Bowdun Offshore Wind Farm, Offshore EIA Report

Volume 3, Technical Appendix 7.1: Physical Processes Baseline Environment

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Glossary

Defined Term	Definition
Array Area	The Array Area is the area in which the Offshore Generation Assets will be located.
Benthic	Living on or in the seabed.
Chlorophyll-a	Chlorophyll-a is the green substance used by plants to photosynthesise (creating sugars from basic chemical building blocks, using sunlight).
Effect	Term used to express the consequence of an impact (i.e. the result of change or changes on specific environmental resources or receptors). The significance of an effect is determined by correlating the magnitude of the impact with the importance, or sensitivity of the receptor or resource in accordance with defined significance criteria.
Environmental Impact Assessment (EIA)	Process for the assessment of likely significant environmental effects of a project on the physical, biological and human environment during construction, Operation and Maintenance (O&M) and decommissioning.
Export Cable Corridor	The area seaward of Mean High Water Spring (MHWS) which connects the Array Area with the Landfall within which the Offshore Export Cables will be installed.
Halokinesis	The geological processes involving the movement and deformation of salt deposits (evaporites) within the Earth's crust
Hindcast	Re-analysis of historical weather and oceanographic data using numerical models to simulate past conditions
Impact	A change caused by an action that occurs during a project's lifetime.
Inter-Array Cables (IAC)	Cables which link the Wind Turbines to each other and with the Offshore Substation Platforms (OSPs).
Intertidal Area	The area between MHWS and Mean Low Water Springs (MLWS).
Landfall	The area in which the Offshore Export Cables make Landfall and is also the transitional area between the Offshore Transmission Assets and the Onshore Transmission Assets. Located in the Intertidal Area at Benholm.
Marine Directorate (MD)	The Marine Directorate of the Scottish Government, formerly known as Marine Scotland. The planning and licensing authority for Scotland's seas and custodian of Scotland's National Marine Plan (NMP). The Marine Directorate - Licensing and Operations Team (MD-LOT) are specifically responsible for managing Section 36 Consent and Marine Licence Applications seaward of MHWS.
Marine Protected Areas (MPAs)	MPAs are designated under the Marine (Scotland) Act 2010 and the Marine and Coastal Access Act (MCAA) 2009. The MPA network protects nationally and internationally important marine wildlife, habitats, geology, and underwater landforms. Scotland's MPAs are significantly important for European, North East Atlantic, and global MPA networks.
Mean High Water Springs (MHWS)	The average tidal height throughout the year of two successive high waters during those periods of 24 hours when the range of the tide is at its greatest.

Defined Term	Definition
Mean Low Water Springs (MLWS)	The average tidal height throughout the year of two successive low waters during those periods of 24 hours when the range of the tide is at its greatest.
Offshore Substation Platform(s) (OSPs)	OSPs comprise the support structure, topside and electrical components used for collecting and/or converting electricity generated by the Wind Turbines for transmission by the Offshore Export Cables.
Plan Option Area (POA)	A location identified in the Sectoral Marine Plan (SMP) as a preferred area for commercial scale offshore wind development.
Project (the)	An overarching term for the Bowdun Offshore Wind Farm (Bowdun OWF) comprising the offshore and onshore infrastructure required to generate and transmit electricity from the Array Area to the onshore Grid Connection Point (GCP). The Project includes the Offshore Generation Assets, the Offshore Transmission Assets and the Onshore Transmission Assets.
Proposed Development	Term used to define the Offshore Infrastructure associated with the Project seaward of MHWS for which consent is being sought. Further details of the parameters are included in Volume 1, Chapter 3: Project Description.
Site Boundary	The boundary within which all elements of the Proposed Development will be located. The Site Boundary comprises the Array Area and Export Cable Corridor which ends at MHWS.
Spring Tidal Excursion	The distance suspended sediment is transported prior to being carried back on the returning tide.
Study Area	For each environmental topic, the baseline environment will be characterised, and the potential environmental impacts will be described within a topic-specific study area. Specific study areas are defined for each topic and are based on the maximum spatial extent across which potential impacts of the Project may be experienced by the relevant receptors (i.e. Zone of Influence).
Thistle Wind Partners (TWP)	Company established for the development of the Project.
Tidal Ellipse	The illustration of the variance of tidal currents in horizontal space.
Wind Turbines	Structures comprising of a tubular tower, rotor blades, and a nacelle which houses the Wind Turbine generator.

Acronyms

Acronym	Definition
ABPmer	ABP Marine Environmental Research
BGS	British Geological Survey
BODC	British Oceanographic Data Centre
CD	Chart Datum
Cefas	Centre for Environment, Fisheries, and Aquaculture Science
EIA	Environmental Impact Assessment
EMODNet	European Marine Observation and Data Network
IAC	Inter-Array Cable
JNCC	Joint Nature Conservation Committee
LAT	Lowest Astronomical Tide
LGM	Last Glacial Maximum
MBES	Multibeam Echosounder
MHWS	Mean High Water Spring
MLWS	Mean Low Water Spring
MPA	Marine Protected Area
NTSLF	National Tide and Sea Level Facility
O&M	Operation and Maintenance
ODN	Ordnance Datum Newlyn
OSP	Offshore Substation Platform
OWF	Offshore Wind Farm
PEA	Potential Energy Anomaly
PP	Primary Productivity
SCO	Scottish Coastal Observatory
SEA	Strategic Environmental Assessment
SEPA	Scottish Environment Protection Agency
SG	Scottish Government
SMP	Sectoral Marine Plan
SPM	Suspended Particulate Matter
SSS	Side Scan Sonar
TWP	Thistle Wind Partners Limited
UK	United Kingdom
UKCP18	United Kingdom Climate Projections 2018
UKHO	United Kingdom Hydrographic Office

Table of Units

Units	Definition
J/m^3	**Joules per cubic metre**
km	Kilometre
km^2	Square kilometre
m	Metre
m^3	Cubic Metre
mg/l	Milligram per litre
mODN	Metre Ordnance Datum Newlyn
m/s	Metre per second
°	Degree
%	Percent
Hs	Significant Wave Height
Tp	Peak Wave Period
Tz	Mean Zero Crossing Period
S	Second
µm	Micrometre

1 Introduction

1.1.1 This Physical Processes Technical Report presents a baseline description of physical processes for the offshore elements of the Bowdun Offshore Wind Farm (OWF) Project (hereafter referred to as the Proposed Development). The Proposed Development covers the Option Lease Area (OLA) comprises of the Array Area, which is located in the E3 Plan Option Area (POA) detailed in the Scottish Sectoral Marine Plan (SMP) (Scottish Government, 2020), and the Export Cable Corridor. The Array Area is located 38 km from the Aberdeenshire coast at its closest point, covering an area of 187 km^2. The Proposed Development will comprise of Wind Turbines (fixed foundations), Inter-Array Cables (IACs), Offshore Substation Platforms (OSPs), Interconnector Cables, Offshore Export Cables and any necessary Scour/Cable Protection. The Export Cable Corridor will include a maximum of three High Voltage Alternating Current (HVAC) Offshore Export Cables, each with a length of up to 70 km and will make Landfall at Benholm, Aberdeenshire.

1.1.2 Data have been collected through a detailed desktop study of existing resources available for physical processes within the Physical Processes Study Area (Figure 1.1) to set out the 'conceptual understanding' of the coastal system in which the Proposed Development is located.

1.1.3 The information from this technical report informs the assessment of the likely significant environmental effects of the Proposed Development on physical processes receptors. This report accompanies Volume 2, Chapter 7: Physical Processes of the Offshore Environmental Impact Assessment (EIA) Report, supporting the consent application for the Proposed Development.

1.1.4 The aim of this Physical Processes Technical Report is to characterise the marine physical processes environment within and around the Array Area and the Export Cable Corridor, as well as across the wider Physical Processes Study Area – see Section 2 and Figure 1.1.

1.1.5 A number of proposed and operational offshore wind farms are located within the Physical Processes Study Area. Cumulative effects with these other projects are discussed in Volume 3, Technical Appendix 7.3: Physical Processes Technical Assessment. They are not considered further in this report as part of the baseline environment.

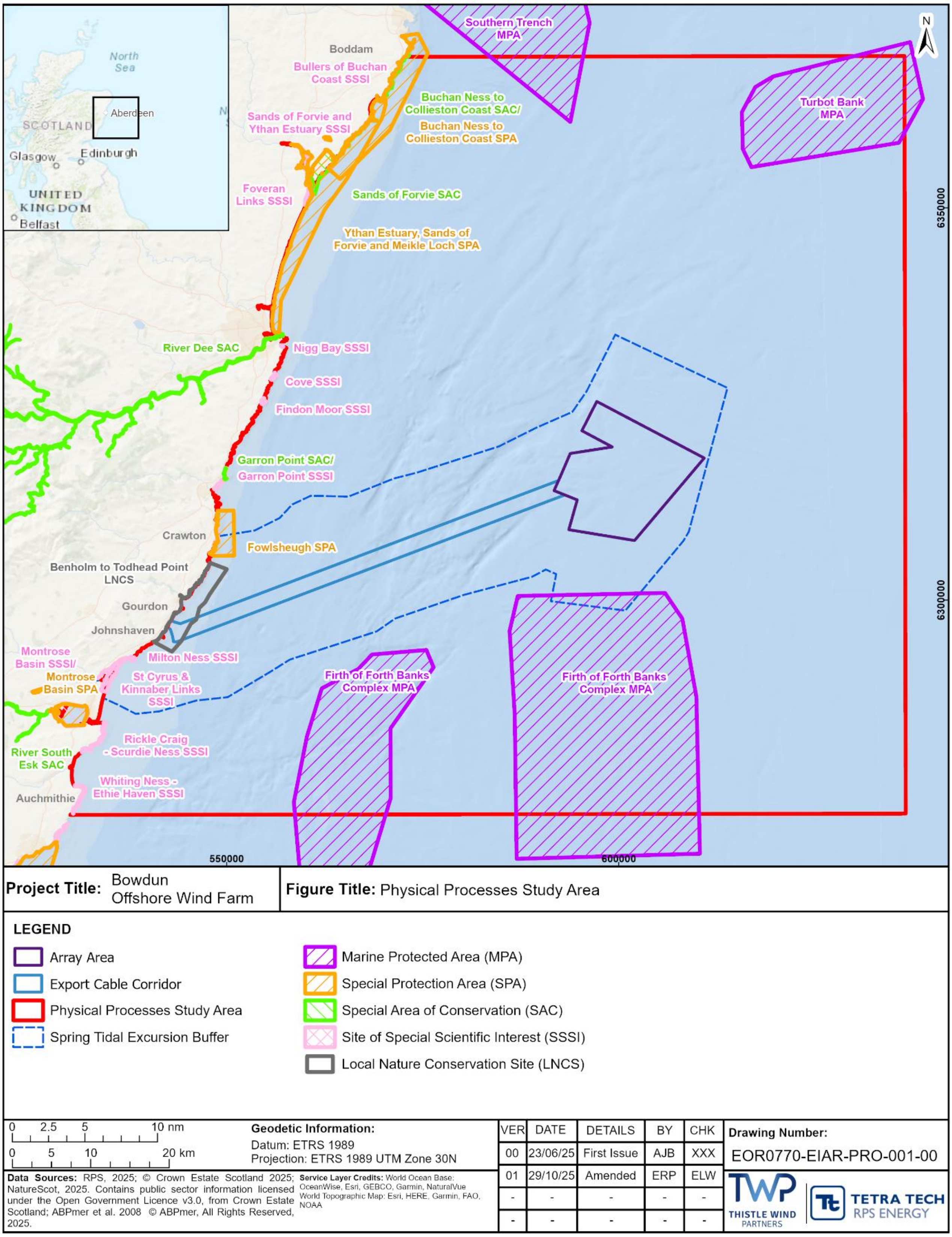


Figure 1.1: Physical Processes Study Area

1.2 Approach

1.2.1 Physical processes within the Physical Processes Study Area have been considered under the following categories:

- metocean regimes:
  - water levels;
  - currents;
  - wind and waves;
  - stratification and frontal systems;
- sediments, sediment transport and morphology; and
- coastlines, beaches and nearshore processes.

1.2.2 The natural variability of the above is explored in the absence of any of the proposed structures for the development. Consequently, this provides the 'baseline' conditions within the Physical Processes Study Area upon which impacts from the Proposed Development can be assessed.

1.2.3 Baseline understanding has been developed in accordance with industry best practice, with attention given to:

- The identification of the processes maintaining the system, the reasons for any past changes, and sensitivity of the system to changes in the controlling processes;
- The identification and quantification of the relative importance of high-energy, low frequency ('episodic' events), versus low-energy, high frequency processes;
- The identification of the processes controlling temporal and spatial morphological change (e.g. longevity and stability of bedforms; cliff recession; loss of beach volume; or bank and channel migration; intertidal accretion/erosion), which may require a review of bathymetric and topographic data;
- The identification of sediment sources, pathways and sinks, and quantification of transport fluxes;
- The identification of the inherited geological, geophysical and geotechnical properties of the sediments at the site, and the depth of any sediment strata;
- The interaction of waves and tides and the subsequent quantification of the extent to which seabed sediment is mobilised; and
- The assessment of the scales and magnitudes of processes controlling sediment transport rates and pathways.

1.3 Nationally and Internationally Designated Sites

1.3.1 The Physical Processes Study Area contains several nationally and internationally designated sites. With the exception of Benholm to Todhead Point Local Nature Conservation Site (LNCS), none of the designated sites identified in Figure 1.1 overlap with the Array Area or Export Cable Corridor. The sites are designated for the habitats they contain as well as (in some instances) for the presence of geological and geomorphological features. This is the case with the Milton Ness Site of Special Scientific Interest (SSSI), which is located approximately 6 km to the south of the Landfall and has been designated for its nationally important Devonian and Quaternary geology (NatureScot, 2025). This is also the case with the Firth of Forth Banks Complex Marine Protected Area (MPA) which is located approximately 7 km to the south of the Array Area and contains moraines considered to be representative of the Wee Bankie Key Geodiversity Area (Joint Nature Conservation Committee (JNCC), 2021). At all sites, changes to the physical characteristics of these sites have the potential to impact the habitats they support and, therefore, consideration is given to them in the physical processes assessment.

2 Physical Processes Study Area

2.1.1 The Physical Processes Study Area was set out in the Physical Processes Chapter of the Bowdun Offshore Wind Farm Scoping Report (BOWFL, 2024a) and in the Physical Processes method statement shared with Marine Directorate and NatureScot in June 2024 (BOWFL, 2024b). It has been defined to fully capture the Zone of Influence (ZoI) across which potential changes to physical processes arising from construction, operation and maintenance (O&M) and decommissioning of the Proposed Development may occur.

2.1.2 The Physical Processes Study Area is located off the east Aberdeenshire coast (Figure 1.1). It has been defined on the basis of:

- the distance away from the Proposed Development which suspended sediment plumes may be advected (and interact with potentially sensitive receptors). This has been defined by a spring tidal excursion ellipse buffer around the Array Area and Export Cable Corridor;
- the distance up/down drift from the Landfall, that littoral processes could theoretically be impacted by Offshore Infrastructure associated with the Proposed Development. This has been defined through consideration of coastal sub-cell information set out in Ramsay and Brampton (2000); and
- the distance from the Array Area that wave blockage impacts could theoretically be detected. This has been informed by expert judgement, drawing upon (amongst other things), the evidence base from other projects and consideration of the prevailing wave directions.

2.1.3 Direct changes to the seabed will be confined to the Array Area and Export Cable Corridor, with indirect changes (e.g. due to disruption of waves, tides or sediment pathways) experienced both inside and outside of the Site Boundary. These indirect changes are expected to diminish with distance from the Array Area and Export Cable Corridor.

3 Methodology

3.1.1 This technical report has used a combination of site-specific surveys undertaken for the Proposed Development and publicly available data to inform the assessment. These various data sources are outlined in Table 3.1 and Table 3.2, with locations of key data, as well as the spatial extent of bathymetry data used to inform the analysis, shown in Figure 3.1.

3.1 Desktop Study

3.1.1 Information on physical processes within the Physical Processes Study Area was collected through a detailed desktop review of existing studies; datasets used to inform the analysis are summarised in Table 3.1.

Table 3.1: Summary of Key Desktop Datasets and Reports for the Physical Processes Baseline

Title	Source	Extent	Year	Author
ABP Marine Environmental Research Limited (ABPmer) SEASTATES	ABPmer	Full coverage of the Physical Processes Study Area	2025	ABPmer
British Geological Survey (BGS) maps	BGS	Partial coverage of the Physical Processes Study Area	2025a	BGS
British Oceanographic Data Centre (BODC)	BODC	Partial coverage of the Physical Processes Study Area	2025	BODC
Centre for Environment, Fisheries and Aquaculture Science (Cefas) WaveNet data	Cefas	Partial coverage of the Physical Processes Study Area	2024	Cefas
Coastal Cells in Scotland: Cell 2 – Fife Ness to Cairnbulg Point	Ramsey and Brampton	Partial coverage of the Physical Processes Study Area	2000	Ramsey and Brampton
Copernicus	European Environment Agency	Full coverage of the Physical Processes Study Area	2025	European Environment Agency
Dynamic Coast (Phase 1 & 2)	Hansom *et al.* Rennie *et al.*	Partial coverage of the Physical Processes Study Area	2017, 2021	Hansom *et al.* Rennie *et al.*

Title	Source	Extent	Year	Author
European Marine Observation and Data Network (EMODnet) Data Layers	EMODnet	Full coverage of the Physical Processes Study Area	2025	EMODnet
(Key publications)	Public and grey literature considering coastal morphology and behaviour at sensitive coastal locations within the Physical Processes Study Area.	Partial coverage of the Physical Processes Study Area	n/a	n/a
Marine Directorate Data Portal	Marine Directorate	Partial coverage of the Physical Processes Study Area	2025	Marine Directorate
Marine Protected Area (MPA) Geodiversity Mapping	Brooks *et al.*	Partial coverage of the Physical Processes Study Area	2013	Brooks *et al.*
Marine Renewables Atlas	ABPmer	Full coverage of the Physical Processes Study Area	2008	ABPmer *et al.*
National Tide and Sea Level Facility (NTSLF)	NTSLF	Partial coverage of the Physical Processes Study Area	2025a	United Kingdom Hydrographic Office (UKHO)
Scottish Coastal Observatory (SCO)	SCO	Partial coverage of the Physical Processes Study Area	2025	SCO
Scottish Environment Protection Agency (SEPA)	SEPA	Partial coverage of the Physical Processes Study Area	2025	SEPA
Scottish Remote Sensing Portal	Scottish Government (SG) and JNCC	Partial coverage of the Physical Processes Study Area	2025	SG and JNCC
Strategic Environmental Assessment (SEA) Data Portal	SEA	Partial coverage of the Physical Processes Study Area	2025b	BGS

Title	Source	Extent	Year	Author
Suspended Particulate Matter mapping	Cefas	Full coverage of the Physical Processes Study Area	2016	Cefas
United Kingdom Climate Projections 2018 (UKCP18)	United Kingdom Climate Projections	Partial coverage of the Physical Processes Study Area	2018	Palmer *et al.*
United Kingdom Hydrographic Office (UKHO) Bathymetric Data	UKHO	Full coverage of the Physical Processes Study Area	2025b	UKHO

3.2 Site-Specific Surveys

3.2.1 A summary of the surveys undertaken to inform the physical processes baseline is outlined in Table 3.2 below.

Table 3.2: Summary of Site-Specific Surveys Undertaken for the Physical Processes Baseline

Title	Extent of Survey	Overview of Survey	Survey Contractor	Date	Reference to Further Information
Geophysical Survey Campaign	Across the Array Area and 1 km wide corridor within the Export Cable Corridor	High resolution side scan sonar (SSS), and multibeam bathymetry.	G-TEC	2023-2024	G-TEC, 2025a, 2025b
Intertidal Survey	Intertidal (from Mean High Water Spring (MHWS) to approximately Mean Low Water Spring (MLWS) at the Landfall)	Phase 1 walk-over survey	TetraTech RPS	2023	Thistle Wind Partners Limited (TWP) (2024)
Benthic Survey	Across the Array Area and Export Cable Corridor	Drop-Down Video (DDV) and grab samples, to determine biotopes and sediment contamination	Ocean Ecology Limited	2024	Ocean Ecology, 2024

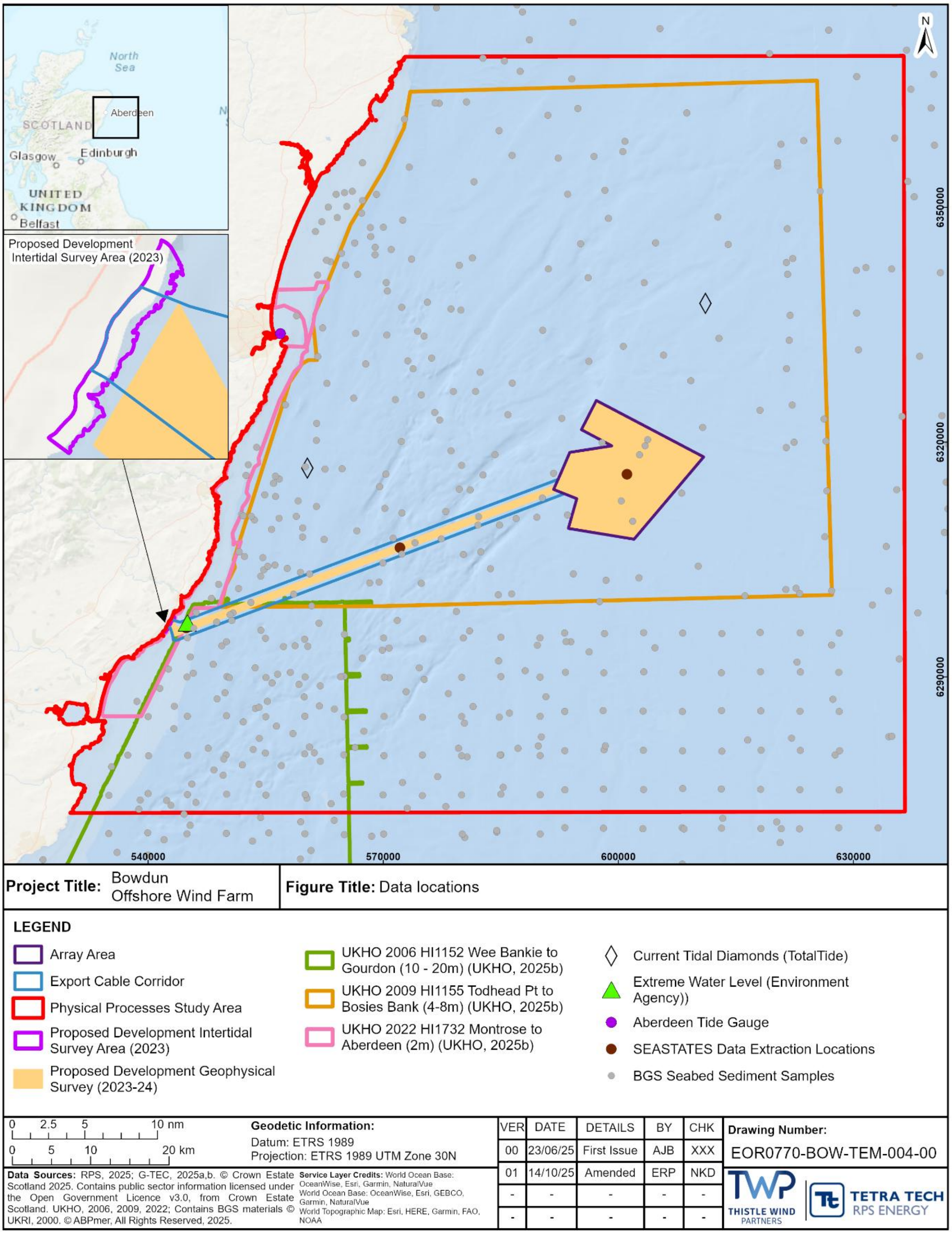


Figure 3.1: Data Locations

4 Metocean Regime

4.1 Water Levels

4.1.1 The Physical Processes Study Area is located within a semi-diurnal tidal environment with a tidal range increasing from north-east to south-west. Within the Array Area, the mean spring tidal range is typically between 2.7 m and 3.0 m, with a mean neap range of approximately 1.5 m (ABPmer *et al*., 2008).

4.1.2 Summary tidal statistics for Aberdeen (to the west of the Array Area and to the north of the Landfall) are shown in Table 4.1. Aberdeen is the closest tidal monitoring station to the Proposed Development.

