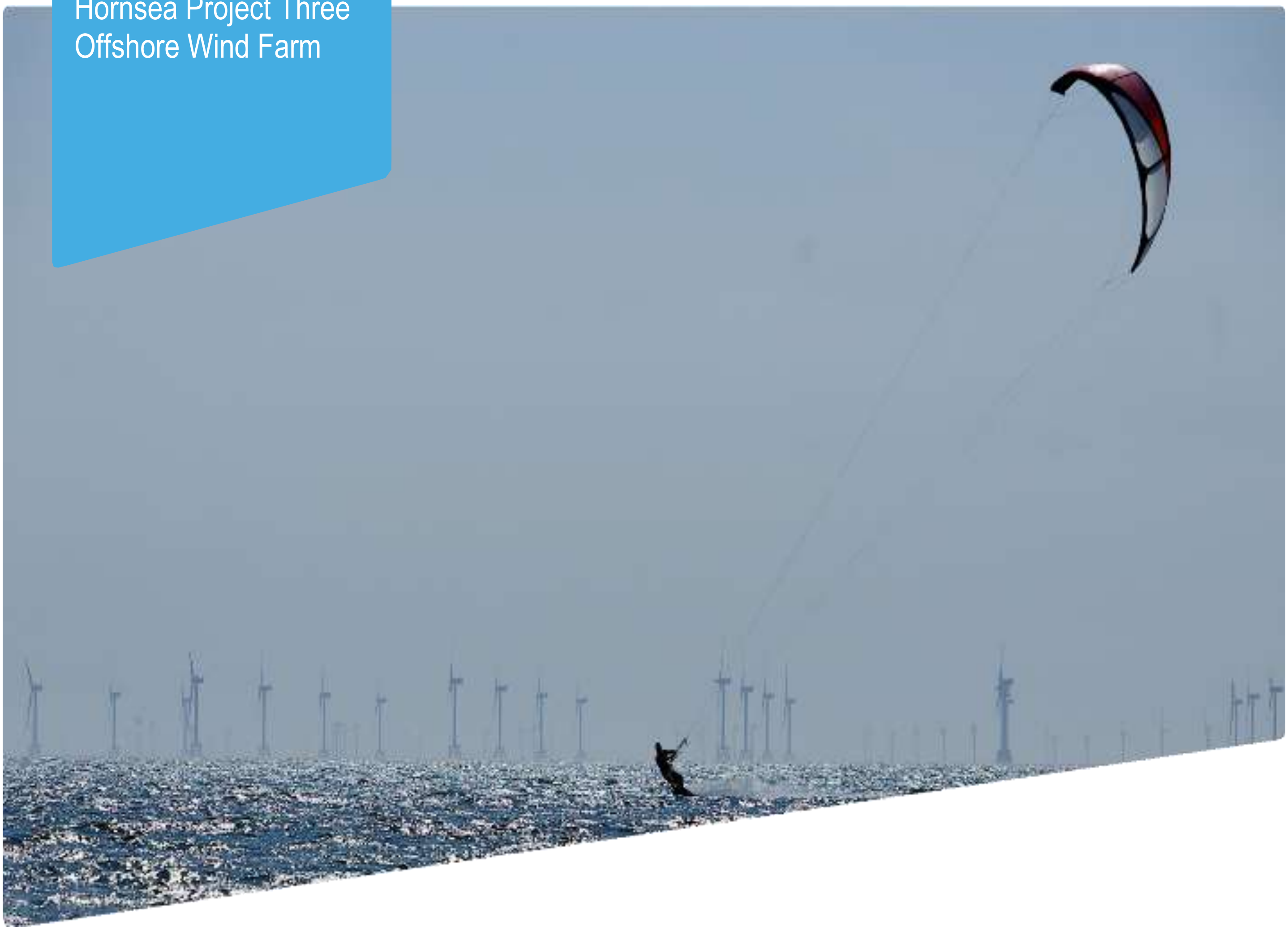
Hornsea Project Three
Offshore Wind Farm



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Appendix 11 to Deadline I submission – Sandwave Clearance Clarification Note

Date: 7th November 2018

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Front cover picture: Kite surfer near a UK offshore wind farm © Ørsted Hornsea Project Three (UK) Ltd., 2018.

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1. Introduction

1.1 This note has been produced to provide clarification on the assessment of the impacts of sandwave clearance for cables within the Hornsea Three offshore cable corridor, as presented in Volume 2, Chapter 1: Marine Processes of the Environmental Statement (Document A6.2.1) and the Report to Inform Appropriate Assessment (RIAA; Document A5.2).

1.2 The Relevant Representations from Natural England and the Marine Management Organisation (MMO) made comments in relation to the evidence supporting the assessments of impacts on the integrity of the sandbank system and the sandwave clearance volume estimates within the draft Development Consent Order (DCO). These comments are set out in the following sections of the Relevant Representations:

- Natural England Relevant Representation: Section 5.3.1, 5.3.4 and 5.3.5; and
- MMO Relevant Representation: Comments 3.9 and 4.7.

1.3 Based on the Relevant Representation points outlined above, the scope of this clarification note is divided into two main sections:

- Section 2: Clarification regarding Race Bank sandwave levelling and recovery monitoring data and its applicability to Hornsea Three. The monitoring evidence from Race Bank offshore wind farm was used to inform the impact assessment within Volume 2, Chapter 1: Marine Processes of the Environmental Statement. This note clarifies why it is appropriate to use this data and evidence as a proxy for Hornsea Three in the following sections:
  - Paragraph 2.1 provides background to the previous assessment of sandwave recovery presented within the DCO Application (Volume 2, Chapter 1: Marine Processes of the Environmental Statement) along with a summary of the evidence from Race Bank;
  - Paragraph 2.13 provides details of analysis undertaken to test the applicability of the Race Bank evidence to Hornsea Three (and with reference to technical detail presented in Appendix C);
  - Paragraph 2.16 *et seq*. details the evidence of sandwave recovery provided by the Race Bank monitoring data; and
  - Paragraph 2.41 *et seq*. presents the implications for sandwave recovery at Hornsea Three.
- Section 3 outlines the methodology, calculations and assumptions used to estimate sandwave clearance volumes for the Hornsea Three offshore cable corridor.

2. Race Bank Sandwave Levelling and Recovery Monitoring Data

Background

2.1 An assessment of the likely nature and timescale for recovery of the affected bedforms was presented within paragraphs 1.11.5.3 to 1.11.5.18 of Volume 2, Chapter 1: Marine Processes of the Environmental Statement, and paragraphs 4.3.4.15 to 4.3.4.20 of Volume 5, Annex 1.1: Marine Processes Technical Report of the Environmental Statement (Document A6.5.1.1). The assessment was undertaken with a theoretical basis by experienced geomorphologists, utilising site specific quantitative information. This was supported with reference to monitoring data that had recently become available from Race Bank. Given the comments raised in the Relevant Representations made by Natural England and the MMO (see Section 1.2), this note has been produced to further clarify the evidence presented by this monitoring data and its applicability to Hornsea Three.

2.2 The relevant conclusions presented within paragraph 1.11.5.9, Volume 2, Chapter 1: Marine Processes of the Environmental Statement are:

"The bedforms along which bed levelling is proposed are part of a dynamic bedform field including (in places) an active sandbank belonging to the North Norfolk Sandbank system. The patterns of processes governing the overall evolution of the systems (the flow regime, water depths and sediment availability) are at a much larger scale than, and so would not be affected by, the proposed local works. As a result, the proposed levelling is not likely to influence the overall form and function of the system and eventual recovery via natural processes is therefore expected.

The rate of recovery would vary in relation to the rate of sediment transport processes, faster infill and recovery rates will be associated with higher local flow speeds and more frequent wave influence. The shape of the bedform following recovery might recover to its original condition (e.g. rebuilding a single crest feature, although likely displaced in the direction of natural migration) or it might change (e.g. a single crest feature might bifurcate or merge with another nearby bedform). All such possible outcomes are consistent with the natural processes and bedform configurations that are already present in the site and would not adversely affect the onward form and function of the individual bedform features, or the sandbank system as a whole."

2.3 A separately presented conclusion was also stated paragraph 4.3.4.3 of Volume 5, Annex 1.1: Marine Processes Technical Report:

"Bedform recovery will likely occur in relation to the migration and sediment transport processes across the system. Estimated recovery rates for sandwaves are in the order of several years, based on representative forcing conditions at a single water depth".

2.4 As transport rates are variable along the Hornsea Three offshore cable corridor, bedform response would be variable, with larger flow speeds or greater transport rates resulting in faster recovery.

2.5 The Race Bank monitoring data was also used to support the impact assessment within paragraph 1.11.5.9 of Volume 2, Chapter 1: Marine Processes of the Environmental Statement as follows:

"Both the Race Bank offshore wind farm export cable and Hornsea Three offshore cable corridor pass through similarly dynamic areas of seabed characterised by highly mobile sediment and migrating bedform features. The conclusions reached in DONG Energy (2016), which are supported

by the monitoring described in DONG Energy (2017), are considered to be also applicable for areas of sandwave clearance by dredging within the Hornsea Three offshore cable corridor".

Race Bank monitoring data

2.6 The Race Bank monitoring data capture the initial stages of sandwave recovery following localised levelling at 15 locations in ten sites within the Race Bank offshore cable corridor and four locations in two sites within the Race Bank array area (see Figure 2-1).

2.7 The monitoring evidence from the 15 locations in ten sites within the Race Bank offshore export cable corridor (DONG Energy, 2017) is available as a series of bathymetry data figures for each site, in three phases, as follows:

- Pre-levelling: 9 August 2016 to 26 August 2016;
- Levelling: 28 August 2016 to 5 September 2016; and
- Post-levelling 15 February 2017 to 17 February 2017.

2.8 The four locations at two sites in the Race Bank array area, have the following time frame:

- Pre-levelling: 5 May 2016 to 6 May 2016;
- Levelling: 6 May 2016 to 7 May 2016; and
- Post-levelling 6 June 2016 to 7 June 2016.

2.9 The Race Bank monitoring data provides observations of the early stages of post-levelling sandwave response and recovery (approximately one to five months following levelling) across a range of similar but also subtly different sandwave bedforms and sedimentary environments. The data are presented as images of seabed bathymetry presented in Appendix A of this Clarification Note. An associated review of the data is provided in Appendix B of this Clarification Note.

2.10 The quality of the bathymetry data presented in the images varies between the survey periods and sites. In many cases the image from each period is actually a composite of data from multiple surveys. Nonetheless, across most of the sites, the bathymetry images provide a sufficient basis for a semi-quantitative assessment of changes that have occurred as a result of the levelling and any subsequent recovery.

2.11 The sandwave orientation, wavelength and any short-term migration during the survey period can be inferred from the bathymetry images using the co-ordinate grid overlay. Whilst it is not possible to accurately determine absolute elevations, areas and volumes from the data in this format, comparisons can be made relative to the surrounding seabed.

2.12 A summary of the 12 sites within the Race Bank offshore cable corridor and array area, and an interpretation of the post levelling sandwave response, are provided in Table 2.1 below. A more detailed description of the properties represented within the bathymetry monitoring images at each site for each phase is provided Appendix B, including:

- Characteristics of the bedforms present, including their approximate size, shape and orientation;
- The nature and dimensions of the sandwave levelling dredging works;
- The nature and magnitude of any changes to sandwave or seabed topography, approximately five months after levelling for the Race Bank offshore export cables and a month for the Race Bank inter-array cables; and
- An interpretation of the nature and magnitude of change contributing to sandwave recovery.

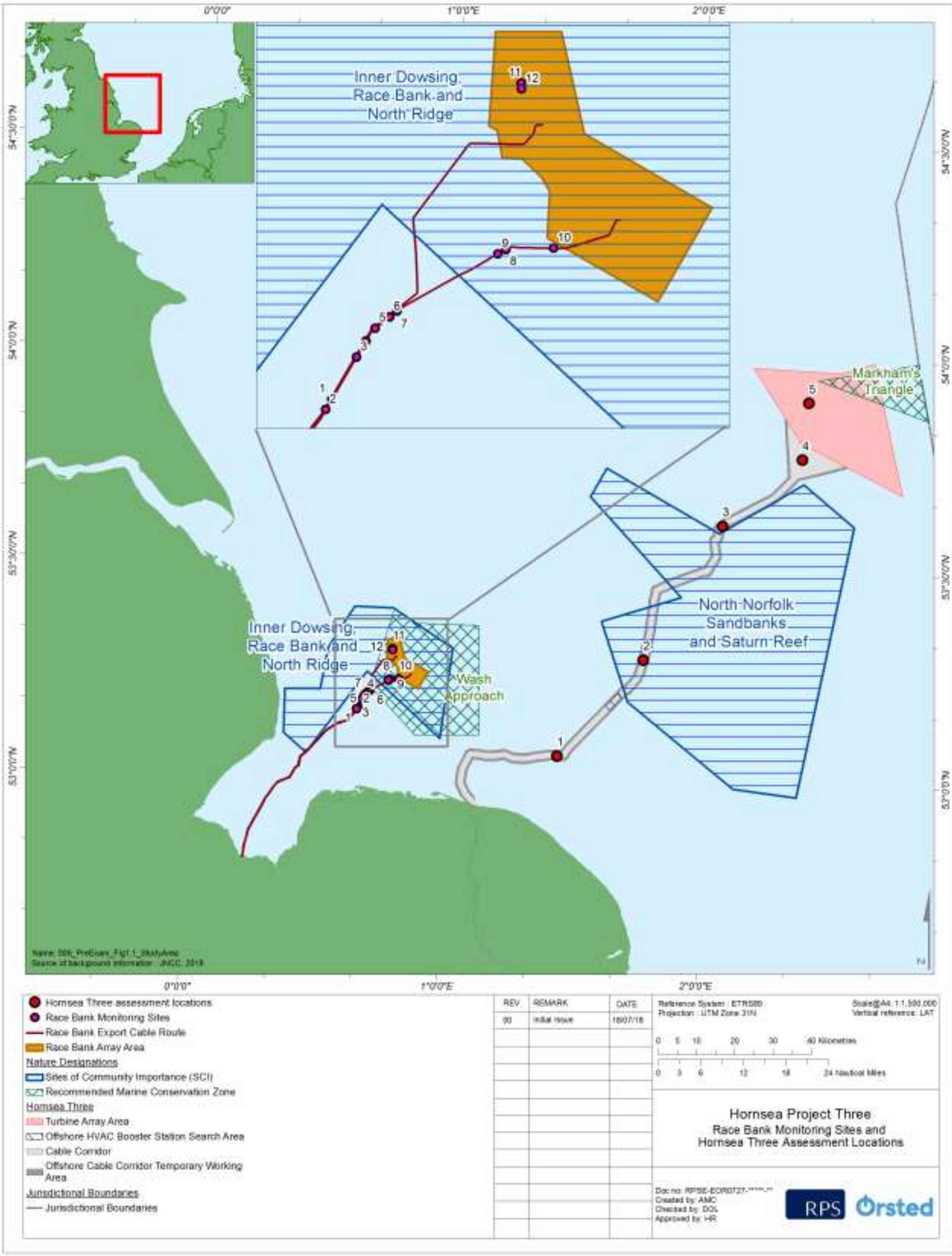

Figure 2-1: Race Bank monitoring sites and Hornsea Three sandwave levelling assessment locations (see Appendix C for further explanation of these)

Table 2.1: Characterisation of Race Bank bedforms.

Race Bank Site number (Levelling Area and KP)	Water depth (mLAT)	Sandwave migration direction and rate	Sediment transport potential and direction of net transport	Interpretation summary
Race Bank offshore cable corridor monitoring sites (Appendix A1)				
1 (A and B; 51.5)	-4.77	Southwest 4.8 m/yr ±0.3 m	Low to Medium, Northwest	Sandwave wavelengths at this site vary between 67 and 133 m. The crest is orientated approximately east to west. Sandwave section is levelled to approximately the same depth as the flanks. From the post-dredge image, migration is apparent across the site, as an unaffected sandwave migrates into the area from southeast to northwest. The dredged sandwave feature is no longer clearly visible in the post-levelling image. More generally, the dredged area appears to have returned to a natural state and local dredge depressions have been largely infilled.
2 (C; 51.5)	-4.29	Southwest 4.8 m/yr ±0.3 m	Low to Medium, Northwest	Unable to ascertain the sandwave wavelength. The crest is orientated approximately east to west. Sandwave section is levelled to the same depth as the surrounding seabed and therefore taken to be the base of the sandwave. The dredged sandwave feature is no longer clearly visible in the post-levelling image. Other un-dredged sandwaves remain in position.
3 (D; 54.2)	-7.03	Southwest 7.8 m/yr ±4.5 m	Low to Medium, Northwest	Asymmetric sandwave, with wavelength of about 64 m. The crest is orientated north-northwest to south-southeast. Sandwave section is levelled to the same depth as the surrounding seabed and therefore taken to be the base of the sandwave. Migration of the affected sandwave sections is evident, with the toe of each sandwave section migrating with a different direction and rate to the main feature (to the north-northwest by about 18 m within the five month period). The dredged gap between the sandwave sections is also marginally narrower. The observed feature migration would seem to be contributing to the recovery of the sandwave at this site.

Race Bank Site number (Levelling Area and KP)	Water depth (mLAT)	Sandwave migration direction and rate	Sediment transport potential and direction of net transport	Interpretation summary
4 (E and F; 55.1)	-5.32	Southwest, 7.8 m/yr ±4.5 m	Low to Medium, Northwest	Asymmetric sandwave, with wavelength of about 164 m. The crest is orientated west-northwest to east-southeast, smaller bedforms are also apparent on the flanks. The levelled area is relatively shallow as only the crest of the sandwave is taken off, approximately to the same depth as the flanks. The post dredge images would suggest that the dredge areas are infilling, with the sandwave sections merging across the dredge area and the crests beginning to reform. However, there is no apparent migration.
5 (G; 55.85)	-4.69	South, 7.8 m/yr ±4.5 m	Low to Medium, Northwest	Asymmetric sandwave, unable to determine full wavelength. The crest is orientated east to west. The levelled area is relatively shallow as only the crests of the sandwave are taken off, approximately to the same depth as the flanks. Similar to site 4 the post-dredge image suggests the dredge area is infilling, with the crests reforming across the dredged area. Limited or no migration, but a small reduction in the crest height either side of the dredged area, which may be contributing to the infilling. The sandwave is recovering in situ.
6 (H; 56.7)	-7.12	South, 7.8 m/yr ±4.5 m	Low to Medium, Northwest	Asymmetric sandwave, with wavelength of about 75 m. The crest is orientated east to west. The levelled area is relatively shallow as only the crests of the sandwave are taken off to the same depth as the flanks. However, the levelled area is fairly wide. Post-dredge, the levelled area is infilling as the height has increased, at the same time the crest heights either side of the levelled are lower, possibly contributing to the infill. No migration is evident, but the feature is recovering in situ.
7 (I; 57.2)	-8.39	South, 7.8 m/yr ±4.5 m	Low to Medium, Northwest	Asymmetric sandwave, with wavelength of about 94 m. The crest is orientated east to west. Sandwave section is levelled to the same depth as the surrounding seabed and therefore taken to be the base of the sandwave. The levelled area is infilling, merging across the levelled area and the crest showing signs of reforming. There is a small reduction in the crest height either side of the dredged area, which is potentially contributing to the infilling. However, there is no observed migration so the sandwave is recovery in situ.

