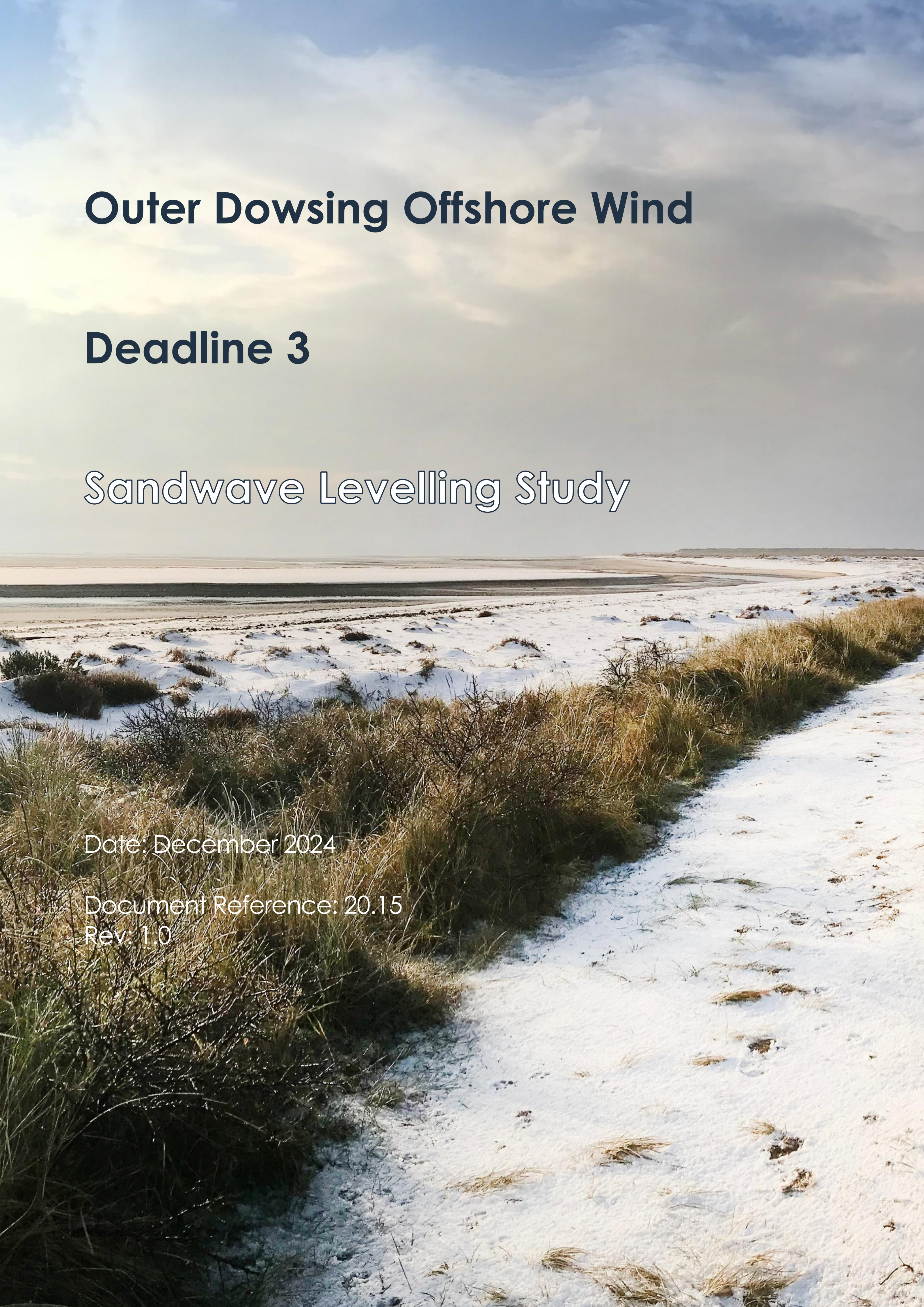

Outer Dowsing Offshore Wind

Deadline 3

Sandwave Levelling Study

Date: December 2024

Document Reference: 20.15
Rev: 1.0

Company:	**Outer Dowsing Offshore Wind**	Asset:	**Whole Asset**
Project:	**Whole Wind Farm**	Sub Project/Package:	Whole Asset
Document Title or Description:	Sandwave Levelling Study		
Internal Document Number:	PP1-ODOW-DEV-CS-STU-0010	3rd Party Doc No (If applicable):	N/A

Rev No.	**Date**	**Status / Reason for Issue**	**Author**	**Checked by**	**Reviewed by**	**Approved by**
1.0	December 2024	Deadline 3 Submission	GoBe/ Cooper Marine Advisors	Outer Dowsing	Shepherd and Wedderburn	Outer Dowsing

Executive Summary

As part of the proposed works associated with cable installation activities in the offshore Export Cable Corridor (ECC) and array area, seabed levelling activities (also referred to as 'sandwave clearance') may be required.

During pre-application consultation, Natural England raised concerns regarding the amount of sandwave clearance/levelling that may be required for the Project, including within the Inner Dowsing Race Bank North Ridge (IDRBNR) Special Area of Conservation (SAC). Natural England requested an explanation as to the rationale for the Maximum Development Scenario (MDS) and for this to be refined where possible. Natural England also specified that, where sandwave clearance was required, impacts to offshore sandbank systems within and near the array area and along the offshore ECC should be considered in relation to the conservation objectives of the SAC, with a focus on the form and function of affected sandbanks and sandwave systems, including evidence for sandwave recovery at other sites.

Following pre-application consultation, and prior to the submission of the application, refinements were made to the MDS. These included a reduction in the total sandwave clearance volumes from 13,672,800m^3 to 11,615,616m^3 in the array area and from 7,413,120m^3 to 4,518,513m^3 outside of the array area. In addition, specific dredging volumes required within each section of the ECC, interlink cables and inter-array cables , both within and outside the SAC, were quantified, as presented in Table 1.

Impacts to offshore sandbank systems within and near the array and along the offshore ECC were considered with reference to the conservation objectives of the SAC, in both Chapter 7 of the Environmental Statement (APP-062) and the Report to Inform Appropriate Assessment (RIAA) (APP-235), through the assessment of effect significance.

Within Natural England's Relevant Representations (RR-045), Natural England stated that they were unable to agree with the conclusions that the magnitude of impact on seabed morphology is low and the conclusions of no Adverse Effect on Integrity (AEoI) in relation to the SAC.

Natural England has recommended that a sandwave levelling study be completed specific to the the Project.

This document responds to this request, and considers the impacts of sandwave clearance and the likelihood of sandwave recovery following proposed seabed levelling activities within discrete sections of the offshore ECC and array area (as identified in Figure 1 and Table 1), with a focus on sandbanks. The document provides further evidence for sandwave recovery following cable installation, including, but not limited to, that from the Race Bank OWF. The study substantiates the conclusions already made as part of Chapter 7: Marine Physical Processes (APP-062) and in the Report to Inform Appropriate Assessment (RIAA) (APP-235).

The reformation and recovery of sandwaves can be expected to commence immediately after sandwave levelling, initially with smaller bedforms evolving rapidly. Any sediment dredged for sandwave clearance within the designated SAC will be retained within the same area. This means

that there will not be a net loss from the wider sedimentary system and once redeposited to the seabed, the disturbed sediment will immediately rejoin the local and regional sedimentary system, resulting in minimal potential to affect the form and function of the sandbank system as a whole. The existing Annex 1 sandbank features will be maintained and therefore the conservation objectives of the SAC will be met.

Table of Contents

Table of Tables

Table of Figures

Acronyms & Definitions

Abbreviations / Acronyms

Abbreviation / Acronym	Description
AEoI	Adverse Effect on Integrity
ANS	Artificial Nesting Structures
ECC	Export Cable Corridor
EIA	Environmental Impact Assessment
IAC	Inter-array Cables
IDRBNR	Inner Dowsing Race Bank North Ridge
JNCC	Joint Nature Conservation Committee
LAT	Low Astronomical Tide
MBES	Multi-beam Echosounder Survey
MDS	Maximum Design Scenario
ODOW	Outer Dowsing Offshore Wind
O&M	Operation and Maintenance
ORCP	Offshore Reactive Compensation Platform
OWF	Offshore Wind Farm
UK	United Kingdom
RIAA	Report to Inform Appropriate Assessment
RSBL	Reference Seabed Level
SAC	Special Area of Conservation
WTG	Wind Turbine Generator

Terminology

Term	Definition
The Applicant	GTR4 Limited (a joint venture between Corio Generation (and its affiliates), TotalEnergies and Gulf Energy Development), trading as Outer Dowsing Offshore Wind.
Array Area	The area offshore within which the generating station (including wind turbine generators (WTG) and inter array cables), offshore accommodation platforms, offshore transformer substations and associated cabling will be positioned, including the ORBA.
Baseline	The status of the environment at the time of assessment without the development in place.
Cable Circuit	A number of electrical conductors necessary to transmit electricity between two points bundled as one cable or taking the form of separate cables, and may include one or more auxiliary cables (normally fibre optic cables).
Effect	Term used to express the consequence of an impact. The significance of an effect is determined by correlating the magnitude of the impact with the sensitivity of the receptor, in accordance with defined significance criteria.

Term	Definition
Environmental Impact Assessment (EIA)	A statutory process by which certain planned projects must be assessed before a formal decision to proceed can be made. It involves the collection and consideration of environmental information, which fulfils the assessment requirements of the EIA Regulations, including the publication of an Environmental Statement (ES).
Environmental Statement (ES)	The suite of documents that detail the processes and results of the EIA.
Impact	An impact to the receiving environment is defined as any change to its baseline condition, either adverse or beneficial.
Inter-array cables	Cable which connects the wind turbines to each other and to the offshore substation(s) , which may include one or more auxiliary cables (normally fibre optic cables).
Interlink cables	Cable which connects the Offshore Substations (OSS) to one another, which may include one or more auxiliary cables (normally fibre optic cables).
Landfall	The location at the land-sea interface where the offshore export cables and fibre optic cables will come ashore.
Maximum Design Scenario	The project design parameters, or a combination of project design parameters that are likely to result in the greatest potential for change in relation to each impact assessed
Mitigation	Mitigation measures are commitments made by the Project to reduce and/or eliminate the potential for significant effects to arise as a result of the Project. Mitigation measures can be embedded (part of the project design) or secondarily added to reduce impacts in the case of potentially significant effects.
Offshore Export Cable Corridor (ECC)	The Offshore Export Cable Corridor (Offshore ECC) is the area within the Order Limits within which the export cables running from the array to landfall will be situated.
Offshore Reactive Compensation Platform (ORCP)	A structure attached to the seabed by means of a foundation, with one or more decks and a helicopter platform (including bird deterrents) housing electrical reactors and switchgear for the purpose of the efficient transfer of power in the course of HVAC transmission by providing reactive compensation
Offshore Substation (OSS)	A structure attached to the seabed by means of a foundation, with one or more decks and a helicopter platform (including bird deterrents), containing— (a) electrical equipment required to switch, transform, convert electricity generated at the wind turbine generators to a higher voltage and provide reactive power compensation; and (b) housing accommodation, storage, workshop auxiliary equipment, radar and facilities for operating, maintaining and controlling the substation or wind turbine generators
Onshore Infrastructure	The combined name for all onshore infrastructure associated with the Project from landfall to grid connection.
Offshore Restricted Build Area (ORBA)	The area within the array area, where no wind turbine generator, offshore transformer substation or offshore accommodation platform shall be erected.

Term	Definition
Outer Dowsing Offshore Wind (ODOW)	The Project
Order Limits	The area subject to the application for development consent, The limits shown on the works plans within which the Project may be carried out
The Planning Inspectorate	The agency responsible for operating the planning process for Nationally Significant Infrastructure Projects (NSIPs).
The Project	Outer Dowsing Offshore Wind, an offshore wind generating station together with associated onshore and offshore infrastructure.
Receptor	A distinct part of the environment on which effects could occur and can be the subject of specific assessments. Examples of receptors include species (or groups) of animals or plants, people (often categorised further such as 'residential' or those using areas for amenity or recreation), watercourses etc.
Study Area	Area(s) within which environmental impact may occur – to be defined on a receptor-by-receptor basis by the relevant technical specialist.
Wind Turbine Generator (WTG)	A structure comprising a tower, rotor with three blades connected at the hub, nacelle and ancillary electrical and other equipment which may include J-tube(s), transition piece, access and rest platforms, access ladders, boat access systems, corrosion protection systems, fenders and maintenance equipment, helicopter landing facilities and other associated equipment, fixed to a foundation

1 Introduction

1.1 Project Background

1. GT R4 Limited (trading as Outer Dowsing Offshore Wind (ODOW)) hereafter referred to as the 'Applicant', is proposing to develop ODOW (the Project). The Project will include both offshore and onshore infrastructure including an offshore generating station (windfarm) approximately 54km from the Lincolnshire coastline in the southern North Sea, export cables to landfall, Offshore Reactive Compensation Platforms (ORCPs), onshore cables, connection to the electricity transmission network, ancillary and associated development and areas for the delivery of up to two Artificial Nesting Structures (ANS) and the creation of a biogenic reef (see Volume 1, Chapter 3: Project Description (APP-058) for full details).

