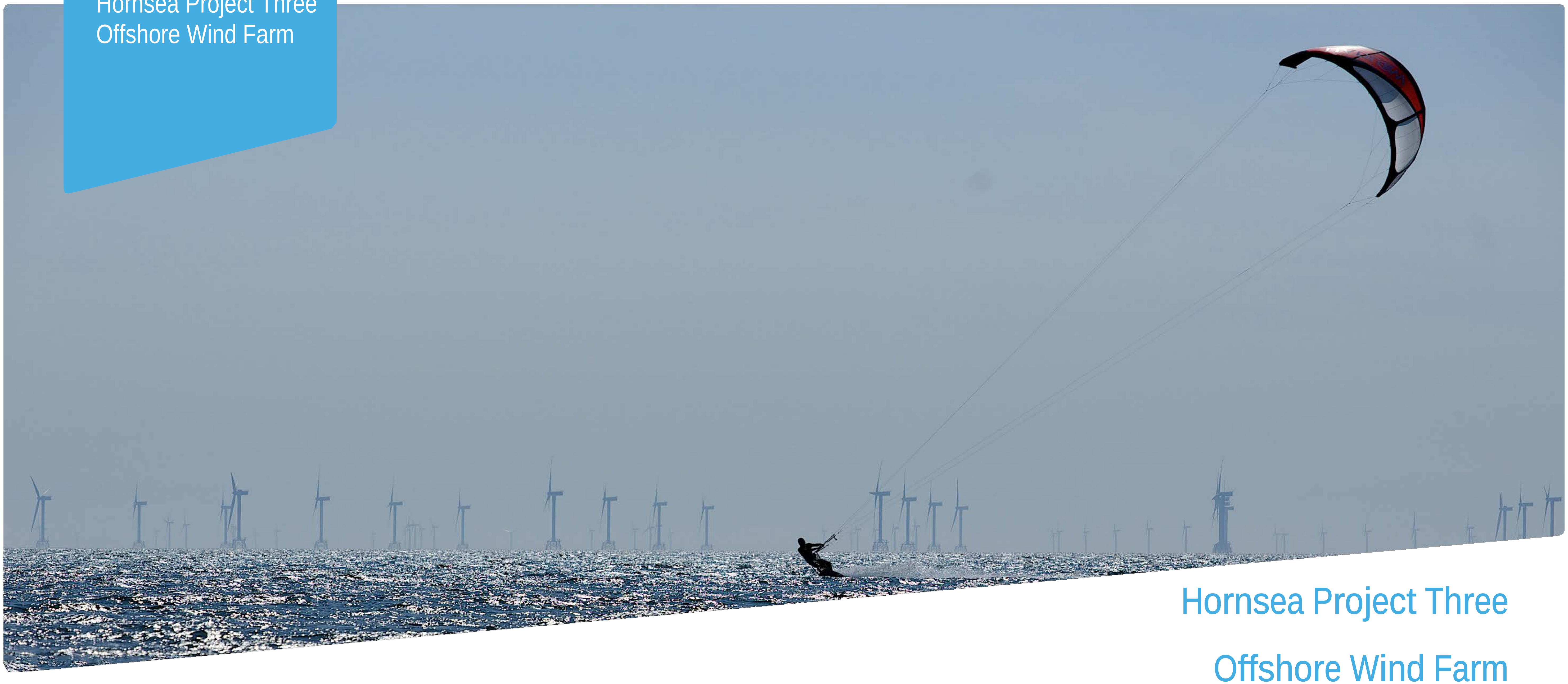
Hornsea Project Three
Offshore Wind Farm



Hornsea Project Three

Offshore Wind Farm

Environmental Statement:
Volume 2, Chapter 1 - Marine Processes

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Hornsea 3
Offshore Wind Farm

Ørsted

Environmental Impact Assessment

Environmental Statement

Volume 2

Chapter 1 – Marine processes

Report Number: A6.2.1

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This report is also downloadable from the Hornsea Project Three offshore wind farm website at:
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5 Howick Place,

London, SW1P 1WG

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Prepared by: ABPmer

Checked by: Felicity Browner

Accepted by: Sophie Banham

Approved by: Stuart Livesey

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Glossary

Term	Definition
Accretion	Build-up (accumulation) of material solely by the deposition of water or airborne material through natural processes.
Astronomical tide	The tide levels and character which would result from the gravitational effects of the earth sun and moon without any atmospheric influences.
Acoustic Wave And Current Profiler (AWAC)	A Nortek instrument which measures wave height, wave direction and the full current profile.
Beach	A deposit of non-cohesive material (e.g. sand, gravel) situated on the interface between dry land and the sea (or other large expanse of water) and actively "worked" by present-day hydrodynamic processes (i.e. waves, tides and currents) and sometimes by winds.
Beach profile	A cross-section taken perpendicular to a given beach contour; the profile may include the face of a dune or seawall, extend over the backshore, across the foreshore, and seaward underwater into the nearshore zone.
Bedforms	Features on the seabed (e.g. sandwaves, ripples) resulting from the movement of sediment over it.
Bedload	Sediment particles that travel near or on the bed.
Bed shear stress	The force exerted by moving water against the bed.
Benthic	A description for animals, plants and habitats associated with the seabed. All plants and animals that live in, on or near the seabed are benthos.
British Oceanographic Data Centre (BODC)	National facility for looking after and distributing data concerning the marine environment.
Breaking	Reduction in wave energy and height in the surf zone due to limited water depth.
Clay	A fine grained sediment with a typical grain size of less than 0.004 mm. Possesses electromagnetic properties which bind the grains together to give a bulk strength or cohesion.
Climate change	A long term trend in the variation of the climate resulting from changes in the global atmospheric and ocean temperatures and affecting mean sea level, wave height, period and direction, wind speed and storm occurrence.
Coast	A strip of land of indefinite length and width that extends from the seashore inland to the first major change in terrain features.
Coastal processes	Collective term covering the action of natural forces on the coastline and adjoining seabed.
Cohesive sediment	Sediment containing a significant proportion of clays, the electromagnetic properties of which cause the particles to bind together.
Diurnal	Having a period of a tidal day 24.84 hours.
European Marine Observation and Data Network (EMODnet)	EMODnet is a Directorate-General for Maritime Affairs and Fisheries (DG MARE) funded network of organisations supported by the European Union's integrated maritime policy. These organisations work together to observe the sea, process the data according to international standards and make that information freely available as interoperable data layers and data products.
Erosion	Movement of material by such agents as running water, waves, wind, moving ice and gravitational creep.

Term	Definition
Geophysical survey	Activities to obtain data on the distribution and nature of geophysical properties of the seabed (e.g. bathymetry, surficial sediment type and bedforms, sub-surface geology). Geophysical survey outputs typically include multibeam bathymetry, side-scan sonar and sub-bottom profiler data.
Habitat	The place in which a plant or animal lives. It is defined for the marine environment according to geographical location, physiographic features and the physical and chemical environment (including salinity, wave exposure, strength of tidal streams, geology, biological zone, substratum, 'features' (e.g. crevices, overhangs, rockpools) and 'modifiers' (e.g. sand-scour, wave-surge, substratum mobility).
Hindcast	The retrospective prediction of historical (wind and wave) conditions.
Hydrodynamic	Of or relating to the motion of fluids and the forces acting on solid bodies immersed in fluids and in motion relative to them.
Intertidal zone	The zone between the highest and lowest tides. May also be referred to as the littoral zone.
Light Detection and Ranging (LiDAR)	A surveying method that measures distance to a target by illuminating that target with a laser light.
Littoral drift, littoral transport	The movement of beach material in the littoral zone by waves and currents. Includes movement parallel (longshore transport) and perpendicular (onshore- offshore transport) to the shore.
Longshore drift	Or alongshore or littoral drift. Movement of sand and shingle along the shore. It takes place in two zones, at the upper limit of wave activity and in the breaker zone. Movement of beach (sediments) approximately parallel to the coastline.
Morphological	Of or relating to the form, shape and structure of landforms
National Tide and Sea Level Facility (NTSLF)	The NTSLF is the UK centre of excellence for sea level monitoring, coastal flood forecasting and the analysis of sea level extremes
Neap tides	Tides with the smallest range between high and low water, occurring at the first and third quarters of the moon.
Optical Backscatter (OBS)	Sensors mounted on bed frames may be used to monitor turbidity and suspended sediment concentrations using OBS technology.
Regime	The behaviour, statistical properties and trends characterising the variability of hydrodynamic, meteorological, sedimentological and morphological parameters.
Return period	In statistical analysis an event with a return period of N years is likely, on average, to be exceeded only once every N years.
Salinity	Measure of all the salts dissolved in water.
Scour	Local erosion of sediments caused by local flow acceleration around an obstacle and associated turbulence enhancement.
Sediment	Particulate matter derived from rock, minerals or bioclastic debris.
Sediment source	A point or area from which sediment arises such as an eroding cliff or river mouth.
Sediment transport	The movement of a mass of sedimentary material by the forces of currents and waves. The sediment in motion can comprise fine material (silts and muds), sands and gravels. Potential sediment transport is the full amount of sediment that could be expected to move under a given combination of waves and currents, i.e. not supply limited.
Sediment transport pathway	The routes along which net sediment movements occur.

Term	Definition
Semidiurnal	Having a period of approximately one half of a tidal day (12.4 hours). The predominating type of tide throughout the world is semidiurnal with 2 high waters and 2 low waters each day.
Significant wave height	The average height of the highest of one third of the waves in a given sea state.
Spring tides	Tides with the greatest range which occurs at or just after the new and full moon.
Seastate	The state of the sea as described using the Douglas sea scale, based on wave height and swell, ranging from 1 to 10, with accompanying descriptions.
Shoreline Management Plan (SMP)	A Shoreline Management Plan (SMP) is a large-scale assessment of the risks associated with coastal processes. It aims to lessen these risks to people and the developed, historic and natural environments.
Suspended Particulate Matter (SPM)	Close to the bed, suspended matter typically consists of re-suspended mineral matter, but higher up in the water column SPM is typically in the form of flocs – loosely bound aggregates composed of mineral matter (e.g. clay minerals) as well as organic matter.
Storm surge	A rise in water level in the open coast due to the action of wind stress as well as atmospheric pressure on the sea surface.
Surficial sediments	Sediments located at the seabed surface (not necessarily of the same character as underlying sediments).
Surge	In water level as a result of meteorological forcing (wind, high or low barometric pressure) causing a difference between the recorded water level and that predicted using harmonic analysis, may be positive or negative.
Suspended load	The material moving in suspension in a fluid, kept up by the upward components of the turbulent currents or by the colloidal suspension.
Suspended Sediment Concentration (SSC)	Mass of sediment in suspension per unit volume of water.
Swell (waves)	Wind-generated waves that have travelled out of their generating area. Swell characteristically exhibits a more regular and longer period and has flatter crests than waves within their fetch.
Tidal asymmetry	1) Relative difference in peak current speed or duration of adjacent flood and ebb half tidal cycles. 2) Relative difference in high or low water levels or duration of adjacent flood and ebb half tidal cycles.
Tidal excursion	The Lagrangian movement (the physics of fluid motion as an individual fluid parcel moves through space and time) of a water particle during a tidal cycle.
Tidal excursion ellipse	The path followed by a water particle in one complete tidal cycle.
Tidal harmonics	Component parts of the tidal (water level) signal at a location. A discrete timeseries of tides can be separated into a variable number of sinusoidal signals of known frequency, phase and amplitude. These can be used to predict values for the same location, outside of the original period of data.
Tide	The periodic rise and fall in the level of the water in oceans and seas; the result of gravitational attraction of the sun and moon.
Till	Collective term for the group of sediments laid down by the direct action of glacial ice without the intervention of water.
Topography	The form of the features of the actual surface of the earth in a particular region considered collectively.

Term	Definition
Turbidity	Turbidity is a measure of the degree to which the water loses its transparency due to the presence of suspended particles. SSC refers to the mineral fraction of the suspended solids load whilst SPM includes both the in-organic and organic component.
United Kingdom Climate Projections (UKCP)	UKCP09 is the name given to the latest UK Climate Projections. UKCP09 provides information on plausible changes in 21st century climate for land and marine regions in the United Kingdom.
Wave propagation	The spread of waves across the sea which in deep water will usually be in the direction of the wind causing them. In shallow water the direction will vary due to the influence of the sea bed and tidal currents.
Wave refraction	When waves approach the shoreline obliquely, the wave crests tend to conform to the bottom (bed) contours; due to the inshore portion of the wave travelling at a lower velocity than the portion in deeper water. The extent of wave refraction depends on the relative magnitudes of water depth to wavelength.

Acronyms

Acronym	Description
AWAC	Acoustic Wave and Current
ABS	Acoustic Backscatter
BERR	Department for Business, Enterprise and Regulatory Reform
BGS	British Geological Survey
BMAPA	British Marine Aggregate Producers Association
BODC	British Oceanographic Data Centre
CCO	Channel Coastal Observatory
CD	Chart Datum
CEA	Cumulative Effects Assessment
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CFSR	Climate forecast system re-analysis
COWRIE	Collaborative Offshore Wind Research into the Environment
CPT	Cone Penetration Test
cSAC	candidate Special Areas of Conservation
CTD	Conductivity Temperature and Depth
DCO	Development Consent Order
DECC	Department of Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
DTI	Department of Trade and Industry
EIA	Environmental Impact Assessment
EU	European Union
GES	Good Environmental Status
GIS	Geographical Information System
HAT	Highest Astronomical Tide
HDD	Horizontal Directional Drilling
Hs	Significant Wave Height
HV	High Voltage
IPC	Infrastructure Planning Commission
JNCC	Joint Nature Conservation Committee

Acronym	Description
LAT	Lowest Astronomical Tide
LiDAR	Light Detection and Ranging
MALSF	Marine Aggregate Levy Sustainability Fund
MCZ	Marine Conservation Zone
MHWN	Mean High Water of Neap Tides
MHWS	Mean High Water of Spring Tides
MLWN	Mean Low Water of Neap Tides
MLWS	Mean Low Water of Spring Tides
MMO	Marine Management Organisation
MODIS	Moderate Resolution Imaging Spectroradiometer
MSL	Mean Sea Level
MW	Megawatt(s)
NCEP	National Centres for Environmental Prediction
NPS	National Policy Statement
NSIP	Nationally Significant Infrastructure Projects
NTSLF	National Tide and Sea level Facility
OBS	Optical Backscatter
ODN	Ordnance Datum Newlyn
OSGB	Ordnance Survey of Great Britain
POL	Proudman Oceanographic Laboratory
REA	Regional Environmental Assessment
REC	Regional Environmental Characterisation
rMCZ	(Recommended) Marine Conservation Zone
SAC	Special Area of Conservation
SCI	Site of Community Importance
SMP	Shoreline Management Plan
SPA	Special Protection Area
SPM	Suspended Particulate Matter
SSC	Suspended Sediment Concentration
SSSI	Sites of Special Scientific Interest
TSHD	Trailing Suction Hopper Dredger
UK	United Kingdom
UKCP09	United Kingdom Climate Projections 2009
UKHO	United Kingdom Hydrographic Office
ZoC	(former) Hornsea Zone Characterisation
ZoI	Zone of Influence

Units

Unit	Description
g	gram
GW	Gigawatt (power)
km	Kilometre (distance)
kV	Kilovolt (electrical potential)
kg	Kilogram
kW	Kilowatt (power)
m	Metre (distance)
MW	Megawatt (power)
mg/l	Milligram / litre (concentration)
Ma	Million years

1. Marine Processes

1.1 Introduction

1.1.1.1 This chapter of the Environmental Statement presents the results of the Environmental Impact Assessment (EIA) for the potential impacts of the Hornsea Project Three offshore wind farm (hereafter referred to as Hornsea Three) on marine processes. Specifically, this chapter considers the potential impact of Hornsea Three seaward of Mean High Water Springs (MHWS) during its construction, operation and maintenance, and decommissioning phases.

1.1.1.2 Marine processes is a collective term for the following:

- Water levels;
- Currents;
- Waves (and winds);
- Stratification and frontal systems;
- Sediments and geology: (including seabed sediment distribution and sediment transport);
- Seabed geomorphology; and
- Coastal geomorphology.

1.1.1.3 To avoid duplication, potential changes to water (and sediment) quality are not considered in this chapter, but are instead discussed within volume 5, annex 2.2: Water Framework Directive Assessment and volume 5, annex 2.3: Marine Conservation Zone Assessment.

1.1.1.4 In order to assess the potential changes relative to the baseline (existing) coastal and marine environment, a combination of complementary approaches have been adopted. These include:

- The 'evidence base' containing monitoring data collected during the construction, and operation and maintenance of other offshore wind farm developments. The evidence base also includes results from numerical modelling and desk based analyses undertaken to support other offshore wind farm EIAs, especially that used to support the consenting processes for the nearby Hornsea Project One and Hornsea Project Two;
- Analytical and spectral wave modelling to consider potential changes to the wave regime in response to the operation of Hornsea Three, as well as the potential for cumulative changes associated with the operation of Hornsea Project One, Hornsea Project Two and Hornsea Three; and
- Standard empirical equations describing the relationship between (for example) hydrodynamic forcing and sediment transport or settling and mobilisation characteristics of sediment particles released during construction activities (e.g. Soulsby, 1997).

1.1.1.5 For many of the marine processes assessments described in this chapter, the existing evidence base from Hornsea Project One and Hornsea Project Two is used to validate and corroborate the findings of the independent quantitative analyses carried out for Hornsea Three.

1.1.1.6 Consideration of the likely changes to the marine processes has been made, adopting a number of conservative assumptions based around the maximum design characteristics of Hornsea Three. Subsequent effects upon a series of identified marine process receptors have been determined.

1.1.1.7 It is noted here that the receptor groups for several of the potential impact pathways considered within this chapter lie in other offshore EIA topics; namely volume 2, chapter 2: Benthic Ecology, volume 2, chapter 3: Fish and Shellfish Ecology, volume 2, chapter 4: Marine Mammals, volume 2, chapter 5: Offshore Ornithology, volume 2, chapter 9: Marine Archaeology, and volume 2, chapter 10: Infrastructure and Other Users. In such instances, a significance of effect has not been assigned within the marine processes assessment.

1.1.1.8 The more detailed technical information which underpins the impact assessments presented in this chapter is contained within volume 5, annex 1.1: Marine Processes Technical Annex.

1.2 Purpose of this chapter

1.2.1.1 The primary purpose of the Environmental Statement is to support the Development Consent Order (DCO) application for Hornsea Three under the Planning Act 2008 (the 2008 Act) and accompanies the application to the Secretary of State for Development Consent.

1.2.1.2 It is intended that the Environmental Statement will provide statutory and non-statutory consultees with sufficient information to complete the examination of Hornsea Three and will form the basis of agreement on the content of the DCO and/or Marine Licence conditions (as required).

1.2.1.3 In particular, this Environmental Statement chapter:

- Presents the existing environmental baseline established from desk studies and consultation;
- Presents the potential environmental effects on marine processes arising from Hornsea Three, based on the information gathered and the analysis and assessments undertaken;
- Identifies any assumptions and limitations encountered in compiling the environmental information; and
- Highlights any necessary monitoring and/or mitigation measures which could prevent, minimise, reduce or offset the possible environmental effects identified in the EIA process.

1.3 Hornsea Three marine processes study area

1.3.1.1 The Hornsea Three marine processes study area within which baseline conditions and potential changes have been considered is shown in Figure 1.1 and is defined as:

- The Hornsea Three array area;
- The Hornsea Three offshore cable corridor and temporary working areas;
- The Hornsea Three nearshore area between Weybourne and Kelling Hard; and
- The seabed and water column surrounding these areas that may be influenced by changes to marine processes due to Hornsea Three.

1.3.1.2 The spatial extent of the Hornsea Three marine processes study area has primarily been determined using expert judgment, drawing upon knowledge developed from other Round 3 projects and in particular modelling results showing the anticipated extent of change from Hornsea Project One and Hornsea Project Two. Direct changes to the seabed will be confined to the Hornsea Three array area and offshore cable corridor, with indirect changes (e.g. due to disruption of waves, tides or sediment pathways) experienced both inside and outside of the Hornsea Three boundaries. These indirect changes are expected to diminish with distance from the array area and offshore cable corridor.

1.3.1.3 The Hornsea Three marine processes study area for the cumulative effects assessments (CEA) (hereafter referred to as the CEA marine processes study area) is also shown in Figure 1.1. This covers a slightly greater area than for the project alone assessment, reflecting the fact that there exists potential for cumulative changes to occur with respect to changes in the wave environment.

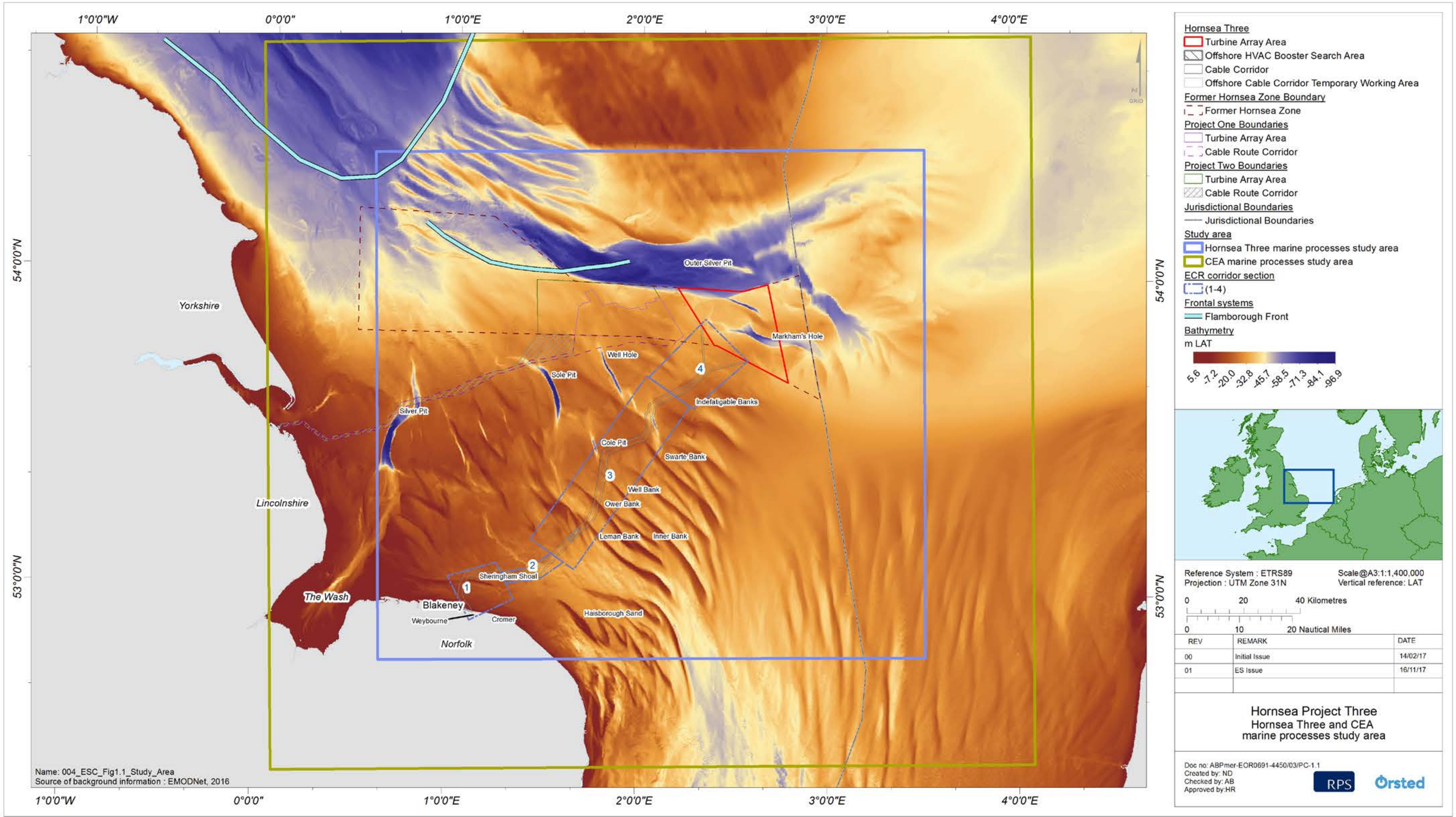

Figure 1.1: Hornsea Three and CEA marine processes study area.

1.4 Planning policy context

1.4.1 National Policy Statements

1.4.1.1 Planning policy on offshore renewable energy Nationally Significant Infrastructure Projects (NSIPs), specifically in relation to marine processes, is contained in the Overarching National Policy Statement (NPS) for Energy (EN-1; DECC, 2011a), the NPS for Renewable Energy Infrastructure (EN-3, DECC, 2011b) and the NPS for Electricity Networks Infrastructure (EN-5, DECC, 2011c).

1.4.1.2 NPS EN-1 and NPS EN-3 include guidance on what matters are to be considered in the assessment. Those matters applicable to marine processes are summarised in Table 1.1 below.

Table 1.1: Summary of NPS EN-1 and EN-3 provisions relevant to marine processes.

Summary of NPS EN-1 and NPS EN-3 provision	How and where considered in the Environmental Statement
Where relevant, applicants should undertake coastal geomorphological and sediment transfer modelling to predict and understand impacts and help identify relevant mitigating or compensatory measures (paragraph 5.5.6 of NPS EN-1)	Assessments have been made through consideration of the existing numerical modelling undertaken to support Hornsea Project One and Hornsea Project Two, analytical assessments of project-specific data, as well as the use of standard empirical equations. Full justification of this evidence based approach is set out in volume 5, annex 1.1: Marine Processes Technical Annex, section 2. The impact of Hornsea Three on identified marine processes receptors is considered in paragraph 1.11.5.1 onwards (for the construction phase), paragraph 1.11.8.1 onwards (for the operation and maintenance phase), paragraph 1.11.9.1 onwards (for the decommissioning phase) and paragraph 1.13.6.1 onwards (in the context of cumulative effects).
The direct effects on the physical environment can have indirect effects on a number of other receptors. Where indirect effects are predicted, the Secretary of State) should refer to relevant sections of this NPS and EN 1 (paragraph 2.6.195 of NPS EN-3).	The predicted changes to the physical environment have been considered in relation to indirect effects on other receptors elsewhere in the Environmental Statement, namely volume 2, chapter 2: Benthic Ecology, volume 2, chapter 3: Fish and Shellfish Ecology, volume 2, chapter 4: Marine Mammals, volume 2, chapter 9: Marine Archaeology, and volume 2, chapter 10: Infrastructure and Other Users.
The methods of construction, including use of materials should be such as to reasonably minimise the potential for impact on the physical environment (paragraph 2.6.196 of NPS EN-3).	Hornsea Three has proposed designs and installation methods that seek to reasonably minimise significant adverse effects on the physical environment. Where necessary, the assessment has set out mitigation to avoid or reduce significant adverse effects.

1.4.1.3 NPS EN-1 and NPS EN-3 also highlight a number of factors relating to the determination of an application and in relation to mitigation. Those matters applicable to marine processes are summarised in Table 1.2 below.

Table 1.2: Summary of NPS EN-1 and NPS EN-3 policy on decision making relevant to marine processes.

Summary of NPS EN-1 and NPS EN-3 policy on decision making (and mitigation)	How and where considered in the Environmental Statement
The Environmental Statement should include an assessment of the effects on the coast. In particular, applicants should assess: • The impact of the proposed project on coastal processes and geomorphology, including by taking account of potential impacts from climate change. If the development will have an impact on coastal processes the applicant must demonstrate how the impacts will be managed to minimise adverse impacts on other parts of the coast; • The implications of the proposed project on strategies for managing the coast as set out in Shoreline Management Plans (SMPs)…any relevant Marine Plans…and capital programmes for maintaining flood and coastal defences; • The effects of the proposed project on marine ecology, biodiversity and protected sites; • The effects of the proposed project on maintaining coastal recreation sites and features; and • The vulnerability of the proposed development to coastal change, taking account of climate change, during the project's operational life and any decommissioning period (paragraph 5.5.7 of NPS EN-1).	• Changes to coastal processes 'pathways' (e.g. elevations in Suspended Sediment Concentration (SSC), scour around foundations etc.) are described in paragraph 1.11.4.8 to 1.11.4.10. The impact of Hornsea Three on identified marine processes receptors is considered in paragraph 1.11.5.1 onwards (for the construction phase), paragraph 1.11.8.1 onwards (for the operation and maintenance phase), paragraph 1.11.9.1 onwards (for the decommissioning phase) and paragraph 1.13.6.1 onwards (in the context of cumulative effects). • The implications of the proposed project on strategies for managing the coast is considered within the nearshore area assessment, presented in paragraph 1.11.5.19 onwards (for the construction phase), paragraph 1.11.8.80 onwards (for the operation and maintenance phase) and paragraph 1.11.9.9 onwards for the decommissioning phase). • The effects of the proposed project on marine ecology, biodiversity and protected sites is set out in volume 2, chapter 2: Benthic Ecology; • The effects of the proposed project on maintaining coastal recreation sites and features is set out in volume 2, chapter 10: Infrastructure and Other users; and • The vulnerability of Hornsea Three to coastal change (taking account of climate change) is considered in the context of nearshore infrastructure, in paragraph 1.11.8.1 onwards.
The applicant should be particularly careful to identify any effects of physical changes on the integrity and special features of Marine Conservation Zones (MCZs), candidate marine Special Areas of Conservation (cSACs), coastal SACs and candidate coastal SACs, coastal Special Protection Areas (SPAs) and potential Sites of Community Importance (SCIs) and Sites of Special Scientific Interest (SSSI) (paragraph 5.5.9 of NPS EN-1).	Designated nature conservation sites within the Hornsea Three and CEA marine processes study area have been described in paragraph 1.7.2.1 to 1.7.2.7. The predicted changes to marine processes have been considered in relation to indirect effects on other receptors elsewhere in the Environmental Statement, in particular volume 2, chapter 2: Benthic Ecology, volume 2, chapter 3: Fish and Shellfish Ecology, volume 2, chapter 4: Marine Mammals, volume 2, chapter 9: Marine Archaeology, and volume 2, chapter 10: Infrastructure and Other Users.
The Secretary of State should not normally consent new development in areas of dynamic shorelines where the proposal could inhibit sediment flow or have an adverse impact on coastal processes at other locations. Impacts on coastal processes must be managed to minimise adverse impacts on other parts of the coast. Where such proposals are brought forward consent should only be granted where the Secretary of State is satisfied that the benefits (including need) of the development outweigh the adverse impacts (paragraph 5.5.11 of NPS EN-1).	A cable nearshore assessment is presented in volume 5, annex 1.1: Marine Processes Technical Annex, section 6. This assessment considers the nature of ongoing shoreline change at the nearshore area and the potential for cables and other project infrastructure to impact coastal processes. Summary details with regards to the coastal processes setting at the nearshore area are provided in paragraph 1.7.1.64 onwards. The significance of effects to coastal morphology are subsequently presented in paragraph 1.11.5.19 onwards (for the construction phase) paragraph 1.11.8.80 onwards (for the operation and maintenance phase) and paragraph 1.11.9.9 onwards (for the decommissioning phase).

Summary of NPS EN-1 and NPS EN-3 policy on decision making (and mitigation)	How and where considered in the Environmental Statement
The resilience of the project to climate change (such as increased storminess) should be assessed in the Environmental Statement accompanying an application (section 4.8 of NPS EN-1).	Potential changes in climate are described in paragraph 1.7.3.1 onwards and are taken into consideration within the assessments presented in section 1.11 and section 1.13.
An assessment of the effects of installing cable across the intertidal zone should include information, where relevant, about: • Any alternative landfall sites that have been considered by the applicant during the design phase and an explanation for the final choice; • Any alternative cable installation methods that have been considered by the applicant during the design phase and an explanation for the final choice; • Potential loss of habitat; • Disturbance during cable installation and removal (decommissioning); • Increased suspended sediment loads in the intertidal zone during installation; and • Predicted rates at which the intertidal zone might recover from temporary effects (paragraph 2.6.81 of NPS EN-3).	Effects of the cable installation in the nearshore area (including seabed disturbance and increased SSC) are presented in paragraph 1.11.5.19 onwards, whilst effects associated with decommissioning activities are presented in paragraph 1.11.9.9 onwards. Where possible, the assessment includes estimates of the rates which the intertidal area might recover from temporary effects. A cable nearshore assessment is also presented in volume 5, annex 1.1: Marine Processes Technical Annex, section 6. This assessment considers the nature of ongoing shoreline change at the nearshore area and the potential for cables and other project infrastructure to impact coastal processes. Details regarding project design at the nearshore area are set out in volume 1, chapter 3: Project Description. Details regarding alternative nearshore areas that have been considered during the design phase and an explanation for the final choice is provided in volume 1; chapter 4: Site Selection and Consideration of Alternatives. The potential for habitat loss is discussed within volume 2, chapter 2: Benthic Ecology.
Where necessary, assessment of the effects on the subtidal environment should include: • Loss of habitat due to foundation type including associated seabed preparation, predicted scour, scour protection and altered sedimentary processes; • Environmental appraisal of array and cable routes and installation methods; • Habitat disturbance from construction vessels' extendible legs and anchors; • Increased suspended sediment loads during construction; and • Predicted rates at which the subtidal zone might recover from temporary effects (paragraph 2.6.113 of NPS EN-3).	Changes to the subtidal environment (including elevations in SSC) are described in paragraph 1.11.4.8 to 1.11.4.10. Where possible, the assessment includes estimates of the rates which the subtidal zone might recover from temporary effects. The impact of Hornsea Three on identified marine processes receptors is considered in paragraph 1.11.5.1 onwards (for the construction phase), paragraph 1.11.8.1 onwards (for the operation and maintenance phase), paragraph 1.11.9.1 onwards (for the decommissioning phase) and paragraph 1.13.6.1 onwards (in the context of cumulative effects). The potential for habitat loss/change is discussed within volume 2, chapter 2: Benthic Ecology.
Assessment should be undertaken for all stages of the lifespan of the proposed wind farm in accordance with the appropriate policy for offshore wind farm EIAs (paragraph 2.6.190 of NPS EN-3).	The impact of Hornsea Three on identified marine processes receptors is considered in paragraph 1.11.5.1 onwards (for the construction phase), paragraph 1.11.8.1 onwards (for the operation and maintenance phase), paragraph 1.11.9.1 onwards (for the decommissioning phase) and paragraph 1.13.6.1 onwards (in the context of cumulative effects).
The Applicant should consult the Environment Agency, Marine Management Organisation (MMO) and Centre for Environment, Fisheries and Aquaculture Science (Cefas) on methods for assessment of impacts on physical processes (paragraph 2.6.191 and 2.6.192 of NPS EN-3).	Consultation on approach to assessment for marine processes has been carried out with the Environment Agency, MMO and Cefas. Details of the approach to consultation are provided in Table 1.4.
Geotechnical investigations should form part of the assessment as this will enable the design of appropriate construction techniques to minimise any adverse effects (paragraph 2.6.193 of NPS EN-3).	Geotechnical data has informed the assessment and project design of Hornsea Three. Details are provided in Table 1.6.
The assessment should include predictions of the physical effect that will result from the construction and operation of the required infrastructure and include effects such as the scouring that may result from the proposed development (paragraph 2.6.194 of NPS EN-3).	Changes to marine processes 'pathways' (e.g. elevated levels of SSC) are described in paragraph 1.11.2.1 onwards (for the construction phase) and paragraph 1.11.3.1 onwards (for the operation phase). The impact of Hornsea Three on identified marine processes receptors is considered in paragraph 1.11.5.1 onwards (for the construction phase) and paragraph 1.11.8.1 onwards (for the operation and maintenance phase). A full scour assessment is presented in volume 5, annex 1.1: Marine Processes Technical Annex, section 11. Results are summarised in paragraph 1.11.3.3 onwards.
Mitigation measures which the Secretary of State should expect the applicants to have considered include the burying of cables to a necessary depth and using scour protection techniques around offshore structures to prevent scour effects around them. Applicants should consult the statutory consultees on appropriate mitigation (paragraph 2.6.197 of NPS EN-3).	The built-in mitigation measures relating to cable burial and scour are set out in volume 1, chapter 3: Project Description.

1.4.2 Other relevant policies

1.4.2.1 A number of other policies are relevant to marine processes including:

- The East Marine Plans (MMO,2014);
- The Marine Strategy Framework Directive (MSFD);
- The UK Marine Policy Statement (HMSO, 2011).

1.4.2.2 Key provisions of these policies are set out in Table 1.3, along with details as to how these have been addressed within the assessment.

1.4.2.3 The overarching goal of the MSFD is to achieve 'Good Environmental Status' (GES) by 2020 across Europe's marine environment. (Although construction of Hornsea Three will not have commenced by 2020, the goals will very likely remain in place after this date.) Annex I of the Directive identifies 11 high level qualitative descriptors for determining GES. Those descriptors relevant to the marine processes assessment for Hornsea Three are listed in , including a brief description of how and where these have been addressed in the assessment.

1.4.2.4 Finally, a list of supporting guidance and best practice for the assessment of marine processes is provided within volume 5, annex 1.1: Marine Processes Technical Annex, section 3.

Table 1.3: Summary of other policies relevant to marine processes.

Summary of policy	How and where considered in the Environmental Statement
Marine Strategy Framework Directive	
MSFD high level descriptors of Good Environmental Status relevant to marine processes Descriptor 6: Sea floor integrity: Seafloor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected.	Predicted changes to the seabed are considered this chapter. The effects on marine ecosystems are considered in other relevant chapters namely volume 2, chapter 2: Benthic Ecology, volume 2, chapter 3: Fish and Shellfish Ecology and volume 2, chapter 4: Marine Mammals.
MSFD high level descriptors of Good Environmental Status relevant to marine processes Descriptor 7: Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems.	Predicted changes to hydrographic conditions are considered throughout this chapter, in particular during the operational phase of Hornsea Three when changes will be greatest (from paragraph 1.11.8.3 onwards for currents and from paragraph 1.11.8.18 onwards for waves). The effects on marine ecosystems are considered in other relevant chapters namely volume 2, chapter 2: Benthic Ecology, volume 2, chapter 3: Fish and Shellfish Ecology and volume 2, chapter 4: Marine Mammals.
Marine Plans	
East Inshore and East Offshore Marine Plans – ECO1 Cumulative impacts affecting the ecosystem of the East marine plans and adjacent areas (marine, terrestrial) should be addressed in decision-making and plan implementation.	Cumulative effects are considered within paragraph 1.13.2.1 onwards.
East Inshore and East Offshore Marine Plans – MPA1 Any impacts on the overall marine protected area (MPA) network must be taken account of in strategic level measures and assessments, with due regard given to any current agreed advice on an ecologically coherent network.	Designated nature conservation sites within the Hornsea Three and CEA marine processes study area have been described in paragraph 1.7.2.1 onwards. The predicted changes to marine processes have been considered in relation to indirect effects on other receptors elsewhere in the Environmental Statement, in particular volume 2, chapter 2: Benthic Ecology, volume 2, chapter 3: Fish and Shellfish Ecology, volume 2, chapter 4: Marine Mammals, volume 2, chapter 5: Offshore Ornithology and volume 2, chapter 9: Marine Archaeology.
UK Marine Policy Statement	
Coastal change and coastal flooding are likely to be exacerbated by climate change, with implications for activities and development on the coast. These risks are a major consideration in ensuring that proposed new developments are resilient to climate change over their lifetime. Account should be taken of the impacts of climate change throughout the operational life of a development including any de-commissioning period.	The vulnerability of Hornsea Three to coastal change (taking account climate change) is considered in the context of nearshore infrastructure, in paragraph 1.11.8.1 onwards.
Interruption or changes to the supply of sediment due to infrastructure has the potential to affect physical habitats along the coast or in estuaries.	Potential changes to sediment supply due to the operational presence of seabed infrastructure are considered in paragraph 1.11.8 onwards The potential for habitat change/ loss is discussed within volume 2, chapter 2: Benthic Ecology.

1.5 Consultation

1.5.1.1 A summary of the key issues raised during consultation specific to marine processes is outlined below, together with how these issues have been considered in the production of this Environmental Statement chapter.

1.5.2 Hornsea Project One and Hornsea Project Two consultation

1.5.2.1 Hornsea Three has similarities, both in terms of the nature of the development and its location, to Hornsea Project One and Hornsea Project Two. The matters relevant to Hornsea Three, which were raised by consultees during the pre-application and examination phases of Hornsea Project One and Hornsea Project Two regarding marine processes, are set out in volume 4, annex 1.1: Hornsea Project One and Hornsea Project Two Consultation of Relevance to Hornsea Three.

1.5.3 Hornsea Three consultation

1.5.3.1 Table 1.4 below summarises the issues raised relevant to marine processes, which have been identified during consultation activities undertaken to date. Table 1.4 also indicates either how these issues have been addressed within this Environmental Statement or how the Applicant has had regard to them. Further information on the consultation activities undertaken for Hornsea Three can be found in the Consultation Report (document reference number A5.1) that accompanies the application for Development Consent.

1.5.4 Evidence Plan

1.5.4.1 The purpose of the Evidence Plan process (see Evidence Plan; document reference number A5.1.1) is to agree with MMO, Natural England and Cefas the information Hornsea Three needs to supply to PINS, as part of a DCO application for Hornsea Three. The Evidence Plan seeks to ensure compliance with the Habitat Regulations Assessment (HRA) and EIA.

1.5.4.2 As part of the Evidence Plan process, the Marine Processes, Benthic Ecology and Fish and Shellfish Ecology Expert Working Group (EWG) was established with representatives from the key regulatory bodies and their advisors and statutory nature conservation bodies, including the MMO, Cefas and Natural England. Representatives from the Wildlife Trust (TWT), who were not part of the Marine Processes, Benthic Ecology and Fish and Shellfish Ecology EWG at the start, joined the Marine Processes, Benthic Ecology and Fish and Shellfish Ecology EWG from February 2017. Since June 2016, further Marine Processes, Benthic Ecology and Fish and Shellfish Ecology EWG meetings have been held that included discussion of key issues with regard to the marine processes elements of Hornsea Three, including characterisation of the baseline environment and the impacts to be considered within the impact assessment. The identification of key issues was informed by consultation on Hornsea Project One and Hornsea Project Two, where appropriate. Matters raised during EWG meetings have been included in Table 1.4 below.

Table 1.4: Summary of key consultation issues raised during consultation activities undertaken for Hornsea Three relevant to marine processes.

Date	Consultee and type of response	Issues raised	Response to issue raised and/or where considered in this chapter
December 2016	Natural England - Scoping	Realistic assessment is required regarding how cables will be buried and what level of protection will be needed where cables cannot be buried. The PEIR should provide details of the quantity, height and seabed take for the export cables and cable protection measures and should also describe preliminary mitigation and monitoring measures. Lessons should be learnt and incorporated from wind farms that have been installed in similar sediment types and water depths.	Maximum design scenario assumptions with regards to sediment disturbance during cable installation have been made to inform the marine processes assessment. Justification for the choice in input parameters is set out within Table 1.11. Where cables cannot be buried, alternative protection measures will be implemented. Full details of these are provided in volume 1, chapter 3: Project Description. A cable burial risk assessment will be undertaken post consent and pre construction to ensure appropriate levels of conservatism are factored into the cable installation plan.
December 2016	Natural England - Scoping	Consideration should be given to the potential for seabed sediment disturbance within the Hornsea Three array area and offshore cable corridor as well as the potential for change outside of this area, in response to material settling out of suspension.	A quantitative assessment of changes in SSC and associated change in bed levels has been carried out for turbine foundation and cable installation activities, as presented in volume 5, annex 1.1: Marine Processes Technical Annex, section 4 and in paragraph 1.11.2.3 of this chapter onwards. This assessment considers the advection and dispersion of sediment plumes within the Hornsea Three array area and offshore cable corridor and across the wider CEA marine processes study area.
December 2016	Natural England - Scoping	Sandwave clearance has now taken place at Race Bank offshore wind farm. Any available data and lessons learnt from this should be incorporated into the assessment as this is a new methodology and there is no empirical evidence regarding the impacts and effectiveness of technique.	A full assessment of sandwave clearance is presented in volume 5, annex 1.1: Marine Processes Technical Annex, section 4 and includes consideration of the sandwave clearance work undertaken at Race Bank offshore wind farm. An impact assessment for this activity is presented in paragraph 1.11.5.3 onwards.
December 2016	Natural England - Scoping	The assessment should consider the cumulative impact on the wave field arising from Hornsea Project One, Hornsea Project Two and Hornsea Three. Any uncertainty in the accuracy of the predictions should be clearly stated and quantified.	The potential for cumulative effects associated with Hornsea Project One, Hornsea Project Two and Hornsea Three are considered in paragraph 1.13.6.14 onwards. The technical information underpinning these assessments is presented in volume 5, annex 1.1: Marine Processes Technical Annex, section 8.
December 2016 February 2017 & November 2016 September 2017	Planning Inspectorate – Scoping Cefas – Expert Working Group Meetings MMO - Section 42	Robust justification is required regarding the application of an evidence based approach.	Justification for adopting an evidence based approach is set out in detail within volume 5, annex 1.1: Marine Processes Technical Annex, section 2. The previous modelling results from Hornsea Project One and Hornsea Project Two have been used alongside available monitoring evidence in a validatory manner to support new assessment of changes to marine processes for scenarios that are sufficiently similar in terms of the activity and environmental setting. New spectral wave modelling has also been undertaken.
April, 2017 December 2016	MMO/ Cefas – Expert Working Group Meetings Marine Management Organisation - Scoping	Concerns regarding the potential for transboundary effects as well as cumulative impacts.	Full justification for the inclusion/exclusion of projects within the CEA is provided in paragraph 1.12.1.5 onwards. A full assessment of cumulative effects is presented in paragraph 1.13.1.1 onwards. The Hornsea Three and CEA marine processes study area extends into the Dutch Exclusive Economic Zone (EEZ) and includes the Dutch Klaverbank SCI designated site. The potential for transboundary effects is considered within paragraph 1.14.1.1 onwards.
May 2017 September 2017	MMO/ Cefas – Expert Working Group Meetings MMO - Section 42	Concerns regarding the evidence based methodology used (in the PEIR) to assess the impact of waves, either as a single project or cumulatively, on sensitive receptors.	New spectral wave modelling has now been undertaken both for the Hornsea Three project alone and for the cumulative scenario involving Hornsea Project One, Hornsea project Two and Hornsea Three. Results are presented in volume 5, annex 1.1: Marine Processes Technical Annex, appendix B and are used to inform the assessment of wave impacts in paragraph 1.11.8.18 onwards for Hornsea Three project alone and in paragraph 1.13.6.12 onwards for Hornsea Three in conjunction with other relevant developments.
September 2017	MMO - Section 42	The MMO recommends that an assessment of the release of chalk subsoils into the water column is included in the Environmental Statement., including potentially large extents of effect for fine grains, and the potential change of seabed sediment type where chalk is deposited.	An assessment of the release of chalk subsoils into the water column as a result of cable installation is provided in paragraph 1.11.2.64 onwards. Finer chalk particles may be transported further, but are therefore also more likely to be more widely dispersed to very low concentrations and are subsequently unlikely to settle and accumulate in measurable quantities locally. Although the dispersion and settling of chalk arisings has been described in the marine processes chapter, the significance of effects to benthic receptors is covered in within volume 2, chapter 2: Benthic Ecology.

Date	Consultee and type of response	Issues raised	Response to issue raised and/or where considered in this chapter
September 2017	MMO/ Natural England - Section 42	Concerns regarding impact of material re-distribution from the mounds [from excavation of the HDD exit pits] throughout the shallow subtidal; permanent change to substrate from digging HDD pits into the chalk base; potential for suspended chalk to persist in the water column. Geophysical data should be collected from the nearshore area to enable consideration of potential geological controls on future morphological change to the beach.	New geophysical data has been collected at the nearshore area and is described in the baseline section (paragraph 1.7.1 onwards). This information has been used to inform the impact assessment (paragraph 1.11.5.19 onwards), in particular providing information with regards to potential morphological controls on the beach/ shallow nearshore seabed. The new geophysical data show that the HDD exit pits are unlikely to require chalk to be excavated during construction of the HDD exit pits. The nearshore assessment has been updated to include an assessment of the potential for the excavated (primarily sand and gravel) material to be redistributed throughout the nearshore area (paragraph1.11.5.24 onwards). The dispersion and settling of sediment disturbed during construction of the HDD exit pits has been described in the marine processes chapter and the significance of effects to benthic receptors is covered in within volume 2, chapter 2: Benthic Ecology.
September 2017	MMO - Section 42 Natural England - Section 42	Offshore sand banks should be included in the shoreline morphology assessment since they form part of coastal protection measures. The MMO also recommends that marine protected areas with designated sandbank features are included in the assessment. Conservation Advice for the site should be referred to when describing the sensitivity/vulnerability of the designated features. Conservation Advice for the North Norfolk Sandbanks and Saturn Reef SAC is available and should be referred to when describing the sensitivity/vulnerability of the designated features (such as sandbanks).	Offshore sandbanks have been included in the assessment of potential changes to coastal morphology (paragraph 1.11.8.22 onwards). Potential changes to marine protected areas with designated sandbank features are considered in paragraph 1.11.8.29 onwards. The assessments of sandbank sensitivity presented in paragraph 1.11.1.1 onwards have been updated to reflect the latest conservation advice for the North Norfolk Sandbanks and Saturn Reef SAC. Further discussion of sandbank recoverability has also been provided.
September 2017	Natural England - Section 42	The following impacts should also be considered as part of the marine processes chapter: • Physical damage to sandbank structure from trenching/jetting for offshore cables; • 'Scars' left from trenching; • Bed preparation for gravity bases: introduction of substrate/substrate change (for example mixed sandy sediments dredged and replaced by gravel/rock for stability and scour protection); • Change to sediment composition and structure (with subsequent effect on flow, sediment transport pathways, benthic ecology).	Consideration of the potential for cable installation activities to affect the integrity of sandbank features is provided in paragraph 1.11.5.12 onwards.. The persistence of scars associated with cable trenching activities is discussed in paragraph 1.11.2.41 (for the Hornsea Three array area) and paragraph 1.11.2.65 (for the Hornsea Three offshore cable corridor). The volumes of material involved with bed preparation/ sandwave clearance activities are presented within Table 1.11 and directly used to inform the assessment. The spatial extent of scour protection that may potentially be required is provided in Table 1.18. The implication of these changes to substrate (sediment composition and structure) on benthic ecology as a consequence of project construction is presented in within volume 2, chapter 2: Benthic Ecology.
September 2017	Natural England - Section 42	Natural England advises that the EIA should consider whether sandwave clearance might be done by other types of dredging. The EIA should also consider a scenario whereby an MMO licence for a new dredge disposal site is not granted and an existing site needs to be used. This may not necessarily be close to the area of dredging, resulting in the material loss from the environment.	The assessment considers sandwave clearance via mass flow excavator and through the use of a Trailing Suction Hopper Dredger (TSHD). These represent the maximum design scenario, both in terms of elevated levels of SSC (mass flow excavator) and deposit thickness (TSHD). Consideration has been given to a scenario whereby material is disposed of some distance away from the dredging area (see paragraph 1.11.5.10).
September 2017	Natural England - Section 42	Consideration should be given to the potential for the HDD exit pits to influence sediment transport.	Consideration of the potential for the HDD exit pits to influence sediment transport is provided in paragraph 1.11.5.19 onwards.
November 2017	Environment Agency - Section 42	The Environment Agency would like to remind Hornsea Three of our shoreline management position for the nearshore area; we no longer actively manage the barrier beach and that this is being allowed to roll back.	The prevailing shoreline management policy has been taken into consideration within the assessment of potential impacts at the nearshore area, presented in paragraph 1.11.5.19 onwards (for the construction phase) and paragraph 1.11.8.80 onwards (for the operation phase).
December 2017	British Marine Aggregate Producers Association (BMAPA) - Section 42	Supporting information provided for the alternative offshore routes makes no reference to potential interactions with existing marine aggregate interests (licensed/application/optioned), in accordance with Policies AGG1 and AGG2 of the East Inshore/Offshore Marine Plan.	Full justification for the inclusion/exclusion of projects within the CEA is provided in paragraph 1.12.1.5 onwards. A full assessment of cumulative effects is presented in paragraph 1.13.1.1 onwards. Licensed/consented/ aggregate extraction areas scoped into the assessment are as follows: • Humber 3 (484); • Humber 4 and 7 (506); and • Humber 5 (483).

