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Identifying the possible impacts of rock dump from oil and gas decommissioning on Annex I mobile sandbanks

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JNCC EQA Statement:

This report is compliant with the JNCC Evidence Quality Assurance Policy http://jncc.Defra.gov.uk/default.aspx?page=6675.

This report provides initial conclusions regarding the implications of rock dump in the North Norfolk Sandbanks and Saturn Reef cSAC/SCI for impact assessment of plans and/or projects. As such, JNCC does not yet consider it appropriate to use the conclusions directly in Habitats Regulations Assessments without further consideration of the evidence gaps detailed in the report and consideration of the applicability of the evidence presented.

Summary

The Joint Nature Conservation Committee (JNCC) commissioned this project to generate an improved understanding of the impacts of rock dump from oil and gas decommissioning on Annex I mobile sandbanks, using the North Norfolk Sandbanks and Saturn Reef (NNSSR) candidate Special Area of Conservation (cSAC)/Site of Community Importance (SCI) as a case study. This work aimed to provide an evidence base to support management advice for similar Marine Protected Areas, identify evidence gaps where appropriate and the areas of future work that could be undertaken.

Over the next three decades, the UK will be subject to a significant decommissioning programme of oil and gas (O&G) infrastructure, with over 800 platforms and wells requiring removal or burial. Where the infrastructure cannot be removed (such as pipelines), protection by rock dump has previously been used to stabilise and remove the risk of snagging by fishing vessels operating trawl nets once the infrastructure is decommissioned. Rock dump is also used as a means of stabilising rigs and jack-up barges used during decommissioning operations. The impacts of decommissioning on Marine Protected Areas designated under the Habitats Directive (92/43/EEC) have the potential to affect the sites conservation objectives and integrity. This report is a review of existing literature, publicly available data, and a qualitative evaluation of the impacts of rock dump on Annex I habitats in the NNSSR cSAC/SCI.

The sediment characteristics of the NNSSR cSAC/SCI are dominated by sand with scattered areas of coarser sediments. Rock protection designs for all shapes and functions are based upon the local metocean (meteorological and oceanographic) conditions, including the geophysical conditions on which the rock protection is deployed.

Based on Environmental Statements for decommissioning programmes undertaken in areas of soft sediment communities in the North Sea (and where applicable mobile sandbanks), impacts to Annex I sandbanks from rock dump have been identified. These impacts are related to the physical and biological processes influencing the designated Annex I sandbank feature within the NNSSR cSAC/SCI, and include:

Supporting Physical Processes:

- Current and tidal flow disturbance.
- Sediment supply disturbance.
- Increase in scour.

Biological Processes:

- Changes in biodiversity from new substrate.

This report identified that there is currently insufficient information to quantify or qualify the implications of rock dump in the NNSSR cSAC/SCI from a physical and biological perspective. It is not possible to quantify or qualify the movement of sandbanks around or over existing or applied rock dump. Theoretically, the mobile sandbanks may cyclically cover applied rock dump and there is the potential for scour to be induced if an appropriate design is not chosen. Without further information on rock berm design, monitoring studies and numerical modelling of such behaviour, the short-term and long-term implications of both theoretical behaviours are difficult to determine.

Contents

List of Figures

List of Tables

1 Background and Introduction

Over the next three decades, the UK will be subject to a significant decommissioning programme of oil and gas (O&G) infrastructure, with over 800 platforms and wells requiring removal or burial. Much of this established infrastructure was constructed before 1992 and the adoption of the Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora, known as the Habitat Directive. Through the Habitats Directive, over 1,000 animal and plant species, as well as 200 habitat types, listed in the directive's annexes are protected in various ways in order to contribute to their favourable conservation status. The listed species and habitats are protected through a coherent European ecological network of protected sites, which includes Special Areas of Conservation (SAC). Oil and gas infrastructure installation prior to the designation of these protected areas would have conducted Environmental Impact Assessment (EIA) however, activities would not have considered the conservation objectives of subsequent marine protected areas not yet defined.

The decommissioning of O&G infrastructure in the UK is governed by the Energy Act 2016 (and formerly the Petroleum Act 1998), which applies to Great Britain including the "Crown Land". Meanwhile, the OSPAR Convention oversees the protection of the marine environment in the North-East Atlantic and includes guidance on the decommissioning of O&G infrastructure. In addition to the OSPAR Convention which covers the North Sea, the UK's international obligations, as specified by the United Nations Convention on the Law of the Sea (UNCLOS) Article 60(3) include the following:

"Any installations or structures which are abandoned or disused shall be removed to ensure the safety of navigation, taking into account any generally accepted international standards established in this regard by the competent international organisation. Such removal shall also have due regard to fishing, the protection of the marine environment, and the rights and duties of other States. Appropriate publicity shall be given to the depth, position and dimensions of any installations or structures not entirely removed." [United Nations Convention on the Law of the Sea (UNCLOS) Article 60(3)].

The competent international authority for the UNCLOS convention is the International Maritime Organisation (IMO). In 1989, the IMO adopted the IMO Guidelines and Standards for the Removal of Offshore Installations and Structures, which outlines the minimum global standards for the removal of offshore installations (DECC 2011a) on the Continental Shelf and in the Exclusive Economic Zone (EEZ).

In line with Article 60(3) of UNCLOS, the Petroleum Act 1998 and current UK guidance (DECC 2011b) allows for pipelines (or sections thereof) to be left in place if there are no suitable alternative means of decommissioning. There are a number of reasons to decide to leave infrastructure *in situ*, these include:

- removal, using current technology, is currently unfeasible;
- removal increases health and safety risks;
- deterioration of the infrastructure increases the risks associated with removal;
- potential release of harmful chemicals if infrastructure is dismantled or other unexceptable environmental concerns are raised;
- cost of removal, using current technology.

Where the infrastructure cannot be removed (such as pipelines), protection by rock dump has previously been used to stabilise and remove the risk of snagging by fishing vessels operating trawl nets once the infrastructure is decommissioned. Rock dump is also used as a means of stabilising rigs and jack-up barges used during decommissioning operations. Oil and gas companies consider that any existing rock protection is unlikely to be removed. The current DECC guidelines suggest that existing rock dump providing for pipeline protection will remain in place, unless there are special circumstances that would warrant consideration of removal (DECC 2011b).

The impacts of decommissioning on marine protected areas designated under the Habitats Directive (92/43/EEC) have the potential to have an adverse effect on site integrity by undermining the achievement of the site conservation objectives. Therefore, decommissioning activities permitted under the Energy Act 2016 using DECC (2011a) guidance will also need to consider the requirements of the Habitats Directive.

1.1 Aims and Objectives

The aim of this report is to provide evidence of the impacts associated with rock dumping during the decommissioning of oil and gas infrastructure on mobile Annex I sandbanks which are slightly covered by seawater all the time. This report uses the North Norfolk Sandbanks and Saturn Reef (NNSSR) candidate Special Area of Conservation/Site of Community Importance (cSAC/SCI) as a case study. The site is designated in its entirety as a representative functioning example of EC Habitats Directive Annex I listed feature ‘Sandbanks which are slightly covered by sea water all the time’ and also for Annex I ‘Reefs’ (*Sabellaria spinulosa* reef) (Figure 1).

The JNCC have considered the biological communities related to the NNSSR cSAC/SCI (Parry *et al* 2015) and identified that coarse and mixed sediment biotopes are considered to be part of the biological components of the sandbank feature and integral to the functioning of the feature across the site.

The conservation objectives for the NNSSR cSAC/SCI are to restore the Annex I Sandbanks which are slightly covered by seawater all the time and Annex I Reef to Favourable Condition, such that:

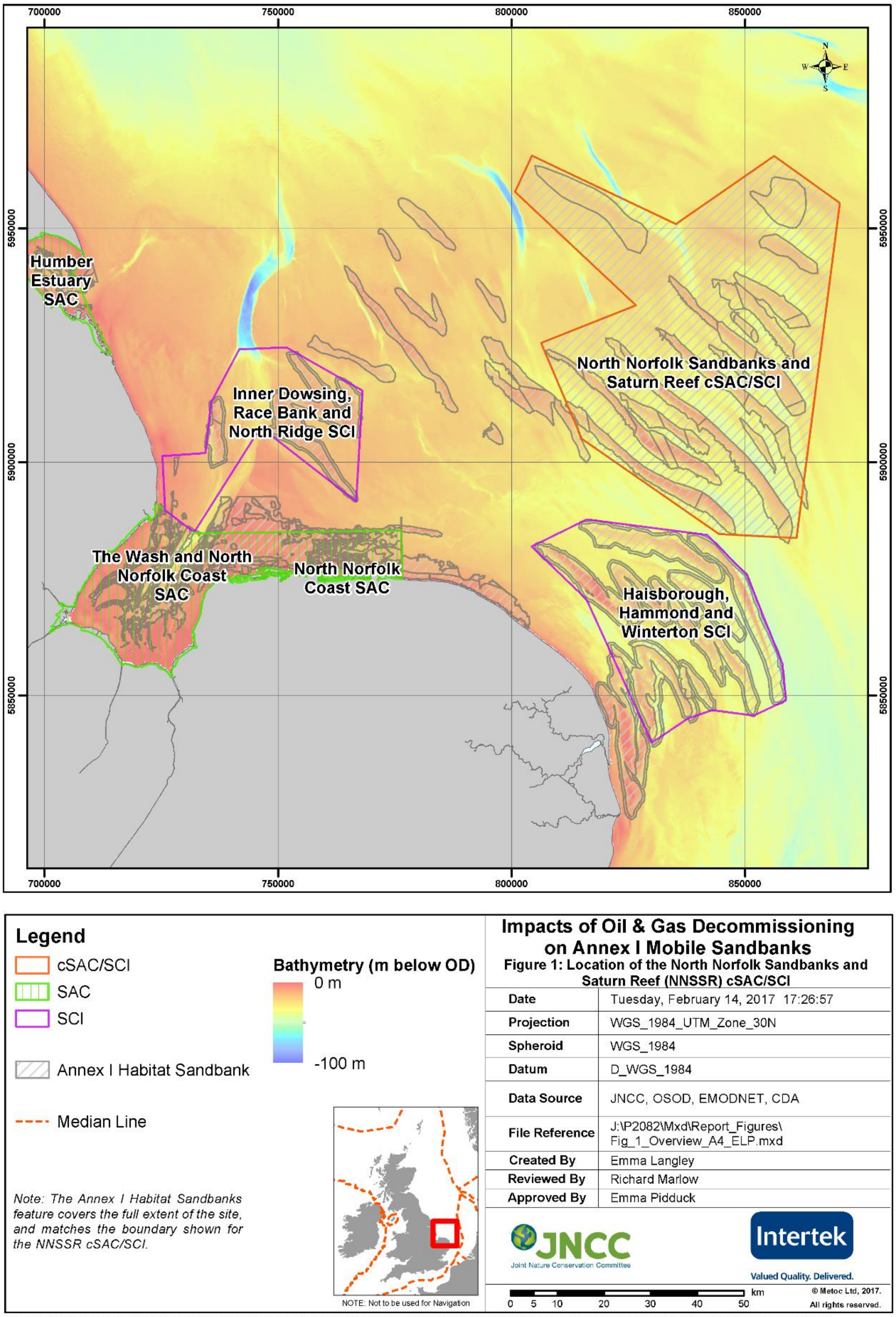
- the natural environmental quality is restored;
- the natural environmental processes and the extent are maintained;
- the physical structure, diversity, community structure and typical species, representative of sandbanks which are slightly covered by seawater all the time, in the Southern North Sea, are restored (JNCC 2012).

The NNSSR cSAC/SCI sandbank feature is currently considered to be highly vulnerable to physical loss through obstruction (by oil and gas infrastructure); and at moderate risk of damage from oil and gas infrastructure. The vulnerability of the NNSSR cSAC/SCI reef structure from physical loss is currently unknown as it is unquantifiable. While there is no direct evidence of feature damage or deterioration, it is subject to unprecedented levels of existing obstruction from infrastructure associated with oil and gas activities (JNCC 2012).

Therefore the objectives of this report are as follows:

- Identify the sediment characteristics of rock dump operations used on sandbanks (with a particular focus on mobile sandbanks).
- Identify sediment characteristics of the NNSSR cSAC/SCI.
- Compare and contrast rock dump profiles that would typically be required for or have been used in the NNSSR cSAC/SCI, and those used elsewhere in mobile sandbanks or designated Annex I habitat sites.

- Investigate how the introduction of rock dump could affect the natural supporting processes, sandbank movement, and the biological communities of the NNSSR cSAC/SCI.
- Assess, using literature and publicly available data, if previous rock dump applications in mobile sandbanks have remained on the surface or have been buried (permanently or cyclically).



The bathymetric metadata and Digital Terrain Model data products have been derived from the EMODnet Bathymetry portal - http://www.emodnet-bathymetry.eu. Contains Ordnance Survey data © Crown copyright and database right 2013. Copyright JNCC and BGS 2016. © Crown copyright 2016. © Crown Copyright. Contains public sector information licensed under Open Government Licence v3.0.

Figure 1: Location of the North Norfolk Sandbanks and Saturn Reef (NNSSR) cSAC/SCI.

1.2 Oil and Gas Infrastructure

The Southern North Sea has been developed extensively for oil and gas exploitation; with gas development predominant. Installations and a comprehensive pipeline infrastructure have developed to process and then export hydrocarbons to onshore terminals. Table 1 provides an overview of the existing infrastructure within the NNSSR cSAC/SCI (shown graphically in Figure 2). Of the 587 reported wells in the NNSSR cSAC/SCI, 190 have been plugged and abandoned during decommissioning exercises; similarly, of the 74 platforms in the NNSSR cSAC/SCI, two have been removed during decommissioning in 2014. These activities will be further discussed in Section 3.

Table 1: Summary of existing oil and gas infrastructure in the NNSSR cSAC/SCI.

Wells	587
Platforms	74
Pipelines	134
Assorted Subsea Infrastructure	48

Source: UK Oil and Gas Data (March 2017)

1.2.1 Decommissioning Methods and Process

In most instances, decommissioning activity aims to remove and recycle O&G assets (ABB 2015); however, in some cases it may not be possible to remove the infrastructure. In this case, the aim is to identify and mitigate the potential adverse effects of leaving O&G infrastructure in place. The existing infrastructure can loosely be divided into “surface” and “subsea”, where platforms and associated infrastructure (such as steel installations, jackets, topsides, *etc*.) can be classed as surface, and pipelines, gravity bases and wells as “subsea”.

This report refers to the use of rock dump as a means of:

- protection for subsea pipelines (i.e. that have not been trenched or buried within the substrata, are no longer buried to the optimal depth, or where spanning occurs); and
- application on the seabed to stabilise the foundations for jack-up drilling rigs or barges, (i.e. those that are used to plug and abandon wells or to support the removal of surface infrastructure).

It is currently recognised that removal of rock dump is unlikely to be practicable as it is uneconomical and technically challenging to remove. It is assumed therefore that rock-dump will remain in place, unless there are special circumstances that would warrant consideration of removal as per the DECC guidance notes (2011b). Rock dumping has been proposed as an option in all decommissioning environmental statements reviewed in this document that were publicly available at the time of writing.

There is relatively little information regarding the amount of rock dump that has been used to date in the North Sea.

