | 219 dB | 0.06 km² | 140 m | 140 m | 140 m |
| | HF | 230 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 25 km² | 2.9 km | 2.7 km | 2.8 km |
| | PCW | 218 dB | 0.09 km² | 170 m | 170 m | 170 m |
| S | LF | 219 dB | 0.04 km² | 120 m | 120 m | 120 m |
| | HF | 230 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 16 km² | 2.3 km | 2.3 km | 2.3 km |
| | PCW | 218 dB | 0.06 km² | 140 m | 140 m | 140 m |
| HVAC | LF | 219 dB | 0.06 km² | 140 m | 140 m | 140 m |
| | HF | 230 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 25 km² | 2.8 km | 2.8 km | 2.8 km |
| | PCW | 218 dB | 0.09 km² | 170 m | 170 m | 170 m |

**Table 14: Summary of the $SPL_{peak}$ Southall et al. (2019) TTS impact ranges for the four modelling locations considering the maximum design monopile input parameters.**

| Southall et al. (2019) – TTS | | | Maximum design – Monopile (5,000 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Unweighted $SPL_{peak}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 213 dB | 0.57 km$^2$ | 430 m | 430 m | 430 m |
| | HF | 224 dB | < 0.01 km$^2$ | 60 m | 50 m | 60 m |
| | VHF | 196 dB | 130 km$^2$ | 6.6 km | 6.3 km | 6.5 km |
| | PCW | 212 dB | 0.82 km$^2$ | 510 m | 510 m | 510 m |
| E | LF | 213 dB | 0.57 km$^2$ | 430 m | 430 m | 430 m |
| | HF | 224 dB | < 0.01 km$^2$ | 60 m | 50 m | 60 m |
| | VHF | 196 dB | 130 km$^2$ | 7.0 km | 6.0 km | 6.5 km |
| | PCW | 212 dB | 0.82 km$^2$ | 510 m | 510 m | 510 m |
| S | LF | 213 dB | 0.39 km$^2$ | 360 m | 350 m | 350 m |
| | HF | 224 dB | < 0.01 km$^2$ | 50 m | 50 m | 50 m |
| | VHF | 196 dB | 80 km$^2$ | 5.2 km | 5.0 km | 5.1 km |
| | PCW | 212 dB | 0.56 km$^2$ | 430 m | 420 m | 430 m |
| HVAC | LF | 213 dB | 0.57 km$^2$ | 430 m | 430 m | 430 m |
| | HF | 224 dB | < 0.01 km$^2$ | 60 m | 50 m | 60 m |
| | VHF | 196 dB | 130 km$^2$ | 6.4 km | 6.3 km | 6.3 km |
| | PCW | 212 dB | 0.82 km$^2$ | 510 m | 510 m | 510 m |

**Table 15: Summary of the impulsive $SEL_{cum}$ Southall et al. (2019) PTS impact ranges for the four modelling locations considering the maximum design monopile input parameters assuming a fleeing receptor.**

| Southall et al. (2019) – PTS | | | Maximum design – Monopile (5,000 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Weighted $SEL_{cum}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 183 dB | 66 km$^2$ | 6.9 km | 3.7 km | 4.5 km |
| | HF | 185 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 155 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 185 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| E | LF | 183 dB | 76 km$^2$ | 11 km | 1.6 km | 4.3 km |
| | HF | 185 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 155 dB | 0.09 km$^2$ | 450 m | < 100 m | 100 m |
| | PCW | 185 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| S | LF | 183 dB | 5.6 km$^2$ | 2.5 km | < 100 m | 1.0 km |
| | HF | 185 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 155 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 185 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| HVAC | LF | 183 dB | 65 km$^2$ | 5.8 km | 3.5 km | 4.5 km |
| | HF | 185 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 155 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 185 dB | < 0.01 km$^2$ | < 100 km$^2$ | < 100 m | < 100 m |

**Table 16: Summary of the impulsive $SEL_{cum}$ Southall et al. (2019) TTS impact ranges for the four modelling locations considering the maximum design monopile input parameters assuming a fleeing receptor.**

| Southall et al. (2019) – TTS | | | Maximum design – Monopile (5,000 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Weighted $SEL_{cum}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 168 dB | 2200 $km^2$ | 36 km | 21 km | 26 km |
| | HF | 170 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 140 dB | 860 $km^2$ | 20 km | 15 km | 17 km |
| | PCW | 170 dB | 670 $km^2$ | 18 km | 13 km | 15 km |
| E | LF | 168 dB | 1800 $km^2$ | 42 km | 16 km | 23 km |
| | HF | 170 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 140 dB | 810 $km^2$ | 25 km | 12 km | 16 km |
| | PCW | 170 dB | 640 $km^2$ | 22 km | 10 km | 14 km |
| S | LF | 168 dB | 1200 $km^2$ | 27 km | 13 km | 19 km |
| | HF | 170 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 140 dB | 460 $km^2$ | 15 km | 9.4 km | 12 km |
| | PCW | 170 dB | 340 $km^2$ | 13 km | 8.2 km | 10 km |
| HVAC | LF | 168 dB | 1800 $km^2$ | 32 km | 16 km | 24 km |
| | HF | 170 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 140 dB | 840 $km^2$ | 19 km | 14 km | 16 km |
| | PCW | 170 dB | 660 $km^2$ | 17 km | 12 km | 14 km |

**Table 17: Summary of the non-impulsive $SEL_{cum}$ Southall et al. (2019) PTS impact ranges for the four modelling locations considering the maximum design monopile input parameters assuming a fleeing receptor.**

| Southall et al. (2019) – PTS | | | Maximum design – Monopile (5,000 kJ) / Non-impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Weighted $SEL_{cum}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 199 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | HF | 198 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 173 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 201 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| E | LF | 199 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | HF | 198 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 173 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 201 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| S | LF | 199 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | HF | 198 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 173 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 201 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| HVAC | LF | 199 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | HF | 198 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 173 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 201 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |

**Table 18: Summary of the non-impulsive $SEL_{cum}$ Southall et al. (2019) TTS impact ranges for the four modelling locations considering the maximum design monopile input parameters assuming a fleeing receptor.**

| Southall et al. (2019) – TTS *Weighted $SEL_{cum}$* | | | Maximum design – Monopile (5,000 kJ) / Non-impulsive criteria | | | |
|---|---|---|---|---|---|---|
| | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 179 dB | 300 km² | 13 km | 8.4 km | 9.8 km |
| | HF | 178 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | VHF | 153 dB | 5.3 km² | 1.7 km | 1.0 km | 1.3 km |
| | PCW | 181 dB | 11 km² | 2.3 km | 1.6 km | 1.8 km |
| E | LF | 179 dB | 290 km² | 18 km | 5.4 km | 9.0 km |
| | HF | 178 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | VHF | 153 dB | 7.7 km² | 2.7 km | 380 m | 1.3 km |
| | PCW | 181 dB | 14 km² | 3.4 km | 800 m | 1.9 km |
| S | LF | 179 dB | 97 km² | 8.0 km | 3.2 km | 5.3 km |
| | HF | 178 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | VHF | 153 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | PCW | 181 dB | < 0.01 km² | 170 m | < 100 m | < 100 m |
| HVAC | LF | 179 dB | 290 km² | 12 km | 7.3 km | 9.6 km |
| | HF | 178 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | VHF | 153 dB | 4.5 km² | 1.4 km | 1.1 km | 1.2 km |
| | PCW | 181 dB | 9.5 km² | 1.9 km | 1.6 km | 1.7 km |

**Table 19: Summary of the $SPL_{peak}$ Southall et al. (2019) PTS impact ranges for the four modelling locations for the initial piling strike considering the maximum design monopile input parameters.**

| Southall et al. (2019) – PTS *Unweighted $SPL_{peak}$* | | | Maximum design – Monopile, first strike (1,000 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 219 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | HF | 230 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 1.7 km² | 740 m | 740 m | 740 m |
| | PCW | 218 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| E | LF | 219 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | HF | 230 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 1.7 km² | 740 m | 740 m | 740 m |
| | PCW | 218 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| S | LF | 219 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | HF | 230 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 1.1 km² | 600 m | 590 m | 590 m |
| | PCW | 218 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| HVAC | LF | 219 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | HF | 230 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 1.7 km² | 740 m | 740 m | 740 m |
| | PCW | 218 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |

**Table 20: Summary of the $SPL_{peak}$ Southall et al. (2019) TTS impact ranges for the four modelling locations for the initial piling strike considering the maximum design monopile input parameters.**

| Southall et al. (2019) – TTS | | | Maximum design – Monopile, first strike (1,000 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Unweighted $SPL_{peak}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 213 dB | 0.03 km² | 100 m | 100 m | 100 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 13 km² | 2.1 km | 2.1 km | 2.1 km |
| | PCW | 212 dB | 0.04 km² | 120 m | 120 m | 120 m |
| E | LF | 213 dB | 0.03 km² | 100 m | 100 m | 100 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 13 km² | 2.1 km | 2.0 km | 2.1 km |
| | PCW | 212 dB | 0.04 km² | 120 m | 120 m | 120 m |
| S | LF | 213 dB | 0.02 km² | 80 m | 80 m | 80 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 8.4 km² | 1.6 km | 1.6 km | 1.6 km |
| | PCW | 212 dB | 0.03 km² | 100 m | 90 m | 100 m |
| HVAC | LF | 213 dB | 0.03 km² | 100 m | 100 m | 100 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 13 km² | 2.1 km | 2.1 km | 2.1 km |
| | PCW | 212 dB | 0.04 km² | 120 m | 120 m | 120 m |

Impact ranges – maximum design pin pile

**Table 21: Summary of the $SPL_{peak}$ Southall et al. (2019) PTS impact ranges for the four modelling locations considering the maximum design pin pile input parameters.**

| Southall et al. (2019) – PTS | | | Maximum design – Pin pile (3,000 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Unweighted $SPL_{peak}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 219 dB | 0.03 km² | 100 m | 100 m | 100 m |
| | HF | 230 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 13 km² | 2.1 km | 2.0 km | 2.1 km |
| | PCW | 218 dB | 0.04 km² | 120 m | 120 m | 120 m |
| E | LF | 219 dB | 0.03 km² | 100 m | 100 m | 100 m |
| | HF | 230 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 13 km² | 2.1 km | 2.0 km | 2.0 km |
| | PCW | 218 dB | 0.04 km² | 120 m | 120 m | 120 m |
| S | LF | 219 dB | 0.02 km² | 80 m | 80 m | 80 m |
| | HF | 230 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 8.6 km² | 1.7 km | 1.7 km | 1.7 km |
| | PCW | 218 dB | 0.03 km² | 100 m | 100 m | 100 m |
| HVAC | LF | 219 dB | 0.03 km² | 100 m | 100 m | 100 m |
| | HF | 230 dB | < 0.01 km² | < 50 km² | < 50 m | < 50 m |
| | VHF | 202 dB | 13 km² | 2.1 km | 2.1 km | 2.1 km |
| | PCW | 218 dB | 0.04 km² | 120 m | 120 m | 120 m |

**Table 22: Summary of the $SPL_{peak}$ Southall et al. (2019) TTS impact ranges for the four modelling locations considering the maximum design pin pile input parameters.**

| Southall et al. (2019) – TTS | | | Maximum design – Pin pile (3,000 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Unweighted $SPL_{peak}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 213 dB | 0.27 km² | 300 m | 300 m | 300 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 79 km² | 5.1 km | 4.9 km | 5.0 km |
| | PCW | 212 dB | 0.39 km² | 360 m | 360 m | 360 m |
| E | LF | 213 dB | 0.27 km² | 300 m | 290 m | 300 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 78 km² | 5.4 km | 4.7 km | 5.0 km |
| | PCW | 212 dB | 0.39 km² | 360 m | 350 m | 360 m |
| S | LF | 213 dB | 0.18 km² | 240 m | 240 m | 240 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 48 km² | 4.0 km | 3.9 km | 3.9 km |
| | PCW | 212 dB | 0.27 km² | 290 m | 290 m | 290 m |
| HVAC | LF | 213 dB | 0.27 km² | 300 m | 300 m | 300 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 76 km² | 5.0 km | 4.9 km | 4.9 km |
| | PCW | 212 dB | 0.4 km² | 360 m | 360 m | 360 m |

**Table 23: Summary of the impulsive $SEL_{cum}$ Southall et al. (2019) PTS impact ranges for the four modelling locations considering the maximum design pin pile input parameters assuming a fleeing receptor.**

| Southall et al. (2019) – PTS | | | Maximum design – Pin pile (3,000 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Weighted $SEL_{cum}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 183 dB | 42 km² | 5.8 km | 2.9 km | 3.6 km |
| | HF | 185 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | VHF | 155 dB | 160 km² | 8.8 km | 6.6 km | 7.2 km |
| | PCW | 185 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| E | LF | 183 dB | 53 km² | 9.2 km | 930 m | 3.5 km |
| | HF | 185 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | VHF | 155 dB | 170 km² | 12 km | 4.9 km | 7.2 km |
| | PCW | 185 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| S | LF | 183 dB | 1.5 km² | 1.5 km | < 100 m | 440 m |
| | HF | 185 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | VHF | 155 dB | 51 km² | 5.0 km | 3.3 km | 4.0 km |
| | PCW | 185 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| HVAC | LF | 183 dB | 41 km² | 4.7 km | 2.7 km | 3.6 km |
| | HF | 185 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | VHF | 155 dB | 160 km² | 7.9 km | 6.6 km | 7.2 km |
| | PCW | 185 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |

**Table 24: Summary of the impulsive $SEL_{cum}$ Southall et al. (2019) TTS impact ranges for the four modelling locations considering the maximum design pin pile input parameters assuming a fleeing receptor.**

| Southall et al. (2019) – TTS | | | Maximum design – Pin pile (3,000 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Weighted $SEL_{cum}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 168 dB | 2000 km$^2$ | 35 km | 20 km | 25 km |
| | HF | 170 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 140 dB | 2500 km$^2$ | 36 km | 24 km | 28 km |
| | PCW | 170 dB | 480 km$^2$ | 15 km | 11 km | 12 km |
| E | LF | 168 dB | 1600 km$^2$ | 40 km | 15 km | 22 km |
| | HF | 170 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 140 dB | 2100 km$^2$ | 42 km | 19 km | 25 km |
| | PCW | 170 dB | 470 km$^2$ | 19 km | 8.9 km | 12 km |
| S | LF | 168 dB | 1000 km$^2$ | 26 km | 12 km | 18 km |
| | HF | 170 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 140 dB | 1400 km$^2$ | 29 km | 16 km | 21 km |
| | PCW | 170 dB | 220 km$^2$ | 10 km | 6.8 km | 8.4 km |
| HVAC | LF | 168 dB | 1700 km$^2$ | 31 km | 15 km | 23 km |
| | HF | 170 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 140 dB | 2200 km$^2$ | 33 km | 20 km | 26 km |
| | PCW | 170 dB | 480 km$^2$ | 14 km | 11 km | 12 km |

**Table 25: Summary of the non-impulsive $SEL_{cum}$ Southall et al. (2019) PTS impact ranges for the four modelling locations considering the maximum design pin pile input parameters assuming a fleeing receptor.**

| Southall et al. (2019) – PTS | | | Maximum design – Pin pile (3,000 kJ) / Non-impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Weighted $SEL_{cum}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 199 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | HF | 198 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 173 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 201 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| E | LF | 199 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | HF | 198 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 173 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 201 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| S | LF | 199 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | HF | 198 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 173 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 201 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| HVAC | LF | 199 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | HF | 198 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 173 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 201 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |

**Table 26: Summary of the non-impulsive $SEL_{cum}$ Southall et al. (2019) TTS impact ranges for the four modelling locations considering the maximum design pin pile input parameters assuming a fleeing receptor.**

| Southall et al. (2019) – TTS | | | Maximum design – Pin pile (3,000 kJ) / Non-impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Weighted $SEL_{cum}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 179 dB | 240 $km^2$ | 12 km | 7.5 km | 8.7 km |
| | HF | 178 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 153 dB | 290 $km^2$ | 12 km | 8.7 km | 9.6 km |
| | PCW | 181 dB | 0.44 $km^2$ | 640 m | 140 m | 360 m |
| E | LF | 179 dB | 240 $km^2$ | 17 km | 4.7 km | 8.1 km |
| | HF | 178 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 153 dB | 290 $km^2$ | 15 km | 6.7 km | 9.4 km |
| | PCW | 181 dB | 1.7 $km^2$ | 1.4 km | < 100 m | 510 m |
| S | LF | 179 dB | 67 $km^2$ | 6.8 km | 2.5 km | 4.4 km |
| | HF | 178 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 153 dB | 110 $km^2$ | 7.4 km | 4.9 km | 6.0 km |
| | PCW | 181 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| HVAC | LF | 179 dB | 230 $km^2$ | 11 km | 6.6 km | 8.6 km |
| | HF | 178 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 153 dB | 290 $km^2$ | 11 km | 8.7 km | 9.6 km |
| | PCW | 181 dB | 0.24 $km^2$ | 380 m | 210 m | 280 m |

**Table 27: Summary of the $SPL_{peak}$ Southall et al. (2019) PTS impact ranges for the four modelling locations for the initial piling strike considering the maximum design pin pile input parameters.**

| Southall et al. (2019) – PTS | | | Maximum design – Pin pile, first strike (600 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Unweighted $SPL_{peak}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 219 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | HF | 230 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 0.45 $km^2$ | 380 m | 380 m | 380 m |
| | PCW | 218 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| E | LF | 219 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | HF | 230 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 0.45 $km^2$ | 380 m | 380 m | 380 m |
| | PCW | 218 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| S | LF | 219 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | HF | 230 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 0.29 $km^2$ | 310 m | 310 m | 310 m |
| | PCW | 218 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| HVAC | LF | 219 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | HF | 230 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 0.45 $km^2$ | 380 m | 380 m | 380 m |
| | PCW | 218 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |

**Table 28: Summary of the $SPL_{peak}$ Southall et al. (2019) TTS impact ranges for the four modelling locations for the initial piling strike considering the maximum design pin pile input parameters.**

| Southall et al. (2019) – TTS | | | Maximum design – Pin pile, first strike (600 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Unweighted $SPL_{peak}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 213 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 3.9 km² | 1.1 km | 1.1 km | 1.1 km |
| | PCW | 212 dB | < 0.01 km² | 60 m | 60 m | 60 m |
| E | LF | 213 dB | < 0.01 km² | 50 m | 50 m | 50 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 3.9 km² | 1.1 km | 1.1 km | 1.1 km |
| | PCW | 212 dB | < 0.01 km² | 60 m | 60 m | 60 m |
| S | LF | 213 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 2.5 km² | 900 m | 890 m | 890 m |
| | PCW | 212 dB | < 0.01 km² | 50 m | 50 m | 50 m |
| HVAC | LF | 213 dB | < 0.01 km² | 50 m | 50 m | 50 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 3.9 km² | 1.1 km | 1.1 km | 1.1 km |
| | PCW | 212 dB | < 0.01 km² | 60 m | 60 m | 60 m |