Table 4.1: Summary Tidal Statistics for Aberdeen

Tidal Level	Aberdeen (m Chart Datum (CD))	Aberdeen (m Ordnance Datum Newlyn (ODN))
Highest Astronomical Tide	4.88	2.63
MHWS Tide	4.30	2.05
Mean High Water Neap Tide	3.40	1.15
Mean Tide Level	2.55	0.3
Mean Low Water Neap Tide	1.70	-0.55
MLWS Tide	0.80	-1.45
Lowest Astronomical Tide (LAT)	0.03	-2.22
Mean Spring Range	3.50	3.50
CD to ODN	**–2.25**	

Source: NTSLF, 2025; UKHO, 2025a

4.1.3 Extreme water levels within the Physical Processes Study Area typically result from storm surge propagation within the North Sea. The processes associated with storm surge propagation in the North Sea are generally well understood, having been extensively studied. In brief, a storm surge is produced when high winds drive an increase in water level, further exacerbated by the effects of low atmospheric pressure (Prichard, 2013). The 50-year return period surge level (tide + surge) at the Landfall is predicted to be 3.38 mODN (Environment Agency, 2019). The impact of a surge will depend critically on the associated state of the tide with the biggest risk of flooding and erosion occurring if the surge peak coincides with high water on a larger (e.g. spring) tide.

4.2 Currents

4.2.1 Maps of surface current speeds (and directions) at low water and high water on a representative mean spring tide are shown in Figure 4.1. Within the Physical Processes Study Area, tidal currents are generally of moderate strength, with mean spring peak current speeds typically less than approximately 0.7 m/s. The strongest currents are found just off Crawton (immediately to the north of the Landfall) and off Boddam (in the north of the Physical Processes Study Area).

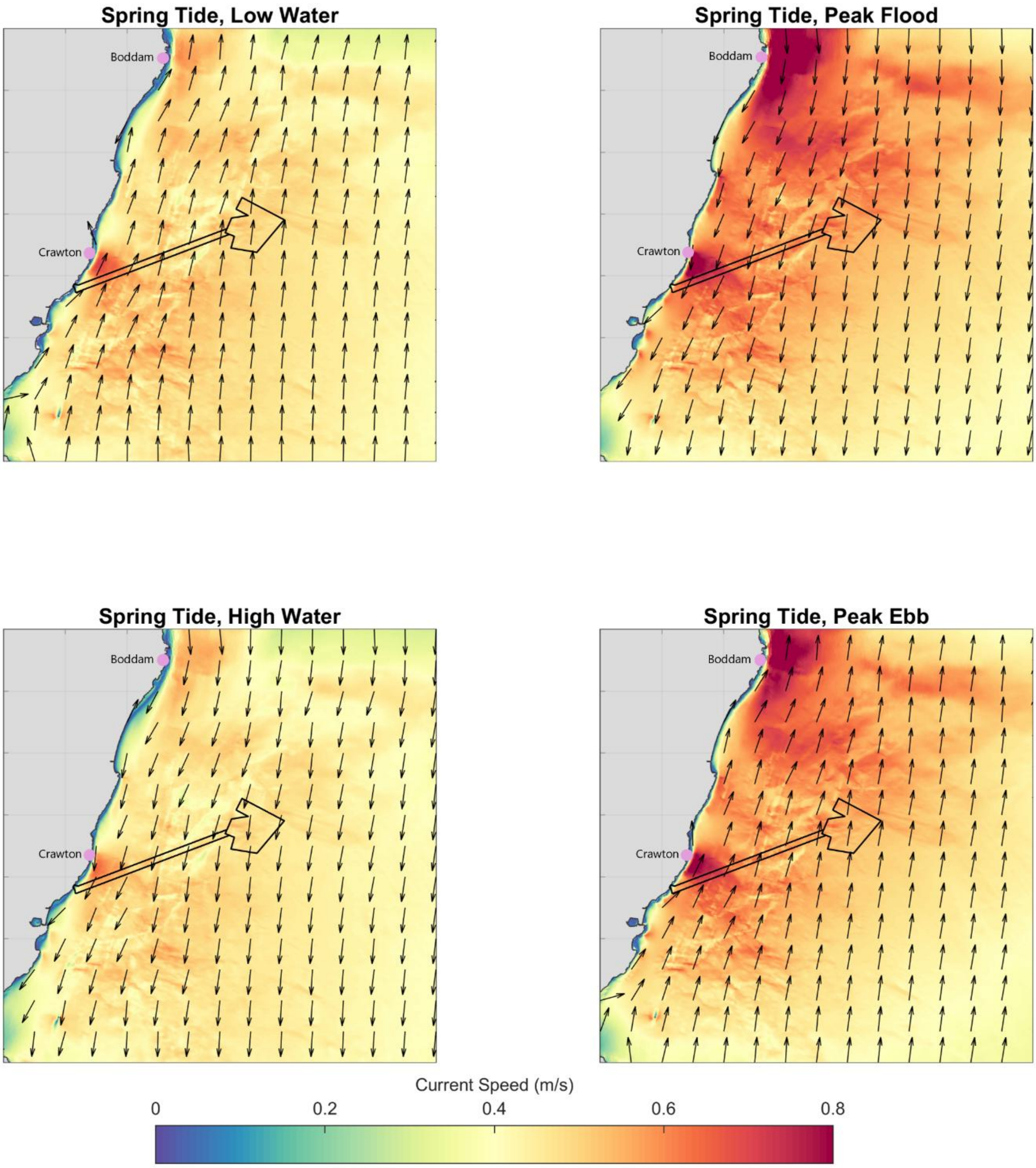


Figure 4.1: Baseline Tidal Current Speed and Direction During a Representative Spring Tidal Condition

4.2.2 Figure 4.2 shows modelled residual tidal flow across the Physical Processes Study Area. Finer sediment held in suspension for timescales longer than several tidal cycles (days to weeks) will generally and gradually be transported in the direction of residual current flow. This is, therefore, an important consideration for the assessment of sediment plumes associated with construction-related activities. On the basis of Figure 4.2, residual flow fields are found to be relatively weak and highly variable across the Physical Processes Study Area. This is also the case within the Array Area and along the Export Cable Corridor: the residual transport direction shows a high degree of local variability, with circulatory patterns of residual flow present.

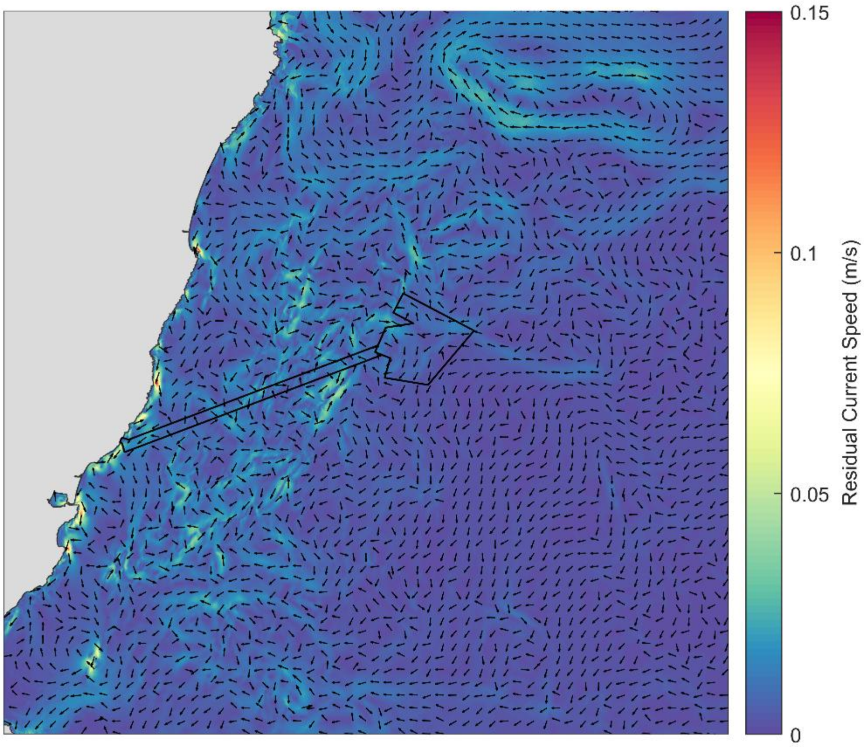


Figure 4.2: Baseline Residual Tidal Current Speed and Direction Measured Over a Representative Spring-Neap Period

4.2.3 Spring tidal excursion ellipses are shown in Figure 4.3. The ellipses illustrate the approximate displacement path of water during a representative tidal cycle and so illustrate the spatial variation in the orientation of the tidal axis, the degree of directional rotation and the magnitude of tidal current speed. In general, tidal flow is relatively rectilinear (with a clearly defined flood and ebb direction) across the Export Cable Corridor and Array Area, with spring tidal excursion distances typically between 9 km to 11 km and with a north-north-east to south-south-west axis.

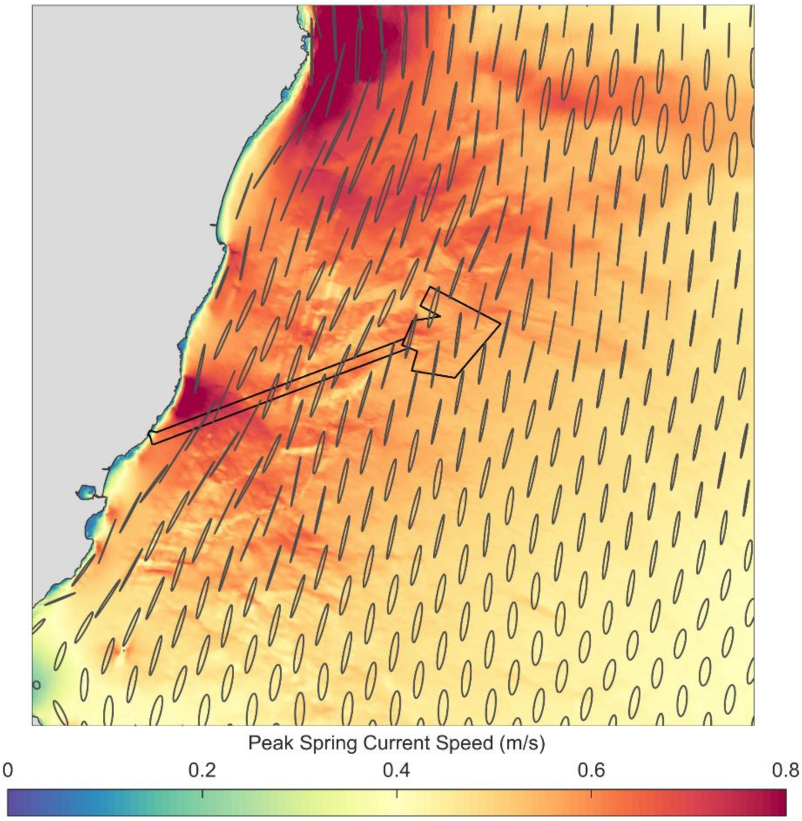


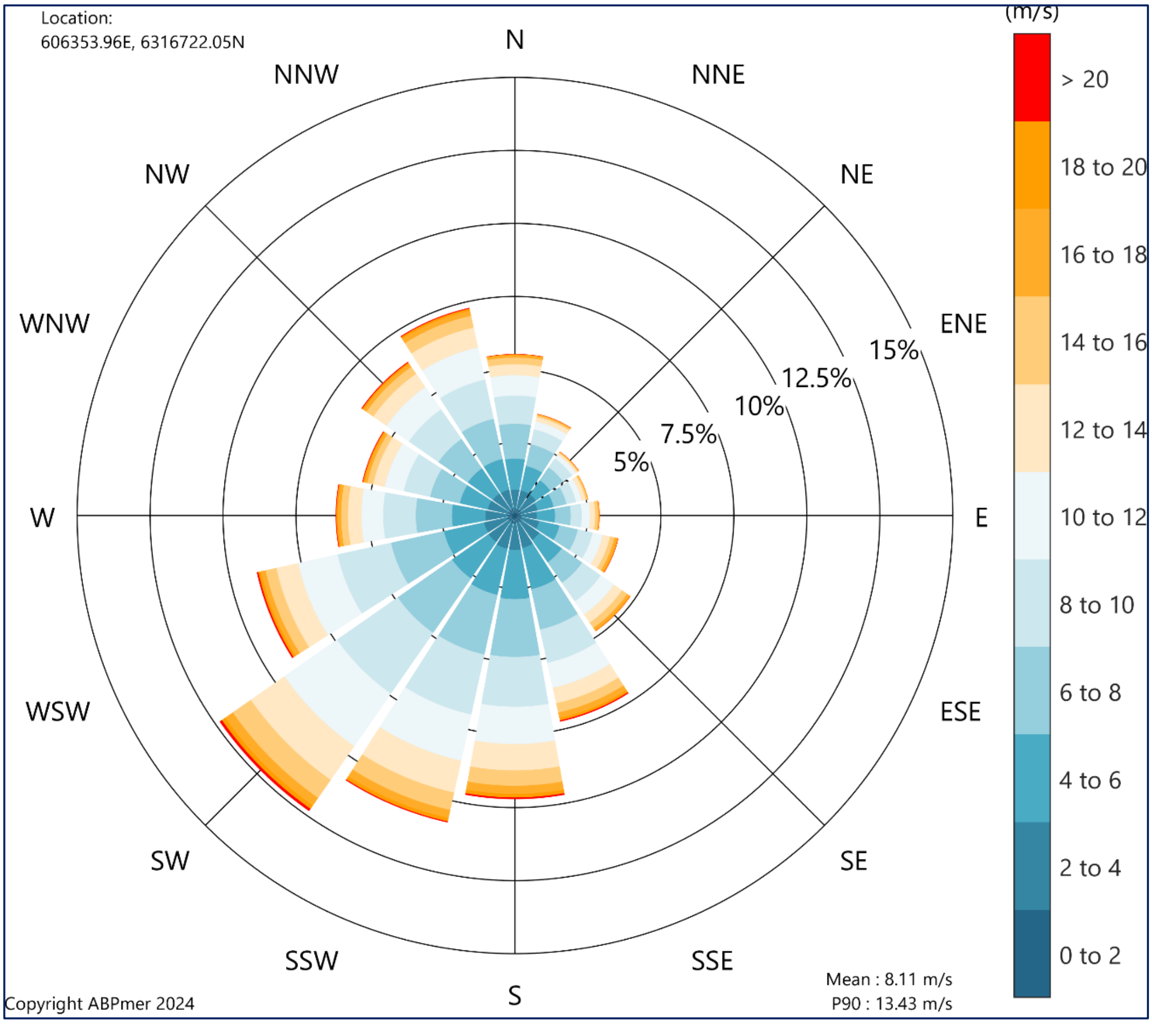
Figure 4.3: Baseline Peak Tidal Current Speed and Spring Tidal Excursion Ellipses

4.3 Winds

4.3.1 An understanding of the wind climate is relevant to physical processes in so far as it is a controlling parameter in the prevailing wave regime and non-tidal water levels and currents. The relationship between wave generation and meteorological forcing means that the wind and wave regimes are similarly episodic and exhibit both seasonal and inter-annual variation in proportion with the frequency and magnitude of changes in wind strength and direction.

4.3.2 A long-term hindcast record of wind data within the Physical Processes Study Area has been derived from ABPmer's SEASTATES models (ABPmer, 2025a). A frequency analysis of the data is presented as a wind rose in Figure 4.4, along with frequency scatter tables of wind speed against direction in Table 4.2, Table 4.3 and Table 4.4 (for the Landfall, the Export Cable Corridor and the Array Area, respectively). In these tables, values are colour coded from green (lowest) to red (highest). These show that:

- The dominant wind directions are from the south and south-west, with winds occurring from these directions for around 40% of the time;
- The strongest winds observed in the record most commonly occur from south-westerly directions; and
- The maximum observed wind speeds in the records are 32.30 m/s in the Array Area, 29.90 m/s along the Export Cable Corridor and 28.37 m/s at the Landfall.



Source: ABPmer SEASTATES

Figure 4.4: Rose Plot of Wind Speed and Direction for the Array Area, 1979 to 2022

Table 4.2: Frequency Scatter Tables of Wind Speed vs Wind Direction – Landfall

Bowdun Landfall - WndSpd WndDir Scatter Table - All Data - Percentage (occurences as proportion of all data)

Wind Speed (m/s)		Wind Direction (degN, Coming)										
Lower (>=)		337.5	22.5	67.5	112.5	157.5	202.5	247.5	292.5		Cum.	
	Upper (<)	22.5	67.5	112.5	157.5	202.5	247.5	292.5	337.5	Sum	Sum	Exced.
30	32										100.00	0.00
28	30	0.00								0.00	100.00	0.00
26	28	0.00					0.00			0.00	100.00	0.00
24	26	0.00					0.00	0.00	0.00	0.01	100.00	0.00
22	24	0.00	0.00				0.01	0.00	0.00	0.01	99.99	0.01
20	22	0.00	0.00	0.00	0.00	0.01	0.03	0.01	0.00	0.06	99.98	0.02
18	20	0.01	0.01	0.00	0.01	0.03	0.09	0.03	0.01	0.18	99.92	0.08
16	18	0.03	0.02	0.02	0.04	0.09	0.24	0.10	0.03	0.58	99.74	0.26
14	16	0.09	0.04	0.08	0.14	0.25	0.58	0.24	0.12	1.55	99.16	0.84
12	14	0.30	0.10	0.20	0.34	0.64	1.41	0.55	0.28	3.82	97.61	2.39
10	12	0.69	0.25	0.36	0.65	1.30	2.69	1.17	0.70	7.81	93.79	6.21
8	10	1.41	0.62	0.57	1.16	2.29	4.59	2.16	1.47	14.25	85.98	14.02
6	8	2.19	1.16	1.05	1.99	3.29	6.08	3.43	2.41	21.60	71.72	28.28
4	6	2.53	1.64	1.54	2.81	4.05	5.40	3.96	2.68	24.62	50.12	49.88
2	4	1.95	1.80	1.93	2.73	2.95	2.85	2.86	2.12	19.19	25.51	74.49
0	2	0.67	0.71	0.82	0.85	0.87	0.85	0.80	0.76	6.32	6.32	93.68
Sum		9.89	6.35	6.57	10.73	15.75	24.82	15.31	10.57	100.00		

Source: ABPmer SEASTATES, 2025a

Table 4.3: Frequency Scatter Tables of Wind Speed vs Wind Direction – Export Cable Corridor

Bowdun Export Cable Corridor - WndSpd WndDir Scatter Table - All Data - Percentage (occurences as proportion of all data)

Wind Speed (m/s)		Wind Direction (degN, Coming)										
Lower (>=)		337.5	22.5	67.5	112.5	157.5	202.5	247.5	292.5		Cum.	
	Upper (<)	22.5	67.5	112.5	157.5	202.5	247.5	292.5	337.5	Sum	Sum	Exced.
30	32										100.00	0.00
28	30	0.00					0.00			0.00	100.00	0.00
26	28	0.00					0.00			0.00	100.00	0.00
24	26	0.00					0.00	0.00	0.00	0.00	100.00	0.00
22	24	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02	99.99	0.01
20	22	0.00	0.00	0.00	0.00	0.02	0.03	0.01	0.00	0.07	99.97	0.03
18	20	0.01	0.00	0.01	0.02	0.05	0.06	0.02	0.02	0.19	99.91	0.09
16	18	0.04	0.01	0.02	0.06	0.19	0.20	0.06	0.06	0.65	99.71	0.29
14	16	0.12	0.03	0.07	0.19	0.48	0.51	0.15	0.17	1.72	99.06	0.94
12	14	0.35	0.07	0.18	0.36	0.97	1.21	0.37	0.44	3.95	97.35	2.65
10	12	0.75	0.19	0.35	0.69	1.87	2.44	0.81	1.05	8.14	93.40	6.60
8	10	1.51	0.44	0.59	1.20	3.06	4.25	1.61	1.94	14.59	85.25	14.75
6	8	2.38	0.96	0.89	1.87	4.17	5.70	2.72	3.03	21.73	70.66	29.34
4	6	2.78	1.42	1.35	2.41	4.57	5.18	3.27	3.06	24.03	48.93	51.07
2	4	2.02	1.63	1.59	2.32	3.08	3.01	2.68	2.22	18.56	24.90	75.10
0	2	0.69	0.71	0.77	0.84	0.83	0.86	0.86	0.78	6.34	6.34	93.66
Sum		10.66	5.45	5.82	9.97	19.28	23.46	12.57	12.78	100.00		

Source: ABPmer SEASTATES, 2025a

Table 4.4: Frequency Scatter Tables of Wind Speed vs Wind Direction – Array Area

Bowdun Array Area - WndSpd WndDir Scatter Table - All Data - Percentage (occurences as proportion of all data)													
			Wind Direction (degN, Coming)										
	Lower (>=)		337.5	22.5	67.5	112.5	157.5	202.5	247.5	292.5		Cum.	
		Upper (<)	22.5	67.5	112.5	157.5	202.5	247.5	292.5	337.5	Sum	Sum	Exced.
Wind Speed (m/s)	34	36										100.00	0.00
	32	34						0.00			0.00	100.00	0.00
	30	32	0.00					0.00			0.00	100.00	0.00
	28	30	0.00					0.00			0.00	100.00	0.00
	26	28	0.00				0.00	0.01	0.00	0.00	0.01	100.00	0.00
	24	26	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.03	99.99	0.01
	22	24	0.00	0.00	0.00	0.01	0.03	0.04	0.01	0.01	0.10	99.96	0.04
	20	22	0.02	0.01	0.01	0.02	0.08	0.09	0.04	0.05	0.32	99.86	0.14
	18	20	0.07	0.02	0.03	0.08	0.23	0.26	0.11	0.11	0.90	99.53	0.47
	16	18	0.19	0.04	0.10	0.22	0.55	0.57	0.23	0.27	2.16	98.63	1.37
	14	16	0.48	0.07	0.21	0.42	1.01	1.32	0.47	0.61	4.59	96.47	3.53
	12	14	0.79	0.19	0.39	0.70	1.72	2.46	0.97	1.12	8.33	91.89	8.11
	10	12	1.43	0.36	0.57	1.13	2.52	3.91	1.62	1.87	13.41	83.56	16.44
	8	10	1.92	0.74	0.80	1.52	3.37	4.74	2.34	2.45	17.89	70.15	29.85
	6	8	2.34	1.09	1.06	1.82	3.80	4.38	2.56	2.43	19.48	52.26	47.74
	4	6	2.07	1.26	1.27	1.95	3.30	3.05	2.32	2.06	17.29	32.78	67.22
	2	4	1.31	1.24	1.09	1.49	1.83	1.71	1.50	1.37	11.54	15.49	84.51
	0	2	0.46	0.48	0.46	0.51	0.53	0.52	0.52	0.47	3.95	3.95	96.05
	Sum		11.08	5.52	5.99	9.87	18.96	23.06	12.70	12.82	100.00		

Source: ABPmer SEASTATES, 2025a

4.4 Waves

4.4.1 The wave climate is the result of the transfer of wind energy to the sea, creating seastates and the propagation of that energy across the water surface by wave motion. The amount of wind energy transfer and wind-wave development is a function of the available fetch distance across which the wind blows, wind speed, wind duration and the original state of the sea. The longer the fetch distance, the greater the potential there is for the wind to interact with the water surface and generate waves. In shallower water, water depth is an additional limiting factor on the size of waves.