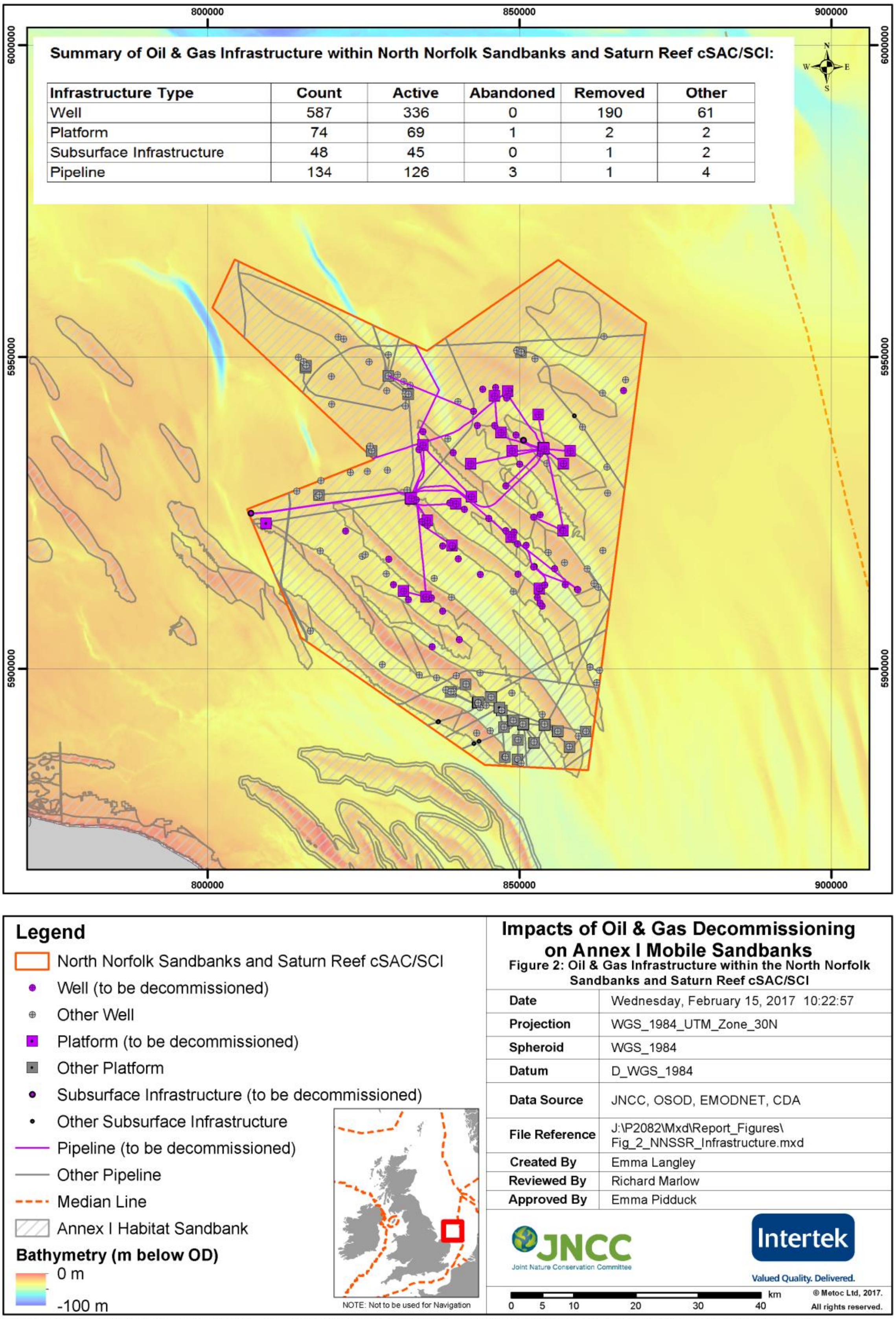


Figure 2: Oil and Gas infrastructure within the North Norfolk Sandbanks and Saturn Reef cSAC/SCI.

1.2.2 Surface Infrastructure

Removal of 'surface' infrastructure and the associated substructure (such as steel infrastructure and floating infrastructure) is typically undertaken in one of the following ways:

- Piece small: the removal of platforms in small sections, typically less than 20 tonnes. Sections are usually shipped to shore in containers. Here, topside modules would be dismantled offshore and facilities would be cut into manageable pieces for transportation to the shore on supply vessels.
- Piece large: the removal of the platform in sections of up to 5,000 tonnes. Sections are loaded onto a flat-top barge or crane vessel for transport to the shore.
- Single lift: the removal of the platform topsides in a single unit, with the jacket also being removed in the same manner. Here, a heavy lift vessel or cargo barge would be used to lift the entire structure and transport to shore.
- Reverse float-over/installation: topside is removed in an approach that is a reversal of a float-over installation process i.e. installed from a barge. The topside module is cut from the jacket and taken ashore in one piece.
- Buoyancy removal: buoyancy tanks are installed on the jacket legs to raise the infrastructure to the surface for removal.

All these methods could be applied to infrastructure in the NNSSR cSAC/SCI. The application of rock protection in the removal of surface infrastructure would typically be to stabilise jack-up barges that may be required to undertake any of the aforementioned activities.

1.2.3 Pipelines and Subsea Infrastructure

The OSPAR convention has not made any recommendation for the removal of pipelines; therefore, there is no obligation or legal requirement for their removal. In most North Sea countries (with the exception of Denmark), pipeline decommissioning is subject to a comparative assessment process, which is done in consultation with other North Sea stakeholders. A report published by the Health and Safety Executive (HSE 1997) estimated that there is approximately 9,670km of pipeline infrastructure in the Greater North Sea (OSPAR 2000) (area bound by the coastlines of England, Scotland, Norway, Sweden, Denmark, Germany, the Netherlands, Belgium, and France) associated with O&G, and OSPAR estimates that less than 4% of these pipelines laid are removable by reel vessel (Cox & Gerard 2001).

Options to decommission pipelines include:

- Reverse reel: Pipelines would be exposed where required using jetting/excavation methods, and would be removed by reverse reel prior to transport to the shore. This method would be used for more flexible pipelines that could be 'coiled' on a reel. It would not be suitable for rigid pipelines or those coated in concrete.
- Reverse S-lay: Pipelines would be exposed where required using jetting/excavation and would be removed by picking up one end of the pipe and cutting into sections aboard a vessel. The 'S-lay' refers to the shape of the curve of the pipeline from the vessel to the seabed. This method is suitable for more rigid pieces of pipeline, including those coated in concrete.
- Cut and lift: Pipelines would be exposed where required using jetting/excavation and would be removed by cutting the pipeline into sections using an underwater pipeline cutter. Cut sections would then be lifted onto barges/vessels, and transported to the shore. This method would be suitable for the full or partial removal of short sections of plastic or concrete-coated pipelines.

- Cut, float and tow: This method is suitable for longer lengths of pipeline. Sections are exposed and cut as required, then lifting handles and buoyancy tanks are fitted by divers to allow the pipeline to be raised to the surface. The pipeline would then be towed to the shore for dismantling.
- Decommissioning *in situ*: include minor intervention where pipelines are left in place such that they do not pose a threat to other sea users. This might include reburial or rock dump on exposed, at-risk or pipeline ends. Minimum intervention would be to cut the pipeline at either end and then protect the exposed ends either by re-trenching or rock dump.

Wells are required to be ‘plugged and abandoned’, a process during which connecting hardware is removed, plugs are inserted and cement is squeezed into the annuli at specified depths to act as permanent barriers to pressure from above and below. Once the cement has set and a ‘rock-to-rock’ barrier is in place, the wellhead is removed. The process temporarily disturbs the seabed surface, but in the long-term leaves no visible signs of the well above the seabed.

This process is considerably more economical if the drilling rig remains above the well-head and can be used to plug and abandon, such as would be the case when plugging and abandoning an appraisal or exploration well. In the case where a drilling rig is not in place throughout the lifetime of the well, i.e. a satellite production well, a jack-up barge may be required to complete the plug and abandon process once production has ceased. In the event of a jack-up barge being required, rock dump may be used to stabilise and protect the legs from scour during works on the well-head.

1.3 North Norfolk Sandbanks and Saturn Reef

The North Norfolk Sandbanks and Saturn Reef (NNSSR) is a cSAC/SCI located approximately 40km (22 nautical miles) off the north-east coast of Norfolk out to approximately 100km (60 nautical miles) (see Figure 1) (Parry *et al* 2015). The cSAC/SCI comprises the most extensive example of offshore linear ridge sandbank feature in UK waters (Jenkins *et al* 2015). It has been designated as a cSCI/SAC for the protection of two EC Habitats Directive Annex I habitats; these habitats, as defined by EC/92/43/EEC, are:

- ‘Sandbanks which are slightly covered by sea water all the time’;
- ‘Reefs’ (specifically the biogenic reef built from tubes created by the polychaete worm *Sabellaria spinulosa*).

The whole NNSSR cSAC/SCI is considered to be a representative example of the Annex I sandbank feature and an integrated sandbank system, which includes five individually named sandbanks (‘Leman’, ‘Ower’, ‘Well’, ‘Broken’ and ‘Swarte’), with a further four sandbanks that are labelled as the ‘Indefatigables’. Current velocities (Figure 3 and Figure 4) at the site can reach up to $1.5m.s^{-1}$ during spring peak flow (ABPmer Tidal Atlas 2008), with the strongest currents measured on the near-shore sandbanks and decreasing with distance offshore. The general current flow is to the south-east towards the Netherlands.

1.3.1 Annex I Sandbanks

Annex I ‘Sandbanks slightly covered by seawater all the time’ occur in areas of sand where distinct elevated topographic features are predominantly surrounded by deeper water and where the top of the sandbank is in less than 20m water depth. However, the sides of these sandbanks can extend into deeper water up to 60m whilst still being considered the feature. Within UK waters, these sandbanks consist of mainly sandy sediments, however, larger grain sizes (boulders and cobbles) or smaller grain sizes (mud) may also be present (European Commission 2013).

Types of sandbanks can be categorised by factors including sediment and topography. The two types of topographic sandbanks are sandy mounds and current tidal sandbanks. Mobile sandbanks fall under the ‘current tidal sandbank’ category. The extent and distribution of current tidal sandbanks are actively influenced by ongoing hydrodynamic processes and subsequently change naturally over time. Types of current tidal sandbank include:

- Open shelf ridge sandbanks.
- Estuary mouth sandbanks.
- Headland associated banks (Dyer & Huntley 1999).

In the context of Annex I of the Habitats Directive classification, the subtidal mobile sandbank biotope complex identified at the NNSSR cSAC/SCI is included in the broad habitat of Annex I ‘sandbanks slightly covered by seawater all the time’.

Depending on conditions, subtidal sandbanks can be highly dynamic and unstable in their nature. Due to the mobility of sediment, the biological communities typical of sandbanks can vary significantly depending on sediment type and depth (Elliott *et al* 1998). In more stable conditions, sandbanks are dominated by burrowing worms, crustaceans, bivalve mollusc and echinoderms, with shrimps and crabs on the surface. Where more complex substrates are present (boulders, large shells and biogenic reefs), seaweeds and hydroids may also be found. Species found in subtidal mobile sandbanks are typically tolerant to regular and/or periodic disturbance (Maddock 2008). These habitats are also often important nursery grounds for fish and feeding grounds for seabirds and marine mammals under the correct conditions.

The North Norfolk Sandbanks are the most extensive example of the offshore linear ridge sandbank type in UK waters (JNCC 2012). The relative surface area of this Annex I habitat is approximate as it is not possible to calculate an accurate total extent for Annex I shallow sandbank habitat for UK waters (JNCC 2010). With this in mind, a best minimum estimate based on the mapped area of sandy sediments in <20m water depth, is 733,100 hectares (JNCC 2010). JNCC considers the whole of NNSSR cSAC/SCI as a representative functioning example of Annex I sandbanks. The sandbanks are subject to a range of current strengths; strongest on the banks closest to shore, reducing towards offshore. The outer banks are reported to be the best example of open sea, tidal sandbanks in moderate current strength in UK waters (JNCC 2010, 2012). These linear sandbanks or tidal sand ridges are rhythmic features with typical length and width scales of the order of 10km (up to 80km) and 1km respectively (Sanay *et al* 2007). Sandwaves are present, being best developed on the inner banks; outer banks having small or no sandwaves associated with them (Collins *et al* 1995). Megaripples/sand waves systems have been recorded with height and wavelength scales of the order of 1 and 10m, respectively (Sanay *et al* 2007).

The North Norfolk Sandbanks are characterised by invertebrates which are typical of sandy sediments in the southern North Sea such as polychaete worms, isopods, crabs and starfish (DECC 2016). Where the sediment is highly mobile, fewer infauna are present. Under the JNCC Marine Habitat Classification and European Nature Information System (EUNIS) Biotope classification, the biological communities found within the sandbanks are typical of Infralittoral mobile clean sand with sparse fauna (SS.SSa.IFisa.IMoSa/A5.231). The description of this biotope identifies common epifaunal species such as *Pagurus bernhardus, Carcinus maenas* and *Asterias rubens*. Typical infaunal species associated with this biotope include the polychaete worm *Nephtys cirrosa*, and the isopod *Eurydice pulchra*.

Descriptions of the sediment include medium to fine sandy sediment often formed into dunes on exposed or tide swept coasts (JNCC 2010; Jenkins *et al* 2015).

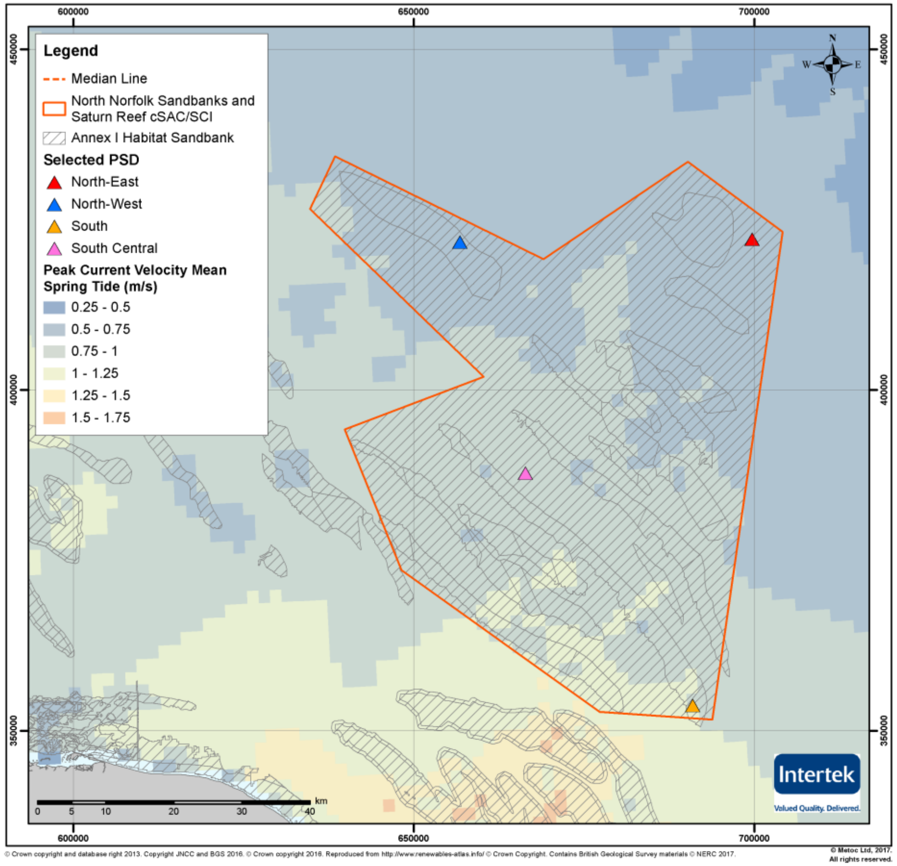


Figure 3: Typical peak current velocities during mean spring tide (from ABPmer Tidal Atlas 2008).