Date	Consultee and type of response	Issues raised	Response to issue raised and/or where considered in this chapter
February 2018	MMO/ Cefas – Expert Working Group Meetings	Consideration to be given to the potential for multiple parallel sets of cable protection to block sediment transport. Timescales to be provided where possible for various assessed rates of change or recovery.	Consideration of the potential for cable protection to influence sediment transport is provided in paragraph 1.11.8.52 onwards. Timescales have been provided where possible, noting that the rate of some processes may vary greatly, e.g. depending on the frequency and intensity of storm events.

1.6 Methodology to inform the baseline

1.6.1 Overview

1.6.1.1 Understanding of the baseline conditions has been developed through consideration of both existing publicly available datasets and reports, as well as from the project-specific survey data. An overview of these various datasets is provided in this section. The adequacy of these surveys for informing the marine processes baseline has been agreed with regulators and stakeholders at the Hornsea Three Marine Processes, Benthic Ecology and Fish and Shellfish Ecology EWG meetings (6 June 2016, 12 July 2016, 17 November 2016, 1 February 2017, 11 April 2017, 4 December 2017 and 23 February 2018).

1.6.1.2 The approach proposed by Hornsea Three for the purposes of characterising marine processes is an evidence based approach to the EIA, which involves utilising existing data and information from sufficiently similar or analogous studies to inform the baseline understanding (and/or impact assessments) for a new proposed development. A more detailed discussion of the application of an evidence based approach to marine processes is provided in volume 5, annex 1.1: Marine Processes Technical Report.

1.6.2 Desktop study

1.6.2.1 Information on marine processes within the Hornsea Three and CEA marine processes study area was collected through a detailed desktop review of existing studies and datasets. These are summarised at Table 1.5 below.

Table 1.5: Summary of key desktop reports.

Title	Source	Year	Author
General			
Hornsea Project Two Environmental Statement: volume 2, chapter 1: Marine Processes (including supporting annexes and survey reports)	PINS Document Reference 7.2.1.	2015	SMart Wind
Hornsea Project One Environmental Statement: volume 2, chapter 1: Marine Processes (including supporting annexes and survey reports)	PINS Document Reference 7.2.1.	2013	SMart Wind
(former) Hornsea Zone Characterisation	11/J/1/06/1638/1254.	2012	SMart Wind
Water levels and currents			
Admiralty tide tables	United Kingdom Hydrographic Office (UKHO)	2017	-
Observational water level records	National Tide and Sea Level Facility (NTSLF) (https://www.ntslf.org/)	2017	-
Atlas of UK Marine Renewable Energy Resources	www.renewables-atlas.info/.	2008	ABPmer *et al.*
Observational current records	British Oceanographic Data Centre (BODC) (https://www.bodc.ac.uk/)	2016	-
Winds and waves			
Observational wave records	Cefas (http://cefasmapping.defra.gov.uk/TextSummary)	2017	-
Hindcast wind and wave data (1979 to 2015)	ABPmer SEASTATES (www.seastates.net/)	2016	-
Stratification and frontal systems			
Observational Conductivity-Temperature-Depth (CTD) records	BODC (https://www.bodc.ac.uk/)	2016	-
Stratified and non-stratified areas in the North Sea: long-term variability and biological and policy implications	Journal of Geophysical Research: Oceans. Vol 120(7)	2015	Van Leeuwen *et al.*
Dynamics of tidal mixing fronts in the North Sea	Philosphical Transactions: Physical Sciences and Engineering Vol 343(1669): understanding the North Sea System	1993	Hill *et al.*
Sediments and geology			
British Geological Survey (BGS) Offshore GeoIndex	(http://www.bgs.ac.uk/geoindex)	2017	-
Cromer Shoal Chalk Beds benthic survey	(http://data.cefas.co.uk/#/View/3821)	2015	Defra
Markham's Triangle rMCZ benthic survey	Defra Project Code: MB0120	2014	Defra
North Norfolk sandbanks survey	JNCC/Cefas Partnership Report, No. 7	2015	Cefas and JNCC
Southern North Sea synthesis	(unpublished)	2015	Cefas
The geology of the southern North Sea.	BGS United Kingdom offshore regional report:	1992	Cameron *et al.*,
North Sea Geology	BGS. Strategic Environmental Assessment – SEA2 and SEA3	2002	Balson *et al.*

Title	Source	Year	Author
Humber Regional Environmental Characterisation	BGS Open Report OR/10/54	2011	Tappin *et al.*
Seabed sediment, Quaternary geology and solid geology maps	BGS 1:250,000 map series	1987-1991	-
Satellite derived Suspended Particulate Matter (SPM) observations	Marine Aggregate Levy Sustainability Fund (MALSF) Project 09-P114	2011	Dolphin *et al.*
Observational records of SSC	Natural Environment Research Council (NERC) Land-Ocean Interaction Study (LOIS)	2000	Huntley *et al.*
Suspended Sediment Climatologies around the UK	Report for the UK Department for Business, Energy and Industrial Strategy offshore energy Strategic Environmental Assessment programme.	2016	Cefas
A synthesis of current knowledge on the genesis of the Great Yarmouth and Norfolk Bank Systems	Crown Estate, Research contract reference: OSR 06 06	2008	Cooper *et al.*
Southern North Sea Sediment Transport Study Phase 2 (SNS2)	(http://www.sns2.org/)	2002	HR Wallingford *et al.*
Sandbanks, sand transport and offshore wind farms	Department of Trade and Industry (DTI) Technical Report	2005	Kenyon and Cooper
Seabed geomorphology			
UK Hydrographic Office INSPIRE portal	UKHO (http://aws2.caris.com/ukho/mapViewer/map.action)	2017	-
Harmonised Digital Terrain Model (DTM) for the European sea regions	EMODnet Bathymetry partnership (www.emodnet-hydrography.eu/)	2017	-
North Norfolk sandbanks survey	JNCC/Cefas Partnership Report, No. 7	2015	Cefas and JNCC
Cromer Shoal Chalk Beds survey	(http://data.cefas.co.uk/#/View/3330)	2012-2014	Defra
Nearshore area geomorphology			
Regional Coastal monitoring data (including aerial photography, beach topographic data and Light Detection and Ranging (LiDAR) data	Anglia Regional Coastal Monitoring Programme (http://www.channelcoast.org)	1995 - present	-
LiDAR	Environment Agency contemporary and historic LiDAR	1999 – present	-
National Coastal Erosion Mapping	Environment Agency mapping http://maps.environment	2011	-
The North Norfolk Shoreline Management Plan SMP6: Kelling Hard to Lowestoft Ness (second generation)	(http://www.eacg.org.uk/smp6.asp)	2010	North Norfolk District Council
Sheringham Shoal Offshore Wind Farm Environmental Statement	www.marinedataexchange.co.uk/	2006	Scira Offshore Energy Ltd.
Dudgeon Offshore Wind Farm Environmental Statement;	www.marinedataexchange.co.uk/	2009	Dudgeon Offshore Wind Ltd

1.6.3 Identification of designated sites

1.6.3.1 All designated sites within the Hornsea Three and CEA marine processes study area that could be affected with respect to marine processes by the construction, operation and maintenance, and decommissioning of Hornsea Three, were identified using the three-step process described below:

- Step 1: All designated sites of international, national and local importance within the Hornsea Three and CEA marine processes study area were identified using a number of sources. These included JNCC, Natural England and the European Environment Agency (for the locations of non-UK designated sites);
- Step 2: Information was compiled on the relevant geomorphological features for each of these sites;
- Step 3: Using the above information and expert judgement, sites were included for further consideration if:
    - A designated site directly overlaps with Hornsea Three;
    - Sites and associated features were located within the potential Zone of Impact (ZoI) for impacts associated with Hornsea Three; and
    - A site is located in an area anticipated to be subject to some (greater than ~5% change in wave height) modification to the wave regime.

1.6.4 Site specific surveys

1.6.4.1 In order to inform the EIA, site-specific surveys were undertaken, as agreed with the statutory consultees (see Table 1.4 for further details). A summary of the surveys undertaken to inform the marine processes EIA is outlined in Table 1.6 below.

1.6.4.2 Table 1.6 and Figure 1.2 also provide a summary of the information previously collected from the former Hornsea Zone, which has been used to help inform understanding of the marine processes environment across the wider regional-scale.

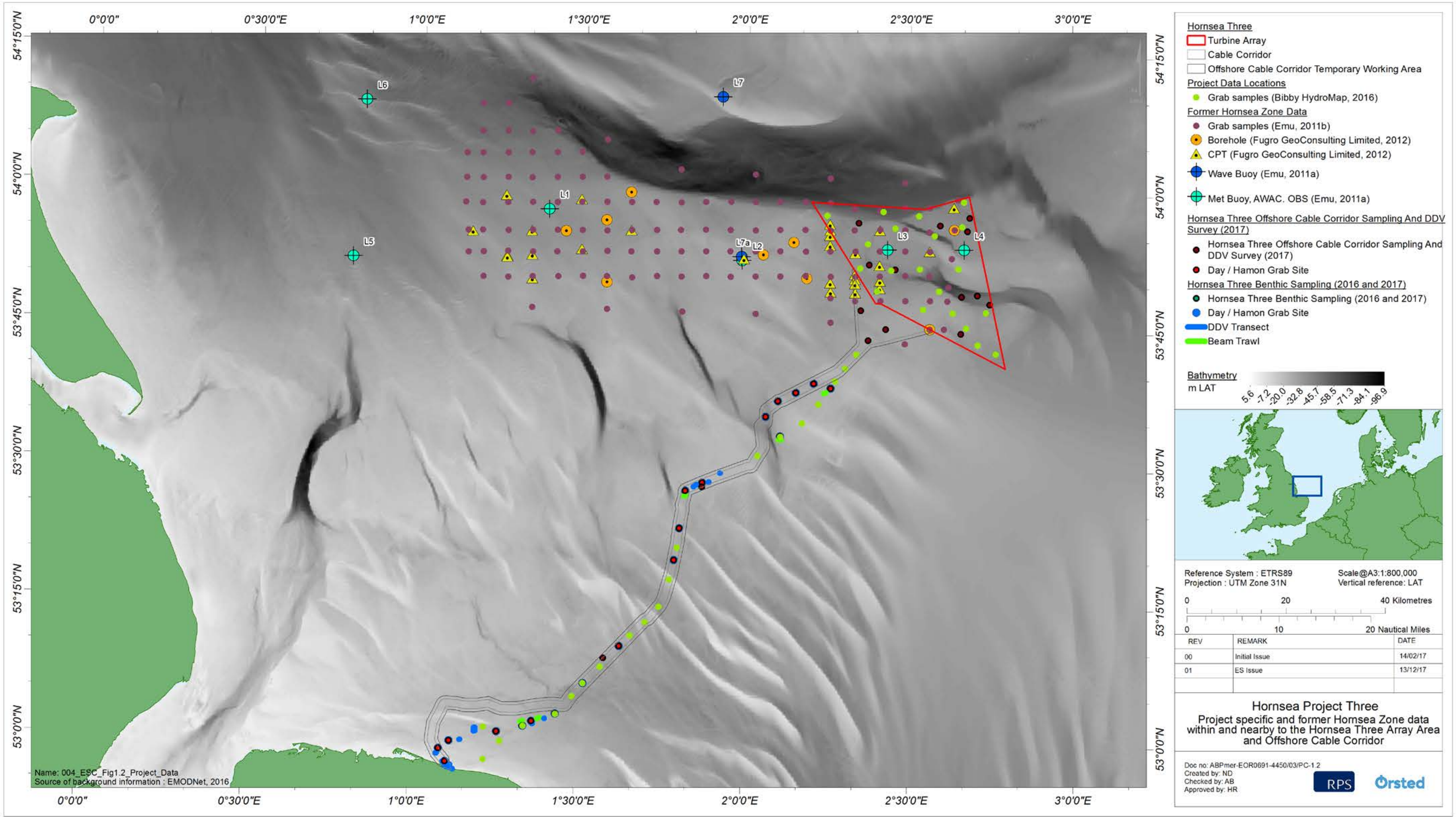

Figure 1.2: Project specific and former Hornsea Zone data within and nearby to the Hornsea Three array area and offshore cable corridor.

Table 1.6: Summary of site-specific and former Hornsea Zone survey data.

Title	Extent of survey	Overview of survey	Survey contractor	Date	Reference to further information
Hornsea Three nearshore bathymetric and geophysical survey	Hornsea Three nearshore	Bathymetric and geophysical survey consisting of dual frequency side scan sonar, seismic survey and magnetometer	Fugro GB Marine	2017	Fugro GB Marine (2017a). Volume 5, annex 2.1: Benthic Ecology Technical Report
Hornsea Three nearshore DDV surveys	Hornsea Three nearshore	Drop down video survey transects in nearshore area to help ground truth the geophysical survey.	Fugro GB Marine	2017	Fugro GB Marine (2017b). Volume 5, annex 2.1: Benthic Ecology Technical Report
Hornsea Three benthic sampling survey - within 60 nm	Hornsea Three offshore cable corridor out to 60 nm	14 combined Hamon grab sampling and DDV stations, 15 stations for DDV only, 5 stations for sediment chemistry only, five beam trawls.	Ocean Ecology	2017	Ocean Ecology (2017). Volume 5, annex 2.1: Benthic Ecology Technical Report
Hornsea Three benthic sampling survey - beyond 60 nm	Cable fan section of Hornsea Three offshore cable corridor and three sampling stations in Markham's Hole within the Hornsea Three array area	Six stations, three of which were also sampled for sediment chemistry, and 10 stations for DDV only	Gardline	2017	Gardline (2017). Volume 5, annex 2.1: Benthic Ecology Technical Report)
Hornsea Three survey of the intertidal nearshore area	Hornsea Three intertidal nearshore area (mean low water spring (MLWS) to MHWS)	Phase I walkover habitat survey habitat with 0.1 m^2 dig-over sampling	RPS Energy	2016	RPS Energy (2016). Volume 5, annex 2.1: Benthic Ecology Technical Report
Hornsea Three array area bathymetric and geophysical survey	Hornsea Three array area and cable fan area (100 m by 100 m line spacing)	Multibeam echo sounder, backscatter and sub bottom profiler.	Clinton	2016	Clinton (2016)
	Hornsea Three array area (500 m by 500 m line spacing)	Bathymetric and geophysical survey consisting of dual frequency side scan sonar, ultra-high resolution seismic survey, magnetometer and 20 ground truthing grab samples.	EGS	2016	EGS (2016)
Hornsea Three offshore cable corridor bathymetric and geophysical survey	Hornsea Three offshore cable corridor. The survey corridor width was 1.5 km, the line spacing varied between 55 and 60 m depending on the water depth, with 55 m spacing used in the shallower areas. There were also cross-lines along the entire route spaced at a nominal 1 km.	Bathymetric and geophysical survey consisting of dual frequency side scan sonar, seismic survey and magnetometer and 19 combined DDV and Hamon grab samples plus one DDV sample.	Bibby HydroMap	2016	Bibby HydroMap (2016)
Former Hornsea Zone metocean survey	Former Hornsea Zone	The Acoustic Wave and Current (AWAC) profilers recorded current profiles, tidal heights, directional wave data and acoustic backscatter (ABS) profiles. In addition, the frames were equipped with environmental sensors fitted with optical backscatter (OBS) and temperature sensors. Deployment locations L3 and L4 are located with the Hornsea Three array area (Figure 1.2). 432 days of water level and wave data is available from L3; whilst 344 days of data is available from L4. Meteorological data buoys were deployed at locations 1 to 6 (L1 to L6). A suite of sensors mounted on each of the data buoys was used to collect wind data (average and gust), atmospheric pressure, air temperature, humidity and rainfall intensity data.	Emu	2010 to 2011	Emu (2011a) (Reported in SMart Wind, 2012)
Former Hornsea Zone geotechnical survey	Former Hornsea Zone	Borehole (9 no.) and Cone Penetration Tests (CPTs) (27 no.) from locations across the former Hornsea Zone	Fugro GeoConsulting Limited	2011	Fugro GeoConsulting Limited (2012)
Zone characterisation (ZoC) benthic sampling survey	Former Hornsea Zone	Former Hornsea Zone benthic survey (27 no. grab samples within the Hornsea Three array area)	EMU	2010	Emu (2011b)

1.7 Baseline environment

1.7.1 Characterisation of the baseline environment

Overview

1.7.1.1 The characterisation of baseline marine processes within the Hornsea Three and CEA marine processes study area (Section 1.3;Figure 1.1) has been sub-divided into the following broad categories, namely:

- Water levels;
- Currents;
- Winds and waves;
- Stratification and frontal systems;
- Sediments and geology: (including seabed sediment distribution and sediment transport);
- Seabed geomorphology; and
- Nearshore geomorphology.

1.7.1.2 The baseline characterisation describes the natural variability of these regimes, both in terms of seasonal temporal change as well as medium/longer term change anticipated to occur over the lifetime of the project, in the absence of the proposed infrastructure. The baseline characterisation provides the reference condition against which to compare the impacts associated with Hornsea Three, enabling and providing the basis to inform the assessment of the significance of any consequential changes to the baseline.

1.7.1.3 This baseline characterisation of marine processes has been developed through the analysis and interpretation of data and information from a variety of sources, including a programme of site-surveys (section 1.6.4), pre-existing datasets and the existing evidence base consisting of available published and grey literature (section 1.6.2).

1.7.1.4 In this section, the following terminology is used to characterise geographical areas of the Hornsea Three offshore cable corridor:

- Nearshore area (0 mLAT contour out to ~ -5 mLAT contour);
- Inshore area (~ -5 mLAT contour out to ~ -20 mLAT contour); and
- Offshore area (seaward of the ~ -20 mLAT contour).

Water levels

Hornsea Three array area

1.7.1.5 Tidal characteristics of the Hornsea Three array area have been determined on the basis of the project-specific metocean deployments (Emu, 2012a) (Table 1.7), with a regional-scale overview provided by the Atlas of UK Marine Renewable Energy Resources (ABPmer *et al.*, 2008) and UKHO Co-tidal and Co-range charts (UKHO, 1996). Together, these show that the site is situated in a semi-diurnal tidal setting with a meso-tidal range. In this area, the tidal wave propagates from north to south (i.e. high tide occurs earlier in the north and moves southwards and tidal range is found to increase in an east to west direction). At deployment location L4 (eastern margin of the Hornsea Three array area) (Figure 1.2), the mean spring range is approximately 2.0 m, increasing to approximately 2.5 m along the western margin of the Hornsea Three array area.

1.7.1.6 Water levels in the region are occasionally affected by storm surges. The 50-year return period positive storm surge elevation (above the expected tidal water level) is approximately 2 m within the Hornsea Three array area (Flather, 1987; HSE, 2002).

Table 1.7: Summary of water level measurements from the Hornsea Three array area (L3 and L4) and near the nearshore area (measurement locations shown in Figure 1.2).

Level	Location		
	Weybourne Hope [a] (m above LAT)	L3 (m above LAT)	L4 (m above LAT)
Highest Astronomical Tide (HAT)	-	3.2	3.0
Mean High Water Springs (MHWS)	5.4	2.7	2.5
Mean High Water Neaps (MHWN,)	4.1	2.1	2.0
Mean Sea Level (MSL)	2.7	1.6	1.5
Mean Low Water Neaps (MLWN)	1.9	1.0	1.0
Mean Low Water Springs (MLWS)	0.5	0.5	0.5
Lowest Astronomical Tide (LAT)	-	0	0
Mean Spring Range (MSR)	4.9	2.2	2.0

a Levels at Weybourne based on ODN 2.75 m above Admiralty Chart Datum (CD) at Cromer. CD at Cromer 0.1 m above LAT

Source: UKHO (2007)

Hornsea Three offshore cable corridor

1.7.1.7 Along the Hornsea Three offshore cable corridor the tidal range increases with proximity to the Norfolk coast. At the offshore end of the cable corridor, the mean spring tidal range is approximately 2.5 m whereas at the nearshore area the tidal range is approximately 5.0 m (Table 1.7) (ABPmer *et al*., 2008; UKHO, 2007).

1.7.1.8 The 50-year return period positive storm surge elevation (above the expected tidal water level) is approximately 2 m at the offshore end of the Hornsea Three offshore cable corridor, increasing to around 2.5 m at the nearshore area (Flather, 1987; HSE, 2002).

1.7.1.9 Information on extreme return period total water levels (including both tide and storm surge contributions) is also available from the Environment Agency (Environment Agency, 2011). In this report, statistical analyses (skew surge joint probability method) have been applied to surge water level data from the POL continental shelf tide-surge (CSX3) model (12 km resolution) to provide extreme return-period total water level predictions for Weybourne. It is predicted that the 1-year total extreme positive water level elevation for Weybourne is 3.44 m above Ordnance Datum Newlyn (ODN) (6.19 m above LAT) whilst the 50-year prediction is 4.21 m ODN (6.96 m above LAT).

Currents

Hornsea Three array area

1.7.1.10 A regional-scale overview of the spatial variation in tidal current speed and direction is provided in Figure 1.3 and Figure 1.4, with more detailed information for the Hornsea Three array area available from the project-specific metocean survey (Emu, 2011a). Ebb tidal currents are to the northwest and peak close to the time of local low water; flood tidal currents are to the southeast and peak close to the time of local high water. The magnitude of peak tidal current speed increases from east to west. At deployment location L4 (the eastern margin of the Hornsea Three array area), maximum (metonic) tidal current speeds are 0.67 m/s; at deployment location L3 (the western margin of the Hornsea Three array area), maximum tidal current speeds are 0.71 m/s. More generally, peak mean spring tidal current speeds within the site are ~0.5 m/s; peak mean neap tidal current speeds are ~0.25 m/s (Emu, 2011a).

1.7.1.11 Spring tidal excursion ellipses (showing the approximate path that a package of water would follow over the course of a mean spring tide) are relatively rectilinear in nature (typically closely aligned to a main tidal axis with relatively small deviations in direction during flood and ebb tides) across the Hornsea Three array area and are typically between ~6 and 8 km in length (Figure 1.4). However, the presence of asymmetric crested bedforms within the Hornsea Three array area potentially suggests some variation between ebb and flood tidal characteristics. The implications of this for sediment transport are discussed in paragraph 1.7.1.42.

1.7.1.12 The mean or residual drift component of the current is small with speeds typically <0.02 m/s, typically orientated towards the east-northeast. Ninetieth percentile values for the residual velocity component of the flow are small when compared with their tidal counterparts demonstrating that the current experienced in this region are predominantly tidal with minimal distortion of tidal ellipses (Emu, 2011a).

1.7.1.13 However, whilst the observed currents are largely tidally dominated with most of the energy associated with the semi-diurnal harmonics, high current speeds associated with meteorological forcing may occur for short periods of time. Indeed, such flows (which often exceed that of the tidal component) were experienced during storm events recorded during the former Hornsea Zone metocean survey campaign, indicating the potentially important (temporary) influence of meteorological forcing on current speed (Emu, 2011a). In addition to the above, localised flows associated with frontal mixing may also occur in summer months. These are described further in paragraph 1.7.1.27.

Hornsea Three offshore cable corridor

1.7.1.14 Tidal streams along the Hornsea Three offshore cable corridor are broadly aligned to the coast and therefore in an approximate northwest to southeast orientation, becoming more east-west aligned at the nearshore area (Figure 1.4). More complex flow patterns will occur in the vicinity of the sandbank systems located along the offshore cable corridor and these areas may also be associated with local asymmetry in the relative strength, duration and direction of ebb and flood currents.

1.7.1.15 Similar to the gradient in tidal range, peak mean spring tidal current speeds increase from around 0.5 m/s at the offshore terminus of the Hornsea Three offshore cable corridor, to approximately 1.0 m/s in the vicinity of the nearshore area (ABPmer *et al*., 2008) (Figure 1.3). This gradient in flow speed is accompanied by an offshore to nearshore increase in the length of spring tidal excursion ellipses, which reach a maximum length of approximately 18 km off the Norfolk coast (Figure 1.4).

1.7.1.16 Non-tidal factors may also have important short-term influences on current speed and direction in the Hornsea Three offshore cable corridor. Wind and wave induced flows become increasingly important in shallow nearshore areas whilst currents associated with large storm surge events may be of similar magnitude to peak spring tidal current speeds, especially in the furthest offshore sections of the offshore cable corridor (ABPmer *et al*., 2008; HSE, 2002).

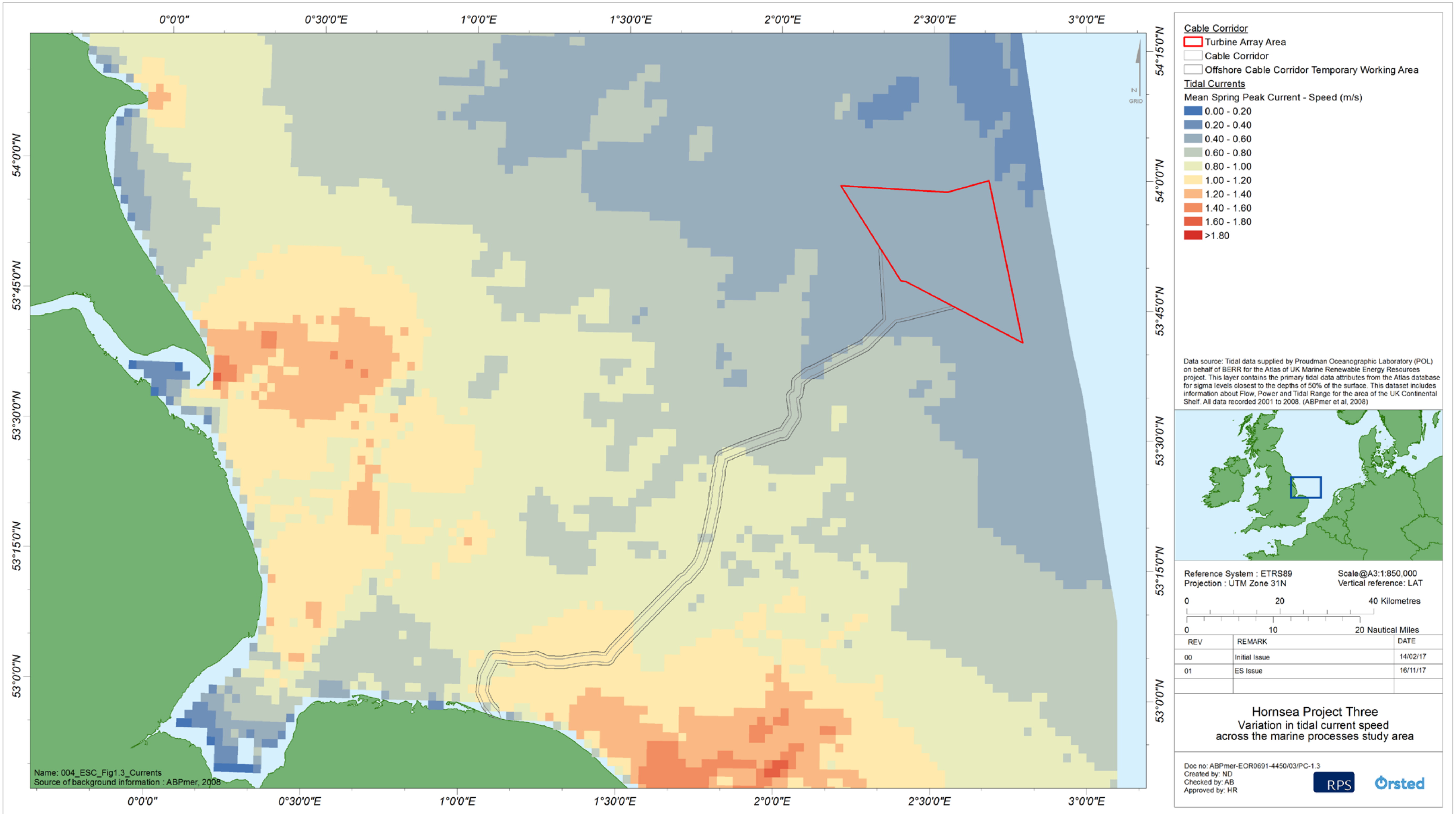

Figure 1.3: Variation in tidal current speed across the Hornsea Three marine processes study area.

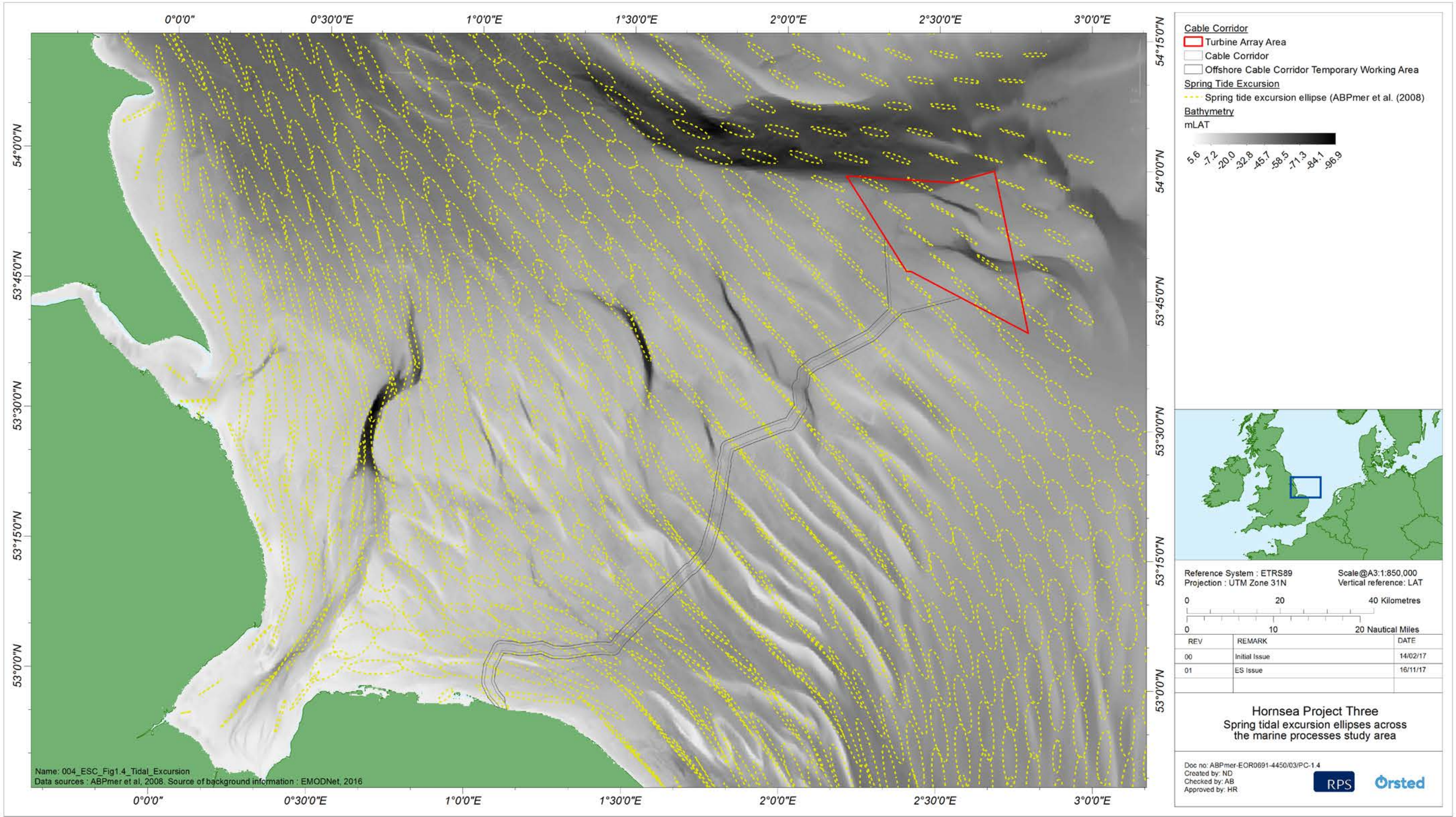

Figure 1.4: Spring tidal excursion ellipses across the Hornsea Three marine processes study area.

Winds and waves

Hornsea Three array area

1.7.1.17 Figure 1.5 presents a wind rose for the Hornsea Three array area. The wind rose is based on 36 years of hindcast wind records from the National Centers for Environmental Prediction (NCEP) Reanalysis-2 (Saha *et al.*, 2010), Climate Forecast System Re-analysis (CFSR) (http://rda.ucar.edu/datasets/ds093.1/) and CFSRv2 (http://rda.ucar.edu/datasets/ds094.1/) wind hindcasts. In the vicinity of the Hornsea Three array area, during summer and autumn, the prevailing winds come from the southwesterly quadrant. An analysis of the data shows that during the winter and spring, winds from northerly sectors are more common and often these are associated with longer period swell waves propagating into the North Sea from the North Atlantic. Importantly, the only directional sectors from which Hornsea Three can potentially influence the nearshore wind-wave climate along the north Norfolk and Lincolnshire coast are (approximately) north through east. However, winds from these directions typically only occur for approximately 23% of the time (Table 1.8). Conversely, for the majority of time (~77%) winds (and so the majority of waves) are directed away from, or parallel to, the coastline.

Table 1.8: Wind direction frequencies within the Hornsea Three array area. Based on hindcast wind data from NCEP for the period 1979 to 2015.

Directional sector	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Frequency (% of time)	5.4	4.5	4.3	4.3	4.6	4.6	4.2	4.8	6.7	8.5	9.9	10.2	9.0	6.8	6.2	6.2

1.7.1.18 Figure 1.6 presents a series of wave roses from locations within the Hornsea Three array area as well as along the offshore cable corridor. These wave roses are based on 36 year hindcast wave records from the ABPmer SEASTATES wave hindcast database (ABPmer, 2013a). Collectively, they illustrate spatial variation in wave conditions across this region. These hindcast records are broadly consistent with the observational wave records collected during the former Hornsea Zone metocean campaign in that they show a dominant wave direction within the Hornsea Three array area from the northwest to north. However, this dominance is more exaggerated in the observational records, potentially reflecting a greater occurrence of waves from the northwest to north during the ~1 year zonal metocean campaign than typically is the case over longer time-scales.

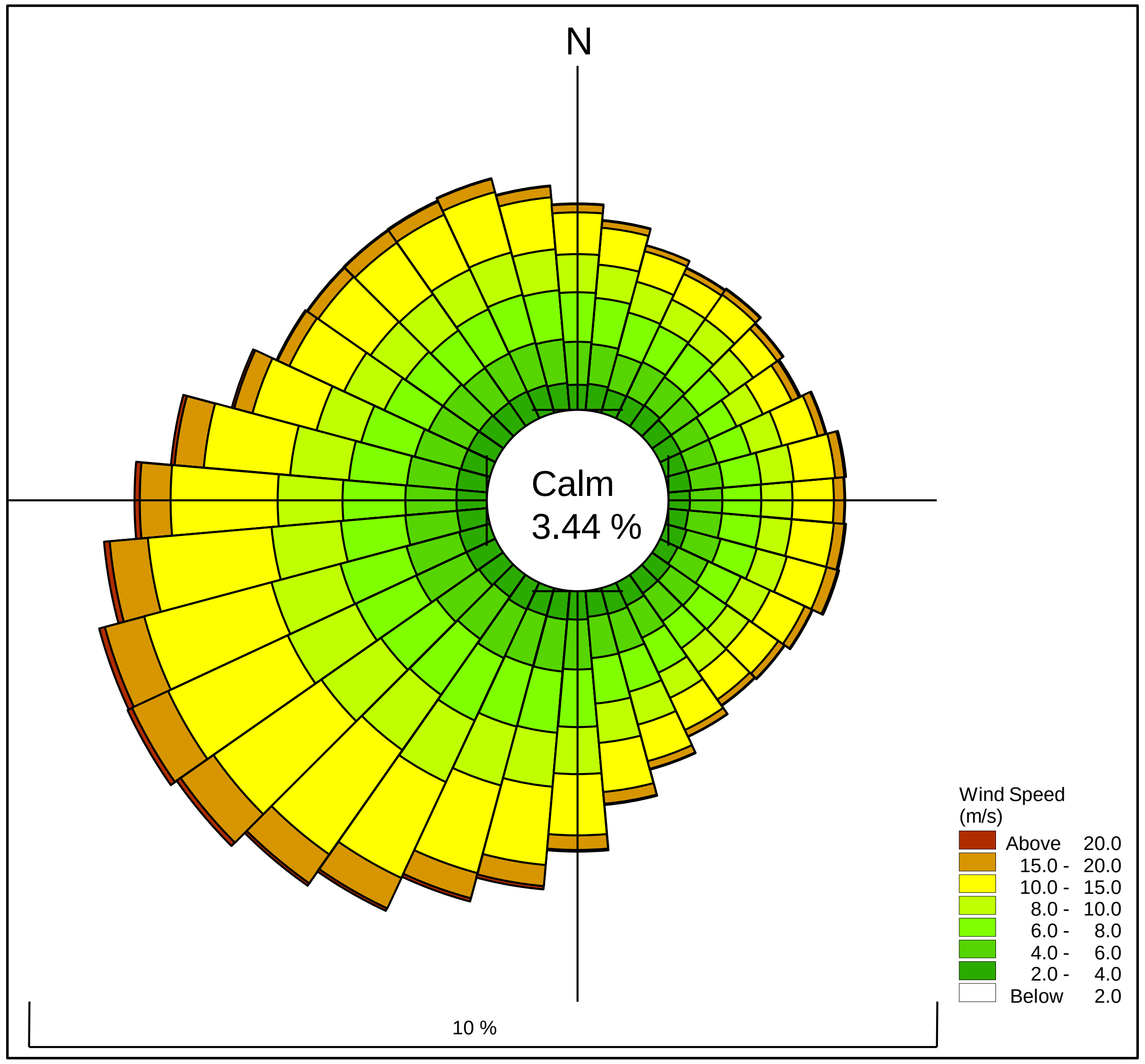

Figure 1.5: Wind rose for the Hornsea Three array area. Based on hindcast wind data from NCEP for the period 1979 to 2015.

1.7.1.19 Winds most frequently come from the southwest quadrant but also come from all other directions with some regularity. The wave climate at any particular location offshore is affected by both the local wind waves (driven by the wind climate) and also a swell component, which may be generated by distant storms. As such, peaks in wave energy are also observed from northerly and southerly directions, corresponding to relatively longer fetch lengths. The directional distribution and peaks in wave energy are also affected by the relative distribution of shallow water and the position of adjacent coastlines, which may provide sheltering from certain directions.

1.7.1.20 The former Hornsea Zone metocean survey results demonstrate that under certain prevailing wave directions, spatial variation may occur in instantaneous wave height across the Hornsea Three array area. For example, during the storm of the 24 July 2011, deployment location L3 recorded a peak significant wave height of 6.67 m, which was around 1.4 m higher than the maximum value observed at L4 (which recorded a peak significant wave height of 5.24 m) (SMart Wind, 2012). Such spatial variation at any particular time is likely to reflect both the influence of bathymetry on wave characteristics, variation in fetch distances and patterns of wind speed at the scale of the individual storm. However, variations in longer term wave climate between Hornsea project One, Hornsea Project Two and Hornsea Three are relatively minor (Figure 1.6).

1.7.1.21 On the basis of the former Hornsea Zone metocean survey (described in SMart Wind, 2012), the 90th percentile significant wave height (representing the wave height value that 90% of the record are either less than or equal to) is between approximately 1.7 m to 1.9 m during summer months and between 2.5 m and 2.7 m in winter months. Associated values for wave periods are between 5.8 s and 6.6 s (for summer months) and between 6.6 s and 7.1 s (for winter months). However, it is noted that during the metocean survey wave peak periods were found to vary between 2 seconds and 20 seconds, indicating that the waves recorded include both locally generated wind waves and remotely generated swell waves (SMart Wind, 2012).

1.7.1.22 Significant wave height return period statistics have been generated for the Hornsea Three array area using the observational wave records from the former Hornsea Zone metocean survey (locations L3 and L4; Figure 1.2). The derived return period statistics are presented in SMart Wind, 2012) and are almost identical for both measurement locations: the 1:1 year significant wave height is calculated as 5.9 m, whereas equivalent values for the 1:10 year and 1:50 year event are 6.9 m and 7.5 m, respectively (SMart Wind, 2012).

<u>Hornsea Three offshore cable corridor</u>

1.7.1.23 In the deeper offshore areas of the Hornsea Three offshore cable corridor, waves will propagate without major modification and the wave regime will have similar characteristics to that described above for the Hornsea Three array area. However, as waves move into shallower water, refraction, shoaling (wave steepening) and potentially wave breaking may occur, modifying individual waves and the collective wave climate. Across the shallow banks of the Norfolk Sandbank system, maximum wave heights will become ‘depth limited’ with the potential for wave breaking to occur during storm events and/or around low tide. As a consequence of the above processes, the wave regime within inshore and nearshore areas will be of a generally similar or smaller wave height and period than offshore areas, but may also exhibit a degree of spatial variability owing to the sheltering effect of the banks further offshore (Figure 1.6).

1.7.1.24 In offshore areas, waves will tend to only periodically stir the bed and will not contribute regularly to the net transport of sediment. However, in shallower nearshore areas they have a more important role to play in alongshore and cross-shore sediment transport and will play a key role in driving morphological change.

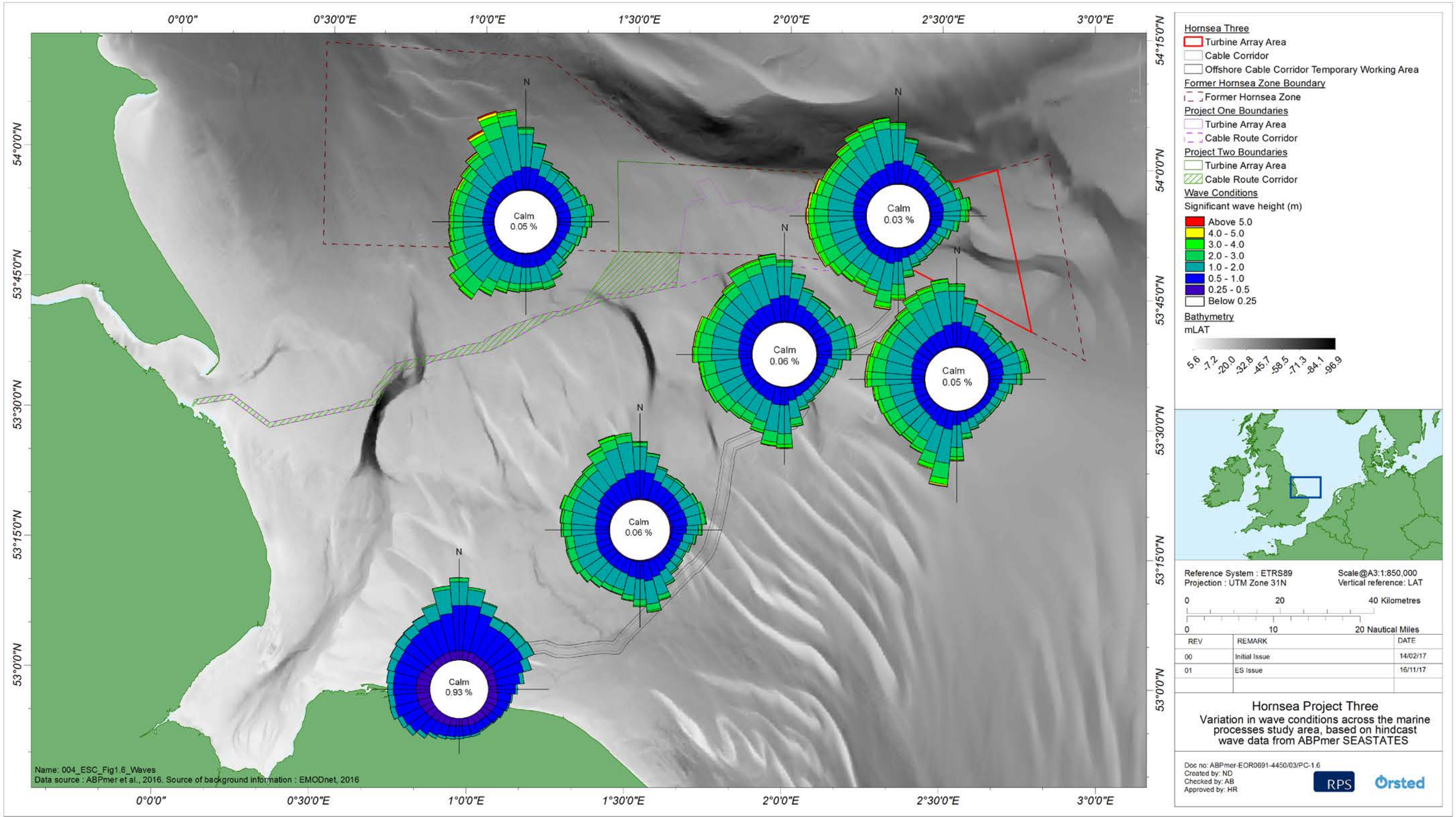

Figure 1.6: Variation in wave conditions across the Hornsea Three marine processes study area. Based on hindcast wave data from ABPmer SEASTATES for the period 1979 to 2015.

Stratification and frontal systems

1.7.1.25 Stratification is a seasonal feature of the North Sea. During the summer, increased heat from solar radiation and higher air temperatures preferentially warm the upper parts of the water column, creating temperature differences of up to 10 degrees with the cooler bottom layer. The difference in temperature (sometime also enhanced by differences in salinity) results in a difference in water density and a layer of more buoyant (warmer fresher) water overlying more dense (colder, saltier) water with a relatively steep gradient separating the two layers. Such stratification is typically confined to areas of deeper water. In shallower water, turbulence from wind stress at the water surface and bottom friction at the bed can penetrate more easily throughout the water column and will tend to prevent or break down stratification (Carpenter *et al*., 2016). The Hornsea Three array area is located in an intermittently stratified region, with the offshore cable corridor almost entirely located in permanently mixed waters (Figure 1.7a-c) (van Leeuwen *et al*., 2015). Indeed, for in excess of ~80% of the time throughout the analysis period (1958 to 2008), the water column within the Hornsea Three array area could be classified as intermittently stratified (Figure 1.7b). Conversely, along almost the entire Hornsea Three offshore cable corridor the water column was mixed for in excess of ~90% (Figure 1.7c).

1.7.1.26 The Flamborough Front is a key oceanographic feature that occurs where the different water masses from the northern and southern North Sea combine (Figure 1.7a). This creates an area rich in nutrients, forming an important ecological feature. The Flamborough Front extends offshore from Flamborough Head and through the general area of the former Hornsea Zone in summer months. It is the interface between areas of more stratified water in the generally colder, deeper, northern North Sea, and more well-mixed water in the generally warmer, shallower, southern North Sea.

1.7.1.27 The Flamborough Front is characterised by a distinct temperature gradient between the waters north and south of the Flamborough headland (Pingree and Griffiths 1978). It is predominantly a bottom feature but has a weak surface signature and is visible in satellite infrared images (Hill *et al*., 2005). Circulation patterns at the front are complex. The most pronounced feature is an along-front jet driven by the cross-front density-induced pressure gradient. This current is expected to be in the order of 0.15 m/s, occurring in an offshore direction towards Dogger Bank (Hill *et al*., 2005). Secondary circulation perpendicular to the Flamborough Front, of the order <0.05 m/s, is predicted to be driven by pressure field instabilities causing upwelling of cold bottom water on the mixed front (Simpson *et al*., 1978).

1.7.1.28 The Flamborough Front is located in close proximity to the Hornsea Three array area (Figure 1.7). However, its position is likely to exhibit significant inter-annual variability in response to similar variability in wind forcing – i.e. the front could extend to the north, south or through the Hornsea Three array area at various times during summer months. In addition, spring-neap and longer tidal cycles will modulate the level of tidal stirring causing periodic advance and retreat of the mean frontal position.

Sediments and geology

<u>Hornsea Three array area</u>

Surficial and sub-seabed sediments

1.7.1.29 The characterisation of geology and seabed sediments (in terms of type and thickness) is important as these sediments may be disturbed by bed preparation and/or drilling activities during the construction phase. The presence of older (pre-Holocene) deposits at or near to the seabed surface may also present a potentially erosion resistant surface that limits the potential for seabed change once the wind farm infrastructure is installed.

1.7.1.30 A summary is provided below based on the Hornsea Three geophysical data and existing zonal-scale information. The site stratigraphy can be broadly divided into (i) seabed sediments); (ii) Quaternary units; and (iii) solid geology (bedrock). Bedrock is defined as deposits which pre-date the Quaternary (i.e. being older than 2.6 Ma). Maps showing the distribution and thickness of these various units are provided in volume 5, annex 1.1: Marine Processes Technical Annex, section 4.

Seabed sediments

1.7.1.31 The Hornsea Three array area is characterised by the presence of coarse grained sediments with both sand and sandy gravel particularly prevalent (Figure 1.8) (Emu, 2011b; Clinton, 2016; EGS, 2016). In many areas, these coarse grained sediment units also contain some finer muddy material, reflecting lower energy settings more conducive to sediment deposition. This is particularly the case within the areas of deep water associated with Markham's Hole and Outer Silver Pit, a finding that is consistent with regional scale seabed mapping from the BGS (BGS and Rijks Geologische Dienst, 1987).

1.7.1.32 Most of this surficial sediment within the Hornsea Three array area is predominantly derived from reworking of Quaternary deposits, with a limited contribution from modern sources (fluvial and soft cliff erosion). The main control on the present distribution of seabed sediments was the sea level rise that took place at the end of the last glaciation (Tappin *et al*., 2011).

1.7.1.33 Together, the borehole and CPT records (collected during the former Hornsea Zone surveys) along with the Hornsea Three geophysical survey show that surficial sediment units are typically less than 1 m thick across large areas of the Hornsea Three array area (Fugro GeoConsulting Limited, 2012). Notable departures from this general pattern are Outer Silver Pit and Markham's Hole where the muddy sand sediment units reach ~35 m in thickness (EGS, 2016). It is suggested that these deeps may have been acting as sediment traps since the early Holocene (Zagwijn and Veenstra, 1966; Eisma, 1975).