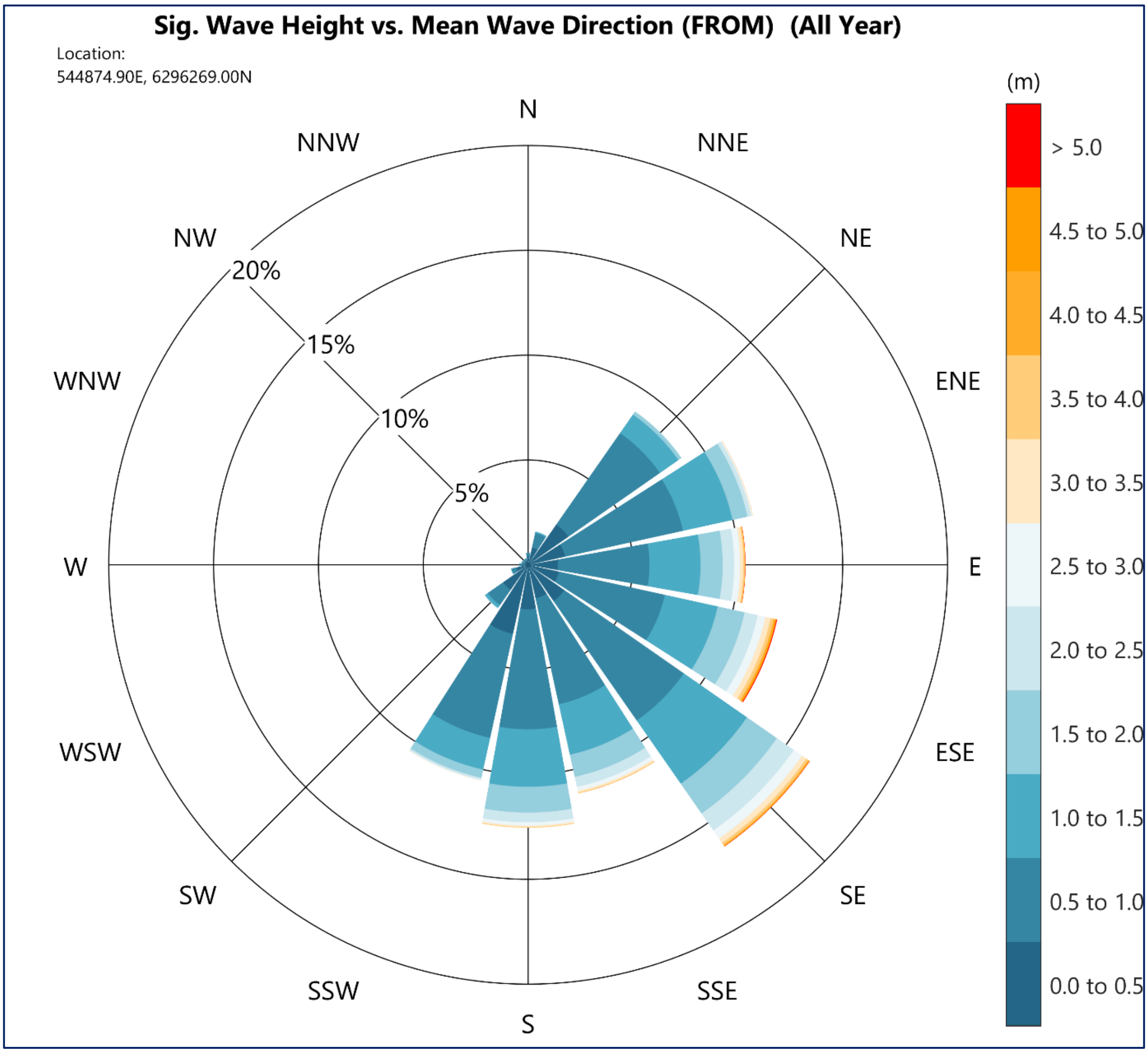
4.4.2 A long-term hindcast record of wave data within the Physical Processes Study Area has been derived from ABPmer's SEASTATES models (ABPmer, 2025a). The wave regime is dominated by locally generated wind waves across the wider North Sea region. The Array Area is exposed to longer wave fetches (distances of open water over which waves can develop) from the north to north-east. Smaller, but more frequently occurring, wave conditions generated by local winds predominantly come from southerly directions.

4.4.3 Further inshore, towards the Landfall, waves are progressively refracted to approach the adjacent coastline from a more easterly direction. Across the wider Physical Processes Study Area, the local orientation of the coastline relative to the predominant wave direction will influence local conditions of sheltering, resulting sediment transport rates and directions.

4.4.4 The wave regime has been summarised in a series of wave roses (Figure 4.5 to Figure 4.7), as well as frequency scatter tables of wave height, period and direction (Table 4.5 to Table 4.10). In these tables, values are colour coded from green (lowest) to red (highest).

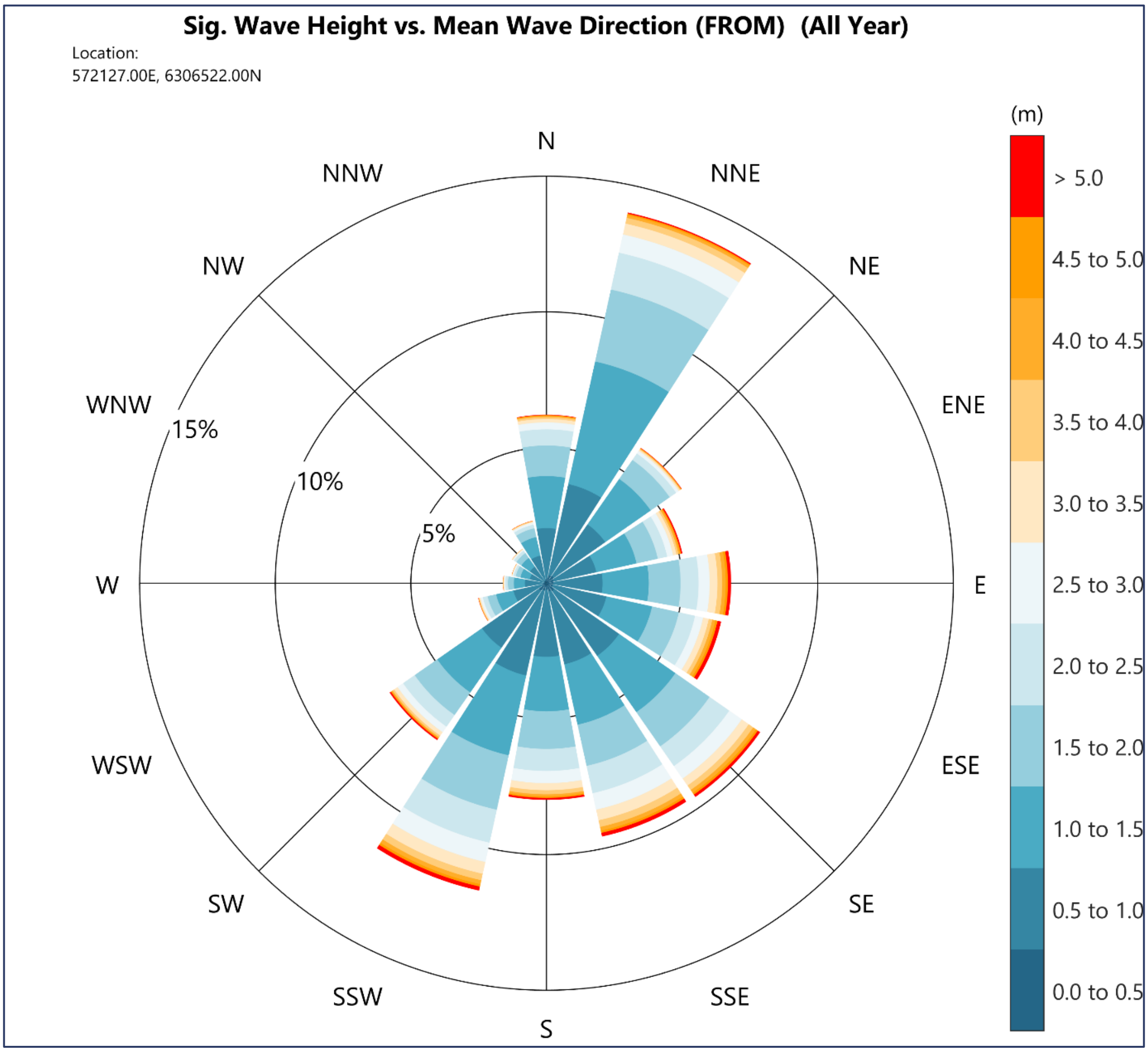
4.4.5 This analysis shows that:

- the most frequent wave direction at the Landfall is from the south-east, which accounts for approximately 30% of the record. The largest significant wave height observed in the record was 6.92 m;
- the most frequent wave direction along the Export Cable Corridor was also from the north north-east, accounting for 14% of the record. The largest significant wave height observed in the record at this location was 11.22 m;
- the most frequent wave direction at the Array Area is from the north (12% of the record). The next most frequent wave directions are from the north north-east and south-west, each accounting for 11% of the record. The largest significant wave height observed in the record in the Array Area was 12.72 m;
- 93% of the record at the Landfall comprises waves with a mean period ≤6 s. This decreases to 88% of the record at the Array Area; and
- longer period waves ($T_p \geq 8$ s) are observed, accounting for approximately 24% of the record of peak wave periods at the Landfall and increasing to around 34% in the Array Area (Table 4.5).



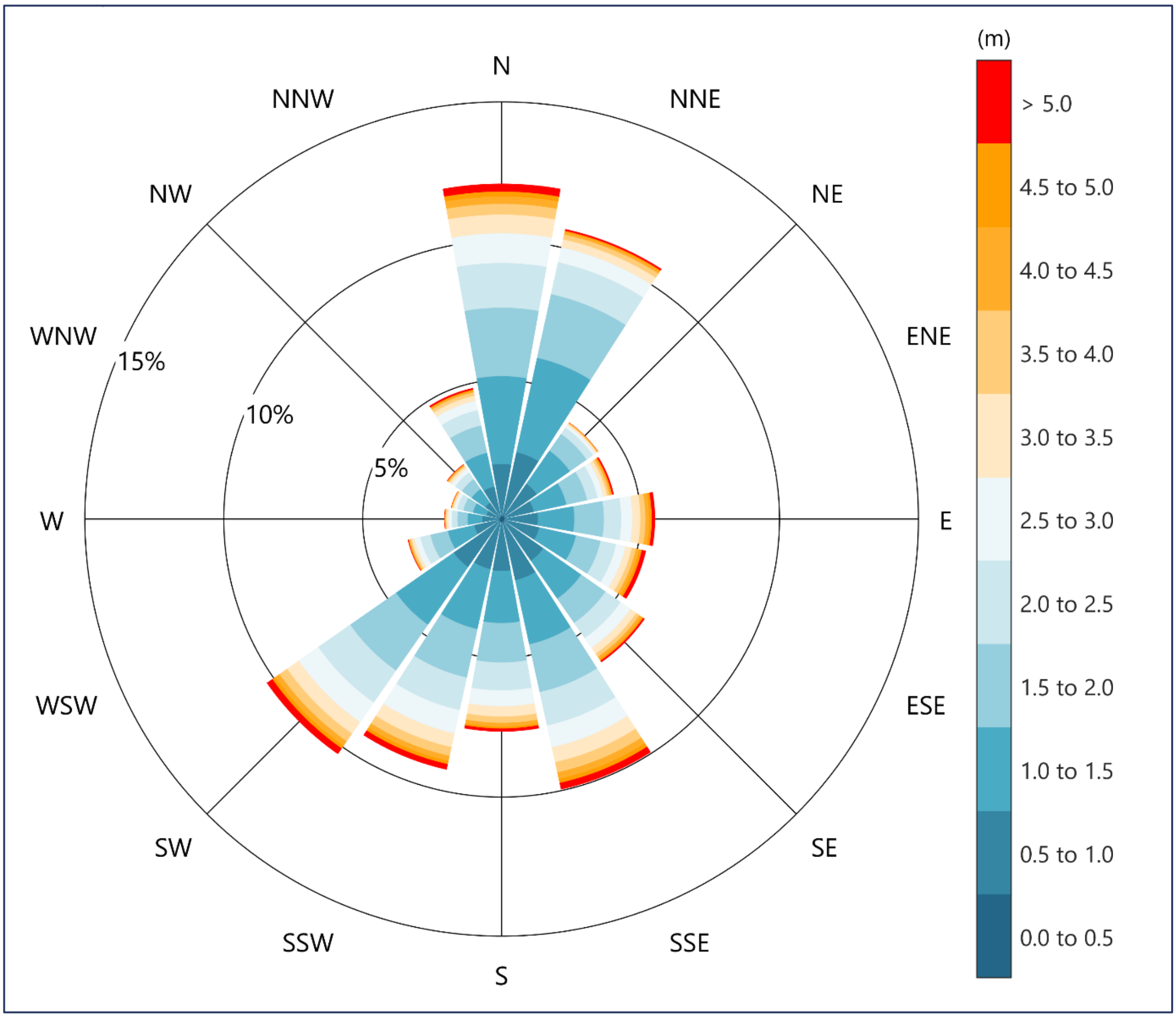
Source: ABPmer SEASTATES, 2025a

Figure 4.5: Rose Plot of Significant Wave Height and Direction Near the Landfall, Over the Period 1979 to 2023 (directions indicate ‘coming from’)



Source: ABPmer SEASTATES, 2025a

Figure 4.6: Rose Plot of Significant Wave Height and Direction at a Location Representative of the Export Cable Corridor (middle), Over the Period 1979 to 2023 (Directions Indicate 'Coming From')



Source: ABPmer SEASTATES, 2025a

Figure 4.7: Rose Plot of Significant Wave Height and Direction at a Location Representative of the Array Area, Over the Period 1979 to 2023 (Directions Indicate 'Coming From')

Table 4.5: Frequency Scatter Table of Significant Wave Height vs Peak Wave Period –Landfall

Bowdun Landfall - Hs Tp Scatter Table - All Data - Percentage (occurences as proportion of all data)																			
	Peak Wave Period, Tp (s)																		
Significant Wave Height, Hs (m)	Lower (>=)		0	2	4	6	8	10	12	14	16	18	20	22	24	26		Cum.	
		Upper (<)	2	4	6	8	10	12	14	16	18	20	22	24	26	28	Sum	Sum	Exced.
	7.0	7.5																100.00	0.00
	6.5	7.0						0.00									0.00	100.00	0.00
	6.0	6.5						0.01	0.00								0.01	100.00	0.00
	5.5	6.0					0.00	0.01	0.01								0.02	99.99	0.01
	5.0	5.5					0.00	0.03	0.01								0.04	99.97	0.03
	4.5	5.0					0.02	0.06	0.01								0.08	99.93	0.07
	4.0	4.5				0.00	0.07	0.10	0.00								0.17	99.85	0.15
	3.5	4.0				0.00	0.21	0.17	0.01								0.40	99.69	0.31
	3.0	3.5				0.05	0.55	0.20	0.02								0.82	99.29	0.71
	2.5	3.0			0.00	0.34	0.96	0.26	0.03	0.00	0.00						1.60	98.47	1.53
	2.0	2.5			0.03	1.45	1.49	0.37	0.06	0.02	0.00						3.42	96.87	3.13
	1.5	2.0		0.00	0.63	4.01	2.34	0.54	0.21	0.03	0.01	0.00					7.78	93.45	6.55
	1.0	1.5		0.05	5.52	8.67	3.10	1.02	0.66	0.19	0.04	0.01	0.00				19.26	85.67	14.33
	0.5	1.0	0.00	3.72	22.63	11.23	3.00	2.44	1.82	0.71	0.23	0.09	0.02	0.00			45.90	66.41	33.59
	0.0	0.5	0.13	8.47	7.06	2.09	0.43	0.85	0.72	0.51	0.21	0.04	0.00	0.00	0.00		20.51	20.51	79.49
	Sum		0.13	12.25	35.88	27.85	12.16	6.07	3.56	1.46	0.48	0.14	0.03	0.00	0.00		100.00		
	Cumulative Sum		0.13	12.37	48.25	76.10	88.26	94.33	97.89	99.35	99.83	99.97	100.00	100.00	100.00	100.00			
	Exceedence		99.87	87.63	51.75	23.90	11.74	5.67	2.11	0.65	0.17	0.03	0.00	0.00	0.00	0.00			

Source: ABPmer SEASTATES, 2025a

Table 4.6: Frequency Scatter Table of Significant Wave Height vs Mean Wave Direction – Landfall

Bowdun Landfall - Hs Mdir Scatter Table - All Data - Percentage (occurences as proportion of all data)												
Significant Wave Height, Hs (m)		Mean Wave Direction, Pdir (degN, Coming)										
Lower (>=)		337.5	22.5	67.5	112.5	157.5	202.5	247.5	292.5		Cum.	
	Upper (<)	22.5	67.5	112.5	157.5	202.5	247.5	292.5	337.5	Sum	Sum	Exced.
7.0	7.5										100.00	0.00
6.5	7.0				0.00					0.00	100.00	0.00
6.0	6.5			0.01	0.00					0.01	100.00	0.00
5.5	6.0			0.01	0.01					0.02	99.99	0.01
5.0	5.5			0.02	0.02	0.00				0.04	99.97	0.03
4.5	5.0		0.00	0.04	0.04	0.00				0.08	99.93	0.07
4.0	4.5		0.00	0.06	0.09	0.01				0.17	99.85	0.15
3.5	4.0			0.16	0.20	0.04				0.40	99.69	0.31
3.0	3.5		0.00	0.30	0.41	0.11				0.82	99.29	0.71
2.5	3.0		0.01	0.53	0.76	0.29	0.00			1.60	98.47	1.53
2.0	2.5	0.00	0.11	0.99	1.54	0.77	0.01	0.00		3.42	96.87	3.13
1.5	2.0	0.01	0.67	1.96	2.98	2.05	0.10	0.01	0.00	7.78	93.45	6.55
1.0	1.5	0.04	2.67	4.59	6.23	5.13	0.54	0.03	0.02	19.26	85.67	14.33
0.5	1.0	0.38	9.45	9.00	12.26	11.55	2.83	0.26	0.17	45.90	66.41	33.59
0.0	0.5	0.84	3.86	2.93	3.72	4.60	3.49	0.64	0.42	20.51	20.51	79.49
Sum		1.28	16.77	20.59	28.27	24.54	6.98	0.94	0.62	100.00		

Source: ABPmer SEASTATES, 2025a

Table 4.7: Frequency Scatter Table of Significant Wave Height vs Peak Wave Period – Export Cable Corridor

Bowdun Export Cable Corridor - Hs Tp Scatter Table - All Data - Percentage (occurences as proportion of all data)																
Significant Wave Height, Hs (m)		Peak Wave Period, Tp (s)														
Lower (>=)		0	2	4	6	8	10	12	14	16	18	20	22		Cum.	
	Upper (<)	2	4	6	8	10	12	14	16	18	20	22	24	Sum	Sum	Exced.
11.5	12.0														100.00	0.00
11.0	11.5							0.00						0.00	100.00	0.00
10.5	11.0							0.00						0.00	100.00	0.00
10.0	10.5						0.00							0.00	100.00	0.00
9.5	10.0						0.00							0.00	100.00	0.00
9.0	9.5						0.00	0.00						0.00	100.00	0.00
8.5	9.0					0.00	0.01	0.00						0.01	99.99	0.01
8.0	8.5					0.00	0.01	0.00						0.02	99.98	0.02
7.5	8.0					0.01	0.01	0.01						0.03	99.96	0.04
7.0	7.5					0.01	0.03	0.01						0.05	99.93	0.07
6.5	7.0				0.00	0.03	0.04	0.00						0.07	99.89	0.11
6.0	6.5				0.00	0.08	0.06	0.01						0.15	99.82	0.18
5.5	6.0				0.00	0.13	0.09	0.01						0.23	99.67	0.33
5.0	5.5				0.01	0.22	0.12	0.01	0.00					0.36	99.44	0.56
4.5	5.0				0.03	0.40	0.17	0.03	0.01					0.64	99.08	0.92
4.0	4.5			0.00	0.16	0.61	0.23	0.04	0.00					1.04	98.44	1.56
3.5	4.0			0.00	0.49	0.82	0.31	0.06	0.00					1.69	97.40	2.60
3.0	3.5			0.02	1.26	1.08	0.48	0.08	0.00	0.00	0.00			2.93	95.71	4.29
2.5	3.0			0.17	2.51	1.43	0.69	0.13	0.01	0.00	0.00			4.94	92.77	7.23
2.0	2.5		0.00	0.88	4.31	2.44	1.02	0.28	0.05	0.01	0.00	0.00		8.99	87.83	12.17
1.5	2.0		0.01	4.32	5.83	4.05	1.68	0.48	0.09	0.02	0.01			16.49	78.84	21.16
1.0	1.5		0.38	10.58	8.38	5.35	2.31	0.63	0.16	0.05	0.01	0.01		27.87	62.35	37.65
0.5	1.0	0.00	5.63	12.73	7.53	2.90	1.21	0.55	0.22	0.08	0.02	0.00		30.88	34.48	65.52
0.0	0.5	0.00	2.06	1.02	0.28	0.09	0.07	0.04	0.02	0.01	0.00			3.60	3.60	96.40
Sum		0.00	8.08	29.74	30.79	19.65	8.57	2.37	0.58	0.16	0.04	0.01		100.00		
Cumulative Sum		0.00	8.08	37.82	68.61	88.26	96.83	99.20	99.78	99.95	99.99	100.00	100.00			
Exceedence		100.00	91.92	62.18	31.39	11.74	3.17	0.80	0.22	0.05	0.01	0.00	0.00			

Source: ABPmer SEASTATES, 2025a

Table 4.8: Frequency Scatter Table of Significant Wave Height vs Mean Wave Direction – Export Cable Corridor

Bowdun Export Cable Corridor - Hs Mdir Scatter Table - All Data - Percentage (occurences as proportion of all data)												
		Mean Wave Direction, Pdir (degN, Coming)										
Significant Wave Height, Hs (m): Lower (>=)		337.5	22.5	67.5	112.5	157.5	202.5	247.5	292.5		Cum.	
	Upper (<)	22.5	67.5	112.5	157.5	202.5	247.5	292.5	337.5	Sum	Sum	Exced.
11.5	12.0										100.00	0.00
11.0	11.5	0.00	0.00							0.00	100.00	0.00
10.5	11.0	0.00	0.00							0.00	100.00	0.00
10.0	10.5				0.00					0.00	100.00	0.00
9.5	10.0				0.00	0.00				0.00	100.00	0.00
9.0	9.5	0.00	0.00	0.00	0.00	0.00	0.00			0.00	100.00	0.00
8.5	9.0	0.00	0.00	0.00	0.00	0.00	0.00			0.01	99.99	0.01
8.0	8.5	0.00	0.00	0.01	0.01	0.00	0.00			0.02	99.98	0.02
7.5	8.0		0.00	0.01	0.01	0.01	0.01			0.03	99.96	0.04
7.0	7.5	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.05	99.93	0.07
6.5	7.0	0.00	0.00	0.02	0.02	0.01	0.01	0.00	0.00	0.07	99.89	0.11
6.0	6.5	0.01	0.01	0.03	0.04	0.04	0.02	0.00	0.00	0.15	99.82	0.18
5.5	6.0	0.01	0.01	0.05	0.07	0.05	0.03	0.00	0.00	0.23	99.67	0.33
5.0	5.5	0.02	0.02	0.08	0.09	0.08	0.05	0.00	0.00	0.36	99.44	0.56
4.5	5.0	0.06	0.05	0.16	0.16	0.12	0.08	0.01	0.00	0.64	99.08	0.92
4.0	4.5	0.11	0.06	0.23	0.29	0.20	0.12	0.01	0.01	1.04	98.44	1.56
3.5	4.0	0.23	0.13	0.30	0.44	0.35	0.21	0.02	0.02	1.69	97.40	2.60
3.0	3.5	0.41	0.24	0.48	0.68	0.61	0.42	0.05	0.05	2.93	95.71	4.29
2.5	3.0	0.71	0.46	0.72	1.11	1.03	0.70	0.10	0.10	4.94	92.77	7.23
2.0	2.5	1.48	0.99	1.18	1.80	1.81	1.30	0.21	0.21	8.99	87.83	12.17
1.5	2.0	2.76	2.46	2.16	2.89	2.96	2.40	0.43	0.44	16.49	78.84	21.16
1.0	1.5	4.71	5.01	3.34	4.64	4.36	4.10	0.86	0.86	27.87	62.35	37.65
0.5	1.0	4.08	4.87	3.59	5.43	5.15	4.98	1.45	1.33	30.88	34.48	65.52
0.0	0.5	0.35	0.64	0.48	0.67	0.48	0.58	0.23	0.17	3.60	3.60	96.40
Sum		14.97	14.95	12.86	18.37	17.27	15.03	3.36	3.20	100.00		

Source: ABPmer SEASTATES, 2025a

Table 4.9: Frequency Scatter Table of Significant Wave Height vs Peak Wave Period – Array Area

Bowdun Array Area - Hs Tp Scatter Table - All Data - Percentage (occurences as proportion of all data)

Significant Wave Height, Hs (m) / Peak Wave Period, Tp (s)

Lower (>=)	Upper (<)	0–2	2–4	4–6	6–8	8–10	10–12	12–14	14–16	16–18	18–20	20–22	22–24	24–26	Sum	Cum. Sum	Exced.
13.0	13.5															100.00	0.00
12.5	13.0							0.00							0.00	100.00	0.00
12.0	12.5							0.00							0.00	100.00	0.00
11.5	12.0															100.00	0.00
11.0	11.5							0.00							0.00	100.00	0.00
10.5	11.0						0.00								0.00	100.00	0.00
10.0	10.5						0.01	0.00							0.00	100.00	0.00
9.5	10.0						0.01	0.00							0.01	99.99	0.01
9.0	9.5					0.00	0.01	0.00							0.01	99.98	0.02
8.5	9.0					0.00	0.02	0.00							0.03	99.97	0.03
8.0	8.5					0.01	0.02	0.01							0.03	99.95	0.05
7.5	8.0					0.01	0.03	0.01							0.05	99.91	0.09
7.0	7.5				0.00	0.03	0.05	0.01	0.00						0.09	99.86	0.14
6.5	7.0					0.07	0.07	0.01	0.00						0.15	99.77	0.23
6.0	6.5				0.00	0.13	0.12	0.01	0.01						0.26	99.62	0.38
5.5	6.0				0.00	0.24	0.16	0.02	0.00						0.41	99.35	0.65
5.0	5.5				0.01	0.39	0.23	0.02	0.00						0.65	98.94	1.06
4.5	5.0			0.00	0.05	0.69	0.27	0.04	0.00						1.05	98.28	1.72
4.0	4.5			0.00	0.29	1.06	0.31	0.05	0.00	0.00					1.72	97.23	2.77
3.5	4.0			0.00	0.96	1.27	0.39	0.08	0.01	0.00	0.00				2.71	95.51	4.49
3.0	3.5			0.01	2.16	1.50	0.53	0.12	0.03	0.01					4.35	92.80	7.20
2.5	3.0			0.12	4.06	1.95	0.76	0.26	0.06	0.01	0.00				7.22	88.45	11.55
2.0	2.5		0.00	1.22	6.07	2.75	1.19	0.46	0.08	0.02	0.00				11.78	81.22	18.78
1.5	2.0		0.01	5.93	6.21	4.20	2.06	0.55	0.11	0.03	0.01	0.00			19.10	69.44	30.56
1.0	1.5		0.18	11.12	7.52	4.74	2.09	0.57	0.14	0.04	0.02	0.01			26.42	50.34	49.66
0.5	1.0	0.00	3.81	9.86	5.12	2.16	0.88	0.23	0.16	0.06	0.01	0.00			22.29	23.92	76.08
0.0	0.5	0.00	0.83	0.57	0.11	0.05	0.03	0.02	0.01	0.00	0.00	0.00	0.00		1.62	1.62	98.38
Sum		0.00	4.82	28.84	32.56	21.25	9.21	2.47	0.62	0.17	0.04	0.02	0.00		100.00		
Cumulative Sum		0.00	4.82	33.66	66.22	87.47	96.68	99.15	99.77	99.94	99.98	100.00	100.00	100.00			
Exceedence		100.00	95.18	66.34	33.78	12.53	3.32	0.85	0.23	0.06	0.02	0.00	0.00	0.00			