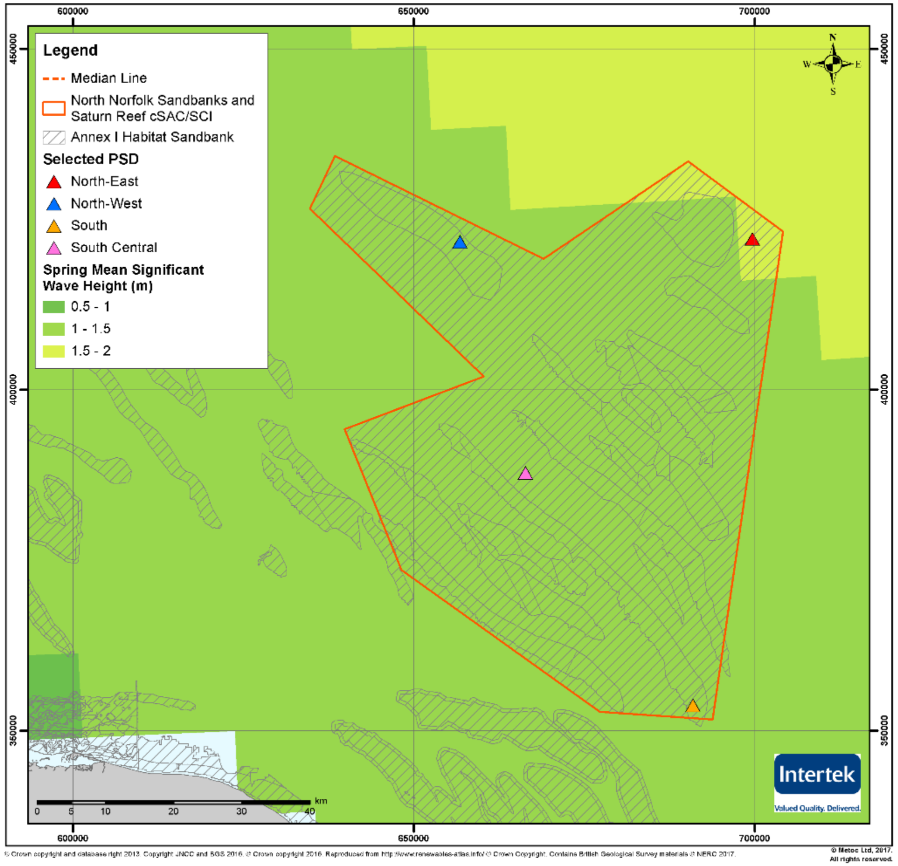


Figure 4: Typical wave height during mean spring tide (from ABPmer Tidal Atlas 2008).

2 Methods

This report is a review of existing literature, publicly available data, and a qualitative evaluation of the impacts of rock dump on Annex I habitats in the NNSSR cSAC/SCI. A wide range of publicly available literature was reviewed and assessed, with key information extracted and discussed accordingly in this report. Our search incorporated industry knowledge, internet search engines, the BEIS Oil and Gas website (specifically for ESs), the MEDIN database and relevant in-house environmental statement references. The key words included sandbanks, mobile sandbanks, rock dump, rock berm, rock design, scour, habitat change and physical processes.

Reports collected were recorded in a collection log after which each source was analysed by an appropriately experienced and qualified member of staff to determine the quality, relevance and application of each reference. Relevant or reviewed references were recorded in an Evidence Log, while those directly referred to in the report are listed in the references. A copy of the evidence log can be found in **Appendix 1 – Evidence Log** and report references can be found in **Section 7 References**.

3 Results and Discussion

This section outlines the results of the literature review and assessment of publicly available data. The rock dump applications, including design theory are discussed first, as the information therein feeds directly into the discussion about sediment characteristics in the NNSSR cSAC/SCI and other mobile sandbank sites. Finally, the implications of rock dump on the Annex I habitat ‘sandbanks slightly covered by seawater all the time’ is discussed.

3.1 Sediment Characteristics

This section outlines the sediment characteristics of the NNSSR cSAC/SCI. The aim of this section is to qualitatively describe the differences in bed conditions and the impact of the differences on both rock berm design and stability. The implications of rock dump on Annex I habitats are discussed in Section 3.3.

Sediment transport occurs as a result of two processes:

1. Suspended load transport. This requires sufficient energy to maintain particulate matter in suspension in the water column, with subsequent transport over large spatial and temporal scales. The main mineral component transported by this mechanism is fine particulate material (clays and silts). In addition, low density material such as organic detritus, and plankton form part of the suspended material in the water column (Robins *et al* 2014). Deposition of fine suspended mineral material occurs in waters where bottom currents are low, for example in depressions in the seabed.
2. Bed load transport. This takes place just above or at the seabed level and responds instantaneously to the local conditions (Robins *et al* 2014). Bed load transports heavier particles, such as the fine and coarse sand observed in the NNSSR cSAC/SCI, just above the bed, which mediates to coastal morphology and sediment supply to beaches and offshore sandbanks.

The end result of both suspended load transport and bottom load transport is a net transfer of material away from high energy environments, where the resultant sediments tend to be coarse in nature, towards low energy environments where fine sediments predominate. Superimposed on this general pattern are local, source dependent, variations. These may be the result of terrestrial inputs or outcropping of differing sediments (e.g. clays, shales or gravel beds)

Data obtained from the British Geological Survey (BGS) and the Centre for Environment, Fisheries and Aquaculture Science (Cefas) reported sediment particle size distribution (PSD) data from 152 sites within the NNSSR cSAC/SCI (Figure 5). Of these, 88% contained between 80 and 100% sand. Three samples, taken from the north-west of the NNSSR cSAC/SCI, included less than 40% sand; however, data does not indicate the size distribution of the remainder.

Both Figures 6 and 7 show a dominance of sand fraction (0.1 to 1mm) material. Figure 5 shows data from five sites on a single 6km transect. One site (SBT05D) differs from the rest in having a markedly high coarse fraction. Fine particles are a minor component at all these sites, suggesting high bottom energy. Figure 6 shows particle size distribution from four sites, superimposed on a combined data set. The generalised dataset (Figure 6) suggests that the particle size distribution is tri-modal, with sands centred around 0.2mm generally being the most important component, followed by smaller but varying proportions of silts and clays centred around 0.01mm, and even fewer large pebbles or small boulders centred around 100mm. It is likely that the presence of significant quantities of fine or coarse material is the result of the underlying geology, rather than variations in near bottom energy.

PSD data for the NNSSR cSAC/SCI show a dominance of sand particles, as would be expected (Figure 7), with fewer than 50 of the 300+ profiles containing sediments of greater than 2mm (the Wentworth scale value for 'gravel'). Figure 5 demonstrates all the Cefas PSD within the NNSSR cSAC/SCI as grey circles. Four profiles (shown by the coloured triangles in Figure5) have been identified and used as examples of the differences in characteristics across the NNSSR cSAC/SCI. These profiles have been selected to show the variation in particle size distributions within the site. To the north-east there is a decrease in the volume of sand and an increase in the number of larger cobbles and boulders shown by the 'spike' of the red line in the section labelled 'boulders and cobbles' (Figure 6). These are likely to be the result of geological features from the Flandrian transgression. This PSD (red triangle, Figure 5) demonstrated the widest range of particle sizes of the four selected profiles. In contrast, the sample taken in the north-west (blue triangle) shows a much higher volume of sand particles, with some larger pebbles and a few bigger boulders/cobbles, but no fine silt. To the south (orange triangle) and south-central (pink triangle), there are a higher number of silt/sand grains with very few larger sand particles, or cobbles and boulders.

3.1.1 Particle Size Distribution across a Sandbank in the NNSSR cSAC/SCI

Figure 6 demonstrates the PSD for five samples taken across one of the Indefatigable sandbanks, also reported as North Norfolk Sandbank 12, located to the north east of the NNSSR cSAC/SCI. These five stations show an example of the changing sediment characteristics across a distance of 6km over a sandbank. The near-shore sample (shown geographically in Figure5), Station SBT05A (yellow star), consists primarily of sand. Conversely, at Station SBT05E (red star), which is on the edge of the eastern side of the bank, equal weight was measured for both sand and cobbles and boulders, and would resemble a coarser substrate. Samples SBT05A and SBT05E are on either side of the sandbank. The central sample, SBT03C (purple star), shows a marginally broader sand composition but is still constrained within the sand range.

Evidence Gaps:

- PSD Spatial Distribution of Samples are generally located around specific assets and are not representative of the wider sandbank feature.
- Existing data sets are not directly comparable due to differences in size bands reported.
- Further statistical analysis of these datasets (e.g. cluster analysis) is required to accurately characterise the sediment particle distribution over the NNSSR cSAC/SCI.

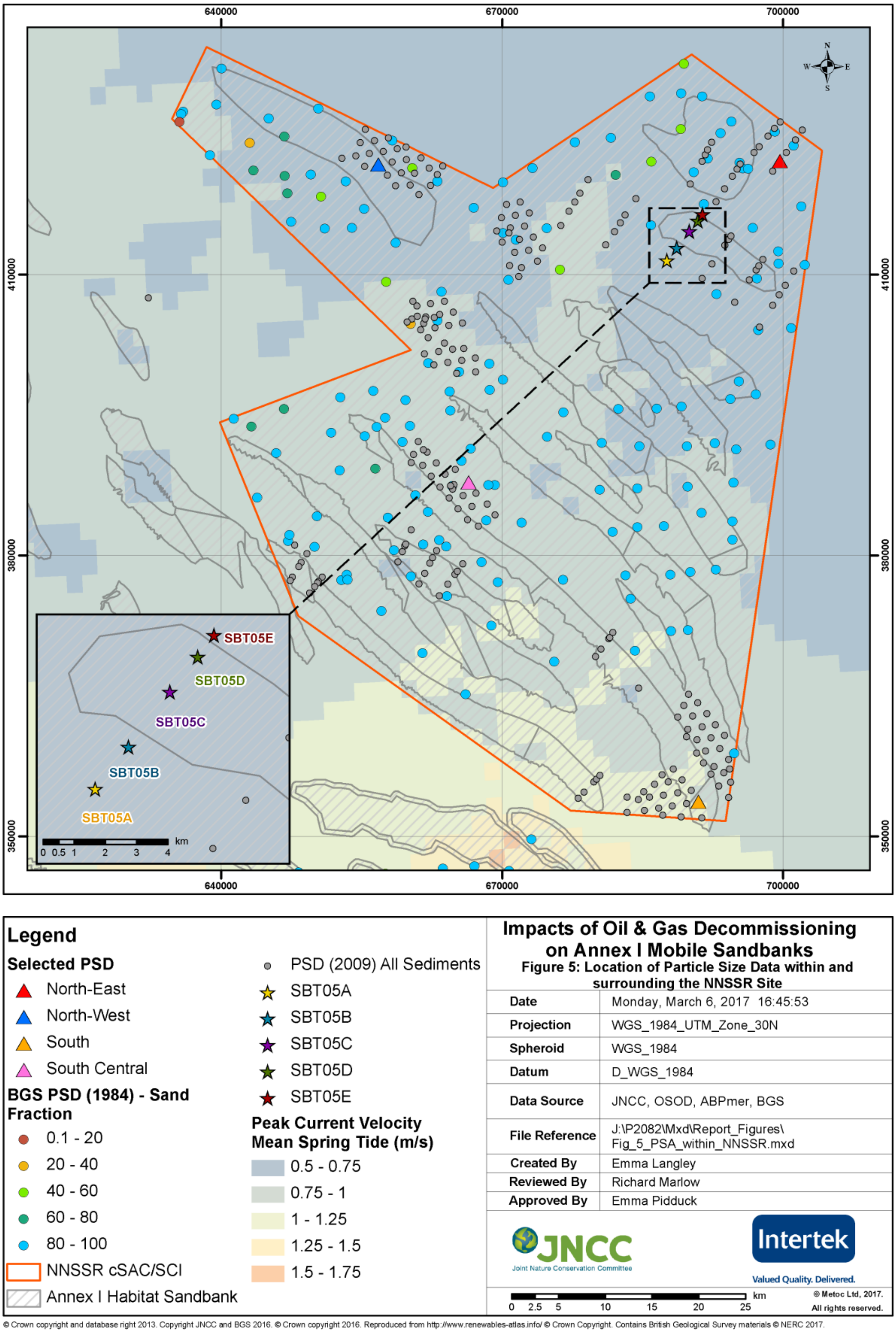


Figure 5: Location of particle size data within and surrounding the NNSSR cSAC/SCI. Background colours represent peak spring current velocities.

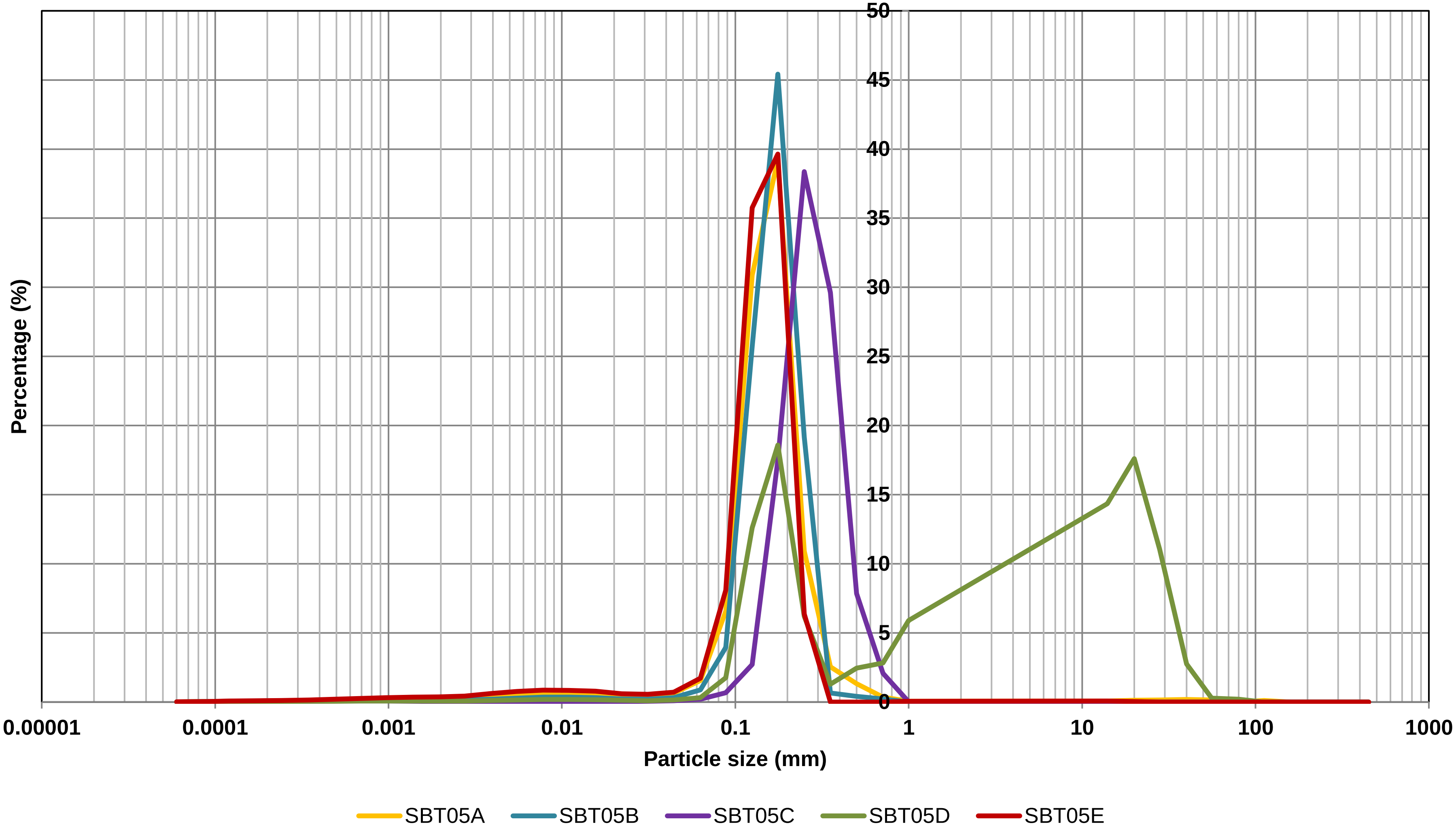


Figure 6: Particle size distributions across one of the Indefatigable sandbanks (see Figure 5 insert).

