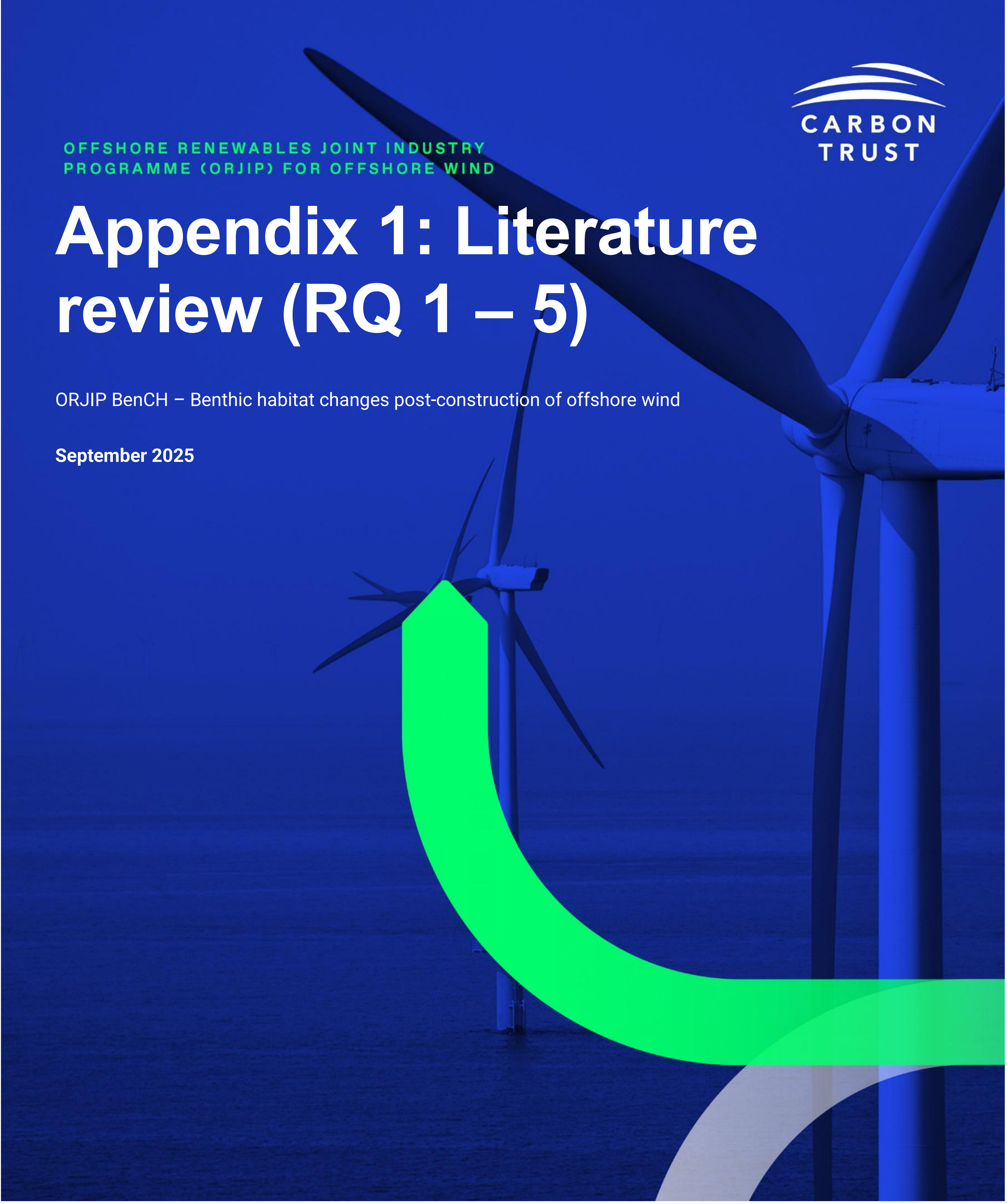
CARBON TRUST

OFFSHORE RENEWABLES JOINT INDUSTRY PROGRAMME (ORJIP) FOR OFFSHORE WIND

Appendix 1: Literature review (RQ 1 – 5)

ORJIP BenCH – Benthic habitat changes post-construction of offshore wind

September 2025



orjip working to accelerate offshore consenting

ORJIP Offshore Wind

The Offshore Renewables Joint Industry Programme (ORJIP) for Offshore Wind is a collaborative initiative that aims to:

- Fund research to improve our understanding of the effects of offshore wind on the marine environment.
- Reduce the risk of not getting, or delaying consent for, offshore wind developments.
- Reduce the risk of getting consent with conditions that reduce viability of the project.

The programme pools resources from the private sector and public sector bodies to fund projects that provide empirical data to support consenting authorities in evaluating the environmental risk of offshore wind. Projects are prioritised and informed by the ORJIP Advisory Network which includes key stakeholders, including statutory nature conservation bodies, academics, non-governmental organisations and others.

The current stage is a collaboration between the Carbon Trust, EDF Energy Renewables Limited, Ocean Winds UK Limited, Equinor ASA, Ørsted Power (UK) Limited, RWE Offshore Wind GmbH, SSE Renewables Services (UK) Limited, TotalEnergies OneTech, Crown Estate Scotland, Scottish Government (acting through the Offshore Wind Directorate and the Marine Directorate) and The Crown Estate Commissioners. For further information regarding the ORJIP Offshore Wind programme, please refer to the Carbon Trust website, or contact Ivan Savitsky (ivan.savitsky@carbontrust.com) and Žilvinas Valantiejus (zilvinas.valantiejus@carbontrust.com).

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- Joint Nature Conservation Committee (JNCC)
- Natural England
- Department for Environment, Food & Rural Affairs (Defra)
- NatureScot
- Scottish Government's Marine Directorate

This report was sponsored by the ORJIP Offshore Wind programme. For the avoidance of doubt, this report expresses the independent views of the authors.

Who we are

Our mission is to accelerate the move to a decarbonised future. We have been climate pioneers for more than 20 years, partnering with leading businesses, governments and financial institutions globally. From strategic planning and target setting to activation and communication - we are your expert guide to turn your climate ambition into impact.

We are one global network of 400 experts with offices in the UK, the Netherlands, Germany, South Africa, Singapore and Mexico. To date, we have helped set 200+ science-based targets and guided 3,000+ organisations in 70 countries on their route to Net Zero.

Contents

Figures

Tables

Executive summary

A substantial amount of Offshore Wind Farm (OWF) monitoring data has been accumulated in recent years along with the rapid expansion of this industry, resulting in several publications aimed at documenting potential impacts of OWFs on the marine environment.

The aim of this project has been to collate available information relating to a number of potential impacts of OWFs on benthic habitats and species, referring to the findings of post-construction monitoring programmes for multiple wind farms as well as a wider literature review to address a specific set of questions. It provides an up-to-date indication of currently available data and information and highlights some potential knowledge gaps.

Five research questions have been evaluated for this project:

- RQ1: Are there suitable metrics to detect changes in benthic habitats that could be applied to offshore wind assessments?
- RQ2: Is there a measurable change (increase/decrease) in biodiversity and/or species composition?
- RQ3: Are there localised and regional ecological effects around the infrastructure?
- RQ4: Is there change in ecological function (e.g. functional groups) as a result of biological changes?
- RQ5: Can recovery and/or enhancement be demonstrated and in what timeframe?

The project's main outputs are a literature review outlining the responses to RQ1-5 (current report), a data mapping summary report (APEM, 2025), followed by a presentation at the interim workshop to the ORJIP OSW (Offshore wind) Steering Group and Project Expert Panel and a go/no go decision for further analysis was made based on data availability (hereafter referred to as 'Project Stage Gate').

The two main approaches to obtaining the information for this review were; collation and review of pre- and post-construction monitoring data for offshore wind farms; and wider review of published literature and grey literature. The pre- and post-construction monitoring reports were key to providing the information for responses for RQ1-2 and they were also referred to for aspects of the responses to RQs 3-5, as appropriate. For RQ3-5 there was limited information available in the OWF monitoring reports, and a wider literature review was required to outline in more detail the key potential ecological effects of OWF developments on benthic ecology receptors.

A total of 47 wind farms were selected to obtain copies of pre-construction and post-construction monitoring reports and associated raw data sets. For 18 constructed OWFs, sufficient sets of monitoring reports (pre- and post-construction) were available to include in the review (with assessment of colonisation of turbine foundations included in monitoring programmes for seven OWFs).

Regarding RQ1, numerous metrics were found to be frequently used in monitoring reports and scientific literature to detect changes in benthic habitats and communities. These metrics can be used to provide understanding of community structure, biodiversity and ecosystem health and determine changes over time. The most frequently used metrics included; abundance, species/taxon richness, Particle Size Analysis data, habitat distribution and composition, followed by cluster analysis/nMDS and summary statistics (e.g. Pielou's eveness and Shannon Weiner diversity index). Although the range of metrics frequently applied are generally effective at demonstrating changes in benthic communities/habitats, there is a lack of information relating to the effects of such changes on ecological function at a community/habitat level. This lack of information is applicable to all types of coastal and offshore marine development including OWFs.

The most frequently used metrics are also not designed to indicate potential disturbance of the benthic communities beyond changes in relative abundances of species and providing an indication of dominance of specific taxa. It is recommended that the current suite of frequently applied metrics is retained, but supplementary metrics could also be calculated from the benthic ecology data sets to provide some additional information which could inform understanding of wider ecosystem level changes at a local and regional scale. Consequently, as part of the project, the additional metrics Infaunal Trophic Index (ITI), AZTI Marine Biotic Index (AMBI), ABC curves, Infaunal Quality Index (IQI), Benthic Ecosystem Quality Index (BEQI) and biological trait analysis have been considered to be applied to available datasets to determine what additional value could be provided to inform assessment of ecological effects (see Data Mapping Summary report (APEM, 2025)).

For RQ2, the focus was on identifying where measurable change has been recorded in sediment composition or species/community composition post-construction at OWF developments. To examine consistency in approach across different reports in more detail, some key aspects applicable to the design of benthic ecology surveys and of relevance to OWF post-construction monitoring were determined. Consequently, information relating to the following four aspects was reviewed for each post-construction monitoring report: Survey design and statistical approach; Methodology; Correlation analysis; and Power analysis. According to the monitoring reports reviewed, there were measurable changes in biodiversity and / or species composition at the majority of offshore wind farm sites. In all instances, however, any changes identified at the OWFs were attributed to natural variability. Changes attributed directly to the presence of OWFs were primarily documented within turbine colonisation reports which provided data for epifaunal fouling communities on OWF structures.

In the context of the response to RQ3, "local" refers to the area within, and in the immediate vicinity of the project site (i.e. within a few miles or kilometres) and to ecosystems that are directly affected by the project's construction, operation and maintenance. The term "regional" refers to the broader geographical area or territory that extends beyond the immediate location of an offshore wind project and may be subject to more indirect impacts associated with OWFs. Localised effects, in the immediate vicinity of turbine structures, typically arise from the presence of OWF structures and the associated construction processes, which alter the physical environment and can disturb existing benthic communities. The introduction of artificial hard substrates, such as turbine foundations and scour protection, can provide habitats for the colonisation of hard-substrate species driving shifts in community composition and which can also potentially affect sediment characteristics and associated communities. Regional impacts are often driven by factors such as altered hydrodynamic conditions, the introduction and spread of non-native species, and the creation of new ecological connections between different marine habitats. Some dedicated research programmes which have been referred to in Section 6 aim to fill some of these data gaps to address the research question in more detail.

RQ4 explores how changes in benthic communities induced by OWFs affect ecological function, focusing on biological changes and their implications for functional group dynamics. In particular, it examines how shifts in benthic community composition influence key ecosystem processes such as nutrient cycling, sediment bioturbation, and organic matter decomposition, with attention to transitions in relative abundance of species belonging to different functional groups like deposit feeders, scavengers, and filter feeders. In general, there is a substantial lack of studies that explicitly investigate changes in ecological functioning as a result of changes to soft sediments and associated benthic communities within and around OWFs. However, OWF installation alters habitats and creates additional hard substrate, which has the potential to act as an artificial reef affecting local ecosystem diversity and ecological function. Another key area of interest is the long-term succession patterns of fouling communities on artificial structures and their cascading effects on regional ecosystem functioning in addition to the anticipated localised changes to sediment type and concentration of organic matter in sediments. Additionally, the role of hydrodynamic changes, such as altered sediment transport and larval settlement, on benthic community dynamics and functional roles warrants further exploration.

With regards to RQ5, for this report recovery has been considered as a scenario where an adverse impact has been identified due to construction or operation of an OWF and recovery is the shift back towards the pre-construction baseline. In terms of the post-construction monitoring reports considered in this review, however, timescales for recovery could not be determined as all of the reports had concluded that any changes in benthic habitats/species noted were due to natural variation as opposed to effects of the OWF. Understanding the recovery potential of marine ecosystems requires comprehensive data related to environmental pressures and associated long-term monitoring across relevant timescales and spatial scales (locally and regionally) which is key to tracking changes at OWFs post-construction. In addition, effective survey design for monitoring programmes, and selection of a sufficient number of suitable reference stations is essential to clarify whether changes evident are due to natural variability or relate to effects of OWFs.

OWFs have not traditionally been designed for ecological enhancement, but there is potential for this to change in the future following the introduction of marine net gain policies. The introduction of OWF structures such as turbine foundations and scour protection can increase biodiversity, in some instances be associated with the re-establishment of rare species such as native oyster, and have reserve effects due to spatial restrictions of fishing activities. Nevertheless, artificial habitats can differ significantly from natural ones, with increased hard substrate necessitating careful monitoring of ecological impacts. Consequently, it is considered that OWFs can potentially play a positive role in marine habitat recovery and enhancement, however, more long-term studies are needed to understand their full ecological impact and to optimise future developments for biodiversity gains.

Overall, this review has provided key information to address the five main research questions indicated above. It has indicated some key data gaps (with application of novel metrics investigated in latter stages of the current project) and is designed to promote discussion, inform policy discussions and identify areas where further research would be beneficial going forward.

1. Introduction

1.1. Background

Urgent calls have been made to ramp up the production of renewable energy worldwide. In particular, the UK Government has made commitments to deliver 50 gigawatts (GW) of offshore wind by 2030. Currently, 13.9 GW of OW is fully commissioned, with another 77 GW in some phase of development or set aside for upcoming seabed lease auctions (Department of Business and Trade, 2024).

Existing data reviews focus on several aspects of Offshore Wind Farms (OWFs), and specific considerations for benthic ecology include temporary and permanent environmental impacts associated with the installation and physical presence of structures in the water column and on the seabed (including the presence of turbine foundations, scour protection, cable protection and substation/converter platform foundations); changes to hydrodynamic regime and sediment transport; changes to the underwater soundscape; the presence of submarine cables and associated electromagnetic fields; and a number of other effects which will be considered in this review. In addition, different impacts and potential effects are specific to the construction, operational, and decommissioning phases depending on the approaches to be taken.

A substantial amount of monitoring data has been accumulated in recent years along with the rapid expansion of this industry, resulting in several publications aimed at documenting potential impacts. A recent extensive review of literature relating to the environmental impacts of wind energy devices, however, indicated that there were far fewer literature sources available for benthic invertebrates, compared to birds, fish and marine mammals (Galparsoro *et al*., 2022). In addition, few long-term studies exist, and the majority of research projects aimed at documenting impacts do so based on short-term datasets, 1 – 5 years after construction (Zucco *et al*., 2006; Jak & Glorius, 2017). The need for longer-term studies has been emphasised in relation to developing our understanding of many of the potential effects of OWFs including the succession and changes in fouling communities on turbines and scour protection (artificial reef effects), impacts on soft sediment communities owing to altered hydrodynamics and nutrient enrichment (Coates *et al*., 2014; Lefaible *et al*., 2023).

The aim of this project has been to collate available information relating to a number of potential impacts of OWFs on benthic habitats and species, referring to the findings of post-construction monitoring programmes for multiple wind farms as well as a wider literature review. It provides an up-to-date indication of currently available data and information and highlights some potential knowledge gaps that could potentially be investigated further beyond the Stage Gate (see Section 1.2) for this project.

This project has been undertaken as part of the Offshore Renewables Joint Industry Programme for Offshore Wind ("ORJIP Offshore Wind") research and development programme under the Carbon Trust management team. It will contribute to the 'Impacts on Benthic Ecology' priority focus area of the wider ORJIP programme.

1.2. Purpose and scope

This project will serve to fill important knowledge gaps to ensure potential effects of OWFs on benthic habitats/species post-construction are more fully understood.

Five research questions have been evaluated for this project:

- RQ1: Are there suitable metrics to detect changes in benthic habitats that could be applied to offshore wind assessments?
- RQ2: Is there a measurable change (increase/decrease) in biodiversity and/or species composition?
- RQ3: Are there localised and regional ecological effects around the infrastructure?
- RQ4: Is there change in ecological function (e.g. functional groups) as a result of biological changes?
- RQ5: Can recovery and/or enhancement be demonstrated and in what timeframe?

The main outputs of the project are:

- A literature review outlining the responses to RQ1-5 (the current report)
- A data mapping summary report (APEM, 2025)
- Presentation at an interim workshop to the ORJIP OSW (Offshore wind) Steering Group and Project Expert Panel

There will then be a Stage Gate where it will be evaluated whether, based on the evidence presented, there would be potential to continue investigation of each research question using the raw data sets obtained for different OWF projects.

Within this review some potential approaches for further evaluation of research questions have been provided which will be discussed further at the interim workshop.

2. Project team

This project has been coordinated and delivered by APEM Ltd with extensive literature review contributions by Dr Talicia Pilay and Dr Lisa Skein of the National Oceanography Centre. External review for RQ3, RQ4 and RQ5 has been provided by Dr Katrien Van Landegham of Bangor University who is the Principal Investigator for the ECOWind-ACCELERATE project

3. Methodology

There were two main approaches to obtaining the information for this review:

- Collation and review of pre- and post-construction monitoring data for offshore wind farms; and
- Wider review of published literature and grey literature

3.1. Collation of pre- and post-construction monitoring reports

For RQ1 and RQ2 in particular, data from the pre- and post-construction monitoring reports has been key to providing the information to inform the review and they have also been referred to for aspects of the responses to RQs 3-5, as appropriate. A total of 47 wind farms were selected to obtain copies of pre-construction and post-construction monitoring reports and associated raw data sets. Based on the timeframe available it was necessary to focus on a sub-section of available wind farm reports so UK wind farms were selected and all but one of the sets of reports obtained were for wind farms in the UK (the non-UK wind farm included was Princess Amalia wind farm in the Netherlands for which a long-term post-construction monitoring data set was available).

The main data sources used to obtain the relevant reports and data sets are indicated below.

Table 1. Data sources to obtain OWF monitoring reports.

Source	Description/Documents downloaded
Marine Data Exchange **(https://www.marinedataexchange.co.uk/)**	Digital platform of industry marine survey data, research and evidence created by the Crown Estate. Documents downloaded for analysis included: Pre-construction and post-construction benthic survey reports.
Marine Environmental Data and Information Networks (MEDIN) **(https://medin.org.uk/)**	Digital platform which collated marine environmental data recorded by multiple organisations in the UK. Documents downloaded included: Pre-construction and post-construction benthic survey reports.
Direct requests to developers	For wind farms for which data could not be obtained via the MDE or Medin, direct requests were sent to developers, primarily via the Carbon Trust.

Partial sets of monitoring reports were available for the majority of the 47 OWFs, however, a full set of pre-construction and post-construction[1] monitoring reports and associated data sets was available for 12 of these and for a further six, sufficiently detailed reference to the pre-construction data was made in the post-construction monitoring reports to include them in the review (Table 2).

Table 2. Offshore Wind Farms for which set of required reports were collated.

OWF site (Owner)	Commissioned	Sampling technique(s)	Surveys collated
Barrow OWF (Ørsted)	2006	Grab, Divers (foundation colonisation survey), Trawl	Post-construction (Year 1, Year 2 and Year 3)
Beatrice OWF (SSE Renewables)	2019	Grab, DDV, ROV (foundation colonisation survey)	Pre-construction Post-construction (Year 1 and Year 2)
Blyth Demo OWF (EDF Renewables)	2018	Grab, DDV, Trawl	Pre-construction Post-construction (Year 1)
Burbo Bank OWF (Ørsted A/S)	2007	Grab, Divers (foundation colonisation survey), Trawl (pre-construction only)	Pre-construction Post-construction (Year 1 and Year 3)
Greater Gabbard OWF (SSE; RWE Npower Renewables)	2012	Grab, DDV, Trawl, ROV (foundation colonisation survey)	Post-construction (Year 1, Year 5 and Year 10)
Gunfleet Sands I&II OWF (Ørsted A/S)	2010	Grab	Pre-construction Post-construction (Year 1, Year 2, Year 3)
Kentish Flats OWF (Vattenfall)	2005	Grab, Divers (foundation colonisation survey)	Post-construction (Year 1, Year 2, Year 3)
London Array OWF (Orsted A/S; E.ON Climate & Renewables UK Ltd; Masdar)	2013	Grab, Trawl	Post-construction (Year 1)
Lynn and Inner Dowsing OWF (Macquarie Asset Management)	2009	Grab, DDV, Trawl	Pre-construction Post-construction (Year 2, Year 3, Year 4)
North Hoyle OWF (Greencoat UK Wind)	2004	Grab, Trawl, Divers (foundation colonisation survey)	Pre-construction Post-construction (Year 1 and Year 2)

[1] For six OWFs the pre-construction report was not available but sufficiently detailed reference to the pre-construction data was made in the post-construction monitoring reports to include them in the review.

Ormonde OWF (Vattenfall)	2012	Grab, DDV, Trawl	Pre-construction Post-construction (Year 1 and 2)
Princess Amalia	2008	Dredge/trawl, Box core, Divers (foundation colonisation survey)	Pre-construction Post-construction (Year 4, Year 5, Year 9 and Year 15)
Robin Rigg East & West OWF (RWE Renewables)	2010	Grab, DDV, Trawl	Pre-construction Post-construction (Year 1, Year 2 and Year 3)
Scroby Sands OWF (RWE Renewables)	2004	Grab	Pre-construction Post-construction (Year 1)
Sheringham Shoal OWF (Equinor)	2012	Grab, DDV/Video transect, Trawl	Pre-construction Post-construction (Year 2)
Thanet OWF (Vattenfall)	2010	Grab, DDV , Trawl	Post-construction (Year 1)
Walney 1&2 OWF (Ørsted; Greencoat UK; PGGM)	2011	Grab, DDV	Post-construction (Year 3)
Westermost Rough OWF (Orsted A/S)	2015	Grab, DDV	Pre-construction Post-construction (Year 1, Year 2 and Year 3)

3.2. Wider literature review

For RQ3-5 there was limited information available in the OWF monitoring reports, and a wider literature review was conducted.

Peer-reviewed journal articles were reviewed (~ 200 in total) and referenced where possible, however, other literature considered to be equally important and informative such as grey literature reports were also reviewed (~50 in total).

NOC have conducted extensive research specifically addressing some of these research questions within projects including ECOWind-ACCELERATE and BOWIE and have gained a thorough knowledge of the various data sources available. We had input from the Principal Investigator of the ECOWind-ACCELERATE project (Dr Katrien Van Landegham) to ensure that the review was comprehensive and reflective of the most recent findings related to the benthic impacts of OWFs. Where appropriate, discussions were held with colleagues involved in these projects to corroborate the information being provided and the work was presented internally at NOC to engage with the wider seafloor habitat mapping community.

Depending on data availability, information from industry outside OWF (e.g. oil and gas platforms) was also sought, as appropriate, to inform the key research questions outlined below. This helped provide context for many of the questions and helped draw on research that highlighted lessons learnt and provided guidance for future work. The review also references governmental programmes and guidance that are currently in place, namely the creation of the Great British Energy company and milestones set out by the offshore wind environmental improvement package that will be achieved in collaboration with Defra; including consideration of the Marine Recovery Fund.

This wider literature search has been used to outline the key potential ecological effects of OWF developments on benthic ecology receptors for discussion with the ORJIP OSW Steering Group.

4. RQ1: Are there suitable metrics to detect changes in benthic habitats that could be applied to offshore wind assessments?

4.1. Background

The effects of anthropogenic disturbances on benthic habitats and associated communities can include changes in diversity, biomass, community composition and the trophic or functional structure of communities.

Numerous metrics are available to detect changes in benthic habitats and communities (e.g. Pinto *et al*., 2008; Borja *et al*.,2015) and these metrics can be used to provide understanding of community structure, biodiversity and ecosystem health and determine changes over time. For the purposes of this response, the term metric has been taken to include indicators or indices that describe or measure change in benthic communities and associated summary statistics. In addition, for the purposes of the response, frequency of use of commonly deployed statistical approaches has also been considered. The majority of these metrics are commonly applied to benthic assessments for marine developments in general, and this review has focussed on those which have currently been applied at OWFs and those which could be applied in the future.

It is important to note that the types of metrics which are applicable can vary according to the survey approach. For example, benthic grab samples obtained within the wind farm site, cable route and reference stations would usually be analysed to determine sediment composition and macroinvertebrate community structure (Franco *et al*.,2015). The data obtained are quantitative and macro-invertebrate community structure and sediment distributions are typically investigated by employing univariate diversity indices and multivariate statistical analysis (Coolen *et al*.,2020, Coolen *et al*.,2022).

Video footage from Drop Down Video (DDV) or Remotely Operated Vehicle (ROV) is usually analysed using a more semi-quantitative or qualitative approach, providing a visual description of substrate composition, and an associated species list, often with related species abundance information. Benthic habitats would typically be investigated with the SACFOR abundance scale (Ter Hofstede *et al*.,2022) or univariate biological analysis approaches (Coolen *et al*.,2022). In addition, specific metrics can be applied to specific habitat types e.g. measures of 'reefiness' for biogenic reef or cobble/stony reef.

An overview of the main metrics which have been applied in OWF post-construction monitoring reports has been provided in this review.

4.2. Results

The monitoring programmes for 18 constructed OWFs were reviewed to analyse the use of benthic community metrics in OWF benthic monitoring programmes (Table 1). Pre- and post-construction monitoring programmes were reviewed and information on the metrics used and their frequency of use was collated.

The frequency of use for each metric is indicated in Figure 1 and information for each metric is provided below.

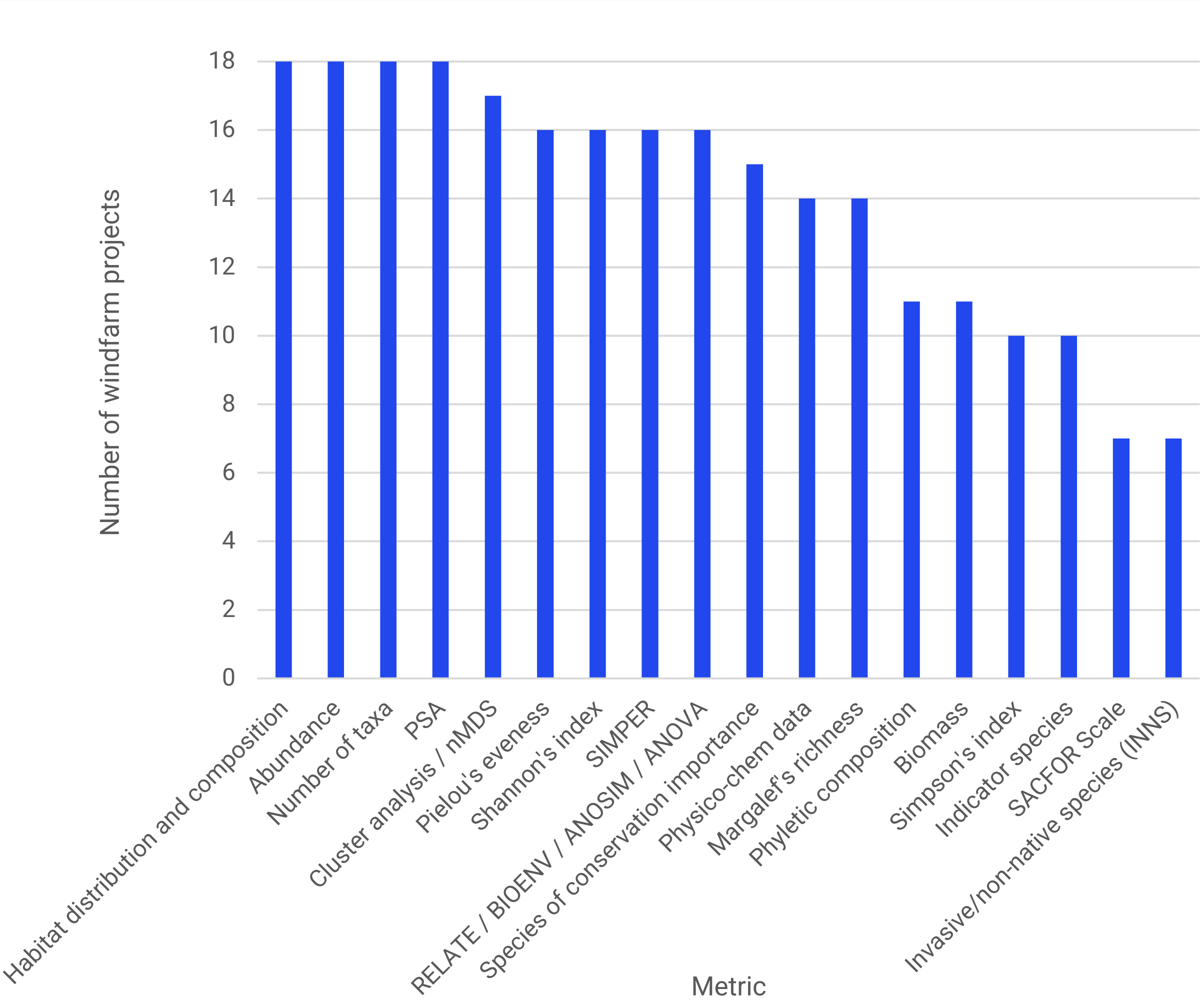

Figure 1. Metrics used in offshore wind farm post-construction monitoring survey reports.

4.2.1. Biota

4.2.1.1. Abundance

Applied across all 18 of the reviewed sets of monitoring reports. This is the number of invertebrate individuals present in samples. This value is relatively easy to obtain and can be used in combination with species richness to provide diversity data. This metric can also be used to determine density based on the area of sediment sampled (number of individuals per m^2).

4.2.1.2. Species/Taxon richness

Applied across all 18 sets of monitoring reports. This is the number of species within a defined area or region, commonly obtained through sampling or via census. When considering benthic data, taxon richness is frequently used instead of species richness as often some individuals cannot be identified to species level. In very simple terms a higher taxon/species richness value can indicate a healthier more stable environment, although context is important in terms of the type of environment when making such interpretations. It is a straightforward statistic to calculate and can be applied across a range of habitats, however it does not account for the relative abundance of individuals within each taxon and is therefore usually provided in combination with diversity metrics.

4.2.1.3. Habitat distribution and composition

Applied across all 18 sets of monitoring reports. Benthic community and sediment composition data are usually used to determine which biotopes/EUNIS habitats are present at the project site during each monitoring survey. The number of different biotopes/habitats or the number of samples/replicates assigned to a particular habitat/biotope provides information on the spatial distribution and abundance of different benthic habitats across a survey area. This information can help indicate if habitats in the area are relatively homogeneous across large areas, or heterogeneous varying across small spatial scales.

4.2.1.4. Univariate diversity metrics

Shannon-Wiener Diversity Index (H'): Applied in 16 of the sets of monitoring reports. H' integrates the number of species and individual abundance to provide a summary value reflecting the diversity of biota at a station. This index of diversity is influenced by both species richness (i.e. the number of species) and evenness (or equitability) of distribution of individuals between species (Clarke & Warwick, 2001). It is a measure of the difficulty of predicting the identity of an individual based on overall community composition and a higher Shannon-Wiener value indicates greater community diversity. The Shannon-Wiener diversity index is calculated using the following formula:

$$H' = -\sum_{i=1}^{s} p_i \log_n p_i$$

H' = Shannon-Wiener Diversity Index

Pi = proportion of the total number of individuals from the ith species

n = log base value

Pielou's Evenness Index (J'): Applied in 16 of the sets of monitoring reports. Evenness (or equitability) is a representation of how uniformly individuals are distributed between species in a sample (Pielou, 1969). It is a component of, and calculated using, the Shannon-Wiener Diversity Index. Values range from 0 to 1 where 1 indicates perfect evenness (i.e. each species has the same abundance within a sample). Lower values indicate that abundance is dominated by a small number of species within a sample, which may indicate environmental stress or disturbance where opportunistic species are able to dominate. Pielou's index is calculated as follows:

$$J = \frac{H'}{Log_n S}$$

J = Pielou's Evenness

H' = Shannon-Wiener Diversity index

S = total number of species in a sample

Margalef's Species Richness (d): Applied in 14 of the sets of monitoring reports. This is a commonly used measure of species richness that accounts for the total number of species and the number of individuals in a sample (Margalef, 1968). Unlike the 'taxon richness' metric described above, which is a simple count of taxa within a sample, Margalef's metric adjusts for sample size, making it more useful for comparing samples with different abundances. Higher values indicate higher species richness with lower values indicating lower species richness which may be indicative of environmental stress or disturbance where fewer opportunistic species may dominate. The formula for this metric is:

$$D = \frac{(S-1)}{\ln(N)}$$

D = Margalef's Richness Index value

S = total number of species found

N = total number of individuals in the sample

Simpson's Diversity (1-λ): Applied in 10 of the sets of monitoring reports. Simpson's is a diversity index derived from the probability of picking two individuals from a community at random that are from the same species. Simpson's diversity index ranges from 0 to 1 and will be lower when a community is dominated by one or a few species but higher when the community is diverse. It is calculated as 1- λ where:

$$1 - \lambda = 1 - (\Sigma P_i^2)$$

1 - λ = Simpson's Diversity Index

Pi = proportion of the total number of individuals from the ith species.

