Seabed Infrastructure in Marine Protected Areas with Designated Subtidal Sandbanks

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Report details

Authors

Ian Reach, Principal Marine Consultant (MarineSpace Ltd)

Dr Rebecca Hitchin, Principal Marine Consultant (MarineSpace Ltd)

Matt Kyle-Henney, Marine Consultant (MarineSpace Ltd)

Katie Cross, Principal Marine Consultant (MarineSpace Ltd)

Iain Warner, Principal Marine Consultant (MarineSpace Ltd)

Rory Bardner, Marine Consultant (MarineSpace Ltd)

Ana Chaverra Valencia, Marine Consultant (MarineSpace Ltd)

Prof. Justin Dix, Technical Director (MarineSpace Ltd)

Dr Dafydd Lloyd Jones, Technical Director (MarineSpace Ltd)

Sam Strutton, Senior Marine Consultant (MarineSpace Ltd)

Natural England Project Manager

Lucy May Lucy.may@naturalengland.org.uk

Contractor

MarineSpace

AN ERM GROUP COMPANY

Address:
2nd Floor Exchequer Court,
33 St Mary Axe,
London,
England, EC3A 8AA.

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Foreword

Seabed rock protection deposited by energy infrastructure in sandbank Marine Protected Areas (MPAs) poses a significant problem, contributing to the unfavourable condition of several Special Areas of Conservation (SACs). This issue has led to the need for government derogations for various offshore wind projects and has spurred a large-scale strategic habitat compensation programme. Additionally, it plays a crucial role in determining the locations of offshore wind farms. However, there remains considerable uncertainty about the ecological impacts of rock protection on sandbank habitats.

The project aims to provide recommendations for Natural England that can be considered in Marine Protected Area (MPA) site condition assessments, particularly regarding the impacts of deposited rocky substrate on the extent and distribution of sandbanks. These recommendations will serve two main purposes:

1. They will directly help inform the decision-making process that underpins the condition assessments.
2. They will guide future work and projects needed to better understand the impacts of rocky substrate on the integrity of sandbanks.

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Executive summary

This report has been produced by MarineSpace Ltd to assist Natural England in reviewing its current approach to the condition assessment of designated Annex I habitat (H1110) ‘sandbanks slightly covered by seawater all the time’ features’; particularly the extent and distribution attributes of these designated features.

Subtidal sandbanks occur in many coastal and shelf seas. They require (or have historically required) mobile sediment to develop, either sourced from the local seabed, or from ongoing coastal, and nearshore, hydrodynamic processes e.g. near seabed sediment cells and transport systems.

Each subtidal sandbank, and associated system, is composed of a range of different physical environments, related to water depth, hydrodynamics, and sediment transport systems with their associated geomorphological processes.

Subtidal sandbanks can be sub-divided/classified at a gross-level by their geomorphological activity. Some subtidal sandbanks are still actively evolving and moving as they are associated with coastal and nearshore physical processes that are still ‘forming’ and ‘shaping’ the features. Some features are effectively dissociated from active sediment supply and are considered to be ‘moribund’ or ‘relict’.

Designated subtidal sandbanks features within Marine Protected Areas have been a focus of recent Nationally Significant Infrastructure Project examinations, Habitats Regulations Assessment derogation procedures, and associated compensation schemes for Round 3 Offshore Wind Farm projects.

This report makes recommendations that can be considered by Natural England. Specifically, the report is intended to assist Natural England when determining condition assessments, and the significance of effects from deposited hard infrastructure in relation to extent and distribution attributes of subtidal sandbanks features.

The determinations, and associated recommendations, are:

- Recommendation 1;
    - A ‘live’ (real-time) cross-industry database of actual installed (as-laid) infrastructure is required;
- Recommendation 2;
    - MMO and OPRED provision of as-laid quantities and footprints of rock needs to include both area of seabed footprint and volume installed, accommodating all previously as-laid values;
- Recommendation 3;
    - Update, and regularly maintain, geomorphological/seabed sediment transport models, based on current data, as well as from evidence collected on future surveys;

- Recommendation 4;
    - Asset/infrastructure monitoring data should consistently be provided in a format that is agreed by stakeholders to inform better understanding of environmental functionality of hard infrastructure in relation to subtidal sandbanks features;
- Recommendation 5;
    - Consider, and incorporate, temporal patterns of burial of infrastructure into condition assessment;
- Recommendation 6;
    - Increase knowledge and understanding of the scale, ecological dynamics and hydrodynamics of marginal areas and halos associated with changes in abiotic and biotic properties of seabed sediments and ecological effects of rock-based communities;
- Recommendation 7;
    - Develop understanding of patterns of predator-prey linkage between classified breeding SPA populations and Annex II SAC populations with subtidal sandbanks MPAs, to provide further clarification of areas of heightened vulnerability to impacts from rock protection;
- Recommendation 8;
    - Full audit of hard substrata to validate in-combination impact on extent and distribution, and structure and function attributes on a range of scales associated with sub-compartmentalisation of subtidal sandbanks features within an MPA; and
- Recommendation 9;
    - Supplementing current condition assessments with more detailed analysis based on FAO/ICES VME assessment frameworks.

This report highlights future investigations and related projects for Natural England with the aim being to assist with condition assessment and operationalisation of conservation objectives to underpin advice on site management and casework.

Contents

Introduction

This report has been produced by MarineSpace Ltd (MarineSpace) to assist Natural England review its current approach to the condition assessment of designated Annex I habitat (H1110) ‘sandbanks slightly covered by seawater all the time’ features[1] (hereafter referred to as subtidal sandbanks) of Marine Protected Areas (MPAs) (sites contributing to the UK post-EU exit National Site Network[2]). A focus on considering the impacts of seabed infrastructure on this habitat feature is provided.

Several Special Areas of Conservation (SACs) were designated in the 2000’s and 2010’s to protect coastal and marine habitats with latter designations focusing on sandbanks and reefs in the southern North Sea, including Inner Dowsing, Race Bank and North Ridge SAC (IDRBNR SAC), The Wash and North Norfolk Coast SAC, Haisborough Hammond and Winterton SAC (HHW SAC) and North Norfolk Sandbanks and Saturn Reef SAC (NNSSR SAC). In the 2010’s a number of Marine Conservation Zones (MCZs) such as the Cromer Shoal Chalk Beds MCZ were designated in the southern North Sea to protect a range of seabed habitats.

The Statutory Nature Conservation Body (SNCB) responsible for nature conservation of English inshore waters (0-12 nm from the coast) is Natural England (NE) and the SNCB responsible offshore (12-200 nm from the coast) is the Joint Nature Conservation Committee (JNCC). As such, the lead on conservation advice for the sites considered here is split between Natural England (HHW SAC, IDRBNR SAC) and JNCC (NNSSR SAC, Dogger Bank SAC). NE and JNCC each have statutory responsibilities to provide conservation advice on the features designated within the appropriate MPAs. These responsibilities also require assessment and reporting on the condition of the features within the appropriate MPAs, as well as assessment and reporting of the condition of these features at a UK scale.

Subtidal sandbanks features within these sites have been a habitat focus of recent Nationally Significant Infrastructure Project (NSIP) examinations, Habitats Regulations Assessment (HRA) derogation procedures, and associated compensation schemes for Round 3 Offshore Wind Farm (OWF) projects. Additionally, ongoing decommissioning of Oil and Gas (O&G) assets may be able to provide some understanding of issues that might be expected regarding assessment of potential impacts on these features.

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[1] https://eunis.eea.europa.eu/habitats/10003

[2] The National Site Network (of designated and classified nature sites) was established as part of the UK post-EU exit process. The network and includes international sites such as Natura 2000 sites, along with domestic sites such as Marine Conservation Zones – also referenced as Marine Protected Areas, where these sites have a coastal and/or marine component/boundary.

In recognition of the ongoing complexity of the issue, Natural England and JNCC hosted a workshop in January 2021 which brought together experts on marine infrastructure and subtidal sandbanks feature ecology[3]; see section on Subtidal Sandbanks Workshop 2021.

Subtidal sandbanks features occur where areas of seabed, primarily consisting of sand (and also with some mixed and coarse sediments), are predominantly surrounded by deeper water, and where the tops of the sandbanks are in less than 20 m water depth (EUR28)[4]. Generally, the subtidal sandbanks remain submerged during all tidal states; although some inshore features do have small areas that may become emerged during extreme low water spring tides e.g. small discrete areas of Margate Sandbank in the Margate and Long Sands Special Area of Conservation (MLS SAC), in the outer Thames Estuary. Flanks (sides) of the subtidal sandbanks can extend into 'deep' water with the toe (base) of the features occurring in water up to 60 m deep (EUR28).

Subtidal sandbanks occur in many coastal and shelf seas where the currents are able to move large quantities of sediment (sediment classes associated with Annex I subtidal sandbanks predominantly include sands, mixed, and coarse sediments – related in greater detail in the Folk (1954) sediment classification). The generation of many subtidal sandbanks within southern North Sea MPAs is associated with post-glacial sediment processes and marine transgression (sea-level rise) events following the retreat of glaciers at the end of the last glaciation. The subtidal sandbanks required a source of mobile sediment to develop, either sourced from the local seabed, or from ongoing coastal, and nearshore, hydrodynamic processes e.g. near seabed sediment cells and transport systems. As this feature is defined by topography and substratum type, its range is determined by geological and/or hydrodynamic processes depending on the type of

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[3] This followed previous Natural England and JNCC workshops on subtidal sandbanks; commencing with agreement of the 'Sandbank Principles' in 2015, seeking to provide evidence to the Statutory Nature Conservation Bodies Chief Scientists Group.

[4] The Interpretation Manual of European Union Habitats (EUR28) gives the most up-to-date definition:

1110 Sandbanks which are slightly covered by sea water all the time

1. Sandbanks are elevated, elongated, rounded or irregular topographic features, permanently submerged and predominantly surrounded by deeper water. They consist mainly of sandy sediments, but larger grain sizes including boulders and cobbles, or smaller grain sizes including mud, may also be present on a sandbank. Banks where sandy sediments occur in a layer over hard substrata are classed as sandbanks if the associated biota are dependent on the sand rather than on the underlying hard substrata.

"Slightly covered by sea water all the time" means that above a sandbank the water depth is seldom more than 20m below chart datum. Sandbanks can, however, extend beneath 20m below chart datum. It can, therefore, be appropriate to include in designations such areas where they are part of the feature and host its biological assemblages.

sandbank (http://jncc.defra.gov.uk/page-1452). Although the surface area of this feature may have declined due to the presence of infrastructure and abrasion[5], there is no evidence that has significantly affected the geographic spread of this feature. Area of sandbanks are determined by the presence of suitable substrate and the hydrological regime maintaining the sandbank and is, therefore, unlikely to significantly change overtime. However, anthropogenic activities may have caused localised losses of area.

Annex I subtidal sandbanks in the UK National Site Network vary hugely in physical and biological character. For example, the UK National Site Network incorporates small, dynamic, interlinked shallow-water sandbanks found in estuaries and embayments to large, discrete, stable structures found in offshore, or deeper water environments. Each subtidal sandbank is composed of a range of different physical environments, related to water depth, hydrodynamics, and sediment transport systems, and associated geomorphological processes. In addition, topographical environments include crests (bank tops), flanks (sides of banks) and toes (the foot of banks where they intersect with the prevalent seabed), and troughs (the spaces) between each discrete topographical seabed feature i.e. the physical subtidal sandbanks.

Subtidal sandbanks can be sub-divided/classified at a gross-level, by their geomorphological activity. Some subtidal sandbanks are still actively evolving, as they are associated with coastal and nearshore physical processes, which are still ‘forming’ and ‘shaping’ the features (Stride, 1982). These types of subtidal sandbanks are colloquially referred to as ‘active’ banks; sinusoidal (or S-type) or ‘alternating ridges’ subtidal sandbanks are a ‘classic’ example of active features – such as the Newarp Banks within the Haisborough, Hammond and Winterton SAC (HHW SAC), north of Great Yarmouth and Winterton, off the Norfolk coast.

In contrast, many subtidal sandbanks in the UK nearshore and offshore environments are no longer associated with active coastal physical processes. These features are effectively dissociated from active sediment supply, are discrete self-supporting physical seabed features, and are considered to be ‘moribund’ or ‘relict’ (Stride, 1982). An example of a moribund subtidal sandbanks feature is Smith’s Knoll in the HHW SAC. This bank is located within waters ranging 13-58 m deep, and receives no active sediment supply; existing as a discrete subtidal sandbanks feature (JNCC & Natural England, 2010a).

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[5] A split between presence of infrastructure and abrasion is not provided. The mapping of this feature has been improved and updated since the last Article 17 reporting round. There is also a new definition of sandbanks for some offshore marine protected areas where troughs of the banks included in addition to the actual elevated sandbanks. As a result of improved mapping and a definition change, the surface area of range for sandbanks has changed from 103,943 km² to 105,785 km²; an increase of 1,841 km².

An Annex I designated subtidal sandbank feature, that can be considered to be unique in the context of all other subtidal sandbanks in UK waters, is the subtidal sandbanks designated feature of Dogger Bank SAC (DB SAC), located in the southern North Sea[6]. Dogger Bank itself would not be classified as a subtidal sandbanks feature based entirely upon its geology and geomorphology. It is actually a deposit of sediment overlying a post-glacial Holocene deposit i.e. it is not constituted of marine ‘sandy’ sediment throughout its three-dimensional section. However, the depth of surficial sediment is deep enough to support subtidal sandbanks infaunal communities. The elevation of the banked feature in the southern North Sea water column (averaging 13 m below Chart Datum (bCD)), means that the feature, and associated habitats, function biologically and ecologically in the same way as more ‘classic’ nearshore and offshore subtidal sandbanks features. These factors meet the requirements of the EUR28 feature definition:

“…**where sandy sediments occur in a layer over hard substrata [these features can be] classed as sandbanks if the associated biota are dependent on the sand rather than on the underlying hard substrata**.”

Dogger Bank is so remote from any possible interaction with seabed sediment transport systems (150 km northeast of the Humber Estuary), and nearshore sediment transport processes, and deep (the designated feature extends down to 58 m bCD), that it is in effect a relict feature; discrete and completely disconnected from any, and all other, subtidal sandbanks features, and supporting physical processes, in the North Sea.

Whilst geomorphological processes such as nearbed sediment supply and transport systems, may no longer be integral to supporting and maintaining the physical structure and function of a proportion of the nearshore and offshore subtidal sandbanks features, other processes, such as, tide-related hydrodynamic flows, do continue to interact with these physical structures. Seabed physical features, such as sandwaves, ‘move through’ MPAs that contain subtidal sandbanks features, transiting around, and up, and across these structures. This mobility of surficial sediments influences the types and ranges of benthic communities and biotopes that are considered to be sub-features (where appropriate[7]), of the subtidal sandbanks feature themselves. These physical processes

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[6] For the purposes of this report it is important to note that the Dogger Bank physical feature itself is sometimes considered in its entirety as a physical seabed feature. The Dogger Bank SAC does not encompass the full extent of the Dogger Bank feature itself – some parts of that physical feature are outside the boundary of the Dogger Bank SAC. Where the designated subtidal sandbanks feature within the Dogger Bank SAC is being discussed, that is referenced as Dogger Bank SAC or the feature of the DB SAC.

[7] JNCC does specifically relate site conservation objectives to sub-features. The conservation advice focuses on high-level habitat attributes, compared to Natural England’s use of biotopes related as distinct sub-features of the subtidal sandbanks habitat itself; where these fine-scale sub-features are known.

and interactions can be a significant structural force on the localised extent and distribution of the benthic sub-features within an MPA.

Annex I subtidal sandbanks (and associated sub-features, where considered), are also associated with wider ecosystem services. This is particularly the case for far-ranging foraging populations of species afforded conservation status in other MPAs. This could be important in the context of numerous classified Special Protection Area (SPA) populations of seabirds and designated Annex II populations of pinnipeds and cetacean species; such as northern gannet *Morus bassanus*, black-legged kittiwake *Rissa tridactyla*, lesser black-backed gull *Larus fuscus*, various tern species and auk species are all recorded foraging within all four SACs considered in this report. These classified populations are associated with, but not limited to, SPAs such as; Flamborough and Filey Coast SPA, Humber Estuary SPA, North Norfolk Coast SPA, Alde-Ore Estuary SPA etc.

Similarly, harbour seal *Phoca vitulina* (S1365) and grey seal *Halichoerus grypus* (S1364) designated populations of The Wash SAC, and the Humber Estuary SAC and North Norfolk Coast SAC, respectively. These MPA populations interact with Inner Dowsing, Race Bank and North Ridge SAC (IDRBNR SAC). Also, the harbour porpoise *Phocoena phocoena* (S1351) designated population of the Southern North Sea SAC (SNS SAC) interacts with several MPAs (SACs) for which subtidal sandbanks are primary designated features e.g. DB SAC, North Norfolk Sandbanks and Saturn Reef SAC (NNSSR SAC), and HHW SAC. This is important to consider, as the designated Annex I habitat features also contribute to conservation objectives for those designated Annex II populations through their own MPA-specific conservation objectives[8]. This is primarily associated with subtidal sandbanks enabling provision of/supporting habitat for prey species that those designated populations predate.

Many of the nearshore and offshore MPAs designated for subtidal sandbanks features also fall within the foraging ranges of classified populations of seabirds from coastal and nearshore MPAs, such as Special Protection Areas (SPAs) and Marine Conservation Zones (MCZs). Notably, these interactions occur in the North Sea with DB SAC, IDRBNR SAC, NNSSR SAC and HHW SAC; along with MLS SAC.

Where possible, observations relevant to these other MPAs, and their prey-related conservation objectives, are considered within this report.

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[8] It may be relevant for Natural England and JNCC for a link to be made between this report and outputs from a project that JNCC commissioned end of financial year 2022-23 regarding consideration of conservation object 3 (CO3) for SNS SAC – i.e. habitat supporting prey species for the designated Annex II population of harbour porpoise.

In the North Sea, all of the MPAs with designated subtidal sandbanks habitat features have some degree of anthropogenic hard substrata[9] associated with them. There is a legacy of anthropogenic structures that have historically interacted with these physical seabed features. At the time of designation these historic deposits and footprints were generally not considered to result in unfavourable condition, or a requirement for restorative conservation objectives to be proposed for the sites.

The environmental conditions in this area make it highly attractive to developments, initially relating to oil and gas fields and more recently offshore renewables. Development pressure is already significant and likely to intensify following the publication of the British Energy Security Strategy.

Some MPAs, such as NNSSR SAC and HHW SAC, have O&G infrastructure integrally associated with their designated subtidal sandbanks features; with well-heads, platform jacket footprints, scour protection pads (SPPs), pipelines, and a variety of hard substrata securing exposed sections of pipelines installed before designation. Since designation, much of this infrastructure has been subject to decommissioning.

In addition, the post-designation construction of offshore wind farms (OWFs) have introduced wind turbine generator (WTG) monopile foundations, offshore sub-station (OSS) jackets, and associated SPPs, along with rock berms and rock bags securing inter-array cables and export (transmission) cables.

This post-designation OWF construction has, however, become an ongoing, additive process with additional infrastructure material being laid down mainly associated with Operations and Maintenance (O&M) activities (and associated consenting/licence applications/variations to existing licenses).

In addition, there are reasonably foreseeable plans and projects associated with new additions of anthropogenic structures, along with decommissioning of existing infrastructure.

As stated, at the time of designation in the late 2000s, each of the subtidal sandbanks MPAs in the North Sea were originally considered to be in favourable condition (with the exception of NNSSR SAC), and thus predominantly with ‘maintain’ conservation objectives. Subsequent to designation, changes in perception of pressures exerted by both ongoing, and new activities, has resulted in a shift of condition assessment from

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[9] For this report the physical nature of a material is considered as substratum (singular) and substrata (plural), rather than the use of the term ‘substrate’ which is considered ostensibly as terminology derived from the study of chemistry.

favourable to unfavourable. This has subsequently linked to changes in MPA-specific conservation objectives advice, from maintain, to restore, for these sites.

Recovery from physical impacts for these types of sandbanks will depend on prevailing environmental conditions, on-going additional disturbance from human activities, habitat resilience, species life history traits, environmental connectivity between populations and habitat suitability, and the longevity of the environmental pressures associated with the anthropogenic infrastructure.

Due to the aforementioned interaction of subtidal sandbanks with O&M projects, and reasonably foreseeable plans and projects, there is an on-going stream of Marine Licence (ML), deemed Marine Licence (dML), and Development Consent Order (DCO) casework interacting with designated sandbanks in the southern North Sea. This is generally related to the addition of hard substrata into the MPAs associated with existing O&M pipeline integrity and cable protection, along with the construction and installation phases of new projects. It is recognised that protection associated with seabed infrastructure projects is a not an immaterial issue regarding the appropriate management advice concerning MPAs with subtidal sandbanks features, the condition of many of these features, and their associated Favourable Conservation Status (FCS)[10].

In-combination effects associated with rock protection deposited by ‘energy’ infrastructure on benthic habitats is currently the main focus for potential adverse effects on the integrity of sandbanks sites. Of greatest concern are cable protection rock berms (inter-array and export cable) and SPPs associated with OWF O&M, and foreseeable plans and projects. The effects of these infrastructure protection measures are currently a reason why several MPAs are advised as being in unfavourable condition:

“…**it is a reason why several offshore wind projects have required government derogation and is driving a large strategic habitat compensation programme, it is also an important factor controlling where offshore wind farms are built.**” – Natural England’s Request for Quote (RfQ) for this project.

The effects of O&G infrastructure, and their historic and on-going interaction with subtidal sandbanks features, will also be of significance in considering the impacts of OWF. The focus developed over the last few years concerning the decommissioning of O&G infrastructure in the central and southern North Sea fields will continue to ‘ramp up’, and blocks on offer in the 33rd Offshore Licensing Round include those in sandbank habitats. This directly relates to questions concerning the value of removal, or leaving *in situ*,

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[10] As required under Article 17 of the Habitats Directive

platform and well-head infrastructure, pipelines, and rock protection and/or concrete mattresses; particularly in relation to the potential for adverse effects on site integrity[11].

JNCC notes in their Supplementary Advice on Conservation Objectives (SACO) for both DB SAC and NNSSR SAC that they do not consider it likely that human activities taking place within the site have the potential to permanently impact on the large-scale topography of the subtidal sandbanks in those offshore sites. As such, the conservation objectives focus on more localised attributes for the features such as smaller scale topography, characteristic communities, and sediment characteristics. As part of that, JNCC also advises that the extent of the sandbank feature in terms of its sedimentary composition and biological assemblages has been reduced and it continues to be reduced by ongoing activities; albeit by an unquantifiable amount.

Natural England has identified that there is significant uncertainty regarding how infrastructure, and its associated protection, has the potential to affect the conservation objectives of designated subtidal sandbanks habitats; particularly through alteration of extent and distribution. When undertaking subtidal sandbanks condition assessments, Natural England references various ‘attributes’ associated with the MPA’s conservation objectives. These are primarily associated with two ‘tests’:

1. Does the area of rock placement in the site represent a loss in the ‘extent’ or ‘distribution’ of sandbank habitat?; and
2. Is the change in extent and distribution of sandbank (caused by the introduced rocky substrata) significant enough that the integrity of the designated site is adversely affected[12]?

Whilst both of these tests focus on loss or change in extent of the habitat feature, and its distribution within the MPA being assessed, other attributes such as maintaining the structure and function of subtidal sandbank features (both the physical/geomorphological and ecological aspects) may actually prove to be more appropriate/useful metrics for determining feature condition, maintain or restore conservation objectives, and testing the potential for adverse effects on site integrity.

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[11] This report makes no consideration of the potential complexities of the asset-owner’s legal liability/risk concerning leaving infrastructure on the seabed in perpetuity. The report is entirely focused on the nuances of nature conservation management and reporting considerations.

[12] As per the tests imposed by Article 6.3 of the EU Habitats Directive Council Directive 92/43/EEC https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31992L0043 of 21 May 1992 (and as amended) and as per the Interpretation Manual of European Union Habitats - EUR28 https://ec.europa.eu/environment/nature/legislation/habitatsdirective/docs/Int_Manual_EU28.pdf

Subtidal Sandbanks Workshop 2021

In recognition of the complexity of the issue, Natural England and JNCC facilitated a workshop (January 2021) which brought together experts on marine infrastructure and subtidal sandbanks feature ecology (Natural England, 2021). The workshop attendees determined that:

"…**there was agreement that some level of seabed change through rock and concrete would adversely affect the structure and function of sandbank sites**." – Natural England, 2021.

However, it was also noted that MPAs with subtidal sandbanks designated features could accommodate some level of seabed change without having significant adverse effects on the structure and function. Critically however, there was no agreement on what magnitude of change could result in subtidal sandbanks being affected to a level resulting in feature 'unfavourable' condition, or adverse effects on site integrity (Natural England, 2021).

Natural England noted that:

"**In absence of information outlining the impacts of rock protection on large sandbank sites a relatively precautionary approach was necessarily adopted and the condition of several sandbank MPAs has been determined as unfavourable due to the presence of seabed infrastructure. In addition, several habitats regulations assessments for national infrastructure developments have concluded that the levels of seabed change in some sites, due to rock deposited by infrastructure, are large enough to cause adverse effects on their ecological integrity.**" – Natural England's RfQ for this project.

The workshop attendees observed that the most critical degree of 'uncertainty' is associated with the fact that subtidal sandbanks features, and their associated MPAs, are large in extent, and that the structure and function of these features is dependent upon physical/geomorphological and biological/ecological processes and systems occurring over very large areas (sea-scale and regional-scale).

It is paramount to develop an understanding of the magnitude of effect associated with extents of seabed change associated with anthropogenic infrastructure and its significance; especially when any single project's installation of rock protection can be extremely small when considered as a proportion of the site/feature as a whole (<0.1% of surface area extent of a subtidal sandbank feature); let alone the occurrence of the features as part of the entire National Site Network. Whilst these interactions with feature surface area extent are very small at a feature- or site-scale, the introduction of anthropogenic structures on designated Annex I subtidal sandbanks features could be considered significant at a localised-scale within an area/location of any one particular subtidal sandbank. Natural England are seeking additional evidence to assist an understanding of whether this is critical to the maintenance of the feature's structure and function, and thus the overall MPA site's conservation objectives.

This report is intended to reduce the uncertainty for Natural England associated with delivering its statutory role concerning condition assessments, and given the interaction of site integrity with HRA Stage 2 Appropriate Assessment, and Derogation procedures (Stage 3 Identification of Alternative Solutions, Stage 3 Imperative Reasons of Overriding Public Interest, and compensation measures/packages), also informing HRAs. A focus is to facilitate a practical and realistic precautionary approach where possible. As stated in the RfQ:

"**The level of offshore energy development proposed by the British Energy Security Strategy will result in significant amounts of rock and concrete being placed on the seabed for many years to come. The risks of making the wrong decisions are significant, if we underestimate the impact of seabed change there could lasting damage to our sandbank ecosystems and their associated marine life. Conversely, if we overestimate the effects there could be unnecessary impediments on offshore infrastructure and energy security**." – Natural England's RfQ for this project.

While SNCB monitoring surveys and sector-specific data provide increasing amounts of information about interactions with, and potential impacts upon, designated subtidal sandbanks, there is still a degree of uncertainty concerning levels of effect on this habitat.

This report considers the questions posed around the understanding of anthropogenic infrastructure (from different seabed user sectors) *in situ* on, and within, subtidal sandbanks across several MPAs in the North Sea. It looks at the evidence base for, and the environmental effects of, anthropogenic infrastructure on/with the habitat. The intention is to assist Natural England in its statutory remit concerning advice for condition assessment of subtidal sandbanks designated sites, and the relation to their conservation objectives.

Scope of this report

This report is intended to make observations and recommendations which can be used by Natural England in its statutory role (including MPA site condition assessments). Specifically, the report will assist Natural England in what to consider when determining the significance of effects from deposited hard infrastructure (rock and concrete) on designated Annex I subtidal sandbanks feature extent and distribution.

The recommendations are intended to inform two key points for Natural England:

1. They will directly help inform the decision-making process which underpins the condition assessment; and
2. They will direct what work and future projects need to be undertaken to better understand the impacts of hard infrastructure on subtidal sandbanks integrity (focused on extent and distribution, and structure and function, attributes).

As identified in the RfQ, there are primary ‘tests’ associated with subtidal sandbank designated feature condition assessments:

1. Does the area of rock placement in the site represent a loss in the extent or distribution of sandbank habitat?; and
2. Is the change in extent and distribution of sandbank (caused by the introduced rocky substrata) significant enough that the integrity of the protected site is adversely affected?

The Scope of Works (SoW) for the project poses a series of questions that Natural England would like to answer, as far as it is currently possible to do so. The answers to the questions are provided using various types of literature and research, as well MarineSpace’s expert understanding of marine ecological processes. In addition, the report presents expert understanding of physical and geomorphological processes that are of paramount significance for the project deliverables.

In addition, Natural England has sought views/suggestions concerning what information it should obtain, and any associated analyses could be undertaken, to achieve a more comprehensive answer to the questions posed.

This report considers the questions posed around the understanding of anthropogenic infrastructure (from different seabed user sectors) *in situ* on, and within, subtidal sandbanks across four MPAs in the North Sea; Dogger Bank (DB) Special Area of Conservation (SAC), Inner Dowsing, Race Bank and North Ridge SAC (IDRBNR SAC), North Norfolk Sandbanks and Saturn Reef SAC (NNSSR SAC), and Haisborough, Hammond and Winterton SAC (HHW SAC).

A systematic evidence review of pertinent literature and publicly accessible data has been conducted. This covers physical and ecological considerations relevant to subtidal sandbanks features and associated MPAs, along with the evidence base to enable proposed observations and recommendations in relation to the project’s SoW.

No statements regarding environmental effects of deposited hard infrastructure (rock and concrete) in the nearshore environment and the status of coastal erosion should be inferred from this report. The SoW is entirely focused on the determining the significance of effects from hard infrastructure on designated Annex I subtidal sandbanks features, and associated condition assessments.

Methodology

Literature and dataset acquisition and review

A systematic evidence review was conducted using relevant publicly available primary and grey literature, data sources, and datasets. The initial focus of the evidence review has included relevant information and source material identified within the Natural England (2021) workshop report. This has then been expanded based upon MarineSpace's Project Team's expert knowledge.

The initial data search focused on specific sources available for MPAs (SACs and their designated Annex I subtidal sandbanks habitat features) in the North Sea; to ensure the most relevant available data are obtained. Information concerning regional-scale models and understanding of sediment transport processes have also been identified (so far as is reasonably practicable to do so). Constraints associated with data/information concerning known footprints of anthropogenic infrastructure have also been identified.

Considering the SoW, the following areas were the focus of data collation:

- Hard substrata emplacement activities known to have occurred to date within the four MPAs as identified with Natural England;
- The physical and biological environment within the four MPAs as identified with Natural England, including a review of physical functionality of those site-specific subtidal sandbanks;
- Sensitivity of key receptor features (and sub-features for MPAs predominantly within inshore waters where Natural England was the 'lead' designation agency (sub-feature biotopes)), associated with subtidal sandbanks (and including 'offshore' advice from JNCC);
    - Achieved by searching the Supplementary Advice on Conservation Objectives (SACOs) and Advice on Operations from Natural England and JNCC;
    - With a focus on the "Physical change (to another seabed type)" pressure;
- Marine Evidence based Sensitivity Assessment (MarESA), and other known sources of species sensitivity assessment;
- Condition assessments of designated subtidal sandbanks (and those providing supporting habitat for other MPAs with far-ranging populations) in relation to environmental effects associated hard substrata infrastructure;
- Existing mitigation practices, based on knowledge and implementation in both UK waters, and abroad, where appropriate; and
- SNCB literature and reports regarding previous projects involving subtidal sandbanks.

The evidence review has been conducted by 'keyword' and 'citation' pursuit searches of Scopus and Google Scholar.

Gap analysis and confidence assessment

A confidence assessment was conducted during the evidence review, followed by a gap analysis, to identify potential data limitations and gaps in understanding/knowledge.

As part of the review, MarineSpace has conducted a Confidence Assessment of the literature (presented in Appendix 1). The confidence assessment has been adapted from Kvile and others (2014). It provides a semi-quantitative assessment of the quality and applicability of the literature used or identified in the Project.

Data and literature attributes were assigned as per Table 1.

Table 1: Data and literature review attributes

Vintage	Resolution	Spatial Overlap	Document Type	Evidence Type
1 = >20 years old	1 = Not topic specific, however high level information can be utilised to inform evidence review.	1 = Poor Spatial overlap with Study Area(s)	1 = Non-Professional	1 = Non quantified, expert opinion, formal consensus
2 = 11 ≤ 20 years old	2 = Not topic specific, however proxies can be used (e.g. proxy species, activities) to confidently inform the evidence review.	2 = Reasonable spatial overlap with Study Area(s)	2 = Commercial/ Industry	2 = Case studies, semi-quantified
3 = ≤ 10 years old	3 = Topic specific information available and relevant for evidence review(e.g. for a	3 = High spatial overlap with Study Area(s)	3 = Independent Peer-reviewed or Government Report	3 = Quantified detailed meta-analysis (multiple data sets) and/or systematic review (e.g. long-term data

Vintage	Resolution	Spatial Overlap	Document Type	Evidence Type
	given receptor, activity, impact pathway, or Study Area etc.)			sets, repeated sampling)

The quality of the information available for each attribute was scored on a scale of 1-3, as presented in Table 1.

Summing the various scores for all of the attributes results in a ‘total confidence score’. For the purposes of this report, and the associated SoW, a score of ≥10 represents data, literature or information that is deemed appropriate to inform a robust evidence base and subsequent determinations.

The literature review process had the potential to identify information gaps or areas of disparity between particular sources of information. Where appropriate this has been taken into consideration during the Confidence Assessment process. The data and literature review spreadsheet is presented in Appendix 1.

Evidence review: Existing hard substrata in subtidal sandbanks sites to date

This section describes the structures typically used within offshore marine developments (projects) that are likely to introduce hard substrata onto, or within, the seabed. It also provides a high-level overview of the design parameters (associated with rock berms) that must be considered when determining the material and scale of hard substrata required to be installed.

Hard substrata can be utilised in numerous ways, ranging from concrete gravity base foundations for WTGs, to the use of rock bags and grout bags for prevention of isolated seabed scour around cables and pipelines. Rock berms, Scour Protection Pads (SPPs), and concrete mattresses, are used in most offshore development industries to stabilise and protect structures. The design parameters of these types of protection are inherently project- and local environment-driven, and thus variable in design. This section focusses on the general principles of rock berm design.

Design parameters

The considerations around the design parameters of hard substrata are made based on physical (metocean and geophysical) factors. One of the most common vectors of introducing hard substrata is through the practice of rock emplacement. This technique is used to create berms for cable or pipeline stabilisation, punch-through and hang-up remediation foundations for jack-up vessels and drilling rigs, and as a remedial measure to mitigate against seabed scour around existing structures.

Environmental costs associated with the emplacement of any hard substrata on subtidal sandbanks may include the following:

- The physical alteration of habitat and loss of associated fauna through the preparation of seabed prior to emplacement of hard substrata;
- The potential loss of subtidal sandbank habitat within the footprint of the emplaced hard substrata on the seabed;
- The physical alteration of near-bed physical processes (such as increased or decreased water velocity) and associated water quality parameters (e.g. oxygen concentration); and
- Indirect effects (e.g. the artificial reef effect) that may result in alteration of nutrient availability or trophic interactions.

Whilst rock berms and concrete mattresses represent the most likely source of surficial hard substrata on subtidal sandbanks (as opposed to buried within the seabed), other structures may be present.

Rock berms

The design parameters for rock emplacement are dependent on site-specific physical processes, substrate type, and the functional requirements of the emplaced rock. As an example, physical factors associated with rock berm design considerations are listed below:

- Significant wave height (H_s (m)) – the greater the significant wave height, the more energy is present within the water column and therefore the larger the footprint and volume of the rock required to ensure berm stability;
- Wave frequency (F (Hz)) or wave period (T_m (s)) – the greater the frequency (or smaller the period) of waves, the more energy is present within the water column and therefore the larger the footprint and volume of the rock required to ensure berm stability;
- Water depth above the structure (h_c (m)) - the shallower the water depth, the larger the footprint and volume of the rock required to ensure berm stability;
- Near-bed current velocity (u (m/s)) or depth-average velocity (U (m/s)) – the greater the velocity of moving water, the more energy is present within the water column and therefore the larger the footprint and volume of the rock required to ensure berm stability;
- Bed shear stress (T_C (N/m²)) or shear velocity (u* (m/s)) – the greater the profile of the berm, the greater the shear stress or shear velocity exerted by consequent changes in water flow (e.g. vortices) compared to a flat seabed plane, and thus the greater the risk of scour and/or instability of the rock berm; and
- Shear stress due to waves (T_W (N/m²)) – the greater the shear stress due to waves, the more energy is present within the water column and therefore the larger the footprint and volume of the rock required to ensure berm stability.