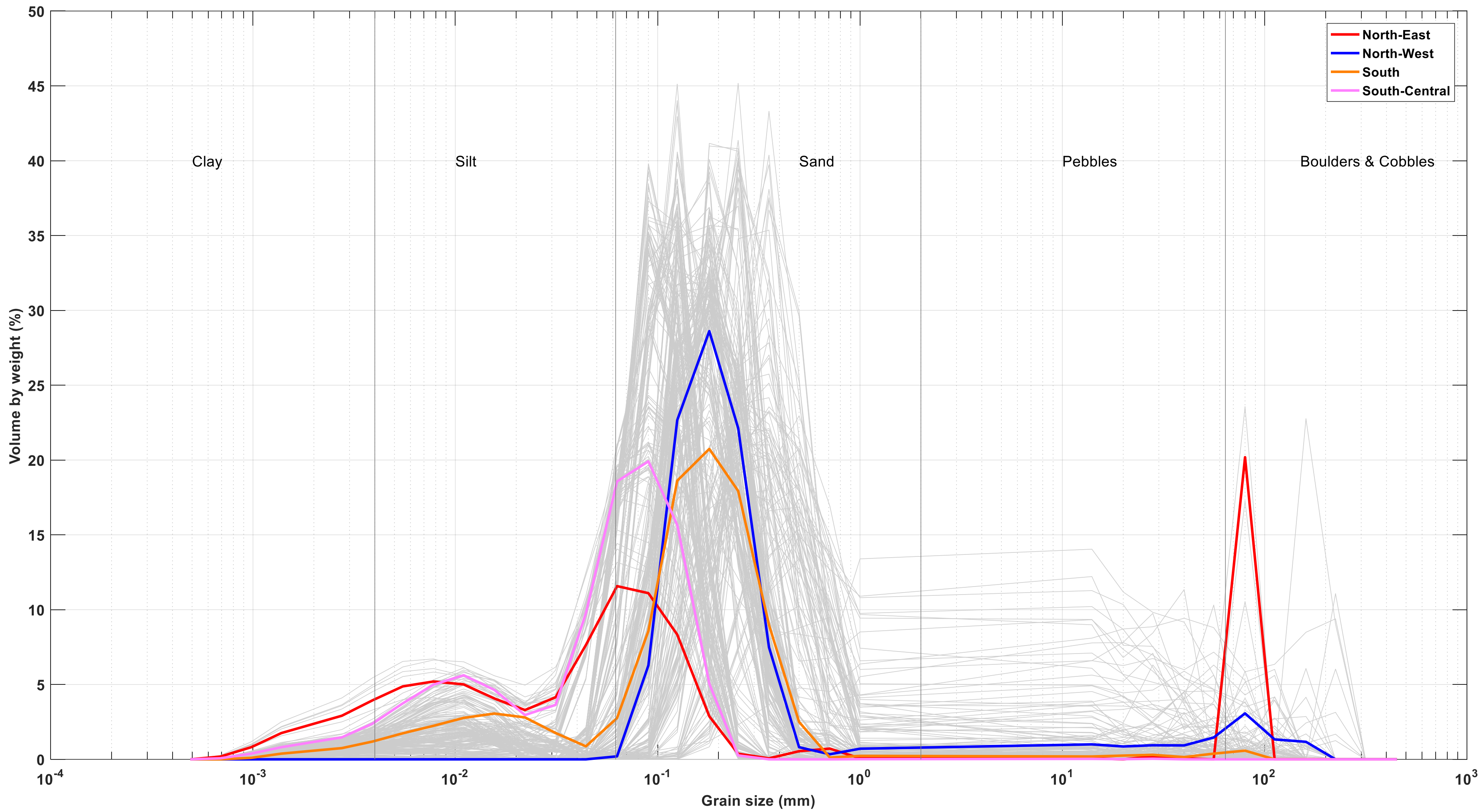


Figure 7: Particle size data obtained from Cefas for the NNSSR cSAC/SCI. Four profiles have been highlighted for comparisons. The corresponding sites have been chosen according to geographic location within the site (see Figure 5 insert).

3.2 Rock Dump Applications

This section outlines the basics of rock dump design; the key controlling parameters; how the design of each of the applications might be achieved; and the relationship to the bed strata, including sand.

As discussed in **Section 1.2**, rock dump can be used as a protection method for un-trenched pipelines (as well as subsea cables), and as a foundation stabilising material for drilling rigs and jack-up barges. Possible implications of not using rock dump include:

- Punch-through: Whereby the spud-cans of the drilling rig/jack-up barge can slowly or suddenly punch through the seabed. Implications would be instability due to uneven distribution of weight, or listing of the rig/barge;
- Hang-up: Whereby the spud-cans of the vessel penetrate through the seabed to a depth that prevents the uniform removal of the four legs. This could lead to instability and possible capsize of the rig/barge;
- Seabed scour around the spud-cans that could lead to listing of the drilling rig/jack-up barge.
- Seabed scour along pipelines that could lead to free-spans, increased scour and subsequent failure.
- Introduction of snagging hazard on the pipeline, either at the unprotected ends or on possible free-spans.

Seabed scour is particularly relevant to mobile sand conditions, where sand may be swept around seabed structures, including pipelines and legs of the rig/barge, leading to instability, possible pipeline free-spans and short-term changes to the local bathymetry.

3.2.1 Rock Berm Design Theory

Rock protection designs for all shapes and functions (i.e. whether for pipeline, foundation stability or scour protection) are based upon the local metocean (meteorological and oceanographic) conditions, including the geophysical conditions on which the rock protection is deployed. Metocean data can be measured *in situ* or derived from satellite data. Relevant factors include, but are not limited to (see glossary in Appendix 3 for full definition of terms):

- significant wave height (H_s (m)) - the larger the significant wave height, the more energy and thus the larger the size of the rock required to have a stable berm;
- number of waves in the considered sea state;
- wave period (T_s);
- water depth on top of structure (h_c (m)) - the shallower the water depth, the greater the required rock size to stabilise the berm;
- near-bed current velocity (u) or depth-average velocity (U);
- bed shear stress (τ_c) or the shear velocity (u_*); and
- shear stress due to waves (τ_w).

The most important factors in the stability of a rock berm during its design life are:

- sieve size (D (m)) or nominal diameter (D_n (m)) of the 'armour stone', or the mass (kg);
- relative buoyancy of the armour stone; and
- slope angle of the sides and ratio to the height/width of the design.

The armour stone is the stone used to protect the structure.

The design theory also depends on the requirement for the berm to be a 'static' berm, where no stones move during the lifetime, or a 'dynamic' berm whereby the stones are allowed to change as the hydrodynamic conditions affect them, until a 'stable' arrangement is reached naturally (Chamizo *et al* 2012). These are applicable to rock dump application for pipeline protection/stabilisation and scour prevention.

For the static design, some scour can be expected around the edges of the rock dump such that the scoured edges of the rock protection form a 'falling apron' (Figure 8), the extent of which must be sufficiently wide that the required rock protection remains stable. This means that the initial diameter or dimensions of the rock dump application must be large enough to accommodate the maximum extent of the falling apron (Den Boon *et al* 2004). See Figure 8 by Froehlich (2009).

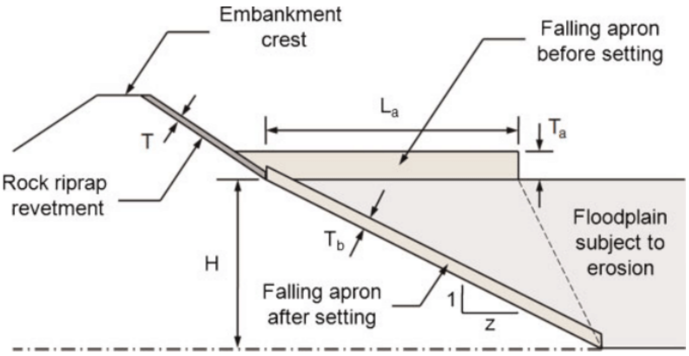


Figure 8: An example application of a 'falling apron' design used in rock dump for river bank stabilisation.

For a dynamic design, the seabed around the base may be allowed to develop a large scour pit which is later filled with rock. This application is only suitable where the stability of the item requiring protection from rock is not required immediately, as it can take a long time for the scour pit to reach maximum size (Den Boon *et al* 2004).

The Critical Shear Methodology

The most commonly used and traditional method to design a berm with hydraulic stability is the Critical Shear Method, as described in detail in the CIRIA Rock Manual (CIRIA 2007). The stability of the seabed sediments is determined by the threshold of motion of the particle and the shear stresses induced on the sediments by wave or current forcing, also known as the 'threshold bed shear stress'.

The armour stone size used in the construction of the rock dump is determined such that the individual rocks are stable during the lifetime of the application, which typically has a return period (recurrence interval) of 100 years. The stability of the rock protection is dependent upon establishing a minimum particle size (or rock size, as the case may be) that will not be subject to near-bed forces and therefore stay in position, taking into consideration the current velocity and wave energy at a particular location. This calculation is undertaken with a given berm design in mind, where the design may be subject to additional constraints (footprint, volume, cost, height, *etc*.). For a stable seabed, the D_{50}[1] of the seabed particles needs to be greater than the D_{50} corresponding to the threshold bed shear stress.

Stability of the rock protection method can also be determined using the critical velocity, instead of shear stress, where velocity data is more readily available. However, it should be

[1] The D_{50} value is the median diameter of the particle size at 50% in the cumulative distribution of particle sizes in the sample.

noted that in the majority of stability calculations for velocity, the near-bed velocity is required and not depth-averaged velocity. Near-bed velocity is harder to achieve and shear stress is more readily calculated from current velocity.

Once the stable rock size has been calculated, a subsequent amplification factor must be applied to take into account the stability of the overall berm, based on a given design. A typical pipeline protective berm, according to CIRIA Rock Manual (2007), has a slope ratio of 1:2.5 with a relatively low construction height (typically 0.6m). Some berms have been designed to 1:3 and 1:4 slope ratio to ensure stability but this increases the overall footprint area and volume of the rock berm, and therefore the cost and an increased potential for environmental effects.

Different rock berm designs are used for differing applications. Figures 9a illustrates a typical rock berm design for the protection of a pipeline, where H_s and T_m are the significant wave height and wave period, u is the current velocity, h is the depth of the water, h_c is the depth of water above the crest of the rock design and d the diameter of the armour stone. Figure 9b shows another rock design with steeper sides, and Figure 9c shows an example of the protection used to stabilise the bed surrounding a slender object, such as a monopile foundation or jack-up leg.

Figure 10 presents the results of parametric study based on Shields method (Thusyanthan *et al* 2013) to determine the stable D_{50} (median rock diameter) under combined wave and current conditions on a flat seabed for a depth-averaged velocity of 0.5m.s^{-1}, a wave period (T_s) of 8s, and significant wave heights (H_s) of between 1m – 12m as shown by the purple lines. The lowest purple line represents 1m significant wave height, while the upper purple line represents a 12m significant wave height. The graph can be used to determine the stable median rock diameter for the armour stone.

This graph can be used as a representative example for the NNSSR cSAC/SCI as the current velocities measured are typically in the region of 0.25 – 1m.s^{-1} (ABPmer Tidal Atlas – see Figure 3). Wave conditions reported in the NNSSR cSAC/SCI demonstrate maximum significant wave heights of 6m, with a more commonly reported value of 1.5-2m (ABPmer Tidal Atlas - see Figure 4).

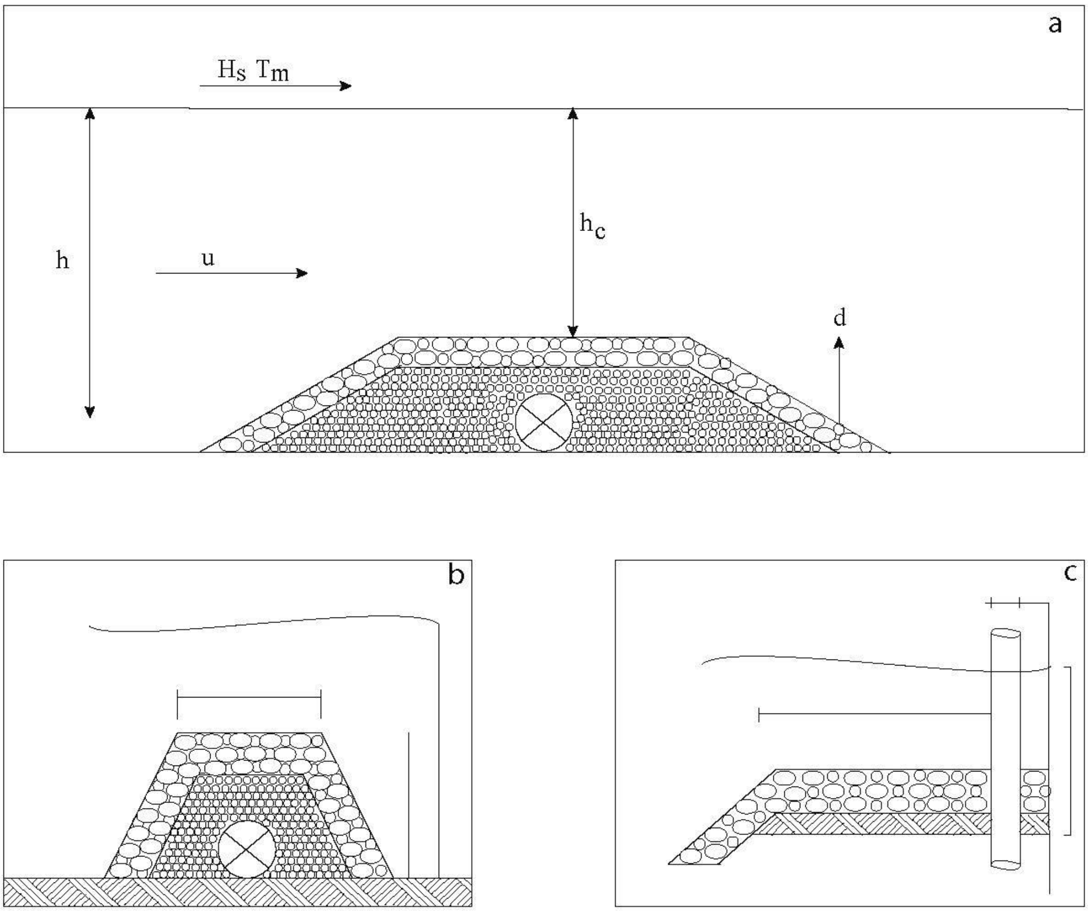


Figure 9: a) An overview of a typical rubble mound or rock protection method used for pipelines, including symbols for key parameters. b) An example of a pipeline protection rock berm. c) An example of a rubble mound used for the stabilisation of slender monopile-type foundations used in subsea infrastructure. Adapted from the CIRIA Rock Manual (2007).

