Hornsea Project Four

Clarification Note on the Installation of Two Monopile Foundations Sequentially

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Revision Summary

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Glossary

Term	Definition
Demersal	Relating to the seabed and area close to it. Demersal spawning species are those which deposit eggs onto the seabed.
Development Consent Order (DCO)	An order made under the Planning Act 2008 granting development consent for one or more Nationally Significant Infrastructure Projects (NSIP).
Effect	Term used to express the consequence of an impact. The significance of an effect is determined by correlating the magnitude of the impact with the importance, or sensitivity, of the receptor or resource in accordance with defined significance criteria.
Environmental Impact Assessment (EIA)	A statutory process by which certain planned projects must be assessed before a formal decision to proceed can be made. It involves the collection and consideration of environmental information, which fulfils the assessment requirements of the EIA Directive and EIA Regulations, including the publication of an Environmental Impact Assessment (EIA) Report.
Export cable corridor (ECC)	The specific corridor of seabed (seaward of Mean High Water Springs (MHWS)) and land (landward of MHWS) from the Hornsea Four array area to the Creyke Beck National Grid substation, within which the export cables will be located.
Fish larvae	The developmental stage of fish which have hatched from the egg and receive nutrients from the yolk sac until the yolk is completely absorbed.
Hornsea Project Four Offshore Wind Farm	The term covers all elements of the project (i.e. both the offshore and onshore). Hornsea Four infrastructure will include offshore generating stations (wind turbines), electrical export cables to landfall, and connection to the electricity transmission network. Hereafter referred to as Hornsea Four.
Maximum Design Scenario (MDS)	The maximum design parameters of each Hornsea Four asset (both on and offshore) considered to be a worst case for any given assessment.
Order Limits	The limits within which Hornsea Four (the 'authorised' project) may be carried out.
Orsted Hornsea Project Four Ltd.	The Applicant for the proposed Hornsea Project Four Offshore Wind Farm Development Consent Order (DCO).
Planning Inspectorate (PINS)	The agency responsible for operating the planning process for Nationally Significant Infrastructure Projects (NSIPs).
Spawning	The release or deposition of eggs and sperm, usually into water, by aquatic animals.

Acronyms

Term	Definition
DCO	Development Consent Order
ECC	Export Cable Corridor
EIA	Environmental Impact Assessment
ES	Environmental Statement
HF	High Frequency Cetaceans
ICES	International Council for the Exploration of the Sea
IHLS	International Herring Larvae Survey
LF	Low Frequency Cetaceans
MDS	Maximum Design Scenario
MHWS	Mean High Water Springs
MMO	Marine Management Organisation
PCW	Phocid Carnivores in Water
PINS	Planning Inspectorate
PTS	Permanent Threshold Shift
TTS	Temporary Threshold Shift
VHF	Very High Frequency Cetaceans

1 Introduction

1.1.1.1 Orsted Hornsea Project Four Limited (hereafter the Applicant) has submitted a Development Consent Order (DCO) application to the Planning Inspectorate (PINS), supported by a range of plans and documents including an Environmental Statement (ES) which set out the results of the Environmental Impact Assessment (EIA) on the Hornsea Project Four Offshore Wind Farm (hereafter Hornsea Four) and its associated infrastructure.

1.1.1.2 To inform the marine mammal (**A2.4 Marine Mammals (APP-016)**) and fish and shellfish ecology assessments within the ES (**A2.3 Fish and Shellfish Ecology (APP-015)**), predictive underwater noise modelling was undertaken for different piling scenarios (most-likely and maximum design scenario (MDS)), different pile types (monopiles and pin piles), simultaneous piling (two piling installations occurring simultaneously at separated foundations locations – monopiles and pin piles), and sequential piling of pin piles (three piles installed at the same location in a 24-hour period). The methodology and results of this modelling is set out in **A4.4.5 Subsea Noise Technical Report (APP-043 & APP-044)**. This modelling was used to determine potential impacts associated with underwater noise on fish and marine mammal receptors as a result of the installation of foundations during the construction of Hornsea Four.

1.1.1.3 Within the Marine Management Organisation (MMO) Relevant Representation (paragraph 3.7.10, RR-020), it was noted that *"based on the modelling presented, only a single monopile will be installed in a 24-hour period, although up to three pin piles could be installed in a 24-hour period. The MMO requests that this is clarified and the modelling is updated if more than one monopile is installed"*. In response, the Applicant has undertaken additional noise modelling for the sequential installation of two monopiles within 24 hours in the same area of the Hornsea Four array (northwest corner). This note has been prepared to present the results of this additional noise modelling and to provide assurance to the MMO that this scenario will not result in any change to the significance of effects on marine mammal and fish receptors above that concluded within their receptive ES chapter assessments (**A2.4 Marine Mammals (APP-016)** and **A2.3 Fish and Shellfish Ecology (APP-015)**, respectively).

1.2 Additional Noise Modelling

1.2.1.1 **Appendix B** of this note provides the methodology and results of the additional noise modelling for the sequential installation of two monopiles within a 24-hour period. The modelling location in the NW corner of Hornsea Four has been considered along with its closest neighbour, which is situated approximately 1.2 km to the SE. The modelling assumes that the monopile foundation at the NW corner is installed, followed immediately by the neighbouring monopile foundation. This is considered precautionary as it does not allow additional flee time for a marine mammal between the two monopile installations. Timings do not influence the stationary receptor modelling used for fish.

2 Marine Mammals

2.1.1.1 The impact areas produced by the installation of a single foundation at the NW corner of Hornsea Four using the MDS monopile parameters, as given in the original modelling (**A4.4.5 Subsea Noise Technical Report (APP-043 & APP-044)**) have been presented in **Table 1** and **Table 2** alongside the two sequential monopile impact areas modelled in this exercise.

Table 1: Comparison between the impact areas of a single MDS monopile modelling and the sequential MDS monopile modelling using the impulsive Southall *et al.* (2019) SEL$_{cum}$ criteria, assuming a fleeing receptor.

Southall *et al.* (2019) Weighted SEL$_{cum}$ – Impulsive criteria			*Single MDS Monopile*	*Sequential MDS Monopiles*
Permanent Threshold Shift (PTS)	Low Frequency Cetaceans (LF)	183 dB	66 km^2	68 km^2
	High Frequency Cetaceans (HF)	185 dB	<0.01 km^2	<0.01 km^2
	Very High Frequency Cetaceans (VHF)	155 dB	<0.01 km^2	0.41 km^2
	Phocid Carnivores in Water (PCW)	185 dB	<0.01 km^2	<0.01 km^2
Temporary Threshold Shift (TTS)	LF	168 dB	2,200 km^2	2,200 km^2
	HF	170 dB	<0.01 km^2	<0.01 km^2
	VHF	140 dB	860 km^2	880 km^2
	PCW	170 dB	670 km^2	680 km^2

Table 2: Comparison between the impact areas of a single MDS monopile modelling and the sequential MDS monopile modelling using the non-impulsive Southall *et al.* (2019) SEL$_{cum}$ criteria, assuming a fleeing receptor.

Southall *et al.* (2019) Weighted SEL$_{cum}$ – Impulsive criteria			*Single MDS Monopile*	*Sequential MDS Monopiles*
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	300 km^2
	HF	178 dB	<0.01 km^2	<0.01 km^2
	VHF	153 dB	5.3 km^2	7.1 km^2
	PCW	181 dB	11 km^2	12 km^2

2.2 Implications of this Additional Noise Modelling on the Marine Mammal Assessment

2.2.1.1 The largest predicted increase in impact area is for low frequency cetaceans (minke whales) where the cumulative PTS-onset area increases from 66 km^2 for a single monopile to 68 km^2 for sequential monopiles (**Table 1**). Therefore, the modelling for second monopile installed sequentially makes a negligible difference to the resulting cumulative PTS-onset impact areas for marine mammals. As such, there is no change to the magnitude of the impact and no change to the resulting impact significance.

3 Fish Ecology

3.1.1.1 As agreed through Evidence Plan Technical Panel meetings (Table 3.5 of **A2.3 Fish and Shellfish Ecology (APP-015)**), and as presented in the fish and shellfish ecology assessment of the ES (**A2.3 Fish and Shellfish Ecology (APP-015)**), spawning herring (*Clupea harengus*) were identified as the key fish receptor regarding impacts from underwater noise. It is on this basis, that the noise modelling presented within this note has a sole focus on herring. For the full suite of noise modelling on all fish receptors, see **Appendix B**.

3.1.1.2 **Table 3** below shows the noise modelling for injury ranges for fleeing (receptors fleeing from the source at a consistent rate of 1.5 ms^{-1}), and stationary (to account for spawning activity) herring for the relevant criteria, for both the installation of a single monopile, and the sequential installation of two monopile foundations.

Table 3: Comparison between the impact areas of a single MDS monopile modelling and the sequential MDS monopile modelling using the Popper *et al.* (2014) SEL_{cum} criteria for impact piling, assuming fleeing and stationary receptors.

Receptor	Popper *et al.* (2014) Unweighted SEL_{cum} – Impact piling criteria		*Single MDS Monopile*	*Sequential MDS Monopiles*
Fleeing herring	Mortality and potentially mortal injury	207 dB	<0.01 km^2	<0.01 km^2
	Recoverable injury	203 dB	<0.01 km^2	<0.01 km^2
	TTS	186 dB	890 km^2	900 km^2
Stationary herring	Mortality and potentially mortal injury	207 dB	80 km^2	170 km^2
	Recoverable injury	203 dB	210 km^2	380 km^2
	TTS	186 dB	2,500 km^2	3,400 km^2

3.1.1.3 As shown in **Table 3**, when considering a fleeing animal, the impact area only increases for TTS, and only slightly, with the introduction of a second monopile installed sequentially. This is because the receptor has travelled to a distance where the noise levels are much lower by the time the second monopile begins, resulting in a lower added exposure. For stationary animals, the ranges are larger for two monopiles installed sequentially as the receptor is receiving twice the total noise exposure compared to a single monopile.

3.2 Implications of this Additional Noise Modelling on the Fish and Shellfish Ecology Assessment

3.2.1.1 As stated above, spawning herring (*Clupea harengus*) are the key receptor when regarding impacts from underwater noise, due to their increased sensitivity to underwater noise (herring possess a swim bladder that is used in hearing (Popper *et al.*, 2014)), and due to the presence of spawning grounds in the vicinity of Hornsea Four (**A5.3.1 Fish and Shellfish Ecology Technical Report (APP-071)**). Herring are demersal spawners, laying their eggs on the sediment, and require specific sediment types for their eggs to successfully develop with a high level of year-to-year spawning ground dependency (i.e. they spawn in the same areas on specific habitat types each year, as opposed to many fish species that are broadcast spawners with low or no habitat dependency spawning over large areas). It is on this basis, that herring are considered to be potentially vulnerable to noisy impacts such as piling during spawning as any disturbance during this activity could, in theory, lead to an effect on spawning success which may not be easily recovered in the same spawning season.

3.2.1.2 The nearest herring spawning ground to Hornsea Four is the Banks (Central North Sea) spawning ground (**Figure 1**). The Banks spawning ground is located to the west of the Hornsea Four array area, lying just north of the Export Cable Corridor (ECC) (**Figure 2**).

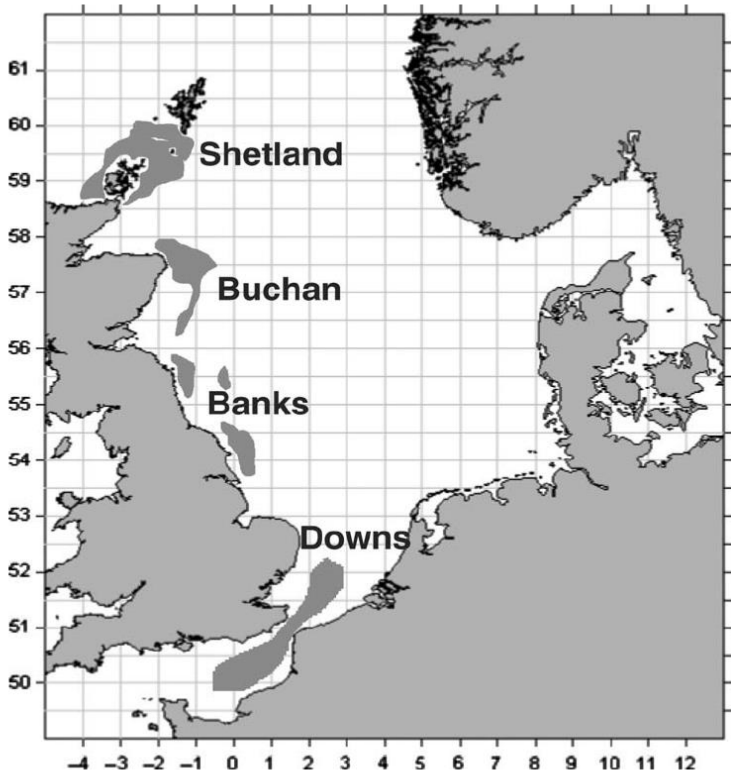


Figure 1: Herring spawning grounds within the North Sea (Beirman *et al.*, 2010).

3.2.1.3 Underwater noise modelling (as presented in **Table 3** above), presents the impact areas of mortality and potential injury, recoverable injury and TTS for both fleeing and stationary herring (to account for spawning activity).

3.2.1.4 As shown in **Table 3**, the impact areas of mortality and potential injury and recoverable injury remain the same with the introduction of a second monopile installed sequentially when considering fleeing herring. Therefore, there is no change to the outcome of the fish and shellfish ecology assessment (**A2.3 Fish and Shellfish Ecology (APP-015)**), as the impact areas are the same as those presented in the ES, therefore the conclusion of a **slight** significance of effect (not significant in EIA terms) is still appropriate.

3.2.1.5 The impact area in relation to TTS when considering fleeing receptors increases from 890 km^2 to 900 km^2. This increase in area (1.12%) is considered negligible in the context of the wider environment, and therefore the conclusion of a **slight** significance of effect (not significant in EIA terms) is still appropriate. It is on this basis, that when considering the potential impact from the addition of a second monopile installed sequentially on fleeing herring, the conclusions made within the fish and shellfish assessment of the ES (**A2.3 Fish and Shellfish Ecology (APP-015)**) remain unchanged.