Sometimes the Simpson's Dominance value is provided which is 'λ'.

4.2.1.5. Multivariate analysis

In addition to univariate analyses, data can be subjected to multivariate analysis using a number of different methods. Multivariate analyses can highlight trends in datasets that cannot be identified when using univariate techniques in isolation. Some commonly applied statistical approaches are indicated below.

Cluster analysis and non-Metric Multidimensional Scaling (nMDS): Applied in 17 of the sets of monitoring reports. Cluster analysis is used to determine whether groups of samples are statistically indistinguishable at the 5% significance level, and indicates groupings of stations by creating a dendrogram with black lines indicating statistical distinctions between sampling stations and red lines indicating where the samples are statistically inseparable. Non-metric multidimensional scaling (nMDS) is a type of ordination method that creates a 2- or 3-dimensional 'map' of the samples (or stations) from the similarity matrix. The dendrogram generated by cluster analysis indicates the percent similarity between samples, and the schematic of the nMDS displays the distances between samples which are representative of their similarity/dissimilarity.

SIMPER: Applied in 17 of the sets of monitoring reports. This analysis is used in combination with the Bray-Curtis cluster analysis to rank species in terms of their contribution to both the internal group similarity and "between" group dissimilarity (%). SIMPER is used to determine the distinctiveness of each group identified and indicate the characterising taxa for each group.

RELATE & BEST (BIO-ENV): Applied in 11 of the sets of monitoring reports. This analysis is applied to determine if there is a correlation between the biotic assemblages and a given environmental parameter (e.g. sediment composition, sediment chemical concentrations).

ANOVA: Applied in seven of the sets of monitoring reports. ANOVA is used to assess the difference between the means of more than two groups. This can be applied to biological and sediment metrics. For instance, a one-way ANOVA test may be used to test for differences in abundance of individuals or mean sediment size between years (pre-construction and post-construction). Results of ANOVA tests are given as p values, with 0.05 being the typical threshold for rejection of the null hypothesis.

ANOSIM: Applied in 14 of the sets of monitoring reports. ANOSIM is a multivariate equivalent of an ANOVA test. It is applied to a priori structured data sets to test for differences between pre-selected groups of samples or stations. For instance, ANOSIM may be used to test whether the biota found <1 km of an offshore installation differs from that found at >1 km. The result of such an analysis might provide an indication of whether the installation and operation of offshore facilities has affected the benthic community. Results of ANOSIM tests are given as r values that range from 0 (no difference) to 1 (highly different), and the significance is determined by comparison to the randomly permuted distribution of the samples included in the analysis. PERMANOVA can also be used to provide insight into elements such as the main effect of a factor (e.g. year of survey) and its interactions with other factors (e.g. Site: OWF, Cable Route, Reference). This is particularly useful for unbalanced designs. Results of PERMANOVA are given as a pseudo-F ratio with larger values corresponding to larger proportional importance of the grouping factor.

4.2.1.6. Biomass

Applied in 11 of the sets of monitoring reports. The biomass statistic is the total mass of organisms in a given area or sample and is defined by the weight (preferably wet weight but can be dry weight) of each recorded taxa. Biomass data can supplement abundance data and help describe benthic community structure, understand energy availability for higher trophic levels and indicate environmental disturbance.

4.2.1.7. Phyletic composition

Applied in 11 of the sets of monitoring reports. Phyletic composition is an indication of the taxonomic makeup of the benthic community and can include identification of the relative proportions of taxa from each of the major taxonomic groups (e.g. Annelida, Crustacea, Mollusca and Echinodermata).

4.2.1.8. Species/habitats of conservation importance

Indicated in 15 of the sets of monitoring reports. This refers to a report making specific reference to the presence and abundance of any species/habitats of conservation importance (e.g. *Sabellaria* spp. reef), or it is stated that no species/habitats of conservation importance were recorded.

4.2.1.9. Non-native species

In all sets of monitoring reports reviewed, biota was identified to species level or the lowest taxonomic level practicable. Non-native species were indicated in seven of the sets of monitoring reports. This refers to a report making specific reference to any non-native species present or indicates that no non-native species were recorded.

4.2.1.10. Indicator species

Indicator species, such as opportunistic species or disturbance tolerant species, were identified in ten of the sets of monitoring reports. Monitoring reports would either identify specific indicator species or potential habitat indicators which indicate environmental disturbance. Species found were often indicators of physical sediment disturbance such as change in sediment type, scour disturbance and sediment instability.

4.2.1.11. SACFOR abundance scale

Indicated in seven of the sets of monitoring reports. In the context of OWFs this metric is mainly applicable to monitoring surveys utilising underwater video analysis. SACFOR is a semi-quantitative scale used for rapid assessment of species composition and abundance during time-limited surveys and provides a unified system for recording the abundance of marine benthic biota (Hiscock, 1996).

Table 3. Table showing the SACFOR abundance scale parameters

Growth Form			Size of individuals/colonies				Density
%cover	Crust /Meadow	Massive /Turf	<1cm	1-3cm	3-15cm	>15cm	
>80%	S		S				>1/0.001m^2
40-79%	A	S	A	S			1-9/0.001m^2
20-39%	C	A	C	A	S		1-9/0.01 m^2
10-19%	F	C	F	C	A	S	1-9/0.1 m^2
5-9%	O	F	O	F	C	A	1-9/ m^2
1-5% or density	R	O	R	O	F	C	1-9/10 m^2
<1% density		R		R	O	F	1-9/100 m^2
					R	O	1-9/1000 m^2
						R	<1/1000 m^2

Key:
S = Superabundant, **A** = Abundant, **C** = Common, **F** = Frequent, **O** = Occasional, **R** = Rare, **P** = present (used when the abundance of an organism could not be estimated accurately).

4.2.2. Sediment

4.2.2.1. Particle Size Analysis (PSA)

Applied across all 18 of the sets of monitoring reports. Sediment particle size data are used to produce sediment classifications following Wentworth (1922) or Folk (1954) to describe the contribution of different sediment types (e.g. relative proportion of mud, sand, gravel) in a given area or sample, and can be used to determine changes to substrate type. This metric can be used in combination with biota metrics (e.g. abundance and taxon richness) and multivariate analyses to allocate biotopes/EUNIS habitats based on sample data and determine if changes to substrate type contribute to changes in benthic communities.

4.2.2.2. Physico-chemical data

Applied across 14 of the sets of monitoring reports. Measurements of physico-chemical parameters such as sediment contaminants (e.g. metals) and total organic carbon can be useful metrics in terms of assessing whether changes in these parameters could potentially be contributing to changes in benthic communities/habitats.

4.3. Discussion

The most frequently used metrics included; habitat distribution and composition, abundance, species/taxon richness and PSA, followed by cluster analysis/nMDS, diversity indices (Shannon-Weiner and Pielou's evenness), SIMPER analysis, and RELATE / BIOENV / ANOSIM / ANOVA, and a range of other metrics are also regularly applied (Figure 1).

Four OWF projects also assessed *Sabellaria* 'Reefiness' using the assessment criteria from Gubbay (2007), Hendrick & Foster Smith (2006) and Limpenny *et al*. (2010); one of which also assessed stony reef resemblance using Irving (2009). These were not included in Figure 1, however, as the use of this metric was only applicable at locations where reef habitat (biogenic or stony reef) had been present pre-construction.

It is considered that the metrics frequently applied are suitable and effective at determining changes in benthic communities and habitats (biotopes) at OWF sites and associated cable corridors. To ensure the results are robust, however, a key consideration is effective survey design and having a sufficient number of stations within the OWF, along the cable corridor and sufficient reference stations at appropriate locations with a consistent number of replicates collected at each station. In addition, it is essential that consistency of sample locations from year to year is retained as far as possible.

It was surprising that only seven of the 18 sets of monitoring reports made reference to non-native species (either in terms of being present or absent). Due to the importance of understanding potential sources of introduction and spread of non-native species (especially invasive non-native species) in the marine environment, it is recommended that all monitoring reports make specific mention of any non-native species/taxa recorded, including cryptogenic species (origins unknown) where possible, and indicating where none were recorded.

Although the range of metrics frequently applied are generally effective at demonstrating changes in benthic communities/habitats, there is a lack of information relating to the effects of such changes on ecological function at a community/habitat level (see response to RQ4 in Section 7 for further information). This lack of information is applicable to all types of coastal and offshore marine development including OWFs. The metrics currently used are also not designed to indicate potential disturbance of the benthic communities beyond changes in relative abundances of species and providing an indication of dominance of specific taxa. This has led to consideration of the additional metrics indicated in Section 4.3.1 which provide additional information beyond the standard metrics commonly applied.

4.3.1. Additional biotic metrics

Highlighted below are some other biotic metrics that were not applied within the reviewed OWF monitoring programmes but have been applied previously to benthic ecology studies and could be considered for OWFs.

4.3.1.1. Infaunal Trophic Index (ITI)

Although not utilised in the reviewed post-construction monitoring reports for OWFs, the Outer Dowsing Offshore Wind Preliminary Environmental Information Report (GeoXYZ, 2023) applied the Infaunal Trophic Index developed by Codling & Ashley (1992). This was used to indicate the relative proportion of individuals belonging to different feeding groups within the main community types identified via cluster analysis.

This is a biological trait index, which classifies species into one of four feeding classes: filter feeders (class 1) interface feeders (facultative filter and deposit feeders, class 2), deposit feeders (class 3) and subsurface deposit feeders (class 4). The index value ranges from 100% (only filter feeders) to 0% (only subsurface deposit feeders). It is potentially useful as changes to feeding modes provides an indication of potential modification of ecological function at the community level, associated with changes in taxonomic composition of communities. For the Outer Dowsing project, all four trophic feeding guilds were observed across the Export Cable Corridor, with suspension feeders (ITI 1) dominating three of the four macrofauna clusters, while surface detritus feeders (ITI 2) dominated the remaining cluster. Overall, the ITI scores in two clusters reflected a 'normal' seabed due to the wide range of species recorded (GeoXYZ, 2023).

The formula for this metric is:

$$ITI = 100 - \frac{100}{3}\left(\frac{N_2 + 2N_3 + 3N_4}{N_1 + N_2 + N_3 + N_4}\right)$$

*N_n is the number of individuals within the respective feeding group.

4.3.1.2. AZTI Marine BIOTIC Index (AMBI)

AMBI was also applied in the Outer Dowsing Offshore Wind Preliminary Environmental Information Report (GeoXYZ, 2023) but was not applied in the reviewed post-construction monitoring reports for OWFs. The AZTI Marine Biotic Index (AMBI) is based on the proportion of disturbance-sensitive taxa, which are categorised into five ecological groups, depending on their dominance along a gradient of organic enrichment, and provides insight into the ecological quality status of soft-bottom marine benthic communities (Borja and Muxika, 2005; WFD-UKTAG, 2014). The AMBI value ranges from 0 (unpolluted) to 6 (heavily polluted) and 7 represents azoic conditions (extremely polluted), (WFD-UKTAG, 2014). The AMBI is effectively a ratio between the proportion of disturbance sensitive and tolerant taxa within a sample (Borja & Muxika, 2005). For the Outer Dowsing assessment it was concluded that the degree of disturbance from anthropogenic pollution was unlikely to have differentiated the clusters derived from multivariate analysis, due to the overlaps in AMBI score between the cluster groups (GeoXYZ, 2023).

Previous studies have shown that AMBI is useful when comparing the ecological quality of the soft-bottom benthos in environmental impact studies (Muxika *et al.,*2005), however, it may be more appropriate for detecting potential effects along organic enrichment gradients as it accounts for the tolerance of species to increased concentrations of organic compounds. It has been indicated that AMBI is potentially less useful in naturally stressed and poor communities such as high hydrodynamic energy areas and subtidal sandbanks (Muxika *et al.,* 2005), and these habitat types are often characteristic of OWF sites so further clarity is required to determine how useful this metric could be for assessments for OWFs. It is known that following colonisation of turbine foundations, especially by mussels, organic matter can accumulate local to the structures (Dewsbury and Fourqurean, 2010; Coates *et al*., 2014). Due to the sampling stations for OWF monitoring surveys often being located some distance from turbine foundations, however, it is unclear if any trends in relation to concentration of organic compounds with increased distance from turbines could be detected via AMBI.

Multivariate AMBI (M-AMBI) is calculated by combining the AMBI score, Shannon-Wiener Diversity (H') and species richness (S), (Fitch *et al*., 2014). M-AMBI was recently applied to assessment of natural gradients and low oxygen stress in an estuarine environment, however, results were inconclusive and it was determined that M-AMBI demonstrates potential at smaller, local scales, but additional studies are needed to validate its performance in different coastal environments and under different conditions (Paul *et al.,* 2023).

4.3.1.3. Infaunal Quality Index (IQI)

The IQI was not applied in the reviewed post-construction monitoring reports for OWFs. It assesses the ecological status based on the soft sediment infaunal communities and forms the basis for Water Framework Directive assessment. This metric is sensitive (i.e. able to detect slight change) to nutrient enrichment, chemical pollutants and physical disturbance (i.e. smothering) (Phillips *et al.,* 2014). IQI is calculated by comparing three ecological metrics (AMBI, Simpsons Diversity Index and Species Richness). Each value is compared to a reference assemblage metric based on the sample's salinity and sediment statistics (Phillips *et al.,* 2014). The results are reported as an Ecology Quality Ratio (EQR) value with different value ranges representing ecological status of Bad, Poor, Moderate, Good or High (WFD-UKTAG, 2014). The waterbody IQI classifications are used within the EU Marine Strategy Framework Directive.

The potential use of the IQI for offshore wind developments was assessed by Moore (2023) and it was applied to data sets for Burbo Bank, Gunfleet, Greater Gabbard and Walney offshore wind farms to compare data pre-construction and one year post-construction. Although benthic community assemblages were indicated to differ significantly between pre and post construction following multivariate analysis, it was found that there was no significant change in the ecological quality ratio (EQR) between pre and post construction for each wind farm (Moore, 2023). It was concluded that the IQI metric may be limited at detecting benthic community quality change at a waterbody level due to construction and operation of OWF developments (Moore, 2023).

4.3.1.4. Benthic Ecosystem Quality Index (BEQI)

The Benthic Ecosystem Quality Index (BEQI) adopts a multilevel ecosystem approach (Coates *et al.,* 2015) and consists of three levels:

1. The level of the ecosystem (e.g. water body)
2. the subsequent level with the distribution of habitats
3. the level that determines the benthic habitat quality

Level 3 evaluates the difference in benthic parameters (density, biomass, number of species and species composition) between two data sets. The difference between the two datasets is expressed as Ecological Quality Ratio (EQR), scaled between 0 and 1. An EQR value below 0.6 indicates the difference between the two data sets to be large and unwanted, requiring a detailed analysis of the outcome. Additionally, the BEQI tool is used to carry out an assessment confidence (statistical power) of each parameter, based on the probability of creating a Type II error, depending on the variance in the data, the effect size and the choice of the significance level (0.05 in the BEQI—tool).

Coates *et al*. (2015) applied the BEQI to investigate recovery of the microbenthic community following dredging activity and it was concluded that the application of benthic indices such as BEQI, provide a fast tool to determine if changes are acceptable or not (e.g. Borja *et al*. 2011).

4.3.1.5. ABC Curves

Abundance–Biomass Comparison (ABC) models are tools for detecting the effects of anthropogenic perturbation of biological communities (Warwick, 1986). ABC models are underpinned by the r- and K-selection theories and involve plotting k-dominance curves (Lambshead *et al*., 1983) along with k-biomass curves on the same graph for comparative purposes.

Taxa are ranked on a logarithmic scale on the x-axis, with cumulative percentage dominance (in terms of abundance and biomass) displayed on the y-axis. Taxa are displayed in a different order on the x-axis for the abundance and biomass curves. Hence, taxa identities do not match up and the model should be read by separately considering the dominance structure of the community captured for abundance and biomass (Warwick, 1986).

4.3.1.6. Biological trait analysis

A trait-based approach to data analysis has the potential to identify the impact that the presence of the OWF may have on functional diversity and ecosystem functioning (Boutin *et al.*, 2023). Biological traits analysis uses a series of life history, morphological and behavioural characteristics of species present in assemblages to indicate aspects of their ecological functioning. Changes in the patterns of trait expression within benthic assemblages (for example changes in the relative abundance of taxa exhibiting the traits), can be used to indicate the effects of disturbance on ecological functioning (Bremner *et al*., 2006).

One method for extracting trait-based information from benthic data is by using the Cefas data set 'key biological traits of marine benthic invertebrates surveyed in Northwest Europe' (Clare *et al.,* 2022). The data set can be used to match the relevant functional traits to the collated benthic species recorded during the OWF monitoring. Species within samples can be assigned to groups for the following biological traits according to their behavioural, morphological and reproductive characteristics (see biological trait descriptions in Clare *et al.,* 2022).

- Maximum size;
- Morphology;
- Lifespan;
- Egg development location;
- Larva development location;
- Living habitats;
- Sediment position;
- Feeding mode;
- Mobility; and
- Bioturbation.

A biological trait-based analysis has the potential to identify shifts in benthic community composition due to disturbance effects and associated changes in functional diversity and the analysis can be tailored to detect specific functional changes reflective of disturbance impacts from OWF construction. This type of analysis may be a useful tool in OWF monitoring as it would be complimentary to traditional analyses that focus primarily on abundance and diversity, so has the potential to provide a more complete picture of OWF disturbance effects.

4.4. RQ1: Conclusion for project stage gate

Consequently, it is recommended that the current suite of frequently applied metrics is retained, but supplementary metrics could also be calculated from the benthic ecology data sets to provide some additional information which could inform understanding of wider ecosystem level changes at a local and regional scale. Of those indicated above, ITI information could be provided for example, to indicate whether there are notable changes in the dominance of particular types of feeding class (filter feeders, deposit feeders (surface and sub-surface)) associated with changes in community composition, or this could be included in broader biological trait analysis. Similarly, there is scope for further exploration of the usefulness of AMBI to demonstrate changes in conditions (from undisturbed to disturbed) which is mainly associated with organic enrichment gradients. This is particularly applicable noting potential localised increases in the level of deposition of organic compounds around turbine foundations, especially when there are high levels of colonisation of blue mussels.

These options for further analysis to investigate this question are discussed in more detail in the 'Data mapping summary report' (APEM, 2025).

5. RQ 2: Is there a measurable change (increase/decrease) in biodiversity and/or species composition?

5.1. Background

As mentioned in the response to RQ1, previous pre- and post-construction surveys have often adopted a multimetric approach to identifying changes to benthic habitats over time (Borja *et al.,* 2011, Coolen *et al*. 2022). For this research question, the focus was on identifying where measurable change has been recorded in sediment composition or species/community composition post-construction at OWF developments. Reports from post-construction surveys were reviewed for constructed OWF developments to assess whether any measurable changes were detected after installation and how data were evaluated to determine such changes.

The development of OWF infrastructure can lead to both temporary (short-term) and permanent (long-term) disturbance effects and impacts on benthic environments. Temporary impacts and effects can be associated with short-term construction or maintenance activities such as cable burial techniques (e.g. jetting or dredging), the use of anchors, jack-up rigs and pile driving. Impact pathways from these activities include penetration and/or abrasion of the seabed, changes in suspended sediment and generation of underwater noise and vibration. Permanent benthic changes identified directly within or around the footprint of the marine infrastructure associated with OWFs (localised changes) are caused by the direct placement of infrastructure onto the seafloor, leading to a permanent loss of existing habitat (often soft sedimentary habitat) replaced with artificial hard substrate (e.g. concrete foundations, rock scour protection), and a shift in community composition and biodiversity can occur (Coolen *et al*., 2022).

Marine flora and fauna have been observed to rapidly colonise the hard structures of OWF developments, often leading to increased species diversity and biomass dominated by epifaunal species (Coolen *et al.,* 2022; Wilhelmsson and Malm, 2008) (also see response to RQs 3-5 (Sections 6 to 8) for more detail). This is often the most visually apparent aspect of ecological change at OWFs, and one or more surveys of colonisation of foundation structures were conducted for seven of the 18 OWFs for which pre- and post-construction monitoring reports were reviewed (Table 2).

The colonisation of a physical structure above the seabed can also lead to changes in local biodiversity and trophic interactions, altering the surrounding habitats adjacent to the OWF structures. This is caused by a change in hydrodynamic patterns, scouring, sediment dynamics and organic matter build-up leading to shifts in benthic biomass, diversity, and composition (Duzbastilar *et al.,* 2006; Wilhelmsson and Malm 2008). An increase in total organic matter from material that originates from fish and other organisms on and around the turbine foundations can cause changes in macroinvertebrate species assemblages and influence sediment chemistry (Bomkamp *et al.*, 2004; Falcão *et al.*, 2007), and notable changes in benthic habitats up to a 100 m radius from OWF infrastructure have been recorded (Hutchinson *et al.*, 2020).

The placement of offshore wind developments is also associated with more widespread impacts to benthic habitats. This includes hydrodynamic changes (water flow) leading to impacts on stratification, and water column mixing, sediment movement (e.g. sediment movement, smothering and siltation rates), as well as impacts of noise and vibration and electromagnetic fields for infauna and epibenthic species (Bailey *et al*., 2014). Further information on localised and regional ecological effects associated with OWF infrastructure is presented in the response to RQ3 (Section 6).

Consequently, there are a number of potential impacts due to OWFs which could potentially influence benthic species/habitats. Post-construction monitoring surveys for OWFs are usually designed to address specific consent requirements, and can be modified based on e.g. specific requirements for certain habitat types. Ultimately, however, the main purpose of the post-construction monitoring surveys is to determine whether any changes observed in sediment type or benthic communities (as required based on conditions for consent) are due to the construction and the presence of the wind farm. There are standard best-practice approaches to benthic survey design (e.g. Noble-James et al. 2018), and part of this assessment considers approaches undertaken for the OWFs considered in this review.

5.2. Metrics used to detect change

A range of metrics are used to detect changes in biota and sediment for OWF monitoring programmes as outlined in the response to RQ1 above. Key metrics are summarised below.

5.2.1. Biota

The metrics commonly used to identify biotic changes in benthic environments are summarised below;

- Abundance/Density
- Species/Taxon Richness
- Habitat distribution and composition
- Univariate diversity metrics
    - Shannon-Wiener Diversity Index (H’)
    - Pielou’ Evenness Index (J’)
    - Margalef’s Species Richness (d)
    - Simpson’s Diversity Index (1-λ)
- Multivariate analysis
    - Cluster analysis and non-Metric Multidimensional Scaling (MDS)
    - SIMPER
    - RELATE & BEST (BIO-ENV)
    - ANOVA
    - ANOSIM
- Biomass
- Phyletic composition
- Species/habitats of conservation importance
- Indicator species
- Non-native species
- SACFOR abundance scale

A combination of univariate and multivariate analysis methods is often used to detect potential shifts in abundance of different taxa and community composition (including changes in biotope allocation and distribution).

5.2.2. Sediment

Benthic habitats and the associated species assemblages are intrinsically linked to sediment type and physico-chemical factors including depth, turbidity, organic matter and contaminants in the marine benthos (Manokaran *et al*., 2022). The metrics commonly used to identify changes in sediment and the associated physico-chemical parameters for benthic environments are summarised below:

- Particle Size Analysis (PSA); and
- Physico-chemical data

5.3. Assessment of measurable change: Criteria considered

Although many of these metrics were calculated and referred to in the majority of the post-construction monitoring reports reviewed (Annex 1a), how they have been considered and how the information has been presented varies considerably across the reports for the different OWFs.

To examine consistency in approach across different reports in more detail, some key aspects applicable to the design of benthic ecology surveys and of relevance to OWF post-construction monitoring were determined. Consequently, information relating to the following four aspects was reviewed for each post-construction monitoring report:

- Survey design and statistical approach
- Methodology
- Correlation analysis
- Power analysis

Further detail associated with consideration of each of these aspects is provided below.

Information for each aspect has been tabulated for each monitoring report reviewed, identifying how each monitoring programme applied the above criteria and summarising any key additional information (Annex 1b).

5.3.1. Survey design and statistical approach

A key challenge in measuring change in ecological assessment is the ability to isolate human-induced effects from potential natural variability associated with ecosystem structure and function. Monitoring surveys should be designed to enable the distinction between anthropogenic effects and natural variation and allow the application of appropriate statistical tests to measure significant change.

The Before/After/Control/Impact (BACI or beyond-BACI) approach is often applied for sampling design and analysis methods to detect potential effects of human impacts from natural variability (Osenberg & Schmitt, 1996; Terlizzi *et al*., 2005). In this approach, a potential impact (e.g. from the construction and operation of an OWF) or no impact can be detected based on statistical comparisons of data for potentially impacted areas (e.g. within the wind farm or cable route) and reference (control) stations located beyond the potential zone of influence of the wind farm project. For many of the reviewed OWF post-construction monitoring survey programmes, as well as allocating reference stations to apply the BACI approach, stations were also allocated to primary/secondary and sometimes tertiary impact zones (areas within the predicted OWF zone of influence) with the aim to detect potential changes in each of these areas.

In general, based on the reports reviewed, reference stations frequently made up approximately 15-25% of all sampling stations (see Annex 1b), and a percentage towards the higher value of this range would provide more information to help detect change than the lower values. However, there is no specific guidance for a preferred proportion of reference stations for OWF monitoring, or benthic ecology monitoring in general. Some key considerations when assigning reference stations are provided in Noble-James *et al*. (2018).

The various considerations associated with sampling design were outside the scope of this review and, therefore, differences in sampling design between OWF monitoring programmes were not assessed. Noble-James *et al.* (2018) presents JNCC's best practice guidance for survey design for the monitoring of marine benthic habitats. Sampling design selection can depend on a number of factors that would be unique to the specific sampling site, such as the heterogeneity of sediments and environmental pressures across the survey area (Noble-James *et al.* 2018). A range of sampling design options (e.g. simple random, stratified random and systematic sampling) are typically recommended depending on project-specific considerations (Noble-James *et al.* 2018; Parker *et al*. 2022a, b and c).

Statistical analysis testing methods, including the traditional analysis of variance (ANOVA) and analysis of similarities (ANOSIM) methods, are widely adopted for detecting post-impact changes within environmental studies (Clarke, 1993). Univariate tests can be applied to conduct pairwise comparisons for a given response variable (metric), e.g. comparing total abundance across years, while multivariate cluster analyses/nMDS approaches can reveal groupings of stations and degree of similarity/dissimilarity between stations based on community composition. In addition, multivariate techniques such as ANOSIM/PERMANOVA can be applied to indicate more complex interrelationships for a given metric between grouped stations (such as stations in the OWF or cable route, primary or secondary impacts zones, reference stations) and a factor (e.g. survey years). Guidance documents such as the Natural England Phase I and Phase III best practice advice documents (Parker *et al.* 2022a & 2022b) can be referred to when considering the preliminary processing and analysis of benthic survey samples, including the use of multivariate indices to measure metrics such as diversity and species richness.

For the purposes of this review, the main assessment criteria considered for survey design and statistical approach were:

- Has a clear distinction been made between potential 'impact' zones (within the construction/development area) and 'reference' areas (outside the predicted Zone of Influence) stations?
- Have suitable statistical analyses been carried out to determine whether changes (temporal or control vs impact) are statistically significant for hypothesis testing (e.g. application of ANOSIM)?
- Does the interpretation in the report comment on whether changes in biodiversity/composition have also changed the underlying habitat type and/or the extents/areas of a particular habitat?
- Does the interpretation include a robust assessment on whether observed changes represent natural variability or result from anthropogenic impacts?
- Has any comparison been made to additional historical or external data/reports for the area which are not related to the project-specific survey regime, to further contextualise the results?

Key information in relation to these aspects has been indicated in the table in Annex 1b.

5.3.2. Methodology

A primary consideration is the design of a given monitoring programme, and how effectively it has been set up to detect a measurable change, accounting for spatial and temporal replication. Marine biodiversity and species assemblages can vary greatly according to location, the time of year (seasonal), and between years (Buckland *et al*., 2005). Consequently, there needs to be a sufficient number of stations within the OWF site and any other zones of interest, including reference areas, to detect change, ideally representing a range of habitat types in those areas. Replicate samples would usually be collected at each monitoring station to allow for application of more robust statistical analysis.

Integral to survey design is repeatability of the survey to limit interference from any external factors (i.e. any impacts other than the OWF development itself) that may compromise results and reduce the reliability of the findings to address hypotheses being investigated (Beard *et al.,* 1999). Therefore, for sampling at an OWF consistency is required in terms of survey methods (which should follow best practice approaches), sampling locations, number of sampling stations, number of replicates collected, and laboratory analysis methods. In addition, any repeat sampling should be conducted at the same time of year as far as possible (Parker *et al*., 2022c). Notes on each of these aspects have been taken for the reviewed OWF post-construction monitoring reports and the main assessment criteria considered were:

- Have surveys been carried out using consistent methodology (same locations, same number of sampling stations/replicates)?
- Has sampling been carried out at the same time of year (to eliminate potential seasonal effects)?
- Has the benthic and/or PSA samples been analysed using consistent laboratory methodologies (taxonomic resolution etc.) in each year and if not, has this been accounted for in the interpretation?
- Have multiple methodologies been used and interpreted in the context of one-another (e.g. benthic grabs, physico-chemical, DDV, geophysical)?
- Has monitoring data been collected for more than one year post-construction?

5.3.3. Correlations with environmental variables

Correlation analysis is a statistical test used to identify and investigate linear relationships between two variables. To understand how marine faunal abundance/assemblages interact with the physical environment, the linear relationships for biodiversity/species composition to changes in physical data (sediment composition, depth, hydrology, contaminant concentrations) can be studied using correlation tests such as RELATE or BEST (Bio-Env). These tests aim to identify the best subset of environmental variables which maximises the correlation between community and environmental distance (Clarke and Ainsworth, 1993; Turunen *et al.,* 2021).

The main aspect considered for correlation analysis was:

- Has the study correlated any observed changes in biodiversity/species composition to changes in physical data (sediment composition, depth, hydrology, contaminant concentrations) using RELATE or BEST (Bio-Env) tests or an equivalent correlation?

5.3.4. Power analysis

Power analysis is an important step within the design process of scientific experiments and studies. This step aims to determine the minimum sample size required to detect an effect with a certain degree of confidence. The key components of power analysis involve statistical power (the probability that a false

H_0 will be correctly rejected), sample size (number of observations), significance level (alpha), and effect size (magnitude of the difference or relationship being studied), (Cohen, 1992).

Franco *et al*. (2015) analysed data for a number of UK wind farms and determined that based on the average sampling effort applied in the OWF case studies (4 stations per impact type area and 3 replicates per station), the studies had sufficient power to detect a ≥50% change between areas in mean benthic species richness. Due to their higher variability, more stations per impact type area were required to reliably detect a ≥50% change between areas for mean benthic abundance (5 stations per area) and mean biomass (10 stations per area). It was determined that a much higher sampling effort would be required to detect a 10% change in these parameters (Franco *et al*. 2015).

The assessment criteria for power analysis was:

- Has any kind of *post-hoc* power analysis been carried out to assess whether the sampling design is sufficient to detect a pre-determined level of change (sufficient numbers of samples/replicates)?

5.4. Results

Overall, the monitoring programmes for 18 constructed OWF developments were reviewed for this research question (Table 2). The survey reports chosen for review from each monitoring programme included pre-construction (where available) and post-construction benthic monitoring reports, and post-construction monopile colonisation reports (with assessment of colonisation of turbine foundations included in monitoring programmes for seven OWFs). The results of the assessment are presented in Annex 1b and a summary of the main findings is presented here.

5.4.1. Statistical approach

There was variation in sample zones, with a range of primary, secondary and tertiary impact zones used throughout monitoring programmes (Annex 1b). The primary impact zone generally covered the areas within the array area or cable route extent that were considered likely to be subjected to more direct effects due to the OWF. Second and tertiary impact zones were often used to monitor effects within the tidal excursion areas located outside the primary OWF array area.

The use of reference (or control) and impact zone (or zone of influence) sampling stations to detect measurable temporal and spatial change was applied for all 18 OWF monitoring programmes. The reasoning for locations of reference stations was not always stated, but in a number of reports they were indicated to be beyond the limit of a tidal excursion. The number of reference stations used in each monitoring programme varied from two to 18 reference stations and this ranged from 3% to 50% of all sampling locations surveyed per OWF, however, for many of the OWFs the number of reference stations allocated represented 15-25% of the stations. Survey stations were sampled along the cable route for 13 of the 18 OWF monitoring programmes.

For 14 of the monitoring programmes, monitoring reports indicated that statistical tests for significance, such as ANOVA or ANOSIM, were performed to investigate significant temporal change between survey years and spatial variation between the OWF development site (array area/export cable corridor) and reference stations. Where statistical tests were undertaken, however, the level of detail provided was varied.

Variability in the direction of change in sediment particle size, invertebrate abundance and taxon richness when comparing results for pre-construction with post-construction and for multiple post-construction monitoring surveys is highlighted in Annex 1c. Based on the variability in changes observed and comparing data available for the OWF (and other potentially impacted stations) and reference stations, all of the OWF development monitoring programmes concluded that the observed changes in benthic infaunal community structure and biodiversity at the OWF array and export cable corridor were likely a result of natural variability alone.

Comparison with available local or regional datasets outside the OWF studies was included in reports for six of the OWFs, although it is appreciated that in some areas historic data from other sources may not have been available.