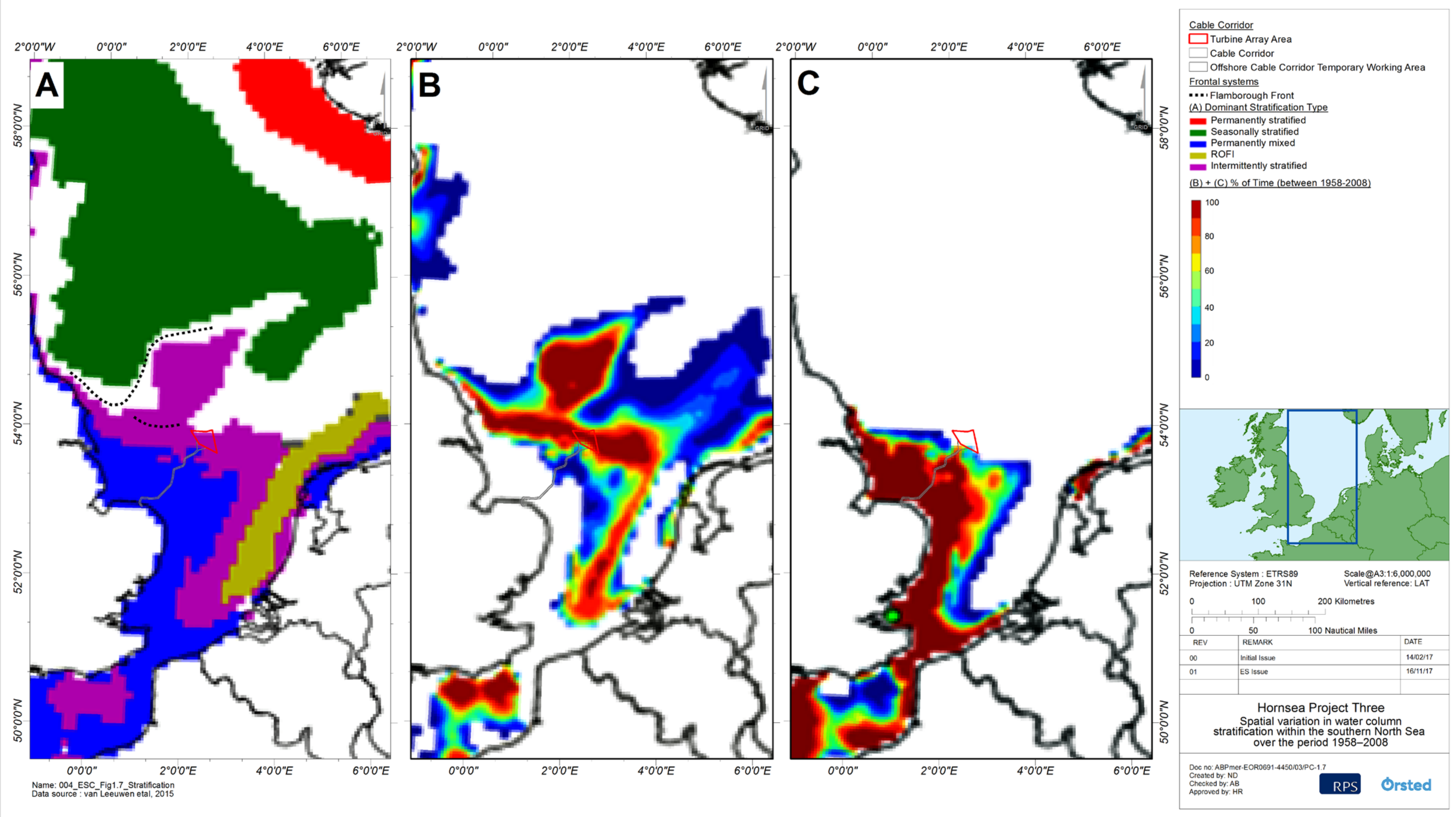

Figure 1.7: Spatial variation in water column stratification within the southern North Sea over the period 1958 to 2008 (reproduced from van Leeuwen *et al*., 2015).

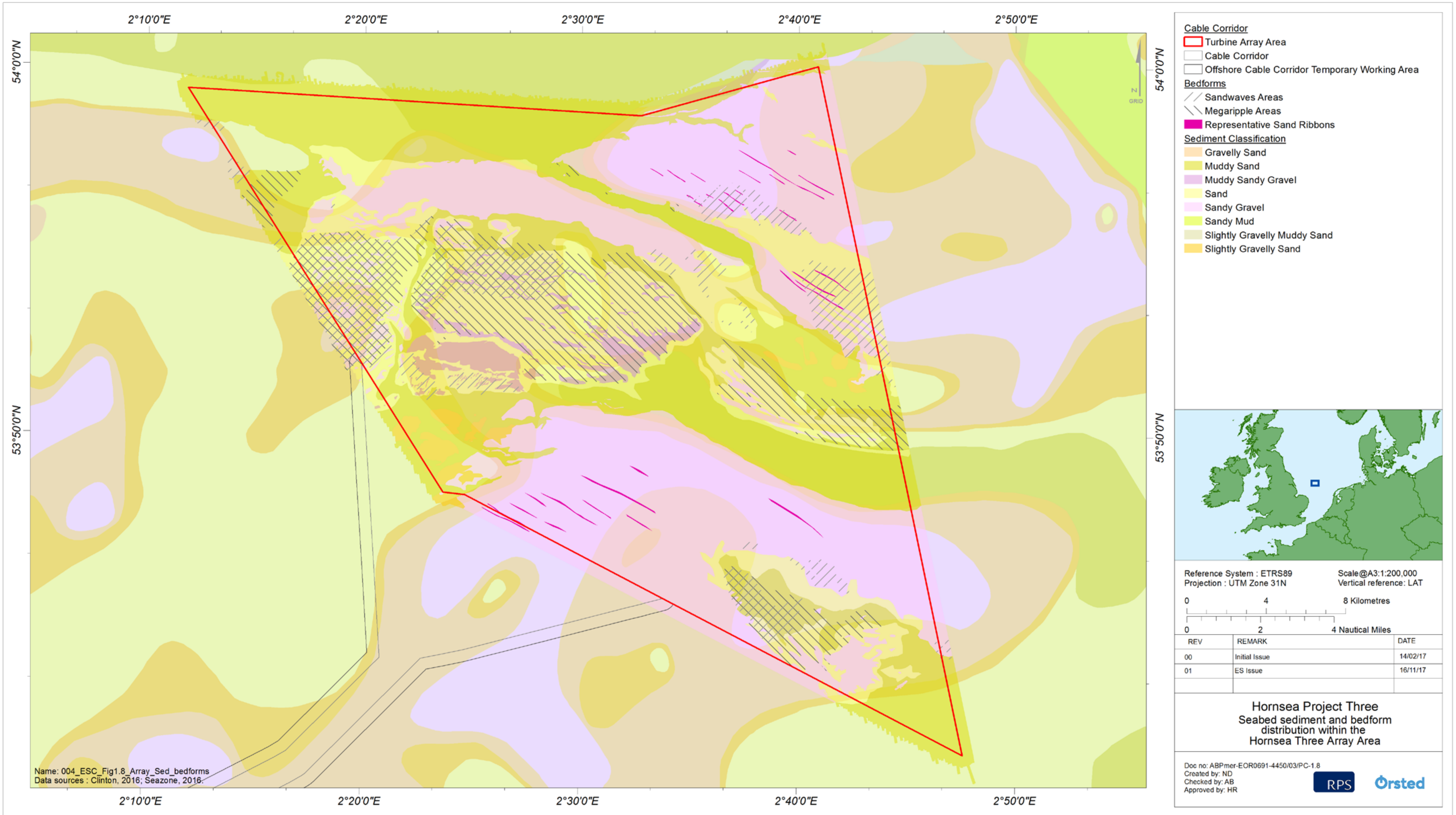

Figure 1.8: Seabed sediment and bedform distribution within the Hornsea Three array area.

Quaternary units

1.7.1.34 The Quaternary Period consists of the Pleistocene and Holocene Epochs and encompasses the period during which humans first occupied and exploited the landscape. During glacial maxima, lower sea levels exposed the Hornsea Three array area as land (e.g. Brooks *et al*., 2011). Hence, the underlying geology comprises unconsolidated sediments of glacial and fluvial origin. Post-glacial marine transgression led to the re-working of these sediments.

1.7.1.35 The complete succession of Quaternary deposits within the former Hornsea Zone consists of (youngest to oldest):

- Botney Cut Formation (mainly sands);
- Bolders Bank Formation (stiff diamictons with widely ranging grain sizes);
- Eem Formation (very fine to medium-grained, slightly gravelly, shelly sands);
- Egmond Ground Formation (gravelly sands interbedded with silt and clay);
- Swarte Bank Formation (mainly glacio-fluvial sands); and
- Yarmouth Roads Formation (characterised by a range of sediment types). (BGS, 1986; 1987; 1991; Cameron *et al*., 1992).

1.7.1.36 Deposits belonging to the Bolders Bank formation are found very close (< ~1 m) to the seabed surface across the vast majority of the Hornsea Three array area. Deposits belonging to the Botney Cut formation are also both widespread and encountered at shallow (< ~5 m) depths below the seabed surface. Conversely, the Yarmouth Roads, Swarte and Eem Formations are far less common, with the Yarmouth Roads and Swarte formations only encountered within Outer Silver Pit and the Eem Formation only present on the margins of Outer Silver Pit and Markham's Hole.

Solid geology (bedrock)

1.7.1.37 Consideration of the BGS 1:250 000 Solid Geology Sheet suggests that the bedrock in this region is likely to be chalk, argillaceous (clay) rock or mudstone comprising Tertiary, Mesozoic or Paleozoic aged units (BGS, 1987; Cameron *et al*., 1992). However, the available survey data suggests that bedrock is not exposed anywhere within the Hornsea Three array area and is instead overlain by varying thicknesses of Quaternary sediments. At no location is bedrock found within 50 m of the seabed and therefore it will not be disturbed by any project construction-related activities (EGS, 2016).

Suspended sediments

1.7.1.38 As part of the former Hornsea Zone metocean sampling campaign, optical back scatter (OBS) and acoustic backscatter (ABS) data were used to infer local SSC in the water column and near-seabed locations over an approximate 1 year period (2010/2011) EMU, 2011a) (Table 1.9 and Table 1.10 (see Figure 1.2 for locations). Relatively poor consistency was found between the ABS and OBS records from the Hornsea Three array area (deployment locations L3 and L4); however, it is understood that the OBS sensor at L4 may have been affected by biofouling, thereby providing erroneously high levels of turbidity. More generally, ABS and OBS sensors often have relatively poor consistency because they have variable sensitivity depending on the distribution of grain sizes in suspension. OBS sensors are more sensitive to (and therefore more accurately measure) the concentration of fine material, while the ABS is more sensitive to coarser material. Taking the above into consideration, SSC within the Hornsea Three array area was typically found to be in the range 10 to 30 mg/l although slightly higher values were experienced during spring tides and storm conditions (EMU, 2011a).

Table 1.9: Near-bed SSC statistics (derived from optical backscatter data) from each location.

Measurement Location	L1	L2	L3	L4	L5	L6
Minimum (mg/l)	0.1	0	0.2	0.07	0.02	0
Mean (mg/l)	17.5	4.9	26.5	66.2 [a]	31.8	17.2
Standard deviation (mg/l)	66.7	10.4	34	55	48	30.8

a Likely to be erroneous due to influence of biofouling

Table 1.10: Near seabed SSC statistics (derived from acoustic backscatter data) from each location.

Measurement Location	L1	L2	L3	L4	L5	L6
Minimum (mg/l)	6.5	0	2.5	3.4	1.9	3.6
Mean (mg/l)	14.6	5	10.9	9.9	11.6	11.4
Max (mg/l)	40.9	15.8	34	24.2	49.3	28.1
Standard deviation (mg/l)	3.8	2.4	5.6	3.6	7.7	3.8

1.7.1.39 The inference of relatively low turbidity levels made on the basis of the former Hornsea zone metocean sampling campaign is consistent with the synoptic sea surface turbidity maps of the North Sea available from Dolphin *et al*., (2011) and Cefas (2016), based on satellite observations. According to Dolphin *et al*., during the winter months, mean surface SPM concentrations are typically around 5 mg/l in the vicinity of the Hornsea Three array area, reducing to approximately 0 to 5 mg/l during summer months (Figure 1.9). This inferred seasonal variation is also supported by previous studies from the region which find that SSC is much lower during the summer than winter (Gerritsen *et al*., 2000; HR Wallingford *et al*., 2002).

1.7.1.40 A primary feature of the suspended sediment regime in the wider Hornsea Three marine processes study area is the East Anglia Plume. This is a region of elevated turbidity extending across the Southern Bight of the North Sea, the Dutch sector and eventually reaching the German Bight. The main axis of the plume is generally located approximately 50 km to the south of the Hornsea Three array area, as shown in Figure 1.9a. The plume passes to the south of the Hornsea Three array area, as such SSC within the array area itself generally remains low.

1.7.1.41 The sediments within the East Anglia Plume originate from river outlets (in particular the Thames Estuary and Humber Estuary) and also from localised cliff erosion, especially along the East Anglia coast (Dyer and Moffat 1998; van Raaphorst *et al*., 1998). Further offshore (but in water depths less than ~50 m), an additional sediment input comes from erosion of the sea floor during storm events.

Sediment transport

1.7.1.42 Within the vicinity of the Hornsea Three array area, including the area of Markham's Triangle rMCZ, tidal currents are the main influence on offshore sediment transport, rather than the wave climate. The relative importance of surge driven transport may increase in areas of normally weaker tidal flow (i.e. to the east of the Hornsea Three array area) (Kenyon and Cooper, 2005; HR Wallingford *et al*., 2002; Stride, 1982). Existing regional-scale mapping suggests that bedload sediment transport is broadly to the northwest in the vicinity of the Hornsea Three array area (e.g. Kenyon and Cooper, 2005; SMart Wind, 2015) and some evidence is available from the Hornsea Three array area (in the form of bedform asymmetry analysis of the 2016 bathymetry) to support this general interpretation (Figure 1.10).

1.7.1.43 Whilst broad regional scale net transport patterns have been inferred by previous studies, local sediment transport pathways may be more variable in rate and direction. The available bathymetry and geophysical data from both the Hornsea Three array area and the adjacent Hornsea Project One and Hornsea Project Two array areas reveals marked local variation in bedform asymmetry and therefore inferred transport direction (EGS, 2016; SMart Wind 2013, 2015). Several areas show no obvious bedform asymmetry and on this basis, only limited net rates of sediment transport are actually expected in the vicinity of the Hornsea Three array area.

1.7.1.44 The inference of limited net sediment transport is entirely consistent with theoretical estimates of bed shear stress for the Hornsea Three array area, based upon consideration of the prevailing hydrodynamic regime and threshold bed shear stresses required to initiate transport (Soulsby, 1997). It is also the case that:

- There is likely to be relatively little spatial variation in tidal current induced bed shear stress across the Hornsea Three array area, reflecting the fact that only minor variations in tidal current speeds are encountered (Figure 1.3);
- Under tidal current forcing alone, medium sand sized material is expected to be mobilised during spring tides whilst during neap tides only very fine sand will be mobilised. Gravel sized material will not be mobilised by the action of tidal currents; and
- In shallower areas of the site, storm surge and/or long period orbital currents may enable larger grain sizes (up to and including granule sized gravel) to be mobilised. However, these episodes will be infrequent.

1.7.1.45 Suspended sediment transport is more diffuse and ephemeral. However, a general northeasterly flux of suspended sediment occurs during winter months as part of the East Anglia Plume (Dyer and Moffat, 1998; Cefas, 2016).

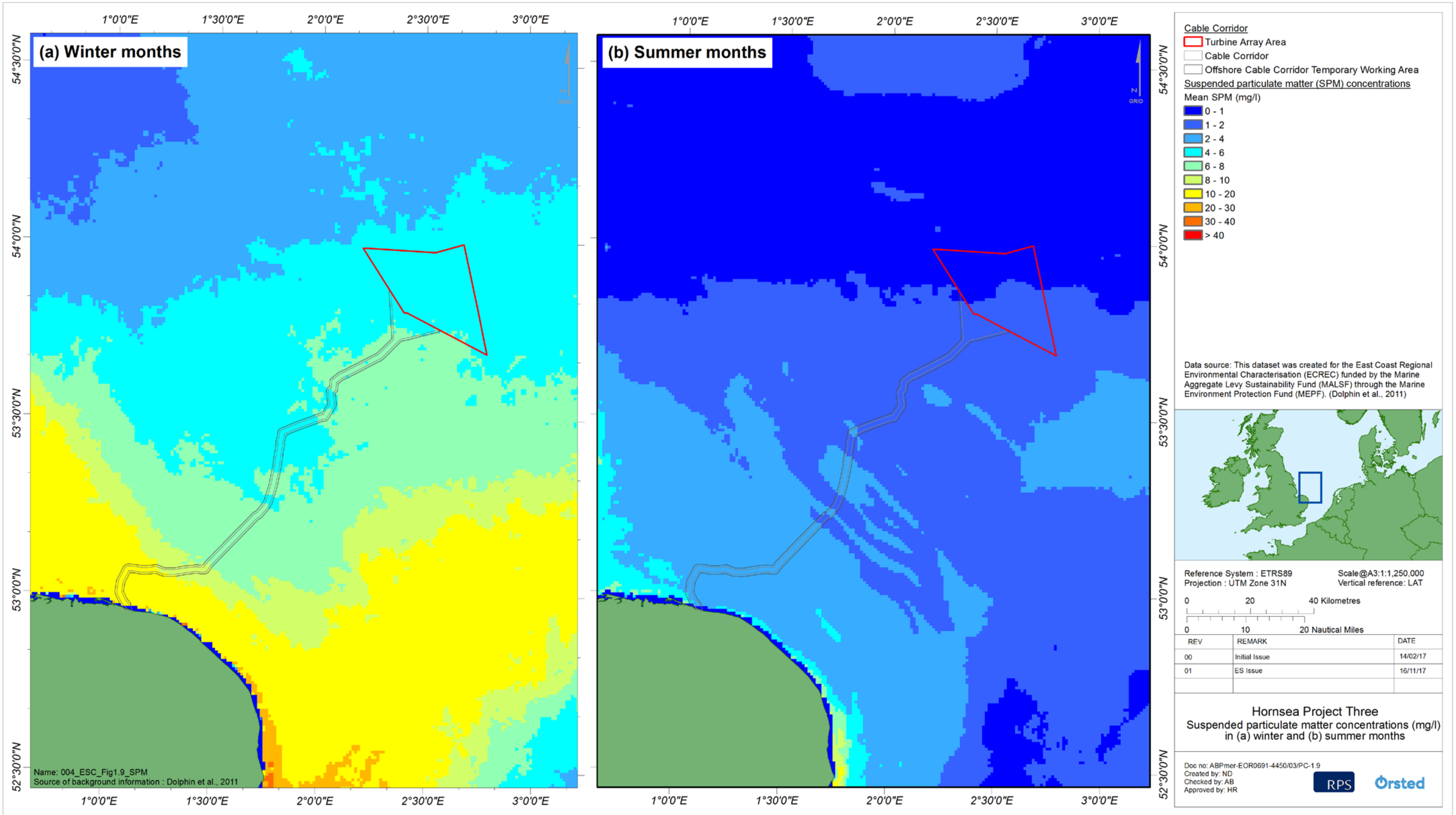

Figure 1.9: Suspended particulate matter concentrations (mg/l) in (a) winter and (b) summer months.

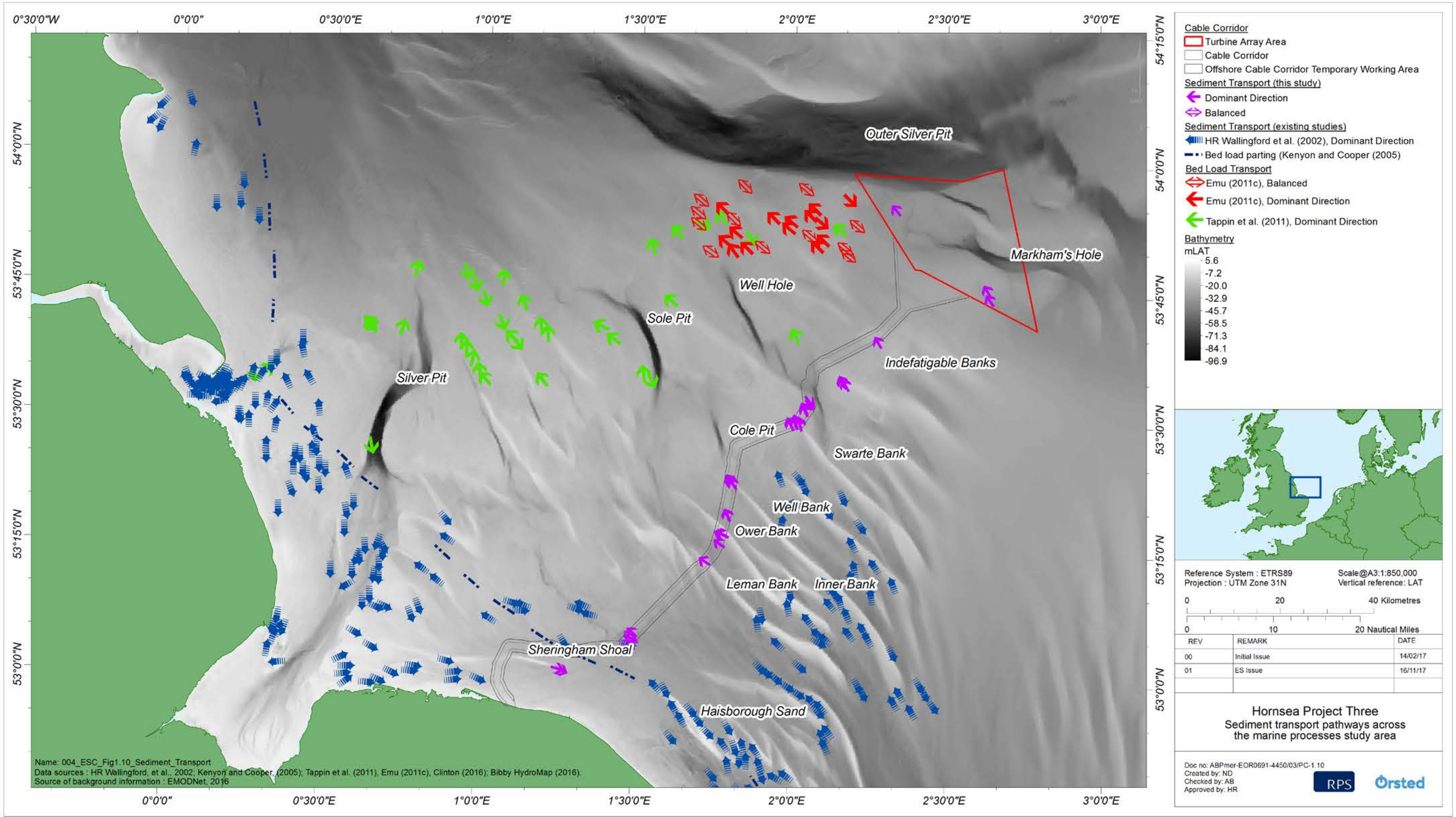

Figure 1.10: Sediment transport pathways across the Hornsea Three marine processes study area.

Hornsea Three offshore cable corridor

Surficial and sub-seabed sediments

1.7.1.46 A summary of the distribution of surficial and sub-seabed sediments is provided below, based on the Hornsea Three offshore cable corridor geophysical data, as well as existing publically available data (Table 1.5). As for the Hornsea Three array area, the Hornsea Three offshore cable corridor stratigraphy can be broadly divided into (i) seabed sediments; (ii) Quaternary units; and (iii) solid geology (bedrock). Maps showing the distribution and thickness of these various units are provided in volume 5, annex 1.1: Marine Processes Technical Annex, section 4.

Seabed sediments

1.7.1.47 The seabed along the Hornsea Three offshore cable corridor dominantly comprises coarse grained sand and gravel sediments (Figure 1.11) (Bibby HydroMap, 2016). The relative proportion of sands and gravels varies along the Hornsea Three offshore cable corridor, with more sandy sediments associated with the flanks and crests of sandbanks and more gravelly sediments encountered in the sandwave troughs and elsewhere. Finer grained muddy material are also present within the coarse grained sediment units encountered inshore of Leman Bank and in the vicinity of Sheringham Shoal. However, the occurrence of these finer grained sediments probably relates to sampling of the underlying pre-Holocene units.

1.7.1.48 The thickness of the surficial Holocene sediments along the Hornsea Three offshore cable corridor is highly variable. In many areas, the base of the Holocene sediments is found ~<1 m below the seabed, with the Holocene unit rarely greater than 5 m thick. This is particularly the case in the vicinity of the Indefatigable Banks, just to the northwest of Swarte Bank and close to the nearshore area within the Cromer Shoal Chalk Beds MCZ (Bibby HydroMap, 2016; Gafeira *et al*., 2010). However, where the Hornsea Three offshore cable corridor crosses Ower Bank and Leman Bank the thickness of Holocene sediments may locally exceed 10 m.

Quaternary units

1.7.1.49 Two glacial till units have been identified by the Hornsea Three offshore cable corridor geophysical survey and these are widely encountered at shallow (~<5 m) depths below the seabed. The upper unit is anticipated to comprise gravelly sandy clays of the Bolders Bank Formation whilst the lower glacial till unit probably comprises sands and gravels, with interbedded silts and clays belonging to the Egmond Ground Formation. In many areas, these units have been incised by channels with the thickness of channel infill (thought to comprise laminated clays and sands) typically in the range of 0 m to 5 m, and very occasionally exceeding 10 m (Bibby HydroMap, 2016).

Solid geology (bedrock)

1.7.1.50 Along almost the entire Hornsea Three offshore cable corridor, pre-Quaternary geology is generally not encountered at depths which could be impacted by cable installation activities. The only exception to this general pattern occurs within nearshore/inshore areas off Cromer where Cretaceous chalk is either found exposed at or very close (<5 m) to the seabed (Bibby HydroMap, 2016; Fugro, 2017; Gafeira *et al*., 2010).

1.7.1.51 On the basis of the interpretation of the geophysical data, sediments belong to the Bolders bank, Botney Cut and Egmond Ground Formations have the potential to be disturbed by drilling activities associated with foundation installation within the offshore HVAC booster station search area.

Suspended sediments

1.7.1.52 The turbidity maps presented in Dolphin *et al*. (2011) have been used to characterise spatial and temporal variation in SPM along the Hornsea Three offshore cable corridor (Figure 1.9). During the winter months, mean surface SPM concentrations are typically around 5 mg/l in the vicinity of the Hornsea Three array area, increasing to around 50 mg/l within inshore areas of the Hornsea Three offshore cable corridor. During summer months, mean SPM is usually in the range 0 to 5 mg/l, with values increasing with greater proximity to the coast. However, within inshore and (especially) nearshore areas where water depths are very shallow, strong tidal currents combined with wave stirring of the bed will result in high turbidity levels. These will be greatest closer to the seabed, in nearshore areas (i.e. < -5 mLAT), in areas exposed to larger waves and may be in the order of 100’s to 1,000’s mg/l during storm conditions.

Sediment transport

1.7.1.53 Existing regional-scale mapping suggests that at the offshore terminus of the Hornsea Three offshore cable corridor, bedload sediment transport is broadly to the northwest and towards the south/southeast within inshore/nearshore areas. The two regions of sediment transport are separated by a bedload parting zone which runs in an approximately shore parallel direction, at a distance of approximately 15 km from the coast (Figure 1.10). These regional scale patterns are broadly consistent with the directions of sediment transport inferred from bed forms mapped as part of the Hornsea Three offshore cable corridor geophysical survey.

1.7.1.54 Although these broad regional-scale transport pathways may be recognised, more complex localised patterns are also present. This is particularly the case in the vicinity of the sandbank systems where circulatory patterns of transport occur.

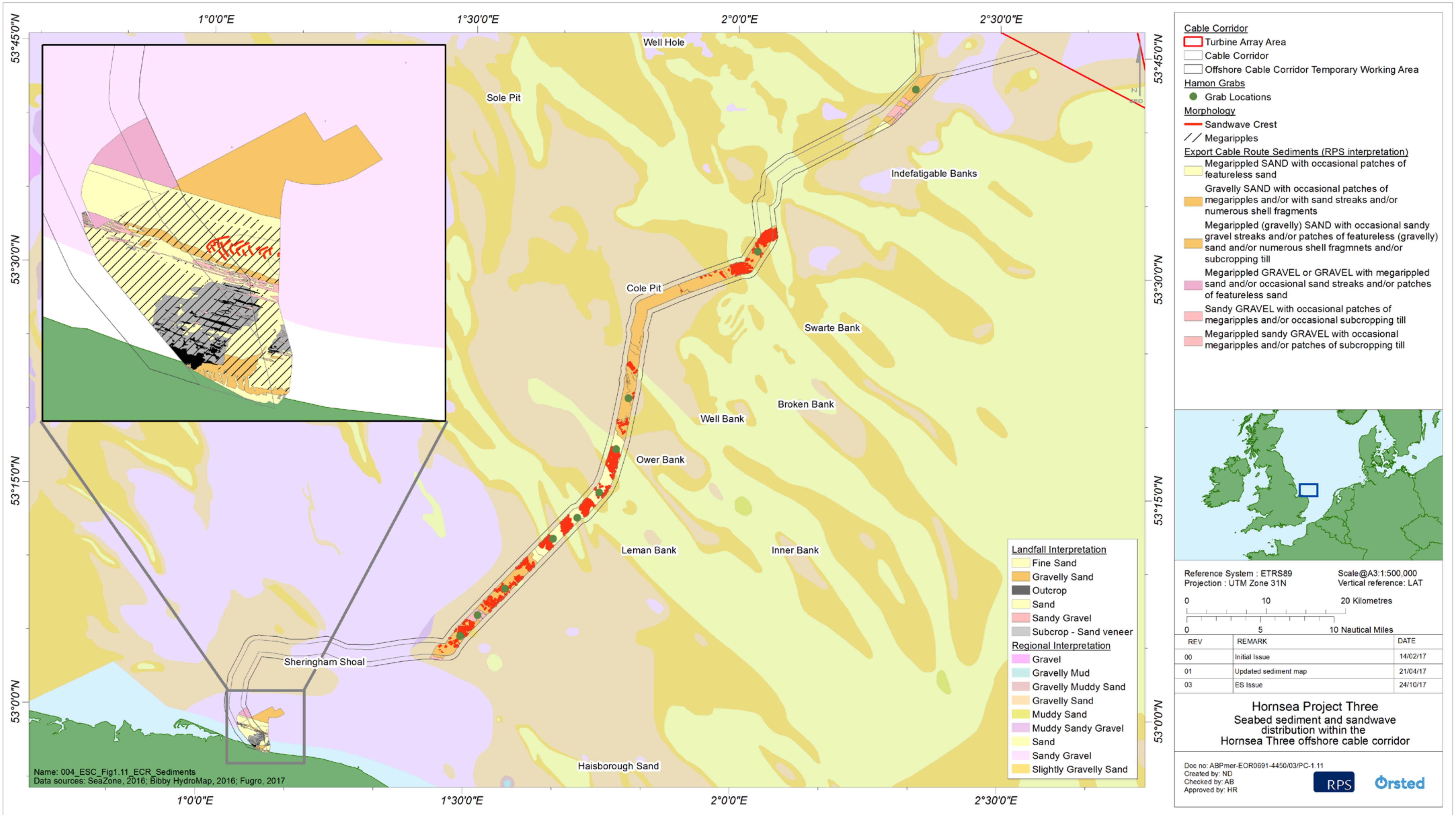

Figure 1.11: Seabed sediment and sandwave distribution within the Hornsea Three offshore cable corridor.

1.7.1.55 In general terms, sediment mobility is expected to increase with greater proximity to the coast as a result of the increase in tidal current speed. Based upon consideration of the prevailing hydrodynamic regime and threshold bed shear stresses required to initiate transport (Soulsby, 1997). In all areas, medium sized sand is expected to be mobilised to some degree by the action of tidal currents alone whilst in the area of higher current speeds encountered off the northeast Norfolk coast gravel sized material is also expected to be mobile. The influence of wave induced orbital currents on sediment mobility will vary spatially in response to both water depth as well as the height, period and direction of prevailing waves. However, within nearshore areas (as well as over the crest of shallow sandbanks) wave driven transport becomes increasingly important and in these shallow areas, both sand and gravel sized material is expected to be mobile.

Seabed geomorphology

Hornsea Three array area

1.7.1.56 Within the Hornsea Three array area, water depths vary from approximately -26.6 mLAT to -72.7 mLAT (Figure 1.12) (EGS, 2016). The average depth is -39.2 mLAT whilst the modal depth is -36.8 mLAT (Clinton, 2016). The shallowest depths are found in the central eastern parts of the site. Deeper areas are also present within the Hornsea Three array area with depths of up to approximately -60 mLAT along the northern boundary (associated with Outer Silver Pit) and depths of up to approximately -73 mLAT in central areas (associated with Markham's Hole). Outer Silver Pit and Markham's Hole are interpreted as glacial tunnel valleys formed during Quaternary glacial episodes by pressurized water flowing beneath an ice sheet (Praeg, 2003). Glacial tunnel valleys are widespread within the North Sea and are a characteristic feature of the regional-scale bathymetry (Graham *et al*., 2011).

1.7.1.57 In addition to these relict glacial features, a number of tidal current bedforms are also widely distributed (Figure 1.8) (EGS, 2016). Sandwaves (characterised by wave lengths >25 m and heights >0.3 m) are encountered in a small number of locations in the far western area of the site. Although the wavelengths of these features may exceed 400 m, heights do not exceed ~2 m. Megaripples (wave lengths <25 m and heights <0.3 m) are also widespread and are often found superimposed on the sandwaves. Within northeastern and central areas, sand ribbons are also encountered. These elongate low elevation (typically less than 1 m in height) longitudinal bedforms extend for a distance of several kilometres and in all areas are aligned to the tidal axis (northwest to southeast). Sand ribbons are indicative of sediment starved environments with strong (> ~0.9 m/s) tidal flows (Kenyon, 1970).

1.7.1.58 The distribution of tidal bedforms present will depend upon the current velocity and sediment supply (Stride, 1982). Consideration of peak spring tidal current velocities within the Hornsea Three array area alongside tidal current velocity thresholds for bedform development (Belderson *et al*., 1982) suggests that the sandwaves and megaripples are likely to be active. However, given that peak tidal current speeds within the Hornsea Three array area are below the inferred minimum threshold for sand ribbon formation provided by Belderson *et al*., it is possible that these bedforms are largely relict, formed when sea level was lower and tidal currents in this area were higher.

Hornsea Three offshore cable corridor

1.7.1.59 The Hornsea Three offshore cable corridor is fairly shallow throughout, with water depths typically less than -30 mLAT. In offshore areas, the shallowest water depths are associated with the crests of the Norfolk sandbanks which shallow to approximately -5 mLAT (Bibby HydroMap, 2016) (Figure 1.13). The greatest water depths are encountered where the Hornsea Three offshore cable corridor crosses the southern margins of Well Hole, a glacial tunnel valley. Well Hole is located approximately 85 km offshore with water depths of approximately -64 mLAT.

1.7.1.60 In addition to these glacial tunnel valleys, other prominent relict features include the Indefatigable Banks located close to Hornsea Three array area. The Indefatigable Banks form part of the north Norfolk sandbank system and formed during the mid-Holocene post-glacial transgression (Kenyon *et al*., 1981; Cooper *et al*., 2008). The Indefatigable Banks contrast with other sandbanks also belonging to the north Norfolk sandbanks but which are located closer inshore and are known to be active under present day hydrodynamic conditions (Kenyon and Cooper, 2005). These banks (shown on Figure 1.1) are:

- Swarte Bank;
- Well Bank;
- Ower Bank;
- Inner Bank; and
- Leman Bank.

1.7.1.61 Together, these banks underpin the qualifying features of the North Norfolk Sandbanks and Saturn Reef SAC (paragraph 1.7.2.4).

1.7.1.62 The Hornsea Three offshore cable corridor geophysical survey identified that much of the route is characterised by the presence of megaripple bedforms and sandwaves. These bedforms develop where peak spring tidal currents are moderately strong (circa 0.6 to 1.3 m/s) with crests orientated transverse to the main axis of flow. Sand ribbons are also understood to be present within the vicinity of the offshore cable corridor, between approximately 5 and 35 km offshore (Belderson *et al*., 1971).

1.7.1.63 The most extensive sandwave fields are located inshore from Ower Bank although all of the Norfolk sandbanks are typically associated with sandwave fields, superimposed with megaripples. In places these sandwaves are up to 6 m in height, with localised gradients of >11° (Bibby HydroMap, 2016). No direct measurements of bedform migration rates are presently available for these features within the Hornsea Three offshore cable corridor; however, observational evidence from analogous settings elsewhere in the southern North Sea suggests rates of migration may be in the order of several metres per year in the vicinity of sandbank systems (Knaapen et al, 2005).

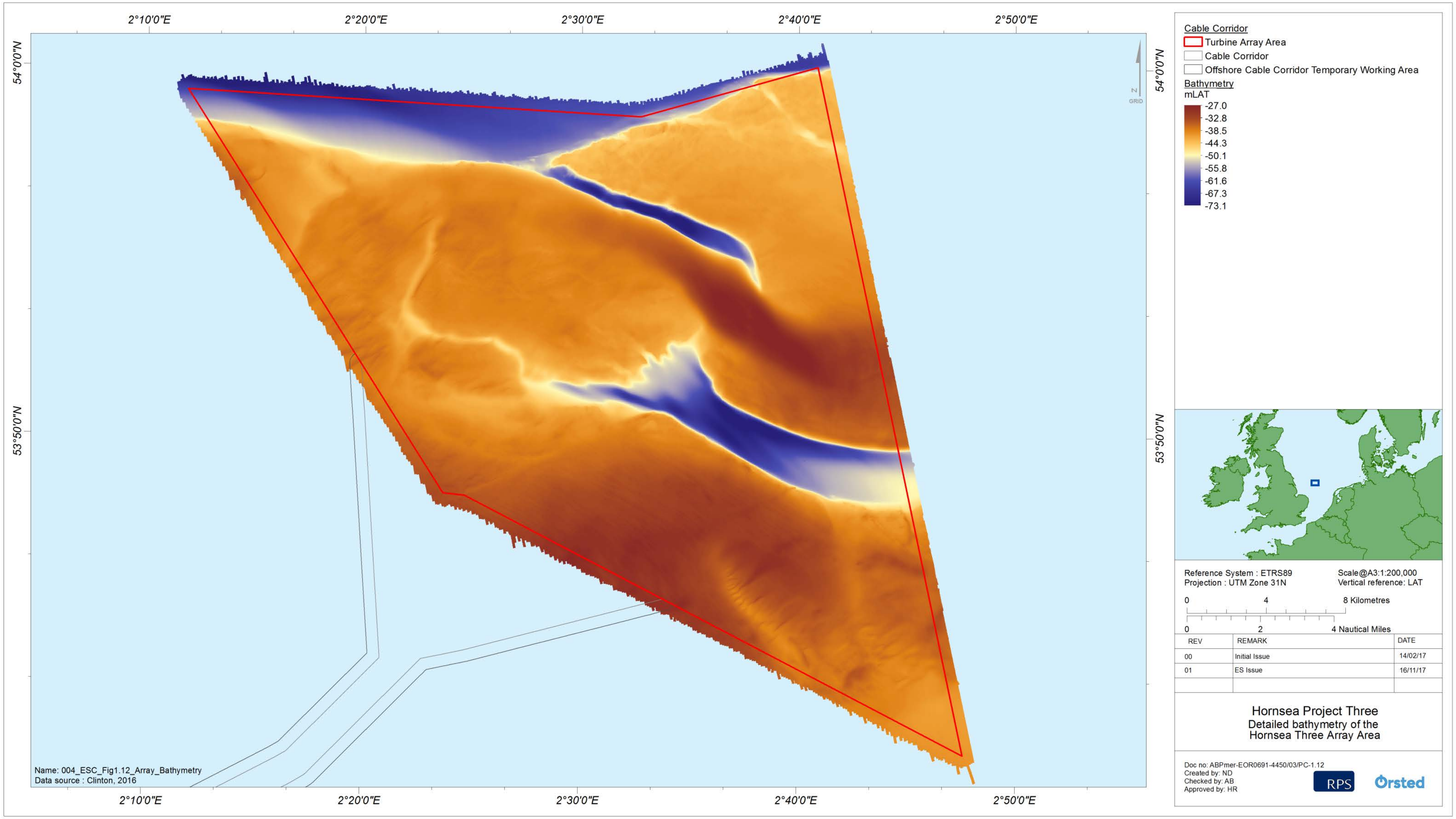

Figure 1.12: Detailed bathymetry of the Hornsea Three array area.

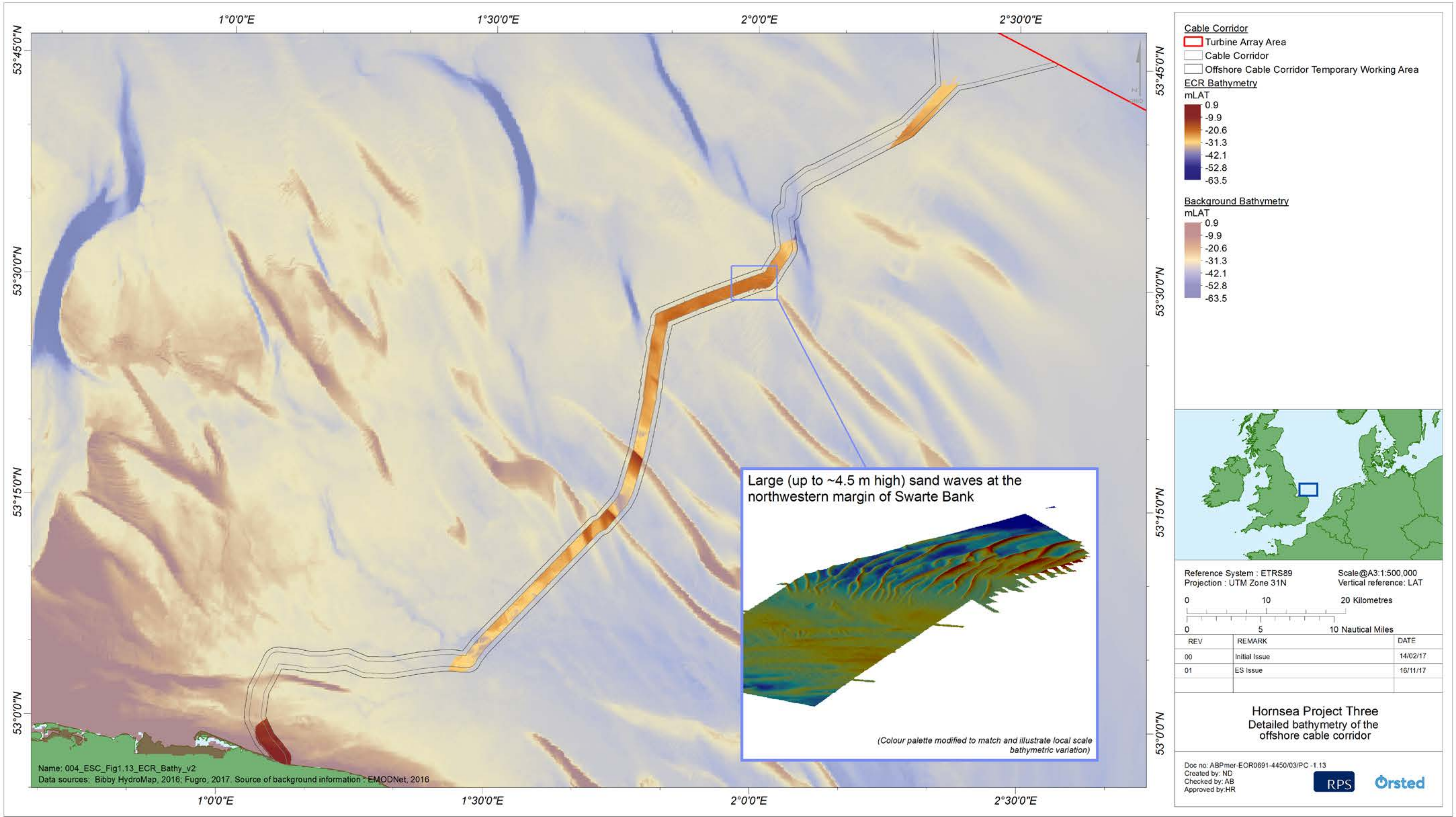

Figure 1.13: Detailed bathymetry of the Hornsea Three offshore cable corridor.

Nearshore geomorphology

1.7.1.64 Moving towards the coast, from inshore to nearshore areas (i.e. into areas < -5 mLAT), water depth decreases relatively gradually although a number of coastal bathymetric features are also present, including those associated with the Cromer Shoal chalk beds found to the east of the nearshore area. The intertidal zone across the nearshore area is characterised by the presence of a shingle beach which, to the east and west of Weybourne, is backed by eroding cliffs. Both the Sheringham Shoal and Dudgeon offshore wind farm export cables also come ashore at Weybourne Hope and the baseline characterisation studies for these separate developments have been used here to help characterise this nearshore area location, together with other available data sources, as outlined in Table 1.5.

1.7.1.65 Much of the shoreline in the area of the nearshore area is formed of a steep shingle beach, fronting eroding cliffs of glacial till over a chalk base (Figure 1.14). However, areas of lower ground are also present at Weybourne Hope, the location of the Sheringham Shoal and Dudgeon offshore wind farm export cable landfalls. Where the backshore is low, the shingle beach forms a barrier ridge and is the main defence against backshore flooding (Scira Offshore Energy Ltd, 2006).

Figure 1.14: Weybourne Hope shingle ridge beach, with low cliffs in the background.

1.7.1.66 To the west of the nearshore area, the low cliffs give way to the shingle ridge of Blakeney Point and further sand/shingle barrier island features fronting the low-lying coast. To the east, the chalk formation dips down, leaving the softer more readily erodible glacial till cliffs, protected by a shingle beach.

1.7.1.67 The coast at the nearshore areais characterised by ongoing retreat as a result of cliff and near shore seabed erosion along the coast and the landward migration of the shingle beach. Indeed, historic map analysis indicates that cliff erosion rates along the North Norfolk coast vary from 0.3 m/yr up to as much as 2.0 m/yr, with an average of about 0.5 m/yr along the frontage from Kelling to Sheringham (Scira Offshore Energy Ltd, 2006).

1.7.1.68 Analysis of Environment Agency LiDAR data been undertaken and presented in volume 5, annex 1.1: Marine Processes Technical Annex, section 6. A summary of the findings is presented in Figure 1.15 (N.B. in Figure 1.15, LiDAR data below (approximately) the MLWN tide mark has been removed as it typically represents the level of the water surface rather than the beach). At the nearshore area, the following general trends are observed from the available LiDAR data (which covers the period 1999 to 2014):

- The beach at the nearshore area is dynamic, with elevational changes up to ~3 m occurring over the analysis period; and
- There is a relatively high degree of spatial variability with regards to the magnitude of change to beach elevations, with the greatest change observed around the MHWS mark. Conversely, relatively limited change is seen seaward of the MSL mark.

1.7.1.69 The Southern North Sea Sediment Transport Study provides a summary of past studies into longshore sediment transport rates in this region as well as offering modelled rates of potential net transport. This modelling suggests high (up to c. 100,000 m^3/yr) potential net rates of drift in the vicinity of the nearshore area, but with considerable localised spatial variability in the rate and direction of net transport (HR Wallingford *et al*., 2002). The later work of HR Wallingford (2004) confirms this high potential for annual variability in drift rates, which are anticipated to reverse between years, depending on the prevailing wave conditions.

1.7.1.70 The preferred shoreline management plan option for the nearshore area has been described in the Kelling to Lowestoft Ness Shoreline Management Plan (SMP 6) (North Norfolk District Council, 2010). It is understood that the Environment Agency no longer actively manage the barrier beach and that it is being allowed to roll back (EA, Section 42 response, November 2017).

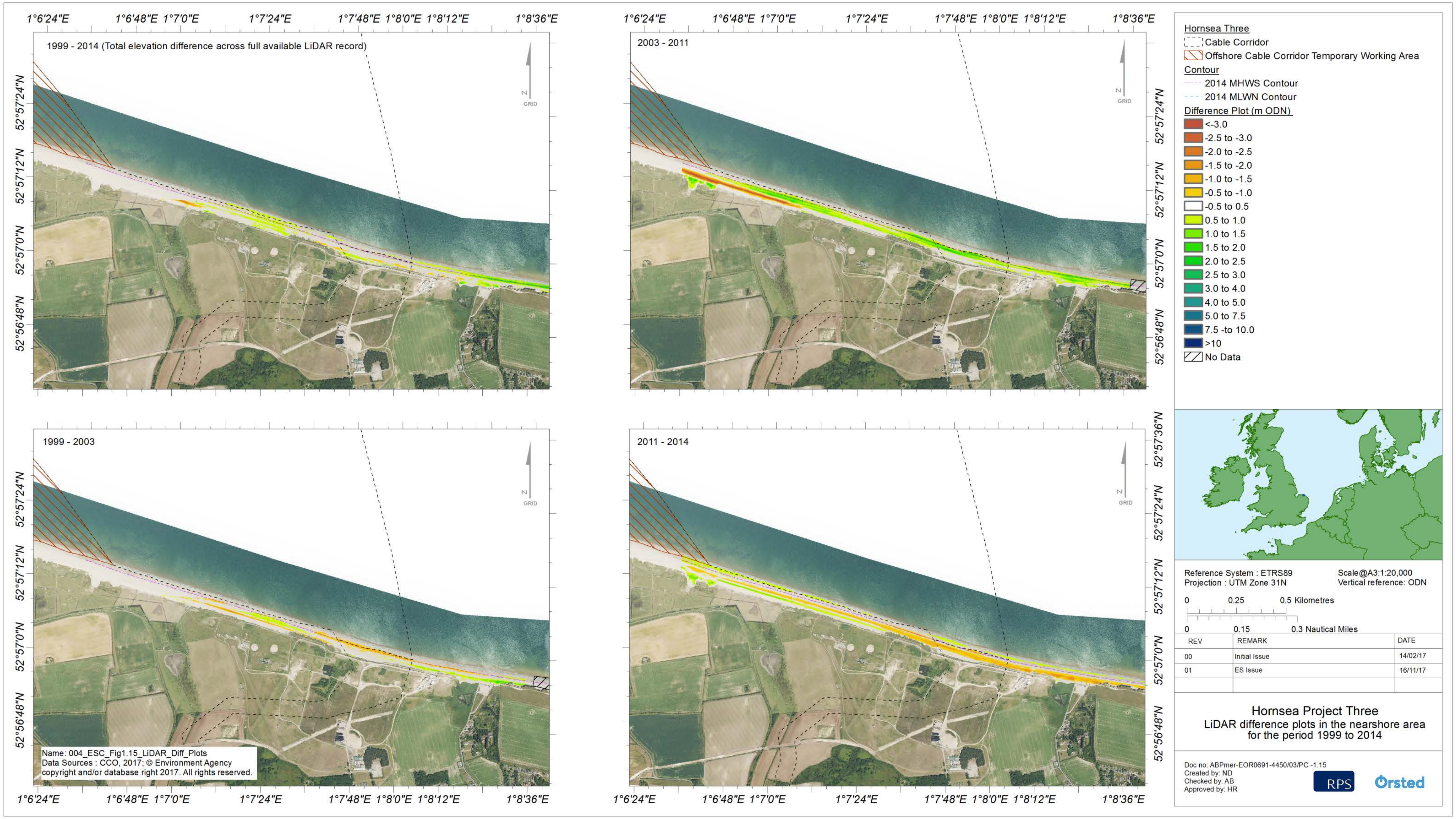

Figure 1.15: LiDAR difference plots in the nearshore area for the period 1999 to 2014.

1.7.2 Designated sites

1.7.2.1 Designated sites (of relevance to marine processes) within close proximity to Hornsea Three and therefore potentially affected by activities associated with it, are described below.

Hornsea Three array area

1.7.2.2 The Hornsea Three array area does not overlap with any currently designated nature conservation areas (Figure 1.16). However, it does partially overlap with Markhams Triangle rMCZ, a gravel and sand plain supporting populations of sandeel.

1.7.2.3 The Hornsea Three array area is within relatively close proximity (~10 km) to:

- The North Norfolk Sandbanks and Saturn Reef SAC that contains the Annex I habitats 'Sandbanks which are slightly covered by sea water all the time' and 'Reefs'.
- The Klaverbank SCI. The Klaverbank SCI contains Annex I 'Reef' habitat.