The footprint and volume of emplaced rock are not the only design parameters considered when ensuring the stability of rock berms. Other factors considered as part of the design include:

- Sieve size (D (m)) or nominal diameter (Dn (m)) of rock;
- Mass (m (kg)) of rock;
- Relative buoyancy (B (N)) of rock; and
- Slope angle (α (degrees)) or height: width ratio of the rock berm.

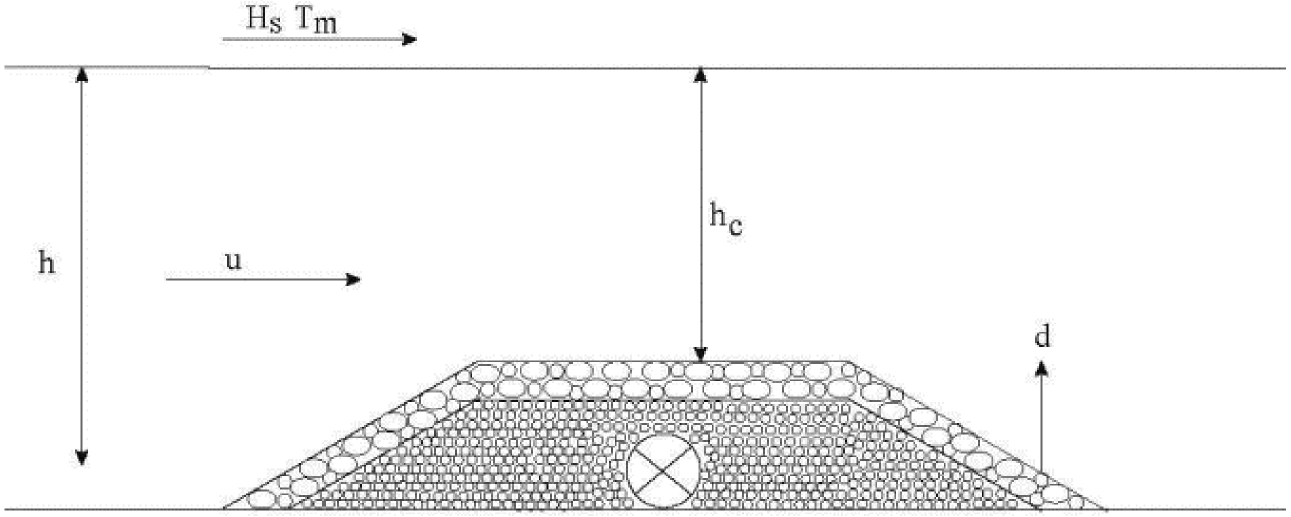

Figure 1: A cross-sectional schematic drawing of a typical rock berm used to protect offshore pipelines laid on the seabed. The design of the rock berm is dependent on a number of key parameters, including depth (h), near-bed current velocity (u), significant wave height (H_s) and period (T_m), depth of the berm crest (h_c) and the diameter of the armour stone (d). From Pidduck and others, 2017

Rock berm designs can be considered static or dynamic, dependent on the mobility of the sediments upon which they are emplaced. Static designs assume that a limited percentage of rock is moved by natural processes, and would be primarily utilised within stable environments. Conversely, dynamic designs allow for the natural settlement of rock in a stable position as a result of natural processes (Chamizo and others, 2012); and would be primarily utilised to stabilise structures in the long term (i.e. would not be used as a seabed scour or stability remediation measure). In the case of a stable rock berm design, the size and relative buoyancy of rock is fundamental to ensuring that the berm is not going to be influenced by near-bed physical factors. Upon calculating the critical shear threshold for the rock berm construction material, an amplification factor must be applied to ensure the stability of the material is sufficient to ensure the stability of the rock berm structure itself.

The stability of a rock berm can be managed by altering the slope angle of the berm (by changing footprint and height) to minimise cost and potential for environmental impacts associated with the introduction of hard substrata onto the seabed. For example, a typical protective berm for an offshore pipeline would have a slope ratio of 1:2.5 and a height of 0.6 m (CIRIA, CUR, CETMEF, 2007). However, some rock berms are designed with shallower slope ratios (e.g. 1:3 or 1:4) to increase stability of the rock berm itself, resulting in an increased footprint and consequently an increased monetary and/or environmental cost.

Concrete mattresses

Concrete mattresses form an alternative protection system (to rock berms) that is commonly used to add weight and stabilisation to seabed objects, prevent scour, and provide cross-over support and separation for pipelines and umbilicals. They are composed of series of pre-made mattresses of sizes often around 6 m x 3 m x 0.15/0.3 m, and are designed to be flexible. The mattresses are connected together by either ultraviolet stabilised polypropylene rope or more recent non-plastic alternatives.

Concrete mattress design can be more adaptable than that of rock berms, for example, in the addition of buoyant fronds composed of polypropylene or other non-plastic material, The fronds create a drag barrier to reduce current velocity and cause sediment to accumulate on top of the mattress[13].

Unlike rock berms, concrete mattresses have the potential to be repositioned after initial installation if damage or failure occurs, and they are potentially removable at decommissioning.

Stability of mattresses on the seabed relates to:

- Degree of embedding of the mattress into the sediment, particularly when the corners of the mattress become covered over;
- Orientation to seabed slope, with risk of mattresses sliding increasing when they are placed on slopes or over structures subjected to different forces from those laid flat on the seabed;
- Orientation and placement on underlying assets, for example, a mattress placed with its edge too close to the pipeline may have a lower resistance to the edge of that mattress flipping (Godbold, Sackmann & Cheng, 2014);
- Proximity to nearby structures and the changes they represent in shear stress and water particle velocities. Mattresses which may be stable under given hydrodynamic load conditions become unstable when placed around / adjacent to a structure (Godbold, Sackmann & Cheng, 2014);
    - This is particularly important to consider when the concrete mattresses are placed around a structure for scour protection or stabilisation of that structure;
- Density, shape, and dimensions of the mattress; and
- Use of edge lift straps.

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[13] Note that fronds on concrete mattresses use the same physical processes for trapping sediment as frond mats.

Footprint of hard substrata

Table 2 provides a description of common structures likely to be present *in situ* or proposed *ex situ* as a source of hard substrata on subtidal sandbanks. The seabed footprints associated with subsea cables, pipelines, cable/pipeline protection systems, and cable crossings are dependent on the length and width of the structure, and therefore a ‘typical seabed footprint’ value (in m^2) cannot be accurately determined within Table 2 for these structures.

The seabed footprint of man-made structures, and the associated emplacement of hard substrata, is typically captured as part of the project design envelope (PDE) for marine developments. The PDE accounts for the worst-case scenario for the maximum seabed footprint associated with the development, to be assessed as part of the Environmental Statement, and to provide contingency for engineering and operational limitations. Therefore, the worst-case scenario PDE is generally not representative of the as-laid or *in situ* extent of hard substrata. Furthermore, the exact designs of *in situ* structures such as rock berms and cable crossings are not captured within the PDE before assessment and are not publicly available. Therefore, an evidence gap exists regarding the effects of different rock berm designs within similar environments, in particular with respect to rock berm effects on subtidal sandbanks features.

In addition, legacy offshore wind projects do not necessarily provide a seabed footprint value for transmission assets as a requirement within transmission close out reports following construction, reporting only the volume of material used to create rock berms. The extent of seabed footprint for *in situ* rock berms is inferred from back-calculation using an average berm height and volume, and therefore represents another evidence gap when considering cumulative impacts of multiple *in situ* and proposed development projects on subtidal sandbanks habitat and associated biota.

Table 2: Descriptions of existing structures that may provide a source of hard substrata on subtidal sandbanks. (Sourced from Reach and others, 2012) Peritus International Ltd, 2022)

Structure (including Industry)	Primary materials	Typical seabed footprint (m²)	Description
Monopile foundations **(Offshore wind)**	Steel Grout	12-300 (including scour protection pads)	Steel structures driven into the seabed. Seabed footprint is limited for the pile itself, but associated rock/concrete scour protection pads represent the greatest proportion of maximum seabed footprint.
Concrete gravity base foundations **(Offshore wind)**	Concrete Steel	300-3,500 (including scour protection pads)	Concrete and steel structures with a large seabed footprint.
Jacket/tripod foundations **(Offshore wind)**	Steel	6-500 (including scour protection pads)	Steel frame structures with high complexity. Seabed footprint is limited to 3 or 4 legs per structure, but associated rock/concrete scour protection pads represent the greatest proportion of maximum seabed footprint.
Suction caisson foundations **(Offshore wind)**	Steel Concrete	175-2,000 (including scour protection pads)	Steel and concrete cylinders that are driven into the seabed by water pressure (through the lowing of relative pressure within the cylinder). Seabed footprint is second largest of the fixed foundation methods used in offshore wind developments.

Structure (including Industry)	Primary materials	Typical seabed footprint (m²)	Description
Subsea wellheads and associated protective structure only (excluding any pipeline mattresses) **(Oil and Gas)**	Steel	~30	Steel structures used to seal and access oil and gas wells. Seabed footprint is limited, and minimal after decommissioning.
Pipelines **(Oil and Gas)**	Steel Plastic	Length of pipeline x width of trench/pipeline	Pipelines are typically buried and will have variable seabed footprints dependent on the length of the pipeline and the width of the trench within which the pipeline is buried. Once buried, the seabed footprint of hard substrata is nil until the pipeline is exposed via free spanning.
Subsea cables (surficial or buried) **(Power)**	Plastic	Length of cable x width of trench/cable	Subsea cables can be buried, surficial (on the seabed), or dynamic (in the water column). Buried cables, as with pipelines, will have variable seabed footprints dependent on the length and width of the cable and the width of the trench within which the cable is buried. Once buried, the seabed footprint of hard substrata is nil until the cable is exposed via free spanning or external cable protection is placed.

Structure (including Industry)	Primary materials	Typical seabed footprint (m²)	Description
			NB: power cables have larger widths than telecommunication cables and thus greater surficial seabed footprints.
Subsea cables (surficial or buried) **(Telecommunication)**	Plastic	Length of cable x width of trench/cable	Subsea cables can be buried, surficial (on the seabed), or dynamic (in the water column). Buried cables, as with pipelines, will have variable seabed footprints dependent on the length and width of the cable and the width of the trench within which the cable is buried. Once buried, the seabed footprint of hard substrata is nil until the cable is exposed via free spanning or external cable protection is placed. NB: telecommunication cables have smaller widths than power cables and thus lesser surficial seabed footprints.
Subsea cable/pipeline protection/stabilisation systems **(Various industries)**	Rock Concrete Grout Plastic Bitumen	Length x width of rock berm/rock bag/scour protection pad/concrete mattress/frond mattress/bitumen mattress (legacy)	Subsea cable/pipeline protection takes numerous forms; however, rock berms generally represent the maximum potential seabed footprint of all cable/pipeline protection/stabilisation systems.

Structure (including Industry)	Primary materials	Typical seabed footprint (m²)	Description
Subsea cable crossings **(Various industries)**	Rock Concrete	Length x width of rock berm/concrete bridge	Subsea cable crossings are mandatorily protected, typically from, or supported by, rock berms; however, some applications utilise concrete bridges. Rock berms represent the maximum potential seabed footprint. NB: Amounts of protection can be mitigated by reducing number of crossings where possible.

Evidence review: Known substrata emplacement

Each of the MPAs that are the subject of this report have hard substrata placed within them, currently have rock emplacement activities, and/or are the subject of future emplacement of hard substrata. However, data on substrate emplacement is dispersed across several maritime sectors and different maintained databases. Data held within these different sources is maintained for different regulatory, operational, licensing, lease and reporting requirements, and there is currently no single coordinated, cross-sectoral source, or data integration, that is publicly available.

Available data sources

There is not a complete understanding of hard substrata associated with offshore development within the UK. However, there are several sectoral datasets, data collection activities, and projects that might form part of a resource; to develop a comprehensive understanding, and a collated database.

1) OPRED's Technical Note "Review of rock and other protective material use in offshore oil and gas operations in the UK Continental Shelf" (undertaken by Genesis) to assess the current status of deposits made on the United Kingdom Continental Shelf (UKCS), through compilation and analysis of the offshore oil and gas industry deposit returns data, providing a report on the location, volume and extent of the protection material used. The data provided by OPRED covers the period 2011–2016. Prior to 2013, data were created from Petroleum Operations Notice No. 15. From 2013, data were provided from the Portal Environmental Tracking System (PETS);
2) Intertek's 2020 collation exercise reported as MBIEG (2020) which sought to collate information from a range of sources on the location of deposited protection around offshore windfarm installations and protection systems applied to cable installations;
3) RPS Ltd and The Crown Estate's (RPS/TCE) study on cable connections and protection (RPS 2019) to collate information on offshore electrical cable installation techniques and seabed recovery, in support of the Plan Level Habitats Regulations Assessment (HRA) for Offshore Wind Leasing Round 4;
4) MMO's Public Register containing the particulars prescribed in the Marine Licensing (Register of Licence Information) Regulations 2011;
5) National Significant Infrastructure Projects (NSIP) Register provides access to all NSIP projects registered with the Planning Inspectorate including documentation associated with project applications that are planned to be submitted, those under examination and those on which a decision has been made to grant or refuse development consent;

6) OPRED Decommissioning Hub provides a list of proposed and existing decommissioning programmes;
7) Kingfisher Information Service Offshore Renewables and Cables Awareness Map and Plotter data (KIS-ORCA) maps and data maintained for the fishing community The database is a is a joint initiative between the European Subsea Cables Association (ESCA) and the Kingfisher Information Service of Seafish;
8) Oil and Gas Authority/North Sea Transition Authority: National Data repository provided by the Oil and Gas Authority;
9) OSPAR Inventory of offshore installation plans;
10) Admiralty Marine Data Portal allows access to UKHO data relevant to marine navigation; and
11) Crown Estate: Marine Data Exchange When an offshore Agreement is entered into with The Crown Estate, an obligation to provide survey data collected in respect of the Agreement is included in the data clause.

Results from OPRED's Technical Note

OPRED's Technical Note provides a series of data tables and basic analysis of worst-case scenario protection emplacement but only from one short period of time for offshore oil and gas operations in the UK Continental Shelf[14]. Of particular relevance here are the two tables reproduced below (for the MPAs being considered in this report), showing total area impacted by seabed deposits associated with O&G activity on the UKCS (2011–2016) (Table 3) within Protected Areas and total area impacted by deposits on the UKCS (2013–2016) (Table 4) by sea area and type of material used.

Table 3: Total Area Impacted by Seabed Deposits on the UKCS within Protected Areas by Oil and Gas activity (2011–2016).

	Total areas of designated site (m^2)	Total area impacted by deposits (m^2)	Area of impact as a percentage of designated site (%)
DB SAC	12,337,180,118	64,763	0.000525
HHW SAC	1,468,698,947	44,299	0.003016

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[14] It is important to note that this only represents one single sector's evidence, and for a very short time period within that industry's history. True values/figures for the SACs are going to be larger.

	Total areas of designated site (m^2)	Total area impacted by deposits (m^2)	Area of impact as a percentage of designated site (%)
NNSSR SAC	3,609,157,647	48,268	0.001337
SNS SAC	36,942,100,161	195,369	0.00053

Table 4: Total Area Impacted by Deposits on the UKCS by Oil and Gas activity (2013–2016); by Defined Sea Area and Type of Material Used.

	Clean inert rock (m^2)	Gravel (m^2)	Hessian bags containing grout (m^2)	Hessian bags containing sand (m^2)	Mattresses (m^2)	Other (not specified) (m^2)	Total
DB SAC	56,706	4,904	147	-	3,006	-	64,763
HHW SAC	6,909	-	-	-	-	-	6,909
NNSSR SAC	42,670	3,303	-	-	592	528	47,903

Data availability

While BEIS (2021) and MBIEG (2020) have started to address the data gap regarding placement of hard substrata in the southern North Sea subtidal sandbanks MPAs, two major issues need to be addressed; to enable an understanding of the complete areas of extent and volumes of as-laid material, in-combination. These are:

- Availability of **all** as-laid footprint data for O&G operations, O&G decommissioning, OWF projects, and subsea cable projects;
    - This will include understanding the full lifecycle of each project from construction to the end of decommissioning, including knowledge of whether hard substrata placement is temporary, long-term (lasting) temporary or permanent;
- Availability of comparable data;
    - When as-laid data for OWFs are available, extents and volumes are very often inconsistently reported between generation assets and transmission assets;

- With generation assets reporting seabed area extent and volume of rock installed, compared to transmission assets, where most often only the volume of rock is reported. Project-specific variations in berm designs make back-calculating volumes to seabed area footprint very challenging.

Southern North Sea sandbank systems

Subtidal sandbanks can be classified by their physical functionality/geomorphological activity. Some subtidal sandbanks are still actively associated with coastal and nearshore physical processes. These topographical features are evidencing small-scale bed mobility through the presence of fields of megaripples and sandwaves on their flanks and sand ribbons showing across-bank transport. In some cases, the physical footprint and extent, and local-scale geospatial position, may vary/fluctuate. These types of subtidal sandbanks are referred to as ‘active’ banks.

In contrast, many subtidal sandbanks in the UK nearshore and offshore environments are no longer associated with active coastal physical processes. These features are effectively dissociated from active sediment supply, are discrete self-supporting physical seabed features, and are considered to be ‘moribund’ or ‘relict’ (Stride, 1982). This distinction is critical in understanding temporal significance of impact, and so is elaborated further below.

In this section (and associated sub-sections) the names of subtidal sandbanks relate to the physical marine systems themselves, and not inherently the SACs after which systems those sites are named i.e. parts of The Dogger Bank extend beyond the boundary of the Dogger Bank SAC.

Regional Geomorphology of the southern North Sea

The Dogger Bank (DB), Inner Dowsing, Race Bank and North Ridge (IDRBNR), North Norfolk Sandbanks and Saturn Reef (NNSSR), Haisborough, Hammond and Winterton (HHW), are four large-scale marine sandbank systems located in the southern North Sea, off the East Yorkshire, Lincolnshire, and Norfolk. In this region, Holocene sediments generally form a thin drape that overlies Pleistocene deposits and so the modern seabed, in general, approximates to the pre-Holocene landscape (Limpenny and others, 2011). The Pleistocene and Holocene sediments are largely derived from glaciogenic or fluvial sources (HR Wallingford, 2002); composed primarily of sandy materials although gravel deposits are also relatively widespread. These Late Quaternary sediments are generally relatively thin, excluding the thick sediment deposits forming the sandbank features, and bedrock is commonly present within 20 m of the seabed (Harrison, 1992).

Southern North Sea sandbank morphology

It is fundamental for SNCB staff to understand the large-scale overriding geophysical (geomorphological) processes that influence the extent and distribution (and structure and function) of subtidal sandbanks features.

Dyer & Huntley (1999) classify the IDRBNR, NNSSR, and HHW sandbanks to be Type 3A alternating ridges. These form where there is active retreat of a headland and sediment sources due to relative sea-level (RSL), resulting in an elongated spit behind which a flood channel develops. The ridge gradually extends offshore and becomes separated by a landward trough formed through tidal current erosion, leaving banner banks offshore that continue to respond to the flow field resulting from tidal or storm induced currents (Swift, 1975). Differing erosional rates either side of the headland as the ridge develops and separates may result in consequent ridges forming on either side. These ridges guide the flow and produce ebb-flood avoidance channels which are sub-parallel to the primary ridge, creating ‘V’- or ‘S’-shaped features termed “alternating ridges”, as most clearly seen in the HHW sandbank system. The connecting shoals between the main banks are formed by ‘tails’ of sand waves that are either flood- (running west to east) or ebb- (running east to west) oriented (Burningham & French, 2016). These parabolic terminal banks may consequently ‘blow out’ to leave a set of parallel linear open shelf features again seen in bathymetry data across all three sandbank regions.

Following from the alternating ridges model of Dyer & Huntley (1999) it would be expected that beneath these sedimentary banks, bedrock cores of the relict headlands would be present. Preliminary analysis by MarineSpace (unpublished) of seismic lines crossing the sandbank systems that have been acquired (from the British Geological Survey GeoIndex Offshore portal) since the work of Dyer & Huntley (1999) show no such high-amplitude reflections representing these headlands. It is therefore likely that these banks formed through a more complex interaction of processes rather than the simple alternating ridges model. The initiation of the bank deposits may have instead completely resulted from the reworking of tidal flat and glacial deposits without the control of a headland due to seafloor erosional processes (Cooper, 2008). Therefore, whilst the initiation of the banks can be attributed to a post-glacial transgression, subsequent analysis is required to better understand their early formation.

Inner Dowsing, Race Bank and North Ridge marine sandbank system

The Inner Dowsing, Race Bank and North Ridge sandbank system is located off the South Lincolnshire coast (

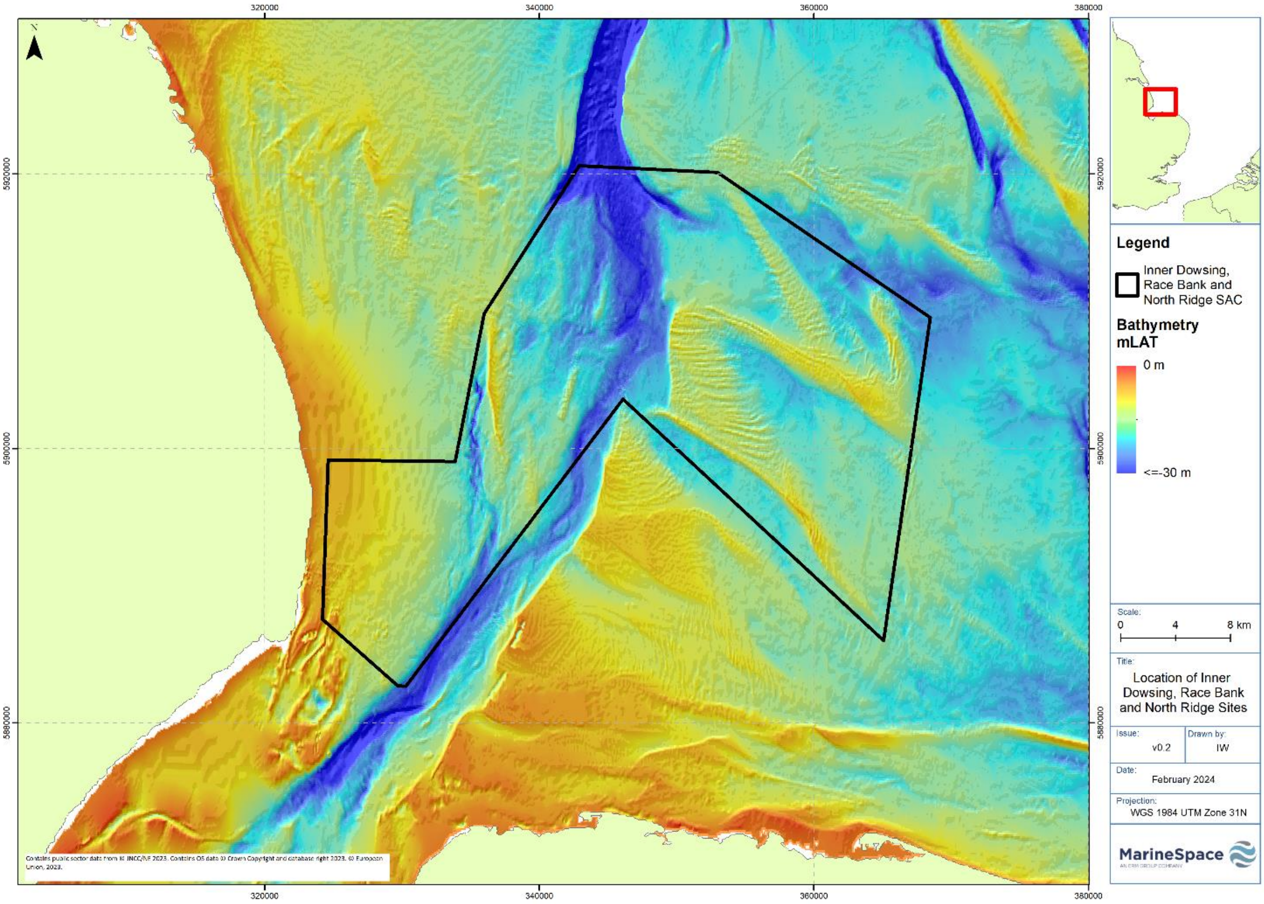

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Figure **2**). The area holds a significant position at the entrance to The Wash, influencing tidal flows and sediment transport processes into The Wash and along the Norfolk Coastline (JNCC & Natural England, Special Area of Conservation (SAC): Inner Dowsing, Race Bank and North Ridge, 2010). Across the site water depths are mostly less than -30 mLAT, with crest heights beaching less than -5 mLAT. In contrast to sandbank systems further offshore, the IDRB group of banks lies almost entirely upon the glacial till of the Bolders Bank Formation. The surrounding surface therefore displays a greater topography than the wider region, with a number of basal mounds and channel-like hollow features forming the basal surface, which later infilled with bank sediment (Cooper, 2008).

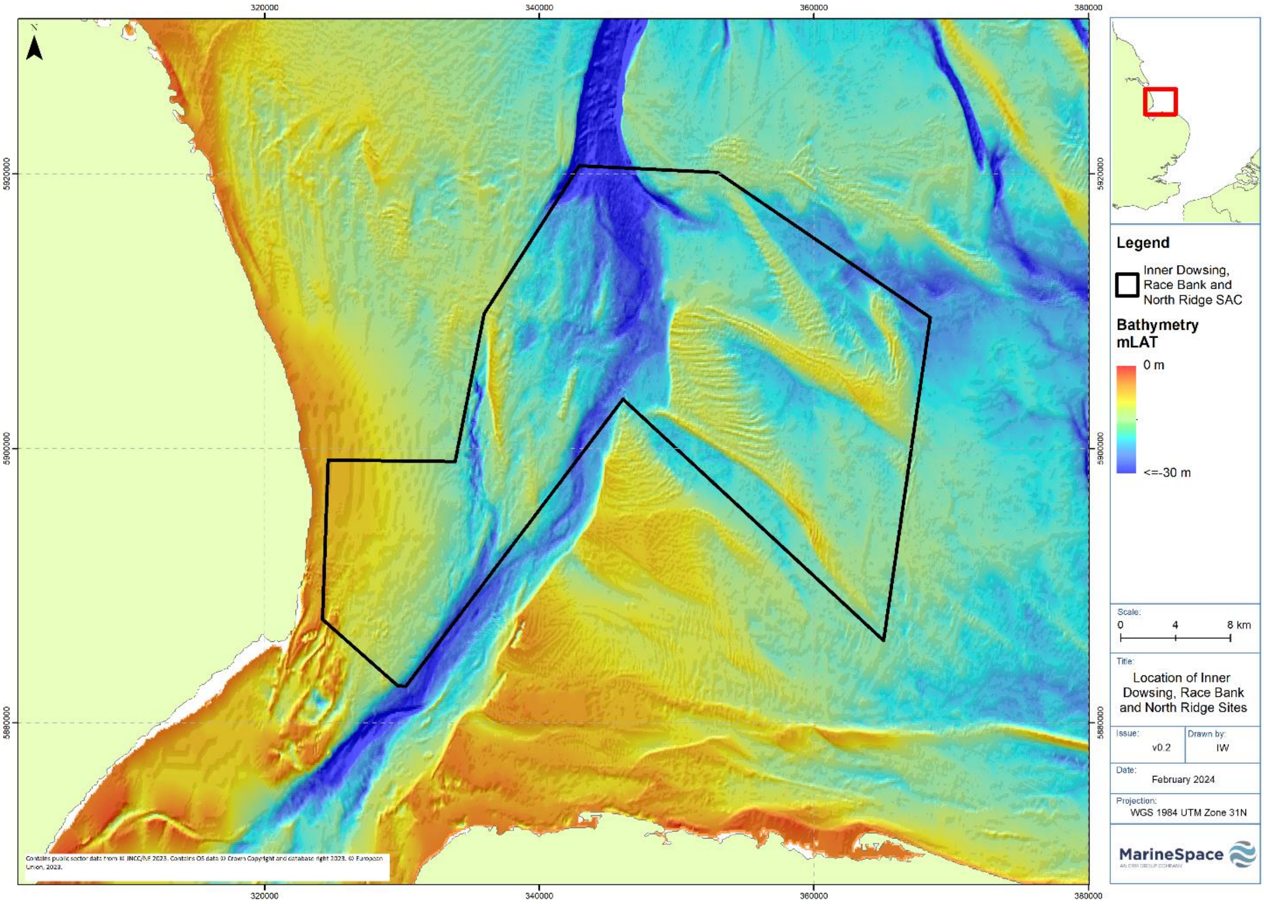


Figure 2: The Inner Dowsing, Race Bank and North Ridge site. From JNCC & Natural England (2010). Contains public sector data from © JNCC/NE 2023 Crown Copyright and database right 2023. © European Union

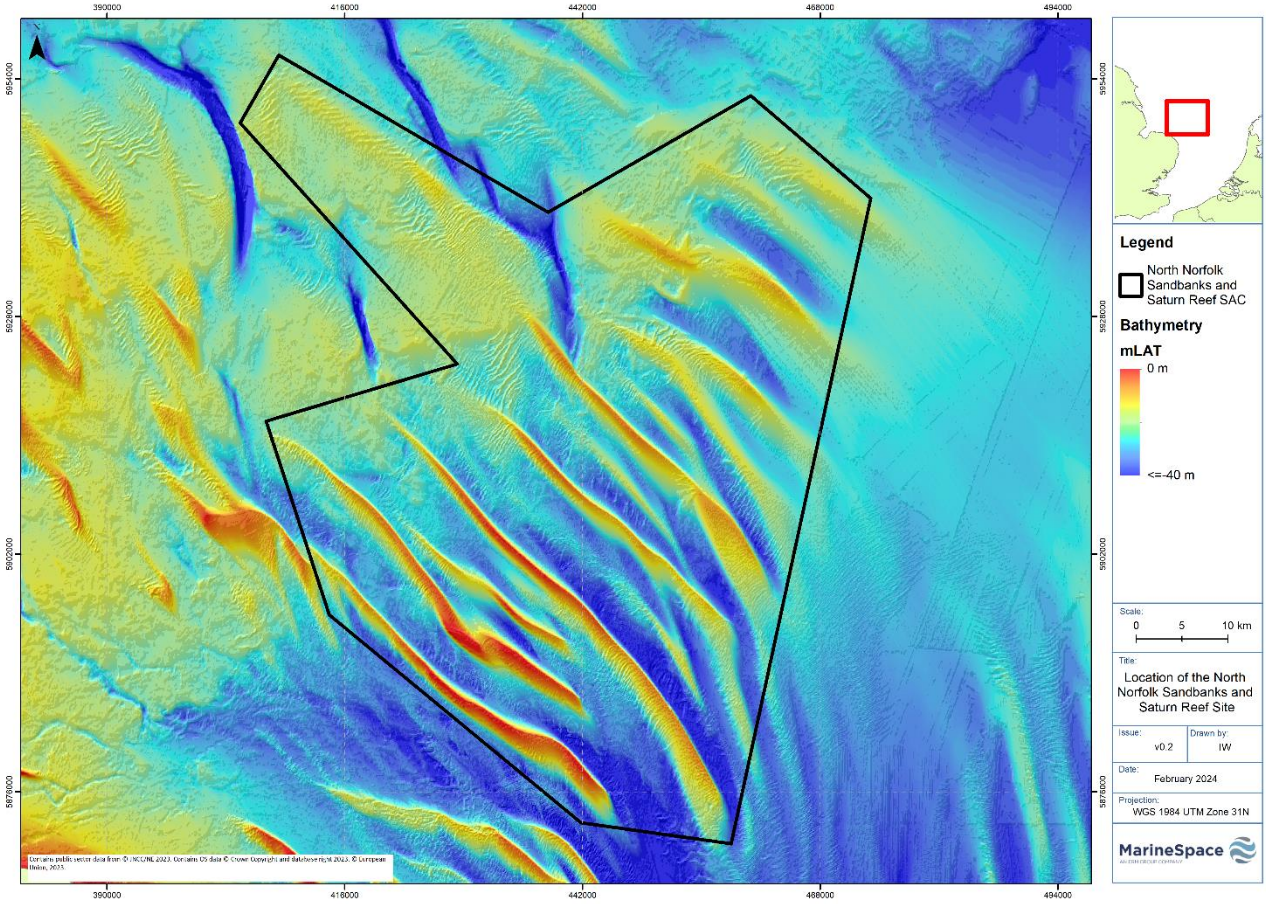
The area encompasses a range of sandbank types and biogenic *S. spinulosa* reef. The Race Bank, North Ridge and Dudgeon Shoals display the S-shape formation also present in the HHW site. They are generally between 15-20 km long and 1.5-3 km wide and composed of fine to medium sands, predominantly derived from coastal erosional processes (Cooper, 2008). A complex arrangement of smaller sandbanks forming a ‘comb-like’ pattern are associated with them, extending downstream to the east and uniquely distinctive in this bank system. Race Bank and Dudgeon Shoal both show asymmetrical cross-sections with a steeper southwest flank, suggesting southwest movement of these banks. Internal southwest dipping reflectors appear to confirm this migration, which opposes the northwest movement of the HHW banks.

The elongate-shaped Inner Dowsing sandbank, consisting primarily of coarse sands and patches of gravel, is separated from other banks by the Well channel. It is thought to be a relict bank sitting on a linear basement layer carved by glacial processes, where tidal currents maintain the feature (ENTEC UK, 2008). Tidal disturbance of sediments appears to increase towards its southern sections, indicating finer sediments and/or increased tidal currents there (IECS, 1999). Comparable to the HHW site, the crests of the sandbanks here are characterised by low diversity communities whilst the flanks and trough deposits support a diverse mosaic of biotypes in the more hydrodynamically sheltered environment (JNCC & Natural England, Special Area of Conservation (SAC): Inner Dowsing, Race Bank and North Ridge, 2010).

There are multiple, publicly available, swath bathymetry data available across this sandbank system which have been acquired, for a series of offshore windfarm sites and by the Civil Hydrography Programme, between 2005 and 2021. Full quantitative analyses of these data would provide significant insights into both smaller bedform scale mobility as well as full bank scale change. Historic chart analysis, undertaking using the approach of (Burningham & French, 2016) for HHW systems would provide an understanding of decadal to centennial scale change.

North Norfolk Sandbanks and Saturn Reef marine sandbank system

The North Norfolk Sandbanks and Saturn Reef site lies further offshore than the HHW and IDRBNR sites, extending from approximately 40–110 km off the northeast coast of Norfolk (Figure **3**).



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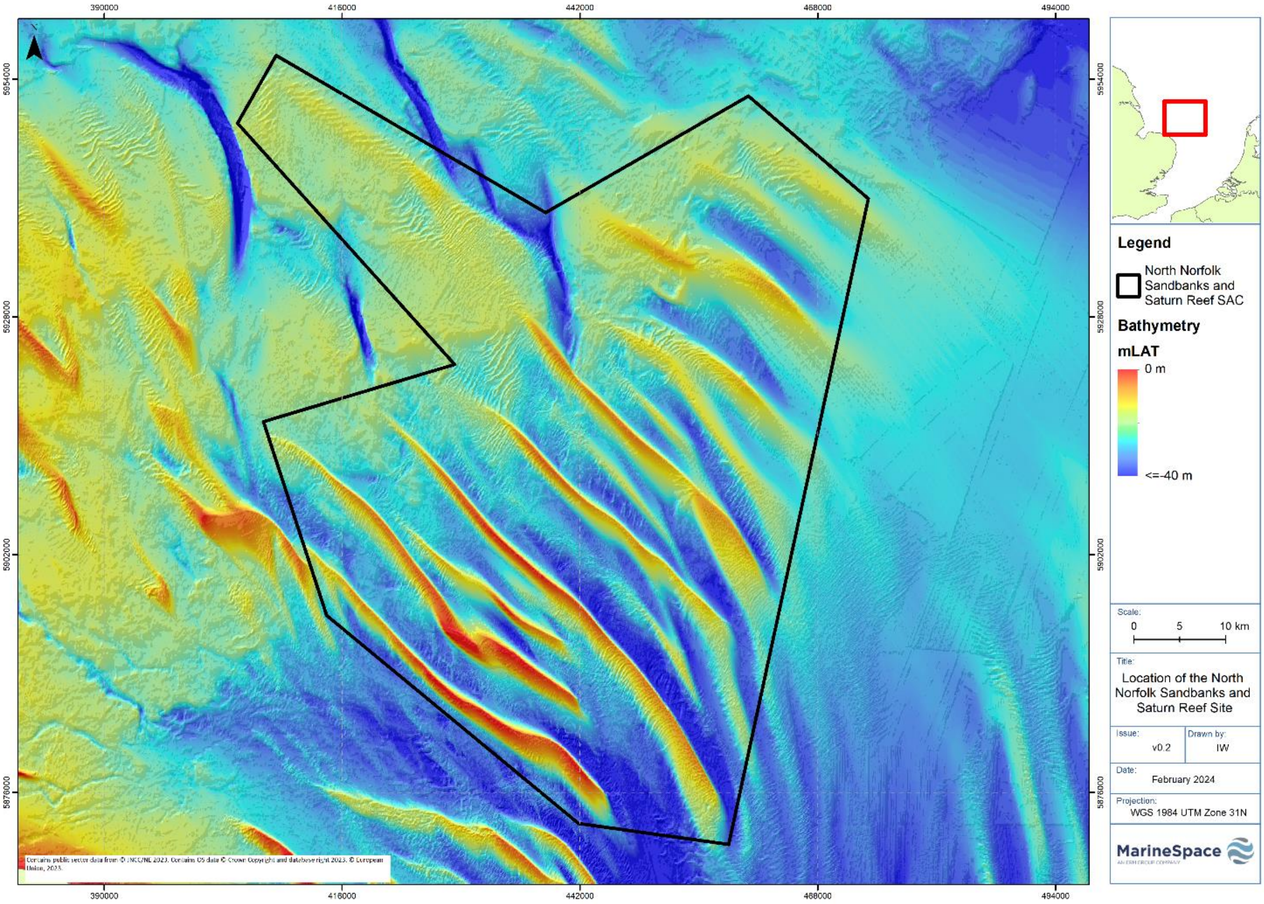

Figure 3: The North Norfolk Sandbanks and Saturn Reef SAC showing the sandbanks. (From: JNCC, 2010). Contains public sector data from © JNCC/NE 2023 Crown Copyright and database right 2023. © European Union

The site comprises a series of 10 main sandbanks, oriented northwest to southeast, and associated fragmented smaller banks formed through tidal processes; along with areas of *Sabellaria spinulosa* biogenic reef. The summits of the banks lie at depths <-20 mLAT and the flanks extend into waters up to -40 mLAT. This group of banks are the most extensive example of the offshore linear ridge sandbank type in UK waters (Graham and others, 2001).