3.2.1.6 When considering stationary receptors (representative of spawning herring), the impact areas of mortality and potential injury and recoverable injury increase from 80 km^2 to

170 km^2 (112.50% increase), and 210 km^2 to 380 km^2 (80.95% increase), respectively with the introduction of a second monopile installed sequentially. The impact area for TTS shows the largest range of impact, increasing from 2,500 km^2 to 3,400 km^2 (36.00% increase).

3.2.1.7 The impact areas for TTS in stationary receptors (for both the installation of a single monopile (as assessed within **A2.3 Fish and Shellfish Ecology (APP-015)**) and the sequential installation of two monopiles (as assessed in **Appendix B**) have the largest extents of impact, and therefore represent the worst-case impact areas[1]. These impact areas have been presented alongside the locations of active herring spawning grounds in **Figure 2**. The spawning grounds have been defined using the following datasets:

- Fisheries Sensitivity Maps in British Waters (Coull *et al.*, 1998); and
- International Herring Larvae Survey (IHLS) dataset (ICES, 1967-2021).

3.2.1.8 The Coull *et al.* (1998) dataset presents historical fish sensitivity maps (inclusive of maps of spawning and nursery grounds) for commercial species across the Northeast Atlantic area. This dataset is considered precautionary and more representative of the greatest theoretical area within which herring could spawn or have been recorded spawning historically, rather than necessarily indicating currently used areas.

3.2.1.9 More accurate and contemporary data on actual spawning activity is provided by the IHLS survey data. These data provide quantitative estimates of herring larval abundances across the North Sea, and therefore provide a representation of the locations of active spawning grounds for herring. The IHLS data (from the past 14 years (2007-2021)) have been interpolated to show the 'hot spots' of herring spawning activity (i.e. the areas of most regular and high intensity spawning activity) and have been presented alongside the Coull *et al.* (1998) dataset to discern active spawning areas and refine the spawning grounds.

3.2.1.10 In order to determine the potential for effect of the sequential installation of two monopiles within 24 hours on spawning herring, the noise modelling contours for TTS (worst-case impact areas) for both the installation of a single monopile (as assessed with the ES) and the sequential installation of two monopiles (additional noise modelling) have been superimposed on the known (and potential) herring spawning grounds as defined by Coull *et al.* (1998) and the IHLS survey data (ICES, 2007-2021) (interpolated to show herring spawning activity 'hot spots').

3.2.1.11 By superimposing the worst-case noise contour for the sequential installation of two monopile foundations in the northwest corner of the array area onto the spawning grounds defined by Coull *et al.* (1998) and active spawning areas as defined by the IHLS data, it is evident that there will be no interaction of the noise contour with the IHLS herring spawning 'hot spot' (see **Figure 2**)[2]. Whilst there is an overlap of the TTS noise contour with the Coull *et al.* (2014) spawning ground, as noted above in **paragraph 3.2.1.8**, the Coull *et al.* (2014) dataset is considered highly precautionary, showing the greatest theoretical spawning areas for herring, whilst the IHLS dataset provides locations of active spawning areas for herring in recent years. The reliance on the IHLS dataset to determine the potential for effects on spawning herring is therefore considered appropriate to inform this assessment.

3.2.1.12 It is important to note that the temporal nature of effects from the sequential installation of two monopiles in the northwest corner of the Hornsea Four array area are anticipated to be less than those assessed within the fish and shellfish assessment of the ES (**A2.3 Fish and**

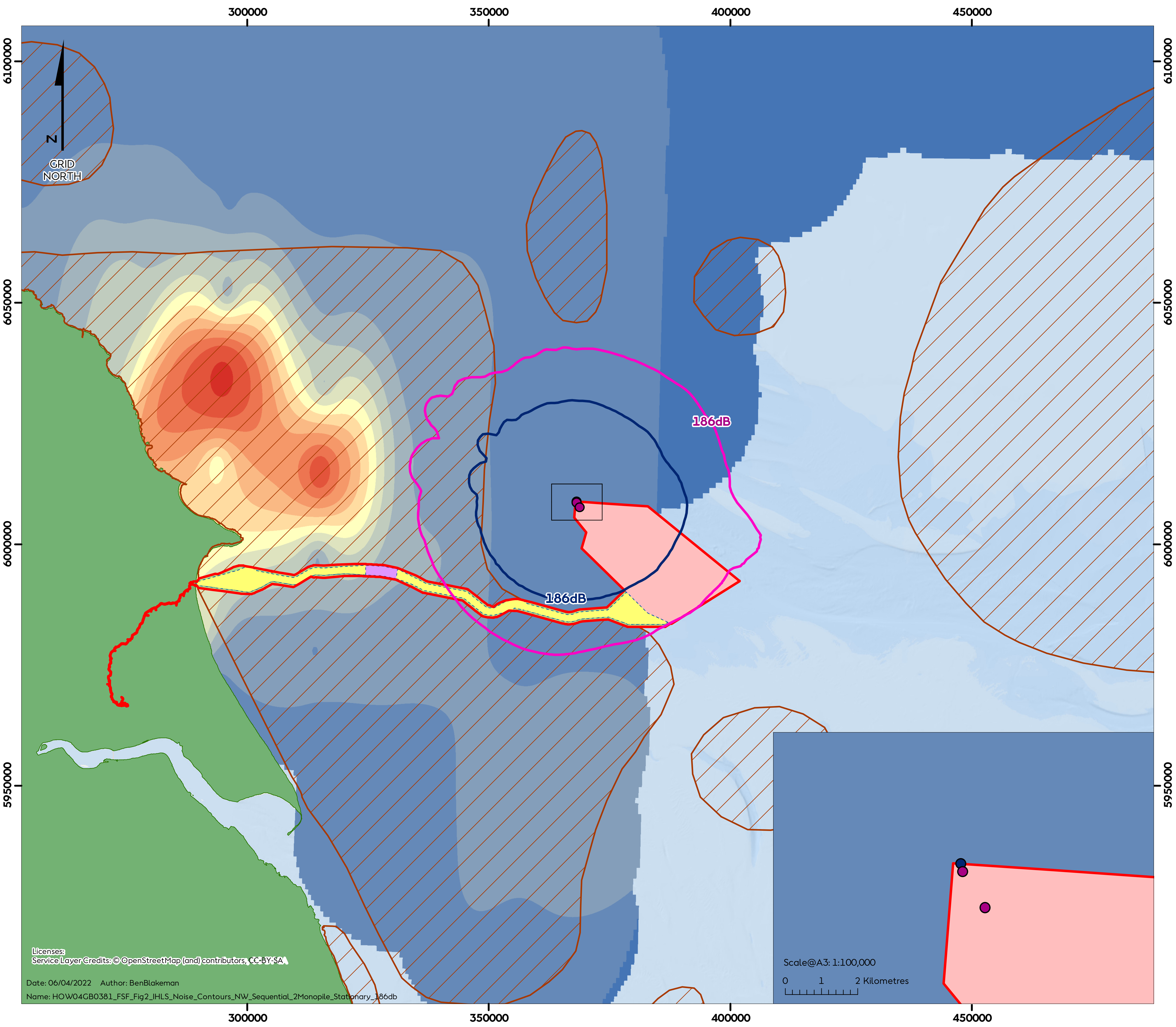
1 Impact areas for mortality and potential injury, and recoverable injury will lie within the impact area of TTS.

2 For a year-by-year breakdown of the IHLS data see **Appendix A** of this note.

Shellfish Ecology (**APP-015**)), as the sequential installation of monopiles will significantly reduce the overall duration of piling.

3.2.1.13 Taking into account the reduced temporal impacts, and the lack of direct overlap from the worst-case noise contour (TTS on stationary receptors) from the sequential installation of two monopiles with the IHLS 'hotspots' of spawning activity and applying the EIA methodology (as detailed within **A1.5 Environmental Impact Assessment Methodology (AS-007)**) the magnitude of effect on spawning herring is considered to be **minor**. This conclusion of magnitude of effect remains unchanged from that presented within **A2.3 Fish and Shellfish Ecology (APP-015)**.

3.2.1.14 Considering the **minor** magnitude of effect, and the **high** sensitivity of spawning herring to underwater noise, the overall effect on herring is predicted to be of **slight** significance which is not significant in EIA terms. The Applicant therefore concludes that there will no population level effects on spawning herring from the sequential installation of monopiles within the Hornsea Four array area. As such, the conclusions made within **Volume A2, Chapter 3: Fish and Shellfish Ecology (APP-015)** therefore remain unchanged.



Hornsea Four

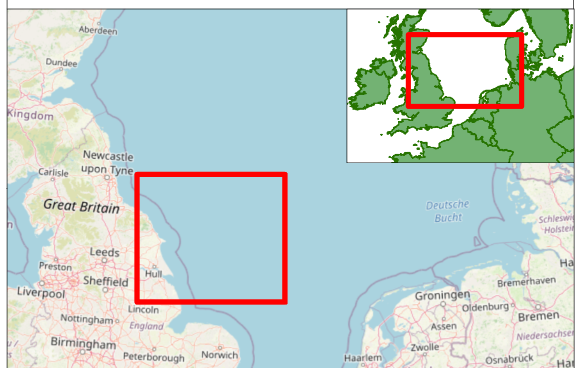
Figure 2

Sequential piling of two monopile foundations at two different locations within the northwest area of the array area (IHLS 2007/2008 – 2021)

- Order Limits
- Array Area
- HVAC Booster Station Works Area
- Offshore Export Cable Corridor
- Offshore Temporary Works Area
- Herring Spawning Grounds (Coull *et al.*, 1998)
- NW Array Area Monopile Piling Location
- Monopile Contours (186dB SELcum) - Stationary Receptors
- NW Array Area Monopile Sequential Piling Location
- Monopile contour (186dB SELcum) for sequential piling scenario (stationary)

IHLS 2007/2008-2020/2021 Banks Data - Total Larval Abundance Per m²

- 0
- 0.1 - 1,500
- 1,500.1 - 6,000
- 6,000.1 - 12,750
- 12,750.1 - 20,500
- 20,500.1 - 28,500
- 28,500.1 - 36,500
- 36,500.1 - 45,500
- 45,500.1 - 55,000
- 55,000.1 - 66,000
- 66,000.1 - 77,250
- 77,250.1 - 100,000
- 100,000.1 - 120,000



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0 10 20 Nautical Miles

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NW Sequential Noise Contour
Stationary Receptors 186dB
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Checked by: PN
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4 References

Bierman, S. M., Dickey-Collas, M., van Damme, C. J. G., van Overzee, H. M. J., Pennock-Vos, M. G., Tribuhl, S. V., and Clausen, L. A. W. 2010. Between-year variability in the mixing of North Sea herring spawning components leads to pronounced variation in the composition of the catch. – ICES Journal of Marine Science, 67: 885–896.

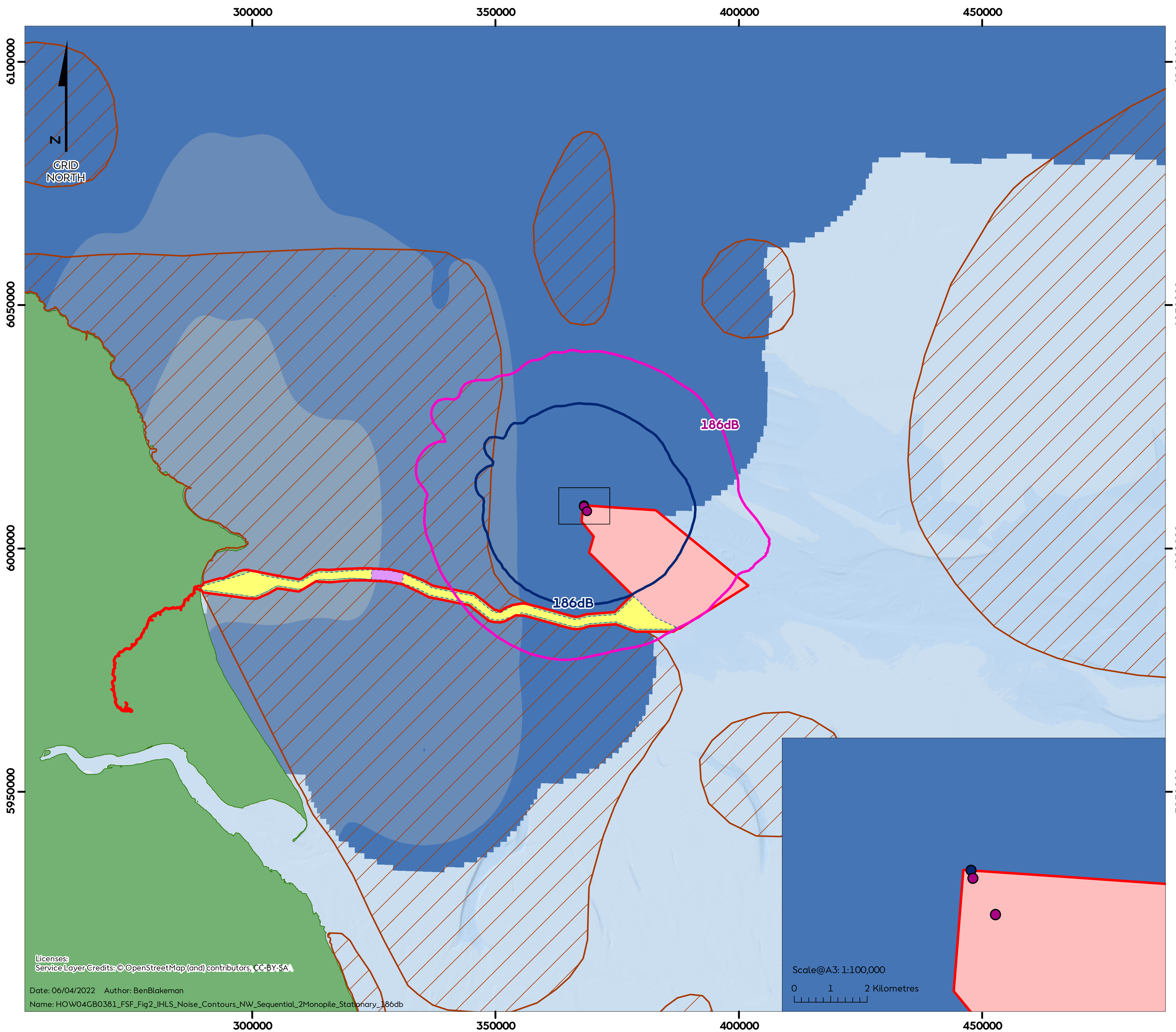
Coull, K.A., Johnstone, R., and S.I. Rogers. 1998. Fisheries Sensitivity Maps in British Waters. Published and distributed by UKOOA Ltd.