Hornsea Three offshore cable corridor

1.7.2.4 The Hornsea Three offshore cable corridor crosses the following designated areas of seabed (which are shown in Figure 1.16):

- The North Norfolk Sandbanks and Saturn Reef SAC contains the Annex I habitats 'Sandbanks which are slightly covered by sea water all the time' and 'Reefs'. The Norfolk sandbanks are the most extensive example of the offshore linear ridge sandbanks in UK waters (Graham et al., 2001). The Saturn Reef is a biogenic reef structure formed of *Sabellaria spinulosa*;
- The Cromer Shoal Chalk Beds MCZ features outcropping chalk reef structures such as boulders, stacks and arches within a wider area that is predominantly sandy (Defra, 2016; Wildlife Trusts, 2016);
- The Wash and North Norfolk Coast SAC contains a range of Annex I habitats including 'Mudflats and sandflats not covered by seawater at low tide', 'Sandbanks which are slightly covered by sea water all the time' and 'Reefs'; and
- The Southern North Sea cSAC contains a mixture of habitats such as sandbanks and gravel beds. However, the primary reason for identification is due to it being an area of importance for harbour porpoise. Potential impacts to these receptors are considered within volume 2, chapter 4: Marine Mammals.

1.7.2.5 It is noted here that the Haisborough, Hammond & Winterton SAC is located just within a spring tidal excursion ellipse buffer surrounding the Hornsea Three offshore cable corridor whilst the Inner Dowsing, Race Bank and North Ridge SAC is just outside of the buffer. However, based on avaialble monitoring evidence (e.g. BERR, 2008) and expert understanding developed from other offshore wind farm export cable assessments, measurable changes to hydrodynamics, waves and sediment transport processes (including changes in SSC) arising from construction, operation and maintenance, and/or decommissioning activities are not expected to extend to these sites. The limited expected potential changes to marine processes near to these sites are presented in paragraph 1.11.2 onwards.

Hornsea Three nearshore area

1.7.2.6 The nearshore area overlaps with the Weybourne Cliffs SSSI, Cromer Shoal Chalk Beds MCZ, the North Norfolk Coast SSSI and the Wash and North Norfolk Coast SAC. In brief:

- The Weybourne Cliffs SSSI afford the best Pleistocene sections showing the pre-Cromerian deposits of the Cromer Forest bed (English Nature, 1985); and
- The North Norfolk Coast SSSI is a composite site which extends for approximately 40 km between Hunstanton and Weybourne. The reason for notification is the presence of intertidal sands and muds, saltmarshes, shingle banks and sand dunes with shingle habitats present at the nearshore area (English Nature, 1986).

1.7.2.7 It is noted here that the Hornsea Three offshore cable corridor goes through the Greater Wash pSPA whilst the nearshore area is located immediately adjacent to the North Norfolk Coast SPA. However, potential effects on feeding birds within these designated sites is considered within volume 2, chapter 5: Offshore Ornithology.

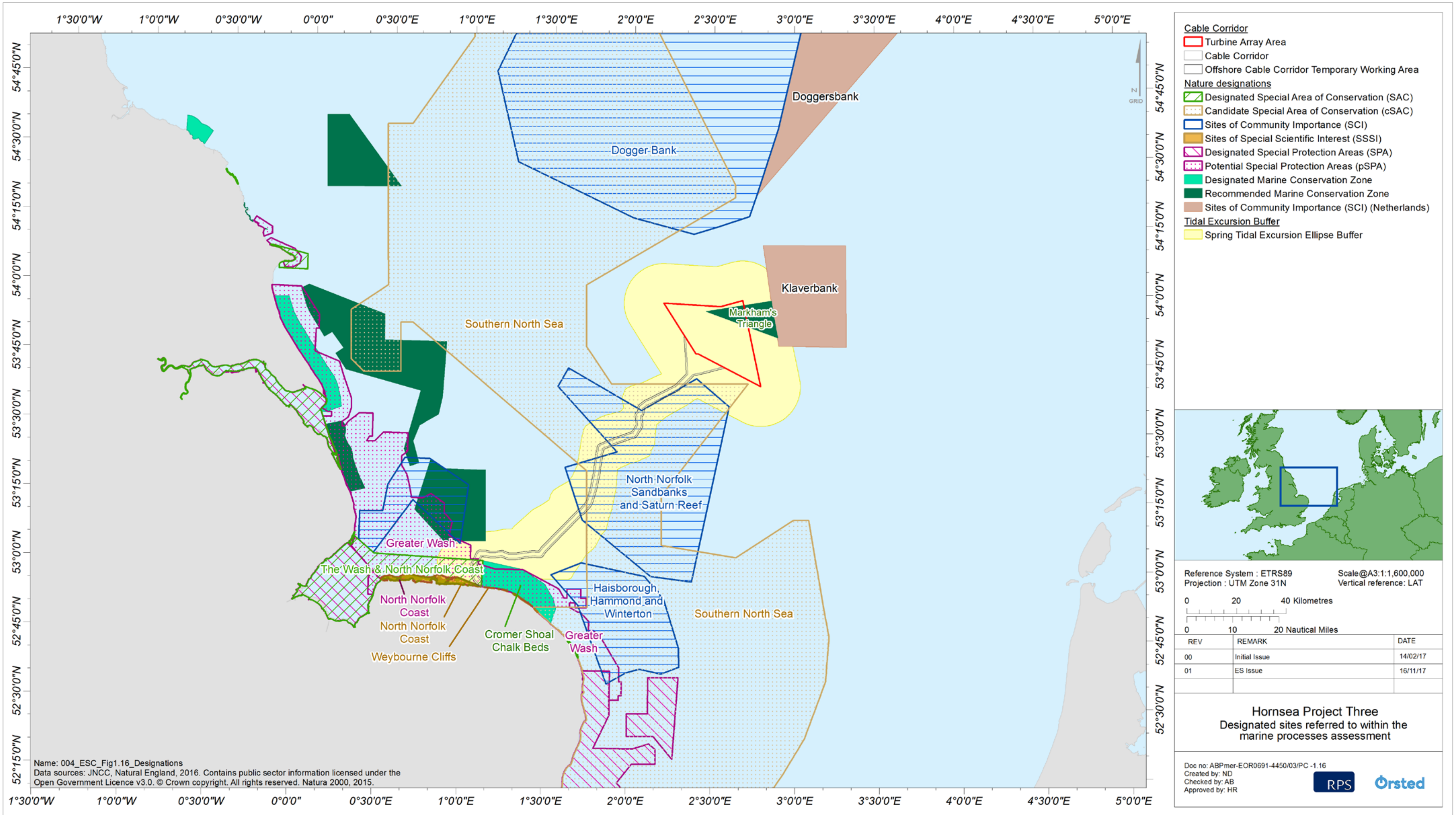

Figure 1.16: Designated sites referred to within the marine processes assessment.

1.7.3 Future baseline scenario

1.7.3.1 The Infrastructure Planning (Environmental Impact Assessment) Regulations 2017 requires that "*an outline of the likely evolution thereof without implementation of the development as far as natural changes from the baseline scenario can be assessed with reasonable effort on the basis of the availability of environmental information and scientific knowledge*" is included within the Environmental Statement.

1.7.3.2 In the event that Hornsea Three does not come forward, an assessment of the future baseline conditions has been carried out and is described within this section.

1.7.3.3 The baseline environment is not static and will exhibit some degree of natural change over time (within the lifetime of Hornsea Three), with or without Hornsea Three in place, due to naturally occurring cycles and processes. Therefore, when undertaking impact assessments, it will be necessary to place any potential impacts in the context of the envelope of change that might occur naturally over the timescale of the project.

1.7.3.4 Further to potential change associated with existing cycles and processes, it is necessary to take account of potential effects of climate change on the marine environment. Mean sea level is likely to rise during the 21st Century as a consequence of either vertical land (isostatic) movements or changes in eustatic sea level. It is predicted in UKCP09 that by 2050, relative sea level will have risen by approximately 0.35 m above 1990 levels (medium emissions scenario) at the nearshore area with rates of change increasing within this time frame (Lowe *et al*., 2009). A rise in sea level may allow larger waves, and therefore more wave energy, to reach the coast in certain conditions and consequently result in an increase in local rates or patterns of erosion and the equilibrium position of coastal features.

1.7.3.5 UKCP09 also includes projections of storm surges in the future as a result of climate change. However, UKCP09 analyses suggest that the 50 year return surge level will decrease by ~0.15 mm/yr along this coast (95% confidence level). A change of such small magnitude will be indistinguishable from natural variability (Lowe *et al*., 2009).

1.7.3.6 It is possible that climate change could impact on the wave regime in the future. Under a medium emission scenario, mean winter maxima of significant wave heights are generally expected to decrease very slightly over the same period, by approximately 0.1 m (Lowe *et al*., 2009). However, there are large uncertainties especially with the projected extreme values and the wave climate is naturally variable and there is no consensus on the future storm and wave climate. This uncertainty stems from diverse projections of future storm track behaviour (Woolf and Wolf, 2013).

1.7.4 Data limitations

1.7.4.1 A large body of project and non-project specific data is available to characterise the environmental setting of the Hornsea Three array area and offshore cable corridor (section 1.6). Collectively, the combined datasets provide sufficient detail to enable robust characterisation of the Hornsea Three array area and offshore cable corridor in terms of the metocean, seabed and sub-seabed setting. Although new survey data is not available for the entire Hornsea Three offshore cable corridor, the availability of existing information has enabled a robust assessment to be undertaken.

1.8 Key parameters for assessment

1.8.1 Maximum design scenario

1.8.1.1 The maximum design scenarios identified in Table 1.11 have been selected as those having the potential to result in the greatest effect on an identified receptor or receptor group. These scenarios have been selected from the details provided in the project description (volume 1, chapter 3: Project Description). Effects of greater adverse significance are not predicted to arise should any other development scenario, based on details within the project Design Envelope (e.g. different turbine layout), to that assessed here be taken forward in the final design scheme.

1.8.2 Impacts scoped out of the assessment

1.8.2.1 No impacts have been scoped out of the assessment.

Table 1.11: Maximum design scenario considered for the assessment of potential impacts on marine processes.

Potential impact/ change	Maximum design scenario	Justification
Construction phase		
Increases in SSC and deposition of disturbed sediments to the seabed due to drilling for foundation installation within the Hornsea Three array area. *It is noted that the receptor groups for this potential impact lie in other offshore EIA topics, namely benthic intertidal ecology, fish and shellfish ecology, marine mammals, marine archaeology and infrastructure and other users. As such, a significance of effect will not be assigned within the marine processes assessment.*	• Largest turbine monopile foundations (up to 160 monopiles), associated diameter 15 m, drilling to 40 m penetration depth, spoil volume per foundation 7,069 m^3, up to 10% of foundations may be drilled, total spoil volume 113,097 m^3 (160 x 10% x 7,069 m^3); • Largest offshore transformer substation piled jacket foundations (up to 12 foundations), 24 piles per foundation (six legs, four piles per leg), 4 m diameter, drilling to 70m penetration depth, spoil volume per foundation up to 21,112 m^3, up to 100% of foundations may be drilled, total spoil volume up to 253,338 m^3 (12 x 21,112 m^3); • Largest offshore High Voltage Direct Current (HVDC) converter substation piled jacket foundations (up to four foundations), 72 piles per foundation (18 legs, four piles per leg), 3.5 m diameter, drilling to 70 m penetration depth, spoil volume per foundation up to 48,490 m^3, up to 100% of foundations may be drilled, total spoil volume up to 193,962 m^3 (four x 48,490 m^3); • Largest offshore accommodation platform monopile foundations (up to 3 monopiles), associated diameter 15 m, drilling to 40 m penetration depth, spoil volume per foundation up to 7,069 m^3, up to 100% of foundations may be drilled, total spoil volume 21,207 m^3 (three x 7,069 m^3); • Drilling rate of 0.2 to 0.5 m/hour per hour; • Up to two foundations may be simultaneously drilled, minimum spacing 1,000 m; and • Disposal of drill arisings at or above water surface. Hornsea Three array area construction duration: up to eight years over two phases. A gap of up to three years will occur between an activity finishing in the first phase and starting in the second phase of construction. Pre-construction activities will occur one to two years prior to the start of the eight year construction. Foundation installation will occur over a period of up to 2.5 years within the eight year construction period.	Drilling of individual turbine monopile foundations results in the release of relatively larger volumes of relatively finer sediment, at relatively lower rates, than similar potential impacts for bed preparation via dredging for individual gravity base foundations (which are separately assessed). Drilling of the maximum number of turbine monopile foundations results in the release of a relatively smaller overall sediment volume than bed preparation via dredging for gravity base foundations (which is separately assessed). The greatest volume of sediment disturbance by drilling, for both individual foundations and for the array as a whole, is associated with the largest diameter monopile and piled jacket foundations for substations in the array area. The volume of sediment released through drilling of other turbine and offshore accommodation platform foundation types (e.g. piled jackets) is smaller than for monopiles. The HVDC transmission system option (up to12 offshore transformer substations and up to four offshore HVDC converter substations) results in the largest number of offshore substation foundations and the largest total volume of associated sediment disturbance in the array area.

Potential impact/ change	Maximum design scenario	Justification
Increases in SSC and deposition of disturbed sediments to the seabed due to dredging for seabed preparation prior to installing gravity base foundations within the Hornsea Three array area. *It is noted that the receptor groups for this potential impact lie in other offshore EIA topics, namely benthic intertidal ecology, fish and shellfish ecology, marine mammals, marine archaeology and infrastructure and other users. As such, a significance of effect will not be assigned within the marine processes assessment.*	*Greatest Volume of Sediment Disturbed and Released from a Single Foundation Location* • Largest turbine gravity base foundation (up to 160 gravity base foundations), associated base diameter 53 m, associated bed preparation area diameter 61 m, average depth 2 m), spoil volume per foundation up to 5,845 m^3; • Largest offshore transformer substation gravity base foundation (up to 12 gravity base foundations), associated base dimensions 75 m, associated bed preparation area dimensions 175 m, average depth 2 m, spoil volume per foundation up to 61,250 m^3); • Largest offshore HVDC converter substation gravity base foundation (up to four gravity base foundations), associated base dimensions 90 x 170 m, associated bed preparation area dimensions 98 x 178 m, average depth 2 m, spoil volume per foundation up to 34,888 m^3); • Largest offshore accommodation platform gravity base foundation (up to three gravity base foundations), associated base diameter 53 m, associated bed preparation area diameter 61 m, average depth 2 m), spoil volume per foundation up to 5,845 m^3; • Disposal of material on the seabed within the Hornsea Three array area; and Dredging carried out using a representative trailer suction hopper dredger (11,000 m^3 hopper capacity with split bottom for spoil disposal). Up to two dredgers to be working simultaneously, minimum spacing 1,000 m. *Greatest Volume of Sediment Disturbed and Released across the Entire Array Area* • Greatest number of turbine gravity base foundations (up to 300 gravity base foundations), associated base diameter 43 m, associated bed preparation area diameter 51 m, average depth 2 m, total spoil volume up to 1,225,692 m^3 (300 x 4,086 m^3); • Largest offshore transformer substation gravity base foundation (up to 12 gravity base foundations), associated base dimensions 75 m, associated bed preparation area dimensions 175 m, average depth 2 m, total spoil volume up to 735,000 m^3 (12 x 61,250 m^3); • Largest offshore HVDC converter substation gravity base foundation (up to four gravity base foundations), associated base dimensions 90 m, associated bed preparation area dimensions 90 x 170 m, average depth 2 m, total spoil volume up to 139,552 m^3 (four x 34,888 m^3); • Largest number of offshore accommodation platform gravity base foundations (up to three gravity base foundations), associated base diameter 53 m, associated bed preparation area diameter 61 m, average depth 2 m, total spoil volume up to 17,535 m^3 (three x 5,845 m^3); • Total spoil volume for all foundation types up to 2,117,779 m^3 (1,225,692 m^3 + 735,000 m^3 + 139,552 m^3 + 17,535 m^3); • Disposal of material on the seabed within the array area; and • Dredging carried out using a representative trailer suction hopper dredger (11,000 m^3 hopper capacity with split bottom for spoil disposal). Up to two dredgers to be working simultaneously, minimum spacing 1,000 m. Hornsea Three array area construction duration: up to eight years over two phases. A gap of up to three years will occur between an activity finishing in the first phase and starting in the second phase of construction. Pre-construction activities will occur one to two years prior to the start of the eight year construction. Foundation installation will occur over a period of up to 2.5 years within the eight year construction period.	Dredging as part of seabed preparation for individual gravity base foundation foundations results in the release of relatively smaller overall volumes of relatively coarser sediment, at relatively higher rates, than similar potential impacts for drilling of individual monopile or piled jacket foundations (which are separately assessed). Dredging as part of seabed preparation for all gravity base foundation foundations in the array area results in the release of a relatively greater overall sediment volume than drilling of monopile or piled jacket foundations (which are separately assessed). Two maximum design scenarios are identified, corresponding to the greatest volume of sediment disturbance locally (from a single foundation) and across the entire array (from all foundations). The greatest sediment disturbance from a single gravity base foundation location is associated with the largest diameter or dimension gravity base foundation, which results in the greatest volume of spoil from a single foundation. Due to differences in both scale and number, gravity base foundations for turbines, electrical substations and offshore accommodation platforms are separately considered. The greatest volume of disturbance across entire array area is associated with the greater number of the smaller diameter foundations, which results in the greatest total volume of spoil from all (gravity base foundation) foundations. The HVDC transmission system option (up to12 offshore transformer substations and up to four offshore HVDC converter substations) results in the largest number of offshore substation foundations and the largest total volume of associated sediment disturbance in the array area.

Potential impact/ change	Maximum design scenario	Justification
Increases in SSC and deposition of disturbed sediments to the seabed due to cable installation within the Hornsea Three array area. *It is noted that the receptor groups for this potential impact lie in other offshore EIA topics, namely benthic intertidal ecology, fish and shellfish ecology, marine mammals, marine archaeology and infrastructure and other users. As such, a significance of effect will not be assigned within the marine processes assessment.*	*Array cables* • Installation method: mass flow excavator; • Total length 830 km; • V-shape trench; width = 6 m; depth =2 m; volume = (830 km x 6 m x 2 m x 0.5 (i.e. to account for V-shape of trench)) = 4,980,000 m³; and • Installation rate of 1.5 to 5 km/day. *Substation interconnector cables* • Installation method: mass flow excavator; • 15 in-project cables, total length 225 km; • V-shape trench; width = 6 m; depth =2 m; volume = (225 km x 6 m x 2 m x 0.5 (i.e. to account for V-shape of trench)) = 1,350,000 m³; and • Installation rate of 1.5 to 5 km/day. If and where the cable is not buried sufficiently deeply during the initial burial attempt, remedial cable burial activities (one to three additional passes of the jetting tool) may be required in localised areas. The nature and spatial dimensions of the remedial jetting disturbance will be similar or less than that for the first pass (described above). Remedial activities would be undertaken typically within a matter of months (up to 12 months) after the initial burial attempt. Hornsea Three array area construction duration: up to eight years over two phases. A gap of up to three years will occur between an activity finishing in the first phase and starting in the second phase of construction. Pre-construction activities will occur one to two years prior to the start of the eight year construction. Cable installation will occur over a period of up to 2.5 years within the eight year construction period.	Cable installation may involve ploughing, trenching, jetting, rock-cutting, surface laying with post lay burial, and/or surface laying installation techniques. Of these, jetting (by mass flow excavation) will most energetically disturb the greatest volume of sediment in the trench profile and as such is considered to be the maximum design scenario for sediment dispersion.
Increases in SSC and deposition of disturbed sediments to the seabed due to sandwave clearance within the Hornsea Three array area. *It is noted that the receptor groups for this potential impact lie in other offshore EIA topics, namely benthic intertidal ecology, fish and shellfish ecology, marine mammals, marine archaeology and infrastructure and other users. As such, a significance of effect will not be assigned within the marine processes assessment.*	• Sandwave clearance by dredging or mass flow excavation, resulting in removal of up to 71,150 m³ within the Hornsea Three array area, (based on the Hornsea Three array area geophysical survey data combined with cable installation design specifications). Hornsea Three array area construction duration: up to eight years over two phases. A gap of up to three years will occur between an activity finishing in the first phase and starting in the second phase of construction. Pre-construction activities will occur one to two years prior to the start of the eight year construction. Cable installation will occur over a period of up to 2.5 years within the eight year construction period.	The volume of material to be cleared from individual sandwaves will vary according to the local dimensions of the sandwave (height, length and shape) and the level to which the sandwave must be reduced (also accounting for stable sediment slope angles and the capabilities and requirements of the cable burial tool being used). These details are not fully known at this stage, however, based on the available geophysical data, it is anticipated that the bedforms requiring clearance in the array area are likely to be in the range 1 to 2 m in height. Sandwave clearance may involve dredging or mass flow excavation tools. Of these, mass flow excavation will most energetically disturb sediment in the clearance profile and as such is considered to be the maximum design scenario for sediment dispersion causing elevated SSC over more than a very short period of time. Dredging will result in a potentially greater instantaneous local effect in terms of SSC and potentially a greater local thickness of sediment deposition, but likely of a shorter duration and smaller extent, respectively.
Increases in SSC and deposition of disturbed sediment to the seabed due to drilling for foundation installation within the Hornsea Three offshore cable corridor. *It is noted that the receptor groups for this potential impact lie in other offshore EIA topics, namely benthic intertidal ecology, fish and shellfish ecology, marine mammals, marine archaeology and infrastructure and other users. As such, a significance of effect will not be assigned within the marine processes assessment.*	• Largest offshore HVAC booster station piled jacket foundations (up to four foundations, up to six legs, up to four piles per leg, 4 m pile diameter, penetration depth up to 70 m, total spoil volume up to 84,448 m³ (four x 21,112 m³); and • Disposal of drill arisings at or above water surface. Hornsea Three offshore cable corridor construction duration: up to eight years over two phases. A gap of up to three years will occur between an activity finishing in the first phase and starting in the second phase of construction. Pre-construction activities will occur one to two years prior to the start of the eight year construction. Substation installation will occur over a period of up to eight months (two months per substation) within the eight year construction period.	Drilling of jacket foundations results in the release of relatively smaller overall volumes of relatively finer sediment, at lower rates, than similar potential impacts for bed preparation via dredging for gravity base foundations (which are separately assessed). Offshore HVAC booster stations installed on piled jacket foundations may require drilling to assist with pin pile penetration. The foundation option with the largest total volume of spoil is accounted for. The HVAC transmission system option (up to four offshore HVAC booster substations) results in the largest number of offshore substation foundations and the largest total volume of associated sediment disturbance in the offshore cable corridor.

Potential impact/ change	Maximum design scenario	Justification
Increases in SSC and deposition of disturbed sediments to the seabed due to dredging for seabed preparation prior to installing gravity base foundations within the Hornsea Three offshore cable corridor. *It is noted that the receptor groups for this potential impact lie in other offshore EIA topics, namely benthic intertidal ecology, fish and shellfish ecology, marine mammals, marine archaeology and infrastructure and other users. As such, a significance of effect will not be assigned within the marine processes assessment.*	• Largest offshore HVAC booster station gravity base foundations (up to four foundations, associated base dimensions 75 m, associated bed preparation area dimensions 175 m, average depth 2 m, total spoil volume up to 245,000 m^3 (4 x 61,250 m^3)); • Disposal of material onto the seabed; and • Dredging carried out using a representative trailer suction hopper dredger (11,000 m^3 hopper capacity with split bottom for spoil disposal). Up to 2 dredgers to be working simultaneously, minimum spacing 1,000 m. Hornsea Three offshore cable corridor construction duration: up to eight years over two phases. A gap of up to three years will occur between an activity finishing in the first phase and starting in the second phase of construction. Pre-construction activities will occur one to two years prior to the start of the eight year construction. Substation installation will occur over a period of up to eight months (two months per substation) within the eight year construction period.	Dredging as part of seabed preparation for gravity base foundation foundations results in the release of relatively larger overall volumes of relatively coarser sediment, at higher rates, than similar potential impacts for drilling of piled jacket foundations, which are assessed separately. Offshore HVAC booster stations installed on gravity base foundations will require seabed preparation via dredging. The foundation option with the largest total volume of spoil is accounted for. The HVAC transmission system option (up to four offshore HVAC booster substations) results in the largest number of offshore substation foundations and the largest total volume of associated sediment disturbance in the offshore cable corridor.
Increases in SSC and deposition of disturbed sediment to the seabed due to cable installation within the Hornsea Three offshore cable corridor. *It is noted that the receptor groups for this potential impact lie in other offshore EIA topics, namely benthic intertidal ecology, fish and shellfish ecology, marine mammals, marine archaeology and infrastructure and other users. As such, a significance of effect will not be assigned within the marine processes assessment.*	• Up to six cable trenches; each 191 km in length (1,146 km in total); • Installation method: mass flow excavator; • V-shape trench; width = 6 m; depth = 2 m; volume = (6 x 191 km x 6 m x 2 m x 0.5 (i.e. to account for V-shape of trench)) = 6,876,000 m^3; and • Installation rate of 1.5 to 5 km/day. If and where the cable is not buried sufficiently deeply during the initial burial attempt, remedial cable burial activities (one to three additional passes of the jetting tool) may be required in localised areas. The nature and spatial dimensions of the remedial jetting disturbance will be similar or less than that for the first pass (described above). Remedial activities would be undertaken typically within a matter of months (up to 12 months) after the initial burial attempt. Hornsea Three offshore cable corridor construction duration: up to eight years over two phases. A gap of up to three years will occur between an activity finishing in the first phase and starting in the second phase of construction. Pre-construction activities will occur one to two years prior to the start of the eight year construction. Cable installation will occur over a period of up to three years within the eight year construction period.	Cable installation may involve ploughing, trenching, jetting, rock-cutting, surface laying with post lay burial, and/or surface laying installation techniques. Of these, mass flow excavation will most energetically disturb the greatest volume of sediment in the trench profile and as such is considered to be the maximum design scenario for sediment dispersion.
Increases in SSC and deposition of disturbed sediment to the seabed due to sandwave clearance within the Hornsea Three offshore cable corridor. *It is noted that the receptor groups for this potential impact lie in other offshore EIA topics, namely benthic intertidal ecology, fish and shellfish ecology, marine mammals, marine archaeology and infrastructure and other users. As such, a significance of effect will not be assigned within the marine processes assessment.*	• Sandwave clearance: up to 1,202,956 m^3 (via either a dredger or mass flow excavator) within the Hornsea Three offshore cable corridor, (based on the Hornsea Three offshore cable corridor geophysical survey data combined with cable installation design specifications); and Hornsea Three offshore cable corridor construction duration: up to eight years over two phases. A gap of up to three years will occur between an activity finishing in the first phase and starting in the second phase of construction. Pre-construction activities will occur one to two years prior to the start of the eight year construction. Cable installation will occur over a period of up to three years within the eight year construction period.	The volume of material to be cleared from individual sandwaves will vary according to the local dimensions of the sandwave (height, length and shape) and the level to which the sandwave must be reduced (also accounting for stable sediment slope angles and the capabilities and requirements of the cable burial tool being used). These details are not fully known at this stage, however, based on the available geophysical data, it is anticipated that the bedforms requiring clearance are likely to be in the range 1 to 6 m in height and located in offshore sections of the cable corridor. Sandwave clearance may involve dredging or mass flow excavation tools. Of these, mass flow excavation will most energetically disturb sediment in the clearance profile and as such is considered to be the maximum design scenario for sediment dispersion causing elevated SSC over more than a very short period of time. Dredging will result in a potentially greater instantaneous local effect in terms of SSC and potentially a greater local thickness of sediment deposition, but likely of a shorter duration and smaller extent, respectively.

Potential impact/ change	Maximum design scenario	Justification
Change to seabed morphology due to indentations left by jack-up vessels	*Hornsea Three array area and offshore cable corridor* • Jack-up operations expected for up to 300 wind turbine foundations, up to three offshore accommodation platforms, up to 12 offshore transformer substations and up to four offshore HVDC converter substations. • Jack-up vessels with six legs; • Only one barge required per foundation; and • Area of each jack-up spud-can 170 m^2; total area per vessel = 1,020 m^2 (six legs x 170 m^2) *Hornsea Three nearshore area* • Five Jack-up operations expected for each HDD exit pit (40 in total) • Jack-up vessels with four legs; and • Area of each jack-up spud-can 1.13 m^2; total area per vessel = 4.52 m^2 (four legs x 1.13 m^2)	Assumes the use of jack-up vessels over dynamic positioning vessel as the former will encounter the seabed.
Removal of sandwaves impacting sandbank systems within proximity of the Hornsea Three array area and offshore cable corridor.	• Up to 1,202,956 m^3 (via either a dredger or mass flow excavator) within the Hornsea Three offshore cable corridor, (based on the Hornsea Three offshore cable corridor geophysical survey data combined with cable installation design specifications).	The volume of material to be cleared from individual sandwaves will vary according to the local dimensions of the sandwave (height, length and shape) and the level to which the sandwave must be reduced (also accounting for stable sediment slope angles and the capabilities and requirements of the cable burial tool being used). These details are not fully known at this stage, however, based on the available geophysical data, it is anticipated that the bedforms requiring clearance are likely to be in the range 1 to 6 m in height and located in offshore sections of the cable corridor.

Potential impact/ change	Maximum design scenario	Justification
Changes to hydrodynamics, sediment transport and beach morphology at the nearshore area.	*Open cut trenching* • Up to six cable trenches; • V-shape trench; width = 6 m; depth = 2 m • Trenches to be open for no longer than two weeks. *HDD with cofferdam option* • The cofferdam dimensions which will contain each exit pit are 50 m (length) x 5 m (width); • Up to two exit pits with cofferdams may be in place simultaneously although there is the potential for up to four cofferdams to be present for a very short period (i.e. order of a few days); • Each of the cofferdams will be in place for up to four months ; • The actual pull through of the cable may occur in the year after the HDD duct is installed. In this case, a small area of the backfilled exit pit would be locally excavated again (without the use of a cofferdam) to expose the HDD duct and access the messenger wire to allow pull through. The excavated area would only be open for a matter of days to a few weeks; • Material excavated from within the cofferdam will be side-cast to the adjacent seabed, with material subsequently used as backfill; and • Additional material (diameter up to 250 mm) may be required to make up for any loss when backfilling HDD exit pit. *HDD without cofferdam option* • Up to eight HDD exit pits may be required; • Exit pits likely to be located between approximately 200 m ('short' HDD; c. -1 mLAT) and 800 m ('long' HDD; c-7 m LAT) from the MHWS mark; • Each exit pit up to 30 m (length) x 30 m (width). (Depths will vary depending on surficial sediment cover but are anticipated to range from circa 2.5 m for the short HDD option to circa 6 m for the long HDD option); • Up to two exit pits may be open simultaneously although there is the potential for up to four exit pits to be open for a very short period (i.e. order of a few days); • Each of the HDD exit pits may be open for up to four months (which consists of: one month site setup (including pit excavation), two months pit fully open, drilling & duct pull-in happening; and one month reinstatement (including backfill); • The actual pull through of the cable may occur in the year after the HDD duct is installed. In this case, a small area of the backfilled exit pit would be locally excavated again (without the use of a cofferdam) to expose the HDD duct and to allow cable pull through. The excavated area would only be open for a matter of days to a few weeks; • Material will be side-cast adjacent to each exit pit, with material subsequently used as backfill; and • Additional material (diameter up to 250 mm) may be required to make up for any loss when backfilling HDD exit pit.	The methods that may be used to install cables across the intertidal area are HDD or open-cut. There are two primary means by which the morphology of the nearshore area could potentially be impacted during the construction phase: • Disturbance of sediments during (open cut) cable trenching across the beach, resulting in associated changes to bed levels; and • Changes to the nearshore wave regime/longshore sediment transport due to the presence of cable protection measures and HDD exit pits.

Potential impact/ change	Maximum design scenario	Justification
Operation and maintenance phase		
Changes to the tidal regime, with associated potential impacts to sandbanks	• Largest number of gravity base foundations for turbines (up to 300 at 43 m diameter) and offshore accommodation platforms (up to three 41 m diameter) and the largest dimensions of gravity base foundation for offshore transformer substations (up to 12 at 75 m length scale) and offshore HVDC converter substations (up to four 75 m length scale) in the array area; • Largest number of offshore HVAC booster station gravity base foundations (up to four foundations, associated base dimensions 75 m) in the Hornsea Three offshore cable corridor; • Minimum spacing of 1,000 m; and • Operation and maintenance phase lasting 35 years	The greatest total in-water column blockage to currents is presented by the greatest number of gravity base foundation foundations in the array area, with at least the minimum spacing between turbines. This combination was determined via calculations that quantitatively compare the blockage presented by a range of minimum and maximum sizes of varying foundation types and numbers (see volume 5, annex 1.1: Marine Processes Technical Annex, section 7 for details).
Changes to the wave regime, with associated potential impacts to sandbanks and along adjacent shorelines.	• Largest number of gravity base foundations for turbines (up to 300 at 43 m diameter) and offshore accommodation platforms (up to three 41 m diameter) and the largest dimensions of gravity base foundation for offshore transformer substations (up to 12 at 75 m length scale) and offshore HVDC converter substations (up to four 75 m length scale) in the array area; • Largest number of offshore HVAC booster station gravity base foundations (up to four foundations, associated base dimensions 75 m) in the Hornsea Three offshore cable corridor; • Minimum spacing of 1,000 m; and • Operation and maintenance phase lasting 35 years.	The greatest total in-water column blockage to waves is presented by the greatest number of gravity base foundation foundations in the array area, with at least the minimum spacing between turbines. This combination was determined via calculations that quantitatively compare the blockage presented by a range of minimum and maximum sizes of varying foundation types and numbers (see volume 5, annex 1.1: Marine Processes Technical Annex, section 8 for details).
Scour of seabed sediments.	• Largest turbine monopile foundations (up to 160 monopiles), associated diameter 15 m; and • Greatest seabed footprint of all scour protection 678,584m² (up to 160 monopiles, associated diameter of 15 m).	Each foundation type may produce different scour patterns therefore monopiles, gravity base foundations and jacket foundations will all be considered. The foundation type, size and number producing the greatest area and/or volume of influence cannot be identified in advance of the assessment. Suction caissons for jackets and monopiles are not explicitly assessed as they fall within the envelope of change of the other three foundation types.

Potential impact/ change	Maximum design scenario	Justification
Changes to sediment transport and sediment transport pathways with associated potential impacts to sandbanks.	*Foundations* • Largest number of gravity base foundations for turbines (up to 300 at 43 m diameter) and offshore accommodation platforms (up to three 41 m diameter) and the largest dimensions of gravity base foundation for offshore transformer substations (up to 12 at 75 m length scale) and offshore HVDC converter substations (up to four 75 m length scale) in the Hornsea Three array area. • Largest number of offshore HVAC booster station gravity base foundations (up to four foundations, associated base dimensions 75 m) in the Hornsea Three offshore cable corridor. • Minimum spacing of 1,000 m. *Cable protection measures (all)* • Sloped profile above seabed level: 7 m overall width and 2 m maximum height; Export cable (total length for all water depths) • Six cable trenches, each 191 km in length; • Cable protection covering sections of one or more cables up to 10% of the total length = 114.6 km (1,146 km x 10%); • Total area of cable protection, 802,200 m^2; and • Total volume of cable protection, 1,146,000 m^3. *Array cables* • Cable protection covering sections of one or more cables up to 10% of the total length = 83 km (830 km x 10%); • Total area of cable protection, 581,000 m^2; and • Total volume of cable protection, 830,000 m^3. *Substation interconnector cables* • Cable protection covering sections of one or more cables up to 10% of the total length = 22.5 km (225 km x 10%); • Total area of cable protection, 157,500 m^2; and • Total volume of cable protection, 225,000 m^3. *Cable crossings - Export cable* • Up to 44 crossings; • Total impacted area, 660,000 m^2; Cable/pipe crossings total protection volume (including operation) of 693,000 m^3. *Cable crossings - Array cables* • Up to 5 crossings; • Total impacted area, 12,500 m^2; • Cable/pipe crossings pre-lay cable protection volume of 3,125 m3 (including operational replenishment); and • Cable/pipe crossings post-lay cable protection volume of 10,000 m3 (including operational replenishment). *Cable crossings - Interconnector cables* • Up to two crossings; • Total impacted area, 75,000 m^2; • Cable/pipe crossings total protection volume of 78,750 m^3. Operation and maintenance phase lasting 35 years.	The greatest number of turbines with the minimum spacing between turbines, combined with the largest proposed foundation option (gravity base foundation) presents the maximum blockage, and hence the greatest influence on sediment transport. The greatest local dimensions and overall length of cable protection, including cable crossings, represents the maximum blockage, and hence greatest potential for influence on sediment transport.

Potential impact/ change	Maximum design scenario	Justification
Changes to water column stratification with associated potential impacts to the Flamborough Front.	• Largest number of gravity base foundations for turbines (up to 300 at 43 m diameter) and offshore accommodation platforms (up to three 41 m diameter) and the largest dimensions of gravity base foundation for offshore transformer substations (up to 12 at 75 m length scale) and offshore HVDC converter substations (up to four 75 m length scale) in the Hornsea Three array area; • Largest number of offshore HVAC booster station gravity base foundations (up to four foundations, associated base dimensions 75 m) in the Hornsea Three offshore cable corridor; • Minimum spacing of 1,000 m; • Operation and maintenance phase lasting 35 years.	The main pathway via which the Flamborough Front could be impacted is through modification of the hydrodynamic regime due to the presence of infrastructure foundations. (Changes in SSC due to sediment disturbance activities during the construction/ operation and maintenance/ decommissioning phase will not influence the primary characteristics of the Front.) The greatest potential for change to water column stratification will be associated with greatest total in-water column blockage presented by the greatest number of gravity base foundation foundations in the array area, with at least the minimum spacing between turbines. This combination was determined via calculations that quantitatively compare the blockage presented by a range of minimum and maximum sizes of varying foundation types and numbers (see volume 5, annex 1.1: Marine Processes Technical Annex, section 10 for details).
Increase in SSC and deposition of disturbed sediment to the seabed due to cable maintenance within the Hornsea Three array area. *It is noted that the receptor groups for this potential impact lie in other offshore EIA topics, namely benthic intertidal ecology, fish and shellfish ecology, marine mammals, marine archaeology and infrastructure and other users. As such, a significance of effect will not be assigned within the marine processes assessment.*	*Array Cable Remedial Burial* • Up to 830 km of array cables are present; • Up to total of 12 remedial burial events over the lifetime of Hornsea Three; • Reburial of up to 2 km of cable using jetting per event. • Maximum cable trench disturbance width up to 10 m; *Array Cable Repair* • Up to 830 km of array cables are present; • Up to total of 300 individual repair events over the lifetime of Hornsea Three (one per WTG cable); • Up to 2 km cable recovered per repair; • Maximum cable trench width 10 m; • Maximum area of sediment disturbance 25,000 m^2; • Seabed disturbance from jack-up vessel (up to 10 events within 200 m of the OSS) 1,020 m^2 (six legs x 170 m^2 per leg) per repair event.	The greatest foreseeable number of cable reburial and repair events is considered to be the maximum design scenario for sediment dispersion, alongside the use of jetting as a technique.
Increase in SSC and deposition of disturbed sediment to the seabed due to cable maintenance within the Hornsea Three offshore cable corridor. *It is noted that the receptor groups for this potential impact lie in other offshore EIA topics, namely benthic intertidal ecology, fish and shellfish ecology, marine mammals, marine archaeology and infrastructure and other users. As such, a significance of effect will not be assigned within the marine processes assessment.*	*Export Cable Remedial Burial* • Up to six export cables are present; • Average of 2.5 remedial burial events per cable, up to total of 15 events over the lifetime of Hornsea Three; • Reburial of up to 2 km of cable using jetting per event. • Maximum cable trench disturbance width is the greater of 10 m or 2 x water depth; *Export Cable Repair* • Up to six export cables are present; • Up to total of 15 individual repair events over the lifetime of Hornsea Three; • Up to 200m cable recovered per repair; • Maximum cable trench width 10 m; • Either Omega dredged pit with dimensions (250 m x 100 m, 2 m deep): area 25,000 m^2, volume 50,000 m^3; • Or 500 m long section of rock berm; • Seabed disturbance from jack-up vessel (up to 6 events within 200 m of the OSS) 1,020 m^2 (six legs x 170 m^2 per leg) per repair event.	The greatest foreseeable number of cable reburial and repair events is considered to be the maximum design scenario for sediment dispersion, alongside the use of jetting as a technique.

Potential impact/ change	Maximum design scenario	Justification
Changes to beach morphology, hydrodynamics and sediment transport (littoral drift) at the nearshore area.	Buried cables • Target burial depth to be determined pending the outcome of the site investigation works at the nearshore area. • Set back distance for transition jointing bay infrastructure to be determined pending the outcome of the nearshore area assessment to inform engineering design; • Operation and maintenance phase lasting 35 years. *Cable protection measures* (offshore*)* • Sloped profile above seabed level: 7 m overall width and 2 m maximum height.	Minimum cable burial depth (and therefore the greatest risk of cable exposure due to erosion). Closest distance to the beach for transition jointing bay infrastructure therefor greatest potential for impact associated with beach roll back
Decommissioning phase		
Increases in SSC and deposition of disturbed sediment to the seabed within the Hornsea Three array area. *It is noted that the receptor groups for this potential impact lie in other offshore EIA topics, namely benthic intertidal ecology, fish and shellfish ecology, marine mammals, marine archaeology and infrastructure and other users. As such, a significance of effect will not be assigned within the marine processes assessment.*	*Cutting off jacket foundations below the seabed surface* • Largest number of piled jacket foundations for turbines (up to 300), four piles per foundation (four legs, one pile per leg), 4 m diameter; • Largest number of piled jacket foundations for offshore transformer substations (up to 12), 24 piles per foundation (six legs, four piles per leg), 4 m diameter; • Largest number of piled jacket foundations for large offshore HVDC converter substations (up to four), 72 piles per foundation (18 legs, four piles per leg), 3.5 m diameter); and • Largest number of piled jacket foundations for offshore accommodation platforms (up to three), four piles per foundation (four legs, one pile per leg), 4 m diameter. *Removal of gravity base foundations* • Largest number of gravity base foundations for turbines (up to 300 at 43 m diameter) and offshore accommodation platforms (up to three 41 m diameter) and the largest dimensions of gravity base foundation for offshore transformer substations (up to 12 at 75 m length scale) and offshore HVDC converter substations (up to four 75 m length scale) in the array area. *Removal of array, interconnector or offshore accommodation platform cables* • Removal (total or partial) of limited sections of the array cables and offshore platform interconnector cables. (To be determined in consultation with key stakeholders as part of the decommissioning plan).	When cutting off jacket foundations below the seabed surface, the greatest disturbance results from the greatest number of foundations. When removing gravity base foundations, the greatest disturbance results from the greatest number of foundations. When removing array, platform interconnector or offshore accommodation platform cables, only limited lengths are likely to be removed, from locations to be agreed at a later date. Decommissioning activities would not be continuous throughout the eight year period. Further details are provided within volume 1, chapter 3: Project Description.
Increases in SSC and deposition of disturbed sediment to the seabed within the Hornsea Three offshore cable corridor. *It is noted that the receptor groups for this potential impact lie in other offshore EIA topics, namely benthic subtidal and intertidal ecology), fish and shellfish ecology, marine mammals, marine archaeology and infrastructure and other users. As such, a significance of effect will not be assigned within the marine processes assessment.*	*Cutting off jacket foundations below the seabed surface* • Largest number of piled jacket foundations for offshore HVAC booster station (up to four), 24 piles per foundation (six legs, four piles per leg), 4 m diameter. *Removal of gravity base foundations* • Largest number of offshore HVAC booster station gravity base foundations (up to four), associated base dimensions 75 m. *Removal of export cables* • Removal of export cables. (To be determined in consultation with key stakeholders as part of the decommissioning plan).	When cutting off jacket foundations below the seabed surface, the greatest disturbance results from the greatest number of foundations. When removing gravity base foundations, the greatest disturbance results from the greatest number of foundations. When removing export cables, only limited lengths are likely to be removed, from locations to be agreed at a later date.

Potential impact/ change	Maximum design scenario	Justification
Removal of sandwaves impacting sandbank systems within proximity to the Hornsea Three array area and offshore cable corridor.	• Removal of export cables. (to be determined in consultation with key stakeholders as part of the decommissioning plan.) • Removal of sandwaves via dredging or jetting methods. • Dredging carried out using a representative trailer suction hopper dredger (11,000 m^3 hopper capacity with split bottom for spoil disposal).	When removing export cables, only limited lengths are likely to be removed, from locations to be agreed at a later date.
Changes to hydrodynamics, sediment transport and beach morphology at the nearshore area.	• Partial removal of the cable by pulling the cables back out of the cable ducts; and • Ducts will be filled following the removal of the cable.	Maximum disturbance of seabed resulting from partial removal or cable and filling of HDD ducts.

1.9 Impact assessment methodology

1.9.1 Overview

1.9.1.1 The marine processes EIA has followed the methodology set out in volume 1, chapter 5: Environmental Impact Assessment Methodology. Specific to the marine processes EIA, the following guidance documents have also been considered:

- Environmental impact assessment for offshore renewable energy projects (BSI, 2015);
- Review of environmental data associated with post-consent monitoring of licence conditions of offshore wind farms (Fugro-Emu, 2014);
- Guidelines for Data Acquisition to Support Marine Environmental Assessments of Offshore Renewable Energy Projects (Cefas, 2011);
- Identifying the possible impacts of rock dump from oil and gas decommissioning on Annex I mobile sandbanks (JNCC, 2017);
- General advice on assessing potential impacts of and mitigation for human activities on Marine Conservation Zone (MCZ) features, using existing regulation and legislation (JNCC and Natural England, 2011);
- Further review of sediment monitoring data (ABPmer *et al*., 2010);
- Coastal Process Modelling for Offshore Wind farm Environmental Impact Assessment: Best Practice Guide (ABPmer and HR Wallingford, 2009);
- Guidelines in the use of metocean data through the lifecycle of a marine renewables development (ABPmer *et al*., 2008a);
- Review of Cabling Techniques and Environmental Effects applicable to the Offshore Wind farm Industry (BERR, 2008);
- Review of Round 1 Sediment process monitoring data - lessons learnt (ABPmer *et al*., 2007);
- Dynamics of scour pits and scour protection - Synthesis report and recommendations (HR Wallingford *et al*., 2007);
- Offshore Windfarms: Guidance note for Environmental Impact Assessment in Respect of FEPA and CPA requirements (Cefas, 2004); and
- Potential effects of offshore wind developments on coastal processes (ABPmer and METOC, 2002).

1.9.2 Impact assessment criteria

1.9.2.1 From the outset it should be recognised that for the most part, marine processes are not in themselves receptors. However, changes to marine processes have the potential to indirectly impact other environmental receptors (Lambkin *et al*., 2009). For instance, the creation of sediment plumes (which is considered in the marine processes assessment) may lead to settling of material onto benthic habitats. Similarly, scour around Hornsea Three marine infrastructure may lead to a loss or modification of seabed habitat. The potential significance of these particular changes would be assessed within volume 2, chapter 2: Benthic Ecology. Other indirect impacts resulting from potential changes to marine processes are also assessed in volume 2, chapter 3: Fish and Shellfish Ecology, volume 2, chapter 4: Marine Mammals, volume 2, chapter 5: Offshore Ornithology, volume 2, chapter 9: Marine Archaeology, and volume 2, chapter 10: Infrastructure and Other Users. Accordingly, the approach adopted is to describe the potential changes to marine processes due to Hornsea Three, but not provide an assessment of the significance.

1.9.2.2 In addition to the indirect changes described above, the presence of Hornsea Three marine infrastructure will lead to a direct loss (or temporary/permanent change) of seabed habitat. The spatial extent of seabed loss associated with the presence of certain infrastructure elements is briefly summarised in Table 1.11 whilst turbine foundation footprints are reported in the discussion of scour (paragraph 1.11.3.3 onwards). However, more detailed quantification and assessment of seabed loss is provided in volume 2, chapter 2: Benthic Ecology, using the design information set out in volume 1, chapter 3: Project Description.

1.9.2.3 Whilst marine processes can largely be considered as pathways, a small number of features have been identified as potentially sensitive marine processes receptors. These are:

- The shoreline;
- Offshore sandbanks; and
- The Flamborough Front.

1.9.2.4 Where these receptors have the potential to be affected by changes to marine processes, a full impact assessment (i.e. assigning sensitivity, magnitude and significance) has been carried out and presented in paragraph 1.11.5.1 onwards.

1.9.2.5 The criteria for determining the significance of effects is a two stage process that involves defining the sensitivity of the receptors and the magnitude of the impacts. This section describes the criteria applied in this chapter to assign values to the sensitivity of receptors and the magnitude of potential impacts. The terms used to define sensitivity and magnitude are based on those used in the DMRB methodology, which is described in further detail in volume 1, chapter 5: Environmental Impact Assessment Methodology.

1.9.2.6 The criteria for defining sensitivity in this chapter are outlined in Table 1.12 below.

Table 1.12: Definition of terms relating to the sensitivity of the receptor.

Sensitivity	Definition used in this chapter
Very High	Receptor is high value or critical importance to local, regional or national economy or environment. Receptor is highly vulnerable to impacts that may arise from the project and recoverability is long term or not possible.
High	Receptor is of moderate value with reasonable contribution to local, regional or national economy or environment. Receptor is generally vulnerable to impacts that may arise from the project and / or recoverability is slow and/or costly.
Medium	Receptor is of minor value with small levels of contribution to local, regional or national economy or environment. Receptor is somewhat vulnerable to impacts that may arise from the project and has moderate to high levels of recoverability.
Low (or lower)	Receptor is of low value with little contribution to local, regional or national economy or environment. Receptor is not generally vulnerable to impacts that may arise from the project and/or has high recoverability.
Negligible	Receptor is of negligible value with no contribution to local, regional or national economy or environment. Receptor is not vulnerable to impacts that may arise from the project and/or has high recoverability.

1.9.2.7 The criteria for defining magnitude in this chapter are outlined in Table 1.13 below. The timescales outlined in this table are indicative only.

Table 1.13: Definition of terms relating to the magnitude of an impact.

Magnitude of impact	Definition used in this chapter
Major	Total loss of function. Impact is of extended temporal or physical extent and/or of long-term duration (i.e. approximately >20 years duration).
Moderate	Loss or alteration to significant portions of key components of current function. Impact is of moderate temporal or physical extent and/or of medium-term duration (i.e. two to 20 years).
Minor	Minor shift away from baseline, leading to a change in function. Impact is of limited temporal or physical extent and/or of short-term duration (i.e. less than two years).
Negligible	Very slight change from baseline condition. Physical extent of impact is negligible and / or of short-term duration (i.e. less than two years).
No change	No change from baseline conditions.

1.9.2.8 The significance of the effect upon marine processes is determined by correlating the magnitude of the impact and the sensitivity of the receptor. The particular method employed for this assessment is presented in Table 1.14. Where a range of significance of effect is presented in Table 1.14, the final assessment for each effect is based upon expert judgement.

1.9.2.9 For the purposes of this assessment, any effects with a significance level of minor or less have been concluded to be not significant in terms of the EIA Regulations.

Table 1.14: Matrix used for the assessment of the significance of the effect.

		Magnitude of impact				
		No change	*Negligible*	*Minor*	*Moderate*	*Major*
Sensitivity of receptor	*Negligible*	Negligible	Negligible	Negligible or minor	Negligible or minor	Minor
	Low	Negligible	Negligible or minor	Negligible or minor	Minor	Minor or moderate
	Medium	Negligible	Negligible or minor	Minor	Moderate	Moderate or major
	High	Negligible	Minor	Minor or moderate	Moderate or major	Major or substantial
	Very high	Negligible	Minor	Moderate or major	Major or substantial	Substantial

1.10 Measures adopted as part of Hornsea Three

1.10.1.1 As part of the project design process, a number of designed-in measures have been proposed to reduce the potential for impacts on marine processes (see Table 1.15). As there is a commitment to implementing these measures, they are considered inherently part of the design of Hornsea Three and have therefore been considered in the assessment presented in section 1.11 below (i.e. the determination of magnitude and therefore significance assumes implementation of these measures). These measures are considered standard industry practice for this type of development.