The banks are subject to a range of bottom currents which are strongest on those closer to shore and reduce offshore towards the outer banks (Collins and others, 1995). The inner banks appear more pronounced, exhibiting shallower crests and deeper troughs than the offshore banks (Jenkins and others, 2015). The inner banks, which are analogous in nature to the Haisborough grouping, also having sandwaves on their flanks whilst the outer banks show no such superimposed features. At least parts of the NNSSR sandbank system are active and, although at a very slow rate, thought to be progressively elongating in a north-easterly direction (Cooper, 2008). Eggleton and others (2020) provided results from a 2016 cruise, which showed no changes in the position and profile of one of the Indefatigable Banks compared to 2013 and other data collected in 2016. For Leman Bank, the same survey showed that there was little change in the shallower and flatter regions of the bank, but with an obvious shift in the “shape of the main sandbank feature between 2013 and 2016” wherein the slope has shifted approximately 30 m northwest.

The main banks are generally asymmetric with a steeper face of approximately 6° facing the northeast. Observations of water movement, sandwave asymmetry and sand tracers also support an offshore sediment transport direction (Collins and others, 1995), although whether bank migration occurs at the present time and at what rate is difficult to determine (Cooper, 2008). Collins and others (1995) describe the sandbanks as stepping stones transporting sand from the coastline seaward, where the material transported offshore partly contributes to the maintenance of the banks before eventually dissipating into deeper waters.

As observed across the HHW and IDRBNR sites, species numbers and abundances are generally lower on the crests compared to the flanks and troughs for both near and offshore sandbanks due to the hydrodynamic regime (Jenkins and others, 2015). Regionally, currents on the innermost banks are stronger than the outer banks, which also results in a change in biological community across the site. The communities present therefore represent a gradient across the banks, with fewer species present on the more disturbed inner banks and increasing species numbers on the more stable outer banks (JNCC, Offshore Special Area of Conservation: North Norfolk Sandbanks and Saturn Reef, 2010).

There is a significant absence of publicly available swath bathymetry data for these banks with only a single, 2D echosounder, survey from 1991 being easily accessible. Consequently, quantifying annual mobility of either small- or large-scale morphological features is currently not possible. Historic chart analysis, using the approach of (Burningham & French, 2016) for the HHW system would provide an understanding of decadal to centennial scale change.

Haisborough, Hammond and Winterton marine sandbank system

The Haisborough, Hammond and Winterton sandbanks system lies off the coast of Norfolk to the northeast of Great Yarmouth (

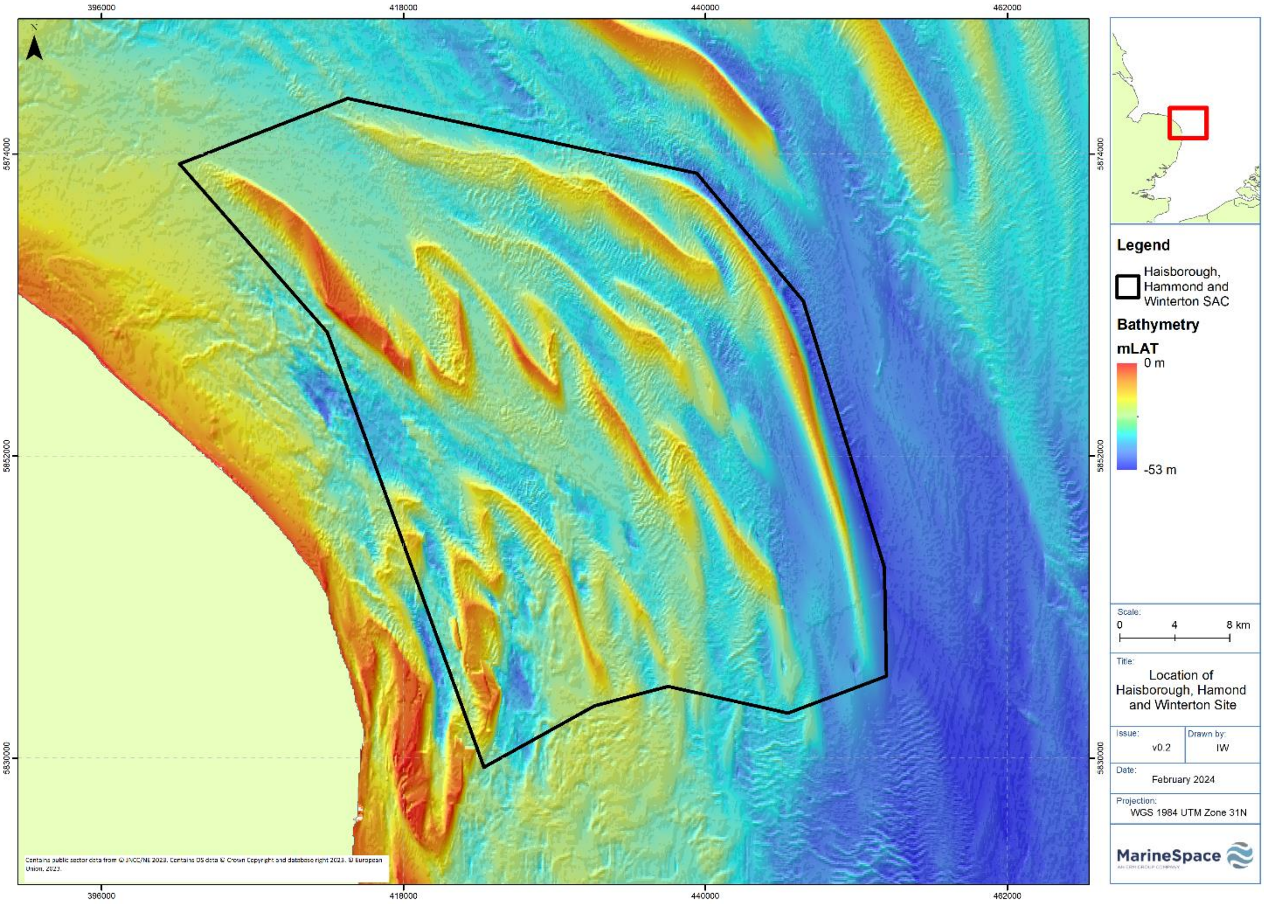

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Figure **4**). It consists of a series of sinusoidal sandbanks aligned approximately north northwest – south southeast which show a slight curvature following the coastline, although each exhibit significant variations in their footprint, with fluctuating widths along their lengths, and a distinctive S-shaped, or ‘sawtooth’, morphology. Cooper (2008) suggest they represent a time-transgressive evolution with the Hewett Ridge and Smiths Knoll banks representing the oldest (~7 kaBP) sequence of sandbank ridges located along the outer site boundary. The central bank system of Haisborough Sand, Haisborough Tail, Hammond Knoll, Winterton Ridge and Hearty Knoll having formed ~5 kaBP, whilst further inshore the Newarp Banks and North and Middle Cross banks are believed to be geologically recent, their genesis dating to around 1.5 kaBP (Cooper, 2008). It should be noted that these timings are made through a simple spatial correlation against a previous (Shennan and others, 2000), version of the Shennan, Bradley & Edwards (2018) sea level curves previously described.

Strong tidal currents across the area are capable of mobilising the sandy sediments, although present-day bank migration appears to be slow (HR Wallingford, 2002). Over the past 200 years, Haisborough Sand has maintained a relatively consistent volume of sediment and its crest has remained around the level of mean low water spring tides, slightly oscillating laterally. Haisborough Tail, Winterton Ridge and Hearty Knoll have deepened (rates of 2-3 cm/yr) and Hammond Knoll has accreted at a similar rate (Burningham & French, 2016). Bathymetry data since the 1840s shows the whole system to be moving in a general northwards direction, although different banks show varying azimuths of movement at a differing rate. The banks show very strong morphological alignments with the dominant tidal streams across the site, which also determine their small-scale migration. Along-bank variation in movement is exhibited by Haisborough Sand, whereby the southern tip and northern half of the bank are moving on- and offshore respectively at similar rates (9.1±1 m/yr), resulting in its clockwise rotation of 7-8° over the past 200 years. The average rates of movement across the other major banks are comparable at approximately 4.5±1 m/yr (Burningham & French, 2016). A summary of morphological change across the site and implied forcing by tidal currents is shown in Figure 5.

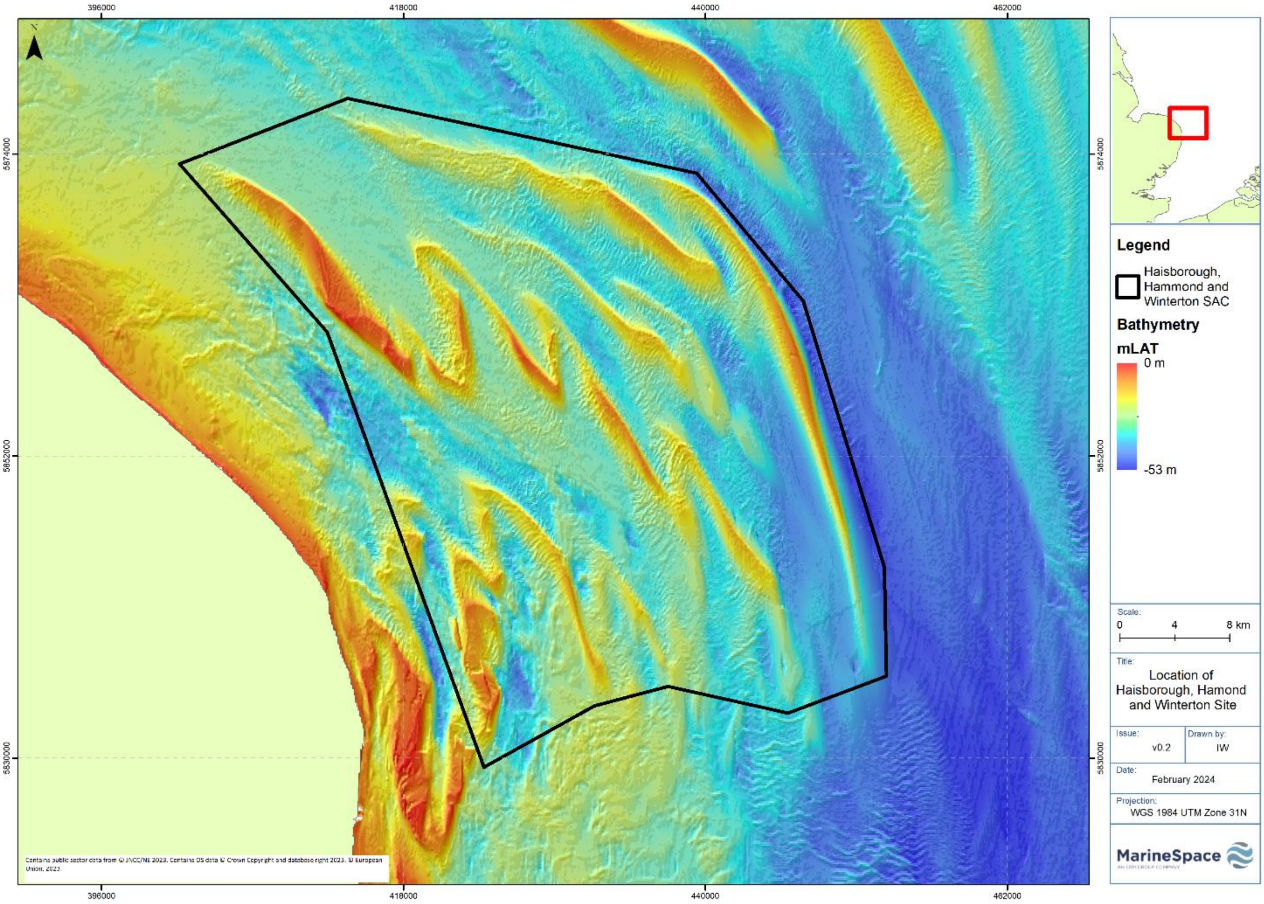

Figure 4: The Haisborough, Hammond and Winterton SAC showing the sandbanks system (From: JNCC and Natural England. 2010a). Contains public sector data from © JNCC/NE 2023 Crown Copyright and database right 2023. © European Union

The respective sandbanks within the HHW system do show evidence of small-scale bed mobility at some point during their history through the presence of fields of megaripples and sandwaves on their flanks and sand ribbons showing across-bank transport. Analysis of the 5 available swath bathymetry surveys acquired between 2009 and 2018, and publicly available from the Admiralty data portal, would provide quantitative evidence of the magnitude of mobility under the current hydrodynamic conditions. JNCC & Natural England (2010) have suggested that the local hydrodynamic regime results in elevated sediment mobility across the crests of sandbanks, prompting a relatively species-poor infaunal and epifaunal community due to the associated disturbance and scour. These communities show more diversity across the flanks of the banks and towards the troughs between them, where sediments are more stable with gravels exposed in areas.

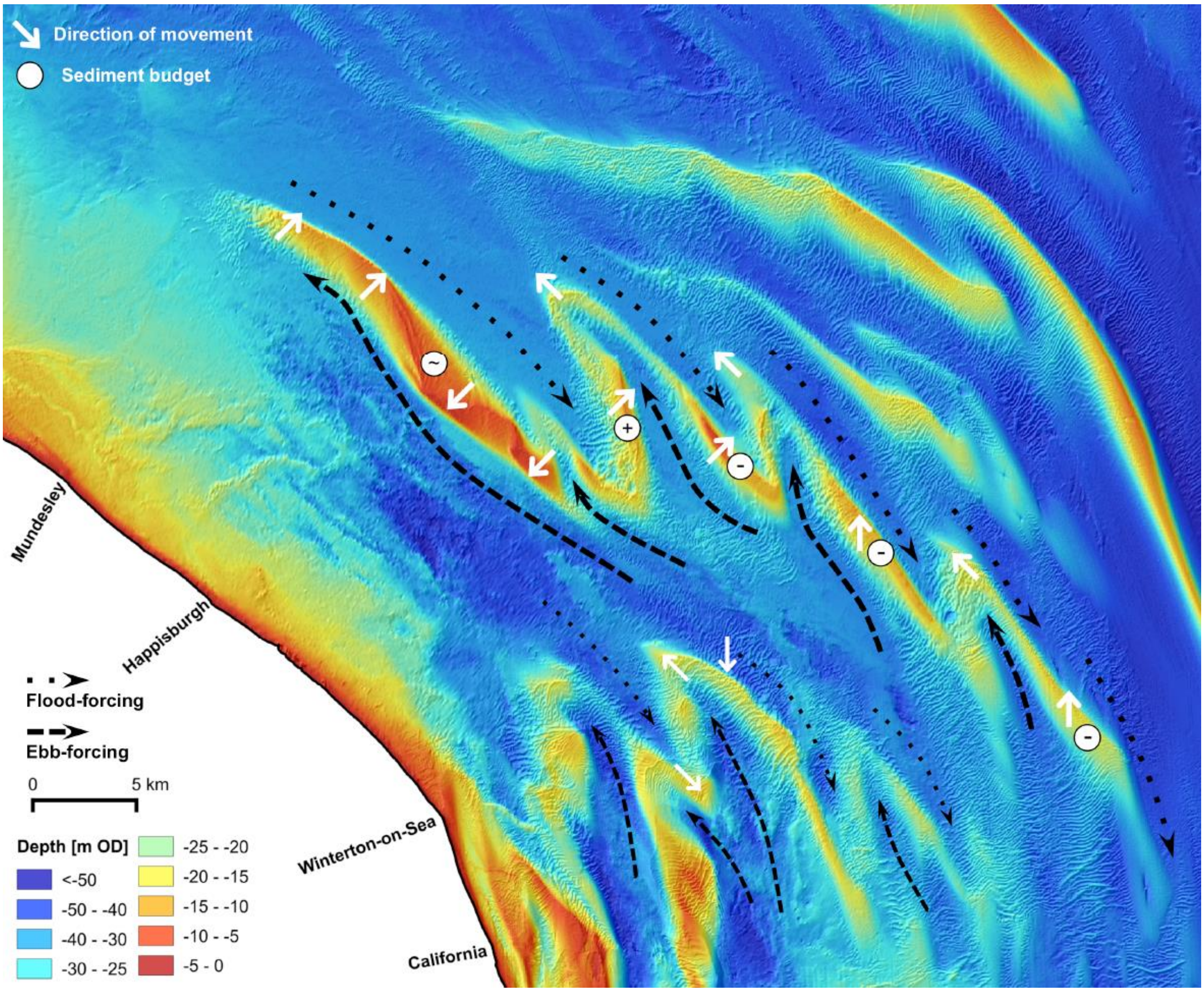

Figure 5: Summary of morphological change across the site and implied forcing by tidal currents (Source: Burningham, H., and French, J. 2016). Open under Open Government Licence.

Dogger Bank marine sandbank system

As described previously Dogger Bank is dominated by glaciotectonised and almost certainly over-consolidated glacial deposits with a relatively thin veneer of potential mobile Holocene marine sands. Consequently, at a gross scale the bank shows considerable gross stability at the decadal to centennial scales, evidenced by historic chart analysis undertaken previously by MarineSpace (Dix and others, 2023). At a small-scale analysis of publicly available, swath bathymetry on the southern margin of the bank has identified the presence of 2 scales of “sorted bedforms”: a very large-scale series of north-northwest to south-southeast oriented ridge; and runnel bedforms with lengths of >10 km widths up to 2 km and vertical relief of between 1-4 m (Dix and others, 2023). The runnels, linear depressions that parallel the ridges are dominated by coarser grained sediments that typically support small scale ripples. On occasion parasitic transverse bedforms occur on top of the ridges and are probably mobile on an annual scale. These very large scale features have been shown to be stable on annual to decadal scale except for decametre-scale oscillations on their flanks resulting in <1 m of vertical relief change.

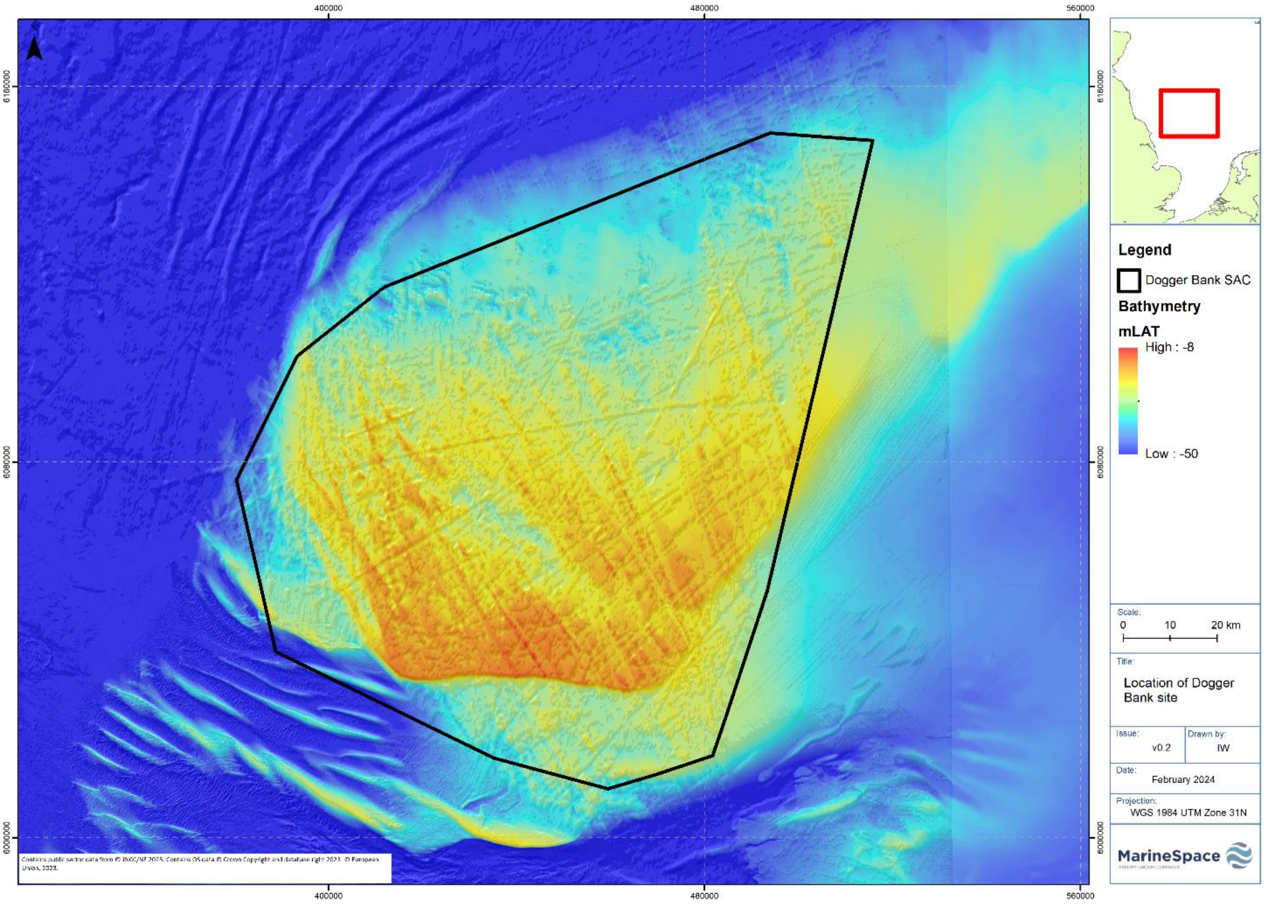

Figure 6: The Dogger Bank SAC showing the sandbank system (From: JNCC, 2011). Contains public sector data from © JNCC/NE 2023 Crown Copyright and database right 2023. © European Union

Similarly, there are present fields of smaller scale, circular to ovid to elongate “ripple scour depressions” with typical dimensions 10-100’s metres and reliefs of <1.4 m (Riera and others, 2023). The base of these features, like the runnels, are typically composed of coarser grained rippled sediments but with fine grained berms of accumulated fine-grained sediments along their downstream margins.

Both scales of these sorted bedforms are believed to form under storm conditions where enhanced turbulence associated with the coarser bed, rippled basal surfaces restrict the settling of fine grain sediments which are advected and accumulated on the ridges or associated berms of the rippled scour depressions.

Physical connectivity: within and between MPAs

This sub-section concerns physical connectivity and geomorphology of subtidal sandbanks. It is not commenting on the biological connectivity of habitats and associated communities.

Subtidal sandbanks can be classified by their physical functionality/geomorphological activity. Some subtidal sandbanks are still actively associated with coastal and nearshore physical processes. These topographical features are evidencing small-scale bed mobility through the presence of fields of megaripples and sandwaves on their flanks and sand ribbons showing across-bank transport. In some cases, the physical footprint and extent, and local-scale geospatial position, may vary/fluctuate. These types of subtidal sandbanks are referred to as ‘active’ banks.

In contrast, many subtidal sandbanks in the UK nearshore and offshore environments are no longer associated with active coastal physical processes. These features are effectively dissociated from active sediment supply, are discrete self-supporting physical seabed features, and are considered to be ‘moribund’ or ‘relict’ (Stride, 1982).

The review of physical functionality of marine sandbanks systems has enabled an initial overview of the connectivity of these seabed habitat features within each of the four MPAs, and also between each of the MPAs, to be made. It is evident, even from the 2002 Southern North Sea Sediment Transport Study (HR Wallingford, 2002), that all four MPAs are isolated from each other regarding connectivity of nearbed sediment supply. Evidence presented in this Southern North Sea sandbank systems section of the report, substantiates these observations. The discrete physical processes, and especially the sediment transport systems between each MPA, are not connected in such a way that impingement of the southern North Sea processes could be interrupted or adversely affected. This is in relation to the historic, current, and foreseeable amounts of hard infrastructure installed, or which could be installed.

Further, an interesting observation is the relationship of the physical functionality of the marine sandbanks systems, and the associated designated Annex I subtidal sandbanks features at the north-western perimeter of HHW SAC; and in-particular Haisborough Bank. In relation to hard infrastructure footprints associated with gas pipelines it can be seen (inferred) that the hard infrastructure protecting pipelines is associated with the east-west pivoting and ‘oscillation’ of Haisborough Bank as presented in Figure 5.

Whilst these remedial works have been required, it is relevant to note that the pipeline assets have been *in situ* for several decades, and have not impeded the physical structure and functioning of the subtidal sandbanks. Indeed, anecdotal evidence (monitoring data from asset owners) shows that the marine sandbanks within HHW SAC, have the physical power to translocate embedded gas pipeline assets[15]. This is due to the overriding physical (geomorphological) processes within the associated marine sandbanks system. Pipelines, installed within the 3D section of Haisborough Bank, do not impinge upon the physical functioning of that subtidal sandbanks feature.

A similar case may be the OWF transmission assets (export power cables) in the IDRBNR SAC. Here, export power cables are generally installed to shallow depths of sub-seabed surface e.g. 2-3 m below surface (Centrica, 2007). The physical processes associated with the IDRBNR marine sandbank system e.g. sandwave migration, is such that these assets can be exposed and potentially compromised. This requires remedial cable protection to be installed. The occurrence of these additional hard infrastructure emplacements (usually rock berms) are evident at post-construction and O&M works.

Active versus moribund sandbanks

Evidence presented in this section of the report, shows that certain individual subtidal sandbanks features in IDRBNR SAC, NNSSR SAC, and HHW SAC, are not inherently dependent upon one another. Effects associated with the installation of hard infrastructure in small locations of one bank, are unlikely to affect the physical functioning of other subtidal sandbanks features within the same MPA; certainly not at the current scale of *in situ*, and reasonably foreseeable, scale of hard infrastructure. The current understanding of southern North Sea subtidal sandbanks (as presented throughout this section of the report) demonstrates that there is no geomorphological connectivity that could be impacted between any of the designated subtidal sandbanks between each of the four SACs considered in this report.

The current understanding of the physical (geomorphological) functionality of subtidal sandbanks features within the four MPAs specifically considered in this report is presented in Table 5.

However, there are still uncertainties about scale and associated data. Ultimately, on a gross-scale Dogger Bank appears to be stable, but the Haisborough/Hammond system has been moving by several hundred metres offshore on a centennial scale (accepting the uncertainties in the data concerning this point). It is obvious that at the heads and tails of many of the individual subtidal sandbanks (in HHW SAC) there is potentially significant oscillatory movement. At smaller scale there is obvious movement at the bedform-scale.

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[15] Although the accessibility of these data and reports is less than transparent/easy at the moment for the SNCBs.

This links to Recommendation 3 described in the ‘Discussion and recommendations’ section of this report.

Table 5: Physical (geomorphological) functional classification of subtidal sandbanks features in four southern North Sea Marine Protected Areas.

Marine Protected Area	Subtidal Sandbanks	Physical functional classification	Connectivity between sandbanks within each MPA
Inner Dowsing, Race Bank and North Ridge SAC	Inner Dowsing	Moribund/Relict	No connectivity
Inner Dowsing, Race Bank and North Ridge SAC	Race Bank, North Ridge, and Dudgeon Shoal	All active	Yes – between the 3 sandbanks No connectivity with Inner Dowsing
North Norfolk Sandbanks and Saturn Reef SAC	Leman, Inner, Ower, Well, Broken, and Swarte	All active	Yes – between the 6 sandbanks
North Norfolk Sandbanks and Saturn Reef SAC	4 sandbanks collectively known as the ‘Indefatigables’	? – Potentially Moribund/Relict [Note 1] Requires further modelling and analysis	The sandbanks may be isolated from the other 6 sandbanks in the MPA
Haisborough, Hammond and Winterton SAC	Haisborough	Active	No connectivity
Haisborough, Hammond and Winterton SAC	Newarp Banks	Active	No connectivity

Marine Protected Area	Subtidal Sandbanks	Physical functional classification	Connectivity between sandbanks within each MPA
Haisborough, Hammond and Winterton SAC	Hammond	Moribund/Relict	No connectivity
Haisborough, Hammond and Winterton SAC	Winterton	Moribund/Relict	No connectivity
Haisborough, Hammond and Winterton SAC	Smith’s Knoll	Moribund/Relict	No connectivity
Dogger Bank SAC	Dogger Bank	Moribund/Relict	Isolated from all other sandbanks

Note 1: [The Indefatigable Field Platforms and Pipeline Decommissioning Programmes report indicates that the 24” pipeline PL81 remained buried (0.5-2.5 m bRSL) for 17 years (Shell, 2007). It is also noted that there is an absence of sandwaves on the flanks of these sandbanks compared to the other sandbanks within the NNSSR SAC. This implies that at least certain parts of the Indefatigables bank system are moribund/relict.].

Consideration of whether any individual subtidal sandbanks feature is ‘Active’ or ‘Moribund’/’Relict’ may be of considerable consequence in relation to considering the installation, and embedment, of hard infrastructure on/within the MPAs. There could be a difference in any adverse effect on the physical structure and functioning of active features compared to moribund features. For active features, infrastructure may be able to anchor parts of the subtidal sandbanks features, and interrupt that functioning.

However, the continued, and uninterrupted, physical functioning of active marine sandbanks systems, with a multidecadal legacy of hard infrastructure on, and within, some of those features (as is the case for NNSSR SAC and HHW SAC) implies that this ‘pinning’ does not occur. However, this would need to be kept under consideration in sites where there is a continued ramp-up of infrastructure (e.g. HHW SAC and IDRBNR SAC) to ensure that this does not start to occur.

Condition of MPA designated subtidal sandbanks

UK condition (2019)

The UK reports on the implementation of the EU Habitats Directive every six years[16], providing information on the conservation status of habitats and species listed in Annexes I, II, IV and V of the Directive. The fourth UK report was submitted to the EU in 2019, and contains the current status of Annex I subtidal sandbanks. This status is represented in Table 6. Details for the four subtidal sandbanks MPAs considered in this report, including site condition are presented in Appendices 2-5.

Table 6: The 2019 conservation status assessment of subtidal sandbanks habitat. From: JNCC, 2019

Metric	Summary
Range	As this feature is defined by topography and substrate type, its range is determined by geological and/or hydrodynamic processes depending on the type of sandbank (http://jncc.defra.gov.uk/page-1452). The nature of these processes means that the geographic range of this feature is likely to have remained the same in recent geological times. Although the surface area of this feature may have declined due to the presence of infrastructure and abrasion, there is no evidence that has significantly affected the geographic spread of this feature. Therefore, the short-term trend is thought to be stable.
Surface area of range	As a result of improved mapping and a definition change, the surface area of range for sandbanks is larger than the figure reported in 2013. Area is a more specific parameter than range and we don't generally have good enough data to establish a trend. Area of sandbanks are determined by the presence of suitable substrate and the hydrological regime maintaining the sandbank and is, therefore, unlikely to change significantly overtime. However, anthropogenic activities may have caused localised losses of area.

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[16] Under Article 17 of the EU Habitats Directive

Metric	Summary
Condition of habitat	The area of habitat in 'good' (favourable), 'not good' (unfavourable) and unknown condition was assessed in each of the four inshore areas and also in the offshore area and the results were summed. 47% of the habitat is thought to be in unfavourable (not good) condition, 46% of the habitat is thought to be in favourable (good condition) and 7% of the habitat is in unknown condition. The structure and functions conservation status is, therefore, unfavourable-bad. In 2013, it was unfavourable-inadequate. The change in status of this parameter, is due to a change in method with the indicator 'Extent of Physical Damage to Predominant and Special Habitats (BH3)' (OSPAR Commission, 2017) being used to assess the condition of offshore sandbanks. However, there is low confidence in the assessment.
Future prospects	The Future prospects are good because the future trend for range is thought to be stable and the range conclusion is favourable. The future prospects were also good in 2013. Range - The future prospects are poor because the future trend for area is thought to be negative and the area conclusion is unknown. The future trend has been identified as negative as a result of windfarm developments that are predicted to impact large areas of offshore sandbanks and because fisheries management measures are not currently in place. The trend could potentially be very negative; however, negative has been selected as a result of low confidence in the data. Area - The future prospects are bad because the trend for structure and functions is thought to be negative and the structure and functions conclusion is unfavourable-bad. The future prospects were poor in 2013. This change was the result of improved knowledge on trends and a change in the structure and functions conclusion. The future trend has been identified as negative as a result of windfarm developments that are predicted to impact large areas of offshore sandbanks and because fisheries management measures are not currently in place. The trend could potentially be very negative; however, negative has been selected as a result of low confidence in the data.

Attributes associated with feature condition

This section provides a brief overview of the condition (and favourable conservation status (FCS)) of designated subtidal sandbanks (and those providing a supporting habitat for prey required for Habitats Directive designated Annex II populations and Annex I and II Birds Directive classified populations) in relation to adverse effects from hard substrata infrastructure.

The placement of hard substrata in a subtidal sandbanks MPA is believed to impact Annex I subtidal sandbanks in a number of ways; which, for condition assessments, can be assigned to one, or more, of the three high-level feature attribute themes; extent and distribution, structure and function, and supporting processes.

The **extent and distribution** of a habitat feature refers to the total area in the site occupied by the qualifying feature and must also include consideration of its distribution. A reduction in feature extent has the potential to alter the physical and biological functioning of sediment habitat types (Elliott and others, 1998). The distribution of a habitat feature influences the component communities present and can contribute to the condition and resilience of the feature (JNCC, 2004).

Structure and functioning encompasses the physical components of a habitat type as well as the biological communities present. Physical structure refers to topography, sediment composition and distribution. Physical structure can have a significant influence on the hydrodynamic regime operating at varying spatial scales in the marine environment, as well as influencing the presence and distribution of associated biological communities (Elliott and others, 1998). The biological structure refers to the key and influential species, non-native species and pathogens and characteristic communities present. Biological communities are important in not only characterising the sandbank feature but supporting the health of the feature i.e. its conservation status and the provision of ecosystem services by performing functional roles. The function of habitat features includes processes such as; sediment reworking (e.g. through bioturbation) and habitat modification, primary and secondary production, and recruitment dynamics. Habitat features rely on a range of supporting processes (e.g. hydrodynamic regime, water quality and sediment quality) which act to support their functioning as well as their resilience (e.g. the ability to recover following impact).

Supporting processes. This report is focused on the attributes ‘Supporting processes: sediment movement and hydrodynamic regime (habitat)’ and ‘Supporting processes: energy/exposure’ (in relation to extent and distribution, and structure and function). The rationale for this approach is that these attributes are effectively linked to the over-arching considerations for extent and distribution, and structure and function. Other supporting processes attributes are not relevant to the consideration of the effects of pressures from inert hard infrastructure on subtidal sandbanks features (physico-chemical properties (habitat); sediment contaminants; water quality - contaminants (habitat); water quality -

dissolved oxygen (habitat); water quality - nutrients (habitat); water quality - turbidity (habitat)).