1.2 Document Purpose

2. As part of the proposed works associated with cable installation activities in the offshore Export Cable Corridor (ECC) and in the array area, seabed preparation activities (also referred to as 'sandwave clearance', 'seabed levelling', or 'sandwave levelling') may be required.
3. This document comprises a sandwave levelling study in response to concerns raised by stakeholders, particularly Natural England, during both the statutory pre-application consultation process and within relevant representations submitted to the Planning Inspectorate. The study considers discrete sections of the offshore ECC and array area (as identified in Figure 1 and Table 1), with a focus on sandbank areas, providing information on the likelihood of sandwave recovery following proposed seabed levelling activities. The study provides further detail and clarification to the conclusions made within Chapter 7: Marine Physical Processes (APP-062) and the Report to Inform Appropriate Assessment (RIAA) (APP-235).
4. This document has been prepared by Cooper Marine Advisors Ltd. Bill Cooper has contributed to more than 40 offshore wind farm marine processes studies across the UK and globally and has also been a leading author in the development of associated industry guidance and good practice.
5. The study utilises an evidence-based approach; available evidence includes:
   - Regional scale baseline data and understanding.
   - Project level surveys and interpretative reports.
   - Monitoring of sandwave recovery from related activities.
   - Expert views and technical understanding, including peer reviewed publications.
   - The study examines the following aspects:
   - The areas where sandwaves and sandbanks are considered most prevalent across the Project area identified from available evidence;
   - The likely scale of dredging to clear sandwaves;

- The relative mobility of the dredged areas with respect to local metocean and sediment characteristics to help deduce the potential for sandwave recovery; and
- Sandwave clearance and recovery, with regard to relevant evidence.

2 Study Context

2.1 Annex 1 Sandbanks

6. The environmental receptors directly affected by sandwave levelling, and considered in this document, are ‘sandbanks which are slightly covered by sea water all the time’, as listed under Annex 1 of EC Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. The location of applicable receptors has been determined by the overlap between the Order Limits of the Project and mapped Annex 1 Sandbanks in the UK version 3 – 2019, published by Joint Nature Conservation Committee (JNCC) (JNCC, 2020), including those within the Inner Dowsing, Race Bank, and North Ridge (IDRBNR) Special Area of Conservation (SAC), as shown in Figure 1. The regional net sand transport pathways deduced by Kenyon and Cooper (2005) are also presented for reference, as well as cable sections A to H of the Project (see Table 1and Section 5).
7. The conservation objective for the IDRBNR SAC is ‘to maintain or restore the habitat Annex 1 Sandbanks which are slightly covered by seawater all the time in Favourable Condition’.

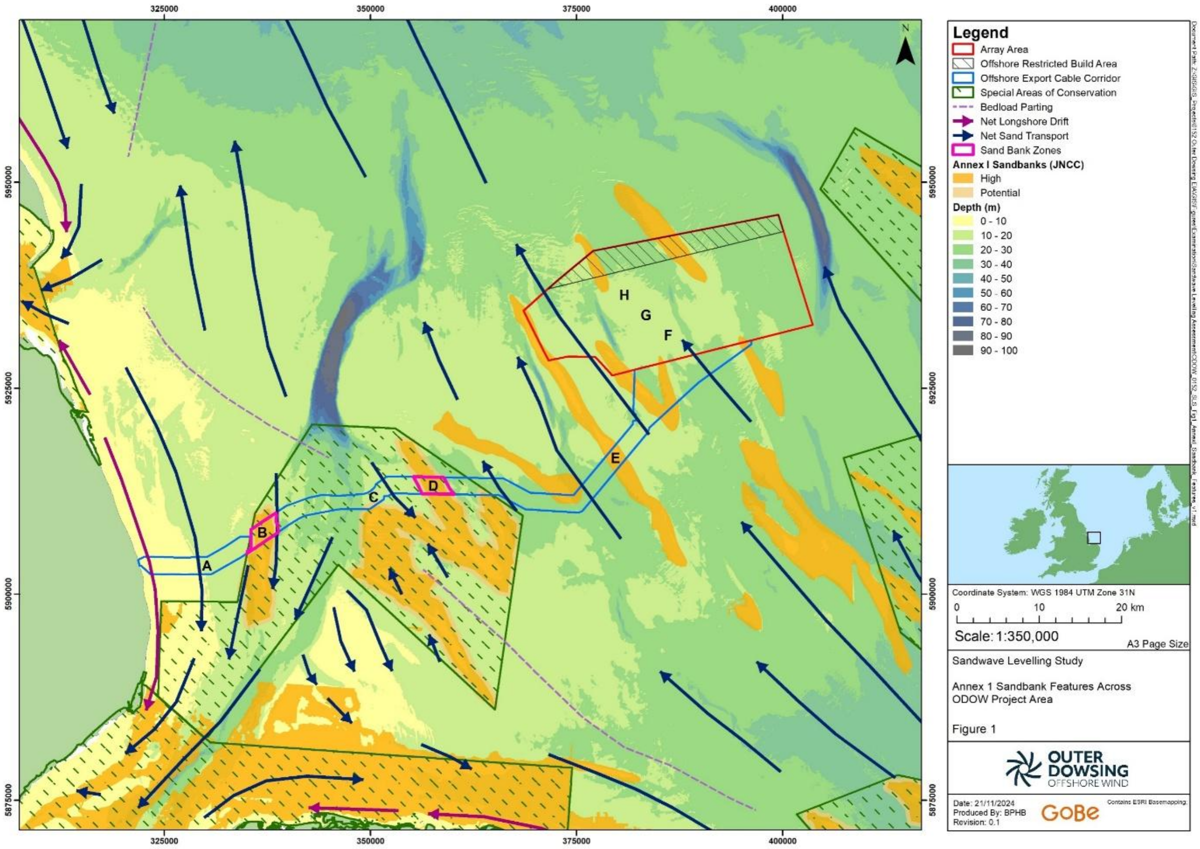

Figure 1 Annex 1 sandbank features across the Project area.

8. The method for the identification of Annex 1 sandbanks is based on the following criteria:
   - Permanently submerged.
   - Top of bank is generally in < 20m of water depth.

- Composed mainly of sandy sediment.
- May be non-vegetated or vegetated with Zostera marina (sea grass) and/or free living species of the Corallinaceae family (maerl).
- Predominantly surrounded by deeper water.
- Banks where sandy sediments occur in a layer over hard substrata are classed as 'sandbanks' if the associated biota are dependent on the sand rather than on the underlying hard substrata.
- Sandbanks can, however, extend beneath 20m below chart datum. Therefore, it can be appropriate to include in designations such areas where they are part of the feature and host its biological assemblages.

2.2 Proposed Sandwave Levelling Works

9. The Project's Maximum Design Scenario (MDS) includes cable laying along the ECC for up to four circuits, within the array area for inter-array cables (IAC) between wind turbine generators (WTG), and up to six interlink cable circuits. In some locations along the cable route, sandwave levelling may be required so that cable laying tools are not impeded by abrupt seabed slopes (e.g. greater than around 10°) and cables can be buried below the trough level of mobile sandwaves where required.
10. In addition, dredging may be used to remove surface layers of mobile sediment to the depth considered to be the reference seabed level (RSBL). The RSBL is defined as the 'non-mobile' reference level beyond which the seabed will not fall within the lifetime of the windfarm. These areas of mobile sediment may be identified by the presence of megaripples, by reference to sub-bottom profiling, or by change analysis between successive periods of survey data.
11. Both sandwave clearance and the removal of a mobile surface layer to the RSBL are important measures to help protect cables and mitigate against cable exposure, and can reduce or avoid the need for remedial cable protection measures.
12. Pre-construction geophysical surveys (GEOxyz, 2022c) provide the basis for establishing the locations along cable routes where sandwave clearance may be required, as well as estimated seabed clearance volumes. The requirement for sandwave clearance is highly variable across the Project development area, reflecting the presence/absence of various bedform types, and has been developed independently of the mapping of Annex 1 sandbanks.
13. Table 1 presents indicative maximum design parameters for cable installation requirements across the Project area, broken into cable sections A to H, as shown on Figure 1. This information is based on details presented in Chapter 3: Project Description (APP-058).

Table 1 MDS sandwave clearance quantities for the Project.

Cable section (as identified in Figure 1)	Length (km), per circuit	Length (km), all circuits	% Length requiring clearance	Width of clearance (m)	Dredging volume (m^3), all circuits
A: ECC - Nearshore	16.77	67.08	20.0	33	751,296
B: ECC - Sandbank Area 1 – SAC	2.00*	8.00	100.0	51	960,000
C: ECC – SAC	23.70	94.82	13.0	30	591,652
D: ECC - Sandbank Area 2 – SAC	2.00*	8.00	100.0	33	512,000
E: ECC – Offshore	38.03	152.10	20.0	33	1,703,565
F: ECC - Array area	27.50	110.00	20.0	33	1,232,000
Total for ECC (including within the Array Area)	110.00	440.00			5,750,513
G: Interlink – Array Area		123.75	32.5	33	2,563,945
H: IAC – Array Area		377.42	32.5	33	7,819,671

*2.00km represents the approximate width of the sandbank feature where dredging is targeted rather than the width of the cable section.

14. For reference, Sandbank Area 1 and Area 2 are identified in Volume 2, Figure 7.6 (APP-093) and were originally established in OWC (2023).
15. The requirement for sandwave clearance along the offshore ECC is relatively identifiable due to the defined corridor and the certainty of required cable lengths. In contrast, sandwave clearance within the Array Area, i.e. for inter-array cables, interlink cables, and a section of the export cable which connects with the offshore substations, depends on the final WTG layout which will only be confirmed following detailed engineering design after the Project receives consent. For example, the Maximum Design Scenario (MDS) provisions for IAC sandwave clearance vary from 6,181,439m^3 to 7,819,671m^3 depending on the number of WTG finally installed (and associated IAC cable lengths vary from 298.4km to 377.4km, respectively), as well as the final cable layout relative to areas requiring sandwave clearance.

2.3 Stakeholder Consultation

16. Part of the proposed seabed levelling works will occur on features identified as Annex 1 habitat sandbanks, as detailed previously in Section 1.2. These features are located across the study area, both outside and within the IDRBNR SAC.

17. Natural England has raised concerns about the proposed seabed levelling works, and are seeking further clarification on planned sandwave clearance and subsequent sandwave recovery. In particular, Natural England has recommended further information is provided in the following areas:

- Additional detail to explain the rationale for the MDS for sandwave clearance and anticipated depth of sandwave clearance.
- The impacts of sandwave clearance to offshore sandbank systems within and near the array, along with the offshore ECC, notably features identified as Annex 1 sandbanks.
- A wider body of supporting evidence for sandwave recovery which is not limited to Race Bank Offshore Wind Farm (OWF).

18. Details of the relevant consultation as part of the Examination process are provided in Table 2 alongside information on how the issues raised have been considered in the production of this document. Details of earlier consultation stages are presented in Table 7.2 of APP-062.

Table 2 Consultation in relation to sandwave clearance for the Project.