Race Bank Site number (Levelling Area and KP)	Water depth (mLAT)	Sandwave migration direction and rate	Sediment transport potential and direction of net transport	Interpretation summary
8 (J and K; 62.8)	-13.34	North, 6.8 m/yr ±5.5 m	Low, Northwest	Asymmetric sandwave, with wavelength of about 59 m. The crest is orientated east to west. Sandwave section is levelled to the same depth as the surrounding seabed and therefore taken to be the base of the sandwave. A large area is levelled and results in two distinct and separate features. Migration is clearly evident in the post-dredge image of the sandwaves, with each section behaving differently (across both sandwaves). Migration of the affected sandwave sections is evident, with the toe of each sandwave section migrating with a different direction and rate to each other and to the main feature (the western section migrates north by about 15 m in the five month period, whereas the eastern section migrates west into the dredge area by about 53 m). The behaviour is the same for both sandwaves within this site. The westerly migration results in clearly defined crests moving into the dredge area, rather than reforming in situ. Also, due to the varying migration speeds and the narrowing dredge gap, suggests that the sandwave sections will eventually merge. The observed feature migration would seem to be contributing to the recovery of the sandwave at this site.
9 (L, M and N; 62.8)	-9.53	North, 6.8 m/yr ±5.5 m	Low, Northwest	Symmetrical sandwaves, with wavelengths between 25 m and 63 m for the affected sandwaves. The crests are orientated east to west. The levelled area is relatively shallow as only the crests of the sandwave are taken off to the same depth as the flanks. In the post-dredge image at this site, the dredge area is infilled and the crest has reformed to the same height as the unaffected part of the sandwave. Migration is also evident, with the entire sandwave migrating to the north by a few metres. The available information would suggest that all three sandwaves have fully recovered in height, shape and form within the five month period after dredging. Also the recovery is most likely to have occurred in situ, with migration occurring afterwards, as the entire length of the sandwave has moved with no evidence of the levelled area. At the same time the recovery does not seem to have influenced the crest height either side of the levelled area, as there is no change.

Race Bank Site number (Levelling Area and KP)	Water depth (mLAT)	Sandwave migration direction and rate	Sediment transport potential and direction of net transport	Interpretation summary
10 (O; 65.6)	-8.15	North, 3.0 m/yr ±3.7 m	Low to Medium, Northwest	Asymmetric sandwave, with a wavelength of about 45 m. The crest is orientated west-northwest to east-southeast. Sandwave section is levelled to the same depth as the surrounding seabed and therefore taken to be the base of the sandwave. The cable is orientated nearly parallel to the sandwave crest, so a large section of the sandwave is levelled. No infilling is visible in the levelled area and no migration is apparent in the post-dredge image, which illustrates two distinct and separate features. The image would suggest there is no recovery of the sandwave at this site, within the five month period.
Race Bank array area, cable dredge trials (Appendix A2)				
11 Z01 – A02	-13.5	North, 25 m/yr ±2 m	Low, Northwest	Asymmetric sandwaves, with a wavelength between 40 and 70 m. The crests are orientated east-northeast to west-southwest. All three sandwaves are levelled to the same depth as the surrounding seabed and taken to be the base of the sandwave. One levelled sandwave has completely reformed, while the remaining two still show signs of infilling and merging across the levelled area. There is no apparent reduction in the crest height either side of the dredged areas or migration of the bedforms. Therefore, the sandwaves are recovering in situ.
12 C06 – B05	-14.0	North, 4.0 m/yr ±4.5 m	Low, Northwest	Asymmetric sandwave, with a wavelength of about 45 m. The crest is orientated east-northeast to west-southwest. Sandwave section is levelled to the same depth as the surrounding seabed and therefore taken to be the base of the sandwave. Levelled area is in proximity to a region of converging and bifurcating sandwaves and is therefore in an active and dynamic area. The levelled area is infilling and merging across. There is no observed migration so the sandwave is recovery in situ, with no observable change to the nearby evolving bedforms.

Evidence of Sandwave Recovery from Race Bank Monitoring Data

2.13 As outlined in paragraph 2.6 *et seq*., the Race Bank monitoring data captured the initial stages of sandwave recovery following localised levelling at 15 locations in ten sites within the Race Bank offshore cable corridor and four locations in two sites within the Race Bank array area. The data are presented as images of seabed bathymetry presented in Appendix A, with associated review of the data summarised in Table 2.1 and provided in full in Appendix B of this Clarification Note.

2.14 The interpretation of the bathymetry images indicates at least partial sandwave recovery at most of the observed locations, which is consistent with the Race Bank site being an active and dynamic sedimentary environment that is conducive to the development, maintenance and migration of sandwave bedforms.

2.15 In the five months after levelling, there was evidence of partial to complete sandwave recovery at ten of the twelve Race Bank monitoring sites, associated with 14 of the 19 levelled sandwaves. At the remaining three sites, there seems to be either no change, or the affected sandwaves are no longer visible in the available post-dredge imagery.

Full Recovery

2.16 The bathymetry images from site 9 suggest complete recovery of the height, shape and form of the three affected sandwaves. Very slight migration, by only a few metres, is observed with the sandwaves at this site, with movement towards the north, in line with the underlying migration direction (ABPmer, 2016). The dredging at this site was relatively shallow with respect to the sandwave height, as only the crest was removed.

2.17 The shallow dredge depth and the limited amount of material to replace, potentially contributes to the complete recovery observed with the sandwaves at site 9. It is not clear from the available data if infill of the dredge area occurred from the sandwave parts migrating into the dredge area to reattach with each other, or if there was an influx of material through sediment transport process, with the sandwave crest reforming after infill. However, what is apparent is that the northerly migration observed in the post-levelling image is consistent along the entire sandwave, suggesting infill occurred first, followed by migration.

2.18 Full recovery is observed at one of three adjacent sandwaves at site 11 (located within the Race Bank array area). The three sandwaves all appeared to have been dredged to full depth (i.e. to the base of the sandwave). The exact timing or mechanism of the recovery in the post-levelling period cannot be resolved but appears to have mainly occurred in situ, without significant migration of the feature. The importance of the observation is that the nature of the recovery process can be localised to individual features within a local group. The rate of recovery at one location may not necessarily be the same at other nearby locations (within tens of metres), even though the general environmental setting is likely to be very similar.

Partial Recovery

2.19 Partial recovery is observed at sites 3, 4, 5, 6, 7, 8, 11 and 12. Water depths in these sites range between -4 mLAT to -14 mLAT. The levelling activities at these sites appeared to remove only part of the sandwave crest height.

2.20 Sandwave migration is identified at sites 3 and 8, with evidence of partial recovery of the levelled sandwaves. The sandwaves at these sites are generally levelled to their base and thereby create two distinct local features separated by the dredged area. Although migration is observed post-levelling, the migration direction is completely different from the underlying migration characteristics determined from previous studies. The observed post-levelling migration occurs laterally across the dredged area in the direction of the crest axis (i.e. the crest of one part migrates into the dredged area, while the other part migrates further away). As an example, at site 3, the migration assessed in previous studies is to the southwest (ABPmer, 2016). However post-levelling, the sandwave segments both migrate to the north. The dredged gap is therefore displaced and slightly narrowed by the migration, but without noticeable recovery of the sandwave body in the gap.

2.21 At sites 4, 5, 6, 7, 11 and 12, the interpreted partial recovery is considered to relate to the infill of the dredged area, without any migration of the sandwave feature. Although the sandwaves are not completely reformed within the dredged area, there is a relative depth change indicating shallowing of the seabed within the dredge area. The infill mainly seems to occur from the margins of the dredged sandwave into the dredged area. This is because in the post dredge images, there is a slight reduction in the crest height of the unaffected part of the sandwave, which is likely contributing to the infilling within the dredge area. At these sites, no migration is apparent either of the entire sandwave or the sandwave sections.

2.22 The sandwaves at sites 4, 5, 6, 7, 11 and 12 are recovering in situ, as a result of infilling in the dredge area, with some sediment input from the unaffected part of the sandwave. Other sediment sources are likely to relate to the sediment transport processes through the area and potentially from smaller ripple and mega-ripple bedforms. However, the available bathymetry images are not able to show this.

No recovery or sandwave no longer identified

2.23 The available bathymetry images would suggest there is potentially a loss of the levelled sandwaves, at the point of monitoring, at sites 1 and 2, which are in the shallowest water depths of around -4 mLAT. At sites 1 and 2 it is noted that the bathymetry is relatively complex and the sandwave features are not very clearly resolved by the survey data images at the different phases. The affected sandwave sections around the dredged area become less pronounced or are possibly absent in the post-dredge image. Without interim survey data it is not possible to know whether the features have migrated out of the survey extent, or if they have been dispersed more widely, or if they have been redistributed locally (contributing to the infill of the dredged area), or if the features are actually still present but simply not clearly visible in the bathymetric data, or some combination of these reasons.

2.24 There is limited or no evidence of sandwave recovery, evolution or migration at site 10. The dredging at this site is to the base of the sandwave, relative to the depths of the surrounding seabed, and is nearly parallel with the sandwave alignment. As a result, a relatively large area and volume of the sandwave has been levelled. Migration is not apparent in the bathymetry images and if any infilling is occurring it is also not evident. The general lack of notable change suggests an overall lower rate of sediment mobility, rather than any fundamental difference in the processes that are active, or the potential for sandwave recovery over longer timescales at this location.

Observed mechanisms and factors influencing sandwave recovery

2.25 The Race Bank monitoring data indicate that the locally levelled sandwaves continue to evolve in a manner that is consistent with recovery towards a new natural equilibrium state in the medium to long-term (in the order of months to years) post-levelling. Where observed, this evolution and recovery is occurring at varying rates and by different mechanisms across most of the sites in the one to five months after dredging.

Mechanisms for sandwave recovery

2.26 The recovery mechanisms interpreted from the bathymetry images are:

- Infilling of the dredge area with the affected sandwaves remaining in situ; and
- Recovery associated with the migration of the sandwaves.

2.27 In terms of the recovery by infilling, the sandwave reforms in situ within the levelled area. This is typically observed to occur without significant migration or erosion of the remaining sandwave crest adjacent to the levelled area.

2.28 In relation to the recovery associated with sandwave migration, the adjacent sandwave crest and flanks can migrate into the levelled area, which can be in an apparently different direction to the migration rate and direction of the sandwave feature as a whole.

Factors influencing sandwave recovery

2.29 The main factors that are considered to influence the recovery potential (i.e. the mechanism and speed of recovery) of the levelled sandwaves are:

- The dimensions of the dredged area, particularly the width and depth of the dredged channel relative to the overall sandwave height, and the alignment of the dredged channel relative to the crest axis; and
- The degree of sediment mobility at the dredge location, which is in turn controlled by the environmental forcing conditions and water depth.

2.30 Shallower levelling/dredging (relative to the sandwave height and irrespective of the water depth) was associated with faster rates of recovery. The locally dredged areas appeared to infill mainly in situ, with some contribution of sediment volume from the adjacent sandwave crest, and typically without significant migration.

2.31 Deeper levelling/dredging (i.e. to the base of the sandwave) separates the sandwave into two discrete features that are then more likely to locally evolve or migrate with different rates and directions to that of the main sandwave body.

2.32 The sites where at least partial sandwave recovery is observed in the post levelling period were typically characterised by persistent but relatively low magnitude rates of sediment transport. The predicted potential sediment transport regimes (the frequency and range of magnitudes of transport) during the short term post-levelling period at these locations are similar to the long term patterns (as shown in Appendix C), and so the observed patterns of recovery are likely to be representative of what might be expected to naturally occur during other similar time frames in the past, or in the future. The observed recovery is not the result of a period of unusual sediment mobility.

2.33 The relative contributions of everyday conditions and occasional larger storm events to the observed recovery in the post-levelling period cannot be reliably separated; however, past and future conditions will likely include a similar distribution of (everyday and storm) conditions when considered over seasonal to annual timescales (three to 12 months).

2.34 Overall sediment mobility is described by the long term distribution of instantaneous sediment transport rates, and the net sediment transport rate over time, taking account of the direction of transport. These quantities are a function of the tidal and wave regimes, the water depth and the type and quantity of sediment available for transport locally. Relatively higher sediment mobility is more likely to transport a greater sediment volume, in a shorter timescale, to enable in situ recovery by net sediment deposition in the dredged area, or recovery through migration of the remaining sandwave feature.

2.35 Given a generally similar tidal current regime and seabed sediment type, relatively greater water depths will reduce the contribution of wave action at the seabed, reducing the instantaneous sediment transport rate. Moving from relatively shallow (e.g. 5 to 10 m) to intermediate (e.g. 10 to 15 m) water depths, the difference may be mainly a reduction in the magnitude of transport resulting from frequent wave effects. Moving from intermediate to deeper water (greater than 15 m), the frequency of any wave contribution may also become limited to only larger storm events.

Applicability of Race Bank Monitoring Data to Hornsea Three

2.36 In order to demonstrate the applicability of the Race Bank monitoring data to Hornsea Three, an analysis has been undertaken to identify any similarities and differences between the sites in terms of their underlying environmental settings and particularly the aspects of the settings that will govern the potential for sandwave recovery following levelling. This analysis is presented in detail in Appendix C. Comparative consideration has been given to parameters such as total (tide and surge) water levels, current speed and direction, and coincident wave height, period and direction. This was used to calculate potential sediment transport rates and direction at each site and comparative levels of sediment mobility and used alongside an understanding of sea bed and sandwave bedform characteristics. On the basis of these comparisons, conclusions can be drawn on the validity of Race Bank as an analogue for Hornsea Three, in the context of sandwave recovery.

2.37 There is a clear underlying similarity in the general environmental setting of the observed Race Bank sandwave levelling locations, and the areas of sandwaves in Hornsea Three that might be subject to levelling in the future. This similarity is most simply demonstrated by the presence of actively migrating sandwave features in both locations. Common factors contributing to this similarity include a sufficient supply of potentially mobile, predominantly sandy sediment, and tidal and wave regimes (and water depths) that result in net sediment transport. In practice, there will be localised differences in sediment type, tidal and wave forcing and water depth that will affect the rate of sediment transport and sandwave migration. However, given the general similarity in the underlying environmental factors, and the ubiquitous nature of sediment transport and morphological processes, it is reasonable to expect similarity in long term patterns of bedform evolution and response to changes such as localised levelling.

2.38 The most notable difference between the Race Bank and Hornsea Three environmental settings is the water depth. Water depths within the Race Bank levelled areas range between approximately -4 mLAT to -14 mLAT. The sandwave bedforms at Race Bank are therefore in relatively shallow water depths, with wave effects likely to contribute more frequently to sediment transport processes. Within the part of the North Norfolk Sandbanks and Saturn Reef SAC which coincides with the Hornsea Three offshore cable corridor (i.e. where sandwave clearance is likely to be required for cable installation), water depths are -17 m LAT and greater, so are likely to have a typically lower magnitude of, or less frequent exposure to, wave effects at the seabed and so lower overall rates of sediment mobility. Variation in the grainsize distribution of the sand which is present locally may also have some more limited effect on rates of sediment mobility but would not affect the nature of the sediment transport or morphological processes.

2.39 The Race Bank sandwave levelling evidence covers a wide range of levelling corridor widths, lengths and depths, through a range of sandwave feature sizes. At most of the Race Bank monitoring sites, the depth of sandwave levelling is relatively limited in relation to sandwave height (i.e. only the crests were levelled). The only four exceptions are sites 3 and 8 in the Race Bank offshore cable corridor and sites 11 and 12 within the Race Bank array area, where the levelling was to the base of the sandwave, which resulted in the creation of two separate and distinct features either side of the dredged area. A range of relative orientations between the dredged section and the sandwave crest are observed. The dredged area is approximately perpendicular at site 4, nearly parallel at site 10, and at some intermediate oblique alignment to the sandwave crests at all other sites. Comparative information is not presently available for Hornsea Three.

2.40 Overall, it can be concluded that Race Bank is an appropriate analogue for the Hornsea Three array area and offshore export cable corridor (see Appendix C for further technical detail supporting this conclusion).

Implications of Race Bank Monitoring Data for Sandwave Recovery at Hornsea Three

2.41 The nature and speed of recovery of levelled sandwaves at Hornsea Three will be subject to the same factors that are considered to influence the sandwave recovery at the Race Bank monitoring sites. Both the Race Bank and Hornsea Three offshore cable corridors transit areas of seabed characterised by mobile sediment and migrating bedform features. Most of the two study areas are characterised by similar ranges of tidal current speeds and wave climate, although generally greater water depths within the Hornsea Three array area and offshore cable corridor would lead to less influence of waves at the seabed (and so lower overall rates of instantaneous and net sediment transport). The Hornsea Three array area also has generally lower current speeds than the Hornsea Three offshore cable corridor.

2.42 There may be some local variation in the local seabed sediment grainsize distribution between locations, however, the presence of actively evolving sandwave bedforms (JNCC 2017: Jenkins *et al*., 2015) suggests a broad similarity of sediment type, sediment availability, sedimentary processes and overall mobility.

2.43 On this basis, levelled sandwaves within the Hornsea Three offshore cable corridor and array area can be expected to recover, over timescales primarily depending on the depth and volume of the applied dredge.

2.44 The presence of actively evolving sandwave bedforms within and near to the Hornsea Three array area and offshore cable corridor demonstrate that both the local and regional scale environmental conditions are conducive to the development and maintenance of these features. The Race Bank monitoring sites have demonstrated that levelling activities do not locally (or therefore regionally) disrupt these environmental conditions.

2.45 The recovery of levelled areas over time to a new equilibrium state is a natural process and therefore very likely under a wide range of possible circumstances. The main likely difference in sandwave recovery potential between the Race Bank and Hornsea Three locations is the likely speed of recovery. The Race Bank sites typically demonstrated some degree of partial recovery occurring one to five months post-levelling. Relatively lower sediment mobility in those parts of the Hornsea Three array area and offshore cable corridor that might require sandwave levelling, mean that the recovery time frames may be relatively longer but consistent with the conclusions of Volume 2, Chapter 1: Marine Processes of the Environmental Statement that the levelled sandwaves would recover in the order of months to years to a natural equilibrium state.

Conclusions

2.46 From the review of the Race Bank monitoring data and characterisation of the sandwaves at both Hornsea Three and Race Bank it can be concluded that Race Bank is an appropriate analogue for the Hornsea Three array area and offshore cable corridor.

2.47 The theoretical assessments for Hornsea Three (paragraph 1.11.5.12 of Volume 2, Chapter 1: Marine Processes of the Environmental Statement) stated that the environmental conditions which govern the development and maintenance of the sandwave bedforms occur at much larger scales and would not be disrupted by local levelling works. The Race Bank monitoring provides empirical evidence to support this. The changes to the seabed and remaining parts of the sandwave features observed post-levelling are consistent with continuation of key natural processes such as sediment mobility and bedform migration.

2.48 The theoretical assessment for Hornsea Three (paragraph 1.11.5.10 of Volume 2, Chapter 1: Marine Processes of the Environmental Statement) concluded that the levelled sandwaves would recover with time (in the order of months to years) to a natural equilibrium state, either close to their original shape and location, or, with a different shape and/or position. The Race Bank monitoring provides empirical evidence to support this, indicating that the locally levelled sandwaves and surrounding seabed can visibly evolve post-levelling, in timescales of one to five months, in a manner that is consistent with recovery towards a new natural equilibrium state.