Impact ranges – most likely monopile

**Table 29: Summary of the $SPL_{peak}$ Southall et al. (2019) PTS impact ranges for the four modelling locations considering the most likely monopile input parameters.**

| Southall et al. (2019) – PTS | | | Most likely – Monopile (4,000 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Unweighted $SPL_{peak}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 219 dB | 0.04 km² | 120 m | 120 m | 120 m |
| | HF | 230 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 19 km² | 2.5 km | 2.5 km | 2.5 km |
| | PCW | 218 dB | 0.07 km² | 150 m | 140 m | 150 m |
| E | LF | 219 dB | 0.04 km² | 120 m | 120 m | 120 m |
| | HF | 230 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 19 km² | 2.6 km | 2.4 km | 2.5 km |
| | PCW | 218 dB | 0.07 km² | 150 m | 140 m | 150 m |
| S | LF | 219 dB | 0.03 km² | 100 m | 100 m | 100 m |
| | HF | 230 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 13 km² | 2.0 km | 2.0 km | 2.0 km |
| | PCW | 218 dB | 0.04 km² | 120 m | 120 m | 120 m |
| HVAC | LF | 219 dB | 0.04 km² | 120 m | 120 m | 120 m |
| | HF | 230 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 19 km² | 2.5 km | 2.5 km | 2.5 km |
| | PCW | 218 dB | 0.07 km² | 150 m | 140 m | 150 m |

**Table 30: Summary of the $SPL_{peak}$ Southall et al. (2019) TTS impact ranges for the four modelling locations considering the most likely monopile input parameters.**

| Southall et al. (2019) – TTS | | | Most likely – Monopile (4,000 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Unweighted $SPL_{peak}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 213 dB | 0.42 km² | 370 m | 370 m | 370 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 110 km² | 6.0 km | 5.7 km | 5.8 km |
| | PCW | 212 dB | 0.61 km² | 440 m | 440 m | 440 m |
| E | LF | 213 dB | 0.42 km² | 370 m | 370 m | 370 m |
| | HF | 224 dB | < 0.01 km² | 50 m | 50 m | 50 m |
| | VHF | 196 dB | 110 km² | 6.3 km | 5.5 km | 5.8 km |
| | PCW | 212 dB | 0.61 km² | 440 m | 440 m | 440 m |
| S | LF | 213 dB | 0.29 km² | 300 m | 300 m | 300 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 66 km² | 4.7 km | 4.5 km | 4.6 km |
| | PCW | 212 dB | 0.41 km² | 370 m | 360 m | 370 m |
| HVAC | LF | 213 dB | 0.42 km² | 370 m | 370 m | 370 m |
| | HF | 224 dB | < 0.01 km² | 50 m | 50 m | 50 m |
| | VHF | 196 dB | 100 km² | 5.8 km | 5.7 km | 5.7 km |
| | PCW | 212 dB | 0.61 km² | 440 m | 440 m | 440 m |

**Table 31: Summary of the impulsive $SEL_{cum}$ Southall et al. (2019) PTS impact ranges for the four modelling locations considering the most likely monopile input parameters assuming a fleeing receptor.**

| Southall et al. (2019) – PTS | | | Most likely – Monopile (4,000 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Weighted $SEL_{cum}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 183 dB | 31 km² | 4.8 km | 2.4 km | 3.1 km |
| | HF | 185 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | VHF | 155 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | PCW | 185 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| E | LF | 183 dB | 41 km² | 7.7 km | 780 m | 3.1 km |
| | HF | 185 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | VHF | 155 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | PCW | 185 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| S | LF | 183 dB | 0.59 km² | 1.0 km | < 100 m | 250 m |
| | HF | 185 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | VHF | 155 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | PCW | 185 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| HVAC | LF | 183 dB | 32 km² | 3.9 km | 2.6 km | 3.2 km |
| | HF | 185 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | VHF | 155 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | PCW | 185 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |

**Table 32: Summary of the impulsive $SEL_{cum}$ Southall et al. (2019) TTS impact ranges for the four modelling locations considering the most likely monopile input parameters assuming a fleeing receptor.**

| Southall et al. (2019) – TTS | | | Most likely – Monopile (4,000 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Weighted $SEL_{cum}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 168 dB | 1800 $km^2$ | 32 km | 20 km | 24 km |
| | HF | 170 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 140 dB | 570 $km^2$ | 16 km | 12 km | 13 km |
| | PCW | 170 dB | 430 $km^2$ | 14 km | 11 km | 12 km |
| E | LF | 168 dB | 1500 $km^2$ | 38 km | 15 km | 21 km |
| | HF | 170 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 140 dB | 560 $km^2$ | 20 km | 10 km | 13 km |
| | PCW | 170 dB | 430 $km^2$ | 17 km | 8.8 km | 12 km |
| S | LF | 168 dB | 970 $km^2$ | 25 km | 12 km | 17 km |
| | HF | 170 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 140 dB | 290 $km^2$ | 12 km | 8.1 km | 9.5 km |
| | PCW | 170 dB | 200 $km^2$ | 9.6 km | 6.9 km | 8.0 km |
| HVAC | LF | 168 dB | 1600 $km^2$ | 29 km | 15 km | 22 km |
| | HF | 170 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 140 dB | 580 $km^2$ | 15 km | 12 km | 14 km |
| | PCW | 170 dB | 440 $km^2$ | 13 km | 11 km | 12 km |

**Table 33: Summary of the non-impulsive $SEL_{cum}$ Southall et al. (2019) PTS impact ranges for the four modelling locations considering the most likely monopile input parameters assuming a fleeing receptor.**

| Southall et al. (2019) – PTS | | | Most likely – Monopile (4,000 kJ) / Non-impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Weighted $SEL_{cum}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 199 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | HF | 198 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 173 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 201 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| E | LF | 199 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | HF | 198 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 173 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 201 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| S | LF | 199 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | HF | 198 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 173 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 201 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| HVAC | LF | 199 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | HF | 198 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 173 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 201 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |

**Table 34: Summary of the non-impulsive $SEL_{cum}$ Southall et al. (2019) TTS impact ranges for the four modelling locations considering the most likely monopile input parameters assuming a fleeing receptor.**

| Southall et al. (2019) – TTS *Weighted $SEL_{cum}$* | | | Most likely – Monopile (4,000 kJ) / Non-impulsive criteria | | | |
|---|---|---|---|---|---|---|
| | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 179 dB | 210 $km^2$ | 11 km | 7.1 km | 8.1 km |
| | HF | 178 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 153 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 181 dB | 0.35 $km^2$ | 470 m | 160 m | 330 m |
| E | LF | 179 dB | 210 $km^2$ | 15 km | 4.5 km | 7.6 km |
| | HF | 178 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 153 dB | 0.18 $km^2$ | 440 m | < 100 m | 160 m |
| | PCW | 181 dB | 1.1 $km^2$ | 980 m | < 100 m | 410 m |
| S | LF | 179 dB | 56 $km^2$ | 6.3 km | 2.4 km | 4.0 km |
| | HF | 178 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 153 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 181 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| HVAC | LF | 179 dB | 210 $km^2$ | 9.7 km | 6.6 km | 8.1 km |
| | HF | 178 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 153 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 181 dB | 0.16 $km^2$ | 270 m | 190 m | 220 m |

**Table 35: Summary of the $SPL_{peak}$ Southall et al. (2019) PTS impact ranges for the four modelling locations for the initial piling strike considering the most likely monopile input parameters.**

| Southall et al. (2019) – PTS *Unweighted $SPL_{peak}$* | | | Most likely – Monopile, first strike (800 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 219 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | HF | 230 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 0.99 $km^2$ | 560 m | 560 m | 560 m |
| | PCW | 218 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| E | LF | 219 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | HF | 230 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 0.98 $km^2$ | 560 m | 560 m | 560 m |
| | PCW | 218 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| S | LF | 219 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | HF | 230 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 0.64 $km^2$ | 450 m | 450 m | 450 m |
| | PCW | 218 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| HVAC | LF | 219 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | HF | 230 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 0.99 $km^2$ | 560 m | 560 m | 560 m |
| | PCW | 218 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |

**Table 36: Summary of the $SPL_{peak}$ Southall et al. (2019) TTS impact ranges for the four modelling locations for the initial piling strike considering the most likely monopile input parameters.**

| Southall et al. (2019) – TTS | | | Most likely – Monopile, first strike (800 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Unweighted $SPL_{peak}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 213 dB | 0.02 km² | 70 m | 70 m | 70 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 8.1 km² | 1.6 km | 1.6 km | 1.6 km |
| | PCW | 212 dB | 0.02 km² | 90 m | 90 m | 90 m |
| E | LF | 213 dB | 0.02 km² | 70 m | 70 m | 70 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 8 km² | 1.6 km | 1.6 km | 1.6 km |
| | PCW | 212 dB | 0.02 km² | 90 m | 90 m | 90 m |
| S | LF | 213 dB | < 0.01 km² | 60 m | 60 m | 60 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 5.1 km² | 1.3 km | 1.3 km | 1.3 km |
| | PCW | 212 dB | 0.02 km² | 70 m | 70 m | 70 m |
| HVAC | LF | 213 dB | 0.02 km² | 70 m | 70 m | 70 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 8.1 km² | 1.6 km | 1.6 km | 1.6 km |
| | PCW | 212 dB | 0.02 km² | 90 m | 90 m | 90 m |

Impact ranges – most likely pin pile

**Table 37: Summary of the $SPL_{peak}$ Southall et al. (2019) PTS impact ranges for the four modelling locations considering the most likely pin pile input parameters.**

| Southall et al. (2019) – PTS | | | Most Likely – Pin pile (1,750 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Unweighted $SPL_{peak}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 219 dB | < 0.01 km² | 60 m | 60 m | 60 m |
| | HF | 230 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 5.6 km² | 1.3 km | 1.3 km | 1.3 km |
| | PCW | 218 dB | 0.02 km² | 70 m | 70 m | 70 m |
| E | LF | 219 dB | < 0.01 km² | 60 m | 60 m | 60 m |
| | HF | 230 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 5.5 km² | 1.3 km | 1.3 km | 1.3 km |
| | PCW | 218 dB | 0.02 km² | 70 m | 70 m | 70 m |
| S | LF | 219 dB | < 0.01 km² | 50 m | 50 m | 50 m |
| | HF | 230 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 3.6 km² | 1.1 km | 1.1 km | 1.1 km |
| | PCW | 218 dB | < 0.01 km² | 60 m | 60 m | 60 m |
| HVAC | LF | 219 dB | < 0.01 km² | 60 m | 60 m | 60 m |
| | HF | 230 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 5.6 km² | 1.3 km | 1.3 km | 1.3 km |
| | PCW | 218 dB | 0.02 km² | 70 m | 70 m | 70 m |

**Table 38: Summary of the $SPL_{peak}$ Southall et al. (2019) TTS impact ranges for the four modelling locations considering the most likely pin pile input parameters.**

| Southall et al. (2019) – TTS | | | Most Likely – Pin pile (1,750 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Unweighted $SPL_{peak}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 213 dB | 0.1 km$^2$ | 180 m | 180 m | 180 m |
| | HF | 224 dB | < 0.01 km$^2$ | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 38 km$^2$ | 3.5 km | 3.4 km | 3.5 km |
| | PCW | 212 dB | 0.15 km$^2$ | 220 m | 220 m | 220 m |
| E | LF | 213 dB | 0.1 km$^2$ | 180 m | 180 m | 180 m |
| | HF | 224 dB | < 0.01 km$^2$ | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 37 km$^2$ | 3.6 km | 3.3 km | 3.5 km |
| | PCW | 212 dB | 0.15 km$^2$ | 220 m | 220 m | 220 m |
| S | LF | 213 dB | 0.07 km$^2$ | 150 m | 150 m | 150 m |
| | HF | 224 dB | < 0.01 km$^2$ | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 23 km$^2$ | 2.8 km | 2.7 km | 2.7 km |
| | PCW | 212 dB | 0.1 km$^2$ | 180 m | 180 m | 180 m |
| HVAC | LF | 213 dB | 0.1 km$^2$ | 180 m | 180 m | 180 m |
| | HF | 224 dB | < 0.01 km$^2$ | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 37km$^2$ | 3.5 km | 3.4 km | 3.4 km |
| | PCW | 212 dB | 0.15 km$^2$ | 220 m | 220 m | 220 m |

**Table 39: Summary of the impulsive $SEL_{cum}$ Southall et al. (2019) PTS impact ranges for the four modelling locations considering the most likely pin pile input parameters assuming a fleeing receptor.**

| Southall et al. (2019) – PTS | | | Most Likely – Pin pile (1,750 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Weighted $SEL_{cum}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 183 dB | 0.43 km$^2$ | 1.2 km | < 100 m | 240 m |
| | HF | 185 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 155 dB | 31 km$^2$ | 3.6 km | 2.9 km | 3.1 km |
| | PCW | 185 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| E | LF | 183 dB | 4.8 km$^2$ | 3.2 km | < 100 m | 780 m |
| | HF | 185 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 155 dB | 36 km$^2$ | 4.6 km | 2.1 km | 3.2 km |
| | PCW | 185 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| S | LF | 183 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | HF | 185 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 155 dB | 3 km$^2$ | 1.2 km | 760 m | 970 m |
| | PCW | 185 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| HVAC | LF | 183 dB | 0.21 km$^2$ | 550 m | < 100 m | 180 m |
| | HF | 185 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 155 dB | 30 km$^2$ | 3.2 km | 3.0 km | 3.1 km |
| | PCW | 185 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |

**Table 40: Summary of the impulsive $SEL_{cum}$ Southall et al. (2019) TTS impact ranges for the four modelling locations considering the most likely pin pile input parameters assuming a fleeing receptor.**

| Southall et al. (2019) – TTS | | | Most Likely – Pin pile (1,750 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Weighted $SEL_{cum}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 168 dB | 1300 $km^2$ | 26 km | 17 km | 20 km |
| | HF | 170 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 140 dB | 1500 $km^2$ | 26 km | 20 km | 22 km |
| | PCW | 170 dB | 180 $km^2$ | 8.9 km | 7.0 km | 7.6 km |
| E | LF | 168 dB | 1100 $km^2$ | 33 km | 12 km | 18 km |
| | HF | 170 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 140 dB | 1300 $km^2$ | 31 km | 16 km | 20 km |
| | PCW | 170 dB | 190 $km^2$ | 11 km | 5.6 km | 7.6 km |
| S | LF | 168 dB | 6.3 $km^2$ | 2.6 km | 120 m | 1.2 km |
| | HF | 170 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 140 dB | 850 $km^2$ | 20 km | 13 km | 16 km |
| | PCW | 170 dB | 64 $km^2$ | 5.2 km | 4.0 km | 4.5 km |
| HVAC | LF | 168 dB | 1100 $km^2$ | 24 km | 14 km | 19 km |
| | HF | 170 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 140 dB | 1400 $km^2$ | 24 km | 18 km | 21 km |
| | PCW | 170 dB | 180 $km^2$ | 8.1 km | 7.4 km | 7.6 km |

**Table 41: Summary of the non-impulsive $SEL_{cum}$ Southall et al. (2019) PTS impact ranges for the four modelling locations considering the most likely pin pile input parameters assuming a fleeing receptor.**

| Southall et al. (2019) – PTS | | | Most Likely – Pin pile (1,750 kJ) / Non-impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Weighted $SEL_{cum}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 199 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | HF | 198 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 173 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 201 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| E | LF | 199 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | HF | 198 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 173 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 201 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| S | LF | 199 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | HF | 198 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 173 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 201 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| HVAC | LF | 199 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | HF | 198 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 173 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 201 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |

**Table 42: Summary of the non-impulsive $SEL_{cum}$ Southall et al. (2019) TTS impact ranges for the four modelling locations considering the most likely pin pile input parameters assuming a fleeing receptor.**

| Southall et al. (2019) – TTS | | | Most Likely – Pin pile (1,750 kJ) / Non-impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Weighted $SEL_{cum}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 179 dB | 73 $km^2$ | 6.9 km | 3.9 km | 4.8 km |
| | HF | 178 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 153 dB | 83 $km^2$ | 5.9 km | 4.8 km | 5.1 km |
| | PCW | 181 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| E | LF | 179 dB | 82 $km^2$ | 10 km | 2.0 km | 4.6 km |
| | HF | 178 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 153 dB | 91 $km^2$ | 7.3 km | 3.7 km | 5.3 km |
| | PCW | 181 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| S | LF | 179 dB | 630 $km^2$ | 20 km | 9.4 km | 14 km |
| | HF | 178 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 153 dB | 20 $km^2$ | 3.0 km | 2.2 km | 2.5 km |
| | PCW | 181 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| HVAC | LF | 179 dB | 74 $km^2$ | 5.9 km | 4.0 km | 4.9 km |
| | HF | 178 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 153 dB | 82 $km^2$ | 5.4 km | 5.0 km | 5.1 km |
| | PCW | 181 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |

**Table 43: Summary of the $SPL_{peak}$ Southall et al. (2019) PTS impact ranges for the four modelling locations for the initial piling strike considering the most likely pin pile input parameters.**

| Southall et al. (2019) – PTS | | | Most Likely – Pin pile, first strike (350 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Unweighted $SPL_{peak}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 219 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | HF | 230 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 0.08 $km^2$ | 170 m | 160 m | 170 m |
| | PCW | 218 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| E | LF | 219 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | HF | 230 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 0.08 $km^2$ | 170 m | 160 m | 170 m |
| | PCW | 218 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| S | LF | 219 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | HF | 230 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 0.06 $km^2$ | 130 m | 130 m | 130 m |
| | PCW | 218 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| HVAC | LF | 219 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | HF | 230 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |
| | VHF | 202 dB | 0.08 $km^2$ | 170 m | 160 m | 170 m |
| | PCW | 218 dB | < 0.01 $km^2$ | < 50 m | < 50 m | < 50 m |

**Table 44: Summary of the $SPL_{peak}$ Southall et al. (2019) TTS impact ranges for the four modelling locations for the initial piling strike considering the most likely pin pile input parameters.**

| Southall et al. (2019) – TTS *Unweighted $SPL_{peak}$* | | | Most Likely – Pin pile, first strike (350 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 213 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 0.79 km² | 500 m | 500 m | 500 m |
| | PCW | 212 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| E | LF | 213 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 0.78 km² | 500 m | 500 m | 500 m |
| | PCW | 212 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| S | LF | 213 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 0.51 km² | 410 m | 400 m | 410 m |
| | PCW | 212 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| HVAC | LF | 213 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | HF | 224 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | VHF | 196 dB | 0.79 km² | 500 m | 500 m | 500 m |
| | PCW | 212 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |

Impact ranges –maximum design multiple pin piles

**Table 45: Summary of the impulsive $SEL_{cum}$ Southall et al. (2019) PTS impact ranges for three consecutive piles installed at the NW modelling location considering the maximum design pin pile input parameters assuming a fleeing receptor.**

| Southall et al. (2019) – PTS *Weighted $SEL_{cum}$* | | | Maximum design – 3x Pin piles (3,000 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 183 dB | 43 km² | 5.8 km | 2.9 km | 3.7 km |
| | HF | 185 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | VHF | 155 dB | 170 km² | 9.1 km | 6.7 km | 7.3 km |
| | PCW | 185 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |

**Table 46: Summary of the impulsive $SEL_{cum}$ Southall et al. (2019) TTS impact ranges for three consecutive piles installed at the NW modelling location considering the maximum design pin pile input parameters assuming a fleeing receptor.**

| Southall et al. (2019) – TTS *Weighted $SEL_{cum}$* | | | Maximum design – 3x Pin piles (3,000 kJ) / Impulsive criteria | | | |
|---|---|---|---|---|---|---|
| | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 168 dB | 2000 km² | 35 km | 20 km | 25 km |
| | HF | 170 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | VHF | 140 dB | 2500 km² | 37 km | 24 km | 28 km |
| | PCW | 170 dB | 500 km² | 16 km | 12 km | 13 km |

**Table 47: Summary of the non-impulsive $SEL_{cum}$ Southall et al. (2019) PTS impact ranges for three consecutive piles installed at the NW modelling location considering the maximum design pin pile input parameters assuming a fleeing receptor.**

| Southall et al. (2019) – PTS | | | Maximum design – 3x Pin piles (3,000 kJ) / Non-impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Weighted $SEL_{cum}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 199 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | HF | 198 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 173 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | PCW | 201 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |

**Table 48: Summary of the non-impulsive $SEL_{cum}$ Southall et al. (2019) TTS impact ranges for three consecutive piles installed at the NW modelling location considering the maximum design pin pile input parameters assuming a fleeing receptor.**

| Southall et al. (2019) – TTS | | | Maximum design – 3x Pin piles (3,000 kJ) / Non-impulsive criteria | | | |
|---|---|---|---|---|---|---|
| *Weighted $SEL_{cum}$* | | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | LF | 179 dB | 240 km$^2$ | 12 km | 7.6 km | 8.8 km |
| | HF | 178 dB | < 0.01 km$^2$ | < 100 m | < 100 m | < 100 m |
| | VHF | 153 dB | 300 km$^2$ | 12 km | 8.8 km | 9.7 km |
| | PCW | 181 dB | 0.67 km$^2$ | 750 m | 250 m | 450 m |

Discussion of Marine Mammal Results

5.2.2.6 The ranges of impact using the Southall et al. (2019) criteria vary depending on the hearing (species) group and severity of impact. Looking at the monopile results for the maximum design parameters as an example (**Table 15** and **Table 16**), the $SEL_{cum}$ results using the LF weighting lead to the greatest ranges as the HF, VHF and PCW weightings filter out much of the piling energy at lower frequencies. It is also worth noting that the greatest ranges are calculated for the transects travelling through the deepest water and the number of transects on this trajectory are somewhat limited; therefore only a small proportion of the site is subject to these noise levels. This is clearly shown in **Section 5.1**.