Impact of rock placement regarding extent and distribution conservation objectives

As identified in the Project's SoW, two primary 'tests' associated with subtidal sandbanks designated feature condition assessments were posited by Natural England: these are associated with the impacts of rock infrastructure on subtidal sandbanks integrity, with a focus on extent and distribution. This section considers these tests, and associated questions in detail, making observations and proposing recommendations; to assist Natural England in future consideration of subtidal sandbanks condition monitoring.

Test 1: Does the area of rock placement in the site represent a loss in the extent of sandbank habitat?

Q1 What qualities and functionality of a sandbank habitat are likely to be lost by the covering of soft sediment with rocky substrate? What species, life stages and ecological resources i.e. feeding or shelter could be lost?

Qualities of subtidal sandbanks communities

The biological communities typical of subtidal sandbanks can vary greatly depending on hydrodynamics, sediment type and depth, as well as fine-scale physical, chemical, and biological processes such as; availability of shelter either within the sediment or on the sediment surface, feeding opportunities, and spawning surfaces. Fluctuating, tide-swept, conditions often restrict diversity by eliminating more sedentary forms and encouraging the numerical dominance of agile swimmers and scavengers. Densities are kept low by the disturbance of sediment in high energy areas. The combination of smaller-scale morphological features (such as sandwaves and megaripples), bioturbation and sediment disturbance is likely to further increase the ecological complexity of sandbank habitats with differing levels of bioturbation and bioirrigation providing different depths of oxygen sequestration and nutrient transfer into the sediment (Weber and others, 2004). In coarser sediments, these transfers can also occur through surface sediment mobility and pore water advection (Neumann and others, 2021)

Communities tend to be dominated by infaunal/epifaunal small crustaceans (such as amphipods and isopods), polychaetes and molluscs which are adapted to the changing environment through:

- The ability to re-burrow rapidly after being washed-out of the sediment during storms (Vanosmael and others, 1982). More sedentary forms of molluscs tend to be restricted;
- Generally being short-lived with high growth rates and rapid maturation (Jennes & Duineveld, 1985);
- Extended reproductive periods, including brooding and/or continuous reproduction; and
- Swimming and feeding in the water column at high tide and only shelter temporarily in the sediment at low tide (Peterson, 1991).

In general, the tops (crests) of subtidal sandbanks in the southern North Sea (and, to a lesser degree, bank flanks) have sediment that is continually disturbed by tidal flows (and waves on the crests of banks in shallower waters). This exposes fauna to abrasion and scour, prevents the build-up of organic matter in/on the substrata and restricts the development of distinct ecological niches. The crests of subtidal sandbanks therefore tend to support relatively impoverished communities, characterised by low species diversity and richness, with an abundance of amphipods and polychaetes; which are adapted to the environment and are able to re-bury themselves rapidly (ENTEC UK, 2008). Exceptions to this occur, such as the diverse nematode communities found at Inner Dowsing bank by Schratzberger & Larcombe (2014). Mobile scavenger and predator species such as hermit crabs, flatfish and starfish also live on top of the sandbank. Stable epifaunal communities are known to establish on the flanks of subtidal sandbanks, but are considered to be generally absent from the bank tops themselves. Ambush predation on the tops of sand ridges has also been observed in the northwest Atlantic, where fish such as the Northern stargazer *Astroscopus guttatus* and the Snakefish *Trachinocephalus myops* are an important component of the sand ridge fish fauna (Vasslides & Able, 2008).

Sediments in the troughs between subtidal sandbanks tend to show higher surficial sediment heterogeneity. In these areas, if the influence of tidal scour is reduced, finer sediments (silt and mud) are often present which tend to support richer and more diverse infaunal communities of polychaetes, burrowing bivalve molluscs and crustaceans. However, areas of coarse sediment such as gravels, pebbles, cobbles and even boulders can also be present. Diverse epifaunal communities may be present in areas which provide suitable sites for the attachment of sessile epifauna such as hydroids, anemones, tube-dwelling worms such as *Sabellaria spinulosa*, bryozoans, and tunicates (ENTEC UK, 2008). Troughs may accumulate organic particulate material and larvae if there are reduced currents.

A range of fish species use subtidal sandbanks as feeding and nursery grounds including; sandeels *Ammodytes* spp., dragonets *Callionymus* spp., gobies *Pomatoschistus* spp., elasmobranchs (primarily skates and rays), lesser weever *Echiichtys vipera*, European plaice *Pleuronectes platessa*, common dab *Limanda limanda* and benthopelagic species such as Atlantic cod *Gadus morhua* and whiting *Merlangius merlangus*. Sandeels can often be found in high densities on sandbanks and have high site fidelity meaning repeated extraction or changes in sediment composition could have negative impacts on their behaviour and local populations.

Eggleton and others (2020) noted that fish communities on all topographical zones of the Indefatigable Bank (in the NNSSR SAC) were dominated by solenette *Buglossidium luteum* and to a lesser extent scaldfish *Arnoglossus laterna*. *E. vipera* was characteristic of the crest and flanks communities. The 2016 data revealed that some fish species were consistently present at certain locations on the banks. However, it was not possible to ascertain the precise nature of their relationship with these topographical zones; whether they were acting as nursery or feeding grounds for example.

Functions of subtidal sandbanks communities

In this context functions are ecological processes that include sediment processing, secondary production, habitat modification, supply of recruits, bioengineering and biodeposition (i.e. not geological or geomorphological functions). These ecological functions rely on the supporting natural processes and the growth and reproduction of those biological communities which characterise the habitat and provide a variety of functional roles within it (Norling and others, 2007).

Foraging seabirds, pinnipeds, and cetaceans may also be found in greater numbers in the vicinity of subtidal sandbanks (e.g. Daunt and others, 2008; Scott and others, 2010; Camphuysen, Scott & Wanless, 2011; McConnell and others, 1999, Jones and others, 2013). This is related to the trophic system functioning of subtidal sandbanks acting as supporting habitats for these predators. These functions and processes contribute to ensuring that prey is available, as well as providing *refugia* for some species.

Whilst the addition of hard substrata does not necessarily present a loss in biomass or nutrient cycling (Coolen and others, 2020a), it will present a loss in all associated sandbank biotopes and associated taxonomy due to high sensitivity to changes in seabed type. Therefore, certain aspects of sandbank-specific habitat quality and functioning on a small scale will also be lost. It is important to note that the scale of this effect is limited to the area immediately beneath the rock substrate and potentially the immediate area surrounding it (through predation halos, and potentially dead zones and/or scour), and therefore is not necessarily applicable to the whole sandbank feature (Pidduck and others, 2017).

Addition of hard substrata habitats

When rocky substrate is placed on the seabed, water flow and pore water advection occur at a reduced rate, and therefore the concentrations of oxygen and nutrients within the covered substrata are likely to reduce in the short-term (Rouse, Porter & Wilding, 2019). As fauna develop on the rocky substrate, nutrients may accumulate onto the sediment over time and cause localised eutrophication of the substrata (Janßen and others, 2015).

Prolonged hypoxia, one of the main symptoms of eutrophication, is often referred to as a ‘dead zone’, and represents an area inhospitable to most benthic fauna.

The fauna typically associated with subtidal sandbanks habitats are unlikely to tolerate hypoxic conditions associated with reduced water flow and dead zones. Whilst infauna such as nematode species have been shown to exhibit a degree of tolerance to hypoxia (Taheri and others, 2014), greater oxygen stress is likely to be exerted upon epifaunal species and larval stages associated with sandbank biotopes (Levin and others, 2009). Despite this, the fundamental attributes associated with habitat functioning of the sandbank below the rock substrate can be considered lost for all fauna as a result of reduced potential for oxygenation by water flow; with food web linked impacts for larger vertebrate species, including reduction of prey availability for a number of fish, seabird, and marine mammal species.

Epibenthic colonisation of clean rock or other hard substrate is a multistage process that begins at the microbial scale (Causon & Gill 2018). Following immersion and settlement, a biofilm will develop, followed by microscopic eukaryotes, such as diatoms, fungi and other heterotrophic eukaryotic organisms (Dobretsov and others, 2006; Qian and others, 2007). These biofilms are potentially important for future larval or spore settlement (Qian and others, 2007; Dobretsov, 2010). Colonisation of a new hard substrate will vary spatially, with different organisms settling, and having greater survival rates, on vertical surfaces, horizontal surfaces or in depth bands.

The communities that develop on rock berms remain poorly known in the North Sea, though increasing need for video monitoring from industrial operations may provide a considerable increase in evidence, if such videos are made publicly available. There is not yet consensus as to whether artificial hard substrata will be colonised by epifaunal assemblages similar to those of nearby reefs and natural substrate (Coolen and others, 2020a; Causon & Gill 2018) nor yet understanding of whether epifaunal assemblages would impact the surrounding areas. The introduction of epibenthic assemblages can also modify the local hydrodynamic regime, biochemistry and benthic sediment composition (Boehlert and Gill, 2010; Byford and others, 2011; Miller and others, 2013; Vaissière and others, 2014). Hiscock and others, 2002) also suggested that alteration of local hydrodynamic regimes may lead to turbulences that cause resuspension of fine sediments, reducing light penetration and smothering existing benthic communities.

Coolen and others (2020a) and Coolen and others (2020b) note that there are many physical and biological variables that may be important in understanding presence on hard substrates, including depth, materials used, size of substrata, structure (straight surfaces differ from more complex surface area including holes and small-scale variation in surface orientation), presence of keystone species, predators, scavengers, and invasive non-native species (INNS). It is often the case that the introduction of artificial habitats catalyses the settlement of novel (but native) species to the area and INNS that may outcompete or predate upon the species that characterise sandbank biotopes, both within the emplaced rocky substrate and the sandbank habitat surrounding the feature (Coolen and others, 2020a.). Established artificial reefs often exemplify increased predation rates by exhibiting a halo of barren substrate surrounding the rocky substrate, which is dependent on the foraging ranges of the novel species or INNS (Reeds and others, 2018).

However, it may be of use to discuss high-level characteristics of rocky reef assemblages. Moderately tide-swept, moderately wave-exposed bedrock or boulders are exposed to varying amounts of scour (due to nearby patches of sediment) and, as a consequence, is characteristically dominated by dense *Flustra foliacea*, a range of colonial ascidians, hydroids, sponges and a variety of other scour/silt-tolerant species. Varying amounts of the soft coral *Alcyonium digitatum* may be recorded, depending on the amount of scouring which may vary locally. Where scour is a major factor, species such as the scour tolerant *Urticina felina* are frequently observed. Mobile fauna includes *Cancer pagurus* may be observed finding refuge in crevices and under boulders. More ubiquitous species present include echinoderms such as *Asterias rubens*, *Crossaster papposus*, *Ophiothrix fragilis* as well as hermit crabs such as *Pagurus bernhardus*.

Furthermore, the presence of rock emplacements is known to act as a fish aggregation device (FAD). Species, such as Atlantic cod are known to increase in population density around artificial reefs associated with offshore wind farms than the surrounding sandy seabed (Reubens and others, 2012; de Troch and others, 2013). The mechanism behind the FAD effect associated with artificial reefs is complex. Rocky substrata may attract adult and/or larvae, and so may have a ‘population absorbing’ effect on the local population in the short-term, i.e. the individuals within the surrounding area are attracted to the artificial reef but are not replaced within their original territories. Furthermore, this FAD effect will concentrate predation and nutrient enrichment on and around the reef. However, there is an evidence gap in the assessment of fish population depletion around a new artificial reef, indicative of the ‘population absorbing’ effect (de Troch and others, 2013; Layman & Allgeier, 2020). This relates to an understanding of whether there is an ‘overspill’ effect, or return, of fish to their original territories. Over time, the regional population may fill the trophic gaps left by the ‘absorbed’ individuals, or the reef itself may boost the population directly, resulting in a dispersal of fish into the depleted areas (Smith, Lowry & Suthers, 2015).

Artificial reefs associated with hard structures such as OWF foundations and jackets are known to attract fish species such as pouting *Trisopterus luscus*, goldsinny wrasse *Ctenolabrus rupestris*, and viviparous eelpout *Zoarces viviparus* (Stenberg and others, 2015). These species prefer rock over sand as the dominant substratum type. Whilst some of these species may be present before the emplacement of rocky substrates (e.g. pouting), the populations of rock-preferring and sand-preferring species are likely to be enhanced in the presence of an artificial reef (Stenberg and others, 2015). Despite this, evidence is emerging that species associated with sandy substrata do not exhibit a reduction in condition or fecundity as a result of the addition of hard substrata (Buyse and others, 2023). In this instance, Buyse and others (2023) observed a shift in diet as a result of the artificial reef effect for European plaice *Pleuronectes platessa*, and observed an increase in the size and number of females present within wind farm arrays compared to control areas. Whilst this may be attributed to a reduction in fishing pressure within wind farm arrays, it cannot be ruled out that the addition of hard substrata, and consequent artificial reef effect, was not a contributing factor to the results.

Mobile epifauna associated with sandbanks are likely to benefit from the addition of rocky substrata in a similar manner to fish, in that they may exploit the increased shelter and feeding opportunities associated with the rock emplacement.

From a physical process perspective, the addition of elevated rock substrate within the water column will introduce the potential for scour, dependent on the direction of water flow in relation to the rock substrate (Roulund and others, 2018). For example, if a single large rock is placed on the seabed, the water flow will be directed around the rock and increase in velocity behind the rock. This increase in velocity mobilises the sediment and removes it, causing a reduction in the height of the seabed behind the rock in relation to the height of the seabed in front of the rock. The depth and spatial footprint of scour is dependent on the velocity and direction of water flow, the cohesion of the substrate, and the height and shape of the rock (Roulund and others, 2018).

In the case of the emplacement of rock berms, berm design considers the shear stress of the substrata upon which it is placed (Reach and others, 2011). Taller rock berms and other hard structures, such as wind turbine foundations, are likely to result in more acute scouring of the seabed. Scour surrounding foundations is often mitigated by the construction of SPPs, increasing the footprint of artificial hard substrata on the seabed and therefore replacing sandbank habitat. If the sandbank habitat itself has been indirectly removed as a result of scour associated with the emplacement of hard structures, or replaced by the emplacement of rocky substrates, there will be a fundamental loss in sandbank habitat quality and functioning.

Q2 Would any species or resources associated with the sandbank continue to be found in the area covered by rocky substrate e.g. fish, mobile epifauna such as amphipods, burrowing polychaetes? Are there lessons to be learnt from studies of where rocky substrate has been placed on intertidal or near shore soft sediment (where it is easier to study)?

Characteristic communities and sandbank biotopes may be lost from the area upon which rock is emplaced, however, there will remain some crossover of infaunal, epifaunal, and mobile species between the habitats, dependent not least on the amount of rock exposed and the ecology of the key species involved in neighbouring biotopes/communities. Depending on the area upon which rock is placed, biotopes surrounding the rock may be classified as coarse sediment or mixed sediment, both of which can have significant epifaunal components (e.g. A5.141 *Pomatoceros triqueter* with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles) as well as infaunal components. Taxonomic and functional crossover is likely to change temporally, and potentially cyclically.

Should the emplaced rock be entirely covered by the original substrata, and should hydrodynamic conditions and sediment load remain the same, it could be expected that recovery of sandbanks communities would occur, and subtidal sandbanks habitat function could be possible for the time period in which the rock was buried to the required depth for infaunal function (Tillin and Tyler-Walters, 2014). The exact depth of the sediment above the emplaced rocky substrata required to allow a full recovery of subtidal sandbanks biotopes is unknown, however it is generally accepted that larger infauna associated with southern North Sea subtidal sandbanks require around 30 cm of sediment depth to colonise (Gray and Elliott, 2009).

While hard substrata and the surrounding sandbanks sediment form discrete and fundamentally different habitats, species present within each habitat will start to interact in a limited way in the narrow zone where the two habitats meet. Understanding the development and composition of these communities around the base of the rock emplacement will require evidence of how sandbank sediment interacts with the emplaced rock, as well as understanding how species characteristic of both sediment (infaunal and epifaunal) and rock (epifaunal) habitats interact. Composition of species, and abundance, in these marginal communities will depend on water depth, sediment composition, grain size, food availability, level of disturbance and current and tidal regimes (e.g. Pidduck and others 2017). These marginal communities are considered on both sand, and rock, below.

Development of marginal communities on the sandbanks

Byford and others (2011) investigated possible small-scale impacts of turbine scour protection on the soft sediment macrobenthos of Thornton Bank. They found a spatial succession over 200 m from a species poor, homogenous sandbank to a heterogeneous, highly diverse area linked to the Thorntonbank OWF, with potential biotope changes within 7 m of the scour protection. This area contained decreased median grain size and an increase in polychaete densities (e.g. *Lanice conchilega* and *Spiophanes bombyx*). This area also included certain hard substrate species (*Monocorophium acherusicum* and *Jassa herdmani*) in high densities in the soft sediment. Byford and others (2011) noted that these species are known for stabilising soft substrates and them to provide a clear indication of a shifting macrobenthic ‘edge’ community. Moving further away from the scour protection, relative abundances of *M. acherusicum*, *J. herdmani* and *L. conchilega* decreased with increasing distance from the scour protection system. However, *S. bombyx* increased dominance (in relation to the other species) further away from the turbine. The typical soft-sediment macrobenthos seen on Thornton Bank showed the same trend as *S. bombyx* with higher mean densities at stations further from the turbines.

Coolen and others (2015) assessed the diversity and abundance of taxa in rocky reefs (gravel fields and large rocks), *L. conchilega* beds, and sand environments on the Borkum Reef Grounds. They showed that *L. conchilega* creates an intermediate ‘sand-reef system’ which is available for species that live both on rocks and sand. Coolen and others (2015) also found an overlap in species composition of 32% between rocky reefs and sand communities.

Lengkeek (2017), as part of their considerations of eco-friendly scour protection, provided a list of focal species that would settle on hard artificial substrate in the North Sea wind farms. The focal list of species was created by combining policy-relevant species lists, excluding species that were exclusive to soft substrates, the intertidal zone or coastal areas. Lengkeek (2017) should be investigated in more detail alongside Coolen and others (2018) and Coolen and others (2019. Coolen and others (2018 and 2019) provide further detailed understanding on fauna on scour protection associated with Egmond aan Zee OWF, Princess Amalia OWF, and the L15-A and K9-A gas platforms. Communities on scour protection were mostly made up of gammarid crustaceans (in particular *J. herdmani*, *Monocorophium* spp. and *Stenothoe monoculoides*), the plumose sea anemone *Metridium senile* (=*dianthus*), *Mytilus edulis*, and crust-forming bryozoans such as *Conopeum reticulum* and *Electra pilosa*. *Asterias rubens* was also common. Coolen and others (2018) in particular noted that scour protection holds a low percentage of non-indigenous species compared to turbine foundations (especially shallow parts of the foundation) while hosting a number of species that are also found on natural rocky reefs.

Coolen and others (2022) continued their study of southern North Sea OWFs in the Netherlands, Belgium and Germany with a meta-analysis to identify temporal and spatial scales to guide future monitoring studies on the effect of hard structures on soft bottom seabed structures. They collated and analysed existing data sets from 3 national benthic macrofauna monitoring programs in European OWFs, using 2,849 sampling points converted to a set of biodiversity response metrics. This concluded that, very close to foundations, diversity was higher than at intermediate distances, with this response attributable to either increased epifaunal communities colonizing the hard substrates and an associated depositional flow of faeces and other organic material to create organic enriched sediments (Kerckhof and others, 2010), or the presence of fouling species being detached from hard substrates, creating an ‘artificially’ increased diversity in the very local seabed (Mavraki and others, 2020).

While these studies have been found in non-UK sections of the southern North Sea, and are generally based around scour protection for turbines rather than protection for cables/pipelines, extrapolation should be possible into potential outcomes for localised areas of the sandbank sites next to rock protection. Changes to local sandbank habitat may include:

- Near rock protection, there may be a close-range shift in species present, with some influx of epibenthic mobile and immobile species from rock communities that have colonised the rock emplacement.
- Near rock protection, there may be increased abundance of reef-building fauna in the sediments (especially polychaetes such as *L. conchilega* or amphipods such as *Ampelisca* spp.)
- Near rock protection, there may be the formation of microhabitats associated with a fining of sediment.
- The native macrobenthos could shift to species which are more adapted to the changed sediments, hydrodynamics and disturbance.
- In comparison to boulders, gravel protections may result in a lower biodiversity increase and abundance of organisms due to the more unstable environment which they provide (Langhamer, 2012).
- Scouring may increase the difference in the communities seen close to the rock protection.

Sandbank communities on rock

Development of sandbank communities on or within the rocky substrate will be dependent on the overlap between the rock and sediment, i.e. how, where, and how much, sandbank sediment epifaunal and infaunal communities transition into the rocky area. It is likely that the sediment will partially backfill space between rocks and therefore allow for likely shallow settlement of infauna.

A rock berm is by necessity composed of clasts considerably larger than that of the native sediments, leaving interstitial spaces between the rocks (Pidduck and others, 2017). As an example, in NNSSR SAC, the outer layers of rock dump used in ConocoPhillips decommissioning comprised of particles of 11-200 mm, designed to withstand storm conditions. This particle size is at least two orders of magnitude greater than the natural median particle size of NNSSR SAC (Pidduck and others, 2017). Dernie and others (2003) postulated that infilling rates (and presumably biological recovery) in unconsolidated clean sands are dominated by physical processes (i.e. the local hydrodynamic regime), and with the dynamic seabed sediment of sandbanks, sediment is likely to enter these interstitial spaces over time (Ørsted, 2018, Vanagt and Faasse 2014):

“As the accumulated sediment volume increases, any open voids in the protection would become infilled and a sediment slope would develop on the updrift side (with a maximum slope angle equal to the angle of repose for sand ~30 degrees). As the stable slope approaches the top of the protection (up to 2 m above the seabed), the blockage effect of the cable protection will be progressively reduced to near zero and sediment will subsequently be transported directly over the obstacle (via the sediment slope and/or in saltation or suspension) unimpeded, at the naturally occurring ambient rate and direction” (Ørsted, 2018).

However, the evidence base for the development of infaunal and epifaunal communities develop on and within rock protection is extremely limited, and is generally based on infilling studies from pipelines, expert judgement, anecdotal evidence, or interpretation from databanks such as MarESA. Of this limited evidence base, two studies are publicly available. In Lengkeek and others (2017) summary of the monitoring of the development of benthic communities on scour protection at Dutch and Danish OWFs, they found that colonisation by native North Sea species was variable and dependent on the types of rock protection used and the local environmental conditions (e.g. at Princess Amalia wind farm, some infilling of rock protection was observed in the lower energy environment).

A physical modelling study (An and others, 2015 reported in Ørsted, 2017) also noted that sediment accumulation occurred within the voids of the rock berm, with 70%-100% of the void space being infilled both on the edges and over the top of the structure - when the supply of sediment from upstream was sufficient. When the supply of sediment from upstream was relatively restricted, the volume of sediment accumulated in the voids could be reduced. The bed level both upstream and downstream of the berm was equal at the end of the experiment, meaning there was no net accumulation or scouring of sediment at these locations and therefore no net blockage or enhancement effect of the berm on sediment transport. The infilling of the voids over the whole surface of the berm created an almost continuous sediment surface.

It is worth noting that some of the natural sandbanks biotopes are infaunal, and some are epifaunal. Expert judgement and ecological understanding would suggest that initial communities to develop would be epifaunal, with infaunal communities developing more slowly. Osman (1977) studied the factors found to be important to development of epifaunal communities and their distribution on rocks. He noted that colonization of a substratum was dependent upon the abundance of settling larvae, which in turn related to seasonality and selectivity of site attachment. Colonisation will be highly variable and may change seasonally, related to the epifaunal and infaunal communities available within connectivity pathways across the sandbanks system.

Effects on mobile sediments

The above observations should be interpreted in terms of scale. Cable protection has generally been calculated as between 0.5-1 m increase in height above RSL (aRSL) for cables on seabed and between 1.0-2.0 m aRSL at the locations of cable crossings. The protection is up to 5m in width. At SPPs for oil and gas, and OWF structures, the height of the protection may be higher e.g. 3 m aRSL.

Where cables are set to run through mobile sediments, sandwave levelling is often undertaken to provide underlying stability to the cable and protection. The horizontal and vertical scales to which levelling is needed provides an indication of the spatial mobility of the sediments, whilst baseline and monitoring data can provide temporal understanding of mobility. These effects generally occur across discrete locations of a sandbank. Whilst sandwave levelling temporarily removes these finescale geomorphological and structural features, the scale of effect is most often not across the whole of the top (crest) of a bank.

It is clear from Q2 that the ecological boundary between rock and sand is somewhat blurred, with marginal communities potentially occurring on both rock and sand, out to distances of 10s of metres (from the infrastructure). One would expect the composition and occurrence of these communities to be constantly in flux, dependent both on storm events (storm-derived wave turbation) and ongoing sediment movement (Coolen and others, 2018, 2019).

In areas of active sediment transport, while any linear protrusion on the seabed may initially disrupt local bedload sediment transport processes, one would expect partial or full burial to occur in a timely fashion, as long as the expected sandwave movement will attain 0.5-2 m above that of the height of the rock (Ørsted, 2017). Sand would first accumulate one side or both sides of the obstacle (depending on the gross and net transport at that location) to the height and relative orientation of the protrusion (up to 0.5-1.0 m in most cases). A ‘ramp’ would then develop over which sand transport would eventually occur by bedload processes, thereby by-passing the protection (Ørsted, 2018). Initial deposition of rock would be expected to remain within the Environmental Impact Assessment (EIA)/Habitats Regulations Assessment (HRA) envelopes assessed for the installation.

It is apparent from ongoing O&M licence variation requests for work on scour protection and cable protection that, at least for the foreseeable future (though see Evidence: Mitigation for future trends), additions to some areas of as-laid rock will continue to be requested. These additions may be on the same footprint as rock previously laid, thereby avoiding further impact on subtidal sandbanks habitat extent and distribution. The footprint may also be additional to the original footprint but within the consented envelope of impact, or may exceed the original assessment envelope for consent. Without understanding this, along with what actual means that not only are project baselines likely to not truly represent the impact of other projects, but neither will the impact to be added from the project under consideration be accurate as-laid on the seabed.

Cumulation of impacts based on projections, rather than as-laid numbers, over several layers of addition (i.e. from area of impact on a sandwave to sandwave to sandbank to sandbank site) may lead to over-precaution when it comes to assessment of condition. While additive processes simplify the cumulative impact assessment (CIA) and in-combination assessment, it further does not consider multiplicative or antagonistic effects that may be present for certain attributes at a higher level than site- or project-specific effects.

As such it is recommended that any cumulative (EIA) or in-combination (HRA) effects for determining adverse effects at a site-level, or for use in condition assessment, includes:

- The as-laid footprint of infrastructure assessed as part of the baseline;

- A small buffer around the direct footprint of the infrastructure to account for predation halo (this may be up to 10 m); and
- As-laid footprint of new hard substratum (or a percentage range of likely footprints given understanding of similar as-laid protection in the same sandbanks system).

The project team recommends that CIAs are considered from an additive and non-additive (multiplicative/synergistic/antagonistic) basis to ensure that the impacts and effects that drive cumulative effects can be understood. Modelling that takes account of these issues is considered best practice in many complex ecosystems (e.g. Great Barrier Reef Marine Park Authority 2018). The project team also suggests that any ‘bottom-up’ cumulative addition of project-level impacts is accompanied by a ‘top-down’ analysis of impact on the site features as a whole. This would allow a better understanding of how impact works on both smaller and larger scales in a site.

Understanding the dynamics of the cyclical or noncyclical interplay between sandwave and rock will need further study, especially with modelling.

Test 2: Is the change in extent and distribution of sandbank (caused by the introduced rocky substrata) significant enough that the integrity of the protected site is adversely affected?

Q3 Could some level of deposition of rocky substrata occur on a sandbank habitat without causing a significant change in population structure, ecological or physical structure of the sandbank?

This is likely to be site-specific, bank-specific, and related to the PDE of the infrastructure. However, it is likely that some degree of deposition of rock substrata may not result in adverse effects.

If the concept of significant impact is accepted, it also has to be accepted that there are non-significant impacts. The level of this non-significance, in terms of the amount of deposition, is likely to be related to the results of a vulnerability assessment (see Q5). This would need to consider; scale, sensitivity, fragility, and connectivity, further interpreted in terms of in-combination impacts.

Thresholds

Any thresholds concerning adverse effects/lack of adverse effects will need to contain precaution that is proportionate to the uncertainty of the situation, combined with the potential risk of harm. Where much remains unknown, and the statistical power of baseline information is low, and where there is potential for lasting harm, precaution requires that a conservative approach is taken towards environmental management and assessment (Hitchin and others, 2023). Hitchin and others (2023) also highlight that initial thresholds should also be conservative, but which may later be adjusted once more monitoring data and technical knowledge are available.

Defining a level of harm threshold for any agency or regulator requires a multi-criteria judgement ideally based on empirical data, ecological understanding of the impacts on temporal and spatial scales, and a consideration of the losses in comparison to the benefits expected to be gained. It should allow the detection of change and it should be set within a monitoring regime entailing sufficient statistical power to reliably separate acceptable values from unacceptable ones.

It seems challenging to define a single threshold of extent, particularly with the challenge of temporal changes in rock exposure. Thresholds, among many other things, will depend on:

- Scales of the data available;
- For mobile sediments - speed in which the sediment moves and the dimensions through which it travels. Sand mobility may lead to the need for a range of thresholds, or a moving threshold value;
- For moribund sediments - recoverability of sandbank communities / biotopes on rock protection. For example, a precautionary limit of X% of the sandbank footprint would not be a robust threshold for determining a limit at which cumulative impacts become significant; as it cannot be guaranteed that a hypothetical extent of *in situ* hard substrata on a sandbank would remain constant over time, due to potential burial or re-exposure by mobile sediments;
- Extrapolation of local-scale effects to population level impacts or site level impact; and
- Levels of expert judgement allowable.

Determination of a significant change in population structure, ecological or physical structure of a subtidal sandbanks feature, will more often than not, require detailed consideration of all aspects associated with Q4 and Q5. Therefore, these two questions will be addressed first.

Q4 Sandbank SACs are very large sites and the sandbanks features cover 100s or 1000s of square kilometres. The introduced rocky substrata whilst being locally extensive e.g. 100,000s square meters, makes up a very small proportion of this feature due to the sheer size of the site/feature e.g. >0.1%. What could be a logical way of assessing ecological impacts at these scales? Are there lessons that can be learnt

from other areas of ecology where proportionally small effects on large habitats have been studied?

Q4 is inherently associated with scale, both of features, and also for pressure footprints and associated impacts.

Scale of impact

Subtidal sandbanks SACs in the southern North Sea are very large sites, and the subtidal sandbanks features cover 100s or even 1000s of square kilometres. As such, the SACs, subtidal sandbanks features, and even the banks themselves are also often many times larger than direct or indirect loss of sandbank caused by hard infrastructure emplacement. A sense of scale is therefore vital when considering loss of specific ecological functions of small areas of subtidal sandbanks habitat.

Various authors have considered the various scales present within sandbank sites. Larsen and others (2016), in their study of Race Bank OWF, discuss the various scales and properties of bedforms in the area and their relation to design and operation (Table 7).

Sandbanks, and associated bedforms, such as sand waves, and to a lesser extent, megaripples have dimensions which are significant for WTG foundation design, as well as considerations of cable installation and viable cable burial depths (Deltares, 2023). They also highlight the risk of predicted seabed level changes interacting with design and planning for OWFs, particular seabed lowering. To mitigate this, increased initial cable burial depths and scour protection extents are required.

While sandbanks can often be considered to be stationary for the lifetime of an OWF array, bedforms such as sand waves typically migrate fast enough to cause (up to) metres of seabed variation; dependent upon the orientation, and migration, of the bedforms (e.g. sand waves) relative to the infrastructure (Deltares, 2023, Larsen and others 2016).

The Deltares (2023) research team highlight that exposed pipelines or cables are expected to influence seabed dynamics only locally (about 100m from the object) and therefore mainly influence megaripples.

The Bureau of Ocean Energy Management, Regulation and Enforcement provided an illustration of how they have perceived cable protection interaction with sandwaves on the United States outer continental shelf (Sharples, 2011):

“Protecting the cable against the movement of sand waves after installation: rock can be used to stabilize the area and this slows, but does not stop the issue if the sand wave is moving: the sand waves will spread engulfing the rock berm and then over time lower the rock berm as the trough of the sand wave passes, but the cable itself does not get exposed; The rock cover dimensions, and grading can be adapted to allow erosion of sand from under the rock cover. This will result in a gradual lowering of the rock cover including the cable as the crest of the sand wave recedes. Once the lowest point is reached, accretion will bury the rock berm until some other sand wave trough will re-expose and potentially further erode the sand from under the berm. The volume of rock and initial geometry to be placed has to be considered carefully based on details of the sand wave characteristics to allow the reshaping of the berm without losing the protective function."

Table 7: Morphodynamic seabed features and some typical characteristics of sandbanks based on hindcast and forecast analyses for Dutch offshore renewables strategic planning and UK offshore wind farm construction. Capital "O(.)" indicates "In the order of". O(1) m indicates dimensions the order of metres (e.g. 1 or 15 m). Values are based on expert judgement, existing literature and morphodynamic studies in comparable areas. Adapted from: Deltares (2023) and Larsen and others (2016)

	Scale	Wave length (m)	Wave height (m)	Related flow	Mobility	Permanency	Threat to cables and foundations
Ripples	Micro (not visible on MBES)	O (0.1)m	O (0.01)m	Wave and tide; high flow conditions	Hours (1m/day)	Transient	Minimal
Megaripples	Micro	O (10)m	O (0.1)m	Tide (near bed currents); high flow conditions	Hours – days (100m/year)	Transient	Small
Sandwaves	Meso; overlain by micro features	O (100)m	O (1)m	Tide (near bed residual currents)	Days – decades (10m/year)	Persistent	Large
Sandbanks	Macro; overlain by meso and micro features	O (1000)m	O (10)m	Tide (depth averaged residual currents)	Years – centuries (1m/year)	Lasting	Minimal

Understanding these different bedforms is essential for interpreting the significance of impact. It is suggested that appropriate scales for subtidal sandbanks MPAs are:

- Impact compared to all surficial seabed sediment within the site boundary (‘MPA’ level);
- Impact compared to the area of all the delineated subtidal sandbanks features within the site (‘sandbanks system’ level);
- Impact compared to the area of the single delineated (discrete) sandbank (or banks actively linked together) (‘sandbank’ level);
    - This should make consideration of whether the ‘sandbank’ is active or moribund/relict;
    - If active, then consideration may need to be made of the other sandbanks which are actively/geomorphologically linked to that bank (i.e. indirect effects on the physical structure of the active bank system as a whole);
    - If moribund/relict, then the sandbank can be considered in isolation (of all other sandbanks within the site); and
- Impact compared to a localised area of a single sandbank, focusing on interactions at a very fine-scale with attributes such as sandwaves on the crest (‘local’ level).

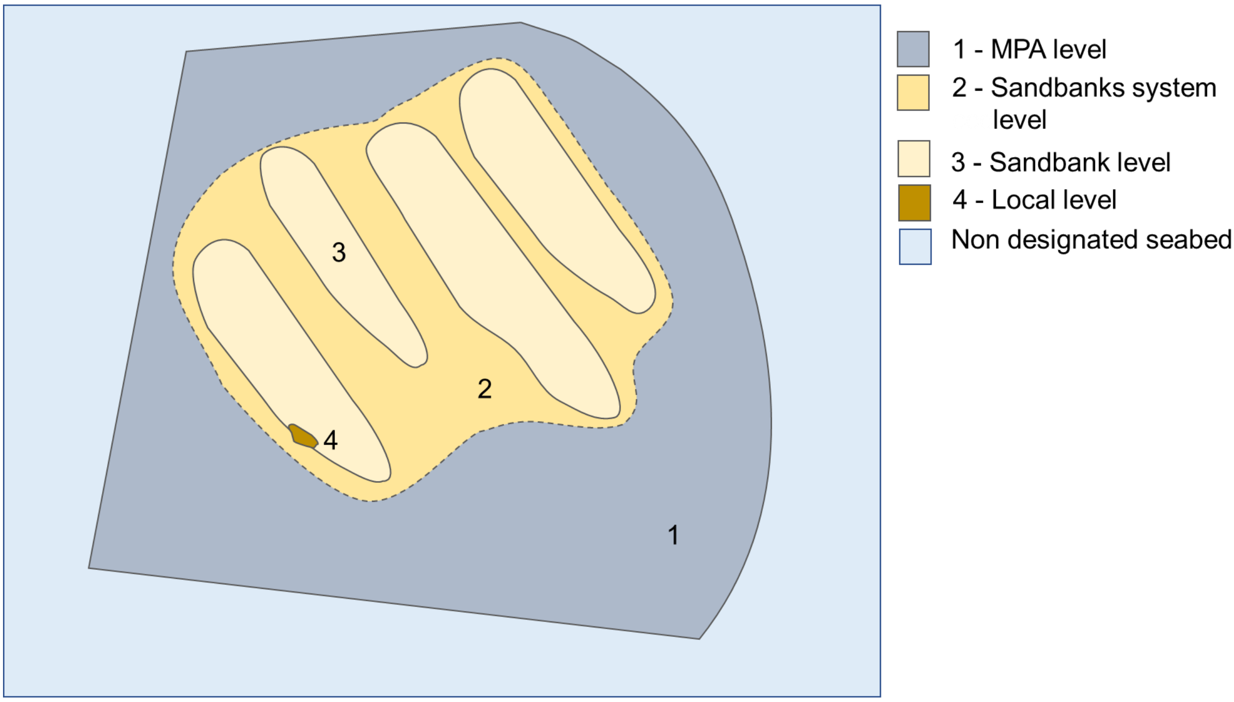

Figure 7: Proposed geospatial scales of subtidal sandbanks Marine Protected Area assessment

Understanding the interaction of these scales will prove useful in comprehending the significance of impact. Condition assessment focusses on the larger scales, looking at the status of the subtidal sandbanks within the site; whereas conservation objectives often look in more detail, at extent and distribution, structure and function attributes associated with sandwaves and megaripples compared to the status of the site as a whole. Individual licensed operations may look in even more focused spatial detail at impact on the biotope sub-features (where used) or sediment composition of an area of a particular bank. Thus, within the different processes and assessments there are different scales of granularity.