Date and consultation phase	Consultation and key issues raised	Section where comment addressed
Relevant Representation (Natural England, 13th June 2024) – B21	The seabed mobility assessment for the initial operational period of the OffOWF based on a 25-year life of development. However, the OWF is expected to operate for at least 35 years. Natural England advises that the seabed mobility assessment for the initial operational period of the wind farm should be revisited to reflect the predicted OWF lifespan of 35 years. And any necessary changes made to the impact assessment.	The reference to a 25-year initial operational period in Appendix 7.3: Seabed Mobility Report (APP-152) is made in relation to estimated changes in bed elevation. As outlined in PD1-071, APP-152 was prepared as a preliminary study to inform engineering and design requirements, not to inform environmental assessment. The baseline understanding of the Marine Physical Processes within the study area has been developed through consideration of a range of project-specific and existing data sources including APP-152, as outlined in Section 7.4.2 of Chapter 7 Marine Physical Processes (APP-062) and Appendix 6.3.7.1 Chapter 7 Appendix 1 Physical Processes Technical Baseline (APP-150). The assessment of environmental effects, drawing on the suite of information used to characterise the baseline, has been carried out on the basis of a 35-year operational period. Detailed characterisation of the Project area is presented throughout Section 4 with reference to current speeds, water depths, and surficial sediment type. Evidence is provided in the form of bedforms identified from Project-specific geophysical survey data (GEOxyz, 2022c). Where available, a sample of sandwave attributes (such as crest height) is also presented based on interpretations from APP-152. This evidence is separate from the bed elevation estimates provided in APP-152, and does not rely on the assumption of a 25-year operational

Date and consultation phase	Consultation and key issues raised	Section where comment addressed
		life. The conclusions presented in Section 6 are based on the application of the evidence base to the environmental setting, and are applicable regardless of the operational life of the windfarm (i.e the conclusions presented are valid for an operational period of 35 years or more).
Relevant Representation (Natural England, 13th June 2024) – B21	The seabed mobility assessment for the initial operational period of the OffOWF based on a 25-year life of development. However, the OWF is expected to operate for at least 35 years. Natural England advises that the seabed mobility assessment for the initial operational period of the wind farm should be revisited to reflect the predicted OWF lifespan of 35 years. And any necessary changes made to the impact assessment.	The reference to a 25-year initial operational period in Appendix 7.3: Seabed Mobility Report (APP-152) is made in relation to estimated changes in bed elevation. As outlined in PD1-071, APP-152 was prepared as a preliminary study to inform engineering and design requirements, not to inform environmental assessment. The baseline understanding of the Marine Physical Processes within the study area has been developed through consideration of a range of project-specific and existing data sources including APP-152, as outlined in Section 7.4.2 of Chapter 7 Marine Physical Processes (APP-062) and Appendix 6.3.7.1 Chapter 7 Appendix 1 Physical Processes Technical Baseline (APP-150). The assessment of environmental effects, drawing on the suite of information used to characterise the baseline, has been carried out on the basis of a 35-year operational period.
Relevant Representation (Natural England, 13th June 2024) – B33	For the reasons set out in our advice to the Environmental Impact Assessment (EIA) above regarding impacts to physical features of the IDRBNR SAC (Annex I Sandbanks and sandwaves) from construction related activities within the ECC including the ORCP, and should cable protection be required in the Operational and Maintenance (O&M) phase, we are unable to agree to	A project-specific consideration of the likelihood of sandwave recovery is provided throughout this document, with conclusions presented in Section 6. This has been prepared in order to provide further detail and clarification to the conclusion of minor adverse significance to seabed morphology (Impact 2) identified within Chapter 7, Marine Physical Processes (APP-062).

Date and consultation phase	Consultation and key issues raised	Section where comment addressed
	the Applicant's conclusion of no potential for an adverse effect on intergrity (AEoI) to the conservation objectives of the Annex I Sandbank feature of the IDRBNR SAC. This is in relation to 'changes to physical processes' impact.	

3 Baseline Conditions

3.1 Existing Environment

19. The existing environment across the study area is described in detail in Appendix 7.1: Marine Processes Technical Baseline (APP-150). Both the array area and offshore ECC are located in areas of glacial till deposits overlying bedrock, overlain in turn by a veneer of surficial Holocene sediments. These surficial sediments generally comprise a mix of sand and gravel, with the thickness of sediments dependent on morphology. A series of sandbank features are present across the study area, as identified previously in Section 3. Tidal flows within the array area are generally oriented to the southeast on the flood tide and northwest on the ebb tide, whereas closer inshore flows become orientated in a more northerly to southerly direction.

3.2 Conceptual Understanding of Bedforms

3.2.1 Overview

20. A conceptual understanding of bedforms is provided to highlight well-established properties of the types of features that are relevant to areas where cables are planned to be installed across the array area and offshore ECC. This overview is developed with particular relevance to the following publications, amongst others:

- Chapter 3. Bedforms. Belderson R.H., Johnson, M.A. and Kenyon N.H. in Offshore Tidal Sands. Processes and Deposits. Edited by Stride A.H. 1982. Pp. 27 – 57.
- Sand banks, sand transport and offshore windfarms. Kenyon N.H. and Cooper W.St.J. 2005.Bedforms and roughness. van Rijn L. and Dronkers J. 2024. Available from: https://www.coastalwiki.org/wiki/Bedforms_and_roughness.

21. Bedforms are rhythmic arrangements of mobile sediment forming a distinctive pattern on the seabed developed by bedload transport of non-cohesive sediment, typically from well-sorted sand-sized grains. The presence, size, and mobility of bedforms evolve to be in equilibrium with local conditions, principally; sediment type and availability and metocean conditions (e.g. water depth, flows, waves, etc.).
22. The mobility of bedforms is developed from bedload transport moving material across the surface of the seabed feature, leading to erosion of the stoss slope and accretion of the (steeper) lee slope. Accordingly, the core of the bedform is not immediately subject to any transport and larger bedforms with larger cores move at comparatively slower rates.
23. Under unidirectional flow (e.g. riverine conditions), the lee and stoss slopes are distinctly asymmetric in profile whereas in a reversing ebb and flood tidal flow of equal magnitude the slopes are typically more symmetrical. In some situations, the asymmetry may also reverse between flood and ebb phases of the tide, although this is typically limited to smaller scale bedforms. If flows become too strong they may also wash away small-scale bedforms, leading to flow aligned sand ribbons.

24. In some cases, bedforms may have originally developed under former environmental conditions which have subsequently become more benign, leaving a moribund (inactive / relict) feature. A typical example is a sandbank established during the Holocene marine transgression[1] which subsequently became submerged by a rapidly rising sea level, leaving the feature stranded under a weaker set of contemporary metocean conditions with much reduced bedload transport.
25. The scale of a bedform is typically classified according to its crest to crest wave length and crest to trough wave height. Bedform crests are aligned transverse to the direction of critical flow speeds (i.e. flow conditions which develop a mobile seabed). In the case of sandbanks, the length scale is established from the head to tail of the feature, also noting that the alignment of the crest is slightly offset (anticlockwise) to the direction of peak flow. The height of a sandbank is determined from the base to the crest.
26. Figure 2 presents a schematic of tidal bedform environments organised according to increasing magnitude of near-surface peak flows of a mean spring tide for conditions with a high availability of sandy sediment.

[1] The Holocene marine transgression occurred at the end of the Pleistocene Ice Age when melting glaciers created rapid sea level rise.

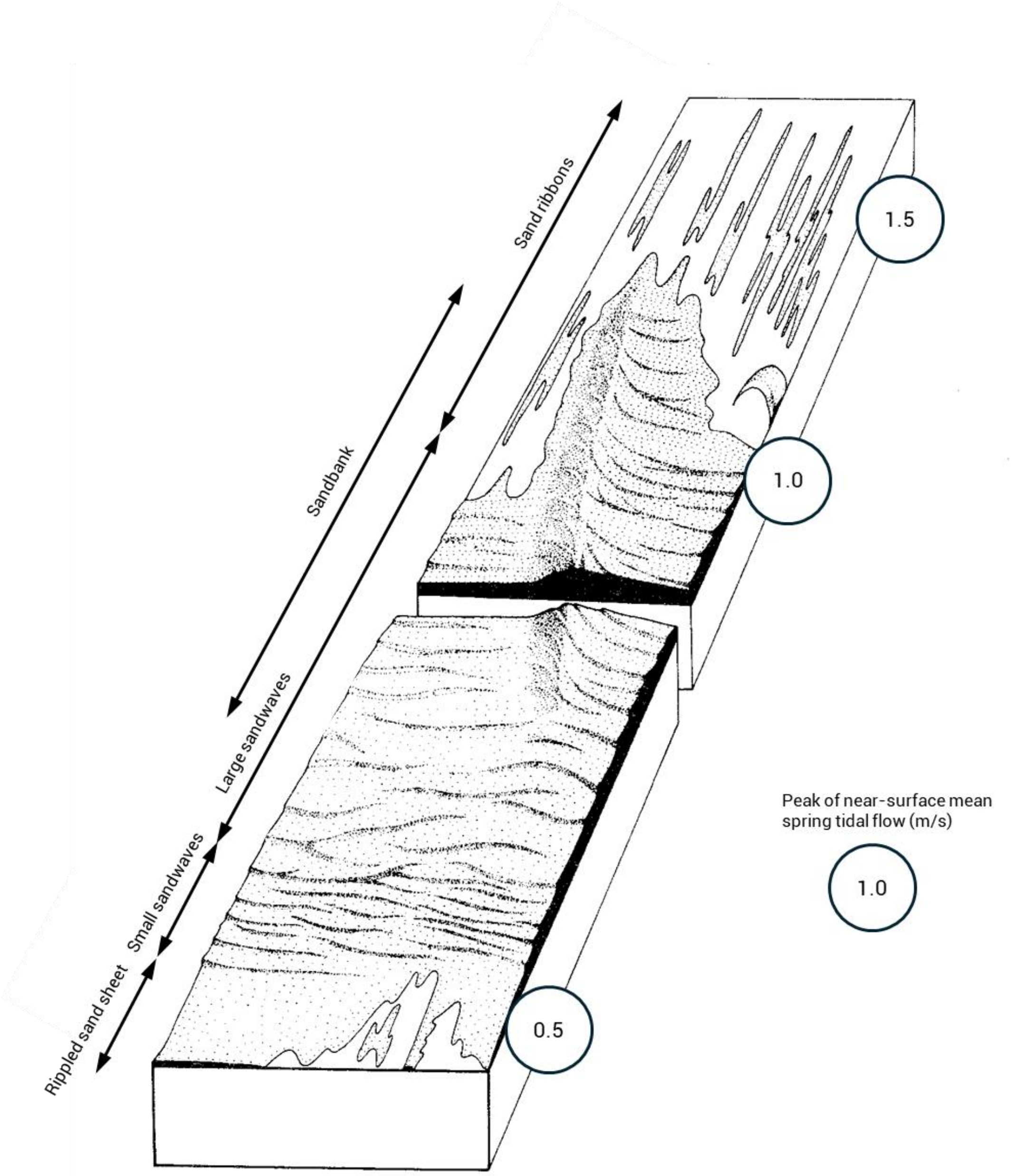

Figure 2 Schematic of bedform zones in a tidal environment with high sediment availability (after Belderson, et al., 1982).

3.2.2 Ripples

27. Ripples are the smallest (micro-scale) type of bedform with wave lengths up to around 1m and wave heights up to around 0.1m. Ripples form rapidly under suitable wave or tidal conditions and may also disperse quickly when conditions exceed criteria formation. They are typically observed as a sheet of features demonstrating a response of the seabed to local metocean conditions rather than being observed as a single isolated bedform. Due to their small scale, they are not fully resolved with a conventional multi-beam echosounder survey (MBES). For reference, the Project-specific MBES survey is reported at a highest resolution of 0.25m centres. The mobility of ripples is rapid and occurs over a period of minutes to hours.

3.2.3 Megaripples

28. Megaripples are regarded as a similar type of micro-scale bedform feature as ripples, but are an order of magnitude larger with wave lengths up to around 30m and wave heights up to around 1m. The height to length ratio of megaripples is typically in the range of 1:10 to 1:25 (Ashley, 1990). Megaripples generally form under tidal conditions and are the smallest bedform which can be resolved by a high resolution (< 1m centres) MBES survey, as in the case of the Project-specific survey. The mobility of megaripples is expected to occur over a period of hours to days (Knaapen, 2005).

3.2.4 Sandwaves

29. Sandwaves are flow transverse meso-scale bedform features which can form at different scales typically established in terms of crest height and wave length. In the absence of a standard classification scheme, the following classes of sandwaves is put forward:
    - Small – crest heights between 1 to 2m
    - Medium – crest heights between 2 to 5m
    - Large – crest heights between 5 to 10m
    - The height to length ratio of sandwaves is typically in the range of 1:30 to 1:100 (Ashley, 1990).
30. In few cases, giant sandwaves 15 to 25m high have also been observed (e.g. in Dover Strait up to 16m high with wave lengths up to 270m, and in Taiwan Strait 15 to 25m high with wave lengths of 750 to 1,000m), although their migration behaviour seems to differ from smaller scale features.
31. The migration of sandwaves can be observed over a period of days (small sandwaves) to decades (large sandwaves). Sandwaves can be identified from MBES surveys as individual features, and their migration and development can normally be monitored through successive surveys obtained over a suitable time interval.
32. The asymmetry in the cross-section profile of sandwaves can help deduce a direction of net migration, however, in some situations sandwave asymmetry is known to reverse between ebb and flood phases of the tide, or a balance in ebb and flood influence can produce a more symmetrical profile.

33. Megaripples frequently form over the surface of larger sandwaves with the convergence of megaripples being a typical instigating process for sandwave development.
34. Mobile sandwaves are considered to be the bedform type that presents the greatest hazard to cables (laying and burial) and foundations.

3.2.5 Sandbanks

35. Sandbanks are (near) flow aligned macro-scale bedforms which typically develop from the convergence of multiple sandwaves to form a local sediment circulation cell and store. Both megaripples and sandwaves may be present across the sandbank, however, sandwaves are likely to be absent where waves can sweep across shallow sandbank crests.
36. In the northern hemisphere, sand transport can be preferentially influenced by a clockwise Coriolis force which helps maintain the sediment cell. This process is typically demonstrated by opposing sandwave asymmetry either side of the sandbank with net northerly transport on the western flank and net southerly transport on the eastern flank (Kenyon & Cooper, 2005).
37. The location of sediment cells is typically associated with either tidal gyres formed in the lee of headlands (singular banner banks) or on the open shelf as a group of banks (open shelf linear sandbanks controlled by rectilinear reversing tidal currents), such as the Norfolk Banks. Sandbanks can also form where sand is driven into estuaries such as the Solway, Thames, and The Wash. In these locations, channel migration can become the dominant influence on the form and mobility of the banks.
38. Open shelf sandbanks can exhibit partial mobility in terms of migration of associated sandwaves along their flanks, as well as some variability in the shallow profile across the bank crest, especially where this is subjected to wave action. The main base of sandbanks is typically quasi-stationary under a consistent set of environmental conditions, but may vary slightly in position over periods of decades and longer, depending on the type and location of the feature.