ICES. The International Herring Larvae Surveys. Available online at http://eggsandlarvae.ices.dk. Consulted on 2022-02-22.

Popper, A.; Hice-Dunton, L.; Jenkins, E.; Higgs, D.; Krebs, J.; Mooney, A.; Rice, A.; Roberts, L.; Thomsen, F.; Vigness-Raposa, K.; Zeddies, D.; Williams, K. (2022). Offshore wind energy development: Research priorities for sound and vibration effects on fishes and aquatic invertebrates. The Journal of the Acoustical Society of America, 151, 205-215. https://doi.org/10.1121/10.0009237.

Popper, Arthur & Hawkins, Anthony & Fay, Richard & Mann, David & Bartol, Soraya & Carlson, Thomas & Coombs, Sheryl & Ellison, William & Gentry, Roger & Halvorsen, Michele & Løkkeborg, Svein & Rogers, Peter & Southall, Brandon & Zeddies, David & Tavolga, William. (2014). Sound Exposure Guidelines. 10.1007/978-3-319-06659-2_7.

Appendix A: Presentation of Sequential Piling Scenario Alongside Annual IHLS Data.



Hornsea Four

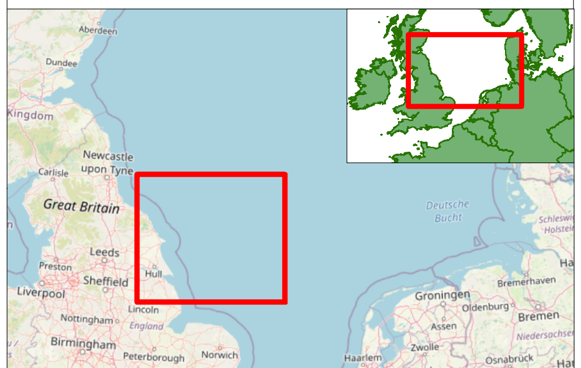
Figure 3

Sequential piling of two monopile foundations at two different locations within the northwest area of the array area (IHLS 2007/2008)

- Order Limits
- Array Area
- HVAC Booster Station Works Area
- Offshore Export Cable Corridor
- Offshore Temporary Works Area
- Herring Spawning Grounds (Coull *et al.*, 1998)
- NW Array Area Monopile Piling Location
- Monopile Contours (186dB SELcum) - Stationary Receptors
- NW Array Area Monopile Sequential Piling Location
- Monopile contour (186dB SELcum) for sequential piling scenario (stationary)

IHLS Banks Data 2007/2008 - Larval Abundance Per m²

- 0
- 0.1 - 150
- 150.1 - 600
- 600.1 - 1,275
- 1,275.1 - 2,050
- 2,050.1 - 2,850
- 2,850.1 - 3,650
- 3,650.1 - 4,450
- 4,450.1 - 5,300
- 5,300.1 - 6,300
- 6,300.1 - 7,425
- 7,425.1 - 9,325



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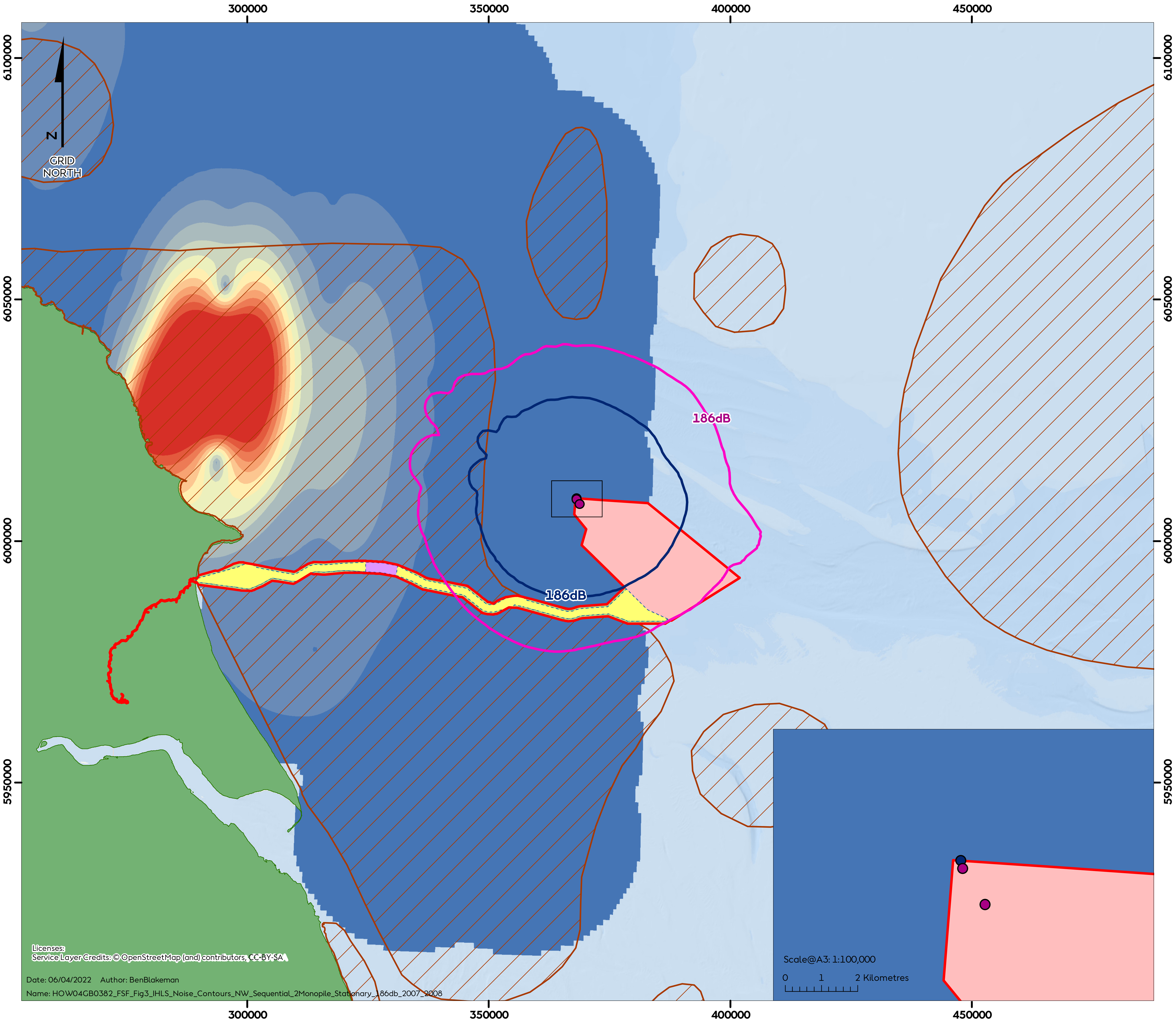


Hornsea Four

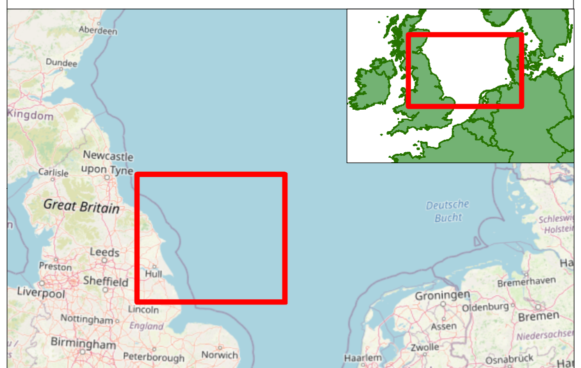
Figure 4

Sequential piling of two monopile foundations at two different locations within the northwest area of the array area (IHLS 2008/2009)

- Order Limits
- Array Area
- HVAC Booster Station Works Area
- Offshore Export Cable Corridor
- Offshore Temporary Works Area
- Herring Spawning Grounds (Coull *et al.*, 1998)
- NW Array Area Monopile Piling Location
- Monopile Contours (186dB SELcum) - Stationary Receptors
- NW Array Area Monopile Sequential Piling Location
- Monopile contour (186dB SELcum) for sequential piling scenario (stationary)

IHLS Banks Data 2008/2009 - Larval Abundance Per m²

- 0
- 0.1 - 150
- 150.1 - 600
- 600.1 - 1,275
- 1,275.1 - 2,050
- 2,050.1 - 2,850
- 2,850.1 - 3,650
- 3,650.1 - 4,450
- 4,450.1 - 5,300
- 5,300.1 - 6,300
- 6,300.1 - 7,425
- 7,425.1 - 9,325



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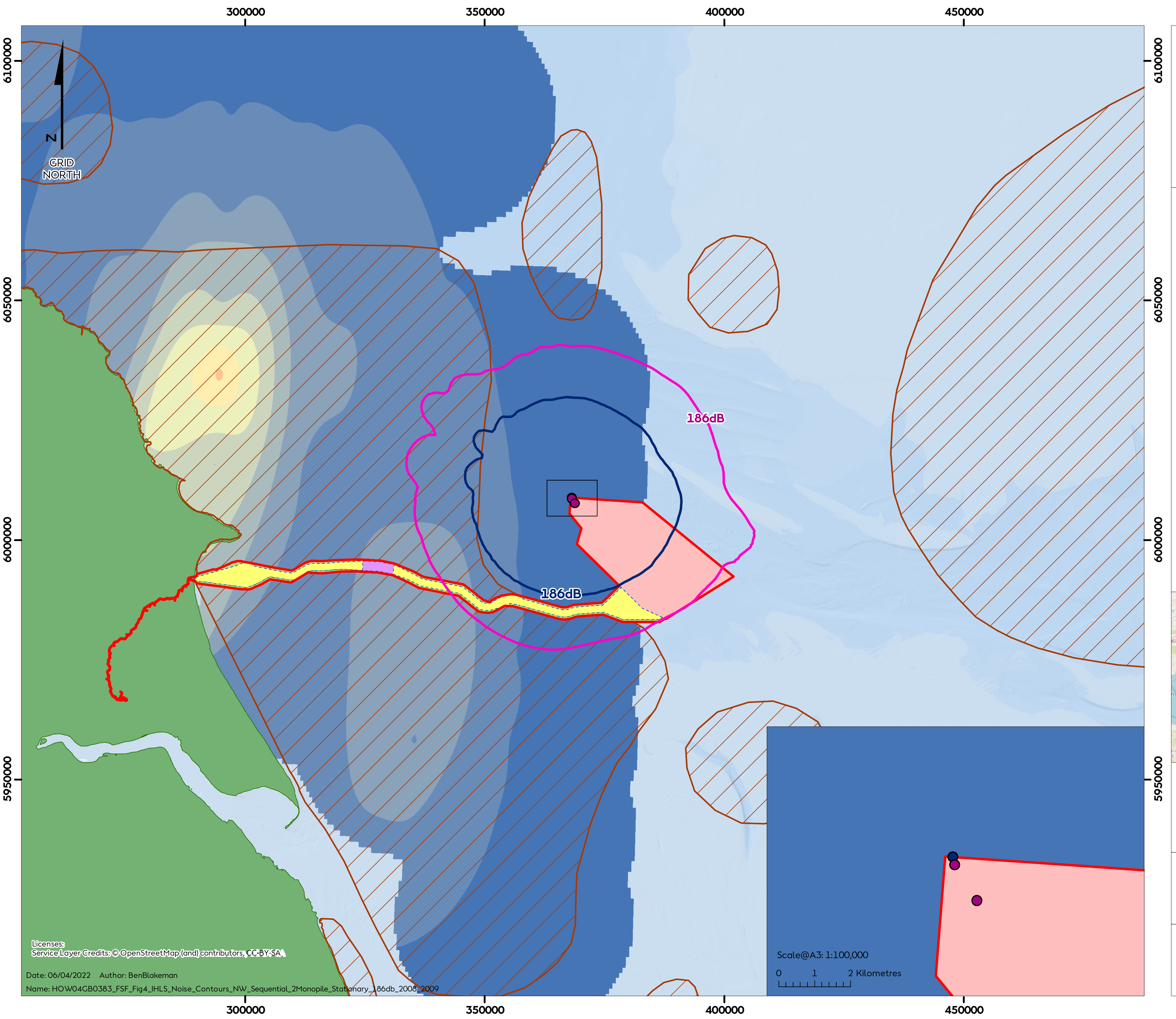

Date: 06/04/2022 Author: BenBlakeman

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Hornsea Four

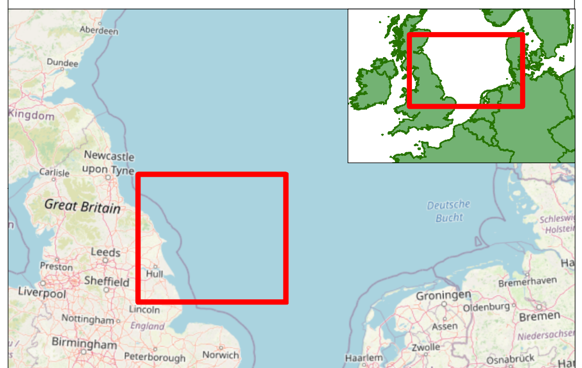
Figure 5

Sequential piling of two monopile foundations at two different locations within the northwest area of the array area (IHLS 2009/2010)

- Order Limits
- Array Area
- HVAC Booster Station Works Area
- Offshore Export Cable Corridor
- Offshore Temporary Works Area
- Herring Spawning Grounds (Coull *et al.*, 1998)
- NW Array Area Monopile Piling Location
- Monopile Contours (186dB SELcum) - Stationary Receptors
- NW Array Area Monopile Sequential Piling Location
- Monopile contour (186dB SELcum) for sequential piling scenario (stationary)

IHLS Banks Data 2009/2010 - Larval Abundance Per m²

- 0
- 0.1 - 150
- 150.1 - 600
- 600.1 - 1,275
- 1,275.1 - 2,050
- 2,050.1 - 2,850
- 2,850.1 - 3,650
- 3,650.1 - 4,450
- 4,450.1 - 5,300
- 5,300.1 - 6,300
- 6,300.1 - 7,425
- 7,425.1 - 9,325



Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:750,000

0 20 40 Kilometres

0 10 20 Nautical Miles

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NW Sequential Noise Contour
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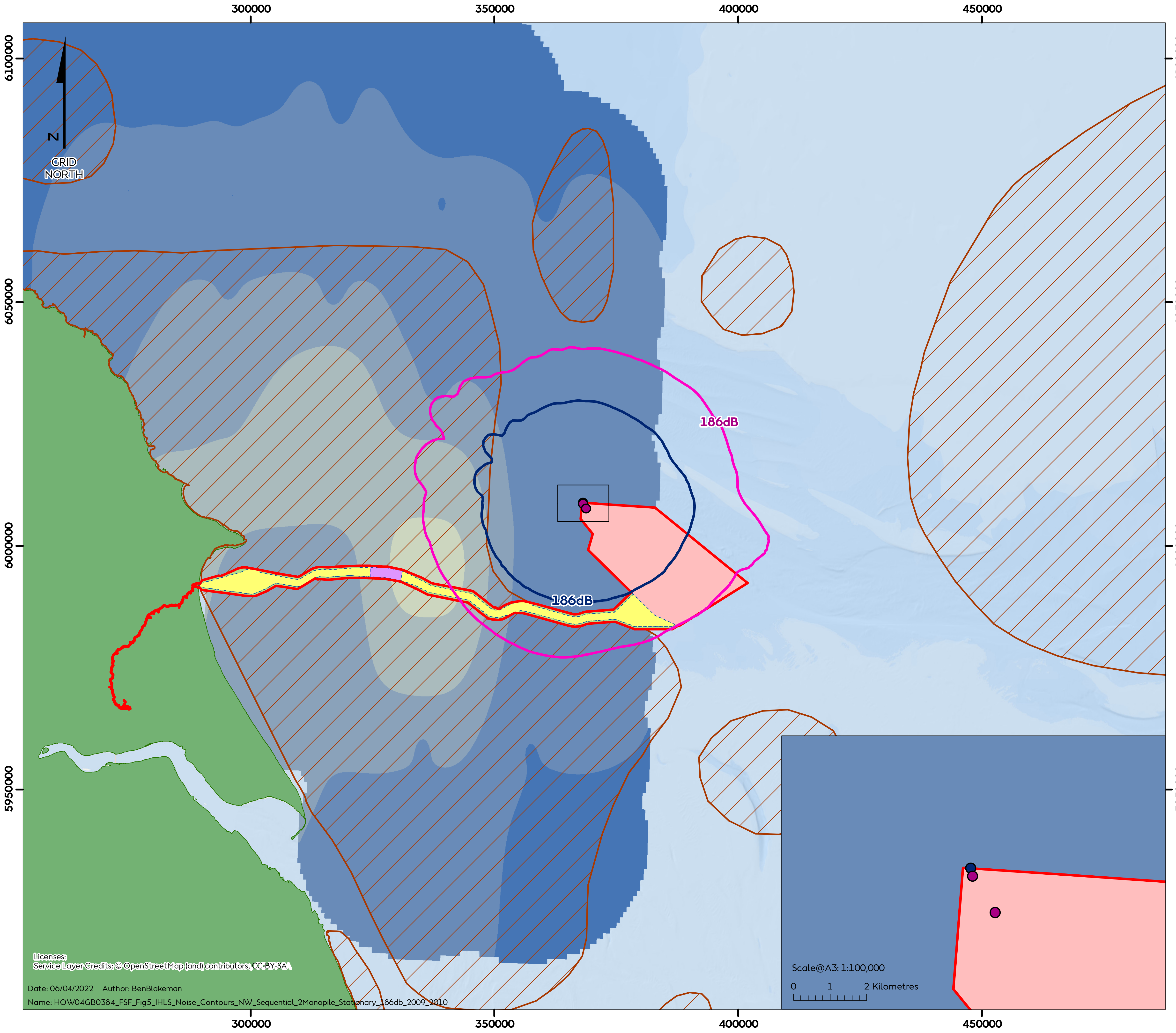
Figure 6

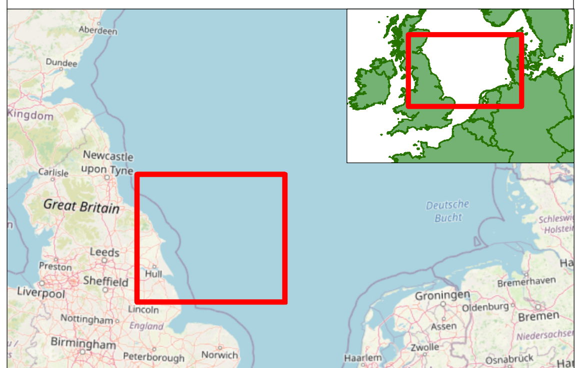
Sequential piling of two monopile foundations at two different locations within the northwest area of the array area (IHLS 2010/2011)



- Order Limits
- Array Area
- HVAC Booster Station Works Area
- Offshore Export Cable Corridor
- Offshore Temporary Works Area
- Herring Spawning Grounds (Coull *et al.*, 1998)
- NW Array Area Monopile Piling Location
- Monopile Contours (186dB SELcum) - Stationary Receptors
- NW Array Area Monopile Sequential Piling Location
- Monopile contour (186dB SELcum) for sequential piling scenario (stationary)

IHLS Banks Data 2010/2011 - Larval Abundance Per m²

- 0
- 0.1 - 150
- 150.1 - 600
- 600.1 - 1,275
- 1,275.1 - 2,050
- 2,050.1 - 2,850
- 2,850.1 - 3,650
- 3,650.1 - 4,450
- 4,450.1 - 5,300
- 5,300.1 - 6,300
- 6,300.1 - 7,425
- 7,425.1 - 9,325



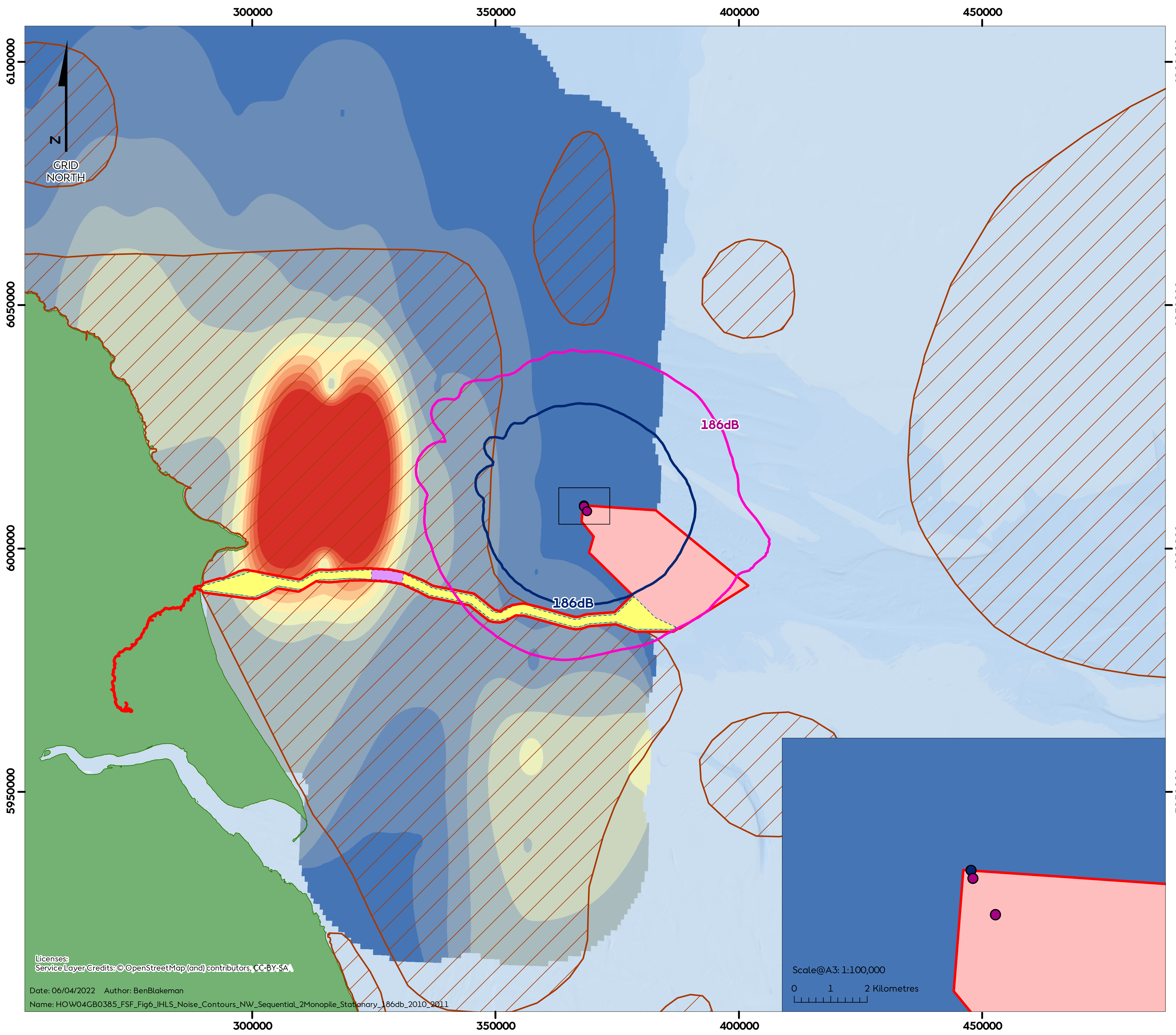
Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:750,000

0 20 40 Kilometres

0 10 20 Nautical Miles

REV	REMARK	DATE
....	First Issue for Examination Support	06/04/2022

NW Sequential Noise Contour
Stationary Receptors 186dB
Document no: HOW04GB0385
Created by: BPHB
Checked by: PN
Approved by: LK



Hornsea Four

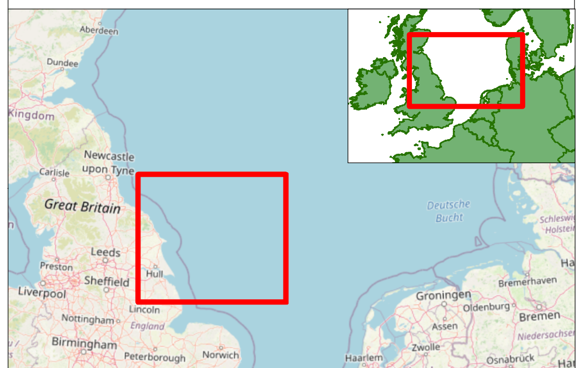
Figure 7

Sequential piling of two monopile foundations at two different locations within the northwest area of the array area (IHLS 2011/2012)

- Order Limits
- Array Area
- HVAC Booster Station Works Area
- Offshore Export Cable Corridor
- Offshore Temporary Works Area
- Herring Spawning Grounds (Coull *et al.*, 1998)
- NW Array Area Monopile Piling Location
- Monopile Contours (186dB SELcum) - Stationary Receptors
- NW Array Area Monopile Sequential Piling Location
- Monopile contour (186dB SELcum) for sequential piling scenario (stationary)

IHLS Banks Data 2011/2012 - Larval Abundance Per m²

- 0
- 0.1 - 150
- 150.1 - 600
- 600.1 - 1,275
- 1,275.1 - 2,050
- 2,050.1 - 2,850
- 2,850.1 - 3,650
- 3,650.1 - 4,450
- 4,450.1 - 5,300
- 5,300.1 - 6,300
- 6,300.1 - 7,425
- 7,425.1 - 9,325



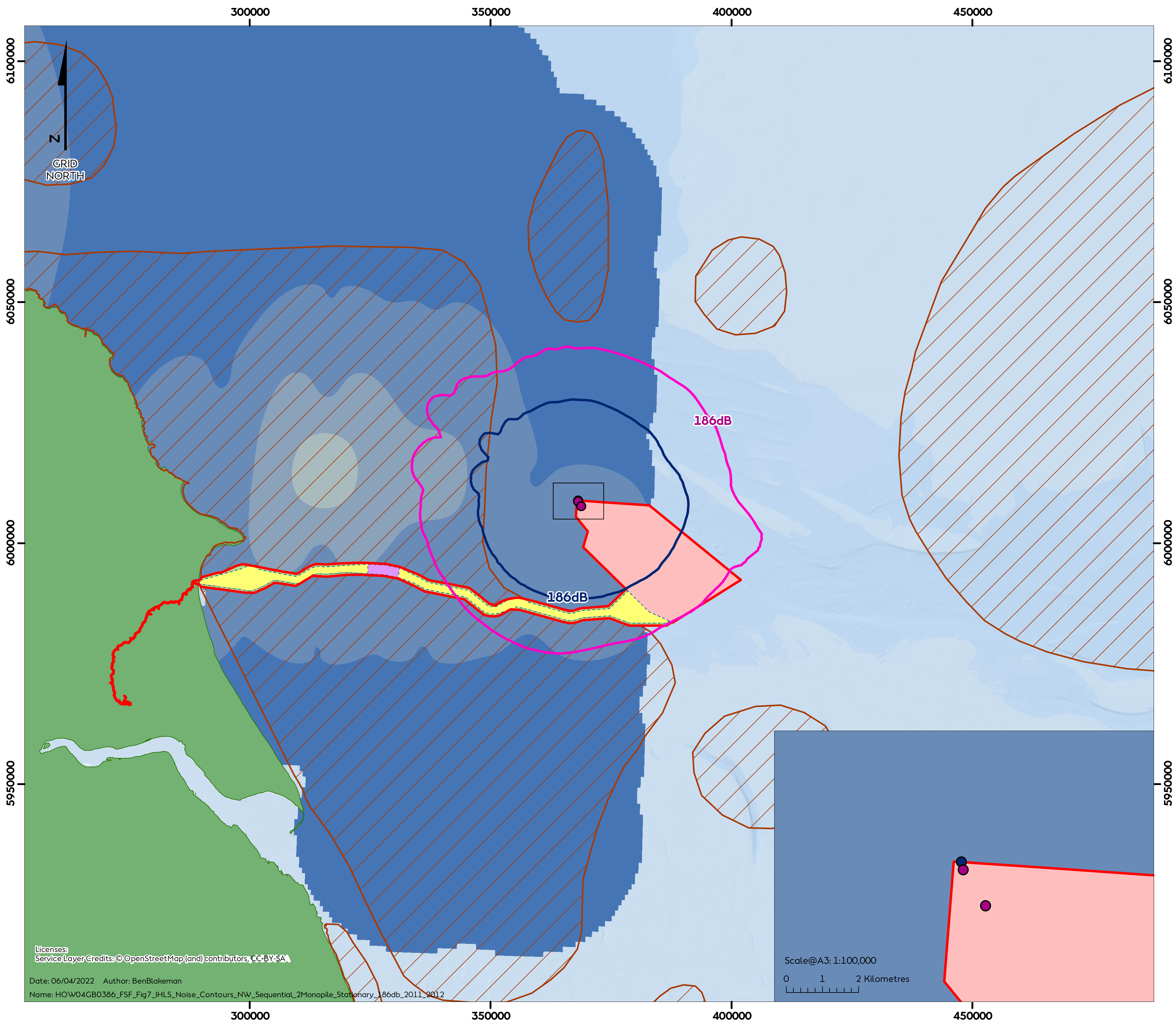
Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:750,000