5.4.2. Methodology

The most commonly applied survey method for collecting benthic data was benthic grab sampling (biota and sediment analysis) which was integral to the monitoring programmes for all 18 OWFs reviewed. This was followed by trawls (beam trawl or rockhopper) for epibenthic sample collection which was applied at 12 OWF sites and underwater imagery of the seabed using DDV survey (ten OWF sites). Colonisation of monopiles was monitored by ROV for two OWFs, and diver survey for five of the OWFs (Table 2).

In nearly all cases methods were deployed using consistent approaches across surveys, including station locations, and where this did vary it was clearly indicated in the survey reports. This was also the case in terms of seasonality of sampling, with repeat surveys at the same time of year conducted as far as possible.

For 14 of the OWFs, data were available from multiple years of survey usually with two to three surveys conducted, although the frequency of monitoring surveys varied from every year, to once every five years for ten years (Greater Gabbard OWF) and the longest timeframe over which surveys were conducted was 15 years (Princess Amalia OWF), (Table 2).

5.4.3. Correlation with environmental variables

PSA data were collected within all monitoring programmes whilst physico-chemical data, such as Total Organic Carbon (TOC) and Total Organic Matter (TOM), were recorded for 14 of the OWFs.

Eleven out of the 18 monitoring programmes (61%) correlated observed changes in biodiversity/species composition to changes in recorded physical data using RELATE or BEST (Bio-Env) tests (Annex 1b).

5.4.4. Power analysis

The use of *post-hoc* power analysis to assess the appropriate survey sample size was not specified in reports for any of the monitoring programmes.

5.5. Discussion

According to the monitoring reports reviewed, changes in sediment particle size or community parameters such as abundance and taxon richness were observed at a number of wind farms and changes were not in a consistent direction at a number of the sites (see Annex 1c). Consequently, there were measurable changes in biodiversity and / or species composition.

In all instances, however, any changes identified at the OWFs were attributed to natural variability. This was often based on similar trends being observed at reference stations and in some cases also taking account of inconsistent directions of change of parameters when multiple post-construction monitoring surveys were conducted.

Changes attributed directly to the presence of OWFs were primarily documented within colonisation reports which surveyed fouling communities on OWF structures.

5.5.1. Changes in benthic communities

Overall, the majority of OWF monitoring programmes recorded temporal changes in benthic infaunal species/habitats for impact zones and reference stations. Changes were often associated with differences in abundance and diversity leading to shifts in faunal community assemblages/biotopes. Similar conclusions were documented for the majority of OWF sites, with slight variants of similar benthic communities identified over time and often fluctuations in the relative dominance of a small number of taxa were driving the patterns observed. This is not an unexpected finding as the OWF development areas are often situated in exposed environments subject to high degrees of sediment disturbance. This results in a relatively unstable benthic community that fluctuates naturally over time, characterised by species tolerant to high levels of sediment disturbance.

As an example, at the Kentish Flats OWF site it was found that polychaetes and molluscs generally dominated stations across survey years (EMU, 2006; 2007; 2008c). However, a slight reduction was observed in polychaete species density over the four-year monitoring period, as well as fluctuations in abundance of dominant mollusc species over that time. Such changes in dominant species abundance led to variation in biotope allocation. Statistical analysis of pre- and post-construction matrices found a high level of overlap in terms of the species present and fluctuations were attributed to natural variation.

Significant changes in sediment composition and physical-chemical parameters were observed throughout a number of monitoring programs. However, these changes did not appear to impact benthic community structure across sites. For example, results from some surveys indicated an increase in TOC within the wind farm area which was attributed to the potential for decreased water movement due to the presence of turbine structures and organic matter accumulated below large mussel *Mytilus edulis* aggregations that had colonised monopile structures (e.g. RPS energy, 2014; Bomkamp *et al.,* 2004; Falcão *et al.,* 2007; Alonso-Pérez *et al*., 2010). Where abundance of infauna was correlated with increased TOC it was noted that similar changes in abundance had been recorded at stations where TOC had not changed. Similarly, a change to sediment composition within the impact zone of the Burbo Bank OWF development area was observed over time, with a significant increase in the proportion of silt. Such changes in sediment composition appeared to have no significant impact on benthic community structure and evidence suggested that increased silt was a result of natural sporadic sediment influxes that could not be attributed to the presence of the windfarm (Seascape energy, 2011).

The proportion of reference stations compared to stations within the OWF impact zones varied greatly between monitoring programmes. Reference stations were typically placed in broadly similar habitats to those inside the OWF and cable corridor impact zones, and the maximum distance of tidal excursion was often used to differentiate reference and impact stations (as recommended by CEFAS, 2004). However, such information was not always documented clearly in reports. As indicated in Section 5.4.1, the proportion of reference stations varied considerably across wind farms. This did not influence the conclusions of natural variability driving change for each OWF although in some instances reservations were indicated about the number or suitability of selected references stations. It can be difficult to allocate reference stations that have the same sediment type/environmental conditions as the OWF site, especially when they are located at a distance beyond a tidal excursion. Where only one pre-construction monitoring survey has been conducted, however, the trends at the reference stations provide the only data for comparison with changes at the OWFs or cable routes. Consequently, for limited additional survey effort it is recommended that sufficient consideration is given to the location and number of reference stations to provide a robust basis for conclusions when considering changes due to natural variability.

Power analysis was not detailed in monitoring reports to assess sampling methods. This may suggest that power analysis was either not applied during the survey design of monitoring programmes to determine sample size to detect a measurable effect size, or it is possible that power analysis was undertaken but not referenced within the survey report methods. If power analysis was not undertaken, the sampling design lacks evidence to support a minimum sample size to detect an effect with a certain degree of confidence (Cohen, 1992). The use of power analysis before monitoring commences is recommended to ensure there is sufficient statistical power for subsequent analyses to detect meaningful changes (Parker *et al*. 2022c). It is noted, however, that regulators do not provide set guidance on the level of change to be detected and this will need discussion on a project-specific basis. In addition, to conduct power analysis, knowledge of the variance estimate for the sample population is required (although this can be obtained from baseline data or pre-construction monitoring data). It is appreciated that using power analysis when monitoring such large study areas could generate a very large number of proposed stations, depending on the level of change targeted, and professional judgement may then need to be applied to develop a practicable monitoring programme in consultation with relevant stakeholders (Parker *et al*. 2022c).

Image and video analysis accompanied grab and/or trawl data for under half of the OWF monitoring programmes. The requirements for image and video analysis were largely linked to monitoring epibenthic communities, identifying broader habitats present in the survey areas, as well as notable species and protected habitats, such as *Sabellaria spinulosa* reefs and horse mussel beds *Modiolus modiolus*. The requirement for such monitoring was typically a result of previous observations indicating the presence of species/habitats of conservation importance during historical, baseline or pre-construction surveys.

The use of underwater video to gather footage of the seabed to supplement grab data is beneficial in terms of providing additional information to determine changes in epifaunal abundance and diversity within wind farms, and providing a wider view of potential changes in ecological function of benthic communities in the vicinity of turbine foundations and other areas of potential impact. The outputs, however, are often less amendable to statistical analysis than more quantitative sampling methods.

5.5.2. Colonisation of turbine foundations

Turbine foundation colonisation reports were available for seven of the reviewed OWF developments and all survey conclusions revealed that encrusting faunal assemblages had colonised the introduced structures. The largely epifaunal communities recorded differed considerably to the infaunal dominated communities in the surrounding soft sediment habitats.

Results from all seven post-construction colonisation reports, used imagery/video footage to demonstrate that the entire subtidal length of turbines had been rapidly colonised by marine species within one to three years post-construction (EMU, 2008a, 2008b; Bunker, 2004; Seascape Energy, 2009; APEM, 2021, 2022; CMACS, 2013; Vanagt *et al*., 2013). This included faunal turf and aggregations of species such as the blue mussel *M. edulis* and the plumose anemone *Metridium senile*, which supported diverse communities including mobile epifauna. Taxon diversity and invertebrate abundance was notably higher on, or very close to, OWF structures compared to surrounding areas.

There was some variation between foundations at the different wind farms and some differences noted between OWFs, for example at Greater Gabbard OWF formation of a crust of *Sabellaria* spp. was recorded on one of the turbine foundations (CMACS, 2013). In general, however, the changes recorded reflected similar findings for previous research studies on fouling communities for offshore wind (Wilhelmsson and Malm, 2020; Coolen *et al*., 2022) whereby foundation structures were rapidly colonised by species of mobile crustaceans and molluscs such as *Mytilus* spp. within one to two years after construction (further information is provided in the response to RQ3 (Section 6).

Biological zonation on monopile structures was consistently documented within each foundation colonisation monitoring report. Green algae and barnacles often covered the upper to middle intertidal zone of the monopile structures, followed by a band of dense mussel aggregations, typically *M. edulis*. Associated with these mussel aggregations was a diversity of species, such as the common starfish *Asterias rubens,* the plumose anemone *M. senile,* and several small crustacean species. As depth increased into subtidal areas, mussel aggregations decreased and a gradual increase in coverage of species such as *M. senile* and short hydroid turf was observed. Many of these species are commonly found on hard substrata in UK coastal areas and were most likely recruited from nearby locations (Bunker, 2004).

Concerns have been raised regarding the potential for OWF structures to act as 'stepping stones' contributing to the spread of non-native species (Adams *et al.,* 2013; Johnston *et al.,* 2017; Castro *et al*., 2022). Out of the seven sets of OWF monopile colonisation reports reviewed, five did not indicate the presence of non-native species. The only non-native species identified in the reviewed colonisation survey reports were the modest barnacle *Austrominius modestus* (previously *Elminius modestus*) and leathery sea squirt *Styela clava* recorded at the Kentish Flats OWF, as well as the Japanese skeleton shrimp *Caprella* mutica recorded on one of the turbines 6 years post-construction at the Princes Amalia OWF (further consideration of non-native species is provided in the response to RQ3 (Section 6).

5.6. RQ2: Conclusion for project stage gate

The review of post-construction monitoring reports for RQ2 has indicated changes in sediment particle size and benthic community parameters such as abundance and taxon richness have been recorded between pre- and post-construction monitoring surveys at many OWFs; and no detectable change in these parameters has also been recorded for a number of OWFs (Annex 1c). The primary consideration, however, in terms of determining potential for effects on benthos due to the construction and presence of an OWF is that in all cases the changes observed were attributed to natural variation. In some cases this was supported by observations from a relatively low number of reference stations (e.g. <15%, see Section 5.3.1 for further details about proportions of reference stations for monitoring surveys).

There are a number of potential options for further analysis that could be considered to investigate this question further in later stages of the project. One such option, for OWF sites where a complete dataset is available (comprising all data from pre- and post-construction surveys), data could be re-analysed to perform a multi-site analysis to identify and compare potential trends in benthic community structure after construction of multiple OWF sites. Such analyses have been conducted previously, for example Coolen *et al*. (2022) analysed biodiversity changes across multiple wind farms and correlated them with spatial and temporal patterns, identifying trends that were not evident with single monitoring studies.

The analysis options presented for RQ1 in Section 4.3 above also have the potential to be used to further investigate RQ2. These considerations are discussed in more detail in the 'Data mapping summary report' (APEM, 2025).

6. RQ3: Are there localised and regional ecological effects around the infrastructure?

6.1 Background

The development of OWFs is increasing as a sustainable energy solution, but their installation and operation can cause significant changes to the surrounding shelf sea environment, which can be important for global productivity and carbon cycling (Mackenzie *et al*., 2004). These changes can be categorised into localised and regional effects on benthic communities, which are crucial for maintaining the ecological balance of coastal and shelf ecosystems (Isaksson *et al*., 2023). Understanding the impacts of OWFs on benthic habitats is essential for evaluating their potential ecological consequences and informing future management strategies.

In the context of this review, "local" refers to the area within, and in the immediate vicinity of the project site (i.e. within a few miles or kilometres) and to ecosystems that are directly affected by the project's construction, operation, and maintenance. The term "regional" refers to the broader geographical area or territory that extends beyond the immediate location of an offshore wind project and may be subject to more indirect impacts associated with OWFs.

In addition, “effects” are interpreted as physical modifications to environmental parameters (e.g. changes to substrate characteristics, hydrodynamic regimes, sediment chemistry), and “impacts” as the consequences experienced by ecological components (species, communities) or ecological functioning (nutrient reworking, functional roles, energy transfer) as driven by a particular effect(s) (following Boehlert and Gill, 2010).

Localised effects, in the immediate vicinity of turbine structures, typically arise from the presence of OWF structures and the associated construction processes, which alter the physical environment and disturb existing benthic communities. These effects can include changes in habitat complexity, sediment dynamics, water flow patterns and substrate availability, leading to shifts in species composition. The development of biofouling communities on hard structures can contribute to changes in local biodiversity and trophic interactions, while regional effects encompass broader-scale impacts, such as changes in species distribution, nutrient cycling, and potential long-term shifts in biodiversity. Regional impacts can be driven by factors such as altered hydrodynamic conditions, the introduction and spread of non-native species, and the creation of new ecological connections between different marine habitats.

To date, most fixed-foundation OWFs have monopile foundations (Lacal-Arántegui *et al*., 2018) and it is from such structures that the majority of effects and impacts have been studied. This review considers existing literature on the ecological effects of OWFs, focusing on benthic habitats, and sources include peer-reviewed studies, government reports and expert opinions with outputs based on field observations, experimental studies, and modelling techniques.

The key potential sources of impacts on benthic habitats/species at different stages within the life cycle of an OWF, at both local and regional scales, are summarised in Annex 1d and further detail is provided below.

6.2 Changes to flows, seabed and physical habitat complexity at regional and local scales

6.2.1 Installation of infrastructure and biofouling communities

Sand and coarse substrate represent some 94% of the total OWF site footprint in the UK (MRAG, 2023). These are soft sediments that are mobile at least some of the time due to background hydrodynamic forces. With wind farms planned further offshore, the substrates at wind farm sites are likely to become finer, and background hydrodynamic forces may be reduced. OWFs can therefore significantly alter physical habitat complexity through the introduction of artificial structures, including turbine foundations, scour protection and associated infrastructure.

Artificial installations can sometimes be referred to as 'artificial reefs' as they provide habitat and added refuge for species (e.g. Wilson, 2007; Langhamer, 2012; Nakata, 2020; Glarou *et al*., 2020). Technically, an artificial reef has been defined as 'a submerged structure placed on the seabed deliberately, to mimic some characteristics of a natural reef' (as per Jackson and Buceta Miller, 2009). Although OWF structures are not artificial reefs in this technical sense, they can mimic reef effects. The presence of OWF structures can result in the establishment of hard substratum communities on immobile turbines and scour protection rocks resulting in an increase in the number of taxa and abundance of biota in the respective area (De Mesel *et al*., 2015; Degraer *et al*., 2019; Dannheim *et al*., 2020).

OWF foundations and associated scour protection can act as new habitats that are quickly colonised, mainly by larvae of benthic species such as gastropods, bivalves, crustaceans, and polychaetes (Wilhelmsson and Malm, 2008; Zupan *et al*., 2023). OWF foundations and scour protection change the local environment from largely mobile soft-bottom habitats (gravely, sandy, silty, muddy sediments) characterised by infauna (which is often sparse in habitats such as sandbanks) to immobile hard-substrate ecosystems characterised by epifauna. This can alter the local biodiversity and ecological dynamics by favouring species adapted to rocky or artificial reef environments over those that rely on mobile sediment substrates. Species richness and abundance on hard substrates is usually higher than on mobile and softer sediment and will increase over time post-construction (e.g. Vanagt *et al*., 2013; Li *et al*., 2023).

Species not typically associated with mobile substrata, such as mussels, sea urchins, and anemones, have been recorded to contribute significantly to biomass increases, while smaller organisms such as amphipods have been reported to contribute to high densities on turbine foundations (Vanagt *et al*., 2013; De Mesel *et al*., 2015). Habitat-forming species such as mussels and reef-building polychaetes, regarded as ecosystem engineers, can further enhance complexity by creating complex, three-dimensional interstitial spaces that offer additional favourable microhabitats for smaller fauna (Gutiérrez *et al*., 2003; Yakovis *et al*., 2017).

Biofouling communities on OWF structures display typical vertical zonation, with algae and intertidal filter-feeding species such as mussels and barnacles dominating the upper zones of the turbine foundations, likely as a result of greater food availability (e.g. plankton and detritus) in the upper light penetration zone (De Mesel *et al*., 2015; Slavik *et al*., 2019; Kerckhof *et al*., 2019). Biofouling assemblages on turbines and scour protection rocks have been documented to progress through successional stages transitioning from pioneer (0 – 2 years), intermediate (3 – 5 years) and climax stages (6+ years), the latter typically dominated by species such as the blue mussel *M. edulis* and plumose anemone *M. senile* (Lindeboom *et al*., 2011; Vanagt *et al*., 2013). However, not all biofouling assemblages follow these patterns, with some communities still remaining unstable after 11 years, as has been shown in a study at Belgian OWFs (Zupan *et al*., 2023). This highlights that patterns of community succession and associated dynamics on OWF infrastructure are likely influenced by site-specific variation in biological and physical environmental effects.

For seven of the 18 OWFs for which post-construction monitoring reports were collated for the current project (Section 3.1), colonisation of the foundations structures was monitored. For five of these, reports were available for a single survey, usually 1-2 years post construction (EMU, 2008a, 2008b; Bunker, 2004; Seascape Energy, 2009). In general, patterns of colonisation reflected those indicated above, with an intertidal algae and barnacle zone, often extensive colonisation by blue mussels *M. edulis* near the top of the submerged monopile which usually gradually decreased in abundance with depth to be replaced by a higher abundance of plumose anemones *M. senile*, and near the bases larger epifauna were generally more sparse with biota including keel worms and barnacles. Where scrapes were taken, abundance was often dominated by the amphipod *Jassa* spp., with numerous other species present including other amphipods, isopods, hydrozoans and bryozoans. Starfish, sea urchins and crabs were often recorded on the foundation structures and around the bases while fish including flatfish were often abundant at the turbine base and fish were also recorded as being present along the foundations in some of the reports. There was some variation between foundations at the different wind farms and some differences noted between OWFs. For example, at Greater Gabbard OWF formation of a crust of *Sabellaria* spp. was recorded on one of the turbine foundations (CMACS, 2013). In addition, at the Beatrice OWF there was dense coverage of macroalgae including kelp in the intertidal and shallow sections of the foundation structures (as opposed to just filamentous green algae) and no mussels were present one year post-construction, with only a very small number recorded two years post-construction (APEM, 2021; 2022). For the two OWFs at which repeat surveys were conducted (one and two years for Beatrice with a final survey to be completed in 2025, and three and a half and six years post construction at the Princess Amalia wind farm in the Netherlands) patterns of colonisation were found to be very similar across the two surveys (Vanagt *et al.,* 2013; Vanagt and Faasse, 2014; APEM, 2021, 2022). In the case of the Princess Amalia wind farm it was suggested that biomass and density may have been close to their maximum after three years.

Installation of networks of turbines does not only represent introduction of additional hard substrata, but also potential stepping stones that may promote connectivity among populations of local and epifaunal non-native species (Section 4.2.2). The distributional capabilities of sessile benthic species are limited by the duration of pelagic larval stages, and installations have been shown to play a role in the dispersal of native benthic species (Dannheim *et al*., 2018; Henry *et al*., 2018; van der Molen *et al*., 2018). This may be particularly important when structures are placed at the distribution limits of certain benthic species (Adams *et al*., 2014). For example, Hiscock *et al*. (2002) noted that for the molluscs *Macoma balthica* and *Abra alba*, decreased flow rate may limit the dispersion of larvae, to the extent that they settle back into the parent population and are likely to be preyed upon by deposit feeders. However, studies quantifying these roles for OWF infrastructure are sparse, and much of what is currently known is from monitoring of offshore oil and gas installations.

Deposition from fouling communities on OWF structures can also enhance organic matter accumulation local to the structures (Dewsbury and Fourqurean, 2010; Coates *et al*., 2014). Coates *et al*., 2014 indicated a notable local increase in organic matter in samples 15 m from an OWF (2.5 ± 0.9%) compared to those collected 100 m away (0.4 ± 0.01%) which was accompanied by a significant decrease in sediment grain size and an increase in macrobenthic density (Coates *et al*., 2014). Effects may also be apparent at a regional scale, for example, it was predicted that for a future OWF scenario in the Belgian Coastal Zone the flux of TOC could increase by 50% in a 5 km area surrounding monopile turbines and effects could extend up to 30 km away from monopiles (Ivanov *et al*., 2021). This was based on the anticipated faecal pellet production resulting from the high densities of fouling organisms, in particular the mussel *M. edulis*.

SEER (2022) also noted that faecal matter from mussels or other epifaunal organisms that colonise the Block Island OWF in the United States was deposited in the surrounding sediment increasing the amount of total organic carbon and mineralisation rates. This has resulted in the sediment surrounding the foundations transitioning into a fine grained, organically enriched sediment, which supports a different benthic community in comparison to pre- installation. In a four year study, also at the Block Island OWF (Fonseca, 2025), it was found that significant changes in the benthic community only occurred in the immediate footprint of the turbines and no evidence was found for a progressive distance-dependent effect on benthic communities.

Increased scavenging opportunities can also change due to the presence of OWF infrastructure. Live mussels that detach from the structure can be deposited in scour pits and can attract scavengers such as starfish *Asterias rubens* and flatfish such as plaice *Pleuronectes platessa* and flounder *Pleuronectes flesus*. Significantly greater abundance of hermit crabs (*Pagurus bernhardus*) and brittle stars (Ophiurids) found within wind farms post-construction may be explained by greater scavenging opportunities when epifauna colonise monopiles (Bunker, 2004; Hiscock *et al*., 2002).

Localised increases in invertebrate abundance and subsequent attraction of scavengers and predators can also increase food availability for higher trophic levels (fish, birds, marine mammals) (Degraer *et al*., 2020), resulting in ecosystem-wide effects.

6.2.2 Non-native Species

The artificial hard substrata provided by OWFs can serve as vectors for epifaunal non-native species and facilitate their spread (Sheehy and Vik, 2010; Bulleri and Airoldi, 2005; Glasby *et al*., 2007), allowing them to extend beyond their natural ranges and connect otherwise isolated populations (Langhamer, 2012; De Mesel *et al*., 2015; Kerckhof *et al*., 2011). Here, we follow the definition of non-native (alien) species provided in Robinson *et al*. (2016), namely "species whose presence in a region is attributable to human actions that enabled them to overcome fundamental biogeographical barriers (i.e. human-mediated extra-range dispersal)".

While most non-native species are harmless, it is estimated that 10-15% of non-native species in Great Britain cause significant negative environmental, social and economic impacts, and these are termed invasive non-native species (Defra, 2023). The environmental impacts that invasive non-native species cause include direct and indirect competition with native species, the introduction and spread of novel diseases, and habitat alteration, leading to invasive non-native species being recognised as a major driver of global biodiversity loss (IPBES, 2023).

Artificial hard substrata are characterised by physical structural features that promote the settlement of non-native species (Mineur *et al*., 2012; Airoldi *et al*., 2015). Differences in community composition between natural vs artificial substrata also mean that the classic ecological structuring forces (i.e. biotic interactions like competition, predation, and parasitism), may be markedly different in communities on artificial substrata (Wilhelmsson and Malm, 2008) and in a natural rocky habitat, these biotic interactions may act to limit or prevent the establishment of particular species in the community. Indeed, many non-native species capitalise on empty ecological niches within artificial habitats (Kimbro *et al*., 2013; Godoy, 2019).

Non-native species are well-known to colonise offshore oil and gas installations (Fenner and Banks, 2004; Sammarco *et al*., 2004; Page *et al*., 2006; Braga *et al*., 2021; Kur *et al*., 2021). Oil and gas installations and OWFs differ significantly in their design, operation, and environmental impacts, meaning that direct comparisons may not be appropriate. Structurally, oil and gas platforms are centralised and designed for resource extraction, often involving extensive seafloor disturbance from drilling and pipeline installation (Cordes *et al*., 2016). In contrast, OWFs consist of dispersed turbines optimised for energy generation that inherently represent a network of colonisable substrata potentially acting as stepping stones for the dispersal and spread of epifaunal non-native species (Bulleri and Airoldi, 2005; Glasby *et al*., 2007).

Few studies have focused on explicitly reporting non-native species from OWFs, but De Mesel *et al*. (2015) has indicated occurrences of non-native barnacles, amphipods, crabs, oysters and limpets on Belgian OWFs. No non-native species were recorded within five of the seven sets of OWF monopile colonisation reports reviewed for the current project (Table 2; EMU, 2008a; APEM, 2021, 2022; Bunker 2004; Seascape Energy, 2009). Species in monopile colonisation surveys that were identified as non-native were the modest barnacle *Austrominius modestus* and a single leathery sea squirt *Styela clava* recorded at the Kentish Flats OWF (3 years following construction; EMU, 2008b), and the Japanese skeleton shrimp *Caprella mutica* and *A. modestus* recorded on one turbine structure of the Princes Amalia OWF (6 years following-construction; Vanagt and Fasse, 2014).

6.2.3 Impact on the benthos from changing flows and sediment transport capability

Variation in sediment composition (e.g. proportion of mud, sand, gravel) can support different benthic communities (Cahoon *et al*., 1999; Seiderer and Newell, 1999; Degraer *et al*., 2008; Cooper *et al*., 2011; Vanaverbeke *et al*., 2011; Coates *et al*., 2015; Lefaible *et al*., 2023), and biodiversity in soft sediment habitats can vary according to exposure to environmental stress. Coarse sand sediments exposed to high wave and tidal action are typically impoverished and can be characterised by opportunistic *Capitellid* and *Spionid* polychaetes and isopods, whereas fine sand communities are usually more diverse (Maddock, 2008) and can be characterised by polychaetes belonging to the families *Capitellidae, Cirratulidae, Glyceridae, Lumbrineridae, Serpulidae, Spionidae, Terebellidae* along with the phylum *Nemertea* (Cooper and Barry, 2017). Shifts in macrofaunal diversity are likely to have broad consequences for the entire system, and whilst the hydrodynamic aspects of impacts from OWF are not the focus of this review, any OWF-induced changes to sediment composition are expected to potentially influence benthic communities as indicated below.

During construction, benthic disturbance from displacement and suspension of seafloor sediment tends to be temporary, and recovery of the physical and biological conditions on the seafloor typically occurs within a few years (SEER, 2022). A study by Coates *et al*. (2015) distinguished OWF-related effects from natural variability using long-term datasets. The infaunal community at an impacted Danish sandbank demonstrated signs of stress during OWF construction, with dominance shifts in species like the polychaete *Nephtys cirrosa* and the amphipod *Urothoe brevicornis*. These changes were attributed to pre-construction dredging, which creates a sediment plume through the re-suspension of finer particles, resulting in increased abundance of opportunistic species such as the polychaete *Spiophanes bombyx* during the construction period, but communities returned to pre-construction states within 1.5 years (Coates *et al*. 2015). Such findings align with other studies in the North Sea and Mediterranean, where opportunistic species dominated shortly after disturbance, but some communities have demonstrated recovery within two years (van Dalfsen *et al*., 2000). While short-term impacts on soft sediment communities are evident, large-scale or long-term effects, particularly on higher trophic levels, remain uncertain (Kenny and Rees, 1996; Coates *et al*., 2015).

Post construction, marine renewable energy installations can change hydrographic conditions at a regional and local level. One driver of change at basin-scale is the impact from the wind field, resulting in changes to mean ocean current speed changes of less than 0.01 m s^{-1} and changes to mixed layer depths of less than 3 m (Daewel *et al*., 2022). Another driver of change comes from the flows interacting with the submerged components of the OWF infrastructure. The turbulent wake flows have variable large-scale impacts on circulation, stratification, water column mixing, and sediment resuspension, and effects can potentially be evident on a regional scale at distances of hundreds of kilometres from the wind farms (Baeye and Fettweis, 2015; Bailey *et al*., 2014; Forster, 2018; van Berkel *et al*., 2020). Locally, this flow diversion causes increased bed shear stress, both immediately below the monopile (Nielsen *et al*., 2010), and within a few tens of meters in the near-field (Austin *et al*., 2025). Such complex wake flow structure also drives changes in organic enrichment, which can influence the structure and complexity of benthic habitats (Donadi *et al*., 2015). Following review of 314 pieces of evidence on the effects of offshore wind farms, Watson *et al*. (2024) found no more than 10 studies on the effect of offshore wind farms on sediments, with most of those focused on sediment plumes and carbon storage (Ivanov *et al*., 2021). Through the ongoing ECOWind-ACCELERATE project, it appears that there is a dominant role of turbulence in assessing changes to seabed substrates away from wind farm monopiles, with effects on magnitude and extent of turbulence influencing sediment transport capability (Austin *et al*., 2025; Unsworth *et al*. 2022; Van Landeghem *et al*., 2023). These turbulent wake flows can drive changes in sediment composition through erosion, deposition, and the re-distribution of grain sizes if the original seabeds are heterogenous, either laterally or in the shallow sub-surface. Such changes to sediment grain size can have subsequent effects on benthic communities.

6.3 Ecological effects from Electromagnetic Fields (EMFs)

Little is known about the local and regional effects of Electromagnetic Fields (EMF) from subsea power cables on benthic species (SEER, 2022). The results from a study by Chapman *et al*. (2023), are consistent with the majority of the limited EMF work currently conducted for benthic species, indicating little to no effect on invertebrate species. In general, however, results of studies examining the effects of EMF on invertebrates have been mixed, within and across different species, life stages, and parameters measured (Albert *et al*., 2020; Scott *et al*., 2020), which highlights the need for more research within this field.

Transmission of electricity through subsea cables emits EMFs and both high voltage alternating current (HVAC) and direct current (HVDC) shielded cables directly emit magnetic fields into the environment. The same cables do not directly emit electric fields, but the magnetic fields induce electric fields when water or organisms move through them (Gill *et al*., 2012). These effects are anticipated to be highly localised to the cables, however, the strength of these fields comes within the detection range of electro- and magneto-sensitive species (Gill, 2005; Peters *et al*., 2007). With the expansion of offshore wind energy production, the deployment of subsea cables and their associated EMF emissions is set to increase. Cabling associated with OWFs that emit EMFs includes varied configurations of inter-array cables between individual turbines/devices and connections to substations, as well as export cables that transmit energy to the shore (Hutchinson *et al*., 2021).

EMFs generated by underwater power cables have been shown to result in physiological impacts on benthic species in the vicinity of offshore wind farm cables. These fields can influence movement, feeding, and migratory behaviour of benthic species, potentially causing them to avoid areas near the wind farm infrastructure (Scott *et al*., 2020). In addition, gaining a deeper understanding of how EMF interactions influence commercially important species is crucial for informing effective management decisions associated with cable installation (Hutchinson *et al*., 2021).

For several species, translating the fragmented understanding of individual-level EMF effects into meaningful assessments of biologically or ecologically significant population impacts remains challenging (Boehlert and Gill, 2010). Currently, focusing on model species to enhance the "effects" knowledge base would be particularly advantageous. In some instances, specific commercially important species may warrant targeted consideration. Broadly, efforts to expand this knowledge should prioritise understanding of population-level impacts, where possible, integrating factors such as life-history traits and behavioural ecology of different species. Crucially, the context of these effects must account for the likely encounter rate, which depends on the ecology of specific species and the properties of subsea cables (Hutchinson *et al*., 2021).

A recent literature review concluded that, with regards to crustaceans specifically, there is potential for EMFs to influence general behaviour, however results obtained to date prevent a clear understanding of the extent or severity of impacts (Scott *et al*., 2020). For example, a study by (Chapman *et al*., 2023) indicated that no significant differences were found in either behavioural or physiological responses of *Asterias rubens, Echinus esculentus, Necora puber* and *Littorina littorea*, in their study investigating EMF exposure on righting reflex. In contrast, short-term experimental studies have demonstrated that larval development of adult edible crab *Cancer pagurus* and European lobster *Homarus gammarus* can be negatively affected by EMFs, resulting in smaller sized individuals (Scott *et al*., 2018, 2020), and disruptions to circadian rhythms and stress responses were also documented in these crustaceans. Whilst physiological impacts can be studied in laboratory settings, the implications of these impacts on populations at ecologically relevant spatial and temporal scales in the natural environment remain unclear.

6.4 Impacts from underwater man-made noise and vibration

Activities during all phases of the lifetime of a wind farm (construction, operation and ultimately decommissioning) produce underwater noise and vibration (Mooney *et al*., 2020), which can impact marine life in many ways. For example, pile driving during construction generates substrate-borne vibrations. A field study on the giant scallop *Placopecten magellanicus* demonstrated that vibrations from pile driving triggered valve closure behaviour, even at distances up to 50 meters from the source. These behavioural responses may have long-term energetic consequences, increasing the scallop's vulnerability to predation and affecting their ecological and commercial viability (Jézéquel *et al*., 2023; Cones *et al*., 2024).

At a regional scale, it's the pile driving activity during turbine installation that result in the greatest acoustic disturbance in UK waters, potentially causing behavioural changes in marine mammals at ranges of many kilometres from the windfarm (Nedwell *et al*., 2007; Dahl *et al*., 2014), although the distance at which invertebrates could be affected is unknown. Peak underwater sound pressure levels from piling can range depending on pile size and type, and 220 dB re 1 μPa has been recorded at a range of ~10 m from 0.75-m-diameter piles with 200 dB re 1 μPa recorded at a range of 300 m from piles that are 5 m in diameter (Dahl *et al*., 2015). Vibratory piling reduces noise levels and newer vibratory pile driving methods with lower noise emissions are under development (Tsetas *et al*., 2023).