3.2.6 Summary of bedform relationships

39. For a seabed of non-cohesive sandy sediment, the near-bed rate of sediment movement is highest as bedload transport. Under certain conditions, this transport can combine with friction and near-bed turbulence to modify the profile of the seabed and help form and drive the mobility of bedform features. Smaller bedforms have the potential to form and migrate at the fastest rate and larger bedforms at the slowest rate. Smaller bedforms of ripples and megaripples are also commonly present across the surface of sandwaves as well as existing independently. A group of converging sandwaves can form and help maintain sandbanks to become larger persisting and quasi-stationary features.

4 Site Characterisation and Planned Sandwave Levelling

4.1 Export Cable Corridor

40. Each of the cable sections shown on Figure 1 have been reviewed in turn, with a focus given to locations associated with Annex 1 sandbanks and associated sandwaves. The latest high-resolution bathymetry (GEOxyz, 2022c) has been presented with an exaggerated hillshade to help identify larger bedforms likely to be the target of sandwave clearance, along with the spatial distribution of bedform zones resolved from the surveys which exhibit megaripples, sandwaves, and sandbanks. Where available, a sample of sandwave attributes is also presented based on interpretations offered by East Point Geo Ltd. (2023) (Appendix 7.3: Seabed Mobility Report (APP-152)). The anticipated maximum depth of sandwave clearance relates to the crest height of the sandwaves, which also varies from section to section.
41. The surfical sediment properties of sandwaves are based on particle size analysis obtained during the benthic ecology survey (Appendix 9.1 and 9.2, Benthic Ecology Technical Report for the Array and ECC (APP-154 and APP-155)), with metocean data from the local model (details of which are provided in Appendix 7.2: Marine Physical Processes Modelling Report (APP-151), with updates provided in Appendix B Blockage Modelling Results of Procedural Deadline – 15.9B Offshore Restricted Build Area and Revision to the Offshore Export Cable Corridor (PD1-084)). The combination of this information enables the deduction of the likely occurrence of seabed mobility during the tidal cycle and for various wave conditions (P50% - for typical waves and 1 year return period for storms) for various grades of sediment. The bed shear stresses and corresponding critical depth-averaged current speed values required for the transportation of different sediment grain sizes have been calculated using standard methods described by Soulsby (1997), with the baseline characterisation presented in Appendix 7.1: Marine Processes Technical Baseline (APP-150). A 0% occurrence represents an immobile seabed where the influence of local metocean conditions remains below the threshold for sediment mobility, whereas a 100% occurrence represents sediment which is fully mobile all the time. In general, sediment mobility during a spring tide is expected to be higher than during a neap tide, with highest mobility occuring around times of peak flows.

4.1.1 Section A: ECC – Nearshore

42. The nearshore section of the ECC (Section A) is up to 16.77km long, extending from the landfall up to the western limit of ECC – ‘Sandbank Area 1 – SAC’ (Section B). There are no Annex 1 sandbanks in this section of the ECC, however, the geophysical survey (GEOxyz, 2022c) identifies a small isolated area of sandwaves developed in a slightly wider area of megaripples (Figure 3).

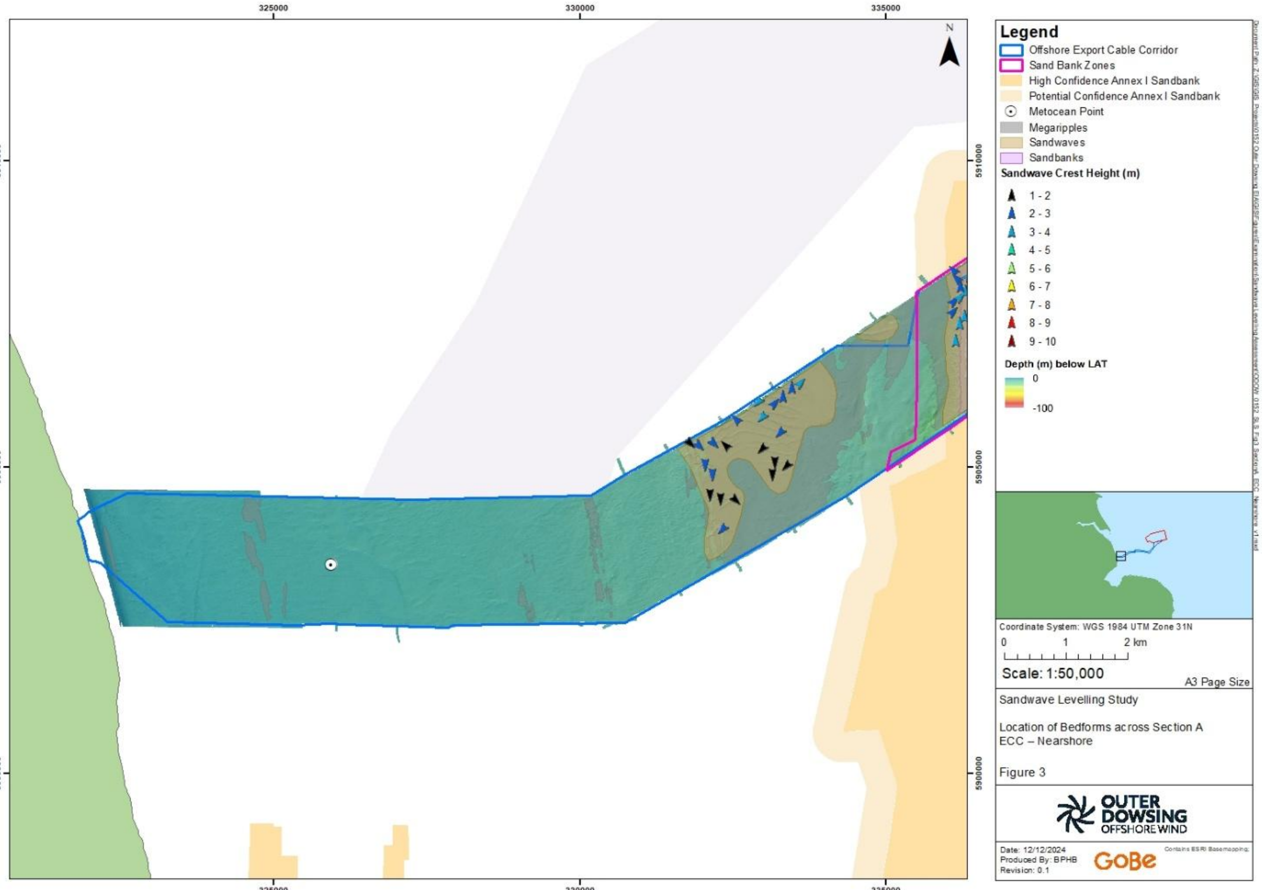

Figure 3 Location of bedforms across Section A: ECC – Nearshore.

43. The sandwave clearance MDS includes a provision for dredging up to 20% of the length of this section of the ECC and up to 751,296m^3 of sediment. The majority of dredging is likely to occur through the sandwave area shown in Figure 3. This group of sandwaves has crest heights in the range 1 to 4m and are distributed across a seabed with water depths around 13 to 14m.
44. The most westerly set of bedforms in this area are a sequence of barchan dunes (crescent shaped sandwaves) with a distinctive steep lee slope which is indicative of net migration to the south-south-west. These sandwaves also tend to be devoid of megaripples in the relative shelter of the leeward side of the crest. The main group of sandwaves further to the west are more symmetrical in cross-section but also with a slight asymmetry indicating net migration to the south-west. The overall direction of sandwave migration deduced from sandwave asymmetry is considered consistent with the regional pathways for net sediment transport.
45. The surficial sediment composition of the sandwave area is described by the baseline environmental survey (GEOxyz, 2022b (APP-155)) as poorly-sorted medium sand. The sand content alone is around 91%, including 9% coarse sand, 59% medium sand, and 22% fine sand.
46. Any planned sandwave clearance activity in this area, which also maintains the local sediment budget, is not expected to interfere with the adjacent Inner Dowsing Annex 1 sandbank since local sediment availability for a net southerly transport pathway connecting with this feature (Figure 1) would be unchanged.

4.1.2 Section B: ECC - Sandbank Area 1 – SAC

47. Sandbank Area 1 – SAC (Section B) lies on the western part of the SAC and extends around 3.80km across the northern section of Inner Dowsing (Annex 1 sandbank), and from the eastern limit of the nearshore section (Section A) up to the western limit of the SAC (Section C). The geophysical survey (GEOxyz, 2022c) delimitates the width of the sandbank in this section at around 0.6 to 0.9km, along with four main areas with sandwaves (Figure 4):
    a) a set of relatively small sandwaves (2 to 4m crest heights) along the base of the steeper inshore facing western flank, with asymmetry indicating net migration in a northerly direction along a well-defined bank boundary;
    b) occasional larger sandwaves on the eastern flank (3 to 4m high, with a longer wavelength) with an asymmetric cross-section profile indicating net migration to the south; and
    c) a more remote set of sandwaves (2 to 6m crest heights) off the base of the longer sloped eastern flank (within the area marked “Potential”), with a barchan type shape and asymmetry indicating net migration in a southerly direction. These sandwaves also appear to extend beyond the eastern boundary of Sandbank Area 1.
48. The orientation of sandwave asymmetry along the east and west flanks of Inner Dowsing is consistent with a clockwise transport pathway around the sandbank. Water depths across the crest of Inner Dowsing shallow to around 5m below Lowest Astronomical Tide (LAT), suggesting this part of the bank is also susceptible to frequent wave activity. The top of the bank appears to be the smoothest part of the area.

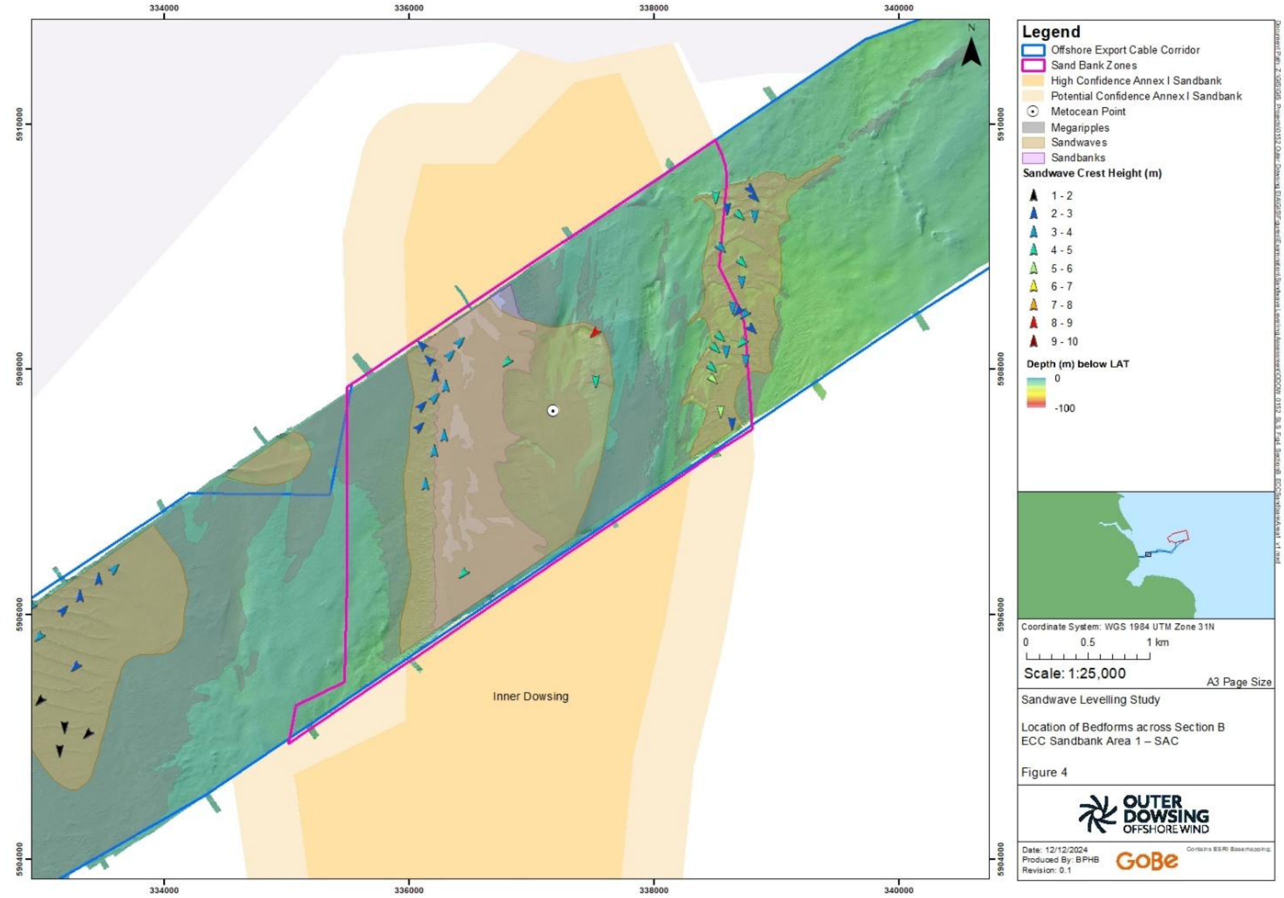

Figure 4 Location of bedforms across Section B. ECC Sandbank Area 1 – SAC.