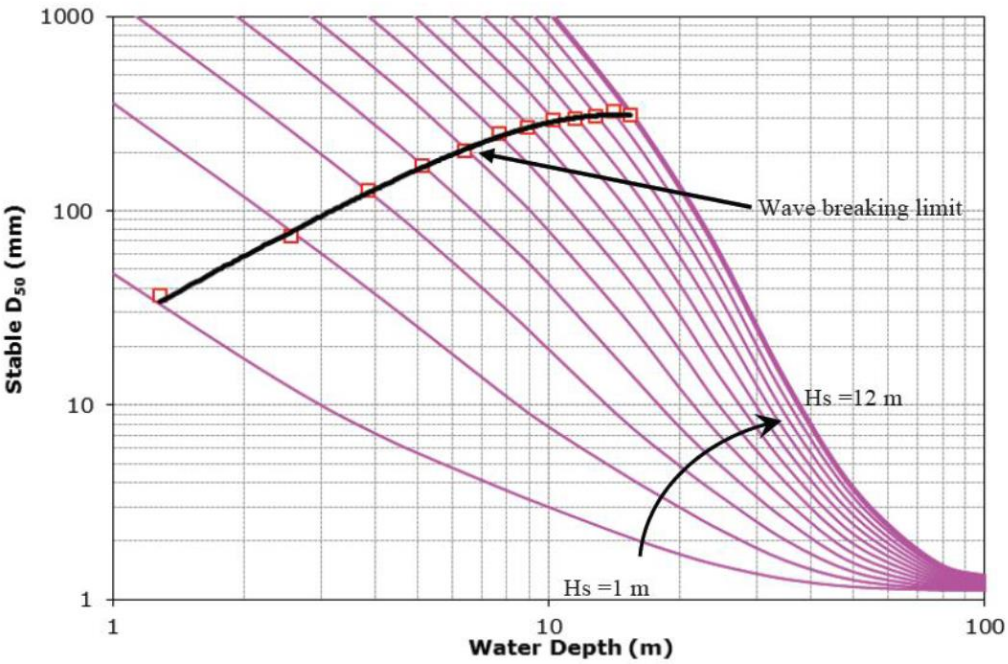


Figure 10: Stable D_{50} particle size required for $U_c = 0.5 m.s^{-1}$, $T_s = 8s$ and $H_s = 1m - 12m$ (from Thusyanthan *et al* 2013).

Table 2 presents the stable D_{50} for two significant wave heights and depths that are representative of the south North Sea. These have been determined using Figure 10, and are therefore compatible with the conditions represented. The significant wave heights used are a typical average value (3m) and a storm event significant wave height (6m). The results of the assessment yield stable particle sizes that decrease with increasing depth, and increase with increasing significant wave height.

Table 2: Stable D_{50} on a flat seabed for two significant wave heights observed in the south North Sea.

Significant Wave Height (m) (max)	20m Water Depth	40m Water Depth	60m Water Depth
3	5mm	1.8mm	1mm
6	18mm	3.5mm	1mm

The calculations presented in Table 2 are based upon a flat seabed where a greater level of critical shear is required to lift a particle. Therefore, a correction or 'amplification' factor must be applied to take into account the slope angle of the berm. Amplification curves are presented in the study by Thusyanthan *et al* (2013) and application of the amplification factor has been applied in Table 3.

Table 3: Minimum rock sizes for a 1:3 slope berm design (theoretical) in the NNSSR cSAC/SCI.

Significant Wave Height (m) (max)	20m Water Depth	40m Water Depth	60m Water Depth
3	25.2mm	4.32mm	2.1mm
6	90mm	8.75mm	2.7mm

3.2.2 Rock Dump on Sand

While the hydrodynamic details can be used to determine a stable application of rock, including the required rock size, the implications of placing rock dump in an area of mobile sand can cause problems during the lifetime of the application. Evidence collected in recent years suggests that rock berms could lose stability due to the following reasons:

- Leeward vortices could damage the downstream slope of the berm (Hinwood & Lipski 2002).
- Excessive bed shear could cause particles to roll away from the rock berm and destabilise the overall structure (Hinwood & Lipski 2002).
- Suction removal of sediment from between and under armour stones could result in sinkage of the rock berm (Sumer *et al* 2001; Dixen *et al* 2008; Nielsen *et al* 2012).

The suction removal of sediment between and under armour stones is only likely where there is little or no sediment supply to replace the removed sediment. This would not be the case with progressive offshore sandwaves, such as those observed in the NNSSR cSAC/SCI, which transport sediment from the nearshore area towards the offshore.

Another commonly reported occurrence is the cyclical coverage of rock protection by migrating sandwaves; this is not a problem for the rock dump application provided that the rock protection does not become unstable. Biological implications are discussed in Section 3.3.

3.2.3 Rock Dump in Mobile Sandbanks

Table 4 presents historic rock dump applications in the southern North Sea, as detailed in the ConocoPhillips Environmental Statement (2015). The cumulative volume presented in this table equates to 59,400 tonnes, of which many details are missing. These rock dump applications were used as a means of stabilisation in the majority of cases, which is likely to have been required due to the highly mobile nature of the NNSSR cSAC/SCI sand.

Limited information about the size of rock used in the rock dump applications is presented; provided only by the author of the report. Examination of the Environmental Statements that were publicly available did not highlight the rock sizes used to further enhance the information in Table 4.

Rock sizes reported in the ConocoPhillips applications of rock dump ranged from 11 - 95mm (ConocoPhillips 2015) and are consistent with the hypothetical calculations provided in Table 3. The Environmental Statement associated with the first Viking Decommissioning Program (VDP1) also discusses the types and sizes of rock used in proposed designs. The proposed design indicates three layers within the rock berm for jack-up stabilisation; the first (on the seabed) is a filter layer comprised of 0.2mm sediment. This particle size is approximately twice the median particle size observed in the NNSSR cSAC/SCI and is designed to prevent sand grains 'winnowing through' gaps in between larger sized rocks. This layer would be installed directly on the seabed and a second layer placed directly on top. The second layer is proposed to have rock sizes of between 1 – 5mm, which is at least one order of magnitude greater than the natural median particle size of the NNSSR cSAC/SCI. This layer is designed to prevent segregation of the sediments during placement. Finally, the third layer (top layer) will comprise particles of 30mm which will cover the other two layers and is designed to withstand storm conditions. This particle size is two orders of magnitude greater than the natural median particle size of the NNSSR cSAC/SCI.

Table 4: Historic rock dump placed during operational life at platforms in the southern North Sea (adapted from ConocoPhillips ES 2015).

Platform / Block	Operator	Date on location	Deposition details
Vanguard QD	ConocoPhillips	February – June 2013	Seabed stabilisation. 8,000 tonnes of rock/gravel. Rock/gravel ranged from 5 – 20cm.
South Valiant TD	ConocoPhillips	April – August 2014	Seabed stabilisation. 30,000 tonnes of rock/gravel. Rock/gravel ranged from 11 – 22mm.
North Valiant 1 PD Platforms	ConocoPhillips	December 2014 – present	Seabed stabilisation to prevent scour. 4,100 tonnes rock/gravel ranging from 11 – 22mm. 6,850 tonnes of rock/gravel ranging from 22 – 95mm.
Block 49/27a	Perenco UK Ltd.	March 2014	3,000 tonnes rock material. No size data.
Block 48/8	Shell UK Ltd.	April 2014	2,200 tonnes of rock material. No size data.
Block 48/19	Shell UK Exploration and Production Ltd.	May 2015	No details available.
Block 49/26	Perenco (gas) Ltd.	July 2014	No details available.
Block 49/27	Perenco UK Ltd.	October 2014	1,350 tonnes of rock material. No size data.
Block 48/7b	Perenco UK Ltd.	November 2014	3,500 tonnes of rock material. No size data.
Block 48/14	Shell UK Ltd.	November 2014	400 tonnes of gravel.

Further to the information in Table 4, ConocoPhillips supplied a proposed rock berm design to be used within the NNSSR cSAC/SCI for jack-up stabilisation, shown in Figure 11 below. The dimensions supplied indicate a rock berm of up to 7,884m^2 with a slope gradient of 1:5. This slope dimension is shallower than the more commonly used 1:3. The height of the rock berm is larger than would be used for pipeline protection as it has to withstand the weight of the rig. For pipeline protection, a typical rock dump height is 0.6 – 1m, depending on the external threats (i.e. fishing activity and shipping activity). The reduced height of the rock dump required for the pipeline protection would also reduce the required surface footprint of the application, compared to that required for rig stabilisation or scour prevention.

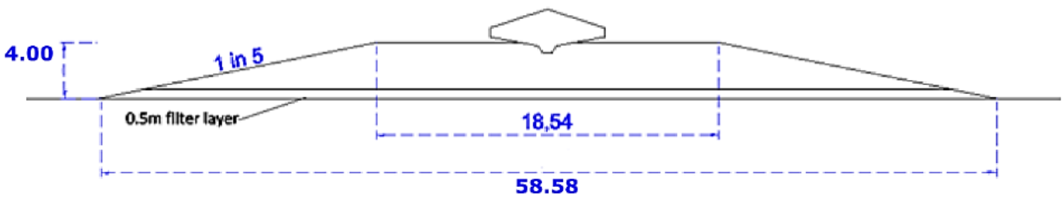


Figure 11: Cross-section of proposed rock placement under each jack-up leg at the Viking HD Platform. *Source: ConocoPhillips Environmental Statement (2015) (Source: Global Maritime (2015).*

Of the decommissioning exercises proposed, completed or under consideration in the UK, to date, it was found that five additional locations had existing or were proposing to use rock dump. Further details are described below:

- **Camelot CA** platform-Block 53/2, located within the Haisborough, Hammond and Winterton cSAC/SCI, was decommissioned during 2011. Rock dump was used to protect the Camelot CA pipeline system which was placed prior to operations in this field. The project undertook pre- and post-decommissioning surveys (in 2012 and 2014) for which the results of the most recent surveys are not publicly available.
- **Welland Field**-Blocks 53/4a, 49/28a and 49/29b, was decommissioned in 2011 and while no additional material was used, it is reported that there is existing rock dump totalling 1,810m^2, which was used in pipeline stabilisation. There is no information regarding the status of the existing rock dump and there is no available close out report detailing how the decommissioning was undertaken.
- **Tristan NW field**-Block 49/29b was decommissioned in 2010 and while no additional material was proposed, 18,410 tonnes of rock dump was left *in situ*. The close out report for Tristan NW field does not provide sufficient detail, such as imagery or coverage statistics, to determine the interaction between existing rock dump and the outlying mobile sandbanks to the NNSSR cSAC/SCI.
- **Indefatigable Field Platforms (Kilo, Lima, Mike and November) and associated Pipelines**-Blocks 49/19 and 49/24 were decommissioned between 2011 and 2013. Six platforms, 26 wells, five pipelines and two hoses were decommissioned. During this decommissioning, it was found that existing rock dump had been hardened using slag, and was left *in situ* wherever possible. No additional rock was introduced during the decommissioning. Instead, mass flow excavation was used to ensure that pipelines were buried to the appropriate depth. It was not reported how much of the existing rock dump was left in place.
- **Brent Remote Flare Structure**-Block 211/29 was decommissioned between 2004 and 2005. The proposed method included application of rock dump to capped ends of pipelines with a rock berm design slope not exceeding 1:3. This is the only industry reported value of a rock berm design in an area of mobile sandbanks. There is no close out report publicly available for this decommissioning exercise and it was not possible to determine the relationship between mobile sandbanks and rock dump.

It has been suggested during discussions with members of the oil and gas industry that the use of rock dump in stabilising the foundations for jack-up rigs depends on the type of rig being used. Lighter ‘utility’ jack-up rigs require more stabilisation in mobile sandbanks, while heavier, larger drilling jack-up rigs do not.

Evidence Gaps:

- Rock Berm Design. Information is not publicly available therefore difficult to compare effects of different designs within similar environments.

- Volumes or coverage (footprint) of rock berms left *in situ* not reported.

3.3 Annex I Habitat Sensitivities to Decommissioning

This section outlines the sensitivities of the Annex I sandbank features found within the NNSSR cSAC/SCI and the potential impacts of rock dump from O&G decommissioning in the area.

3.3.1 Annex I Habitat - Sandbanks slightly covered by water all the time

Subtidal mobile sandbanks are potentially sensitive to dredging and spoil disposal; aggregate extraction; fishing; and oil and gas exploration, development and production (Elliot *et al* 1998).

Biological sensitivities include:
- reduction/increase in species diversity;
- introduction of pollution (transition elements and organo-metals, hydrocarbons and Polycyclic aromatic hydrocarbons (PAH);
- destruction of fauna; and
- changes in community structure.

Hydrological sensitivities include:
- water flow and/or tidal current changes;
- local salinity changes;
- local temperature changes;
- depth characteristics; and
- change in sediment dynamics and supporting processes.

Physical sensitivities include:
- abrasion/disturbance on the surface of the seabed;
- changes in suspended sediment;
- direct loss/changes; and
- reductions in habitat extent.

Evidence suggests that sandbanks are highly vulnerable to direct physical damage and or abrasion. However, sandbanks can be the result of relatively high energy conditions may be flexible to changes caused by storm events or human activities.

3.3.2 Potential effects of rock dump from oil and gas decommissioning on Annex I Habitats ‘Sandbanks slightly covered by water all the time’

For this assessment, 32 approved and six under consideration decommissioning programmes were reviewed in order to understand the commonly identified impacts from rock dump and the alternatives provided. Of these, 20 approved and three under consideration programmes considered the use of rock dump with five approved and one programme considering the use of rock dump in areas of known sandbanks (or within close proximity) including the NNSSR cSAC/SCI and wider area. These programmes were all taken from the North Sea.

Based on the impacts identified from the Environmental Statements (ES), a literature review of the likely impacts of rock dump within the receiving environments and the associated habitat components was undertaken. These are listed here and summarised individually below:

Supporting Physical Processes:
- current and tidal flow disturbance;
- sediment supply disturbance - Suspended sediment dispersion and deposition; and
- increase in scour.

Biological Processes
- changes in biodiversity from new substrate; and

- recoverability of soft bottom communities.

3.3.3 Supporting Physical Processes

Current and tidal flow disturbance
The addition of artificial structures on the seabed has the potential to cause hydrological changes such as changes in water movement associated with tidal streams. Rock dumping has the potential to alter flow speed and direction which in turn may impact the sediment supply/transport to an area due to associated seabed elevation changes (Tillin & Tyler-Walters 2015). Furthermore, alterations to soft bottom sediments can impact current patterns causing scour and changes in sand ripple patterns and sediment grain size (Davis *et al* 1982).

The existing water current and tidal conditions within the NNSSR cSAC/SCI are described as energetic consisting of a variety of current strengths which are strongest on the banks closest to shore, reducing gradationally in strength with increasing distance offshore (Jenkins *et al* 2015).

The ConocoPhillips Phase I Decommissioning Project ES (ConocoPhillips 2015) for the Viking Field (within the NNSSR cSAC/SCI) has identified the potential for morphological change due to the presence of rocks on the seabed in context with current knowledge of seabed dynamics in the NNSSR cSAC/SCI. The recommended option for decommissioning the 10 infield pipelines *in situ* is to place a maximum of 25 tonnes of graded rock over of the pipeline ends, adjacent to the satellite platforms. Following the removal of 5m of pipeline from each of the cut ends, example calculations within the NNSSR cSAC/SCI suggested that the footprint resulting from leaving 10 pipelines and associated supporting material *in situ* was estimated to be 0.306km^2 representing 0.0085% of the area of the NNSSR cSAC/SCI (3,603km^2). Existing stabilisation features (mattresses, grout bags and rock-placement) will be decommissioned *in situ* to minimise the amount of additional rock-placement required. Approximately 125 tonnes of rock (25 tonnes x 5 sites) will be required to provide sufficient cover for all five of the VDP1 gas pipelines and their piggybacked methanol lines (five pipeline ends) and will result in an approximate footprint of 0.0001km^2 (0.000003% of the NNSSR cSAC/SCI) from the addition of rock dump during decommissioning.