0 20 40 Kilometres

0 10 20 Nautical Miles

REV	REMARK	DATE
....	First Issue for Examination Support	06/04/2022

NW Sequential Noise Contour
Stationary Receptors 186dB
Document no: HOW04GB0386
Created by: BPHB
Checked by: PN
Approved by: LK



Hornsea Four

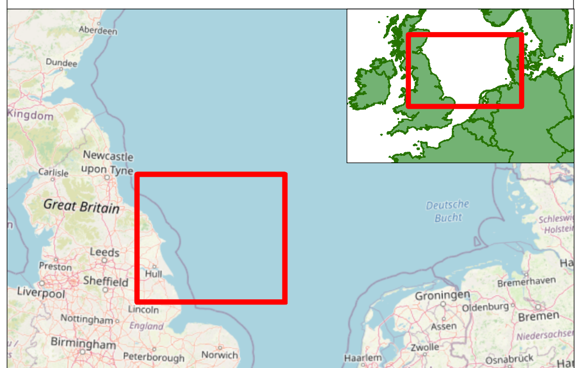
Figure 8

Sequential piling of two monopile foundations at two different locations within the northwest area of the array area (IHLS 2012/2013)

- Order Limits
- Array Area
- HVAC Booster Station Works Area
- Offshore Export Cable Corridor
- Offshore Temporary Works Area
- Herring Spawning Grounds (Coull *et al.*, 1998)
- NW Array Area Monopile Piling Location
- Monopile Contours (186dB SELcum) - Stationary Receptors
- NW Array Area Monopile Sequential Piling Location
- Monopile contour (186dB SELcum) for sequential piling scenario (stationary)

IHLS Banks Data 2012/2013 - Larval Abundance Per m²

- 0
- 0.1 - 150
- 150.1 - 600
- 600.1 - 1,275
- 1,275.1 - 2,050
- 2,050.1 - 2,850
- 2,850.1 - 3,650
- 3,650.1 - 4,450
- 4,450.1 - 5,300
- 5,300.1 - 6,300
- 6,300.1 - 7,425
- 7,425.1 - 9,325



Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:750,000

0 20 40 Kilometres

0 10 20 Nautical Miles

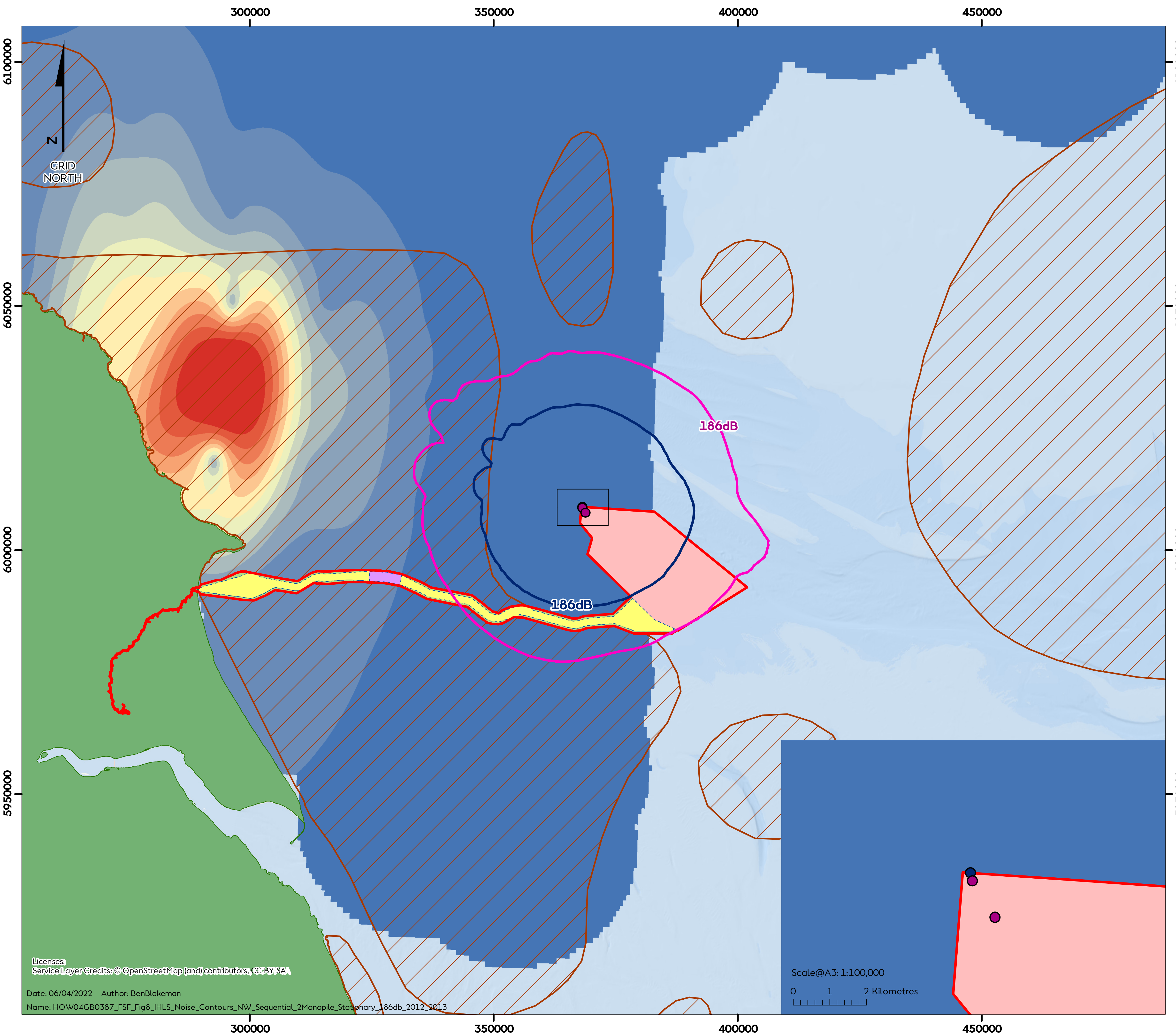
REV	REMARK	DATE
....	First Issue for Examination Support	06/04/2022

NW Sequential Noise Contour
Stationary Receptors 186dB
Document no: HOW04GB0387
Created by: BPHB
Checked by: PN
Approved by: LK

Hornsea Four

Figure 9

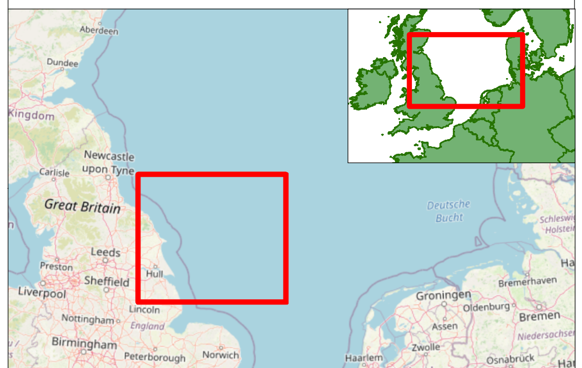
Sequential piling of two monopile foundations at two different locations within the northwest area of the array area (IHLS 2013/2014)



- Order Limits
- Array Area
- HVAC Booster Station Works Area
- Offshore Export Cable Corridor
- Offshore Temporary Works Area
- Herring Spawning Grounds (Coull *et al.*, 1998)
- NW Array Area Monopile Piling Location
- Monopile Contours (186dB SELcum) - Stationary Receptors
- NW Array Area Monopile Sequential Piling Location
- Monopile contour (186dB SELcum) for sequential piling scenario (stationary)

IHLS Banks Data 2013/2014 - Larval Abundance Per m²

- 0
- 0.1 - 150
- 150.1 - 600
- 600.1 - 1,275
- 1,275.1 - 2,050
- 2,050.1 - 2,850
- 2,850.1 - 3,650
- 3,650.1 - 4,450
- 4,450.1 - 5,300
- 5,300.1 - 6,300
- 6,300.1 - 7,425
- 7,425.1 - 9,325



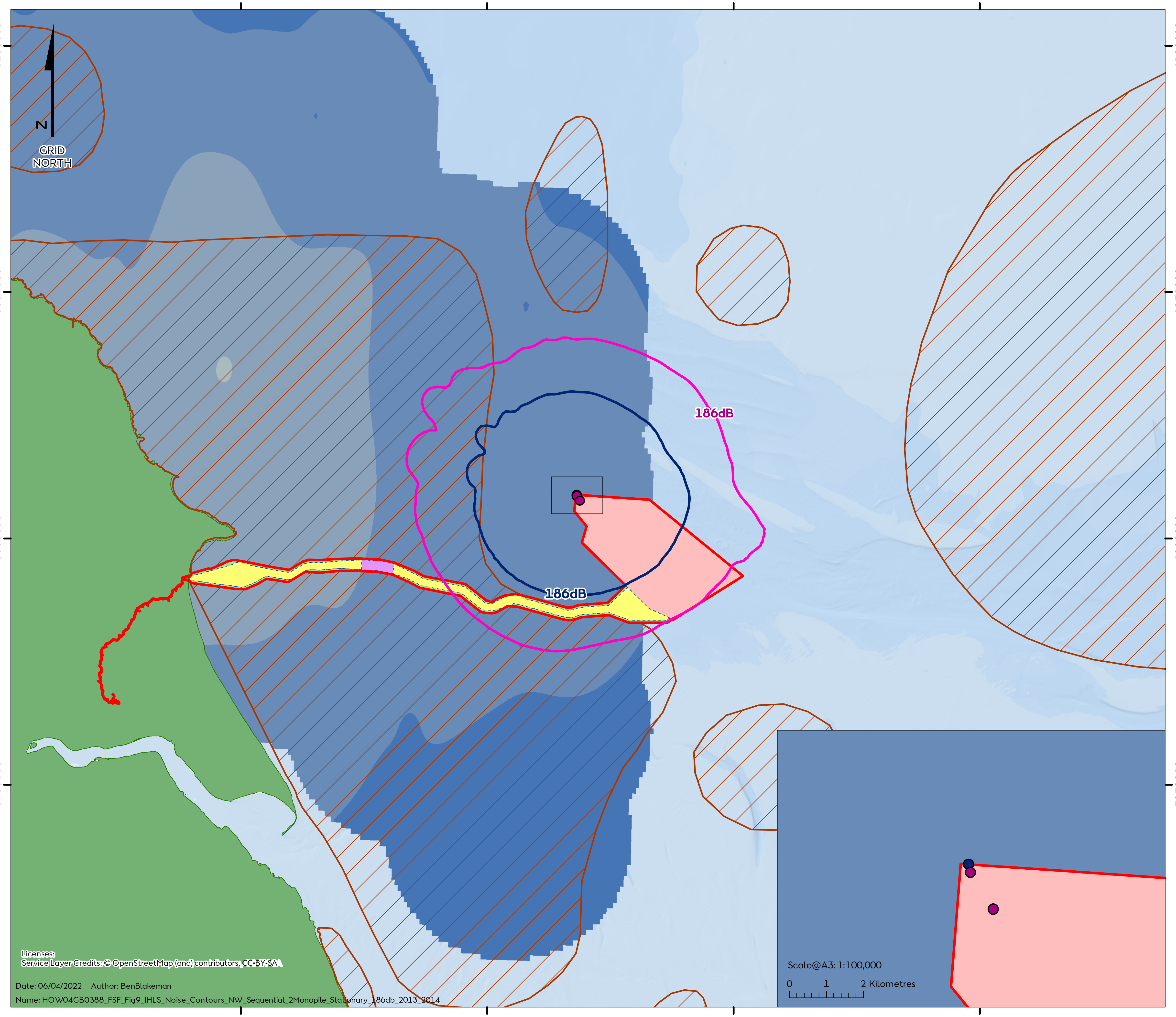
Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:750,000

0 20 40 Kilometres

0 10 20 Nautical Miles

REV	REMARK	DATE
....	First Issue for Examination Support	06/04/2022

NW Sequential Noise Contour
Stationary Receptors 186dB
Document no: HOW04GB0388
Created by: BPHB
Checked by: PN
Approved by: LK



Hornsea Four

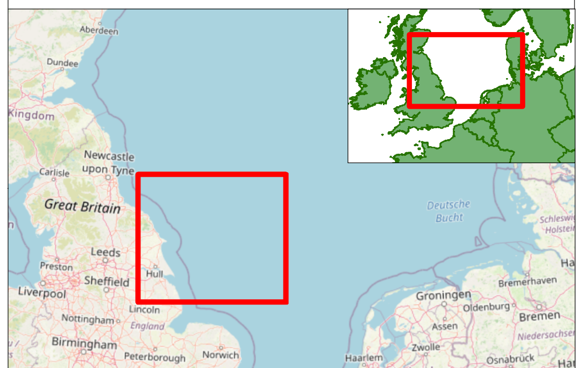
Figure 10

Sequential piling of two monopile foundations at two different locations within the northwest area of the array area (IHLS 2014/2015)

- Order Limits
- Array Area
- HVAC Booster Station Works Area
- Offshore Export Cable Corridor
- Offshore Temporary Works Area
- Herring Spawning Grounds (Coull *et al.*, 1998)
- NW Array Area Monopile Piling Location
- Monopile Contours (186dB SELcum) - Stationary Receptors
- NW Array Area Monopile Sequential Piling Location
- Monopile contour (186dB SELcum) for sequential piling scenario (stationary)

IHLS Banks Data 2014/2015 - Larval Abundance Per m²

- 0
- 0.1 - 150
- 150.1 - 600
- 600.1 - 1,275
- 1,275.1 - 2,050
- 2,050.1 - 2,850
- 2,850.1 - 3,650
- 3,650.1 - 4,450
- 4,450.1 - 5,300
- 5,300.1 - 6,300
- 6,300.1 - 7,425
- 7,425.1 - 9,325



Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:750,000

0 20 40 Kilometres

0 10 20 Nautical Miles

REV	REMARK	DATE
....	First Issue for Examination Support	06/04/2022

NW Sequential Noise Contour
Stationary Receptors 186dB
Document no: HOW04GB0389
Created by: BPHB
Checked by: PN
Approved by: LK

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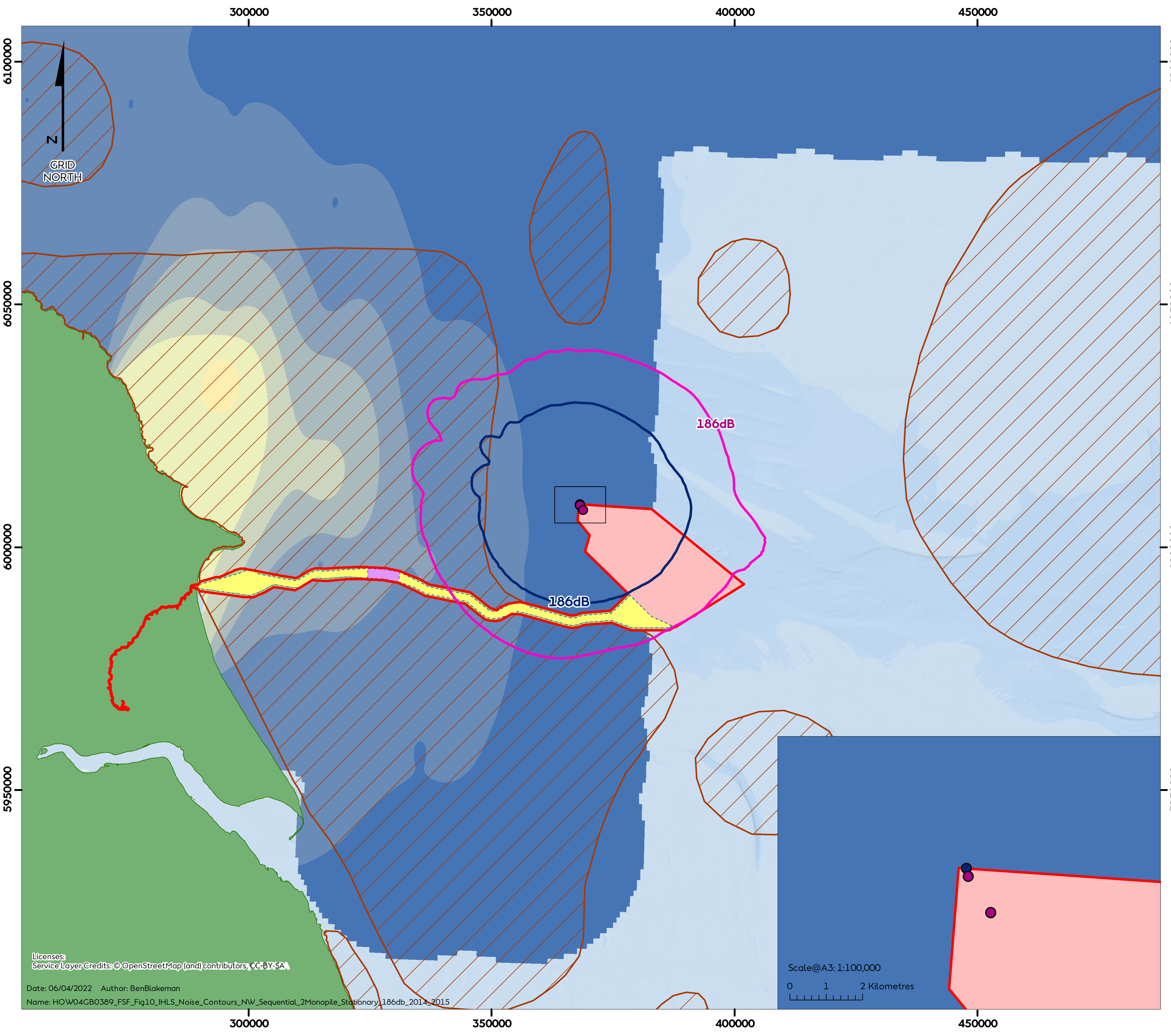


Hornsea Four

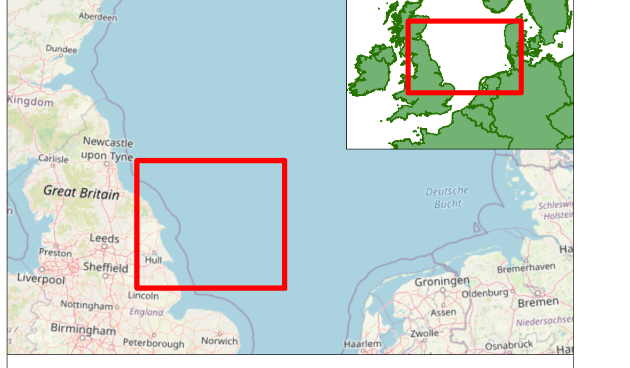
Figure 11

Sequential piling of two monopile foundations at two different locations within the northwest area of the array area (IHLS 2015/2016)

- Order Limits
- Array Area
- HVAC Booster Station Works Area
- Offshore Export Cable Corridor
- Offshore Temporary Works Area
- Herring Spawning Grounds (Coull *et al.*, 1998)
- NW Array Area Monopile Piling Location
- Monopile Contours (186dB SELcum) - Stationary Receptors
- NW Array Area Monopile Sequential Piling Location
- Monopile contour (186dB SELcum) for sequential piling scenario (stationary)

IHLS Banks Data 2015/2016 - Larval Abundance Per m²

- 0
- 0.1 - 150
- 150.1 - 600
- 600.1 - 1,275
- 1,275.1 - 2,050
- 2,050.1 - 2,850
- 2,850.1 - 3,650
- 3,650.1 - 4,450
- 4,450.1 - 5,300
- 5,300.1 - 6,300
- 6,300.1 - 7,425
- 7,425.1 - 9,325



Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:750,000
0 20 40 Kilometres
0 10 20 Nautical Miles

REV	REMARK	DATE
....	First Issue for Examination Support	06/04/2022

NW Sequential Noise Contour
Stationary Receptors 186dB
Document no: HOW04GB0390
Created by: BPHB
Checked by: PN
Approved by: LK

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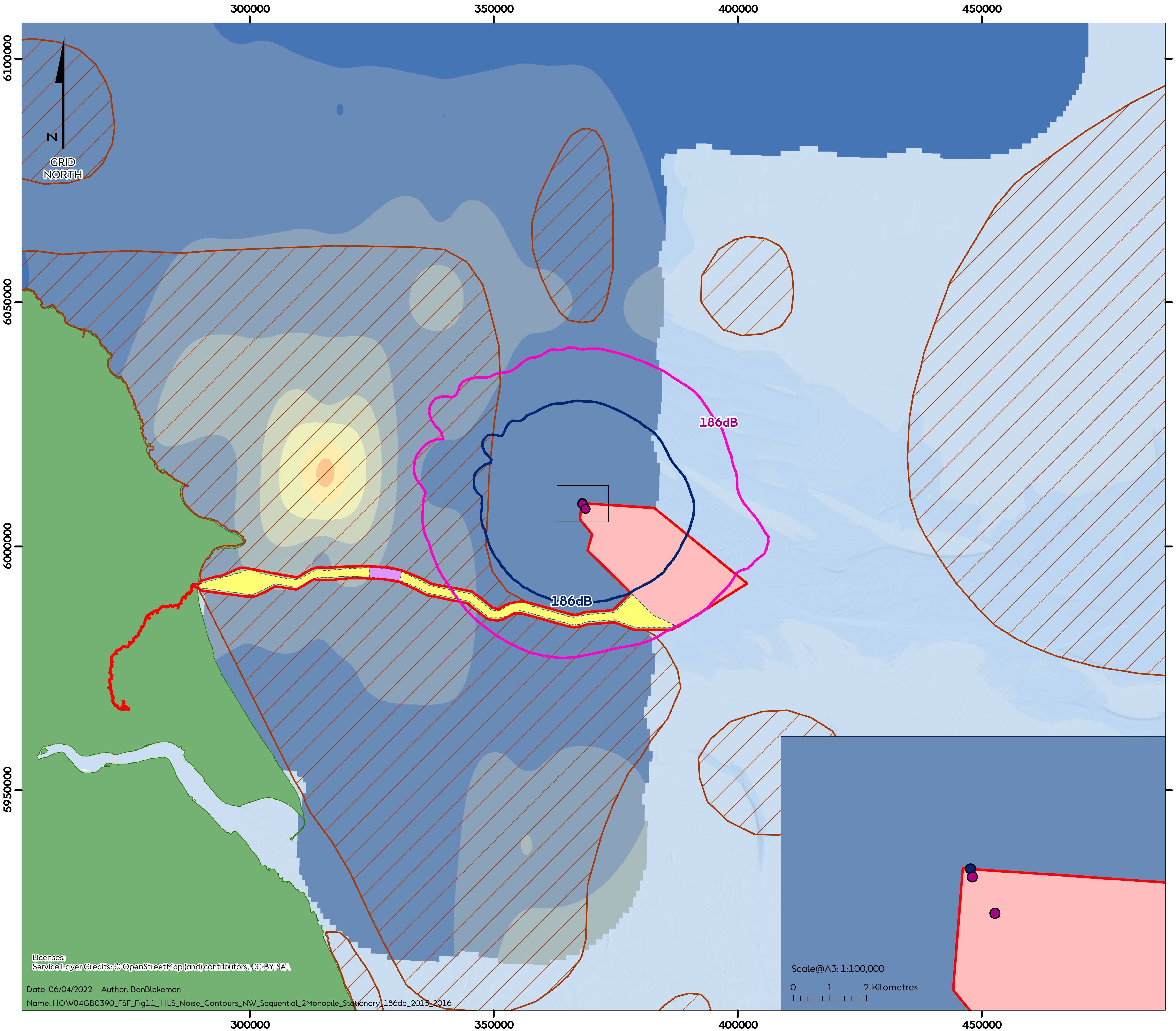


Hornsea Four

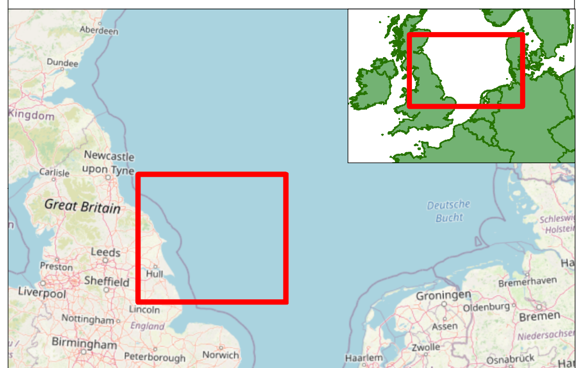
Figure 12

Sequential piling of two monopile foundations at two different locations within the northwest area of the array area (IHLS 2016/2017)

- Order Limits
- Array Area
- HVAC Booster Station Works Area
- Offshore Export Cable Corridor
- Offshore Temporary Works Area
- Herring Spawning Grounds (Coull *et al.*, 1998)
- NW Array Area Monopile Piling Location
- Monopile Contours (186dB SELcum) - Stationary Receptors
- NW Array Area Monopile Sequential Piling Location
- Monopile contour (186dB SELcum) for sequential piling scenario (stationary)

IHLS Banks Data 2016/2017 - Larval Abundance Per m²

- 0
- 0.1 - 150
- 150.1 - 600
- 600.1 - 1,275
- 1,275.1 - 2,050
- 2,050.1 - 2,850
- 2,850.1 - 3,650
- 3,650.1 - 4,450
- 4,450.1 - 5,300
- 5,300.1 - 6,300
- 6,300.1 - 7,425
- 7,425.1 - 9,325



Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:750,000

0 20 40 Kilometres

0 10 20 Nautical Miles

REV	REMARK	DATE
...	First Issue for Examination Support	06/04/2022

NW Sequential Noise Contour
Stationary Receptors 186dB
Document no: HOW04GB0391
Created by: BPHB
Checked by: PN
Approved by: LK

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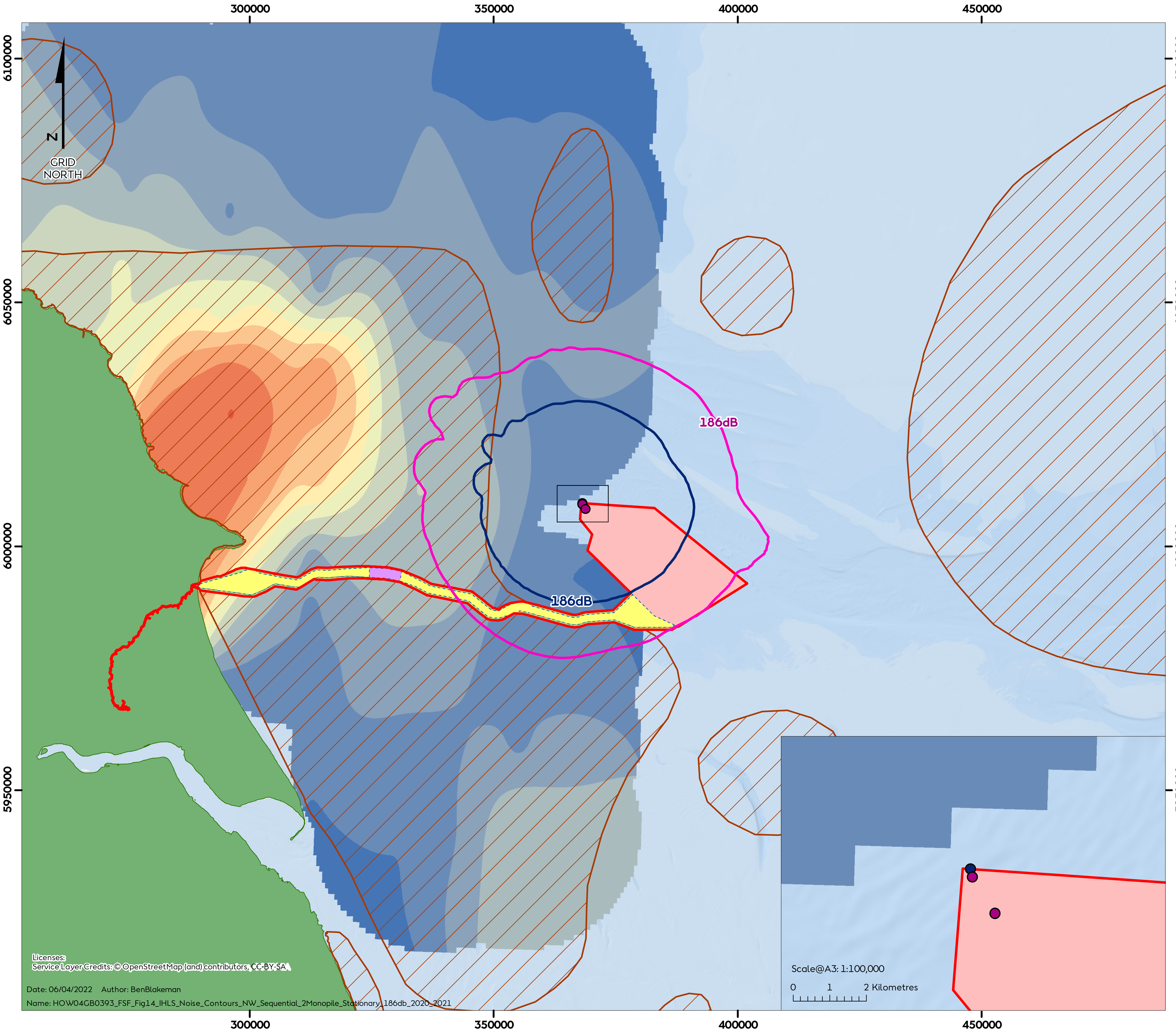