2.49 The theoretical assessments for Hornsea Three (paragraph 1.11.5.13 of Volume 2, Chapter 1: Marine Processes of the Environmental Statement) concluded that the rate of recovery would vary in relation to the rate of local sediment transport processes. The Race Bank monitoring provides empirical evidence to support this, as apparently faster recovery is observed at locations with the more frequent occurrence of relatively higher transport rates. These rates are typically associated with shallower water depths and so more frequent exposure of the seabed to wave effects.

2.50 Supported by the empirical evidence provided by the Race Bank monitoring data, partial recovery from the proposed similar sandwave levelling activities in Hornsea Three is therefore expected to become evident within months, but more complete recovery is more likely to be in the order of several years. In comparison to the Race Bank examples, a relatively longer timeframe for full recovery might be (theoretically) expected in Hornsea Three due to the generally greater water depths and resulting lower rates of sediment transport. However, the underlying similarity in the environmental setting (i.e. all of the factors contributing to the presence of actively migrating sandwave features) provides strong evidence that the same natural processes leading to sandwave recovery observed at Race Bank will also be active at Hornsea Three.

2.51 The conclusions of this Clarification Note, which are informed by the empirical evidence provided by the monitoring data for Race Bank, are therefore in agreement and consistent with the conclusions of the Hornsea Three Environmental Statement, described above.

3. Sandwave Clearance Maximum Design Scenario

Introduction

3.1 As outlined in Section 1, this part of the clarification note outlines the calculations used to estimate sandwave clearance volumes for the installation of the Hornsea Three offshore export cables within the Hornsea Three offshore cable corridor, as presented in Volume 1, Chapter 3: Project Description of the Environmental Statement (Document A6.1.3). Due to the stage of the project development, the exact routes for electrical cabling have not yet been finalised, hence clearance values are based on a number of precautionary assumptions, associated with the Hornsea Three offshore cable corridor. To inform assessments of individual nature conservation designations, sandwave clearance volumes within designated areas (e.g. Marine Conservation Zones; MCZs and Special Areas of Conservation; SACs) were also reported separately. The location of the Hornsea Three array area and the Hornsea Three offshore cable corridor in relation to designated sites is presented in Figure 3-1.

3.2 The approach utilised to estimate the sandwave clearance volumes for the export cables is outlined in the following sections including all relevant assumptions. The calculation for clearance volumes in the Hornsea Three offshore cable corridor includes the length from landfall to the point at which the Hornsea Three offshore cable corridor meets the Hornsea Three array area (see Figure 3-1).

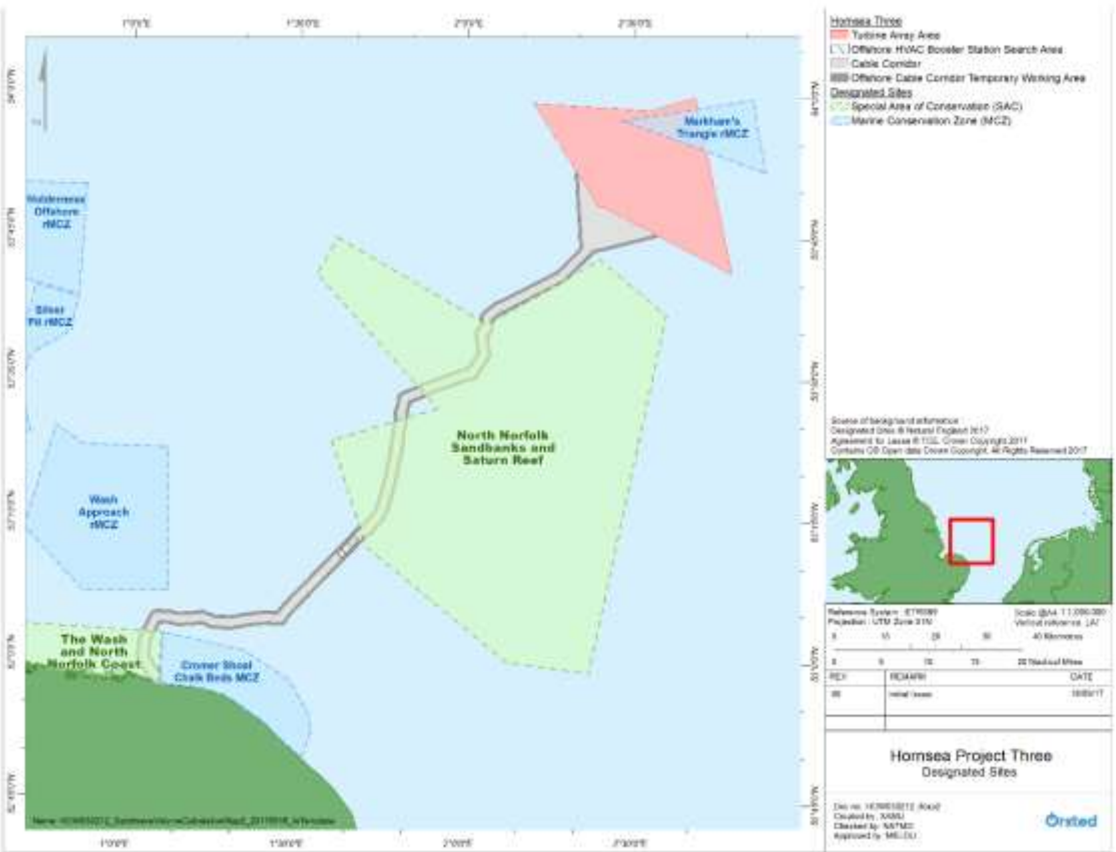

Figure 3-1: Hornsea Three array area and offshore cable corridor

Dataset and Attributes

- Offshore Export Cable Centreline;
- Bathymetry data for the Hornsea Three offshore cable corridor (Bibby Hydromap, 2016); and
- Bathymetry data for North Sea (Seazone).

Primary Assumptions

3.3 The assumptions required to estimate the sandwave clearance volumes along the offshore cable corridor are outlined below.

- The project will require the maximum six export cables (paragraph 3.6.10.1, Volume 1, Chapter 3: Project Description of the Environmental Statement);
- The disturbance corridor associated with each offshore export cable will be 30 m;
- The offshore export cables are to be 100 m apart;
- Any features smaller than 0.7 m in height are not cleared based on recent project experience using typical cable installation tools (e.g. cable ploughs) considered within Volume 1, Chapter 3: Project Description of the Environmental Statement;
- Where there are 3rd party crossings along the cable route; a 100 m buffer either side of the 3rd party asset is taken and it is assumed there is no clearance within this area; and
- Clearance values were estimated on currently available data; it must be assumed that the seabed is static for these clearance values to be relevant, however contingency in the volumes calculated has been included to account for natural variation and data uncertainties (discussed further in paragraph 3.6).

Primary Methodology

3.4 The outlined methodology was utilised to estimate the sandwave clearance volumes along the Hornsea Three offshore cable corridor:

- The centreline of the Hornsea Three offshore cable corridor was plotted with a 15 m buffer (30 m width total) as the first indicative offshore export cable corridor;
- Five additional cable corridors were plotted (six in total) in parallel to the centre line, three south of the centreline and two north of the centreline. Each offshore export cable was offset by 100 m from the last as indicated in Figure 3-2;
- Each offshore export cable route was then buffered by 15 m to create 30 m wide offshore cable corridors (i.e. six cables x 30m): and
- A reference seabed level was generated based on the 2016 Bibby Hydromap bathymetry data, the undertaken process is briefly outlined below and illustrated in Figure 3-5:
    - Analysis was run through the bathymetric data to determine locations where slope angles exceed 2°, to identify sandwaves initially;
    - A second analysis tool was also run to ensure that the full extent of sandwave was identified. The second tool is a hydrology tool which uses modelled flow to delineate surfaces that water cannot come to rest on;
    - Areas identified by the two analysis tools are removed from the bathymetry data set to create a flattened bathymetry profile, which is the new reference seabed level. The natural

neighbouring GIS method was used to assist with the development of the reference seabed level;

- A comparison of the established reference seabed level and the original bathymetry data was completed to establish all locations where sandwaves would have to be cleared. This comparison made use of the GIS cut fill method; further discussed in paragraph 3.8 *et seq*.;
- The six indicative offshore export cable corridors were then run through the data comparison, to establish where the offshore export cable corridors interact with sandwaves indicating where clearance is needed; and
- All sandwaves volumes identified were summed to give the approximate volume of sandwave clearance required for the offshore cable corridor.

3.5 Due to the reroutes along the offshore cable corridor, clearance volumes have been revised. This revision of clearance volumes was completed using desktop data sources, where limited site specific survey data were available; the assumption and methodology for this process are outlined in paragraphs 3.6 to 3.7 below. Final clearance values are provided in paragraph 3.11.

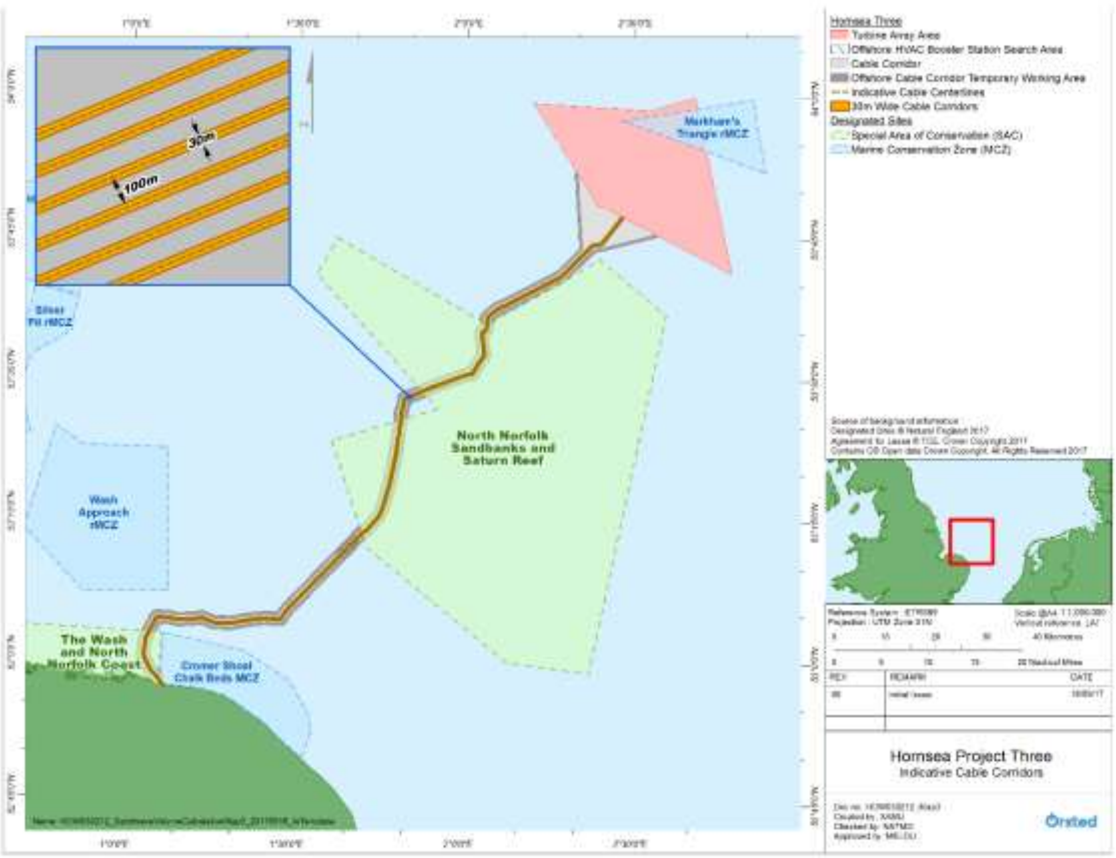

Figure 3-2: Indicative Cable Clearance Corridors (six x 30m wide)

Methodology and Assumptions for Rerouted Sections

3.6 The outlined methodology below was utilised to estimate the sandwave clearance volumes along the lengths of the offshore export cable corridor where rerouting was undertaken during the pre-application phase. This adjusted methodology has been used due to limited site specific bathymetry data along the rerouted lengths; along these lengths more coarse (i.e. less detailed) bathymetry data was available from desktop data sources (including Seazone data).

- The reroute was broken down into a number of sections of approximately 1 km in length;
- The same process as is outlined in paragraph 3.4 was initially undertaken on the coarse bathymetry in each section along the Hornsea Three offshore cable corridor reroute and the rest of the established Hornsea Three offshore cable corridor route for comparison (discussed below);
- The results from this process were then reviewed in conjunction with those established from the detailed bathymetry sections adjacent to the sections of the rerouted offshore cable corridor;
- Similar sections were also selected and compared to more accurately calculate the required sandwave clearance volumes; and
- Based on this comparison of similar route sections of coarse bathymetry (desktop data) and detailed (site specific) bathymetry; approximate correction factors were established for clearance volumes in the coarse data. This process was utilised to ensure that the coarse bathymetry did not underestimate the amount of sandwave clearance.

3.7 Where the coarse bathymetry was considered particularly limited (i.e. a large discrepancy with the site specific dataset), higher correction factors were utilised to account for the potential for underestimating sandwave clearance volumes.

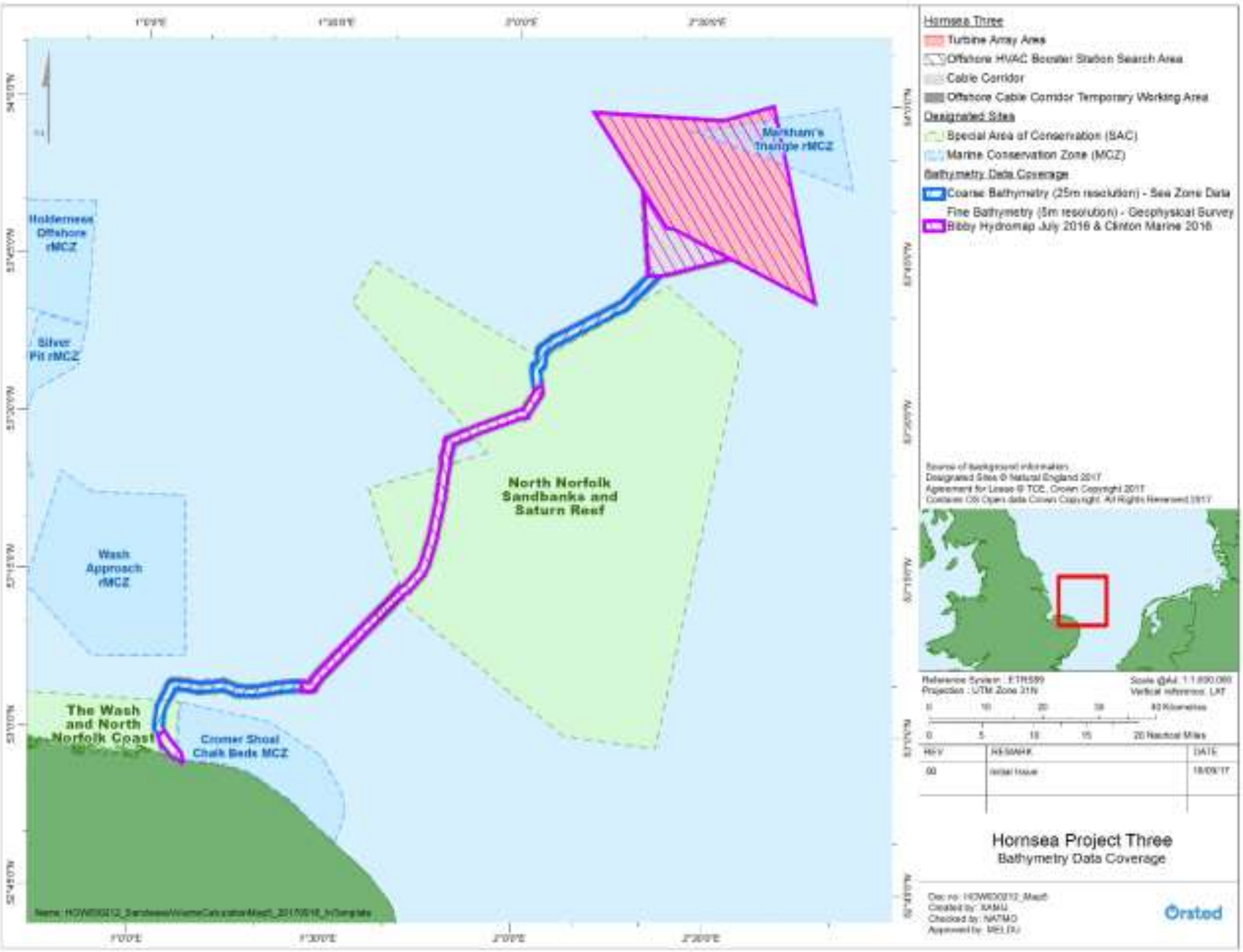

Figure 3-3: Site specific (fine) and desktop (coarse) bathymetric data coverage for Hornsea Three offshore cable corridor

Sandwave identification using GIS:

3.8 This section details the procedure used to identify sandwaves in order to measure sandwave clearance volume. Sandwaves are identified using cut and fill operation within GIS (Geographical Information Science).

3.9 A cut-and-fill operation is a procedure in which the elevation of a landform surface is modified by the removal or addition of surface material. The cut-and-fill tool summarises the areas and volumes of change from a cut-and-fill operation by taking after and before surfaces of a given location, it identifies regions of surface material removal, surface material addition, and areas where the surface has not changed.

3.10 For sandwave clearance volumes, a cut-and-fill method was used within ESRI's ArcGIS software. In this case two input surfaces were used to calculate clearance volume; these are explained below:

- Bathymetry surface: Bathymetry data from the Hornsea Three offshore cable corridor (Bibby Hydromap, 2016) is used. Original surveyed bathymetry data was 1 m resolution this was resampled to 5 m resolution, which is considered more appropriate for the accuracy of this assessment.
- Reference Surface: Reference surface is generated within GIS from surveyed Bathymetry Data, by removing slope areas greater than two degrees as well as removing areas where sandwaves and megaripples occurs. Resulting reference surface is then raised to 0.7 m to remove small bedforms which do not require clearance for cable installation activity within the Hornsea Three offshore cable corridor.