Footprint calculations for stabilising rock berms which provide extra support for accommodation work vessel jack up legs within VDP1 have been calculated for four adjoining locations on the seabed i.e. one for each leg. The amount of rock used in this stabilisation is dependent on local bathymetry and sediment structure. Based on a worst-case mass of rock required at five VDP1 locations of 135,500 tonnes, the introduction of rock was calculated to impact 0.035km^2 of the seabed (0.00095% of the NNSSR cSAC/SCI). Combined with the proposed rock placement over the pipeline ends for 10 pipelines (0.0001km^2) the placement of rock berm for the accommodation work vessel (0.0348km^2) will potentially result in a modification of the substrate and habitat type in the local area equivalent to 0.035km^2. ConocoPhillips (2015) concluded that this was not likely to constitute a significant impact as it represents approximately 0.001% of the total area of the NNSSR cSAC/SCI.

To assess the potential for long-term cumulative impacts on sediment dynamics from pipelines and associated support structures, ConocoPhillips commissioned an independent review of pipeline route inspection data at points where pipelines crossed the Swarte Bank. Pipelines had been in place for between 3 and 37 years. Data collected via sidescan sonar identified that no apparent damage to the form and function of the sandbank or surface features such as ripple marks had occurred. ConocoPhillips (2015) concluded, based on the results from this survey, that the presence of supporting structures such as rock dump is unlikely to compromise the integrity of the NNSSR cSAC/SCI through the alteration of seabed morphology (ConocoPhillips 2015). Comparisons were also made to the Scroby Sands Wind Farm located on the Scroby Sands mobile sandbank 2.5km off the coast of Great Yarmouth. This infrastructure is located on a highly mobile environment and has not been shown to influence the overall form and function of the sandbank (Cefas 2006).

Sediment supply disturbance - Suspended sediment dispersion and deposition
Recent decommissioning programs in the vicinity of sandbanks in the southern North Sea include the Camelot Platform and pipelines (2012), Welland (Perenco UK 2010), and Tristan NW Field (Silverstone 2010) and Indefatigable Fields (Shell 2007). The Welland (2010) ES predicted that areas under the influence of strong seabed currents and mobile sediments would be potentially infilled and/or weathered. This is in line with typical seabed undulations from any seabed disturbance resulting from decommissioning activities in areas of mobile sandbanks. However, for the five programmes listed above, the approved decommissioning options were to decommission pipelines *in situ* or remove for disposal rather than use the rock dump option. As no rock dump was used, any predictions based on these reports on effects to sandbanks from rock dump are hypothetical.

An ES undertaken in the Cygnus Field Development Phase I (GDF SUEZ 2009) provide a comparative insight into the potential implications of rock dump on sediment dynamics within shallow ‘sandy mound’ sandbanks during the development phase of a field. The programme was located in UKCS Blocks 44/11a and 44/12a of the Southern North Sea, approximately 159km north-east of the North Norfolk coastline and within the Dogger Bank cSAC/SCI. It reported that at the Cygnus exploration well drilled in 2005, an urgent consent to deposit rock for the purposes of rig stabilisation was required after very heavy weather and significant waves (above 5m, in water depths of 20m) caused scour around the rig legs. The rig was noted to move down 35cm over the period of a day. 950 tonnes of rock (size ranging from 2.5 to 8cm) was positioned arounf two of the jack-up legs. A further 35 tonnes of gravel bags were placed around the starboard leg and 304 tonnes of gravel bags around the port leg over a period of four days. The area impacted by rock dumping was estimated at 300m^2.

A post-drilling seabed clearance survey around the Cygnus exploration well (three months after rock dump was completed) suggested that the rock dump had either been dispersed or covered with a thin layer of sand (GDF SUEZ 2009).

Rig stabilisation was also required during December 2008 whilst drilling the Cygnus appraisal well; also on top of the Dogger Bank sandbank in water depths of less than 20m. 900 tonnes of material was positioned around the three jack-up legs. A remotely operated underwater vehicle (ROV) survey at the end of the campaign identified no areas of rock within 100m of the site, i.e. it had been covered by sand (GDF SUEZ 2009).

Evidence from this ES show that rock dump in soft sediment areas have the potential to be buried naturally by sediment suggesting little or no impacts to sediment dispersion and deposition. Further conclusions are not able to be drawn due to limited data.

Increase in scour
Scour is the removal of granular seabed material around coastal structures by hydrodynamic forces which can directly impact the extent and topography of existing habitats. Rock dump is a method used to reduce the scour around an artificial structure on the seabed to increase its stabilisation (Langhamer 2012). However, rock dump left on the seabed following decommissioning has the potential to cause scour in itself and modify sandbank topography.

The placement of artificial structures creates the potential for scour pits to form around the base of the structure. Examples of this have been identified in the North Hoyle offshore windfarm where scour pits up to 6m in depth with hole diameters of 24-40m form around monopile foundations. Evidence from swathe bathymetry surveys has suggested that changes to ambient soft sediment conditions around monopiles could occur within 6 to 10 diameters of the structure, to a depth of 1.4m (i.e. for a 5m monopole, scour could occur up to between 30 and 50m). Monitoring surveys were undertaken at six monthly intervals for three years after construction was completed. Surveys showed that due to local sedimentary conditions the maximum scour depth recorded was 0.5m although the overall dimensions of the scour holes were unclear. Rock scour protection was placed around the exposed cables at the J-tubes at the base of the monopile between July and October 2004. To date, no long-term scour is developing at the North Hoyle Offshore Wind Farm. No environmental implications to the regional sediment transport regime within the North Hoyle site were identified as no distinct scour pits had developed. Placement of rock around the J-tubes generally remained *in situ* with potential movement occurring at only three locations (OSPAR 2008).

The effects of scour on habitat loss within the NNSSR cSAC/SCI will be dependent on existing seabed conditions such as depth, current speed, wave propagation, sediment type and the presence of stabilising fauna and or flora. Sandbanks within the NNSSR cSAC/SCI are described as an energetic environment (Jenkins *et al* 2015); scour and sediment deposition is a continual process with the potential to reduce the height of sandbank areas.

Previous areas of scour have been identified on the lee side of oil and gas structures and wrecks during 2013 geophysical surveys within VDP1 area with similar occurrences potentially resulting from the introduction of rock structures. The areas of scour identified were minimal with the majority of pipelines and associated materials reported to be still buried (ConocoPhillips 2015).

Evidence Gaps:

- Quantification and determination of significant effects within protected sites. What footprint of rock dump within a protected site would be deemed a ‘significant impact’?

- The formal habitat classification of sandbanks after rock dump has the capacity to change. There is currently no clear information in the public domain related to sandbank habitat and changes from rock dump. Guidance notes to industry (DECC 2011a) state that “*Pre- and post-environmental surveys will normally be required for all decommissioning programmes*”. Current close out reports for decommissioning programmes do provide an overview of post decommissioning environmental surveys especially in relation to sediment contamination. However, further publicly available data (such as monitoring surveys) of long-term physical and biological impacts to sensitive habitats would be beneficial in predicting any changes to supporting physical processes.

- Scour around rock berm is not currently required to be modelled/monitored therefore habitat effects from rock installation are not captured and/or publicly available.

3.3.4 Biological Processes

Changes in biodiversity from sediment composition
Changes in sediment composition from anthropogenic activities are reported in literature (Gill 2005; Seiderer & Newell 1999). Spatial heterogeneity influences important ecosystem features including population structures and community composition. Major disturbance events have the potential to affect the structure and function of ecological communities

(Barnes & Hughes 2009). Evidence suggests that greater habitat complexity and heterogeneity facilitate higher species diversity (Gray 2002; Barnes & Hughes 2009).

The introduction of hard substrate to soft bottom communities has the potential to act as an artificial reef and support the growth of reef associated species which, in the long term, may result in a localised change to the benthic communities associated with the Annex I feature for which the NNSSR cSAC/SCI has been protected. Research into the ecological impacts of offshore windfarms can provide useful insights into the indirect impacts of changing the complexity of the habitat. A windfarm in the Dutch coastal zone in soft bottom communities concluded that no major differences in community composition, densities, biomass and diversity were recorded on the sandy sediment between monopole structures a few months after their construction indicating no clear short term effects. However, on the structures themselves 33 different species were observed and on the scour protection rock 11-17 hard substratum benthos species were detected. This was identified as a significant increase to the biodiversity of the area (Lindeboom *et al* 2011). Other studies into macrobenthos around offshore turbines on Thornton sandbank (Belgium North Sea) identified (through monitoring) that the soft sediment macrobenthic community densities at distances of 1m and 7m from the scour protection system around the turbines were in close correlation to the presence of hard substrate epifauna such as juvenile starfish, brittlestars and hydrozoans as well as tube building amphipods. An increase was also noted in the generally rare soft sediment macrofauna suggesting the creation of a microhabitat in the vicinity of scour protection influencing the macrofaunal community. A succession was observed from a species poor, homogenous sandbank to a heterogeneous, highly diverse area linked to the Thornton bank windfarm (Coates *et al* 2011).

Further studies (although limited) into the effects of artificial structures on adjacent soft sediments have provided contrasting results. Changes in localised community structure as a result of changes in sediment texture have previously been identified by Ambrose and Anderson (1990). Results showed reduced densities of some taxa near artificial structures which may have either resulted from increased predation as reef-associated fish move over sand to feed or changes in localised sediment composition creating a less suitable habitat for certain species. In contrast to this, Davis *et al* (1982) identified no measureable decrease in adjacent infauna densities at a distance of 4m from artificial structures over the two period since their introduction (Danovaro *et al* 2002).

The type of substrate used in rock dump may influence the magnitude of change to the existing biodiversity. As previously discussed, hard substrate from boulders have the potential to support a higher biodiversity and species abundance than soft bottom substrates. 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).

A survey of NNSSR cSAC/SCI in 2013 concluded that 11 different EUNIS biotope classifications are present through the cSAC/SCI. Biotopes present on the sandbanks generally matched either A5.233- *Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand or A5.231 or Infralittoral mobile clean sand with sparse fauna (Jenkins *et al* 2015) under the EUNIS Classification. Monitoring surveys from windfarm projects have identified potential biotope changes within 7m of scour protection in sandbanks (Coates *et al* 2011). There is therefore a potential for a change to the existing sandbank biotope of 'infralittoral mobile clean sand with sparse fauna' if rock dumping occurs directly on/or within the vicinity of a sandbank.

The introduction of rock into an environment dominated by sand such as the NNSSR cSAC/SCI will inevitably support the settlement of non-local hard bottom fauna that may not be representative of the features for which the MPA has been designated. Changes in the structure of the local sand communities in the immediate vicinity of such ´artificial reef` could be expected. The existing submarine pipelines and/or cables themselves if not buried/covered along the seafloor will provide a solid substrate for a variety of species which may give rise to a habitat change within that footprint, regardless of the addition of rocks during decommissioning triggering another change to the NNSSR cSAC/SCI. Previous studies have shown the larvae of sessile encrusting organisms (encrusting corals, sponges, and anemones) have been observed settling on and colonising cable surfaces (Meißner 2006). Evidence suggests that effects on the local fauna in soft sediment areas will in most cases be very localised but long-term.

It is impossible to predict the overall changes in biotope from rock dump as changes would be site specific, depend on water depth and existing features such as sediment composition, level of disturbance and current and tidal regimes. Similar impacts to those identified at Thornton bank may occur within the NNSSR cSAC/SCI including the potential shift from the existing ‘infralittoral mobile clean sand with sparse fauna’ present on the North Norfolk Sandbanks to more diverse biotopes and/or the creation of microhabitats in the immediate vicinity of rock. Shifts in biotopes have the potential to affect the Annex I sandbank feature. However, there is currently little information currently available documenting these changes within sandbanks as a result of rock dump.

3.3.5 Recoverability of soft bottom communities

In terms of the recovery of the soft bottom communities following disturbance, studies (Dernie *et al* 2002; Newell *et al* 1998); have shown that initial recolonisation takes place rapidly following a disturbance event with certain species returning almost immediately to the disturbed site.

The time taken for the seabed to recover from disturbance is dependent on a number of characteristics including the nature of the seabed, the community types present, the duration and footprint of the proposed activity and the degree of disturbance already experienced at the site (BERR 2008). Previous studies such as Dernie *et al* (2002) have shown that in shallow water and estuarine environments where disturbance is more frequent and opportunistic species are more likely to dominate the community structure, recovery occurs rapidly. In deeper undisturbed areas, the recovery to a more stable community could take many years. Rates of recovery of invertebrate communities appear to be associated with the rate of recovery of the seabed sediment characteristics (e.g. particle size).

Experiments undertaken to record recovery at different intensities of physical disturbance from digging on soft sediment communities off the south east coast of Anglesey (not with a sandbank feature) revealed that when sediment was removed to a depth of 10cm, recovery of the faunal communities occurred within 64 days of the disturbance. However, when sediment was removed to a depth of 20cm, recovery was not complete until after 107 days but had occurred within 208 days of the disturbance. This suggests that recovery from more intense disturbance may take soft sediment communities twice as long to recover in comparison than a less intense disturbance. The higher intensity disturbance did not however have a significantly greater effect on the community than was found in the less intense disturbance (BERR 2008; Dernie *et al* 2002). Furthermore, the recolonisation rates following dredging activities on various habitats including freshwater mud and sand-gravels show variations in recovery times of 12 years and >7 years respectively (BERR 2008).

The physical disturbance to the seabed resulting from the introduction of rock dump to soft sediment communities would be extremely localised with sandy soft-bottom communities able to recover quicker following this minor disturbance in comparison to the complete removal of sediment as described in Dernie *et al* (2002). ConocoPhillips (2015) estimates that the proposed rock placement for the 10 pipeline ends and for the stabilisation of the accommodation work vessel within VDP1 will result in a modification of the existing substrate and habitat type in the local area ($0.035km^2$). With the area of the NNSSR cSAC/SCI potentially affected by these activities so low (approximately 0.001%), the likelihood of a significant impact to the existing Annex I 'sandbanks slightly covered by water all the time' is considered low by ConocoPhilips (ConocoPhillips 2015).

Small-scale rock-placement activities from Oil and Gas operators within the NNSSR cSAC/SCI have the potential to cause cumulative impacts. These must also be considered when identifying the overall change to the existing Annex I sandbank feature within the NNSSR cSAC/SCI.

Evidence Gaps:

- The formal habitat classification of sandbanks after rock dump has the capacity to change. There is currently no clear information in the public domain related to sandbank habitat and changes from rock dump. Guidance notes to industry (DECC 2011a) state that "*Pre- and post-environmental surveys will normally be required for all decommissioning programmes*". Current close out reports for decommissioning programmes do provide an overview of post decommissioning environmental surveys especially in relation to sediment contamination. Further publicly available data (such as monitoring surveys) of ***long-term*** physical and biological impacts to sensitive habitats would be beneficial in predicting any changes to biological processes and existing biotopes.

- The implications of localised habitat changes to the wider associated habitats and ecosystem is not currently considered.

- There is currently not enough information to determine the cumulative effects of small-scale rock placement within the NNSSR cSAC/SCI.