Hornsea Four

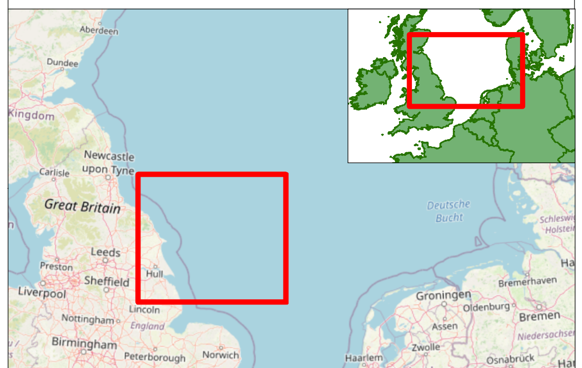
Figure 13

Sequential piling of two monopile foundations at two different locations within the northwest area of the array area (IHLS 2019/2020)

- Order Limits
- Array Area
- HVAC Booster Station Works Area
- Offshore Export Cable Corridor
- Offshore Temporary Works Area
- Herring Spawning Grounds (Coull *et al.*, 1998)
- NW Array Area Monopile Piling Location
- Monopile Contours (186dB SELcum) - Stationary Receptors
- NW Array Area Monopile Sequential Piling Location
- Monopile contour (186dB SELcum) for sequential piling scenario (stationary)

IHLS Banks Data 2019/2020 - Larval Abundance Per m²

- 0
- 0.1 - 150
- 150.1 - 600
- 600.1 - 1,275
- 1,275.1 - 2,050
- 2,050.1 - 2,850
- 2,850.1 - 3,650
- 3,650.1 - 4,450
- 4,450.1 - 5,300
- 5,300.1 - 6,300
- 6,300.1 - 7,425
- 7,425.1 - 9,325



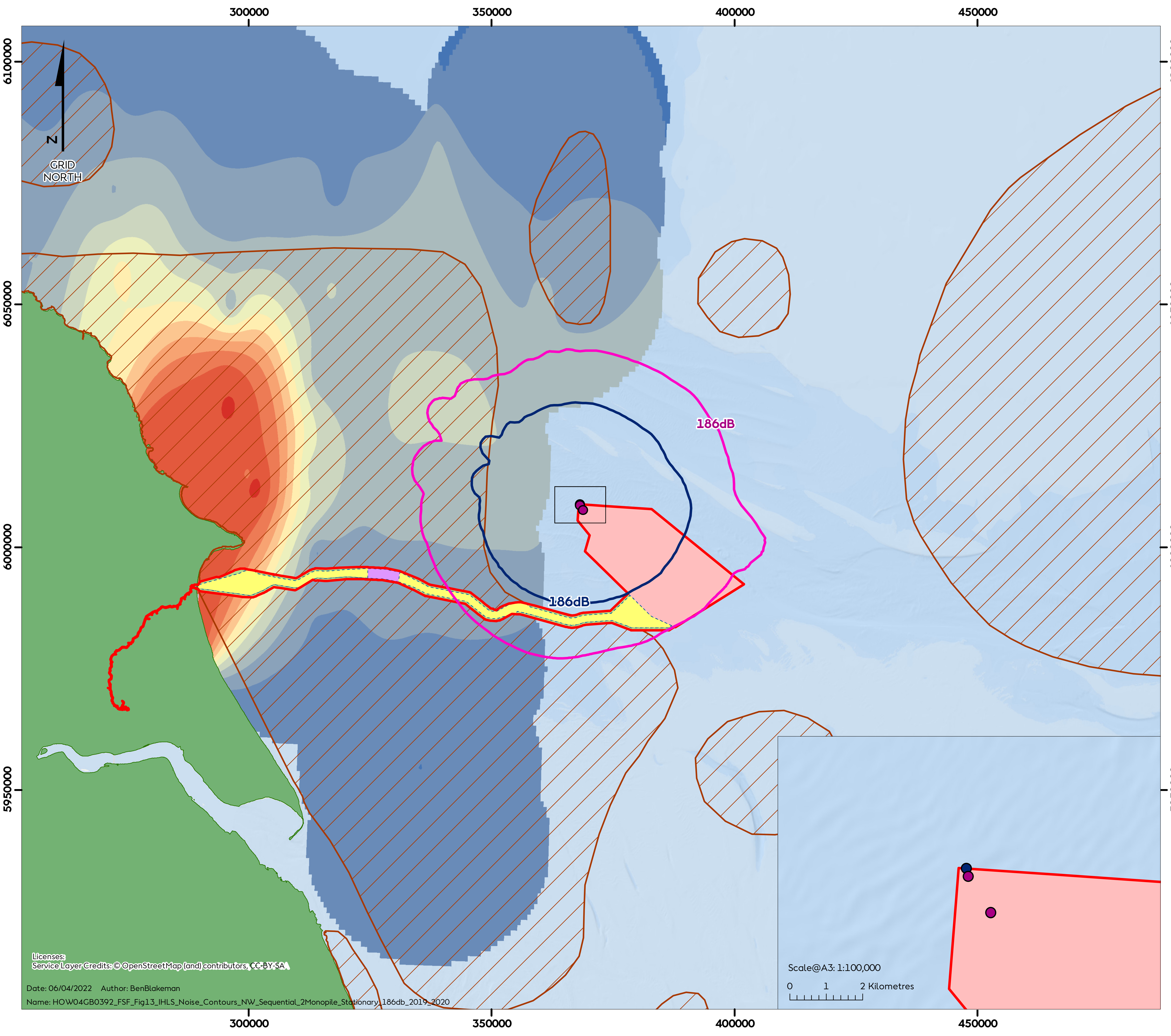
Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:750,000

0 20 40 Kilometres

0 10 20 Nautical Miles

REV	REMARK	DATE
....	First Issue for Examination Support	06/04/2022

NW Sequential Noise Contour Stationary Receptors 186dB
Document no: HOW04GB0392
Created by: BPHB
Checked by: PN
Approved by: LK



Hornsea Four

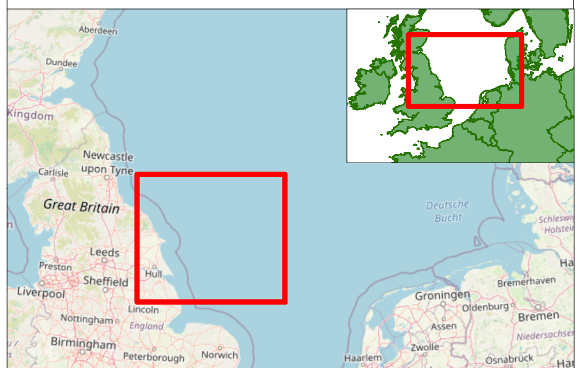
Figure 14

Sequential piling of two monopile foundations at two different locations within the northwest area of the array area (IHLS 2020/2021)

- Order Limits
- Array Area
- HVAC Booster Station Works Area
- Offshore Export Cable Corridor
- Offshore Temporary Works Area
- Herring Spawning Grounds (Coull *et al.*, 1998)
- NW Array Area Monopile Piling Location
- Monopile Contours (186dB SELcum) - Stationary Receptors
- NW Array Area Monopile Sequential Piling Location
- Monopile contour (186dB SELcum) for sequential piling scenario (stationary)

IHLS Banks Data 2020/2021 - Larval Abundance Per m²

- 0
- 0.1 - 150
- 150.1 - 600
- 600.1 - 1,275
- 1,275.1 - 2,050
- 2,050.1 - 2,850
- 2,850.1 - 3,650
- 3,650.1 - 4,450
- 4,450.1 - 5,300
- 5,300.1 - 6,300
- 6,300.1 - 7,425
- 7,425.1 - 9,325



Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:750,000

0 20 40 Kilometres

0 10 20 Nautical Miles

REV	REMARK	DATE
....	First Issue for Examination Support	06/04/2022

NW Sequential Noise Contour
Stationary Receptors 186dB
Document no: HOW04GB0393
Created by: BPHB
Checked by: PN
Approved by: LK

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Project title	Hornsea Four: Piling two monopiles sequentially
Project number	P222
Author(s)	Richard Barham
Company	Subacoustech Environmental Ltd.
Report number	P222IR0501
Date of issue	21 March 2022

Introduction

Following the underwater noise modelling study carried out by Subacoustech Environmental for the Hornsea Four Offshore Wind Farm (Hornsea Four), additional underwater noise modelling has been carried out to identify the impacts of two monopile foundations installed sequentially. The original study contained modelling for sequential installation of jacket (using pin piles) foundations, as well as concurrent foundation installation of at the farthest extents of the Hornsea Four site.

Unlike pin piles, where foundation piles in a jacket frame are installed in very close proximity for the same WTG foundation, monopiles will be installed at greater distances. For this exercise, the WTG location in the NW corner of Hornsea Four has been considered along with its closest neighbour, which is situated approximately 1.2 km to the SE. The locations are summarised in Table 1. The modelling assumes that the monopile foundation at the NW corner is installed, followed immediately by the neighbouring monopile foundation. This is considered precautionary as it does not allow additional flee time for a marine mammal between the two monopile installations. Timings do not influence the stationary receptor modelling used for fish.

Table 1 Summary of the underwater noise modelling locations

Modelling locations	**1st location (NW corner)**	**2nd location (1.2 km away)**
Latitude (Decimal degrees)	54.2083°N	54.1995°E
Longitude (Decimal degrees)	000.9795°N	000.9895°E
Water depth (mean tide)	53.7 m	50.8 m

The maximum design scenario (MDS) monopile parameters have been used from the original study, along with the same assumptions and parameters. This involves monopiles up to 15 m in diameter, installed using a maximum blow energy of 5,000 kJ.

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 sound energy from double the number of pile strikes to the water.

The following section presents contour plots for the multiple location piling scenarios alongside tables showing the overall areas of impact.

Modelling results

The results of modelling are shown in Figure 1 to Figure 3 with impact areas summarised in Table 2 to Table 4, assessed using the Southall *et al*. (2019) criteria for marine mammals and the Popper *et al*. (2014) criteria for fish.

Single-line impact ranges have not been presented as there are two starting points for receptors. Fields with areas of <0.01 km^2 show where there is no cumulative effect when the two piles are installed sequentially, generally where the individual ranges are small enough that the second 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.

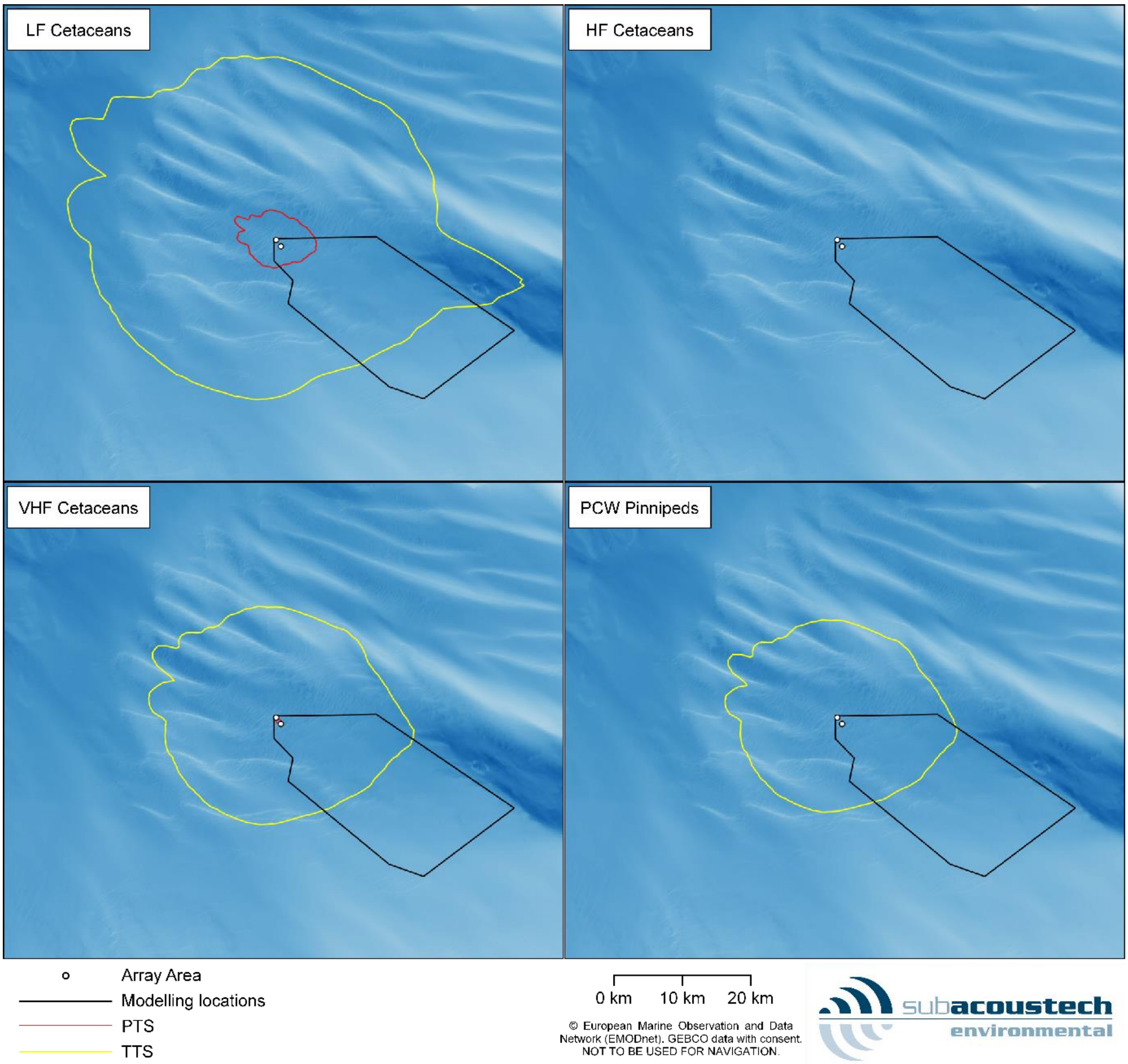

Figure 1 Contour plots showing the SEL_{cum} impact areas for piling the sequential installation of two monopile foundations using the MDS parameters at two separate locations at the NW of Hornsea Four using the impulsive Southall et al. (2019) SEL_{cum} criteria, assuming a fleeing receptor