Each of these scales may provide a different understanding of impact. Mestdagh and others (2020) state that changes on an individual subtidal sandbank itself, may not be a significant impact on the whole subtidal sandbanks system within a site. JNCC note in their SACOs for NNSSR SAC and DB SAC that they do not consider it likely that human activities taking place within the site have the potential to permanently impact on the large-scale topography of subtidal sandbanks (JNCC, 2018, 2022a). However, understanding those effects may be relevant to determining the significance of localised impact (Mestdagh and others, 2020) i.e. impacts may be relevant to the condition assessment of that individual bank feature (localised), but not significant to all the subtidal sandbanks features within the MPA, or the MPA as a whole.

It is also important to understand that the ecology of subtidal sandbanks feature is starting to be quantified through work in various areas of the North Sea (e.g. Coolen and others, 2020a; Coolen and others, 2020b). Mestdagh and others (2020) note that from studies on Brown Bank, off the Netherlands coast, that macrobenthic community compositions appear to be largely determined by topographic position (as determined by hydrodynamics and sediment dynamics), with higher biodiversity in the sandbank troughs (flanks) than on the crest (also see Ellis and others, 2011; van Dijk and others, 2012, Parry et al 2015). They also note that communities may interact with, and change, given natural hydrodynamic conditions in the site i.e. can be forced by storm events.

At the scale of communities and associated seabed surficial sediments, there will be sediment transport, which is not inherently associated with the geomorphological movement of a subtidal sandbanks feature, regardless of whether the bank is active or moribund e.g. sandwaves or megaripples can move across the features, and within the MPA. The natural dynamic environment exposes infauna to abrasion and scour, prevents the build-up of organic matter in the substrata and restricts the development of distinct niches. These factors do not favour the establishment of stable and diverse communities and the crests of sandbanks tend to support relatively impoverished communities consisting of low numbers of a few species of amphipod crustaceans and polychaete worms which are adapted to this stressful environment (MarLIN, 2023[17]; JNCC, 2023[18]).

The over-riding natural physical processes, including sediment transport systems, can result in hard infrastructure being covered and uncovered during its lifespan within a site

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[17] MarLIN - The Marine Life Information Network - Subtidal sands and muddy sands

[18] Sublittoral sediment - JNCC Marine Habitat Classification

(excluding DB SAC). Importantly, as noted above, storm events are known to cover or uncover large pieces of infrastructure within single discrete temporal events. Subtidal sandbanks features and associated habitats, are naturally exposed to a continual flux of community structure. Infaunal and epifaunal communities will dominate and regress dependent on normal hydrodynamics.

Evolving the intermediate/localised scales

As noted in the SoW, and in representations provided by Natural England and JNCC in the examination processes of OWF applications, understanding the significance of effect of very small-scale/small percentage impacts is challenging. However, as also noted by Chapman & Tyldesley (2016) amongst others, values or percentages of total area lost should not be the only metric providing an understanding of significance of impact.

Simple percentage/area scales of loss as discussed above could be further supplemented by:

- Determining values of loss from part of a particular biotope within the MPA, or on a particular sandbank;
- Determining values of loss of a particular sediment class across the MPA, or on a particular sandbank;
- The inclusion of secondary areas of effect associated with downstream effects from infrastructure (such halos of physico-chemical change or effects from mobile predators colonising the infrastructure); and
- An update to the case studies and tables presented in Chapman & Tyldesley (2016) with regard to percentages of feature loss by which courts consider significance, to extend beyond Europe, and with a focus on subtidal sandbanks/marine sediments.

These issues are elaborated further in Q5.

Q5 Could there be parts of a sandbank where a loss or change in seabed habitat would have a greater or lesser effect on the ecology of the sandbank? For example should we consider how much of a particular seabed type is present in the site, whether some communities are spatially limited, whether some parts of the site have particularly high biodiversity or functional value, for example the troughs often have higher biodiversity, and the slopes are often important fish feeding areas for fish and demersal species during tidal flows.

Q5 is associated with assigning value to areas of subtidal sandbanks that may be impacted through loss or change in seabed habitat (related to the feature). As shown in Q4, this can be assessed using different spatial scales (of physical and ecological characteristics). Project-level impacts leading to the potential loss or change of subtidal sandbanks extent and distribution, structure and function, as discussed here in Q5, relate to the ‘sandbank’ and ‘local’ levels of impacts.

Different topographical parts/sub-components of subtidal sandbanks support different communities, and also ecosystem functionality. These parts of a bank may be more or less vulnerable to pressures associated with the installation or removal of hard infrastructure. Understanding the vulnerability of these sub-components of subtidal sandbanks across the whole sandbank will help focus condition assessments in the context of relatively small scale losses in discrete areas of the sandbank.

In terms of international understanding of vulnerability, vulnerability is related to the likelihood that a population, community, or habitat will experience substantial alteration from short-term or chronic disturbance, and the likelihood that it would recover, and in what time frame (FAO, 2009). The most vulnerable ecosystems are those that are both easily disturbed and very slow to recover, or may never recover.

As such, it may be beneficial to approach subtidal sandbanks condition assessments, and management advice, with a novel subtidal sandbanks-specific scheme for understanding areas of highest vulnerability. This needs to be evidence-based and ideally consulted upon by known experts on subtidal sandbanks, as per the January 2021 workshop (Natural England, 2021). This could be used to complement and refine understanding of condition from higher-level conservation objective attributes.

This complementary scheme could be based on an internationally agreed habitat vulnerability framework initiated by the FAO (2009). This approach has been used regionally by ICES in fisheries management, and by Scottish Government in designation of Scottish MPAs to understand areas of greatest/greater vulnerability. It should be noted that Vulnerable Marine Ecosystems (VMEs) are not the same in concept or operation as VERs (Valued Ecological Receptors); the use of which has been challenged through the HRA process.

The United Nations Food and Agriculture Organisation (FAO, 2009) considers the following list of characteristics that should be used as criteria in the identification of Vulnerable Marine Ecosystems (VMEs):

I. Uniqueness or rarity – an area or ecosystem that is unique or that contains rare species whose loss could not be compensated for by similar areas or ecosystems. These include:

    - habitats that contain endemic species;
    - habitats of rare, threatened or endangered species that occur only in discrete areas; or
    - nurseries or discrete feeding, breeding, or spawning areas.

II. Functional significance of the habitat – discrete areas or habitats that are necessary for the survival, function, spawning/reproduction or recovery of fish stocks, particular life-history stages (e.g. nursery grounds or rearing areas), or of rare, threatened or endangered marine species.

III. Fragility – an ecosystem that is highly susceptible to degradation by anthropogenic activities.

IV. Life-history traits of component species that make recovery difficult – ecosystems that are characterized by populations or assemblages of species with one or more of the following characteristics:

  - slow growth rates;
  - late age of maturity;
  - low or unpredictable recruitment; or
  - long-lived.

V. Structural complexity – an ecosystem that is characterized by complex physical structures created by significant concentrations of biotic and abiotic features.

A subtidal sandbanks-specific vulnerability framework, based on the use of the FAO (2009) VME approach (and associated criteria), could provide an extra set of criteria that provides Natural England with a framework for understanding areas that would be more highly vulnerable to change. The VME assessment approach can be used to consider different parts of an individual sandbank and decide which areas are higher priority for protection. These areas would be considered more vulnerable concerning rock emplacement.

This sandbanks-specific VME assessment approach could be comprised as follows[19]:

I. **Uniqueness or rarity – an ecosystem or feature that is unique or that contains rare species whose loss could not be compensated for by similar areas or ecosystems.** These include:

  - Habitats that contain endemic species;

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[19] Note that this approach is a standardised framework for assessing all aspects of vulnerability. It could be adapted to highlight aspects that Natural England considers important. For this to be most effective at a UK-wide level, allowing comparison across devolved administrations, it would be important to include all attributes, such as endemicity, as a starting point for assessment.

- Habitats that contain global or regional rareness;
- Habitats of rare, threatened or endangered species that occur only in discrete areas;
    - *Sabellaria spinulosa* reefs (qualifying) (Annex I, others);
    - *Arctica islandica* (OSPAR Threatened and Declining Species List);
    - Subtidal seagrass (*Zostera* spp.), maerl or macroalgae biotopes;
- Rare, threatened or endangered habitats that occur only in discrete areas;
    - Any habitats (proxied by communities or biotopes) that are only present in discrete locations/extents of any single bank feature e.g. on one aspect of bank topography;
    - Any habitats present only in one geographically discrete area of an MPA, or which have low connectivity with the same habitats in other locations within the whole site;
    - Any habitats present only in one subtidal sandbanks MPA;
- Habitats of rare or unusual traits;
    - May be focused on habitats that have been surveyed and demonstrate variations to the ‘normal’ occurrence of that habitat in the region e.g. exceptional occurrences of biogenic reef or epifaunal communities.
    - Areas of rare sediment composition;
    - Notable variations from sand sediment classes;
        - Non-bedrock geogenic reef;
        - Muds.

II. Functional significance of the habitat – discrete areas or habitats that are necessary for the survival, function, spawning/reproduction or recovery of fish stocks, particular life-history stages (e.g. nursery grounds or rearing areas), or of rare, threatened or endangered marine species.

- Nurseries or discrete feeding, breeding, or spawning areas;
    - Relate to information and evidence detailed within Q2;
    - Reference to Ellis and others (2012), Atlantic herring potential spawning habitat mapping, sandeel supporting habitat mapping;
    - Feeding areas for designated Annex II populations and classified seabird populations (can be associated with Conservation Objectives for these populations relating to habitat provision for prey species) – can be supplemented by ‘hotspots’ data e.g. Waggitt and others (2020) and FAME/STAR data;

- Areas of the site with particularly high biodiversity or functional value;
    - Relate to information and evidence detailed within Q2;
    - The troughs often have higher biodiversity;

    - Slopes are often important fish feeding areas for fish and demersal species during tidal flows.

III. **Fragility – an ecosystem that is highly susceptible to degradation by anthropogenic activities.**

- Noting that the evidence review and understanding of physical processes suggest that subtidal sandbanks ecosystems could be considered as relatively robust and resilient at the site- and regional-scale; though placement of rock may lead to permanent loss;
- *S. spinulosa* reefs, though noting that disturbance may well lead to encouragement of reef evolution/development nearby or elsewhere.

IV. **Life-history traits of component species that make recovery difficult – ecosystems that are characterized by populations or assemblages of species with one or more of the following characteristics:**

- *A. islandica* has slow growth rates, a late age of maturity, low or unpredictable recruitment and has long-lived individuals.

V. **Structural complexity – an ecosystem that is characterized by complex physical structures created by significant concentrations of biotic and abiotic features.**

- Areas of cobble reef or stony reef;
- Areas of persistent *S. spinulosa* reef.

It may also be useful to consider whether the extension of the FAO VME analysis process, by ICES (2020), to look at significant adverse impacts (defined as those impacts that compromise ecosystem integrity (i.e. ecosystem structure or function)), could be beneficial to assist with both condition assessments and site integrity tests.

This analysis, when coupled with a scaled approach to assessment (as discussed in Q4) would then allow Natural England to:

1. Create a heat map of vulnerability of subtidal sandbanks within an MPA, its sandbanks system, and the individual sandbanks; and
2. This will facilitate an understanding of the most vulnerable areas within a subtidal sandbanks MPA that should avoid having infrastructure placed upon them.

Common Standard Monitoring guidance

The review conducted in this report agrees with the SNCBs that the existing Common Standard Monitoring (CSM) guidance may benefit from revision (JNCC, 2004, JNCC 2022) to aid in wider understanding for monitoring and assessment.

The current 2004 CSM guidance captures condition assessment of all sublittoral sediment types that may be a constituent of MPA designated Annex I features (and by proxy Habitat Features of Conservation Interest (FOCI) of MCZs in English waters). Understanding of habitat functionality, and site-based assessment rationale have evolved in the last two decades.

The review presented in this report suggests that it may be appropriate to develop specific CSM guidance for subtidal sandbanks features. The review shows that the features have their own inherent considerations, associated with understanding and assessing physical processes and context, let alone also biological, ecological, and ecosystem-scale factors.

In-particular it is proposed that cross-reference to the principles described in the discussion for Q5, and the use of characteristics associated with VME may be beneficial (FAO, 2009; ICES, 2020). See the Discussion and Recommendation 9.

Discussion and recommendations

Understanding the impact of hard infrastructure on the extent and distribution, as well as the structure and function of, subtidal sandbanks features needs to be based on an understanding of the hard substrata installed in the site; both its direct footprint, and its indirect footprint (secondary effects from abiotic and biotic influences of the infrastructure), as well as the changes in the amounts and burial status of the hard substrata through time.

Current evidence/evidence requirements

Currently, the evidence available to the SNCBs is that provided in applications to the regulators, i.e. the amount of rock or other hard substrata expected to be laid down in a site, in whatever detail is provided in an individual application. The expected PDE is often subject to operational changes before, or during, installation, and may lead to different volumes or extents of infrastructure, being laid than originally proposed. However, during construction phase (at least for OWF projects) these changes in amounts are usually still within the worst-case environmental assessment envelope. It is during the O&M phase that unforeseen failures in infrastructure are most often encountered; resulting in an increased requirement for hard infrastructure to be installed to secure assets, than may have originally been foreseen. These incidences invariably require consent/licence variations.

The as-laid amount of hard infrastructure, associated with O&G decommissioning operations, is provided to OPRED as part of a close-out report; which details the fate of all materials in the decommissioning inventory. These publicly available documents can be used to audit the known amounts of hard substrata that have been installed compared to the worst-case environmental assessment scenario. In addition, projects associated with OWF, and subsea cable associated dMLs, require the provision of as-laid close-out reports to be submitted to MMO. A critical observation is that certain, but not all, reports are readily available to the SNCBs.

An example of these conditions is provided in the Norfolk Vanguard Offshore Wind Farm Order 2022 Schedule 9 (also Schedule 11). It reads:

"22 (1) Not more than 4 months following completion of the construction phase of the authorised scheme, the undertaker must provide the MMO and the relevant statutory nature conservation bodies with a report setting out details of the cable protection and scour protection used for the authorised scheme.

(2) The report must include the following information—

(a) location of the cable protection and scour protection;

(b) volume of cable protection and scour protection;

(c) any other information relating to the cable protection as agreed between the MMO and the undertaker."

The premise here, for this Marine Licence condition is:

"…to prevent loss of seabed sediment around any marine structure placed in or on the seabed by use of protective aprons, mattresses with or without frond devices, or rock and gravel placement".

Recommendation 1

A 'live' (real-time) database of actual installed infrastructure is required.

This will allow a better understanding of the amount of infrastructure placed onto, and removed from, MPAs, which can be used in understanding significance of environmental effect and site condition.

This process could be facilitated by the SNCBs seconding a staff member into both of the regulators to undertake the data acquisition for as-laid quantities and footprints in a format useable by the SNCBs.

Alternatively, discrete funding for MMO and OPRED staff should/could be provided to deliver the recommendation, including maintaining and updating the database.

It is noted that there is a problematic inconsistency in the way that as-laid assets of infrastructure associated with generation and transmission of offshore renewables projects are historically reported; and also in comparison with O&G projects. For OWF projects there is a regulatory requirement to report as-laid dimensions as conditions associated with dMLs. Many historic OWF generation assets report both seabed area extent and volume of rock installed. However, for transmission assets, most often only the volume of rock is reported (certainly for Round 1 and 2 projects). This inconsistency is problematical as understanding the seabed area of extent of infrastructure is critical to assessing the direct impact of those structures on subtidal sandbanks features.

Project-specific variations in SPP and rock berm designs make back-calculating volumes into seabed area footprints very challenging. The SPPs and rock berms may vary across the array of an individual OWF project, let along between different OWF projects.

In contrast, O&G as-laid infrastructure dimensions appear to always be recorded as both seabed area extent and volume of rock/concrete mattresses installed.

Availability of comparable data between all OWFs (for both generation and transmission assets) and with all O&G installation is critical to inform Recommendation 1.

In addition, an understanding of the actual as-laid quantities, areas of extent and volumes are critical to understand, in relation to initial worst-case scenario Rochdale Envelopes assessed for construction of projects. In most cases the Rochdale Envelope is not achieved, yet cumulative impacts assessments and in-combination assessments between successive projects are not able to effectively use the correct as-laid footprints from earlier projects in their own calculations. This means that cumulative and in-combination assessments regularly vastly over-estimate combined theoretical footprints of infrastructure, rather than actual as-laid values: especially in-combination across different projects within one regulator’s statutory role, let alone between different seabed user sectors and their own regulators.

To further compound this cumulative and in-combination assessment issue, numerous O&M asset remediation/remedial works can often exceed the volumes of rock berms and/or concrete mattresses associated with the project’s O&M licence. A lack of proper understanding of multi-project as-laid footprints within any particular subtidal sandbanks

MPA compounds the additional cumulative and in-combination assessments; this often means that Natural England has no option but to advise in a very precautionary manner.

Recommendation 2

Before Recommendation 1 is started, MMO and OPRED should consistently provide cross-industry as-laid quantities and footprints of rock in a format that is agreed by stakeholders.

For each location of infrastructure, the database needs to include both area of seabed footprint and volume installed, accommodating all previously as-laid values.

This will allow a better understanding of the amount of infrastructure placed onto, and removed from, MPAs, and facilitate better informed cumulative impact assessments and in-combination assessments for all seabed user sectors, their regulators and SNCBs.

Beyond these as-laid footprints (areas and volumes), other sources of evidence should also be made available.

Geomorphological models that build on the most up-to-date survey results from industry and UK inshore and offshore monitoring data (Cefas/Natural England/JNCC surveys) would provide updated understanding in how physical processes influence each of the marine sandbanks systems for each of the MPAs considered in this report. In addition, historical charts for the regions are available dating back to the early 19th Century, and a similar exercise for the Dogger Bank, IDRBNR, and NNSSR marine sandbanks systems could be conducted with reference to these historical data (as per HHW system). This would allow new understanding of how the hard substrata *in situ* would interact with the marine sandbanks systems.

It is important to note that while the evolution of previous models would be extremely valuable in understanding temporal evolution of sandbank and hard substrata communities, publicly available data provided in enough resolution to use in modelling remains elusive.

Recommendation 3

Update, and regularly maintain, geomorphological/seabed sediment transport models, based on current data, as well as from evidence collected on future surveys.

This should be a collaborative process between SNCBs and developers, with input from specialists in the field of seabed geomorphological modelling.

Alongside modelling, monitoring data will be critical in understanding the reality of what happens after hard substrata are installed. Again, access to these data are challenging, as noted in Cefas (2021) and Pidduck and others (2017).

Recommendation 4

Monitoring data should consistently be provided in a format that is agreed by stakeholders, to be included in a real-time database of actual installed infrastructure as described in Recommendation 1.

Development of monitoring survey schedules should become a collaborative process amongst SNCBs and developers, and their specialist advisors, to ensure that both Natural England, and developers, gain the required data to inform application processes.

Data are routinely acquired by operators/asset owners concerning the *in situ* post-construction/post-installation status of infrastructure assets. These survey data and observations are incredibly informative regarding the status of subtidal sandbanks features reacting to/recovering from the installation of hard infrastructure, including sediment and bedform coverage and exposure of these assets.

Unfortunately, these data and reports do not appear to be readily available to Natural England.

Facilitating access to these data/reports will be informative to Natural England, and will likely validate post-construction and O&M EIA/HRA assessment envelopes to allow better informed advice from SNCBs and enhanced condition assessments.

Changes in habitats with rock emplacement

The epifaunal habitats likely to form on hard substrata are different from what is generally perceived to be associated with sediment habitats associated with subtidal sandbanks features. However, it is important to understand that many such designated features have habitats (biotopes/sub-features) consisting of pebble, cobble, and boulder habitats. These are predominantly associated with discrete locations on the tops (crests), and flanks, and troughs, of certain sandbanks, and associated sandbanks systems.

When hard substrata are deposited on a subtidal sandbanks feature, and associated habitats, both physical and biological processes will operate on them. Surrounding sediments may then pass-over, or bury, and also begin to integrate with the inert artificial hard substrata. This can result in the development of a surficial sediment layer over the hard substrata, and continued transport of nearbed sediments. In subtidal sandbanks MPAs associated with active banks (where there is active movement of sediments on, and around the bank structures), this burial may not be permanent, and therefore an understanding of how burial-unburial-reburial patterns occur is critical.

Hard infrastructure burial modelling and monitoring could provide both expectations, and ground-truthing, of how small-scale sediment features infill and move across local-scale hard substrata.

In addition, the physical presence of hard infrastructure and the associated evolution of communities may only be temporary. This relates to statements in current condition assessments where much of the infrastructure currently *in situ* is assessed as:

"…a temporary impact for the lifetime of the [OWF] project".

However, to date, no OWF projects have been decommissioned, and relatively few, if any removal of O&G associated rock installation has ever occurred (Natural England, 2022). Natural England prefer to use the term 'lasting' (in regard to the temporal longevity of effects/impacts). This is related to uncertainty of the temporal scales that infrastructure is/will be present upon the seabed. This relates to 'vagaries' around the temporal lifespan of projected-related infrastructure deposited upon the seabed. In other words, whilst removal and restoration is possible, and often expected (to distinguish it from a permanent impact such as removal of habitat), this is yet to be evidenced.

Condition assessment, and use of associated conservation objectives, are currently a 'snapshot' at the time of assessment. Therefore the process fails to capture the temporal nature of pressures on subtidal sandbanks. Considering the previous observations concerning the potential for some structures to show different stages of burial and unburial within the natural functioning ecosystem, this current condition assessment rationale may benefit from a review.

Recommendation 5

Need to consider, and incorporate, temporal patterns of burial of infrastructure.

Gather an evidence base to allow better understanding of temporal burial patterns, including a review of all MBES bathymetry and imagery data for the four MPAs.

Asset owners routinely acquire data to ensure the integrity of their assets. These data are incredibly useful to inform this recommendation. Existing processes do not appear to make these acquired data available to inform this process.

This recommendation is synergistic with Recommendation 3.

It is currently accepted that whilst the infrastructure is *in situ* this represents a reduction of the area of natural subtidal sandbanks communities directly associated with the physical seabed footprint of the infrastructure. However, it is apparent that there is often secondary effect halos and associated marginal areas resulting from the presence of the infrastructure which are associated with changes in abiotic conditions such as increased nutrification of the surrounding seabed sediments. There are also effects associated with biotic factors such as mobile predators foraging out from the infrastructure and altering surrounding infaunal communities.

Increasing knowledge around the scale, ecological dynamics and hydrodynamics of marginal areas from generally impoverished infaunal sand communities to those influenced by rock-based epifaunal scoured communities would aid in understanding how significant these transitions are. Particularly in terms of area of effect, given that several of the biotopes associated with subtidal sandbanks features have very few key species, are separated only on amphipod species-level identification, or are flagged as transitional, or variants of other more stable biotopes.

Recommendation 6

Increase knowledge and understanding of the scale, ecological dynamics and hydrodynamics of marginal areas and halos associated with changes in abiotic properties of seabed sediments and ecological effects of rock-based epifaunal scoured communities including mobile predators, would aid in understanding how significant these transitions are.

The above knowledge may result in further consideration of the actual ecological footprint of hard infrastructure beyond just assessing direct habitat loss associated purely with the direct physical footprint of the infrastructure.

This recommendation is inherently linked to considerations of scale of effects.

Changes in functions with rock emplacement

Understanding function is more challenging given the lack of understanding of the full range of subtidal sandbanks ecosystem services provided by the related benthic communities, for each site as a whole. Subtidal sandbanks MPAs provide important functionality for wider trophic systems associated with provision of feeding areas, spawning areas, and nursery grounds for mobile species such as crustaceans and fish. In turn these species and populations act as prey sources for higher trophic-level predators. Most of the designated subtidal sandbanks features fall within foraging halos for significant SPA breeding seabird populations and also interact/support designated Annex II populations (of marine mammals).

There are numerous classified SPA populations of seabirds along the coastline of the of the North Sea. These are known to travel significant distances whilst foraging from colonies during the breeding season. In-particular northern gannet, black-legged kittiwake, lesser black-backed gull, various tern species and auk species are all recorded foraging within all four SACs considered in this report. These classified populations are associated with, but not limited to, SPAs such as; Flamborough and Filey Coast SPA, Humber Estuary SPA, North Norfolk Coast SPA, Alde-Ore Estuary SPA etc.

The SACOs for these SPAs present attributes which detail ecological characteristics or requirements of the classified species in relation to Supporting habitat: extent, distribution, and availability of supporting habitat for the breeding season:

“Maintain the extent, distribution and availability of suitable breeding habitat which supports the feature for all necessary stages of its breeding cycle (courtship, nesting, feeding) at existing level.”

Marine mammals such as harbour seal and grey seal have been recorded travelling from their coastal SACs on the east coast of England, to all of the subtidal sandbanks MPAs considered within this report. DB SAC, NNSSR SAC and HHW SAC all interact spatially with the Southern North Sea SAC (JNCC, 2017). These factors suggest that all of the four MPAs considered in this report contribute to wider support of designated Annex II populations in the southern North Sea.

For example for designated Annex II harbour porpoise population of the Southern North Sea SAC, Conservation Objective 3 reads:

“The condition of supporting habitats and processes, and the availability of prey is maintained”.

Maintenance of supporting habitats and processes contributes to ensuring that prey is maintained and availability to classified SPA populations and designated Annex II populations. These population’s distribution and condition may strongly reflect the availability and energy density of its prey, and the habitat provision from DB SAC, IDRBNR SAC, NNSSR SAC and HHW SAC.

This functional provision for the wider ecosystem, from the subtidal sandbanks MPAs, may benefit from more refined consideration.

Recommendation 7

Given the direct predator-prey linkage between numerous classified breeding SPA populations and Annex II SAC populations with subtidal sandbanks MPAs, increasing understanding patterns of prey in the sites may provide further clarification of areas of heightened vulnerability to impacts from rock protection.

Understanding scale of impact

The scales of surficial sediment movement, as well as scales of impact within a site, are essential in understanding both condition assessment and operationalisation of conservation objectives to underpin advice on site management and casework.

The United Kingdom has been obliged to report on the conservation status of the habitats and species listed under Annexes I and II of the Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora (92/43/EEC) every 6 years in Article 17 reporting. The most recent Article 17 report (JNCC, 2019) shows that the short-term trend of habitat area in good condition is decreasing, with 45% of the sandbank area assessed in ‘good’ condition.

At site-level, all features of the four MPAs are considered to be in unfavourable condition, with restoration required for many of the extent and distribution, and structure and function attributes, based on expert knowledge. In many cases, high-level vulnerability assessments, which include sensitivity and exposure information for features and activities in a site, have been used as a proxy for condition. JNCC acknowledges for DB SAC and NNSSR SAC that confidence in objectives would be improved by longer-term monitoring and access to better information on the activities taking place within the site. This position correlates with the observation and recommendations made within this report. It is particularly expected that implementing Recommendations 1–6 would have considerable impact.

Many emplacements of hard substrata impact the subtidal sandbanks MPAs on a local-scale. However, there are numerous existing projects, foreseeable and unforeseeable O&M operations, decommissioning campaigns, and reasonably foreseeable plans and projects that involve hard substrata which will interact both spatially and temporally within the MPAs. Understanding the full effect of all hard substrata in-combination is required to inform a better understanding of feature condition.

It will be useful to understand if the following points could be used to better inform condition assessment:

- Decouple individual subtidal sandbanks features within an MPA?;
    - This could be appropriate, as the understanding of the physical processes supporting the extent and distribution, and structure and function of the features is more clearly understood and can also be enhanced as per Recommendation 3;
    - Subtidal sandbanks features can be grouped together, or identified as individual features, dependent upon whether they are active or moribund/relict (see Table 5);

    - Using this approach, one bank/bank unit could be unfavourable and others favourable (for example). This could give a more in-depth and nuanced view of condition; and
- Undertaking an audit of combined infrastructure, as noted in Recommendation 1, will allow Natural England to better understand the scales on which condition assessment and conservation advice are based.

All of the points above will assist in assessing feature and site condition at appropriate scales for subtidal sandbanks MPAs as discussed and detailed in answering Q4 in this report.

Recommendation 8

Use a full audit of hard substrata to look at in-combination impact on extent and distribution, and structure and function attributes on a range of scales associated with sub-compartmentalisation of subtidal sandbanks features within an MPA.

This recommendation can be considered to be synergistic with Recommendations 1-3. The difference being that this recommendation would use the information derived from Recommendations 1-3 and validate a new approach to determining appropriate scales, and their use, in sub-compartmentalisation of subtidal sandbanks MPAs. The aim being to assist with condition assessment and operationalisation of conservation objectives to underpin advice on site management and casework.

Recommendation 9

Use the outcomes from Recommendation 8 to assess possible ways to supplement current understanding of condition.

Possible options should include:

Supplementing current condition assessments with more detailed analysis based on FAO/ICES VME assessment frameworks.

Thoughts on future potential mitigation

Various projects have the capacity to adapt and change their engineering PDE within a worst-case Rochdale Envelope defined during the EIA process, and the PDE also assessed through HRA. As such, there is potential to work with developers and regulators to mitigate impacts related to current, and future O&M, and decommissioning pressures, as well as those associated with reasonably foreseeable construction.

Mitigation measures are available, and an outline for potential future topics is considered in Appendix 8, noting that all will rely on MPA site-specific characteristics. The discussion and suggestion in Appendix 8 results in the following recommendations.

Recommendation 10

Undertake modelling of the interaction of berms/hard substrata with sediment transport pathways through an MPA to allow potential prioritisation of hard substrata options from developers.

Recommendation 11

Review emergent technology to assess viability of novel and/or developing potential for mitigation of likely significant effects and adverse effects on the integrity of MPAs with subtidal sandbanks features.

Recommendation 12

Better understand emergent technology with the potential to mitigate likely significant effects and adverse effects on the integrity of MPAs with subtidal sandbanks features through direct engagement with operators and technology developers.

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Glossary

Term	Meaning
AEoSI	Adverse Effect on Site Integrity
aRSL	Above Relative Sea-level
BBF	Boulders Bank Formation
bCD	Below Chart Datum
BCF	Botney Cut Formation
BEIS	Department for Business, Energy & Industrial Strategy
BGS	British Geological Survey
BSW	Broad Sediment Wedges
CGBF	Concrete Gravity Base Foundation
Clasts	Fragments of rock of any size
CSM	Common Standards Monitoring
DB	Dogger Bank
DBF	Dogger Bank Formation
DCO	Development Consent Order
Dead zone	An area within a water body in which oxygen concentration has been depleted to a level that cannot support life
dML	Deemed Marine Licence

Term	Meaning
EIA	Environmental Impact Assessment
ESCA	European Subsea Cables Association
FAD	Fish Aggregation Device
FCS	Favourable Conservation Status
FOCI	Features of Conservation Interest
Forebulge Collapse	The isostatic subsidence around the margin of an ice sheet immediately after deglaciation
Glaciotectonised	Sub-glacial sediments that have been deformed by over-riding ice
HHW	Haisborough, Hammond and Winterton
HRA	Habitats Regulations Assessment
Hypoxia	A reduction in oxygen below a threshold in which an organism cannot effectively maintain homeostasis
ICES	International Council for the Exploration of the Sea
IDRBNR	Inner Dowsing, Race Bank, North Ridge
INNS	Invasive Non-native Species
JNCC	Joint Nature Conservation Committee
ka	Thousand years
kaBP	Thousand years Before Present
KIS-ORCA	Kingfisher Information Service – Offshore Renewable & Cable Awareness

Term	Meaning
LGM	Last Glacial Maximum
LSE	Likely Significant Effect
MarESA	Marine Evidence based Sensitivity Assessment
MBIEG	Marine Biodiversity Impacts Evidence Group
MCZ	Marine Conservation Zone
MIS	Marine Isotope Stage
ML	Marine Licence
mLAT	Mean Lowest Astronomical Tide
MLS	Margate and Long Sands
MMO	Marine Management Organisation
MPA	Marine Protected Area
NNSSR	North Norfolk Sandbanks and North Ridge
NSIP	Nationally Significant Infrastructure Project
O&G	Oil and Gas
OPRED	Offshore Petroleum Regulator for Environment and Decommissioning
OSPAR	Oslo Paris Convention
OSS	Offshore Substation
OWF	Offshore Wind Farm

Term	Meaning
PDE	Project Design Envelope
PETS	Portal Environmental Tracking System
Pore Water Advection	The movement of water through a porous substrate as a result of a potential difference in pressure across the substrate. This is usually caused by the interaction of water currents with topographical features of the seabed
pSAC	Possible Special Area of Conservation
RfQ	Request for Quotation
RSL	Relative Sea-level
SAC	Special Area of Conservation
SACO	Supplementary Advice for Conservation Objectives
Scaphiform Valleys	Sub-glacial tunnel valleys formed by high discharge, high hydrostatic pressure meltwater channels under a temperature ice sheet
SCI	Site of Community Importance
SNCB	Statutory Nature Conservation Body
SNS	Southern North Sea
SoW	Scope of Works
SPA	Special Protected Area
SPP	Scour Protection Pad
Subglacial Tunnel Valleys	Valleys carved into sediments by subglacial meltwater erosion

Term	Meaning
TCE	The Crown Estate
Terminal Moraine Belt	A morphological feature indicating the maximum extent of an ice sheet
UKCS	United Kingdom Continental Shelf
UKHO	United Kingdom Hydrographic Office
VME	Vulnerable Marine Environment
WTG	Wind Turbine Generator

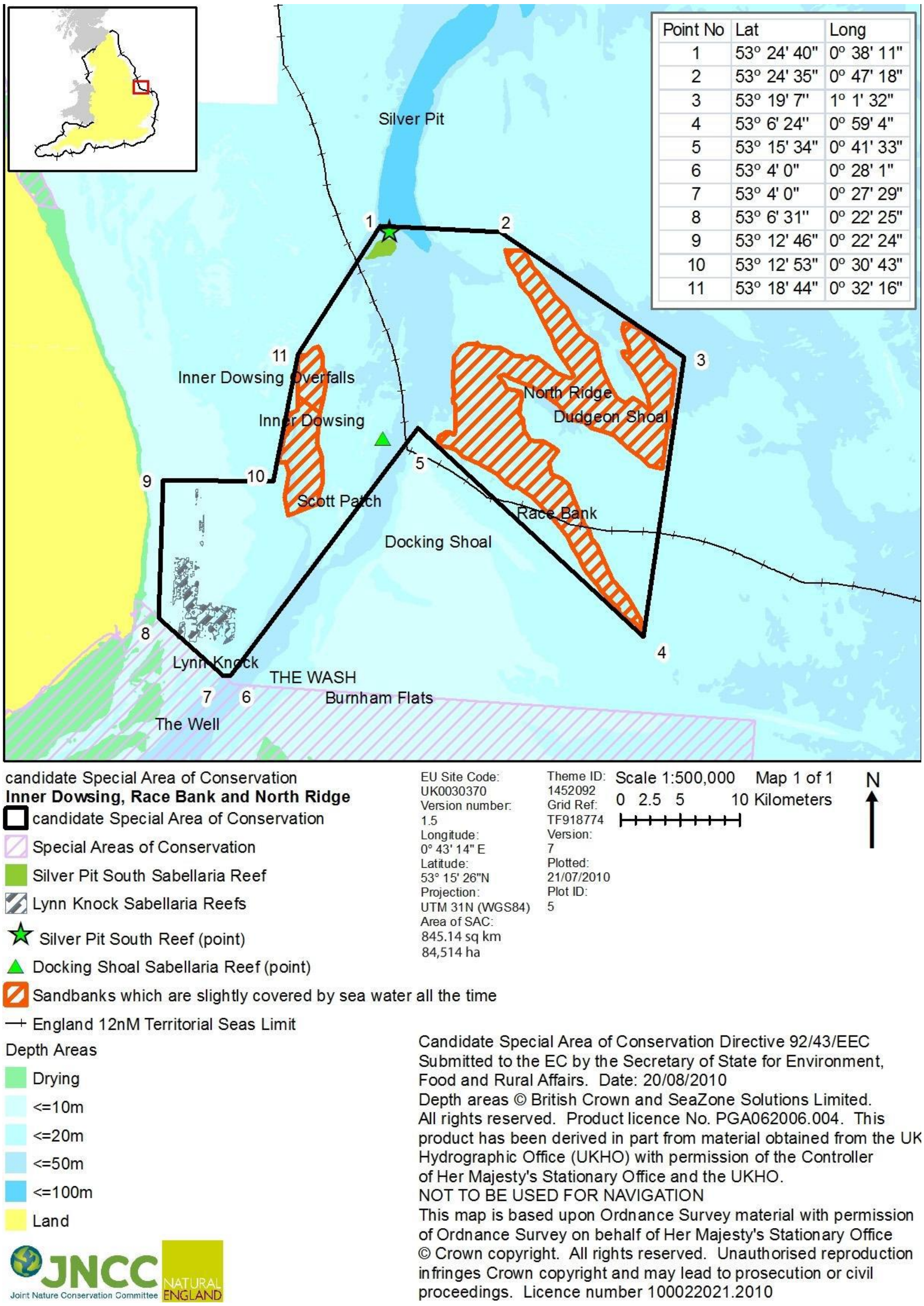
Appendices

Appendix 1

This appendix is presented in a supplementary file:
NECR550 Appendix 1 Sandbank MPAs_Literature and Confidence Assessment
It can be downloaded from the report homepage.