49. Sandwave clearance includes a MDS provision for dredging 100% of a 2.00km width across the sandbank for up to four cable circuits each up to 51m wide. The MDS dredging volume is up to 960,000m^3 of sediment and is expected to include areas with sandwaves as well as areas with layers of mobile sediment associated with megaripples.
50. The surficial sediment composition of the sandbank is described by the baseline environmental survey (GEOxyz, 2022b (APP-155)) as moderately-sorted slightly gravelly sand based on a sample location on the eastern flank. The sand content alone is over 98%, including 41% coarse sand and 46% medium sand.
51. Based on a regular neap and spring tidal cycle, the relative occurrence of sediment mobility for coarse sand at this location is assessed to be around 18% during a neap tide and 64% on a spring tide. This increases to 38% and 74%, respectively, for medium sand (Appendix 7.1: Marine Physical Processes Technical Baseline (APP-150)). The shallowest parts of the bank are also considered to be mobile under typical wave conditions, especially around times of low water. In contrast, if water depths exceed around 15m then only tidal influences will develop seabed mobility and wave activity is unlikely to have any contributing affect in stirring local seabed sediments, even during storm conditions.

4.1.3 Section C: ECC – SAC

52. This 23.70km section of the ECC falls between Sandbank Area 1 (Section B) and Sandbank Area 2 (Section D) and crosses the IDRBNR SAC. The geophysical survey (GEOxyz, 2022c) identifies a small (unnamed) sandbank in the central section which has a flat crest at around 16m below LAT and is orientated north to south (Figure 5). There is a series of barchan dune type sandwaves on the eastern flank of this sandbank which show a distinct asymmetric profile which indicates a net southerly migration. This area of sandwaves is also associated with megaripples. There are no sandwaves identified on the western flank of the sandbank or elsewhere along this section of the ECC, however there are areas identified with megaripples between the sandbank and Sandbank Area 2 (Section D), mainly along the southern part of the corridor. These megaripples appear associated with the very northern limit of the Race Bank Annex 1 sandbank for the area identified by JNCC as "Potential Confidence". This part of the feature represents a 500m uncertainty buffer where qualifying evidence indicates an Annex 1 Sandbank is present (or could be present due to migration) but the evidence is insufficient to support "High" confidence. The Race Bank OWF is immediately to the south of this part of the ECC.

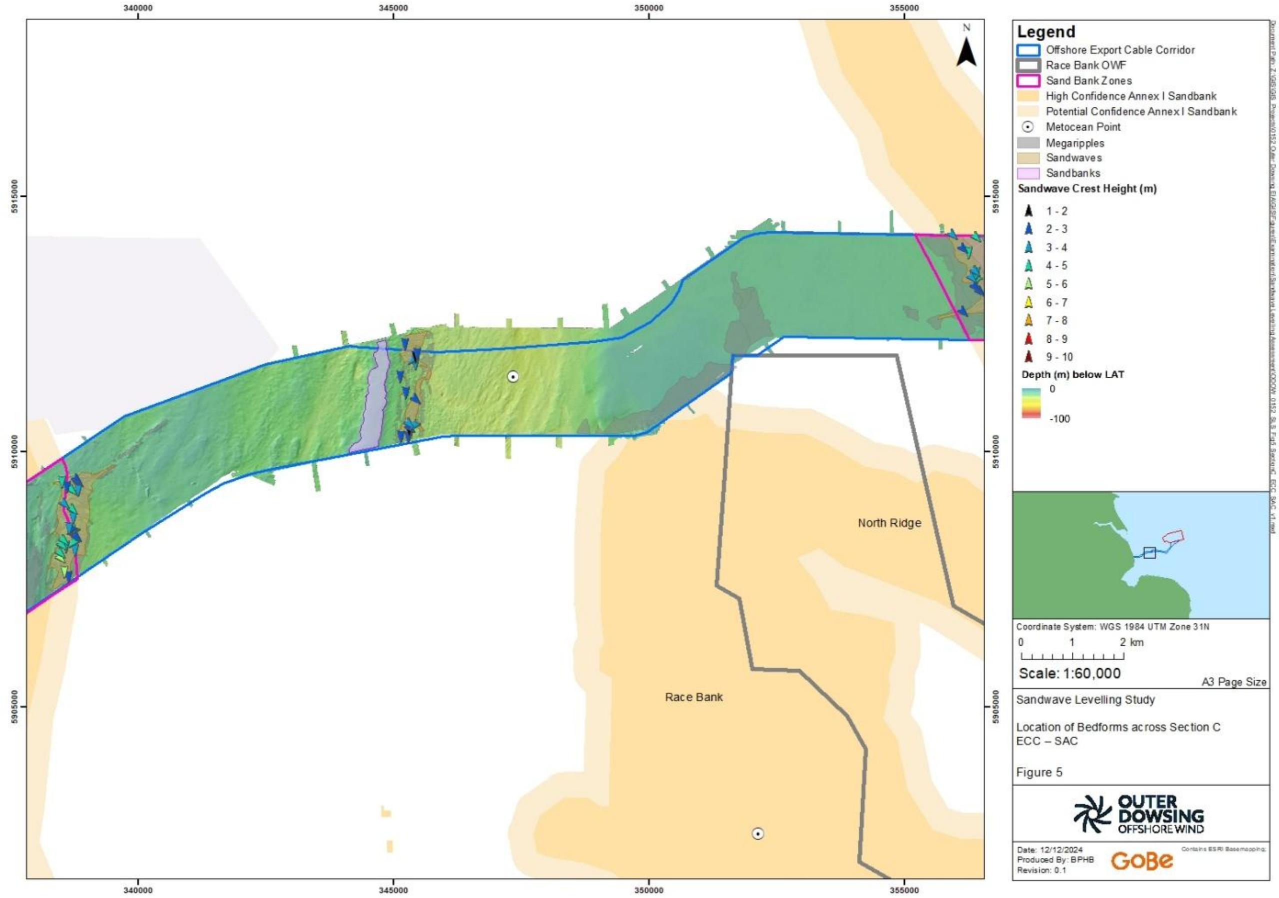

Figure 5 Location of bedforms across Section C. ECC – SAC.

53. The sandwave clearance MDS includes a provision for dredging 13% of the length of this section of the ECC for up to four cable circuits each up to 30m wide. The MDS dredging volume is up to 591,652m^3 of sediment and is expected to include areas with sandwaves, as well as locations with mobile sediment if such areas are considered to present a risk to maintaining the cable burial depth.
54. The surficial sediment composition of the sandwaves is described by the baseline environmental survey (GEOxyz, 2022b (APP-155)) as poorly-sorted gravelly sand. The sand content alone is over 89%, including 23% very coarse sand, 42% coarse sand, and 22% medium sand.
55. Based on a regular neap and spring tidal cycle, the relative occurrence of sediment mobility for very coarse sand at this location is assessed to be around 2% during a neap tide and 42% on a spring tide. This increases to 19% and 65%, respectively, for coarse sand and 39% and 74%, respectively, for medium sand (APP-150). Due to the local water depths (around 16m below LAT), only storm conditions are likely to develop large enough waves which are sufficient to stir local seabed sediments in the area of sandwaves, increasing seabed mobility at these times.

4.1.4 D: ECC - Sandbank Area 2 – SAC

56. Sandbank Area 2 (Section D) falls within the eastern part of the SAC and extends around 3.60km across a sandbank identified as an Annex 1 feature, as well as by the geophysical survey (GEOxyz, 2022c). This is an unnamed feature, extending north-west from North Ridge, comprising a sandbank around 2km wide covered by flow-transverse sandwaves which are themselves covered by megaripples (Figure 6). This area of megaripples also extends over a slightly broader area than the sandbank and sandwaves.

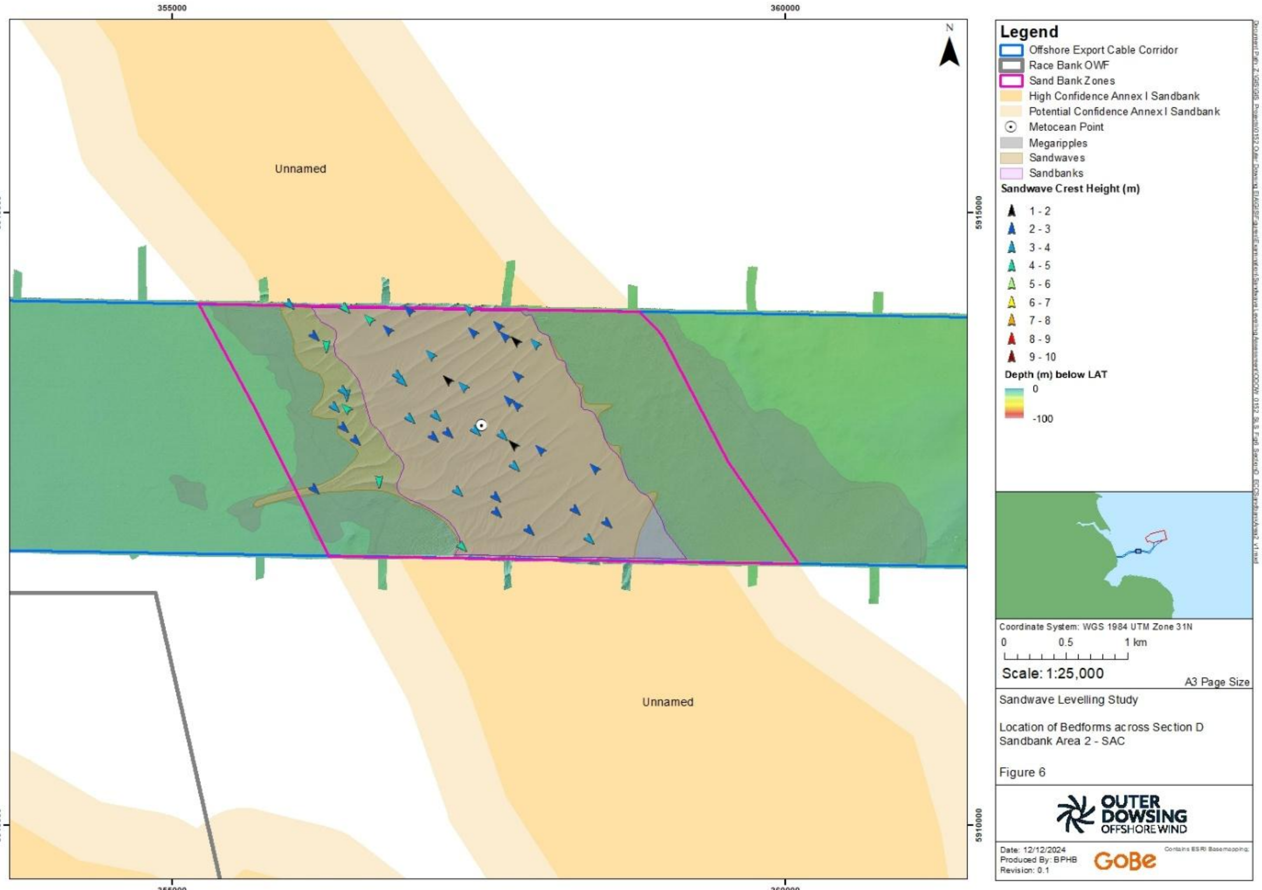

Figure 6 Location of bedforms across Section D: Sandbank Area 2 – SAC.

57. The inshore facing flank of the sandbank exhibits a steeper slope compared to the offshore facing flank. The shallowest part of the bank is around 12m below LAT, although individual sandwaves may lead to localised shallower depths.
58. The sandwaves across the sandbank are near-symmetrical, but with an overall tendency for a north-westerly direction of net migration. The most distinctive sandwaves are towards the westerly flank with crest heights up to 5m.
59. The sandwave clearance MDS includes a provision for dredging 100% of the width of the sandbank for up to four cable circuits each up to 33m wide. The MDS dredging volume is up to 512,000m^3 of sediment and is expected to include areas with sandwaves as well as areas with layers of mobile sediment.
60. The surficial sediment composition of the sandbank is described by the baseline environmental survey (GEOxyz, 2022b (APP-155)) as moderately-sorted to moderately well-sorted slightly gravelly sand. The sand content alone is around 97 to 99% (multiple samples), including 2 to 19% coarse sand, 43 to 52% medium sand, and 21 to 48% fine sand.