4 Recommendations

There are a number of evidence gaps which have been identified above regarding the impacts of rock dump on Annex I sandbanks slightly covered by water all the time. The following section lists the recommendations which may improve knowledge regarding any subsequent changes to supporting physical processes and biological communities.

Monitoring surveys
Monitoring surveys post rock dump in sensitive areas have the potential to give valuable insights in to the integrity of the existing environment post decommissioning. Current close out reports from Oil and Gas decommissioning programmes occur within four months of the completion of offshore work including debris clearance and post-decommissioning surveys. Information included within close-out reports includes results of post-decommissioning environmental sampling including any immediate consequences of the decommissioning activity. A strategy for long term monitoring is required as part of the decommissioning plan. This strategy can be modified as a result of data obtained, for example, where evidence shows no detectable changes (DECC 2011b). Tailoring future environmental monitoring surveys, for instance using cameras to assess the seabed, may provide a more accurate insight to any changes in Annex I features (extent, height and biodiversity), in this case sandbanks which are slightly covered by seawater all the time.

Publicly available data
A consistent evidence gap throughout this report is the lack of publicly available data. Consulting with industry to identify studies that are not publicly available, but could be used to inform this assessment may aid with accurately predicting the impacts of rock dump on sensitive habitats.

In order to provide clear information in the public domain related to sandbank habitat and changes from rock dump, a recommendation would be to publicise more widely the requirements for input to MEDIN and Crown Estate Marine Data Exchange potentially making it a requirement of the licence conditions to publish information.

Long term impact data
At present data resulting from post-decommissioning surveys is largely restricted to that in close out reports. This has resulted in a significant evidence gap as long term impacts of rock dumping cannot be reliably determined. This situation is expected to improve as long term post decommissioning survey results become publicly available. It is therefore recommended that research into the impacts of rock dump within the NNSSR cSAC/SCI is revisited in a few years once further close out and monitoring reports (where necessary) are available. Until this information is available, the JNCC should continue with a precautionary approach to the impacts of rock dump within the NNSSR cSAC/SCI.

Modelling
The effects of scour have been identified as site specific, dependent on existing conditions (depth, current speed, wave propagation). In order to fully assess the impacts of scour and changes in sandbank topography in the NNSSR cSAC/SCI, numerical modelling may be undertaken to predict the impacts to the existing extents of sandbanks from the introduction of rock dump. Modelling would provide information on the potential movement of sediment across the sandbank and how rock dump may influence the existing habitat.

5 Conclusions

The primary conclusion of the work undertaken is that there is insufficient information to quantify or qualify the implications of rock dump in the NNSSR cSAC/SCI from a physical and biological perspective. It is not possible to quantify or qualify the movement of sandbanks around or over existing or applied rock dump. Theoretically, the mobile sandbanks may cyclically cover applied rock dump and there is the potential for scour to be induced if an appropriate design is not chosen. Without review of rock berm design, monitoring studies and numerical modelling of such behaviour, the short-term and long-term implications of both theoretical behaviours are difficult to determine. Sandbanks within the NNSSR cSAC/SCI are dynamic environments which naturally fluctuate in extent and height.

Similarly, beyond the ‘direct’ impacts of rock dump on biological aspects of Annex I habitats, such as smothering and obstruction, it is not possible to quantify or qualify the indirect impact of rock dump beyond that of a theoretical description.

The effects of decommissioning methods of oil and gas infrastructure have the potential to delay or even hamper the achievement of the conservation objectives of protected features designated under the Habitats directive (92/43/EEC) and the integrity of the designated site. The appropriate authority must ensure that the necessary surveillance is carried out on an on-going basis to provide evidence to establish the effects to the Annex I habitats and ensure that new operations involving rock dump are carefully considered within the consenting process.

Table 5 outlines the current evidence gaps established during this study, as well as the associated key points, impacts, requirements and recommendations.

Table 5: Evidence gaps identified during the study.

Evidence Gaps	Key Points	Impacts	Requirements	Recommendations
PSD Spatial Distribution of Samples	Sample locations are generally located around specific assets and are not representative of the wider sandbank feature. Existing data sets are not directly comparable due to differences in size bands reported. Further statistical analysis of these datasets (e.g. cluster analysis) is required to accurately characterise the sediment particle distribution over the NNSSR cSAC/SCI.	• Penetration/disturbance of substratum below the surface of the seabed; • Changes in suspending sediment; • Habitat structure changes; • Siltation rate changes; and • Direct physical loss/change.	Monitoring Tool	Sample location plan approval prior to survey to provide suitable data to understand baseline conditions. Further statistical analysis of these datasets (e.g. cluster analysis) is required to accurately characterise the sediment particle distribution over the NNSSR cSAC/SCI.
Post Rock Dump/ Decommissioning Surveys	Scour around rock berm is not required to be modelled therefore habitat effects from installation are not captured and/or publicly available.	Potentially all impacts listed above	Monitoring	Provide guidance for habitat assessment and modelling standards. Consult industry to identify if any other studies are available but not yet made public.
Rock Berm Design	Information is not publicly available therefore difficult to compare effects of different designs within similar environments.	• Penetration/disturbance of substratum below the surface of the seabed; • Changes in suspending sediment; • Habitat structure changes;	Evaluation	Request information from operators where possible and review different rock berm designs to better understand the potential effects to different seabed habitats.

Evidence Gaps	Key Points	Impacts	Requirements	Recommendations
	Volumes or coverage (footprint) of rock berms left *in situ* not reported.	• Siltation rate changes; and • Direct physical loss/change.		
Quantification and determination of significant effects within protected sites	No regulator guidance on percentage of site considered to create habitat change/significant impact. Limited information addressing cumulative impacts from small-scale rock dump placement.	• Habitat structure changes; • Siltation rate changes; and • Direct physical loss/change.	Quantitative Assessment	Guidance required to enable cumulative effects within a protected area to be established. Numerical modelling required to predict the impacts to the existing extents of sandbanks.
No clear information in the public domain related to sandbank habitat and changes from rock dump	Enable assessment of the extent of any habitat changes from rock dumping.	• Habitat structure changes; • Siltation rate changes; and • Direct physical loss/change.	Evaluation	Publicise more widely the requirements for input to MEDIN and Crown Estate Marine Data Exchange. Make it a requirement of the licence conditions to publish information. Consider requesting post decommissioning surveys.
Formal habitat classification of sandbanks - Rock dump has the capacity to change the habitat classification.	The introduction of different substrates to soft sediments can change the habitat type and faunal populations. This will provide a different baseline for further development or decommissioning operations within the same area.	• Habitat structure changes; • Siltation rate changes; and • Direct physical loss/change.	Monitor, gather evidence and Evaluate	Review pre- and post-installation/decommissioning survey and monitoring reports to identify habitat and faunal changes.

Evidence Gaps	Key Points	Impacts	Requirements	Recommendations
The implications of localised habitat changes to the wider associated habitats and ecosystem is not currently considered.	Habitat change and scour may be localised or have wider effects on the associated Annex I habitats: • Estuaries; • Mudflats and sandflats not covered by seawater at low tide; • Coastal Lagoons; • Large shallow inlets and bays	Potentially all impacts listed above	Survey, monitor, gather evidence and evaluate	Review potential for and extent of change over wider areas.

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Appendix 1: Evidence Log

Ref	Evidence	Evidence Date	Source	Type	Relevance	Quality	Reviewer
1	North Sea and English Channel Sediment Particle Size Analysis	2009 - 2011	CEFAS Data Hub	Data	High	High	Emma Pidduck
2	Benthos Sampling Data - Biotopes	2004 - 2007	CEFAS Data Hub	Data	High	High	Emma Pidduck
2a	Benthos Sampling Data - North Sea Sandbanks Biomass Data	2006	CEFAS Data Hub	Data			Robyn Jones
2b	Benthos Sampling Data - North Sea Meiofauna Data	2006	CEFAS Data Hub	Data			Robyn Jones
2c	Benthos Sampling Data - North Sea Gravel Abundance Data	2006	CEFAS Data Hub	Data			Robyn Jones
2d	Benthos Sampling Data - North Sea Sandbanks Abundance Data	2006	CEFAS Data Hub	Data			Robyn Jones
2e	Benthos Sampling Data - North Sea Gravel Biomass Data	2006	CEFAS Data Hub	Data			Robyn Jones
2f	Benthos Sampling Data - North Sea Station Data	2006	CEFAS Data Hub	Data	High	High	Emma Pidduck
2g	Benthos Sampling Data - North Sea Cruise Report	2006	CEFAS Data Hub	Report	Medium	High	Emma Pidduck
3	MEFEPO North Sea Atlas	2009	MEFEPO Website - University of Liverpool	Report	Low	Medium	Emma Pidduck
4	OGP Options for Decommissioning Subsea Bundles	2014	International Associated of Oil & Gas Producers	Report	High	High	Emma Pidduck
5	North Sea and English Channel Sediment Profiling Image Analysis	2010	CEFAS Data Hub	Data	High	High	Emma Pidduck
6	North Sea and English Channel Sediment Profiling Image Analysis	2009	CEFAS Data Hub	Data	Low	High	Emma Pidduck
7	Offshore Oil & Decommissioning - ABB	2015	ABB	Report	Medium	High	Emma Pidduck
8	The Environmental Assessment of Southern North Sea Pipeline Decommissioning	2001	Centre for Environmental Risk	Report	High	Medium	Emma Pidduck
9	Environmental Performance Review	2012	Centrica Energy		Irrelevant	N/A	Emma Pidduck

Ref	Evidence	Evidence Date	Source	Type	Relevance	Quality	Reviewer
10	Common Standards Monitoring Guidance for Inshore Sublittoral Sediments Habitats	2004	JNCC	Report	Medium	Medium	Robyn Jones
11	Design of marine structures	2007	CIRIA	Book Chapter	High	Medium	Emma Pidduck
12	Fife, Fergus, Flora and Angus Fields Decommissioning Programmes Close-Out Report	2014	HESS	Report	Medium	Medium	Emma Pidduck
13	International rules on decommissioning of offshore installations: some observations	2003	Hamzah Marine Policy	Scientific Article	Low	High	Emma Pidduck
14	Managing environmental and social risks in international oil and gas projects: Perspectives on compliance	2010	Wagner & Armstrong	Scientific Article	Low	High	Emma Pidduck
15	Janice, James and Affleck Decommissioning Programmes	2016	Maersk Oil	Report	Low	Low	Emma Pidduck
16	Offshore Special Area of Conservation: North Norfolk Sandbanks and Saturn Reef	2012	JNCC	Report	High	Medium	Emma Pidduck
17	Cable Installation Study for DOWEC	2001	Van Oord ACZ	Report	Medium	High	Emma Pidduck
18	Decommissioning Financial Planning & Analysis	2012	Co-ordinating Committee for Geoscience Programmes in East and Southeast Asia (CCOP)	Presentation	Medium	Medium	Emma Pidduck
19	Stability of Rock Berm under Wave and Current Loading	2013	Proceedings of the Twenty-third International Offshore and Polar Engineering, by the International Society of Offshore and Polar Engineers (ISOPE)	Scientific Article	High	High	Emma Pidduck
20	Decommissioning in the North Sea	2014	ARUP for Decom North Sea and Scottish Enterprise	Report	High	High	Emma Pidduck
21	*Sabellaria spinulosa*	2010	OSPAR Commission Quality Status Report	Report	High	High	Robyn Jones
22	*Sabellaria spinulosa* - Definition of Reef	2007	JNCC	Report	High	High	Robyn Jones

Ref	Evidence	Evidence Date	Source	Type	Relevance	Quality	Reviewer
23	UK Biodiversity Action Plan Priority Habitat Descriptions	2008/2011/2016	JNCC	Report	High	Medium	Emma Pidduck
24	Assessing the sensitivity of *Sabellaria spinulosa* reef biotopes to pressures associated with marine activities	2014	JNCC	Report	Medium	High	Robyn Jones
25	Biogenic reefs	1998	Holt *et al*. SAMS	Report	Medium	Medium	Robyn Jones
26	SNS Phase 1 Decommissioning Project	2015	ConocoPhillips	Report	Medium	Medium	Robyn Jones
27	Scour and Erosion	2014	ICSE	Book Chapter	Medium	High	Emma Pidduck
28	Effect of sediment supply on suction scour under a rock berm	2014	ICSE Scour and Erosion Book	Book Chapter	High	High	Emma Pidduck
29	Stability of Rock Berms in Liquefied Soil	2014	Advanced Series on Ocean Engineering - Liquefaction Around Marine Structures Volume 39	Book Chapter	High	High	Emma Pidduck
30	UK Biodiversity Action Plan Priority Habitat Descriptions - *Sabellaria*	2016	JNCC	Report	High	High	Robyn Jones
31	*Sabellaria spinulosa* reef: Ecology and Ecosystem Services	2013	The Crown Estate, Pearce *et al*.	Report	High	High	Robyn Jones
32	*Sabellaria spinulosa* reef: a scoring system for evaluating reefiness in the context of the Habitats Directive	2006	Running Head: *Sabellaria spinulosa:* Scoring Reefiness	Report	High	High	Robyn Jones
33	Environmental Impact Assessment of a scrap tyre artificial reef	2002	Collins *et al.* ICES Journal of Marine Science	Scientific Article	Medium	High	Robyn Jones
34	Interpretation Manual of European Union Habitats	2013	European Commission	Report	Medium	High	Robyn Jones
35	Intertidal sand and mudflats and subtidal mobile sandbanks	1998	Institute of Estuarine and Coastal Studies	Report	High	Medium	Robyn Jones
36	The origin, classification and modelling of sandbanks and ridges	1999	Continental Shelf Research	Scientific Article	High	High	Robyn Jones
37	JNCC Marine Habitats GIS Version 3: its structure and content. British Geological Survey Commissioned Report, CR/01/238	2001	British Geological Survey	Report	Medium	High	Robyn Jones

Ref	Evidence	Evidence Date	Source	Type	Relevance	Quality	Reviewer
38	Tidal asymmetry and residual circulation over linear sandbanks and their implication on sediment transport: A process-orientated numerical study	2007	Sanay *et al.* Journal of Geophysical Research	Scientific Article	Medium	High	Robyn Jones
39	Water and sediment movement in the vicinity of linear sandbanks: the Norfolk Banks, southern North Sea	1995	Collins *et al.* Marine Geology	Scientific Article	Medium	High	Robyn Jones
40	UK Biodiversity Action Plan; Priority Habitat Descriptions	2008	Maddock. JNCC	Report	Medium	Medium	Robyn Jones
41	*Sabellaria spinulosa* reef in The Wash and North Norfolk Coast cSAC and its approaches: Part III, Summary of knowledge, recommended monitoring strategies and outstanding research requirements	2003	Foster-Smith & Hendrick. English Nature Reports	Scientific Article	Medium	High	Robyn Jones
42	*Sabellaria spinulosa* reef in The Wash and North Norfolk Coast cSAC and its approaches: Part I, mapping techniques and ecological assessment.	2001	Foster-Smith & Hendrick. English Nature Reports	Scientific Article	Medium	High	Robyn Jones
43	Impacts of tidal-stream arrays in relation to the natural variability of sedimentary processes	2014	Robins *et al*. Renewable energy	Scientific Article	Medium	High	Robyn Jones
44	Sizewell-Dunwich Banks Field Study	1983	Lees. Institute of Oceanographic Sciences	Report	Medium	Medium	Robyn Jones
45	Revised list of definitions of pressures and benchmarks for sensitivity assessment	2015	Tillin & Tyler-Walters. The Marine Biological Association	Report	High	Medium	Robyn Jones
46	Man-made structures on marine sediments: Effects on adjacent benthic communities	1982	Davis *et al*. Marine Biology	Scientific Article	High	High	Robyn Jones
47	Marine Habitat Reviews: A summary of ecological requirements and sensitivity characteristics for the conservation and management of marine SACs. Joint Nature Conservation Committee, Peterborough. (UK Marine SACs Project report)	2000	Jones *et al.* JNCC	Report	High	High	Robyn Jones
48	Cygnus Field Development Phase I-Environmental Statement	2009	GDF-Suez E&P UK Ltd	Report	High	Medium	Robyn Jones