Locally, within the close vicinity of turbines, benthic species will be exposed to consistent emissions from sound and vibrations through the seabed during operation. No studies have investigated the extent of potential impacts on benthic communities (Scott *et al*., 2020), however, operational noise levels of up to 177dB re 1 μPa have been recorded which is generally above ambient noise levels but below typical noise levels for large vessels (Stöber and Thomsen (2021)). Other sources of additional OWF-related sound come from increased shipping activities for repairs (Bailey *et al*., 2014).

The frequencies (140–180 Hz) of these sounds at all spatial scales are typically within the hearing ranges of some demersal fish, although its long-term behavioural and physiological impacts have not been studied (Zhang *et al*., 2021). Studies investigating such impacts on benthic invertebrates are lacking (Solan *et al*., 2016; Edmonds *et al*., 2016; Scott *et al*., 2020; Popper *et al*., 2022; Wang *et al*., 2022), although in different settings noise has been shown to result in impacts on larval settlement, predator avoidance behaviour, and orientation (Edmonds *et al*., 2016; de Soto and Kight, 2016). It also remains difficult to extrapolate responses from animals kept in captivity to the natural environment (Hawkins *et al*., 2015).

Key knowledge gaps therefore include the magnitude and extent of impacts on benthic invertebrates in relation to displacement and other behavioural responses to sound, hearing sensitivity related to particle motion, and effects of substrate vibration and sound pressure (Scott *et al*., 2020). Consequently, no threshold criteria are available for these aspects to inform ecological impact assessment (in contrast to e.g. available criteria for fish such as Popper *et al*. (2014)). Due to this, assessment of the potential impact of underwater noise and vibration on benthic invertebrates is particularly challenging and it is often not included in Environmental Impact Assessments for offshore wind farms. Recent studies have been conducted to better understand noise generated during vibratory pile driving (Molenkamp *et al*., 2023), model air-bubble curtains to mitigate high noise levels (Peng *et al*., 2021), and propagate mitigated noise fields (Jestel *et al*., 2021).

The impact of noise from OWF construction on benthic communities is a current notable knowledge gap. Construction activities, particularly pile driving, generate intense underwater noise that can propagate over several kilometres. It is not currently clear if this noise may cause physiological stress, behavioural changes, and altered burrowing activity in more noise-sensitive invertebrates such as some bivalves and crustaceans. In addition, it is not known if prolonged exposure can disrupt key ecological functions, including sediment bioturbation and nutrient cycling, by affecting the feeding and movement patterns of benthic organisms (Roberts *et al*., 2016). Although less intense than pile driving noise and vibration, operational noise and vibration from turbines may still contribute to long-term localised disturbance, and further information/investigation would be beneficial to fully understand its ecological consequences.

6.5 Ongoing research examining effects of OWFs on benthos

There are several recent and ongoing research projects that are focussing on the impact of wind farms on the benthic environment. For the ECOWind-ACCELERATE project, scientists are studying the impacts of climate change and offshore wind farms on seabed sediment transport capacity, habitats and biodiversity distribution, considering the present-day scenario, and scenarios for 2050 and 2100. They are also working on an expansion of JNCC's universal Asset Service Matrix with Ecosystem Services assessments of habitats created by the OWF infrastructure. The ECOWind-BOWIE project aims to provide a detailed understanding of seabed habitats and species and their interactions with the wider marine ecosystem and quantifying impacts of offshore wind development on seabed habitats and species within the context of climate change. Part of the BOWIE project involves conducting laboratory experiments to study the effects of man-made noise and vibrations and EMF on benthic species.

The benthic component of the research from the POSEIDON project (Planning Offshore Wind Strategic Environmental Impact Decisions) is set out in the online POSEIDON Benthic Storyboard[2], and builds on OneBenthic[3], a "big data" initiative that brings together disparate benthic datasets from grab/core, trawl and imagery surveys into a high-quality, standardised dataset, made accessible through new mapping tools. This is led by Cefas and will focus on the collection of strategic environmental baseline data and updated spatial models for key species (receptors), assemblages, and a suite of ecological metrics (diversity, functional traits).

6.6 Summary

There is potential for impacts of OWFs on benthic communities at both local and regional scales due to processes including changes to physical habitat complexity and environmental conditions. Locally, the introduction of artificial hard substrates, such as turbine foundations and scour protection, can provide habitats for the colonisation of hard-substrate species including mussels (*Mytilus* spp.), anemones, polychaetes, and sea urchins. This can lead to replacement of the soft-sediment species in the footprint of the infrastructure, potentially driving shifts in community composition (Petersen and Malm, 2006; Wilding *et al*., 2017). Biofouling communities rapidly colonise turbine surfaces and scour protection layers,

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[2] https://rconnect.cefas.co.uk/POSEIDON/OneBenthicPOSEIDONstoryboardv1.html

[3] https://rconnect.cefas.co.uk/onebenthic_portal/

leading to increased species richness, organic matter deposition, and sediment enrichment. Such changes can benefit scavengers like starfish and hermit crabs while contributing to shifts in sediment characteristics (Boutin *et al*., 2023). Hydrodynamic changes caused by turbines can influence water flow, leading to sediment resuspension, redistribution, and the formation of scour pits that favour opportunistic species and affect prey availability, sediment granulometry and nutrient cycling (Roberts *et al*., 2016).

Regionally, OWFs can act as stepping stones for the dispersal of non-native species, including barnacles and crabs, raising concerns about broader ecological consequences (De Mesel *et al*., 2015) although at this stage there is less evidence to indicate notable colonisation of OWF infrastructure by non-native species compared to, for example, offshore oil and gas installations. OWFs may also enhance regional connectivity by promoting the movement and genetic exchange of benthic populations across larger areas. However, the extent and ecological implications of this connectivity remain site-specific and require further investigation (Kerckhof *et al*., 2011).

The impacts on benthic habitats vary across the different phases of OWFs (Annex 1d). During the installation phase, habitat loss, sediment suspension, underwater noise and vibration are key pressures that can cause short-term disturbances to benthic organisms (Roberts *et al*., 2016). In the operational phase, the persistent presence of artificial structures, continuous noise and vibration from turbines, altered hydrodynamics, and EMFs emitted by subsea cables could potentially influence species distribution and behaviour (Gill *et al*., 2014). The decommissioning phase poses uncertain effects, as the specific steps required to minimise environmental impacts have yet to be fully established but a number of impact pathways have the potential to be consistent with construction phase impacts, and decommissioning could involve the removal of infrastructure which would remove associated benthic communities.

Key receptors affected by these changes include ecologically and commercially important species, such as mussels (*Mytilus spp.*), scallops (e.g. *P. magellanicus*), polychaetes, starfish, and crabs. The potential introduction and spread of non-native species also requires consideration due to habitat creation and enhanced dispersal opportunities provided by OWFs. While multiple post-construction surveys are usually available for OWFs, there is a notable lack of pre-construction data, which limits our ability to accurately assess baseline conditions, determine natural variability, and distinguish between localised and regional ecological effects around the infrastructure. This is particularly important as some disturbances, such as construction-related sediment suspension, are temporary with partial recovery over a few years, while longer-term shifts in community composition and sediment characteristics have the potential to persist throughout the operational phase. Increasing the number and duration of pre-construction surveys, where practical, would strengthen the evidence base and improve interpretation of potential effects associated with OWF developments. These findings underscore the importance of continued research to better understand and mitigate the long-term and regional-scale ecological impacts of OWFs on marine benthic ecosystems.

6.7 RQ3: Conclusion for Project Stage Gate

It is evident that there are a range of data gaps associated with the localised and regional effects of OWFs, however, the OWF post-construction monitoring data sets collated for this project are not considered to provide sufficient resolution to form a basis for further investigation of this research question. Some dedicated research programmes have been referred to in the sections above which are aiming to fill some of these data gaps such as ECOWind-ACCELERATE, ECOWind-BOWIE and POSEIDON, and these types of dedicated long-term research projects are required to address the research question in more detail.

Consequently, there are no proposals to investigate this research question further beyond Stage Gate. Priority research needs will be considered and indicated in the 'Data mapping summary report' (APEM, 2025).

7. RQ4: Is there change in ecological function (e.g. functional groups) as a result of biological changes?

7.1 Background

The presence of OWFs represent a transformative addition to marine environments, with the potential to significantly alter benthic ecosystems. This review section explores how changes in benthic communities induced by OWFs affect ecological function, focusing on biological changes and their implications for functional group dynamics. In particular, it examines how shifts in benthic community composition influence key ecosystem processes such as nutrient cycling, sediment bioturbation, and organic matter decomposition, with attention to transitions within functional groups like deposit feeders, scavengers, and filter feeders.

A major focus is the shift in community structure resulting from the introduction of hard substrates, which promotes a transition from infaunal, soft sediment-dwelling species, such as polychaetes and burrowing crustaceans, to epifaunal species, such as mussels and barnacles, which dominate artificial structures (Petersen and Malm, 2006; Wilding *et al*., 2017). There has also been progress with the application of a trait-based approach to assess the ecological consequences of these biological changes in relation to functional diversity (Boutin *et al*., 2023).

Taking consideration of the localised and regional impacts of OWFs, insight is provided into how marine ecosystem functioning and biodiversity are reshaped at multiple scales. Physical environmental changes (see RQ3 (Section 6)) inherently lead to shifts in benthic community composition and characteristic fauna, which, in turn, modify the ecological functions linked to these assemblages. Therefore, it is essential to assess not only traditional community metrics such as abundance, diversity and species richness but also evolving biotic interactions and the distribution of functional roles within benthic communities.

Ecological function in this context refers to processes and interactions that sustain ecosystem structure, biodiversity, and functionality. These functions include nutrient cycling, climate regulation, biomass production, organic matter decomposition, and the maintenance of species interactions, as described by Chapin *et al*. (2002).

7.2 Changes in ecological function as a result of changes in soft sediment benthic communities

Epifauna on turbine foundations enhance organic matter deposition on the seabed through the sedimentation of faeces and detritus and by filtering suspended particulate matter from the water column (Maar *et al*., 2009). Additionally, finer sediment reduces pore-water flow within the seabed, resulting in decreased organic matter being removed from the ecosystem (Janssen *et al*., 2005; Coates, 2014). These environmental changes prompt shifts in the macrobenthic community, with increases in density and diversity and a notable change in species dominance (Coates *et al*., 2014) which can be reflected by a change in functional groups and ecosystem function.

For example, Pratt *et al*. (2014) observed reductions in measures of macrofaunal diversity and decreases in the maximum density of key bioturbating bivalves with increased mud content. Concurrently, the maximum rates of sediment oxygen consumption, NH_4^+ efflux and gross primary production also decreased. In contrast, *Echinocardium cordatum* has been shown to be the most important bioturbator in the German part of the North Sea (Wrede *et al*., 2017) and prefers organically fine sediments (Wieking and Kröncke, 2003; Kröncke *et al*., 2004), in this case a coarsening of sediment could lead to lower bioturbation activity of this species.

When studying oil and gas platforms Chen *et al*. (2024) noted that there was a reduction in the individual mean body mass of infaunal benthic invertebrates in the contaminated sites closer to the platforms, compared to those further away from platforms. This implies that larger organisms are generally more susceptible to the environmental impacts of oil and gas platforms, however, contamination levels at wind farms are usually low and similar effects associated with sediment contamination may not be applicable to OWFs. The findings of Chen *et al*. (2024) are consistent with the pattern of benthic succession following exposure to organic enrichment and metal pollution described in previous benthic studies (Pearson and Rosenberg, 1978; Ryu *et al*., 2011).

The "artificial reef" impacts of OWFs on surrounding soft sediment habitats was investigated in Lefaible *et al.* (2023). The study of two OWFs located in the Belgian part of the North Sea identified consistent trends of high macrobenthic abundance and species richness in soft sediment communities near OWF foundations (distance of 37.5 m) compared to locations at greater distances (350 or 500 m), with differences being more pronounced in deeper sediment (e.g. sand gullies/scour pits). Higher fine sand fractions closer to the jacket foundations were also found to be positively correlated with strong benthic enrichment, along with higher occurrences of coastal species and habitat diversification leading to a shift in functional groups nearby (Lefaible *et al.* 2023). These patterns were evident at the OWF which had jacket foundations, but not the OWF with monopile foundations, which were indicated to have "lower fouling impact potential" on nearby soft sediment communities compared to jacket foundations. It was suggested that differences between the foundation types could be a result of a number of factors such as jacket foundations being known as "hotspots" for *M. edulis* compared to monopiles where *M. edulis* are typically restricted to depths of 20 m (Hutchison *et al.,* 2020).

Benthic habitats/species are often features of Special Areas of Conservation (SACs) designated under the EU Habitats Directive and can provide supporting habitats for bird features in SPAs designated under the EU Birds Directive, with SACs and SPAs forming part of the UK's network of protected sites. SACs can include soft-sediment features, such as mudflats, sandbanks, and other marine habitats that are important for species and biodiversity. For example, the Dogger Bank SAC, located in the North Sea, is known for its sandbank, which is a soft-sediment feature, valued for its role as a supporting habitat for a range of benthic invertebrate species, and sandeels are an important prey resource found at the bank supporting a variety of species including fish, seabirds and cetaceans. (JNCC, 2023). The construction of OWFs in these types of habitats can potentially result in temporary habitat disturbance during construction and minor permanent habitat loss due to infrastructure (RWE Renewables UK, 2024) and potential effects on benthic features/supporting habitats of SACs, SPAs and other protected sites is a key consideration for OWF development. However, there remains a knowledge gap relating to the intersection of protected sites and OWFs, and the possible changes in ecological function that may result.

In general, there is a substantial lack of studies that explicitly investigate changes in ecological functioning as a result of changes to soft sediments surrounding OWFs, and the ECOWind ACCELERATE project will focus on this gap in knowledge. For benthic communities in particular, an approach that could be taken to better understand how changes in assemblages may affect ecological functioning, is to consider functional roles of taxa that are present pre- and post-construction.

7.3 Changes in ecological function as a result of introduction of new communities on hard structures.

The introduction of hard infrastructure (such as offshore wind turbine foundations), within soft sediment habitats causes significant shifts in benthic community composition. Pre-construction soft sediment habitats are typically dominated by infaunal species such as polychaetes, bivalves, and burrowing crustaceans, which play key roles in sediment bioturbation and nutrient cycling (Reiss *et al*., 2009). In contrast, during the post-construction operational phase of an OWF, hard substrates are colonised by epifaunal species such as mussels, barnacles and other fouling organisms, which contribute to suspension feeding and habitat provision (Petersen and Malm, 2006). This transition results in a localised shift from deposit-feeding and sediment-based energy processing to suspension feeding and increased organic matter deposition around turbine bases (Maar *et al*., 2009; Coates *et al*., 2014). Additionally, the structural complexity of hard substrates supports higher species diversity, including predators and mobile fauna that benefit from the habitat and increased prey availability (Wilding *et al*., 2017).

These changes have broader ecosystem-level implications. The dominance of suspension feeders increases water column filtration, altering nutrient dynamics and enhancing sediment organic matter deposition, which promotes opportunistic species growth (Coates *et al*., 2014; Krone *et al*., 2013). The presence of hard structures also attracts species from higher trophic levels, creating localised biodiversity hotspots (Wilhelmsson and Malm, 2008; Langhamer, 2012). The shift in functional groups and ecosystem processes highlights the profound impact of hard infrastructure on benthic ecosystems, leading to alterations in energy flow, nutrient cycling and habitat complexity. As well as having localised effects, there is potential for these effects to influence regional biodiversity and ecosystem functioning in areas with offshore wind farms (Causon and Gill, 2018), (see Section 6.2.1).

Hutchinson *et al*. (2020) observed significant changes in benthic community composition, biological traits, and ecological function three years post-construction at Block Island Wind Farm, Rhode Island. While polychaetes remained part of the community, the biotope became co-dominated by *Balanus spp.* (barnacles) and *M. edulis* (mussels). The high abundance of these sessile filter feeders, found both on and under the jacket structures, was strongly associated with the colonisation of OWF foundation structures. The shift highlights the influence of artificial hard substrates on community dynamics. Polychaetes, which play key roles as deposit- and filter-feeding, burrowing bioturbators, were joined by species such as barnacles and mussels that offer sediment consolidation, with barnacles contributing encrusting structures and mussels forming beds (Hutchings, 1998; Trager *et al*., 1990; Riisgård *et al*., 2011; Fariñas-Franco *et al*., 2014). This coexistence suggests changes in functional diversity as polychaetes continue to bioturbate local sediments while filter-feeding species enhance water clarity and nutrient cycling.

Zupan *et al*. (2023), used an 11-year time series dataset on biofouling fauna from two OWFs to understand succession patterns and to unravel the role of biological interactions in shaping community development. The study highlighted the abundance of foundation species, predators, and space occupiers was significantly related to species richness and/or diversity. The trends in richness, diversity, and community composition suggest that no permanent stable climax was reached after 11 years. Other studies, however, have suggested there are usually successional community stages with climax communities reached after 6+ years (e.g. Lindeboom *et al*., 2011; Vanagt *et al*., 2013).

Whilst increased physical habitat complexity is often referred to as being analogous to artificial reef effects, a better understanding of how these effects may influence the ecological functioning of a system requires an analysis of the functional traits of those fauna present. Functional trait-based approaches, where species in different communities are categorised according to biological traits, can be helpful when trying to predict which assemblages may be expected to settle on OWF infrastructure and the subsequent ecological effects (Boutin *et al*., 2023). This approach was applied by Boutin *et al*. (2023) and trait profiles of potential colonising species at a planned OWF in the English Channel were developed. This included information on larval stages, life span, and feeding mode (among others) of the species that may be expected to establish following infrastructure installation. In keeping with fouling community succession patterns studied at other artificial infrastructure, functional diversity and richness peaked during the intermediate stage, but had decreased by the climax stage (Boutin *et al*., 2023).

Some species, like the mussel *M. edulis* which is frequently recorded on OWF turbines, are noted to have positive effects on diversity through ecosystem engineering that facilitates establishment of other taxa on infrastructure (Kerckhof *et al*., 2019). At the same time there could be potential impacts on sediment communities by way of organic enrichment (De Borger *et al*., 2021; Ivanov *et al*., 2021) potentially increasing local carbon sequestration rates (Krone *et al*., 2013; Wilhelmsson *et al*., 2006; Coates *et al*., 2014). Later stage colonisers such as plumose anemone *M. senile* could potentially reduce diversity through high ingestion rates of free-swimming larvae although it is unclear how localised these effects would be in an open sea environment.

The suspension feeding activity of organisms such as mussels and barnacles, can filter water, reducing turbidity and enhancing light penetration. This "biofilter" effect has been observed both locally and in laboratory settings, though its large-scale implications remain under-researched (Dannheim *et al*., 2020; Reichart *et al*., 2017; Mavraki, 2020). Higher-trophic-level species (sea urchins, gastropods, crabs) are also drawn to OWFs, likely for food and shelter, and while these effects may seem minor in isolation, they may indicate broader ecological impacts (Wilding *et al*., 2017).

OWF installation therefore alters habitats and creates additional hard substrate, which has the potential to act as an artificial reef, likely affecting ecosystem diversity and the relative abundance of organisms belonging to different benthic functional groups (Dannheim *et al*., 2020).

7.4 Changes in ecological function as a result of hydrodynamic regimes and sediment dynamics

Modified hydrodynamics due to the construction and operation of OWFs may influence the distribution of sediment and therefore the structure of infaunal and epifaunal benthic communities and their related roles in the affected habitats. Taking a functional trait-based approach, where the life history, behavioural, morphological, or physiological traits of affected species are considered, can help to predict how and which species are likely to be affected and how this could translate to changes to ecological functioning. The settlement of benthic larvae can be affected by localised alterations in the hydrodynamic environment, where solid structures may generate turbulent currents and variations in flow velocity, thereby influencing the movement of larvae toward the sediment (Rodriguez *et al*., 1993). These changes may have measurable effects on the composition of the benthic assemblages close to piles (Coates *et al*., 2014), but likely not at a larger scale (Bergman *et al*., 2015). Any functional group changes related to alteration of flow, depend on the sensitivity of benthic species and habitats to the alteration of energy in the environment (Shields *et al*., 2011). Benthic organisms that have low mobility or are completely sessile may be displaced when flow strength increases beyond the levels that they can tolerate resulting in dislodgement (Gaylord *et al*., 2001). Some species may be displaced (Levinton, 1995) resulting in substrate becoming available for new colonisers with the physiological ability to cope with stronger flow regimes (Powilleit *et al*., 2006).

For instance, changes in sediment transport regime due to hydrodynamic changes and increased mobilisation of sediments, can affect species that rely on stable conditions, such as deposit-feeding and burrowing organisms, which are crucial for nutrient cycling and sediment turnover (Coates *et al*., 2014; Wilhelmsson *et al*., 2006). Filter feeders such as bivalves, and reef-associated organisms, play a significant role in increasing organic matter deposition and may contribute to greater carbon burial in the surrounding sediments (De Borger *et al*., 2021).

Sediment dynamics affect underwater light conditions, which influence availability of nutrients, and can in turn affect the reproduction, distribution and settlement of benthic fauna (Gill, 2005; Trancoso *et al*., 2005). Dredging activities during construction of OWFs, may lead to increased mortality and reduction of biomass of sediment infauna, and resultant changes to community dynamics (Newell *et al*., 1998; Seiderer and Newell, 1999). Survival of buried organisms depends on the ability to migrate vertically through sediment (Maurer *et al*., 1986; Bolam, 2011; Hutchison *et al*., 2016) and the overall resilience to smothering which can vary depending on physical properties such as the thickness of deposited layer, grain size, organic enrichment and temperature (Maurer *et al*., 1986; Chandrasekara and Frid, 1998; Cottrell *et al*., 2016; Hendrick *et al*., 2016; Hutchison *et al*., 2016). Macrobenthic communities have been demonstrated to have variable recovery rates following dredging/disposal activities; between 0.5 – 3 years (Newell *et al*., 1998). Short-term recolonising communities are often dominated by opportunistic species, whereas recovery to pre-dredging states can be variable and is influenced by sediment stabilisation and habitat restoration initiatives (Coates *et al*., 2015).

Changes in the functional trait compositions that are represented by particular benthic communities, such as the shift from deposit-feeding, soft-sediment-dwelling species to filter-feeding, hard-substrate-associated species, can substantially alter ecological functions. A soft-sediment community dominated by deposit feeders, for example, supports bioturbation, sediment reworking, and organic matter breakdown. In contrast, a community dominated by sessile filter feeders contributes more to sediment stabilisation, water column filtration, and nutrient cycling (Pearson and Rosenberg, 1978; Danovaro *et al*., 2008; Wilding, 2014). Such functional shifts can influence ecosystem-level processes like sediment resuspension and primary productivity. The transition from polychaete-dominated (representative of soft sediments) to mollusc/epifauna-dominated (representative of hard substrata) communities, as evident at OWFs, underscores the ecological consequences of altered habitat conditions. Further research is essential to better understand the long-term ecological implications of shifts in the functions represented by altered benthic communities.

7.5 Summary

The construction and operation of OWFs induce significant ecological and environmental changes that affect benthic communities, their functional roles, and associated ecosystem processes. Physical changes to sediment characteristics, such as shifts in grain size and organic matter deposition near turbine foundations (Coates *et al*., 2014), alter community composition and functional group dominance. For instance, the transition from soft sediment communities dominated by infaunal deposit feeders to hard substrate communities dominated by epifaunal suspension feeders can significantly influence ecosystem function, such as nutrient cycling, sediment bioturbation, and carbon sequestration (Petersen and Malm, 2006; Krone *et al*., 2013). These shifts reflect broader changes in ecosystem-level processes, such as increased water column filtration.

Changes in hydrodynamic regimes and sediment transport due to turbine infrastructure also shape benthic community structure and functional dynamics. Species that rely on stable sediment conditions, such as deposit feeders, may decline near turbines, whereas opportunistic colonisers and suspension feeders may thrive (Shields *et al*., 2011; De Borger *et al*., 2021). Additionally, dredging during construction can temporarily disrupt benthic habitats, with recovery dominated by opportunistic species and contingent on sediment stabilisation (Coates *et al*., 2015). While many studies focus on traditional metrics such as species richness and diversity, there remains a need to explore changes in functional traits and roles to better understand how these communities support ecosystem functioning in OWF environments (Boutin *et al*., 2023).

Future research should prioritise understanding the interplay between ecological functions and changes in benthic community composition caused by OWFs. Specifically, trait-based approaches could be expanded to investigate functional diversity shifts in response to OWF development; however, this requires robust pre-construction surveys to establish baseline data relating to functional traits and ecological processes. Without these baseline assessments, it remains difficult to disentangle natural variability from OWF-induced changes and to fully understand how biological shifts translate into altered ecosystem functioning. While existing studies focus on traditional metrics like abundance, diversity, and species richness, these do not reveal how altered communities influence ecosystem processes, such as nutrient cycling, sediment bioturbation, or organic matter decomposition (Mouillot *et al*., 2013; Martini *et al*., 2021). Developing comprehensive databases of the functional traits of different species (e.g. feeding modes, reproductive strategies, mobility) and applying these to pre- and post-construction assessments could provide valuable insights into the ecosystem-level impacts of OWFs (Boutin *et al*., 2023). Integrating this approach with high-resolution monitoring and modelling would improve predictions of benthic community shifts and associated ecological function changes (Reiss *et al*., 2009; Coates *et al*., 2014).

Another area of interest is the long-term succession patterns of fouling communities on artificial structures and their cascading effects on regional ecosystem functioning. While early studies suggest there is increased biodiversity and changes in trophic interactions near turbines (Krone *et al*., 2013; Wilding *et al*., 2017), the regional-scale implications of these shifts remain unclear. Additionally, the role of hydrodynamic changes, such as altered sediment transport and larval settlement, on benthic community dynamics and functional roles warrants further exploration (Coates *et al*., 2014; Ivanov *et al*., 2021).

7.6 RQ4: Conclusion for project stage gate

The review has highlighted a range of data gaps in relation to changes in ecological function due to OWFs, and some of these are being addressed under research programmes such as the ECOWind-ACCELERATE project. It is proposed that a potential area for further investigation beyond Stage Gate is an assessment of different options for utilisation of the currently available data sets to calculate metrics which provide an indication of some aspects of ecological function of species as opposed to focusing on enumeration of individuals, number of taxa, diversity and community composition metrics. This will provide additional information that could be considered at the ecosystem level, supporting a more ecosystem-wide assessment of effects.

There is also potential that this information could be provided with limited additional analysis effort required in the post-construction monitoring reports provided by developers. The metrics could include ITI (accounting for different feeding modes of benthic invertebrate species) or aspects of an ecological trait-based approach to assessment which would likely be more complex. As part of the Stage Gate it would be determined which approaches could be applied most readily in practice as part of the analyses conducted in post-construction monitoring reports, with the intention to provide a worked example for a selection of the OWF datasets.

Consequently, it is proposed that via this approach there is potential to investigate this research question further beyond Stage Gate. This proposal is also incorporated within the proposal for further analyses that can be undertaken in relation the RQ1 ‘Are there suitable metrics to detect changes in benthic habitats that could be applied to offshore wind assessments?’. Other priority research needs which are anticipated to be beyond the scope of the project have been considered in the ‘Data mapping summary report’ (APEM, 2025).

8. RQ5: Can recovery and/or enhancement be demonstrated and in what timeframe?

8.1 Background

The installation and operation of OWFs has become a key part of global renewable energy initiatives, but their interaction with marine ecosystems introduces both opportunities and challenges. The installation of OWF infrastructure, including turbine foundations, scour protection and cable protection measures creates hard substrata in soft-sediment habitats, providing a new environment for benthic fauna to colonise. These structures can enhance biodiversity by supporting species such as mussels, barnacles, and commercially valuable crustaceans. Additionally, they may have the potential to aid in species conservation, as demonstrated by the restoration of native species like the European flat oyster *Ostrea edulis* in several wind farms.

While OWFs can lead to positive ecological outcomes, the effects on species recovery and habitat enhancement are still not fully understood. Recovery of soft-sediment communities typically occurs within a few years, but comprehensive long-term monitoring remains sparse. The presence of turbine foundations has been shown to increase local species richness and biomass, but the full extent of these benefits, particularly for epifaunal species, remains uncertain. Moreover, the exclusion of bottom-trawling fisheries in the vicinity of turbines in OWFs may further enhance biodiversity through reserve effects, although more research is needed to confirm the lasting impacts of these protected zones.

Looking ahead, OWFs may increasingly be designed with biodiversity enhancement in mind, especially if policies like Marine Net Gain (MNG) are introduced in the future as anticipated. To maximise their ecological value, future wind farm projects could incorporate features that support ecosystem services and biodiversity. Decommissioning strategies will also play a pivotal role in ensuring positive outcomes. To optimise these benefits, further long-term monitoring and adaptive management are essential to better understand the recovery and enhancement potential of OWFs.

A key consideration when determining potential effects of OWFs on the marine environment is the potential for recovery and timeframes associated with recovery of species/habitats (where relevant) following construction. In addition, enhancement opportunities require investigation to see how construction and operation of OWFs can potentially deliver benefits to benthic habitats/species and the wider marine ecosystem. The definitions of recovery and enhancement considered in this report have been agreed with the ORJIP Steering group and are outlined below:

The term **recovery** in this context refers to a scenario where an adverse impact has been identified due to construction or operation of an OWF (e.g. in year one post-construction monitoring such as a change in benthic community parameters) and recovery is the shift back towards the pre-construction baseline conditions (Nature Scot, 2024a).

For the purposes of this review, the term **enhancement** refers to an improvement in the quality, size, geographic distribution and/or functionality of a habitat compared to the recorded baseline condition. This involves various mechanisms such as habitat or species recovery, regeneration, restoration, and habitat creation (Nature Scot, 2024b).

8.2 Recovery of benthic habitats/species at OWFs

The impacts of OWF construction on soft sediment communities are not well understood, despite most OWFs being installed in these habitats (Degraer *et al*., 2019; Lefaible *et al*., 2019; Dannheim *et al*., 2018

Hutchinson *et al*., 2020). Significant alterations are rarely reported (Daan *et al*., 2006; Leonhard and Pedersen, 2006; Degraer and Brabant, 2009), and high natural variability in these areas can limit the ability to detect impacts and study recovery (Coates *et al*., 2014; Vandendriessche *et al*., 2014; Degraer and Brabant, 2009). The construction phase typically has the greatest impact, but soft sediment communities often demonstrate resilience, with biotopes re-establishing during the operational phase (Walls *et al*., 2013). Recovery potential is influenced by environmental variability such as strong currents, cold winters and severe storms creating dynamic macrofaunal communities that are better adapted to disturbance. Having long-term pre-impact datasets increases understanding of natural variability in the benthic environment and associated communities at a given location, although such data sets are rarely available (Coates *et al*., 2015). Consequently, having an increased number of pre-construction monitoring surveys would be beneficial in terms of providing increased evidence of habitats/benthic community stability, or high levels of natural variability, prior to the introduction of an OWF. Ultimately, this would be anticipated to facilitate determination of whether any adverse effects have occurred due to the construction and presence of the OWF and if consideration of recovery of habitats/species is applicable. It is understood that there are numerous constraints to such an approach including associated costs and timeframes, and in the absence of such datasets, there is an increased reliance on reference stations to provide data to indicate natural environmental and benthic community changes over time. As such, the selection of a sufficient number of suitable reference stations is of key importance to assess the effects of OWFs. How stable or dynamic an environment is naturally can influence potential for recovery. For example, in frequently disturbed environments, macrofaunal communities have demonstrated rapid recovery, with North Sea OWF infauna returning to pre-construction states within two years (Coates *et al*., 2015), which is similar to recovery timelines reported for sediment communities after dredging activity (van Dalfsen *et al*., 2000).

The majority of datasets relating to benthos at OWFs are focused on infauna (sediment-dwelling organisms), which is likely due to the fact that OWFs are mainly installed in areas characterised by soft sediments. These studies involve survey of sites within, and in the vicinity of, the OWF pre- and post-construction (e.g. Lefaible *et al.,* 2023; Teschke *et al.,* 2023). Standardised survey methodologies are less readily available for epifauna and generally information for epifauna would need to be collected via trawling or underwater video survey. This may limit the ability to study recovery in epifaunal populations in areas where they could be affected by OWFs. In fact, Vandendriescche *et al*. (2015) stated that the ability to detect significant differences in epifaunal communities via a BACI (Before-After-Control-Impact) design may be limited by several factors including insufficient numbers of suitable reference stations (due to differences in communities, topography, and fishing pressure etc. between OWFs), variable timespans of post-construction surveys and the fact that post-construction surveys tended to stop collecting / reporting on data before novel epifaunal communities had stabilised. There are exceptions, however, and an assessment of the effects of the Princess Amalia Wind Farm in the Netherlands was based on statistical analysis of epifaunal trawl data across a 15-year survey period. The study showed no significant differences in soft-bottom benthic fauna between areas inside and outside the wind farm across this timeframe, with similar species abundance, diversity indices, and community composition (Leewis and Klink, 2022).

There are health and safety and logistic concerns regarding sampling in the vicinity of turbines and in many cases (e.g. Wilhelmsson *et al*., 2006; Bergström *et al*., 2012, 2013) benthic effects in close proximity to the turbines can be harder to establish, especially if a larger vessel Is being deployed (a minimum distance between a turbine foundation and benthic grab station is often stipulated with survey designs for post-monitoring programmes, e.g. 50 m). Where underwater video is obtained via a Drop-Down Video system towed behind a vessel a buffer distance would usually be required in the vicinity of turbines and a potential solution is collection of data using a Remotely Operated Vehicle to collect video footage which enables closer and safer access to the turbine foundations.