61. Based on a regular neap and spring tidal cycle, the relative occurrence of sediment mobility for coarse sand at this location is assessed to be around 19% during a neap tide and 81% on a spring tide. This increases to 44% and 96%, respectively, for medium sand and 51% and 98%, respectively, for fine sand (APP-150). Only storm conditions are likely to develop large enough waves sufficient to stir local seabed sediments on the shallowest parts of the bank, locally increasing seabed mobility at these times.

4.1.5 E: ECC – Offshore

62. This 38.03km section of the ECC falls between Sandbank Area 2 (Section D) and the Array Area (Sections F, G and H), and includes the funnel area of the ECC which adjoins with the array area (Figure 7).

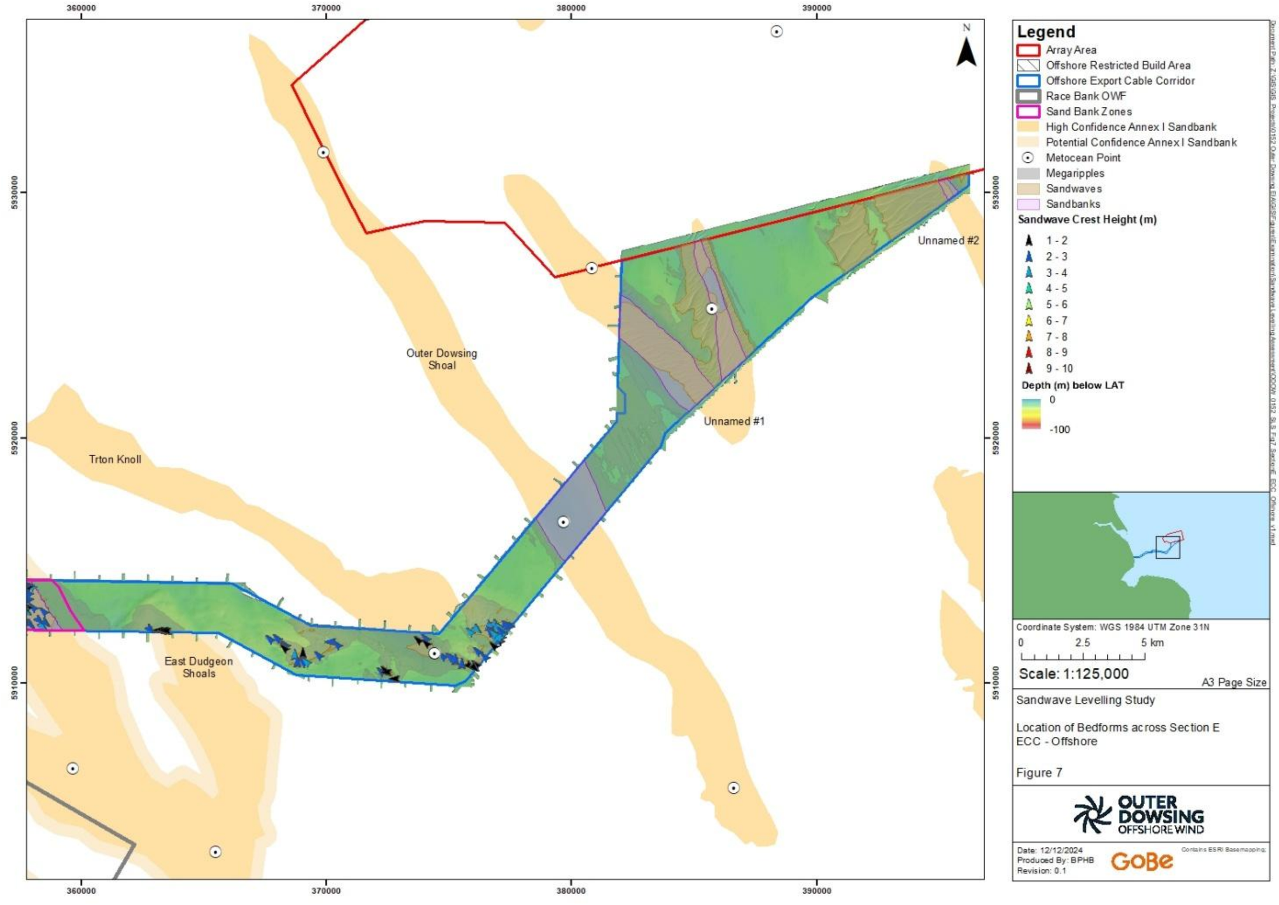

Figure 7 Location of bedforms across Section E. ECC – Offshore.

63. The MDS provisions for sandwave clearance include dredging for 20% of the length of this section of the ECC for up to four circuits each 33m wide and removing up to 1,703,565m^3 of sediment in total.

64. There are five Annex 1 sandbanks along this section of the ECC where dredging is a likely consideration. These sandbank areas are reviewed west to east to account for likely variability between locations.

4.1.6 East Dudgeon Shoals

65. The westerly section of this part of the ECC partially overlaps with the northern tip of Annex 1 area of East Dudgeon Shoals, as defined by JNCC (2020). This overlap includes an area marked with "Potential" confidence and a smaller area marked with "High" confidence. "High" confidence denotes a high level of supporting background data and "Potential" denotes a 500m uncertainty buffer where qualifying evidence indicates an Annex 1 Sandbank is present, or could be present due to migration, but the evidence is insufficient to support "High" confidence.
66. For reference, neither the charted position of East Dudgeon Shoals (as defined by the 15m isobath – source: VisitMyHarbour.com) or the latest high-resolution evidence from the geophysical survey (GEOxyz, 2022c) show any overlap of East Dungeon Shoals sandbank with the ECC, as suggested by the sandbank boundary established by JNCC (2020). Instead, the geophysical evidence for this section of the ECC resolves a field of megaripples ("Bedforms formed by tidal related bottom currents") which is likely to be associated with the shoals to the south, along with a small set of sandwaves with crest heights up to 2m which are present close to the southern margin of the ECC.
67. The surficial sediment composition of the area of megaripples is described by the baseline environmental survey (GEOxyz, 2022b (APP-155)) as poorly-sorted gravelly sand. The sand content is around 80%, including 14% very coarse sand, 7% coarse sand, 29% medium sand, and 29% fine sand.
68. Based on a regular neap and spring tidal cycle, the relative occurrence of sediment mobility for very coarse sand at this location is assessed to be around 19% during a neap tide and 81% on a spring tide. This increases to 44% and 96%, respectively, for medium sand and 51% and 98%, respectively, for fine sand (APP-150). Only storm conditions are likely to develop large enough waves sufficient to stir local seabed sediments on the shallowest parts of the bank, locally increasing seabed mobility at these times.

4.1.7 Triton Knoll Sandbank

69. The south-eastern limit of the Annex 1 Triton Knoll sandbank partially overlaps with the ECC. For reference, the chartered position of this part of Triton Knoll (as defined by the 20m isobath: source: VisitMyHarbour.com) is fairly consistent with the area identified for the Annex 1 sandbank, although much less extensive on the eastern side, in comparison. The geophysical evidence (GEOxyz, 2022c) only identifies megaripples and occasional sandwaves for this area, despite a general variation in the seabed profile indicative of a wider sandbank.
70. The occasional sandwaves across this section of the ECC have crest heights up to 4m and are mostly symmetrical in cross-section with occasional asymmetry indicating a net transport pathway to the north, which is consistent with the regional pathway for net sand transport (Figure 1).

71. The surficial sediment composition of the megaripples area just south of the sandbank is described by the baseline environmental survey (GEOxyz, 2022b (APP-155)) as poorly-sorted gravelly sand. The area of sandwaves immediately to the east of Triton Knoll is described as well-sorted medium sand. The sand content here is around 100%, including 70% medium sand, and 24% fine sand.
72. Based on a regular neap and spring tidal cycle, the relative occurrence of sediment mobility for medium sand at this location is assessed to be around 29% during a neap tide and 69% on a spring tide. This increases to 36% and 73%, respectively, for fine sand (APP-150). Only storm conditions are likely to develop large enough waves sufficient to stir local seabed sediments on the area of sandwaves, locally increasing seabed mobility at these times.

4.1.8 Outer Dowsing Shoal

73. Further offshore of Triton Knoll and Outer Dowsing Channel, the ECC fully overlaps with a mid-section of the Annex 1 sandbank, Outer Dowsing Shoal. At this location, the geophysical survey (GEOxyz, 2022c) indicates the bank to be around 3km wide, whereas the JNCC mapping suggests a narrower sandbank at around 2km wide. The geophysical survey does not identify any sandwaves at this location, only megaripples covering the profile of the bank. Other notable features of the sandbank include a steeper inshore flank slope compared to the offshore flank, along with a relatively flat crest between 8 to 11m below LAT across the width of the ECC.
74. Although sandwaves are not present across this part of the sandbank there may still be a requirement to remove any mobile layer of sediments to achieve the RSBL for cable installation.
75. The surficial sediment composition of the sandbank is described by the baseline environmental survey (GEOxyz, 2022b (APP-155)) as moderately well-sorted slightly gravelly sand. The sand content here is around 95%, including 29% medium sand, and 65% fine sand.
76. Based on a regular neap and spring tidal cycle, the relative occurrence of sediment mobility for medium sand at this location is assessed to be around 50% during a neap tide and 85% on a spring tide. This increases to 54% and 87%, respectively, for fine sand (APP-150). Additional seabed mobility is likely under typical wave conditions for fine sands in the shallowest areas, but requires larger storm waves for medium sands and slightly deeper areas.

4.1.9 Unnamed sandbank #1

77. The ECC overlaps with an unnamed Annex 1 sandbank (#1) in the western part of the funnel area which approaches the Array Area. This is a hook-shaped sandbank covered with sandwaves and megaripples formed from a shallower western arm (around 9m below LAT) with a slightly deeper eastern arm (around 14m below LAT). The sandwaves demonstrate a general asymmetric cross-section indicating net migration to the north-west, consistent with the direction of regional net sand transport. Larger sandwaves appear on the eastern part of this feature and tend to be slightly more symmetrical in profile, with crest heights up to 8m compared with up to 3m on the western part.
78. Since the distribution of sandwaves fully extends across the width of the ECC at this location then some level of sandwave clearance is inevitable for each of the four cable circuits.

79. The surficial sediment composition of the sandbank is described by the baseline environmental survey (GEOxyz, 2022b (APP-155)) as well-sorted medium sand for the western arm of the sandbank, and well-sorted medium sand and poorly-sorted gravelly sand for the eastern arm. The sand content for the western arm is around 99%, including 29% medium sand, and 65% fine sand. The sand content for the eastern arm varies between around 93 to 100%, including up to 22% very coarse sand, up to 27% coarse sand, 29 to 63% medium sand, and up to 14% fine sand (multiple samples).
80. Based on a regular neap and spring tidal cycle for the eastern arm, the relative occurrence of sediment mobility for medium sand at this location is assessed to be around 41% during a neap tide and 71% on a spring tide. This increases to 47% and 73%, respectively, for fine sand (APP-150). Additional seabed mobility is only likely under storm conditions for both fine and medium sands.

4.1.10 Unnamed sandbank #2

81. The ECC overlaps with a 1.2km section of an unnamed Annex 1 sandbank (#2) at the eastern limit of the funnel area. The sandwaves in this area demonstrate a general asymmetric cross-section indicating net migration to the north-west, consistent with the direction of regional net sand transport. Sandwave crest heights reach up to 4m.
82. Although the distribution of sandwaves fully extends across the width of the ECC at this location, the final cable routing for all four circuits is unlikely to pass through this area.
83. The surficial sediment composition of the sandwaves to the west of the sandbank are described by the baseline environmental survey (GEOxyz, 2022b (APP-155)) as moderately well-sorted medium sand and moderately well-sorted slightly gravelly sand. The sand content for this location is around 97 to 98%, including 12 to 23% coarse sand, 56 to 63% medium sand, and 14 to 18% fine sand (multiple samples).

4.2 Array Area

84. The local evidence from the geophysical survey (GEOxyz, 2022c) identifies that the seabed across the Array Area is predominantly formed of sands and gravels in various compositions (e.g. sand, sandy gravel, gravelly sand, etc.), with a relatively low content of fines. Different scales of bedforms are also present in some areas including widespread areas of megaripples and sandwaves, along with discrete sandbanks, noting not all areas with megaripples and sandwaves are directly associated with the local sandbanks.

85. Large expanses of the seabed in the Array Area also appear largely devoid of bedforms, a notable example is the area which adjoins with the ECC funnel area. Sandwave clearance for Cable Section F (ECC - Array Area) is likely to occur in this relatively bedform sparse area to connect with offshore sub-stations. The MDS provisions for dredging are 20% of a total of 110km of cables to a width of 33m for each of up to four circuits. In contrast, the dredging provisions for interlink and inter-array cables is 32.5%, noting these cables could be present at any location across the array area, including the areas with a higher presence of bedforms. The total associated MDS dredging provisions for Section F (ECC - Array Area), G (Interlink – Array Area), and H (IAC – Array Area) amount to 11,615,616m^3 (based on Table 1).