1.10.1.2 This approach has been employed in order to demonstrate commitment to measures by including them in the design of Hornsea Three and these measures have therefore been considered in the assessment presented in below. These measures are considered standard industry practice for this type of development. Assessment of sensitivity, magnitude and therefore significance includes implementation of these measures.

Table 1.15: Designed-in measures adopted as part of Hornsea Three.

Measures adopted as part of Hornsea Three	Justification
Scour protection	Where scour protection is absent and where the hydrodynamic/ seabed geology allow, scour has the potential to form around turbine and substation/platform foundations. This may lead to the release of material into suspension (higher turbidity) and a change to seabed habitat immediately adjacent to the structure. This will be reduced with the introduction of scour protection, where necessary.
Development of, and adherence to, a Cable Specification and Installation Plan.	The Cable Specification and Installation Plan will set out measures to minimise adverse impacts to potentially sensitive receptors. It will also set out appropriate cable burial depth in accordance with industry good practice, minimising the risk of cable exposure.
Cable trench infill at the nearshore area	Cable installation at the nearshore area may be achieved using open cut trenching methods. It is anticipated that the same shingle excavated from the beach during cable installation would subsequently be used to backfill the trench once the cables had been laid. This would minimise the risk of future erosion.

1.11 Assessment of significance

1.11.1.1 As stated in paragraph 1.9.1 onwards, for the most part marine processes (such as waves, tides and sediment transport) are not themselves receptors but are instead pathways. The only potentially sensitive receptors are the shoreline, offshore sandbanks and the Flamborough Front. This distinction between assessments of pathways and receptors is summarised in Table 1.16, for each of the potential impacts/changes identified in Table 1.11.

1.11.1.2 In this section, the assessment of change to marine processes pathways (during the construction, operation and maintenance, and decommissioning phase) is presented first, followed by an assessment of the significance of effects to marine processes receptors. In those instances where a change may be considered both a pathway and a receptor, the change is assessed in the significance of effects to marine receptors assessment section (section 1.11.5 onwards.) The assessments presented in this section are a summary of the full assessment presented in volume 5, annex 1.1: Marine Processes Technical Annex.

Table 1.16: Summary of potential impacts/ changes considered in the marine processes assessment.

Potential impact/change	Pathway/receptor
Construction phase	
Increases in SSC and deposition of disturbed sediments to the seabed due to drilling for foundation installation within the Hornsea Three array area.	Pathway
Increases in SSC and deposition of disturbed sediments to the seabed due to dredging for seabed preparation prior to installing gravity base foundations within the Hornsea Three array area.	Pathway
Increases in SSC and deposition of disturbed sediments to the seabed due to cable installation within the Hornsea Three array area.	Pathway
Increases in SSC and deposition of disturbed sediments to the seabed due to sandwave clearance within the Hornsea Three array area.	Pathway
Increases in SSC and deposition of disturbed sediment to the seabed due to drilling for foundation installation within the Hornsea Three offshore cable corridor.	Pathway
Increases in SSC and deposition of disturbed sediments to the seabed due to dredging for seabed preparation prior to installing gravity base foundations within the Hornsea Three offshore cable corridor.	Pathway
Increases in SSC and deposition of disturbed sediment to the seabed due to cable installation within the Hornsea Three offshore cable corridor.	Pathway
Increases in SSC and deposition of disturbed sediment to the seabed due to sandwave clearance within the Hornsea Three offshore cable corridor.	Pathway
Change to seabed morphology due to indentations left by jack-up vessels	Pathway
Removal of sandwaves impacting sandbank systems within proximity to the Hornsea Three array area and offshore cable corridor.	Pathway and receptor
Changes to hydrodynamics, sediment transport and beach morphology at the nearshore area.	Pathway and receptor
Operation and maintenance phase	
Changes to the tidal regime, with associated potential impacts to sandbanks	Pathway and receptor
Changes to the wave regime, with associated potential impacts to sandbanks and along adjacent shorelines.	Pathway and Receptor
Scour of seabed sediments	Pathway
Changes to sediment transport and sediment transport pathways with associated potential impacts to sandbanks.	Pathway and receptor
Changes to water column stratification with associated potential impacts to the Flamborough Front.	Pathway and receptor
Increase in SSC and deposition of disturbed sediment to the seabed due to cable maintenance within the Hornsea Three array area.	Pathway
Increase in SSC and deposition of disturbed sediment to the seabed due to cable maintenance within the Hornsea Three offshore cable corridor.	Pathway

Potential impact/change	Pathway/receptor
Changes to beach morphology, hydrodynamics and sediment transport (littoral drift) at the nearshore area.	Pathway and receptor
Decommissioning phase	
Increases in SSC and deposition of disturbed sediment to the seabed within the Hornsea Three array area.	Pathway
Increases in SSC and deposition of disturbed sediment to the seabed within the Hornsea Three offshore cable corridor.	Pathway
Removal of sandwaves impacting sandbank systems within proximity to the Hornsea Three array area and offshore cable corridor.	Pathway and receptor
Changes to hydrodynamics, sediment transport and beach morphology at the nearshore area.	Pathway and receptor

1.11.2 Construction phase: changes to pathways

1.11.2.1 The changes to marine processes in response to the offshore construction of Hornsea Three have been described in this section. The potential changes arising from the construction of Hornsea Three are listed in Table 1.11 along with the maximum design scenario against which each construction phase change has been assessed.

1.11.2.2 As previously stated, the assessments presented within this section consider pathways only and as such do not provide a conclusion regarding the significance of effect. Instead the significance of effect is considered in the various relevant receptor chapters, namely volume 2, chapter 2: Benthic Ecology, volume 2, chapter 3: Fish and Shellfish Ecology, volume 2, chapter 4: Marine Mammals, volume 2, chapter 5: Offshore Ornithology, volume 2, chapter 9: Marine Archaeology, and volume 2, chapter 10: Infrastructure and Other Users.

Increases in SSC and deposition of disturbed sediments to the seabed due to drilling for foundation installation within the Hornsea Three array area

1.11.2.3 Drilling may be required for the following foundations:

- Turbine or offshore accommodation platform monopile foundations;
- Offshore transformer substation piled jacket foundation pin piles; and
- Offshore HVDC converter substation piled jacket foundation pin piles.

1.11.2.4 Monopile foundations and pin piles for piled jacket foundations will be installed into the seabed using standard piling techniques. In some locations, the particular geology may present some obstacle to piling, in which case, some or all of the seabed material might be drilled from within the pile footprint to assist in the piling process. Up to 10% of turbine foundations and any or all other foundations may require drilling to assist with installation.

1.11.2.5 The impact of drilling operations for monopile installation mainly relates to the release of drilling spoil at or above the water surface which will put sediment into suspension and the subsequent re-deposition of that material to the seabed. The nature of this disturbance will be determined by the rate and total volume of material to be drilled, the nature of the seabed/ underlying geology and the drilling method (affecting the texture and grain size distribution of the drill spoil).

1.11.2.6 In order to inform the assessment of potential changes to SSC and bed levels arising from drilling, a number of spreadsheet based numerical models have been developed, taking into consideration information on:

- Flow speed;
- Direction;
- Lateral dispersion;
- Settling velocities; and
- Sediment properties (seabed and sub-seabed).

1.11.2.7 Full results are provided in volume 5, annex 1.1: Marine Processes Technical Annex, section 4. The results from these assessments have been validated against Hornsea Project One and Hornsea Project Two numerical plume modelling outputs (SMart Wind, 2013; 2015), as well as modelling and monitoring from other analogous activities.

1.11.2.8 Two maximum design scenarios are identified in Table 1.11, corresponding to the greatest volume of drilled sediment disturbance locally (from a single foundation) and across the entire array (from all foundations).The distribution of grain/clast sizes in the drill arisings is not known in advance, so results are provided separately in volume 5, annex 1.1: Marine Processes Technical Annex, section 4 for scenarios where 100% of the material is assumed to be either fines, sand or gravel. In practice, depending on the actual ground conditions and drilling tools used, the distribution of grain/clast size in the spoil will be some variable mixture of these with a corresponding intermediate duration, extent and magnitude of change.

1.11.2.9 The following observations (based on the spreadsheet based numerical model results) are consistent with the previously modelled patterns of change in Hornsea Project One and Hornsea Project Two (SMart Wind, 2013; 2015), similarly modelled patterns of change in assessments for other wind farms, and the wider monitoring evidence base.

1.11.2.10 Assuming that a mixture of sediment grain sizes are present, the overall spatial pattern of change due to drilling of a single foundation is summarised as follows:

- SSC will be increased by tens to hundreds of thousands of mg/l at the point of sediment release, which is at or near the water surface;
- SSC of low tens of mg/l will be present in a narrow plume (tens to a few hundreds of metres wide, up to one tidal excursion in length (~7 km on spring tides and 3.5 km on neap tides) aligned to the tidal stream downstream from the source;
- If drilling occurs over more than one flood or ebb tidal period, the plume feature may be present in both downstream and upstream directions;
- Outside of the area up to one tidal excursion upstream and downstream of the foundation location, SSC less than 10 mg/l may occur more widely due to ongoing dispersion and dilution of material;
- Sufficiently fine sediment may persist in suspension for hours to days or longer, but will become diluted to very low concentrations (<5 mg/l, indistinguishable from natural background levels and variability) within timescales of around one day; and
- Over longer timescales, net movement of any fine grained material persisting in suspension would generally be in a northeasterly direction in accordance with the direction of residual flow in this area.

1.11.2.11 Sediment deposition as a result of drilling for a single foundation installation are characterised as follows:

- Deposits of mainly coarse grained and clastic sediment deposits will be concentrated within an area in the order of 25 to 100 m downstream/upstream and a few tens of metres wide from individual foundations, with an average thickness in the order of one to ten metres (limited to realistically likely values);
- Deposits of mainly sandy sediment deposits will be concentrated within an area in the order of 200 m to 700 m downstream/upstream and tens to one hundred metres wide from individual foundations, with an average thickness in the order of tens of centimetres to one metre;
- Fine grained material will be dispersed widely within the surrounding region and will not settle with measurable thickness; and
- It is noted that, while the absolute width, length, shape and thickness of local sediment deposition as a result of drilling is estimated above but cannot be predicted with certainty and are likely to vary due to the nature of the drill spoil, the local water depth and the ambient environmental conditions during the drilling activity. Other possible combinations of shape, area and thickness of sediment deposition are provided in volume 5, annex 1.1: Marine Processes Technical Annex, section 4.

1.11.2.12 The local patterns of change to SSC and sediment deposition are described above, as a result of drilling activities for individual foundations of any type. In the array area, up to 16 (10% of 160) monopiles for turbines, up to three monopiles for accommodation platforms, up to 12 piled jackets for offshore transformer substations, and up to three piled jackets for offshore HVDC converter substations may be installed using drilling. The total sediment volume potentially released by drilling of all foundations has also been assessed with respect to the total potential extent and thickness of sediment deposition, as summarised below.

1.11.2.13 The actual shape, width, length and thickness of local or regional sediment deposition as a result of drilling cannot be predicted with certainty and is likely to vary according to the final distribution of foundations, the local nature of the drill spoil, the local water depth and the ambient environmental conditions during the drilling activity. The maximum total (in situ) volume released from all foundations of all types (up to 581,603 m^3) is known with more certainty and is used to conservatively infer the following maximum areas of change (as a proportion of the total array area, 696 km^2), conservatively assuming that the sediment is deposited with a relatively small average thickness of 0.05 m:

- Total for all turbine foundations – up to 0.54% of the Hornsea Three array area with an average deposit thickness of 0.05 m;
- Total for all offshore transformer substation foundations – up to 1.21% of the Hornsea Three array area with an average deposit thickness of 0.05 m;
- Total for all offshore HVDC converter substation foundations – up to 0.93% of the Hornsea Three array area with an average deposit thickness of 0.05 m;
- Total for all accommodation platform foundations – up to 0.10% of the Hornsea Three array area with an average deposit thickness of 0.05 m;
- Total for all foundations - up to 2.8% of the Hornsea Three array area with an average deposit thickness of 0.05 m; and
- A larger average deposit thickness will result in a proportionally smaller area of change; and
- The total area of change will realistically comprise multiple smaller areas (as described in the previous paragraphs for individual foundations) that will not necessarily overlap.

1.11.2.14 If drilling, or any other activity causing sediment disturbance, is undertaken simultaneously at two or more locations that are aligned in relation to the ambient tidal streams, then there is potential for overlap between the areas of effect on SSC and sediment deposition. The effect on SSC in areas of overlap will be additive if the downstream activity occurs within the area of effect from upstream (i.e. sediment is disturbed within the sediment plume from the upstream location). The effect on SSC will not be additive (i.e. the effects will be as described for single occurrences only) if the areas of effect only meet or overlap downstream following advection or dispersion of the effects. Effects on sediment deposition will be additive if and where the footprints of the deposits overlap. Given that the minimum spacing between foundations is 1000 m, it is unlikely that sands or gravels put into suspension will be dispersed far enough (i.e. between adjacent foundation locations) to cause any overlapping effects before being redeposited to the seabed. Only relatively fine sediment is likely to be advected far enough to potentially cause overlapping effects on SCC.

Increases in SSC and deposition of disturbed sediments to the seabed due to dredging for seabed preparation prior to installing gravity base foundations within the Hornsea Three array area

1.11.2.15 Two potential sources of sediment release associated with bed preparation activities have been assessed: overspill during the dredging of sediment from the seabed; and, the disposal of dredged sediment back to the seabed at a nearby location. The sediment release rate from overspill during dredging will be much smaller than that from dredge spoil disposal, and will be more quickly dispersed by tidal currents. Accordingly, the focus of the assessment is on the highest concentration increases in SSC associated with dispersion from dredge spoil disposal activities.

1.11.2.16 It is assumed that dredging would be undertaken with a dredger with a hopper volume of ~11,000 m^3 and disposal of dredged material is assumed to take place approximately 500 m from the seabed preparation site. These assumptions are consistent with those made for the assessment of sediment plume dispersion for Hornsea Project Two (SMart Wind, 2015).

1.11.2.17 The potential for changes in SSC and associated changes in bed levels have been calculated using a spreadsheet based numerical model, with results described in detail within volume 5, annex 1.1: Marine Processes Technical Annex, section 4. These results have subsequently been validated using the sediment plume modelling results from the Hornsea Project One and Hornsea Project Two assessments (SMart Wind, 2013, 2015), as well as modelling and monitoring from other analogous activities.

1.11.2.18 As described in Table 1.11, two maximum design scenarios are identified corresponding to the greatest volume of sediment disturbance locally (from a single foundation) and across the entire array (from all foundations). In both instances, the maximum design scenario involves dredging by hopper suction dredger with a split bottom for disposal (i.e. release of material at the water surface).

1.11.2.19 The following summary observations (based on the spreadsheet based numerical model results) are consistent with the previously modelled patterns of change in Hornsea Project One and Hornsea Project Two (Smart Wind, 2013; 2015), similarly modelled patterns of change in assessments for other wind farms, and the wider monitoring evidence base. A full description of the models used and results are presented in volume 5, annex 1.1: Marine Processes Technical Annex, section 4.

1.11.2.20 Across much of the site, the seabed sediment comprises coarse sand and gravel (Figure 1.18), with very limited (< ~5%) fines. Dredging of these sediment units would not create persistent plumes as the coarse material would quickly settle to the seabed. However, in several areas of the site these coarse sediment units also contain some finer muddy material (up to ~50%). The disturbance of these finer grained sediments has the potential to give rise to more persistent plumes that settle out of suspension over a wider area than for coarse grained sediments.

1.11.2.21 The dredger will operate at a given location until the required volume has been dredged or the hopper is sufficiently full. The dredged material (spoil) will then be returned to the seabed nearby as a relatively sudden release from under the vessel. If the volume to dredge at a given location is greater than the hopper capacity (11,000 m^3) then multiple dredging and disposal cycles will be required. It will take the equivalent of:

- 0.5 dredging cycles for one (large) turbine;
- 111.4 dredging cycles for all 300 (smaller) turbines;
- 5.6 dredging cycles for one offshore transformer substation;
- 66.8 dredging cycles for all 12 offshore transformer substations;
- 3.2 dredging cycles for one offshore HVDC converter substation;
- 12.7 dredging cycles for all four offshore HVDC converter substations;
- 0.5 dredging cycles for one accommodation platform;
- 1.6 dredging cycles for all three accommodation platforms; and
- A total of 193 dredging cycles for all foundations.

1.11.2.22 When the dredged material is released from the hopper, approximately 90% will fall directly to the bed as a single mass (termed the dynamic phase of the plume). The remaining approximately 10% will become more dispersed and stay in suspension (termed the passive phase of the plume). The grain size distribution of material in each phase will be representative of the grain size distribution of the dredged material, which may vary.

1.11.2.24 The scale of change associated with the dynamic phase of the plume from a single full hopper dredge spoil disposal event can be summarised as follows:

- Duration within the water column - order of seconds to minutes;
- Duration at the seabed - order of seconds to minutes before becoming part of the background sedimentary environment;
- Spatial extent in the water column - order of tens of metres (both laterally and vertically); and
- SSC levels in the water column will be very high in the dynamic phase (far in excess of natural ranges), however these high concentrations will only last for the duration of time taken for the material to fall to the bed and settle (i.e. order of seconds to minutes).

1.11.2.25 The scale of change associated with the passive phase of the plume from a single full hopper dredge spoil disposal event can be summarised as follows:

- Sand sized material could remain in suspension for up to approximately 15 minutes. During this time, the sediment in suspension could be transported (advected) up to approximately 0.5 km at representative peak tidal current speeds. This distance will, however, typically be less during non-peak flows or during neap tidal periods. The footprint and concentration of the plume would spread and dilute slightly due to diffusion and dispersion with time and distance. The overall direction of transport would be to the northwest during the ebb tide or to the southeast during the flood tide;
- SSC levels in the water column within the footprint of the plume may possibly be in excess of natural ranges over this short timescale;
- Finer sediment fractions (i.e. fine sand or less) present in the passive phase would have a slower settling velocity than the medium sized sands described above and may persist in suspension for longer (i.e. order of hours to days), increasing the extent and duration of change;
- Away from the release locations (i.e. order of hundreds of metres to a few kilometres), elevations in SSC above background levels are relatively low (i.e. less than ~20 mg/l) and are within the range of natural variability. After 24 hours, elevations in SSC will typically be less than 5 mg/l; and
- On the basis of the numerical modelling undertaken for Hornsea Project Two, peak increases in depth-averaged SSC of more than 2 mg/l above background levels are anticipated up to ~16 km outside of the array, whilst increases in depth-averaged SSC of more than 10 mg/l are anticipated up to ~14 km outside of the Hornsea Three array area.

1.11.2.26 Previous research and metocean data collected from the former Hornsea Zone indicate that SSC levels are found to be in the range 0 to 30 mg/l, although under storm conditions these SSC values can increase by (approximately) an order of magnitude (e.g. up to a few hundred mg/l) (Table 1.10). Localised increases in SSC of up to several hundred mg/l in the immediate vicinity of the release location are considerably higher than background levels but are very localised and last for a very short period of time (less than two hours).

1.11.2.27 Over longer timescales, net movement of any fine grained material remaining in suspension would generally be in a northeasterly direction, following the direction of residual tidal flow in this area.

1.11.2.28 In terms of bed level changes associated with installation of a single turbine foundation, it is found that:

- The actual shape and thickness of the seabed deposit resulting from the release of material from the dredger at the water surface cannot be predicted accurately in advance and in any case is likely to vary. A range of possible configurations of area and thickness are presented in volume 5, annex 1.1: Marine Processes Technical Annex, section 4. From this range, the following examples represent a relatively widely spread deposit which is the maximum design scenario for the area of seabed affected (by a nominal average thickness of 0.05 m). In practice, the deposit may comprise several individual releases from multiple dredging cycles and the deposits are likely to be relatively thicker, with a correspondingly smaller area of effect;
- If up to 5,845 m^3 of material is displaced during the installation of one turbine or accommodation platform gravity base foundation, an area measuring 116,900 m^2 (nominally 342 m x 342 m) could potentially be covered by an average thickness of 0.05 m;
- If up to 61,250 m^3 of material is displaced during the installation of one offshore transformer substation gravity base foundation, an area measuring 1,225,000 m^2 (nominally 1107 m x 1107 m) could potentially be covered by an average thickness of 0.05 m;
- If up to 34,888 m^3 of material is displaced during the installation of one offshore HVDC converter substation gravity base foundation, an area measuring 697,760 m^2 (nominally 835 m x 835 m) could potentially be covered by an average thickness of 0.05 m;
- A greater average thickness of material would lead to a smaller area of impact and vice versa. For example, a 0.10 m average thickness deposit would affect an area two times smaller than that described above (for an average deposition thickness of 0.05 m); and
- Deposits resulting from fine sediment that is much more widely dispersed in the passive phase of the plume will have an average thickness less than the diameter of a grain of sand, and therefore would not be measurable in practice. Furthermore, this material would be readily re-mobilised and dispersed and transported further away from the release location, in the direction of the ambient tidal flow.

1.11.2.29 In terms of bed level changes associated with dredging for installation of all foundations (up to 300 turbines, 12 offshore transformer substations, four offshore HVDC boosters and three accommodation platforms), it is found that:

- If the total volume of dredge spoil from all foundations (up to 2,111,557 m^3) was distributed equally across the Hornsea Three array area (696 km^2), the average increase in bed elevation would be 0.003 m;
- An area equal to approximately 6.0% of the Hornsea Three array area could potentially be covered by an average thickness of 0.05 m of material; and
- In practice, the change will comprise a series of discrete deposits (smaller overlapping or non-overlapping deposits, potentially from multiple dredging cycles around each dredged area), distributed throughout the parts of the array area that turbines are located. Individual deposits are likely to be relatively thicker on average than the example value of 0.05 m, with a correspondingly smaller area of effect.

1.11.2.30 If dredging, or any other activity causing sediment disturbance, is undertaken simultaneously at two or more locations that are aligned in relation to the ambient tidal streams, then there is potential for overlap between the areas of effect on SSC and sediment deposition. The potential for in-combination effects on SSC and sediment deposition are discussed in paragraph 1.11.2.14.

Increases in SSC and deposition of disturbed sediments to the seabed due to cable installation within the Hornsea Three array area

1.11.2.31 The maximum design scenario is that the total length of array cables may be up to 830 km and the total length of interconnector cables may be up to 225 km. (Table 1.11). Cables will be installed into a V-shaped cable trench measuring, on average, 6 m wide by 2 m deep. As a result, a total of up to ~4,980,000 m^3 of sediment may be disturbed in relation to array cables and a total of up to ~1,350,000 m^3 of sediment may be disturbed in relation to substation interconnector cables. A small proportion of the same seabed area and sediment volume might be disturbed again by local remedial cable burial activities up to 12 months following initial burial.

1.11.2.32 The impact of cable burial operations mainly relates to a localised and temporary re-suspension and subsequent settling of sediments (BERR, 2008). The exact nature of this disturbance will be determined by the sediment conditions within the Hornsea Three array area, the length of installed cable, the burial depth and burial method.

1.11.2.33 The potential for changes in SSC and associated changes in bed levels have been calculated using a spreadsheet based numerical model, with results described in detail within volume 5, annex 1.1: Marine Processes Technical Annex, section 4. These results have subsequently been validated using the sediment plume modelling results from the Hornsea Project One and Hornsea Project Two assessments (SMart Wind, 2013, 2015), as well as modelling and monitoring from other analogous activities.

1.11.2.34 In terms of sediment disturbance, mass flow excavation and vertical injection (i.e. jetting) techniques represent the maximum design scenarios, as they have the greatest potential to energetically fluidise and eject material from the trench into suspension. By contrast, the other cable installation techniques described in the project design statement (volume 1, chapter 3: Project Description) are expected to re-suspend a smaller amount of material into the water column. Due to spatial variation in the geotechnical properties of the underlying geology within this region, it is possible that a combination of techniques may be used.

1.11.2.35 It is impractical to capture the full detail of sediment heterogeneity along the offshore cable corridor within the context of assessing changes in SSC. Instead, the assessment has considered a series of worst case 'end-member' scenarios. These are:

- Mass flow excavation through 100% (coarse) gravel (15,000 µm);
- Mass flow excavation through 100% (medium) sand (375 µm); and
- Mass flow excavation through 100% (fine) silt (10 µm).

1.11.2.36 These three scenarios represent the full potential range of change both in terms of the duration, spatial extent of change to SSC, and maximum thicknesses of sediment deposition. In practice, a release comprising entirely fines is very unlikely.

1.11.2.37 Results are presented in volume 5, annex 1.1: Marine Processes Technical Annex, section 4 for a range of representative current speeds, noting that cable burial will continue through all states of the tide, including current speeds lower than the highest locally possible (peak) value. Because of the uncertainty with regards to how high into the water column from the bed material may be ejected or re-suspended, results are provided for a realistic range of heights (1, 5 and 10 m). A greater height of ejection will lead to a potentially longer plume duration and a greater distance of influence, but also a corresponding reduction in SSC and deposition thickness. Because the cable burial tool moves relatively quickly (208 m/hr, or 17 s per metre of cable burial), the influence of the plume experienced downstream will be similarly limited in duration to approximately tens of seconds, after which time, the plume will have been advected downstream past the location of the receptor, or will be instead affecting an area of seabed elsewhere further along the route.

1.11.2.38 In summary:

- Due to the expected low height of ejection, the effect of sand and gravels on SSC and deposition will be spatially limited to within metres (up to 20 metres) downstream of the cable for gravels and within tens of metres (up to a few hundred metres) for sands; and
- Finer material will be advected away from the release location by the prevailing tidal current. High initial concentrations (similar to sands and gravels) are to be expected but will be subject to rapid dispersion, both laterally and vertically, to near-background levels (tens of mg/l) within hundreds to a few thousands of metres of the point of release. In practice, only a small proportion of the material disturbed is expected to be fines, with a corresponding reduction in the expected levels of SSC.

1.11.2.39 Irrespective of sediment type, the volumes of sediment being displaced and deposited locally are relatively limited (up to 6 m^3 per metre of cable burial) which also limits the combinations of sediment deposition thickness and extent that might realistically occur. Fundamentally, the maximum distance from each metre of cable trench over which 6 m^3 of sediment can be spread to an average thickness of 0.05 m is 120 m; any larger distance would correspond to a smaller average thickness. The assessment suggests that the extent and so the area of deposition will normally be smaller for sands and gravels (although leading to a greater average thickness of deposition in the order of tens of centimetres to a few metres) and that fine material will be distributed much more widely, becoming so dispersed that it is unlikely to settle in measurable thickness locally.

1.11.2.40 If cable burial, or any other activity causing sediment disturbance, is undertaken simultaneously at two or more locations that are aligned in relation to the ambient tidal streams, then there is potential for overlap between the areas of effect on SSC and sediment deposition. The potential for in-combination effects on SSC and sediment deposition are discussed in paragraph 1.11.2.14.

1.11.2.41 It is noted that cable trenching has the potential to leave scars on the seabed in the footprint of the cable trench. Where the seabed material is not normally mobile, this disturbance may remain present and visible for some time after the initial disturbance. There will be no visible effect if and where the area is covered by mobile sediment. The nature and persistence of such features will depend on the characteristics of the trenching process used, the local geological and seabed sediment characteristics and the ambient hydrodynamic conditions (e.g. as described in BERR, 2008). In many areas of the Hornsea Three array area, the surficial sediments are relatively thin (<1 m thick) or absent and cables are likely to be trenched into the relatively immobile underlying Quaternary units. This may result in potentially long-term (lasting months or years) or permanent localised disturbance of the seabed in the footprint of the cable trench, which may be visible when the location is not covered by mobile sediment. Other than perhaps a slight depression, the nature of the seabed (with or without mobile sediment cover) within the area of effect will not be greatly different to the surrounding area and the form and function of the seabed (as a habitat) would not necessarily be affected

Increases in SSC and deposition of disturbed sediments to the seabed due to sandwave clearance within the Hornsea Three array area

1.11.2.42 A number of sandwaves are located within the Hornsea Three array area. The majority are small although in a few places they are up to 2 m high. Where larger sandwaves intersect a planned cable route, localised clearance of a path through the feature may be required to achieve the necessary cable burial depth below the long term stable seabed level. These operations may result in the displacement of up to 71,150 m^3 of sediment either by dredging or use of a mass flow excavator tool (Table 1.11). Of this total volume from the Hornsea Three array area, up to 7,463 m^3 will be excavated from within Markham's Triangle rMCZ. Dredging is likely to result in a greater sediment deposit thickness while the mass flow excavator is likely to be more energetic and cause the greatest localised elevations in SSC.

1.11.2.43 As previously discussed, much of the Hornsea Three array area is characterised by the presence of sands and gravels (Figure 1.18). Once disturbed, these coarse grained sediments will settle out of suspension in close proximity to the release location causing only short term and localised elevations in SSC. The material being released and deposited is the same as that already present in the natural environment and so would not affect seabed sediment character or be any more or less susceptible to remobilisation than the baseline environment, once initially deposited. Deposited sediments would be rapidly incorporated into the seabed and local accumulations would be subject to redistribution under the prevailing hydrodynamic conditions.

1.11.2.44 In some parts of the site, muddy sediments are present and this is especially the case within the deep central eastern areas of the site (associated with Markham's Hole) and central northern areas (associated with Outer Silver Silver). If sediment is disturbed in these areas, any fine grained sediment may enter into suspension and be advected away from the release location by tidal currents. This material may remain in suspension for a period of several days and be transported a distance of several tens of kilometres. However, at this distance and after this time, concentrations would be very low (approximately a few mg/l) and well within the range of natural variability.

1.11.2.45 Dredging for sandwave clearance will result in the same potential changes to SSC and sediment deposition to the seabed as described for dredging and dredge spoil disposal in relation to seabed preparation for gravity base foundations (paragraph 1.11.2.15). It will typically take the equivalent of less than one (but potentially up to between one and two for larger features) full hopper dredging cycles to clear a single crossing point and the equivalent of up to 6.5 full hopper dredging cycles for total volume expected to be dredged in the Hornsea Three array area. Of this total number in the array area, approximately 0.7 hopper loads will be from within the Markham's Triangle rMCZ.

1.11.2.46 Previous assessments of sandwave clearance using dredging or mass flow excavation in the Hornsea Project Two array area used numerical sediment plume modelling to simulate plumes associated with sandwave clearance operations and two concurrent gravity base foundation bed preparation activities (SMart wind, 2015). Key findings are summarised below:

- Sandwave clearance using a TSHD leads to increases in depth-averaged SSC of 5 to 10 mg/l, extending up to 12.5 km northwest and 13 km southeast of the dredging/disposal/sandwave clearance locations; and
- Sandwave clearance using a mass excavator tool leads to increases in depth-averaged concentration of 5-10 mg/l, extending up to 17.5 km northwest and 13 km southeast of the dredging/disposal/sandwave clearance locations.

1.11.2.47 Given the overall similarities with regards to flow regime and the likely characteristics of the disturbed sediment, these results for Hornsea Project Two are also considered to be valid for Hornsea Three (this is the basis of the evidence based approach, as described in volume 5, annex 1.1: Marine Processes Technical Annex, section 2). The plume extents described above are likely to be conservative (i.e. an providing an over-estimate of the extent to be expected in Hornsea Three) because peak flow speeds are slightly faster in the Hornsea Project Two array area (approximately 0.9 m/s) than in the Hornsea Three array area (approximately 0.7 m/s). Therefore, for identical sediment releases, the maximum plume extent would be expected to be greater in the vicinity of the Hornsea Project Two array area.

1.11.2.48 If sandwave clearance, or any other activity causing sediment disturbance, is undertaken simultaneously at two or more locations that are aligned in relation to the ambient tidal streams, then there is potential for overlap between the areas of effect on SSC and sediment deposition. The potential for in-combination effects on SSC and sediment deposition are discussed in paragraph 1.11.2.14.

Increases in SSC and deposition of disturbed sediment to the seabed due to drilling for foundation installation within the Hornsea Three offshore cable corridor

1.11.2.49 Up to four offshore HVAC booster stations may be installed within the offshore HVAC booster station search area using piled jacket foundations, resulting in a total displaced volume of up to 84,448 m^3 (21,112 m^3 per foundation). Depending on the nature of the underlying geology, the jacket piles may require drilling. The potential for changes in SSC and associated changes in bed levels have been calculated using a spreadsheet based numerical model, with results described in detail within volume 5, annex 1.1: Marine Processes Technical Annex, section 4.

1.11.2.50 The potential for changes in SSC and associated changes in bed levels have been calculated using a spreadsheet based numerical model, with results described in detail within volume 5, annex 1.1: Marine Processes Technical Annex, section 4. These results have subsequently been validated using the sediment plume modelling results from the Hornsea Project One and Hornsea Project Two assessments (SMart Wind, 2013, 2015), as well as modelling and monitoring from other analogous activities.

1.11.2.51 The potential for increases in SSC as a consequence of drilling for offshore HVAC booster substation foundations in the Hornsea Three array area has previously been described in paragraph 1.11.2.3 onwards. The plume characteristics described for the Hornsea Three array area remain broadly valid for the offshore HVAC booster station search area because:

- The analyses carried out for the Hornsea Three array area have considered a range of 'end member' sediment characteristics, capturing the full range of sediment types which could be encountered for any drill location; and
- The drill rates will be the same within the Hornsea Three array area and offshore HVAC booster station search area.

1.11.2.52 Higher peak current speeds within the offshore HVAC booster station search area compared with the Hornsea Three array area means that it is possible the plume extents may be slightly greater. However, the resulting increase in dispersion would also mean lower overall levels of SSC within the plume.

1.11.2.53 The total extent and thickness of bed level change associated with drilling would be dependent upon the nature of the drill arisings, in particular the extent to which the material disaggregates under drilling. However:

- If 21,112 m^3 of material were displaced during the installation of one jacket structure, a maximum area of up to 703,717 m^2 (nominally 839 m x 839 m) could potentially be covered by an average of 0.05 m of material; and
- A greater thickness of material will lead to a smaller area of impact and vice versa. For example, a 0.10 m thick deposit would affect an area half that discussed above for the deposition of 0.05 m of material.

1.11.2.54 If dredging, or any other activity causing sediment disturbance, is undertaken simultaneously at two or more locations that are aligned in relation to the ambient tidal streams, then there is potential for overlap between the areas of effect on SSC and sediment deposition. The potential for in-combination effects on SSC and sediment deposition are discussed in paragraph 1.11.2.14.

Increases in SSC and deposition of disturbed sediments to the seabed due to dredging for seabed preparation prior to installing gravity base foundations within the Hornsea Three offshore cable corridor

1.11.2.55 Up to four offshore HVAC booster stations may be installed within the offshore HVAC booster station search area using gravity base foundations, resulting in a total spoil volume of up to 245,000 m^3 (61,250 m^3 per foundation). Bed preparation would be carried out using a TSHD, assumed to be of comparable size to that for bed preparation activities within the Hornsea Three array area. Dredged material would be deposited at a nearby location, via split bottom disposal.

1.11.2.56 The potential for changes in SSC and associated changes in bed levels have been calculated using a spreadsheet based numerical model, with results described in detail within volume 5, annex 1.1: Marine Processes Technical Annex, section 4. These results have subsequently been validated using the sediment plume modelling results from the Hornsea Project One and Hornsea Project Two assessments (SMart Wind, 2013, 2015), as well as modelling and monitoring from other analogous activities.

1.11.2.57 The potential for increases in SSC as a consequence of bed preparation for turbines in the Hornsea Three array area has previously been described in paragraph 1.11.2.15 onwards. Although the total volume of material requiring dredging may be greater for an offshore HVAC booster station than for a turbine foundation, the overall patterns of increase in SSC are expected to be broadly comparable for both structures. This is because elevated levels of SSC will be largely controlled by the dredging process (dredger type and volume) rather than the overall volume of material excavated.

1.11.2.58 On the basis of the numerical modelling undertaken for bed preparation activities in the Hornsea Project Two array area, peak increases in depth-averaged SSC of more than 2 mg/l above background levels are anticipated up to ~16 km outside of the array, whilst increases in depth-averaged SSC of more than 10 mg/l are anticipated up to ~14 km outside of the array (SMart Wind, 2015). Whilst these figures remain broadly valid, the higher flow speeds within the Offshore HVAC Booster Station Search Area compared with the Hornsea Three array area means that it is possible the plume extents are slightly greater than this. However, the greater dispersion would also mean lower overall levels of SSC within the plume.

1.11.2.59 Although levels of SSC are anticipated to be broadly similar between dredging activities for turbine and offshore HVAC booster station sea bed preparation, it is not the case that associated changes in bed levels would also be comparable. Here, the much larger volume of dredging associated with offshore HVAC booster station bed preparation activities would result in a greater change in bed levels following disposal of the dredged material. The total extent and thickness of change would be dependent upon the nature of the dredged material. However,

- If 61,250 m^3 of material were displaced during the installation of one gravity base structure, a maximum area of up to 1,225,000 m^2 (nominally 1,107 m x 1,107 m) could potentially be covered by an average of 0.05 m of material.

1.11.2.60 If dredging, or any other activity causing sediment disturbance, is undertaken simultaneously at two or more locations that are aligned in relation to the ambient tidal streams, then there is potential for overlap between the areas of effect on SSC and sediment deposition. The potential for in-combination effects on SSC and sediment deposition are discussed in paragraph 1.11.2.14.

Increases in SSC and deposition of disturbed sediment to the seabed due to cable installation within the Hornsea Three offshore cable corridor

1.11.2.61 The maximum design scenario is that six export cables may be installed, each 191 km in length, with a total length of up to 1,146 km (Table 1.11). Cables will be installed into a V-shaped cable trench measuring, on average, 6 m wide by 2 m deep. As a result, a total of up to ~6,876,000 m^3 of sediment may be disturbed in relation to export cables. A small proportion of the same seabed area and sediment volume might be disturbed again by local remedial cable burial activities up to 12 months following initial burial.

1.11.2.62 The impact of cable burial operations mainly relates to a localised and temporary re-suspension and subsequent settling of sediments (BERR, 2008). The exact nature of this disturbance will be determined by the sediment conditions within the Hornsea Three offshore cable corridor, the length of installed cable, the burial depth and burial method.

1.11.2.63 The potential for changes in SSC and associated changes in bed levels have been calculated using a spreadsheet based numerical model, with results described in detail within volume 5, annex 1.1: Marine Processes Technical Annex, section 4. These results have subsequently been validated using the sediment plume modelling results from the Hornsea Project One and Hornsea Project Two assessments (SMart Wind, 2013, 2015), as well as modelling and monitoring from other analogous activities.

1.11.2.64 The changes in SSC and seabed sediment deposition associated with cable burial in the Hornsea Three offshore cable corridor are the same as described for the Hornsea Three array area (paragraph 1.11.2.31), making appropriate allowance for local variation in peak current speeds along the export corridor and geology. Specific results are also described in detail within volume 5, annex 1.1: Marine Processes Technical Annex, section 4, including consideration of the anticipated changes associated with the installation of cables into chalk, which may be encountered at or very close to the surface at the landward end of the Hornsea Three offshore cable corridor. In summary, cable burial into chalk will locally give rise to elevated SSC of up to hundreds of thousands of mg/l for several seconds at locations immediately adjacent (i.e. within a few tens of metres) to the cable trench. Any fine chalk arisings may persist in suspension for longer than sand sized material (order of days) but the plume will be subject to significant dispersion in that time, reducing any change to SSC to tens of mg/l or less in the same timeframe. As a result of dispersion, no measurable thickness of accumulation of fine sediment is expected. Further details are provided within volume 5, annex 1.1: Marine Processes Technical Annex, section 4.

1.11.2.65 It is noted that cable trenching has the potential to leave scars on the seabed in the footprint of the cable trench. Where the seabed material is not normally mobile, this disturbance may remain present and visible for some time after the initial disturbance. There will be no visible effect if and where the area is covered by mobile sediment. The nature and persistence of such features will depend on the characteristics of the trenching process used, the local geological and seabed sediment characteristics and the ambient hydrodynamic conditions (e.g. as described in BERR, 2008). Where surficial sediments are relatively thin (<1 m thick) or absent, cables may be trenched into the relatively immobile underlying Quaternary units. This may result in potentially long-term (lasting months or years) or permanent localised disturbance of the seabed in the footprint of the cable trench, which may be visible when the location is not covered by mobile sediment. Other than perhaps a slight depression, the nature of the seabed (with or without mobile sediment cover) within the area of effect will not be greatly different to the surrounding area and the form and function of the seabed (as a habitat) would not necessarily be affected.

Increases in SSC and deposition of disturbed sediment to the seabed due to sandwave clearance within the Hornsea Three offshore cable corridor

1.11.2.66 A number of sandwaves are located within the Hornsea Three offshore cable corridor. The majority are small (1 to 2 m) although in a few places they are up to 6 m high. Where cables intersect a large sandwave, localised clearance of a path through the feature may be required to achieve the necessary cable burial depth below the long term stable seabed level. These operations may result in the displacement of up to 1,202,956 m^3 of sediment either by dredging or use of a mass flow excavator tool (Table 1.11). Of this total volume from the Hornsea Three offshore cable corridor, up to 619,689 m^3 will be excavated from within the North Norfolk Sandbanks and Saturn Reef SAC, up to 132,737 m^3 from the North Norfolk Coast and the Wash SAC and up to 1,329 m^3 will be excavated from within the Cromer Shoal Chalk Beds MCZ. Dredging is likely to result in a greater sediment deposit thickness and has a greater potential for sediment displacement while the mass flow excavator is likely to be more energetic and cause the greatest localised elevations in SSC but may not displace sediment so far from its original location.

1.11.2.67 Much of the Hornsea Three offshore cable corridor is characterised by the presence of sands and gravels (Figure 1.11). Once disturbed, these coarse grained sediments will settle out of suspension in close proximity to the release location causing only short term and localised elevations in SSC. The material being released and deposited will typically be the same as that already present in the local natural environment and so would not necessarily affect seabed sediment character or be any more or less susceptible to remobilisation than the baseline environment, following initial deposition. Where the sands are deposited into areas of different seabed type (e.g. areas of slightly coarser seabed in some sandwave troughs), the seabed may become locally relatively finer in texture until the body of sand has been winnowed away or reincorporated into a bedform migrating over that location. In all cases, the deposited sediments would be rapidly incorporated into the seabed and local accumulations would be subject to redistribution under the prevailing hydrodynamic conditions.

1.11.2.68 Any fine grained sediment disturbed may enter into suspension and be advected away from the release location by tidal currents. This material may remain in suspension for a period of several days and be transported a distance of several tens of kilometres. However at this distance and after this time, concentrations would be very low (approximately a few mg/l) and well within the range of natural variability.

1.11.2.69 Dredging for sandwave clearance will result in the same potential changes to SSC and sediment deposition to the seabed as described for dredging and dredge spoil disposal in relation to seabed preparation for gravity base foundations (paragraph 1.11.2.15 onwards for the Hornsea Three array area and paragraph 1.11.2.55 onwards for the Hornsea Three offshore cable corridor). It will typically take the equivalent of less than one (but potentially up to between one and two for larger features) full hopper dredging cycles to clear a single crossing point and the equivalent of up to 89.0 full hopper dredging cycles for the total volume expected to be dredged in the Hornsea Three offshore cable corridor. Of this total number in the Hornsea Three offshore cable corridor, approximately 56 hopper loads will be from within the North Norfolk Sandbanks and Saturn Reef SAC and approximately 0.1 hopper loads will be from within the Cromer Shoal Chalk Beds MCZ.

1.11.2.70 Sandwave clearance (via dredging and/or mass flow excavator) was previously considered for Hornsea Project Two, using numerical modelling (SMart Wind, 2015). The nature of the sediment disturbance, the sediment type and other environmental conditions are sufficiently similar to that being considered for Hornsea Three that the previous modelling is considered to provide directly applicable results in this regard. The results of the Hornsea Project Two plume modelling suggest:

- Increases of approximately 900 mg/l in depth-averaged SSC above background levels in an area close to the sandwave location;
- High levels of SSC (i.e. hundreds of mg/l) near to the point of release are predicted to occur for a short period of time (less than one hour);
- Sandwave clearance using a Trailing Suction Hopper Dredger (TSHD) leads to increases in depth-averaged SSC of 5 to 10 mg/l, extending up to 12.5 km northwest and 13 km southeast of the dredging/disposal/sandwave clearance locations; and
- Sandwave clearance using a mass excavator tool leads to increases in depth-averaged concentration of 5-10 mg/l, extending up to 17.5 km northwest and 13 km southeast of the dredging/disposal/sandwave clearance locations.

1.11.2.71 Given the overall similarities with regards to flow regime and the likely characteristics of the disturbed sediment, these results for Hornsea Project Two are also considered to be valid for Hornsea Three (this is the basis of the evidence based approach, as described in volume 5, annex 1.1: Marine Processes Technical Annex, section 2).

1.11.2.72 The resulting thickness of accumulation of sand will be relatively large (order of tens of centimetres to several metres thick) which is in proportion to the large volume of sediment being cleared and the limited area within which it is expected to settle (within tens to a few hundreds of metres).

1.11.2.73 If sandwave clearance, or any other activity causing sediment disturbance, is undertaken simultaneously at two or more locations that are aligned in relation to the ambient tidal streams, then there is potential for overlap between the areas of effect on SSC and sediment deposition. The potential for in-combination effects on SSC and sediment deposition are discussed in paragraph 1.11.2.14.

1.11.2.74 The nature, magnitude, duration and extent of impacts relating to individual dredging operations are inherently limited by the nature of the process and the vessel. An increase or decrease in the total volume of sediment to be dredged for sandwave clearance does not change these short term characteristics. A greater total volume of sediment to dredge overall will, however, require a greater total duration of dredging. Irrespective of the total duration and number of locations, the impacts caused by individual dredging or spoil disposal activities are equally characterised as short term and localised.

1.11.2.75 Specific results are also described in detail within volume 5, annex 1.1: Marine Processes Technical Annex, section 4.

Change to seabed morphology due to indentations left by jack-up vessels

1.11.2.76 Some of the vessels used during the construction and operation phase may potentially impact the local seabed morphology. This is particularly the case for those vessels that use jack-up legs to hold station and to provide stability for the working platform. Where legs have been inserted into the seabed and then removed, there is the potential for an indentation proportional to the dimensions of the object to remain. The volume and dimensions of the depression may reduce over time (within months to years) due to local seabed movement under gravity and in proportion to the rate of sediment transport through the area. The presence of such an indentation feature does not necessarily imply a difference in sedimentary environment in the area of the effect, but this would depend upon the nature and depth of the sub-surface sediments.

1.11.2.77 As described in Table 1.11, the maximum design scenario vessel footprint for the Hornsea Three array area and offshore cable corridor would be caused by jack-up barges with a maximum of six legs per barge, with each leg occupying an area of 170 m^2. The maximum size of the resulting depression per leg could be up to ~14.7 m diameter. In the nearshore region of the Hornsea Three offshore cable corridor, considerably smaller jack-up barges will be used with a maximum of four legs per barge, with each leg occupying an area of 4.52 m^2.

1.11.2.78 The depth of each indentation would be highly dependent upon the nature of the surficial sediments and underlying geology. In the majority of areas within the Hornsea Three array area, surficial sediments are less than 1 m thick, immediately overlying deposits belonging to the Bolders Bank formation. In these areas, indentations are likely to be in the order of a few metres.

1.11.2.79 As the leg is inserted, the already partially consolidated seabed sediments would primarily be compressed downwards and then displaced laterally sideways. This may cause the seabed around the inserted leg to be raised in a series of concentric pressure ridges. The seabed response is dependent upon the actual dimensions of the leg and the local geotechnical properties of the sediment units.

1.11.2.80 As the leg is subsequently retracted, the force which is holding the sediments laterally would be reduced. Some of the material that has been previously pushed sideways would return to the hole via mass slumping under gravity. Any loose sediment would avalanche back into the depression until a maximum stable slope angle is achieved.

1.11.2.81 In cohesive sediments, the footprints associated with the use of jack-up barges may, depending upon the ambient rate of sediment transport, persist long after installation operations are completed. For example, the use of jack-up vessels for the construction of the Kentish Flats offshore wind farm resulted in spudcan impressions in the London clay seabed sediments that were visible several years after construction and completion of the wind farm (Emu, 2005). The frequency with which sediments are mobilised by the prevailing hydrodynamic conditions normally experienced within the Hornsea Three array area has been discussed in paragraph 1.7.1.42 onwards. Because of the generally low rates of sediment transport, it is likely that any depressions left by the jack-up barges would only be infilled over relatively short timescales (i.e. months to years).

1.11.2.82 It is not expected that footprints from jack-up barges will have implications for sediment transport; they are simply local depressions that will infill over time (within months to years).

1.11.3 Operational and maintenance phase: changes to pathways

1.11.3.1 The changes to marine processes in response to the offshore operation and maintenance of Hornsea Three have been described in this section. The potential changes arising from the operation and maintenance of Hornsea Three are listed in Table 1.11 along with the maximum design scenario against which each operation and maintenance phase change has been assessed.

1.11.3.2 As previously stated, the assessments presented within this section consider pathways only and as such do not provide a conclusion regarding the significance of effect. Instead the significance of effect is considered in the various relevant receptor chapters.

Scour of seabed sediments

1.11.3.3 The term scour refers here to the development of pits, troughs or other depressions in the seabed sediments around the base of wind turbine foundations. Scour is the result of net sediment removal over time (typically within a matter of days in mobile sediemnts) due to the complex three-dimensional interaction between the foundation and ambient flows (currents and/or waves). Such interactions result in locally accelerated time mean flow and locally elevated turbulence levels that also locally enhance sediment transport potential. The resulting dimensions of the scour features and their rate of development are, generally, dependent upon the characteristics of the:

- Obstacle (dimensions, shape and orientation);
- Ambient flow (depth, magnitude, orientation and variation including tidal currents, waves, or combined conditions); and
- Seabed sediment (geotextural and geotechnical properties).

1.11.3.4 Scour assessment for EIA purposes is considered here for monopile, jacket and gravity base foundations. The potential concerns include the seabed area that may be modified from its natural state (potentially impacting sensitive receptors through habitat alteration) and the volume and rate of additional sediment re-suspension, as a result of scour.

1.11.3.5 The seabed area directly affected by scour may be modified from the baseline (pre-development) or ambient state in several ways, including:

- A different (coarser) surface sediment grain size distribution could develop due to winnowing of finer material by the more energetic flow within the scour pit;
- Seabed slopes could be locally steeper in the scour pit; and
- Flow speed and/or turbulence would be locally elevated, on average.

1.11.3.6 The scale of change would vary depending upon the foundation type, the local baseline oceanographic and sedimentary environments and the type of scour protection implemented (if needed). In some cases, the modified sediment character within a scour pit may not be so different from the surrounding seabed. However, changes relating to bed slope and elevated flow speed and (near-field) turbulence are still likely to apply. As such, depending upon the sensitivities of the particular ecological receptor, not all scouring necessarily correspond to a loss of habitat. This is discussed further in volume 2, chapter 2: Benthic Ecology.

1.11.3.7 Scour assessment for EIA purposes is considered here for three foundation types: monopiles; piled jacket foundations (a four legged version); and gravity base foundation structures. Each foundation type may produce different scour patterns therefore monopiles, gravity base foundations and jacket foundations have all been considered. Suction caisson foundations (for monopods and jackets) have not been considered in the assessment below because these will fall within the envelope of change associated with the other three foundation types.