Despite the limitations outlined above, a small number of studies have demonstrated recovery for some long-lived epifaunal species, including the European flat oyster *Ostrea edulis* and hydroid *Sertularia cupressina* at Danish OWFs (Vattenfall and Skov-og, 2006). In cases where baseline environmental surveys establish the presence of epifaunal species with high ecological value and potential increased vulnerability to destructive impacts, careful planning and collaboration is required to minimise impacts of OWFs and maximise recovery potential of such taxa. For example, the pre-OWF identification of *Sabellaria spinulosa* reefs in the English southern North Sea, influenced the siting of turbines at the Thanet OWF (Pearce *et al*., 2014). Post-construction monitoring subsequently found no negative impacts following installation on *S. spinulosa* reefs, instead reporting an increase in the extent of reef cover that may also be partly due to a reduction in bottom trawling that would usually have resulted in degradation of *S. spinulosa* reef (Pearce *et al*., 2014). Presence of *S. spinulosa* reef post-construction was also evident at some locations in the Greater Gabbard wind farm during the surveys conducted five- and ten-years post-construction (NIRAS, 2023). *Sabellaria* spp. aggregations had been present at the OWF site pre-construction and overall it was concluded that it was not possible to determine whether the extent and nature of *Sabellaria* dominated communities had been influenced by the development of the OWF (NIRAS, 2023).

8.2.1 Consideration of recovery in OWF post-construction monitoring reports

The project-specific review of post-construction monitoring reports for 18 OWF's was conducted to determine trends in change in sediment particle size, abundance and taxon richness pre- and post-construction (Table 2). Due to the considerable variation in terms of how clearly data were provided in reports, and differences in the scale of different OWFs and monitoring programmes, specific numbers have not been provided but general variations in terms of the direction of change have been indicated (Annex 1c).

Generally, differences were apparent for sediment particle size and/or the number of benthic invertebrate individuals and taxa when comparing the pre-construction and the first post-construction surveys (noted for 11 of the OWFs for particle size, 14 of the OWFs for abundance, and 15 of the OWFs for taxon richness), (Annex 1c). Where there was a direction of change for abundance between pre-construction and the first post-construction survey, it was indicated to be an increase for nine OWFs and a decrease for four OWFS. The trend for abundance was generally reflected by the change in taxon richness.

For particle size, for ten of the OWFs with more than one post-construction monitoring report, the direction of change was not consistent. No consistent trend was also allocated to the five OWFs with only one post-construction monitoring report due to lack of sufficient data. In nearly all cases, the trend or lack of trend in changes in particle size at the OWF site or on cable routes was also apparent at the reference stations (Annex 1c).

When considering abundance, no consistent trends were recorded for nine of the OWFs, and for 11 of the OWFs no consistent trends were indicated for taxon richness. Trends or lack of trends were generally reflected at reference stations.

Changes in sediment characteristics and community parameters were invariably attributed to natural variation across OWFs. This conclusion was mainly supported in the post-construction monitoring reports by the fact that changes between years were reflected at reference stations, and where there was an inconsistent direction of change across multiple survey years this was referred to. The clarity with which changes in the OWF or cable route stations compared data directly with reference stations, however, differed considerable across the post-construction monitoring reports, and in some cases statistical significance was indicated while for others it was not.

It should be noted that during the review of monitoring reports for multiple OWFs, the term 'recovery' was referred to in the monitoring reports for a number the OWFs where a change was noted between pre- and post-construction monitoring surveys and each time it was in relation to numbers of individuals and taxa as opposed to changes in particle size. In each case, however, the term was used in relation to returning to a pre-construction scenario although, as indicated above, the conclusion had been that there was no evidence that the OWF construction/operation had resulted in the observed change and that changes from the pre-construction scenario had been natural changes. Consequently, this use of the term 'recovery' differs from the definition considered for this question (Section 8.1).

The duration of post-construction monitoring varied across projects. For five of the OWFs only the first post-construction survey report was available for review, and variation in recorded parameters should be interpreted with caution as additional surveys may suggest fluctuations in parameter values rather than a consistent trend. The longest benthic monitoring periods were for Greater Gabbard OWF with monitoring reports for 1-, 5- and 10-years post-construction available and Princess Amalia wind farm in the Netherlands with benthic monitoring reports for 5-, 6-, 10- and 15-years post-construction (epifaunal dredge data).

As no reports indicated adverse effects of wind farms on benthic habitats / species no timeframe to demonstrate recovery of the benthos at OWFs is apparent based on the review.

It is clear, however, that data collected for more years prior to construction would also provide more information in relation to natural variability in the parameters recorded, but it is understood the practicalities for increasing the number of pre-construction surveys are limiting. As such, it is key to determine a sufficient number of suitable reference stations to facilitate interpretation of the data obtained and assess potential effects of the OWFs. In addition, the results at OWFs and reference stations should be clearly indicated and differentiated to evidence conclusions.

8.3 Enhancement of benthic habitats/species at OWFs

To date, the majority of OWF infrastructure has not been explicitly designed or deployed for purposes of ecological enhancement. It is unclear if this may change going forward if there is future introduction of MNG requirements for marine developments (Defra conducted a public consultation in relation to MNG in 2022, with a summary of results published in 2023[4]), and noting recent announcement of a new Marine Recovery Fund to support sustainable OWF development. Unless otherwise modified, the physical orientation, structure and complexity of OWF infrastructure differs from natural hard substrata, and comparisons between benthic assemblages inhabiting natural vs OWF-associated infrastructure have found significantly different community composition, diversity and species richness (e.g. Wilhelmsson and Malm, 2008).

8.3.1 Presence of infrastructure

It is evident that OWF infrastructure in the water column (including turbine foundations and scour protection) can be colonised by a range of marine organisms resulting in an increase in the number and abundance of species and associated biomass in the respective area (De Mesel *et al*., 2015; Degraer *et al*., 2019; Dannheim *et al*., 2020). This is discussed in more detail in the response to RQs 3 (Section 6) and 4 (Section 7). Such an effect increases local biodiversity, and changes have been observed that can be

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[4] https://www.gov.uk/government/consultations/consultation-on-the-principles-of-marine-net-gain/outcome/summary-of-responses

regarded as being beneficial to some ecological components. For example, 3.5 years post-construction a number or rare species, and species not previously recorded from the area, were present at the Princess Amalia Wind Farm (Vanagt *et al*., 2013), and 6 years post-construction further rare species were recorded, as well as an attached but empty native oyster shell (a species that has nearly disappeared from the Southern North Sea) and a cheliped of the European lobster *H. gammarus*, suggested these species may have utilised the infrastructure (Vanagt and Faasse, 2014).

A meta-analysis, based on 531 effect sizes from 109 studies by Lemasson *et al*. (2024), however, indicated that OWFs and oil and gas installations had limited ecological impact, showing minor or non-significant benefits, particularly for invertebrate communities and overall biodiversity. In this study OWFs, in particular, were shown to not significantly enhance biomass or diversity and primarily influenced local fish abundance. The study did also emphasise the importance of long term monitoring studies to better discuss the impacts these artificial structures have on the surrounding benthic communities, in order to gain a better understanding of the ecological impacts.

The increased biomass of benthic species on turbine infrastructure can also have effects along the food chain resulting in increased presence of scavenging species and fish (e.g. Hutchinson *et al*. 2020). Not all changes in biodiversity, and particularly those related communities on introduced artificial hard substrata, are necessarily positive depending on the changes observed and the species being introduced to an area (Firth *et al*., 2020). It has been suggested that improved ecological condition (e.g. through enhancement of biodiversity) owing to artificial structures should only be referred to as such when the design of those structures has been specifically modified for this goal, and when contrasted against structures without any structural modifications (Evans *et al*., 2019). The use of biodiversity enhancement as a nature positive measure in itself is not straightforward, and often its measures of success are through metrics such as abundance or species richness, without consideration of the functional roles of the species that characterise the newly established communities (Firth *et al*., 2020). Moreover, there is a paucity of studies that have appropriate spatial and temporal replication concerning artificial reef communities, and so it is uncertain how these effects will translate at the true operational scale at which infrastructure is planned to be installed (Evans *et al*., 2019). For example, it has been mentioned in this review for RQ4 (Section 7) that community composition and dynamics on OWF turbines change over time as these communities progress through succession patterns and in many cases the climax community is dominated by species such as the mussel *M. edulis* and plumose anemone *M. senile* (Lindeboom *et al*., 2011, Degraer *et al*. 2020; Vanagt and Faasse, 2014). Determining temporal changes in functional roles associated with these communities is required to develop an increased understanding of ecological impacts in the long-term. For example, Boutin *et al*. (2023) predicted that while the functional profiles of turbine fouling communities may resemble those of communities in natural hard substrata, this is likely to change through time. Enhancement as defined in this review (Section 8.1), also encapsulates different perspectives for example, post-construction monitoring at Thanet OWF subsequently found no negative impacts on *S. spinulosa* reefs following installation (Pearce *et al*. 2014) and this study reported an increase in the extent of reef cover, a secondary effect which could also be partly due to a reduction in bottom trawling that would usually have resulted in degradation of *S. spinulosa* reef (Pearce *et al*. 2014).

8.3.2 Reserve effects

The exclusion of fishing activity around turbines (bottom trawling in particular) in combination with the addition of hard substrata has underpinned statements that OWFs can have reserve effects (Ashley *et al*., 2014; Hammar *et al*., 2016). In a statement in January 2025 by the Minister for Water and Flooding[5], the

[5]https://questions-statements.parliament.uk/written-statements/detail/2025-01-29/hcws394

UK government announced the setting up Great British Energy, a publicly owned company to invest in clean energy, produced in-country. Great British Energy in collaboration with Defra, have implemented an offshore wind environmental improvement package. Two of the milestones include: ensuring that compensatory measures for unavoidable environmental impacts to Marine Protected Areas (MPAs) can be delivered strategically rather than on a project-by-project basis including through a library of measures that Defra is developing in collaboration with stakeholders; and the launch of a Marine Recovery Fund in late 2025 to provide an optional mechanism for developers to fund delivery of strategic compensatory measures.

Dunkley and Solandt (2022) recorded a 77% reduction in fishing rate from bottom-towed gear in the UK following installation of OWFs. Fisheries exclusion in close proximity to turbines in combination with additional prey availability (e.g. mussels) that colonise infrastructure may have positive effects on the abundance of larger crustaceans. Indeed, the abundance of benthic/demersal taxa including mussels, brown crab and edible crab have been reported to increase around some OWF installations (Wilhelmsson and Malm 2008; Vandendriessche *et al*., 2014; Krone *et al*., 2017; Danheim *et al.,* 2020). Whilst these increases may be attributed partly to the exclusion of bottom-trawling and increased abundance of prey items, there are other factors that may further result in increased numbers of commercially valuable benthic species. For example, Hooper and Austen (2014) demonstrated that turbines with rock armouring / scour protection supported a higher population of lobsters than turbines without these protective measures (MRAG, 2023). Assessments for other wind farms have found no evidence of changes in benthic epifauna due to a reduction in fishing effort (in exclusion zone) within an OWF (e.g. Leewis and Klink, 2022). Overall, uncertainties regarding the strength of reserve effects remain, particularly since some studies were completed within the first couple of years following construction (e.g. Krone *et al*., 2017), so the long-term influence of reserve effects have not been confirmed (Isaksson *et al.,* 2023).

OWFs increase the diversity and abundance of certain species, similar to other human-made marine structures (Coolen and Jak, 2018). However, OWFs alter natural ecosystems, leading to communities dominated by a few species like tube-building amphipods, anemones, hydroids, blue mussels, and shrimps, although these macrofauna communities may be impoverished relative to the communities that are expected on natural hard substrata (Perrow, 2019). Similarly, fish communities near OWFs often show higher total abundance but lower species richness and diversity compared to the surrounding seafloor (Wilhelmsson *et al*., 2006). Benthic communities also shift, becoming dominated by mussels and anemones (Degraer *et al*., 2020) altering native assemblages. As indicated in Section 4.2.2, OWFs can also act as vectors for any colonising non-native species, facilitating their spread by providing artificial hard substrata that enable species to overcome natural biogeographical barriers and connect otherwise isolated populations (Sheehy and Vik, 2010; Bulleri and Airoldi, 2005; Glasby *et al.,* 2007; Langhamer, 2012; De Mesel *et al*., 2015; Kerckhof *et al*., 2011). Consequently, OWFs can increase local invertebrate abundance and biomass through reef effects, however, further research is required to determine how much the altered communities differ from natural ecosystems and whether they can support long-term biodiversity conservation (Ashley *et al*., 2014; Wilhelmsson *et al.,* 2006; Bergström *et al.,* 2013; Stenberg et al., 2015; Degraer *et al.,* 2020).

8.3.3 Co-location initiatives

The restoration of habitats like native oyster reefs within OWFs represents just one of the many potential positive co-location initiatives. Initiatives like the Essex Native Oyster Restoration Initiative (ENORI) illustrate how OWFs can aid ecological restoration. ENORI focuses on rebuilding native oyster *O. edulis* reefs by deploying broodstock oysters and cultch, which promote larval settlement and may support increases in biodiversity (Robertson *et al.,* 2021). ENORI, in collaboration with Blue Marine Foundation (BLUE) and Ørsted, conducted a feasibility study to explore use of the Gunfleet Sands Offshore Wind Farm as a broodstock site for oyster restoration. The study assessed the site's environmental conditions, hydrodynamic factors, and operational feasibility. However, the feasibility study at Gunfleet Sands OWF found many challenges, for example it is a high-energy environment with a sandy seabed, strong tidal currents and sediment movement, increasing the risk of sedimentation, scour, and cage instability. Additionally, limited habitat suitability, exposure to extreme flows, and a narrow window for larval dispersal reduced the likelihood of successful oyster settlement and long-term population growth. As a result, the Eneco Luchterduinen OWF was used as a case study. This wind farm installed artificial reef structures and oyster cages to assess the feasibility of offshore oyster restoration. Nature-inclusive elements were considered, and an artificial reef structure was installed as part of the "Rich North Sea" initiative, aiming to enhance underwater biodiversity. The results demonstrated that native oysters *O. edulis* can survive and reproduce in offshore wind farms, with an 80% survival rate and *O. edulis* larvae were also detected. However, challenges such as cage sinking and sediment movement highlighted the need for improved reef and housing designs to ensure long-term restoration success (Robertson *et al.,* 2021).

8.3.4 Decommissioning considerations

Effects associated with infrastructure that may result in potential enhancement of benthic communities, including the artificial reef effect and reserve effects that may be derived by co-location of activities, will all be influenced by different decommissioning options for OWFs. To date, there are no set methods or protocols for the decommissioning of retired OWF turbines, although OSPAR Decision 98/3 (Disposal of Disused Offshore Installations) states that the dumping, and the leaving wholly or partly in place, of disused offshore installations within the maritime area is prohibited. Derogations could be obtained to leave structures in place on a project-specific basis, however, if colonisation of OWF infrastructure or other aspects such as the reserve effect was determined to have some benefits for benthic habitats/species and the wider marine environment then these benefits will be lost or greatly reduced if structures are completely removed. Spielmann *et al*. (2023) investigated effects of different decommissioning options on benthic communities and ultimately recommended an approach where scour protection should be left in place (if used), and for foundation structures to be cut above the seabed. They assessed 15 locations from 5 OWF sites, all along the south and east North Sea coast (Belgium to Denmark). The results indicated that leaving the scour protection layer *in situ* preserved the majority of hard-substrate-associated species. On average, 69.16% of species found at wind farm sites were associated with scour protection. In some locations, such as Horns Rev 1, up to 90% of species richness was maintained when scour protection was left untouched. Cutting monopile or gravity-base foundations 5 meters above the seabed slightly increased the percentage of species retained, but only by about 2–9%, meaning it had a minimal additional effect on biodiversity compared to leaving scour protection in place. However, for jackets without scour protection, cutting them above the seabed preserved 77% of species, making it a viable alternative where scour protection is absent. Rather than viewing decommissioning as habitat loss, the findings in (Spielmann *et al.,* 2023) indicate that leaving some of these structures in place can support enhancement of marine ecosystems. By leaving scour protection intact, selectively cutting foundation structures, and implementing targeted habitat modifications, OWFs could transition into long-term ecological assets that support biodiversity and ecosystem resilience.

With few long-term (> 6 years) benthic monitoring datasets available, it remains difficult to answer questions regarding the development of OWF benthic communities over the entire operational phase and the effects of these communities in the long-term. Changes in benthic communities colonising OWF infrastructure have not been assessed over the full operational phase of an OWF, and this also complicates quantifying the potential importance of such infrastructure in supporting connectivity between populations of conservation or commercial interest and determine potential enhancement measures.

8.3.5 Consideration of enhancement in OWF monitoring reports

As part of the project-specific review of post-construction monitoring reports for 18 OWF's it was determined that none of the monitoring reports included discussion of any aspects of nature positive design or enhancement. This is not unexpected due to the age of the reports (Table 2) and the fact that increased consideration for nature positive design / enhancement is more of a recent potential requirement for OWFs in the future. Use of such terminology is anticipated to be more commonplace in reports going forward, especially if requirements for such measures and associated monitoring become more formalised via future policy/legislation.

8.4 Summary

Understanding the recovery potential of marine ecosystems requires comprehensive data related to environmental pressures and associated long-term monitoring. Regular surveys across relevant time scales (including where possible determining potential effects of seasonal variation and storm events) and spatial scales (locally and regionally) recording species composition, habitat distribution, and ecosystem function are key to tracking changes at OWFs post-construction. In addition, effective survey design for monitoring programmes, including an increased number of pre-construction surveys if possible, and selection of a sufficient number of suitable reference stations is essential to clarify whether changes evident are due to natural variability or relate to effects of OWFs.

While the impacts of OWF construction on soft sediment communities are not fully understood, they often show resilience, with biotopes re-establishing during the operational phase. Recovery times vary, but in some cases, benthic infauna has returned to pre-construction conditions within two years. The lack of long-term datasets limits the ability to assess changes, particularly for epifaunal species, as standardised monitoring techniques are less common. Some studies, such as those on the Princess Amalia Wind Farm, however, provide valuable long-term insights (Leewis and Klink, 2022).

OWFs have not traditionally been designed for ecological enhancement, but if MNG policies are introduced in the future it may change this. Turbine foundations and scour protection layers increase biodiversity and support species such as mussels, barnacles, and anemones. Some wind farms have aided in species conservation (oyster restoration), with the re-establishment of rare species like the European flat oyster. However, artificial habitats can differ significantly from natural ones, necessitating careful monitoring of ecological impacts (refer to RQ3 (Section 6) and RQ4 (Section 7) for more information).

OWFs can potentially have reserve effects due to restrictions on fishing, particularly bottom trawling, which can enhance the presence of commercially valuable species like brown crab and lobster. However, the long-term strength of these reserve effects remains uncertain, as studies have primarily focused on short-term impacts. OWFs present opportunities for habitat restoration, such as native oyster reef restoration projects like the Essex Native Oyster Restoration Initiative (ENORI). A feasibility study at Eneco Luchterduinen Wind Farms demonstrated that oysters can survive and reproduce in OWF environments, if certain criteria are met. However, challenges such as cage sinking and sediment movement highlight the need for improved restoration designs (Robertson *et al.,* 2021).

Overall, OWFs can potentially play a positive role in marine habitat recovery and enhancement, particularly through artificial reef effects and fisheries exclusion. However, more long-term studies are needed to understand their full ecological impact and to optimise future developments for biodiversity gains.

8.5 RQ5: Conclusion for project stage gate

In relation to the context of using available data sources for further investigation, a principal consideration is that none of the post-construction monitoring reports reviewed concluded that the OWF was having an adverse effect on any aspects of benthic ecology. Consequently, the data sets cannot be used to consider timeframes required for recovery according to the definition in Section 8.1. The datasets clearly indicate notable variability in the trends observed at OWFs in relation to particle size, abundance and taxon richness (Annex 1c) and in many cases patterns were not consistent between monitoring periods.

Similarly, none of the reports addressed any considerations associated with enhancement. There is potential that such requirements may be in place in the future, but it was not part of the assessments for the reviewed monitoring reports. This is as expected as delivery of enhancement measures has not been a consent requirement for UK OWFs.

Taking these aspects into consideration, there are no proposals to investigate this research question further beyond Stage Gate. Priority research needs will be considered and indicated in the 'Data mapping summary report' (APEM, 2025).

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Annex 1a RQ 1 pre- and post-construction monitoring reports: Metrics applied in reports

Title of document	Date produced	Author and summary	Metrics included	Key Specific information (e.g. habitat, bathymetry, geographical location and degree of exposure)
Barrow Offshore Wind Farm				
Barrow OWF **Post Construction Monitoring Report. First Annual Report** **First Post Construction Benthic Ecology Report (Two years following construction)**	Jan 2008	Barrow Offshore Wind Ltd This report presents the results of the post-construction survey performed in 2007 (year two) and compares data with previous monitoring results from pre-construction surveys (2004) at the Barrow OWF site. Appendices include the benthic survey technical report (July 2007) and comparative analysis (Nov 2007)	Univariate analysis Multivariate Analysis INNS Phyletic composition Characteristic species Habitat distribution/composition Sediment composition Physico-chemical data	• Univariate analysis: Abundance, Taxon Richness, Margalef's Richness, Pielou's Evenness, Shannon's Index • Multivariate analysis: MDS, SIMPER, BIOENV • Invasive species abundance and distribution discussed • Phyletic composition and dominant taxa presented and compared • Characteristic species: *Sabellaria spinulosa*, *Modiolus modiolus* • Habitat distribution/composition: *Sabellaria spinulosa* habitat distribution and density assessment included in survey • Sediment composition: PSA • Physico chemical data: metals, TPH, TOC. Compared with 2002 and 2004 data, and other European locations • Standard methodology: Laboratory processing carried out according to The Natural History Museum standard operating procedures
Barrow OWF **Post-construction Monitoring Report. Second Annual Report** **Second Post Construction Benthic Ecology Report (Three years following construction)**	Jan 2009	Barrow Offshore Wind Ltd This report presented results for the monopile ecological survey, investigating colonisation of monopiles using video footage and scrape samples. A comparison of results was also made between the current study and the 2008 post-construction survey, which was completed approximately eight months after the installation of the monopiles.	Univariate analysis SACFOR Phyletic composition Biomass Characteristic species Habitat distribution/composition Sediment composition	• Univariate analysis: Abundance, Taxon Richness • Phyletic composition presented in full species list appendix • Conspicuous characterising species discussed • Habitat description based on taxa • Sediment composition: limited to visual description • Standard methodology: Survey design included consultation with Natural England, Monopile epifauna survey design based on FEPA licence conditions. Laboratory participated in the NMBAQC scheme • Colonisation of monopiles was investigated by using MNCR Phase II biological recording from real time video footage.
Barrow OWF **Post-construction Monitoring Report. Third Annual Report and Overall Conclusions. Final Report** **Third Post Construction Benthic Ecology Report (Four years following construction)**	Mar 2010	Barrow Offshore Wind Ltd This report presents the results of the third post-construction survey performed in 2009. Appendices include the benthic survey technical report (Oct 2009) and comparative analysis (Dec 2009)	Univariate analysis Multivariate Analysis Phyletic composition Characteristic species Habitat distribution/composition Sediment composition Physico-chemical data (TOC)	• Univariate analysis: Abundance, Taxon Richness, Margalef's Richness, Pielou's Evenness, Shannon's Index • Multivariate analysis: MDS, SIMPER • Phyletic composition and dominant taxa presented and compared • Characteristic species: *Sabellaria spinulosa, Modiolus modiolus, Mytilus edulis* • Habitat distribution/composition: JNCC biotopes • Sediment composition: PSA • Physico-chemical data: TOC • Standard methodology: Survey designs summarised and agreed with CEFAS

Beatrice Offshore Wind Farm				
Beatrice OWF **OWF Pre-construction Benthic Survey Report – APEM Ltd** **Pre-construction Benthic Ecology Report**	Nov 2015	APEM Ltd This report summarises the results of the pre-construction survey performed in 2015	Univariate analysis Multivariate Analysis Habitat distribution/composition Characteristic species INNS Phyletic composition Biomass Sediment composition	• Univariate analysis: Abundance, Taxon Richness, Mean Density, Shannon-Wiener, Margalef's Species Richness, Pielou's Evenness, Simpson's Index • Multivariate analysis: MDS, SIMPER, RELATE, BIOENV • Habitat distribution/composition: Biotope assignment with JNCC and EUNIS codes, description includes characteristic species • INNS: No invasive non-native species observed • Phyletic composition: Percent contribution • Biomass • Sediment composition: PSA • Standard methodology: Lab processing NMBAQC scheme
Beatrice OWF **Post-construction Monitoring Benthic Grab Survey Report** **First Post Construction Benthic Ecology Report (One year following construction)**	Apr 2021	APEM Ltd This report summarises the results of the post-construction survey performed in 2020, including comparison with the 2010 EIA characterisation survey and 2015 pre-construction survey	Univariate analysis Multivariate Analysis Habitat distribution/composition Characteristic species INNS Phyletic composition Biomass Sediment composition	• Univariate analysis: Abundance, Taxon Richness, Mean Density, Shannon-Wiener, Margalef's Species Richness, Pielou's Evenness, Simpson's Index • Multivariate: MDS, ANOSIM, SIMPER, RELATE, BIOENV • Habitat distribution/composition: Biotope assignment with JNCC and EUNIS codes, description includes characteristic species • INNS: No invasive non-native species observed • Phyletic composition: Percent contribution • Biomass • Sediment composition: PSA • Standard methodology: Lab processing NMBAQC scheme
Beatrice OWF **Post-construction Monitoring Year 2 (2021): Benthic Grab Survey Report** **Second Post Construction Benthic Ecology Report (Two years following construction)**	Jan 2022	APEM Ltd This report summarises the results of the post-construction survey performed in 2021, including comparison with the 2010 EIA characterisation survey, 2015 pre-construction survey and 2020 post-construction survey	Univariate analysis Multivariate Analysis Biomass Habitat distribution/composition Characteristic species INNS Phyletic composition Sediment composition	• Univariate analysis: Abundance, Taxon Richness, percent contribution, Mean Density, Shannon-Wiener, Margalef's Species Richness, Pielou's Evenness, Simpson's Index • Multivariate: MDS, ANOSIM, SIMPER, RELATE, BIOENV • Habitat distribution/composition: Biotope assignment with JNCC and EUNIS codes, description includes characteristic species • INNS: No invasive non-native species observed • Phyletic composition: Percent contribution • Biomass • Sediment composition: PSA • Standard methodology: Lab processing NMBAQC scheme
Beatrice OWF	September 2021	APEM Ltd	Univariate analysis	• Colonisation survey carried out on the four jacket legs at each of four turbine foundation locations as part of the wider post construction benthic survey

Post-construction Monitoring: Turbine Foundation Marine Ecology Survey Report **First Post Construction Turbine Foundation Colonisation Report (One year following construction)**		This report presents the results of the first round of post-construction underwater video survey of foundation jacket legs and surrounding seabed conducted in March 2020	SACFOR Habitat distribution/composition Characteristic species INNS	• Univariate analysis: Taxon Richness • SACFOR scale • Habitat distribution/composition: EUNIS habitat classification used for surrounding sediment • Characteristic species – variation in colonising species composition in each depth band discussed • INNS: No invasive non-native were observed • Standard methodology: ROV and DDV
Beatrice OWF **Post-construction Monitoring Year 2 (2021): Turbine Foundation Marine Ecology Survey Report** **Second Post Construction Turbine Foundation Colonisation Report (Two years following construction)**	Jan 2022	APEM Ltd This report presents the results of the second round of post-construction underwater video survey of foundation jacket legs and surrounding seabed conducted in June 2021	Univariate analysis SACFOR Habitat distribution/composition Characteristic species INNS	• Colonisation survey carried out on the four jacket legs at each of four turbine foundation locations as part of the wider post construction benthic survey • Univariate analysis: Taxon Richness • SACFOR scale • Habitat distribution/composition: EUNIS habitat classification used for surrounding sediment • Characteristic species – variation in colonising species composition in each depth band discussed • INNS: No invasive non-native species were observed • Standardised methodology: ROV
Blyth Offshore Demonstrator Project				
Blyth Offshore Demo **Pre-construction Benthic Monitoring Report – Array 2**	Dec 2016	EDF Energy This report presents the results of pre-construction benthic survey conducted in May-June 2016	Univariate analysis Multivariate Analysis Habitat distribution/composition Sediment composition Physico-chemical data (TOC)	• Univariate analysis: Abundance, Taxon Richness, Shannon-Wiener, Margalefs Richness, Simpsons Diversity, Pielou's Evenness • Multivariate analysis: MDS, SIMPER, Bray-Curtis, ANOSIM • Habitat distribution/composition: Biotope classification • Sediment composition: PSA • Physico-chemical data: TOC
Blyth Offshore Demo **Post-Construction Benthic Monitoring Report - Array 2** **First Post Construction Benthic Ecology Report (One year following construction)**	Nov 2019	Blyth Offshore Demonstrator Limited. Post-construction survey to provide a comparison with the EIA baseline and pre-construction characterisation of benthic ecology present.	Univariate analysis Multivariate Analysis Habitat distribution/composition Sediment composition Physico-chemical data (TOC)	• Univariate analysis: Abundance, Taxon Richness, Shannon-Wiener, Margalefs Richness, Simpsons Diversity, Pielou's Evenness • Multivariate analysis: MDS, SIMPROF, Bray-Curtis, ANOSIM • Habitat distribution/composition: Biotope classification • Sediment composition: PSA • Physico-chemical data: TOC
Burbo Bank Offshore Wind Farm				
Burbo Bank OWF	Aug 2006	CMACS	Univariate analysis	• Univariate analysis: Abundance, Taxon Richness, Shannon's Index,

Pre-construction Sub-tidal Benthic Ecology Investigation		This report presents the findings of the pre-construction monitoring survey that was undertaken across the OWF, export cable and reference sites in Summer 2006	Multivariate Analysis Phyletic composition Habitat distribution/composition Characteristic species Sediment composition Physico-chemical data	• Multivariate analysis: MDS • Phyletic composition and dominant taxa presented • Habitat distribution/composition: JNCC biotopes • Characteristic species: No rare or unusual species recorded • Sediment composition measured and discussed • Physico-chemical data: TOC • Standard methodology: Survey design based on FEPA licence requirements
Burbo Bank OWF **Post-construction 2007 (Year 1) Benthic Grab Survey** **First Post Construction Benthic Ecology Report (One year following construction)**	August 2008	CMACS Ltd This report summarises the results of the post-construction benthic survey performed in 2007, including comparison with the 2005 pre-mid-construction survey.	Univariate analysis Multivariate Analysis Habitat distribution/composition Characteristic species Sediment composition Physico-chemical data	• Univariate analysis: Abundance, Taxon Richness, Margalef's Richness, Pielou's Evenness, Shannon's Index), • Multivariate Analysis: nMDS to assess temporal and spatial differences • Habitat distribution/composition: JNCC biotopes • Characteristic species: includes comments on changes in abundance of characterising taxa and the nationally scarce crab Thia scutellate • Sediment composition: PSA • Physico-chemical data: TOC and bathymetry • Standard methodology: based on Cefas aggregate extraction monitoring guidance as bespoke OWF guidance was not available at the time of reporting
Burbo Bank OWF **Post-construction Year 2 Environmental Monitoring Report** **Second Post Construction Benthic Ecology Report (Two years following construction)**	November 2009	SeaScape Energy This report summarises various elements of the environmental monitoring programme undertaken during the second year of windfarm operation	Characteristic species	• FEPA licence provided guidance on survey design – benthic grab survey not included • Characteristic species: most dominant species on monopiles
Burbo Bank OWF **Post-construction Year 3 Grab Survey Report** **Third Post Construction Benthic Ecology Report (Three years following construction)**	December 2011	Seascape Energy. This report presents and discusses results of the second post-construction benthic survey which was undertaken in September 2009.	Univariate analysis Multivariate Analysis Habitat distribution/composition Characteristic species Sediment composition Physico-chemical data	• Univariate analysis: Abundance, Taxon Richness, Margalef's Richness, Pielou's Evenness, Shannon Wiener • Multivariate analysis nMDS, SIMPER, ANOSIM • Sediment composition: PSA • Physico-chemical data: TOC • Standard methodology: The survey was designed to provide detailed information about benthic populations and sub-tidal sediment types in and around the development – As required by the FEPA licence,
Burbo Bank OWF **Diver Survey of Wind Turbine Foundations**	November 2009	SeaScape Energy	Characteristic species	• Quantitative data lacking due to survey consisting only video imagery • Characteristic species: description of epifauna present at top, middle upper, middle lower and bottom of wind turbine foundations • Standard methodology: Survey strategy included consultation with CEFAS and Natural England