5.2.2.7 The $SEL_{cum}$ results show that larger ranges are expected for pin piles than for monopiles for HF and VHF hearing groups. This is due to the differences between the marine mammal hearing group weightings and the sound frequencies produced by the different size piles.

5.2.2.8 The frequency spectra used as inputs to the model (**Figure 5**) show that the noise from pin piles contains more high frequency components than the noise from monopiles. The overall unweighted noise level is higher for the monopile due to the low frequency components of piling noise (i.e. most of the pile strike energy is in the lower frequencies <250 Hz). The HF and VHF cetacean filters (**Table 1**) both remove much of the low frequency components of the noise, as the species in these groups are much less sensitive to noise at these frequencies. This leaves the higher frequency noise, which in the case of pin piles is higher than that for the monopiles.

5.2.2.9 To illustrate this, **Figure 16** and **Figure 17** show the sound frequency spectra for monopiles and pin piles, adjusted (weighted) to account for the sensitivities of the different cetacean hearing groups. These can be compared to the original unweighted frequency spectra in

Figure 5 (shown faintly in Figure 16 and Figure 17). For the HF and VHF cetacean groups, higher levels are present in the weighted pin pile spectrum compared to the monopile.

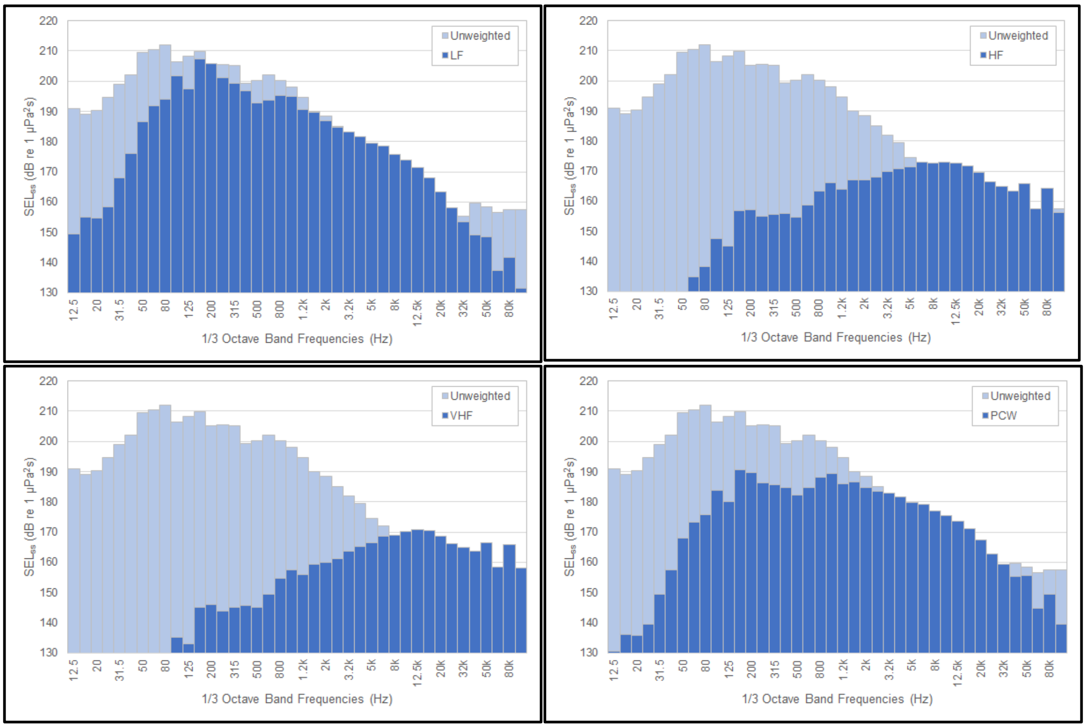



Figure 16: Filtered noise inputs for monopiles using the Southall et al. (2019) weightings. The lighter coloured bars show the unweighted one-third octave levels.

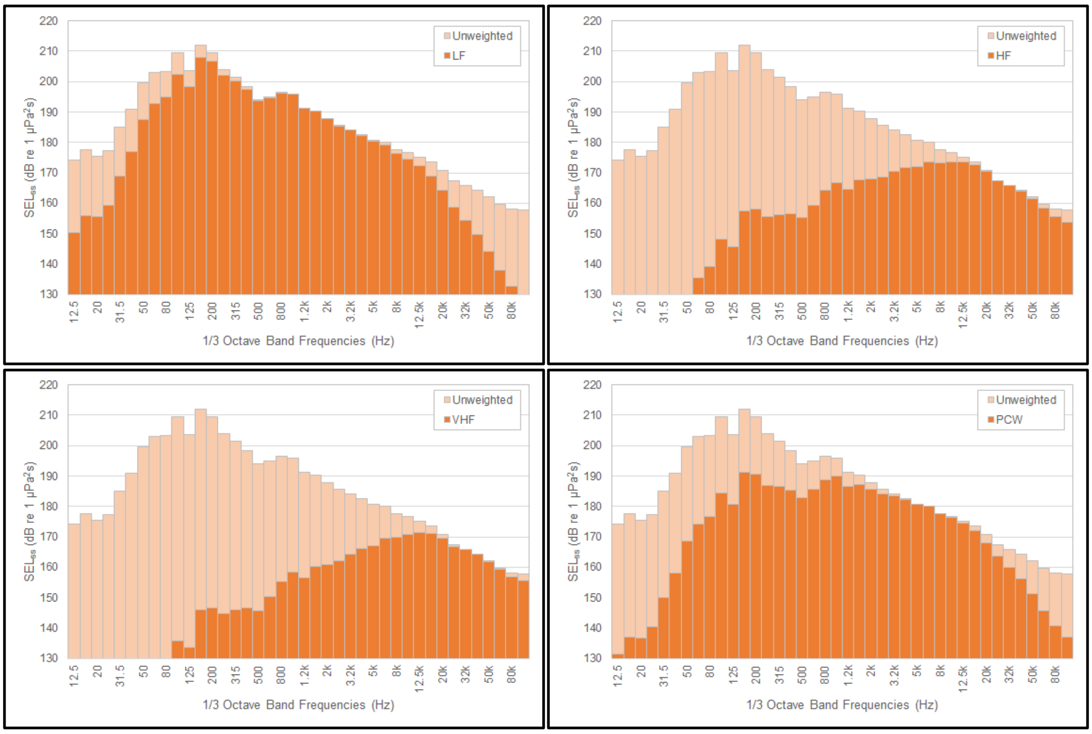



Figure 17: Filtered noise inputs for pin piles using the Southall et al. (2019) weightings. The lighter coloured bars show the unweighted one-third octave levels.

### 5.2.3 Fish criteria

5.2.3.1 **Table 49** to **Table 64** give detailed summaries of the impact ranges for species of fish based on the injury criteria found in the Popper et al. (2014) guidance. Interpretation of these modelling results are provided in **Volume A2, Chapter 3: Fish and Shellfish Ecology**. As discussed in **Section 2.2.2**, the Popper et al. (2014) criteria are given as unweighted $SPL_{peak}$ and unweighted $SEL_{cum}$, grouping fish by physiology with respect to swim bladder. The Popper et al. (2014) criteria for impact piling are given in **Table 4**. In addition, instantaneous $SPL_{peak}$ values for the first strike of each scenario have also been given. A sequential piling scenario of three pin piles installed at the NW location in a 24-hour period has also been considered and results for this are presented in **Table 65** and **Table 66**. Considering a fleeing animal, the addition of the extra piling scenarios does not have a great effect on impact ranges, but larger ranges are predicted for a stationary animal as they are essentially receiving exposure from three times as many pile strikes in a 24-hour period.

5.2.3.2 As discussed in **paragraphs 2.2.2.22** to **2.2.2.24** for $SEL_{cum}$ criteria, both fleeing animal and stationary animal models have been used. For the fleeing animal model, a speed of 1.5 $ms^{-1}$ has been assumed (Hirata, 1999).

5.2.3.3 It should be noted that some of the same noise levels are used as criteria for multiple effects. This is as per the Popper et al. (2014) guidelines (**Table 4**), which is based on a comprehensive literature review. The data available to create the criteria are very limited for fish and most criteria in **Table 4** are "greater than", with a specific threshold not identified. All ranges associated with criteria defined with a ">" are therefore conservative and in practice the actual range at which an effect could occur will be somewhat lower.

5.2.3.4 The results show that the largest impact ranges occur in the deeper water areas, with maximum $SPL_{peak}$ recoverable injury ranges of up to 1.3 km and maximum predicted $SEL_{cum}$ TTS ranges of 26 km assuming a fleeing receptor and 38 km assuming a stationary receptor. Other injury criteria from Popper et al. (2014) result in much smaller ranges.

Impact ranges – maximum design monopile

**Table 49: Summary of the unweighted $SPL_{peak}$ impact ranges for the various impact piling criteria for fish from Popper et al. (2014) considering the maximum design monopile input parameters.**

| **Popper et al. (2014)** | | **Maximum design – Monopile (5,000 kJ)** | | | |
|---|---|---|---|---|---|
| *Unweighted $SPL_{peak}$* | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | 213 dB | 0.57 $km^2$ | 430 m | 430 m | 430 m |
| | 207 dB | 4.9 $km^2$ | 1.3 km | 1.2 km | 1.2 km |
| E | 213 dB | 0.57 $km^2$ | 430 m | 430 m | 430 m |
| | 207 dB | 4.8 $km^2$ | 1.2 km | 1.2 km | 1.2 km |
| S | 213 dB | 0.39 $km^2$ | 360 m | 350 m | 350 m |
| | 207 dB | 3.3 $km^2$ | 1.0 km | 1.0 km | 1.0 km |
| HVAC | 213 dB | 0.57 $km^2$ | 430 m | 430 m | 430 m |
| | 207 dB | 4.9 $km^2$ | 1.2 km | 1.2 km | 1.2 km |

**Table 50: Summary of the unweighted $SEL_{cum}$ impact ranges for the various impact piling criteria for fish from Popper et al. (2014) considering the maximum design monopile input parameters assuming a fleeing receptor.**

| Popper et al. (2014) *Unweighted $SEL_{cum}$* | | Maximum design – Monopile (5,000 kJ) / Fleeing receptor | | | |
|---|---|---|---|---|---|
| | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | 219 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 216 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 210 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 207 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 203 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 186 dB | 890 km² | 21 km | 15 km | 17 km |
| E | 219 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 216 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 210 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 207 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 203 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 186 dB | 830 km² | 26 km | 12 km | 16 km |
| S | 219 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 216 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 210 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 207 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 203 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 186 dB | 470 km² | 15 km | 9.5 km | 12 km |
| HVAC | 219 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 216 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 210 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 207 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 203 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 186 dB | 860 km² | 19 km | 14 km | 17 km |

**Table 51: Summary of the unweighted $SEL_{cum}$ impact ranges for the various impact piling criteria for fish from Popper et al. (2014) considering the maximum design monopile input parameters assuming a stationary receptor.**

| Popper et al. (2014) *Unweighted $SEL_{cum}$* | | Maximum design – Monopile (5,000 kJ) / Stationary receptor | | | |
|---|---|---|---|---|---|
| | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | 219 dB | 1.8 km² | 760 m | 740 m | 750 m |
| | 216 dB | 5.0 km² | 1.3 km | 1.3 km | 1.3 km |
| | 210 dB | 34 km² | 3.4 km | 3.3 km | 3.3 km |
| | 207 dB | 80 km² | 5.1 km | 4.9 km | 5.1 km |
| | 203 dB | 210 km² | 8.4 km | 7.9 km | 8.2 km |
| | 186 dB | 2500 km² | 33 km | 26 km | 28 km |
| E | 219 dB | 1.7 km² | 750 m | 740 m | 750 m |
| | 216 dB | 5.0 km² | 1.3 km | 1.3 km | 1.3 km |
| | 210 dB | 34 km² | 3.5 km | 3.2 km | 3.3 km |
| | 207 dB | 79 km² | 5.4 km | 4.8 km | 5.0 km |

| Popper et al. (2014) *Unweighted $SEL_{cum}$* | | Maximum design – Monopile (5,000 kJ) / Stationary receptor | | | |
|---|---|---|---|---|---|
| | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| | 203 dB | 210 km$^2$ | 9.1 km | 7.4 km | 8.2 km |
| | 186 dB | 2400 km$^2$ | 38 km | 23 km | 27 km |
| S | 219 dB | 1.2 km$^2$ | 630 m | 620 m | 630 m |
| | 216 dB | 3.4 km$^2$ | 1.1 km | 1.0 km | 1.0 km |
| | 210 dB | 22 km$^2$ | 2.7 km | 2.6 km | 2.7 km |
| | 207 dB | 50 km$^2$ | 4.0 km | 4.0 km | 4.0 km |
| | 203 dB | 130 km$^2$ | 6.6 km | 6.3 km | 6.4 km |
| | 186 dB | 1700 km$^2$ | 28 km | 20 km | 23 km |
| HVAC | 219 dB | 1.8 km$^2$ | 760 m | 750 m | 760 m |
| | 216 dB | 5.0 km$^2$ | 1.3 km | 1.3 km | 1.3 km |
| | 210 dB | 34 km$^2$ | 3.3 km | 3.3 km | 3.3 km |
| | 207 dB | 77 km$^2$ | 5.0 km | 5.0 km | 5.0 km |
| | 203 dB | 200 km$^2$ | 8.1 km | 8.0 km | 8.0 km |
| | 186 dB | 2500 km$^2$ | 31 km | 25 km | 28 km |

**Table 52: Summary of the unweighted $SPL_{peak}$ impact ranges for the various impact piling criteria for fish from Popper et al. (2014) for the initial piling strike considering the maximum design monopile input parameters.**

| Popper et al. (2014) *Unweighted $SPL_{peak}$* | | Maximum design – Monopile, first strike (1,000 kJ) | | | |
|---|---|---|---|---|---|
| | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | 213 dB | 0.03 km$^2$ | 100 m | 100 m | 100 m |
| | 207 dB | 0.27 km$^2$ | 300 m | 300 m | 300 m |
| E | 213 dB | 0.03 km$^2$ | 100 m | 100 m | 100 m |
| | 207 dB | 0.27 km$^2$ | 300 m | 300 m | 300 m |
| S | 213 dB | 0.02 km$^2$ | 80 m | 80 m | 80 m |
| | 207 dB | 0.18 km$^2$ | 240 m | 240 m | 240 m |
| HVAC | 213 dB | 0.03 km$^2$ | 100 m | 100 m | 100 m |
| | 207 dB | 0.27 km$^2$ | 300 m | 300 m | 300 m |

Impact ranges – maximum design pin pile

**Table 53: Summary of the unweighted $SPL_{peak}$ impact ranges for the various impact piling criteria for fish from Popper et al. (2014) considering the maximum design pin pile input parameters.**

| Popper et al. (2014) | | Maximum design – Pin pile (3,000 kJ) | | | |
|---|---|---|---|---|---|
| *Unweighted $SPL_{peak}$* | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | 213 dB | 0.27 km² | 300 m | 300 m | 300 m |
| | 207 dB | 2.4 km² | 890 m | 880 m | 880 m |
| E | 213 dB | 0.27 km² | 300 m | 290 m | 300 m |
| | 207 dB | 2.4 km² | 880 m | 880 m | 880 m |
| S | 213 dB | 0.18 km² | 240 m | 240 m | 240 m |
| | 207 dB | 1.6 km² | 720 m | 720 m | 720 m |
| HVAC | 213 dB | 0.27 km² | 300 m | 300 m | 300 m |
| | 207 dB | 2.4 km² | 880 m | 880 m | 880 m |

**Table 54: Summary of the unweighted $SEL_{cum}$ impact ranges for the various impact piling criteria for fish from Popper et al. (2014) considering the maximum design pin pile input parameters assuming a fleeing receptor.**

| Popper et al. (2014) | | Maximum design – Pin pile (3,000 kJ) / Fleeing receptor | | | |
|---|---|---|---|---|---|
| *Unweighted $SEL_{cum}$* | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | 219 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 216 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 210 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 207 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 203 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 186 dB | 620 km² | 17 km | 13 km | 14 km |
| E | 219 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 216 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 210 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 207 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 203 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 186 dB | 590 km² | 22 km | 10 km | 13 km |
| S | 219 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 216 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 210 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 207 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 203 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 186 dB | 300 km² | 12 km | 7.8 km | 9.7 km |
| HVAC | 219 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 216 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 210 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 207 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 203 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 186 dB | 610 km² | 16 km | 12 km | 14 km |

**Table 55: Summary of the unweighted $SEL_{cum}$ impact ranges for the various impact piling criteria for fish from Popper et al. (2014) considering the maximum design pin pile input parameters assuming a stationary receptor.**

| Popper et al. (2014) | | Maximum design – Pin pile (3,000 kJ) / Stationary receptor | | | |
|---|---|---|---|---|---|
| *Unweighted $SEL_{cum}$* | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | 219 dB | 0.86 km² | 530 m | 520 m | 530 m |
| | 216 dB | 2.5 km² | 910 m | 890 m | 900 m |
| | 210 dB | 19 km² | 2.5 km | 2.4 km | 2.4 km |
| | 207 dB | 46 km² | 3.9 km | 3.8 km | 3.8 km |
| | 203 dB | 130 km² | 6.7 km | 6.3 km | 6.5 km |
| | 186 dB | 2000 km² | 29 km | 24 km | 26 km |
| E | 219 dB | 0.86 km² | 530 m | 520 m | 530 m |
| | 216 dB | 2.5 km² | 900 m | 890 m | 900 m |
| | 210 dB | 18 km² | 2.5 km | 2.4 km | 2.4 km |
| | 207 dB | 46 km² | 4.0 km | 3.7 km | 3.8 km |
| | 203 dB | 130 km² | 7.1 km | 6.0 km | 6.5 km |
| | 186 dB | 1900 km² | 34 km | 21 km | 25 km |
| S | 219 dB | 0.59 km² | 440 m | 430 m | 440 m |
| | 216 dB | 1.7 km² | 740 m | 730 m | 740 m |
| | 210 dB | 12 km² | 2.0 km | 2.0 km | 2.0 km |
| | 207 dB | 29 km² | 3.1 km | 3.0 km | 3.0 km |
| | 203 dB | 81 km² | 5.2 km | 5.0 km | 5.1 km |
| | 186 dB | 1400 km² | 25 km | 18 km | 21 km |
| HVAC | 219 dB | 0.86 km² | 530 m | 520 m | 530 m |
| | 216 dB | 2.5 km² | 900 m | 890 m | 900 m |
| | 210 dB | 19 km² | 2.4 km | 2.4 km | 2.4 km |
| | 207 dB | 45 km² | 3.8 km | 3.8 km | 3.8 km |
| | 203 dB | 130 km² | 6.4 km | 6.4 km | 6.4 km |
| | 186 dB | 2000 km² | 28 km | 23 km | 25 km |