Results

3.11 The final clearance volumes related to the Hornsea Three offshore cable corridor, as presented in Volume 1, Chapter 3: Project Description of the Environmental Statement, are outlined in

3.12 Table 3.1.

Table 3.1: Sandwave clearance volumes for the Hornsea Three offshore cable corridor

Designated Sites	Volume (m3)
The Wash and North Norfolk Coast SAC	132,737
North Norfolk Sandbanks and Saturn Reef SAC	619,689
Cromer Shoal Chalk Beds MCZ	1,329
Outside designated sites	449,202
Total	***1,202,956***

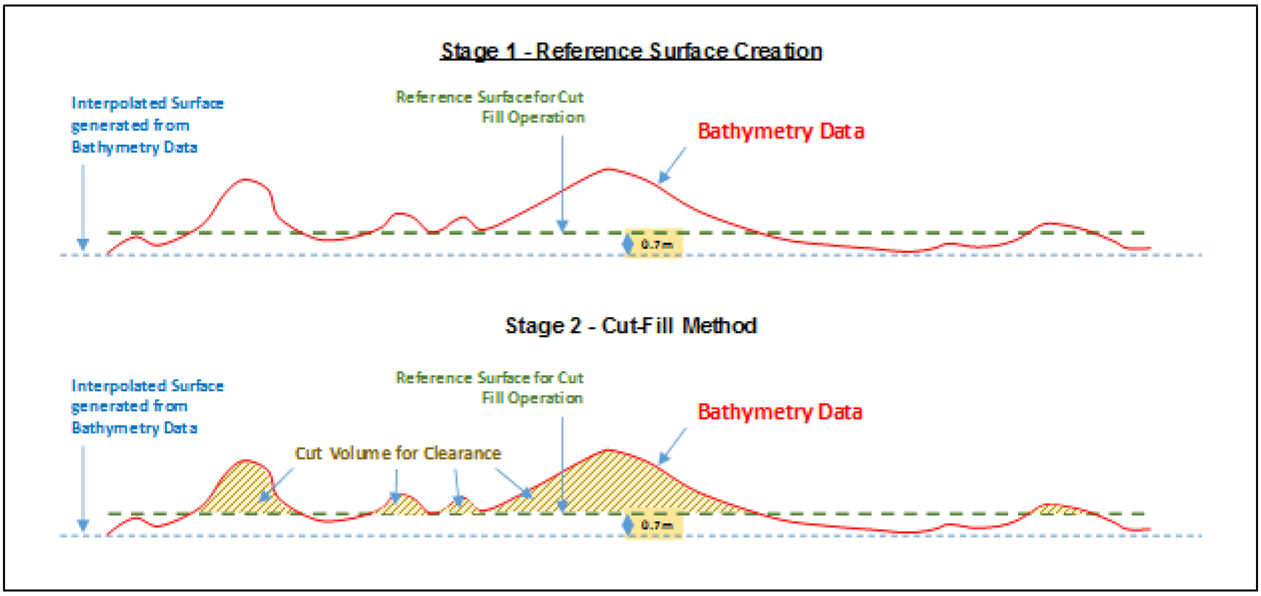

Figure 3-4: Cut-Fill Method Illustration (Hornsea Three offshore cable corridor)

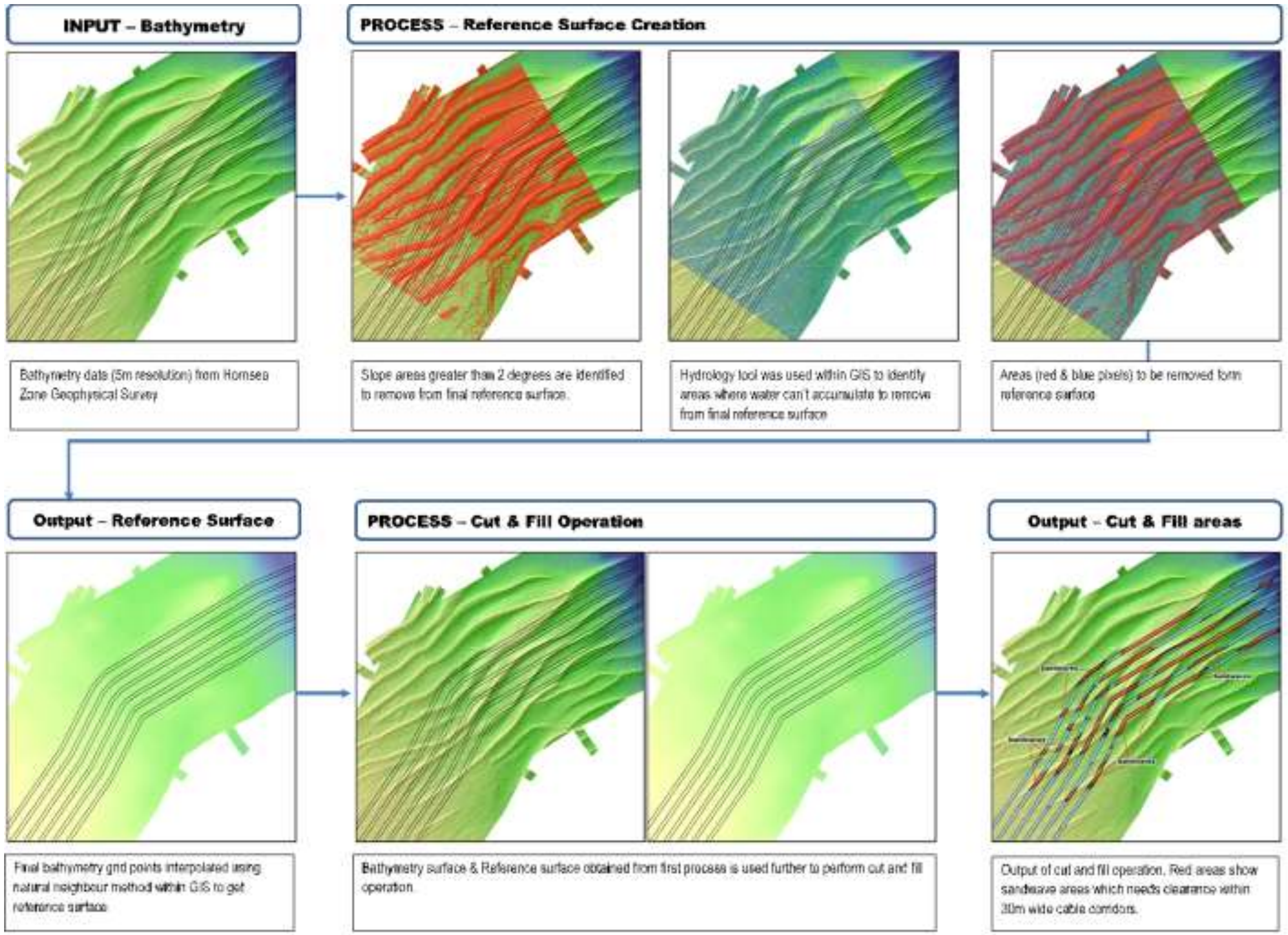

Figure 3-5: Sandwave Identification Process within GIS

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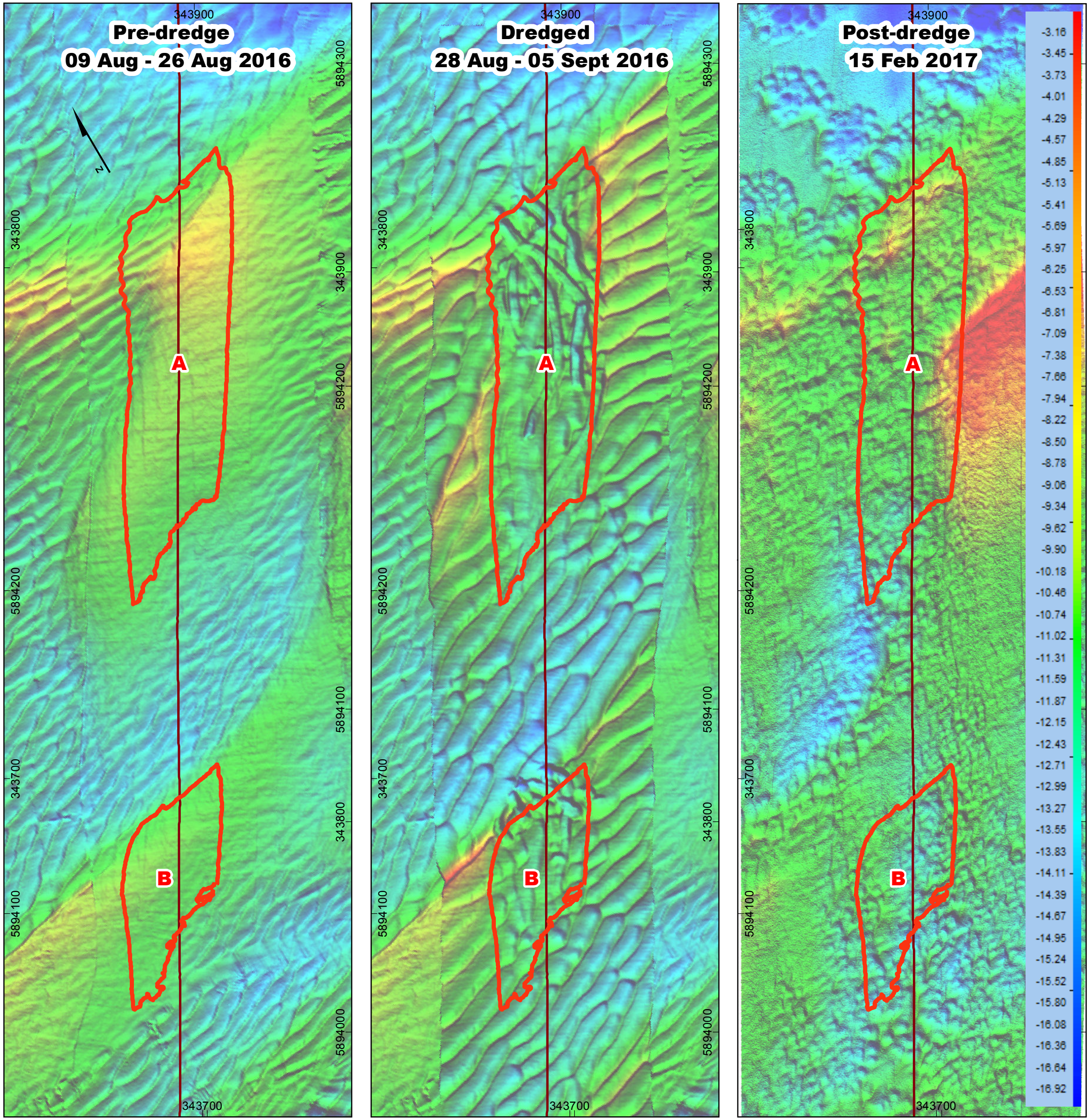
Appendix A Race Bank Sandwave Levelling Monitoring Data

Appendix A1 Race Bank Export Cable Dredge Area (Sites 1-10; see Appendix B)



Race Bank

Dredge Boundary

As Laid Export Cable (Race Bank Offshore Wind Farm)

Legend - Inset Map

Race Bank

Race Bank Offshore Wind Farm

Hornsea Three

Turbine Array Area

Cable Corridor

Source of background information :
Bathymetry: JDN 2016; Spectrum 2017
Nature Conservation Sites © JNCC, Natural England
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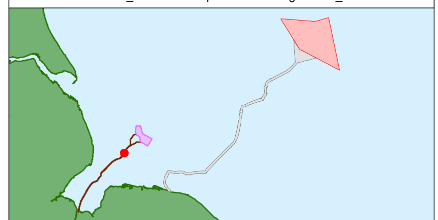

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Hornsea Project Three

Race Bank Export Cable Dredge Area

KP: 51.5

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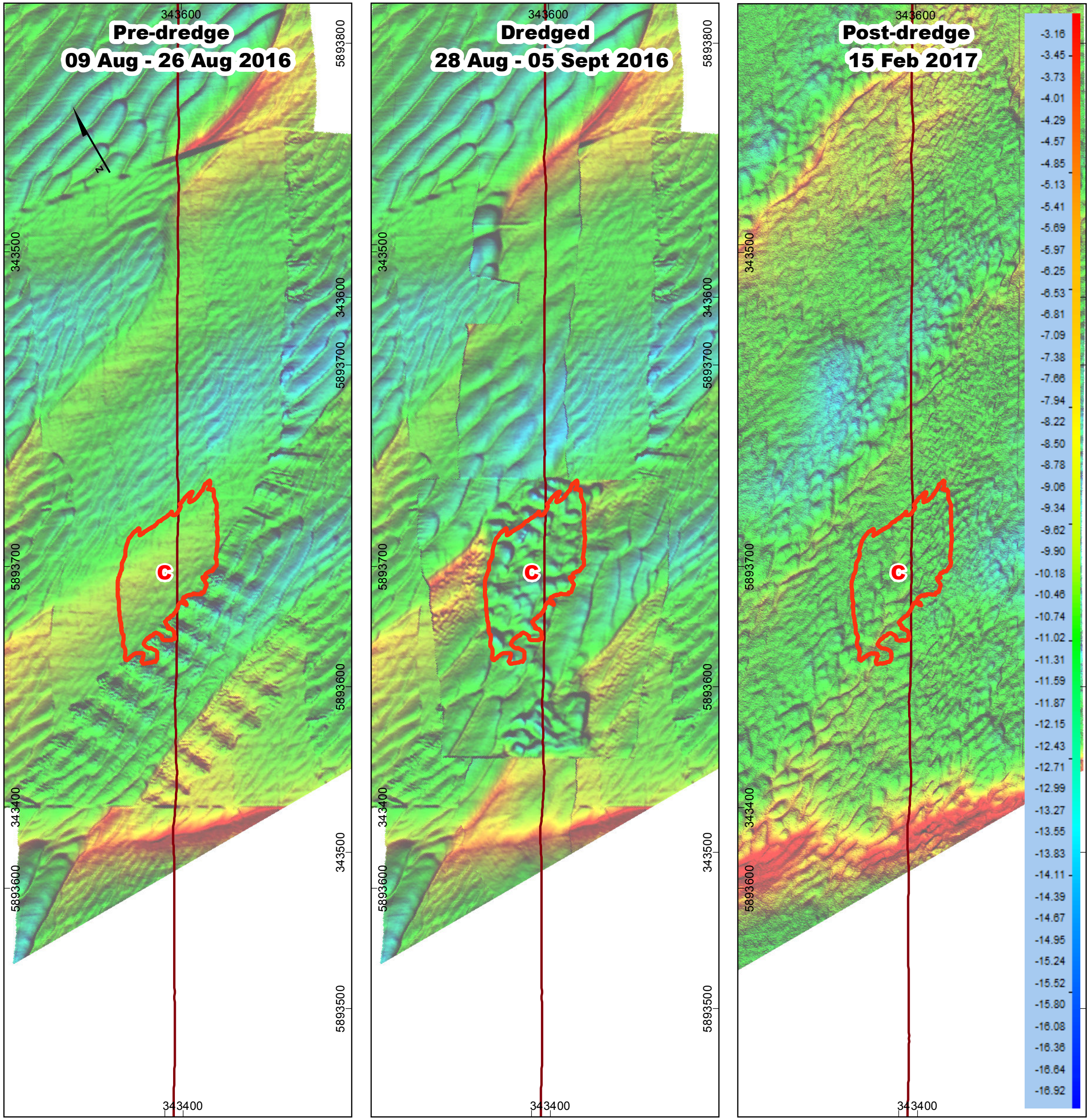

Race Bank

- Dredge Boundary
- As Laid Export Cable (Race Bank Offshore Wind Farm)

Legend - Inset Map

Race Bank

- Race Bank Offshore Wind Farm

Hornsea Three

- Turbine Array Area
- Cable Corridor

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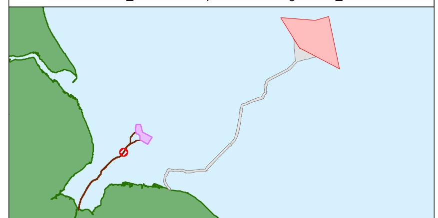

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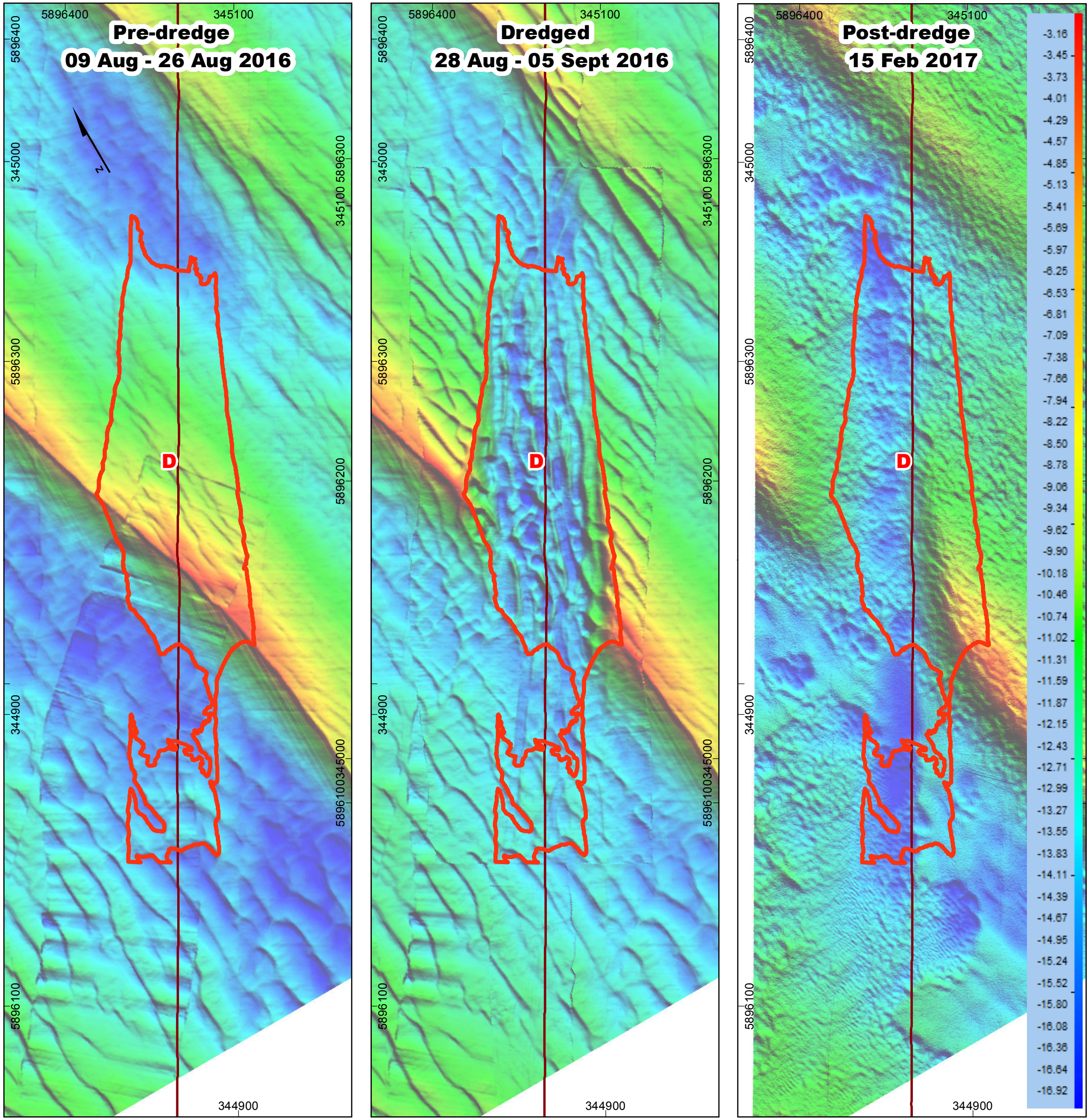

Race Bank

Dredge Boundary

As Laid Export Cable (Race Bank Offshore Wind Farm)