Appendix 2

Evidence review: Inner Dowsing, Race Bank and North Ridge Special Area of conservation



Point No	Lat	Long
1	53° 24' 40"	0° 38' 11"
2	53° 24' 35"	0° 47' 18"
3	53° 19' 7"	1° 1' 32"
4	53° 6' 24"	0° 59' 4"
5	53° 15' 34"	0° 41' 33"
6	53° 4' 0"	0° 28' 1"
7	53° 4' 0"	0° 27' 29"
8	53° 6' 31"	0° 22' 25"
9	53° 12' 46"	0° 22' 24"
10	53° 12' 53"	0° 30' 43"
11	53° 18' 44"	0° 32' 16"

Candidate Special Area of Conservation Directive 92/43/EEC
Submitted to the EC by the Secretary of State for Environment,
Food and Rural Affairs. Date: 20/08/2010
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Figure 8: Inner Dowsing, Race Bank, North Ridge Special Area of Conservation

Table 8: Inner Dowsing, Race Bank and North Ridge Special Area of Conservation information

Feature	Comments
Site name	Inner Dowsing, Race Bank and North Ridge Special Area of Conservation (SAC)
Legislation	EU Habitats Directive 1992 transposed into UK law by The Conservation of Offshore Marine Habitats and Species Regulations 2017 (as amended) This site forms part of the networks of MPAs across the UK and contributes to international MPA networks such as that of the North-east Atlantic under OSPAR.
Dates of designation	February 2010 – possible SAC (pSAC) November 2011 – Site of Community Importance (SCI) September 2017 – SAC
Conservation objectives	The site has a ‘recover’ conservation objective based on the findings of a vulnerability assessment (exposure to activities associated with pressures to which the protected features of the site are considered sensitive).
Conservation status	Annex I sandbanks – unfavourable Annex I reefs – unfavourable For the features to be in favourable condition thus ensuring site integrity in the long term and contribution to Favourable Conservation Status of Annex I Sandbanks which are slightly covered by sea water all of the time and Annex I Reefs. This contribution would be achieved by maintaining or restoring, subject to natural change: • The extent and distribution of the qualifying habitats in the site;

Feature	**Comments**
	- The structure and function of the qualifying habitats in the site; and - The supporting processes on which the qualifying habitats rely.
Size	845 km^2
Water depth	The shallowest depth within the MPA is just 1 m below sea-level, and the deepest is over 70 m below sea-level
Sandbank type	IDRBNR consists of a single relict sandbank to the west (Inner Dowsing, Inner Dowsing Overfalls, and Scott Patch) and a complex, sinusoidal system of major and minor sandbanks to the east (Race Bank, North Ridge, and Dudgeon Shoal). Minor sandbanks form a unique, ‘comb-like’ pattern in an eastward direction from the main line of major sandbank ridges.
Annex I habitat(s)	Sandbanks submerged by seawater at all times Reefs (*Sabellaria spinulosa*)
Subtidal sandbanks biotopes	The following biotopes were identified within the IDRBNR SAC: • A5.1 subtidal coarse sediment ○ A5.13 infralittoral coarse sediment ▪ A5.131 Sparse fauna on highly mobile sublittoral shingle (cobbles and pebbles) ▪ A5.134 *Hesionura elongata* and *Microphthalmus similis* with other interstitial polychaetes in infralittoral mobile coarse sand ▪ A5.135 *Glycera lapidum* in impoverished infralittoral mobile gravel and sand ▪ A5.136 Cumaceans and *Chaetozone setosa* in infralittoral gravelly sand

Feature	Comments
	▪ A5.137 Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand ○ A5.14 circalittoral coarse sediment ▪ A5.141 *Pomatoceros triqueter* with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles ▪ A5.143 *Protodorvillea kefersteini* and other polychaetes in impoverished circalittoral mixed gravelly sand • A5.2 subtidal sand ○ A5.22 ▪ A5.221 Infralittoral mobile sand in variable salinity (estuaries) ▪ A5.222 *Nephtys cirrosa* and *Macoma balthica* in variable salinity infralittoral mobile sand ▪ A5.223 *Neomysis integer* and *Gammarus* spp. in fluctuating low salinity infralittoral mobile sand ○ A5.23 infralittoral fine sand ▪ A5.231 infralittoral mobile clean sand with sparse fauna ▪ A5.232 *Sertularia cupressina* and *Hydrallmania falcata* on tide-swept sublittoral sand with cobbles or pebbles ▪ A5.233 *Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand ○ A5.24 ▪ A5.241 *Echinocardium cordatum* and *Ensis* spp. in lower shore and shallow sublittoral slightly muddy fine sand ▪ A5.242 *Fabulina fabula* and *Magelona mirabilis* with venerid bivalves and amphipods in infralittoral compacted fine muddy sand ▪ A5.243 *Arenicola marina* in infralittoral fine sand or muddy sand ○ A5.26 ▪ A5.261 *Abra alba* and *Nucula nitidosa* in circalittoral muddy sand or slightly mixed sediment • A5.4 subtidal mixed sediment ○ A5.43 infralittoral mixed sediments

Feature	Comments
	▪ A5.432 *Sabella pavonina* with sponges and anemones on infralittoral mixed sediment ○ A5.44 circalittoral mixed sediments ▪ A5.444 *Flustra foliacea* and *Hydrallmania falcata* on tide-swept circalittoral mixed sediment ▪ A5.445 *Ophiothrix fragilis* and/or *Ophiocomina nigra* brittlestar beds on sublittoral mixed sediment
Other Annex I biotopes	• A5.6 sublittoral biogenic reefs ○ A5.61 sublittoral polychaete worm reefs on sediment ▪ A5.611 *Sabellaria spinulosa* on stable circalittoral mixed sediment.
Sandbank feature extent in the site	The site is well characterised by multiple sandbanks, however the IDRBNR SAC boundary also includes seabed that is not characterised as Annex I habitat.
Directly Overlaps	Greater Wash SPA classified for breeding populations of common tern *Sterna hirundo*, little tern *Sterna albifrons*, Sandwich tern *Thalasseus sandvicensis* and non-breeding populations of red-throated diver *Gavia stellata*, common scoter *Melanitta nigra* and little gull *Hydrocoloeus minutus*.
Boundary	The boundary of this SAC is a relatively simple polygon, enclosing (with minimum complexity) the area necessary to ensure protection of the Annex I habitats, and also encompassing the areas of Silver Pit, Lynn Knock, and Docking Shoal *S. spinulosa* reefs. The boundary of the site has been defined to enable conservation of the structure and functions of the sandbanks and to include representation of both more disturbed (inshore) and more stable (offshore) sandbank biological communities.
Activities	***Fisheries*** • There is evidence of mobile demersal, static and pelagic effort within the IDRBNR SAC. UK and non-UK registered vessels have been active in the area;

Feature	Comments
	- The Marine Management Organisation (MMO) is the lead authority regarding the implementation of, and compliance with, any measures to managing fishing activity. Further information on progress is available on the Marine Management Organisation’s webpages; and - Important fisheries byelaw can be found at: The Inner Dowsing, Race Bank and North Ridge Special Area of Conservation (Specified Areas) Prohibited Fishing Gears Byelaw 2022 - GOV.UK (www.gov.uk) ***Licensable activities*** - There are two abandoned, explorative oil wells and four pipelines present within the IDRBNR SAC; - A number of offshore wind developments are present within the IDRBNR SAC, including wind turbine arrays, inter-array and export cables and associated surface and subsurface infrastructure; and - There are two areas licensed (and one in the application stage) for aggregate extraction within the IDRBNR SAC, both of which are situated within The Well channel and not within sandbanks or a 500 m buffer surrounding sandbanks. Several other aggregate extraction areas are present at the northeast and northwest boundaries of the MPA, which spatially overlap sandbanks outside of the IDRBNR SAC boundary.
Sediment	Sediment type is variable throughout the IDRBNR SAC due to the mosaic of sandbanks, *S. spinulosa* reef, and other mixed and gravelly sands associated with The Wells. Within the sandbanks, sediment type (Folk, 1954) varies from Sand to gravelly muddy Sand, with isolated Gravel components considered to be in association with *S. spinulosa* presence. The sandbank system is maintained by tidal currents encircling a linear basement layer carved by glacial processes.
Sensitivities	**Subtidal coarse sediment** - Natural England (2023a) identifies subtidal coarse sediment as sensitive to the following medium-high risk pressures associated with infrastructure on the seabed: ○ Abrasion/disturbance of the substrate on the surface of the seabed

Feature	Comments
	○ Habitat structure changes - removal of substratum (extraction) ○ Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion ○ Physical change (to another seabed type) ○ Physical change (to another sediment type) ○ Smothering and siltation rate changes (light/heavy) ○ Changes in suspended solids (water clarity) ○ Introduction or spread of invasive non-indigenous species (INIS) **Subtidal mixed sediments** • Natural England (2023a) identifies subtidal mixed sediments as sensitive to the following medium-high risk pressures associated with infrastructure on the seabed: ○ Abrasion/disturbance of the substrate on the surface of the seabed ○ Habitat structure changes - removal of substratum (extraction) ○ Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion ○ Physical change (to another seabed type) ○ Physical change (to another sediment type) ○ Smothering and siltation rate changes (light/heavy) ○ Changes in suspended solids (water clarity) ○ Introduction or spread of invasive non-indigenous species (INIS) **Subtidal sand** • Natural England (2023a) identifies subtidal sand as sensitive to the following medium-high risk pressures associated with infrastructure on the seabed: ○ Abrasion/disturbance of the substrate on the surface of the seabed ○ Habitat structure changes - removal of substratum (extraction) ○ Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion

Feature	Comments
	○ Physical change (to another seabed type) ○ Physical change (to another sediment type) ○ Smothering and siltation rate changes (light/heavy) ○ Changes in suspended solids (water clarity) ○ Introduction of light ○ Introduction or spread of invasive non-indigenous species (INIS) **Subtidal biogenic reefs: *Sabellaria* spp.** • Natural England (2023a) identifies subtidal biogenic reefs: *Sabellaria* spp. as sensitive to the following medium-high risk pressures associated with infrastructure on the seabed: ○ Abrasion/disturbance of the substrate on the surface of the seabed ○ Habitat structure changes - removal of substratum (extraction) ○ Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion ○ Physical change (to another sediment type) ○ Barrier to species movement ○ Smothering and siltation rate changes (heavy)
Conservation advice	The 'Conservation advice' section of this table is a summary of supplementary advice for the IDRBNR SAC (Natural England, 2023b). Natural England's Supplementary Advice on Conservation Objectives (SACOs) have set targets using expert judgement based on knowledge of the sensitivity of the feature to activities that are occurring/have occurred on the site. Some SACO targets have been set in the absence of evidence that the feature is being impacted by anthropogenic activities within the IDRBNR SAC, and has been identified within this table where relevant.
Distribution: presence and spatial	A **'Restore'** target has been set for Annex I sandbanks within the IDRBNR SAC.

Feature	Comments
distribution of biological communities	Activities involving habitat modification have the potential to disturb and partially remove sandbanks and biogenic reefs, and therefore reduce the diversity of species present within the local area. Restoring the presence and spatial distribution of biological communities would boost biodiversity and the resilience of the feature.
Extent and distribution	A **'Restore'** target has been set for Annex I sandbanks within the IDRBNR SAC. Activities involving habitat modification have the potential to disturb and partially remove sandbanks and biogenic reefs, and therefore reduce the diversity of species present within the local area. Restoring extent and distribution would boost biodiversity and the resilience of the feature.
Structure and function: presence and abundance of key structural and influential species	Target not yet set for Annex I sandbanks within the IDRBNR SAC. Activities involving habitat modification have the potential to disturb and partially remove sandbanks and biogenic reefs, and therefore reduce the diversity of species present within the local area. Maintaining, recovering or restoring the presence and abundance of key structural species (habitat-building or define a key biotope) and influential species (key to the overall structure and function of the habitat) would improve the integrity of the community and ecosystem functioning associated with the feature.
Structure: non-native species and pathogens (habitat)	A **'Restrict'** target has been set for Annex I sandbanks within the IDRBNR SAC. This target has been set due to a lack of evidence that the feature is being impacted by anthropogenic activities. Activities involving habitat modification, particularly by introducing novel habitats to a previously uniform habitat (e.g. the introduction of hard substrates) have the potential to introduce non-native species and pathogens (habitat). This may result in local species being out-competed for resources and may consequently alter the structure and functioning of the sandbank or biogenic reef feature.

Feature	Comments
Structure: sediment composition and distribution	A **‘Restore’** target has been set for Annex I sandbanks within the IDRBNR SAC. Activities involving habitat modification have the potential to disturb sediment character associated with sandbanks outside of natural variation, and therefore alter biological communities naturally present within the local area. Restoring sediment composition and distribution would ensure changes to biological communities remain within natural flux and boost the resilience of the feature.
Structure: species composition of component communities	A **‘Maintain’** target has been set for Annex I sandbanks within the IDRBNR SAC. Activities involving habitat modification and the removal of target species have the potential to alter biological communities associated with sandbanks and biogenic reefs by altering relative abundance. Maintaining species composition of component communities would prevent changes to biological communities that may shift patterns of species dominance and diminishing biodiversity.
Structure: topography	A **‘Maintain’** target has been set for Annex I sandbanks within the IDRBNR SAC. This target has been set due to a lack of evidence that the feature is being impacted by anthropogenic activities. Activities involving habitat modification have the potential to disturb topography associated with sandbanks, which is considered an essential structural component of the feature. Maintaining topographic structures such as crests, ridges, troughs, and mega-ripples would ensure the support of biological communities and sediment variation that may be dependent on large- and small-scale processes associated with topography (e.g. microclimates).
Structure: volume	A **‘Maintain’** target has been set for Annex I sandbanks within the IDRBNR SAC. This target has been set due to a lack of evidence that the feature is being impacted by anthropogenic activities.

Feature	Comments
	Activities involving habitat modification, particularly the removal of substrate, have the potential to alter the structure of sandbanks, with the potential to have knock-on consequences for larger-scale physical processes (e.g. tidal conditions and sediment distribution). Well defined sandbank features (e.g. relict sandbanks) are likely to have a greater influence on large-scale processes than dynamic sandbanks; which may in turn be altered by changes in volume of more stable sandbank features in close proximity.
Supporting processes: energy/exposure	A **'Maintain'** target has been set for Annex I sandbanks within the IDRBNR SAC. This target has been set due to a lack of evidence that the feature is being impacted by anthropogenic activities. Activities involving habitat modification, particularly the placement of berms, have the potential to alter the energy of the sandbank system. Energy is a controlling factor for sandbank systems in particular. Biological communities may be altered through variation in sediment distribution, driven by tidal currents and wave action that influence topographic structures such as sandbank crests, ridges, troughs, and mega-ripples.
Supporting processes: physico-chemical properties (habitat)	A **'Maintain'** target has been set for Annex I sandbanks within the IDRBNR SAC. This target has been set due to a lack of evidence that the feature is being impacted by anthropogenic activities. Activities involving the placement of alien material have the potential to alter the physico-chemical properties of the sandbank or biogenic reef system. Such properties include temperature, pH, and salinity. Whilst embedded mitigation ensures all material deposited on the seabed is physio-chemically inert, the presence of structures on the seabed may introduce microclimates with different physico-chemical properties to the existing habitat. Whilst this is unlikely to result in large-scale changes to the feature, there is potential for overlap in effects associated with invasive non-native species and sediment composition and distribution, with unknown physico-chemical properties at a larger scale.

Feature	Comments
Supporting processes: sediment contaminants	A **'Restrict'** target has been set for Annex I sandbanks within the IDRBNR SAC. Activities involving the placement of alien material and disturbance of sequestered contaminants through seabed disturbance/decommissioning of infrastructure have the potential to introduce sediment contaminants into the sandbank or biogenic reef system. Such contaminants include heavy metals, hydrocarbons, and pesticides (e.g. biofouling agents). Whilst embedded mitigation ensures all material deposited on the seabed is inert, the potential for contaminant spills and upwelling as a result of anthropogenic activities remains.
Supporting processes: sediment movement and hydrodynamic regime (habitat)	A **'Maintain'** target has been set for Annex I sandbanks within the IDRBNR SAC. This target has been set due to a lack of evidence that the feature is being impacted by anthropogenic activities. Activities involving habitat modification, particularly the placement of berms, have the potential to alter the energy of the sandbank or biogenic reef system, and therefore influence sediment movement and hydrodynamic regime.
Supporting processes: water quality – contaminants (habitat)	A **'Reduce'** target has been set for Annex I sandbanks within the IDRBNR SAC. This target has been set due to a lack of evidence that the feature is being impacted by anthropogenic activities. Activities involving the placement of alien material and disturbance of sequestered contaminants through seabed disturbance/decommissioning of infrastructure have the potential to introduce contaminants into the water column. Whilst embedded mitigation ensures all material deposited on the seabed is inert, the potential for contaminant spills and upwelling as a result of anthropogenic activities remains.
Supporting processes: water	A **'Maintain'** target has been set for Annex I sandbanks within the IDRBNR SAC. This target has been set due to a lack of evidence that the feature is being impacted by anthropogenic activities.

Feature	Comments
quality – dissolved oxygen (habitat)	Activities involving the placement large structures on the seabed have the potential to alter physico-chemical properties of, or introduce invasive non-native species into, the sandbank or biogenic reef system. Structures may reduce energy and provide habitat for bacteria, which may combine to form anoxic microclimates into the seabed that would not otherwise be present (e.g. below or downstream of the structure). The quantity of introduced material will determine the scale of potential change to the feature.
Supporting processes: water quality – nutrients (habitat)	A **'Maintain'** target has been set for Annex I sandbanks within the IDRBNR SAC. Activities involving the placement of alien material and disturbance of sequestered nutrients through seabed disturbance/decommissioning of infrastructure have the potential to introduce high concentrations of nutrients into the water column. This may provide an ideal habitat for opportunistic algal blooms and result in reduced dissolved oxygen availability within both the water column and the sediment. Eutrophication is likely to result in a decline in abundance of most species.
Supporting processes: water quality – turbidity (habitat)	A **'Maintain'** target has been set for Annex I sandbanks within the IDRBNR SAC. This target has been set due to a lack of evidence that the feature is being impacted by anthropogenic activities. Activities involving habitat modification or indirectly result in high algal density have the potential to mobilise particulates into the water column and reduce light penetration. Biological communities are at greater risk of clogging of filter-feeding appendages or breathing organs and reduced primary production, which can influence community composition, alter species growth rates, and reduce the survival of larvae.
Hydrodynamic regime	The banks are subject to a range of water current strengths, which are strongest on the banks closest to shore (the 'nearshore banks') and which reduce gradationally in strength with increasing distance offshore (Collins and others, 1995). The banks further offshore (the 'offshore banks) are the best example of open sea, tidal sandbanks in a moderate

Feature	Comments
	current strength in UK waters. Sand waves are present, being best developed on the nearshore banks, indicating the sediment surface is regularly mobilised by tidal currents. The water within the site is a mixture of both northern Fair Isle and southern English Channel waters. The site presents a complex pattern of currents, that are at present not well understood. Water movement is influenced by the local topography, with strongest currents measured on the near-shore sandbanks and decreasing with distance offshore (Jenkins and others, 2015). For example, on one of the banks, near-bed residual tidal currents have been observed to be strongest towards the crestline and in opposing directions on either side of the bank (Caston & Stride 1970; Caston, 1972). Tides over the area are controlled by a progressive tidal wave, moving down the coastline of England. Episodic currents over the wider area of Norfolk Banks induced by storm surges cause sand to be transported in directions other than those caused by the tidal currents alone (Flather, 1987). The former, combined with observed tidal flows (Venn & D'Olier, 1983), is expected to transport sand oblique to the tidal currents and towards the northeast up to about 100 km to seaward, contributing to the sandbank feature's natural progression in this direction (Stride, 1988). A hydrodynamic model developed by CEFAS, currently unpublished, indicates that ocean current flow is predominantly in a south-eastly direction with predicted velocities at seabed reaching a maximum of 2.7 m/s. The wave regime in the site has a marked seasonality. Wave height ranges from 0.5 m to greater than 4 m, with the largest waves being seen in the winter months when waves of over 3 m height are regularly recorded (Draper, 1968; Marshall, 1997). A maintain objective is advised for the hydrodynamic regime based on expert judgment.

Appendix 3

Evidence review: North Norfolk Sandbanks and Saturn Reef Special Area of Conservation

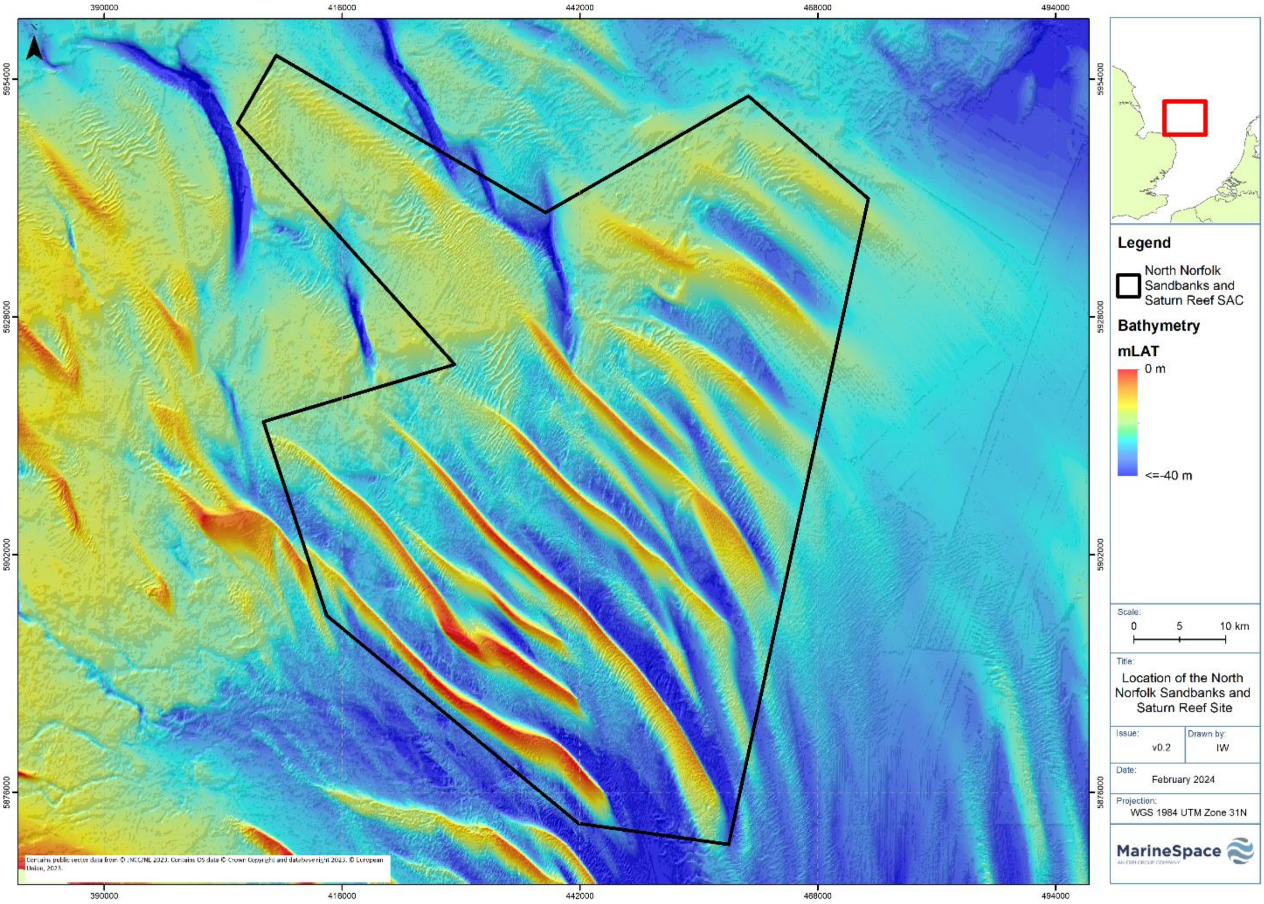


Figure 9: The North Norfolk Sandbanks and Saturn Reef SAC showing the sandbanks. (From: JNCC, 2010). Contains public sector data from © JNCC/NE 2023 Crown Copyright and database right 2023. © European Union

Table 9: North Norfolk Sandbanks and Saturn Reef Special Area of Conservation information

Feature	Comments
Site name	North Norfolk Sandbanks and Saturn Reef Special Area of Conservation (SAC)
Legislation	EU Habitats Directive 1992 transposed into UK law by The Conservation of Offshore Marine Habitats and Species Regulations 2017 (as amended). This site forms part of the networks of MPAs across the UK and contributes to international MPA networks such as that of the North-east Atlantic under OSPAR.
Dates of designation	March 2008 – possible SAC (pSAC) November 2011 – Site of Community Importance (SCI) September 2017 – SAC
Conservation objectives	The site has a ‘recover’ conservation objective based on the findings of a vulnerability assessment (exposure to activities associated with pressures to which the protected features of the site are considered sensitive).
Conservation status	Annex I sandbanks – unfavourable (from designation onwards) Annex I reefs – unfavourable (from designation onwards) For the features to be in favourable condition thus ensuring site integrity in the long term and contribution to Favourable Conservation Status of Annex I Sandbanks which are slightly covered by sea water all of the time and Annex I Reefs. This contribution would be achieved by maintaining or restoring, subject to natural change: • The extent and distribution of the qualifying habitats in the site;

Feature	Comments
	• The structure and function of the qualifying habitats in the site; and • The supporting processes on which the qualifying habitats rely.
Size	3,603 km²
Water depth	The shallowest depth within the MPA is just 3 m below sea-level, and the deepest is over 60 m below sea-level.
Sandbank type	Offshore linear ridge sandbanks. NNSSR consists of a series of ten main sandbanks (Leman, Inner, Ower, Well, Broken, Swarte and four sandbanks collectively known as the Indefatigables) as well as associated fragmented smaller banks.
Annex I habitat(s)	Sandbanks submerged by seawater at all times. Reefs (*Sabellaria spinulosa*).
Subtidal sandbanks biotopes	In total the following biotopes were identified within the NNSSR SAC: • A5.1 subtidal coarse sediment ○ A5.14 circalittoral coarse sediment • A5.2 subtidal sand ○ A5.23 infralittoral fine sand ▪ A5.233 *Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand • A5.4 subtidal mixed sediment ○ A5.44 circalittoral mixed sediments

Feature	Comments
Key information	The entirety of the MPA is considered a representative functioning example of the Annex I feature Sandbanks which are slightly covered by sea water all the time. The whole SAC is designated and viewed as one integrated sandbank system.
Directly Overlaps	Southern North Sea SAC designated for Annex II population of harbour porpoise *Phocoena phocoena*.
Boundary	The boundary of this SAC is a simple polygon enclosing the minimum area necessary to ensure protection of the Annex I habitats, taking into account potential movement of the sandbanks, and also encompassing the area of Saturn reef and surrounding *S. spinulosa* reef. The boundary of the site has been defined to enable conservation of the structure and functions of the sandbanks and to include representation of both more disturbed (inshore) and more stable (offshore) sandbank biological communities.
Activities	***Fisheries*** • There is evidence of mobile demersal, static and pelagic effort within the NNSSR SAC. UK and non-UK registered vessels have been active in the area; • The Marine Management Organisation (MMO) is the lead authority regarding the implementation of, and compliance with, any measures to managing fishing activity. Further information on progress is available on the MMO’s webpages; and • Important fisheries byelaw can be found at: Marine Protected Areas Bottom Towed Fishing Gear Byelaw 2022 (defra.gov.uk). ***Licensable activities***

Feature	Comments
	A considerable number of O&G developments take place within this MPA, including many fields, pipelines, wells, surface and subsurface infrastructure, including extensive O&G decommissioning. The export cables from Hornsea 3 will traverse the site. • There are two areas licensed for aggregate extraction within the MPA; • Two dredge disposal sites are located within the MPA boundary, on the Ower and Leman Banks; and • Several navigational aids are located within the MPA demarking the location of the sandbanks. • Three telecommunications cables currently cross through the MPA.
Sediment	Sand is the dominant sediment type across the MPA, with patches of coarser and mixed sediment, which may then also be associated in places with *S. spinulosa* reef. The sandbank structures are maintained through offshore sediment transport, with each bank acting as a stepping stone, and the development of new sandbanks between existing banks.
Sensitivities	**Subtidal coarse sediment** • JNCC (2018) identifies subtidal coarse sediment as sensitive to: ○ Abrasion/disturbance of the substrate on the surface of the seabed ○ Changes in suspended solids (water clarity) ○ Habitat structure changes - removal of substratum (extraction) ○ Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion ○ Physical change (to another seabed type) ○ Siltation rate changes (high) including smothering (depth of vertical sediment overburden) ○ Siltation rate changes (low) including smothering (depth of vertical sediment overburden) ○ Water flow (tidal current) changes – local, including sediment transport considerations

Feature	Comments
	○ Introduction of light **Subtidal mixed sediments** • JNCC (2018) identifies subtidal mixed sediments as sensitive to: ○ Abrasion/disturbance of the substrate on the surface of the seabed ○ Changes in suspended solids (water clarity) ○ Habitat structure changes - removal of substratum (extraction) ○ Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion ○ Physical change (to another seabed type) ○ Siltation rate changes (high) including smothering (depth of vertical sediment overburden) ○ Siltation rate changes (low) including smothering (depth of vertical sediment overburden) ○ Water flow (tidal current) changes – local, including sediment transport considerations ○ Introduction of light ○ Introduction or spread of invasive non-indigenous species (INIS) **Subtidal sand** • JNCC (2018) identifies subtidal sand as sensitive to: ○ Abrasion/disturbance of the substrate on the surface of the seabed ○ Changes in suspended solids (water clarity) ○ Habitat structure changes - removal of substratum (extraction) ○ Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion ○ Physical change (to another seabed type) ○ Siltation rate changes (high) including smothering (depth of vertical sediment overburden) ○ Siltation rate changes (low) including smothering (depth of vertical sediment overburden) ○ Water flow (tidal current) changes – local, including sediment transport considerations

Feature	Comments
	○ Introduction of light ○ Introduction or spread of invasive non-indigenous species (INIS) **Infralittoral mobile clean sand with sparse fauna, IFiSa.TbAmPo** • Physical change (to another seabed type) – high • Physical change (to another sediment type) - high • Habitat structure changes – removal of substratum – medium • Abrasion / disturbance of the surface of the substratum / seabed - low
Conservation advice	The 'Conservation advice' section of this table is a summary of supplementary advice for the NNSSR SAC (JNCC, 2018). JNCC's Supplementary Advice on Conservation Objectives (SACOs) have set targets using expert judgement based on knowledge of the sensitivity of the feature to activities that are occurring/have occurred on the site.
Extent and distribution	**Restore** JNCC understands that the site has been subjected to activities that have resulted in a change to the extent and distribution of the feature within the site. Installation and/or removal of infrastructure may have a continuing effect on extent and distribution. As such, JNCC advise a restore objective which is based on expert judgment; specifically, our understanding of the feature's sensitivity to pressures which can be exerted by ongoing activities i.e. oil and gas sector activities and cabling.
Structure and function	**Restore**

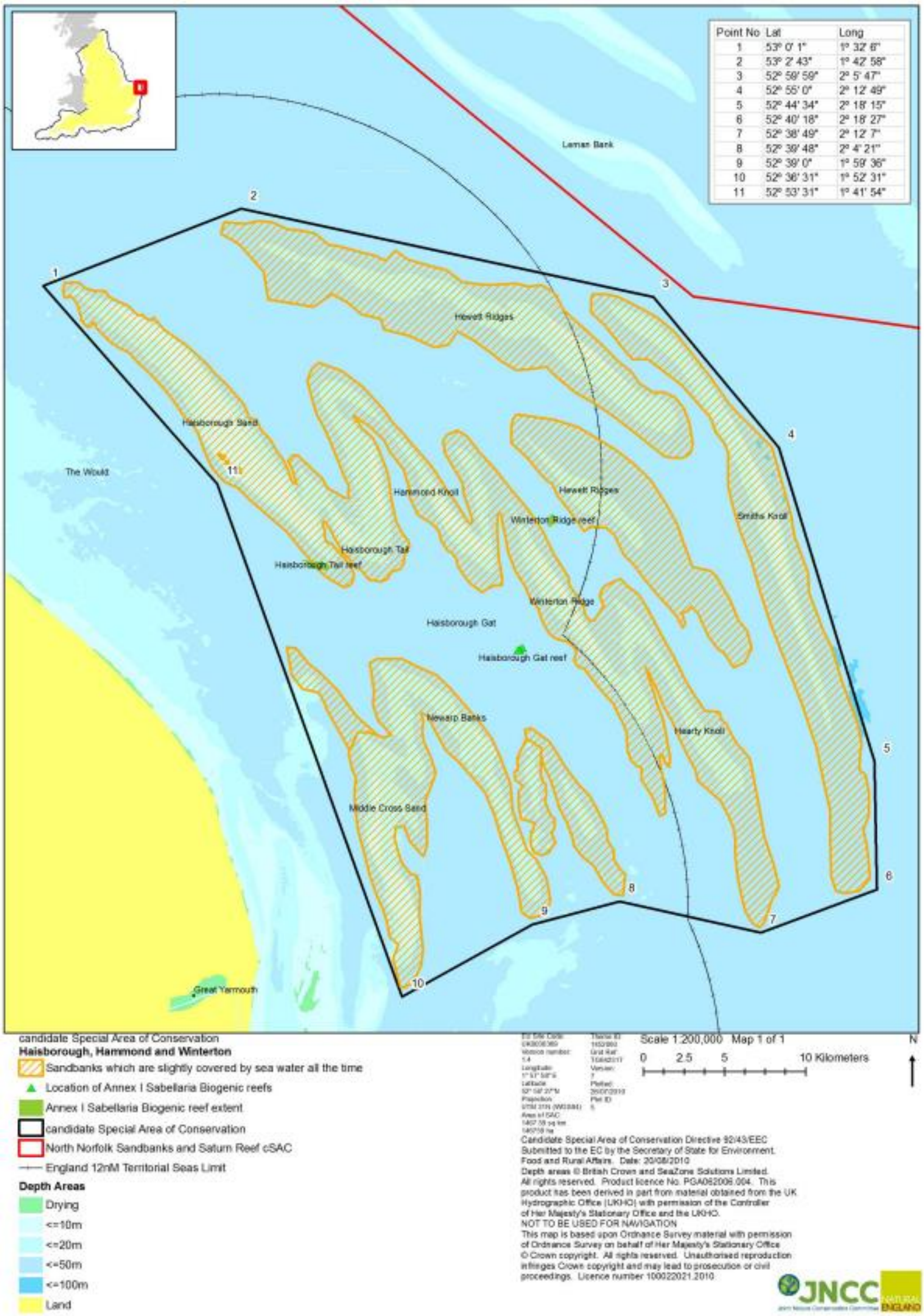
Feature	Comments
	JNCC understands that the site has been subjected to activities that have resulted in a change to the structure and function of the feature within the site. Installation and/or removal of infrastructure may have a continuing effect on structure and function, specifically the finer scale topography, sediment composition and distribution of characteristic communities. The restore objective which is based on expert judgment; specifically, our understanding of the feature's sensitivity to pressures which can be exerted by ongoing activities i.e. demersal fishing, oil and gas sector activities and cabling.
Structure and function: Physical structure	JNCC consider finer-scale topography of the feature may be impacted by the activities occurring within the site and therefore need to be restored. This objective is based on expert judgment; specifically, our understanding of the feature's sensitivity to pressures which can be exerted by ongoing activities i.e. cabling and oil and gas industry.
Structure and function: Biological structure – characteristic communities	A restore objective is advised for characteristic communities of the feature within the site based on expert judgment; specifically, our understanding of the feature's sensitivity to pressures which can be exerted by ongoing activities, i.e. demersal fishing, cabling and oil and gas sector activities.
Structure and function: Function	Ecosystem services that may be provided by Annex I sandbanks within the site include: • Nutrition: due to the level of primary and secondary productivity on or around sandbanks, a range of fish species use these areas as feeding and nursery grounds. Some will migrate to certain parts of the habitat for feeding and breeding e.g. cod, plaice, dab, sole (Ellis et al., 2012), whilst others are more resident e.g. sandeels (Frederiksen et al., 2005; SNH and JNCC, 2012) making the conservation of sandbanks important to the fishing industry;

Feature	Comments
	- • Bird and whale watching: foraging seals, cetaceans and seabirds may also be found in greater numbers in the vicinity of sandbanks due to their shallower nature that enhances the availability of their typical prey items (e.g. Daunt et al., 2008; Scott et al, 2010; Camphuysen et al., 2011; McConnell et al., 1999, Jones et al., 2013); - • Climate regulation: by providing a long-term sink for carbon within sedimentary habitats.
Supporting processes: Hydrodynamic regime	The banks are subject to a range of water current strengths, which are strongest on the banks closest to shore (the 'nearshore banks') and which reduce gradationally in strength with increasing distance offshore (Collins and others, 1995). The banks further offshore (the 'offshore banks) are the best example of open sea, tidal sandbanks in a moderate current strength in UK waters. Sand waves are present, being best developed on the nearshore banks, indicating the sediment surface is regularly mobilised by tidal currents. The water within the site is a mixture of both northern Fair Isle and southern English Channel waters. The site presents a complex pattern of currents, that are at present not well understood. Water movement is influenced by the local topography, with strongest currents measured on the near-shore sandbanks and decreasing with distance offshore (Jenkins and others, 2015). For example, on one of the banks, near-bed residual tidal currents have been observed to be strongest towards the crestline and in opposing directions on either side of the bank (Caston & Stride 1970; Caston, 1972). Tides over the area are controlled by a progressive tidal wave, moving down the coastline of England. Episodic currents over the wider area of Norfolk Banks induced by storm surges cause sand to be transported in directions other than those caused by the tidal currents alone (Flather, 1987). The former, combined with observed tidal flows (Venn & D'Olier, 1983), is expected to transport sand oblique to the tidal currents and towards the northeast up to about 100 km to seaward, contributing to the sandbank feature's natural progression in this direction (Stride, 1988). A hydrodynamic model developed by CEFAS, currently unpublished, indicates that ocean current flow is predominantly in a south-eastly direction with predicted velocities at seabed reaching a maximum of 2.7 m/s. The wave regime in the site has a marked seasonality. Wave height ranges from 0.5 m to

Feature	Comments
	greater than 4 m, with the largest waves being seen in the winter months when waves of over 3 m height are regularly recorded (Draper, 1968; Marshall, 1997). A maintain objective is advised for the hydrodynamic regime based on expert judgment.