First Post Construction Turbine Foundation Colonisation Report (Two years following construction)		This report presents the results of the colonisation survey (May 2009) at 7 wind turbine monopiles		
Greater Gabbard Offshore Wind Farm				
Greater Gabbard OWF Year 1 Post-construction Benthic Ecology Monitoring Survey **First Post Construction Benthic Ecology Report (One year following construction)**	Mar 2014	CMACS This report summarises the results of the post-construction benthic survey performed in 2013, including comparison with the 2005 Gabbard EIA, 2009 Baseline, 2010 Galloper EIA.	Univariate analysis Multivariate Analysis Phyletic composition Characteristic species (*Sabellaria spinulosa*) Biomass Habitat distribution/composition Sediment composition Physico-chemical data	• Univariate analysis: Abundance, Taxon Richness, Pielou's evenness, Shannon's Wiener • Multivariate analysis: nMDS, SIMPER, BIOENV • Phyletic composition and dominant taxa presented • Characteristic species: *Sabellaria spinulosa* • Biomass • Habitat distribution/composition: JNCC biotopes, Sabellaria spinulosa habitat • Sediment Composition: PSA • Physico-chemical data: TOC • Standard methodology: Survey planning for benthic sampling and analyses included consultation with CEFAS. Laboratory procedures followed NMBAQC scheme
Greater Gabbard OWF **Year 5 Post Construction Benthic Survey Technical Report v4** **Second Post Construction Benthic Ecology Report (Five years following construction)**	Jun 2020	NIRAS This report summarises the results of the post-construction benthic survey performed in 2017, for comparison with data from 2013 post construction survey and 2009 baseline survey with reference to data from 2005 and 2010 EIA surveys.	Univariate analysis Multivariate Analysis SACFOR Biomass Phyletic composition Characteristic species Habitat distribution/composition Sediment composition Physico-chemical data	• Univariate analysis: Abundance, Taxon Richness, Pielou's evenness, Shannon's Wiener • Multivariate analysis: SIMPER, BEST/BIOENV, ANOSIM • SACFOR scale for colonial species • Biomass included • Phyletic composition and dominant taxa presented • Characteristic species: *Sabellaria spinulosa* • Habitat distribution/composition: JNCC biotopes • Sediment composition: PSA • Physico-chemical data: TOC • Standard methodology: Laboratory procedures followed NMBAQC scheme
Greater Gabbard OWF **Year 10 Post Construction Benthic Survey Technical Report v4**	Apr 2023	NIRAS This report summarises the results of the post-construction benthic survey performed in 2022 for comparison with data from	Univariate analysis Multivariate Analysis Biomass	• Univariate analysis: Abundance, Taxon Richness, Pielou's Evenness, Shannon's Wiener • Multivariate analysis: SIMPER, ANOSIM • Biomass included • Invasive species abundance and distribution discussed • Phyletic composition and dominant taxa presented • Characteristic species: *Sabellaria spinulosa* and 'reefiness' discussed

Third Post Construction Benthic Ecology Report (Five years following construction)		2017, 2013 post construction survey and 2009 baseline survey.	INNS Phyletic composition Characteristic species (*Sabellaria spinulosa*) Habitat distribution/composition Sediment composition Physico-chemical data	• Habitat distribution/composition: JNCC biotopes • Sediment composition: PSA • Physico-chemical data: TOC • Standard methodology: Laboratory procedures followed NMBAQC
Greater Gabbard OWF Post-construction Turbine Colonisation Survey **First Post Construction Turbine Foundation Colonisation Report (One year following construction)**	Jan 2013	CMACS This survey was completed as part of the wider post-construction survey, identifying marine species colonising representative turbines and investigation the presence of any invasive non-native species	Univariate analysis SACFOR Phyletic composition Characteristic species Habitat distribution/composition INNS	• Colonisation survey as part of the wider post construction benthic survey • Univariate analysis: taxa present • SACFOR abundance scale included • Phyletic composition: limited to ground truth grab samples (no laboratory processing) • Characteristic species: *Sabellaria spinulosa* aggregations discussed • Habitat distribution/composition: Potential JNCC biotopes discussed • Invasive species discussed •
Gunfleet Sands I & II Offshore Wind Farm				
Gunfleet Sands OWF **Year 1 Post-construction Benthic Monitoring Report** **First Post Construction Benthic Ecology Report (One year following construction)**	Dec 2010	CMACS Overview of the 2010 post-construction monitoring survey conducted on the Gunfleet Sands OWF I and II sites. Data from the 2007 and 2010 sampling period were compared to understand natural variation within the area over time and the possible influence of wind farm construction.	Univariate analysis Multivariate Analysis Biomass Phyletic composition Characteristic species Habitat distribution/composition Sediment composition Physico-chemical data (TOC)	• Univariate analysis: Abundance, Taxon Richness, Margalef's Richness; Shannon Wiener; Simpson's Index; Pielou's Evenness); • Multivariate analysis: MDS,ANOSIM; • Biomass • Sediment composition: PSA • Physico-chemical data: TOC
Gunfleet Sands OWF **Year 2 Post-construction Benthic Monitoring Report 2011** **Second Post Construction Benthic Ecology Report (Two years following construction)**	Jun 2012	CMACS Overview of the 2011 post-construction monitoring survey conducted on the Gunfleet Sands OWF I and II sites. Data from the 2007, 2010 and 2011 sampling periods were compared to understand natural variation within the area over time and the	Univariate analysis Multivariate Analysis Biomass Phyletic composition Characteristic species Sediment composition Physico-chemical data	• Univariate analysis: Abundance, Taxon Richness; Margalef's Richness; Shannon Wiener; Simpsons Index; Pielou's Evenness • Multivariate analysis: MDS, ; ANOSIM; BIO-ENV, • Biomass • Sediment composition: PSA • Physico-chemical data: TOC

		possible influence of wind farm construction		
Gunfleet Sands OWF **Year 3 Post-Construction Benthic Monitoring Report 2012** **Third Post Construction Benthic Ecology Report (Three years following construction)**	Feb 2013	CMACS Overview of the 2012 post-construction monitoring survey conducted on the Gunfleet Sands OWF I and II sites. Data from the 2007, 2010, 2011, and 2012 sampling periods were compared to understand natural variation within the area over time and the possible influence of wind farm construction.	Univariate analysis Multivariate Analysis Phyletic composition Sediment composition Physico-chemical data (TOC)	• Univariate analysis: Abundance, Taxon Richness, Margalef's Richness; Shannon Wiener; Simpsons Index; Pielou's Evenness); • Multivariate analysis: MDS,ANOSIM, SIMPROF); • Sediment metrics: PSA • Physico-chemical data: TOC
Kentish Flats				
Kentish Flats OWF **Macrobenthic Ecology Study- 2005** **First Post Construction Benthic Ecology Report (One year following construction)**	Jun 2006	EMU Ltd This study assesses the impacts of the Kentish Flats windfarm on the physical conditions and associated biological communities. Includes comparison with the 2002 baseline study.	Univariate analysis Multivariate Analysis Phyletic composition Sediment composition	• Univariate analysis: Abundance, Taxon Richness, Margalef's Richness, Pielou's Evenness, Shannon Wiener, Simpson's Index • Multivariate analysis: nMDS, SIMPER, BIOENV, ANOSIM. Analysis of both faunal and PSA data used for temporal and spatial comparisons • Phyletic composition and dominant taxa presented • Sediment composition: PSA • The FEPA licence required a post construction benthic survey which was conducted in 2005. • Survey design based on advice given by CEFAS • Taxonomic analysis undertaken by EMU Ltd, participants in the NMBAQC scheme
Kentish Flats OWF **Macrobenthic Ecology Study- 2006** **Second Post Construction Benthic Ecology Report (Two years following construction)**	May 2007	EMU Ltd This study assesses the impacts of the Kentish Flats windfarm on the physical conditions and associated biological communities. Includes comparison with the 2002 baseline study and 2005 post construction study.	Univariate analysis Multivariate Analysis Phyletic composition Habitat distribution/composition Sediment composition	• Univariate analysis: Abundance, Taxon Richness, Margalef's Richness, Pielou's Evenness, Shannon Wiener • Multivariate analysis: nMDS, SIMPER, BIOENV of both faunal and PSD data for temporal and spatial comparisons • Phyletic composition and dominant taxa presented • Sediment composition measured and discussed • The FEPA licence required a post construction benthic survey which was conducted in 2006. • Survey design based on advice given by CEFAS • Taxonomic analysis undertaken by EMU Ltd, participants in the NMBAQC scheme
Kentish Flats OWF **Macrobenthic Ecology Study- 2007** **Third Post Construction Benthic Ecology Report**	June 2008	EMU Ltd This study assesses the impacts of the Kentish Flats windfarm on the physical conditions and associated biological communities. Includes comparison with the 2002	Univariate analysis Multivariate Analysis Phyletic composition Habitat distribution/composition	• Univariate analysis: Abundance, Taxon Richness, Margalef's Richness, Pielou's Evenness, Shannon's Wiener, Simpson's Index • Multivariate Analysis: nMDS, SIMPER, BIOENV, ANOSIM of both faunal and PSD data used for temporal and spatial comparisons • Phyletic composition and dominant taxa presented • Sediment composition measured and discussed • The FEPA licence required a post construction benthic survey which was conducted in 2006. Survey design based on advice given by CEFAS

(Three years following construction)		baseline study, 2005 and 2006 post construction studies.	Sediment composition	• Taxonomic analysis undertaken by EMU Ltd who are participants in the NMBAQC scheme • Habitats illustrated as identified by multivariate analysis
Kentish Flats OWF **Turbine Foundation Faunal Colonisation Diving Survey First Post Construction Turbine Foundation Colonisation Report (Three years following construction)**	Nov 2008	EMU Ltd / Kentish Flats Ltd This report presents the results of the colonisation survey (Jul 2008) at 2 wind turbine monopiles using video, still footage and scrape samples.	Univariate analysis SACFOR INNS Biomass Habitat distribution/composition Sediment composition	• SACFOR abundance scale • Non native species observed • BIOMASS • Habitat distribution/composition: JNCC Biotopes • Sediment description based of visual imagery only • Standard methodology: Survey design included consultation with CEFAS • Methods included MNCR Phase 2, NMBAQC
London Array OWF Year 1 Post-Construction Monitoring Report First Post Construction Benthic Ecology Report (One year following construction)	May 2015	MarineSpace Marine Space Ltd. summarises the findings of the Year 1 post-construction monitoring surveys that have been conducted within the London Array OWF study area, consisting of the OWF site and along the export cable corridor.	Univariate analysis Multivariate Analysis Characteristic species Habitat distribution/composition	• Univariate analysis: Abundance, Taxon Richness, Margalef's Richness; Shannon-Wiener, Pielou's Evenness; Simpson's Index • Multivariate analysis (this was performed but no detail of types of analysis shown in report), • Habitat distribution/composition: Biotope classification.
Lynn and Inner Dowsing Offshore Wind Farm				
Lynn and Inner Dowsing OWF Biological Survey Report Pre-construction Benthic Ecology Report	Feb 2002	AMEC This field report details the survey methodology. Samples and visual observations are detailed.	Sediment composition	• PSA, physico-chemical data, faunal analysis. Very high level report with limited detail of results and analysis of data collected.
Lynn and Inner Dowsing OWF Post-construction survey works (2010). Phase 2 Benthic Ecology Survey First Post Construction Benthic Ecology Report (One year following construction)	Nov 2011	Benthic Solutions Ltd. This report presents the second post-construction marine geophysical and benthic ecology survey of the Lynn and Inner Dowsing (L&ID) offshore wind farm sites and export cable route corridors. This document relates	Univariate analysis Multivariate Analysis Characteristic species Habitat distribution/composition Sediment composition	• Univariate analysis: Abundance, Taxon Richness, Margalef's Richness, Pielou's Evenness, Shannon's Wiener, Simpson's Index • Multivariate analysis: nMDS, SIMPER, ANOSIM • Characteristic species: *Sabellaria* sp, 'reefiness' assessed • Habitat distribution/composition: biotope classification • Sediment composition: PSA

		to Phase 2 of the survey, benthic ecology		
Lynn and Inner Dowsing OWF **Year 3 Post-construction Survey (2011). Phase 2 Benthic Ecology Survey** **Second Post Construction Benthic Ecology Report (Two years following construction)**	Oct 2012	Centrica energy / EGS This report presents the third post-construction marine geophysical and benthic ecology survey of the Lynn and Inner Dowsing (L&ID) offshore wind farm sites and export cable route corridors. This document relates to Phase 2 of the survey, benthic ecology	Univariate analysis Multivariate Analysis Characteristic species Habitat distribution/composition Sediment composition	• Univariate analysis: Abundance, Taxon Richness, Margalef's Richness; Pielou's Evenness; Shannon-Wiener; Simpson's Index • Multivariate analysis: nMDS, SIMPER, ANOSIM • Sediment composition: PSA • Habitat distribution/composition: Biotope classification
Lynn and Inner Dowsing OWF **(October - November 2013) Phase 3 survey report** **Third Post Construction Benthic Ecology Report (Three years following construction)**	Jun 2014	Centrica energy / EGS Ltd. The overall objective of the study was to provide information in support of Operations and Maintenance (O&M) activities which have the potential to interact with the seabed, principally jack-up vessels.	Univariate analysis Multivariate Analysis Characteristic species Habitat distribution/composition Sediment composition	• Univariate analysis: Abundance, Taxon Richness, Margalef's Richness, Shannon Wiener, Pielou's Evenness, Simpsons Index • Multivariate analysis: MDS, SIMPER • Habitat distribution/composition: Biotope classification • Sediment composition: PSA
North Hoyle Offshore Wind Farm				
North Hoyle OWF **Baseline Monitoring Report Pre-construction Benthic Ecology Report**	Jun 2003	North Hoyle This report presents the findings of the baseline monitoring survey undertaken in and around the North Hoyle development site	Univariate analysis Multivariate Analysis Habitat distribution/composition Sediment composition Physico-chemical data	• Univariate analysis: Abundance, Taxon Richness, Pielou's Evenness, Shannon Wiener • Multivariate analysis: MDS • Habitat distribution/composition: JNCC biotopes • Sediment composition: PSA • Physico-chemical data: TOC and Total Nitrogen • Standard methodology: Sampling protocol agreed with CEFAS and County Council for Wales (CCW)
North Hoyle OWF **Annual FEPA Monitoring Report (2004-5)** **First Post Construction Benthic Ecology Report (One year following construction)**	Feb 2006	Npower Renewables This report presents the findings of the monitoring survey undertaken in and around the North Hoyle development site	Univariate analysis Multivariate Analysis Phyletic composition Habitat distribution/composition Sediment composition	• Univariate analysis: Abundance, Taxon Richness, Shannon Wiener • Multivariate analysis: MDS, SIMPER of faunal data to display similarities between fauna at each site based upon pooled data (2002, 2003, 2004). • Phyletic composition and dominant taxa presented • Habitat distribution/composition: JNCC biotopes described • Sediment composition: PSA • Physico-chemical data: TOC • Species of conservation importance discussed

			Physico-chemical data	• Annual report satisfies requirements of the FEPA licence conditions • Benthic surveys undertaken by CMACS
North Hoyle OWF Annual FEPA Monitoring Report (2005-6) Second Post Construction Benthic Ecology Report (Two years following construction)	Mar 2007	Npower Renewables The report describes the post construction monitoring surveys undertaken during 2005-06. Data was compared to 2002 pre-construction survey, 2003 construction and 2004 post construction surveys.	Univariate analysis Multivariate Analysis Sediment composition Physico-chemical data Standard methodology	• Univariate analysis: Abundance, Taxon Richness, Margalef's Richness, Pielou's Evenness, Shannon Wiener • Multivariate analysis: MDS, SIMPER • Sediment composition: PSA discussed and compared with 2002 and 2003, 2004, 2005 • Phyletic composition in appendices (not available) • Physico-chemical data: TOC • Annual report satisfies requirements of the FEPA licence conditions • Benthic surveys undertaken by CMACS • Species of importance as a food source discussed
North Hoyle OWF **Biology & Video Surveys of North Hoyle Wind Turbines** **First Post-Construction Monopile Colonisation Report (One year following construction)**	Aug 2004	CMACS Ltd. The report presents the findings of the monopile colonisation surveys undertaken by dive survey at the North Hoyle offshore wind farm.	Univariate analysis Biomass Habitat distribution/composition	• Univariate analysis: Abundance (including Abundance scales), and Taxon Richness, • Biomass • Sediment composition at foot of turbine (scour zone) analysed through dive survey imagery
Ormonde Offshore Wind Farm				
Ormonde OWF Benthic Survey Report Pre-construction Benthic Ecology Report	Nov 2009	CMACS This report presents the results of the Pre-construction benthic ecological monitoring surveys for the OWF and export cable route	Univariate analysis Multivariate Analysis Phyletic composition Characteristic species Habitat distribution/composition Sediment composition Physico-chemical data	• Univariate analysis: Abundance, Taxon Richness, Margalef's Richness, Pielou's Evenness, Shannon Wiener • Multivariate analysis: MDS • Phyletic composition and dominant taxa presented • Characteristic species: *Sabellaria spinulosa* and *Modiolus modiolus* discussed in report, but not observed • Habitat distribution/composition: JNCC biotopes • Sediment composition: PSA • Physico-chemical data: TOC • Standard Methodology: Laboratory participates in the NMBAQC scheme
Ormonde OWF Annual Monitoring Report **First Post Construction Benthic Ecology Report (One year following construction)**	Jan 2014	RPS Energy, Vattenfall This document contains summaries of the results and conclusions from the year 1 post-construction monitoring surveys and studies undertaken in 2012. The full benthic monitoring survey	Univariate analysis Multivariate Analysis Phyletic composition Characteristic species Habitat distribution/composition	• Univariate analysis: Abundance, Taxon Richness, Pielou's Evenness, Shannon Wiener, Simpson's Index. • Multivariate analysis: MDS, SIMPER, ANOVA • Phyletic composition and dominant taxa presented • Habitat distribution/composition: JNCC biotopes. *Sabellaria spinulosa* discussed in report, but not observed • Sediment composition: PSA • Physico-chemical data: TOC

		report is provided in the appendices.	Sediment composition Physico-chemical data	• Standard methodology: Survey techniques matched the approach adopted in the collection of baseline data (CMACS)
Ormonde OWF **Annual Monitoring Report** **Second Post Construction Benthic Ecology Report (Two years following construction)**	May 2014	RPS Energy, Vattenfall This document contains summaries of the results and conclusions from the year 2 post-construction monitoring surveys and studies undertaken in 2013. The full reports of these surveys are provided in the appendices.	Univariate analysis Multivariate Analysis Phyletic composition Characteristic species Habitat distribution/composition Sediment composition Physico-chemical data	• Univariate analysis: Abundance, Taxon Richness, Pielou's Evenness, Shannon Wiener, Simpson's Index • Multivariate analysis: MDS, SIMPER, ANOSIM • Phyletic composition and dominant taxa presented • Characteristic species: *Sabellaria spinulosa* aggregations discussed in report • Habitat distribution/composition: JNCC biotopes • Sediment composition: PSA • Physico-chemical data: TOC • Standard methodology: Survey techniques matched the approach adopted in the collection of baseline data (CMACS)
Princess Amalia Offshore Wind Farm				
Dutch Wind Farms: North Sea Wind Farms Lot 1 Benthic Fauna. Final Report **Pre-construction Benthic Ecology Report**	Feb 2004	Directorate - General of Public Works and Water Management. National Institute for Coastal and Marine Management / RIKZ This report contains the results and conclusions of the baseline survey within the proposed windfarm area	Univariate analysis Multivariate Analysis Biomass Sediment composition Physico-chemical data	• Univariate: Abundance, Taxon Richness, mean density, Shannon-Wiener, Species Richness, Pielou's Evenness, Simpson's Diversity • Multivariate: ANOVA • Biomass • Sediment composition: PSA • Physico-chemical data: TOM
Princess Amalia OWF **Assessment of the soft sediment fauna five years after construction of the Princess Amalia wind farm** **First Post Construction Benthic Ecology Report (Five years following construction)**	Oct 2013	eCOAST Research Centre This report contains the results and conclusions of the post construction survey, 5 years after construction	Univariate analysis Multivariate Analysis Phyletic composition Biomass Sediment composition Physico-chemical data	• Univariate: Abundance, Taxon Richness, Shannon-Wiener, Pielou's Evenness, Gini-Simpson's Index • Multivariate: MDS, ANOVA • Phyletic composition • Biomass • Sediment composition: PSA • Physico-chemical data: TOM
Princess Amalia OWF **An assessment of the soft sediment fauna six years after construction of the Princess Amalia Wind Farm** **Second Post Construction Benthic Ecology Report (Six years following construction)**	Jan 2014	eCOAST Research Centre This report contains the results and conclusions of the post construction survey, 6 years after construction	Univariate analysis Multivariate Analysis Phyletic composition Biomass Sediment composition Physico-chemical data	• Univariate: Abundance, Taxon Richness, Shannon-Wiener, Pielou's Evenness, Gini-Simpson's Index • Multivariate: MDS, ANOVA • Phyletic composition • Biomass • Sediment composition: PSA • Physico-chemical data: TOM

Princess Amalia OWF **Benthic development in and around offshore wind farm Prinses Amalia Wind Park near the Dutch coastal zone before and after construction (2003-2017)** **Third Post Construction Benthic Ecology Report (Ten years following construction)**	April 2018	Eurofins / AquaSense This report contains the results and conclusions of the post construction survey, 10 years after construction	Univariate analysis Multivariate Analysis Phyletic composition Biomass Sediment composition Physico-chemical data	• Univariate: Abundance, Taxon Richness, Margalef's Richness, Shannon-Wiener, Pielou's Evenness, Simpson's Diversity, ANOVA • Multivariate: MDS; envfit in R • Phyletic composition • Biomass • Sediment composition: PSA • Physico-chemical data: TOM
Princess Amalia OWF **Statistical comparison of benthic fauna inside and outside the Prinses Amalia Wind Park fifteen years after construction; first analysis** **Fourth Post Construction Benthic Ecology Report (Fifteen years following construction)**	Sept 2022	Eurofins / AquaSense This report contains the results and conclusions of the post construction survey, 15 years after construction	Univariate analysis Multivariate Analysis Phyletic composition Biomass Sediment composition Physico-chemical data	• Univariate: Abundance, Taxon Richness, Margalef's Richness, Shannon-Wiener, Pielou's Evenness, ANOVA • Multivariate: MDS • Phyletic composition • Biomass • Sediment composition: PSA
Princess Amalia OWF **Development of hard substrate fauna in the Princess Amalia Wind Farm. Monitoring 3.5 years after construction** **First Post Construction Turbine Foundation Colonisation Report (Three years following construction)**	Jan 2013	eCOAST Marine Research This report presents the results of the colonisation survey (October 2011) at 4 wind turbine monopiles using divers and scrape samples.	Univariate analysis Multivariate Analysis Phyletic composition Biomass	• Univariate analysis: Abundance, Taxon Richness, Pielou's Evenness, Shannon Wiener, Simpson's Index • Multivariate analysis: MDS, SIMPER, ANOSIM • Phyletic composition of scrape samples • Biomass
Princess Amalia OWF **Development of hard substrate fauna in the Princess Amalia Wind Farm. Monitoring 6 years after construction** **Second Post Construction Turbine Foundation**	Apr 2014	eCOAST Marine Research This report presents the results of the colonisation survey (July 2013) at 4 wind turbine monopiles using divers and scrape samples.	Univariate analysis Multivariate Analysis Phyletic composition Biomass	• Univariate analysis: Abundance, Taxon Richness, Pielou's Evenness, Shannon Wiener, Simpson's Index • Multivariate analysis: MDS, SIMPER, ANOSIM • Biomass

Colonisation Report (Six years following construction)				
Robin Rigg Offshore Wind Farm				
Robin Rigg OWF **First Pre Construction Benthic Ecology Report (Six years before construction)**	May 2002	Natural Power This report presents details of the proposed offshore windfarm at robin rigg, including baseline physical and environmental conditions.	Univariate analysis Multivariate analysis Characteristic species INNS Habitat distribution/composition Sediment composition Physico-chemical data	• Univariate analysis: Abundance, Taxon Richness, Margalef's Richness, Shannon-Wiener, Pielou's Evenness • Multivariate analysis: MDS • Habitat distribution/composition: MNCR Biotope, classification, distribution and characteristic species • INNS • Sediment composition: PSA • Physico chemical data: TOC
Robin Rigg OWF **Pre-Construction and Construction Comparison Reports** **Baseline, Pre-construction and Construction Phase Analysis - Fish and Benthic Monitoring** **Analysis of MEMP Ecological Data (Pre-construction vs. Construction Years)** **Two Benthic Ecology Comparison Reports - Pre-construction and Construction Phase (Two years following construction)**	April 2011 March 2012	Entec UK Limited Natural Power Consultants (Canning et al) These reports present the assessment of the demersal fish, epibenthic, and benthic conditions at the site of the Robin Rigg during the pre-construction, construction and post-construction phase.	Univariate analysis Multivariate Analysis Characteristic species Habitat distribution/composition	• Univariate: Abundance, Taxon Richness, Margalef's Index, Pielou's Evenness, Shannon Wiener, Simpson's Index • Multivariate analysis: nMDS, SIMPER, ANOSIM and BIOENV • Phyletic composition not discussed • PSA not discussed in report, but applied to multivariate analysis with benthic fauna • Habitat distribution/composition: JNCC biotopes and characteristic species • Physico chemical analysis conducted but absent from report
Robin Rigg OWF **Analysis of Marine Ecology Monitoring Plan Data from the Robin Rigg Offshore Wind Farm, Scotland (Operational Year 1) - Technical report** **First Post Construction Benthic Ecology Report (Three years following construction)**	Jan 2013	Natural Power This report represents the analysis performed on data collected before construction, during construction and during operation	Univariate analysis – Multivariate analysis Characteristic species Habitat distribution/composition	• Univariate analysis: Abundance, Margalef's index, Pielou's Evenness, Shannon Wiener, Simpson's Index. • Multivariate analysis: ANOSIM, nMDS, SIMPER • Habitat distribution/composition: Biotope and characteristic species.

Robin Rigg OWF **Analysis of Marine Ecology Monitoring Plan Data from the Robin Rigg Offshore Wind Farm, Scotland (Operational Year 2)** **Second Post Construction Benthic Ecology Report (Three years following construction)**	Sep 2013	Natural Power Consultants This report represents the analysis performed on data collected before construction, during construction and during operation	Univariate analysis – Multivariate analysis Characteristic species Habitat distribution/composition Sediment composition	• Univariate analysis: Abundance, Taxon Richness, Margalef's Index, Pielou's Evenness, Shannon Wiener, Simpson's Index. • Multivariate analysis: ANOSIM, nMDS, SIMPER, BIOENV • Habitat extend/composition: Biotope classification • Sediment composition discussed in biotopes, but no statistics
Robin Rigg OWF **Windfarm Site Benthic Macro Invertebrate Data Report, July 2007** **Cable Route Benthic Macroinvertebrate Data Report, May 2007, November 2007** **First Three Pre Construction Benthic Ecology Technical Notes (One year before construction)**	Windfarm Site, Jul 2007 Cable Route, May 2007, Nov 2007	Entec Holdings Ltd Technical notes summarising the methodology and results of their respective surveys. No statistical analysis.	Univariate analysis Sediment composition Physico-chemical data	• Univariate analysis: Abundance only • Sediment composition: PSA • Physico-chemical data: TOC
Robin Rigg OWF **Windfarm Site Benthic Macro Invertebrate Data Report, March 2008, June 2009** **Cable Route Benthic Macro Invertebrate Data Report, May 2008, November 2008, June 2009**	Windfarm Site, Mar 2008, Jun 2009 Cable Route, May 2008, Nov 2008, Jun 2009	Entec Holdings Ltd Technical notes summarising the methodology and results of their respective surveys. No statistical analysis.	Univariate analysis Sediment composition Physico-chemical data	• Univariate analysis: Abundance only • Sediment composition: PSA • Physico-chemical data: TOC
Robin Rigg OWF **Windfarm Site Benthic Macro Invertebrate Data Report, April 2011**	Windfarm Site, April 2011	Entec Holdings Ltd	Univariate analysis Sediment composition Physico-chemical data (TOC)	• Univariate analysis: Abundance only • Sediment composition: PSA • Physico-chemical data: TOC

Cable Route Benthic Macro Invertebrate Data Report, April 2011 **Three of Four Post Construction Phase Benthic Ecology Technical Notes**	Cable Route, April 2011	This technical note summarises methodology and results of the survey. No statistical analysis.		
Robin Rigg OWF **Robin Rigg Monitoring Reports (Technical Notes). Post-construction.** **Reef Monitoring Data Analysis Report, Feb 2011** **Fourth Post Construction Phase Benthic Ecology Technical Notes**	Feb 2011	Entec Holdings Ltd This technical note summarises methodology and results of the survey. No statistical analysis.	SACFOR Multivariate analysis Characteristic species Habitat distribution/composition	• Walk over survey & GPS to map Sabellaria reef. Comparison to 2004 surveys & changes. • Multivariate: ANOVA used to determined changes in sand cover, nMDS
Scroby Sands Offshore Wind Farm				
Scroby Sands OWF **Pre-construction – Likely changes to the benthic fauna following development of the proposed Sarah Jane Windfarm on Middle Scroby Sands** **Pre Construction Benthic Ecology Report**	Nov 1999	Unicomarine This report discusses the benthic ecology in the area and the probable changes resulting from the construction of the monopiles.	Univariate analysis Multivariate Analysis Characteristic species Habitat distribution/composition Sediment composition	• Univariate analysis: Abundance, Taxon Richness, Shannon-Wiener, Pielou's Evenness • Multivariate biological analyses: MDS. • Biomass • Habitat distribution and composition: Biotopes assigned • Characteristic species: Ross worm and sand-mason worm specifically • Sediment composition: PSA
Scroby Sands OWF **Benthic ecology of Scroby Sands windfarm site: results of July 2005 (post-construction) survey and comparison with 1998 (pre-construction) survey**	Jul 2005	Unicomarine This report presents a comparison of sediment composition and benthic fauna assemblages pre- and post-construction	Univariate analysis Multivariate Analysis Biomass Characteristic species Habitat distribution/composition Sediment composition	• Univariate analysis: Abundance, Taxon Richness, Shannon-Wiener, Pielou's Evenness • Multivariate analysis: MDS. • Biomass • Characteristic species: Ross worm and sand-mason worm specifically • Habitat distribution and composition: Biotopes assigned • Sediment composition: PSA

First Post Construction Benthic Ecology Report (One year following construction)				
Sheringham Shoal				
Sheringham Shoal OWF Benthic Ecology and Sabellaria Study 2009 Pre-Construction Benthic Ecology Report	May 2010	Scira Offshore Energy Limited This report presents the findings of the benthic survey, conducted to ascertain whether Sabellaria spinulosa reef had built up in the proposed windfarm turbine areas, or in the associated proposed cable route since previous surveys undertaken in 2008.	Univariate analysis Multivariate Analysis Phyletic composition Characteristic species (*Sabellaria spinulosa*) Habitat distribution/composition	• Univariate analysis: Abundance, Taxon Richness, Margalef's Richness, Pielou's Evenness, Simpson's Diversity • Multivariate analysis: MDS, SIMPER, ANOSIM • Phyletic composition • Characteristic species: *Sabellaria spinulosa* • Habitat distribution/composition: Annex I habitats and JNCC biotopes • Sabellaria "Reefiness" assessment • No sediment composition or physico chem analysis. Sediment description based on seabed imagery • Standard methodology: Survey specification and methods devised following correspondence with Natural England and CEFAS. Laboratory protocol mirrors standards set by NMBAQC scheme
Sheringham Shoal OWF Post-construction Monitoring Benthic Survey First Post Construction Benthic Ecology Report (One year following construction)	Jul 2013	FUGRO EMU Ltd. This report presents the findings of the post-construction monitoring survey that was undertaken across the OWF area, cable corridor and reference areas in 2012	Univariate analysis Multivariate Analysis SACFOR Phyletic composition Characteristic species INNS Habitat distribution/composition Sediment composition	• Univariate analysis: Abundance, Taxon Richness • Multivariate analysis: MDS, SIMPER, • SACFOR abundance scale included • Phyletic composition and dominant taxa presented • Characteristic species: *Sabellaria spinulosa* • Invasive species discussed • Habitat distribution/composition: JNCC habitat • Sabellaria "Reefiness" assessment • Sediment composition: PSD • Standard methodology: Benthic sampling and analyses in accordance with industry guidelines (CEFAS) • Grab and beam trawl samples were returned to Fugro EMU's NMBAQC scheme benthic laboratory for analysis.