1.11.3.8 In order to quantify the area of seabed that might be affected by scour (either the footprint of scour or scour protection), the following provides an estimate of the theoretical maximum depth and extent of scour. This assessment is based upon empirical relationships described in Whitehouse (1998) and is a summary of a more detailed assessment presented in volume 5, annex 1.1: Marine Processes Technical Annex, section 11. Importantly, these estimates are highly conservative as they assume an unlimited depth of erodible sediment and the absence of erosion resistant geology.

1.11.3.9 Results conservatively assume maximum equilibrium scour depths are symmetrically present around the perimeter of the structure in a uniform and frequently mobile sedimentary environment. Derivative calculations of scour extent, footprint and volume assume an angle of internal friction = 32º. Scour extent is measured from the structure's edge. Scour footprint excludes the footprint of the structure. Scour pit volumes for gravity base foundation structures are calculated as the volume of an inverted truncated cone, minus the structure volume; scour pit volume for the jacket foundations are similarly calculated but as the sum of that predicted for each the corner piles.

1.11.3.10 In the following section, the term ‘local scour’ refers to the local response to individual structure members. ‘Global scour’ refers to a region of shallower but potentially more extensive scour associated with a multi-member foundation resulting from the change in flow velocity through the gaps between members of the structure and turbulence shed by the entire structure. Global scour does not imply scour at the scale of the wind farm array.

1.11.3.11 Key findings are summarised below and in Table 1.17 and Table 1.18:

- Overall, scour development within the Hornsea Three array area is expected to be dominated by the action of tidal currents;
- In practice, the thickness of easily erodible sediment over more erosion resistant sediments - (primarily Bolders Bank Formation) - in most of the array area is limited to around one metre. This is likely to lead to a natural limitation of scour depth and a related reduction in the footprint and volume of seabed affected by scour, both for individual foundations and for the array as a whole;
- Of all of the turbine foundation options under consideration, a 15 m diameter monopile foundation has the potential to cause the greatest equilibrium local scour depth (19.5 m), footprint (4,530 m^2) and volume (up to 34,224 m^3), but only in areas where the seabed is potentially erodible by the action of scour to that depth;
- The greatest individual turbine foundation global scour footprint is associated with the larger (40 m base length) piled jacket foundation (4,976 m^2), although with a relatively small average depth (1.8 m);
- For the Hornsea Three array area as a whole, the greatest total turbine foundation local scour footprint is associated with an array of 160 larger (15 m diameter) monopile foundations (724,801 m^2, equivalent to only approximately 0.1% of the array area); and
- For the Hornsea Three array area as a whole, the greatest total turbine foundation global scour footprint is associated with an array of 300 smaller (33 m base diameter) piled jacket foundations (1,018,432 m^2, equivalent to only approximately 0.15% of the array area).

1.11.3.12 Scour protection may be used to protect the stability of foundations if necessary. Where scour protection is used, primary scour is unlikely to occur, although a small amount of secondary scour may develop at the edges of the scour protection. For monopile and piled jacket foundation types the footprint area of scour protection is similar to (or smaller than) the predicted footprint of local scour. For gravity base foundations, the footprint area of scour protection is larger than the predicted footprint of local scour for this foundation type (due to a relatively smaller predicted depth of scour) but more similar to that for monopiles. At most, the maximum footprint of scour protection is equivalent to only approximately 0.17% of the array area (0.23% including the footprint of the foundations also).

1.11.3.13 Scour depth can vary significantly under combined current and wave conditions through time (Harris *et al*., 2010). Monitoring of scour development around monopile foundations in UK offshore wind farm sites suggest that the time-scale to achieve equilibrium conditions can be of the order of 60 days in environments where mobile seabeds exist (Harris *et al*., 2011). These values account for tidal variations as well as the influence of waves. (Near) symmetrical scour will only develop following exposure to both flood and ebb tidal directions.

1.11.3.14 Under waves or combined waves and currents an equilibrium scour depth for the conditions existing at that time may be achieved over a period of minutes, whilst typically under tidal flows alone equilibrium scour conditions may take several months to develop (SMart Wind, 2015).

1.11.3.15 Any elevations in SSC as a consequence of scour will be short lived and localised and within the range of natural variability.

Table 1.17: Summary of predicted maximum scour dimensions for largest individual turbine foundation structures.

Parameter		Foundation type		
		Monopile (15 m diameter)	Four legged jacket (40 m x 40 m base, 4.6 m legs)	Gravity base (53 m base diameter)
Equilibrium Scour Depth (m)^	Steady current	19.5	6.0	1.6
	Waves	Insufficient for scour	Insufficient for scour	2.1
	Waves and current	19.5	6.0	3.4
	Global scour	N/A	1.8	N/A
Extent from foundation [a] (m)	Local scour	31.2	9.6	2.5
	Global scour	N/A	40.0	N/A
Footprint [a] (m^2)	Structure alone	177	50	2,206
	Local scour (exc. structure)	4,530	1,632	444
	Global scour (exc. structure)	N/A	4,976	N/A
Volume [a] (m^3)	Local scour (exc. structure)	34,224	3,948	347
	Global scour (exc. local scour and structure)	N/A	9,156	N/A

Results assume erodible bed and absence of geological controls

a Based upon the scour depth for steady currents. Footprint and volume values are per foundation.

Table 1.18: Total seabed footprint of the different foundation types with and without scour.

Parameter	Monopiles		Four legged jacket		Gravity base	
	(10.7 m diameter)	(15 m diameter)	(33 m base length)	(40 m base length)	(43 m diameter)	(53 m diameter)
Maximum number of foundations	300	160	300	160	300	160
Seabed footprint of all foundations (m^2)	26,976	28,274	7,926	8,042	435,660	352,989
Proportion of array area [a] (%)	0.00	0.00	0.00	0.00	0.06	0.05
Seabed footprint of all local scour (m^2)	691,520	724,801	265,957	261,109	79,474	70,988
Proportion of array area [a] (%)	0.10	0.10	0.04	0.04	0.01	0.01
Seabed footprint of all foundations + local scour (m^2)	718,496	753,075	273,883	269,151	515,135	423,977
Proportion of array area [a] (%)	0.10	0.11	0.04	0.04	0.07	0.06
Seabed footprint of all global scour (m^2)	N/A	N/A	1,018,432	796,205	N/A	N/A
Proportion of array area [a] (%)	N/A	N/A	0.15	0.11	N/A	N/A
Seabed footprint of all scour protection (m^2)	647,426	678,584	190,230	193,019	1,187,522	733,876
Proportion of array area [a] (%)	0.09	0.10	0.03	0.03	0.17	0.11
Seabed footprint of all foundations + scour protection (m^2)	674,402	706,858	198,156	201,062	1,623,182	1,086,865
Proportion of array area [a] (%)	0.10	0.10	0.03	0.03	0.23	0.16

All scour dimensions are based upon the scour depth for steady currents.
Results assume erodible bed and absence of geological controls
a Corresponding proportion of the Hornsea Project Three array area (696 km^2).

Increase in SSC and deposition of disturbed sediment to the seabed due to cable maintenance within the Hornsea Three array area

1.11.3.16 The maximum design scenario is that the total length of array cables may be up to 830 km. If remedial burial is required due to unintended exposure of an otherwise unprotected cable, cables may (depending on sediment type) be reburied locally by jetting. The maximum local length of cable to be reburied is up to 2 km and the maximum width of seabed disturbance from the trenching works will be 10 m.

1.11.3.17 If a section of cable is damaged, the repair may include deburial of up to 2 km of the damaged cable, followed by reburial. The additional cable length required to achieve the repair may be placed into a dredged pit with a maximum area of 25,000 m^2. It is assumed that any or all of the 300 WTG array cables might be replaced at some point in their lifetime.

1.11.3.18 The impact of cable reburial operations mainly relates to a localised and temporary re-suspension and subsequent settling of sediments (BERR, 2008). The exact nature of this disturbance will be determined by the sediment conditions within the Hornsea Three array area, the length of installed cable, the burial depth and burial method.

1.11.3.19 The potential for changes in SSC and associated changes in bed levels have been calculated for initial trenching of the cables, which is similar to the reburial operations, using a spreadsheet based numerical model, with results described in detail within volume 5, annex 1.1: Marine Processes Technical Annex.. These results have subsequently been validated using the sediment plume modelling results from the Hornsea Project One and Hornsea Project Two assessments (SMart Wind, 2013, 2015), as well as modelling and monitoring from other analogous activities.

1.11.3.20 In terms of sediment disturbance, mass flow excavation and vertical injection (i.e. jetting, as used for reburial) techniques represent the maximum design scenarios, as they have the greatest potential to energetically fluidise and eject material from the trench into suspension. By contrast, the other cable installation techniques described in the project design statement (volume 1, chapter 3: Project Description) are expected to re-suspend a smaller amount of material into the water column. Due to spatial variation in the geotechnical properties of the underlying geology within this region, it is possible that a combination of techniques may be used.

1.11.3.21 It is impractical to capture the full detail of sediment heterogeneity in the array area within the context of assessing changes in SSC. Instead, the assessment has considered a series of worst case 'end-member' scenarios. These are:

- Mass flow excavation through 100% (coarse) gravel (15,000 µm);
- Mass flow excavation through 100% (medium) sand (375 µm); and
- Mass flow excavation through 100% (fine) silt (10 µm).

1.11.3.22 These three scenarios represent the full potential range of change both in terms of the duration, spatial extent of change to SSC, and maximum thicknesses of sediment deposition. In practice, a release comprising entirely fines is very unlikely.

1.11.3.23 Results are presented in volume 5, annex 1.1: Marine Processes Technical Annex, for a range of representative current speeds, noting that cable burial will continue through all states of the tide, including current speeds lower than the highest locally possible (peak) value. Because of the uncertainty with regards to how high into the water column from the bed material may be ejected or re-suspended, results are provided for a realistic range of heights (1, 5 and 10 m). A greater height of ejection will lead to a potentially longer plume duration and a greater distance of influence, but also a corresponding reduction in SSC and deposition thickness. Because the cable burial tool moves relatively quickly (208 m/hr, or 17 s per metre of cable burial), the influence of the plume experienced downstream will be similarly limited in duration to approximately tens of seconds, after which time, the plume will have been advected downstream past the location of the receptor, or will be instead affecting an area of seabed elsewhere further along the route.

1.11.3.24 In summary:

- Due to the expected low height of ejection, the effect of sand and gravels on SSC and deposition will be spatially limited to within metres (up to 20 metres) downstream of the cable for gravels and within tens of metres (up to a few hundred metres) for sands; and
- Finer material will be advected away from the release location by the prevailing tidal current. High initial concentrations (similar to sands and gravels) are to be expected but will be subject to rapid dispersion, both laterally and vertically, to near-background levels (tens of mg/l) within hundreds to a few thousands of metres of the point of release. In practice, only a small proportion of the material disturbed is expected to be fines, with a corresponding reduction in the expected levels of SSC.

1.11.3.25 Irrespective of sediment type, the volumes of sediment being displaced and deposited locally are relatively limited (up to 6 m^3 per metre of cable burial) which also limits the combinations of sediment deposition thickness and extent that might realistically occur. Fundamentally, the maximum distance from each metre of cable trench over which 6 m^3 of sediment can be spread to an average thickness of 0.05 m is 120 m; any larger distance would correspond to a smaller average thickness. The assessment suggests that the extent and so the area of deposition will normally be smaller for sands and gravels (although leading to a greater average thickness of deposition in the order of tens of centimetres to a few metres) and that fine material will be distributed much more widely, becoming so dispersed that it is unlikely to settle in measurable thickness locally.

1.11.3.26 If cable burial, or any other activity causing sediment disturbance, is undertaken simultaneously at two or more locations that are aligned in relation to the ambient tidal streams, then there is potential for overlap between the areas of effect on SSC and sediment deposition. The potential for in-combination effects on SSC and sediment deposition are discussed in paragraph 1.11.2.14.

1.11.3.27 It is noted that cable trenching has the potential to change the texture or level of the seabed in the footprint of the cable trench. Where the seabed material is not normally mobile, this disturbance may remain present and visible for some time after the initial disturbance. The nature and persistence of such features will depend on the characteristics of the trenching process used, the local geological and seabed sediment characteristics and the ambient hydrodynamic conditions (e.g. as described in BERR, 2008). In many areas of the Hornsea Three array area, the surficial sediments are relatively thin (<1 m thick) or absent and cables are likely to be trenched into the relatively immobile underlying Quaternary units. This may result in potentially long-term or permanent localised disturbance of the seabed in the footprint of the cable trench, which may be visible when the location is not covered by mobile sediment. The nature of the immobile seabed (without mobile sediment cover) within the area of effect will not be greatly different to the surrounding area. There will be no visible effect if and where the area is covered by mobile sediment.

Increases in SSC and deposition of disturbed sediment to the seabed due to cable maintenance within the Hornsea Three offshore cable corridor

1.11.3.28 The maximum design scenario is for up to six export cables, each might require on average 2.5 reburial events, or a total of 15 events for all cables over the lifetime of the project. If remedial burial is required due to unintended exposure of an otherwise unprotected cable, cables will be reburied locally by jetting. The maximum local length of cable to be reburied is up to 2 km and the maximum width of seabed disturbance from the trenching works will be 10 m.

1.11.3.29 If a section of cable is damaged, the repair may include deburial of up to 200 m of the damaged cable, followed by reburial. The additional cable length required to achieve the repair may be placed into a dredged pit with a maximum area of 25,000 m^2 (approximate dimensions 250 m x 100 m). Alternatively, a short section of rock protection (500 m length, 7 m wide) might be used to cover the repaired section It is assumed a total of 15 repair events for all cables may be required over the lifetime of the project

1.11.3.30 The impact of cable burial operations mainly relates to a localised and temporary re-suspension and subsequent settling of sediments (BERR, 2008). The exact nature of this disturbance will be determined by the sediment conditions within the Hornsea Three offshore cable corridor, the length of installed cable, the burial depth and burial method.

1.11.3.31 The potential for changes in SSC and associated changes in bed levels have been calculated using a spreadsheet based numerical model, with results described in detail within volume 5, annex 1.1: Marine Processes Technical Annex. These results have subsequently been validated using the sediment plume modelling results from the Hornsea Project One and Hornsea Project Two assessments (SMart Wind, 2013, 2015), as well as modelling and monitoring from other analogous activities.

1.11.3.32 The changes in SSC and seabed sediment deposition associated with cable reburial in the Hornsea Three offshore cable corridor are the same as described for cable burial the Hornsea Three array area (paragraph 1.11.2.31), making appropriate allowance for local variation in peak current speeds along the export corridor and geology. Specific results are also described in detail within volume 5, annex 1.1: Marine Processes Technical Annex, including consideration of the anticipated changes associated with the installation of cables into chalk, which may be encountered at or very close to the surface at the landward end of the Hornsea Three offshore cable corridor. In summary, cable burial into chalk will locally give rise to elevated SSC of up to hundreds of thousands of mg/l for several seconds at locations immediately adjacent (i.e. within a few tens of metres) to the cable trench. Any fine chalk arisings may persist in suspension for longer than sand sized material (order of days) but the plume will be subject to significant dispersion in that time, reducing any change to SSC to tens of mg/l or less in the same timeframe. As a result of dispersion, no measurable thickness of accumulation of fine sediment is expected. Further details are provided within volume 5, annex 1.1: Marine Processes Technical Annex,.

1.11.3.33 Finally, it is noted here that cable trenching has the potential to leave scars on the seabed. The persistence of these features will depend on the local seabed characteristics and ambient hydrodynamic conditions. Where cables are trenched into the underlying Quaternary units, a persistent scar is likely which may potentially be visible for many years. Conversely, in areas where mobile sands and gravels are present, the features are likely to be temporary and may only persist for a period of weeks to months.

1.11.4 Decommissioning phase: changes to pathways

1.11.4.1 The changes to marine processes in response to the offshore decommissioning of Hornsea Three have been described in this section. The potential changes arising from the decommissioning of Hornsea Three are listed in Table 1.11 along with the maximum design scenario against which each decommissioning phase change has been assessed.

1.11.4.2 As previously stated, the assessments presented within this section consider pathways only and as such do not provide a conclusion regarding the significance of effect. Instead the significance of effect is considered in the various relevant receptor chapters.

Increases in SSC and deposition of disturbed sediment to the seabed within the Hornsea Three array area

1.11.4.3 The following decommissioning activities could potentially give rise to increases in SSC and associated deposition of material with in the Hornsea Three array area:

- Cutting off of turbine sub-station jacket foundation legs;
- Removal of turbine/sub-station gravity base foundation structures; and
- Removal of array/platform inter-connector cables.

1.11.4.4 Jacket foundations include the greatest number of piles (up to four piles per turbine) so this is considered to be the worst case for sediment disturbance during the cutting off of piles. Piles are likely to be cut off a few metres below the bed, causing a localised disturbance of the bed and a temporary increase in SSC.

1.11.4.5 Gravity base foundations will probably be removed by either floating them (for self-floating designs) or lifting them off the seabed. This operation will also result in some localised disturbance around each gravity base foundation accompanied by temporary increases in SSC.

1.11.4.6 For the purposes of the EIA it has been assumed that all cables will be removed during decommissioning. It is probable that equipment similar to that which is used to install the cables could be used to reverse the burial process and expose the cables. Accordingly, the area of seabed impacted during the removal of the cables would be similar as the area impacted during the installation of the cables.

1.11.4.7 For all of the above, the changes in SSC and accompanying changes to bed levels associated with decommissioning activities are expected to be lesser than that associated with construction. Further information is provided in the construction phase assessment (paragraph 1.11.2.3 onwards).

Increases in SSC and deposition of disturbed sediment to the seabed within the Hornsea Three offshore cable corridor

1.11.4.8 The following decommissioning activities could potentially give rise to increases in SSC and associated deposition of material within the Hornsea Three offshore cable corridor:

- Cutting off of sub-station jacket foundation legs;
- Removal of sub-station gravity base foundation structures; and
- Removal of export cables.

1.11.4.9 Jacket piles are likely to be cut off a few metres below the bed. It is anticipated that gravity base foundations will be removed by removing their ballast and either floating them (for self-floating designs) or lifting them off the seabed. The above operations will result in some localised and temporary disturbance around each foundation. However, the extent of change associated with these decommissioning activities is expected to be lesser than the effects of construction.

1.11.4.10 It is likely that equipment similar to that which is used to install the cables could be used to reverse the burial process and expose them. Therefore, the area of seabed impacted during the removal of the cables could be the same as the area impacted during the installation of the cables. Removal of cables will result in localised disturbance of the seabed, causing temporary increases in SSC and deposition of fine material. However, the extent of change associated with these decommissioning activities is expected to be lesser than the changes associated with construction.

1.11.5 Construction phase: significance of effects

1.11.5.1 The impacts of the offshore construction of Hornsea Three have been assessed on marine processes. The environmental impacts arising from the construction of Hornsea Three are listed in Table 1.11 along with the maximum design scenario against which each construction phase impact has been assessed.

1.11.5.2 A description of the potential effect on marine processes receptors caused by each identified impact is given below.

Removal of sandwaves impacting sandbank systems within proximity to the Hornsea Three array area and offshore cable corridor

1.11.5.3 Within certain sections of the Hornsea Three offshore cable corridor, relatively large mobile sandwave bedforms are present and these may be associated with a considerable thickness (up to 6 m) of coarse grained sediment. To ensure effective burial below the level of the stable bed, it may (in places) be necessary to first remove sections of sandwaves using standard dredging techniques or through the use of a mass excavator tool, before trenching into the underlying bed. The maximum design scenario associated with these activities is set out in Table 1.11.

1.11.5.4 Sandwaves require a plentiful supply of mobile sediment to form and so are often located on top of or in close association with sandbanks. Sandbanks are even larger regional scale accumulations of sediment that result from the convergence of net long term sediment transport pathways over long timescales (hundreds to thousands of years). Sandwaves are visible features on the surface of sandbanks, which evolve and migrate as a result of local sediment transport processes. However, sandwaves have limited direct influence on the form and function of the underlying sandbank (i.e. the overall volume and location of the sandbank body).

1.11.5.5 In addition to short term elevations in SSC (paragraph 1.11.2.42 onwards for the Hornsea Three array area and paragraph 1.11.2.66 onwards for the Hornsea Three offshore cable corridor), this sandwave clearance activity will necessarily result in localised changes to seabed topography. This section assesses the potential for seabed recovery and for longer term changes to sediment transport, based on the analyses presented in volume 5, annex 1.1: Marine Processes Technical Annex, section 4. The focus here is on the Hornsea Three offshore cable corridor since it crosses North Norfolk Sandbanks and Saturn Reef SAC. Conversely, the Hornsea Three array area is not located within an SAC, or in an area with large and extensive mobile bedforms. Accordingly, any sandwave clearance activities will be too far from active sandbank systems to effect change.

Magnitude of impact

1.11.5.6 The volume of material to be cleared from individual sandwaves will vary according to the local dimensions of the sandwave (height, length and shape) and the level to which the sandwave must be reduced (also accounting for stable sediment slope angles and the capabilities and requirements of the cable burial tool being used). The total volume that could be affected by sandwave clearance is presently estimated to be up to 1,202,956 m^3 within the Hornsea Three offshore cable corridor, (based on the Hornsea Three offshore cable corridor geophysical survey data combined with cable installation design specifications). Of this total volume from the Hornsea Three offshore cable corridor, up to 619,689 m^3 will be excavated from within the North Norfolk Sandbanks and Saturn Reef SAC. However, for individual sandbanks the direct impact of sandwave clearance will only be of local spatial extent.

1.11.5.7 The potential for seabed recovery following sandwave clearance along the Race Bank export cable route, as well as for wider changes to sediment transport patterns, for the Inner Dowsing, Race Bank and North Ridge SAC has previously been considered as a detailed desktop study to inform the Race Bank HRA (DONG Energy, 2016).

1.11.5.8 Pre and repeated post construction monitoring (at intervals of days to weeks initially, and up to four months following initial levelling) has also since become available for two offshore locations on the Race Bank offshore cable route (DONG Energy, 2017). In agreement with the conclusions of the desktop study (DONG Energy, 2016), the data show partial recovery of the sandwave crest feature occuring within the levelled corridor towards the end of the four month period for which data are presently available. Recovery was apparently achieved by naturally occuring local sediment accumulation along the previous crest line and was not obviously associated with forward migration of the sandwave crest or erosion of the surrounding non-levelled areas.

1.11.5.9 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. These conclusions are summarised below. An accompanying statement of confidence (either high, medium or low) with respect to Hornsea Three is also provided:

"The bedforms along which bed levelling is proposed are part of a dynamic bedform fields including (in places) 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 [confidence: medium to high].

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 [confidence: high confidence that the seabed will recover to a new natural equilibrium state within a timescale of months to years. However, any predictions of the actual local timescales of change, as well as the form of the 'new' features would have low-medium confidence.].

The levelled areas are not considered likely to create a barrier to sediment movement. Evidence drawn from aggregate dredging activities indicate that if any changes occur to the flow conditions or wave regime, these are localised in close proximity to the dredge pocket. However, the aggregate dredge pockets concerned had widths and lengths of several kilometres. The proposed works are at a much smaller scale and footprint, with trench widths of 13 m along the interlink cable, trench base widths of 25 to 30 m plus side slopes along the export cable or maximum diameter of 55 m for foundation preparation. This means there is likely to be little to no effect on the flow or wave regime, which in turn means no effect on the regional scale sediment transport processes across the array site and export cable route [confidence: medium to high]..*"*

1.11.5.10 Assuming that either a mass flow excavator is used for sandwave clearance, or that any material excavated via the use of a dredger is disposed of in close proximity to the dredge location, no sediment volume will be removed from the sandbank systems overall. The displaced material will be of the same or similar sediment type (mineralogy and grain size distribution) as the surrounding seabed and, following re-settlement, will be immediately available again for transport at the naturally occurring rate and direction, controlled entirely by natural processes. As such, the sediment will have immediately re-joined the natural sedimentary environment within the local area and so by definition is not 'lost from the system' due to the dredging/spoil disposal process. The same sediment might be subsequently transported outside of the sandbank system over time (in the order of tens to hundreds of years) by natural sediment transport processes, but this is no different from the baseline situation. At worst, sediment might be redistributed within the sandbank system so as to cause a temporary local imbalance of sediment budget and a new equilibrium will be established in time (in the order of months to years) through natural sediment transport processes.

1.11.5.11 Should a marine disposal licence for a new disposal site not be granted within the vicinity of the dredging areas, material may have to be transported some distance by vessel and therefore potentially 'lost from the system'. Although this scenario would not be preferable to local disposal, it is still considered unlikely that it would adversely affect the form and function of the designated features within the North Norfolk Sandbanks and Saturn Reef SAC. This is because the area impacted (approximately 5,760,000 m^2) is very small (<0.2 %) relative to the overall size of the SAC (approximately 3,609,000,000 m^2). The volume of sediment currently present in the whole sandwave system cannot be accurately estimated, but (given that only a limited thickness of the sand body is being affected in a locally limited area, and assuming a reasonable thickness of sand present in most areas), it is reasonable to conclude that the volume of sediment being removed is likely also extremely small relative to the total volume of sand present in the sandbank system (<<0.2 %). The area and volume of sandwave material to be cleared is so small in relation to the area and volume of the wider SAC that the assessment is relatively insensitive to the exact clearance volume around this order of magnitude.

1.11.5.12 Sandwave dredging and pre-sweeping of sandwaves superimposed upon sandbanks may disturb sediment at a locally greater scale than jetting/ trenching/ ploughing, etc, but will be confined to those areas of the sandbanks in which larger bedforms are present. Owing to the thickness of sediment in these sandbanks (which ranges from approximately 10 m in the Indefatigable Banks to over 40 m in Leman Bank – Cooper *et al*., 2008) and the limited horizontal and vertical extent of the disturbance, the potential for major disturbance of the sandbank 'core' is considered to be very limited. The macro-scale processes which maintain the form of the banks (i.e. residual patterns of flow circulation, wave action, etc) will be unaffected by any localised disturbance of sediment across the crest/ flanks of the bank and therefore recovery of the feature (in the area of disturbance) to its natural equilibrium state is expected.

1.11.5.13 It is recognised here that all of the Hornsea Three export cables (up to six) will directly cross the Indefatigable Banks, Ower Bank and Leman Bank. Other banks (e.g. Well Bank, Swarte Bank etc) may also be affected, depending upon the final route within the Hornsea Three offshore cable corridor (Figure 1.1). Where sandwaves are absent, cable installation will be achieved via trenching, ploughing or jetting, etc, disturbing sediments to a depth of a few metres at the point of burial. These methods do not necessarily displace all of the sediment volume from the trench cross-section and no net removal of sediment is expected from either the wider sandbank system or the local sedimentary environment. Any local displacement of sediment will be of a very small magnitude relative to the volumes of sediment present both locally and within the sandbank system as a whole. Any locally displaced sediment is expected to be rapidly redistributed and reincorporated, returning the local seabed to a natural equilibrium state in a timescale proportional to the rates of sediment transport through the area. Cable burial activities are therefore very unlikely to directly or indirectly affect the integrity of a sandbank feature.

1.11.5.14 In summary, the impact is predicted to be of local spatial extent, short to medium-term duration, non-continuous and high reversibility. It is predicted that the impact will affect the receptor directly. The magnitude is therefore, considered to be minor.

Sensitivity of the receptor

1.11.5.15 Many of the sandbanks within the Hornsea Three marine processes study area are internationally designated, representing qualifying features of SACs and SCIs. Given their proximity to Hornsea Three, the North Norfolk Sandbanks (which form part of the North Norfolk Sandbanks and Saturn Reef SAC) are of particular relevance to this assessment. These sandbanks are all assigned a high value.

1.11.5.16 According to the available conservation advice for the SAC (JNCC, 2012), the North Norfolk Sandbanks are potentially sensitive to 'physical loss' and 'physical damage'. Although both of these impacts may be associated with sandwave removal, JNCC (2012) note that because the North Norfolk sandbanks are formed by strong tidal currents, it is considered that they could be replenished and recover relatively rapidly from impact. Accordingly, these sandbanks are assessed by JNCC as moderately sensitive to physical loss as well as physical damage via disturbance and abrasion. The field evidence for sandbank recovery in this region from an analogous activity to that considered here is limited and therefore any judgements of recoverability are associated with some residual uncertainty. It is noted here that aggregate extraction operations take place within Area 483 which is located within the North Norfolk Sandbanks and Saturn Reef SAC. However, it is understood that the extraction operations largely target the less mobile gravels, rather than the sandwaves located within the licence area.

1.11.5.17 In summary, sandbanks are deemed to be of moderate vulnerability, moderate recoverability and high value. The sensitivity of the receptor is therefore, considered to be medium.

Significance of the effect

1.11.5.18 Overall, the sensitivity of the receptor is considered to be medium and the magnitude of the impact is deemed to be minor. The effect will, therefore, be of minor adverse significance, which is not significant in EIA terms.

Changes to hydrodynamics, sediment transport and beach morphology at the nearshore area

1.11.5.19 The shoreline in the area of the proposed nearshore area is formed of a steep shingle beach which in places, front eroding cliffs comprising glacial till. The preferred shoreline management plan option for the nearshore area is 'do nothing', allowing continued erosion (North Norfolk District Council, 2010).

1.11.5.20 There are a number of pathways by which the morphology of the nearshore area could potentially be impacted during the construction phase:

- Disturbance of sediments during (open cut) cable trenching across the beach, resulting in associated changes to bed levels;
- Excavation of the seabed could potentially enable more wave energy to propagate further inshore as waves experience less friction and shoaling/breaking effects over and in the lee of the HDD exit pits. The local change in water depth may also cause changes to patterns of wave refraction, slightly changing the direction of travel for wave crests over the excavated area;
- The HDD exit pits could potentially intercept and trap naturally occurring alongshore and cross-shore movement of sediment through passive infilling. This could theoretically lower parts of the beach outside of the initially excavated area and/or reduce the onward supply of sediment to other parts of the beach, resulting in slight changes to sediment budgets and beach morphology;
- Deposition of the excavated material would lead to an increase in local seabed elevation. If these changes are of sufficient magnitude to alter the nearshore wave regime, changes in beach morphology could potentially result; and
- The presence of the cofferdams could modify the nearshore wave regime, influencing rates of alongshore sediment transport. The cofferdams could also physically block the transport of sediment locally.

1.11.5.21 Further details of the maximum design scenario are presented in Table 1.11 and a comprehensive discussion of the potential for changes to hydrodynamics, sediment transport and beach morphology at the nearshore area and nearshoreis presented in volume 5, annex 1.1: Marine Processes Technical Annex, section 6. These are discussed in the following section. (The potential for temporary and localised changes in SSC in the vicinity of the nearshore area as a consequence of cable installation activities is described separately, in paragraph 1.11.2.61 onwards).

1.11.5.22 It is possible that the actual cable pull through will be undertaken after the HDD duct is installed and the exit pit backfilled (associated with the HDD exit pits and cofferdam options described above and assessed in the following sections). In this case, the nature and magnitude of any potential effects of excavating much smaller volume pits, at the same locations, that will be open for much shorter durations, is considered to fall within the envelope of the assessment provided. Given the relatively long timeframe between the two operations, there will be no foreseeable additional overlapping or cumulative effect.

1.11.5.23 It is noted that the nearshore area assessments presented here have been carried out using a desk-based semi-qualitative assessment approach. There is a degree of inherent uncertainty in relation to the range of possible outcomes when making such assessments, including the construction methodology, variability in the environmental conditions that might be experienced at that time, and the actual interaction of processes and response of the environment to any potential change. The assessments are considered to provide realistically likely results based on the information available, but it should be recognised that there is inherent uncertainty in morphological assessments of this type.

Magnitude of impact

Sediment disturbance during trenching

1.11.5.24 Trenching across the intertidal/ shallow subtidal could be achieved using several techniques although ploughing would displace the greatest volume of material out of the trench and therefore is considered to represent the maximum design scenario. Excavation of the trench with a plough would result in the formation of gravel berms either side of the trench. Associated changes in beach/ seabed elevation due to the displacement of gravel from the trench would depend upon several factors including trench width, cable burial depth and the nature of the excavated material. However, for cable burial in a nominal V-shape trench measuring 6 m wide by 2 m deep, the berms created either side of the trench would be ~1.7 m high and with a base width of ~3.5 m (assuming an angle of repose for gravel of 45°)

1.11.5.25 It is possible that whilst the trenches are open, the material in the berms could be mobilised by the action of tidal currents and waves and locally redistributed. Accordingly, the potential extent of change to beach morphology could extend across a wider area than ~3.5 m either side of the trench. However, the gravel berms adjacent to the trench would only be present on the seabed/ beach for a very short period of time (up to 2 weeks) and therefore the extent to which this redistribution of material could occur is anticipated to be limited. Furthermore, given that the berms would only be present for a very short period of time, any changes to hydrodynamics and littoral transport would also be highly localised, of short term duration and reversible. Accordingly, there would be no potential for long term change to coastal morphology.

1.11.5.26 As stated in Table 1.15, it is anticipated that the same excavated shingle would subsequently be used to backfill the trench once the cables had been laid. Because the excavated material would be used for trench backfill, the risk of future erosion to the beach with the cables in place would be no different from the baseline.

Excavation of HDD exit pits

1.11.6 The greatest potential for modification of the local wave regime in response to the HDD exit pits is expected to occur during periods of low water during storm conditions. At this time, waves could theoretically break slightly further inshore (by a distance similar to the dimensions of the HDD exit pits, (i.e. 30 m in length and limited to the width of the pit). If the HDD exit pits were located at their most inshore location (200 m from the MHWS mark at circa -1 mLAT), small changes to waves could potentially extend to the lower beach. In theory, this could cause a slight increase in wave induced sediment transport further up the beach than presently occurs. However, owing to the limited spatial extent (footprint and volume) of the HDD exit pits, the potential for significant resulting morphological change is considered to be low. It is also noted that each of the HDD exit pits will only be open for a maximum of four months (which consists of: one month site setup (including pit excavation); two months pit fully open, drilling & duct pull-in happening; and one month reinstatement (including backfill)) and therefore the potential for localised effects on beach processes and morphology immediately adjacent to each HDD exit pit will be limited to this period.

1.11.7 Change across the upper beach will primarily be driven by larger (storm) waves at higher states of the tide. Such waves have the potential to transport shingle sized material which would otherwise be immobile during calmer conditions. The nearshore area is located in a meso tidal setting and water depths in the vicinity of the most inshore HDD exit pits will be approximately 5 m at MHWS. In such water depths, the potential for modification to storm waves as they propagate across the HDD exit pits will be very much reduced in comparison to equivalent size waves at low water. Accordingly, the wave energy reaching the upper beach is expected to remain largely unaltered with the HDD exit pits in place. Therefore, the risk of beach 'drawdown' is considered to be negligible.

Infilling of HDD exit pits

1.11.7.1 The HDD exit pits could be located within those parts of the nearshore area actively involved in sediment exchange with the adjacent beach (i.e. landward of the depth of closure, which is estimated to be between approximately -4 and -5 mLAT, approximately 200 m offshore of the LAT contour). This means that during storm events, material removed from the beach may be transported across the location of the HDD exit pits. Given the relatively steep gradient of the side slopes and overall depth, it is probable that any sediment entering the HDD exit pits would likely remain there.

1.11.7.2 If a HDD exit pit were to be entirely infilled, this would represent ~1,000 to 2,500 m³ of material. However, total infilling of the exit pit is generally unlikely to happen given the short duration of time that the HDD exit pits will be operational. Moreover, there will be no net loss of material volume from the local area as material excavated from the HDD exit pit will be side-cast and remain locally available for transport.

Deposition of excavated material

1.11.7.3 The dredged material would be side-cast adjacent to the exit pit and subsequently used as backfill. Depending upon the proximity of these mounds to the coast and the water depth in which they are situated, they may have the potential to modify the nearshore wave regime and therefore beach morphology at the nearshore area. In particular, localised changes in water depth over the pits and mounds could allow greater or differently distributed transmission of wave energy to the coast resulting in a localised morphological response.

1.11.7.4 However, for the reasons set out below any impacts to the adjacent beach are considered to be temporary and of limited spatial extent:

- The mounds would be temporary features that would only be present for a short period of time (up to our months: which consists of: one month site setup (including pit excavation); two months pit fully open, drilling & duct pull-in happening; and one month reinstatement (including backfill));
- The footprint of the mounds will be small relative to the wave length of larger incident waves (which are likely to have the greatest influence on the adjacent beach). Accordingly, any wave refraction/ diffraction effect is expected to be limited and localised;
- The greatest potential for changes to the adjacent beach via modification of the wave regime will be during storm events when nearshore sands and gravels are likely be mobilised over relatively larger areas and at a relatively higher rate than in response to 'everyday' wave conditions. Storms only occur intermittently and storms of higher magnitude will occur relatively less frequently. There is, therefore, a limited likelihood of storms (especially larger storms) occurring during the limited time that these temporary features are present. The likelihood of larger storms occurring is also seasonal in nature;
- The excavated material in the mounds will comprise sands and gravels of the same type as the surrounding seabed so the sediments at the surface of the mound will be mobilised at the same rate and in the same manner as the surrounding seabed; and
- Mobilised sediments would be re-distributed by natural sediment transport processes. Depending on the magnitude and pattern of net sediment transport during the limited time that they are present the mounds may evolve from their initial form towards another naturally stable equilibrium shape (likely a relatively lower height and wider extent) over time (based on the response time for naturally occurring nearshore bar features this could be in the timescale of one or more large storm events or more generally in the order of days to weeks during winter months, or in the order of several months during summer). This evolution will tend to progressively reduce any potential effect of the mound on waves and so also the rate of change in the mound shape.

Presence of cofferdams

1.11.7.5 Temporary cofferdams are routinely used to provide a dry, safe and stable working environment during coastal construction works. The design and use of temporary cofferdams in nearshore areas is a mature and common engineering practice which, by using industry best design practices developed through experience, will likely have minimal negative effects on the surrounding coastal area. Examples of uses for cofferdams include HDD exit and transition pits for wind farm export and interconnector cable landfalls, sub-sea pipeline landfalls, coastal defence construction and archaeological excavations.

1.11.7.6 Under the maximum design scenario, cofferdams (measuring 50 m x 5 m, long axis orientated to the cable route) could be located at a minimum distance of ~200 m from the MHWS mark which is approximately 1 mLAT. Although the cofferdam structures could be situated close to the beach and will present a barrier to waves intersecting them, it is considered unlikely that they will cause widespread morphological impacts to the beach for the following reasons:

- The cofferdams will be orientated close to perpendicular to the beach, hence they will present only a limited direct physical barrier to cross-shore sediment transport (in an onshore-offshore direction);
- The majority of sediment transport on the beach is likely to occur in and around the swash zone (i.e. within the inter-tidal area). The cofferdams will not extend into the inter-tidal area but may extend shoreward of the depth of closure. They will therefore present only a limited direct physical barrier to along-shore sediment transport;
- At lower tidal states, larger waves (which will have the greatest potential to influence beach morphology) will have broken before reaching the cofferdams; and
- Individual cofferdam structures will be present for a limited duration of time only (up to four months, which consists of: one month site setup (including pit excavation), two months pit fully open, drilling & duct pull-in happening; and one month reinstatement (including backfill)) and only two will be present at any one time. These factors limit the potential for morphological change to the adjacent beach.

1.11.7.7 All impacts during the construction phase are predicted to be of local spatial extent, short-term duration, continuous and high reversibility. It is predicted that the impacts will affect the receptor directly (in the case of trenching across the beach) and indirectly (in the case of HDD exit pits or cofferdams potentially modifying sediment transport or the nearshore wave regime). The magnitude is therefore, considered to be minor.

1.11.7.8 Given that all impacts at the nearshore area are anticipated to be of local spatial extent and short-term duration, there are no implications for strategies aimed at long term management of the coast as set out in the Shoreline Management Plan and East Marine Plan.

Sensitivity of the receptor

1.11.7.9 The nearshore area is located within the Weybourne Cliffs SSSI, and is immediately adjacent to the North Norfolk Coast SSSI and Wash and North Norfolk Coast SAC. Accordingly, the shoreline at the nearshore area is considered to be of high value. However, the shoreline is typically a dynamic environment which is often subject to a large amount of natural change under baseline conditions. Accordingly, it is assessed to have some capacity to recover from disturbance.

1.11.7.10 In summary, the shoreline is deemed to be of minor vulnerability, moderate to high levels of recoverability and high value. The sensitivity of the receptor is therefore, considered to be medium.

Significance of the effect

1.11.7.11 Overall, the sensitivity of the receptor is considered to be medium and the magnitude of the impact is deemed to be minor. The effect will, therefore, be of minor adverse significance, which is not significant in EIA terms.

Future monitoring

1.11.7.12 No marine processes monitoring to test the predictions made within the construction phase impact assessment is considered necessary.

1.11.8 Operational and maintenance phase: significance of effects

1.11.8.1 The impacts of the offshore operation and maintenance of Hornsea Three have been assessed on marine processes. The environmental impacts arising from the operation and maintenance of Hornsea Three are listed in Table 1.11 along with the maximum design scenario against which each operation and maintenance phase impact has been assessed.

1.11.8.2 A description of the potential effect on marine processes receptors caused by each identified impact is given below.

Changes to the tidal regime, with associated potential impacts to sandbanks

1.11.8.3 Hydrodynamic flow modelling was carried out in support of the Environmental Impact Assessment for Hornsea Project One (SMart Wind, 2013). In brief, the Hornsea Project One tidal modelling simulated 332 conical gravity base foundations with a spacing of 924 m and a foundation base diameter of 50 m (with scour protection extending an additional 20 m from the foot of the gravity base foundation – 90 m diameter in total). This modelling was previously applied in an evidence based approach to the assessment of currents in Hornsea Project Two (SMart Wind, 2015).

1.11.8.4 As the Hornsea Three array area also shares a similar seabed area and baseline flow regime to the Hornsea Project One array area and the number and size of turbines is conservatively similar for Hornsea Project One and Hornsea Three (Table 1.11), the flow modelling work carried out for Hornsea Project One is also applicable to Hornsea Three and has been used here to inform the assessment of changes to the tidal regime. Full justification for this approach is set out in volume 5, annex 1.1: Marine Processes Technical Annex, section 7.

Magnitude of impact

1.11.8.5 The interaction between the tidal regime and the foundations of the wind farm infrastructure will result in a general reduction in current speed and an increase in levels of turbulence locally due to frictional drag and the shape of the structure. Resistance posed by the array (due to the sum of all foundation drag) to the passage of water at a large scale may distort the progression of the tidal wave, also potentially affecting the phase and height of tidal water levels.

1.11.8.6 Changes to the tidal regime may indirectly impact seabed morphology (including bedforms) in a number of ways. In particular, there exists a close relationship between flow speed and bedform type (e.g. Belderson *et al*., 1982) and thus any changes to flows have the potential to alter seabed morphology over the lifetime of Hornsea Three.

1.11.8.7 The greatest mean and maximum blockage density in the Hornsea Three array area is associated with up to 300 conical gravity base foundations with a spacing of 1,000 m and a foundation base diameter of 43 m. Further details with regards to the maximum design scenario (including electricity transmission infrastructure) are provided in Table 1.11.

1.11.8.8 The predicted changes in peak current speeds for Hornsea Project One are shown in Figure 1.17a,b.

1.11.8.9 These figures illustrate that:

- The changes in current speed occur within Hornsea Project One itself and a narrow region just outside of the boundary (up to about 4 km);
- Changes in flow vary from +0.04 m/s to -0.10 m/s;
- Current speed is decreased in a narrow wake extending downstream from each foundation; and
- The relatively regularly gridded layout of foundations modelled for Hornsea Project One is aligned to the tidal current axis and results in the wake from foundations upstream intersecting and combining with the wake from turbines downstream. Conversely, current speed is increased (by a lesser magnitude but in a slightly wider corridor than the area of decreased flow) between the rows of foundations which results in limited net difference in the total flow rate of water through the array area.

1.11.8.10 Given the similarities between Hornsea Project One and Hornsea Three in terms of the tidal regime (water depth, flow speeds, etc.) and the project scope (location and similar number of foundations, but of a smaller size and at a greater minimum spacing within the Hornsea Three array area than Hornsea Project One), it is considered that a similar pattern and a similar or smaller magnitude of change to tidal flows will be observed for Hornsea Three. The spatial extent of these changes for Hornsea Three is shown in Figure 1.17c,d and will be continuous throughout the lifetime of the project (i.e. long-term).

1.11.8.11 The above magnitudes assume the maximum design scenario layout for Hornsea Three which is a regular grid aligned to the tidal axis, providing the greatest potential for interaction of individual wakes. The particular layout of foundations in the Hornsea Three array area is however not fixed in this assessment and so the foundation layout might not necessarily be regularly gridded, and/or aligned to the tidal current axis. Where adjacent foundations are not locally aligned to the tidal axis, the same pattern of wake feature will be generated from each individual foundation, but it would be less likely that wakes will overlap or interact cumulatively between foundations. The likelihood of corridors of increased current speed developing is also reduced. The overall influence of a less regular or less tidally aligned layout will therefore be to reduce the magnitude of the predicted decreases and increases in current speed from that described above.

1.11.8.12 Foundations in the Hornsea Three array area have been shown to cause some redistribution of currents speed including local increases and decreases in flow speed, but with a minimal overall net change in the rate at which water passes through the array area. As such, patterns of natural variability in local and regional water levels are not expected to be affected by Hornsea Three. This includes both tidal and non-tidal (surge) contributions to water levels. This conclusion is entirely consistent with numerical modelling undertaken to inform a wide range of other Round 3 developments (e.g. East Anglia Offshore Wind, 2012; Moray Offshore Renewables Ltd, 2012, Navitus Bay Development Ltd, 2014).

1.11.8.13 Since measurable changes to the tidal regime will not extend to sandbanks systems (the closest of which is approximately 10 km away), the magnitude of change to sandbanks is therefore, considered to be no change.

<u>Sensitivity of the receptor</u>

1.11.8.14 Many of the sandbanks within the Hornsea Three marine processes study area are internationally designated, representing qualifying features of SCIs and SACs. Given their proximity to Hornsea Three, the North Norfolk Sandbanks (which form part of the North Norfolk Sandbanks and Saturn Reef SAC) are of particular relevance to this assessment. These sandbanks are all assigned a high value.

1.11.8.15 According to the available conservation advice for the SAC (JNCC, 2012), the North Norfolk Sandbanks are considered to have high sensitivity to physical loss via obstruction, caused by the presence of structures. However, the majority of the North Norfolk sandbanks (as well as other sandbanks within the Hornsea Three marine processes study area) are dynamic and mobile and therefore considered to have moderate levels of recoverability enabling them to return to a state close to that which existed before any impact. Those designated sandbanks which are considered to be relict (such as the Indefatigable Banks) will be largely insensitive to small and localised changes in tidal currents.

1.11.8.16 In summary, sandbanks are deemed to be of high vulnerability, moderate recoverability and high value. The sensitivity of the receptor is therefore, considered to be high.

<u>Significance of the effect</u>

1.11.8.17 Overall for sandbanks, it is predicted that the sensitivity of the receptor is considered to be high and the magnitude is deemed to be no change. The effect will, therefore, be of negligible significance, which is not significant in EIA terms.

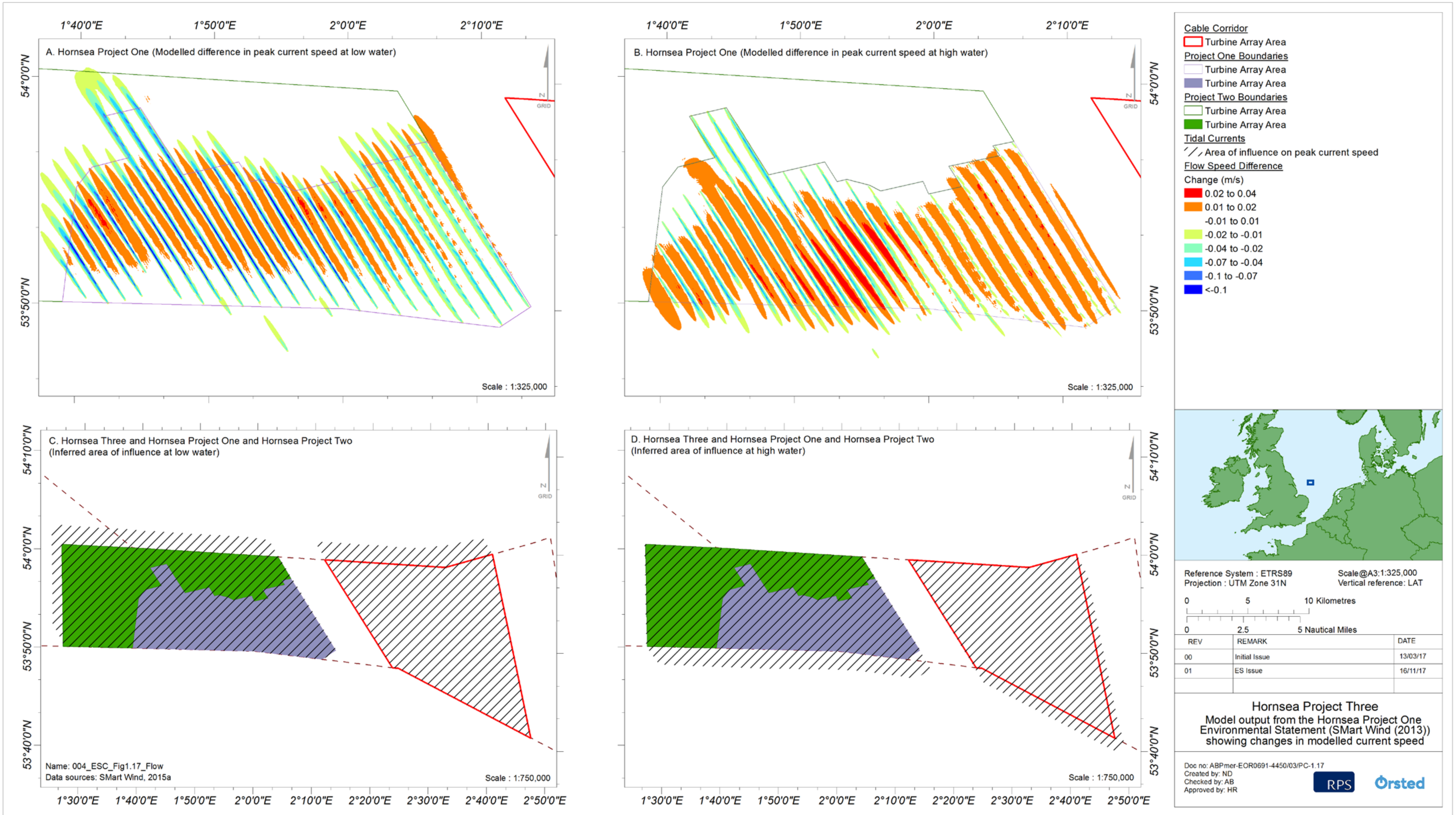

Figure 1.17: Model output from the Hornsea Project One Environmental Statement (SMart Wind (2013)) showing changes in modelled current speed at (a) low water and (b) high water due to turbines in the Hornsea Project One array area. Also shown are the likely patterns, magnitude and extent of influence predicted in the Hornsea Three and Hornsea Project Two array areas at (c) low water and (d) high water.

Changes to the wave regime, with associated potential impacts to sandbanks and along adjacent shorelines

1.11.8.18 The interaction between the waves and the foundations of the wind farm infrastructure may result in a reduction in wave energy locally around foundations. The combined changes arising from all foundations may give rise to an array-scale change that could extend out of the Hornsea Three array area and into the far-field. Where the wave climate is persistently modified, these changes may potentially alter the frequency of sediment mobilisation and therefore seabed morphology in offshore areas, and/or the rate and direction of longshore sediment transport at exposed coastlines.