Legend - Inset Map

Race Bank

Race Bank Offshore Wind Farm

Hornsea Three

Turbine Array Area

Cable Corridor

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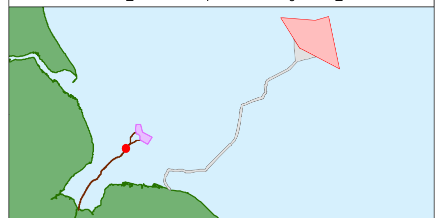

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Race Bank Export Cable Dredge Area

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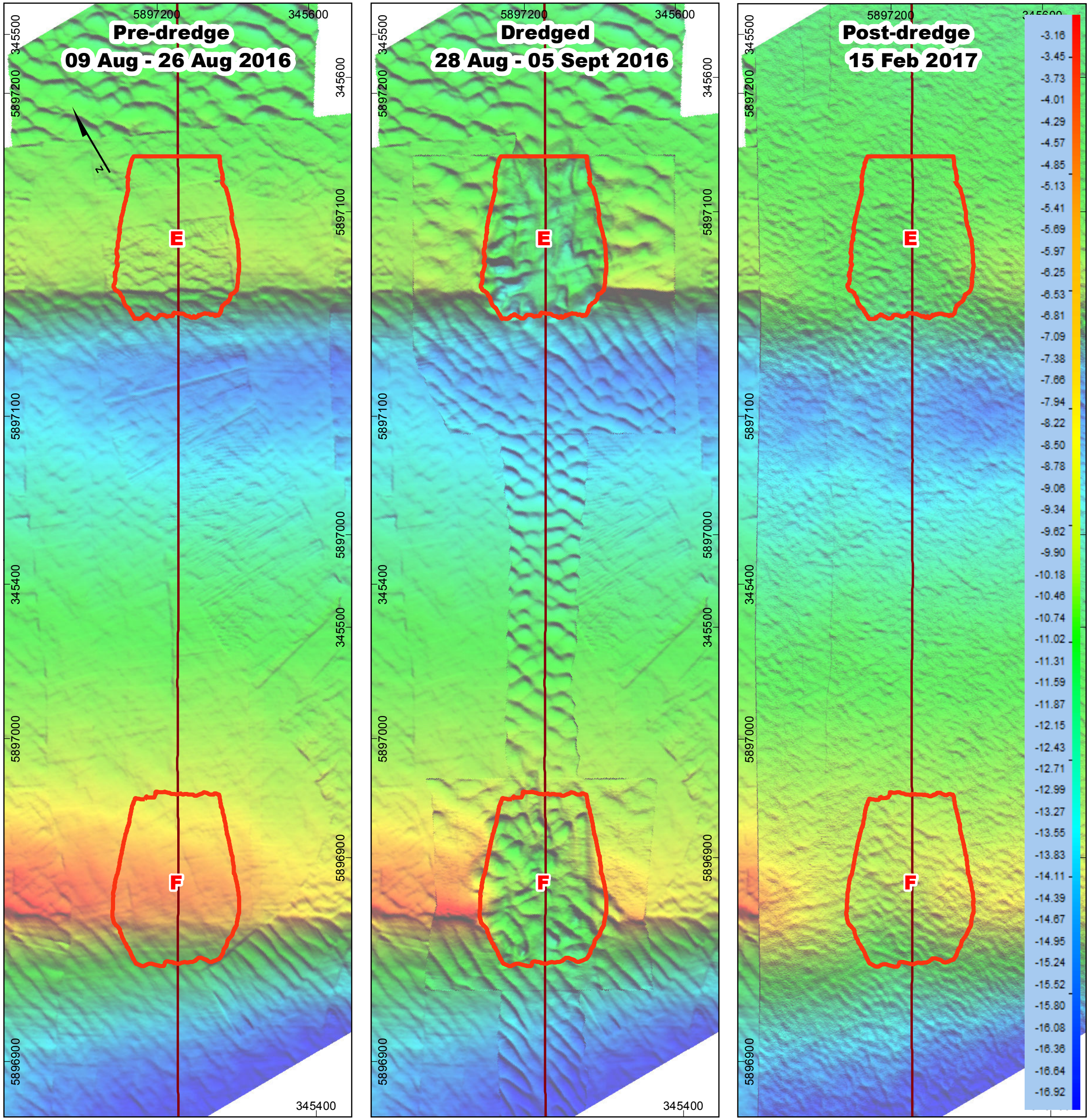

Race Bank

- Dredge Boundary
- As Laid Export Cable (Race Bank Offshore Wind Farm)

Legend - Inset Map

Race Bank

- Race Bank Offshore Wind Farm

Hornsea Three

- Turbine Array Area
- Cable Corridor

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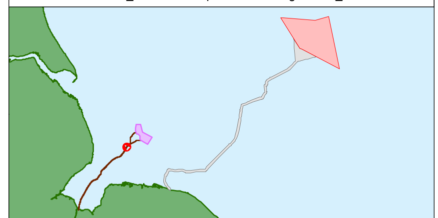

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Race Bank Export Cable Dredge Area

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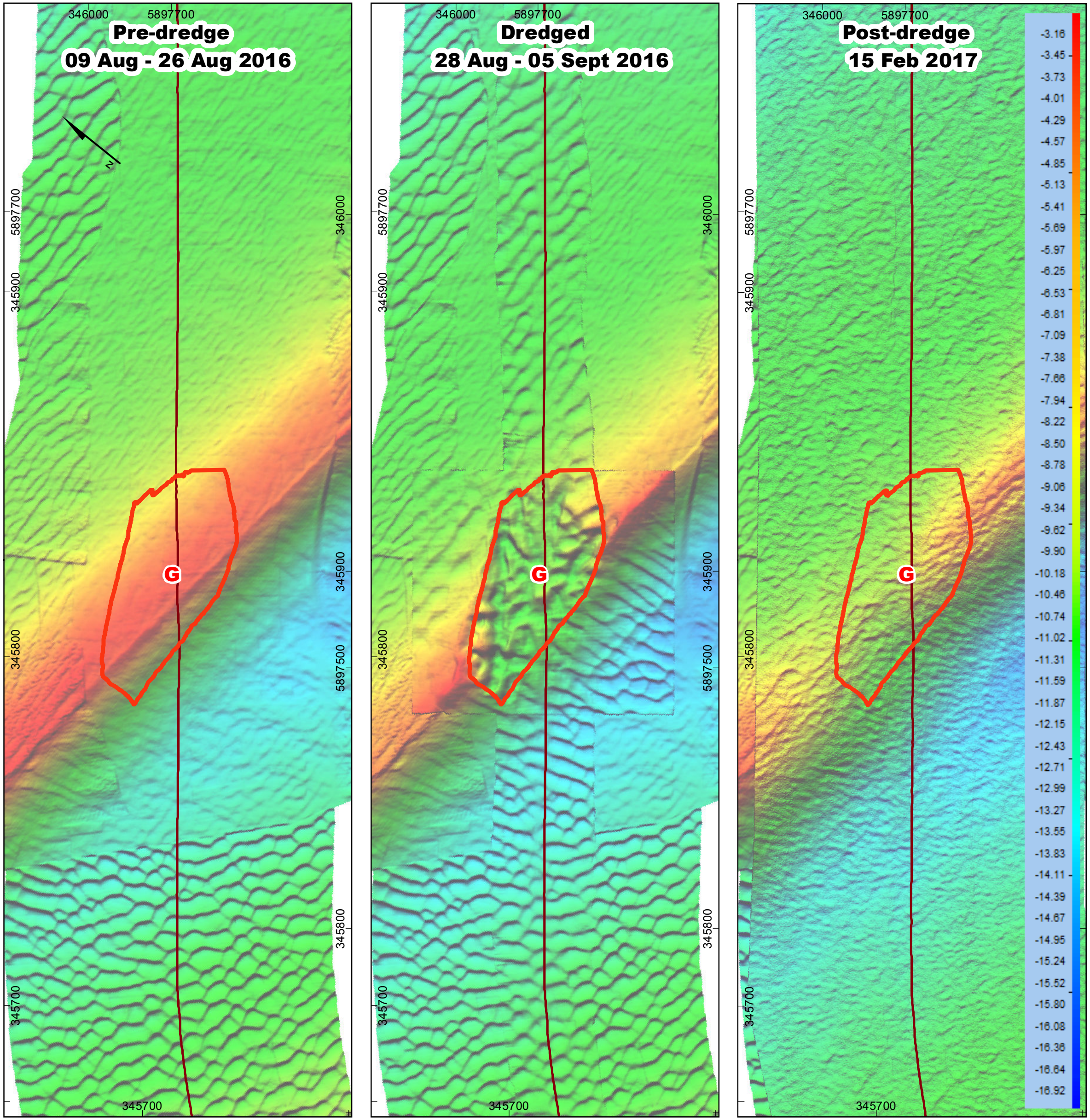

Race Bank

Dredge Boundary

As Laid Export Cable (Race Bank Offshore Wind Farm)

Legend - Inset Map

Race Bank

Race Bank Offshore Wind Farm

Hornsea Three

Turbine Array Area

Cable Corridor

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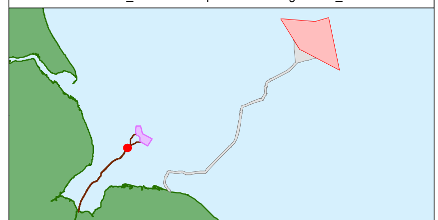

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Race Bank Export Cable Dredge Area

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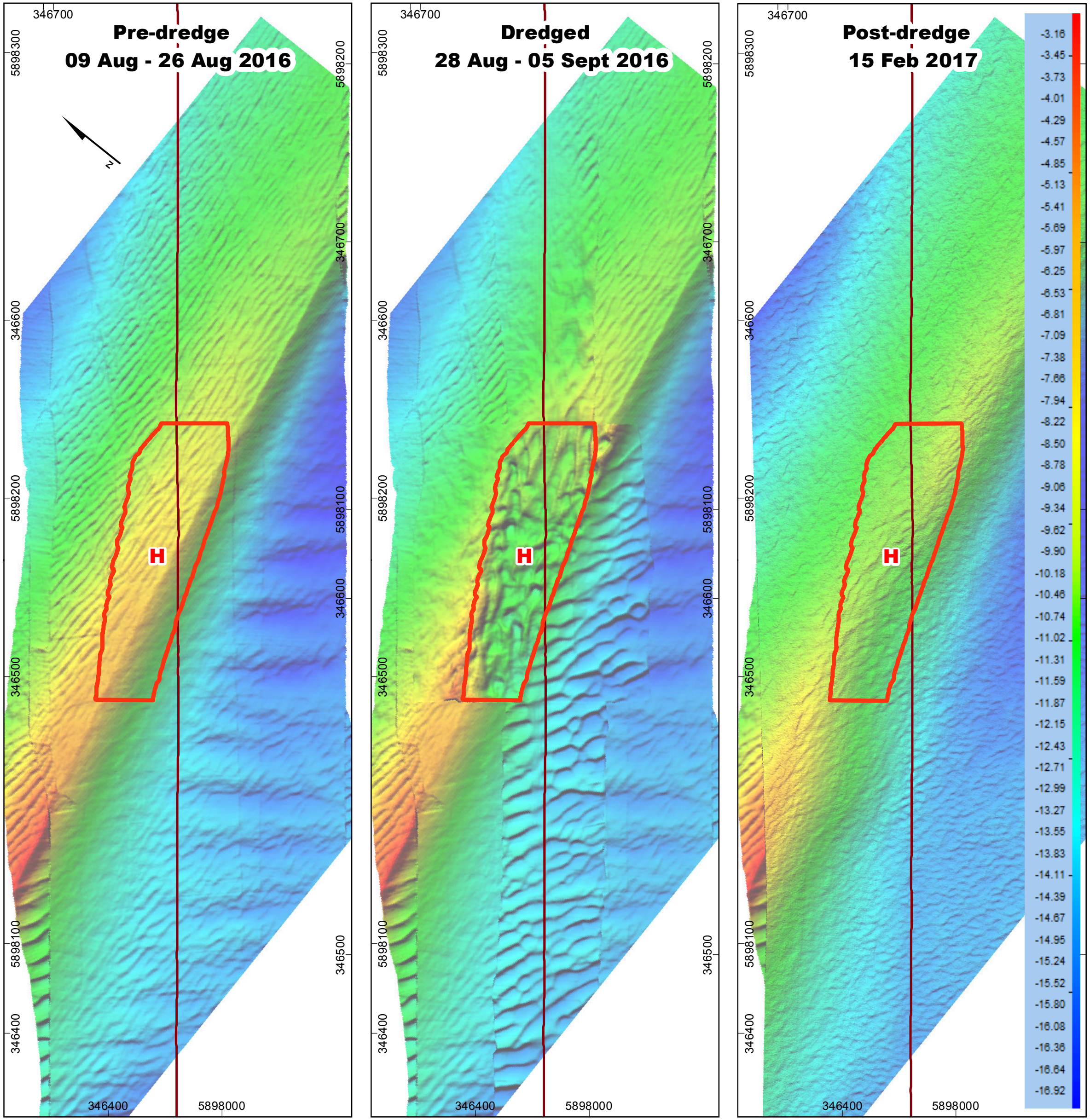

Race Bank

Dredge Boundary

As Laid Export Cable (Race Bank Offshore Wind Farm)

Legend - Inset Map

Race Bank

Race Bank Offshore Wind Farm

Hornsea Three

Turbine Array Area

Cable Corridor

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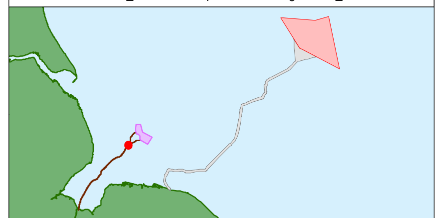

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Hornsea Project Three

Race Bank Export Cable Dredge Area

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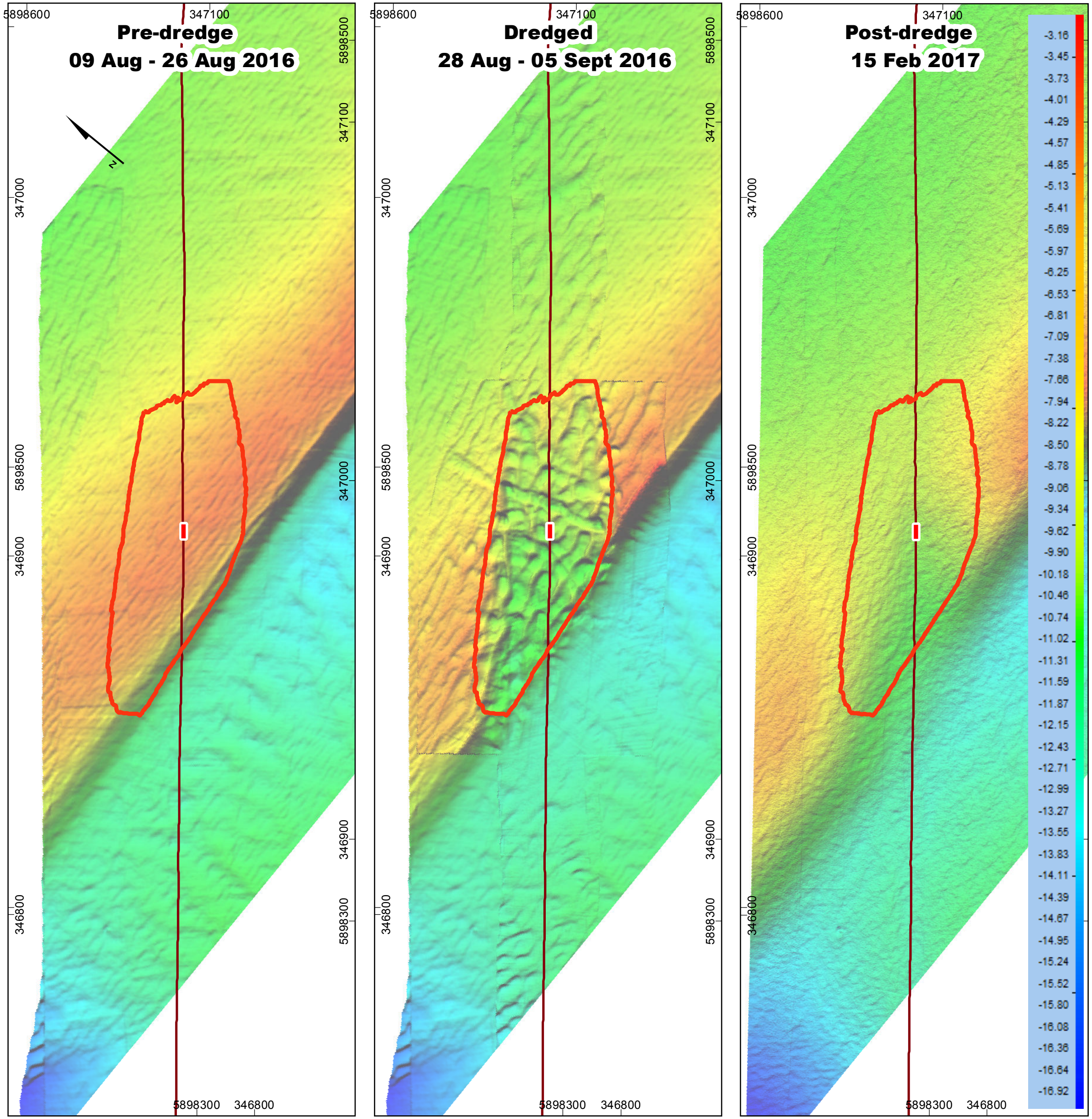

Race Bank

- Dredge Boundary
- As Laid Export Cable (Race Bank Offshore Wind Farm)

Legend - Inset Map

Race Bank

- Race Bank Offshore Wind Farm

Hornsea Three

- Turbine Array Area
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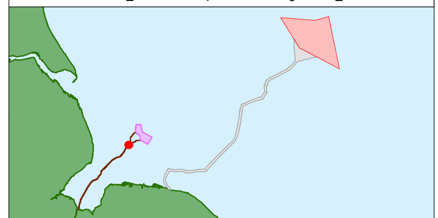