Table 2 – Summary of the impact areas for the sequential installation of two monopile foundations using the MDS parameters at two separate locations at the NW of Hornsea Four using the impulsive Southall et al. (2019) SEL_{cum} criteria, assuming a fleeing receptor

Southall *et al*. (2019) Weighted SEL_{cum} – Impulsive criteria			**MDS Monopile** In-combination area
PTS	LF	183 dB	68 km^2
	HF	185 dB	< 0.01 km^2
	VHF	155 dB	0.41 km^2
	PCW	185 dB	< 0.01 km^2
TTS	LF	168 dB	2,200 km^2
	HF	170 dB	< 0.01 km^2
	VHF	140 dB	880 km^2
	PCW	170 dB	680 km^2

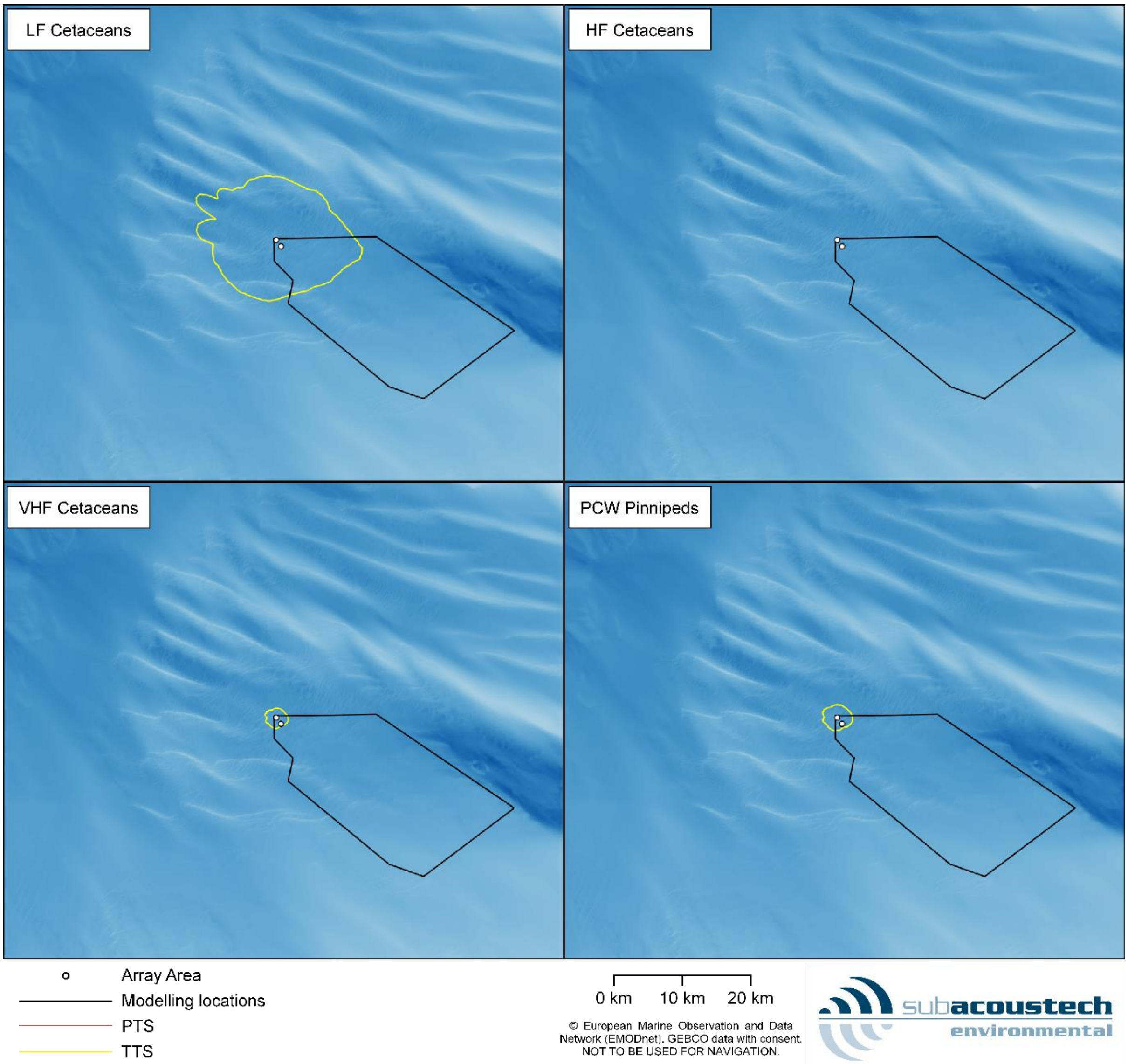

Figure 2 Contour plots showing the SEL_{cum} impact areas for piling the sequential installation of two monopile foundations using the MDS parameters at two separate locations at the NW of Hornsea Four using the non-impulsive Southall et al. (2019) SEL_{cum} criteria, assuming a fleeing receptor

Table 3 – Summary of the impact areas for the sequential installation of two monopile foundations using the MDS parameters at two separate locations at the NW of Hornsea Four using the non-impulsive Southall et al. (2019) SEL_{cum} criteria, assuming a fleeing receptor

Southall *et al*. (2019) Weighted SEL_{cum} – Non-impulsive criteria			**MDS Monopile** In-combination area
PTS	LF	199 dB	< 0.01 km^2
	HF	198 dB	< 0.01 km^2
	VHF	173 dB	< 0.01 km^2
	PCW	201 dB	< 0.01 km^2
TTS	LF	179 dB	300 km^2
	HF	178 dB	< 0.01 km^2
	VHF	153 dB	7.1 km^2
	PCW	181 dB	12 km^2

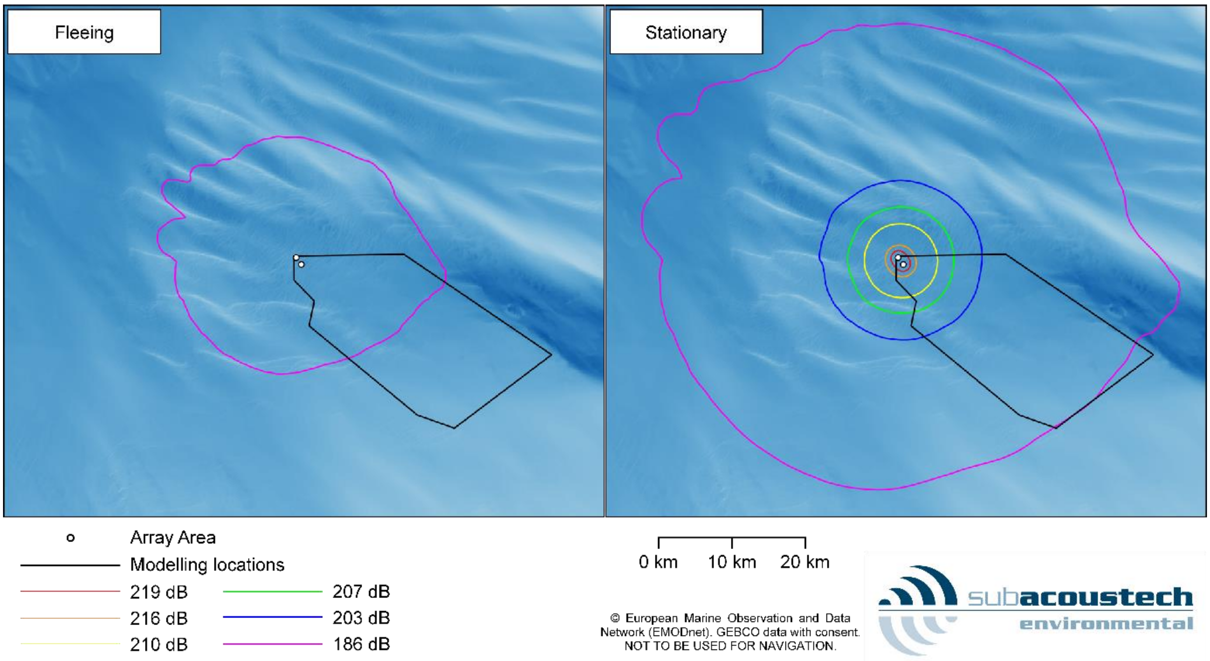

Figure 3 Contour plots showing the SEL_{cum} impact areas for piling the sequential installation of two monopile foundations using the MDS parameters at two separate locations at the NW of Hornsea Four using the Popper et al. (2014) SEL_{cum} criteria for impact piling, assuming both a fleeing and stationary receptor

Table 4 – Summary of the impact areas for the sequential installation of two monopile foundations using the MDS parameters at two separate locations at the NW of Hornsea Four using the Popper et al. (2014) SEL_{cum} criteria for impact piling, assuming both a fleeing and stationary receptor

Popper *et al*. (2014) Unweighted SEL_{cum} – Impact piling criteria		**MDS Monopile** In-combination area
Fleeing	219 dB	< 0.01 km²
	216 dB	< 0.01 km²
	210 dB	< 0.01 km²
	207 dB	< 0.01 km²
	203 dB	< 0.01 km²
	186 dB	900 km²
Stationary	219 dB	5.5 km²
	216 dB	14 km²
	210 dB	80 km²
	207 dB	170 km²
	203 dB	380 km²
	186 dB	3,400 km²

Comparison

In order to give context to the results from the previous section, the impact areas produced by the installation of a single foundation at the NW corner of Hornsea Four using the MDS monopile parameters, as given in the original study, have been presented in Table 5 to Table 7 alongside the two sequential monopile impact areas modelled in this exercise.

From this it can be seen that the impact areas only increase slightly with the introduction of a second monopile installed sequentially when considering a fleeing animal. This is because the receptor has travelled to a distance where the noise levels are much lower by the time the second monopile begins, resulting in a lower added exposure. For stationary animals, the ranges are much larger for two monopiles installed sequentially as the receptor is receiving twice the total noise exposure compared to a single monopile.

Table 5 – Comparison between the impact areas of a single MDS monopile modelling and the sequential MDS monopile modelling using the impulsive Southall et al. (2019) SEL_{cum} criteria, assuming a fleeing receptor

Southall *et al*. (2019) Weighted SEL_{cum} – Impulsive criteria			**Single MDS monopile**	**Sequential MDS monopiles**
PTS	LF	183 dB	66 km^2	68 km^2
	HF	185 dB	< 0.01 km^2	< 0.01 km^2
	VHF	155 dB	< 0.01 km^2	0.41 km^2
	PCW	185 dB	< 0.01 km^2	< 0.01 km^2
TTS	LF	168 dB	2,200 km^2	2,200 km^2
	HF	170 dB	< 0.01 km^2	< 0.01 km^2
	VHF	140 dB	860 km^2	880 km^2
	PCW	170 dB	670 km^2	680 km^2

Table 6 – Comparison between the impact areas of a single MDS monopile modelling and the sequential MDS monopile modelling using the impulsive Southall et al. (2019) SEL_{cum} criteria, assuming a fleeing receptor

Southall *et al*. (2019) Weighted SEL_{cum} – Non-impulsive criteria			**Single MDS monopile**	**Sequential MDS monopiles**
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	300 km^2
	HF	178 dB	< 0.01 km^2	< 0.01 km^2
	VHF	153 dB	5.3 km^2	7.1 km^2
	PCW	181 dB	11 km^2	12 km^2

Table 7 – Comparison between the impact areas of a single MDS monopile modelling and the sequential MDS monopile modelling using the Popper et al. (2014) SEL_{cum} criteria for impact piling, assuming a fleeing receptor

Popper *et al*. (2014) Unweighted SEL_{cum} – Impact piling criteria		**Single MDS monopile**	**Sequential MDS monopiles**
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	900 km²
Stationary	219 dB	1.8 km²	5.5 km²
	216 dB	5.0 km²	14 km²
	210 dB	34 km²	80 km²
	207 dB	80 km²	170 km²
	203 dB	210 km²	380 km²
	186 dB	2,500 km²	3,400 km²

References

Southall, B. L., Finneran, J. J., Reichmuth, C., Nachtigall, P. E., Ketten, D. R., Bowles, A. E., Ellison, W. T., Nowacek, D. P. and Tyack, P. L. (2019). Marine mammal noise exposure criteria: Updated scientific recommendations for residual hearing effects. Aquatic Mammals 2019, 45(20, 125-232, DOI 10.1578/AM.45.2.2019.125.

Popper, A. N., Hawkins, A. D., Fay, R. R., Mann, D. A., Bartol, S., Carlson T. J., Coombs, S., Ellison, W. T., Gentry, R. L., Halvorsen, M. B., Løkkeborg, S., Rogers P. H., Southall, B. L., Zeddies, D. G. and Tavolga, W. N. (2014). Sound exposure guidelines for fishes and sea turtles. Springer Briefs in Oceanography. DOI 10.1007/978-3-319-06659-2.