Appendix 4

Evidence review: Haisborough, Hammond and Winterton Special Area of conservation



Point No	Lat	Long
1	53° 0' 1"	1° 32' 6"
2	53° 2' 43"	1° 42' 58"
3	52° 58' 59"	2° 5' 47"
4	52° 55' 0"	2° 12' 49"
5	52° 44' 34"	2° 18' 15"
6	52° 40' 18"	2° 18' 27"
7	52° 38' 49"	2° 12' 7"
8	52° 39' 48"	2° 4' 21"
9	52° 39' 0"	1° 59' 36"
10	52° 36' 31"	1° 52' 31"
11	52° 53' 31"	1° 41' 54"

Candidate Special Area of Conservation Directive 92/43/EEC
Submitted to the EC by the Secretary of State for Environment.
Food and Rural Affairs. Date: 20/08/2010
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Figure 10: Haisborough, Hammond and Winterton Special Area of Conservation

Table 10: Haisborough, Hammond and Winterton Special Area of Conservation information

Feature	Comments
Site name	Haisborough, Hammond and Winterton Special Area of Conservation (SAC)
Legislation	EU Habitats Directive 1992 transposed into UK law by The Conservation of Offshore Marine Habitats and Species Regulations 2017 (as amended) This site forms part of the networks of MPAs across the UK and contributes to international MPA networks such as that of the North-east Atlantic under OSPAR.
Dates of designation	February 2010 – possible SAC (pSAC) November 2011 – Site of Community Importance (SCI) September 2017 – SAC
Conservation objectives	The site has a ‘recover’ conservation objective based on the findings of a vulnerability assessment (exposure to activities associated with pressures to which the protected features of the site are considered sensitive).
Conservation status	Annex I sandbanks – unfavourable. Annex I reefs – unfavourable. For the features to be in favourable condition thus ensuring site integrity in the long term and contribution to Favourable Conservation Status of Annex I Sandbanks which are slightly covered by sea water all of the time and Annex I Reefs. This contribution would be achieved by maintaining or restoring, subject to natural change: • The extent and distribution of the qualifying habitats in the site;

Feature	Comments
	• The structure and function of the qualifying habitats in the site; and • The supporting processes on which the qualifying habitats rely.
Size	1,467 km^2
Water depth	The shallowest depth within the MPA is just 1 m below sea-level, and the deepest is 52 m below sea-level.
Sandbank type	The HHW SAC consists of a series of sinusoidal sandbanks. The central sandbank system includes Haisborough Sand, Haisborough Tail, Hammond Knoll, Winterton Ridge and Hearty Knoll sandbanks, fringed to the east by the discrete Hewett Ridge and Smiths Knoll sandbanks. Newarp Banks and North and Middle Cross Sands sandbanks form an isolated cluster in the southwest corner of the HHW SAC.
Annex I habitat(s)	Sandbanks submerged by seawater at all times. Reefs (*Sabellaria spinulosa*).
Subtidal sandbanks biotopes	The following biotopes were identified within the HHW SAC: • A5.1 subtidal coarse sediment ○ A5.13 infralittoral coarse sediment ▪ A5.131 Sparse fauna on highly mobile sublittoral shingle (cobbles and pebbles) ▪ A5.134 *Hesionura elongata* and *Microphthalmus similis* with other interstitial polychaetes in infralittoral mobile coarse sand ▪ A5.135 *Glycera lapidum* in impoverished infralittoral mobile gravel and sand ▪ A5.137 Dense *Lanice conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand

Feature	Comments
	○ A5.14 circalittoral coarse sediment ▪ A5.141 *Pomatoceros triqueter* with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles • A5.2 subtidal sand ○ A5.23 infralittoral fine sand ▪ A5.231 infralittoral mobile clean sand with sparse fauna ▪ A5.232 *Sertularia cupressina* and *Hydrallmania falcata* on tide-swept sublittoral sand with cobbles or pebbles ▪ A5.233 *Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand ○ A5.24 infralittoral muddy sand ▪ A5.241 *Echinocardium cordatum* and *Ensis* spp. in lower shore and shallow sublittoral slightly muddy fine sand ▪ A5.242 *Fabulina fabula* and *Magelona mirabilis* with venerid bivalves and amphipods in infralittoral fine muddy sand ▪ A4.243 *Arenicola marina* in infralittoral fine sand or muddy sand ○ A5.26 circalittoral muddy sand ▪ A5.261 *Abra alba* and *Nucula nitidosa* in circalittoral muddy sand or slightly mixed sediment
Other Annex I biotopes	• A4.2 Moderate energy circalittoral rock ○ A4.22 *Sabellaria* reefs on circalittoral rock ▪ A4.221 *Sabellaria spinulosa* encrusted circalittoral rock • A4.2211 *Sabellaria spinulosa* with a bryozoan turf and barnacles on silty turbid circalittoral rock • A4.2212 *Sabellaria spinulosa* didemnid and small ascidians on tide-swept moderately wave-exposed circalittoral rock • A5.6 sublittoral biogenic reefs

Feature	Comments
	- A5.61 sublittoral polychaete worm reefs on sediment - A5.611 *Sabellaria spinulosa* on stable circalittoral mixed sediment.
Key information	The site is well characterised by multiple sandbank systems, however the HHW SAC boundary also includes seabed that is not characterised as Annex I habitat.
Directly Overlaps	Greater Wash SPA classified for breeding populations of common tern *Sterna hirundo*, little tern *Sterna albifrons*, Sandwich tern *Sterna sandvicensis* and non-breeding populations of red-throated diver *Gavia stellata*, common scoter *Melanitta nigra* and little gull *Hydrocoloeus minutus*. Outer Thames Estuary SPA classified for breeding populations of common tern *Sterna hirundo* and little tern *Sterna albifrons*, and non-breeding populations of red-throated diver *Gavia stellata*. Southern North Sea SAC designated for Annex II population of harbour porpoise *Phocoena phocoena*.
Boundary	The boundary of this SAC is a simple polygon, enclosing the minimum area necessary to ensure protection of the Annex I habitats, taking into account potential movement of the sandbanks, and also encompassing the areas of the Winterton Ridge and Haisborough Gat *S. spinulosa* reefs. The boundary of the site has been defined to enable conservation of the structure and functions of the sandbanks and to include representation of more disturbed (inshore) and more stable (offshore) sandbank biological communities.
Activities	***Fisheries*** - There is evidence of mobile demersal, static and pelagic effort within the HHW SAC. UK and non-UK registered vessels have been active in the area;

Feature	Comments
	- The Marine Management Organisation (MMO) is the lead authority regarding the implementation of, and compliance with, any measures to managing fishing activity. Further information on progress is available on the Marine Management Organisation’s webpages; and - Important fisheries byelaw can be found at: Haisborough, Hammond and Winterton European Marine Site (Specified Areas) Bottom Towed Fishing Gear Byelaw - GOV.UK (www.gov.uk) ***Licensable activities*** - A considerable number of oil and gas developments take place within the HHW SAC, including many fields, pipelines, wells, and associated infrastructure; - Export cables from Norfolk Boreas and Vanguard will traverse the siteand - There are three areas licensed (and two in the application stage) for aggregate extraction within the southern section of the HHW SAC, however these licensed areas do not overlap with the designated Annex I features. ***Telecommunications cables*** Telecommunications cables currently pass through the HHW SAC.
Sediment	Sediment type is variable throughout the HHW SAC due to the mosaic of sandbanks, *S. spinulosa* reef, and other mixed and gravelly sands. Within the sandbanks, sediment type (Folk, 1954) varies from sand to gravelly sand, with isolated mixed sediment components considered to be in association with *S. spinulosa* presence. The HHW SAC is noted for its coarser sands compared to the IDRBHR and NNSSR SACs. The sandbank system is maintained by tidal currents encircling a linear basement layer carved by glacial processes.

Feature	Comments
Sensitivities	**Subtidal coarse sediment** • Natural England (2023a) identifies subtidal coarse sediment as sensitive to the following medium-high risk pressures associated with infrastructure on the seabed: ○ Abrasion/disturbance of the substrate on the surface of the seabed ○ Habitat structure changes - removal of substratum (extraction) ○ Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion ○ Physical change (to another seabed type) ○ Physical change (to another sediment type) ○ Smothering and siltation rate changes (light/heavy) ○ Introduction or spread of invasive non-indigenous species (INIS) **Subtidal sand** • Natural England (2023a) identifies subtidal sand as sensitive to the following medium-high risk pressures associated with infrastructure on the seabed: ○ Abrasion/disturbance of the substrate on the surface of the seabed ○ Habitat structure changes - removal of substratum (extraction) ○ Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion ○ Physical change (to another seabed type) ○ Physical change (to another sediment type) ○ Smothering and siltation rate changes (light/heavy) ○ Changes in suspended solids (water clarity) ○ Introduction of light ○ Introduction or spread of invasive non-indigenous species (INIS)

Feature	Comments
	Subtidal biogenic reefs: *Sabellaria* spp. - Natural England (2023a) identifies subtidal biogenic reefs: *Sabellaria* spp. as sensitive to the following medium-high risk pressures associated with infrastructure on the seabed: ○ Abrasion/disturbance of the substrate on the surface of the seabed ○ Habitat structure changes - removal of substratum (extraction) ○ Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion ○ Physical change (to another sediment type) ○ Barrier to species movement ○ Smothering and siltation rate changes (heavy)
Conservation advice	The ‘Conservation advice’ section of this table is a summary of supplementary advice for the HHW SAC (Natural England, 2023d). Natural England’s Supplementary Advice on Conservation Objectives (SACOs) have set targets using expert judgement based on knowledge of the sensitivity of the feature to activities that are occurring/have occurred on the site. Some SACOs have been set in the absence of evidence that the feature is being impacted by anthropogenic activities within the HHW SAC, and has been identified within this table where relevant.
Distribution: presence and spatial distribution of biological communities	A **‘Restore’** target has been set for Annex I sandbanks within the HHW SAC. Activities involving habitat modification have the potential to disturb and partially remove sandbanks and biogenic reefs, and therefore reduce the diversity of species present within the local area. Restoring the presence and spatial distribution of biological communities would boost biodiversity and the resilience of the feature.
Extent and distribution	A **‘Restore’** target has been set for Annex I sandbanks within the HHW SAC.

Feature	Comments
	Activities involving habitat modification have the potential to disturb and partially remove sandbanks and biogenic reefs, and therefore reduce the diversity of species present within the local area. Restoring extent and distribution would boost biodiversity and the resilience of the feature.
Structure and function: presence and abundance of key structural and influential species	Target not yet set for Annex I sandbanks within the HHW SAC. Activities involving habitat modification have the potential to disturb and partially remove sandbanks and biogenic reefs, and therefore reduce the diversity of species present within the local area. Maintaining, recovering or restoring the presence and abundance of key structural species (habitat-building or define a key biotope) and influential species (key to the overall structure and function of the habitat) would improve the integrity of the community and ecosystem functioning associated with the feature.
Structure: non-native species and pathogens (habitat)	A **'Restrict'** target has been set for Annex I sandbanks within the HHW SAC. This target has been set due to a lack of evidence that the feature is being impacted by anthropogenic activities. Activities involving habitat modification, particularly by introducing novel habitats to a previously uniform habitat (e.g. the introduction of hard substrates) have the potential to introduce non-native species and pathogens (habitat). This may result in local species being out-competed for resources and may consequently alter the structure and functioning of the sandbank or biogenic reef feature.
Structure: sediment composition and distribution	A **'Restore'** target has been set for Annex I sandbanks within the HHW SAC. Activities involving habitat modification have the potential to disturb sediment character associated with sandbanks outside of natural variation, and therefore alter biological communities naturally present within the local area. Restoring sediment composition and distribution would ensure changes to biological communities remain within natural flux and boost the resilience of the feature.

Feature	Comments
Structure: species composition of component communities	A **'Restore'** target has been set for Annex I sandbanks within the HHW SAC. Activities involving habitat modification and the removal of target species have the potential to alter biological communities associated with sandbanks and biogenic reefs by altering relative abundance. Maintaining species composition of component communities would prevent changes to biological communities that may shift patterns of species dominance and diminishing biodiversity.
Structure: topography	A **'Maintain'** target has been set for Annex I sandbanks within the HHW SAC. This target has been set due to a lack of evidence that the feature is being impacted by anthropogenic activities. Activities involving habitat modification have the potential to disturb topography associated with sandbanks, which is considered an essential structural component of the feature. Maintaining topographic structures such as crests, ridges, troughs, and mega-ripples would ensure the support of biological communities and sediment variation that may be dependent on large- and small-scale processes associated with topography (e.g. microclimates).
Structure: volume	A **'Maintain'** target has been set for Annex I sandbanks within the HHW SAC. This target has been set due to a lack of evidence that the feature is being impacted by anthropogenic activities. Activities involving habitat modification, particularly the removal of substrate, have the potential to alter the structure of sandbanks, with the potential to have knock-on consequences for larger-scale physical processes (e.g. tidal conditions and sediment distribution). Well defined sandbank features (e.g. relict sandbanks) are likely to have a greater influence on large-scale processes than dynamic sandbanks; which may in turn be altered by changes in volume of more stable sandbank features in close proximity.

Feature	Comments
Supporting processes: energy/exposure	A **'Maintain'** target has been set for Annex I sandbanks within the HHW SAC. This target has been set due to a lack of evidence that the feature is being impacted by anthropogenic activities. Activities involving habitat modification, particularly the placement of berms, have the potential to alter the energy of the sandbank or biogenic reef system. Energy is a controlling factor for sandbank systems in particular. Biological communities may be altered through variation in sediment distribution, driven by tidal currents and wave action that influence topographic structures such as sandbank crests, ridges, troughs, and mega-ripples.
Supporting processes: physico-chemical properties (habitat)	A **'Maintain'** target has been set for Annex I sandbanks within the HHW SAC. This target has been set due to a lack of evidence that the feature is being impacted by anthropogenic activities. Activities involving the placement of alien material have the potential to alter the physico-chemical properties of the sandbank or biogenic reef system. Such properties include temperature, pH, and salinity. Whilst embedded mitigation ensures all material deposited on the seabed is physio-chemically inert, the presence of structures on the seabed may introduce microclimates with different physico-chemical properties to the existing habitat. Whilst this is unlikely to result in large-scale changes to the feature, there is potential for overlap in effects associated with invasive non-native species and sediment composition and distribution, with unknown physico-chemical properties at a larger scale.
Supporting processes: sediment contaminants	A **'Restrict'** target has been set for Annex I sandbanks within the HHW SAC. This target has been set due to a lack of evidence that the feature is being impacted by anthropogenic activities. Activities involving the placement of alien material and disturbance of sequestered contaminants through seabed disturbance/decommissioning of infrastructure have the potential to introduce sediment contaminants into the sandbank or biogenic reef system. Such contaminants include heavy metals, hydrocarbons, and pesticides (e.g. biofouling agents). Whilst embedded mitigation ensures all material deposited on the seabed is inert, the potential for contaminant spills and upwelling as a result of anthropogenic activities remains.

Feature	Comments
Supporting processes: sediment movement and hydrodynamic regime (habitat)	A **'Maintain'** target has been set for Annex I sandbanks within the HHW SAC. This target has been set due to a lack of evidence that the feature is being impacted by anthropogenic activities. Activities involving habitat modification, particularly the placement of berms, have the potential to alter the energy of the sandbank or biogenic reef system, and therefore influence sediment movement and hydrodynamic regime.
Supporting processes: water quality – contaminants (habitat)	A **'Restrict'** target has been set for Annex I sandbanks within the HHW SAC. This target has been set due to a lack of evidence that the feature is being impacted by anthropogenic activities. Activities involving the placement of alien material and disturbance of sequestered contaminants through seabed disturbance/decommissioning of infrastructure have the potential to introduce contaminants into the water column. Whilst embedded mitigation ensures all material deposited on the seabed is inert, the potential for contaminant spills and upwelling as a result of anthropogenic activities remains.
Supporting processes: water quality – dissolved oxygen (habitat)	A **'Maintain'** target has been set for Annex I sandbanks within the HHW SAC. This target has been set due to a lack of evidence that the feature is being impacted by anthropogenic activities. Activities involving the placement large structures on the seabed have the potential to alter physico-chemical properties of, or introduce invasive non-native species into, the sandbank or biogenic reef system. Structures may reduce energy and provide habitat for bacteria, which may combine to form anoxic microclimates into the seabed that would not otherwise be present (e.g. below or downstream of the structure). The quantity of introduced material will determine the scale of potential change to the feature.
Supporting processes: water	A **'Maintain'** target has been set for Annex I sandbanks within the HHW SAC.

Feature	Comments
quality – nutrients (habitat)	Activities involving the placement of alien material and disturbance of sequestered nutrients through seabed disturbance/decommissioning of infrastructure have the potential to introduce high concentrations of nutrients into the water column. This may provide an ideal habitat for opportunistic algal blooms and result in reduced dissolved oxygen availability within both the water column and the sediment. Eutrophication is likely to result in a decline in abundance of most species.
Supporting processes: water quality – turbidity (habitat)	A **'Maintain'** target has been set for Annex I sandbanks within the HHW SAC. This target has been set due to a lack of evidence that the feature is being impacted by anthropogenic activities. Activities involving habitat modification or indirectly result in high algal density have the potential to mobilise particulates into the water column and reduce light penetration. Biological communities are at greater risk of clogging of filter feeding appendages or breathing organs and reduced primary production, which can influence community composition, alter species growth rates, and reduce the survival of larvae.
Supporting processes: Hydrodynamic regime	The banks are subject to a range of water current strengths, which are strongest on the banks closest to shore (the 'nearshore banks') and which reduce gradationally in strength with increasing distance offshore (Collins and others, 1995). The banks further offshore (the 'offshore banks) are the best example of open sea, tidal sandbanks in a moderate current strength in UK waters. Sand waves are present, being best developed on the nearshore banks, indicating the sediment surface is regularly mobilised by tidal currents. The water within the site is a mixture of both northern Fair Isle and southern English Channel waters. The site presents a complex pattern of currents, that are at present not well understood. Water movement is influenced by the local topography, with strongest currents measured on the near-shore sandbanks and decreasing with distance offshore (Jenkins and others, 2015). For example, on one of the banks, near-bed residual tidal currents have been observed to be strongest towards the crestline and in opposing directions on either side of the bank (Caston and Stride 1970; Caston, 1972). Tides over the area are controlled by a progressive tidal wave, moving down the coastline of England.

Feature	Comments
	Episodic currents over the wider area of Norfolk Banks induced by storm surges cause sand to be transported in directions other than those caused by the tidal currents alone (Flather, 1987). The former, combined with observed tidal flows (Venn & D'Olier, 1983), is expected to transport sand oblique to the tidal currents and towards the northeast up to about 100 km to seaward, contributing to the sandbank feature's natural progression in this direction (Stride, 1988). A hydrodynamic model developed by CEFAS, currently unpublished, indicates that ocean current flow is predominantly in a south-eastly direction with predicted velocities at seabed reaching a maximum of 2.7 m/s. The wave regime in the site has a marked seasonality. Wave height ranges from 0.5 m to greater than 4 m, with the largest waves being seen in the winter months when waves of over 3 m height are regularly recorded (Draper, 1968; Marshall, 1997). A maintain objective is advised for the hydrodynamic regime based on expert judgment.

Appendix 5

Dogger Bank Special Area of conservation

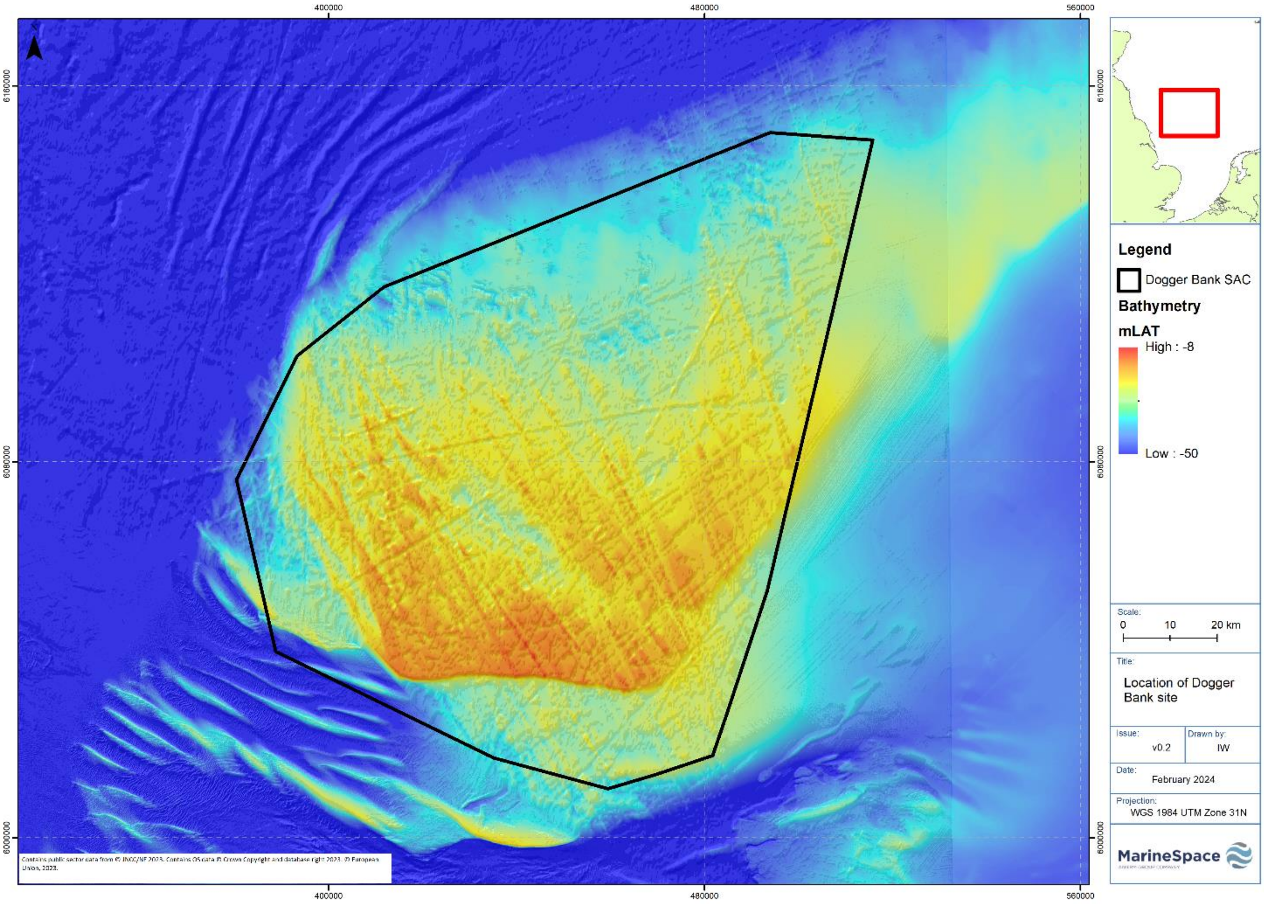

Figure 11: The Dogger Bank SAC showing the sandbank system (From: JNCC, 2011). Contains public sector data from © JNCC/NE 2023 Crown Copyright and database right 2023. © European Union

Table 11: Dogger Bank Special Area of Conservation information

Feature	Comments
Site name	Dogger Bank Special Area of Conservation (SAC)
Legislation	EU Habitats Directive 1992 transposed into UK law by The Conservation of Offshore Marine Habitats and Species Regulations 2017 (as amended) This site forms part of the networks of MPAs across the UK and contributes to international MPA networks such as that of the North-east Atlantic under OSPAR.
Dates of designation	August 2010 – possible SAC (pSAC) November 2011 – Site of Community Importance (SCI) September 2017 – SAC
Conservation objective	The site has a ‘recover’ conservation objective based on the findings of a vulnerability assessment (exposure to activities associated with pressures to which the protected features of the site are considered sensitive).
Conservation status	Annex I sandbanks – unfavourable For the features to be in favourable condition thus ensuring site integrity in the long term and contribution to Favourable Conservation Status of Annex I Sandbanks which are slightly covered by sea water all of the time. This contribution would be achieved by maintaining or restoring, subject to natural change: • The extent and distribution of the qualifying habitats in the site; • The structure and function of the qualifying habitats in the site; and

Feature	Comments
	• The supporting processes on which the qualifying habitats rely.
Size	12,331 km^2
Water depth	The shallowest depth within the MPA is 13 m below sea-level, and the deepest is 58 m below sea-level.
Sandbank type	The DB SAC represents the largest subtidal relict sandbank within UK territorial waters, although the Dogger Bank itself also extends into German and Dutch territorial waters. Dogger Bank was initially formed by glacial processes until it was submerged by rising sea levels.
Annex I habitat(s)	Sandbanks submerged by seawater at all times.
Biotopes	The following biotopes were identified within the DB SAC: • A5.1 subtidal coarse sediment ○ A5.13 infralittoral coarse sediment ○ A5.14 circalittoral coarse sediment ▪ A5.141 *Pomatoceros triqueter* with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles ▪ A5.143 *Protodorvillea kefersteini* and other polychaetes in impoverished circalittoral mixed gravelly sand ▪ A5.144 *Neopentadactyla mixta* in circalittoral shell gravel or coarse sand • A5.2 subtidal sand ○ A5.23 infralittoral fine sand ▪ A5.233 *Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand ○ A5.24 infralittoral muddy sand

Feature	Comments
	○ A5.25 circalittoral fine sand ▪ A5.252 *Abra prismatica*, *Bathyporeia elegans* and polychaetes in circalittoral fine sand ○ A5.27 deep circalittoral sand ▪ A5.272 *Owenia fusiformis* and *Amphiura filiformis* in deep circalittoral sand or muddy sand
Key information	The site represents a single Annex I habitat. The entire spatial extent of the SAC contains a single Annex I sandbanks submerged by seawater at all times feature.
Directly Overlaps	Southern North Sea SAC for designated Annex II population of harbour porpoise *Phocoena phocoena*.
Boundary	The boundary of this SAC is a simple polygon, enclosing the minimum area necessary to ensure protection of the Annex I habitat.
Activities	***Fisheries*** • There is evidence of recent mobile demersal, static and pelagic effort within the DB SAC. UK and non-UK registered vessels have been active in the area previously, however a ban on all ‘bottom towed fishing gear’ was introduced within the DB SAC in 2022; • The Marine Management Organisation (MMO) is the lead authority regarding the implementation of, and compliance with, any measures to managing fishing activity. Further information on progress is available on the Marine Management Organisation’s webpages; • Sandeel fisheries have recently undergone review with management practices proposed; • Important fisheries byelaw can be found at: The Dogger Bank Special Area of Conservation (Specified Area) Bottom Towed Fishing Gear Byelaw 2022 - GOV.UK (www.gov.uk). ***Licensable activities***

Feature	Comments
	- A considerable number of O&G assets are present within the DB SAC, including many fields, pipelines, wells, and associated infrastructure. Decommissioning of the assets is underway as of 2018; and - A number of offshore wind farm developments (Dogger Bank A, B, and C offshore wind farms, and the Sofia Offshore Wind Farm) are present within the DB SAC. Two further projects are proposed and subject to assessments. ***Telecommunications cables*** Four telecommunications cables currently pass through the DB SAC.
Sediment	Sediment type is dominated by Sand and slightly gravelly Sand throughout the DB SAC. The remaining sediment is a mosaic of Gravel, sandy Gravel, gravelly Sand, gravelly muddy Sand, and muddy sandy Gravel.
Sensitivities	**Subtidal coarse sediment** - JNCC (2022b) identifies subtidal coarse sediment as sensitive to. ○ Abrasion/disturbance of the substrate on the surface of the seabed ○ Changes in suspended solids (water clarity) ○ Habitat structure changes - removal of substratum (extraction) ○ Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion ○ Physical change (to another seabed type) ○ Siltation rate changes (high) including smothering (depth of vertical sediment overburden) ○ Siltation rate changes (low) including smothering (depth of vertical sediment overburden) ○ Water flow (tidal current) changes – local, including sediment transport considerations ○ Introduction of light **Subtidal mixed sediments**

Feature	Comments
	• JNCC (2022b) identifies subtidal mixed sediments as sensitive to: o Abrasion/disturbance of the substrate on the surface of the seabed o Changes in suspended solids (water clarity) o Habitat structure changes - removal of substratum (extraction) o Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion o Physical change (to another seabed type) o Physical change (to another sediment type) o Siltation rate changes (high) including smothering (depth of vertical sediment overburden) o Siltation rate changes (low) including smothering (depth of vertical sediment overburden) o Water flow (tidal current) changes – local, including sediment transport considerations o Introduction of light o Introduction or spread of invasive non-indigenous species (INIS) **Subtidal sand** • JNCC (2022b) identifies subtidal sand as sensitive: o Abrasion/disturbance of the substrate on the surface of the seabed o Changes in suspended solids (water clarity) o Habitat structure changes - removal of substratum (extraction) o Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion o Physical change (to another seabed type) o Siltation rate changes (high) including smothering (depth of vertical sediment overburden) o Siltation rate changes (low) including smothering (depth of vertical sediment overburden) o Water flow (tidal current) changes – local, including sediment transport considerations o Introduction of light o Introduction or spread of invasive non-indigenous species (INIS)

Feature	Comments
	Subtidal mud - JNCC (2022b) identifies subtidal mud as sensitive to: ○ Abrasion/disturbance of the substrate on the surface of the seabed ○ Changes in suspended solids (water clarity) ○ Habitat structure changes - removal of substratum (extraction) ○ Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion ○ Physical change (to another seabed type) ○ Siltation rate changes (high) including smothering (depth of vertical sediment overburden) ○ Siltation rate changes (low) including smothering (depth of vertical sediment overburden) ○ Water flow (tidal current) changes – local, including sediment transport considerations ○ Introduction or spread of invasive non-indigenous species (INIS)
Conservation advice	The ‘Conservation advice’ section of this table is a summary of supplementary advice for the DB SAC (JNCC, 2022a). JNCC’s Supplementary Advice on Conservation Objectives (SACOs) have set targets using expert judgement based on knowledge of the sensitivity of the feature to activities that are occurring/have occurred on the site.
Extent and distribution	**Restore** JNCC understands that the site has been subjected to activities that have resulted in a change to the extent and distribution of the feature within the site. Installation and/or removal of infrastructure may have a continuing effect on extent and distribution of the biogenic reef within the site. As such, JNCC advise a restore objective which is based on expert judgment.
Structure and function	**Restore**

Feature	Comments
	JNCC understands that the site has been subjected to activities that have resulted in a change to the structure and function of the feature within the site. Installation and/or removal of infrastructure may have a continuing effect on structure and function, specifically the characteristic communities and sediment composition and distribution. As such, JNCC advises a restore objective which is based on expert judgment.
Structure and function: finer scale topography	JNCC considers finer-scale topography of the feature may be impacted by the activities occurring within the site and therefore continues to need to be restored. This objective is based on expert judgement; specifically, understanding of the feature's sensitivity to pressures which can be exerted by historical and ongoing activities
Structure and function: physical structure – sediment composition and distribution	A restore objective continues to be advised for sediment composition and distribution of the feature within the site based on expert judgement; specifically, understanding of the feature's sensitivity to pressures which can be exerted by historical and ongoing activities
Structure and function: biological structure – characteristic communities	A restore objective continues to be advised for characteristic communities of the feature within the site based on expert judgement; specifically, understanding of the feature's sensitivity to pressures which can be exerted by ongoing activities
Structure and function: function	A restore objective continues to be advised for function within the site based on impacts to the characterising communities and peat deposits from ongoing and historical activities

Feature	Comments
Supporting Processes	**Maintain** JNCC understands that the site has been subjected to activities that have resulted in a change to the supporting processes of the feature within the site. Installation and/or removal of infrastructure may have a continuing effect on supporting processes. As such, JNCC advise a maintain objective which is based on expert judgment.
Hydrodynamic regime	The banks are subject to a range of water current strengths, which are strongest on the banks closest to shore (the ‘nearshore banks’) and which reduce gradationally in strength with increasing distance offshore (Collins and others, 1995). The banks further offshore (the ‘offshore banks) are the best example of open sea, tidal sandbanks in a moderate current strength in UK waters. Sand waves are present, being best developed on the nearshore banks, indicating the sediment surface is regularly mobilised by tidal currents. The water within the site is a mixture of both northern Fair Isle and southern English Channel waters. The site presents a complex pattern of currents, that are at present not well understood. Water movement is influenced by the local topography, with strongest currents measured on the near-shore sandbanks and decreasing with distance offshore (Jenkins and others, 2015). For example, on one of the banks, near-bed residual tidal currents have been observed to be strongest towards the crestline and in opposing directions on either side of the bank (Caston and Stride 1970; Caston, 1972). Tides over the area are controlled by a progressive tidal wave, moving down the coastline of England. Episodic currents over the wider area of Norfolk Banks induced by storm surges cause sand to be transported in directions other than those caused by the tidal currents alone (Flather, 1987). The former, combined with observed tidal flows (Venn & D’Olier, 1983), is expected to transport sand oblique to the tidal currents and towards the northeast up to about 100 km to seaward, contributing to the sandbank feature’s natural progression in this direction (Stride, 1988). A hydrodynamic model developed by CEFAS, currently unpublished, indicates that ocean current flow is predominantly in a south-eastly direction with predicted velocities at seabed reaching a maximum of 2.7 m/s. The wave regime in the site has a marked seasonality. Wave height ranges from 0.5 m to greater than 4 m, with the largest waves being seen in the winter months when waves of over 3 m height are regularly recorded (Draper, 1968; Marshall, 1997).