Source: ABPmer SEASTATES, 2025a

Table 4.10: Frequency Scatter Table of Significant Wave Height vs Mean Wave Direction – Array Area

Bowdun Array Area - Hs Mdir Scatter Table - All Data - Percentage (occurences as proportion of all data)

Significant Wave Height, Hs (m)		Mean Wave Direction, Pdir (degN, Coming)										
Lower (>=)		337.5	22.5	67.5	112.5	157.5	202.5	247.5	292.5		Cum.	
	Upper (<)	22.5	67.5	112.5	157.5	202.5	247.5	292.5	337.5	Sum	Sum	Exced.
13.0	13.5										100.00	0.00
12.5	13.0	0.00								0.00	100.00	0.00
12.0	12.5	0.00								0.00	100.00	0.00
11.5	12.0										100.00	0.00
11.0	11.5	0.00								0.00	100.00	0.00
10.5	11.0						0.00			0.00	100.00	0.00
10.0	10.5	0.00			0.00		0.01			0.01	100.00	0.00
9.5	10.0	0.00			0.00	0.00	0.00			0.01	99.99	0.01
9.0	9.5	0.00	0.00	0.00		0.00	0.01		0.00	0.01	99.98	0.02
8.5	9.0	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.03	99.97	0.03
8.0	8.5	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.03	99.95	0.05
7.5	8.0	0.01	0.00	0.01	0.01	0.01	0.02	0.00	0.00	0.05	99.91	0.09
7.0	7.5	0.01	0.00	0.01	0.01	0.02	0.02	0.00	0.00	0.09	99.86	0.14
6.5	7.0	0.03	0.00	0.02	0.02	0.04	0.04	0.00	0.00	0.15	99.77	0.23
6.0	6.5	0.05	0.01	0.04	0.05	0.05	0.06	0.01	0.01	0.26	99.62	0.38
5.5	6.0	0.09	0.01	0.06	0.06	0.08	0.09	0.01	0.01	0.41	99.35	0.65
5.0	5.5	0.17	0.02	0.09	0.10	0.12	0.13	0.01	0.02	0.65	98.94	1.06
4.5	5.0	0.23	0.03	0.17	0.18	0.18	0.20	0.02	0.04	1.05	98.28	1.72
4.0	4.5	0.37	0.05	0.25	0.27	0.34	0.33	0.04	0.07	1.72	97.23	2.77
3.5	4.0	0.61	0.09	0.33	0.39	0.54	0.57	0.07	0.11	2.71	95.51	4.49
3.0	3.5	1.03	0.15	0.50	0.62	0.87	0.86	0.15	0.18	4.35	92.80	7.20
2.5	3.0	1.73	0.30	0.73	0.99	1.39	1.48	0.28	0.34	7.22	88.45	11.55
2.0	2.5	2.80	0.74	1.16	1.57	2.13	2.32	0.45	0.61	11.78	81.22	18.78
1.5	2.0	4.67	1.83	1.94	2.43	3.06	3.39	0.79	0.99	19.10	69.44	30.56
1.0	1.5	6.02	3.42	2.59	3.60	3.98	4.33	1.16	1.32	26.42	50.34	49.66
0.5	1.0	3.73	2.99	2.39	3.43	3.54	3.51	1.27	1.44	22.29	23.92	76.08
0.0	0.5	0.24	0.30	0.18	0.27	0.24	0.20	0.11	0.09	1.62	1.62	98.38
Sum		21.79	9.94	10.48	14.01	16.58	17.60	4.37	5.22	100.00		

Source: ABPmer SEASTATES, 2025a

4.4.6 Extremes analysis of the long-term wave hindcast record available from the ABPmer SEASTATES model is shown in Table 4.11. Larger waves are typically observed in the Array Area, with significant wave heights of approximately 8.4 m for a 1:1 year event, increasing to 12.2 m for a 1:50 year event. Equivalent extreme values for the Landfall are 4.8 m and 7 m, respectively.

Table 4.11: Extreme Value Analysis of Significant Wave Height and Wave Period

Location	Return Period (years)	Significant Wave Height (Hs) (m)	Mean Wave Period Tz (s)
Landfall	1	4.8	7.8
	5	5.8	8.7
	10	6.2	8.9
	25	6.7	9.2
	50	7	9.4
Export Cable Corridor	1	7.5	7.6
	5	9.1	8.4
	10	9.7	8.6
	25	10.4	8.9
	50	10.9	9.1
Array Area	1	8.4	7.9
	5	10.2	8.7
	10	10.9	8.9
	25	11.7	9.3
	50	12.2	9.5

4.5 Future Change

4.5.1 Information on the rate and magnitude of anticipated relative sea level change during the 21st Century is available from UKCP18 (Palmer *et al*., 2018). By 2065, relative sea level is predicted to have risen by approximately 0.35 m above present day (2025) levels (Representative Concentration Pathway (RCP) 8.5, 95th percentile) at the Landfall, with rates of change increasing over time.

4.5.2 Sea level rise may result in a loss of intertidal habitat through the process of 'coastal squeeze', caused by the presence of coastal defences preventing natural roll back, and future equilibrium position of coastal features (Environment Agency, 2021). A rise in sea level may also 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.

4.5.3 UKCP18 provides projections of changes to storm surge magnitude in the future as a result of climate change. These projections of change in extreme coastal water levels are dominated by the increases in mean sea level with only a minor (<10%) additional contribution due to atmospheric storminess changes over the 21st Century (Palmer *et al*., 2018).

5 Stratification and Frontal Systems

5.1 Overview

5.1.1 Stratification is a naturally occurring seasonal hydrodynamic process related to the vertical and horizontal distribution of seawater density, driven by temperature and/or salinity variations.

5.1.2 During summer, surface waters warm, creating a vertical temperature gradient (thermocline). The development of stratification is counterbalanced by turbulent mixing, which is generated at the seabed by tidal currents and at the surface by wind and wave action. The interplay between these forces determines whether stratification will persist or break down.

5.1.3 Density gradients (pycnoclines) present in stratified water columns act as a physical barrier to vertical mixing (Simpson and Sharples, 2012). This reduces the upward transport of nutrients from deeper waters, which can limit Primary Production (PP) in surface waters as nutrients become depleted over time (Simpson and Sharples, 2012).

5.1.4 Tidal mixing fronts form at the boundaries between well-mixed and stratified waters, creating regions of enhanced biological activity. These fronts, common in shelf seas like the North Sea (Hill *et al.*, 2005; 2008), facilitate nutrient exchange between surface and deeper layers, promoting PP through the stimulation of phytoplankton growth. Fronts act as biological hotspots, concentrating nutrients and attracting higher trophic levels. The strength and position of these fronts are influenced by factors such as tidal current speeds, freshwater inputs, and wind patterns, which can vary on timescales ranging from hours to years.

5.1.5 The North Sea is characterised by significant spatial and temporal variation in the vertical distribution of temperature and salinity. The Array Area is located in an area described by van Leeuwen *et al.* (2015) as being "intermittently stratified", defined as <40 days in the year where the water column is stratified and between 120 and 250 days in the year where the water column is fully mixed.

5.1.6 The baseline understanding of the existing temporal/spatial pattern of stratification and positioning of tidal mixing fronts has been developed using readily available three-dimensional numerical model outputs of temperature, salinity and chlorophyll-a from Copernicus Marine Service (Copernicus, 2025a:2025b). The data source, methodology and results of this baseline analysis are presented in more detail in Volume 3, Technical Appendix 7.4: Assessment of Potential Changes to Stratification and Frontal Systems. The key findings are summarised below, in Section 5.2 and Section 5.3.

5.2 Water Column Stratification

5.2.1 The Potential Energy Anomaly (PEA), ϕ, provides a single, scalar value for the strength of stratification in a water body (Simpson and Bowers, 1981; Gowen *et al*., 1995; Yamaguchi *et al.,* 2019 and Dorell *et al*., 2022). The threshold values of PEA can vary depending on the specific water body. Based on the density profiles and calculated PEA values for the Physical Processes Study Area and its surrounding regions, along with thresholds used in the literature (Gowen *et al.,* 1995; Dorrell *et al*., 2022), the following PEA classifications are applied in this study:

- mixed water column: $\phi < 25$ J/m³;
- weakly stratified water column: $25 \le \phi < 50$ J/m³;
- moderately stratified water column: $50 \le \phi < 100$ J/m³; and
- strongly stratified water column: $\phi > 100$ J/m³.

5.2.2 To assess seasonal and inter-annual variability in stratification strength, monthly mean PEA values were calculated across the Physical Processes Study Area, from January 2010 to December 2023. Figure 5.1, Figure 5.2 and Figure 5.3 illustrate the results for three specific years, 2023, 2012 and 2015, representing years with stronger stratification, intermediate stratification and weaker stratification, respectively. In the figure, seas are partitioned into those defined as mixed (ϕ <25 J/m³) and stratified ($\phi \geq 25$ J/m³).

5.2.3 During the winter months (October to April), reduced solar heating and increased turbulent mixing from wind and waves result in well-mixed waters in the Array Area, characterised by homogeneous temperature and density profiles, with PEA values around 10 J/m³ to 15 J/m³. With the onset of spring and summer, calmer weather and longer, warmer days enhance stratification. From May to September this leads to a vertical temperature gradient and an increase in PEA values. Over the 14-year analysis period (2010 to 2023), PEA typically reaches 40 J/m³ in mid-summer, indicating a weakly stratified water column, consistent with the findings of van Leeuwen *et al.* (2015).

5.2.4 There is variability in the strength of summer stratification from year to year, with mid-summer PEA values ranging from approximately 30 J/m³ (indicating weak stratification) in 2015 to around 60 J/m³ (indicating weak to moderate stratification) in 2023 (Figure 5.4).

5.2.5 To the east of the Array Area, increasing depths lead to stronger stratification with greater distance from the Array Area. Conversely, closer to the coastline, shallower depths and stronger tidal currents result in reduced stratification. Approximately 25 km west of the Array Area, the water column remains well-mixed throughout the year. Immediately west of the Array Area, a deeper region (>100 m) results in a more strongly stratified patch between the weakly stratified waters of the Array Area and well-mixed waters adjacent to the coastline.

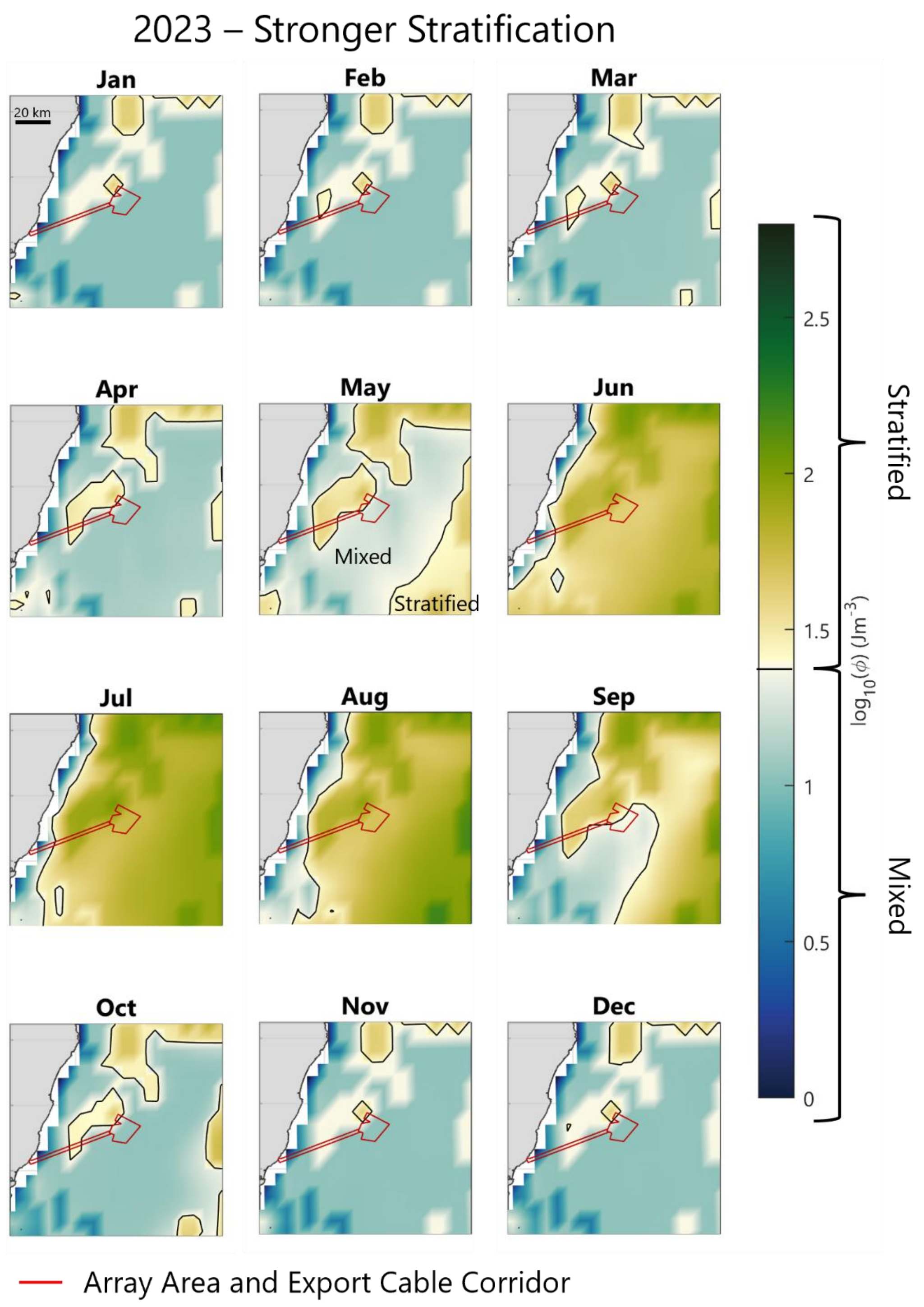


Figure 5.1: Calculated PEA (ϕ), Based on the Copernicus Reanalysis Monthly Temperature and Salinity Data for 2023, a Stronger Stratification Year

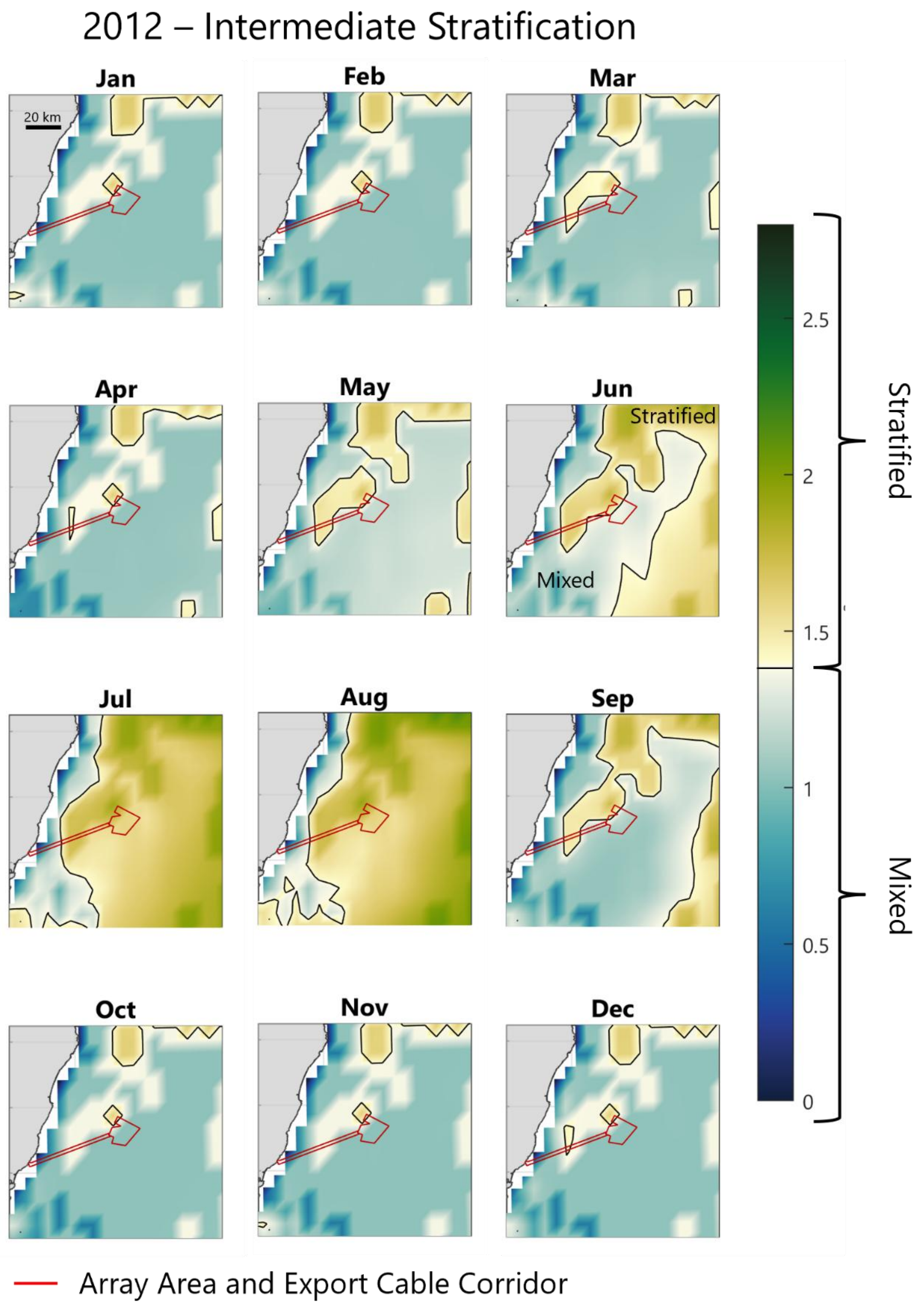


Figure 5.2: Calculated PEA (ϕ), Based on the Copernicus Reanalysis Monthly Temperature and Salinity Data for 2012, an Intermediate Stratification Year

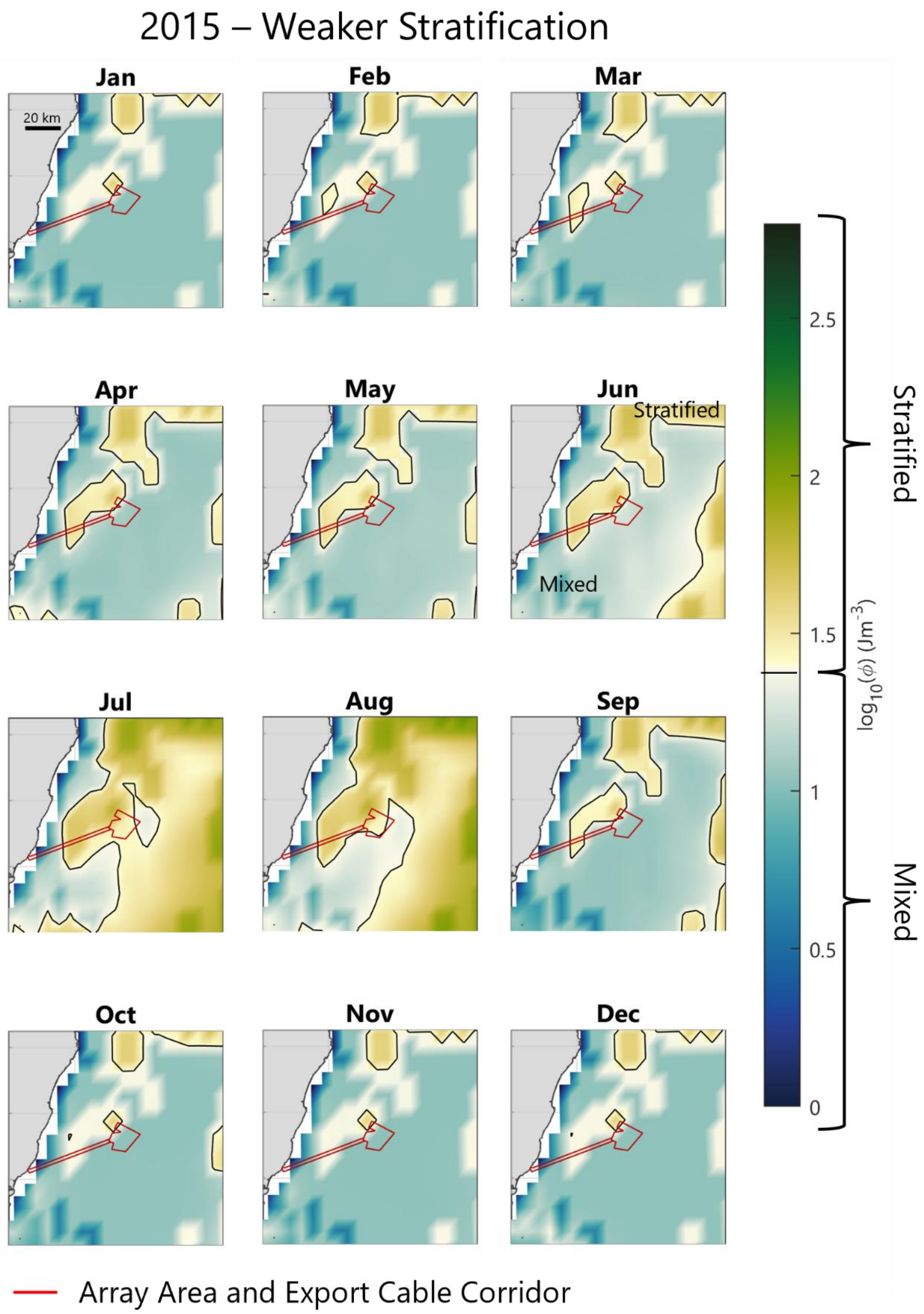


Figure 5.3: Calculated PEA (ϕ), Based on the Copernicus Reanalysis Monthly Temperature and Salinity Data for 2015, a Weaker Stratification Year

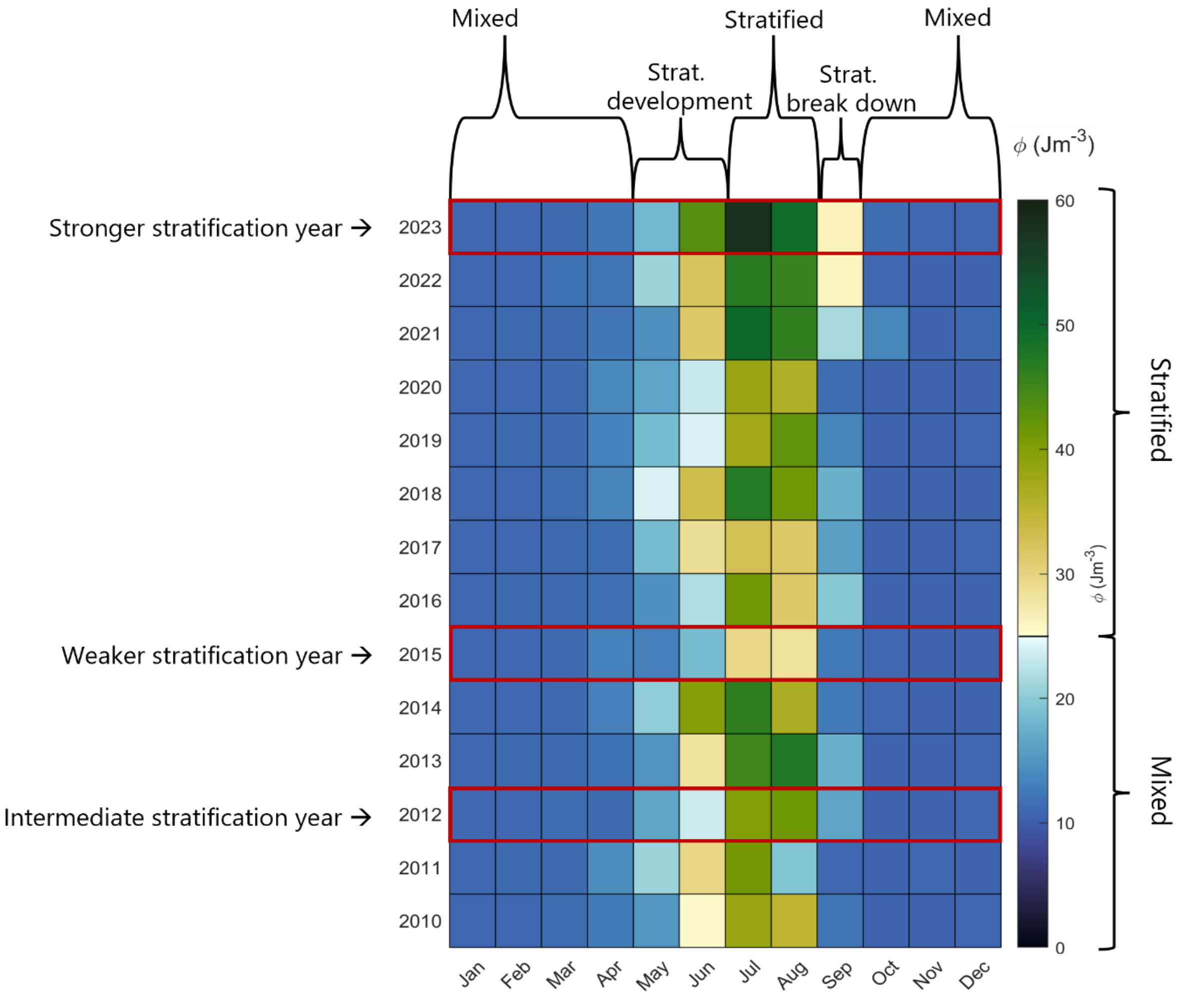


Figure 5.4: Monthly PEA (ϕ) Values, Based on the Copernicus Reanalysis Monthly Temperature and Salinity Data, in the Array Area from 2010 to 2023

5.3 Tidal Mixing Fronts

5.3.1 The physical mixing at fronts locally supplies a relatively higher concentration of nutrients into the sunlit surface layer, therefore creating more favourable conditions for phytoplankton growth by preventing nutrient depletion in the surface layers. As a result, these areas often support higher levels of PP (and chlorophyll-a) compared to both the mixed and stratified waters on either side of the front (Garcia-Nieto *et al.*, 2024). Figure 5.5, Figure 5.6 and Figure 5.7 illustrate the maximum chlorophyll-a concentrations throughout the water column for the years 2023 (stronger stratification year), 2012 (intermediate stratification year) and 2015 (weaker stratification year), capturing both deep chlorophyll maxima and surface peaks. During the summer months, elevated chlorophyll-a concentrations (likely linked to a tidal mixing front) are observed east of the Array Area. This is consistent across all years analysed (2010 to 2023) and suggests that higher PP is occurring at the boundary between the more strongly stratified waters located further offshore, as opposed to the weakly stratified waters in the Array Area. In the Array Area, stratification appears to be a more transient feature, leading to lower and less sustained phytoplankton growth compared to the stable stratification further offshore.