Sheringham Shoal Second Post-Construction Benthic Monitoring Survey Second Post Construction Benthic Ecology Report (Two years following construction)	Nov 2014	Marine Ecological Surveys Limited. This report presents the second post-construction survey of benthic resources undertaken at the Sheringham Shoal Offshore Wind Farm.	Univariate analysis Multivariate Analysis Phyletic composition Characteristic species (*Sabellaria spinulosa*) INNS Habitat distribution/composition Sediment composition	• Univariate analysis: Abundance, Taxon Richness • Multivariate analysis: MDS, RELATE, BIO-ENV, ANOSIM • Phyletic composition • Characteristic species: *Sabellaria spinulosa* • INNS: *Crepidula fornicata* • Habitat distribution/composition: EUNIS habitat classification • Sabellaria "Reefiness" assessment • Sediment composition: PSA • Standard methodology: Marine Ecological Surveys Limited participant in the NMBAQC scheme
Thanet Offshore Wind Farm				
Thanet OWF A Post-construction Monitoring Survey of Benthic Resources First Post Construction Benthic Ecology Report (Two years following construction)	Jan 2013	MES Ltd. This report presents the findings of the post-construction monitoring survey that was undertaken across the TOWF area during two sampling events in August & November 2012.	Univariate analysis Multivariate Analysis Biomass Phyletic composition Characteristic species (*Sabellaria spinulosa*) INNS Habitat distribution/composition Sediment composition Physico-chemical data	• Univariate analysis: Abundance, Taxon Richness • Multivariate analysis: ANOSIM; Bio-Env • Biomass • Phyletic composition and dominant taxa presented and compared • Characteristic species: *Sabellaria spinulosa* • Invasive species abundance and distribution discussed • Habitat distribution/composition: *Sabellaria spinulosa* habitat distribution and density assessment • Sediment composition measured and discussed • Physico-chemical data: TOM • Standard methodology: Laboratory analysis compliant with NMBAQC methodology
Walney I & II Offshore Wind Farm				
Walney OWF Year 3 Post-construction Benthic Monitoring Surveys Third Post Construction Benthic Ecology Report (Three years following construction) (first and second year post-construction survey reports were not available (for 2012, 2013)).	February 2015	CMACS Ltd. This report concentrates on grab and DDV surveys that were carried out in 2014, with comparison of these data against those collected in previous years.	Univariate analysis Multivariate Analysis Biomass SACFOR Phyletic composition Characteristic species (*Sabellaria spinulosa*) Habitat distribution/composition Sediment composition Physico-chemical data	• Univariate analysis: Abundance, Taxon Richness, Margalef's Richness, Pielou's Evenness, Simpson's Indexes, Shannon Wiener, ANOVA, ANOSIM • Multivariate analysis: MDS, SIMPER; Bio-Env • Biomass • SACFOR • Phyletic composition • Characteristic species: *Sabellaria spinulosa* • Habitat distribution/composition: biotope classification, including characterising species • Sediment composition • Physico-chemical data (TOM)

Westermost Rough Offshore Wind				
Westermost Rough OWF Post Construction Benthic Survey 2015 **First Post Construction Benthic Ecology Report (One year following construction)**	April 2016	Precision Marine Survey LTD. The report aims to provide an assessment of the benthic habitats and associated assemblages within and adjacent to the areas of potential impact resulting from the construction and of the WMR OWF (year 1 post-construction)	Univariate analysis Multivariate Analysis Phyletic composition Characteristic species Habitat distribution/composition Sediment composition Physico-chemical data	• Univariate analysis: Abundance, Taxon Richness, Shannon-Wiener, Margalef's Richness, Pielou's evenness. • Multivariate analysis: nMDS, SIMPER, 2STAGE; ANOSIM; BEST • Phyletic composition • Habitat distribution/composition: Biotope classifications and characterising species • Sediment composition: PSA • Physico-chemical data: TOC
Westermost Rough OWF Post Construction Benthic Survey (2019). Technical Report **Second Post Construction Benthic Ecology Report (Two year following construction)**	April 2020	Precision Marine Survey Ltd. / Orsted. The report aims to provide an assessment of the benthic habitats and associated assemblages within and adjacent to the areas of potential impact resulting from the construction of the WMR OWF. It provides a comparison with previous data collected at the development site during year 1 post-construction and pre-construction surveys.	Univariate analysis Multivariate Analysis Phyletic composition Characteristic species Habitat distribution/composition Sediment composition Physico-chemical data	• Univariate analysis: Abundance, Taxon Richness, Shannon-Wiener, Margalef's Richness, Pielou's Evenness. • Multivariate analysis: nMDS, SIMPER, 2STAGE; ANOSIM; BEST • Phyletic composition • Habitat distribution/composition: Biotope classifications and characterising species • Sediment composition: PSA • Physico-chemical data: TOC

Annex 1b RQ 2 pre- and post-construction monitoring reports: Methods and approaches to analysis

Title of document	Date produced	Author and summary	Assessment Criteria and score	Key Specific information
Barrow Offshore Wind Farm				
Barrow Offshore Wind Farm. Post Construction Monitoring Report. First Annual Report First Post Construction Benthic Ecology Report (Two years following construction)	Nov 2007	Barrow Offshore Wind Ltd, RSK. This report presents the results of the post-construction survey performed in 2007 and compares data with previous monitoring results from pre-construction surveys (2004) at the Barrow OWF site.	**Survey design and statistical approach** • Sampling stations located within OWF (no. 5), near-field area of monopile foundations (no. 5), eastern OWF boundary (no. 5), within tidal excursion (no. 5), along cable route (no. 3)[6] • Reference stations: 4 stations - 16% of sampling stations • Text suggests statistical analysis has been undertaken, however, lacks detail in specific analyses • No changes in habitat discussed • Discussion of results in relation to windfarm construction and concludes changes observed due to natural fluctuations • Includes comparisons with historical data for the area to contextualise natural variability **Methodology** • Faunal grabs, anchor dredge, PSA and physico-chemical data collected and compared • Survey repeats same stations as pre-construction 2002 & 2004 surveys • Sampling carried out at same time of year as pre- construction survey (licence condition) • Consistent laboratory methodology used each year • Data from three surveys compared; Pre-construction (2002 & 2004) and current pre-construction survey (2007) **Correlation** • BIOENV statistical correlation carried out to identify the effects of sediment grain size and TOC on faunal community structure **Power analysis** • Power analysis not carried out	• There were differences in the physical and chemical data as well as the biological data collected in the pre and post-construction surveys. These differences were also noted for the data from reference stations, therefore, changes to benthic habitats were concluded to be a result of natural variation. • Results of BIOENV indicated that grain size and TOC influence the communities present, but no other environmental variables had a significant influence on the benthic communities. • Grab surveys indicated higher number of species and individuals recorded in the post-construction surveys compared to pre-construction surveys, with low similarity in communities between years. Low similarity was thought to be a result of high abundances of species such as *Pontocrates altamarinus* and *Nucula nitidose* found in 2007 which were not frequently recorded in pre-construction surveys. However, similar differences were found in reference sites (outside the influence of the OWF). Therefore, changes in species composition were thought to be a result of natural variability.
Barrow Offshore Wind Farm Post-construction	Jan 2009	Barrow Offshore Wind Ltd	**Survey design and statistical approach** • Reference stations – not applicable for colonisation survey	• It was found that, in general, similar dominant species were found between the initial survey conducted in May 2006, and the current survey. The communities identified during the 2008

[6] Where there are multiple surveys for an OWF, numbers of stations including reference stations have only been indicated for the first survey

Monitoring Report. Second Annual Report Second Post Construction Benthic Ecology Report (Three years following construction)		This report presented result for the monopile ecological survey, investigating colonisation of monopiles using video footage and scrape samples. A comparison of results was also made between the current study and the 2008 post-construction survey, which was completed approximately eight months after the installation of the monopiles.	• Sampling stations restricted to monopiles • Statistical analysis not applicable • Habitats on monopiles discussed • Study specifically investigates colonisation of monopiles – anthropogenic impact • Includes general comparisons with historical data for the monopiles. Data is semi-quantitative, and as such no statistical analysis was performed between datasets **Methodology** • Still images/video footage, surface scrapes, core sampling collected and compared • Of the four monopiles surveyed, one was previously surveyed in 2006. Otherwise methodology was consistent • Sampling carried out during spring/summer • Consistent laboratory methodology used (NMBAQC) • Data compared with previous 2006 survey and neighbouring North Hoyle Wind Farm **Correlation** • No statistical correlation carried out	surveys however were well established in comparison to the previous survey, with a dense coverage of organisms on the monopiles. • The species found at both Barrow and North Hoyle OWFs were indicated to be generally comparable, although the community structure varied slightly between the two, which given that they are at different locations, with different physical environmental influences, was not unexpected. • Similar shallow subtidal communities between the Barrow OWF and North Hoyle OWF sites. However, deeper subtidal communities differed due to the presence of the plumose anemone at Barrow OWF which was absent from the North Hoyle OWF.
Barrow Offshore Wind Farm. Post-construction Monitoring Report. Third Annual Report and Overall Conclusions. Final Report Third Post Construction Benthic Ecology Report (Four years following construction)	Mar 2010	Barrow Offshore Wind Ltd. This report presents the results of the year 3 post-construction survey performed in 2009. Appendices include the benthic survey technical report (Oct 2009) and comparative analysis (Dec 2009)	**Survey design and statistical approach** • Sampling stations within OWF windfarm, near-field area of monopile foundation, eastern OWF boundary, within tidal excursion, along cable route, reference stations • Text suggests statistical analysis has been undertaken, however, lacks detail in specific analyses • No changes in habitat discussed • Discussion of results in relation to windfarm construction and concludes changes observed due to natural fluctuations • Includes comparisons with historical data for the area to contextualise natural variability **Methodology** • Faunal grabs, anchor dredge, bathymetry, PSA and physico chemical data collected and compared • Survey repeats same stations as 2004, 2007 and 2009 surveys • Sampling carried out at some time of year (winter/spring) as pre-construction survey (licence condition) • Consistent laboratory methodology used each year • Data from three surveys compared **Correlation** • No statistical correlation carried out	• The changes observed in the benthic community after construction of the wind farm show a higher diversity of species and a higher number of individuals than before construction of Barrow Offshore Wind Farm. • Similar changes are seen both in the wind farm area, the cable area and at the reference stations. This leads to the conclusion that changes over time within the wind farm area have not been caused by the construction or operation of the wind farm, but more likely by the natural dynamics of the Irish Sea where Barrow Offshore Wind Farm is located. • Abundance of marine fauna as indicated by numbers of countable organisms appears higher along and beyond the offshore edge of the array area compared with stations further inshore. • Diversity of organisms was generally slightly higher within and just to the south of the array than elsewhere.

Barrow Offshore Wind Farm Benthic & sediment survey: Comparative analysis of pre- and post-construction benthic and sedimentological data Comparison report after monitoring programme complete	Dec 2009	Barrow Offshore Wind Ltd, RSK. This report summarises the results of the post-construction survey performed in 2009 and compares data with previous monitoring results from the Barrow OWF site.	**Survey design and statistical approach** • Sampling stations located within OWF windfarm, near-field area of monopile foundation, OWF boundary, within tidal excursion, along cable route and outside tidal excursion • Text suggests statistical analysis has been undertaken, however, lacks detail in specific analyses • No changes in habitat discussed • Discussion of results in relation to windfarm construction and concludes changes observed due to natural fluctuations • Includes comparisons with historical data for the area to contextualise natural variability **Methodology** • Faunal grabs, anchor dredge, PSA and physico chemical data collected and compared • Survey repeats same stations as 2004, 2007 surveys • Sampling carried out at some time of year as pre-construction survey (licence condition) • Consistent laboratory methodology used each year • Data from three surveys compared **Correlation** • BIOENV statistical correlation carried out to identify the effects of sediment grain size and TOC on faunal community structure	• There were differences in the physical data as well as the biological data collected in the pre and post-construction surveys. These differences were not restricted to the stations that could have been impacted by the construction or operation of the windfarm - they were also present in the data from stations that were expected to be outside the influence of the windfarm and were regarded as reference locations. • The fact that the results from these references stations show a change between the pre and post-construction surveys suggests that there have been natural changes throughout the area, and that the changes at the stations within the area of possible influence are not caused by the construction or operation of the windfarm. • Statistical test on the environmental variables which have been measured in 2004, 2007 and 2009 appear to show that they are not responsible for the defining the benthic communities present.
Beatrice Offshore Wind Farm				
Beatrice OWF. Post-construction Monitoring Benthic Grab Survey Report First Post Construction Benthic Ecology Report (One year following construction)	Apr 2021	APEM Ltd This report summarises the results of the post-construction survey performed in 2020, including comparison with the 2010 EIA characterisation survey and 2015 pre-construction survey	**Survey design and statistical approach** • Sampling stations within OWF (no. 10) • Reference stations: 2 stations - 17% of sampling stations • ANOSIM testing of data • Changes discussed at both site and habitat level • Discussion of results in relation to windfarm construction and concludes changes observed not due to anthropogenic activities • Includes comparisons with pre-construction data for the area to contextualise natural variability **Methodology** • Faunal grabs, and PSA data collected and compared • Survey repeats same stations as previous surveys • Sampling carried out at some time of year as precious surveys • Consistent laboratory methodology used each year • Data from three surveys compared	• Biotopes at the site are mainly transitional between the '*Moerella* spp. with venerid bivalves in Atlantic infralittoral gravelly sand biotope' and '*Abra prismatica* in circalittoral fine sand' biotopes and results of surveys to date suggest that benthic communities and associated sediment types naturally fluctuate between these biotopes. • There is no evidence that the Beatrice OWF development has had a significant impact on the biotope, and any differences in biotope were likely due to natural variability. This is because similar changes in species composition between years were found in both primary and reference stations.

			Correlation • RELATE and BIOENV statistical correlation carried out to identify the relationship between sediment grain size and faunal community structure **Power analysis** • Power analysis not carried out	
Beatrice OWF. Post-construction Monitoring Year 2 (2021): Benthic Grab Survey Report Second Post Construction Benthic Ecology Report (Two years following construction)	Jan 2022	APEM Ltd This report summarises the results of the post-construction survey performed in 2021, including comparison with the 2010 EIA characterisation survey, 2015 pre-construction survey and 2020 post-construction survey	**Survey design and statistical approach** • Sampling stations within OWF with reference stations • ANOSIM testing of data • Changes discussed at both site and habitat level • Discussion of results in relation to windfarm construction and concludes changes observed not due to anthropogenic activities • Includes comparisons with pre-construction data for the area to contextualise natural variability **Methodology** • Faunal grabs, and PSA data collected and compared • Survey repeats same stations as previous surveys • Sampling carried out at some time of year as precious surveys • Consistent laboratory methodology used each year • Data from four surveys compared **Correlation** • RELATE and BIOENV statistical correlation carried out to identify the relationship between sediment grain size and faunal community structure	• RELATE and BIO-ENV tests between environmental and faunal data which indicated a correlation between the multivariate patterns observed in the sediment data and between faunal communities. Results indicated that environmental factors are likely having an effect on the biological data. • No evidence that the Beatrice OWF development has had an impact on the biotope beyond changes due to natural variation
Post-construction Monitoring: Turbine Foundation Marine Ecology Survey Report First Post Construction Turbine Foundation Colonisation Report (One year following construction)	Sep 2021	APEM Ltd This report presents the results of the first round of post-construction underwater video survey of foundation jacket legs and surrounding seabed conducted in March 2020	**Survey design and statistical approach** • Reference stations – not applicable for colonisation survey • SACFOR scale of abundance used to define vertical zonation. • Discussion of results in relation to windfarm construction and concludes changes observed as a result of rapid colonisation of turbine structure • Compared faunal colonisation with other turbine structures in the North Sea. **Methodology** • ROV used to collect footage of colonisation of turbine and DDV to collect footage of surrounding seafloor sediment (250-500 m from foundation) • First colonisation survey of monitoring programme therefore sampling strategy could not be compared • Survey conducted October **Correlation** • No correlation analysis relevant	• In common with the colonisation of other turbines in the southern North Sea and wider North Sea area, biofouling communities occupied distinct zones dominated by one or two species, with similar depth zones to those reported for natural and artificial hard substrata. • Across all turbines *Metridium senile* was one of the most abundant species accounting for the majority of the total biofouling cover, occupying the central and lower sections, with extensive cover of keel worm *Spirobranchus sp*. on the deepest sections near the jacket leg base.

Post-construction Monitoring Year 2 (2021): Turbine Foundation Marine Ecology Survey Report Second Post Construction Turbine Foundation Colonisation Report (Two years following construction)	Jan 2022	APEM Ltd This report presents the results of the second round of post-construction underwater video survey of foundation jacket legs and surrounding seabed conducted in June 2021	**Survey design and statistical approach** • Reference stations – not applicable for colonisation survey • SACFOR scale of abundance used to define vertical zonation. • Discussion of results in relation to windfarm construction and concludes changes observed as a result of rapid colonisation of turbine structure. Comparisons of faunal community presence and zonation between 2020 and 2021 survey. • Compared faunal colonisation with 2020 survey and other turbine structures in the North Sea. **Methodology** • ROV used to collect footage of colonisation of turbine and also surrounding seafloor sediment (50 m from foundation) • The turbines foundations surveyed are the same as those surveyed in 2020 • Survey conducted at a different time of year (June) compared to 2020 survey (October) • Data compared with the previous monopile survey (2020) **Correlation** • No correlation analysis relevant	• There was extensive biofouling on all turbine jacket legs with signs of zonation and successional development. A range of species had colonised the available substrate which was consistent with the colonisation of turbine foundations at other windfarms. • It was noted that blue mussel *Mytilus edulis*, which often colonises hard structures in the marine environment (e.g. Coolen *et al.*,2015) was recorded at two of the turbine foundations in low numbers during this second Beatrice OWF monitoring survey. Blue mussels were not recorded during the 2020 survey. • Across all turbine foundations the plumose anemone *M. senile* was the most abundant species accounting for the majority of the total biofouling cover and this species occupied the central and lower sections of the jacket legs, with keel worm *Spirobranchus sp*. tending to dominate the deepest sections near the jacket leg base. This was similar to 2020 surveys. • A number of fish species were recorded during the survey, most of which were small pelagic fish and flatfish which could not be identified to species level.
Blyth Offshore Demonstrator Project				
Blyth Offshore Demo Post-Construction Benthic Monitoring Report - Array 2 First Post Construction Benthic Ecology Report (One year following construction)	November 2019	Blyth Offshore Demonstrator Limited. Post-construction survey to provide a comparison with the EIA baseline and pre-construction characterisation of benthic ecology present.	**Survey design and statistical approach** • Sampling stations located within primary (no. 14) & secondary impact zones (no. 4) • Reference stations: 5 stations - 22% of sampling stations • ANOSIM used for comparison of faunal communities and physical characteristics • Comments on significant changes in species diversity and composition leading to overall changes in habitat • Includes robust assessment comparing results of different survey years. Significant changes were found; however, changes were determined as a result of natural variation. • No comparison with historical or external data/reports	• Overall, the infaunal community composition varied significantly over the development periods. Pairwise tests showed the variation was significant at primary impact zone locations between pre-construction and post-construction, with a reduction in the brittlestar *Amphiura filiformis* and the polychaete *Chaetozone christiei*, and an increase in the polychaete *Lumbrineris cf. cingulata* and the bivalve *Thyasira flexuosa*. Given that significant changes also occurred at primary impact zone locations between EIA characterisation and pre-construction, it was indicated that it is difficult to attribute differences to the installation and

			Methodology • Benthic grab, physico-chemical, DDV and Beam trawl • Similar locations have been used to mirror pre-construction surveys in areas without infrastructure, however, it's unclear if the exact stations have been used • Grab survey carried out at the same time of year as pre-construction surveys (June-July), however, epibenthic surveys carried out at different times of year • Benthic and PSA data analysed using consistent methodologies • EIA characterisation, Pre-construction and post-construction (current report) analysed **Correlation** • No correlations between physical and biological data undertaken **Power analysis** • No power analysis indicated	operation of the Blyth Offshore Demonstration Project. Rather. It was suggested that any differences are likely a result of natural variation in environmental variables such as bottom water temperature, bottom water salinity and tidal stress. In addition, winter temperatures, storm frequency and food availability can all drive change in benthic environments.
Burbo Bank Offshore Wind Farm				
Post-construction 2007 (Year 1) Benthic Grab Survey First Post Construction Benthic Ecology Report (One year following construction)	August 2008	CMACS Ltd This report summarises the results of the post-construction benthic survey performed in 2007, including comparison with the 2005 pre-mid-construction survey.	**Survey design and statistical approach** • Sampling stations within OWF (no. 6), near-field of monopile foundations (no. 3), immediately outside OWF (no. 2), seaward of OWF (no. 3), inshore of OWF (no. 1), cable route (no. 3) • Reference stations: 2 stations (one for array area, one cable route) - 10% of sampling stations • No significance testing of data • Changes discussed at both site and habitat level • Discussion of results in relation to windfarm construction and concludes changes observed not due to anthropogenic activities • Includes comparisons with historical data for the area to contextualise natural variability **Methodology** • Faunal grabs, beam trawls, bathymetry and PSA data collected and compared • Survey repeats same stations as 2005 (pre-construction) & 2006 (mid-construction) surveys • Sampling carried out at some time of year as 2005 & 2006 surveys • Consistent laboratory methodology used each year • Data from three surveys compared **Correlation** • No statistical correlation carried out **Power analysis** • Power analysis not carried out	• Sediments and communities along the cable route showed only minor changes between 2005 and 2007, essentially a slight coarsening of sediment in 2006 only, that is consistent with natural variation • Overall, it was concluded that construction of the wind farm has not had major effects on benthic communities within the areas covered by the survey which includes all areas beyond the perimeter of scour protection. Changes in the distribution and abundance of individual species were recorded and were sometimes marked but following the recovery of many species in 2007 after the declines between 2005 and 2006 the report indicated it can be said with some confidence that these changes reflect natural variability. This statement is supported by other evidence, including bathymetric monitoring that shows patchy accretion and erosion of sediments throughout the survey area in a pattern that appears unrelated to turbine position, and historical evidence of benthic faunal and sediment variability dating back to the 1970s. • One site used in the pre-construction survey was moved to avoid sampling directly over a cable.

Burbo Bank OWF Post-construction Year 2 Environmental Monitoring Report Second Post Construction Benthic Ecology Report (Two years following construction)	Nov 2009	CMACS Ltd This report summarises the results of the post-construction environmental monitoring surveys performed in 2008, including comparison with the 2005 pre-mid-construction survey. Benthic fauna surveys were not performed in the year 2 surveys. Monopile colonisation studies were performed but this survey report could not be found for assessment.	The Year 2 surveys did not monitor benthic habitats and species like other years. A summary is presented for Monopile colonisation surveys and sedimentology/scour surveys. Due to the high-level presentation of survey methods and results, the assessment was not carried out for this report.	Sedimentology/Scour • General trend of sediment accretion. • A comparison between surveys in February 2008 and April 2009 revealed accretion of sediments up to 0.8 m away from the scour protection immediately around the monopile, substantial areas of no or minimal change over the area protected by rock placements and no significant areas of scour in the area were identified. Monopile colonisation survey • Both the monopiles and rocky scour protection provide hard substrate habitat in an area otherwise dominated by fine sediments. • The colonisation of monopiles is broadly similar to that observed at North Hoyle wind farm, some 15km west of Burbo Bank. North Hoyle was surveyed some 12 months after wind farm construction whereas monopiles at Burbo had been in position for almost three years. • The same macrofaunal species dominate both sites, • namely mussels, barnacles and anemones with a mobile epifauna of crabs and starfish. Vertical zonation patterns at both sites are also superficially similar.
Burbo Bank OWF Post-construction Year 3 Grab Survey Report Third Post Construction Benthic Ecology Report (Three years following construction)	Dec 2011	Seascape Energy. This report presents and discusses results of the second post-construction benthic survey which was undertaken in September 2009.	**Survey design and statistical approach** • Sampling stations within OWF, near-field of monopile foundations, immediately outside OWF, seaward of OWF, inshore of OWF, cable route, reference stations • ANOVA and ANOSIM testing of data • Changes to sediment, invertebrate habitat and invertebrate communities discussed • Discussion of results in relation to windfarm construction and concludes changes are not believed to be associated with wind farm construction and operation • Includes comparisons with historical data for the area to contextualise natural variability **Methodology** • Faunal grabs, beam trawling, PSA and physico chemical data collected and compared • Survey repeats same stations as 2005, 2006, 2007 surveys • Sampling carried out at some time of year as pre-construction and previous post-construction surveys	• Despite obvious fluctuations in the abundance of individual species there has been relatively little change in overall community structure and statistical testing suggests that there are no significant differences in these communities between survey years. • Biotopes identified in EIA surveys in 2002, or similar communities, are still present across the survey area. • One site used in the pre-construction survey was moved to avoid sampling directly over cable

			• Consistent laboratory methodology used each year • Data from four surveys compared **Correlation** • No BIOENV or RELATE statistical correlation carried out	
Greater Gabbard Offshore Wind Farm				
Greater Gabbard OWF Year 1 Post-construction Benthic Ecology Monitoring Survey First Post Construction Benthic Ecology Report (One year following construction)	Mar 2014	CMACS This report summarises the results of the post-construction benthic survey performed in 2013, including comparison with the 2005 Gabbard EIA, 2009 Baseline, 2010 Galloper EIA.	**Survey design and statistical approach** • Sampling stations within OWF (no. 20), near-field (no. 11), cable route (no. 6) • Reference stations: 12 stations (eight for array area, four for cable route) - 24% of sampling stations • ANOVA and ANOSIM testing of data • Observed changes to sediment, invertebrates discussed • Discussion of results in relation to windfarm construction and concludes changes more likely due to natural variability and storm events • Includes comparisons with historical data for the area to contextualise natural variability **Methodology append** • Faunal grabs, beam trawling, PSA collected and compared • Survey repeats same stations as 2009 survey • Sampling carried out at some time of year as four previous surveys – two other surveys were excluded due to sampling carried out at different time of year • Consistent laboratory methodology used each year • Data from three surveys compared **Correlation** • BIOENV statistical correlation carried out to identify the relationship between environmental variables (sediment grain size, water depth, percentage mud and gravel and total organic matter) and faunal community structure **Power analysis** • Power analysis not carried out	• The sediment types and distribution within and around the Great Gabbard Offshore Wind Farm have generally remained reasonably similar throughout the survey programme. When considered alongside fluctuations apparent at reference stations, this is not likely to have been caused by construction and operation of the wind farm, but is probably due to natural variability arising from storm events instead.
Post-construction - Year 5 Greater Gabbard Year 5 Post Construction Benthic Survey Technical Report v4 Second Post Construction Benthic Ecology	Jun 2020	NIRAS This report summarises the results of the post-construction benthic survey performed in 2017, for comparison with data from 2013 post construction survey and 2009 baseline survey with reference to data from 2005 and 2010 EIA surveys.	**Survey design and statistical approach** • Sampling stations within OWF, near-field, cable route, reference stations • ANOVA and ANOSIM testing of data • Observed changes to sediment, invertebrates discussed • Discussion of results in relation to windfarm construction and concludes changes more likely due to natural variability and storm events • Includes comparisons with historical data for the area to contextualise natural variability **Methodology**	• The results from the two post-construction monitoring surveys show no evidence of significant changes in the benthic community structure that can be attributed to the presence of the offshore wind farm. • fine-scale changes have occurred across all areas, including reference areas and are attributable to natural variability with biotopes either remaining unchanged or as similar variants thereof.

Report (Five years following construction)			• Faunal grabs, beam trawling, PSA collected and compared • Survey repeats same stations as 2013 survey • Sampling carried out at similar time of year as previous survey – two surveys were excluded due to sampling carried out at different time of year • Consistent laboratory methodology used each year • Data from four surveys compared **Correlation** • BEST statistical correlation carried out to identify the relationship between environmental variables (sediment grain size, percentage mud and gravel and total organic carbon) and faunal community structure	
Post-construction - Year 10 Greater Gabbard Year 10 Post Construction Benthic Survey Technical Report v4 Third Post Construction Benthic Ecology Report (Ten years following construction)	Apr 2023	NIRAS This report summarises the results of the post-construction benthic survey performed in 2022 for comparison with data from 2017, 2013 post construction survey and 2009 baseline survey.	**Survey design and statistical approach** • Sampling stations within OWF, near-field, cable route, reference stations • ANOSIM testing of data • Observed changes to sediment and invertebrates discussed between stations and sampling years • Discussion of results in relation to windfarm construction and concludes there is no evidence of significant detrimental change in benthic community structure that can be attributed to the windfarm. It was unclear whether the increases in richness and diversity identified were as a result of the development of the OWF. • Includes comparisons with historical data for the area to contextualise natural variability, and Thanet Coast OWF and other OWF nearby. **Methodology** • Faunal grabs, PSA collected and compared. Beam trawling removed from • Survey repeats same stations as 2017 survey. Changes to locations and replicates taken into account when comparing previous data, and trawl removed from surveys. • Sampling carried out as close as possible to same time period as previous benthic surveys (May – June) • Consistent laboratory methodology used each year • Data from four surveys compared **Correlation** • No BioEnv/BEST statistical correlation carried out	• The results from the three post-construction monitoring surveys show no evidence of significant detrimental changes in the benthic community structure that can be attributed to the presence of the offshore wind farm. Whilst some detectable change has occurred, these are largely increases in richness and diversity of the epifauna and to a lesser extent infauna, but it is unclear to what degree these might be related to the development of the wind farm or part of more widespread natural changes. It could be speculated that changes such as decreased bottom fishing within the wind farm might have contributed to these observations. • Analysis of benthic macrofaunal communities suggests that the fauna within the wind farm area became richer and more diverse following the construction of the wind farm. This is particularly evident at the "mixed" sediment stations where there were statistically significant increases in numbers of both individuals and of taxa in the years following development compared to the baseline survey of 2009. • At a small number of locations within the wind farm areas there were considerable increases in abundance of ross worm, *Sabellaria spinulosa*. here was evidence of communities matching definitions of low reefiness, or medium to possibly high reefiness (This could be a result of increased protection from disturbance (e.g. by fishing) offered by the wind farm).
Greater Gabbard OWF Year 1 Post-construction	Jan 2013	CMACS This survey was completed as part of the wider post-construction survey, identifying	**Survey design and statistical approach** • Reference stations – not applicable for colonisation survey • No significance testing of data	• The survey demonstrated that the entire subtidal length of the two turbines had been colonised by marine species. Faunal turf and species aggregations by *M. edulis* and *S.*

Benthic Ecology Monopile colonisation Monitoring Survey First Post Construction Benthic Ecology Report (One year following construction)		marine species colonising representative turbines and investigation the presence of any invasive non-native species	• Habitats on monopiles discussed • Study specifically investigates colonisation of monopiles – anthropogenic impact • Includes general comparisons with historical data for the monopiles. Data is semi-quantitative, and as such no statistical analysis was performed between datasets **Methodology** • Still images/video footage, surface scrapes, grab sampling collected and compared • First colonisation survey, standard methodology • Sampling carried out during summer • Consistent laboratory methodology used • First survey, no colonisation datasets to compare **Correlation** • No statistical correlation carried out	*spinulosa* supported diverse communities with evident feeding by mobile epifauna.
Gunfleet Sands I & II Offshore Wind Farm				
Gunfleet sands OWF Year 1 Post-construction Benthic Monitoring Report First Post Construction Benthic Ecology Report (One year following construction)	Dec 2010	CMACS Ltd. Overview of the 2010 post-construction monitoring survey conducted on the Gunfleet Sands OWF I and II sites. Data from the 2007 and 2010 sampling period were compared to understand natural variation within the area over time and the possible influence of wind farm construction.	**Survey design and statistical approach** • Sampling stations within OWF (no. 15), near-field (no. 4), cable route (no. 5) • Reference stations: 5 stations - 17% of sampling stations • No testing for statistical significance (e.g. ANOSIM/ANOVA) was undertaken • Comments on changes recorded between the sampling periods, stating there was little variation in biodiversity/composition • Interpretation suggests observed changes are related to natural changes due to little variation found both in primary and reference locations • No comparison made to additional historical or external data/reports **Methodology** • Survey retrieved Grab samples (only) for faunal analysis and sediment characteristics • Survey programme identical to baseline survey, with one additional station added • Sampling carried out at the same time of year (May) as previous surveys • Benthic and PSA samples were analysed using consistent methodologies as previous years • Uses data from pre-construction and post-construction surveys **Correlation** • Does not clearly indicate use of correlation tests between physical and biological data	• Analysis showed that there was little variation in benthic communities between the two sampling periods. Changes that did occur were minor and were exhibited across the entire survey area, not just at stations within the windfarm boundary, suggesting they were related to natural causes as might be expected in shallow coastal locations with mobile fine sediments.

			Power analysis • No power analysis stated	
Gunfleet Sands OWF Year 2 Post-construction Benthic Monitoring Report 2011 Second Post Construction Benthic Ecology Report (Two years following construction)	June 2012	CMACS Ltd. Overview of the 2011 post-construction monitoring survey conducted on the Gunfleet Sands OWF I and II sites. Data from the 2007, 2010 and 2011 sampling periods were compared to understand natural variation within the area over time and the possible influence of wind farm construction	**Survey design and statistical approach** • Sampling stations within OWF, near-field, cable route, reference stations • Use of Kruskal-Wallis and ANOVA; ANOSIM used for differences faunal communities recorded between pre-construction and post-construction, as well as between and primary and reference areas • Comments on change in distribution of species richness between years with no significant difference in diversity and some significant differences in faunal community composition of certain habitat types between years • Includes assessment that detects only small variances in species abundance and faunal composition, which are thought to be linked to natural variability • No comparison made to additional historical or external data/reports **Methodology** • Survey retrieved Grab samples (only) for faunal analysis and sediment characteristics • Surveys carried out using consistent methodologies with same location and sampling stations/replicates. The additional station added in 2010 was removed for 2011 • Sampling carried out at the same time of year (May) as previous surveys • Benthic and PSA samples were analysed using consistent methodologies as previous years • Data from 3 years used (2007, 2010, 2011) **Correlation** • BioEnv used to identify the relationship between environmental variables (sediment type and organic matter) and faunal community structure	• Year to year, the sediment description at several stations has changed but generally only by a single level of classification. Such changes have been seen in both directions (i.e. becoming coarser and finer) at wind farm, near field and reference stations. • Simple interpretation of the data suggest no obvious change in the broad scale distribution of species richness between survey years. Stations located along the export cable route and at both inshore and offshore reference stations have consistently been more species rich than those on the main Gunfleet sand bank and within the wind farm boundaries.
Gunfleet Sands OWF Year 3 Post-Construction Benthic Monitoring Report 2012 Third Post Construction Benthic Ecology Report (Three years following construction)	February 2013	CMACS Ltd. Overview of the 2012 post-construction monitoring survey conducted on the Gunfleet Sands OWF I and II sites. Data from the 2007, 2010, 2011, and 2012 sampling periods were compared to understand natural variation within the area over time and the possible influence of wind farm construction.	**Survey design and statistical approach** • Sampling stations within OWF, near-field, cable route, reference stations • ANOSIM used for differences faunal communities recorded between pre-construction and post-construction, as well as between and primary and reference areas • Comments that observed changes in biodiversity/composition in relation to change in habitat type (Biotope) and habitat distribution • Comments on changes in community composition/biodiversity over time and suggest no major changes from baseline conditions and changes observed are a result of natural variability • No comparison made to additional historical or external data/reports **Methodology** • Survey retrieved Grab samples (only) for faunal analysis and sediment characteristics	• Despite variation in total abundances and number of species, there have been no major changes in community composition from baseline conditions over time. Communities have remained dominated by annelids, molluscs and crustaceans. Total abundances of individual species have shown variability between years but this is to be expected in a highly dynamic environment dominated by shallow waters and offshore sand banks. • It could be assumed that *M. edulis* colonising the wind turbine structures have become encrusted with barnacles and after death/detachment the dead shells, still colonised by barnacles, have been transported generally out of the scoured area.