Ref	Evidence	Evidence Date	Source	Type	Relevance	Quality	Reviewer
49	Scroby Sands Offshore Wind Farm- Coastal Processes Monitoring	2006	Cefas	Report	Medium	High	Robyn Jones
50	Analysis of the relationship between sediment composition and benthic community structure in coastal deposits: Implications for marine aggregate dredging	1999	Seiderer & Newell. ICES Journal of Marine Science	Scientific Article	Low	High	Robyn Jones
51	Effect of habitat complexity attributes on species richness	2014	St. Pierre & Kovalenko. Ecosphere	Scientific Article	Medium	High	Robyn Jones
52	Short-term ecological effects of an offshore wind farm in the Dutch coastal zone: a compilation	2011	Lindeboom *et al*. IOP Publishing. Environmental Research Letters	Scientific Article	Medium	High	Robyn Jones
53	Recolonization of deepwater hard substrate communities	1991	Lissner *et al*. Ecological Applications	Scientific Article	Medium	High	Robyn Jones
54	Guidance Notes - Decommissioning of Offshore Oil and Gas Installations and Pipelines under the Petroleum Act 1998 - Version 6	2011	DECC - Offshore Decommissioning Unit	Report	High	High	Paula Daglish
55	Guidelines for pipeline operators on pipeline anchor hazards	2009	HSE	Report	Low	Medium	Emma Pidduck
56	North Norfolk Sandbanks and Saturn Reef cSAC/SCI management investigation report. JNCC/Cefas Partnership Report, No. 7	2015	Jenkins, C., Eggleton, J. Albrecht, J., Barry, J., Duncan, G., Golding, N. & O’Connor, J.	Report	High	High	Emma Pidduck
57	Offshore Wind Energy Generation: Phase 1 Proposals and Environmental Report, Final Report	2003	BMT Cordah	Report	Medium	High	Emma Pidduck
58	Best methods for evaluating *Sabellaria spinulosa* and cobble reef. Aggregate Levy Sustainability Fund Project MAL 0008	2010	Limpenney *et al.* JNCC	Report	Medium	High	Emma Pidduck
59	ABPmer Tidal Atlas	2008	ABPmer	Data	High	High	Emma Pidduck
60	The origin, classification and modelling of sandbanks and ridges	1999	Dyer & Huntley. Continental Shelf Research	Book Chapter	Medium	High	Emma Pidduck
61	Intertidal sand and mudflats & subtidal mobile sandbanks: An overview of dynamic and sensitivity characteristics for conservation management of marine SACs	1998	Elliot *et al*. SAMS	Report	Medium	High	Robyn Jones

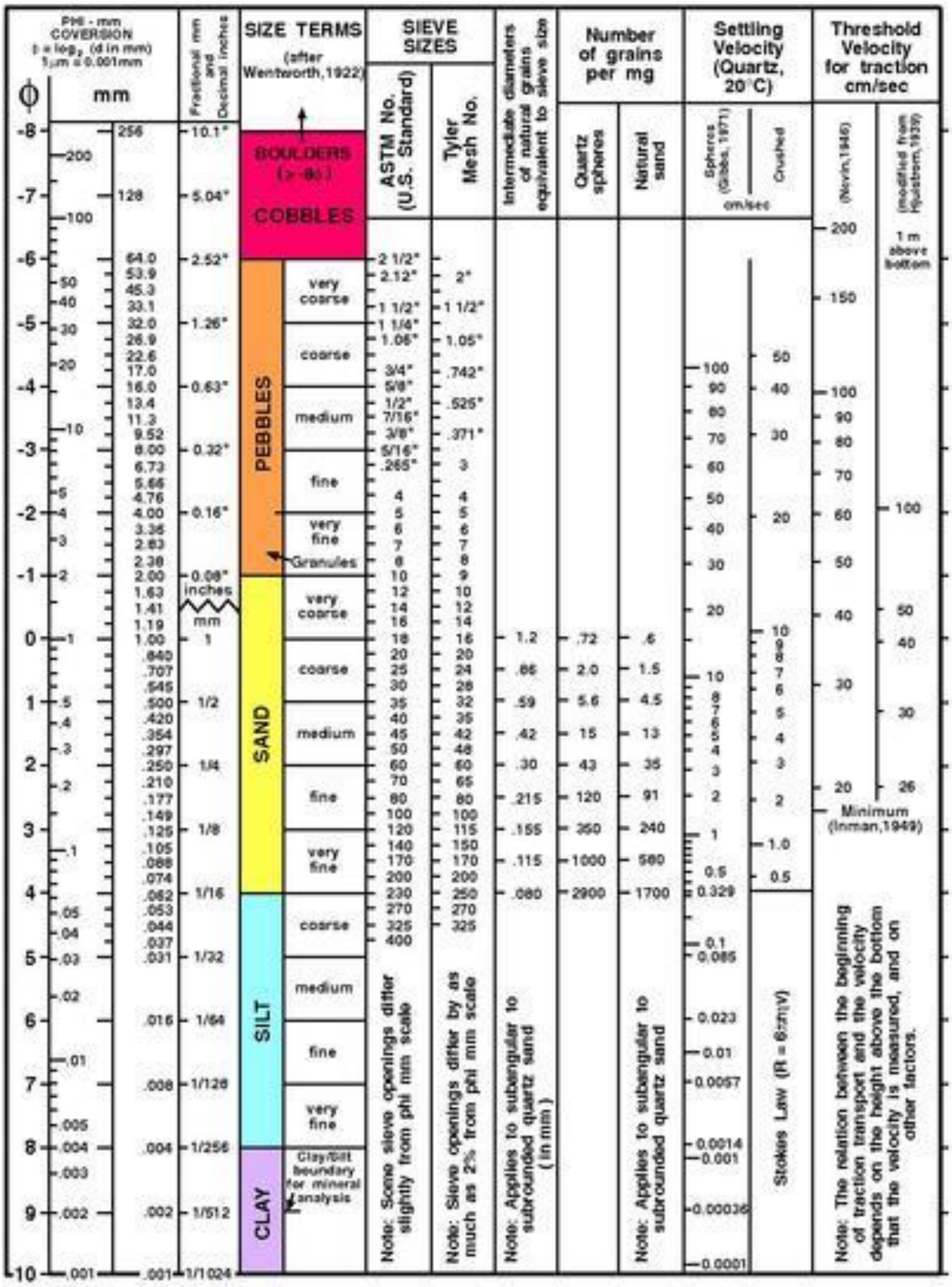
Ref	Evidence	Evidence Date	Source	Type	Relevance	Quality	Reviewer
62	JNCC Marine Habitats GIS Version 3: its structure and content. British Geological Survey Commissioned Report, CR/01/238.	2001	Graham *et al*. JNCC	Report	Medium	High	Robyn Jones
63	*Sabellaria spinulosa* reef: a scoring system for evaluating 'reefiness' in the context of the Habitats Directive	2006	Hendrick & Foster-Smith. Journal of the Marine Biological Association.	Report	Medium	High	Robyn Jones
64	Defining and managing *Sabellaria spinulosa* reefs: Report of an interagency workshop	2007	Gubbay. JNCC	Report	Medium	High	Emma Pidduck
65	Rock berm design for pipeline stability	2012	Chamizo *et al.* The American Society of Mechanical Engineers	Report	High	High	Emma Pidduck
66	The Rock Manual	2007	CIRIA	Book	High	High	Emma Pidduck
67	Failure Modes of Rock Berms for Offshore Pipeline Protection	2002	Hinwood & Lipski. One Petro	Report	High	High	Emma Pidduck
68	Suction removal of sediment from between armour blocks	2001	Sumer *et al.* Journal of Hydraulic Engineering	Report	High	High	Emma Pidduck
69	Wave boundary layer over a stone-covered bed	2008	Dixen *et al.* Coastal Engineering	Report	High	High	Emma Pidduck
70	Suction removal of sediment from between armour blocks: Breaking Waves	2012	Nielsen *et al.* Journal of Hydraulic Engineering	Report	High	High	Emma Pidduck
71	Assessing the sensitivity of *Sabellaria spinulosa* to pressures associated with marine activities. JNCC Report No. 504.	2014	Gibb *et al*. JNCC	Report	Medium	High	Robyn Jones
72	Artificial reef effect in relation to offshore renewable energy conversion. State of the art	2012	Langhamer. The Scientific World Journal	Report	High	High	Robyn Jones
73	Assessment of the environmental impact of offshore wind-farms. Biodiversity Series.	2008	OSPAR	Report	High	High	Robyn Jones
74	Review of cabling techniques and environmental effects applicable to the offshore windfarm industry.	2008	BERR	Report	High	High	Robyn Jones

Ref	Evidence	Evidence Date	Source	Type	Relevance	Quality	Reviewer
75	Recovery of soft sediment communities and habitats following physical disturbance	2002	Dernie *et al*. Journal Experimental Marine Biology	Report	High	High	Robyn Jones
76	Soft sediment macrobenthos around offshore wind turbines in the Belgian Part of the North Sea reveals a clear shit if species composition.	2011	Coates *et al*.	Report	High	High	Robyn Jones
77	Influence of an artificial reef on the surrounding infaunal community	1990	Ambrose & Anderson. Marine Biology	Report	High	High	Robyn Jones
78	Influence of artificial reefs of surrounding infauna: analysis of meiofauna	2002	Danovaro *et al*. ICES Journal of Marine Science	Report	High	High	Robyn Jones
79	Impacts of submarine cables on the marine environment - A literature review	2006	Meißner. Institute of Applied Ecology Ltd.	Report	High	High	Emma Pidduck
80	River bank stabilisation using rock riprap falling aprons	2009	River Research and Applications	Scientific Article	Medium	Medium	Emma Pidduck
81	Scour behaviour and scour protection for monopile foundations of offshore windfarm turbines	2004	Proceedings of the European Wind Energy Conference 2004	Report	Medium	High	Emma Pidduck
82	Offshore Special Area of Conservation: North Norfolk Sandbanks and Saturn Reef. Conservation Objectives and Advice on Operations	2012	JNCC	Report	High	High	Robyn Jones
83	The extent of Annex I sandbanks in North Norfolk Sandbanks and Saturn Reef cSAC/SCI.	2015	Parry *et al*. JNCC	Report	High	High	Robyn Jones
84	Guidance notes for industry. Guidance notes on the Offshore Petroleum Production and Pipelines (Assessment of Environmental Effects) Regulations 1999 (as amended)	2011	DECC	Report	High	High	Robyn Jones
85	Areas 483 and 484 Environmental Statement	2014	DBM Building Materials	Report	Medium	High	Robyn Jones
87	The impact of dredging works in coastal waters: A review of the sensitivity to	1998	Newell *et al*. Oceanography and Marine Biology	Scientific Article	Medium	High	Robyn Jones

Ref	Evidence	Evidence Date	Source	Type	Relevance	Quality	Reviewer
	disturbance and subsequent recovery of biological resources on the seabed.						
88	Offshore Special Area of Conservation: North Norfolk Sandbanks and Saturn Reef	2010	JNCC	Report	Medium	High	Robyn Jones
89	An Introduction to Marine Ecology.	2009	Barnes & Hughes. John Wiley & Sons.	Scientific Article	Medium	High	Robyn Jones
90	Camelot CA Platform, CA Pipelines, CB Pipelines Decommissioning Programmes.	2005	Camelot	Report	Medium	Medium	Robyn Jones
91	SNS Phase 1 Decommissioning Project. Environmental Statement for the SNS Decommissioning Project: Viking VDP1 and LOGGS LDP1.	2015	CONOCOPHILIPS	Report	High	Medium	Robyn Jones
92	The Environmental Assessment of Southern North Sea Pipeline Decommissioning. Centre for Environmental Risk Research	2001	Cox & Gerrard. Centre for Environmental Risk	Report	High	Medium	Robyn Jones
93	River bank stabilisation using rock riprap falling aprons.	2009	Froehlich. River Research and Applications	Scientific Article	Medium	High	Robyn Jones
94	Offshore renewable energy: ecological implications of generating electricity in the coastal zone	2005	Gill *et al.* Applied Ecology	Scientific Article	Medium	High	Robyn Jones
95	Species richness of marine soft sediments	2002	Gray. Marine Ecology Progress Series	Scientific Article	Medium	High	Robyn Jones
96	Appendix 1: Environmental Baseline. Benthos.	2016	DECC	Report	Medium	Medium	Robyn Jones
97	Quality Status Report 2000. Region II Greater North Sea.	2000	OSPAR	Report	Medium	Medium	Robyn Jones
98	Welland Decommissioning Programme.	2010	Perenco	Report	Medium	Low	Robyn Jones
99	Indefatigable field platforms and pipelines decommissioning programmes.	2007	Shell UK	Report	Medium	Low	Robyn Jones

Ref	Evidence	Evidence Date	Source	Type	Relevance	Quality	Reviewer
100	Brent Delta Topside Decommissioning Programme	2015	Shell UK	Report	Medium	Low	Robyn Jones
101	Tristan NW Field Decommissioning Programmes	2010	Silverstone	Report	Medium	Low	Robyn Jones
102	Stability of rock berm under wave and current loading	2013	Thusyanthan *et al.* Proceedings of the Twenty Third International Offshore and Polar Engineering	Scientific Article	High	High	Robyn Jones

Appendix 2: Wentworth Grain Size Chart



Appendix 3: Glossary

Bed shear stress (τ_c): measure of the force of moving water over the seabed.

Depth-average velocity (U): speed of water currents averaged over depth of water column.

Flandrian transgression: the name to the first stage of the Holocene epoch (present glacial period).

J-tube: cable riser at the base of a wind turbine.

Near-bed current velocity (u): speed of water current at or near the seabed.

Shear stress due to waves (τ_w): measure of force due to waves.

Shear velocity (u_*): form by which shear stress may be written in units of velocity.

Significant wave height (Hs (m)): the average height of the highest one-third waves in a wave spectrum.

Wave period (Ts): the measure of time it takes for the wave cycle to complete.

Appendix 4: Acronyms

BEIS	Department for Business, Energy & Industrial Strategy
BERR	Department for Business, Enterprise and Regulatory Reform
BGS	British Geological Survey
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CIRIA	Construction Industry Research and Information Association
cSAC	Candidate Special Area of Conservation
DECC	Department of Energy & Climate Change (now BEIS)
EEC	European Economic Community
EEZ	Exclusive Economic Zone
ES	Environmental Statement
EUNIS	European Nature Information System
GIS	Geographic Information System
Intertek	Intertek Energy & Water Consultancy Services
JNCC	Joint Nature Conservation Committee
MPA	Marine Protected Area
NNSSR	North Norfolk Sandbanks and Saturn Reef
O&G	Oil & Gas
OSPAR	Oslo Paris Convention
PAH	Polycyclic aromatic hydrocarbon
PSD	Particle Size Distribution
ROV	Remotely Operated Underwater Vehicle
SAC	Special Area of Conservation
SCI	Site of Community Importance
SNS	Southern North Sea
UNCLOS	United Nations Convention on the Law Of the Sea
UKCS	United Kingdom Continental Shelf
VDP1	Viking Decommissioning Program 1