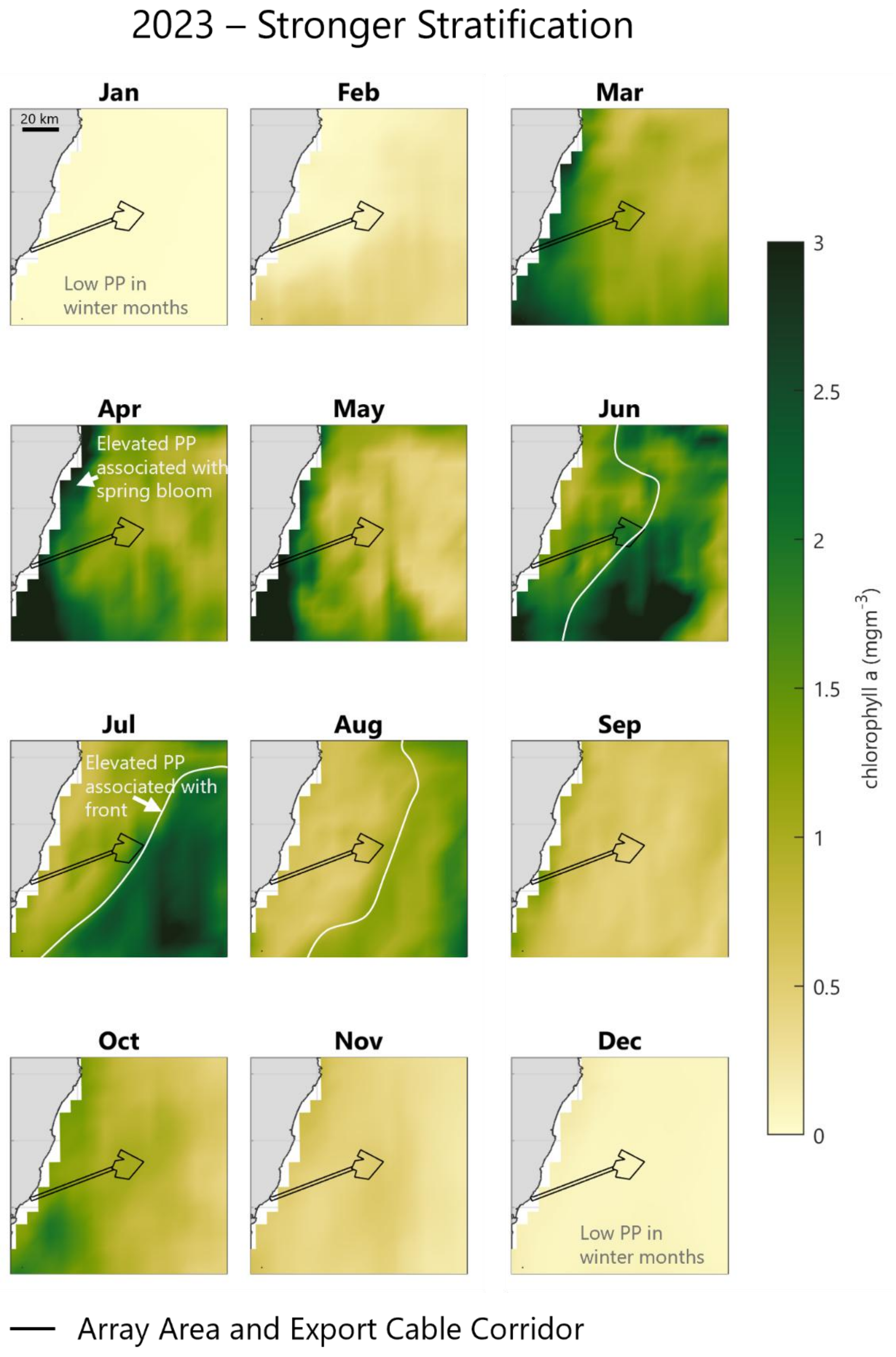


Figure 5.5: Copernicus Reanalysis Monthly Maximum Chlorophyll-a Concentration Throughout the Water Column for 2023 a Stronger Stratification Year

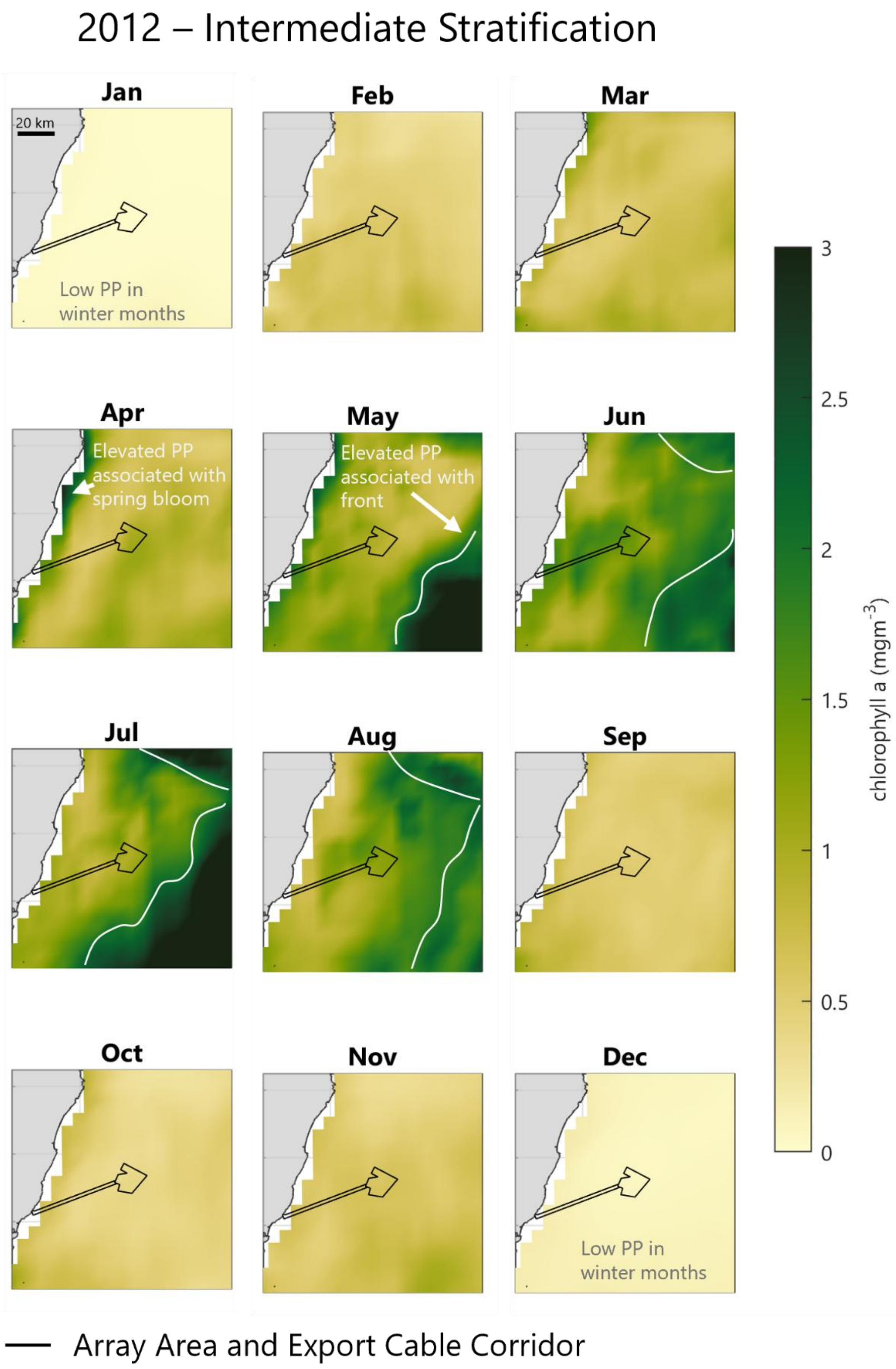


Figure 5.6: Copernicus Reanalysis Monthly Maximum Chlorophyll-a Concentration Throughout the Water Column for 2012 an Intermediate Stratification Year

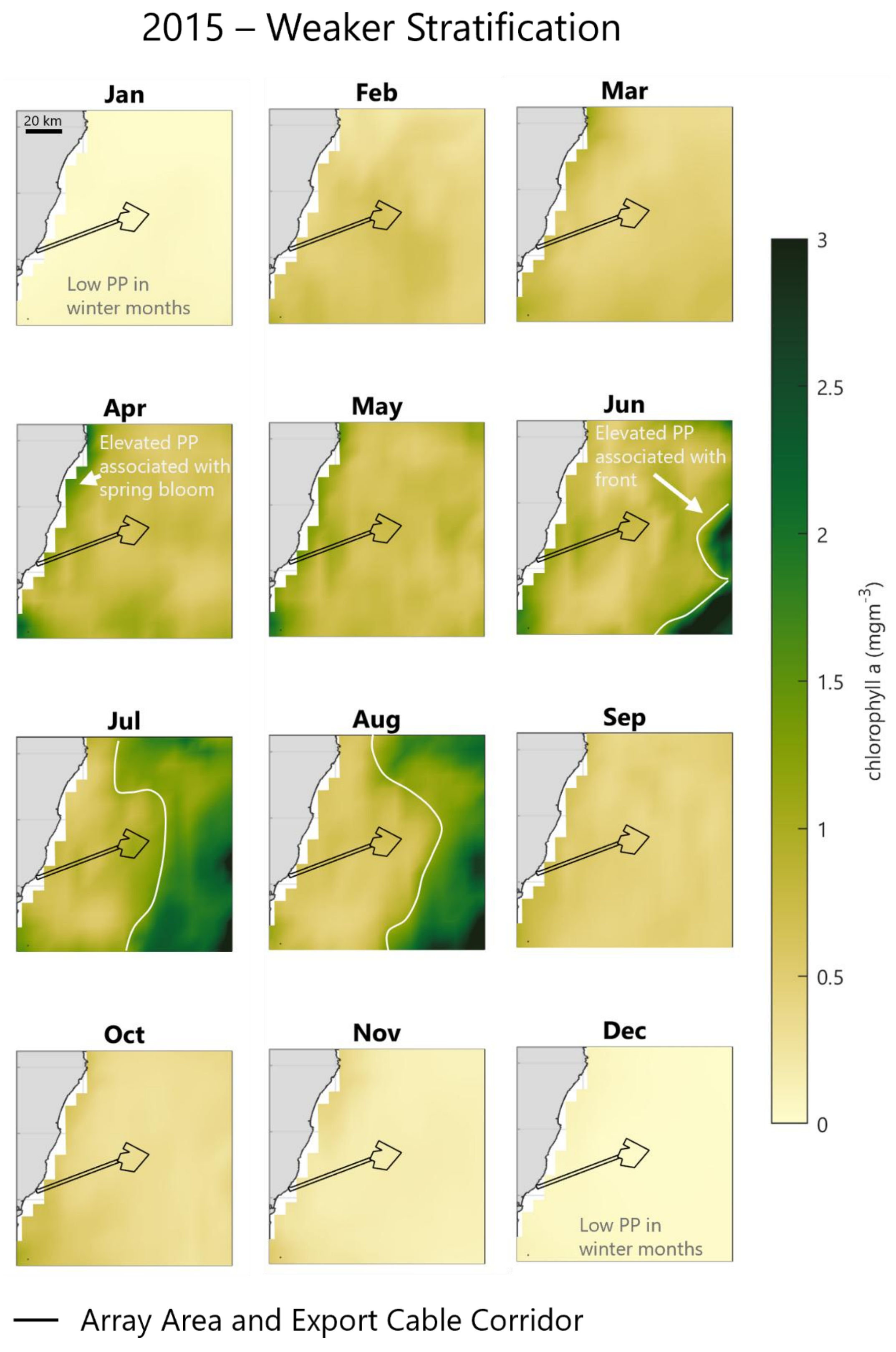


Figure 5.7: Copernicus Reanalysis Monthly Maximum Chlorophyll-a Concentration Throughout the Water Column for 2015 a Weaker Stratification Year

5.4 Future Change

5.4.1 The stratification dynamics in the North Sea are expected to undergo significant changes due to the changing climate. With the Proposed Development potentially beginning commercial operation in 2036, and a project lifetime of up to 30 years, it is important to consider how the timing and strength of stratification will evolve during this time.

5.4.2 The timing of stratification is influenced by the interplay between solar heating and tidal mixing, with a smaller but notable contribution from wind-driven mixing. Global warming and changes to meteorological conditions is likely to alter the timing of spring stratification, and subsequently the timing of the spring phytoplankton bloom.

5.4.3 Model projections suggest that by 2100, the thermal stratification period in UK shelf seas will extend by approximately two weeks (Sharples *et al.,* 2025), with stratification occurring about one week earlier and breaking down five to ten days later than present (Sharples *et al*., 2022). The dominant driver behind this shift is the increase in air temperature, which accelerates solar heating of the surface waters and thus strengthens thermal gradients. Historically, stratification timing in the north-western North Sea has advanced by about 0.5 days per year since the late 1980s, based on analyses from 1974 to 2003 (Sharples *et al*., 2006; Holt *et al*., 2012).

5.4.4 Model projections also suggest that seas across the north-west European shelf, including the northern North Sea, will experience greater surface-to-bottom temperature differences as the seasonal heating cycle intensifies (Tinker *et al*., 2016), resulting in stronger stratification. Alongside the strengthening stratification there will be small shifts in the position of tidal mixing fronts as thermal stratification pushes into shower waters and/or stronger tidal regions.

5.4.5 Strengthening stratification reduces vertical mixing, limiting the upward transport of nutrients from the deep layers to the surface, where they fuel PP. This could lead to a decline in overall PP, as suggested by Chust *et al*. (2014).

6 Surficial Sediments, Sediment Transport Regime and Morphology

6.1 Seabed Sediments

Overview

6.1.1 Seabed sediments across the Physical Processes Study Area are dominated by coarse-grained material, with sands and gravels encountered in most areas (Figure 6.1). Relatively extensive areas of muddy sand are also present in nearshore areas to the south of the Export Cable Corridor, whilst patches of gravelly mud are found such as that to the south of the Array Area and off the coast of Aberdeen. Close to the coast (including at the Landfall), exposed rock is encountered. Where present, the seabed sediments overlie extensive Quaternary sequences, deposited during glacial episodes over the past 2.6 million years.

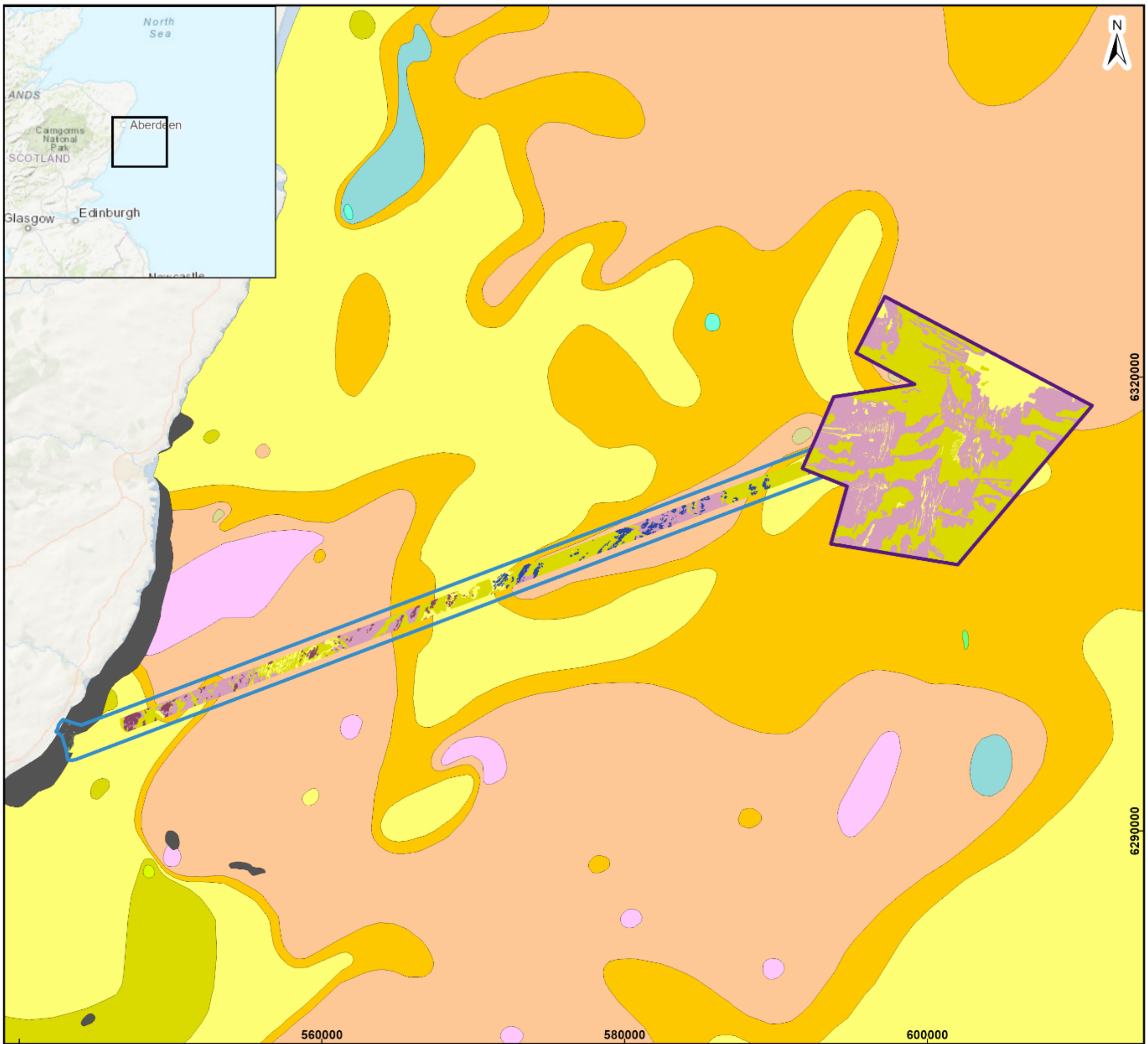
Array Area and Export Cable Corridor

6.1.2 Seabed sediment distributions within the Array Area and along the Export Cable Corridor have been classified by overlapping the Multibeam Echo Sounder (MBES) and SSS data collected during the Proposed Development geophysical survey (G-TEC, 2025a, 2025b).

6.1.3 Across the Array Area, surface sediments are dominated by a mix of sand and silty sand (Figure 6.1), which covers approximately 56% of the site. Silty sand accounts for a further 32%, while sand represents about 12%, occurring most prominently as a broad, continuous unit in the north-eastern sector, where the seabed is notably flat. Silty sand is widely distributed across the northern, central, and southern areas, often associated with megaripples, whereas the transitional mix of sand and silty sand is prevalent through the central and southern regions and corresponds to zones with linear furrows.

6.1.4 Boulder areas cover approximately 19% of the Array Area. Visual analysis of the SSS and MBES data confirms that the highest apparent concentrations occur in the northern and central parts, extending southwards toward the Array Area boundary. In these areas, boulders appear densely clustered. Additionally, isolated boulders are widespread outside mapped Boulder Areas, emphasising that boulder presence is not restricted only to the high-density polygons.

6.1.5 The Export Cable Corridor is predominantly underlain by sand and silty sand, with localised areas of glacial till, boulder fields, and patches of glacial outwash. Nearshore sections around the Landfall are characterised by exposed bedrock outcrops, interpreted to be of Silurian–Devonian in age. Further offshore, thin veneers of mobile sediment locally overlie glacial deposits, resulting in a varied but largely sandy seabed along the route (Figure 6.1).



Project Title:	Bowdun Offshore Wind Farm	**Figure Title:**	Seabed Sediments Within the Array Area, Export Cable Corridor and Across the Wider Physical Processes Study Area

LEGEND

- Array Area
- Export Cable Corridor

Seabed Sediments

- Mud
- sandy Mud
- (gravelly) sandy Mud
- muddy Sand
- Sand
- (gravelly) Sand
- gravelly Sand
- sandy Gravel
- gravelly Mud
- gravelly muddy Sand
- Rock & Boulders
- Mix of Sand and Silty Sand
- Glacial Outwash Sediment
- Glacial Till

0 2.5 5 nm
0 5 10 km

Geodetic Information:
Datum: ETRS 1989
Projection: ETRS 1989 UTM Zone 30N

VER	DATE	DETAILS	BY	CHK
00	20/06/25	First Issue	AJB	XXX
01	16/10/25	Amended	ERP	NKD
-	-	-	-	-
-	-	-	-	-

Drawing Number:
EOR0770-BOW-TEM-004-00

Data Sources: RPS, 2025. G-TEC, 2025a,b. Contains British Geological Survey materials © UKRI 2024. Contains public sector information licensed under the Open Government Licence v3.0. © ABPmer, All Rights Reserved, 2025.

Service Layer Credits: World Ocean Base: OceanWise, Esri, Garmin, NaturalVue
World Topographic Map: Esri, HERE, Garmin, FAO, NOAA, USGS

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Figure 6.1: Seabed Sediments Within the Array Area, Export Cable Corridor and Across the Wider Physical Processes Study Area

6.2 Geology and Sub-Strata

Overview

6.2.1 A regional overview of the geological setting and history has been provided within the Proposed Development geophysical survey reporting (G-TEC, 2025a; 2025b) and is summarised below.