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Hornsea Project Three

Race Bank Export Cable Dredge Area

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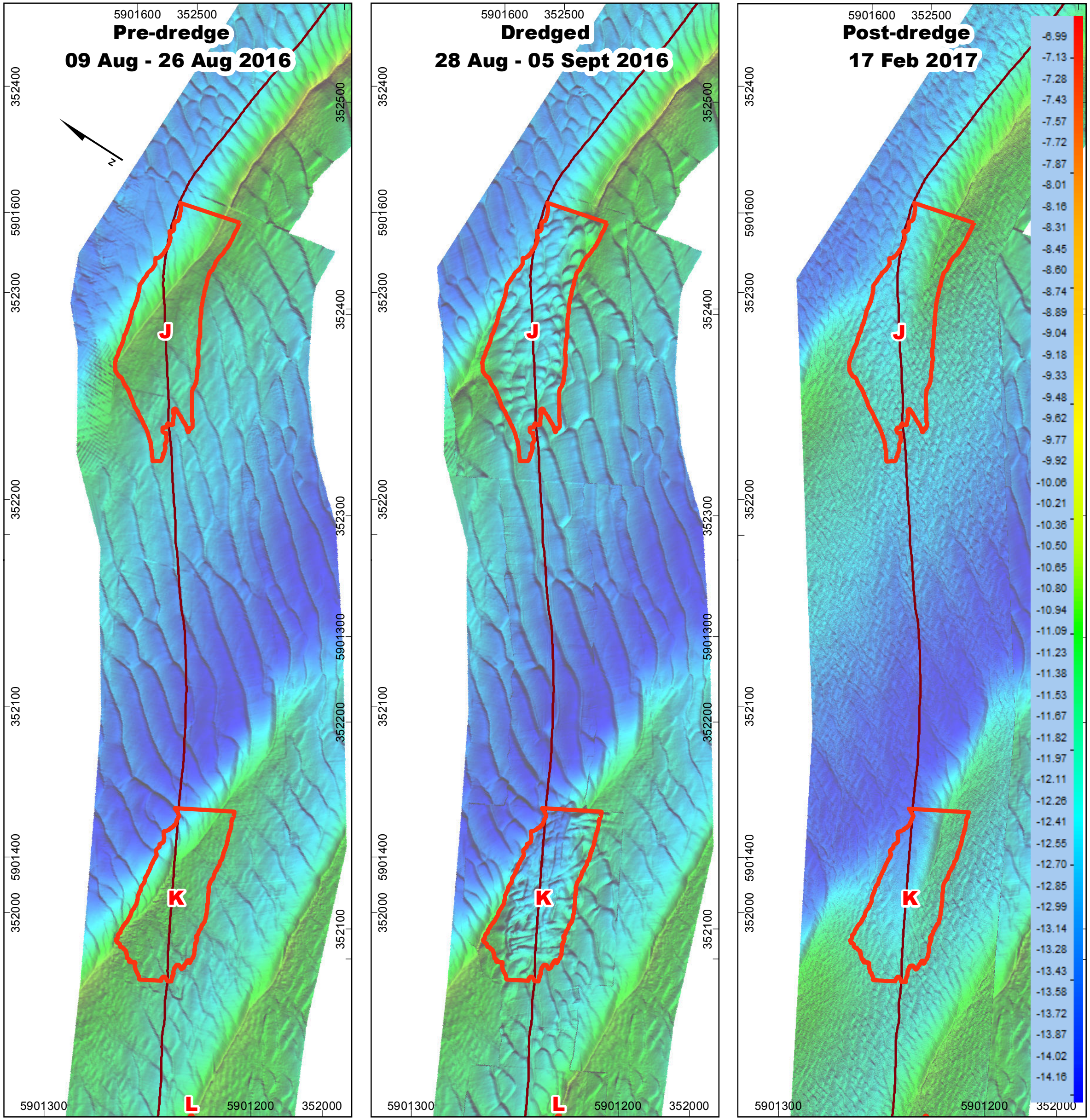


Race Bank

Dredge Boundary

As Laid Export Cable (Race Bank Offshore Wind Farm)

Legend - Inset Map

Race Bank

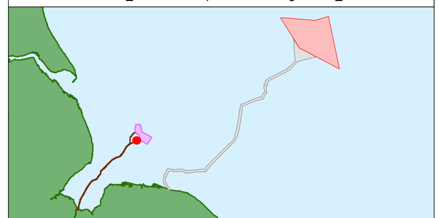
Race Bank Offshore Wind Farm

Hornsea Three

Turbine Array Area

Cable Corridor

Source of background information :
Bathymetry: JDN 2016; Spectrum 2017
Nature Conservation Sites © JNCC, Natural England
Crown Copyright & database rights 2018
Wind Farm Boundaries © TCE, Crown Copyright 2018
Name: HOW030292_RaceBankExportCableDredgeAreas_20180817



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Projection : UTM Zone 31N

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00	Initial Issue	17/08/18

Hornsea Project Three

Race Bank Export Cable Dredge Area

KP: 62.8

(Page 8 of 10)

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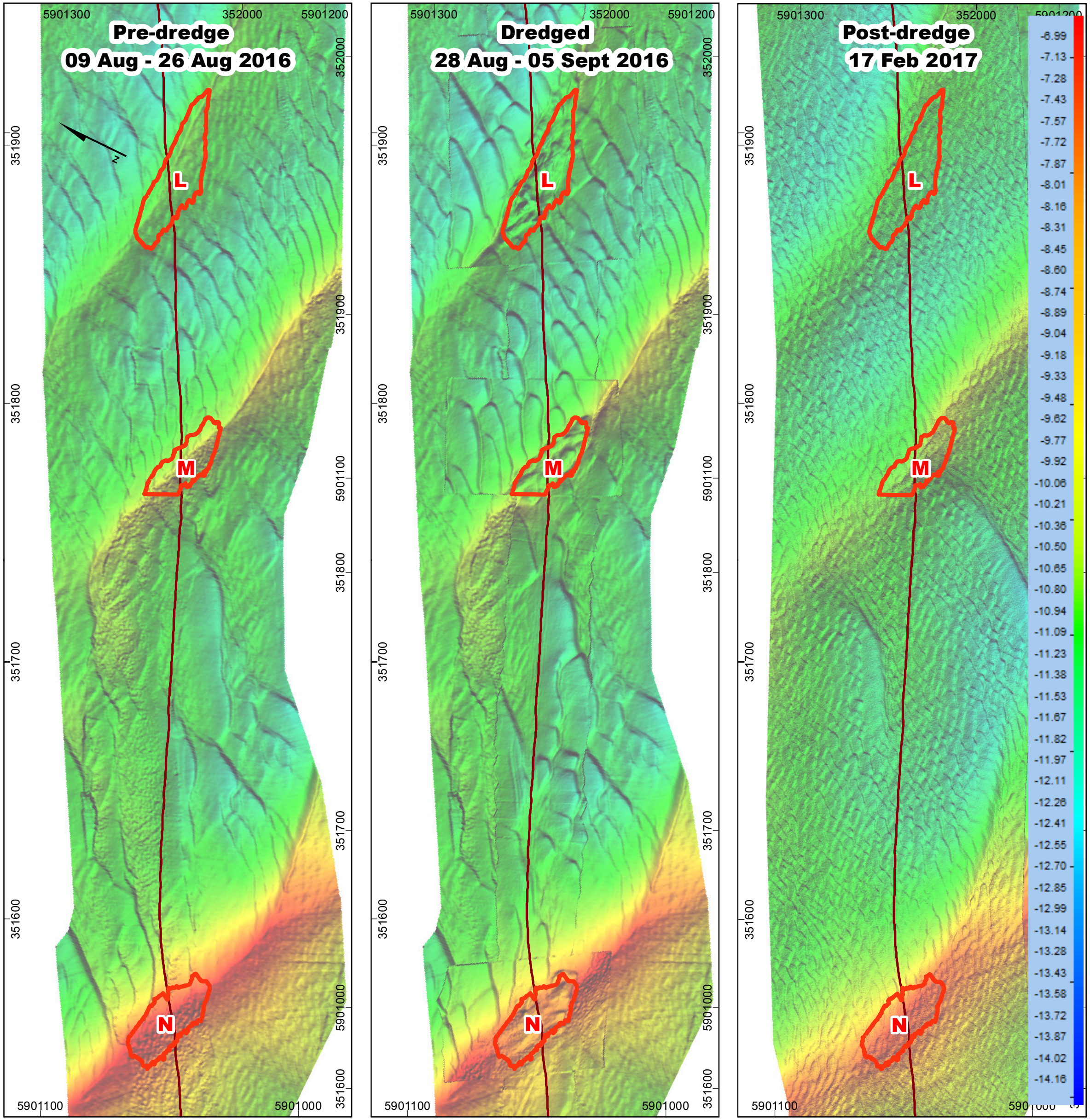

Race Bank

- Dredge Boundary
- As Laid Export Cable (Race Bank Offshore Wind Farm)

Legend - Inset Map

Race Bank

- Race Bank Offshore Wind Farm

Hornsea Three

- Turbine Array Area
- Cable Corridor

Source of background information :
Bathymetry: JDN 2016; Spectrum 2017
Nature Conservation Sites © JNCC, Natural England
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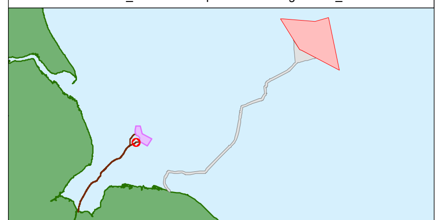
Name: HOW030292_RaceBankExportCableDredgeAreas_20180817



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REV	REMARK	DATE
00	Initial Issue	17/08/18

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Race Bank Export Cable Dredge Area

KP: 62.8

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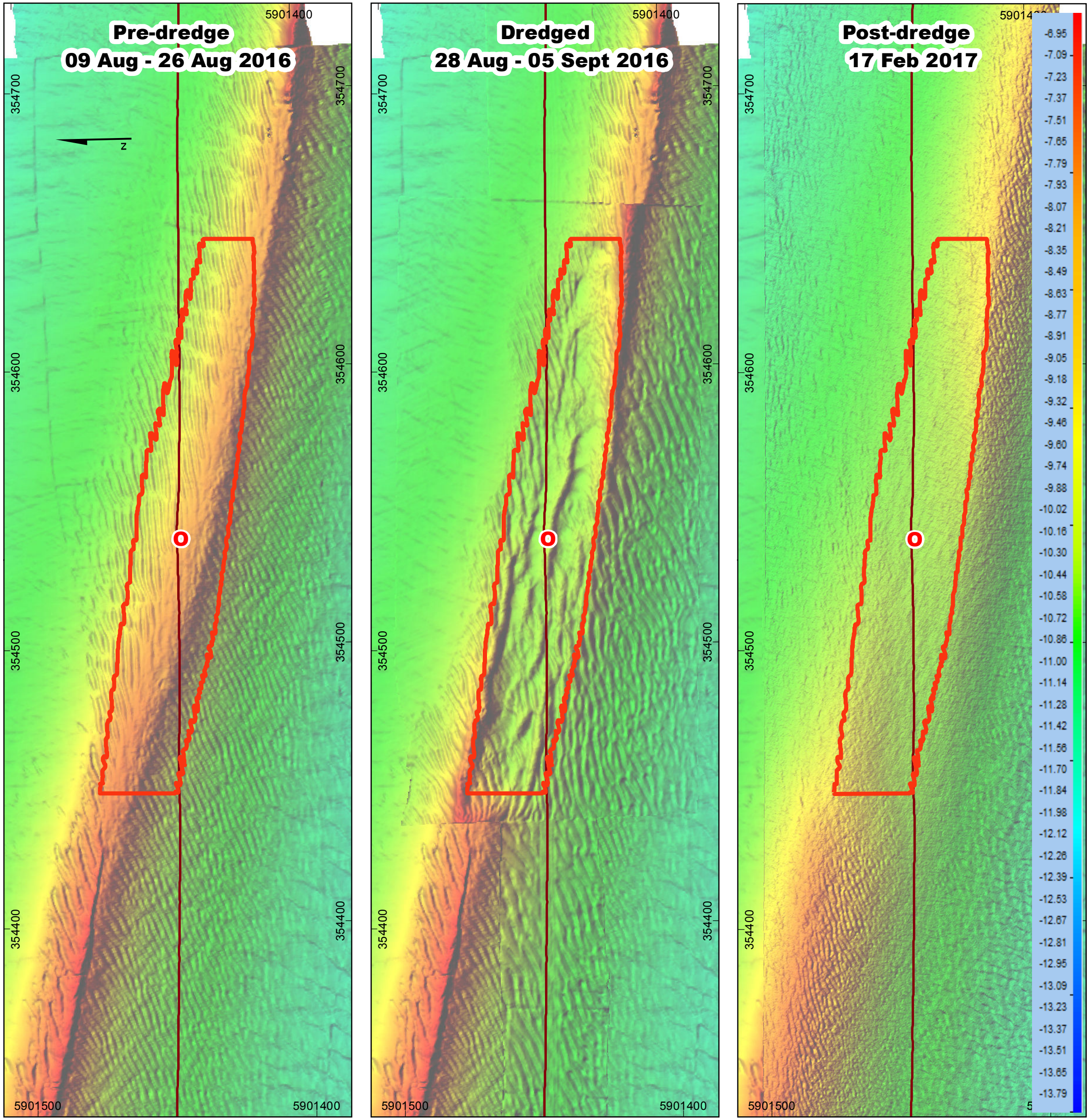

Race Bank

Dredge Boundary

As Laid Export Cable (Race Bank Offshore Wind Farm)

Legend - Inset Map

Race Bank

Race Bank Offshore Wind Farm

Hornsea Three

Turbine Array Area

Cable Corridor

Source of background information :
Bathymetry: JDN 2016; Spectrum 2017
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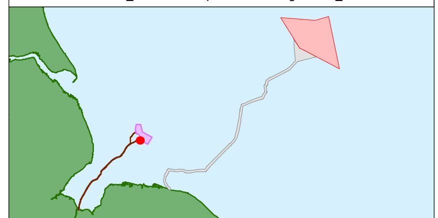
Name: HOW030292_RaceBankExportCableDredgeAreas_20180817



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00	Initial Issue	17/08/18

Hornsea Project Three

Race Bank Export Cable Dredge Area

KP: 65.6

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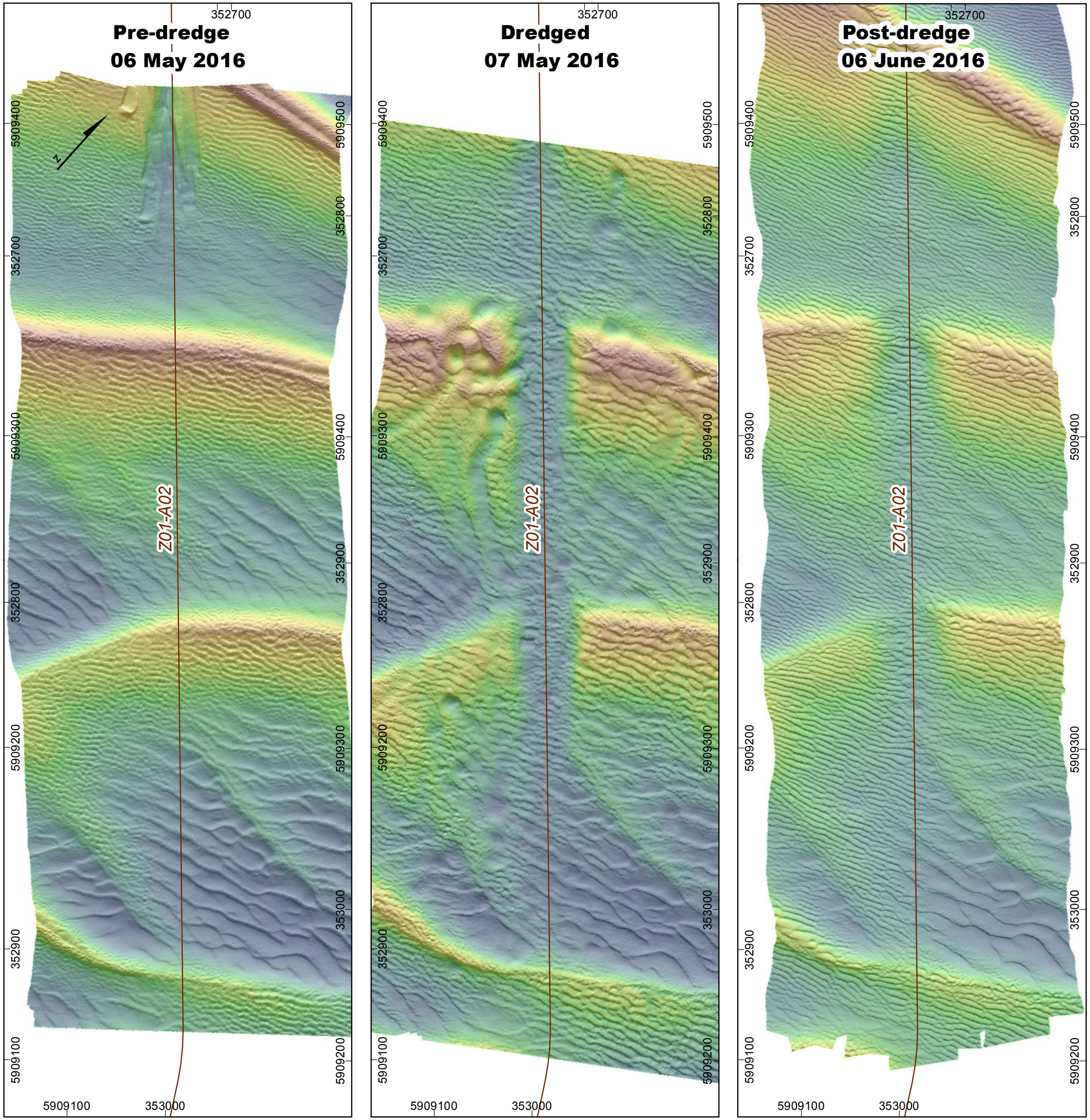
Appendix A2 Race Bank Array Cable Dredge Area (Sites 11 and 12; see Appendix B)



Race Bank

Array Cable Route (Race Bank Offshore Wind Farm)

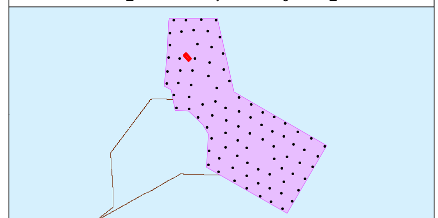
Legend - Inset Map

Race Bank

Race Bank Offshore Wind Farm

Bathymetry (mLAT) Pre-dredge	Bathymetry (mLAT) Dredged	Bathymetry (mLAT) Post-dredge
-10m	-10m	-9m
-15m	-15m	-16m

Source of background information :
Bathymetry: Spectrum 2016
Wind Farm Boundaries © TCE, Crown Copyright 2018
Name: HOW030293_RaceBankArrayCableDredgeAreas_20180817



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0 0.01 0.02 0.03 0.04 Nautical Miles

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Hornsea Project Three

Race Bank Array Cable Dredge Area

(Page 1 of 2)