Feature	Comments
	A maintain objective is advised for the hydrodynamic regime based on expert judgment

Appendix 6

Geomorphology

The North Sea is the product of its Late Quaternary glacial history and subsequent reworking since the Last Glacial Maximum (LGM). The area has been subject to 3 major glaciations during the Middle to Late Pleistocene, the Anglian (MIS 12, ~420 kaBP), Wolstonian (MIS 6, ~130 kaBP) and Devensian (MIS 2 – build-up from ~35-32 kaBP, maximum LGM extent 27-21 kaBP and retreat/readvance phases between 19-17 kaBP) glaciations, respectively. The geology of this area of the southern North Sea is therefore the product of the environmental change driven by the growth and decay of these ice sheets. The exact location of the maximum extent of all these ice sheets is still the subject of debate (Clark and others, 2022); this being most clearly illustrated by the multiple interpreted maximum extents and retreat positions of the LGM ice sheet (

Figure **13**).

The Anglian ice sheet extent reached as far south as Essex, whilst the subsequent Wolstonian glaciation ice sheet extent would also have covered the Holderness coastline, reaching East Anglia and the north Norfolk coastline (Toucanne and others, 2009; Lee, Busschers & Sejrup, 2012). Consequently, the Dogger Bank was affected by all 3 glaciations, although deposits from the Anglian or Wolstonian glaciations are likely to have been overridden by the Devensian glaciation, and thus no remnants of these glaciations are likely to remain in the near surface.

Surrounding and beneath these superficial IDRBNR, NNSSR, and HHW sediment banks, glacial landforms are responsible for the conspicuous variation in the region's observed seabed morphology (Dove and others, 2017). On the largest-scale, a broad, arcuate, low-relief bathymetric high extends eastwards from the coastline, with water depths over the high increasing from 15 m in the west to 30 m in the east. This elevated feature also comprises several finer-scale bathymetric highs termed Broad Sediment Wedges (BSWs) due to their cross-sectional wedge-like morphology with relatively gently dipping northward slopes and steep-dipping southward-facing margins, which are delimited by narrower moraines. These BSWs (observed both at the seabed and in the sub-surface) are interpreted as sub-marginal glacial till wedges, formed by complex accretionary processes involving several terminal positions of the ice margin as it retreated and re-advanced in phases (Dove and others, 2017). A series of discreet groups of subglacial tunnel valleys, reaching depths of up to 100 m below sea level, are incised approximately perpendicularly to this broad high (Dove and others, 2017) and were likely formed due to erosion by over-pressurised subglacial meltwater (e.g., Kehew, Piotrowski & Jorgensen, 2012). The northern and southern limits of individual tunnel valleys are coincident with the northern and southern edges of the BSWs, further evidencing discreet phases of ice sheet margin movement and standstill (

Figure **13**).

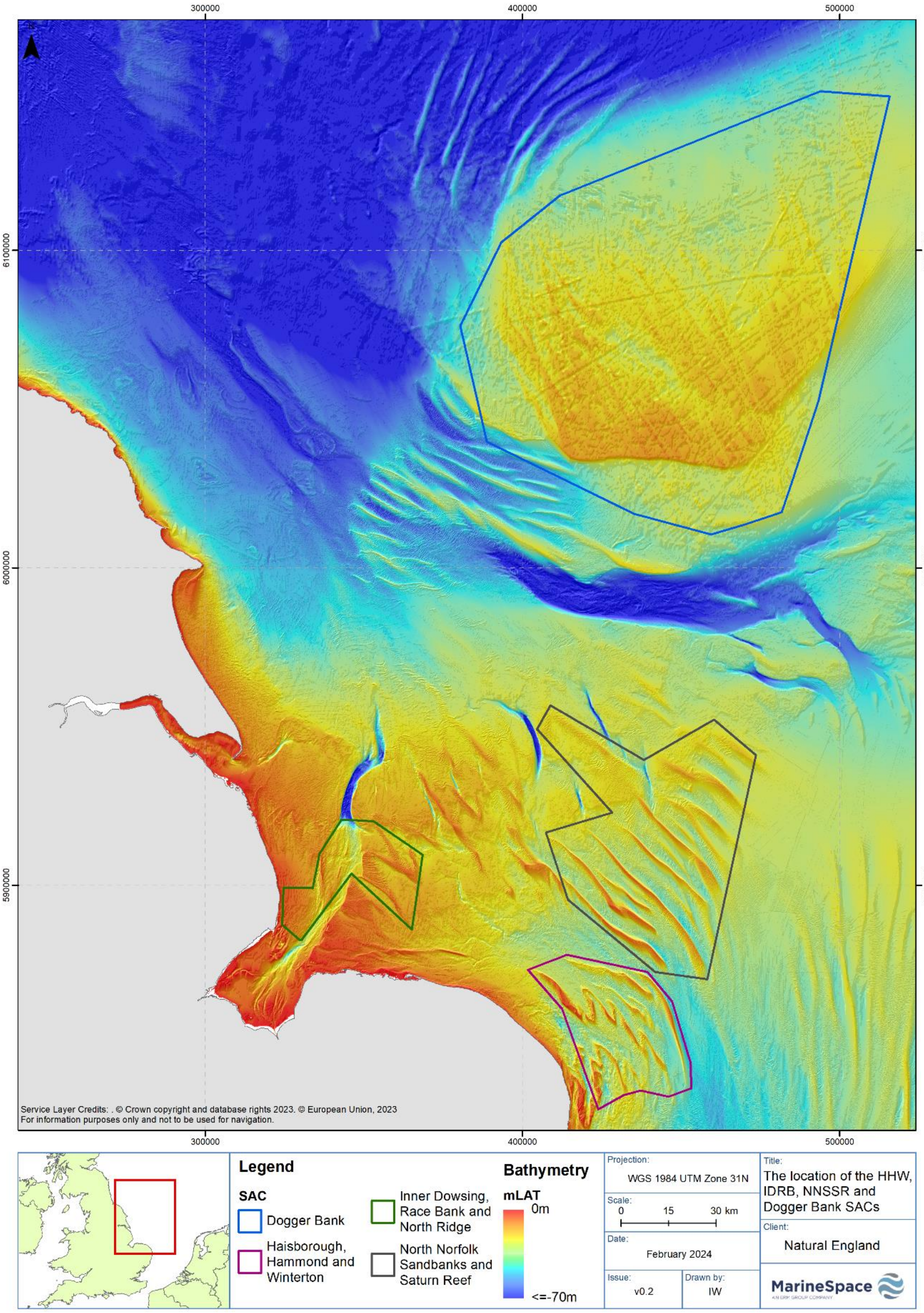

Figure 12: The location of the Dogger Bank, IDRBNR, NNSSR, and HHW SACs in the Southern North Sea.

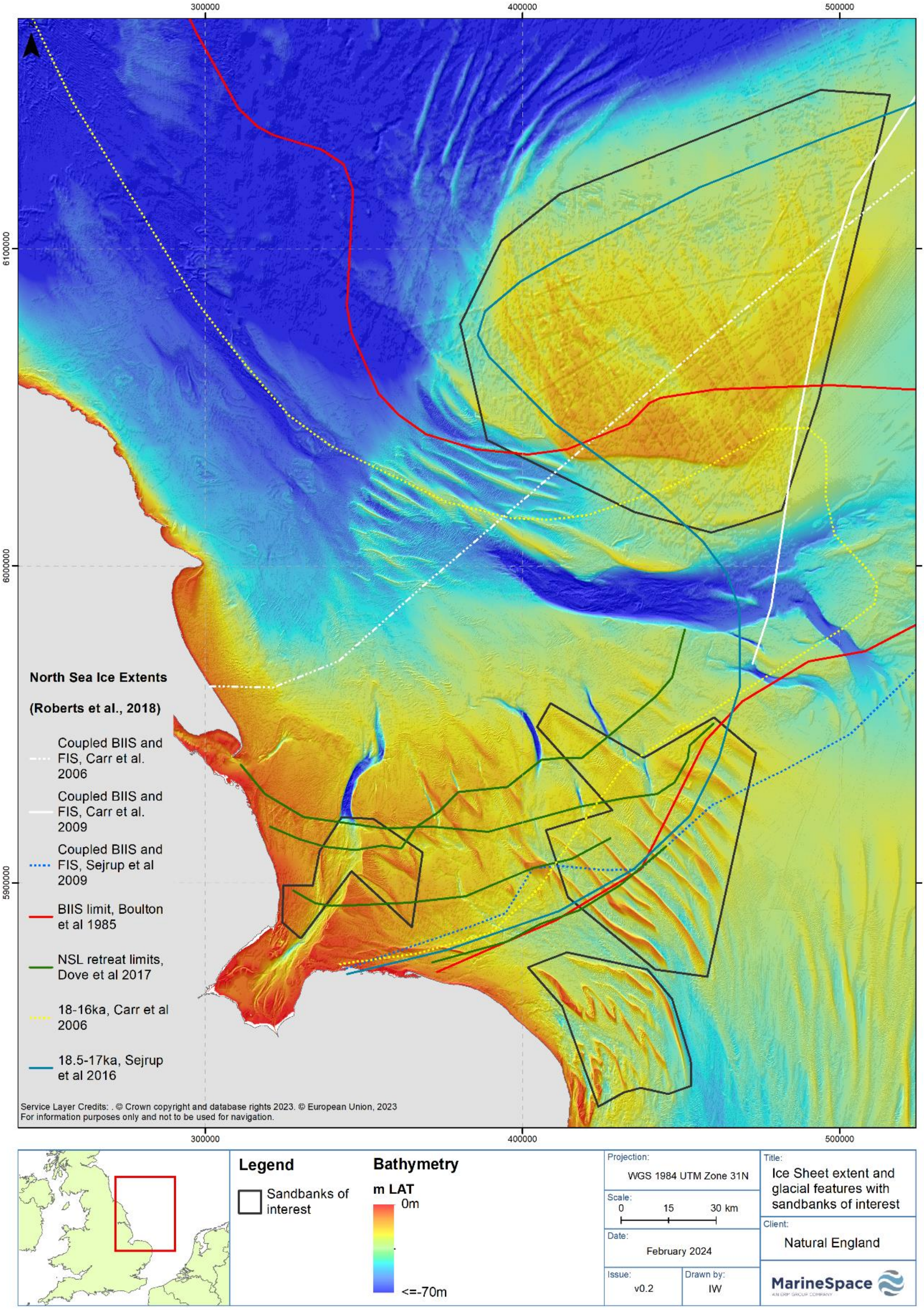

Figure 13: The North Sea mapped ice limits for the LGM, with the Dogger Bank, IDRBNR, NNSSR, and HHW SACs, overlain with BRITICE v2 data (Sources: Roberts and others, 2018; Clark and others, 2017)

The Dogger Bank is interpreted as a strongly glaciotectonised composite terminal moraine belt (Cotterill and others, 2017a; Phillips and others, 2018; Emery and others, 2019a and b; Phillips and others, 2022). The western section of the Bank is made up of 4 main formations of Late Pleistocene to Holocene age. These are the:

- ***Dogger Bank Formation*** (DBF – Late Pleistocene) is a predominantly clay-rich glacial till with laterally discontinuous sand lenses which overlie nearshore marine sands of the mid-Pleistocene (MIS11: ~ 400 kaBP to 120 kaBP) Egmond Ground, Cleaver Bank and Eem Formations (Cotterill and others, 2017a). Cotterill and others (2017a) informally subdivided the DBF into “Basal”, “Older/Lower” and “Younger/Upper” Dogger Bank units based on geotechnical and seismo-stratigraphic differences (Lower and Upper nomenclature was a subsequent refinement made by Phillips and others, 2018 and this will be preferentially used for the rest of this report). The Lower Dogger Bank is thickest towards the west of the area forming a series of complex ridges, with the overlying Upper Dogger Bank deposits filling the depressions between the ridges. The Lower and Upper sub-units both show indications that they have been subject to glaciotectonic deformation (Cotterill and others, 2017a and b; Phillips and others, 2018) with ice advancing from the north/northwest to create a series of ice-push moraines (Phillips and others, 2018). The Upper unit is predominantly of a greenish grey clay, with more sand laminae, particularly towards the base (Phillips and others, 2022) containing organics and detrital micas compared to the Lower Dogger Banks clays. These units represent a transition from periglacial / aeolian conditions (Basal) to glacial conditions (Lower and Upper);
- ***Bolders Bank Formation*** (BBF – Late Pleistocene) typically occurs west of Dogger Bank where it rests directly on the Lower Dogger Bank Formation and interdigitates with the Upper Dogger Bank Formation suggesting it is a contemporaneous unit with the latter. Boreholes from this area suggest it is a stiff to very-stiff, reddish to greyish, massive, slightly sandy and calcareous clay rich till. The presence of lithic clasts distinguish them from the clast poor olive grey clays of the DBF. The spatial restriction of these deposits to the west of the Bank suggest it was deposited by the North Sea lobe which flowed both southwards between Dogger Bank and the Yorkshire coast towards Norfolk, and westwards, entering Yorkshire. The maximum offshore extent is dated to 31.4-25.3 kaBP (Roberts and others, 2018) whilst the maximum readvance reached the north Norfolk coast by (21.5-20.7 kaBP: Evans and others, 2021). There is strong evidence of ice advance and retreat throughout this period, ~28-22 kaBP, both onshore and offshore (Dove and others, 2017; Roberts and others, 2018, Evans and others, 2021:
- Figure **13**). Ice finally retreated from the East Yorkshire coast by ~17.3 kaBP (Evans and others, 2021). The East Yorkshire coastline and seabed eastward to the margins of the Dogger Bank is therefore made up of the subglacial deposits of the BBF and its terrestrial correlatives, which in this area are the Skipsea and Basement Tills;

- ***Botney Cut Formation*** (BCF – Late Pleistocene) tends to exist in scaphiform valleys, up to 100 m deep and <~8 km wide, which radiate out from the western and northwestern limits of the Dogger Bank. The Botney Cut Formation is represented by thinly laminated grey clays with laminae of silt and fine sand, interbedded with sands and occasional gravel horizons, which infill this drainage system. Traditionally, these channels have been interpreted as being of subglacial meltwater origin forming under high pressure as ice sheets decayed (Cameron and others, 1992). However, the radial pattern elucidated by more recent work suggest they may represent a proglacial drainage system (Cotterill and others, 2017a). Associated deposits interpreted as of lacustrine origin, and which contain significant organic matter would support this latter interpretation (Cotterill and others, 2017a); and
- ***Holocene Deposits***: the Holocene across the western part of Dogger Bank is composed of dark olive-grey to very dark grey, fine-to medium-grained sands containing shells and a few rounded to angular, coarse gravel-sized clasts. The degree of consolidation of these sands increases downwards with an upper layer, a few centimetres thick, comprising loose silty sand overlying a much thicker (>10 m thick) sequence of dense to very dense sand. Locally this dense sand rests upon a mica-rich, fine silty sand unit, which in turn overlies a fine to coarse sandy gravel. Thicknesses of these deposits vary from being >25 m where these deposits infill depressions and relic channels, to <1 m thick very thin drapes (Cotterill and others, 2017a).

In summary, the Devensian ice sheet advanced over the Dogger Bank began ~30 kaBP, with maximum extent ~27 kaBP, and full retreat having occurred by ~23 kaBP (Cotterill and others, 2017a; Phillips and others, 2018; Emery and others, 2019a and b). The western side of Dogger Bank shows evidence of multiple readvances (active oscillation) of the Devensian ice sheet margin during deglaciation, indicated by the moraine complexes and deformation of the Dogger Bank Formation sediments (Phillips and others, 2018, Emery and others, 2019b; Phillips and others, 2022). To the west and southwest of Dogger Bank, the North Sea Lobe of the British Irish Ice Sheet underwent a series of advance and retreat phases, with the East Yorkshire coast area not becoming fully ice-free until 17.3 kaBP. The subglacial landscape was subsequently overlain by glaciolacustrine, glaciofluvial outwash and eventually Holocene marine sediments (Evans and others, 2021).

Transgressional Bank Formation

Following the LGM ice sheet retreat, the region was subjected to a rapid late glacial transgression resulting from a combination of eustatic change due to global melt water influx and local isostatic subsidence due to forebulge collapse. Shennan, Bradley & Edwards (2018) present relative sea-level (RSL) curves for 86 regions across Britain and Ireland over the last 20 ka since the ice front retreat, recalibrating and updating predictions with new datasets from previous models (e.g., Shennan & Horton, 2002). These modelled outputs are validated against *in situ* sea-level index points aggregated in a database for the whole of the UK. The output predictions indicate a nationwide RSL rise since the LGM, and also show significant spatial variation attributed to the glacial isostatic adjustment factor. Regions across the ice sheet periphery, notably the southeast of Britain where the sandbanks of interest are located, record up to 120 m of predominantly continuous RSL rise since the LGM and 65 m sea level rise since the start of the Holocene (Figure 14). The flooding of the landscape upon which the modern-day banks lie commenced around 8.5 ka and was probably complete by 7 ka. The plateau's transgression was, therefore, extremely rapid due to its low gradient and this rapid sea-level rise, which may have exceeded 20 mm/year, and is understood to be responsible for the initiation of the sandbanks.

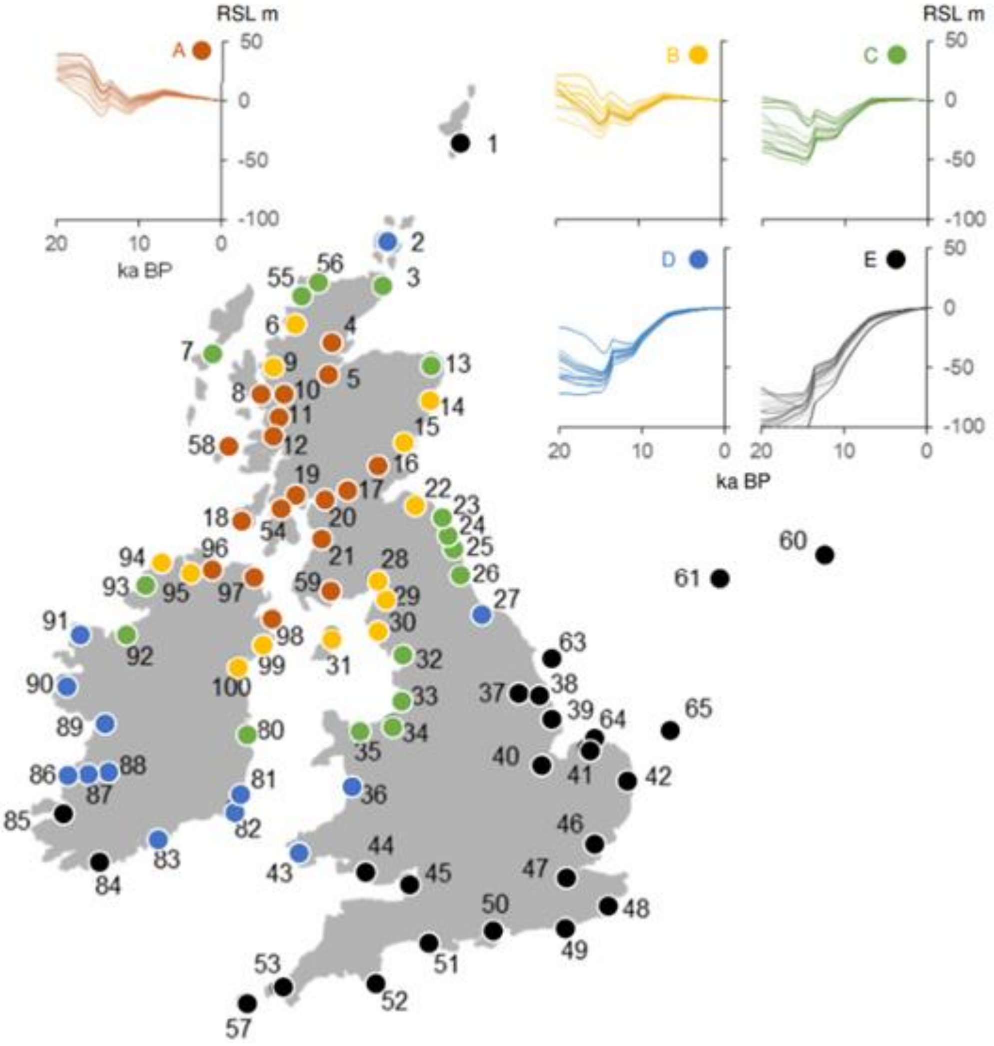

Figure 14: Relative Sea level rise across different regions of the UK since 20 ka BP. (From: Shennan, Bradley & Edwards, 2018)

Future study of sediment mobility

A review of publicly available MBES bathymetry data that covers the four MPAs has been carried out, which can be used in future studies of sediment transport. Datasets were filtered and only those collected from 2005 onwards, with a resolution of 2 m or less, were selected (that could be used in future studies of sediment transport). These datasets are summarised in Table . In addition, historical charts for the region are available dating back to the early 19th Century, and a similar exercise for the Dogger Bank, IDRBNR, and NNSSR marine sandbanks systems could be conducted with reference to these historical data (as already completed for the HHW system).

Appendix 7

MBES surveys

Table 12: Available MBES bathymetry datasets covering the four sites.

Site	Dataset name	Year	Resolution	Source
All sites	D4 EMODnet tile	2020	70 m x 115 m	EMODnet
Dogger Bank	D5 EMODnet tile	2020	70 m x 115 m	EMODnet
Dogger Bank	HI1590 Dogger Bank SW	2019	2 m	UKHO Seabed Mapping Service
Dogger Bank	HI1714 Dogger Bank West	2021	2 m	UKHO Seabed Mapping Service
Dogger Bank	HI1715 Dogger Bank Easternmost Shoal	2022	2 m	UKHO Seabed Mapping Service
Dogger Bank	HI1717 Dogger Ground South	2022	2 m	UKHO Seabed Mapping Service

Site	Dataset name	Year	Resolution	Source
Dogger Bank	MDE 2011 - Gardline Geosurvey, Zone 3, Tranche B, Recon ECR geophysical survey of Dogger Bank	2011	5 m	Marine Data Exchange
Dogger Bank	2013 Zone 3 Dogger Bank Tranche C, Gardline Geosurvey Ltd, Geophysical Survey	2013	N/a	Marine Data Exchange
Haisborough, Hammond and Winterton	East Coast Regional Environmental Characterisation Project	2009	0.5 m and 1 m	Marine Data Exchange
Haisborough, Hammond and Winterton	2015 HI1427 The Would North 1m CUBE	2015	1 m	UKHO Seabed Mapping Service
Haisborough, Hammond and Winterton	2015 HI1427 The Would Centre 1m CUBE	2015	1 m	UKHO Seabed Mapping Service
Haisborough, Hammond and Winterton	2014 HI1428 Newarp Banks to Cross Sands 1m CUBE	2014	1 m	UKHO Seabed Mapping Service
Haisborough, Hammond and Winterton	2014 HI1425 DWR via DR1 Welland Field 1m CUBE	2014	1 m	UKHO Seabed Mapping Service
Haisborough, Hammond and Winterton	2014 HI1426 DWR Via DR1 South Blk1&2 2m CUBE	2014	2 m	UKHO Seabed Mapping Service
Haisborough, Hammond and Winterton	2015 HI1427 The Would South 1m CUBE	2015	1 m	UKHO Seabed Mapping Service

Site	Dataset name	Year	Resolution	Source
Haisborough, Hammond and Winterton	2017 HI1516 Southern Approach to Smiths Knoll Blk 1 0-40m 1m CUBE	2017	1 m	UKHO Seabed Mapping Service
Haisborough, Hammond and Winterton	2017 HI1516 Southern Approach to Smiths Knoll Blk 1 40-60m 2m CUBE	2017	2 m	UKHO Seabed Mapping Service
Haisborough, Hammond and Winterton	2018 HI1580 Hearty Knoll to Haisborough Sand 2m 0-40m SDTP	2018	2 m	UKHO Seabed Mapping Service
Inner Dowsing, Race Bank and North Ridge	2005, EMU Ltd, Lincs Offshore Wind Farm, Geophysical Survey	2005	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2007, Fugro Survey Ltd., Lynn and Inner Dowsing Offshore Wind Farms	2007	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2008, Amec Wind Energy Ltd., Race Bank and Docking Shoal Offshore Wind Farms	2008	2 m	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2008, EMU Limited, Lincs Offshore Wind Farm, Acoustic Surveys	2008	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2009, Lynn and Inner Dowsing, EMU Ltd, Hydrographic Monitoring Survey	2009	N/a	Marine Data Exchange

Site	Dataset name	Year	Resolution	Source
Inner Dowsing, Race Bank and North Ridge	2010, EGS (International) Ltd, Lynn and Inner Dowsing Offshore Wind Farms, Geophysical and Biology	2010	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2010, EGS, Lincs Offshore Wind Farm, Pre-Construction Baseline Survey Works	2010	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2010, Lynn and Inner Dowsing, EGS, Post Construction Benthic and Geophysical Survey	2010	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2011, EGS, Lincs Offshore Wind Farm, Array Cable Geophysical Survey	2011	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2011, EGS, Lincs Offshore Wind Farm, Collector and Array Cables	2011	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2011, EGS, Lincs Offshore Wind Farm, Pre-Construction Baseline Survey Works, Export Cable Route S	2011	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2011, EGS, Lynn and Inner Dowsing Offshore Wind Farms, Post-Construction Array Cable Geophysical	2011	N/a	Marine Data Exchange
Inner Dowsing,	2011, Osiris Projects, Lincs Offshore Wind Farm, Pre-	2011	N/a	Marine Data Exchange

Site	Dataset name	Year	Resolution	Source
Race Bank and North Ridge	construction Acoustic Survey			
Inner Dowsing, Race Bank and North Ridge	2012, EGS, Lynn and Inner Dowsing Offshore Wind Farms, Post Construction Hydrographic and Geophys	2012	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2014, EGS, Inner Dowsing, Turbine ID24 Clearance Survey	2014	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2014, EGS, Lincs Offshore Wind Farm, Post Construction Hydrographic, Geophysical and Benthic Survey	2014	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2014, EGS, Race Bank Offshore Wind Farm, Pre-Construction Inter Array Cables Geophysical Survey	2014	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2014, MMT, Race Bank Offshore Wind Farm, Geophysical Survey	2014	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2015, EGS, Docking Shoal Offshore Wind Farm	2015	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2015, EGS, Lincs Offshore Wind Farm, LS16 Jack-Up Clearance Survey	2015	N/a	Marine Data Exchange

Site	Dataset name	Year	Resolution	Source
Inner Dowsing, Race Bank and North Ridge	2015, EGS, Lincs Offshore Wind Farm, Post Construction Hydrographic, Geophysical and Benthic Survey	2015	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2015, EGS, Lynn and Inner Dowsing Offshore Wind Farms, Post Construction Geophysical Survey	2015	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2015, Spectrum Geosurvey, Race Bank Offshore Wind Farm, ROW1 Offshore Environmental and Engineering Survey	2015	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2016, EGS, Lincs Offshore Wind Farm, Post Construction Geophysical Survey 2016	2016	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2016, EGS, Lynn and Inner Dowsing Offshore Wind Farms, Post Construction Geophysical Survey	2016	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2017, EGS, Lincs Offshore Wind Farm, Lincs LS23 and LS65 Clearance Survey	2017	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2017, EGS, Lincs Offshore Wind Farm, LS68 Clearance Survey 2017	2017	N/a	Marine Data Exchange

Site	Dataset name	Year	Resolution	Source
Inner Dowsing, Race Bank and North Ridge	Winter 2013, Osiris Projects, Lincs Offshore Wind Farm, Post-Construction Geophysical Survey	2013	N/a	Marine Data Exchange
Inner Dowsing, Race Bank and North Ridge	2021 HI1728 Dudgeon Shoal to Sheringham Shoal 2m SDTP	2021	2 m	UKHO Seabed Mapping Service
Inner Dowsing, Race Bank and North Ridge	2020 HI1675 Inner Dowsing 2m SDTP	2020	2 m	UKHO Seabed Mapping Service
Inner Dowsing, Race Bank and North Ridge	2020 2021-145561 Skegness Gibraltar Point	2020	Na	UKHO Seabed Mapping Service
Inner Dowsing, Race Bank and North Ridge	2019 HI1596 Outer Dowsing Channel 0-40m 2m SDTP	2019	2 m	UKHO Seabed Mapping Service
Inner Dowsing, Race Bank and North Ridge	2019 2020-203550 Triton Knoll Wind Farm Cable Route	2019	N/a	UKHO Seabed Mapping Service
Inner Dowsing, Race Bank and North Ridge	2019 2020-203550 Triton Knoll Wind Farm Array	2019	N/a	UKHO Seabed Mapping Service
Inner Dowsing,	2018 HI1515 Haisborough Sand to Outer Dowsing Channel Area 1m CUBE	2018	1 m	UKHO Seabed Mapping Service

Site	Dataset name	Year	Resolution	Source
Race Bank and North Ridge				
Inner Dowsing, Race Bank and North Ridge	2017 2018-056309 The Wash Wainfleet Road 2m	2017	2 m	UKHO Seabed Mapping Service
Inner Dowsing, Race Bank and North Ridge	2016 HI1492 Dudgeon Shoal to Silver Pit 1m CUBE	2016	1 m	UKHO Seabed Mapping Service
Inner Dowsing, Race Bank and North Ridge	2014 HI1447 Blakeney Overfalls 1m CUBE	2014	1 m	UKHO Seabed Mapping Service
Inner Dowsing, Race Bank and North Ridge	2014 HI1423 Docking Shoal to Blakeney Overfalls Area7 1m CUBE	2014	1 m	UKHO Seabed Mapping Service
Inner Dowsing, Race Bank and North Ridge	2014 HI1423 Docking Shoal to Blakeney Overfalls Area6 1m CUBE	2014	1 m	UKHO Seabed Mapping Service
Inner Dowsing, Race Bank and North Ridge	2014 HI1423 Docking Shoal to Blakeney Overfalls Area5 1m CUBE	2014	1 m	UKHO Seabed Mapping Service
Inner Dowsing, Race Bank and North Ridge	2014 HI1423 Docking Shoal to Blakeney Overfalls Area4 1m CUBE	2014	1 m	UKHO Seabed Mapping Service

Site	Dataset name	Year	Resolution	Source
Inner Dowsing, Race Bank and North Ridge	2014 HI1423 Docking Shoal to Blakeney Overfalls Area3 1m CUBE	2014	1 m	UKHO Seabed Mapping Service
Inner Dowsing, Race Bank and North Ridge	2014 HI1423 Docking Shoal to Blakeney Overfalls Area2 1m CUBE	2014	1 m	UKHO Seabed Mapping Service
Inner Dowsing, Race Bank and North Ridge	2014 HI1423 Docking Shoal to Blakeney Overfalls Area1 1m CUBE	2014	1 m	UKHO Seabed Mapping Service
Inner Dowsing, Race Bank and North Ridge	2014 HI1421 Approaches to The Wash 1m CUBE	2014	1 m	UKHO Seabed Mapping Service
Inner Dowsing, Race Bank and North Ridge	2014 2015-070691 Silver Pit rMCZ 2m SDTP	2014	2 m	UKHO Seabed Mapping Service
Inner Dowsing, Race Bank and North Ridge	2006 HI1174 Sledway to Blakeney Overfalls	2006	N/a	UKHO Seabed Mapping Service
North Norfolk Sandbanks and Saturn Reef	2009, Gardline Environmental Limited, Humber Regional Environmental Characterisation Project Geophysical Survey	2009	N/a	Marine Data Exchange

Appendix 8

Thoughts on future potential mitigation

Various projects have the capacity to adapt and change their engineering PDE within a worst-case Rochdale Envelope defined during the EIA process, and the PDE also assessed through HRA. As such, there is potential to work with developers and regulators to mitigate impacts related to current, and future O&M, and decommissioning pressures, as well as those associated with reasonably foreseeable construction.

Mitigation measures are available, and an outline for potential future research topics is considered here, noting that all will rely on MPA site-specific characteristics.

Key points:

Understanding physical characteristics of hard infrastructure, and the associated engineering PDE, which may influence physical and biological impacts, is fundamental. A pertinent question is; should rock berm height or concrete mattress aRSL require greater consideration than the berm's seabed footprint?

- At first, the direct physical seabed footprint of a rock berm or concrete mattress may be considered the most relevant assessment parameter. However, the associations of these infrastructure with biotic and abiotic factors may affect the actual magnitude of effect of the infrastructure on the functioning of the subtidal sandbanks feature. This can relate to associated indirect effects such as artificial reef effects forcing hyper-nutrification of down-stream surficial seabed habitats, and/or predator foraging halos on surrounding infaunal communities (due to mobile predators colonising the infrastructure – for detail see section considering Q1. In actuality, the indirect effects related to the seabed footprint may be greater than the direct footprint of the berm itself. Therefore, can the height (elevation aRSL) and orientation and position of hard substrata, in relation to subtidal sandbanks features, and alignment with physical parameters, minimise significant, or adverse, effects on sediment transport, scour, and changes in seabed nutrification?;
- Use of sandwave clearance and the benefits of this method to install infrastructure (cables) below surficial sediment mobile layers, and therefore potentially reduce or remove need for rock placement may mitigate some potential adverse effects. Failure to achieve cable burial depth below the influence of physical turbation effect envelopes can result in scouring and free-spanning, and the requirement for remedial works that tend to require the emplacement of protective infrastructure to secure the asset;

Understanding the design elements of hard infrastructure that could mitigate barrier effects;

  - Would lowering the height, whilst widening the base of a rock berm, allow sediment to move across the infrastructure? Whilst securing the asset being protected could this adaptation of PDE naturally reduce impact?;
  - Acknowledging that direct pressures (habitat loss/ Physical change (to another seabed type)) may be incurred;

Understanding whether artificial backfill of trenches during construction-phase installation would initiate recovery of sandbank habitats;

- This factor assumes the use of granular in-fill material (gravel phi material) to secure assets, rather than ‘armouring’ with rock berms. This method has been used successfully to remediate export cable scour pits from London Array OWF at the crossing of the BritNed interconnector cable (MarineSpace, 2014);
- Use of low-impact cable-laying techniques to minimise hard substrata impact at the surface;
  - E.g. if the asset (assume an export cable) was to be buried to a 2.5 m below RSL depth and overlaid by 1 m aRSL height rock berm, would there be a case for excavating a wider channel, and backfilling with granular fill, as opposed to using the displaced sediment. Local physical processes may then allow the original substrate to cover the granular infill, reducing both the loss of specific receptor biotope over time, in addition to reducing the likelihood of introducing non-native species and local population ‘absorption’ as a consequence of the artificial reef effect. It may be the case that a slightly larger footprint of initial works would dramatically reduce:
    - The direct presence of hard structures on the surface; and
    - The requirement to introduce seabed disturbance during cable replacement (if the cable is pre-stabilised);
- As conventional rock berms are likely to be cheaper to install, this approach could be specific for infrastructure on features such as Annex I subtidal sandbanks features, but not mandatory in locations outside of MPAs;
- Emerging technology is demonstrating that rock bags may soon be able to use extruded minerals products instead of plastics;
- This will mitigate the delivery of degraded plastics into the marine environment whilst also establishing a more robust/reliable potential for retrieval of these infrastructure during project decommissioning;
- Emerging technology is being investigated to ascertain if extruded minerals products may be used instead of plastics for the fabrication and use of Frond mattresses;
- Frond Mats have been used at a number of cable and pipeline projects for scour protection, preventing free-spanning and increasing the longevity of the

infrastructure by instigating the burial of the infrastructure through interaction with natural sediment transport pathways (MarineSpace, 2021). However, a constraint for their favoured use is associated with the use of a polyester webbing mesh base, onto which a large number of buoyant polypropylene fronds are attached i.e. the use of plastics. If this advance in technology is realised, then frond mats will represent a technology that may negate many of the perceived adverse effects of using hard infrastructure to secure marine infrastructure developments/projects;

- Recent research shows that, similar to rock bag technology, using extruded minerals products may be used instead of plastics (Seabed Scour Control Systems Ltd, pers. comms.);
- Emerging Clamshell technology;
    - An emergent technology using a clamshell sheath-style mechanism is being investigated by several OWF asset owners. This technology is in its infancy regarding the ‘armouring’ of transmission (export) cables at crossing locations with other infrastructure assets such as interconnector cables and pipelines;
    - The deployment of this technology is novel, and is yet to be proven as a viable alternative to existing types of hard infrastructure protection methods, but if successful and viable, it may mitigate the use of rock berms and concrete mattresses to secure/remediate exposed assets.

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