An array comprising 300 gravity base turbine foundations and 19 auxilliary gravity base foundations with a base diameter of 43 m represents the maximum design scenario for the blockage of waves through the Hornsea Three array area. Further details regarding the maximum design scenario are provided in Table 1.11, whilst full justification for the determination of the maximum design scenario is presented in volume 5, annex 1.1: Marine Processes Technical Annex, section 8, appendix A and appendix B.

1.11.8.19 This section only considers change associated with Hornsea Three. Two receptors are considered for this pathway, namely shoreline morphology and sandbanks. These are discussed individually, under separate sub headings. Cumulative changes associated with Hornsea Project One and Hornsea Project Two, as well as other operational wind farms are considered in paragraph 1.13.6.12 onwards.

<u>Magnitude of impact</u>

1.11.8.20 In order to undertake the assessment of potential changes to the wave regime, a rule based numerical model has been used to simulate the patterns of reduction of wave height through the Hornsea Three array area and the subsequent recovery of wave height downwind. The model setup is informed by and validated against the results of spectral wave modelling previously undertaken in support of EIA of Hornsea Project One and Hornsea Project Two, both alone and in combination. The model setup and results for the new scenarios including Hornsea Three, both alone and in combination with Hornsea Project One and Hornsea Project Two, are also validated against the results from a new spectral wave model. Details of the setup, validation and results of the various wave models used are provided in volume 5, annex 1.1: Marine Processes Technical Annex, section 8, appendix A and appendix B.

1.11.8.21 Results from the rule based numerical model are presented in Figure 1.18, for a maximum design scenario represented by an array comprising 300 gravity base turbine foundations and 19 auxilliary gravity base foundations with a base diameter of 43 m (Table 1.11). Only those wave coming directions which have the potential to affect the North Norfolk to Holderness coast and designated North Norfolk sandbanks are shown.

Shoreline morphology

1.11.8.22 The operational presence of the Hornsea Three array area could theoretically, indirectly affect the shoreline by modifying the sediment transport regime. Using the rule based numerical model to assess potential changes in wave conditions arising from the operational presence of Hornsea Three, it is found that:

- The maximum reduction in wave height for a given wave direction scenario occurs around the centre of the downwind edge of the Hornsea Three array area. The maximum wave height reduction magnitude is relatively similar at 13 to 15% for all directions (Figure 1.18); and
- There will be no measurable reduction in wave height (>2.5%) at adjacent coastlines.

1.11.8.23 Differences in wave height of this magnitude are small in both relative and absolute terms. Such small differences are not measurable in practice and would be indistinguishable from normal short term natural variability in wave height (both for individual wave heights and in terms of the overall seastate). Accordingly, these changes are not predicted to have any indirect impact on coastal morphology through changes to sediment transport.

1.11.8.24 The results presented above are entirely consistent with the separate numerical modelling undertaken to inform Hornsea Project One and Hornsea Project Two (SMart Wind, 2013; 2015). These investigations both found that under all wave conditions tested (magnitudes and directions), predicted changes to wave heights due to the operational presence of the wind farms do not extend to the adjacent coastlines. The greatest influence on waves is observed when winds are blowing from the north and even under this scenario changes are limited to the offshore area, approximately 10 km offshore of the shoreline (i.e. measurable changes are not predicted along adjacent shorelines).

1.11.8.25 It is recognised here that the results presented above are for Hornsea Three alone. The potential for cumulative changes to the wave regime as a consequence of the operational presence of Hornsea Project One, Hornsea Project Two and Hornsea Three are discussed separately, in paragraph 1.13.6.12 onwards.

1.11.8.26 It is noted here that up to four offshore HVAC booster stations could be located within the Hornsea Three offshore cable corridor and may be constructed using box-type gravity base foundations (Table 1.11). Wave scattering around the structures will occur, and will be greatest for the gravity base foundation, but the changes will be spatially limited due to the single foundations. Furthermore, as the offshore HVAC booster stations are located in deep water offshore at least 25 km from the coast, they will not affect the wave climate at the shoreline.

1.11.8.27 Finally, since bank systems can provide natural coastal protection (by dissipating wave energy), any changes to their morphology have the potential to impact adjacent coastlines. However, for the reasons set out in the following section (paragraph 1.11.8.29 onwards), no morphological changes are expected to sandbanks within the Hornsea Three marine processes study area. Accordingly, no associated changes to coastal morphology are expected.

1.11.8.28 Since measurable changes to the wave regime are not expected to extend to the coast the magnitude is therefore, considered to be no change.

Sandbanks

1.11.8.29 The operational presence of the Hornsea Three array area could indirectly affect sandbanks by modifying the wave regime. A number of sandbanks are present within the vicinity of the Hornsea Three array area and offshore cable corridor, including: the designated sandbanks belonging to:

- The North Norfolk Sandbanks and Saturn Reef SAC;
- The North Norfolk Sandbanks and Saturn Reef SAC/Wash Approach MCZ; and
- The North Norfolk Coast SAC (Figure 1.16).

1.11.8.30 Sandbanks are tidally induced bedforms, with sandbank formation principally governed by sediment availability and the prevailing tidal current regime. Within the North Norfolk Sandbanks and Saturn Reef SAC (the closest banks to the Hornsea Three array area), it is understood to be the case that the most offshore sandbanks (e.g. Indefatigable Banks) are largely relict features, formed during the mid-Holocene post-glacial transgression (Kenyon *et al*., 1981; Cooper *et al*., 2008). These contrast with sandbanks located closer to shore (e.g. Leman Bank) and which are known to be active under present day hydrodynamic conditions (Kenyon and Cooper, 2005).

1.11.8.31 Waves primarily influence sandbanks by determining the maximum height (minimum depth) to which they can accumulate (Kenyon and Cooper, 2005). The quantitative assessment of potential changes to the wave regime (presented in volume 5, annex 1.1: Marine Processes Technical Annex, section 8) suggests that when waves are coming from the north, north northeast and northeast (approximately 15% of time), there may be a small reduction in wave height of up to 10% in the vicinity of the Indefatigable Bank system up to 5% in the vicinity of the Swarte Bank system and up to ~2.5% in the vicinity of sandbanks closer inshore (e.g. Ower Bank) (Figure 1.18). Waves from the north, north northeast and northeast only occur for approximately 15% of time and therefore whilst impacts to sandbanks could theoretically occur throughout the operational lifetime of Hornsea Three (i.e. be of long term duration), any impacts would be intermittent in nature.

1.11.8.32 However, for the following reasons it is considered extremely unlikely that these changes to wave conditions would result in a corresponding morphological change to the sandbanks in the form of a small increase in crest elevation:

- The wave events that are likely to cause the greatest effects on offshore sandbanks occur during low-frequency high-intensity storm conditions (e.g. 1 in 10 year return period). The numerical modelling undertaken for Hornsea Project One and Hornsea Project Two has demonstrated that whilst some reductions in wave heights under calm conditions (high-frequency low-intensity wave events; 50% no exceedance) may be expected, larger storm waves will be comparatively less affected. Accordingly, the key wave events that control sandbanks do not correspond to the wave events anticipated to undergo the greatest change (SMart Wind, 2015);
- As stated, the Indefatigable Banks (which are the closest sandbanks to the Hornsea Three array area) are understood to be largely relict features. Accordingly, even if wave stirring of the bed were to be slightly reduced across the crest of the sandbanks (which even at their shallowest point are approximately -15 mLAT), the crest elevation would not be expected to increase. This is because the sandbanks are not actively being modified and 'built up' by tidal processes; and
- The sandbanks closer inshore are understood to be highly dynamic bedforms subject to natural changes under baseline conditions. Even if very small reductions in the heights of northerly/northeasterly waves were to occur across these sandbanks, it is extremely unlikely these would manifest in changes to sandbank crest elevation. This is because these sandbanks are also influenced by large waves which won't have travelled through the Hornsea Three array area (Figure 1.6) and which will contribute to flattening of the crests, thereby maintaining their existing (baseline) elevation.

1.11.8.33 On the basis of the above discussion, the impact is predicted to be of regional spatial extent, long-term duration, intermittent and high reversibility. It is predicted that the impact will affect the receptor indirectly. The magnitude is therefore, considered to be negligible.

<u>Sensitivity of the receptor</u>

Shoreline morphology

1.11.8.34 The majority of the North Norfolk, Lincolnshire and Yorkshire shorelines (which are within the Hornsea Three marine processes study area) are covered by nationally and internationally important nature conservation designations and also typically represent areas of high socio-economic importance. As such, the shoreline is considered to be of high value. However, the shoreline is typically a dynamic environment which is often subject to a large amount of natural change under baseline conditions. Accordingly, it is assessed to have some capacity to recover from disturbance.

1.11.8.35 In summary, the shoreline is deemed to be of minor to moderate vulnerability, moderate to high levels of recoverability and high value. The sensitivity of the receptor is therefore, considered to be medium.

Sandbanks

1.11.8.36 Many of the sandbanks within the Hornsea Three marine processes study area are internationally designated, representing qualifying features of SACs and SCIs. Given their proximity to Hornsea Three, the North Norfolk Sandbanks (which form part of the North Norfolk Sandbanks and Saturn Reef SAC) are of particular relevance to this assessment. These sandbanks are all assigned a high value.

1.11.8.37 According to the available conservation advice for the SAC (JNCC, 2012), the North Norfolk Sandbanks are considered to have high sensitivity to physical loss via obstruction, caused by the presence of structures. However, the majority of the North Norfolk sandbanks (as well as other sandbanks within the Hornsea Three marine processes study area) are dynamic and mobile and therefore considered to have moderate levels of recoverability enabling them to return to a state close to that which existed before any impact. Those designated sandbanks which are considered to be relict (such as the Indefatigable Banks) will be largely insensitive to small and localised changes in waves.

1.11.8.38 In summary, sandbanks are deemed to be of moderate vulnerability, moderate levels of recoverability and high value. The sensitivity of the receptor is therefore, considered to be high.

Significance of the effect

1.11.8.39 Overall for shoreline morphology, it is predicted that the sensitivity of the receptor is considered to be medium and the magnitude is deemed to be no change. The effect will, therefore, be of **negligible** significance, which is not significant in EIA terms.

1.11.8.40 Overall for sandbanks, it is predicted that the sensitivity of the receptor is considered to be high and the magnitude is deemed to be negligible. The effect will, therefore, be of **minor** adverse significance, which is not significant in EIA terms.

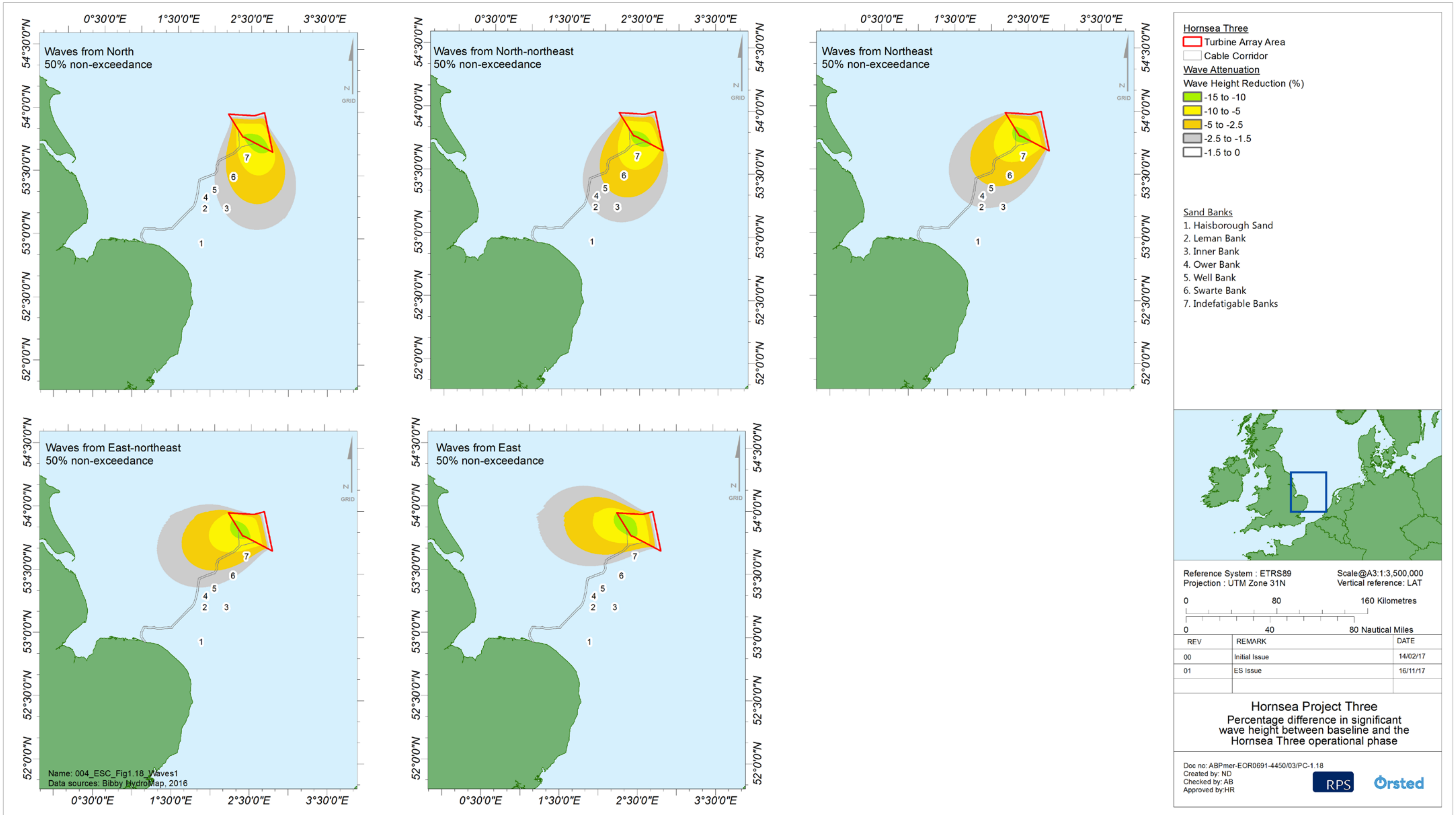

Figure 1.18: Percentage difference in significant wave height between baseline and the Hornsea Three operational and maintenance phase, 50% no exceedance, wave direction (a) north; (b) north-northeast; (c) northeast; (d) east-northeast; (e) east.

Changes to sediment transport and sediment transport pathways with associated potential impacts to sandbanks

1.11.8.41 Modification of existing sediment transport pathways could occur in response to changes in the wave and tidal regime resulting from the presence of turbine and substation foundations and/or the presence of cable protection measures. The presence of cable protection measures may also have the potential to cause a direct (albeit localised) blockage of sediment transport. The above changes could potentially occur over a range of timescales, depending on location and the specific project infrastructure that is interacting with the sediment transport regime.

1.11.8.42 None of the banks within the Hornsea Three marine processes study area will be directly sensitive to a short term difference in the instantaneous rate of sediment transport, if the modified condition remains consistent with the baseline range of natural variability. However, persistent changes in sediment transport patterns over longer timescales (years to decades) may have the potential to cause alterations to seabed and coastal morphology. The potential for such changes to occur is assessed in this section.

1.11.8.43 Details of the maximum design scenario are presented in Table 1.11 and a comprehensive discussion of the potential for changes to sediment transport and sediment transport pathways is presented in volume 5, annex 1.1: Marine Processes Technical Annex, section 9.

Magnitude of impact

Turbine foundations and sub-stations

1.11.8.44 Bed load transport across the Hornsea Three array area and offshore sections of the offshore cable corridor is dominated by the action and asymmetry of tidal currents. The hydrodynamic modelling undertaken to inform the Hornsea Project One Environmental Statement (Smart Wind, 2013; Figure 1.17a,b) has demonstrated that:

- The only changes in current speed are anticipated to occur within the array itself and a narrow region just outside of the boundary (up to about 4 km), and local to foundation structures;
- The predicted changes in peak current speeds for Hornsea Project One vary from +0.04 m/s to -0.10 m/s; and
- Current speed will be reduced in a narrow wake extending downstream from each foundation; Conversely, current speed is increased (by a lesser magnitude but in a slightly wider corridor than the area experiencing decreased flow) between the rows of foundations which results in limited net difference in the total flow rate of water through the Hornsea Three array area.

1.11.8.45 Very similar patterns to that described for Hornsea Project One are anticipated for the Hornsea Three array area (Figure 1.17c, d).

1.11.8.46 The extent to which these continuous but localised changes in flow speed could influence rates of bedload transport within and nearby to the array will depend upon the magnitude of change relative to sediment mobilisation thresholds. In places, it is probable that localised flow reductions of up to 0.10 m/s will lessen the frequency with which sediment particles are mobilised and therefore rates of transport may also be similarly reduced. Conversely, marginally greater rates of sediment transport may be experienced where localised flow accelerations of up to 0.4 m/s are found.

1.11.8.47 The overall result of these slight changes in flow speed could potentially be a very small reduction in the net volume of material transported as bedload through the Hornsea Three array area. However, baseline rates of sediment transport across the Hornsea Three array area are understood to be low and therefore the potential for wider (indirect) morphological change to the surrounding seabed (including sandbanks) is considered to be very limited.

1.11.8.48 It is also noted that the regional sediment transport pathways described by Kenyon and Cooper (2005) are aligned with the tide in a southeast to northwesterly direction. These transport pathways therefore do not connect the Hornsea Three array area with nearby designated seabed areas, in particular the North Norfolk Sandbanks and Saturn Reef SAC (located ~10 km to the south).

1.11.8.49 Up to four offshore HVAC booster stations could be located within the offshore HVAC booster station search area and may be constructed using box-type gravity base foundations (Figure 1.1, Table 1.11). These structures could therefore be located in close proximity to Leman and Ower bank, which form part of the North Norfolk Sandbanks and Saturn Reef SAC. Wave scattering around the structures will occur and they will also give rise to a localised change in the flow field which may extend for a distance of several hundred metres or so. These changes will most likely be greatest for the gravity base foundation.

1.11.8.50 Depending on the characteristics of the seabed sediments local to each foundation (both in terms of grain size and thickness), it is possible that tidally aligned 'scour tails' could form around the structure. The length of these scour tails would vary depending on structure design, hydrodynamic conditions and seabed sediment characteristics although could in theory be several hundred metres in length. (For instance, at Scroby Sands offshore wind farm, scour tails up to 400 m in length have been identified in sandy sediments in response to the presence of the turbine monopole foundations (ABPmer *et al*. 2010).

1.11.8.51 The extent to which any potential scour tails could impact adjacent banks will be dependent upon several factors, not least the proximity of the offshore HVAC booster stations to the banks as well as their alignment relative to the tidal axis (which will be approximately northwest to southeast). However, in theory the substation foundations could result in indirect localised changes to bank morphology.

Cable protection measures

1.11.8.52 Installation of cable protection could result in a local elevation of the seabed profile by up to 2 m (Table 1.11). Cable protection would be placed onto the seabed surface above the cable and therefore could present an obstacle to sediment transport, trapping sediment locally and thereby impacting down-drift locations through a reduction in sediment supply.

1.11.8.53 The JNCC recently commissioned an investigation into the possible impacts of rock dump from oil and gas decommissioning on Annex I mobile sandbanks in the North Norfolk Sandbanks and Saturn Reef SAC (JNCC, 2017). Although the dimensions (i.e. height and width) of rock dump associated with oil & gas infrastructure is likely to be slightly greater for pipelines than for cables, the principles regarding the potential for interaction with naturally occurring sediment transport pathways remain the same. Accordingly, conclusions from the JNCC study are of relevance here. JNCC (2017) identified that:

'…there is currently insufficient information to quantify or qualify the implications of rock dump in the North Norfolk Sandbanks and Saturn Reef [SAC] from a physical (and biological) perspective. It is not possible to quantify or qualify the movement of sandbanks around or over existing or applied rock dump. Theoretically, the mobile sandbanks may cyclically cover applied rock dump and there is the potential for scour to be induced if an appropriate design is not chosen. Without further information on rock berm design, monitoring studies and numerical modelling of such behaviour, the short-term and long-term implications of both theoretical behaviours are difficult to determine.'

1.11.8.54 No additional observational data or information has been found to inform the present study since the publication of JNCC (2017). In the absence of suitable analogous observations, the following theoretical description of the processes involved is considered to provide a conservatively realistic assessment of the potential nature and magnitude of impact.

1.11.8.55 Potential effects on sediment transport can only occur following installation of the cable protection and under conditions where sediment is being actively transported in a manner that is both susceptible to such blockage and in a direction that intersects the cable protection. The potential magnitude of any effect is correspondingly reduced if and when the rate of transport is naturally low, if the mode of sediment transport includes a larger proportion of material in high saltation or suspension, and/or where the axis of the cable protection and the local direction of sediment transport are relatively more aligned.

1.11.8.56 At worst, the obstacle presented by the cable protection will locally prevent the onward passage of all sediment in transport, causing that sediment to accumulate locally. As the accumulated sediment volume increases, any open voids in the protection would become infilled and a sediment slope would develop on the updrift side (with a maximum slope angle equal to the angle of repose for sand ~30 degrees). As the stable slope approaches the top of the protection (up to 2 m above the seabed), the blockage effect of the cable protection will be progressively reduced to near zero and sediment will subsequently be transported directly over the obstacle (via the sediment slope and/or in saltation or suspension) unimpeded, at the naturally occurring ambient rate and direction.

1.11.8.57 The maximum volume of sediment that could potentially accumulate in this way is limited by the dimensions of the protection to approximately 3.46 m^3 of sediment per metre of cable protection, which is small in both absolute and relative terms. The maximum dimensions of morphological change (seabed lowering) that might result from the maximum temporary reduction in sediment supply are therefore proportionally limited (e.g. a maximum of 0.1 m bed lowering might occur in an area up to 34.6 m downstream of the protection, or up to 0.5 m up to 6.92 m downstream, or 0.05 m up to 69.2 m downstream, etc) and is therefore unlikely to measurably affect the form and function of the seabed locally or regionally. The process of accumulating this maximum sediment volume might take place over a period of a few months or less, depending on rates of sediment transport.

1.11.8.58 It is, however, also realistically possible that the rock protection may only cause partial or no measurable blockage of sediment transport, or associated sediment accumulation. In this case, the natural modes of sediment transport (suspension, saltation and bedload locally enhanced by scour-like processes) might be sufficient to collectively allow some or all sediment to simply pass over the obstacle presented by the cable protection with limited or no overall change or interruption to the natural rate or direction.

1.11.8.59 The sediment blockage processes described above considers individual sections of cable protection. Where multiple cables with cable protection are located in relatively close proximity, each cable will undergo the processes described above. The minimum separation distance between the cables is approximately 100 m, therefore, the maximum average bed lowering that might result between a pair of cables from the maximum temporary reduction in sediment supply due to the upstream cable, (or the accumulation of sediment at the downstream cable) is approximately 0.03 m (3.46 m^3 / 100 m), which is very small in both absolute and relative terms, and is unlikely to change the processes and behaviour described above for individual sections of cable. Therefore, there is unlikely to be any additional additive effect for multiple cables with cable protection beyond that described for single cables.

1.11.8.60 The limited blockage effect of cable protection measures on the seabed can be considered broadly analogous to the effect of submerged shore-perpendicular coastal groynes, which act (by design in this case) to accumulate and retain a limited volume of sediment (primarily proportional to the height of the structure), with excess sediment overtopping and bypassing the structure naturally. Where a series of groynes are installed, they produce a similar effect over a larger area; however, the total number of groynes installed does not change the fundamental behaviour of the individual units.

1.11.8.61 Accordingly, for all areas in which cable protection is used (including where sandwaves are present), it is expected that the total volume of sediment supply intercepted by the protection (and so the scale of any consequential effects on seabed morphology downstream) will be very small in both absolute and relative terms. The presence of cable protection will not continue to affect patterns of sediment transport beyond the initial period of accumulation. It is also noted that cable protection measures will only be present locally where required and will not present a continuous blockage along the whole cable route corridor.

1.11.8.62 In summary, any impacts on sandbanks arising from changes to the sediment transport regime are predicted to be of very limited local spatial extent and magnitude, continuous and reversible. Impacts associated with the presence of turbine foundations and sub-stations may be of long-term duration whilst impacts associated with the presence of cable protection measures are more likely to be short-term in nature. For both impact pathways discussed in this section, it is predicted that the impact will affect the receptor indirectly. The overall magnitude of impact is minor.

Sensitivity of the receptor

1.11.8.63 Many of the sandbanks within the Hornsea Three marine processes study area are internationally designated, representing qualifying features of SACs and SCIs. Given their proximity to Hornsea Three, the North Norfolk Sandbanks (which form part of the North Norfolk Sandbanks and Saturn Reef SAC) are of particular relevance to this assessment. These sandbanks are all assigned a high value.

1.11.8.64 According to the available conservation advice for the SAC (JNCC, 2012), the North Norfolk Sandbanks are considered to have high sensitivity to physical loss via obstruction, caused by the presence of structures. However, the majority of the North Norfolk sandbanks (as well as other sandbanks within the Hornsea Three marine processes study area) are dynamic and mobile and therefore considered to have moderate levels of recoverability enabling them to return to a state close to that which existed before any impact.

1.11.8.65 Banks are deemed to be of moderate vulnerability, moderate levels of recoverability and high value. The sensitivity of the receptor is therefore, considered to be high.

Significance of the effect

1.11.8.66 Overall, the sensitivity of the receptor is considered to be high and the magnitude of the impact is deemed to be minor. The effect will, therefore, be of minor adverse significance, which is not significant in EIA terms.

Changes to water column stratification with associated potential impacts to the Flamborough Front

1.11.8.67 Stratification is a naturally occurring seasonal hydrodynamic feature related to the distribution of sea water temperature and salinity, with changes to the availability of nutrients, and the distribution and growth rates of pelagic flora and fauna. Vertical fronts develop at the transition between areas of stratified and non-stratified water and are also associated with (typically relatively enhanced) local patterns of nutrient distribution and ecosystem development. The Flamborough Front is present with the Hornsea Three marine processes study area, in close proximity to the Hornsea Three array area and former Hornsea Zone. It is an ephemeral feature, separating the typically more stratified waters (to the north) from the more mixed waters (to the south) (paragraph 1.7.1.26 onwards).

1.11.8.68 The tendency for stratification to develop is balanced against the ambient rate of turbulent mixing across the density gradient. Turbulence is developed at the seabed by friction with currents, and at the water surface by friction with winds (and any wave breaking). As a result, vertical stratification is more likely to develop in relatively deeper areas, but may also occur in shallower areas with sufficiently low current speeds and exposure to winds and waves.

1.11.8.69 As currents move water past the individual offshore wind farm foundations, a turbulent wake is formed and within the turbulent wake, vertical mixing can be enhanced above ambient levels. The increase in turbulence intensity might potentially contribute to a local reduction in the strength of vertical stratification which in this region, could potentially influence the characteristics of the Flamborough Front.

1.11.8.70 Details of the maximum design scenario associated with the potential impacts to the Flamborough Front are presented in Table 1.11 and a comprehensive discussion of the potential for changes to water column stratification is presented in volume 5, annex 1.1: Marine Processes Technical Annex, section 10.

Magnitude of impact

1.11.8.71 The potential impacts of wind farm turbine foundations on shelf sea stratification have been the focus of two recent investigations by Carpenter *et al*. (2016) and Cazenave *et al*. (2016). Findings from these studies are discussed in detail within volume 5, annex 1.1: Marine Processes Technical Annex, section 10.

1.11.8.72 Carpenter *et al*. (2016) use an idealised (conceptual) numerical model of structure induced turbulent mixing in conjunction with existing environmental hindcast data to consider the potential for large scale change to stratification of the German Bight region of the North Sea in response to planned wind farm developments. The study shows that stratification is only gradually broken down by interaction with the wind farm. A range of 'timescale for (complete) mixing' estimates are provided (in the order of 100 to 500 days) if the same body of initially stratified water is continually passed through the wind farm. In practice, due to non-zero residual rates of tidal advection, the same body of water will not be repeatedly passed through the same wind farm for 100 to 500 days. As a result, the mixing influence of the foundations will only lead to some partial reduction in the strength of stratification in water that passes through the wind farm.

1.11.8.73 Carpenter *et al*. (2016) conclude that no large scale changes to stratification of the North Sea are expected at the current levels of offshore wind farm construction and that 'extensive' regions of the North Sea would need to be covered in offshore wind farms for a significant impact on stratification to occur. The study also found that the results are sensitive to the assumed type (shape and size) of foundation structure being assessed, and to the assumptions made about the evolution of the pycnocline thickness under enhanced mixing conditions.

1.11.8.74 Cazenave *et al*. (2016) use a regional scale 3D hydrodynamic model with a number of wind farm foundations represented as small islands in the mesh. The general results of Cazenave *et al*. (2016) are that wind farm foundations may have some limited influence on the strength of stratification locally but it does not suggest that naturally present stratification would be completely mixed by this process

1.11.8.75 Based on the available evidence (from van Leeuwen *et al*. 2015, Figure 1.7a-c), vertical stratification (and so also the presence of the Flamborough Front) is only expected to occur in or near to the Hornsea Three array area for less than 40 days in the year on average. On the basis of the findings from Carpenter *et al*. (2016) and Cazenave *et al*. (2016), when stratification is present it is possible that foundations in the Hornsea Three array may cause some minor indirect decrease in the strength of water column stratification within the Hornsea Three array area, via increased turbulence. However, it is very unlikely that water which is stratified entering the array area will become fully mixed. Regional scale patterns of stratification in the North Sea will be unaffected and will continue to be subject to natural processes and variability. The location and physical characteristics of the Flamborough Front are therefore unlikely to be measurably affected within the range of natural variability.

1.11.8.76 In summary, the impact is predicted to be of local spatial extent, long-term duration, non-continuous and high reversibility. It is predicted that the impact will affect the receptor indirectly. The magnitude is therefore, considered to be minor.

<u>Sensitivity of the receptor</u>

1.11.8.77 The Flamborough Front is a regional-scale oceanographic feature which supports high biological primary productivity and biodiversity. Accordingly, the feature is considered to be of high value. The feature itself is both highly dynamic and ephemeral and is therefore not considered to be vulnerable to localised, small-scale changes in water column turbulence.

1.11.8.78 In summary, the Flamborough Front is deemed to be of minor vulnerability, high levels of recoverability and high value. The sensitivity of the receptor is therefore, considered to be medium.

<u>Significance of the effect</u>

1.11.8.79 Overall, the sensitivity of the receptor is considered to be medium and the magnitude of the impact is deemed to be minor. The effect will, therefore, be of minor adverse significance, which is not significant in EIA terms.

Changes to beach morphology, hydrodynamics and sediment transport (littoral drift) at the nearshore area

1.11.8.80 Following burial, the only way in which the cables could influence hydrodynamics and beach morphology during operation would be if they became exposed as a consequence of natural changes to beach morphology. Detailed understanding of the likely temporal variability in beach topography throughout the lifetime of the project is therefore critical for the appropriate siting of cables as well as determination of appropriate burial depths. This has been considered through analysis of recent and historic beach monitoring data (including LiDAR) which enables the range of historical natural variability to be determined, including patterns and trends of erosion and accretion. Findings are presented in volume 5, annex 1.1: Marine Processes Technical Annex section 6.

1.11.8.81 In theory the use of cable protection measures in shallow nearshore areas could also influence beach morphology through modification of the wave regime and blockage of sediment transport. The potential for these to occur is also assessed within this section, through consideration of the maximum design scenario details presented in Table 1.11.

<u>Magnitude of impact</u>

1.11.8.82 Key findings from the analysis of the LiDAR and beach topographic data are summarised below:

- The beach at the nearshore area is dynamic, with elevational changes up to ~3 m occurring over the analysis period (1999 to 2014);
- There is a relatively high degree of spatial variability with regards to the magnitude of change to beach elevations, with the greatest change observed around the MHWS mark. Conversely, relatively limited change is seen seaward of ~ the msl mark;
- The position of the MHWS contour has remained relatively constant throughout the analysis period and no clear year-on year trend exists. These findings are consistent with the interpretation of coastal trends carried out by the Environment Agency for the period 1991 to 2011 which suggests very low net rates of beach erosion at the nearshore area (Environment Agency, 2012); and
- Given that longer term erosional and accretionary beach processes appear to be approximately in balance, the relatively large vertical changes in beach elevation observed between the LiDAR datasets are expected to be seasonal fluctuations associated with changes in storm frequency.

1.11.8.83 The natural processes controlling the variability in beach morphology described above will continue to act in the same way following installation of the cables and irrespective of any temporary local disturbance caused.

1.11.8.84 It is anticipated that the above information (in particular the observed range of vertical changes in beach elevation) will feed into a detailed engineering assessment of cable burial depth which will minimise the risk of exposure. It may be possible to optimise the target burial depth across the beach according to the known degree of variability, with deeper burial in areas of high variability and *vice versa*. However, appropriate allowance should be made for the potential influence of climate change which is expected to lead to mean sea level rise and possible increased rates of beach erosion and shoreline retreat.

1.11.8.85 If the export cables are buried at a sufficient depth below the base of the mobile beach material, this will minimise the risk of cable exposure and the cables will have limited potential to influence either hydrodynamics or beach morphology. If a section of a cable does become exposed, it might locally influence beach processes and morphology at a scale proportional to the diameter of the cable (order of a few tens of centimetres) and the length of the exposed section. If the exposure occurs due to a short-term localised lowering of the beach level (e.g. in response to storm activity), it is also possible that that the cable section will become naturally reburied by similar process over time (order of hours during a storm or order of days to months during more benign conditions) as the beach returns to an equilibrium state. If more than one section of Hornsea Three cable is exposed at any one time, the potential impacts of each cable are likely to be localised to a distance much smaller than the separation between them.

1.11.8.86 Cable protection measures will not be used in inter-tidal areas although in theory, up to 10% of the Offshore Cable Corridor within the Cromer Shoal Chalk Beds MCZ could be associated with the use of cable protection measures (assessed in paragraph 1.11.8.52 onwards). If and where cable protection measures are installed in shallow subtidal locations near to the nearshore area, they could also potentially influence the local nearshore wave regime and resulting patterns of sediment transport in the nearshore and intertidal areas. However, it is more realistically assumed that any cable protection measures used in such areas would be installed with a sufficiently low profile and width relative to the surrounding bed so as to present minimal barrier to the passage of waves and so would cause minimal change to patterns of longshore sediment transport.

1.11.8.87 The actual extent of any change will be dependent upon the particular seastate (combination of individual wave heights and periods and directions) relative to the dimensions and orientation of the cable protection measures, and the distance and orientation to the adjacent beach or coastline. As such, the area of change may not even extend as far as the adjacent coastline. No change on wave period is anticipated. As a result, no measurable changes to patterns of longshore sediment transport are expected.

1.11.8.88 Cable protection could also present an obstacle to sediment transport, trapping sediment locally and thereby impacting down-drift locations through a reduction in sediment supply. The potential nature and magnitude of this impact is assessed in paragraph 1.11.8.52 onwards.

1.11.8.89 In summary, any impacts associated with cable exposure are predicted to be of local spatial extent, short-term duration, continuous and high reversibility. Any impacts associated with the presence of cable protection measures are predicted to be of local spatial extent, long-term duration, continuous and high reversibility. It is predicted that any impacts will affect the receptor indirectly. The magnitude is therefore, considered to be negligible.

1.11.8.90 Given that all impacts at the nearshore area are anticipated to be of local spatial extent and short-term duration, there are no implications for strategies aimed at long term management of the coast as set out in the Shoreline Management Plan and East Marine Plan.

Sensitivity of the receptor

1.11.8.91 The nearshore area is located within the Weybourne Cliffs SSSI, and is immediately adjacent to the North Norfolk Coast SSSI and Wash and North Norfolk Coast SAC. Accordingly, the shoreline at the nearshore area is considered to be of high value. However, the shoreline is typically a dynamic environment which is often subject to a large amount of natural change under baseline conditions. Accordingly, it is assessed to have some capacity to recover from disturbance.

1.11.8.92 The shoreline is deemed to be of minor vulnerability, moderate to high levels of recoverability and high value. The sensitivity of the receptor is therefore, considered to be medium.

Significance of the effect

1.11.8.93 Overall, the sensitivity of the receptor is considered to be medium and the magnitude of the impact is deemed to be negligible. The effect will, therefore, be of **negligible** significance, which is not significant in EIA terms.

Future monitoring

1.11.8.94 No marine processes monitoring to test the predictions made within the operation and maintenance phase impact assessment is considered necessary.

1.11.9 Decommissioning phase: significance of effects

1.11.9.1 The impacts of the offshore decommissioning of Hornsea Three have been assessed on marine processes. The environmental effects arising from the decommissioning of Hornsea Three are listed in Table 1.11 along with the maximum design scenario against which each decommissioning phase impact has been assessed.

1.11.9.2 A description of the potential effect on marine processes receptors caused by each identified impact is given below.

Removal of sandwaves impacting sandbank systems within the Hornsea Three offshore cable corridor

1.11.9.3 It is possible that the export cable may be removed as part of the Hornsea Three decommissioning works. In certain areas of the Hornsea Three offshore cable corridor, sandwaves are present and these may migrate across the export cables during the lifetime of Hornsea Three. These sandwaves may potentially require partial removal (via dredging or jetting) prior to the removal of cables, as set out in the maximum design scenario table (Table 1.11). However, such activities are not anticipated to be as extensive as those outlined in paragraph 1.11.5.3 onwards and any morphological changes to the wider sandbank systems are expected to be localised and temporary in nature.

Magnitude of impact

1.11.9.4 For the same reasons set out in paragraph 1.11.5.6 onwards, the impact to sandbanks is predicted to be of local spatial extent, short to medium-term duration, non-continuous and high reversibility. It is predicted that the impact will affect the receptor directly. The magnitude is therefore, considered to be minor.

Sensitivity of the receptor

1.11.9.5 Many of the sandbanks within the Hornsea Three marine processes study area are internationally designated, representing qualifying features of SACs and SCIs. Given their proximity to Hornsea Three, the North Norfolk Sandbanks (which form part of the North Norfolk Sandbanks and Saturn Reef SAC) are of particular relevance to this assessment. These sandbanks are all assigned a high value.

1.11.9.6 According to the available conservation advice for the SAC (JNCC, 2012), the North Norfolk Sandbanks are sensitive to physical loss and physical damage. Although both of these impacts may be associated with sandwave removal, JNCC (2012) note that because the North Norfolk sandbanks are formed by strong tidal currents, it is considered that they could be replenished and recover relatively rapidly from impact. Accordingly, these sandbanks are assessed by JNCC as moderately sensitive to physical loss as well as physical damage via disturbance and abrasion. The available desktop studies and monitoring evidence regarding levelled sandwave crest recovery (DONG Energy, 2016, 2017) suggests that recovery through natural processes is likely over timescales of months to years. It is also noted here that aggregate extraction operations take place within Area 483 which is located within the North Norfolk Sandbanks and Saturn Reef SAC. However, it is understood that the extraction operations largely target the less mobile gravels, rather than the sandwaves located within the licence area.

1.11.9.7 Banks are deemed to be of moderate vulnerability, moderate recoverability and high value. The sensitivity of the receptor is therefore, considered to be medium.

Significance of the effect

1.11.9.8 Overall, the sensitivity of the receptor is considered to be medium and the magnitude of the impact is deemed to be minor. The effect will, therefore, be of **minor** adverse significance, which is not significant in EIA terms.

Impacts to hydrodynamics, sediment transport and beach morphology at the nearshore area

Magnitude of impact

1.11.9.9 The maximum design scenario in terms of the potential for changes to hydrodynamics, sediment transport and beach morphology at the nearshore area and nearshore would be the total removal of all cables and associated infrastructure (Table 1.11). The removal of all cables and infrastructure would cause very short term morphological changes although these would be no greater in magnitude than for the construction phase.

1.11.9.10 Overall, the impact is predicted to be of local spatial extent, short-term duration, continuous and high reversibility. It is predicted that the impact will affect the receptor indirectly. The magnitude is therefore, considered to be negligible.

Sensitivity of the receptor

1.11.9.11 The nearshore area is located within the Weybourne Cliffs SSSI, and is immediately adjacent to the North Norfolk Coast SSSI and Wash and North Norfolk Coast SAC. Accordingly, the shoreline at the nearshore area is considered to be of high value. However, the shoreline is typically a dynamic environment which is often subject to a large amount of natural change under baseline conditions. Accordingly, it is assessed to have some capacity to recover from disturbance.

1.11.9.12 The shoreline is deemed to be of minor vulnerability, moderate to high levels of recoverability and high value. The sensitivity of the receptor is therefore, considered to be medium.

Significance of the effect

1.11.9.13 Overall, the sensitivity of the receptor is considered to be medium and the magnitude of the impact is deemed to be negligible. The effect will, therefore, be of **negligible** significance, which is not significant in EIA terms.

Future monitoring

1.11.9.14 No marine processes monitoring to test the predictions made within the decommissioning phase impact assessment is considered necessary.

1.12 Cumulative Effect Assessment methodology

Screening of other projects and plans into the Cumulative Effect Assessment

1.12.1.1 The CEA takes into account the impact associated with Hornsea Three together with other projects and plans. The projects and plans selected as relevant to the CEA presented within this chapter are based upon the results of a screening exercise undertaken as part of the 'CEA long list' of projects (see annex 5.3: Cumulative Effects Screening Matrix). Each project on the CEA long list has been considered on a case by case basis for scoping in or out of this chapter's assessment based upon data confidence, effect-receptor pathways and the spatial/temporal scales involved.

1.12.1.2 In undertaking the CEA for Hornsea Three, it is important to bear in mind that other projects and plans under consideration will have differing potential for proceeding to an operational stage and hence a differing potential to ultimately contribute to a cumulative impact alongside Hornsea Three. For example, relevant projects and plans that are already under construction are likely to contribute to cumulative impact with Hornsea Three (providing effect or spatial pathways exist), whereas projects and plans not yet approved or not yet submitted are less certain to contribute to such an impact, as some may not achieve approval or may not ultimately be built due to other factors. For this reason, all relevant projects and plans considered cumulatively alongside Hornsea Three have been allocated into 'Tiers', reflecting their current stage within the planning and development process. This allows the CEA to present several future development scenarios, each with a differing potential for being ultimately built out. Appropriate weight may therefore be given to each Tier in the decision making process when considering the potential cumulative impact associated with Hornsea Three (e.g. it may be considered that greater weight can be placed on the Tier 1 assessment relative to Tier 2). An explanation of each tier is included below:

- Tier 1: Hornsea Three considered alongside:
  - Other project/plans currently under construction; and/or
  - Those with consent, and, where applicable (i.e. for low carbon electricity generation projects), that have been awarded a Contract for Difference (CfD) but have not yet been implemented; and/or
  - Those currently operational that were not operational when baseline data was collected, and/or those that are operational but have an on-going impact.
- Tier 2: All projects/plans considered in Tier 1, as well as:
  - Those project/plans that have consent but, where relevant (i.e. for low carbon electricity generation projects) have no CfD; and/or
  - Submitted but not yet determined.
- Tier 3: All projects/plans considered in Tier 2, as well as those on relevant plans and programmes likely to come forward but have not yet submitted an application for consent (the PINS programme of projects and the adopted development plan including supplementary planning documents are the most relevant sources of information, along with information from the relevant planning authorities regarding planned major works being consulted upon, but not yet the subject of a consent application). Specifically, this Tier includes all projects where the developer has advised PINS in writing that they intend to submit an application in the future, those projects where a Scoping Report is available and/or those projects which have published a PEIR.

1.12.1.3 It is noted that offshore wind farms seek consent for a maximum design scenario and the 'as built' offshore wind farm will be selected from the range of consented scenarios. In addition, the maximum design scenario quoted in the application (and the associated Environmental Statement) are often refined during the determination period of the application. For example, it is noted that the Applicant for Hornsea Project One considered a maximum of turbines 332 turbines within the Environmental Statement, but has gained consent for 240 turbines. In addition, it is now known that Hornsea Project One 'as built' will consist of 174 turbines. Similarly, Hornsea Project Two has gained consent for an overall maximum number of turbines of 300, as opposed to 360 considered in the Environmental Statement and the as built number of turbines is likely to be less than this. A similar pattern of reduction in the project envelope from that assessed in the Environmental Statement, to the consented envelope and the 'as built' project is also seen across other offshore wind farms of relevance to this CEA. This process of refinement can result in a reduction to associated project parameters, for example the number and length of cable to be installed and the number of offshore substations. The CEA presented in this chapter has been undertaken on the basis of information presented in the Environmental Statements for the other projects, plans and activities. Given that this broadly represents a maximum design scenario, the level of cumulative impact on marine processes would highly likely be reduced from those presented here.

1.12.1.4 The specific projects scoped into this CEA and the Tiers into which they have been allocated, are outlined in Table 1.19 and shown in Figure 1.19. The projects included as operational in this assessment have been commissioned since the baseline studies for Hornsea Three were undertaken and as such were excluded from the baseline characterisation.

1.12.1.5 Plans are in place for a 'sandscaping' scheme between Bacton and Walcott. In this scheme (which is a partnership between North Norfolk District Council, Perenco UK and Shell UK) 1.5 million m^3 of sand will be placed along the 5 km stretch of coast, widening the beach and reducing the impact of waves on coastal defences by causing them to break further offshore. The scheme is located approximately 25 km from the Hornsea Three offshore cable corridor and 120 km from the Hornsea Three array area. At this distance, there will be no potential for cumulative interaction between sediment plumes. Furthermore, any potential changes to the hydrodynamic/ wave regime associated with the operational presence of Hornsea Three (as well as Hornsea Project One and Hornsea Project Two) will not be of a measurable magnitude at the Bacton – Walcott coast and therefore there is no potential for cumulative changes to beach morphology. Accordingly, the Bacton to Walcott sandscaping scheme has not been considered further in the CEA and is therefore not included in Table 1.19.

1.12.1.6 No oil and gas infrastructure projects (including decommissioning activities) have been included in Table 1.19 as they have been scoped out of the CEA. During operation, blockage (of currents, waves and sediment transport) associated with oil and gas infrastructure are typically highly localised and of insufficient magnitude to give rise to widespread cumulative effects. This is because individual oil and gas platform structures are widely spaced and are typically supported by jacket lattice structures which are largely transparent to waves. During decommissioning, rock placement may be utilised where pipelines are left in situ. However, as previously stated in paragraph 1.11.8.52 onwards, the magnitude of change to patterns of sediment transport associated with the presence of profiled rock berms will be highly localised (order of a few hundred metres) and therefore of insufficient scale to interact cumulatively with Hornsea Three. Accordingly, they are not included within Table 1.19.

1.12.1.7 Finally, it is noted that the Viking Link interconnector (a proposal to build a high voltage direct current (DC) electricity interconnector, between Lincolnshire and Revsing (Denmark), running approximately 15 km to the north of the Hornsea Three array area) has been scoped out of the assessment. This is because the Viking Link interconnector is expected to be operational before construction of Hornsea project Three begins and therefore there will be no potential for interaction of sediment plumes associated construction related activities. Given the distance between the two projects, there will be no potential for cumulative changes to waves, tides and/or sediment transport processes during either the operational phase, or the decommissioning phase. Accordingly, the Viking Link interconnector is not included within Table 1.19.

Table 1.19: List of other projects and plans considered within the CEA.

Tier	Phase	Project/Plan	Distance from Hornsea Three array area (km)	Distance from Hornsea Three offshore cable corridor (km)	Details	Date of Construction (if applicable)	Overlap of construction phase with Hornsea Three construction phase	Overlap of operation phase with Hornsea Three operation phase
1	*Offshore wind farms*							
	Operational	Lincs Offshore Wind Farm	139	38	83 turbines consented, of which 75 turbines were constructed.	Operational since August 2013	-	Yes
		Sheringham Shoal Offshore Wind Farm	109	2	108 turbines consented, of which 88 turbines were constructed.	Operational since April 2013	-	Yes
		Humber Gateway Offshore Wind Farm	128	80	83 turbines consented, of which 73 turbines were constructed.	Operational since 2015	-	Yes
		Westermost Rough Offshore Wind Farm	132	99	80 turbines consented, of which 35 turbines were constructed	Operational since 2015	-	Yes
		Lynn and Inner Dowsing Wind Farms	147	41	60 turbines consented, 54 turbines were constructed.	Operational since March 2009	-	Yes
	Under construction	Dudgeon Offshore Wind Farm	87	11	168 turbines consented, of which 67 turbines were constructed.	2015 to 2017	-	Yes
		Race Bank Offshore Wind Farm	114	21	206 turbines consented, of which 91 turbines to be constructed.	2015 to 2017	-	Yes
		Hornsea Project One Offshore Wind Farm	14	7	332 turbines assessed in the Environmental Statement (although 240 turbines actually consented), of which 174 turbines to be constructed.	2017 to 2019	-	Yes
	Consented/approved	Hornsea Project Two Offshore Wind Farm	20	36	360 turbines assessed in the Environmental Statement (although 300 turbines actually consented).	2020 to 2022	Yes	Yes
		Triton Knoll Offshore Wind Farm	100	44	288 turbines consented, of which 90 to be constructed.	2017 to 2021	Yes	Yes
	Marine Aggregate Extraction							
	Operational	Humber 3 (484)	43	0	17.2 km^2	Operational (15 year licence)	Yes	Yes
		Humber 4 and 7 (506)	13	7	51.18 km^2	Operational (15 year licence)	Yes	Yes

Tier	Phase	Project/Plan	Distance from Hornsea Three array area (km)	Distance from Hornsea Three offshore cable corridor (km)	Details	Date of Construction (if applicable)	Overlap of construction phase with Hornsea Three construction phase	Overlap of operation phase with Hornsea Three operation phase
2	*Marine Aggregate Extraction*							
	Application	Humber 5 (483)	14	2	28.3 km^2	Application sought for 15 year dredging licence	Yes	Yes
3	(No Tier 3 projects have been scoped into the assessment)							

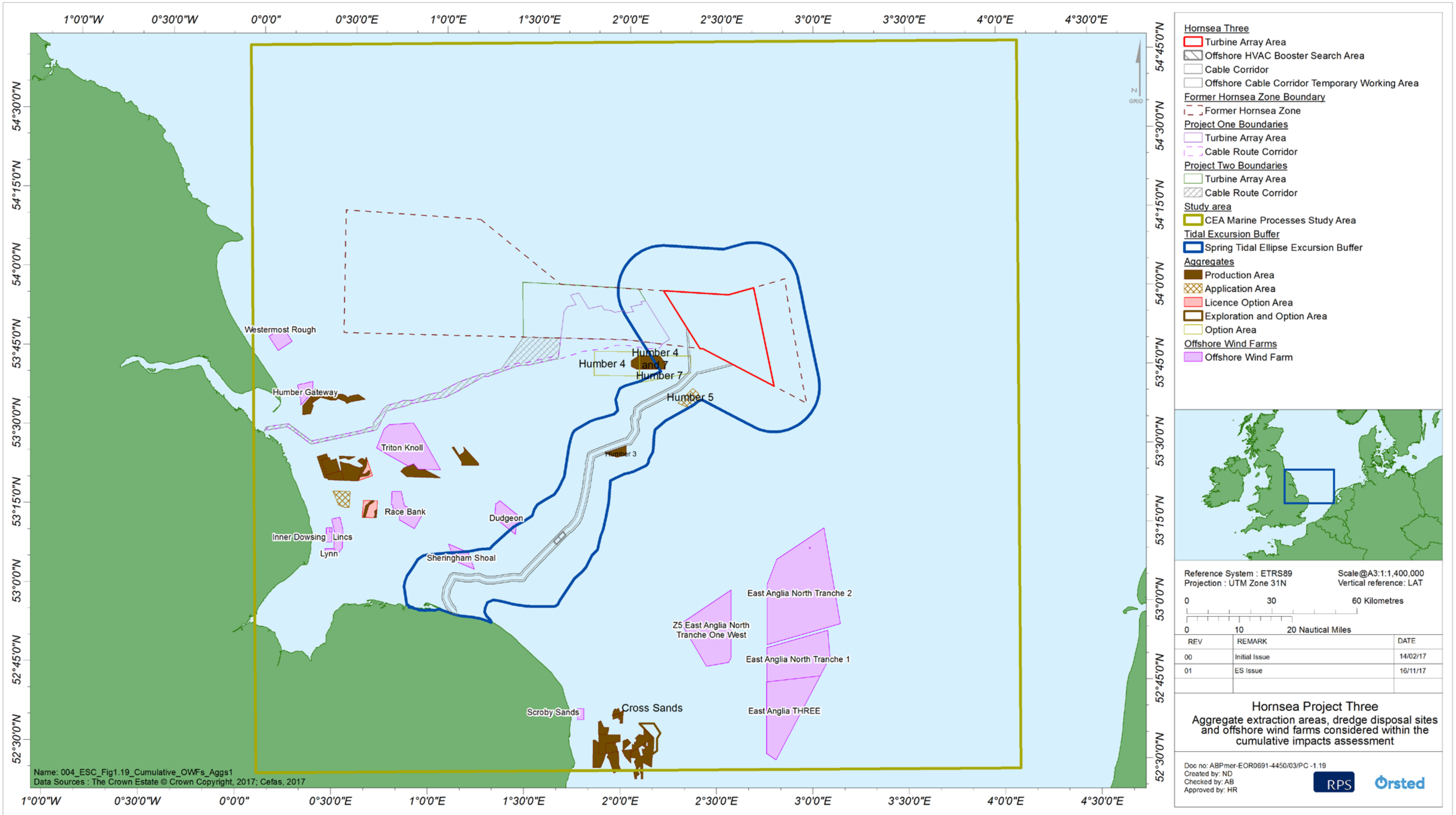

Figure 1.19: Aggregate extraction areas and offshore wind farms considered within the CEA.