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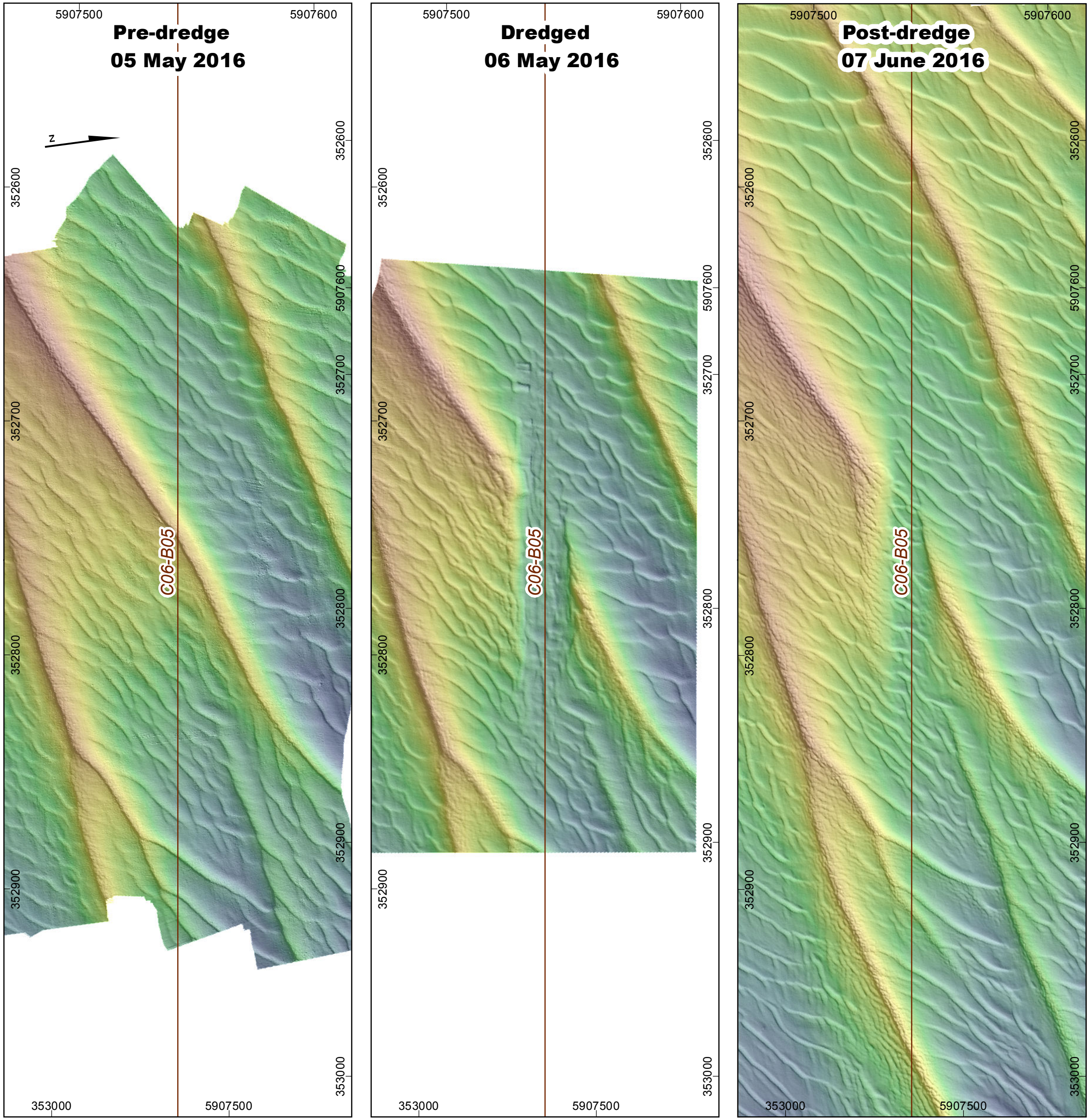


Race Bank

Array Cable Route (Race Bank Offshore Wind Farm)

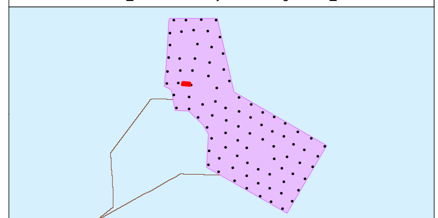
Legend - Inset Map

Race Bank

Race Bank Offshore Wind Farm

Bathymetry (mLAT) Pre-dredge	Bathymetry (mLAT) Dredged	Bathymetry (mLAT) Post-dredge
-11m	-12m	-12m
-17m	-17m	-18m

Source of background information :
Bathymetry: Spectrum 2016
Wind Farm Boundaries © TCE, Crown Copyright 2018
Name: HOW030293_RaceBankArrayCableDredgeAreas_20180817



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Projection : UTM Zone 31N

Scale @A4: 1:3,000
Vertical reference: LAT

0 30 60 90 120 Metres
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REV	REMARK	DATE
00	Initial Issue	17/08/18

Hornsea Project Three

Race Bank Array Cable Dredge Area

Doc no: HOW030293
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Checked by: NATMO
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Appendix B Detailed Interpretation of the Race Bank Sandwave Levelling Monitoring Data

Table B.1 presents a summary description of each the Race Bank monitoring images provided in Appendix A. Site 1 to Site 10 correspond to locations within the Race Bank offshore cable corridor. Site 11 and Site 12 correspond to locations within the Race Bank array area.

A summary of the corresponding but separately determined sediment mobility characteristics, and an overall interpretation of the empirical evidence for each site in terms of sandwave recovery is provided in Table 2.1 of the main report.

Table B.1: Full details of the characterisation of Race Bank bedforms

Location	Data description: Pre-levelling period	Data description: Levelling period	Data description: Post-levelling period
Site 1 -4.77 mLAT Levelling Areas A, B	Sandwave characteristics at this site are complex, with varying wavelengths between approximately 67 m and 133 m. The sandwave crest orientation is approximately east to west, with steeper lee slope to the north and gentler stoss slope to the south. The cable is orientated transverse to the crest. Smaller bedforms are apparent between sandwaves and broadly have the same orientation as the sandwaves.	Sandwave levelled to approximately the same depth as the flanks, but not to the sandwave base.	Migration present as an unaffected sandwave migrates into the image area from the southeast. However in terms of the dredged sandwaves, there is no evidence of these in the post-levelling image. Although infill seems to have occurred within dredge areas, the bathymetry does not clearly represent the sandwaves.
Site 2 -4.29 mLAT Levelling Area C	The sandwave crest orientation is approximately east to west. Unable to ascertain the full extent of the sandwave. Sandwave is symmetrical and the cable is orientated transverse to the perceived crest. The dredge area may be positioned over the tail of the sandwave due to images from the proceeding dredge and post-dredge.	Assumed that the sandwave is levelled to the same depth as the surrounding seabed, which is taken to be the base of the sandwave.	No evidence of the affected sandwave within the post-levelling image. No evidence of migration as an unaffected sandwave south of the dredge area seems to remain in position.
Site 3 -7.03 mLAT Levelling Area D	Steep and clearly defined asymmetric sandwave with the crest orientated approximately north-northwest to south-southeast. The steeper lee slope facing west and gentler stoss slope to	Sandwave levelled approximately to its base, i.e. to the same depth as the surrounding seabed. The levelled section is approximately 73 m wide along the crest and is across the full	Each part of the sandwave seems to have migrated to the north-northwest by about 18 m within the post-levelling monitoring period. The southern part of the original sandwave is moving into

Location	Data description: Pre-levelling period	Data description: Levelling period	Data description: Post-levelling period
	the east. The cable is orientated transverse to the crest and the sandwave wavelength is approximately 64 m.	wavelength of the sandwave. The dredge results in two separate features, north and south of the dredged area. Mega-ripple features are suggested on the stoss slope and seabed between sandwaves.	the dredged are and the northern part is moving further away in the same direction. The wavelength of each part stays approximately the same as the pre-levelling wavelength and also with very similar sandwave crest height. There is less evidence of smaller bedforms on the sandwave slope and between sandwaves and it is not clear if this is due to the bathymetry data.
Site 4 -5.32 mLAT Levelling Areas E, F	Asymmetric sandwave with the crest orientated approximately west-northwest to east-southeast. The steeper lee slope faces southwest, while the gentler stoss slope is to the northeast. The cable is orientated perpendicular to the crest and the sandwave has a wavelength approximately 164 m. Smaller bedforms are more apparent on the lee slope and orientated transverse to the sandwave crest.	Only the crests of the sandwaves are taken off, approximately to the same depth as the flanks. The dredged section is about 44 m wide along the crest and is only across part of the sandwave wavelength. The composite bathymetry would suggest there are mega-ripples between the sandwaves too.	The effect of the levelling is not apparent on levelled sandwave E and it would seem this area has filled in, with the crest partially reforming. The effect of the levelling is more apparent on sandwave F, but the levelled area is again infilling with the crest reforming and remerging across the levelled area. No migration is evident for the two affected sandwaves at this site, while the wavelength seems to remain the same.
Site 5 -4.69 mLAT Levelling Area G	Asymmetric sandwave with crest orientated approximately east to west. The steeper lee slope faces south and the gentler stoss slope is to the north. Unable to determine the full wavelength but it is greater than 11 m	Only the crests of the sandwaves are taken off, approximately to the same depth as the flanks. The dredged section is about 70 m wide along the crest, but is only across the crest area of the sandwave.	The levelled area is infilling with the crest reforming and remerging across the levelled area. No migration is evident and the wavelength stays the same. There is however a small

Location	Data description: Pre-levelling period	Data description: Levelling period	Data description: Post-levelling period
	and the cable is orientated transverse to the crest.		reduction in the crest height either side of the levelled area.
Site 6 -7.12 mLAT Levelling Area H	Asymmetric sandwave with the crest orientated approximately east to west. Steeper lee slope facing south and the gentler stoss slope to the north. The bedform wavelength is approximately 75 m and the cable is orientated transverse to the crest.	Only the sandwave crests are taken off, approximately to the same depth as the flanks. The dredged section is about 100 m wide along the crest, and mainly over the crest area.	The levelled area is infilling with the crest reforming. No migration is evident and the wavelength stays the same. The imagery suggests there is a reduction in the crest height either side of the levelled area.
Site 7 -8.39 mLAT Levelling Area I	Steep and clearly defined asymmetric sandwave with the crest orientated approximately east to west. The steeper lee slope faces south and gentler stoss slope is to the north. The sandwave wavelength is about 94 m and the cable is orientated transverse to the crest.	The sandwave is levelled approximately to its base, i.e. to the same depth as the surrounding seabed. The levelled section is about 77 m wide along crest across most of the wavelength. The dredge results in two separate features, east and west of the levelled area.	The levelled area is infilling, from the margins of the unaffected part of the sandwave. No migration is apparent and the wavelength stays the same. The imagery suggests there is a reduction in the crest height either side of the levelled area.
Site 8 -13.34 mLAT Levelling Areas J, K	Asymmetric sandwaves with their crests orientated approximately east to west. The steeper lee slope faces south and gentler stoss slope is to the north. The sandwave wavelength is about 59 m and the cable is orientated transverse to the crest. Megaripple bedforms are evident between the sandwaves and these are orientated northeast to southwest.	Sandwaves are levelled approximately to their base. A large part of the sandwave is levelled at around a 115 m wide section along the crest. This results in two separate features, east and west of the levelled area.	Migration in evident in the levelled sandwaves here. At the same time, new sandwave crests are also evident within the levelled area. The western part of the original sandwave is moving north by about 15 m, away from the levelled area. The eastern part of the original sandwave has moved west into the levelled area by about 53 m. The levelled section is therefore

Location	Data description: Pre-levelling period	Data description: Levelling period	Data description: Post-levelling period
			narrowing. Away from the levelled sandwaves, other unaffected sandwaves migrate north by about 15 m. The post-levelling imagery indicates that each part of the dredged feature is behaving differently. The wavelength of each sandwave part stays approximately the same as the pre-levelling wavelength with very similar sandwave crest height. There is less evidence of smaller megaripple bedforms between the sandwaves and it is not clear if this is due to the bathymetry data.
Site 9 -9.53 mLAT Levelling Areas L, M, N	Fairly symmetrical sandwaves orientated approximately east to west. The sandwave wavelengths are between 25 m and 63 m for the affected sandwaves. Megaripple bedforms are also evident between the sandwaves and are orientated northeast to southwest.	Only the sandwave crests seem to be levelled, approximately to the same depth as the flanks. The levelled section is about 145 m wide along the crests of each sandwave.	The levelled area is infilled and the crests have reformed to the same height for all three sandwaves. Also there is evidence of very slight migration towards the north, by a few metres.
Site 10 -8.15 mLAT Levelling Area O	Asymmetric sandwave with the crest orientated approximately east-southeast to west-northwest. The steeper lee slope facing south and gentler stoss slope is to the north. The bedform wavelength is approximately	Sandwave is levelled approximately to its base. A large part of the sandwave is dredged at approximately 210 m wide along the crest. The levelling results in two separate features, east and west of the levelled area.	Two separate features are created as a result of the levelling, with no apparent link between each. There does not seem to be any change to the sandwave crest height on either side of the levelled area. The levelled area

Location	Data description: Pre-levelling period	Data description: Levelling period	Data description: Post-levelling period
	45 m and the cable is orientated roughly parallel to the crest. Megaripple bedforms evident between sandwaves and are orientated northeast to southwest.		also covers a large part of the sandwave and there does not seem to be any infill or change to the crest height of the sandwave sections either side of the levelled area. There is no evidence of sandwave migration.
Site 11 -13.5 mLAT Levelling Area 1	Asymmetric sandwaves with the crest orientated approximately east-northeast to west-southwest. The steeper lee slope faces the northwest and gentler stoss slope to the southeast. The sandwave wavelengths vary approximately between 40 and 70 m and the cable is orientated perpendicular to their crests.	Three sandwaves are affected, with the bedforms levelled to the same depth as the surrounding seabed. The levelled section is approximately 30 m wide across the full sandwave wavelength, resulting in two separate features for each sandwave.	For the most northerly affected sandwave, the effect of the levelling is not apparent, as the levelled area has completely filled in and the sandwave crest has reformed. For the remaining two sandwaves, the levelled area is infilling and merging across the levelled area, although not at the same degree as the northerly sandwave. No migration is evident for the three affected sandwaves dredged at this site, while the wavelength seems to remain the same.
Site 12 -14.0 mLAT Levelling Area 2	Asymmetric sandwave with the crest orientated east-northeast to west-southwest. The steeper lee slope faces the northwest and gentler stoss slope to the southeast. The sandwave wavelength is approximately 45 m and the cable is orientated transverse to the crest. Evidence of converging and bifurcating sandwaves nearby.	The sandwave is levelled approximately to its base. A large part of the sandwave is levelled at approximately 45 m wide along the crest. This results in two separate features, east and west of the levelled area. Although the eastern feature is more the tail end of the original sandwave.	The levelled area is infilling, from the margins of the unaffected part of the sandwave and looks like a smoothing of the bedforms across the levelled area. No migration is apparent and the wavelength stays the same. Still evidence of converging or bifurcating sandwaves nearby.

Appendix C Applicability of Race Bank Monitoring Data to Hornsea Three

4.1 As outlined in paragraph 2.36 *et seq*. of the main report, in order to demonstrate the applicability of the Race Bank monitoring data to Hornsea Three an analysis was undertaken to identify any similarities and differences between the sites in terms of their underlying environmental settings and particularly the aspects of the settings that will govern the potential for sandwave recovery following levelling. This analysis was summarised in paragraph 2.36 *et seq*. of the main report and is presented in detail here, including comparative consideration to parameters such as total (tide and surge) water levels, current speed and direction, and coincident wave height, period and direction. This was used to calculate potential sediment transport rates and direction at each site and comparative levels of sediment mobility and used alongside an understanding of sea bed and sandwave bedform characteristics.

Data from previous Race Bank Studies

4.2 Additional information on the water depth and sandwave migration rates and direction around the levelled sandwaves were determined using combinations of historical and recent bathymetric survey data and reported in a previous report (ABPmer, 2016). Relevant information for the locations of the subsequently levelled sandwaves are summarised in Table 2.1 of the main report. This information is used to provide a more complete picture of the sandwave characteristics pre and post-dredge and also to characterise the sediment transport potential across the monitoring site.

Tides, surge, waves and sediment transport

4.3 Hindcast time series of total (tide and surge) water levels, current speed and direction, and coincident wave height, period and direction, were obtained from the regionally validated ABPmer SEASTATES hindcast models (ABPmer, 2013; ABPmer, 2017). SEASTATES provides continuous hindcast timeseries data, at hourly intervals, for a 39 year period between 1 January 1979 and 31 December 2017. Data were extracted for ten locations representative of the 12 Race Bank monitoring sites, and for five locations representative of the range of conditions within the Hornsea Three offshore cable corridor and array area (shown in Figure 2-1 of the main report).

4.4 The SEASTATES environmental time series data were used in conjunction with sediment transport relationships described in Soulsby (1997) to estimate a corresponding historical time-series of the potential sediment transport rate and direction. As is always the case with sediment transport predictions, the resulting absolute quantities are subject to some uncertainty based on the specific choices of the relationships used and the assumed representative sediment grain size and other seabed properties. However, the results can be usefully analysed and compared in terms of the relative magnitude and direction of instantaneous and net potential sediment transport. Relative measures provide a more reliable basis to compare and contrast general patterns of sediment mobility at different locations over a fixed time frame, or over different time frames for a given location.

4.5 The sediment transport calculations are based on a representative grainsize of 350 µm (medium sand) for the Race Bank monitoring sites, while a coarser representative grainsize of 800 µm (coarse sand) was used for the Hornsea Three assessment locations, in accordance with field sampling results for the Hornsea Three array area (Emu, 2011; Clinton, 2016; EGS, 2016; Figure 2-1 of the main report). Histograms of instantaneous sediment transport rates were created for set time periods for each site, in order to compare the dominant sediment transport characteristics. The time scales assessed were:

- Long term – the full 39 year record (i.e. 1 January 1979 to 31 December 2017); and
- Short term – the post-levelling monitoring period for the Race Bank offshore export cables (i.e. 28 August 2016 to 17 February 2017).

4.6 In order to compare the degree of sediment mobility at the various sites in a relative sense, the overall distribution (magnitude and frequency) of predicted potential sediment transport rates are categorised for each site, relative to the values for all of the monitoring and assessment sites, as follows:

- Very Low - transport rates up to 0.01 m3/m/hr;
- Low - transport rates between 0.01 and 0.1 m3/m/hr;
- Medium - transport rates between 0.1 and 1 m3/m/hr; and
- High - transport rates between 1 m3/m/hr and higher.

4.7 A summary statement of the comparative levels of sediment mobility is provided for each Race Bank monitoring location in Table 2.1 of the main report and in Table C.1 below for Hornsea Three. Histograms of the calculated potential sediment transport rates for the Race Bank monitoring sites and for the Hornsea Three assessment locations over the same time period (the post-levelling monitoring period for the Race Bank export cables, i.e. 28 August 2016 to 17 February 2017), are provided in Figure C.1 and Figure C.2, respectively. Combining the magnitude and direction of transport, progressive vector diagrams are provided in Figure C.3 and Figure C.4 below to visualise the patterns and magnitude of net potential sediment transport for the monitoring sites and assessment locations over the post-levelling monitoring period.

Interpretation and comparability with Hornsea Three

4.8 Table 2.1 provides an interpretation of the data presented for the Race Bank offshore cable corridor and array area, and characterises the associated bedform features within this monitoring dataset.

4.9 Five representative locations (shown in Figure 2-1 of the main report) have been selected within the Hornsea Three array area and offshore cable corridor to provide the basis for comparison with the environmental conditions at the Race Bank monitoring sites.

4.10 The Hornsea Three Environmental Statement considers the potential impact of the planned construction activities (sand wave levelling for cable installation) on sandwaves, primarily in the North Norfolk Sandbanks and Saturn Reef SAC, where these are designated features. Therefore, assessment locations 2 and 3 (within or near to the SAC) are of particular interest in this Clarification Note.

4.11 The environmental and seabed properties at all of the selected Hornsea Three assessment locations are summarised in Table C.1. While the tidal and wave regimes are generally similar to those at the Race Bank sandwave levelling monitoring sites along most of the Race Bank offshore cable corridor, the assessment locations in the Hornsea Three array area and offshore cable corridor are typically relatively deeper, resulting in relatively lower predicted magnitudes of instantaneous and net sediment transport potential due to the reduction in bed shear stress from waves. The Hornsea Three array area also has relatively lower typical tidal current speeds than the Hornsea Three offshore cable corridor, which further reduces the frequency and magnitude of sediment mobility in this area.