**Table 56: Summary of the unweighted $SPL_{peak}$ impact ranges for the various impact piling criteria for fish from Popper et al. (2014) for the initial piling strike considering the maximum design pin pile input parameters.**

| Popper et al. (2014) | | Maximum design – Pin pile, first strike (600 kJ) | | | |
|---|---|---|---|---|---|
| *Unweighted $SPL_{peak}$* | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | 213 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | 207 dB | 0.07 km² | 150 m | 150 m | 150 m |
| E | 213 dB | < 0.01 km² | 50 m | 50 m | 50 m |
| | 207 dB | 0.07 km² | 150 m | 150 m | 150 m |
| S | 213 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | 207 dB | 0.05 km² | 120 m | 120 m | 120 m |
| HVAC | 213 dB | < 0.01 km² | 50 m | 50 m | 50 m |
| | 207 dB | 0.07 km² | 150 m | 150 m | 150 m |

Impact ranges – most likely monopile

**Table 57: Summary of the unweighted $SPL_{peak}$ impact ranges for the various impact piling criteria for fish from Popper et al. (2014) considering the most likely monopile input parameters.**

| Popper et al. (2014) | | Most likely – Monopile (4,000 kJ) | | | |
|---|---|---|---|---|---|
| *Unweighted $SPL_{peak}$* | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | 213 dB | 0.42 $km^2$ | 370 m | 370 m | 370 m |
| | 207 dB | 3.7 $km^2$ | 1.1 km | 1.1 km | 1.1 km |
| E | 213 dB | 0.42 $km^2$ | 370 m | 370 m | 370 m |
| | 207 dB | 3.6 $km^2$ | 1.1 km | 1.1 km | 1.1 km |
| S | 213 dB | 0.29 $km^2$ | 300 m | 300 m | 300 m |
| | 207 dB | 2.5 $km^2$ | 890 m | 890 m | 890 m |
| HVAC | 213 dB | 0.42 $km^2$ | 370 m | 370 m | 370 m |
| | 207 dB | 3.7 $km^2$ | 1.1 km | 1.1 km | 1.1 km |

**Table 58: Summary of the unweighted $SEL_{cum}$ impact ranges for the various impact piling criteria for fish from Popper et al. (2014) considering the most likely monopile input parameters assuming a fleeing receptor.**

| Popper et al. (2014) | | Most likely – Monopile (4,000 kJ) / Fleeing receptor | | | |
|---|---|---|---|---|---|
| *Unweighted $SEL_{cum}$* | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | 219 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 216 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 210 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 207 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 203 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 186 dB | 590 $km^2$ | 16 km | 13 km | 14 km |
| E | 219 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 216 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 210 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 207 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 203 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 186 dB | 580 $km^2$ | 20 km | 10 km | 13 km |
| S | 219 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 216 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 210 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 207 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 203 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 186 dB | 300 $km^2$ | 12 km | 8.2 km | 9.7 km |
| HVAC | 219 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 216 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 210 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 207 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 203 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 186 dB | 600 $km^2$ | 15 km | 13 km | 14 km |

**Table 59: Summary of the unweighted $SEL_{cum}$ impact ranges for the various impact piling criteria for fish from Popper et al. (2014) considering the most likely monopile input parameters assuming a stationary receptor.**

| Popper et al. (2014) | | Most likely – Monopile (4,000 kJ) / Stationary receptor | | | |
|---|---|---|---|---|---|
| *Unweighted $SEL_{cum}$* | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | 219 dB | 0.27 $km^2$ | 300 m | 290 m | 300 m |
| | 216 dB | 0.8 $km^2$ | 520 m | 500 m | 510 m |
| | 210 dB | 6.6 $km^2$ | 1.5 km | 1.5 km | 1.5 km |
| | 207 dB | 18 $km^2$ | 2.4 km | 2.4 km | 2.4 km |
| | 203 dB | 58 $km^2$ | 4.4 km | 4.2 km | 4.3 km |
| | 186 dB | 1400 $km^2$ | 24 km | 20 km | 21 km |
| E | 219 dB | 0.27 $km^2$ | 300 m | 290 m | 300 m |
| | 216 dB | 0.8 $km^2$ | 510 m | 500 m | 510 m |
| | 210 dB | 6.5 $km^2$ | 1.5 km | 1.4 km | 1.4 km |
| | 207 dB | 17 $km^2$ | 2.4 km | 2.3 km | 2.4 km |
| | 203 dB | 58 $km^2$ | 4.6 km | 4.1 km | 4.3 km |
| | 186 dB | 1400 $km^2$ | 28 km | 18 km | 21 km |
| S | 219 dB | 0.19 $km^2$ | 250 m | 240 m | 250 m |
| | 216 dB | 0.56 $km^2$ | 430 m | 420 m | 430 m |
| | 210 dB | 4.4 $km^2$ | 1.2 km | 1.2 km | 1.2 km |
| | 207 dB | 11 $km^2$ | 1.9 km | 1.9 km | 1.9 km |
| | 203 dB | 36 $km^2$ | 3.4 km | 3.4 km | 3.4 km |
| | 186 dB | 920 $km^2$ | 19 km | 16 km | 17 km |
| HVAC | 219 dB | 0.27 $km^2$ | 300 m | 290 m | 300 m |
| | 216 dB | 0.8 $km^2$ | 510 m | 500 m | 510 m |
| | 210 dB | 6.6 $km^2$ | 1.5 km | 1.5 km | 1.5 km |
| | 207 dB | 17 $km^2$ | 2.4 km | 2.4 km | 2.4 km |
| | 203 dB | 57 $km^2$ | 4.3 km | 4.3 km | 4.3 km |
| | 186 dB | 1400 $km^2$ | 23 km | 20 km | 21 km |

**Table 60: Summary of the unweighted $SPL_{peak}$ impact ranges for the various impact piling criteria for fish from Popper et al. (2014) for the initial piling strike considering the most likely monopile input parameters.**

| Popper et al. (2014) | | Most likely – Monopile, first strike (800 kJ) | | | |
|---|---|---|---|---|---|
| *Unweighted $SPL_{peak}$* | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | 213 dB | 0.02 $km^2$ | 70 m | 70 m | 70 m |
| | 207 dB | 0.15 $km^2$ | 220 m | 220 m | 220 m |
| E | 213 dB | 0.02 $km^2$ | 70 m | 70 m | 70 m |
| | 207 dB | 0.15 $km^2$ | 220 m | 220 m | 220 m |
| S | 213 dB | < 0.01 $km^2$ | 60 m | 60 m | 60 m |
| | 207 dB | 0.1 $km^2$ | 180 m | 180 m | 180 m |
| HVAC | 213 dB | 0.02 $km^2$ | 70 m | 70 m | 70 m |
| | 207 dB | 0.16 $km^2$ | 220 m | 220 m | 220 m |

Impact ranges – most likely pin pile

**Table 61: Summary of the unweighted $SPL_{peak}$ impact ranges for the various impact piling criteria for fish from Popper et al. (2014) considering the most likely pin pile input parameters.**

| Popper et al. (2014) Unweighted $SPL_{peak}$ | | Most likely – Pin Pile (1,750 kJ) | | | |
|---|---|---|---|---|---|
| | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | 213 dB | 0.1 km² | 180 m | 180 m | 180 m |
| | 207 dB | 0.95 km² | 550 m | 550 m | 550 m |
| E | 213 dB | 0.1 km² | 180 m | 180 m | 180 m |
| | 207 dB | 0.94 km² | 550 m | 550 m | 550 m |
| S | 213 dB | 0.07 km² | 150 m | 150 m | 105 m |
| | 207 dB | 0.62 km² | 450 m | 450 m | 450 m |
| HVAC | 213 dB | 0.1 km² | 180 m | 180 m | 180 m |
| | 207 dB | 0.95 km² | 550 m | 550 m | 550 m |

**Table 62: Summary of the unweighted $SEL_{cum}$ impact ranges for the various impact piling criteria for fish from Popper et al. (2014) considering the most likely pin pile input parameters assuming a fleeing receptor.**

| Popper et al. (2014) Unweighted $SEL_{cum}$ | | Most likely – Pin Pile (1,750 kJ) / Fleeing receptor | | | |
|---|---|---|---|---|---|
| | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | 219 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 216 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 210 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 207 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 203 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 186 dB | 250 km² | 11 km | 8.2 km | 9.0 km |
| E | 219 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 216 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 210 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 207 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 203 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 186 dB | 260 km² | 13 km | 6.7 km | 8.9 km |
| S | 219 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 216 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 210 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 207 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 203 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 186 dB | 100 km² | 6.6 km | 5.0 km | 5.6 km |
| HVAC | 219 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 216 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 210 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 207 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 203 dB | < 0.01 km² | < 100 m | < 100 m | < 100 m |
| | 186 dB | 260 km² | 9.6 km | 8.7 km | 9.1 km |

**Table 63: Summary of the unweighted $SEL_{cum}$ impact ranges for the various impact piling criteria for fish from Popper et al. (2014) considering the most likely pin pile input parameters assuming a stationary receptor.**

| Popper et al. (2014) *Unweighted $SEL_{cum}$* | | Most likely – Pin Pile (1,750 kJ) / Stationary receptor *Area* | *Maximum range* | *Minimum range* | *Mean range* |
|---|---|---|---|---|---|
| NW | 219 dB | 0.07 km² | 150 m | 140 m | 150 m |
| | 216 dB | 0.2 km² | 260 m | 250 m | 260 m |
| | 210 dB | 1.8 km² | 760 m | 740 m | 750 m |
| | 207 dB | 5.0 km² | 1.3 km | 1.3 km | 1.3 km |
| | 203 dB | 19 km² | 2.5 km | 2.4 km | 2.4 km |
| | 186 dB | 850 km² | 18 km | 16 km | 16 km |
| E | 219 dB | 0.07 km² | 150 m | 140 m | 150 m |
| | 216 dB | 0.2 km² | 260 m | 250 m | 260 m |
| | 210 dB | 1.7 km² | 750 m | 740 m | 750 m |
| | 207 dB | 5 km² | 1.3 km | 1.3 km | 1.3 km |
| | 203 dB | 18 km² | 2.5 km | 2.4 km | 2.4 km |
| | 186 dB | 850 km² | 21 km | 14 km | 16 km |
| S | 219 dB | 0.05 km² | 130 m | 120 m | 130 m |
| | 216 dB | 0.13 km² | 210 m | 200 m | 210 m |
| | 210 dB | 1.1 km² | 610 m | 600 m | 610 m |
| | 207 dB | 3.3 km² | 1.0 km | 1.0 km | 1.0 km |
| | 203 dB | 12 km² | 2.0 km | 1.9 km | 1.9 km |
| | 186 dB | 530 km² | 14 km | 12 km | 13 km |
| HVAC | 219 dB | 0.07 km² | 150 m | 140 m | 150 m |
| | 216 dB | 0.2 km² | 260 m | 250 m | 260 m |
| | 210 dB | 1.8 km² | 760 m | 750 m | 760 m |
| | 207 dB | 5 km² | 1.3 km | 1.3 km | 1.3 km |
| | 203 dB | 19 km² | 2.5 km | 2.5 km | 2.5 km |
| | 186 dB | 860 km² | 17 km | 16 km | 17 km |

**Table 64: Summary of the unweighted $SPL_{peak}$ impact ranges for the various impact piling criteria for fish from Popper et al. (2014) for the initial piling strike considering the most likely pin pile input parameters.**

| Popper et al. (2014) *Unweighted $SPL_{peak}$* | | Most likely – Pin pile, first strike (350 kJ) *Area* | *Maximum range* | *Minimum range* | *Mean range* |
|---|---|---|---|---|---|
| NW | 213 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | 207 dB | < 0.01 km² | 70 m | 60 m | 70 m |
| E | 213 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | 207 dB | < 0.01 km² | 70 m | 60 m | 70 m |
| S | 213 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | 207 dB | < 0.01 km² | 50 m | 50 m | 50 m |
| HVAC | 213 dB | < 0.01 km² | < 50 m | < 50 m | < 50 m |
| | 207 dB | < 0.01 km² | 70 m | 60 m | 70 m |

Impact ranges – maximum design, multiple pin piles

**Table 65: Summary of the unweighted $SEL_{cum}$ impact ranges for the various impact piling criteria for fish from Popper et al. (2014) considering the maximum design pin pile input parameters assuming a fleeing receptor.**

| Popper et al. (2014) | | Maximum design – Pin Pile (3,000 kJ) / Fleeing receptor | | | |
|---|---|---|---|---|---|
| *Unweighted $SEL_{cum}$* | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | 219 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 216 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 210 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 207 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 203 dB | < 0.01 $km^2$ | < 100 m | < 100 m | < 100 m |
| | 186 dB | 640 $km^2$ | 18 km | 13 km | 14 km |

**Table 66: Summary of the unweighted $SEL_{cum}$ impact ranges for the various impact piling criteria for fish from Popper et al. (2014) considering the maximum design pin pile input parameters assuming a stationary receptor.**

| Popper et al. (2014) | | Maximum design – Pin Pile (3,000 kJ) / Stationary receptor | | | |
|---|---|---|---|---|---|
| *Unweighted $SEL_{cum}$* | | *Area* | *Maximum range* | *Minimum range* | *Mean range* |
| NW | 219 dB | 5.1 $km^2$ | 1.3 km | 1.3 km | 1.3 km |
| | 216 dB | 13 $km^2$ | 2.1 km | 2.0 km | 2.1 km |
| | 210 dB | 77 $km^2$ | 5.0 km | 4.9 km | 4.9 km |
| | 207 dB | 160 $km^2$ | 7.3 km | 7.0 km | 7.2 km |
| | 203 dB | 370 $km^2$ | 11 km | 11 km | 11 km |
| | 186 dB | 3300 $km^2$ | 38 km | 30 km | 33 km |

## 5.3 Simultaneous piling at two locations

### 5.3.1 Introduction

5.3.1.1 Additional modelling has been carried out to investigate the potential impacts of two piling installations occurring simultaneously at separated foundation locations. Using the MDS monopile and pin pile scenarios from **Section 4.3.2**, modelling has been carried out for piling simultaneously at both the NW and E modelling locations, representing a worst-case spatial spread of locations. All modelling in this section assumes that the two piling operations start at the same time.

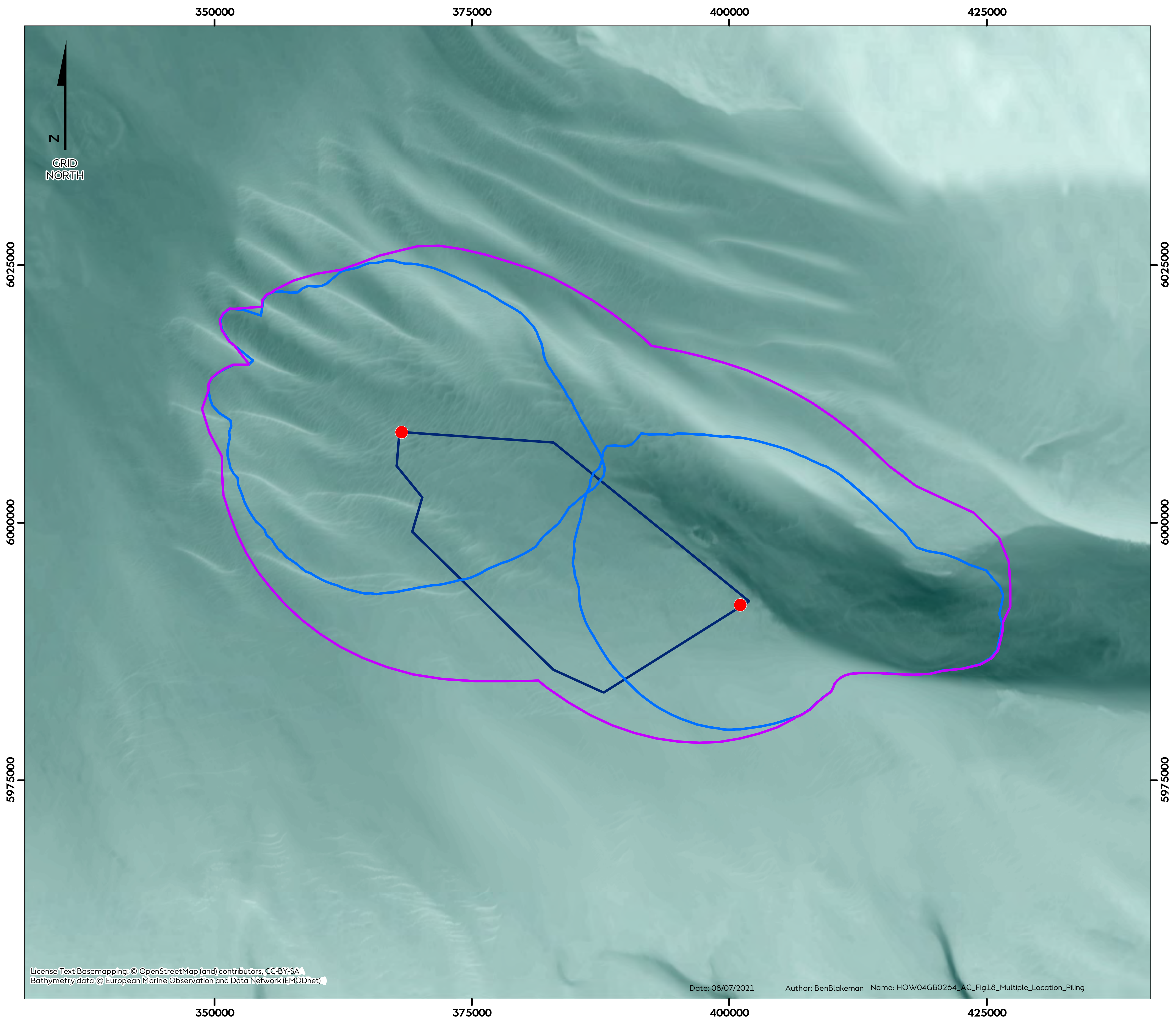
5.3.1.2 When considering $SEL_{cum}$ modelling, piling from multiple sources has the ability to increase impact ranges and areas significantly as, in this case, it introduces double the number of pile strikes to the water. Unlike the sequential piling investigated in the previous sections, the fleeing receptor can be closer to the source for more pile strikes, resulting in higher received noise levels. **Figure 18** shows the TTS contour for fish from Popper et al. (2014) given as unweighted $SEL_{cum}$ for a fleeing receptor. The blue contours show the impact from each modelling location individually (as presented in the previous section), and the red contour shows the increase in impact when both sources occur simultaneously, resulting in a contour encircling the previous two.

5.3.1.3 This modelling scenario was chosen to provide the greatest geographical spread of impact range contours. In a modelling scenario where two piles are installed adjacent to one another, there would be an expansion of the contour in all directions, but smaller than on the NW-E spread extent seen in **Figure 18**. It is understood that for operational 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.