Maximum design scenario

1.12.1.8 The maximum design scenarios identified in Table 1.20 have been selected as those having the potential to result in the greatest effect on an identified receptor or receptor group. The cumulative impact presented and assessed in this section have been selected from the details provided in the Hornsea Three project description (volume 1, chapter 3: Project Description), as well as the information available on other projects and plans, in order to inform a 'maximum design scenario'. Effects of greater adverse significance are not predicted to arise should any other development scenario, based on details within the project Design Envelope (e.g. different turbine layout), to that assessed here be taken forward in the final design scheme.

1.12.1.9 It is noted here that the range of potential cumulative changes/ impacts identified in Table 1.20 is a subset of those considered for the Hornsea Three alone assessment (Table 1.11 and Table 1.16). This is because many of the potential changes/ impacts identified and assessed for Hornsea Three are relatively localised and temporary in nature and therefore have limited or no potential to interact with similar changes associated with other projects (e.g. scour, changes associated with construction at the landfall etc). Accordingly these have been scoped out of the assessment. Similarly, many of the potential changes/ impacts considered within the Hornsea Three alone assessment are specific to a particular project phase (e.g. construction/ operation/ decommissioning). The potential for cumulative changes/ effects with other projects only have the potential to occur if the activities causing the change overlap. This means that whilst a number of potential cumulative changes/ impacts have been identified for the construction/ operation phases, non have been identified for the decommissioning phase as no projects have been identified that have the potential to cumulatively interact during this time period.

Table 1.20: Maximum design scenario considered for the assessment of potential cumulative impacts on marine processes.

Potential impact/ change	Maximum design scenario	Justification
Construction phase		
Cumulative temporary increases in SSC as a result of Project three construction (array and offshore cable corridor) and aggregate extraction activities.	Maximum design scenario as described for construction phase of Hornsea Three (for both foundation and cable installation) assessed cumulatively with the following Tier 1 and Tier 2 licensed/consented/ aggregate extraction areas: • Humber 3 (484); • Humber 4 and 7 (506); and • Humber 5 (483). Assessment assumes aggregate extraction using a large (c.4,500 to 5,000 m^3 hopper) TSHD, with multiple dredgers simultaneously in operation.	Maximum potential for interaction of increased SSC within one tidal excursion as this includes the maximum area of potential overlap for suspended sediments. The potential for cumulative temporary increases in SSC as a result of construction of Hornsea Three and construction of Hornsea Project One and Hornsea Project Two has been screened out of the assessment as the construction periods do not overlap. (Construction of Hornsea Project One will be complete by 2018 whilst Hornsea Project Two will be complete by 2019. Construction of Hornsea Three is anticipated to commence in 2022) (Similarly, the potential for cumulative change during the decommissioning phase has been screened out for the same reason, namely the decommissioning phases will not overlap.)
Operation and maintenance phase		
Cumulative changes to the tidal regime, with associated potential impacts on offshore sandbanks, as a result of the operational presence of Project Three with Hornsea Project One and Hornsea Project Two.	Maximum design scenario as described for the operation and maintenance phase of Hornsea Three assessed cumulatively with the following Tier 1 offshore wind farms: • Lincs; • Sheringham Shoal; • Humber Gateway; • Westermost Rough; • Lynn and Inner Dowsing; • Triton Knoll; • Dudgeon; • Race Bank; • Hornsea Project One; and • Hornsea Project Two. All operational wind farms listed above have been constructed using monopile wind turbine foundations and these have been considered in the assessment. For those projects not yet constructed, maximum design scenario foundation details (in terms of blockage to waves and tides) have been obtained from the respective project Environmental Statements.	Outcome of the CEA will be greatest when the greatest number of other schemes, present or planned, are considered. Cumulative changes to the wave regime associated with wind farms within the East Anglia Zone have been scoped out. This is because the only directions from which waves could pass through the Hornsea Three array area and East Anglia Zone are north through northeast and south through southwest and no marine processes receptors (in particular the coast) aligned with these pathways are located within close enough proximity to be affected.
Cumulative changes to the wave regime, with associated potential impacts along adjacent coastlines, as a result of the operational presence of Hornsea Three and other operational offshore wind farms.		
Cumulative changes to the wave regime, with associated potential impacts on offshore sandbanks, as a result of the operational presence of Hornsea Three and other operational offshore wind farms.		
Cumulative changes to water column stratification with associated potential impacts to the Flamborough Front		

Potential impact/ change	Maximum design scenario	Justification
Decommissioning phase		
(No activities identified)	-	-

1.13 Cumulative Effect Assessment

1.13.1.1 This section follows the same approach to that adopted for the Hornsea Three only assessment (section 1.11), whereby the assessment of change to marine processes pathways is presented first, followed by an assessment of the significance of effects to marine processes receptors.

1.13.2 Construction phase: changes to pathways

1.13.2.1 As previously stated, the assessments presented within this section consider pathways only and as such do not provide a conclusion regarding the significance of effect. Instead the significance of effect is considered in the various relevant receptor chapters.

Cumulative temporary increases in SSC as a result of Hornsea Three construction (array and offshore cable corridor) and aggregate extraction activities

Tier 1

1.13.2.2 As stated in Table 1.19, there are two marine aggregate areas that are already licensed and located within a distance of one spring tidal excursion ellipse from Hornsea Three. These are:

- Humber 3 (484); and
- Humber 4 and 7 (506).

1.13.2.3 The target material at these marine aggregate areas is sands and gravels. Characteristically, the aggregate deposits in this region are understood to contain <5% fines (silt and clay) in situ and, therefore, the concentrations of this fraction in the overflow from the dredging vessels are anticipated to be relatively low.

1.13.2.4 The potential for cumulative effects between Hornsea Three construction activities and aggregate extraction operations has been considered in detail within volume 5, annex 1.1: Marine Processes Technical Annex section 4. Key findings are summarised below.

1.13.2.5 Aggregate extraction operations may release sediment into the water column through overspill and/or screening. The spatial extent of this plume will largely be determined by the sediments being extracted and the local hydrodynamic regime: heavier gravel-sized particles will settle rapidly at the discharge point, whilst sand-sized particles typically settle within about 250 m to 500 m, and within 5 km where tidal currents are strong (Hitchcock and Drucker, 1996; Newell *et al*., 2004). If screening is not used, the volume of discharged sand is much smaller and change may be confined to the extraction area (Newell *et al*., 2004).

1.13.2.6 Of direct relevance to this investigation is the plume dispersion modelling results for Application Areas 483 and 484 (Figure 1.20) (ABPmer, 2013b). In brief:

- Dredging will create a turbid plume, in which its maximum extent is predicted to be 17.0 and 15.5 km in either a northwest or southeast direction from the dredge location (depending whether dredging occurs throughout a flood or ebb tide) for Areas 483 and 484 respectively;
- Maximum increases in near-bed concentrations could potentially exceed 600 mg/l in close proximity to the dredger within the application areas for a period of 1 hour, before reducing to circa 50 to 150 mg/l for the remainder of the dredging period;
- Following the cessation of dredging (i.e. following a single dredge period), SSCs will return to near background concentrations over approximately four days on spring tides, or slightly longer on neap tides; and
- The maximum sedimentation thickness predicted as a result of the dredge plumes is around 1 mm in very close proximity to the dredge location. These sedimentation thicknesses, however, will be transitory (i.e. come and go) with the changing flood/ebb and spring/neap tide variations in the flows

1.13.2.7 The interaction between sediment plumes generated by construction activities along the Hornsea Three offshore cable corridor and those from nearby aggregate dredging could occur in two ways:

- Where plumes generated from the two different activities meet and coalesce to form one larger plume; or
- Where an aggregate dredger is dredging within the plume generated by Project construction activities (or vice versa).

1.13.2.8 For two or more separately formed plumes that meet and coalesce, the physical laws of dispersion theory mean concentrations within the plumes are not additive but instead a larger plume is created with regions of potentially differing concentration representative of the separate respective plumes. In contrast, in the case of plumes formed by a dredging vessel operating within the plume created by foundation installation or bed preparation activities (or vice versa), the two plumes would be additive, creating a plume with higher SSC.

1.13.2.9 It is anticipated that the most common form of plume interaction during the construction phase will be associated with the coalescing of separate plumes. This scenario may result in a combined plume of slightly larger extent than envisaged on the basis of cable and foundation installation alone.

1.13.2.10 Should cable installation or foundation installation be taking place within the Hornsea Three offshore cable corridor at the same time as dredgers were operating along the eastern margin of Humber 7 aggregate area, it is possible that any fine sediment plumes from the respective activities would be additive. This would give rise to higher concentration (maximum a few 10's mg/l) plumes than described for the individual installation activities set out in section 1.11.2. However, these higher concentration plumes would not be expected to persist for much longer than a few hours.

1.13.2.11 The potential for material dispersed during cable laying activities within the Hornsea Three offshore cable corridor to deposit within aggregate dredging areas is considered to be extremely low. This is because the levels of deposition predicted during cable laying activity are minimal (< ~0.06 m within 100 m from the Hornsea Three offshore cable corridor).

1.13.2.12 Finally, it is noted that spring tidal excursion ellipses are relatively rectilinear within and nearby to the aggregate sites. This means that although at times during the construction phase some plume interaction may occur, the number of occurrences is expected to be less than for an equivalent setting with more rotational tidal excursion characteristics.

Tier 2

1.13.2.13 As stated in Table 1.19, there is one marine aggregate area under application located within a distance of one spring tidal excursion ellipse from Hornsea Three, namely Humber 5 (483).

1.13.2.14 The target material at this marine aggregate areas is also sands and gravels. Characteristically, the aggregate deposits in this region are understood to contain <5% fines (silt and clay) in situ and, therefore, the concentrations of this fraction in the overflow from the dredging vessels are anticipated to be relatively low.

1.13.2.15 The potential for cumulative effects between Hornsea Three construction activities and aggregate extraction operations has been considered in detail within volume 5, annex 1.1: Marine Processes Technical Annex. Key findings are the same as those summarised in relation to the Tier 1 developments in paragraph 1.13.2.5 onwards. Should cable installation or foundation installation be taking place within the Hornsea Three offshore cable corridor at the same time as dredgers were operating along the western margin of Humber 5 aggregate area, it is possible that any fine sediment plumes from the respective activities would be additive. As noted, this would give rise to higher concentration (maximum a few 10's mg/l) plumes, however, these would be expected to be of short duration and not to persist for much longer than a few hours.

1.13.3 Operation and maintenance phase: changes to pathways

1.13.3.1 Changes to waves and tides and their potential impact on marine processes receptors are considered together, in section 1.13.6.

1.13.4 Decommissioning phase: changes to pathways

1.13.4.1 No activities identified for assessment.

1.13.5 Construction phase: significance of effects

1.13.5.1 There are no marine processes receptors sensitive to cumulative impacts arising during the construction phase.

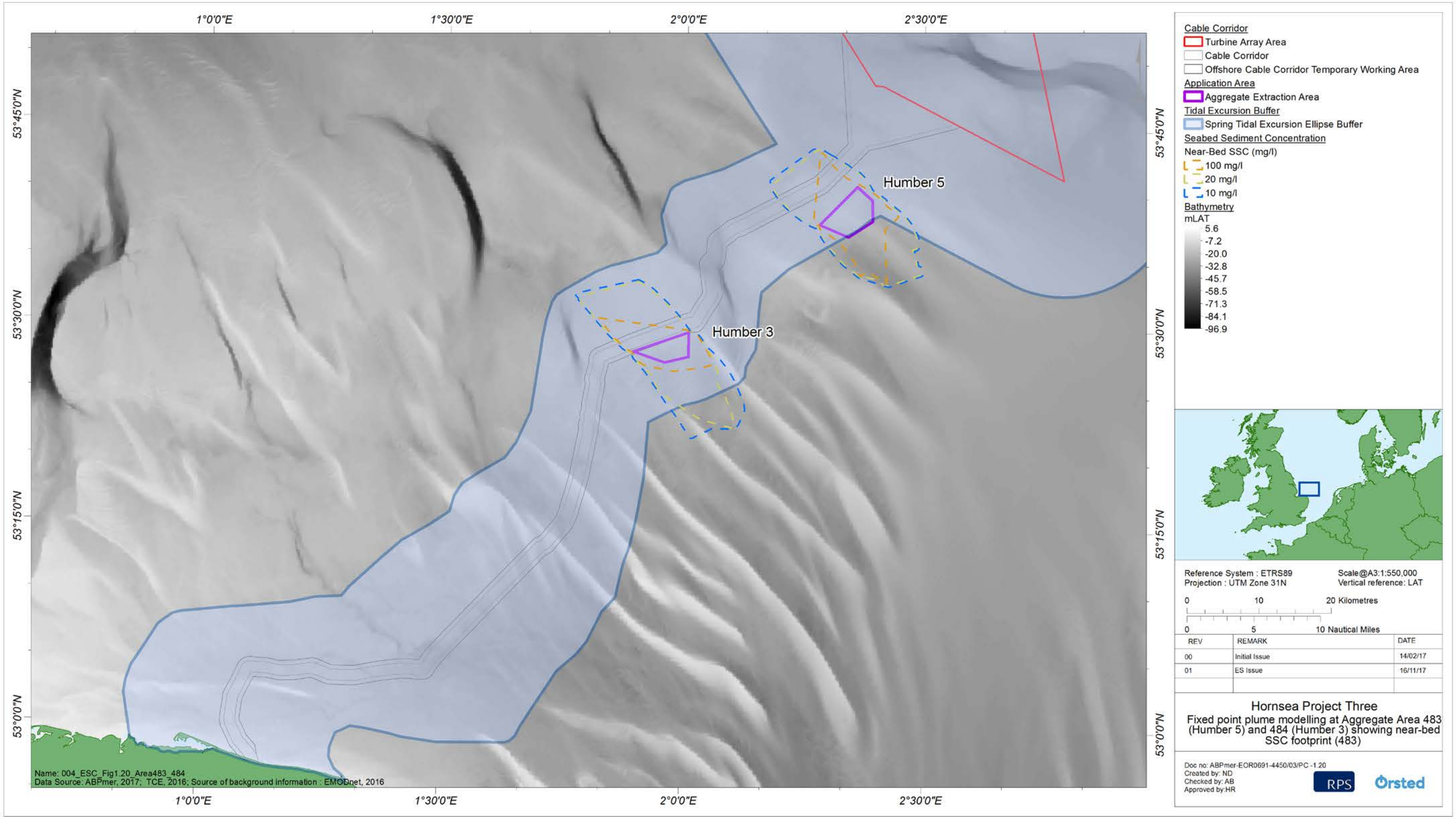

Figure 1.20: Fixed point plume modelling at Aggregate Area 483 (Humber 5) and 484 (Humber 3) showing near-bed SSC footprint.

1.13.6 Operation and maintenance phase: significance of effects

Cumulative changes to the tidal regime with associated potential impacts on sandbanks, as a result of the operational presence of Hornsea Three with Hornsea Project One and Hornsea Project Two

Tier 1

1.13.6.1 Hydrodynamic flow modelling was carried out in support of the Environmental Impact Assessment for Hornsea Project One (SMart Wind, 2013) and this modelling was previously applied in an evidence based approach to the assessment of currents in Hornsea Project Two (SMart Wind, 2015). The Hornsea project One flow modelling has been used here to inform the assessment of cumulative changes to the tidal regime, arising from the operation of Hornsea project One, Hornsea Project Two and Hornsea Three. Full justification for this approach is set out in volume 5, annex 1.1: Marine Processes Technical Annex section 2.

Magnitude of impact

1.13.6.2 Changes to the tidal regime may indirectly impact seabed morphology (including bedforms) in a number of ways. In particular, there exists a close relationship between flow speed and bedform type (e.g. Belderson et al., 1982) and thus any changes to flows have the potential to alter seabed morphology over the lifetime of Hornsea Three.

1.13.6.3 As discussed in paragraph 1.11.8.3 onwards, changes to the tidal regime as a result of Hornsea Three are predicted to largely be localised to the array area. Indeed, on the basis of the numerical modelling carried out for Hornsea Project One (which is analogous to Hornsea Three in terms of foundation number and dimensions), the only changes in current speed are anticipated to occur within the array itself and a narrow region just outside of the boundary (up to about 4 km), and local to foundation structures (Figure 1.17).

1.13.6.4 Owing to the alignment of the tidal axis in this region, the greatest changes are anticipated to occur to the northwest and southeast of the Hornsea Three array, with minimal change to the east and west (Figure 1.17c,d). Given that The Hornsea Three array is located to the east of the Hornsea Project One and Hornsea Project Two arrays, the potential for cumulative interaction is considered to be very low.

1.13.6.5 All other operational offshore wind farms are located at a sufficient distance away from Hornsea Three that interactions will not occur. As such, cumulative changes to the tidal regime resulting from interactions between Hornsea Three and other operational wind farms are not predicted.

1.13.6.6 Since measurable changes to the tidal regime will not extend to sandbank systems (the closest of which are approximately 10 km away), the magnitude of change to sandbanks is therefore, considered to be no change.

Sensitivity of the receptor

1.13.6.7 Many of the sandbanks within the Hornsea Three marine processes study area are internationally designated, representing qualifying features of SACs and SCIs. Given their proximity to Hornsea Three, the North Norfolk Sandbanks (which form part of the North Norfolk Sandbanks and Saturn Reef SAC) are of particular relevance to this assessment. These sandbanks are all assigned a high value.

1.13.6.8 According to the available conservation advice for the SAC (JNCC, 2012), the North Norfolk Sandbanks are considered to have high sensitivity to physical loss via obstruction, caused by the presence of structures. However, the majority of the North Norfolk sandbanks (as well as other sandbanks within the Hornsea Three marine processes study area) are dynamic and mobile and therefore considered to have moderate levels of recoverability enabling them to return to a state close to that which existed before any impact. Those designated sandbanks which are considered to be relict (such as the Indefatigable Banks) will be largely insensitive to small and localised changes in tidal currents.

1.13.6.9 In summary, sandbanks are deemed to be of moderate vulnerability, have moderate levels of recoverability and high value. The sensitivity of the receptor is therefore, considered to be high.

Significance of the effect

1.13.6.10 An assessment of effect significance has been determined by combining the expert judgements of the magnitude of impact and sensitivity of the receptor (above), using the matrix presented in Table 1.14.

1.13.6.11 Overall for the shoreline, it is predicted that the sensitivity of the receptor is considered to be high and the magnitude is deemed to be no change. The effect will, therefore, be of **negligible** significance, which is not significant in EIA terms.

Cumulative changes to the wave regime, with associated potential impacts along adjacent coastlines, as a result of the operational presence of Hornsea Three and other operational offshore wind farms

Tier 1

1.13.6.12 There are ten offshore wind farms (either operational, under construction or consented) within the CEA marine processes study area. These are:

- Hornsea Project One;
- Hornsea Project Two;
- Westermost Rough;
- Humber Gateway;
- Lynn and Inner Dowsing;
- Lincs;
- Sheringham Shoal;
- Triton Knoll;
- Dudgeon; and
- Race Bank.

1.13.6.13 In the following section, potential changes to the wave regime arising from the operational presence of Hornsea Project One and Hornsea project Two are initially considered, followed by a wider discussion of potential changes associated with other offshore wind farms present across the CEA marine processes study area.

Magnitude of impact

Hornsea Three with Hornsea Project One and Hornsea Project Two

1.13.6.14 The same rule based numerical model used to inform the wave assessment for the Hornsea Three array area in isolation (paragraph 1.11.8.20) has also been used to simulate the patterns of reduction of wave height through the combined Hornsea Project One, Hornsea Project Two and Hornsea Three array areas. The model setup is informed by and validated against the results of spectral wave modelling previously undertaken in support of EIA of Hornsea Project One and Hornsea Project Two, both alone and in combination. The model setup and results for the new scenarios including Hornsea Three, both alone and in combination with Hornsea Project One and Hornsea Project Two, are also validated against the results from a new spectral wave model. Details of the setup, validation and results of the various wave models used are provided in volume 5, annex 1.1: Marine Processes Technical Annex, section 8, appendix A and appendix B.

1.13.6.15 For the cumulative assessment scenario, the final approved layout and foundations being built in Hornsea Project One (174 turbines with monopile foundations, diameter 8.1 m), and the consented indicative layout scenarios and foundations in Hornsea Project Two (360 turbines with gravity base foundations, equivalent monopile diameter 32.9 m) (described in SMart Wind 2015), are used to realistically describe the potential distribution and dimensions of foundations within these array areas.

1.13.6.16 The description of Hornsea Project One used in the cumulative scenario assessment (174 monopiles) is therefore different to (much less blockage than) the scenario modelling for the Hornsea Project One and Hornsea Project Two Environmental Statements, which assessed Hornsea Project One based on a maximum design scenario of the greatest number (332) of gravity base foundations. However, as Hornsea Project One has now confirmed its layout and foundations, these have been carried into the assessment to provide a more realistic assessment.

1.13.6.17 The results of the cumulative impact assessment on waves are shown in Figure 1.21 and summarised below:

- Where the two array areas (Hornsea Three and Hornsea Project One plus Hornsea Project Two) are not aligned in the wave coming direction, the magnitude and patterns of change are the same as for each array alone;
- Where the two array areas (Hornsea Three and Hornsea Project One plus Hornsea Project Two) are not aligned in the wave coming direction but there is overlap of the footprints of change, the magnitude of change locally can increase beyond that calculated for either array alone, but is not a simple additive change;
- The maximum reduction in wave height for a given wave direction scenario occurs around the centre of the downwind edge of each array area. The maximum reduction magnitude is 28% in the Hornsea Project Two array area, associated with waves from the east (the longest axis passing through both array areas). The three array areas (Hornsea Three and Hornsea Project One plus Hornsea Project Two) are not closely aligned in directions other than east-west, so the maximum reduction in wave height for directional scenarios from north to east-northeast is similar to or the same as each array alone, but with a wider overall footprint of change;
- There will be no measurable reduction in wave height (>5%) at adjacent coastlines; and
- The maximum extent of a 5% reduction wave height is approximately 60 km, associated with the easterly wave condition for the cumulative Hornsea Three, Hornsea Project One and Hornsea Project Two scenario. The closest UK coastline in this direction is North Norfolk, approximately 90 km from the former Hornsea Zone. For the same northerly wave direction, the closest coastline of any other European nation located directly to the south is much further away, approximately 270 km to Belgium. Therefore, no measurable impact on wave height (>5%) is expected at any coastline as a result of Hornsea Three, either alone or in combination.

1.13.6.18 The cumulative wave modelling undertaken to inform the Hornsea Project Two Environmental Statement found that there would be no measurable reduction in wave height (>5%) at adjacent coastlines. The analyses presented in volume 5, annex 1.1: Marine Processes Technical Annex, section 8 have demonstrated that this finding remains, even with Hornsea Three in place. It follows therefore, that the quantitative estimates of potential change to annual drift rates presented in the Hornsea Project Two Environmental Statement for the north Norfolk and Lincolnshire coasts (which found a maximum reduction in annual drift rate of just 0.7%) will remain broadly the same with Hornsea Three in place.

Other operational offshore wind farms

1.13.6.19 Westermost Rough and Humber Gateway offshore wind farms are situated to the west of the Hornsea Three array area, as shown on Figure 1.19.

1.13.6.20 The Westermost Rough Environmental Statement (DONG Energy, 2009) concluded that changes in wave height along the shore resulting from the presence of the wind farm would be limited in magnitude, and therefore that changes in sediment transport would be insignificant.

1.13.6.21 The Humber Gateway Environmental Statement (E.ON, 2009) considered potential changes to waves and concluded that wave heights will only be slightly reduced by the Humber Gateway project and therefore that there would be no significant impacts to coastal erosion.

1.13.6.22 As can be seen from Figure 1.21 predicted changes to wave heights resulting from the operational presence of Hornsea Project One, Hornsea Project Two and Hornsea Three are expected to be very small (no greater than ~2.5%) as far west as Humber Gateway and Westermost Rough for any of the wave directions tested. Moreover, potential wave interactions between the Hornsea Project One, Hornsea Project Two, Hornsea Three, Westermost Rough and Humber Gateway offshore wind farms will only occur for waves coming from an easterly direction. Based on available 36 year wave hindcast from the Hornsea Three array area, waves from this sector only occur for approximately 15% of the record and the majority of these waves are shorter period wind waves which will have recovered in height before reaching the Humber Gateway and Westermost Rough wind farms. Accordingly, the duration of time over which potential wave interaction could occur is very small and therefore any changes to sediment transport at the coast will be negligible.

1.13.6.23 Lynn and Inner Dowsing, Triton Knoll, Race Bank, Dudgeon, Sheringham Shoal, and Lincs offshore wind farms are all situated to the southwest of the Hornsea Three array area, as shown on Figure 1.19. When waves are coming from the north, north northeast and northeast (approximately 15% of time), the footprint of predicted changes to wave heights resulting from Hornsea Project One, Hornsea Project Two and Hornsea Three overlaps with the location of Lynn and Inner Dowsing, Triton Knoll, Race Bank, Dudgeon, Sheringham Shoal and Lincs offshore wind farms (Figure 1.21).

1.13.6.24 The Lynn and Inner Dowsing Environmental Statement (Centrica and Renewable Energy Ltd, 2003) predicted reductions in wave heights in the lee of the wind farms in the range 3 to 5%. These changes in wave heights were found to extend to the coast, warranting consideration of the potential for net changes in littoral transport. Longshore transport modelling indicated that the sheltering effect of the farms does not result in localised "hot spots" of erosion or accretion along the Lincolnshire coast. Rather the wind farms result in a small reduction in the net southerly transport of sediment to the south of Ingoldmells Point.

1.13.6.25 The Triton Knoll Environmental Statement (RWE npower renewables, 2012) considered potential cumulative changes to the wave regime arising from Triton Knoll offshore wind farm Lincs, LID, Race Bank and Docking Shoal offshore wind farms. The low magnitude of wave height reductions (greatest reduction of 0.02 m) and the small directional changes (<0.54 degrees) were deemed to be of negligible significance.

1.13.6.26 The Environmental Statements for the Race Bank (Centrica Energy, 2009), Dudgeon (Dudgeon Offshore Wind Farm Ltd., 2009), Sheringham Shoal (Scira Offshore Energy Ltd, 2006) and Lincs (Centrica Energy, 2007) offshore wind farms predicted only minor changes in the wave regime, restricted to the wind farm sites themselves. No impacts were predicted on the Lincolnshire or Norfolk coastlines as a result of changes to the wave regime.

1.13.6.27 The cumulative reduction in wave height predicted due to the operational presence of the offshore wind farms presented above are considered to be of very small magnitude and are therefore not predicted to have any influence on sediment transport.

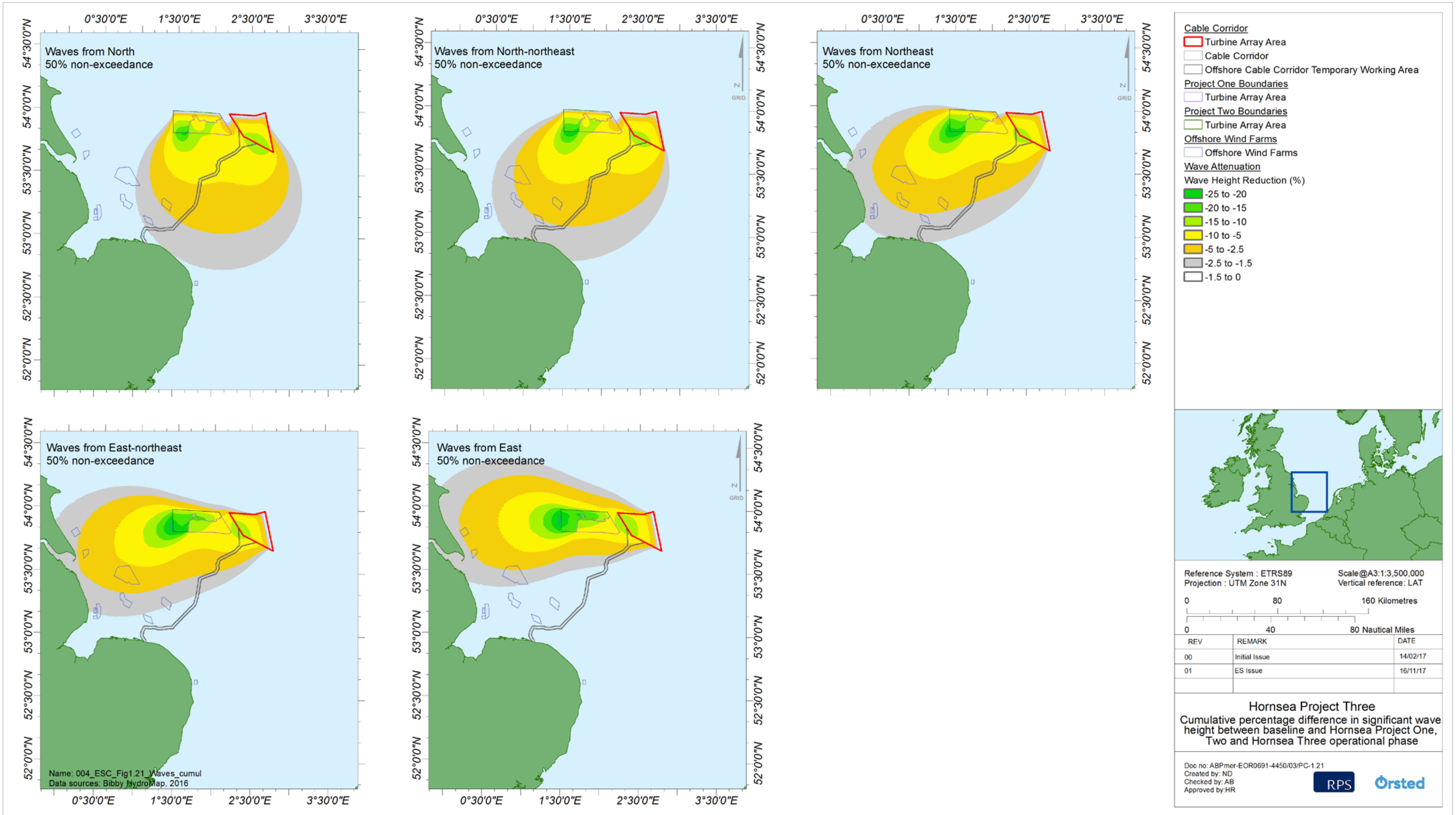

Figure 1.21: Cumulative percentage difference in significant wave height between baseline and the Hornsea Project One, Hornsea Project Two and Hornsea Three operational phase, 50% no exceedance, wave direction (a) North; (b) North-northeast; (c) Northeast; (d) East-northeast; (e) East.

1.13.6.28 In addition to the above discussion, the following points should also be emphasised:

- The assessments of potential change to the wave regime presented in the Environmental Statements for the aforementioned wind farms in the Greater Wash have typically considered an array comprising gravity base foundation structures. These structures will represent the greatest blockage of waves. However, monopiles are the preferred foundation option for these wind farms and these structures will result in a considerably smaller blockage than described for the purposes of EIA;
- Actual rates of longshore sediment transport will vary temporally, on a seasonal and annual basis in response to inter and intra-annual variations in average wave height and direction. (Analysis of the 36 year hindcast wave record from the array reveals an annual average significant wave height of 1.58 m but this varies by up to approximately ±10% between years.) These naturally occurring changes are very likely to far exceed those which theoretically could occur as a result of the presence of the operational wind farms; and
- In this region future changes to the wave climate as a consequence of climate change are predicted to occur as an increase of approximately +0.25 m of the mean annual maxima significant wave height (between 1960 and 1990, to 2070 and 2100) (Lowe *et al*., 2009). These changes, as well as alterations to the directional wave climate driven by changes in large scale climate variability are likely to result in spatial modifications (erosion and accretion) to coastlines due to deviations in longshore sediment transport supply (Splinter *et al*., 2012). Such future changes are also expected to far exceed those which theoretically could occur as a result of the presence of the operational wind farms.

1.13.6.29 In summary, on the basis of the above discussion only small cumulative changes in wave heights and wave direction are predicted to result from the operational presence of Hornsea Three and other operational wind farms. The impact on the shoreline is predicted to be of regional spatial extent, long-term duration, intermittent and high reversibility. It is predicted that the impact will affect the receptor indirectly. The magnitude is therefore, considered to be negligible.

Sensitivity of receptor

1.13.6.30 The majority of the North Norfolk, Lincolnshire and Yorkshire shorelines (which are within the Hornsea Three marine processes study area) are covered by nationally and internationally important nature conservation designations and also typically represent areas of high socio-economic importance. As such, the shoreline is considered to be of high value. However, the shoreline is typically a dynamic environment which is often subject to a large amount of natural change under baseline conditions. Accordingly, it is assessed to have some capacity to recover from disturbance.

1.13.6.31 The shoreline is deemed to be of minor vulnerability, moderate to high levels of recoverability and high value. The sensitivity of the receptor is therefore, considered to be medium.

Significance of the effect

1.13.6.32 Overall, the sensitivity of the receptor is considered to be medium and the magnitude of the impact is deemed to be negligible. The effect will, therefore, be of **negligible** significance, which is not significant in EIA terms.

Cumulative changes to the wave regime, with associated potential impacts on offshore sandbanks, as a result of the operational presence of Hornsea Three and other operational offshore wind farms

Tier 1

Magnitude of impact

1.13.6.33 Sandbanks are tidally induced bedforms, with waves indirectly influencing sandbank morphology by determining the maximum height (minimum depth) to which they can accumulate (Kenyon and Cooper, 2005).

1.13.6.34 The closest sandbanks to the Hornsea Three array area are the Indefatigable Banks which are located approximately 10 km to the southwest of the array. Owing to the (east – west) alignment of the Hornsea Three array area relative to Hornsea Project One and Hornsea Project Two, there is very limited potential for a cumulative reduction in wave energy at these nearby banks. Moreover (for the same reasons set out in paragraph 1.11.8.32 onwards), as the Indefatigable Banks are understood to be largely relict features, it is extremely unlikely that any reductions in wave activity over the bank crests would result in a corresponding morphological change.

1.13.6.35 Elsewhere within the wider CEA marine processes study area, there are a number of other sandbanks which are known to be highly dynamic features. These include those sandbanks slightly closer towards the coast within the North Norfolk Sandbanks and Saturn Reef SAC, as well as the active sandbank systems to the southwest of the Hornsea Three array area in the Greater Wash (such as Triton Knoll, Race Bank and Sheringham Shoal). On the basis of the cumulative wave assessment undertaken in volume 5, annex 1.1: Marine Processes Technical Annex, section 8 and presented in Figure 1.21, it is possible that intermittent reductions in wave height in excess of 5% may occur for short periods of time over these banks when waves are coming from the northeasterly quadrant. However, it is considered extremely unlikely that such modest changes would manifest in morphological change to the crest elevations of the banks. This is because all of these banks will, at various times, be influenced by storm waves which haven't travelled through the wind farm arrays. These waves would be unaltered from their baseline condition and would redistribute material from the crests, maintaining the existing elevation of the banks.

1.13.6.36 For banks, the impact is predicted to be of regional spatial extent, long-term duration, intermittent and high reversibility. It is predicted that the impact will affect the receptor indirectly. The magnitude is therefore, considered to be negligible.

Sensitivity of the receptor

1.13.6.37 Many of the sandbanks within the Hornsea Three marine processes study area are internationally designated, representing qualifying features of SACs and SCIs. Given their proximity to Hornsea Three, the North Norfolk Sandbanks (which form part of the North Norfolk Sandbanks and Saturn Reef SAC) are of particular relevance to this assessment. These sandbanks are all assigned a high value.

1.13.6.38 According to the available conservation advice for the SAC (JNCC, 2012), the North Norfolk Sandbanks are considered to have high sensitivity to physical loss via obstruction, caused by the presence of structures. However, the majority of the North Norfolk sandbanks (as well as other sandbanks within the Hornsea Three marine processes study area) are dynamic and mobile and therefore considered to have moderate levels of recoverability enabling them to return to a state close to that which existed before any impact. Those designated sandbanks which are considered to be relict (such as the Indefatigable Banks) will be largely insensitive to small and localised changes in waves.

1.13.6.39 Overall, banks are deemed to be of moderate vulnerability, have moderate levels of recoverability and high value. The sensitivity of the receptor is therefore, considered to be high.

Significance of the effect

1.13.6.40 Overall, the sensitivity of the receptor is considered to be high and the magnitude of the impact is deemed to be negligible. The effect will, therefore, be of **minor** adverse significance, which is not significant in EIA terms.

Cumulative changes to water column stratification with associated potential impacts to the Flamborough Front

Tier 1

Magnitude of impact

1.13.6.41 Based on the available evidence, vertical stratification (and so also the presence of the Flamborough Front) is only expected to occur in or near to the former Hornsea Zone for less than 40 days in the year on average. When stratification is present, it is possible that foundations in the Hornsea Three array area, and Hornsea Project One and Hornsea Project Two may locally cause some minor decrease in the strength of water column stratification; however, it is very unlikely that water which is stratified entering the array areas will become fully mixed. The Hornsea Three array area is not aligned with Hornsea Project One or Hornsea Project Two along the tidal axis and so there is no potential for cumulative impacts on stratification. Regional scale patterns of stratification in the North Sea will be unaffected and will continue to be subject to natural processes and variability. The location and physical characteristics of the Flamborough Front are therefore unlikely to be measurably affected within the range of natural variability.

1.13.6.42 All other proposed wind farms are located much more than one tidal excursion from the Hornsea Three array area, and Hornsea Project One and Hornsea Project Two, so there is no potential for cumulative impacts on stratification. Regional scale patterns of stratification in the North Sea will be unaffected and will continue to be subject to natural processes and variability. The location and physical characteristics of the Flamborough Front are therefore unlikely to be measurably affected within the range of natural variability.

1.13.6.43 In summary, the impact is predicted to be of local spatial extent, long-term duration, non-continuous and high reversibility. It is predicted that the impact will affect the receptor indirectly. The magnitude is therefore, considered to be minor.

Sensitivity of the receptor

1.13.6.44 The Flamborough Front is a key regional-scale oceanographic feature which supports high biological primary productivity and biodiversity. Accordingly, the feature is considered to be of high value. The feature itself is both highly dynamic and ephemeral and is therefore not considered to be vulnerable to localised, small-scale changes in water column turbulence.

1.13.6.45 In summary, the Flamborough Front is deemed to be of minor vulnerability, high levels of recoverability and high value. The sensitivity of the receptor is therefore, considered to be medium.

Significance of the effect

1.13.6.46 Overall, the sensitivity of the receptor is considered to be medium and the magnitude of the impact is deemed to be minor. The effect will, therefore, be of **minor** adverse significance, which is not significant in EIA terms.

Future monitoring

1.13.6.47 Marine processes monitoring to test the predictions made within the operation and maintenance phase impact assessment is not considered necessary.

1.13.7 Decommissioning phase: significance of effects

1.13.7.1 There are no marine processes receptors sensitive to cumulative impacts arising during the decommissioning phase.

1.14 Transboundary effects

1.14.1.1 A screening of transboundary impacts has been carried out and is presented in annex 5.5: Transboundary Impacts Screening Note. The Hornsea Three and CEA marine processes study area extends into the Dutch EEZ and the screening exercise identified that there was potential for significant transboundary effects with regard to marine processes from Hornsea Three upon the interests of other EEA States.

1.14.1.2 This was highlighted by the screening specifically in relation to the potential for transboundary impacts due to operation and maintenance phase changes to the wave regime. This in turn has the potential to impact on marine processes receptors (namely the shorelines) of other EEA States.

1.14.1.3 The greatest potential change to the wave regime would arise as a result of Hornsea Three cumulatively with other offshore wind farms. More specifically in terms of consideration of the potential for transboundary effects, the greatest potential effects would arise as a result of the operational presence of Hornsea Three, Hornsea Project One and Hornsea Project Two. Analysis of potential changes to the wave regime under this scenario are presented in volume 5, annex 1.1: Marine Processes Technical Annex, section 8, involving the application of a rule based numerical model. Simulations of the patterns of wave height reduction are presented in the annex and the significance of effects is considered in paragraph 1.13.6.12 onwards.

1.14.1.4 The maximum extent of a 5% reduction in wave height is approximately 70 km, associated with the northerly wave condition for the cumulative Hornsea Three, Hornsea Project One and Hornsea Project Two scenario. The closest UK coastline in this direction is North Norfolk, approximately 90 km from the former Hornsea Zone. The closest coastline of any other EEA State is much further away, approximately 145 km to the Netherlands. Therefore, no measurable impact on wave height (>5%) is expected at any coastline as a result of the operational presence of Hornsea Three, either alone or in combination.

1.14.1.5 The Hornsea Three and CEA marine processes study area also includes the Dutch Klaverbank SCI designated site. Outputs from the Hornsea Three marine processes assessment have been used to inform the potential for habitat changes at this site. The results of this assessment are presented in chapter 2: Benthic Ecology.

1.15 Inter-related effects

1.15.1.1 Inter-relationships are considered to be the impacts and associated effects of different aspects of the proposal on the same receptor. These are considered to be:

- Project lifetime effects: Assessment of the scope for effects that occur throughout more than one phase of the project (construction, operational and maintenance, and decommissioning), to interact to potentially create a more significant effect on a receptor than if just assessed in isolation in these three key project stages (e.g. subsea noise effects from piling, operational turbines, vessels and decommissioning).
- Receptor led effects: Assessment of the scope for all effects to interact, spatially and temporally, to create inter-related effects on a receptor. Receptor-led effects might be short term, temporary or transient effects, or incorporate longer term effects.

1.15.1.2 A description of the likely inter-related effects arising from Hornsea Three on marine processes is provided in volume 2, chapter 12: Inter-Related Effects (Offshore).

1.16 Conclusion and summary

1.16.1.1 The baseline environment across the Hornsea Three array area and along the Hornsea Three offshore cable corridor has been characterised using outputs from project-specific surveys, surveys from the former Hornsea Zone as well as existing publicly available data and reports (including from the BGS, UKHO and BODC). The Hornsea Three array area is situated in a meso-tidal setting characterised by peak mean spring tidal current speeds of ~0.5 m/s. Both tidal range and current speed generally increase along the Hornsea Three offshore cable corridor. Water depths within the Hornsea Three array area, vary from approximately -26.6 mLAT to -72.7 mLAT, whilst along the Hornsea Three offshore cable corridor water depths are typically less than 30 mLAT. Both the Hornsea Three array area and offshore cable corridor are characterised by the presence of coarse grained sediments although these coarse grained sediment units also contain some finer muddy material in places. Whilst limited net sediment transport is understood to occur across the Hornsea Three array area, high rates of sediment transport are expected in places along the Hornsea Three offshore cable corridor.

1.16.1.2 For the most part, marine processes are not in themselves receptors but are, instead, 'pathways'. However, changes to marine processes have the potential to indirectly impact other environmental receptors. For instance, the creation of sediment plumes (which is considered in the marine processes assessment) may lead to settling of material onto benthic habitats. Accordingly, the approach adopted is to describe the potential changes to marine processes due to Hornsea Three, but not provide an assessment of the significance. An exception to the approach outlined above occurs when considering physical changes to the shoreline, offshore sandbanks and the Flamborough Front. These features are considered to be sensitive receptors. In these instances, a full impact assessment has been carried out and presented in this chapter.

1.16.1.3 Table 1.21 provides a summary of the potential impact, mitigation measures and residual effects in respect of marine processes. Key potential pathway changes/receptor impacts considered in the assessment for the construction phase include the potential for elevated SSC and bed level change in response to construction activities in the Hornsea Three array area and along the Hornsea Three offshore cable corridor, the latter including morphological change to sandbanks and at the nearshore area. The significance of effect to identified receptors was found to be minor adverse.

1.16.1.4 Key potential pathway changes / receptor impacts considered in the assessment for the operation phase include the potential for morphological change to the coast due to modification of the wave regime by foundations within the Hornsea Three array area as well as impacts to the Flamborough Front in response to changes in water column stratification. The significance of effect to identified receptors was found to be either negligible or minor adverse (Table 1.21).

1.16.1.5 Key potential pathway changes/ receptor impacts considered in the assessment for the decommissioning phase include the potential for elevated SSC and bed level change in response to decommissioning activities as well as morphological change at the nearshore area. The significance of effect to identified receptors was found to be either negligible or minor adverse (Table 1.21).

1.16.1.6 The cumulative effects assessment focused on the potential for cumulative effects with aggregate extraction operations (resulting in elevated levels of SSC) and offshore wind farms (resulting in enhanced blockage of waves). Whilst there are a number of planned, consented and operational offshore wind farms in the within the Hornsea Three marine processes study area, the potential for cumulative changes to the wave regime are found to be limited. Accordingly, any effect on the morphology of the adjacent coast will be of negligible significance.

1.16.1.7 The potential for transboundary effects arising from operation and maintenance phase changes to the wave regime has been considered. However, the assessment concluded that there will be no measurable reductions in wave height (>5%) at adjacent European coastlines due to the operational presence of Hornsea Three, Hornsea Project One and Hornsea Project Two. Accordingly, no morphological changes are expected along any EEA State coastline.

Table 1.21: Summary of potential environment effects, mitigation and monitoring.

Description of impact	Measures adopted as part of the project	Magnitude of impact	Sensitivity of receptor	Significance of effect	Additional measures	Residual effect	Proposed monitoring
Construction phase							
Increases in SSC and deposition of disturbed sediments to the seabed due to drilling for foundation installation within the Hornsea Three array area.	N/A	N/A	N/A	N/A (marine processes receptors insensitive to change)	None	N/A	None
Increases in SSC and deposition of disturbed sediments to the seabed due to dredging for seabed preparation prior to installing gravity base foundations within the Hornsea Three array area.	N/A	N/A	N/A	N/A (marine processes receptors insensitive to change)	None	N/A	None
Increases in SSC and deposition of disturbed sediments to the seabed due to cable installation within the Hornsea Three array area.	N/A	N/A	N/A	N/A (marine processes receptors insensitive to change)	None	N/A	None
Increases in SSC and deposition of disturbed sediments to the seabed due to sandwave clearance within the Hornsea Three array area.	N/A	N/A	N/A	N/A (marine processes receptors insensitive to change)	None	N/A	None
Increases in SSC and deposition of disturbed sediment to the seabed due to drilling for foundation installation within the Hornsea Three offshore cable corridor.	N/A	N/A	N/A	N/A (marine processes receptors insensitive to change)	None	N/A	None
Increases in SSC and deposition of disturbed sediments to the seabed due to dredging for seabed preparation prior to installing gravity base foundations within the Hornsea Three offshore cable corridor.	N/A	N/A	N/A	N/A (marine processes receptors insensitive to change)	None	N/A	None
Increases in SSC and deposition of disturbed sediment to the seabed due to cable installation within the Hornsea Three offshore cable corridor.	N/A	N/A	N/A	N/A (marine processes receptors insensitive to change)	None	N/A	None
Increases in SSC and deposition of disturbed sediment to the seabed due to sandwave clearance within the Hornsea Three offshore cable corridor.	N/A	N/A	N/A	N/A (marine processes receptors insensitive to change)	None	N/A	None
Change to seabed morphology due to indentations left by jack-up vessels.	N/A	N/A	N/A	N/A (marine processes receptors insensitive to change)	None	N/A	None
Removal of sandwaves impacting sandbank systems within proximity to the Hornsea Three array area and offshore cable corridor.	N/A	Minor	Medium	Minor adverse significance	None	N/A	None
Changes to hydrodynamics, sediment transport and beach morphology at the nearshore area.	Use of excavated material as backfill during installation of cables via open cut trenching.	Minor	Medium	Minor adverse significance	Completion of cable specification and installation plan	N/A	None

Description of impact	Measures adopted as part of the project	Magnitude of impact	Sensitivity of receptor	Significance of effect	Additional measures	Residual effect	Proposed monitoring
Operation phase							
Scour of seabed sediments.	Scour protection	N/A	N/A	N/A (marine processes receptors insensitive to change)	None	N/A	None
Increases in SSC and deposition of disturbed sediments to the seabed due to cable maintenance within the Hornsea Three array area.	N/A	N/A	N/A	N/A (marine processes receptors insensitive to change)	None	N/A	None
Increases in SSC and deposition of disturbed sediment to the seabed due to cable maintenance within the Hornsea Three offshore cable corridor.	N/A	N/A	N/A	N/A (marine processes receptors insensitive to change)	None	N/A	None
Changes to the tidal regime, with associated potential impacts to sandbanks.	N/A	No change	High	Negligible significance	None	N/A	None
Changes to the wave regime, with associated potential impacts to sandbanks and along adjacent shorelines.	N/A	No change (for the shoreline) Negligible (for banks)	Medium (for the shoreline) High (for banks	Negligible significance (for the shoreline) Minor adverse significance (for banks)	None	N/A	None
Changes to sediment transport and sediment transport pathways with associated potential impacts to sandbanks.	N/A	Minor	High	Minor adverse significance	None	N/A	None
Changes to water column stratification with associated potential impacts to the Flamborough Front.	N/A	Minor	Medium	Minor adverse significance	None	N/A	None
Changes to beach morphology, hydrodynamics and sediment transport (littoral drift) at the nearshore area.	N/A	Negligible	Medium	Negligible significance	Completion of cable specification and installation plan	N/A	None
Decommissioning phase							
Increases in SSC and deposition of disturbed sediment to the seabed within the Hornsea Three array area.	N/A	N/A	N/A	N/A (marine processes receptors insensitive to change)	None	N/A	None
Increases in SSC and deposition of disturbed sediment to the seabed within the Hornsea Three offshore cable corridor.	N/A	N/A	N/A	N/A (marine processes receptors insensitive to change)	None	N/A	None
Removal of sandwaves impacting sandbank systems within proximity to the Hornsea Three array area and offshore cable corridor.	N/A	Minor	Medium	Minor adverse significance	None	N/A	None
Changes to hydrodynamics, sediment transport and beach morphology at the nearshore area.	N/A	Negligible	Medium	Negligible significance	None	N/A	None

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