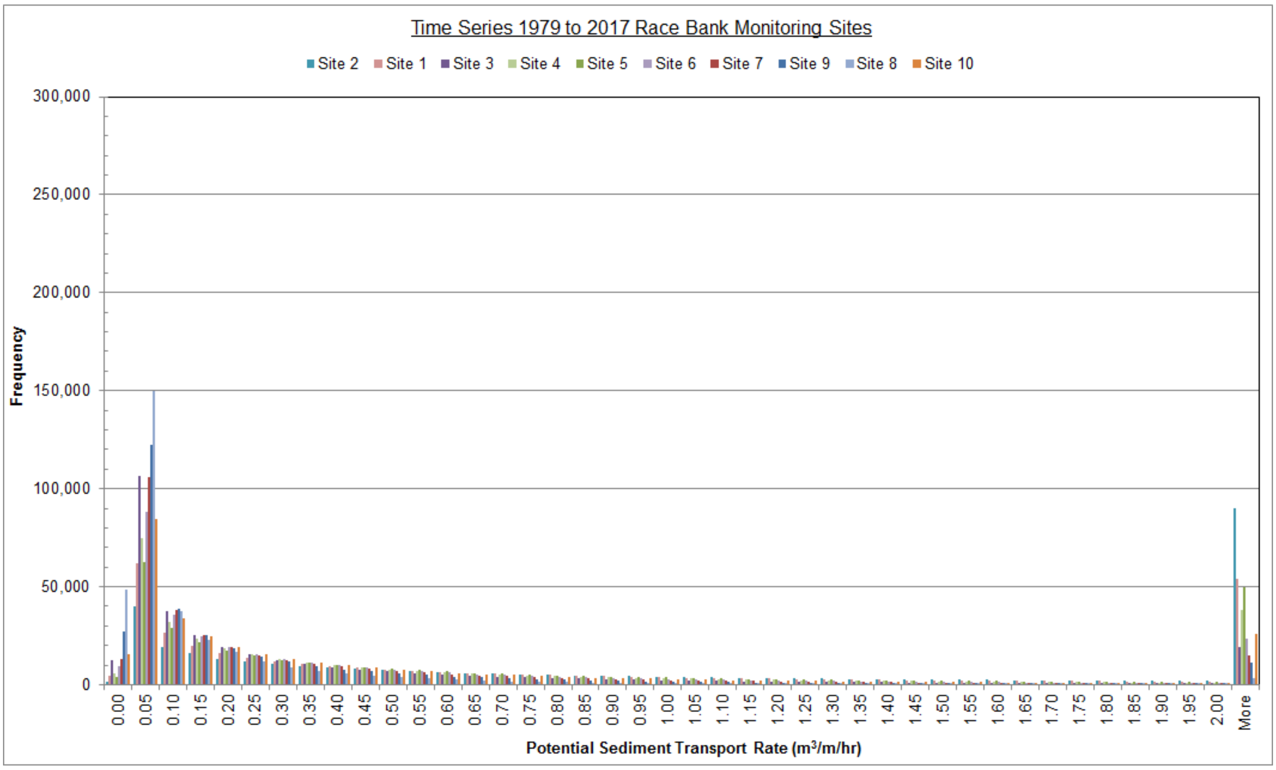
4.12 Data were extracted at these locations from the previously described ABPmer SEASTATES hindcast data bases for the period between 1 January 1979 and 31 December 2017 and used to estimate a corresponding timeseries of potential sediment transport rates. Although a relatively lower overall level of sediment mobility is predicted due to the greater water depth, in practice, the sandwave and sandbank bedforms within the Hornsea Three offshore cable corridor (especially within the North Norfolk Sandbanks and Saturn Reef SAC) are known to be generally mobile, with active sediment transport linkages between these sandbank systems (JNCC 2017: Jenkins *et al*., 2015; Copper *et al*., 2008; Collins *et al*., 1995).

4.13 Histograms summarising and comparing the distribution of instantaneous sediment rates at the Race Bank and Hornsea Three sites are provided in 1 to Figure C.4 below. Summary (categorised) descriptions of sediment transport potential for the five Hornsea Three assessment locations are provided in Table C.1 below.

Table C.1: Characterisation of Hornsea Three bedforms (see Figure 2-1 of the main report).

Assessment location number and description	Water depth (mLAT)	Sediment transport potential	Summary of seabed and sandwave bedform characteristics
1 Within the Hornsea Three offshore cable corridor, closest to the coast.	-28.40	Low	Few sandwaves present within this area. Seabed sediment characterised as coarse sand and gravels.
2 Within the Hornsea Three offshore cable corridor and the North Norfolk Sandbanks and Saturn Reef SAC.	-17.16	Very Low to Low	Large sandbanks present with heights of above 10 m and orientated northwest to southeast. Sandwaves overly sandbanks with heights of up to 4 m and crest alignment northeast to southwest, perpendicular to the sandbanks. There is evidence of sediment redistribution around the sandbanks, which potentially indicates ongoing sandbank migration (JNCC, 2017; Jenkins et al., 2015). The sandwaves overlying the sandbanks also demonstrate variability, although it is not possible to infer a consistent transport direction. Seabed sediment characterised as coarse sand.
3 Within or nearby to the Hornsea Three offshore cable corridor and the North Norfolk Sandbanks and Saturn Reef SAC.	-21.64	Very Low to Low	Same as location 2.
4 Within the Hornsea Three offshore cable corridor, immediately south of the Hornsea Three array area.	-29.31	Very Low to Low	Few sandwaves present within this area. Seabed sediment characterised as coarse sand.
5 Within the Hornsea Three array area.	-36.42	Very Low to Low	Some sandwaves are present within this area. Seabed sediment characterised as coarse sand.

Figure C.1: Race Bank monitoring sites



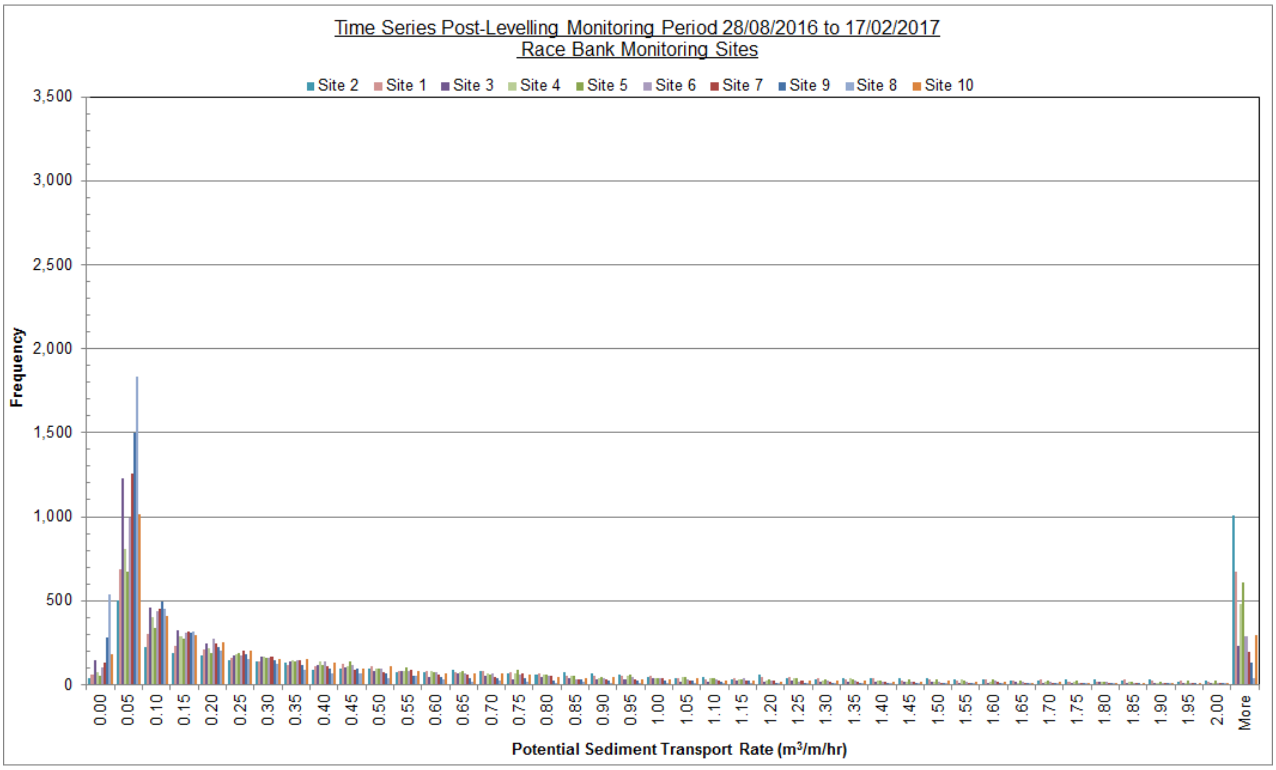
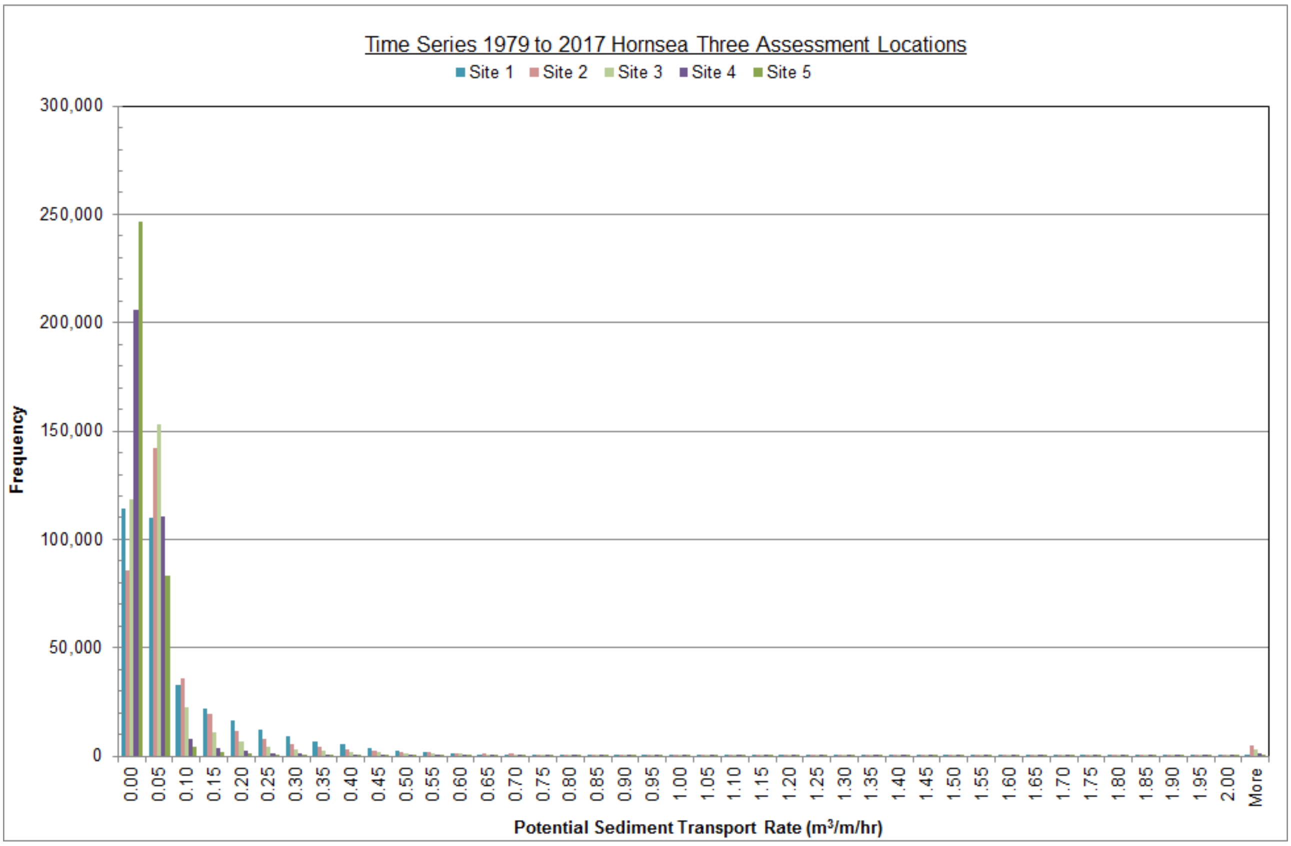


Figure C.2: Hornsea Three assessment locations



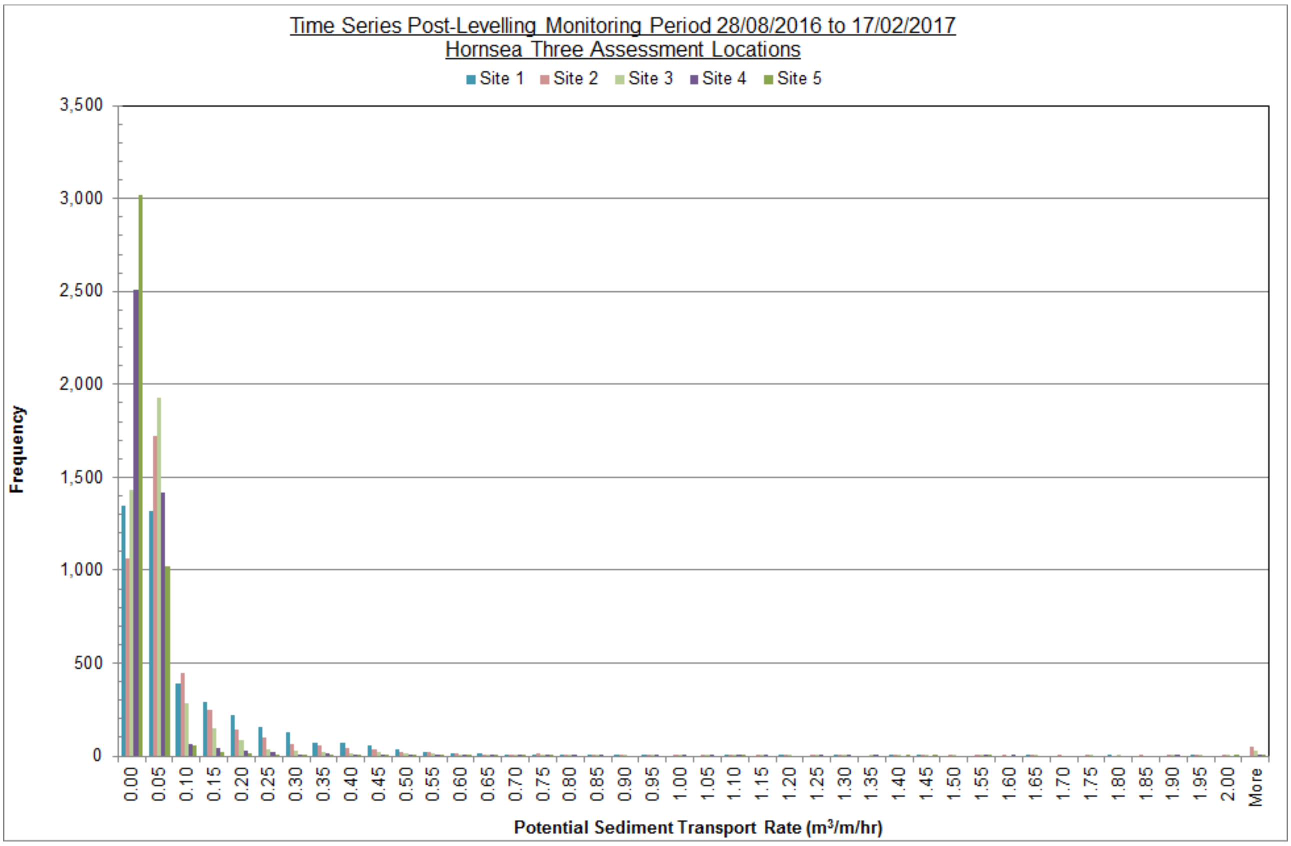


Figure C.3: Race Bank monitoring sites

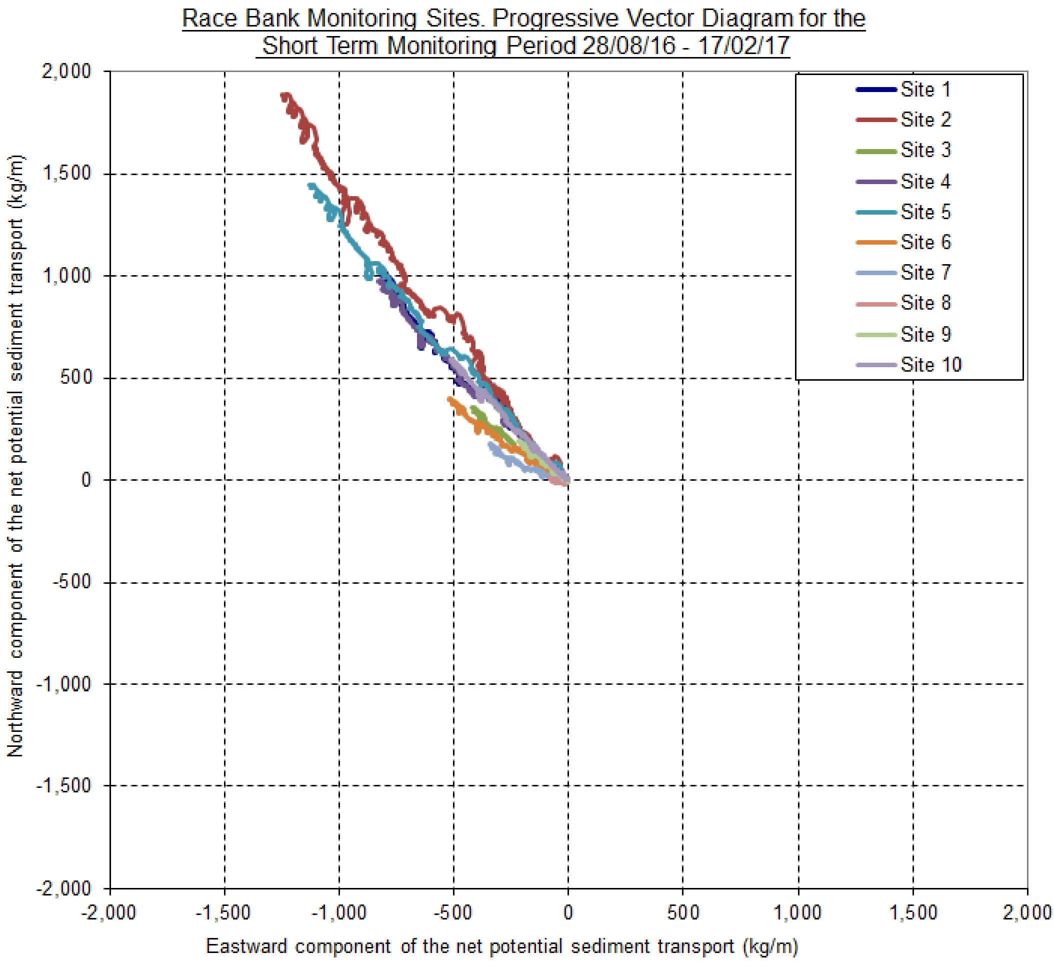


Figure C.4: Hornsea Three assessment locations