# Hornsea Four

## Figure 18

Indicative contour plot showing the interaction between two noise sources when occurring simultaneously






Array Area
Modelling Locations
Single Location
Multiple Locations
Water Depth (m below CD)
10
95


Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:350,000

0 5 10 Kilometres

0 2.5 5 Nautical Miles

| REV | REMARK | DATE |
|---|---|---|
| .... | First Issue fo ES | 08/07/2021 |
| | | |
| | | |
| | | |
| | | |

Multiple Location
Piling
Document no: HOW04GB0264
Created by: BPHB
Checked by: RM
Approved by: LK

5.3.1.4 Section 5.3.2 and Section 5.3.3 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 cumulative effect when the two piles are installed simultaneously, generally where the individual ranges are small enough that the distant site does not produce an influencing additional exposure. Contours that are too small to be seen clearly at the scale of the figures have not been included.

### 5.3.2 Marine mammal criteria

5.3.2.1 Table 67 to Table 70 show a summary of the marine mammal PTS and TTS impact areas for impact piling at the NW and E locations simultaneously, showing the areas for impact piling at the individual locations as well as the in-combination area. These results are also illustrated in Figure 19 to Figure 22.

**Table 67: Summary of the impact areas for the installation of monopile foundations using the maximum design parameters at the NW and E modelling locations for marine mammals using the impulsive Southall et al. (2019) $SEL_{cum}$ criteria assuming a fleeing receptor.**

| Southall et al. (2019) Weighted $SEL_{cum}$ | | | Maximum design – Monopile (5,000 kJ) / Impulsive criteria | | |
|---|---|---|---|---|---|
| | | | NW area | E area | In-combination area |
| PTS | LF | 183 dB | 66 $km^2$ | 76 $km^2$ | 1000 $km^2$ |
| | HF | 185 dB | < 0.01 $km^2$ | < 0.01 $km^2$ | - |
| | VHF | 155 dB | < 0.01 $km^2$ | 0.09 $km^2$ | - |
| | PCW | 185 dB | < 0.01 $km^2$ | < 0.01 $km^2$ | - |
| TTS | LF | 168 dB | 2200 $km^2$ | 1800 $km^2$ | 4500 $km^2$ |
| | HF | 170 dB | < 0.01 $km^2$ | < 0.01 $km^2$ | - |
| | VHF | 140 dB | 860 $km^2$ | 810 $km^2$ | 2400 $km^2$ |
| | PCW | 170 dB | 670 $km^2$ | 640 $km^2$ | 2100 $km^2$ |

**Table 68: Summary of the impact areas for the installation of monopile foundations using the maximum design parameters at the NW and E modelling locations for marine mammals using the non-impulsive Southall et al. (2019) $SEL_{cum}$ criteria assuming a fleeing receptor.**

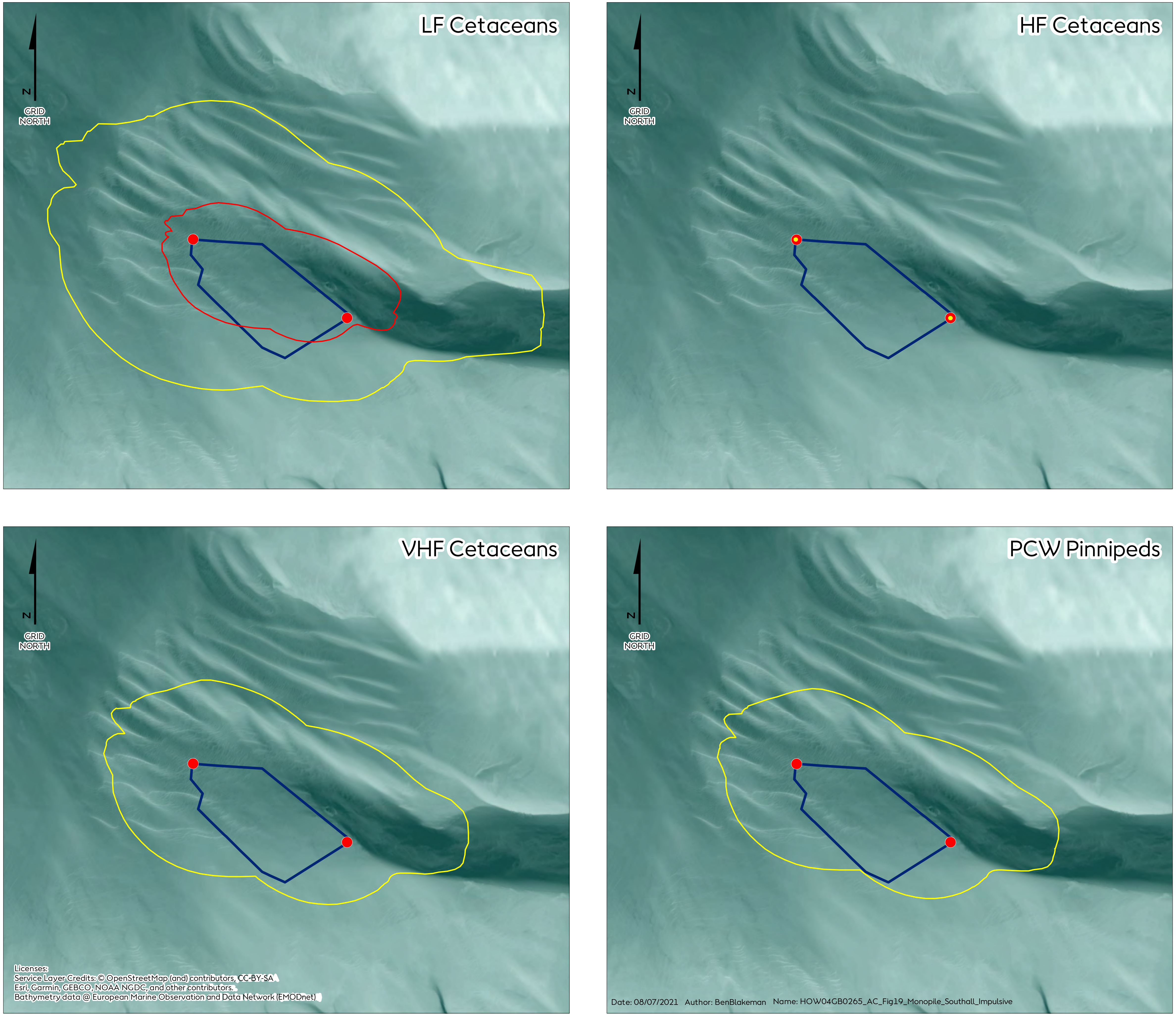
| Southall et al. (2019) Weighted $SEL_{cum}$ | | | Maximum design – Monopile (5,000 kJ) / Non-impulsive criteria | | |
|---|---|---|---|---|---|
| | | | NW area | E area | In-combination area |
| PTS | LF | 199 dB | < 0.01 $km^2$ | < 0.01 $km^2$ | - |
| | HF | 198 dB | < 0.01 $km^2$ | < 0.01 $km^2$ | - |
| | VHF | 173 dB | < 0.01 $km^2$ | < 0.01 $km^2$ | - |
| | PCW | 201 dB | < 0.01 $km^2$ | < 0.01 $km^2$ | - |
| TTS | LF | 179 dB | 300 $km^2$ | 290 $km^2$ | 1600 $km^2$ |
| | HF | 178 dB | < 0.01 $km^2$ | < 0.01 $km^2$ | - |
| | VHF | 153 dB | 5.3 $km^2$ | 7.7 $km^2$ | - |
| | PCW | 181 dB | 11 $km^2$ | 14 $km^2$ | 370 $km^2$ |

**Table 69: Summary of the impact areas for the installation of pin pile foundations using the maximum design parameters at the NW and E modelling locations for marine mammals using the impulsive Southall et al. (2019) $SEL_{cum}$ criteria assuming a fleeing receptor.**

| Southall et al. (2019) Weighted $SEL_{cum}$ | | | Maximum design – Pin pile (3,000 kJ) / Impulsive criteria | | |
|---|---|---|---|---|---|
| | | | NW area | E area | In-combination area |
| PTS | LF | 183 dB | 42 km² | 53 km² | 920 km² |
| | HF | 185 dB | < 0.01 km² | < 0.01 km² | - |
| | VHF | 155 dB | 160 km² | 170 km² | 1100 km² |
| | PCW | 185 dB | < 0.01 km² | < 0.01 km² | - |
| TTS | LF | 168 dB | 2000 km² | 1600 km² | 4200 km² |
| | HF | 170 dB | < 0.01 km² | < 0.01 km² | - |
| | VHF | 140 dB | 2500 km² | 2100 km² | 4700 km² |
| | PCW | 170 dB | 480 km² | 470 km² | 1700 km² |

**Table 70: Summary of the impact areas for the installation of pin pile foundations using the maximum design parameters at the NW and E modelling locations for marine mammals using the non-impulsive Southall et al. (2019) $SEL_{cum}$ criteria assuming a fleeing receptor.**

| Southall et al. (2019) Weighted $SEL_{cum}$ | | | Maximum design – Pin pile (3,000 kJ) / Non-impulsive criteria | | |
|---|---|---|---|---|---|
| | | | NW area | E area | In-combination area |
| PTS | LF | 199 dB | < 0.01 km² | < 0.01 km² | - |
| | HF | 198 dB | < 0.01 km² | < 0.01 km² | - |
| | VHF | 173 dB | < 0.01 km² | < 0.01 km² | - |
| | PCW | 201 dB | < 0.01 km² | < 0.01 km² | - |
| TTS | LF | 179 dB | 240 km² | 240 km² | 1500 km² |
| | HF | 178 dB | < 0.01 km² | < 0.01 km² | - |
| | VHF | 153 dB | 290 km² | 290 km² | 1400 km² |
| | PCW | 181 dB | 0.44 km² | 1.7 km² | - |




# Hornsea Four

## Figure 19

Contour plots showing the cumulative impacts of simultaneous installation of monopile foundations at the NW and E modelling locations for marine mammals using the Southall et al. (2019) impulsive criteria assuming a fleeing receptor

Array Area
Modelling Locations
PTS
TTS
Water Depth (m below CD)
10
95

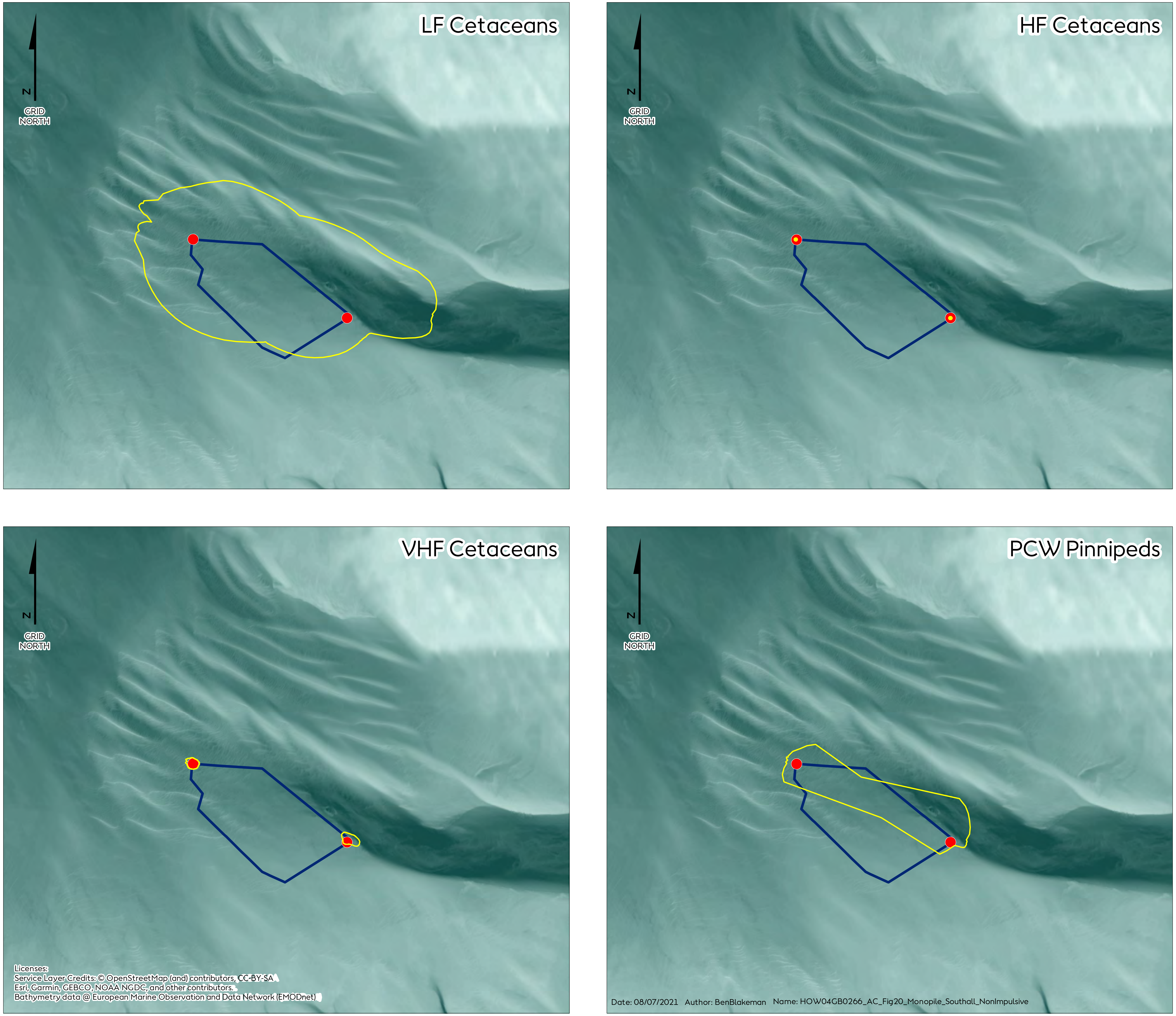

Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:800,000

0 20 40 Kilometres

0 10 20 Nautical Miles

| REV | REMARK | DATE |
|---|---|---|
| .... | First Issue for ES | 08/07/2021 |
| | | |
| | | |
| | | |
| | | |

Figure 19
Multiple Piles
Document no: HOW04GB0265
Created by: BPHB
Checked by: AL
Approved by: LK

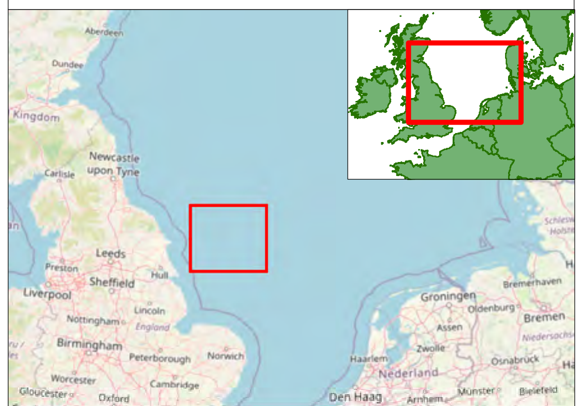



# Hornsea Four

## Figure 20

Contour plots showing the cumulative impacts of simultaneous installation of monopile foundations at the NW and E modelling locations for marine mammals using the Southall et al. (2019) non-impulsive criteria assuming a fleeing receptor

Array Area
Modelling Locations
TTS
Water Depth (m below CD)
10
95



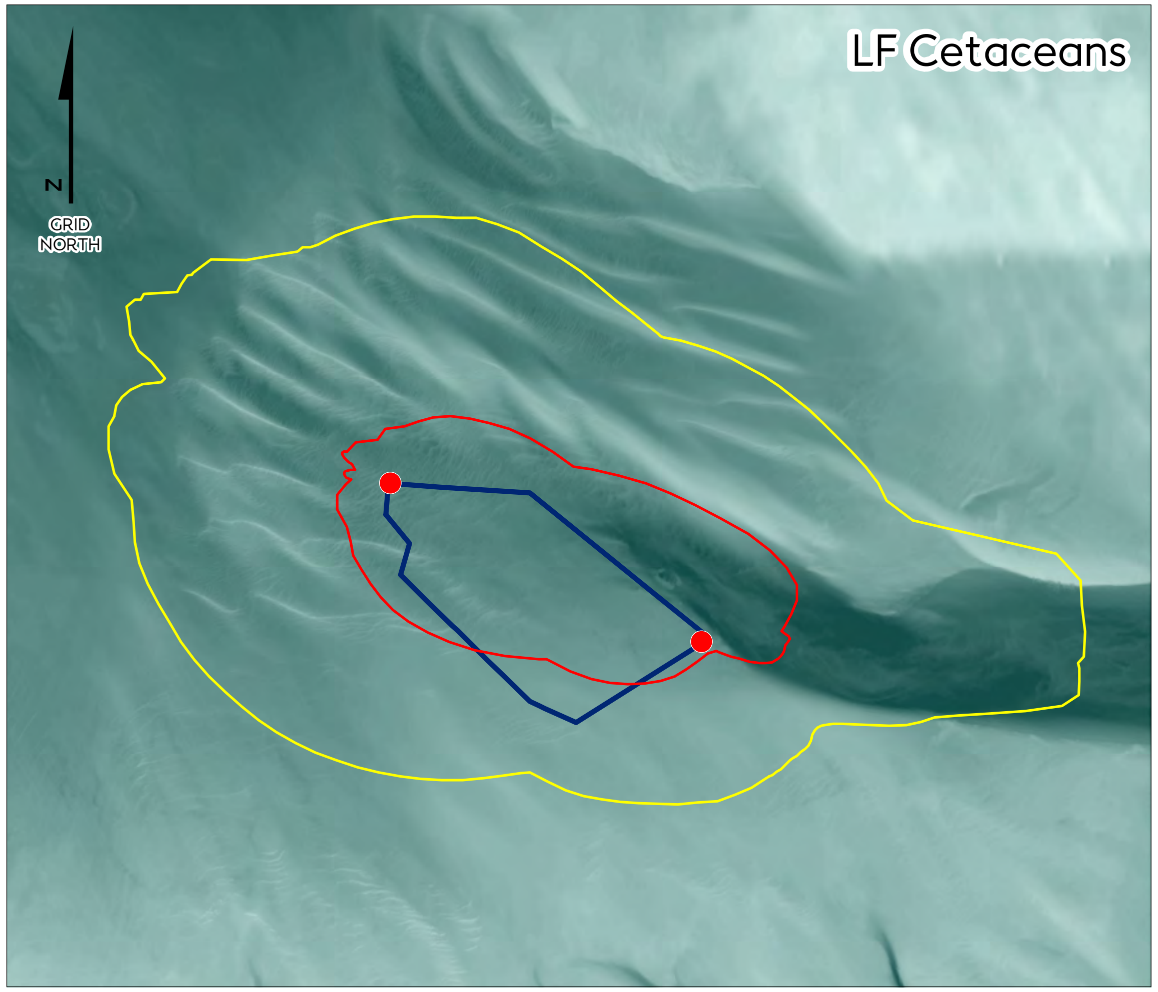
Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:800,000