86. The distribution of resolved bedforms across the Array Area along with the overlap with five Annex 1 sandbanks is presented in Figure 8. The scale of sandwave crests and the inferred direction of cross-sectional asymmetry determined by East Point Geo Ltd. (2023 (APP-152)) is also provided for reference, but these are limited to discrete survey lines rather than provided at full coverage. The bathymetry survey accommodates several exclusion areas around existing oil and gas platforms which appear as gaps.

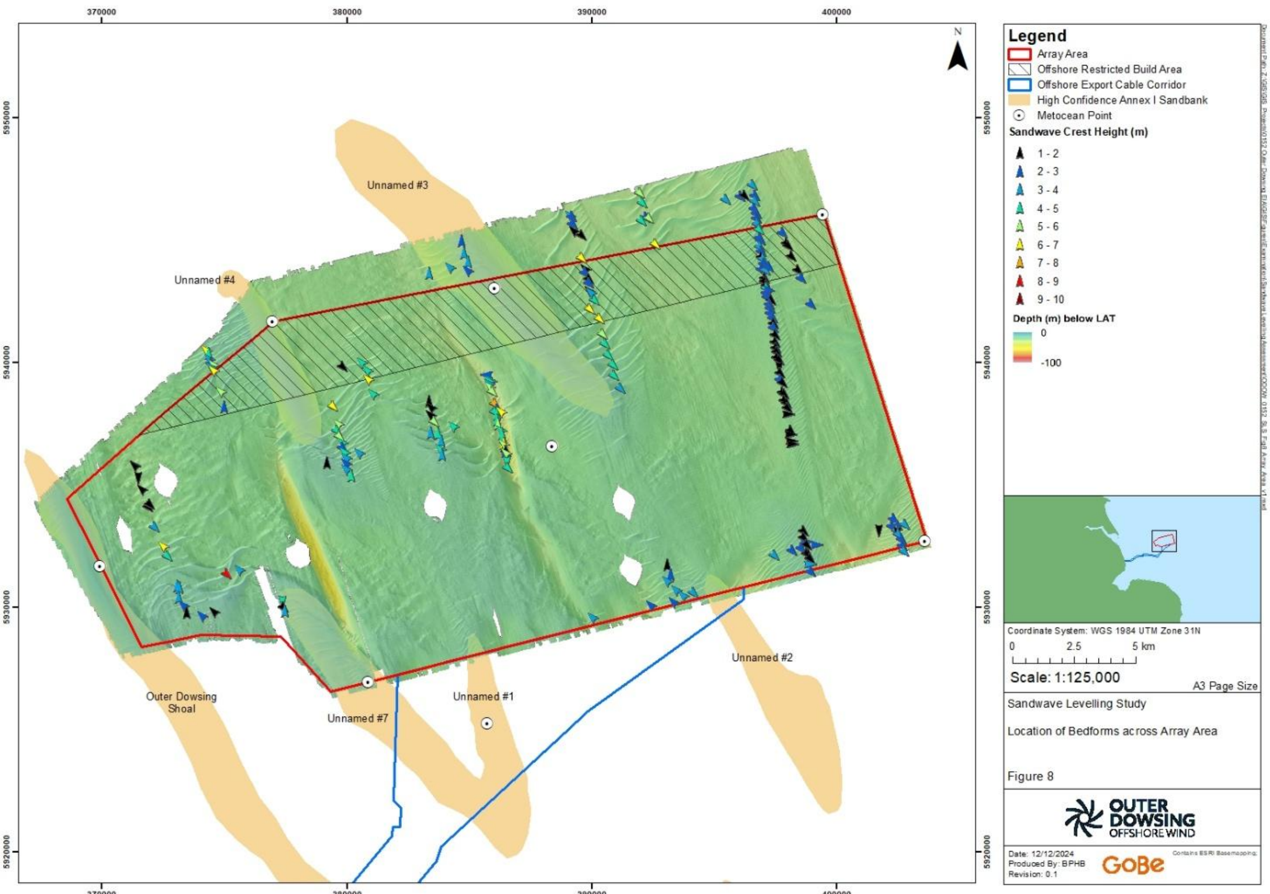

Figure 8 Location of bedforms across Array Area.

4.2.1 Outer Dowsing Shoal

87. The western boundary of the Array Area aligns with a 7.1km long section of the Annex 1 sandbank, Outer Dowsing Shoal which has a crest orientation around 333°N. This is the shallowest sandbank within the Array Area, reaching around 6m below LAT, and generally has a smooth profile largely devoid of smaller scale bedforms, either along the flanks or across the crest of this feature. The main exceptions are across the north-western and south-western parts of the western boundary, locations which are present on the inshore flank of the sandbank. In the north-western corner there is a set of sandwaves with megaripples superimposed across their surface. The sandwaves crest heights are generally between 2 to 3m with an asymmetric cross-section suggesting a direction of net migration to the north-west. In the south-western corner the sandwaves are generally 1 to 2m in height with a similar asymmetry indicating migration to the north-west. Other notable features of the sandbank include a steeper inshore flank slope compared to the offshore flank.
88. The surficial sediment composition of the bank is described by the baseline environmental survey (GEOxyz, 2022a (APP-154)) as well-sorted medium sands, whereas immediately seawards the sediments are described as gravelly sand which varies from moderately to very poorly sorted. The sand content for sites on the top of the sandbank is up to 100%, including up to 4% coarse sand, 64 to 72% medium sand, and around 25 to 31% fine sand (multiple samples).
89. Based on a regular neap and spring tidal cycle for a site on the offshore eastern flank of the sandbank, the relative occurrence of sediment mobility for coarse sand at this location is assessed to be around 19% during a neap tide and 67% on a spring tide. This increases to 39% and 79%, respectively, for medium sand, and 46% and 82%, respectively, for fine sand (APP-150). For low water periods, the shallowest parts of the bank will experience increased seabed mobility under normal wave conditions for all sand sizes. In contrast, if water depths exceed around 10m then normal wave activity is unlikely to have any affect in stirring local seabed sediments. Waves during storm conditions are considered to increase seabed mobility to the base of the sandbank for all sand sizes.

4.2.2 Unnamed sandbank #1

90. The Array Area overlaps with an unnamed Annex 1 sandbank (#1) in two locations along the southern boundary due to the hook shape of this feature, a western arm (shallowing to around 10m LAT with a crest orientation around 323°N) and slightly deeper eastern arm (shallowing to around 16m below LAT with a crest orientation around 346°N). For reference, this is part of the same sandbank that overlaps with Cable Section E (ECC - Offshore ECC).

91. This sandbank is covered with both sandwaves (4 to 5m high) and megaripples. The general shape of the cross-section sandwave profile is fairly symmetrical at both locations, with some indications of a net direction of migration to the north-west, consistent with the regional pathway for net sand transport. The exception is a narrow band of sandwaves local to the offshore flank of the western part of the sandbank, with crest heights around 3m, which indicate an asymmetric profile suggesting net migration to the south-east.

92. The surficial sediment composition of the bank is described by the baseline environmental survey (GEOxyz, 2022a (APP-154)) as poorly sorted gravelly sand (western arm) and moderately well-sorted medium sands (eastern arm). The sand content for the western arm is around 82%, including up to 40% very coarse sand, 14% coarse sand, 20% medium sand, and up to 8% fine sand. The sand content for the eastern arm is around 100%, including up to 14% coarse sand, 66% medium sand, and up to 20% fine sand.

93. Based on a regular neap and spring tidal cycle for the western arm, the relative occurrence of sediment mobility for very coarse sand at this location is assessed to be around 3% during a neap tide and 39% on a spring tide. This increases to 29% and 67%, respectively, for coarse sand, 48% and 76%, respectively, for medium sand, and 48% and 78% for fine sand (APP-150). Additional seabed mobility due to waves at this location is only likely under storm conditions.

4.2.3 Unnamed sandbank #2

94. The Array Area overlaps with a short section (around 850m) of an unnamed Annex 1 sandbank (#2) along the southern boundary, where the eastern end of the ECC funnel area adjoins. The shallowest part of this sandbank is around 17m below LAT with a crest orientation around 333°N.

95. This sandbank is covered with both sandwaves (2 to 3m high) and megaripples. The general shape of the cross-section sandwave profile is fairly symmetrical, with some indications of a net direction of migration to the north-west, consistent with the regional pathway for net sand transport.

96. The surficial sediment composition for a sandwave area associated with the northern tail of the sandbank is described by the baseline environmental survey (GEOxyz, 2022a (APP-154)) as moderately well-sorted slightly gravelly sands, with a further location within this area of sandwaves, slightly to the north, described as moderately well-sorted medium sand. The sand content for this location is around 98%, including 23% coarse sand, 56% medium sand, and 18% fine sand.

4.2.4 Unnamed sandbank #3

97. The Array Area overlaps with a large part (around 9.7km) of an unnamed Annex 1 sandbank (#3) mid-way along the northern boundary. The shallowest part of this sandbank is around 14m below LAT, with a generally long eastern slope compared to the western flank. The crest orientation of this bank is around 320°N.

98. This sandbank is sparsely covered with sandwaves (2 to 4m high), with occasional sets of intervening lower profile and shorter wavelength megaripples. The general asymmetric shape of the sandwave cross-section profile indicates a net migration to the north-west, consistent with the regional pathway for net sand transport. This asymmetry is most distinctive on the northern part of the western flank.

99. There is a wider area of larger sandwaves which appear to be associated with the southern head and eastern flank of this bank. The crest heights of these sandwaves are up to 7m with an asymmetric profile again indicating net migration to the north-west. The sandwaves are located at the end of a long slope extending eastward from the offshore flank of the bank.

100. The surficial sediment composition of the sandbank is described by the baseline environmental survey (GEOxyz, 2022a (APP-154)) as moderately well-sorted medium sand (mid section of bank) and moderately sorted slightly gravelly sand (southern head). The sand content for the mid section is around 100%, including up to 16% coarse sand, 58% medium sand, and up to 24% fine sand. For the southern head, the sand content is around 95%, including up to 9% very coarse sand, up to 33% coarse sand, 44% medium sand, and 9% very fine sand.

101. Based on a regular neap and spring tidal cycle for the mid section of the bank, the relative occurrence of sediment mobility for medium sand is assessed to be around 29% during a neap tide and 67% on a spring tide. This increases to 34% and 70%, respectively, for fine sand (APP-150). Additional seabed mobility due to waves at this location is only likely under storm conditions.

4.2.5 Unnamed sandbank #4

102. The Array Area overlaps with the majority (around 6.6km) of an unnamed Annex 1 sandbank (#4) where there is a change of orientation of the northern boundary. The shallowest part of this sandbank is around 13m below LAT. The crest orientation of this bank is around 334°N.

103. This sandbank is covered with megaripples with sandwaves present along the western flank (2 to 3m high) but are rarely present along the eastern flank. The general asymmetric shape of the sandwave cross-section profile along the western flank indicates a net migration to the north-west, consistent with the regional pathway for net sand transport.

104. Similar to unnamed sandbank #3, there is a wider area of large sandwaves which appear to be associated with the southern head and eastern flank of this bank. The crest height of these sandwaves are up to around 6m with an asymmetric profile again indicating net migration to the north-west.

105. The surficial sediment composition of the sandbank is described by the baseline environmental survey (GEOxyz, 2022a (APP-154)) as well-sorted medium sand (mid and top section of bank) and well-sorted fine sand (southern section). The sand content for all sample locations is around 100%, including up between 40 to 58% medium sand, and between 41 to 60% fine sand.

106. Based on a regular neap and spring tidal cycle for a location on the offshore flank of the bank, the relative occurrence of sediment mobility for medium sand is assessed to be around 29% during a neap tide and 67% on a spring tide. This increases to 34% and 70%, respectively, for fine sand (APP-150). Additional seabed mobility due to waves at this location is only likely under storm conditions.

5 Sandwave Recovery

107. In general, sandwave clearance will locally modify the profile of the seabed, however, this is not expected to change the general conditions responsible for maintaining the wider part of the sandwave fields. Sandwave recovery (regeneration) can be expected to initiate directly following clearance as part of the wider bedform development and migration process. The initial phase of recovery is expected as progressively increasing scales of bedforms, from rapidly forming ripples, to megaripples, to a more gradual recovery of sandwave scales representative of previous equilibrium conditions. The overall rate of recovery is likely to be similar to the rate of migration for the respective scale of bedform. In general, and under ideal conditions, smaller sandwaves may recover as quickly as a few tidal cycles whereas for larger sandwaves may require decades to full recover.

108. The key environmental conditions for sandwave recovery are consistent metocean conditions and availability of sandy sediments, equivalent to the material type removed by sandwave clearance.