6.2.2 The Array Area and Export Cable Corridor is located in the Southern Upland Fault Zone, which comprises several north-east to south-west trending faults associated with the evolution of the Midland Valley and Forth Approaches (during the Late Caledonian). The North Sea Basin formed in response to Late Jurassic–Early Cretaceous rifting followed by thermal cooling and subsidence, tectonic inversion, and basin margin uplift during the Cenozoic. Subsequently, much of the continental shelf was periodically covered by ice sheets and other smaller ice masses throughout the Quaternary Period (the last 2.59 million years), with the last ice sheet reaching its maximum extent between ~30 to 24 thousand years ago.

6.2.3 Throughout the Permian to early Cretaceous, the breaking up of the Pangaea supercontinent and the opening of the Atlantic caused crustal extension and thermal relaxation. This maximum extension was approximately parallel to the existing north–easterly tectonic patterns and resulted in the reactivation of many pre–existing Caledonian Faults creating a series of horst and graben structures forming the basins such as the Forth Approaches across the area. During the Triassic extensive halokinesis of the underlying Zechstein Salt within the Permian strata occurred which resulted in the development of major turtle back anticlines, rim synclines and faulting that affected the sedimentation and the structure of the overlying Triassic beds.

6.2.4 During the periods of maximum cold in the Quaternary, ice streams of hundreds of meters thick curved out from the Highlands to cross the plain of the current North Sea and flow towards ice limits close to the edge of the continental shelf. The impact of these ice-streams caused a significant glacial erosion, which smoothed and rounded hills and ridges and excavated the major firths and valleys. Under these ice sheets, deep and kilometre–wide channels known as the ‘tunnel valleys’, were cut by fast–flowing rivers that ran under these ancient ice sheets and rocks as they were being carried away by the ice carved large–scale lineations into the bedrock. During the intervening warm interglacial periods, the ice disappeared completely from the area.

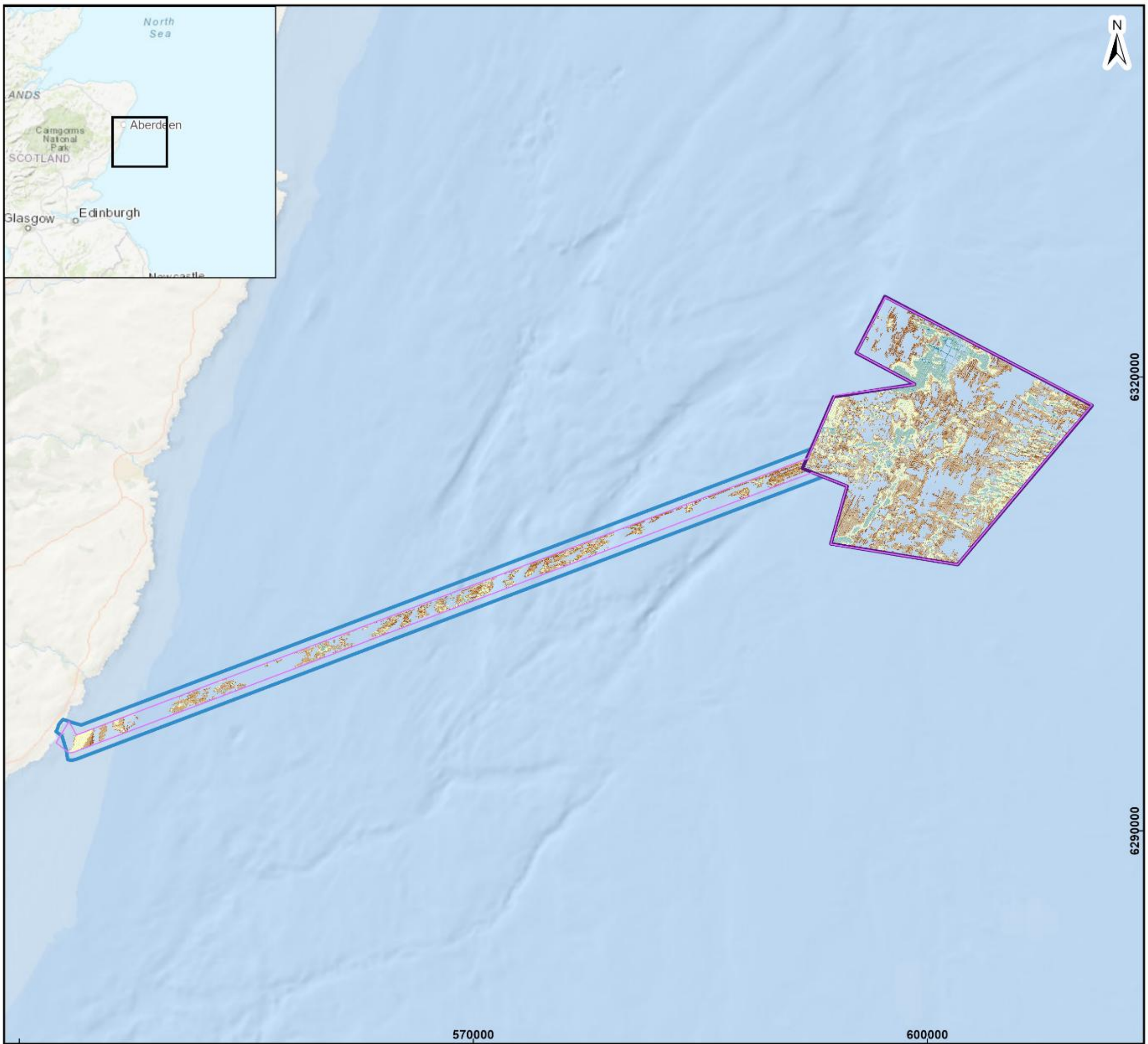
6.2.5 The last ice sheet reached its maximum extent ~30 to 24 thousand years ago, during or slightly after the global Last Glacial Maximum (LGM) (~22 to 27 thousand years ago). Within the North Sea Basin, the Fennoscandian) and British–Irish ice sheets coalesced on multiple occasions, with several scenarios presented for the maximum extent of the LGM. During this period two significant formations were deposited: the Wee Bankie Formation, which is a deposition created by ice in direct contact with the underlying ground, and the Marr Bank Formation, which was deposited in a glacio–marine environment, in fully or partially ice–covered water bodies. The two formations were deposited concurrently and as a result, there is significant mixing and deformation of these sediments due to retreats and advances of these ice sheets.

6.2.6 Following the end of the last glacial period around 11,500 years ago, a sudden shift to warmer climate conditions caused the sea levels to rise rapidly, transforming the area from low–lying terrestrial land and fluvial systems to its current state. As sea levels continued to rise, the area was progressively drowned and allowed for the estuarine and finally marine conditions to be established over the Physical Processes Study Area. During this period the St Abbs and Forth Formation deposits were laid down across the area. These marine processes continued to modify the seabed environment in the present (G-TEC, 2025a; 2025b).

Array Area and Export Cable Corridor

6.2.7 Interpreted seismic units identified across the Array Area and along the Export Cable Corridor are described in G-TEC (2025a; 2025b) and shown in Table 6.1 and Table 6.2. The Array Area is located within a complex geological setting with six stratigraphic units identified. Units U10 to U40 are understood to represent sediments from various glacial depositional environments from the Quaternary, including glacial, glaciomarine, and post–glacial marine settings. These units overlay the pre–Quaternary bedrock (U50) units which likely correlate with the Cretaceous (chalk, mudstone and claystone) and to a lesser extent, Triassic (red sandstone, siltstone, mudstone, and marl) bedrock (Table 6.1). Five stratigraphic units have been identified along the Export Cable Corridor, the majority of which are interpreted as being of Quaternary origin. These units locally outcrop at the seabed along the route and variously include sands, muds, gravels and boulders (Table 6.2).

6.2.8 Surficial sediments are found overlying the Quaternary units but are shown to be spatial variable in thickness (Figure 6.2). Within the Array Area, the surficial sediment unit has a thickness range of approximately 0 m to 11 m, although is more typically in the range 0 m to 2 m. Along the Export Cable Corridor, the unit is found to have a maximum thickness of approximately 9 m although is more typically around 1 m in thickness. In places (including in the westernmost part of the route at the Landfall), it is present only in small, localised pockets. Within the Array Area, Quaternary units are found within a depth range of 0 m to 75 m below the seabed.



Project Title: Bowdun Offshore Wind Farm

Figure Title: Surficial sediment thickness within the Array Area and Export Cable Corridor

LEGEND

- Array Area
- Export Cable Corridor
- Proposed Development Geophysical Survey Extent (2023-24)

Thickness of Surficial Sediment (m)

- 0 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- >5.0

0 2.5 5 nm
0 5 10 km

Geodetic Information:
Datum: ETRS 1989
Projection: ETRS 1989 UTM Zone 30N

Data Sources: RPS, 2025; G-TEC, 2025a,b. © ABPmer, All Rights Reserved, 2025.

Service Layer Credits: World Topographic Map: Esri, HERE, Garmin, FAO, NOAA, USGS
World Ocean Base: OceanWise, Esri, GEBCO, Garmin, NaturalVue

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Drawing Number:
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Figure 6.2: Surficial Sediment Thickness within the Array Area and Export Cable Corridor

Table 6.1: Interpreted Geological Units Mapped Within the Array Area (from G-TEC, 2025a)

Seismic Unit	Sub-Unit	Internal Character	Base Horizon			BGS Correlation		
			Name	Description	m below seabed	Lithological Unit	BGS Description	Age
U10	–	Chaotic to well–stratified.	H10	Mostly flat, erosional, continuous.	0-11	Surficial sediments	Unconsolidated reworked sediments	Holocene to present day
U20	–	Well-stratified restricted to incised valleys. Incision into Marr Bank Formation	H20	Erosional	0-34	Forth Formation	Interbedded sands and clays	Weichselian to Holocene
U30	–	Varied internal character. Sub–parallel and continuous reflectors to more chaotic and localised bright amplitudes. Often disturbed by incisions from the overlying unit and possible small internal erosional events. Displays possible clinoforms and glaciotectonic deformation.	H30	Mostly strong amplitude and planar across the site. Sometimes incised from younger channels.	10-43	Marr Bank Formation	Silty sand, clays, pebbles and boulders	Weichselian
U35	A	Often chaotic and varied amplitude response. Often incising lower U35B.	H35A	Sometimes erosional base but also more planer in places. Difficult to consistently identify.	18-53	Possible correlation: Coal Pit/Fisher/Ling/ Internal U40	Clays, muds gravels & pebbles	Weichselian to Holsteinian
	B	Often chaotic and varied amplitudes.	H35B	Erosional base, difficult to consistently identify.	21-65	Possible correlation: Ling Fm/ Internal U40	silts and stiff clays	Holsteinian to Saalian
U40	–	Varied internal character, sometimes displays similarities to the above sub–units. Usually transparent with discontinuous reflectors. Localised bright amplitude reflectors and incisional character.	H40	Erosional base with clear truncation. Sometimes difficult to identify due to similar amplitudes and dip of reflectors.	18-75	Aberdeen Ground Formation	Clays, sand & gravels, occasional cobbles & boulders	Early Pleistocene to Cromerian
U50	–	Parallel continuous reflectors, displaying deformation (Folding + minor Faulting).	–	Base not observed	-	Bedrock	Mudstones, claystones, sandstones, siltstones & marls	Pre-Quaternary

Table 6.2: Interpreted Geological Units Mapped Within the Export Cable Corridor (from G-TEC, 2025b)

Seismic Unit	Sub-Unit	Distribution	Internal Character	Base Horizon			BGS Correlation		
				Name	**Description**	**m BSF**	**Lithological Unit**	**BGS Description**	**Age**
U10	-	Unevenly distributed	Continuous, sub-parallel reflectors in nearshore. Chaotic to transparent offshore.	H10	Mostly flat, erosional, continuous.	0-9	Surficial sediments.	Medium to fine sand, small amounts of gravel.	Holocene - present day.
U20	A	KP 1.5 to 8	Alternating bright/low amplitudes, sub-parallel and continuous reflectors. Areas of transparent zones.	H20A	Strong continuous and bright amplitude reflector.	0-6	Forth Formation (St-Andrews Bay Member).	Soft mud.	Holocene - Pleistocene.
	B	KP 40 to 42	Chaotic, bright amplitudes.	H20B	Erosional Base.	0-9	Forth Formation (Undivided).	Sand & gravel.	
U30	-	KP 40 to 53	Varied internal character. Chaotic, poorly organised reflectors with areas of transparency.	H30	Bright, strong amplitude reflector. Mostly continuous.	0-18	Marr Bank Formation.	Sand, gravelly till with boulders.	Pleistocene.
U35	A	KP 40 to 42	Transparent and lacking internal structure.	H35A	Faint, deep reflector.	0-15	Possible internal Aberdeen Ground Formation.	Clay, fine to coarse sand, pebbles, boulders.	Holsteinian to Saalian

6.3 Suspended Sediments

6.3.1 Monthly-averaged satellite imagery of Suspended Particulate Matter (SPM) suggests that, within the Array Area, average (surface) SPM is generally very low, between approximately 0.5 mg/l to 2.0 mg/l (Cefas, 2016). During the summer months, values within the Array Area peak around 1 mg/l, increasing slightly in the winter months to ~2 mg/l. Still small, but relatively higher values, are anticipated during larger spring tides and storm conditions. Higher suspended sediment concentrations are also likely to be observed at any given time closer to the seabed.

6.3.2 SPM values along the Export Cable Corridor are also generally very low but increase slightly from the Array Area towards the Landfall. In the winter months, SPM values range from 2 mg/l to 10 mg/l, decreasing to around 1 mg/l to 4 mg/l in summer months.

6.4 Sediment Transport

Overview

6.4.1 Across nearshore areas within the Physical Processes Study Area, net sediment transport is understood to be dominated by tidally driven processes, with transport broadly in a northerly direction in most areas (ABPmer, 2025b). Further offshore (including areas immediately to the east of the Array Area), net rates of tidally driven sediment transport become negligible, with mobilisation of material at the bed only occurring on shoals during large storm events (Kenyon and Cooper, 2005).

6.4.2 Sediment transport at the coast is described within the context of coastal cells and sub-cells in Ramsay and Brampton (2000). The Physical Processes Study Area is within Cell 2 (Fife Ness to Cairnbulg Point). The volume of beach material in many areas is very limited meaning net littoral drift is often negligible. Even where sand is present, such as Lunan Bay (to the south of Montrose) and to the north of Aberdeen, rates of net littoral drift are often low, reflecting a balance between wave and tidally driven processes and/or coastal aspect relative to the prevailing waves (Barne *et al*., 1997a; 1997b).

Array Area and Export Cable Corridor

6.4.3 An analysis of potential sediment mobility within the Array Area and Export Cable Corridor in response to tidal currents is presented in Figure 6.3. This is based on a spring-neap cycle (approximately 16 days) of current data extracted from the hydrodynamic model developed to inform the assessment (Volume 3, Technical Appendix 7.3 Physical Processes Technical Assessment). Key findings are summarised below and in Figure 6.4:

- Across the Array Area, mean spring peak current speeds are typically less than approximately 0.6 m/s. This means that sand-sized material is only mobilised by tidal currents for relatively limited periods of time and therefore residual rates of sand transport are also generally low. Notwithstanding this, where sand is present net bedload transport is expected to be in a southerly direction.

- Residual sediment transport rates are generally higher along the Export Cable Corridor in comparison to the Array Area. The highest rates within the Export Cable Corridor are typically found within approximately 15 km of the coast off Peterhead, coinciding with the higher current speeds in this area (Figure 4.1).
- Residual patterns of sand transport are highly complex and variable along the Export Cable Corridor. This complexity probably reflects the fact that the ebb and flood tide in this area is broadly symmetrical, with very minor changes in either, resulting in a reversal of the net sediment transport direction.
- The finding that residual transport within the Array Area is weak is consistent with the morphological evidence of sediment transport. Very little migration of sandwaves is observed over the period 2009 to 2023-2024 although it is recognised that the relatively low resolution of the older (2009) UKHO survey data (UKHO, 2025b) inhibits robust determination of the rate and direction of movement. The morphological/bathymetric comparison evidence tentatively suggests that migration of sandwaves along the Export Cable Corridor is generally to the south over the period 2009 to 2023-2024 although confidence in this finding is low.

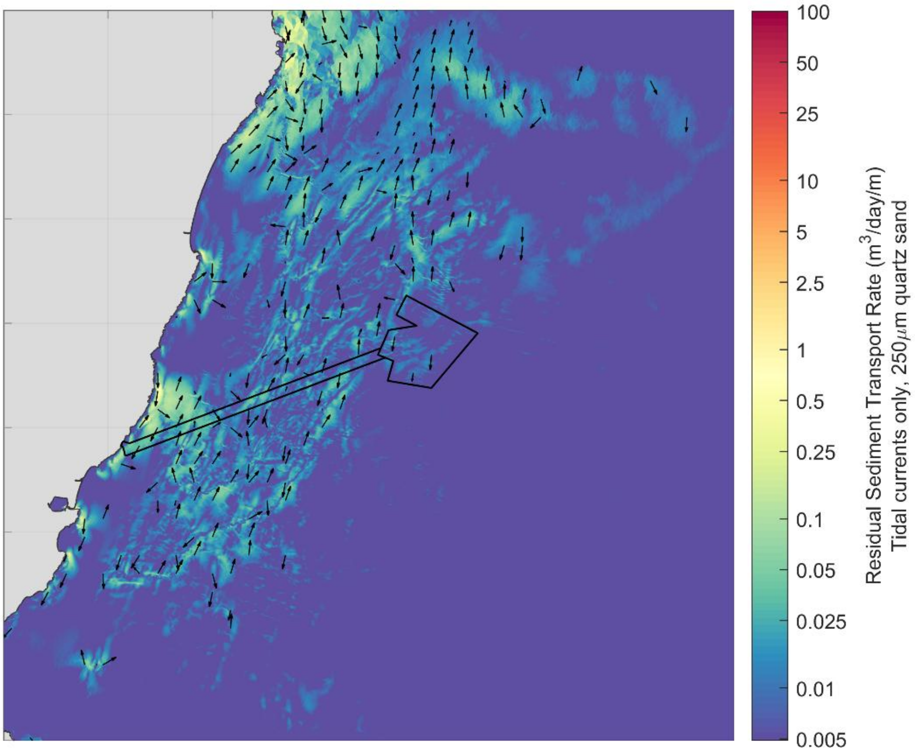


Figure 6.3: Baseline Residual Sediment Transport Rate and Direction, for 250 μm Quartz Sand, Predicted Over a Representative Spring-Neap Tidal Period, Regional View

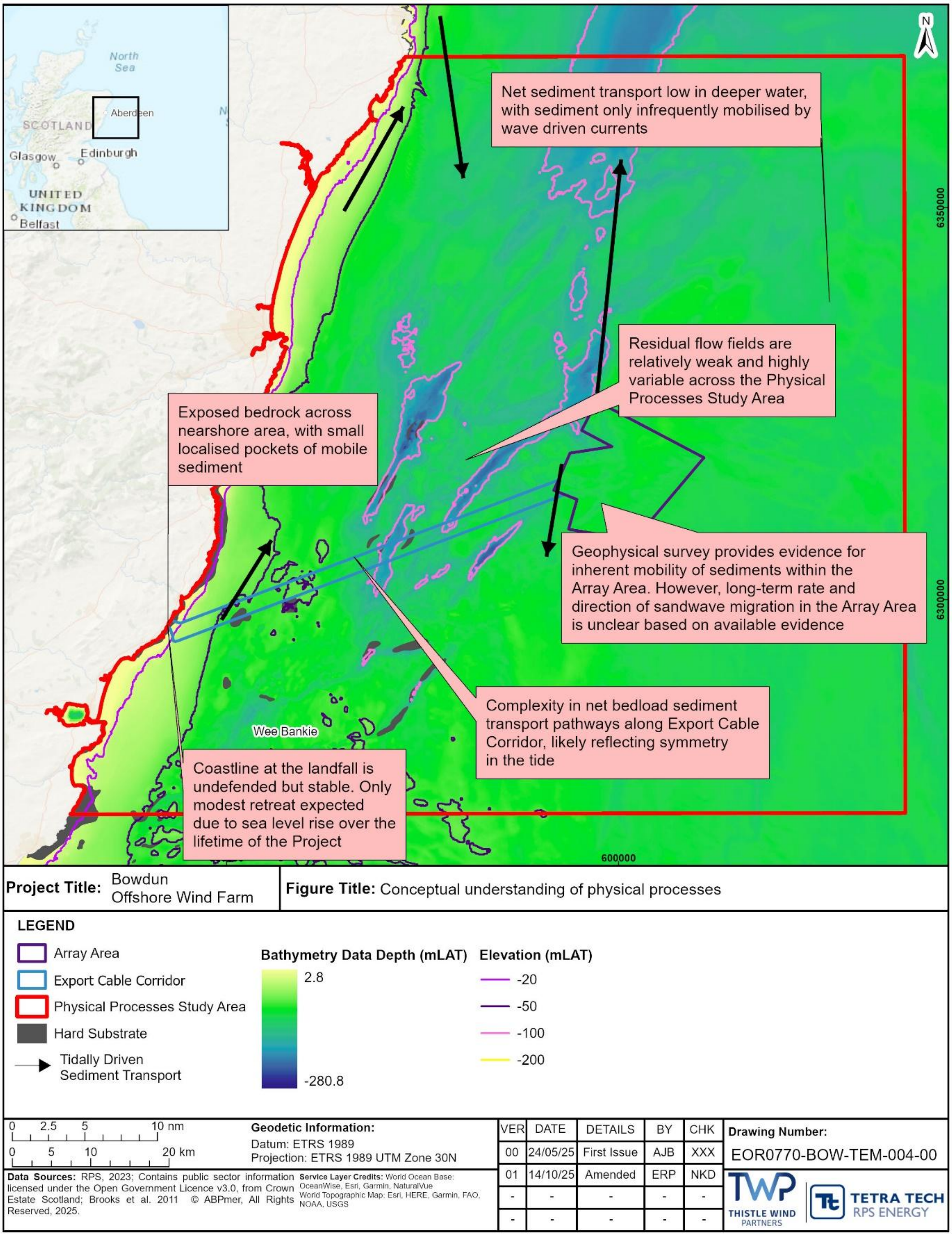


Figure 6.4: Conceptual Understanding of Physical Processes

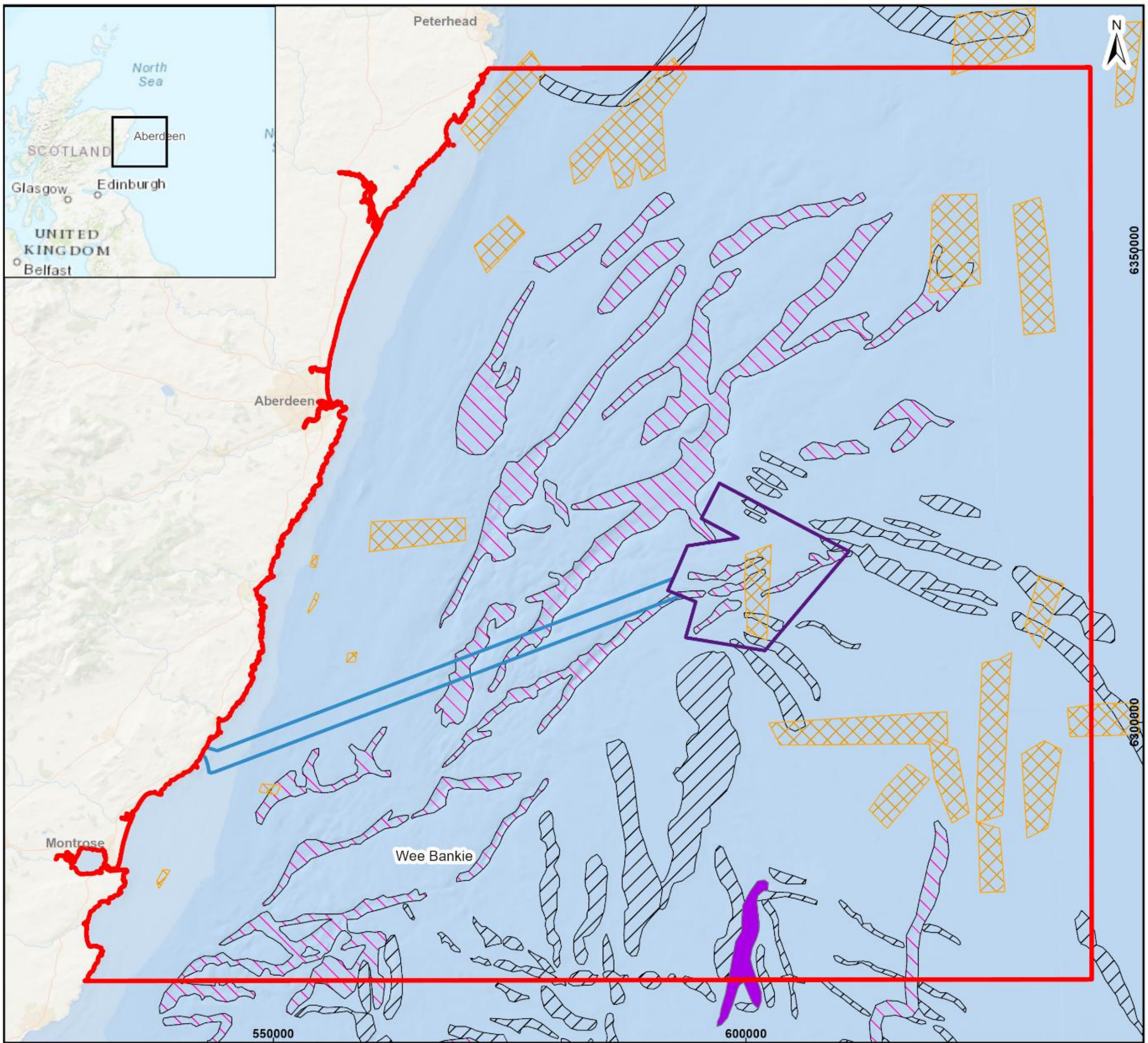
6.5 Morphology

Regional Overview

6.5.1 A range of active and relict (i.e. no longer active) bedforms and geomorphological features are present within the Physical Processes Study Area, reflecting contemporary seabed processes and past glacial and geological activity (Figure 6.5).