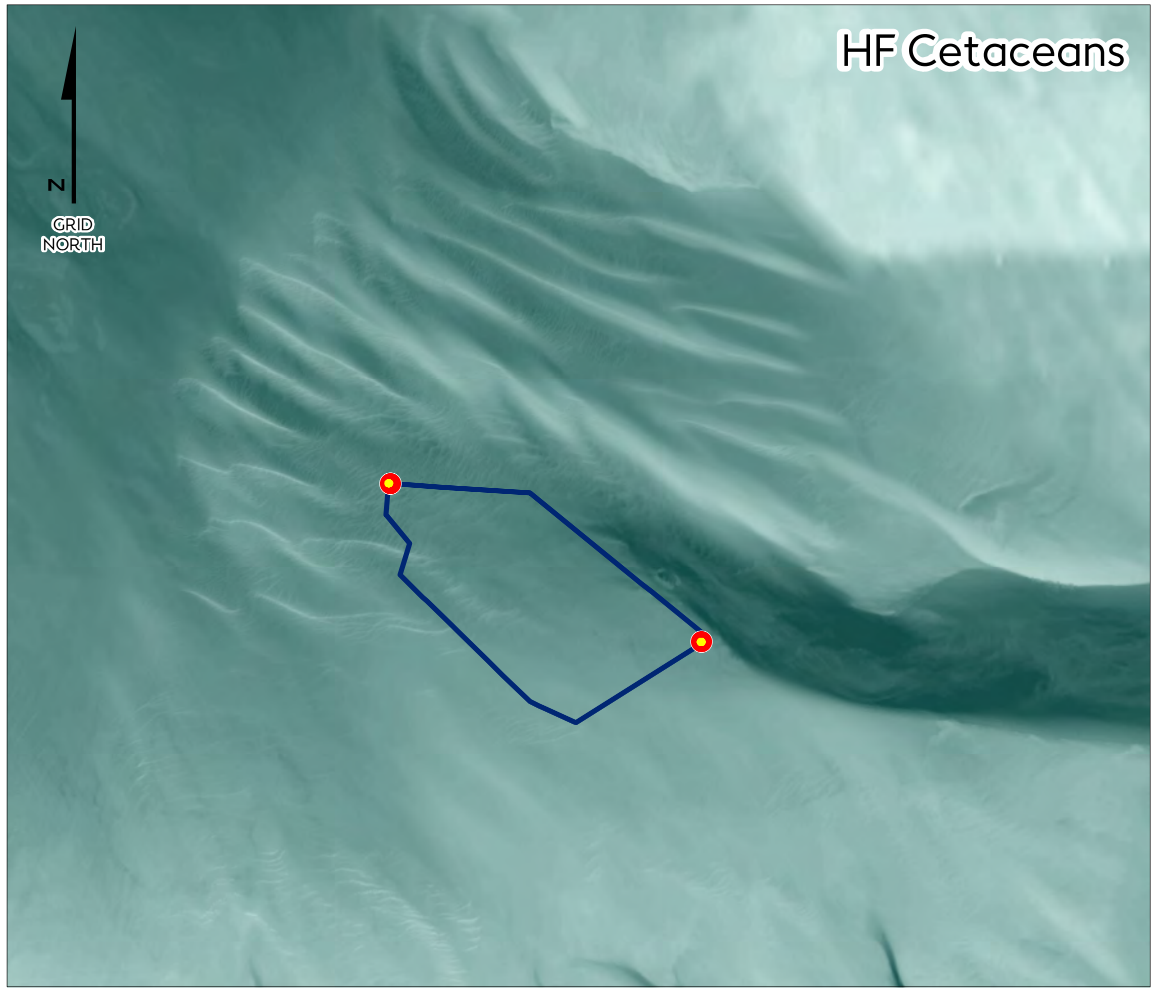
0 20 40 Kilometres

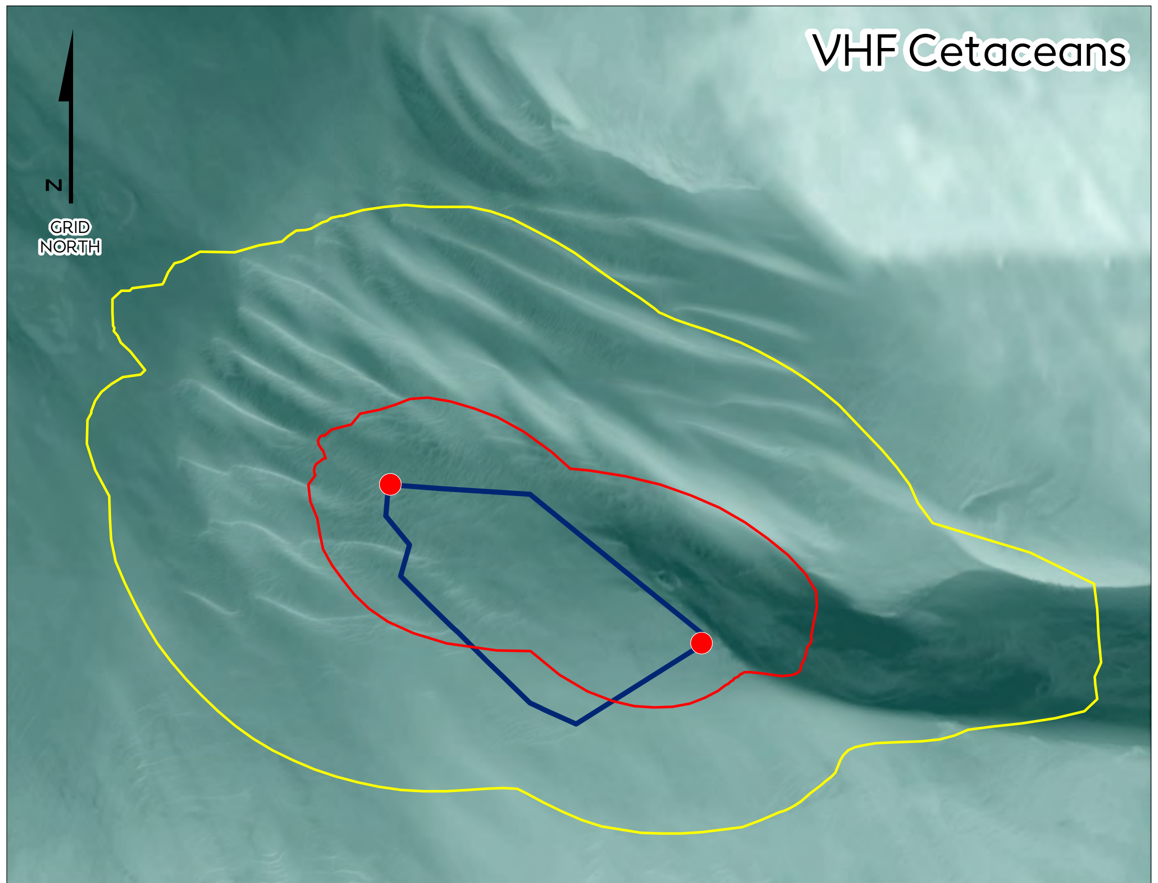
0 10 20 Nautical Miles

| REV | REMARK | DATE |
|---|---|---|
| .... | First Issue for ES | 08/07/2021 |
| | | |
| | | |
| | | |
| | | |

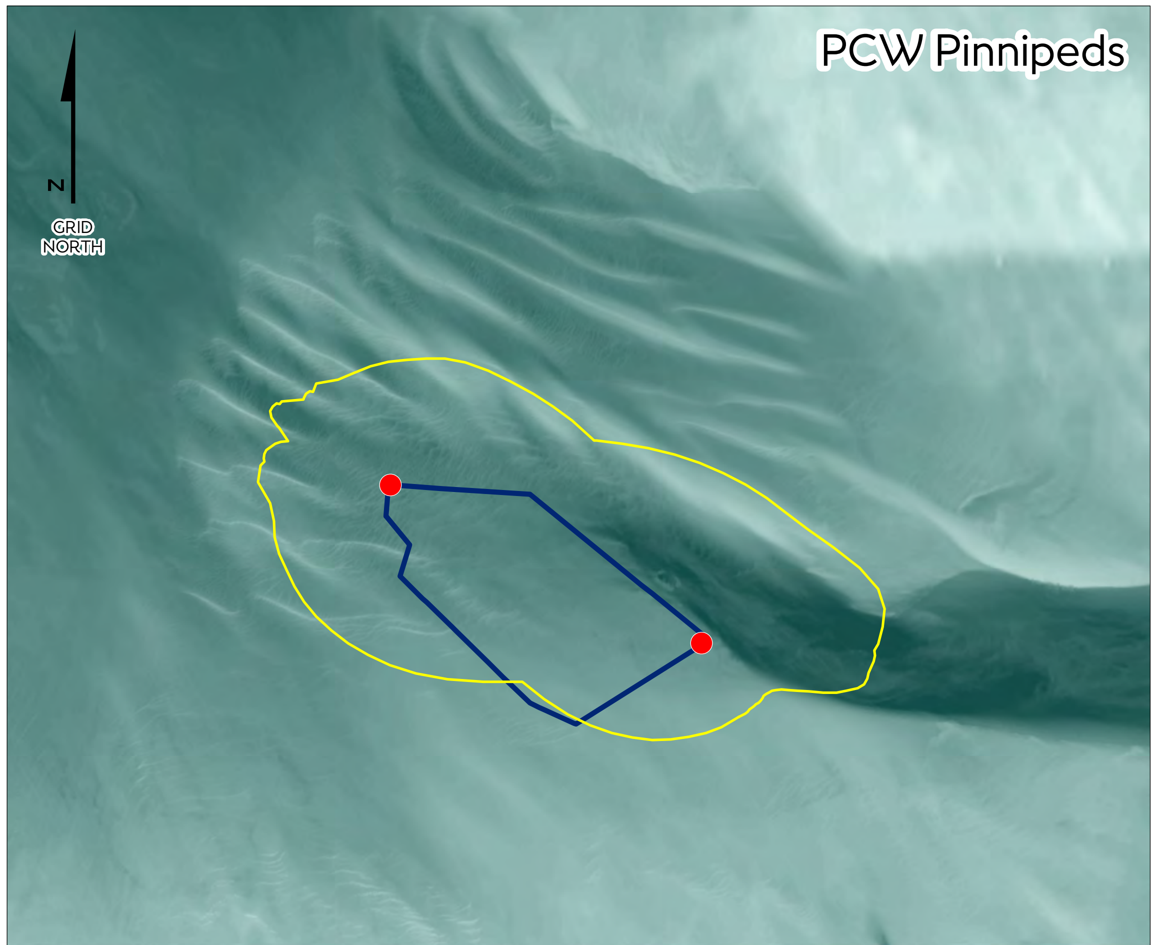
Figure 20
Multiple Piles
Document no: HOW04GB0266
Created by: BPHB
Checked by: AL
Approved by: LK





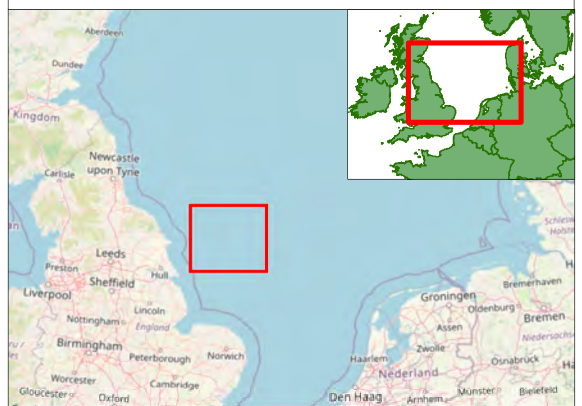

Date: 08/07/2021 Author: BenBlakeman Name: HOW04GB0267_AC_Fig21_Pin_Pile_Southall_Impulsive

# Hornsea Four

## Figure 21

Contour plots showing the cumulative impacts of simultaneous installation of pin pile foundations at the NW and E modelling locations for marine mammals using the Southall et al. (2019) impulsive criteria assuming a fleeing receptor

Array Area
Modelling Locations
PTS
TTS
Water Depth (m below CD)
10
95



Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:800,000

0 20 40 Kilometres
0 10 20 Nautical Miles

| REV | REMARK | DATE |
|---|---|---|
| --- | First Issue for ES | 08/07/2021 |

Figure 21
Multiple Piles
Document no: HOW04GB0267
Created by: BPHB
Checked by: AL
Approved by: LK

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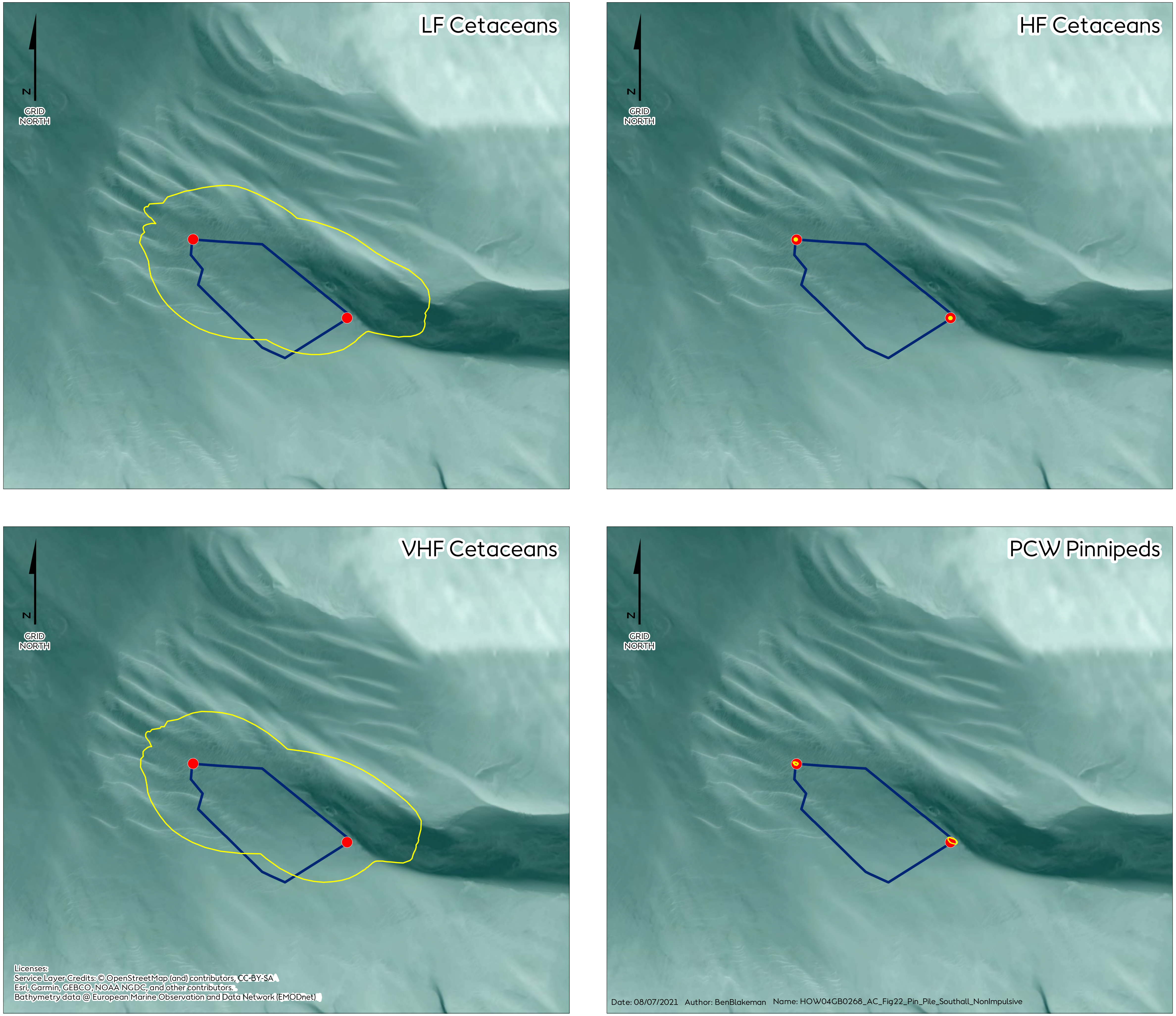
Ørsted




# Hornsea Four

Figure 22

Contour plots showing the cumulative impacts of simultaneous installation of pin pile foundations at the NW and E modelling locations for marine mammals using the Southall et al. (2019) non-impulsive criteria assuming a fleeing receptor

Array Area

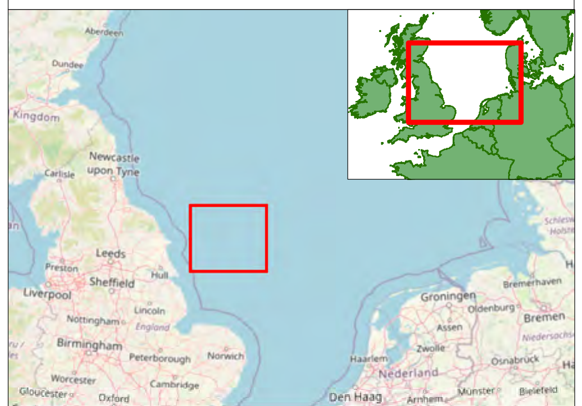
Modelling Locations

TTS

Water Depth (m below CD)

10

95



Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:800,000

0 20 40 Kilometres

0 10 20 Nautical Miles

| REV | REMARK | DATE |
|---|---|---|
| .... | First Issue for ES | 08/07/2021 |
| | | |
| | | |
| | | |
| | | |

Figure 22
Multiple Piles
Document no: HOW04GB0268
Created by: BPHB
Checked by: AL
Approved by: LK

### 5.3.3 Fish criteria

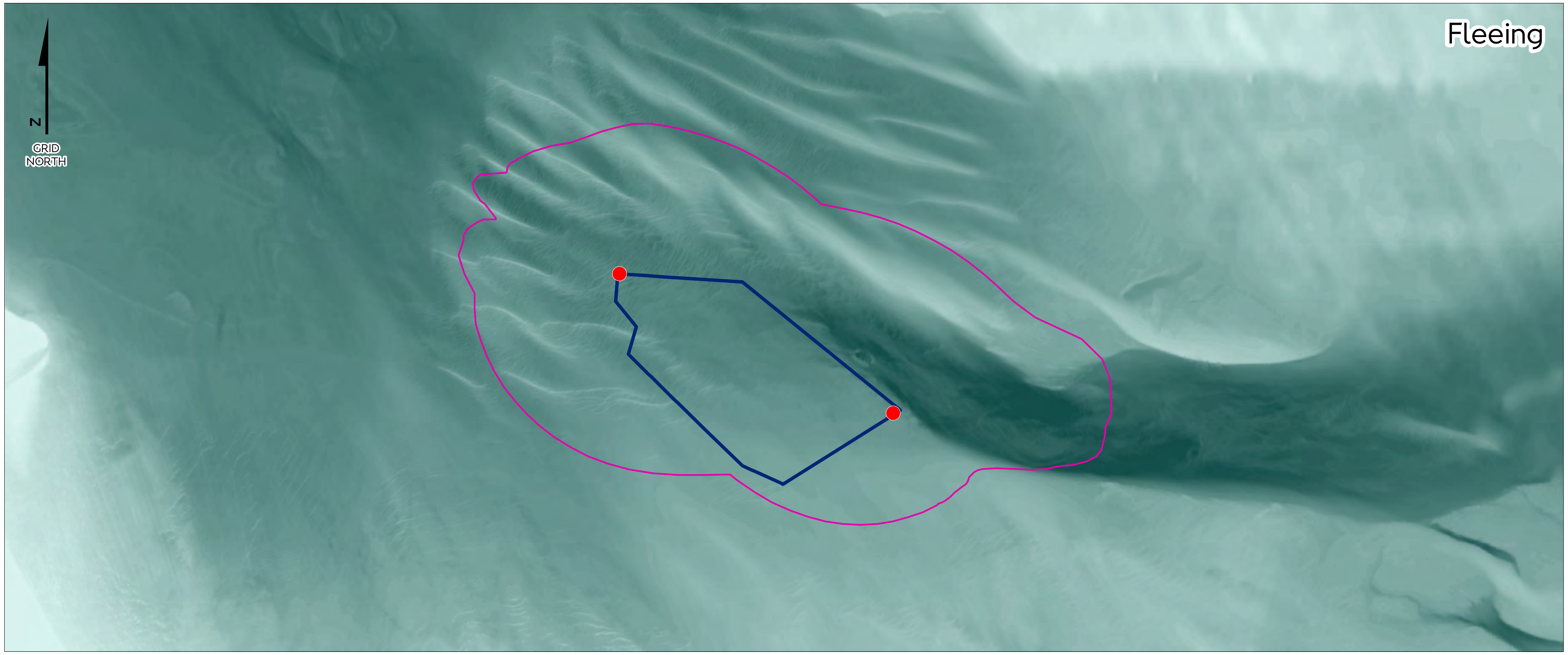
5.3.3.1 The impact areas for fish, using the Popper et al. (2014) criteria, showing the results for impact piling at the NW and E locations, as well as the in-combination area for simultaneous piling are summarised in Table 71 and Table 72. These results are shown as contour plots in Figure 23 and Figure 24.