109. For the Project, once a specific area of sandwaves are cleared then all dredged sediment will be deposited within the Order Limits within an area of similar sediment characteristics, in close proximity to the dredge location in order to retain sediment within the sediment transport system (Reference 6, Schedule of Mitigation (APP-287). In particular, any sediment dredged for sandwave clearance within the designated SAC will be retained within the same area (Reference 7, Schedule of Mitigation (APP-287)). Given that cleared material will be returned to their local sedimentary system in each case, then over time active sediment transport processes will drive bedform recovery towards their local equilibrium state.

5.1 Evidence of Sandwave Recovery

110. Sandwave clearance (and recovery) may occur where the scale of bedforms is considered as an obstacle to a particular activity, such as safe navigation or cable installation, or if the area of sediments is considered as a commercial resource (e.g. aggregate extraction). Evidence of sandwave recovery from a range of these activities is presented below. Each site must be considered in the context of its specific environmental characteristics, and are not necessarily presented as direct analogues.

5.1.1 Sandwave clearance for cables

111. Natural England has previously advised against using evidence of sandwave recovery from Race Bank OWF as an analogue for the Project. However, Race Bank OWF remains an important part of the wider evidence base and usefully demonstrates the process towards full sandwave recovery. This evidence is most applicable to locations with comparable environmental settings and for similar scales of sandwaves, most notably sandwaves in the range 2-3 to 3-4m located in Cable Section D (ECC - Sandbank Area 2 – SAC) which is adjacent to Race Bank OWF.

112. In 2016, sandwave clearance for a trench width of 16m was performed for Race Bank OWF prior to cable laying.

113. Sediments dredged are described as very well-sorted fine to medium sand with a negligible content of fines.

114. As part of the conditions of the marine licence, routine monitoring was undertaken to determine the effectiveness of sandwave recovery.

115. Two locations were monitored for around 11 months after cable laying: Area 1 and Area 2.

116. Sandwaves in Area 1 are located in water depths between 10 to 15m, with original crest heights of 2.8 to 3.5m and wave lengths around 90m. Dredging occurred perpendicular to the sandwave crests which also aligned with the main flow axis. Clear evidence of sandwave recovery was observed after 137 days, with regeneration to 67% to 74% of the pre-dredging crest heights after 330 days (11 months). Migration of sandwaves also continued at the same time.

117. Sandwaves in Area 2 are located in water depths between 12 to 17m, in a pattern which exhibits a tendency for bifurcation and convergence of crests. One feature subject to monitoring held an original crest height of 2.3m and an associated wave length around 35m. Sandwave recovery was observed after 136 days and reached 64% of the original height after 306 days, with the addition of a new bifurcating crestline seemingly to develop with a similar alignment as the trench.

118. Based on fitting the observed rate of sandwave recovery to an asymptotic expression, then regeneration of the crest heights in Area 1 and Area 2 to 90% of their original values is estimated to take around 1.8 years and full recovery (98%) after around three years (Larsen, et al., 2019). In comparison, megaripple regeneration was faster and was observed to occur within a period of days.

119. This evidence is most applicable to Cable Section D (ECC - Sandbank Area 2 – SAC) which is adjacent to Race Bank OWF and for comparable scales of sandwave clearance.

5.1.2 Sandwave clearance for foundations

120. Sandwave clearance and seabed levelling may also be required to prepare the seabed for certain foundation types.

121. Sandwave levelling was performed at the Greater Changhua 1&2a OWF in the Taiwan Strait to prepare the seabed for installation of pin piled jackets. For locations with sandwaves, dredging created rectangular pits 75 by 110m, with the longer dimension orientated perpendicular to the alignment of sandwave crests. Monitoring data over a six year period demonstrated that excavated pits subsequently experienced rapid sediment infilling (due to sandwave migration) and sandwave regeneration. For reference, local sandwaves appear to have crest heights around 5 to 7m (medium scale features), are covered with megaripples, and also demonstrate seasonal reversal in the direction of migration (Roulund, et al., 2023).

122. This evidence demonstrates that although individual sandwaves may undergo cross-sectional and plan form changes, the sandwave field will maintain its characteristics as a whole, with sandwave sections removed by dredging observed to regenerate as the pit slopes encroached into the dredge pit to form sandwaves with the same magnitudes as before engineering works.

5.1.3 Aggregate extraction

123. For three sandbank locations off the Belgian coast, which have been subjected to sand extraction, only one location showed evidence of sandwave recovery after the sites became closed to further dredging. The primary explanation for the lack of sandwave recovery related to the creation of large depressions which removed the top layer of Holocene sands (a possible change in boundary layer turbulence) and the reduction of available sand supply (net removal of sand volumes from the local resource). The single location which retained a layer of Holocene sand demonstrated sandwave recovery over a 5 year period after sand extraction stopped (Krabbendam, et al., 2022).

124. This evidence demonstrates the importance of local sand availability of erodible sand to the recovery of sandwaves.

5.1.4 Navigation dredging

125. In the period 1981 to 1983, maintenance dredging removed around 2.2 million m^3 of sandwaves from the Inosakinotsugai shoal, located in the Bisanseto navigation channel, Japan. This shoal is considered to be an area of active sand accumulation which encourages the development of sandwaves with crest heights up to 5m (medium scale sandwaves) and wave lengths around 100m. Routine surveys in the period 1984 to 1996 showed that sandwaves reformed to again reduce channel depths. After dredging, sandwaves were observed to regenerate to their equilibrium height in around 10 years which appeared to be more rapid where rates of sand accumulation were highest (Katoh, et al., 1998).

126. This evidence demonstrates the importance of local sand supply to the rate of recovery of sandwaves.

5.1.5 Natural variations

127. One of the earliest set of systematic observations documenting bedform recovery was obtained by the Port of London from Longsand Head, Outer Thames, based on regular sidescan sonar transects over the period 1971 to 1974. The study area is around 12m deep and characterised by sandwaves around 4m in height, covered with smaller bedforms (referred to as dunes at the time but equivalent to megaripples). Sediments in this area were determined to be medium to coarse sand.

128. Tidal observations over an 18-day period were used to deduce that the seabed would be mobile for 38% of the time during the flood tide and 26% of the ebb (i.e. flood dominant). The typical tidal conditions were regarded to maintain the equilibrium form of the megaripples with mean wave lengths of around 4.5m.

129. A notable period of gales in October 1974 led to significant wave heights up to 2.8m with wave periods up to 6.1 s. Post-gale observations (gale + 35 hours) showed the bedforms to have shortened in wave length (to circa 1.7m) to become wave-induced megaripples. A further six surveys extending to gale + 203 hours indicated the bedforms returning toward their equilibrium state (80% of pre-gale wavelengths) under normal tidal conditions (Langhorne, 1977).

130. This evidence shows that natural variations can occur to the shape of bedforms due to peak energy events which subsequently recover their former equilibrium profile under typical conditions.

5.2 Sandwave recovery at the Project site

131. The evidence provided in Section 5.1 demonstrates that sandwave recovery (regeneration) can be expected to initiate following levelling operations as part of the wider bedform development and migration process, as well as demonstrating the important of local sediment availability to bedform recovery. As outlined in Section 4, the Project area is characterised by a generally active and dynamic sediment environment that is conducive to the development and maintenance of mobile bedforms. This is in relation to tidal current speeds, water depths, and sediment availability, and has been evidenced by the presence of bedforms (identified as part of the geophysical survey operations) as well as sediment mobility analysis.

132. Recovery of sandwaves can be expected where environmental conditions remain consistent pre- and post-levelling. The tidal current regime (outlined in detail within APP-150) will not be measurably impacted as a result of the localised levelling, and although sediment will be locally redistributed, it will be deposited in close proximity to the dredge location in order to retain sediment within the sediment transport system (Reference 6, APP-287). Although the installation of Project infrastructure has the potential to result in localised tidal blockage, this will be restricted in both spatial and temporal extent (as assessed in Section 7.12.2.1 of APP-062). Estimated changes in sediment mobility as a result of this blockage do not exceed 1% (of total time that sediment is mobile) for any sediment size class, therefore representing only a minimal change to sediment transport. The general conditions responsible for maintaining the overall sediment transport regime will not change, and bedforms are therefore expected to evolve and recover towards their local equilibrium state.

6 Conclusions

133. This document comprises a sandwave levelling study in response to concerns raised by stakeholders, particularly Natural England, during both the statutory pre-application consultation process and within relevant representations submitted to the Planning Inspectorate. The study considers discrete sections of the offshore ECC and array area, with a focus on sandbank areas, providing information on the likelihood of sandwave recovery following proposed seabed levelling activities. The study provides further detail and clarification to the conclusions made within Chapter 7: Marine Physical Processes (APP-062) and the Report to Inform Appropriate Assessment (RIAA) (APP-235).

134. Site surveys undertaken by the Applicant (GEOxyz, 2022c) identify the location and scale of bedform features across the offshore ECC and array area and confirm that the sediment composition of sandwave and sandbank areas is sand rich, mainly comprising medium and coarse grade sands. The direction of net migration of sandwaves has been deduced from the asymmetry of cross-section profiles, which broadly agree with the regional description of net sand transport direction.

135. The relative capacity of metocean conditions to develop seabed mobility confirms that all sandwave locations are actively mobile, mainly in response to tidal processes and occasionally to waves (subject to local water depths and magnitude of wave conditions).

136. Available evidence on sandwave recovery for a range of environmental settings demonstrates that the relative rate of recovery is expected to be faster for medium scale sandwaves (several years) and slower for large scale sandwaves (up to decades) for a given set of conditions, however, the rate of recovery is also linked to sediment availability. Notably, this evidence includes that from Larsen et al. (2019) which provides support and justification for similar seabed recovery processes at comparable parts of the study area (i.e. Cable Section D: ECC - Sandbank Area 2 – SAC).

137. Recovery of sandwaves can be expected when pre- and post-levelling environmental conditions remain consistent, evolving as part of the general sediment regime. This recovery can be assisted by the disposal of dredged material within the local area such that sediment remains available for further bedform evolution and recovery. For the proposed sandwave clearance activities required for the Project, sandwave recovery is anticipated in all cases.

138. With regard to the IDRBNR SAC, the proposed bed levelling areas and volumes within the SAC are much smaller than the total volume present in the wider sandbank system. This means the levelling proposed for the Project only represents a small percentage of the total volume of sediment within the SAC. Any sediment dredged for sandwave clearance within the designated SAC will be retained within the same area, meaning that there will be no net loss from the local sedimentary system. Once returned to the seabed, the deposited sediment will quickly become part of the local sedimentary system, therefore presenting minimal potential to affect the form and function of the sandbank system as a whole. The existing Annex 1 sandbank features will be maintained and therefore the conservation objectives for the SAC will be met.

7 References

Ashley, G. M., 1990. Classification of large-scale subaqueous bedforms: A new look at an old problem. SEPM Bedforms and Bedding Structures. Journal of Sedimentary Research.

Belderson, R. H., Johnson, M. A. & Kenyon, N. H., 1982. Chapter 3 Bedforms. in Offshore Tidal Sands. Processes and Deposits.

EastPointGeo, 2024. Outer Dowsing Offshore Wind. Seabed Mobility Study. Document No.: O-NR-R14-032242-REP001. Client: GTR4.

GEOxyz, 2022a. Benthic Ecology OWF Area Result Report (Vol. 1). UK4855H-824-RR-01. Revision 1.0

GEOxyz, 2022b. Benthic Ecology ECC Area Results Report (Vol. 2). UK4855H-824-RR-02. Revision 1.0.

GEOxyz, 2022c. Offshore & Nearshore Geophysical & Geotechnical Results & Charts (Vol. 5). Environmental, Geophysical and Geotechnical Site Investigations 2022 - Outer Dowsing OWF and ECC. UK4855H-824-RR-05. Revision 0.1.

JNCC, 2020. Creating version 3 of the UK composite map of Annex I Sandbanks. Revised: 24/04/2020. Document Version 3.

Katoh, K., Kume, H., Kuroki, K. & Hasegawa, J., 1998. The development of sand waves and the maintenance of navigation channels in the Bisanseto Sea. ASCE, pp. 3490 - 3502.

Kenyon, N. H. & Cooper, B., 2005. Sand banks, sand transport andoffshore wind farms.

Knaapen, M. A., 2005. Sandwave migration predictor based on shape information. Journal of Geophysical Research, 110(F04S11).

Krabbendam, J. M. et al., 2022. Do tidal sand waves always regenerate after dredging?. Marine Geology, 451(106866).

Langhorne, D. N., 1977. Consideration of meteorological conditions when determining the navigational water depth over a sandwave field. International Hydrographie Review, Volume LIV(1).

Larsen, S. M., Roulund, A. & McIntyre, D. L., 2019. Regeneration of partially dredged sandwaves. pp. 3026-3039.

OWC, 2023. Outer Dowsing Offshore WindFarm. Localised CBRA – Export Cable Route Crossing Sandbanks. Document No.: OWC-LO-R10-0133_CTR008.

Roulund, A., Riezebos, H. J. & Saverymuttu, K., 2023. Foundation installation in sandwave fields. Field observations of sandwave regeneration and sediment infill.