6.5.2 Extensive glacial moraine complexes have been mapped within the Physical Processes Study Area, including Wee Bankie to the south-west of the Array Area (Brooks *et al*., 2011; Clark *et al*., 2018). Channels features (interpreted as tunnel valleys) and glacial meltwater channels have also previously been mapped within this region and can be identified in present day bathymetry (Bradwell *et al*., 2008) (Figure 6.5).

6.5.3 In many areas, active bedforms comprising mobile Holocene sediments are present. In particular, sandwave fields are understood to be relatively widespread across the Physical Processes Study Area (BGS, 1984a; 1984b).



Project Title: Bowdun Offshore Wind Farm

Figure Title: Morphological features within the Physical Processes Study Area

LEGEND

- Array Area
- Export Cable Corridor
- Physical Processes Study Area

Sea Floor Geomorphology

- Channel
- Moraine
- Tunnel Valley
- Sandwave Field

0 2.5 5 10 nm
0 5 10 20 km

Geodetic Information:
Datum: ETRS 1989
Projection: ETRS 1989 UTM Zone 30N

VER	DATE	DETAILS	BY	CHK
00	24/06/25	First Issue	AJB	XXX
01	14/10/25	Amended	ERP	NKD
-	-	-	-	-
-	-	-	-	-

Drawing Number: EOR0770-BOW-TEM-004-00

Data Sources: RPS, 2025; Contains public sector information licensed under the Open Government Licence v3.0, from Crown Estate Scotland; Brooks et al. 2011; EMODnet 2025 © ABPmer, All Rights Reserved, 2025.

Service Layer Credits: World Ocean Base: OceanWise, Esri, GEBCO, Garmin, NaturalVue World Topographic Map: Esri, HERE, Garmin, FAO, NOAA

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Figure 6.5: Morphological Features Within the Physical Processes Study Area

Array Area

6.5.4 Water depths within the Array Area range from −55 m to −75 m Lowest Astronomical Tide (LAT), with a small region of deeper water (-91 mLAT) located near the northwestern corner of the Array Area. Average water depths across the Array Area are approximately −65 m LAT (Figure 6.6). The seabed is predominantly characterised by gentle slopes (≤ 5°); however, localised steeper inclinations are observed, where angles exceed 15°, with some areas reaching more than 30°. These steeper sections are primarily associated with the presence of sandwaves, which locally reach a height of over 6 m in western parts of the Array Area (Figure 6.7).

6.5.5 Seabed morphology varies across the Array Area. North-east to south-west oriented sandwaves are located in southern–central and eastern parts of the Array Area, megaripples and ripples dominating the central, north–eastern, and north–western parts, while linear furrows are widespread across the Array Area but with less occurrence in western parts (G-TEC, 2025a) (Figure 6.7).

6.5.6 Based on understanding of the relationship between peak mean spring current speed (Figure 4.1) and bedform formation (see Belderson *et al*., 1982), the mapped megaripples and sandwaves within the Array Area are expected to be mobile. This is confirmed by the findings from the Proposed Development geophysical survey which was undertaken over consecutive years (2023 to 2024); observations from areas with overlapping survey data confirmed that both horizontal and vertical changes in sediment and bedform geometry occurred over time emphasizing the inherent mobility of sediments. Vertical displacement of approximately 0.3 m was observed in places (G-TEC, 2025a).

6.5.7 A comparison between the survey undertaken for the Proposed Development (in 2023 and 2024) and earlier surveys undertaken by UKHO (2009) has proven problematic owing to data artefacts/datum issues with the earlier UKHO surveys. However, on the basis of the available data, little evidence is found for consistent migration of the larger sandwave features known to be present within the Array Area (Figure 6.8). This pattern of observed change is consistent with the low rates of net sediment transport predicted by the sediment transport modelling (Figure 6.3).

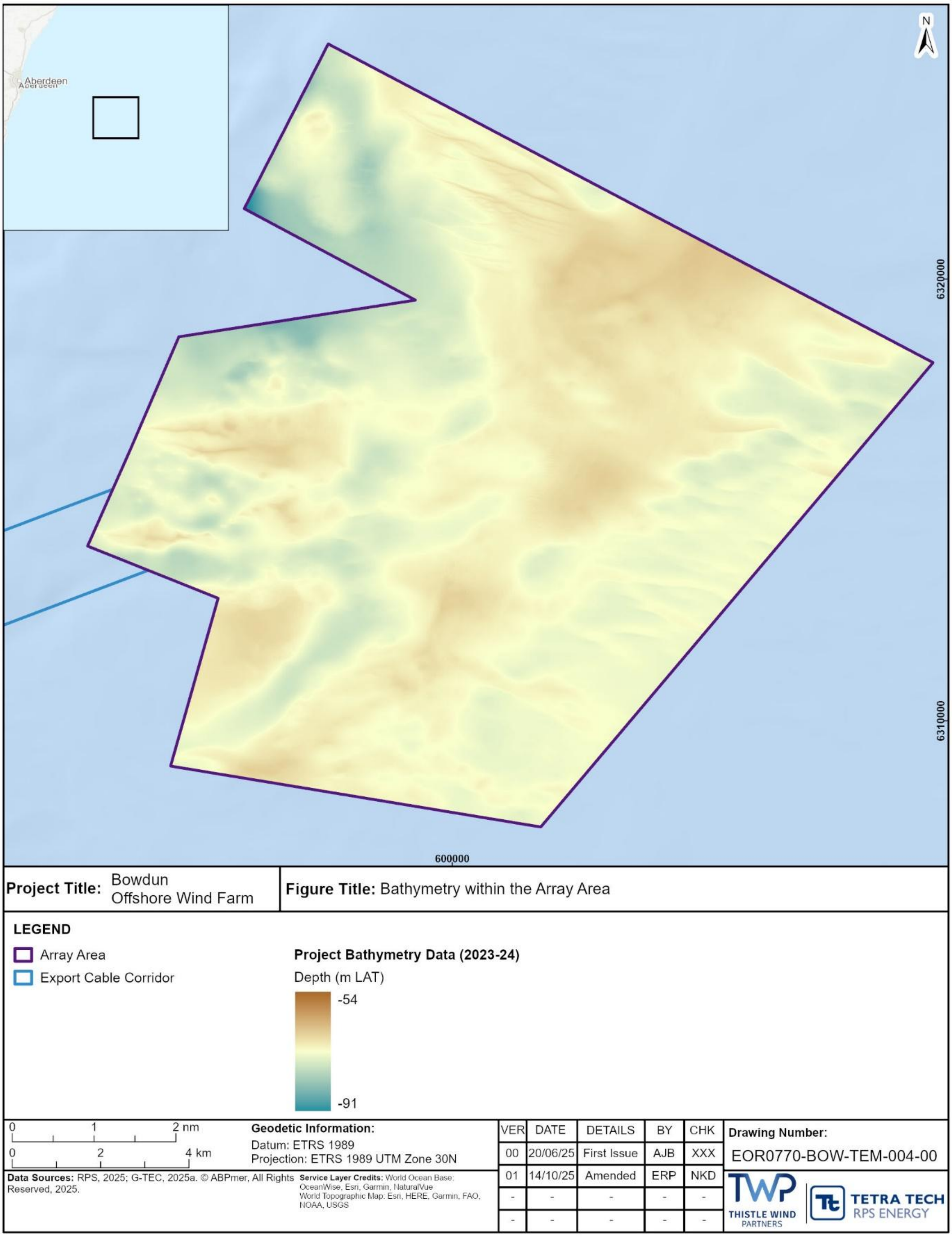


Figure 6.6: Bathymetry Across the Array Area

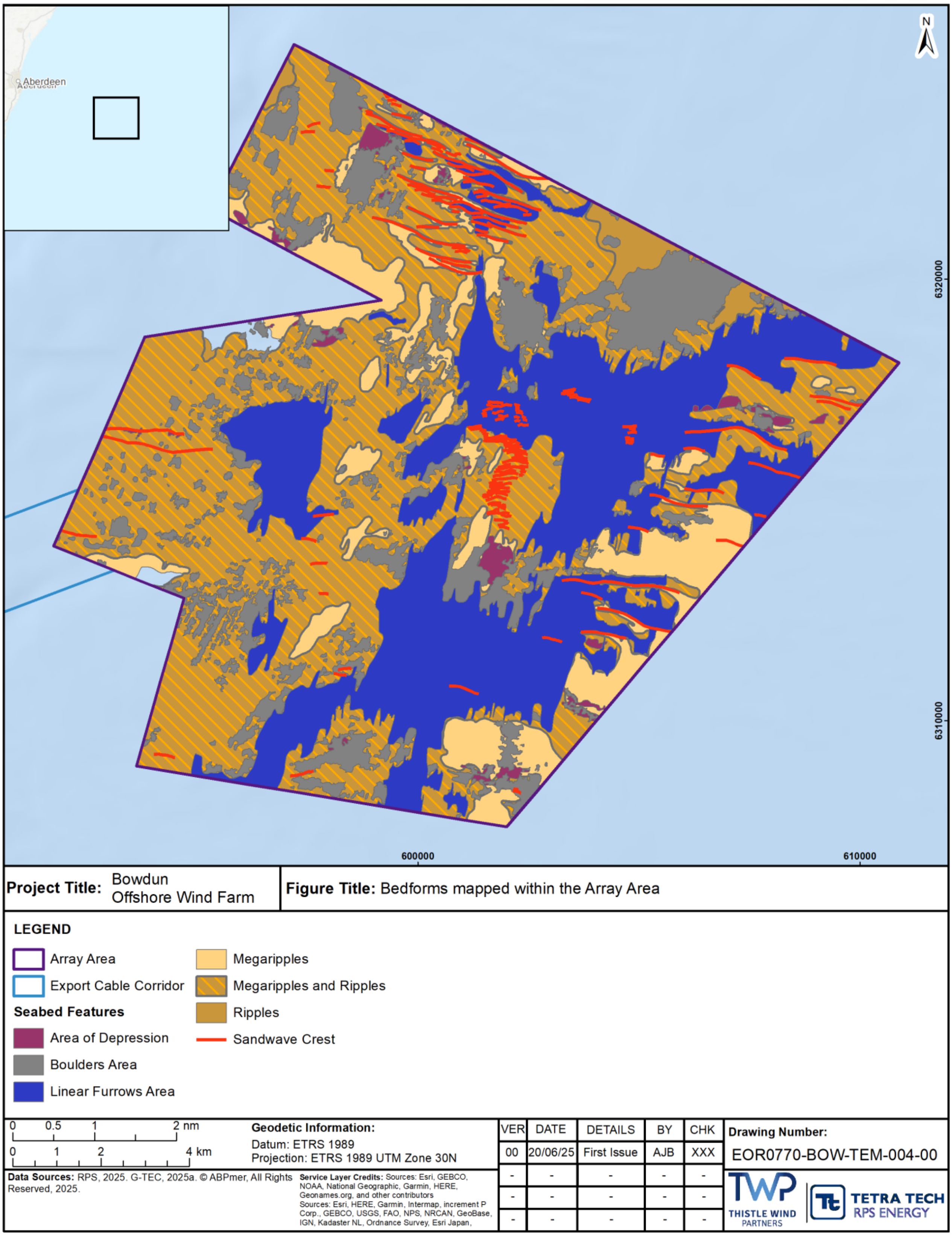


Figure 6.7: Bedforms Mapped Within the Array Area

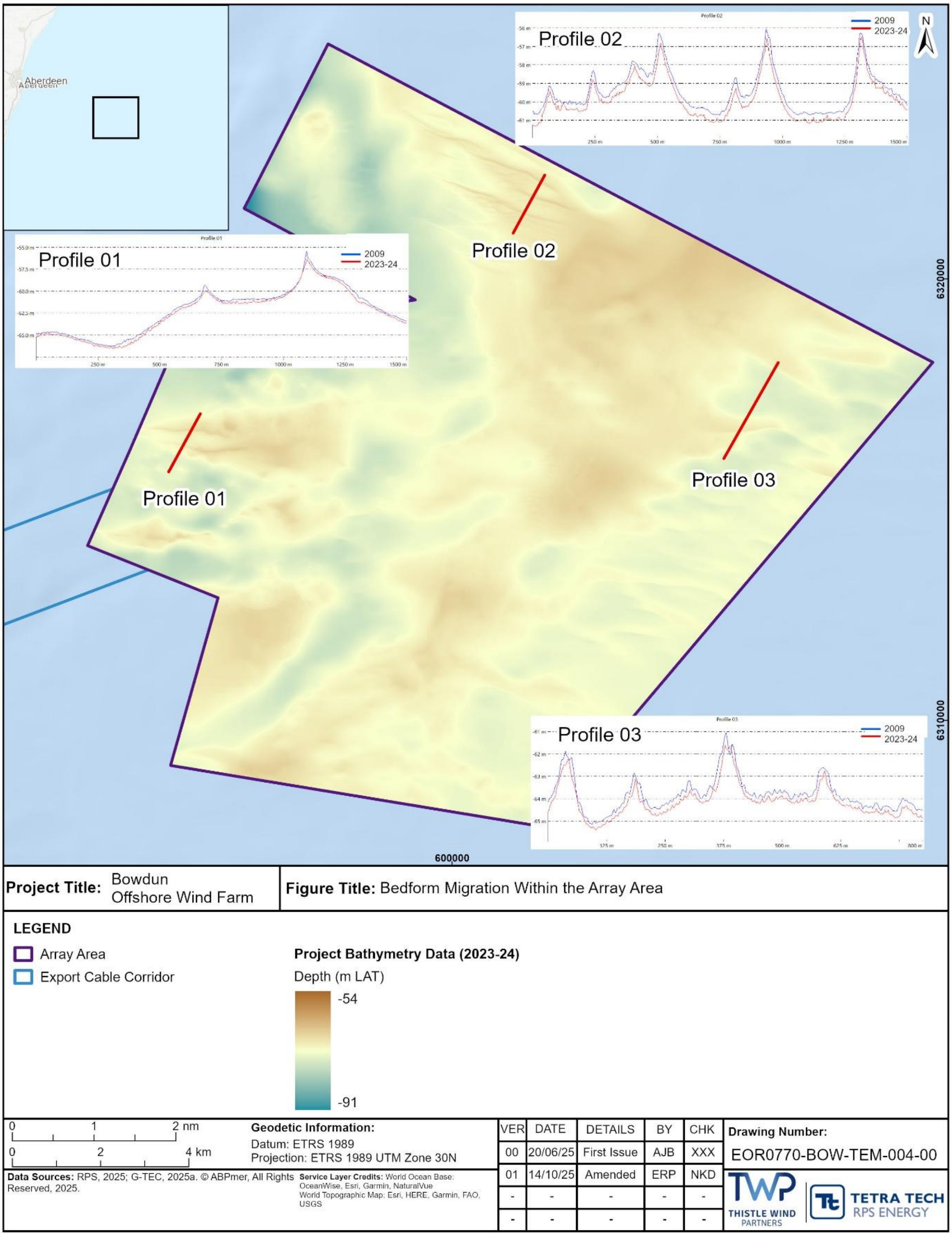


Figure 6.8: Bedform Migration Within the Array Area

Export Cable Corridor

6.5.8 Water depths along the Export Cable Corridor range from 0 m LAT (at the Landfall) to around -113 m LAT, where the route crosses north-east to south-west trending linear depressions (Figure 6.9). These are interpreted as relict glacial tunnel valleys, formed by sub-glacial meltwater processes (Bradwell *et al*., 2008). In the nearshore areas, bedrock outcrops create a complex terrain with significant slope variations, reaching up to 83° in some areas. Further offshore, average slopes are generally below 5° (G-TEC, 2025b).

6.5.9 Sandwaves and megaripples are present in many areas along the route (Figure 6.10), with heights in excess of 6 m in places. Flow speeds are shown in Figure 4.1 and these are found to be sufficiently high throughout the Export Cable Corridor for sand (and associated megaripple and sandwave bedforms) to be mobile (see Belderson *et al*., 1982; Soulsby, 1997).

6.5.10 A comparison between the Proposed Development bathymetric survey (from 2023 to 2024) and older UKHO historic survey data (from 2009) has been undertaken (Figure 6.11). However, given the relatively low resolution of the UKHO data as well as a spatially varying spatial offset between the datasets, it has not been possible to develop a clear picture of how the rate and direction of sandwave migration varies along the route. It is noted though, that in many areas the sandwaves are generally symmetrical in nature which is indicative of no preferred net migration direction. This is consistent with the sediment transport modelling which suggests residual sediment transport is relatively weak in many areas along the Export Cable Corridor (Figure 6.3).