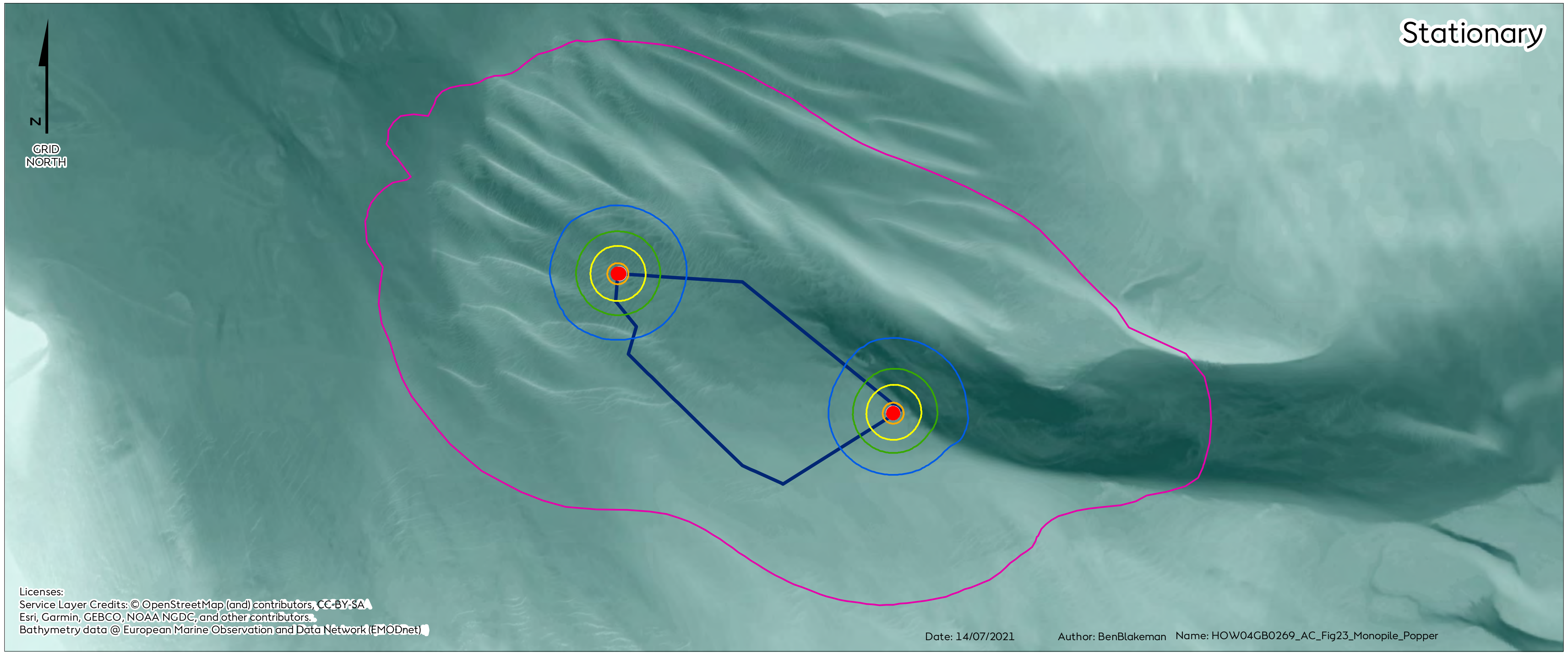
**Table 71: Summary of the impact areas for the installation of monopile foundations using the maximum design parameters at the NW and E modelling locations for fish using the Popper et al. (2014) $SEL_{cum}$ criteria for impact piling assuming both a fleeing and stationary receptor.**

| Popper et al. (2014) Weighted $SEL_{cum}$ | | Maximum design – Monopile (5,000 kJ) | | |
|---|---|---|---|---|
| | | NW area | E area | In-combination area |
| Fleeing | 219 dB | < 0.01 km² | < 0.01 km² | - |
| | 216 dB | < 0.01 km² | < 0.01 km² | - |
| | 210 dB | < 0.01 km² | < 0.01 km² | - |
| | 207 dB | < 0.01 km² | < 0.01 km² | - |
| | 203 dB | < 0.01 km² | < 0.01 km² | - |
| | 186 dB | 890 km² | 830 km² | 2500 km² |
| Stationary | 219 dB | 1.8 km² | 1.7 km² | - |
| | 216 dB | 5.0 km² | 5.0 km² | - |
| | 210 dB | 34 km² | 34 km² | - |
| | 207 dB | 80 km² | 79 km² | - |
| | 203 dB | 210 km² | 210 km² | - |
| | 186 dB | 2500 km² | 2400 km² | 4500 km² |

**Table 72: Summary of the impact areas for the installation of monopile foundations using the maximum design parameters at the NW and E modelling locations for fish using the Popper et al. (2014) $SEL_{cum}$ criteria for impact piling assuming both a fleeing and stationary receptor.**

| Popper et al. (2014) Weighted $SEL_{cum}$ | | Maximum design – Pin pile (3,000 kJ) | | |
|---|---|---|---|---|
| | | NW area | E area | In-combination area |
| Fleeing | 219 dB | < 0.01 km² | < 0.01 km² | - |
| | 216 dB | < 0.01 km² | < 0.01 km² | - |
| | 210 dB | < 0.01 km² | < 0.01 km² | - |
| | 207 dB | < 0.01 km² | < 0.01 km² | - |
| | 203 dB | < 0.01 km² | < 0.01 km² | - |
| | 186 dB | 620 km² | 590 km² | 2000 km² |
| Stationary | 219 dB | 0.86 km² | 0.86 km² | - |
| | 216 dB | 2.5 km² | 2.5 km² | - |
| | 210 dB | 19 km² | 18 km² | - |
| | 207 dB | 46 km² | 46 km² | - |
| | 203 dB | 130 km² | 130 km² | - |
| | 186 dB | 2000 km² | 1900 km² | 3800 km² |




# Hornsea Four

## Figure 23

Contour plots showing the cumulative impacts of simultaneous installation of monopile foundations at the NW and E modelling locations for fish using the Popper et al. (2014) impact piling criteria assuming fleeing and stationary receptors

Array Area
Modelling Locations
Noise Level (dB)
186
203
207
210
216
219
Water Depth (m below CD)
10
95


Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:600,000
0 10 20 Kilometres
0 5 10 Nautical Miles

| REV | REMARK | DATE |
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Figure 23
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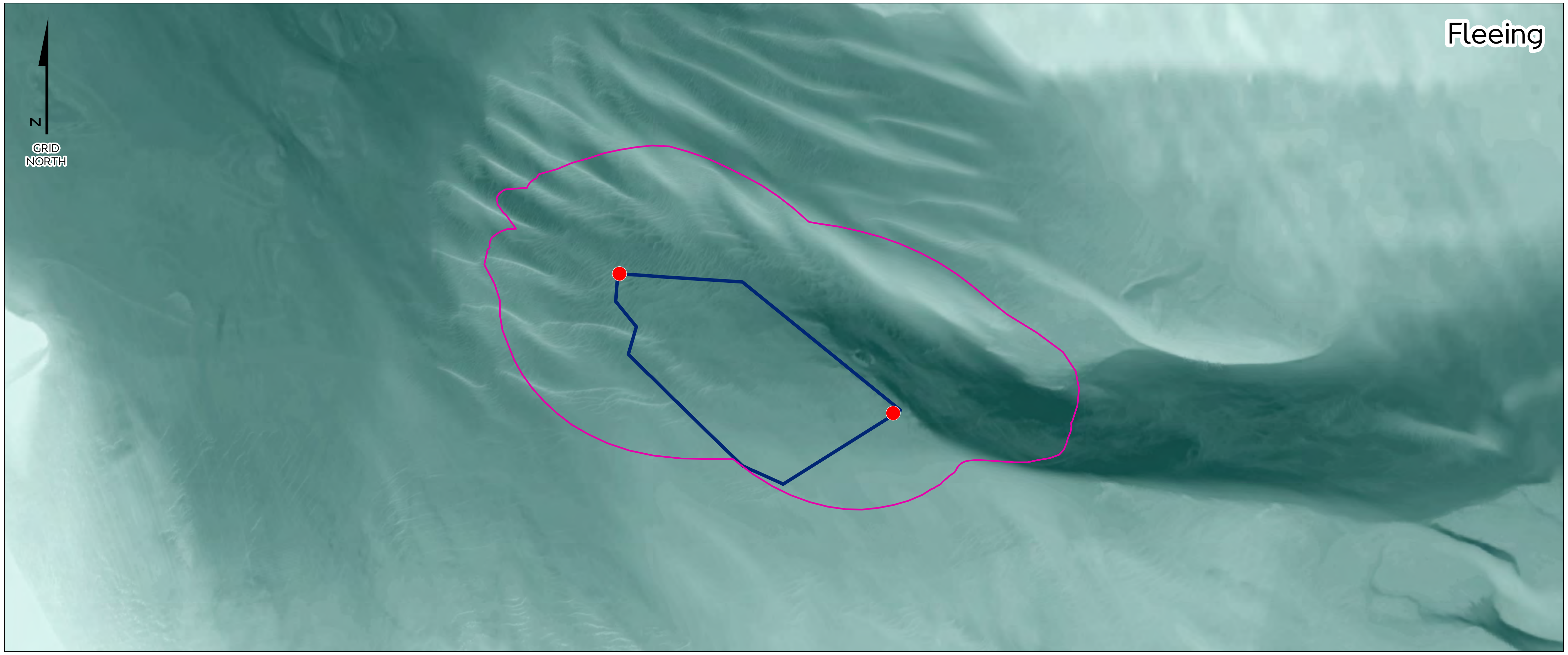
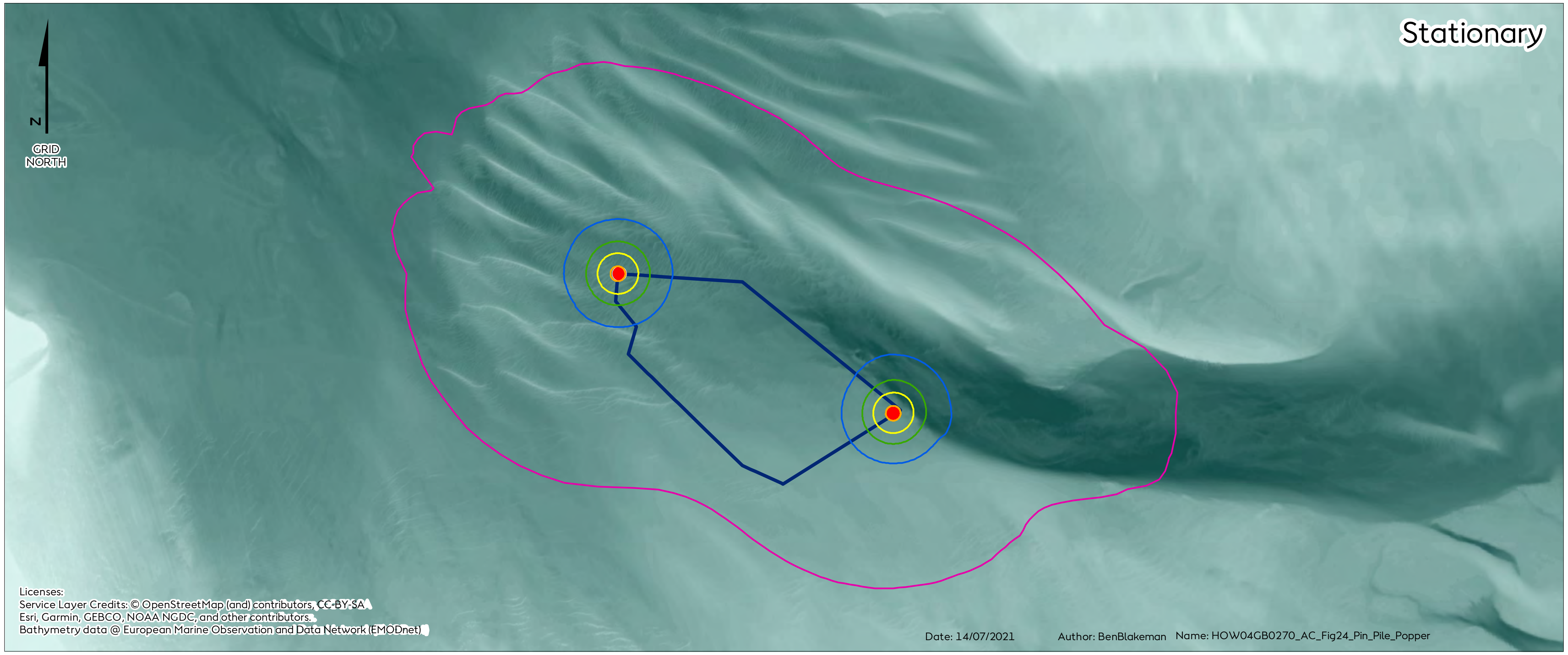



# Hornsea Four

Figure 24

Contour plots showing the cumulative impacts of simultaneous installation of pin pile foundations at the NW and E modelling locations for fish using the Popper et al. (2014) impact piling criteria assuming fleeing and stationary receptors

Array Area

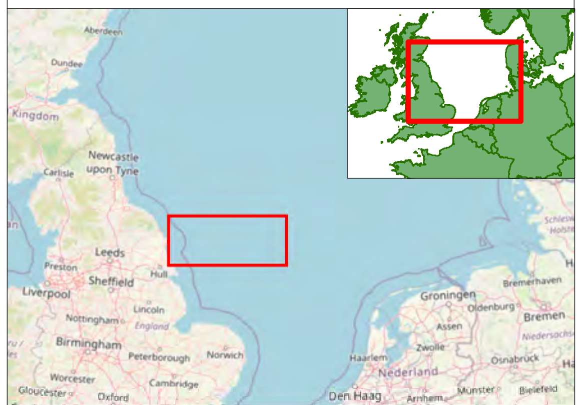
Modelling Locations

Noise Level (dB)

- 186
- 203
- 207
- 210
- 216
- 219

Water Depth (m below CD)

- 10
- 95



Coordinate system: ETRS 1989 UTM Zone 31N

Scale@A3: 1:600,000

0 10 20 Kilometres

0 5 10 Nautical Miles

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# 6 Other Noise Sources

## 6.1 Introduction

6.1.1.1 Although impact piling is expected to be the primary noise source for consideration during offshore wind farm 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.

6.1.1.2 Table 73 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 Hornsea Four.

**Table 73: Summary of the possible noise making activities at Hornsea Four other than impact piling.**

| Activity | Description |
|---|---|
| Dredging | Trailer suction hopper dredger may be required on site for the export cable, array cable and interconnector cable installation, as well as seabed preparation works for certain foundation options. |
| Drilling | Necessary in case of impact piling refusal. |
| Cable laying | Noise from the cable laying vessel and any other associated noise during the offshore cable installation. |
| 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 on site 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. The project design envelope gives turbines with rotor diameters of up to 305 m. |

6.1.1.3 Noise from clearing unexploded ordnance (UXO) is also expected, however an assessment of this has not been undertaken as UXO clearance will not be included in the application. A detailed assessment of UXO clearance will be developed for a separate marine licence at a later stage (this approach was agreed with the Marine Management Organisation (MMO) 26 November 2018 – see **Volume A1, Chapter 4: Project Description**).

6.1.1.4 In addition, a high-level review of potential noise from decommissioning activities is given in **Section 6.4**.

6.1.1.5 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. drilling and cable laying) or where detailed modelling would imply an unwarranted accuracy (e.g. where data is limited such as with large operational WTG noise). The high-level overview of modelling that has been presented is here considered sufficient and there would be little benefit in using a more detailed model at this stage. The limitations of this approach are acknowledged, including the lack of frequency or bathymetry dependence.

## 6.2 Noise making activities

6.2.1.1 For the purposes of identifying the greatest noise levels, approximate subsea noise levels have been predicted using a simple modelling approach based on measured data from Subacoustech Environmental's own underwater noise measurement database, scaled to relevant parameters for the site and specific noise sources to be used at the site. The calculation of underwater noise transmission loss (TL) for the non-impulsive sources is based on an empirical analysis of the noise measurements taken on transects around these sources by Subacoustech. Many of these are identified as a separate section in the References in **Section 8**. It uses an N.log R - $\alpha$ R principle, fitted to the data.

6.2.1.2 Predicted source levels and TL calculations for the construction activities are presented in **Table 74** along with a summary of the number of datasets used in each case. As previously, all $SEL_{cum}$ criteria use the same assumptions as presented in **Section 2.2.2**, and ranges smaller than 50 m (single strike) and 100 m (cumulative) have not been presented. It should be noted that this modelling approach does not take bathymetry or other environmental conditions into account, and as such can be applied to any location in the Hornsea Four project area. Noise from operational WTGs has been reviewed separately in **Section 6.3** and decommissioning noise is reviewed in **Section 6.4**. All RMS values are based on steady-state, continuous, average noise measurements of at least 10 s, and are appropriate for ongoing activities of indeterminate duration. They should not be confused with the exposure metric, SEL, which are accumulative and where the period of exposure is crucial.

**Table 74: Summary of the estimated unweighted source levels for the different construction noise sources considered.**

| Source | Estimated unweighted source level | Approximate TL (N log R - α R) | Comments |
|---|---|---|---|
| Dredging | 186 dB re 1 µPa @ 1 m (RMS) | 19 log R - 0.0009 R | Based on five datasets from suction and cutter suction dredgers. |
| Drilling | 179 dB re 1 µPa @ 1 m (RMS) | 16 log R - 0.0006 R | Based on seven datasets of offshore drilling using a variety of drill sizes and powers. |
| Cable laying | 171 dB re 1 µPa @ 1 m (RMS) | 13 log R (no absorption) | Based on 11 datasets from a pipe laying vessel measuring 300 m in length; this is considered a maximum design noise source for cable laying operations. |
| Rock placement | 172 dB re 1 µPa @ 1 m (RMS) | 12 log R - 0.0005 R | Based on four datasets from rock placement vessel 'Rollingstone.' |
| Trenching | 172 dB re 1 µPa @ 1 m (RMS) | 13 log R - 0.0004 R | Based on three datasets of measurements from trenching vessels more than 100 m in length. |
| Vessel noise (large) | 171 dB re 1 µPa @ 1 m (RMS) | 12 log R -0.0021 R | Based on five datasets of large vessels including container ships, FPSOs and other vessels more than 100 m in length. Vessel speed assumed as 12 knots. |
| Vessel noise (medium) | 164 dB re 1 µPa @ 1 m (RMS) | 12 log R - 0.0021 R | Based on three datasets of moderate sized vessels less than 100 m in length. Vessel speed assumed as 12 knots. |

6.2.1.3 To account for the weightings required for modelling using the Southall et al. (2019) criteria, reductions in source level have been applied to the various noise sources. **Figure 25** shows the representative noise measurements used, adjusted for the source levels in **Table 74**. **Table 75** presents the details of the reductions in source levels used for each of the weightings used for modelling.

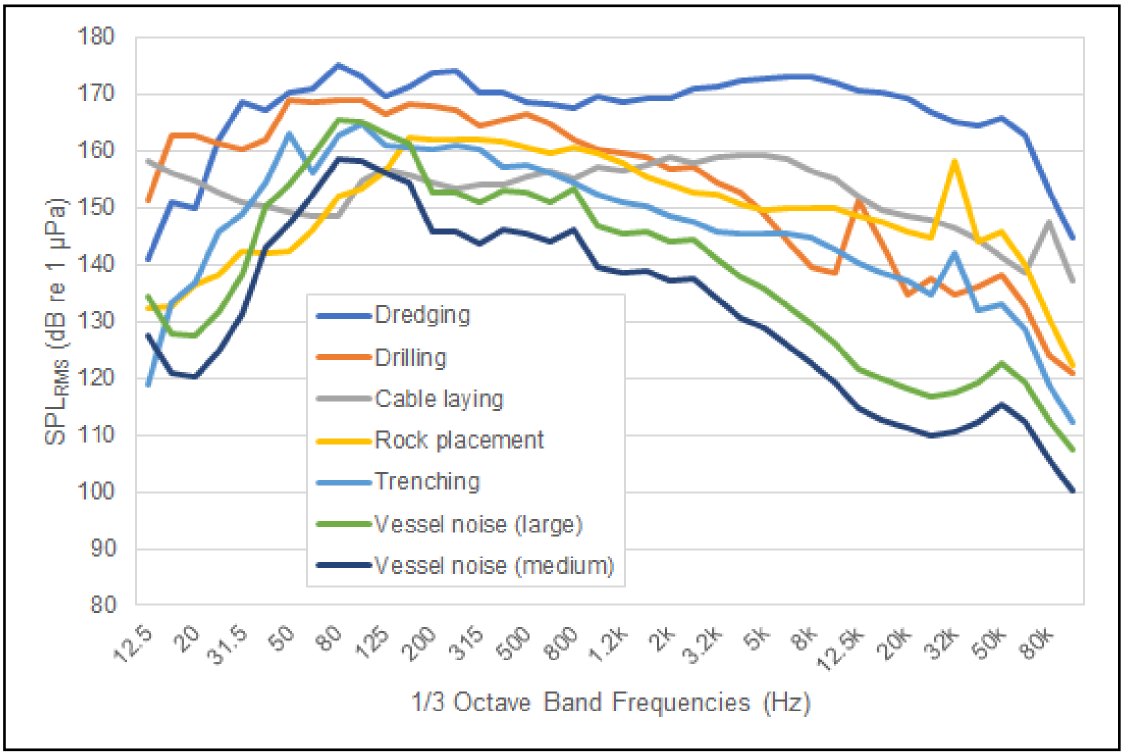


**Figure 25: Summary of the 1/3 octave frequency bands used as basis for the Southall et al. (2019) weightings used in the simple modelling**

**Table 75: Reductions in the source levels for the different construction noise sources considered when the Southall et alet al. (2019) weightings are applied.**

| Source | Reduction in source level from the unweighted level | | | |
|---|---|---|---|---|
| | LF | HF | VHF | PCW |
| Dredging | 2.5 dB | 7.9 dB | 9.6 dB | 4.2 dB |
| Drilling | 4.0 dB | 25.8 dB | 28.4 dB | 13.2 dB |
| Cable laying | 3.6 dB | 22.9 dB | 23.9 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 |

6.2.1.4 Table 76 and Table 77 summarise the predicted impact ranges for these noise sources. It is worth noting that the Southall et al. (2019) and Popper et al. (2014) criteria give different criteria for non-impulsive or continuous noise sources compared to impulsive noise (see Section 2.2.2); all sources in this section are considered non-pulse or continuous-type.

6.2.1.5 Given the modelled impact ranges, any marine mammal would have to, in most case, be less than 100 m from the continuous noise sources 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 speed as in the previous modelling. It should also be noted that this would only mean that the receptor reaches the 'onset' stage, which is the minimum exposure that could potentially lead to TTS. In most hearing groups, the noise levels are low enough that there is negligible risk.

6.2.1.6 For fish, there is a low to negligible risk of any injury or TTS, in line with guidance for continuous noise sources in Popper et al. (2014) and presented in **paragraph 2.2.2.18** and **Table 5**. All sources presented here are much quieter than those presented for impact piling in **Section 5**.

**Table 76: Summary of the impact ranges for the different construction noise sources using the non-impulsive criteria from Southall et alet al. (2019) for marine mammals at Hornsea Four.**

| Southall et alet al. (2019) | | Dredging | Drilling | Cable laying | Rock placement | Trenching | Vessels (large) | Vessels (medium) |
|---|---|---|---|---|---|---|---|---|
| PTS | 199 dB (LF $SEL_{cum}$) | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m |
| | 198 dB (HF $SEL_{cum}$) | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m |
| | 173 dB (VHF $SEL_{cum}$) | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m |
| | 201 dB (PCW $SEL_{cum}$) | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m |
| TTS | 179 dB (LF $SEL_{cum}$) | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m |
| | 178 dB (HF $SEL_{cum}$) | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m |
| | 153 dB (VHF $SEL_{cum}$) | 230 m | < 100 m | < 100 m | 990 m | < 100 m | < 100 m | < 100 m |
| | 181 dB (PCW $SEL_{cum}$) | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m | < 100 m |

**Table 77: Summary of the impact ranges from Popper et alet al. (2014) for shipping and continuous noise, covering the different construction noise sources for species of fish (swim bladder involved in hearing for Hornsea Four.**

| Popper et alet al. (2014) | Dredging | Drilling | Cable laying | Rock placement | Trenching | Vessels (large) | Vessels (medium) |
|---|---|---|---|---|---|---|---|
| **Recoverable injury** *170 dB (48 hours)* *Unweighted $SPL_{RMS}$* | < 50 m | < 50 m | < 50 m | < 50 m | < 50 m | < 50 m | < 50 m |
| **TTS** *158 dB (12 hours)* *Unweighted $SPL_{RMS}$* | < 50 m | < 50 m | < 50 m | < 50 m | < 50 m | < 50 m | < 50 m |

## 6.3 Operational WTG noise

6.3.1.1 The main source of underwater noise from operational WTGs will be mechanically generated vibration from the rotating machinery in the turbines, which is transmitted into the sea through the structure of the turbine tower, pile and foundations (Nedwell et al. 2003a, 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.

6.3.1.2 The project design envelope for Hornsea Four gives the maximum potential WTG rotor diameter as 305 m. A summary of operational WTG where measurements have been collected is given in **Table 78**.

**Table 78: Characteristics of measured operational wind farms used as a basis for modelling.**

| Wind farm | Lynn | Inner Dowsing | Gunfleet Sands 1 & 2 | Gunfleet Sands 3 |
|---|---|---|---|---|
| Type of turbine used | Siemens SWT-3.6-107 | Siemens SWT-3.6-107 | Siemens SWT-3.6-107 | Siemens SWT-6.0-120 |
| Number of turbines | 27 | 27 | 48 | 2 |
| Rotor diameter | 107 m | 107 m | 107 m | 120 m |
| Water depths | 6 to 8 m | 6 to 14 m | 0 to 15 m | 5 to 12 m |
| Representative sediment type | Sandy gravel / muddy sandy gravel | Sandy gravel / muddy sandy gravel | Sand / muddy sand / muddy sandy gravel | Sand / muddy sand / muddy sandy gravel |
| Turbine separation (representative) | 500 m | 500 m | 890 m | 435 m |

6.3.1.3 The estimation of the effects of operational noise in these situations has two features that make it harder to predict compared with noise sources such as impact piling. Primarily, the problem is one of level; noise measurements made at many wind farms have demonstrated that the operational noise produced was at such a low level that it was difficult to measure relative to background noise at distances of a few hundred metres (Cheesman 2016). Secondly, the multiple turbines of an offshore wind farm could be considered as an extended, distributed noise source, as opposed to a "point source" as would be appropriate for pile driving at a single location, for example. The measurement techniques used at the sites above have dealt with these issues by considering the operational noise spectra in terms of levels within and on the edge of the wind farm (but relatively close to the turbines, so that some noise above background could be detected).

6.3.1.4 The considered turbine size for modelling Hornsea Four is larger than those for which data is available. Hornsea Four is also situated in greater water depths, and as such, estimations of a scaling factor must be conservative to minimise the risk of underestimating the noise. However, it is recognised that the available data on which to base the scaling factor is limited and the extrapolation that must be made is significant.

6.3.1.5 The operational source levels (as $SPL_{RMS}$) for the measured sites are given in **Table 79** (Cheesman 2016), with an estimated source level for Hornsea Four in the bottom row. To predict operational WTG noise levels at Hornsea Four, the level sampled at each of the sites has been taken and then a linear correction factor has been included to scale up the source levels (**Figure 26**). A linear fit was applied to the data as this was the most conservative extrapolation, leading to the highest, and thus maximum design, estimation of source level noise from the larger 305 m diameter rotor WTGs. This resulted in an estimated source level of 165.4 dB $SPL_{RMS}$ @ 1 m, 19.4 dB higher than the 120 m diameter rotor WTG; the largest for which noise data is currently available.

**Table 79: Measured operational WTG noise taken at operational wind farms, and the predicted source level for the maximum turbine size considered at Hornsea Four.**

| Site | Unweighted source level |
|---|---|
| Lynn (107 m) | 141 dB re 1 µPa (RMS) @ 1 m |
| Inner Dowsing (107 m) | 142 dB re 1 µPa (RMS) @ 1 m |
| Gunfleet Sands 1 & 2 (107 m) | 145 dB re 1 µPa (RMS) @ 1 m |
| Gunfleet Sands 3 (120 m) | 146 dB re 1 µPa (RMS) @ 1 m |
| Hornsea Four (305 m) | 165.4 dB re 1 µPa (RMS) @ 1 m |

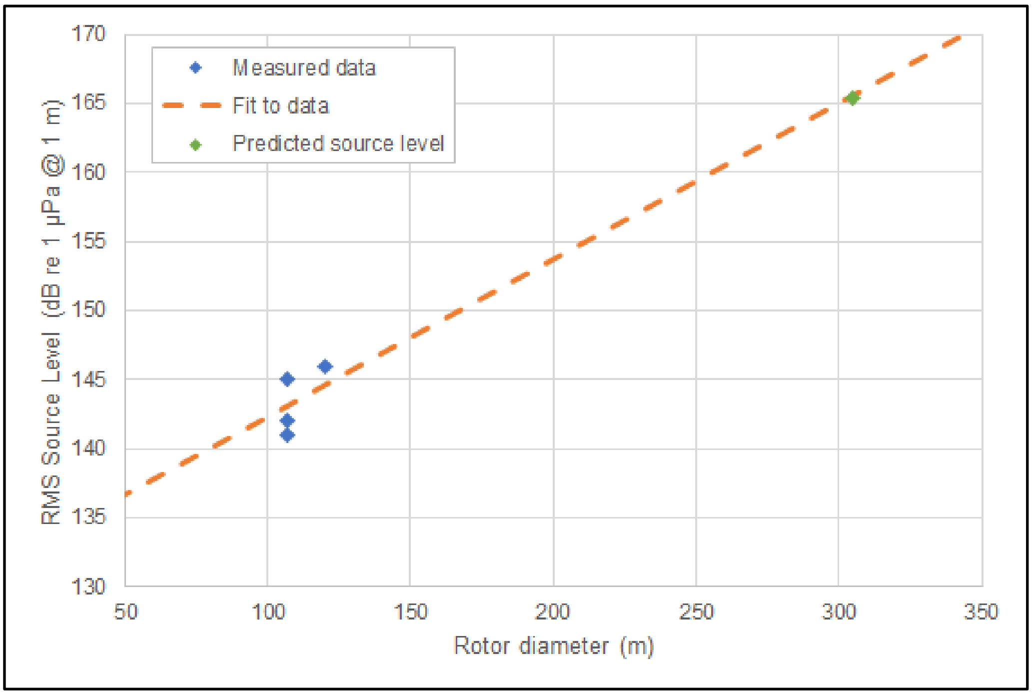


**Figure 26: Extrapolated source levels from operational WTGs plotted with a linear fit to estimate the source level for a WTG with a rotor diameter of 305 m.**

6.3.1.6 It is acknowledged that this fit is speculative: the available data is very limited. Newer, larger, direct-drive (gearbox-less) designs tend to be more efficient and losses (e.g. in energy which produces noise and vibration) are significantly reduced. Preliminary measurements of such direct-drive WTGs have been collected off the east coast of the United States (HDR 2019), showing extrapolated source levels of 136 dB re 1 µPa ($SPL_{RMS}$) @ 1 m for a WTG with a 150 m diameter rotor. Stöber and Thomsen (2021) estimate the direct-drive turbines to be 10 dB quieter than an equivalent gearboxed design. Thus, the linear extrapolation represents a considerably greater noise output and can be considered conservative.

6.3.1.7 A summary of the predicted impact ranges is given in **Table 80** and **Table 81**. All $SEL_{cum}$ criteria use the same assumptions as presented in **Section 2.2.2**, and ranges smaller than 50 m (single strike) and 100 m (cumulative) have not been presented. The operational WTG source is considered a non-impulsive sound by Southall et al. (2019) and a continuous source by Popper et al. (2014). For $SEL_{cum}$ calculations, it has been assumed that the operational WTG noise is present 24 hours a day and that the receptor remains stationary in the vicinity for the duration.

Table 80: Summary of the impact ranges for operational WTGs using the non-impulsive noise criteria from Southall et al. (2019) for marine mammals at Hornsea Four.

| Southall et alet al. (2019) | | Operational WTG (305 m) |
|---|---|---|
| PTS | 199 dB (LF $SEL_{cum}$) | < 100 m |
| | 198 dB (HF $SEL_{cum}$) | < 100 m |
| | 173 dB (VHF $SEL_{cum}$) | < 100 m |
| | 201 dB (PCW $SEL_{cum}$) | < 100 m |
| TTS | 179 dB (LF $SEL_{cum}$) | < 100 m |
| | 178 dB (HF $SEL_{cum}$) | < 100 m |
| | 153 dB (VHF $SEL_{cum}$) | < 100 m |
| | 181 dB (PCW $SEL_{cum}$) | < 100 m |

Table 81: Summary of the impact ranges for shopping and continuous noise from Popper et alet al. (2014) for operational WTGs for species of fish (swim bladder involved in hearing) at Hornsea Four.

| Popper et alet al. (2014) | Operational WTG (305 m) |
|---|---|
| **Recoverable injury**<br>*170 dB (48 hours) Unweighted $SPL_{RMS}$* | < 50 m |
| **TTS**<br>*158 dB (12 hours) Unweighted $SPL_{RMS}$* | < 50 m |

6.3.1.8 These results show that, for operational WTGs, any injury risk is minimal. The impact ranges calculated above are greater than those based on the noise levels estimated in Tougaard et al. (2020). Taking both sets of results into account (operational WTG noise and other noise sources related to construction, see **Section 6.2**), and comparing them to the impact piling results in the **Section 5** (specifically **Section 5.2**), it is clear that noise from impact piling results in much greater levels and impact ranges, and hence should be considered the activity which has the potential to have the greatest effect during the construction and lifecycle of Hornsea Four.

## 6.4 Decommissioning noise

6.4.1.1 Decommissioning noise also needs to be considered even in the light of the expected 35 years of operational life. With present technologies, the following decommissioning techniques have been considered:

- High-powered water jetting/cutting apparatus; and
- Grinding or drilling techniques.

6.4.1.2 It is also worth noting that by the time Hornsea Four is decommissioned, there are likely to be many more options available for decommissioning.

6.4.1.3 Water jetting and grinding techniques would produce noise at a much lower and less intrusive level than impact piling. Decommissioning is anticipated to take approximately five years, about the same duration as expected for construction. Thus, the overall impact is expected to be lower than during the construction phase.

6.4.1.4 Only closer to the time of decommissioning, when local marine life is known and understood, can a realistic and useful assessment of the effects of the noise, and the appropriate mitigation, be carried out. It seems clear that a separate and new impact assessment will be required closer to the time of decommissioning and no further discussion will be made here.

# 7 Discussion

7.1.1.1 This report presents a study presenting the potential levels of underwater noise during the development of Hornsea Four, primarily focussing on impact piling noise as this has been recognised as the activity known to have the greatest potential underwater noise levels.

7.1.1.2 The level of underwater noise from the installation of monopiles and pin piles during construction has been estimated using the INSPIRE subsea noise modelling software, which considers a wide variety of input parameters including bathymetry, hammer blow energy and the frequency content of the noise.

7.1.1.3 Four representative locations were chosen at Hornsea Four array area and the nearby HVAC location to give spatial variation as well as to consider changes in water depth. At each location four scenarios were considered, covering maximum design and most-likely parameters for installing monopiles and pin piles at each location. The maximum design maximum blow energies used for modelling were 5,000 kJ for monopiles and 3,000 kJ for pin piles. Lower blow energies of 4,000 kJ and 1,750 kJ were used for the most-likely scenarios. The results showed that greater levels of noise are predicted along transects travelling through deeper water.

7.1.1.4 The modelling results were analysed in terms of relevant noise metrics and criteria to aid assessments of the impacts from the impact piling noise on marine mammals and fish. Southall et alet al. (2019) was used for various species of marine mammal using unweighted $SPL_{peakj}$ and weighted $SEL_{cum}$ metrics. The largest impact ranges for these criteria are summarised in **Table 82**. For all cases in the table below, the maximum design modelling parameters at the East location provided the largest impact ranges.

**Table 82: Summary of the maximum predicted impact ranges for marine mammal criteria (E location, maximum design parameters).**

| Southall et alet al. (2019) (weighted $SEL_{cum}$) | | Maximum design monopile (5,000 kJ) | Maximum design pin pile (3,000 kJ) |
|---|---|---|---|
| PTS | Low-frequency cetacean (LF) | 11 km | 9.2 km |
| | High-frequency cetacean (HF) | < 100 m | < 100 m |
| | Very high-frequency cetacean (VHF) | 450 m | 12 km |
| | Phocid Carnivore in Water (PCW) | < 100 m | 42 km |
| TTS | Low-frequency cetacean (LF) | 42 km | 40 km |
| | High-frequency cetacean (HF) | < 100 m | < 100 m |
| | Very high-frequency cetacean (VHF) | 25 km | 42 km |
| | Phocid Carnivore in Water (PCW) | 22 km | 19 km |

7.1.1.5 Impact range criteria from Popper et alet al. (2014) was used for various groups of fish, with ranges of up to 1.3 km for recoverable injury ($SPL_{peak}$) and out to 26 km (fleeing) and 38 km (stationary) for TTS ($SEL_{cum}$) at the maximum blow energies when considering the maximum design parameters for monopiles.

7.1.1.6 Noise sources other than piling have been considered using a high-level, simple modelling approach, including dredging, drilling, cable laying, rock placement, trenching, vessel noise 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 potential injurious effects to fish or marine mammals from these sources are expected to be negligible as the noise emissions from these are very close to, or below, the appropriate injury criteria at the source of the noise. Noise during decommissioning techniques has the potential for an effect, however a separate and new impact assessment will be required once the techniques to be used are understood.

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