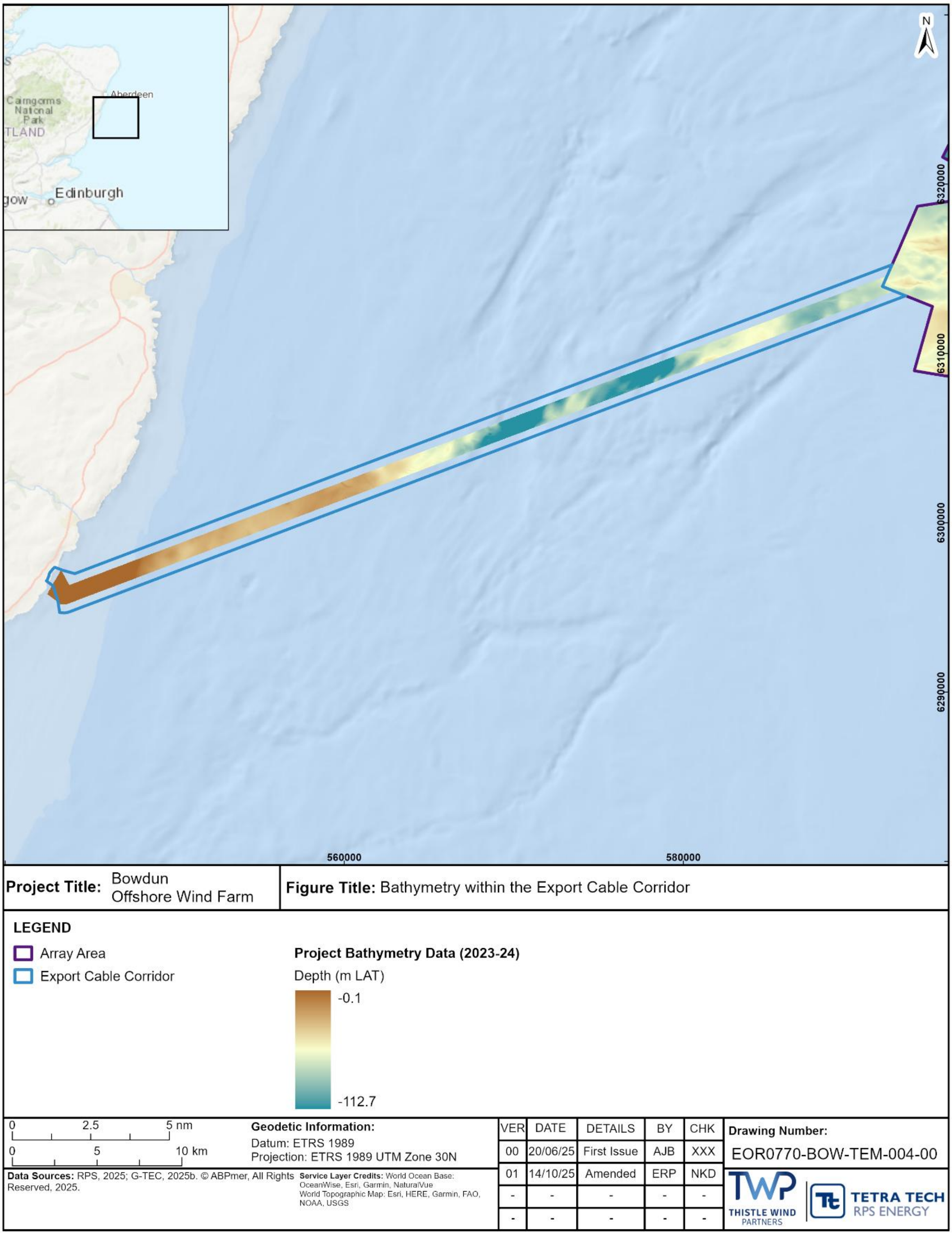


Figure 6.9: Bathymetry Within the Export Cable Corridor

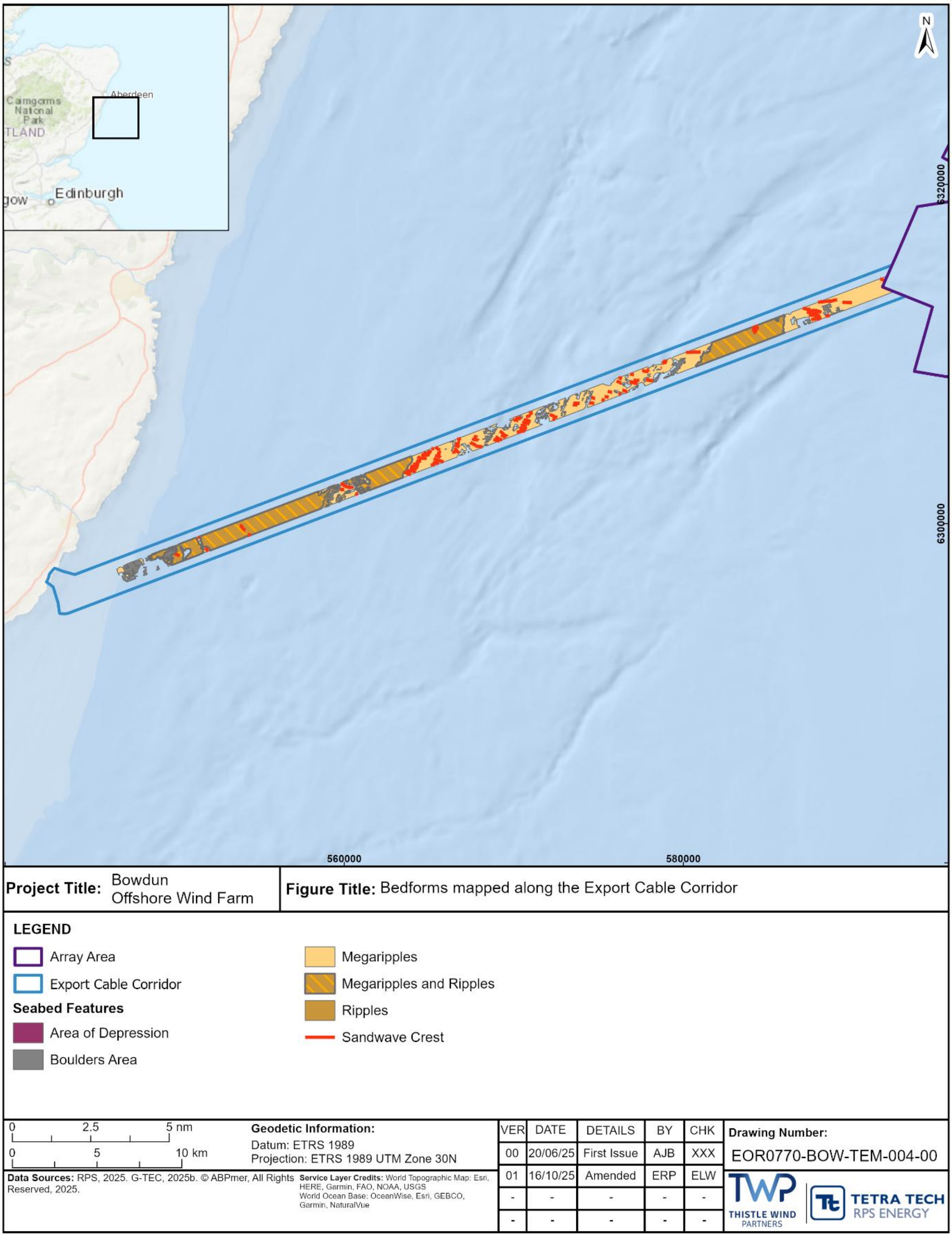
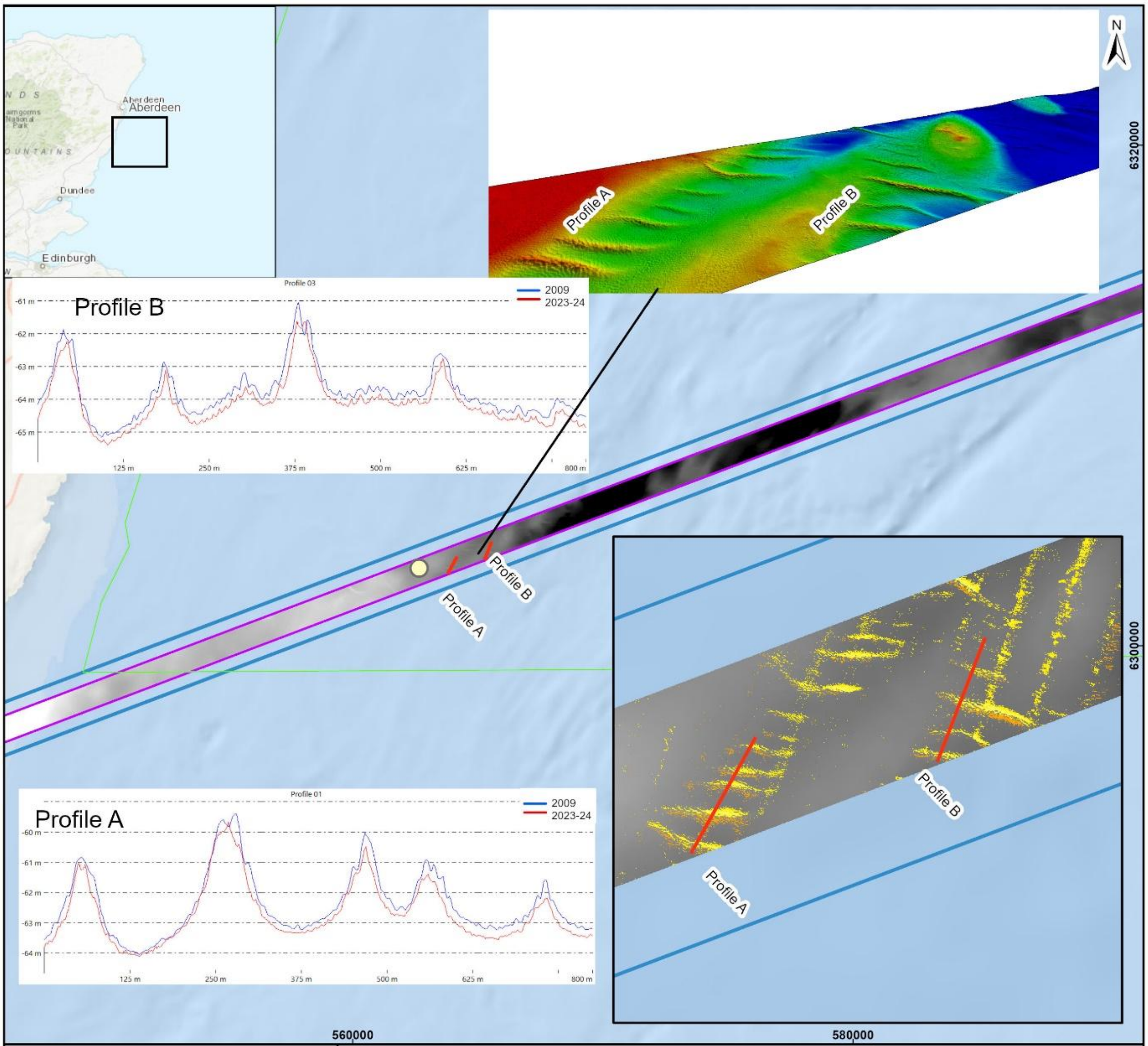


Figure 6.10: Bedforms Mapped Along the Export Cable Corridor



Project Title: Bowdun Offshore Wind Farm

Figure Title: Bathymetric change within the Export Cable Corridor over the period 2009 (UKHO) to 2023-24 (Proposed Development)

LEGEND

Export Cable Corridor

Survey Extent

Site Specific Geophysical Survey (2023 to 2024) (G-TEC, 2025b)

UKHO HI1155 Todhead Pt to Bosies Bank (2009)

Site Specific Geophysical Survey (2023-24) (G-TEC, 2025b)

Depth (m LAT)

-0.1

-112.7

Change in Elevation (m) 2009 to 2023-24

-1.99 to -1.00

-0.99 to -0.5

-0.49 to 0.49

0.5 to 0.99

0 2 4 nm

0 2 4 8 km

Geodetic Information:
Datum: ETRS 1989
Projection: ETRS 1989 UTM Zone 30N

VER	DATE	DETAILS	BY	CHK
00	20/06/25	First Issue	AJB	XXX
01	14/10/25	Amended	ERP	NKD
-	-	-	-	-
-	-	-	-	-

Drawing Number: EOR0770-BOW-TEM-004-00

Data Sources: RPS, 2025. G-TEC, 2025b; UKHO, 2011.

Service Layer Credits: World Ocean Base: OceanWise, Esri, Garmin, NaturalVue
World Topographic Map: Esri, HERE, Garmin, FAO, NOAA, USGS
World Ocean Base: Esri, Garmin, NaturalVue

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Figure 6.11: Bathymetric Change Within the Export Cable Corridor Over the Period 2009 (UKHO) to 2023-24 (Proposed Development)

7 Coastal Geomorphology and Characteristics

7.1 Regional Overview

7.1.1 The coastline within the Physical Processes Study Area extends from Auchmithie (in the south) to Boddam (in the north). Large stretches are characterised by the presence of erosion resistant rock although beaches with dune systems are also present (Figure 7.1). In several areas where these softer, erodible sediments front urban areas (such as Montrose and Aberdeen), coastal defences are present. However, most of the coastline within the Physical Processes Study Area is undefended, reflecting a combination of generally low rates of erosion and a sparsely populated coastal zone.

7.1.2 Along much of the coastline in this region (including at the Landfall), the coastal characteristics are dominated by the underlying hard rock geology. In places, glacial deposits of varying thickness cap the underlying rocks. The thickness of this cover varies greatly, from a thin veneer to over 35 m – such as that found to the north of Stonehaven (Ramsay & Brampton, 2000).

7.1.3 The influence of previous (higher) relative sea levels is evident along the coastline within the Physical Processes Study Area. This includes fossil cliffs and raised beaches, such as that found in Lunan Bay, to the south of Montrose (Ramsay & Brampton, 2000).

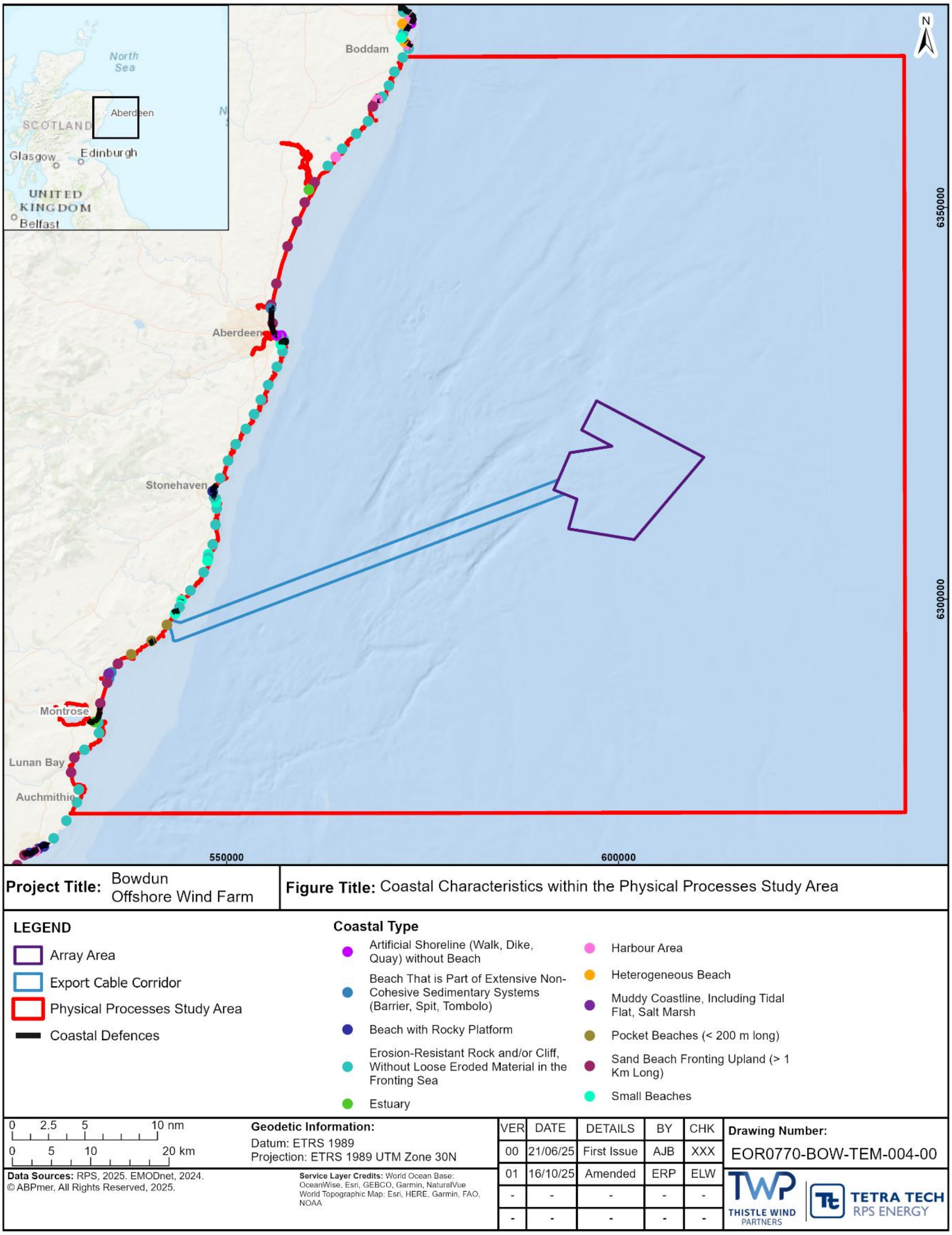

Figure 7.1: Coastal Characteristics Within the Physical Processes Study Area

7.2 Landfall

7.2.1 The Export Cable makes Landfall at Benholm beach which is characterised by a rocky foreshore, with exposed linear bedrock pavements, conglomerate rock, boulders and cobbles. Areas of loose boulders and cobbles are also present on the foreshore, typically contained in channels. These channels are steep-sided features, with narrow or broad channels of cobbles and boulders, and small patches of sedimentary veneer (TWP, 2024). A narrow pebble/cobble beach is located at the MHWS mark. The hinterland landward of the beach is low lying, gently increasing in elevation to around 10 mODN within 100 m to 200 m of the MHWS mark.

7.2.2 The historic mapping evidence presented in Rennie *et al*. (2021) suggests that the position of MHWS has either remained the same or slightly advanced in places over the past century, by approximately 10 m. However, change of this magnitude is likely to fall within the margin of error associated with the historic mapping and it is probable that the position of MHWS has remained largely the same over this period. This pattern of stability is consistent with aerial imagery from the Landfall for the period between 2008 and 2023, available from Google Earth (Figure 7.2).

7.2.3 Little overall bathymetric change is observed in shallow nearshore areas, which is consistent with the available geophysical evidence of a thin surficial seabed sediment layer with outcropping bedrock (G-TEC, 2025b) (Figure 7.3). However, localised change of up to (approximately) ±1 m is observed, likely in response to wave driven sediment transport, which will vary seasonally.

7.2.4 Because of the erosion resistant nature of the coastline at the Landfall, negligible recession in the position of the MHWS contour is predicted by 2060, even under a high sea level rise scenario (Rennie *et al*., 2021) (Figure 7.4).

Figure 7.2: Aerial Imagery of the Landfall (Source: Google Earth)

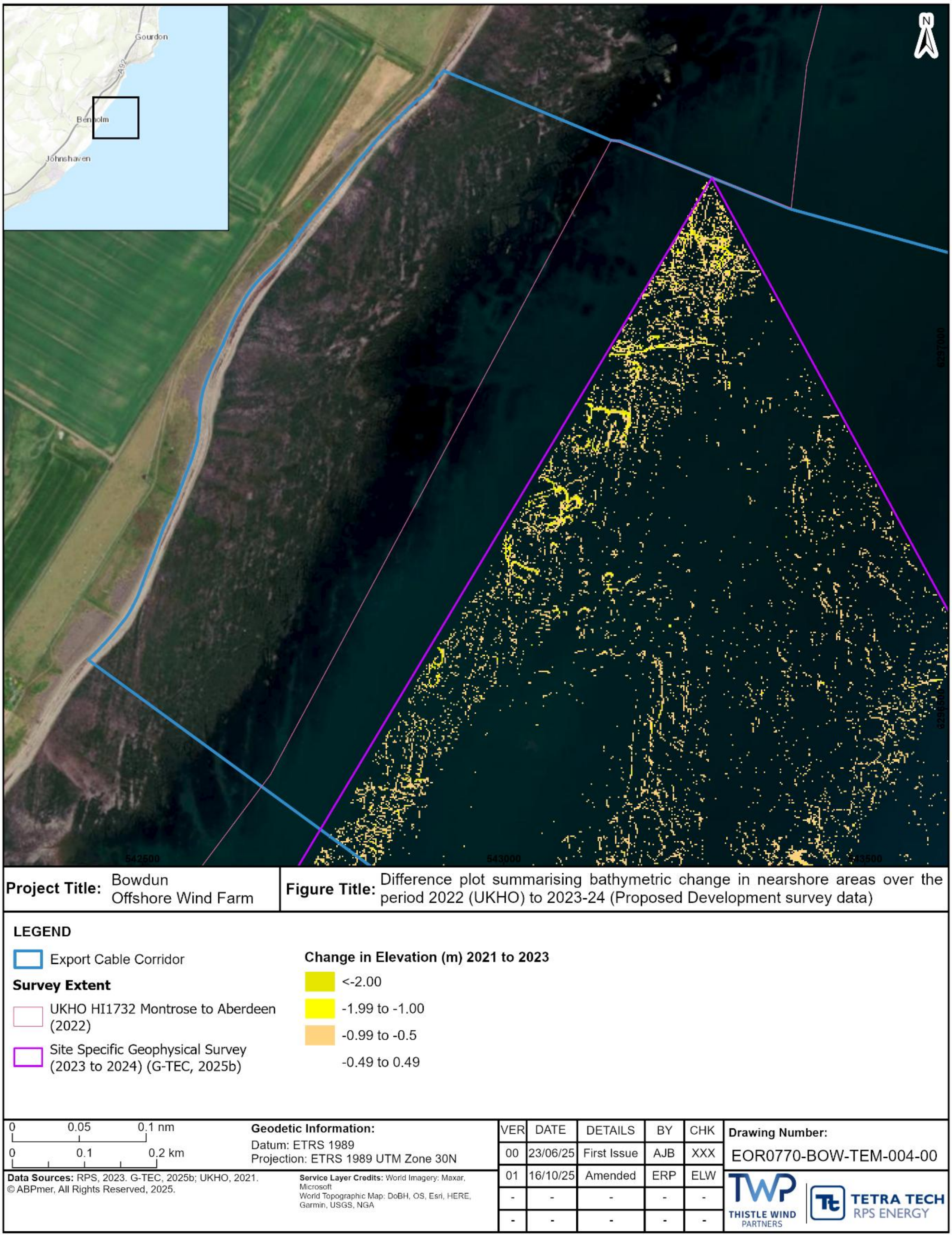

Figure 7.3: Difference Plot Summarising Bathymetric Change in Nearshore Areas Over the Period 2022 (UKHO) to 2023-2024 (Proposed Development Survey Data)

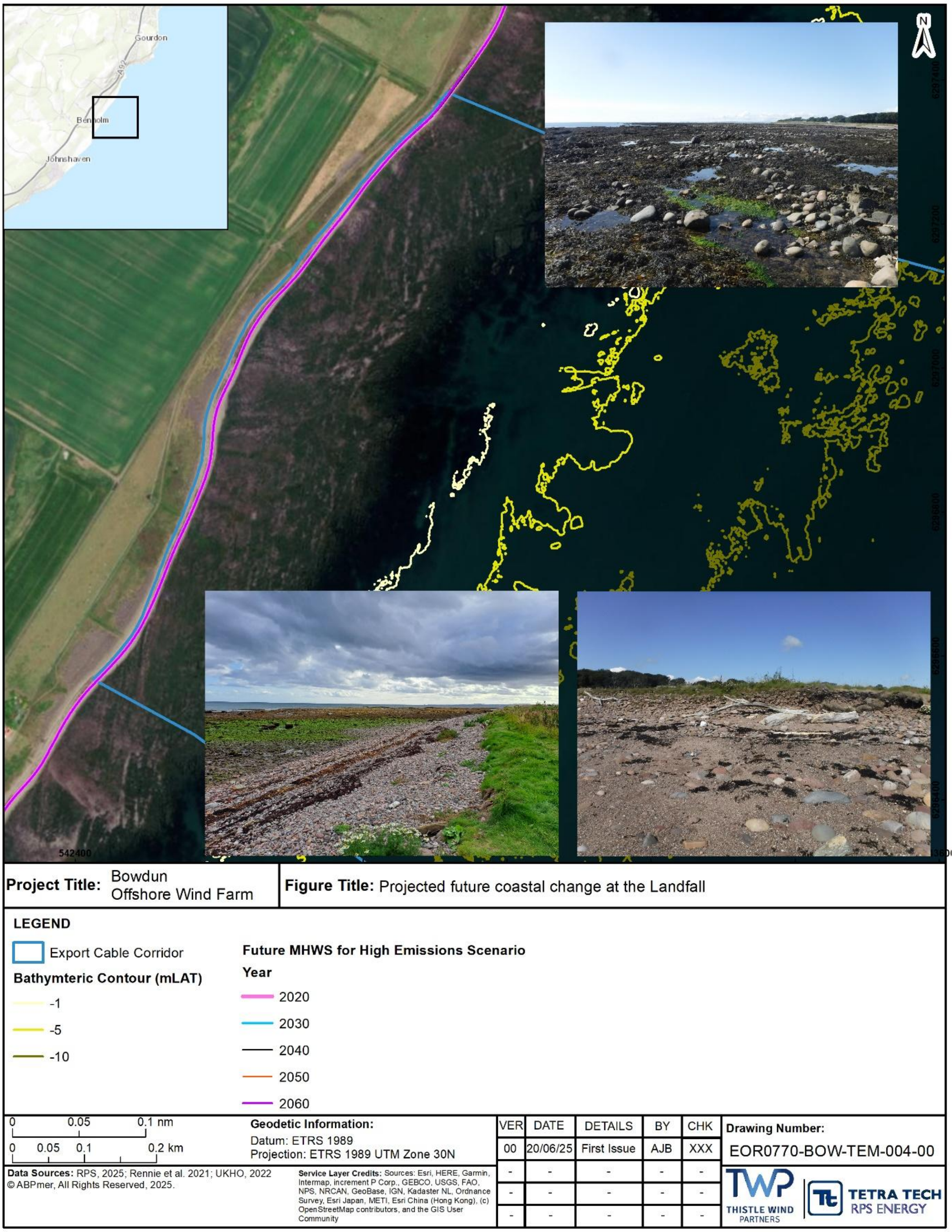

Figure 7.4: Projected Future Coastal Change at the Landfall

8 Summary

8.1.1 This technical report provides a high-level summary of the existing environment across the Physical Processes Study Area, with consideration given to bathymetry, water levels, currents, waves, stratification, seabed sediments and geomorphology. Key aspects are summarised below.

8.1.2 The Physical Processes Study Area is located within a semi-diurnal tidal environment with tidal range increasing from north-east to south-west. Tidal currents are generally of moderate strength, with mean spring peak current speeds typically less than ~0.6 m/s. Some of the strongest currents are found just to the north of the Landfall, with peak current speeds on spring tide reaching ~0.8 m/s.

8.1.3 Waves within the Physical Processes Study Area are a combination of locally generated wind waves and waves generated elsewhere in the North Sea. Within the Array Area waves predominantly come from southerly directions although waves from northerly directional sectors are also common. Wave heights across the Physical Processes Study Area tend to reduce with proximity to the coast, owing to decreasing water depth, decreasing fetch length in the predominant wind direction, and generally greater protection from waves generated elsewhere in the North Sea.

8.1.4 Stratification is a naturally occurring seasonal hydrodynamic feature related to the vertical and horizontal distribution of sea water temperature and salinity, which influences the availability of nutrients, and the distribution and growth rates of pelagic flora and fauna. During the winter months (October to April), reduced solar heating and increased turbulent mixing from wind and waves result in well-mixed waters in the Array Area, characterised by homogeneous temperature and density profiles, with PEA values around 10 J/m^3 to 15 J/m^3. With the onset of spring and summer, calmer weather and longer, warmer days enhance stratification, overcoming the mixing effects of tides. From May to September, this leads to a vertical temperature gradient.

8.1.5 Fronts are relatively widespread features within the North Sea and (at certain times during the year) may extend for a distance of several hundred kilometres. During the summer months, elevated chlorophyll-a concentrations (likely linked to a tidal mixing front) are observed east of the Array Area. This is consistent across all years analysed (2010 to 2023) and suggests that higher PP is occurring at the boundary between the more strongly stratified waters located further offshore, as opposed to the weakly stratified waters in the Array Area. In the Array Area, stratification appears to be a more transient feature, leading to lower and less sustained phytoplankton growth compared to the stable stratification further offshore.

8.1.6 Seabed sediments across the Physical Processes Study Area are dominated by coarse-grained material, with sands and gravels encountered in most areas. Muddy sand is present in places. Close to the coast (including at the Landfall), exposed rock is encountered. Where present, the seabed sediments overlie extensive Quaternary sequences, deposited during glacial episodes over the past 2.6 million years.

8.1.7 Across nearshore areas within the Physical Processes Study Area, net sediment transport is understood to be dominated by tidally driven processes. Further offshore (including areas immediately to the east of the Array Area), net rates of tidally driven sediment transport become negligible, with mobilisation of material at the bed only occurring on shoals during large storm events.

8.1.8 Sediment transport at the coast is described within the context of coastal cells and sub-cells in Ramsay and Brampton (2000). The Physical Processes Study Area is within Cell 2 (Fife Ness to Cairnbulg Point). The volume of beach material in many areas is limited meaning net littoral drift is often low. Even where sand is present rates of net littoral drift are often low, reflecting a balance between wave and tidally driven processes and/or coastal aspect relative to the prevailing waves.

8.1.9 Within the Array Area, water depths range between approximately –54 m to –91 m LAT. The Array Area as a whole is characterised by relatively flat terrain although local gradients increase where bedforms are present. Bathymetry with the Export Cable Corridor ranges from 0 m LAT, in the nearshore area to a maximum depth of -113 m LAT further offshore, where the route crosses a trough. In the nearshore areas, bedrock outcrops create a complex terrain with significant slope variations, reaching up to 83° in some areas. Further offshore, average slopes are generally below 5°.

8.1.10 A range of active and relict (i.e. no longer active) bedforms and geomorphological features are present within the Physical Processes Study Area, reflecting contemporary seabed processes and past glacial and geological activity. Extensive (relict) glacial moraine complexes have been mapped within the Physical Processes Study Area, as well as tunnel valleys. Active bedforms (namely sandwaves and megaripples) comprising mobile Holocene sediments are also present, including locally within the Array Area and Export Cable Corridor where they can exceed 6 m in height. Ripple and smaller megaripple features are known to be mobile within the Array Area and Export Cable Corridor, as demonstrated through bathymetric comparisons in areas with overlapping survey data collected during the 2023 to 2024 Proposed Development survey campaign. However, a comparison between the recent (2023 to 2024) survey data and older (2009) UKHO survey data has not shown clear evidence for consistent migration of the larger sandwave features.

8.1.11 The coastline within the Physical Processes Study Area extends from Auchmithie (in the south) to Boddam (in the north). Large stretches are characterised by the presence of erosion resistant rock although beaches with dune systems are also present. In several areas where these softer, erodible sediments front urban areas (such as Montrose and Aberdeen), coastal defences are present. However, most of the coastline within the Physical Processes Study Area is undefended, reflecting a combination of generally low rates of erosion and a sparsely populated coastal zone. Owing to the erosion resistant nature of the coastline, relatively little change is expected at the Landfall over the lifetime of the Proposed Development and the position of the MHWS contour is predicted to remain largely unaltered.

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