			• Surveys carried out using consistent methodologies with same location and sampling stations/replicates. • Sampling carried out at the same time of year (June) as previous surveys (May) • Benthic and PSA samples were analysed using consistent methodologies as previous years • Data from 4 years used (2007, 2010, 2011, 2014) **Correlation** • Does not state specific tests used but indicates that "Duplicates of the MDS plot were then overlaid with environmental variables (depth and sediment type) to investigate whether clusters were related to particular depths or sediment types"	• With the exception of 2012, when there was a small decrease in TOC in general across the survey area, overall TOC levels have increased year on year since the baseline in 2007. The most notable increase in TOC was exhibited between 2007 and 2010 and was more pronounced at cable route stations than any other treatment zone. • The Annex 1 species, Sabellaria spinulosa, was recorded in all treatment zones except the wind farm. S. spinulosa was found to be abundant in the baseline survey of 2007 and following an initial decrease in abundance between 2007 and 2010, numbers exhibited year on year increases, although distribution was consistently patchy. When *S. spinulosa* was recorded, it was never present in sufficient numbers to suggest the presence of Annex I biogenic reef • Statistically, there were no significant differences in mean phi or Shannon-Wiener diversity index found between years in any of the survey treatment zones.
Kentish Flats Offshore Wind Farm				
Kentish Flats OWF Macrobenthic Ecology Study-2005 First Post Construction Benthic Ecology Report (One year following construction)	Jun 2006	EMU Ltd This study assesses the impacts of the Kentish Flats windfarm on the physical conditions and associated biological communities. Includes comparison with the 2002 baseline study.	**Survey design and statistical approach** • Sampling stations within OWF (no. 5), near-field (no. 3), outside OWF along tidal axis (no. 8), cable route (no. 3) • Reference stations: 4 stations - 17% of sampling stations • Sampling stations located within OWF, cable route, reference stations • ANOSIM Statistical tests applied to PSA and fauna data, including temporal variation • No discussion on change in habitat type (Biotope) and habitat distribution • Comments on changes identified between pre-construction and post-construction surveys, finding statistical differences in sediments and community composition between project phases. Changes thought to reflect area exposed to high degrees of sediment disturbance resulting in unstable benthic communities • Comparison with pre-construction survey **Methodology** • Hamon Grab, beam trawl, PSA • The same areas were sampled for post-construction and pre-construction surveys. Difference in number of replicates between surveys were taken into account • Unclear if preconstruction survey was conducted at the same time frame as current survey (June)– this needs to be confirmed by finding previous reports	• No obvious spatial trends were observed with respect to the benthic communities. • Stations within the reference area showed the highest level of intra sample variability and the largest temporal variation between years • Small scale variability of benthic communities is typical of exposed areas subject to high degrees of sediment disturbance, of which the Kentish Flats area is an example. This results in a relatively unstable benthic community, characterized by species tolerant of high sediment disturbance, which were found to be abundant and widespread across the survey area.

			• No discussion on laboratory methods being consistent with preconstruction survey • 2002 preconstruction, and 2005 current survey analysed **Correlation** • BIOENV correlation analysis between physical (depth and sediment characteristics such as sediment grain size and percentage mud/gravel/sand) and biological data detailed in report **Power analysis** • No power analysis indicated	
Kentish Flats OWF Macrobenthic Ecology Study-2006 Second Post Construction Benthic Ecology Report (Two years following construction)	May 2007	EMU Ltd This study assesses the impacts of the Kentish Flats windfarm on the physical conditions and associated biological communities. Includes comparison with the 2002 baseline study and 2005 post construction study.	**Survey design and statistical approach** • Sampling stations within OWF, near-field, outside OWF along tidal axis, cable route, reference stations • ANOSIM Statistical tests applied to PSA and fauna data, including temporal variation • No discussion on change in habitat type (Biotope) and habitat distribution • Comments on changes identified between pre-construction and post-construction surveys. The faunal communities recorded in 2005 and 2006 were similar in terms of species composition. Overall increase of the species diversity and abundance recorded in 2006 • Comparison with pre-construction survey **Methodology** • Hamon Grab, beam trawl, PSA • The same areas were sampled for post-construction and pre-construction surveys. Difference in number of replicates between surveys were taken into account • survey conducted (June) at the same time frame as previous post-construction survey (May)– this needs to be confirmed by finding previous reports • laboratory methods consistent with previous post-construction survey • 2002 preconstruction, 2005 and 2006 survey analysed **Correlation** • BIOENV correlation analysis between physical (depth and sediment characteristics such as sediment grain size and percentage mud/gravel/sand) and biological data detailed in report	• Comparisons with previous years' survey showed that this pattern of macrofauna distribution was maintained over time, however temporal variations of the benthic community were significant, particularly when in comparison with the 2002 baseline study. • The faunal communities recorded in 2005 and 2006 were similar in terms of species composition and difference were mainly associated with different abundance between years. • Differences with the baseline study included identity as well as abundance of species and were overall significant.
Kentish Flats OWF	Jun 2008	EMU Ltd This study assesses the impacts of the Kentish Flats windfarm on the physical conditions and	**Survey design and statistical approach** • Sampling stations within OWF, near-field, outside OWF along tidal axis, cable route, reference stations	• Comparisons with previous years' survey showed similar macrofauna distribution, however temporal variations of the benthic communities were significant.

Macrobenthic Ecology Study-2007 Third Post Construction Benthic Ecology Report (Three years following construction)		associated biological communities. Includes comparison with the 2002 baseline study, 2005 and 2006 post construction studies.	• ANOSIM Statistical tests applied to PSA and fauna data, including temporal variation • No discussion on change in habitat type (Biotope) and habitat distribution • Comments on changes identified between pre-construction and post-construction surveys. Significant temporal variations observed and considered to be associated with natural variability • Comparison with pre-construction survey **Methodology** • Hamon Grab, beam trawl, PSA • The same areas were sampled for post-construction and pre-construction surveys. Difference in number of replicates between surveys were taken into account • survey conducted (May) at the same time frame as previous post-construction survey (May)– this needs to be confirmed by finding previous reports • laboratory methods consistent with previous post-construction survey • 2002 preconstruction, 2005, 2006 and 2007 survey analysed **Correlation** • BIOENV correlation analysis between physical (depth and sediment characteristics such as sediment grain size and percentage mud/gravel/sand) and biological data detailed in report	• Such differences were not considered to be associated with the construction or operation of the OWF, but rather with natural variability, which may include fluctuations in recruitment success, inter-species competition for space and food and seasonal patterns of disturbance such as storms, harsh winters and oxygen deficiencies.
Kentish Flats OWF Turbine Foundation Faunal Colonisation Diving Survey First Post Construction Turbine Foundation Colonisation Report (Three years following construction)	Nov 2008	EMU Ltd This study presents the results of the colonisation survey (Jul 2008) at 2 wind turbine monopiles using video, still footage and scrape samples.	**Survey design and statistical approach** • Reference stations – not applicable for colonisation survey • Sampling stations restricted to monopiles • No significance testing of data • Habitats and associated species on monopiles discussed • Study specifically investigates colonisation of monopiles – anthropogenic impact • Data is semi-quantitative, and as such no statistical analysis was performed between datasets **Methodology** • Still images/video footage, surface scrapes collected and discussed • Two monopiles surveyed. No previous colonisation surveys, but methodology consistent with similar surveys • No previous colonisation surveys, but sampling carried out in July, similar time of year as benthic post-construction surveys • Consistent laboratory methodology used (NMBAQC) • No previous data compared **Correlation** • No statistical correlation carried out	• The recorded species during the survey were comparable between the turbines surveyed. The two turbines are considered likely to be generally representative of all the turbines on the Kentish Flats offshore wind farm site, notwithstanding the potential for localised features / communities. • The observed biological zonation is not uncommon and has been recorded recently at the North Hoyle Wind Farm site

London Array Offshore Wind Farm				
London Array OWF Year 1 Post-Construction Monitoring Report First Post Construction Benthic Ecology Report (One year following construction)	March 2015	Marine Space Ltd. summarises the findings of the Year 1 post-construction monitoring surveys that have been conducted within the London Array OWF study area, consisting of the OWF site and along the export cable corridor.	**Survey design and statistical approach** • Sampling stations within OWF (no. 28), near turbines (no. 15), near-field (no. 31), far field (no. 56), cable route (no. 9) • Reference stations: 5 stations – 3% of sampling stations • Sampling stations located within wind farm (primary, secondary and tertiary impact zones) and outside wind farm (reference) • Statistical tests for significant of data between pre- and post- construction surveys evident but report does not go into detail regarding type of tests used • Comments that species composition were similar between 2003-2014 with same 5 biotopes recorded • Comments on changes identified between characterisation, pre-construction and post-construction surveys, finding statistical differences in sediments and community composition between project phases. Changes thought to reflect natural variation • No comparison with historical or external data/reports **Methodology** • Grab and epibenthic beam trawl • The same areas were sampled for characterisation and pre-construction surveys, with same number of samples/replicated collected for pre-construction survey • Discussion suggests pre-construction and characterisation surveys took place at different times of year compared to 2014 survey (July) – this needs to be confirmed by finding previous reports • Sample analysis methods not stated in detail • EIA characterisation, Pre-construction and Post-construction (current report) analysed **Correlation** • No correlation analysis between physical and biological data detailed in report **Power analysis** • No power analysis indicated	• The infauna assemblages were similar from 2003 to 2014, with the same five main biotopes consistently present throughout the study area • Some variation was evident between years, reflecting the naturally dynamic environment at the site. • Variations over time in the abundance of the dominant macrofaunal species (Brown Shrimp and brittlestars) were evident in the data. Brown Shrimp abundance was significantly higher in post-construction catch, whereas brittlestars were higher during pre-construction. When examined across all project phases (including characterisation where surveys were undertaken quarterly), it was evident that the seasonal variations in the timing of the surveys was the driving factor behind the changes in abundance between years.
Lynn and Inner Dowsing Offshore Wind Farm				
Lynn and Inner Dowsing OWF Post-construction survey works (2010). Phase 2 Benthic Ecology Survey	Nov 2011	Benthic Solutions Ltd. This report presents the second post-construction marine geophysical and benthic ecology survey of the Lynn and Inner Dowsing (L&ID) offshore wind farm sites and export cable route corridors. This document relates	**Survey design and statistical approach** • Sampling stations OWF (no. 5), near-field (no. 3), far field (no. 2), potential Annex I reef habitat (no. 5), jack-up footprints (no. 2 in footprints, no. 2 just outside footprint) • Reference stations: 2 stations - 10% of sampling stations • Sampling stations located within wind farm (primary) and outside wind farm (reference)	• A comparison with the initial benthic survey data acquired by EMU Ltd in 2005 showed generally similar particle size distributions, but a notably different macro-invertebrate community to that of the present study. This has resulted in a clear separation of the biological communities according to the survey in question when compared statistically, even when reducing the resolution in the taxonomy for both studies. Species richness and

First Post Construction Benthic Ecology Report (One year following construction)		to Phase 2 of the survey, benthic ecology.	• ANOSIM for temporal differences between pre-construction and post-construction, as well as between and primary and reference areas • Changes discussed at both site and habitat level • Discussion of results in relation to variation in biota and sediment between surveys due to presence of OWF. Changes in species richness and abundance were identified between years however, this is thought to be due to variations in sample size between surveys • No comparisons with historical data outside the current survey regime to contextualise variability **Methodology** • Faunal grabs, DDV, and PSA data collected and compared for both surveys • Survey repeats same stations as site characterisation and pre-construction surveys (2005), however, number of replicated varied significantly between surveys (100 in 2005, compared to 36 in 2010) • Sampling was undertaken autumn (between September – November) for all surveys for benthic organisms • Not stated if benthic and PSA samples were analysed consistently across surveys as only 2010 survey methodology provided in depth • Data from two surveys compared **Correlation** • Basic correlation (unspecified) between PSA and Faunal data; RELATE & Bio-Env were not used. Biotopes identified **Power analysis** • No power analysis indicated	abundance appeared to be very poor for the 2005 dataset, resulting in far fewer species and abundance recovered for the same survey effort and thus making an interpretation of changes since 2005 impossible to resolve.
Lynn and Inner Dowsing OWF Year 3 Post-construction Survey (2011). Phase 2 Benthic Ecology Survey Second Post Construction Benthic Ecology Report (Two years following construction)	Oct 2012	Centrica energy / EGS Ltd. This report presents the third post-construction marine geophysical and benthic ecology survey of the Lynn and Inner Dowsing (L&ID) offshore wind farm sites and export cable route corridors. This document relates to Phase 2 of the survey, benthic ecology.	**Survey design and statistical approach** • Sampling stations located within wind farm (primary) and outside wind farm (reference) • No comparison undertaken with previous survey results. • No comment on changes in habitat type between years **Methodology** • Benthic Grab and DDV • Less survey stations were monitored (29) compared to 2010 survey (35) and survey report does not clarify if similar locations were surveyed • Surveys undertaken around same time of year as previous surveys (October – November) • Benthic and PSA samples were analysed using consistent methodologies as previous years • Uses only 2012 survey data - Does not use any previous data for comparison **Correlations** • Does not clearly indicate use of correlation tests between physical and biological data	• The survey report was not a comparison report to compare previous survey data. Rather a survey to solely provide benthic ecology and seabed characteristics information for maintenance and operation activities.

Lynn and Inner Dowsing OWF (October - November 2013) Phase 3 survey report Third Post Construction Benthic Ecology Report (Three years following construction)	Jun 2014	Centrica energy / EGS Ltd. The overall objective of the study was to provide information in support of Operations and Maintenance (O&M) activities which have the potential to interact with the seabed, principally jack-up vessels.	**Survey design and statistical approach** • Sampling stations located within wind farm (primary) and outside wind farm (reference) • Use of ANOSIM or other statistical texts not referenced in text • Comparisons with previous surveys were not made and therefore changes in habitat presence and extent not discussed • Interpretation does not discuss change in habitat presence/extent over time • No comparisons with historical data outside the current survey regimen to contextualise variability **Methodology** • Benthic Grab and DDV • Less survey stations were monitored (29) compared to 2010 survey (35) and survey report does not clarify if similar locations were surveyed. • Survey carried out at the same time of year (autumn – November) as previous benthic surveys • Benthic and PSA samples were analysed using consistent methodologies as previous years • Uses only 2013 survey data - Does not use any previous data for comparison **Correlation** • Does not clearly indicate use of correlation tests between physical and biological data	• The survey report was not a comparison report to compare previous survey data. Rather a survey to solely provide benthic ecology and seabed characteristics information for maintenance and operation activities.
North Hoyle Offshore Wind Farm				
North Hoyle OWF Annual FEPA Monitoring Report (2004-5) First Post Construction Benthic Ecology Report (One year following construction)	Feb 2006	Npower renewables The report describes the post construction monitoring surveys undertaken during 2004-05. Data was compared to 2001 baseline survey, 2002 pre-construction survey and 2003 construction surveys	**Survey design and statistical approach** • Sampling stations OWF (no. 7), cable route (no. 3) • Reference stations: 10 stations - 50% of sampling stations • Sampling stations within OWF, cable route and reference stations • No ANOVA/ANOSIM testing of data • Changes discussed at both site and habitat level • Discussion of results in relation to windfarm construction and concludes changes observed not due to anthropogenic activities • Includes comparisons with previous survey data for the area to contextualise natural variability **Methodology** • Faunal grabs, trawls, PSA, physico chem data collected and compared • Survey repeats same stations as previous surveys • Sampling carried out at same time of year as precious surveys • Consistent laboratory methodology used each year • Data from four surveys compared 2002, 2003, 2004	• Overall, there is no substantial evidence to suggest that the biotopes previously identified at North Hoyle from the baseline survey of 2001 have changed.

			Correlation • No RELATE and BIOENV statistical correlation carried out **Power analysis** • No power analysis indicated	
North Hoyle OWF Annual FEPA Monitoring Report (2005-6) Second Post Construction Benthic Ecology Report (Two years following construction)	Mar 2007	Npower renewables The report describes the post construction monitoring surveys undertaken during 2005-06. Data was compared to 2002 pre-construction survey, 2003 construction and 2004 post construction surveys.	**Survey design and statistical approach** • Sampling stations within OWF, cable route and reference stations • No ANOVA/ANOSIM testing of data • Changes discussed at both site and habitat level • Discussion of results in relation to windfarm construction and concludes changes observed not due to anthropogenic activities • Includes comparisons with previous survey data for the area to contextualise natural variability **Methodology** • Faunal grabs, trawls, PSA, physico chem data collected and compared. Survey repeats same stations as previous surveys • Sampling carried out at similar time as previous surveys • Consistent laboratory methodology used each year • Data from four surveys compared 2002, 2003, 2004, 2005 **Correlation** • No RELATE and BIOENV statistical correlation carried out	• The absence of any identifiable trend in sediment particle size characteristics associated with construction of the offshore wind farm suggests that North Hoyle has not, to date, affected benthic invertebrate communities through this mechanism other than at a very localised scale due to the physical presence of the monopile foundations or, potentially, very localised effects of scour or scour protection within 50m of turbines in areas that are not routinely sampled.
North Hoyle OWF **Biology & Video Surveys of North Hoyle Wind Turbines** **First Post-Construction Monopile Colonisation Report (One year following construction)**	Aug 2004	CMACS Ltd. The report presents the findings of the monopile colonisation surveys undertaken by dive survey at the North Hoyle offshore wind farm.	**Survey design and statistical approach** • Reference stations not applicable to colonisation survey • As this was the first monopile survey, no comparisons of faunal assemblage could be made with previous years • Report does not compare with previous surveys or historical data. **Methodology** • Scrape samples (biomass) and dive survey imagery (faunal analysis) collected • Consistency in laboratory methodology cannot be assessed due to this survey being the first of its kind in the monitoring programme. **Correlation** • No statistical correlation analysis carried out	• Six turbines were investigated to produce a full description of faunal communities and zonation per turbine and compare communities between turbine structures. • Whilst variation was detected between turbines, characteristic vertical zonation of communities was found across all turbine structures. Dominant species included the barnacle *Balanus crenatus*, the amphipod *Jassa falcata* and mussel *Mytilus edulis*. • Scrapes of each turbine were also collected to aid identification of attached fauna and calculate biomass. Calculations estimated that each turbine accommodated around 100 – 1300 kg of attached marine life.
Ormonde Offshore Wind Farm				
Ormonde OWF	Jan 2014	RPS Energy, Vattenfall	**Survey design and statistical approach**	• There were some small changes in infaunal community composition between 2009 and 2012 mainly in the relative abundance rather

Annual Monitoring Report First Post Construction Benthic Ecology Report (One year following construction)		This document contains summaries of the results and conclusions from the year 1 post-construction monitoring surveys and studies undertaken in 2012. The full benthic monitoring survey report is provided in the appendices.	• Sampling stations OWF (no. 6), near field (no. 3), cable route (no. 3) • Reference stations: 12 stations - 50% of sampling stations • Sampling stations located within OWF, cable route, reference stations • ANOSIM for temporal differences between pre-construction and post-construction, as well as between and primary and reference areas • Changes discussed at both site and habitat level • Discussion of results in relation to variation in biota and sediment between surveys due to presence of OWF. Observed changes may be explained by inter-annual variation or the changing of survey methodology. • Comparison with baseline data **Methodology** • Multiple methodologies used and interpreted in context of one another (benthic grab, DDV, PSA, physico-chem) • Similar methodology carried out as the previous baseline survey; however several stations were added/excluded, and PSA obtained from a separate grab • Previous survey undertaken in (April-May) whilst current survey undertaken in (May-Jun) • Same analysis of benthic data as previous surveys • Compared with 2009 baseline survey **Correlation** • No RELATE and BioEnv testing for correlations were used **Power analysis** • No power analysis indicated	than the principal component species of these communities. • Reduction in faunal abundance was seen across the area and was not limited solely to the wind farm sites. Offshore reference stations beyond a tidal excursion away from the Ormonde OWF had the greatest reduction. • Stations within the wind farm area continued to have a higher diversity and species taxa and individual numbers than the reference stations. It is possible the wind farm has a marginally positive effect on the benthic assemblage as it sustains a higher level of biodiversity.
Ormonde OWF Annual Monitoring Report Second Post Construction Benthic Ecology Report (Two years following construction)	May 2014	RPS Energy, Vattenfall This document contains summaries of the results and conclusions from the year 2 post-construction monitoring surveys and studies undertaken in 2013. The full reports of these surveys are provided in the appendices.	**Survey design and statistical approach** • Sampling stations located within OWF, cable route, reference stations • ANOSIM for temporal differences between pre-construction and post-construction, as well as between and primary and reference areas • Changes discussed at both site and habitat level • Discussion of results in relation to variation in biota and sediment between surveys due to presence of OWF. Observed changes may be explained by natural variation or the changing of survey methodology. • Comparison with baseline and 2012 post-construction survey **Methodology** • Multiple methodologies used and interpreted in context of one another (benthic grab, DDV, PSA, physico chem) • Similar methodology carried out as the previous post-construction survey • survey undertaken in same time of year as previous post-construction survey • Same analysis of benthic data as previous surveys	• The seabed habitats and infaunal communities were broadly consistent the previous post-construction and pre-construction survey. • Small changes in the faunal community are likely to be a result of fluctuations in population caused by external factors as they occurred in both the reference and OWF areas and therefore cannot be conclusively linked to the presence and operation of the turbines. • Increase in TOC within the wind farm area, which was also observed in the Walney I and Walney II OWF which may be result of decreased water movement. A dense covering of mussels (Mytilus edulis) has been observed in the splash zone on the jacket structures during the surveys and there is evidence of increased organic input to the benthic ecosystem under large aggregations of mussels (Alonso-Pérez et al., 2010). • The fact that similar results of changes in fauna and organic matter have been recorded at the Walney wind farms suggests that there has

			• Compared with 2009 baseline survey and 2012 post-construction survey **Correlation** • No RELATE and BioEnv testing for correlations were used	been an effect of wind turbine installation and operation on the benthic environment.
Princes Amalia Offshore Wind Farm				
Princess Amalia OWF Assessment of the soft sediment fauna five years after construction of the Princess Amalia wind farm First Post Construction Benthic Ecology Report (Five years following construction)	Oct 2013	eCOAST Research Centre This report contains the results and conclusions of the post construction survey, 5 years after construction	**Survey design and statistical approach** • Sampling stations OWF (no. 47), adjacent buffer zone (no. 6) • Reference stations: 50 stations (25 in Northern reference area; 25 in Southern reference area - 49% of sampling stations • ANOSIM and ANOVA for temporal differences between pre-construction and post-construction, as well as between and primary and reference areas • Changes discussed at both site and habitat level • Discussion of results in relation to variation in biota and sediment between surveys due to presence of OWF. Observed changes may be explained by natural variation or the changing of survey methodology. • Comparison with baseline and 2002 pre-construction survey and four other OWF monitoring studies (Hornsea Rev, Egmond aan Zee, Bligh Bank and Thorton Bank) **Methodology** • Box core and dredge • Similar methodology as pre-construction survey • Survey undertaken in same time of year as previous surveys (March-May) • Sample analysis for sediment samples differed with pre-construction survey • Compared with 2002 pre-construction survey **Correlation** • No RELATE, BioEnv or similar testing for correlations were used **Power analysis** • No power analysis indicated	• In the dredge samples, no significant differences were observed in density, biomass and species richness. *Echinocardium cordatum* dominated in terms of density as well as biomass. *Crangon almanni*, *Echiichthys vipera* and *Solea solea* were only found in the turbine area, although only a few individuals were encountered. • No effect of the presence of the wind farm on K-strategy species of the area could yet be demonstrated
Princess Amalia OWF An assessment of the soft sediment fauna six years after construction of the Princess Amalia Wind Farm Second Post Construction Benthic Ecology	Jan 2014	eCOAST Research Centre This report contains the results and conclusions of the post construction survey, 6 years after construction	**Survey design and statistical approach** • Sampling stations within OWF array and reference stations • ANOSIM and ANOVA for temporal differences between pre-construction and post-construction, as well as between and primary and reference areas • Changes discussed at both site and habitat level • Discussion of results in relation to variation in biota and sediment between surveys due to presence of OWF. • Comparison with baseline and 2002 pre-construction survey, 2012 post-construction survey and four other OWF monitoring studies (Hornsea Rev, Egmond aan Zee, Bligh Bank and Thorton Bank)	• Five and six years after construction, no indications can be found of a direct positive or negative effect of the presence of wind turbines on the benthos. • It was concluded that the only clear immediate effect of the construction and operation of the wind turbines, is the negligible loss of soft sediment surface due to the scour protection around the foundation structures. I • Two reference 'areas' were sampled which included 25 survey stations in each area. (50 reference stations = 48% of sampling locations).

Report (Six years following construction)			**Methodology** • Box core and dredge • Similar methodology as pre-construction and post-construction surveys • Survey undertaken in same time of year as previous surveys (March-May) • Sample analysis for sediment samples differed with pre-construction survey but same as post-construction survey analysis • Compared with 2002 pre-construction survey and 2012 post-construction survey **Correlation** • No RELATE, BioEnv or similar testing for correlations were used	
Princess Amalia OWF Benthic development in and around offshore wind farm Prinses Amalia Wind Park near the Dutch coastal zone before and after construction (2003-2017) Third Post Construction Benthic Ecology Report (Ten years following construction)	April 2018	Eurofins / AquaSense This report contains the results and conclusions of the post construction survey, 10 years after construction	**Survey design and statistical approach** • Sampling stations within OWF array and reference stations • ANOVA and PERMANOVA used to determine statistical differences in community composition between sample groups. • Changes discussed at both site and habitat level • Discussion of results in relation to variation in biota and sediment between surveys due to presence of OWF. Significant changes in species composition were found across years, particularly between 2017 and previous years. This was attributed to a number of causes including temperature, climate conditions, storm events, reduced fishing pressure, and natural variation but not particularly linked to the presence of the OWF. A further survey was recommended to determine extent of change and causes. • Compared with 2002 pre-construction survey and post-construction surveys (2012 & 2013) – some comparison with OWEC wind farm **Methodology** • Dredge with some use of box core • Different methods used for 2017 survey compared to previous surveys with a different sampling strategy. The 2 reference areas (20-30km from site) were not used and instead closer reference sites directly outside array area were used. In the former years, also a box corer was used, however for 2017 the decision was made to use only the dredge. A box corer was used only to determine sediment characteristics in some instances, and the same dredge was used for all years. • Survey undertaken in same time of year as previous surveys (March-May) • Specific regarding sample analysis was not detailed in report (high-level overview), therefore, we cannot conclude that sample analysis was the same as former surveys • Compared with 2002 pre-construction survey and post-construction surveys (2012 & 2013) **Correlations**	• Overall, 2017 seems to be a rather peculiar year, with large differences from previous years. This becomes especially clear from the univariate data, with high abundances and low number of species and diversity. • Abundances were much higher in 2017, even without outliers, and number of species and diversity indices were much lower than previous years. • Text questions whether 10 years after the construction of a wind park is enough to capture the recovery of the species community (advised to conduct another survey campaign) • 20 reference stations (55% of sampling locations)

			• the "envfit" procedure of r package Vegan was used to correlate the environmental variables to the dissimilarity matrix, to assess which variables were best related to the community composition	
Princess Amalia OWF Statistical comparison of benthic fauna inside and outside the Prinses Amalia Wind Park fifteen years after construction; first analysis Fourth Post Construction Benthic Ecology Report (Fifteen years following construction)	Sept 2022	Eurofins / AquaSense This report contains the results and conclusions of the post construction survey, 15 years after construction	**Survey design and statistical approach** • Sampling stations within OWF array and reference stations • ANOSIM and ANOVA for temporal differences between pre-construction and post-construction, as well as between and primary and reference areas. Data of the previous years was not statistically analysed, but a general visual comparison was made. • Changes discussed at both site and habitat level • Discussion of results in relation to variation in biota and sediment between surveys due to presence of OWF. Due to differences in sampling technique, it was difficult to determine the cause of observed change. • Compared with 2002 pre-construction survey and post-construction surveys (2012, 2013 & 2017). **Methodology** • Dredge only • Sampling locations differed from previous years. Reference locations were the same as 2017 but sampling locations within OWF array were at different coordinates. Change was due to the long approaching distance of the dredge for sampling a transect and the need to avoid cables and wind turbines. Due to bad weather, only 28/39 samples could be taken. A different dredge was used for 2022 survey compared to previous. • Survey undertaken in same time of year as previous surveys (March-May) • Specific information regarding sample analysis was not detailed in report (high-level overview), therefore, we cannot conclude that sample analysis was the same as former surveys • Compared with 2002 pre-construction survey and post-construction surveys (2012, 2013 & 2017). Data of the previous years was not statistically analysed, but a general visual comparison was made **Correlation** • No correlation analysis detailed	• Diversity indices Shannon-Wiener and Margalef were only slightly higher in 2022 when compared to other years. Differences found were likely largely caused by quantitative differences between the two types of dredges. • From the general comparison between sampling years it has become clear that the abundances and the number of species found in 2022 were much higher when compared to the other years (2003, 2012, 2013 and 2017) • Overall, the text indicated that there were no significant differences between the locations inside and out-side the OWF array, both in univariate key figures (i.e. abundance and diversity indices) and in community composition. • Since the community found today in the windfarm on soft-sediment was largely present right after the windfarm was put in place, the report could not define an effect of the exclusion of fisheries or the presence of hard-substrates on (the development of) soft sediment benthos
Princess Amalia OWF Development of hard substrate fauna in the Princess Amalia Wind Farm. Monitoring 3.5	Jan 2013	eCOAST Marine Research This report presents the results of the colonisation survey (October 2011) at 4 wind turbine monopiles using divers and scrape samples.	**Survey design and statistical approach** • Reference stations not applicable for monopile surveys. Species composition were compared with adjacent rock hard substrate. • ANOSIM analysis used to determine significant differences between samples and zones. • Zonation was monitored across turbines and compared between turbine structures	• The community that has settled on the monopiles could be divided in two zones: an upper splash zone dominated by algae, mussels, isopods and amphipods, and a lower sublittoral zone, dominated by high densities of amphipods, mussels and anemones. On the scour protection rocks moss animals were dominating, sometimes reaching a covering percentage of over 50%.

<table>
<tr><td>years after construction

First Post Construction Turbine Foundation Colonisation Report (Three years following construction)</td><td></td><td></td><td>As this was the first monopile survey, results could not be compared with previous surveys but were compared to results from other wind farms in the North Sea.
Methodology
Scrape sample and video footage from dive survey
As this was the first monopile survey, methods could not be compared with previous surveys
Survey undertaken in autumn (October)
Correlation
No correlation analysis used</td><td></td></tr>
<tr><td>Princess Amalia OWF

Development of hard substrate fauna in the Princess Amalia Wind Farm. Monitoring 6 years after construction

Second Post Construction Turbine Foundation Colonisation Report (Six years following construction)</td><td>Apr 2014</td><td>eCOAST Marine Research

This report presents the results of the colonisation survey (July 2013) at 4 wind turbine monopiles using divers and scrape samples.</td><td>Survey design and statistical approach
Reference stations not applicable for monopile surveys. Species composition were compared with adjacent rock hard substrate.
ANOSIM analysis used to determine significant differences between samples, zones, and between years.
Zonation was monitored across turbines and compared between turbine structures. Species/composition change between years also observed.
Results compared with first monopile survey, and other wind farms in the North Sea.
Methodology
Scrape sample and video footage from dive survey
Consistent methods to first monopile survey
Survey undertaken at different time (summer – July) of year as the first survey (autumn – October)
Results compared with data collected in first survey
Correlation
No correlation analysis used</td><td>Suspected increase in species richness compared to initial monopile survey
The division of the community in two major zones was reported to have stayed the same: an upper, intertidal zone dominated by algae, mussels and small arthropods, and a sublittoral zone, dominated by large clusters of tube dwelling amphipods (mainly Jassa spp.), mussels, large echinoderms (starfish and sea urchins) and large cnidarians (sea anemones and hydrozoans).
The biomass results presented that a higher biomass of mussels occurred at depth 2m and a higher biomass of mussels and sea anemones (Metridium senile) at depth 17m during the current survey compared to initial survey.
This is with the exception of a number of newly colonised and rare species including; polychaetes Ctenodrilus serratus and Malacoceros fuliginosus, as well as Mollusca Nassarius incrassatus and Onchidoris muricata
the non-native Japanese skeleton shrimp Caprella mutica was recorded on one of the turbine</td></tr>
<tr><td colspan="5">Robin Rigg Offshore Wind Farm</td></tr>
<tr><td>Robin Rigg OWF

Construction Cable Route and Intertidal Surveys Year 1 and 2

Cable Route:</td><td>Cable Route:

May 2008

Jun 2009

Intertidal:</td><td>Entec Holdings Ltd

Technical notes summarising the methodology and results of their respective surveys. No data interpretation included.</td><td>Survey design and statistical approach
Sampling stations OWF (no. 6), cable route (no. 8)
Reference stations: 3 stations - 18% of sampling stations
No statistical analysis done
Sabellaria reef extent, movement and condition comparisons done based on previous surveys</td><td>In 2004 a survey was conducted on the shore adjacent to the two most northern turbines to establish a suitable route across the shore which would minimise any disturbance to the Sabellaria reef. From this survey a corridor of sandy ground was identified between patches of Sabellaria reef which would allow a cable</td></tr>
</table>

Robin Rigg Monitoring Cable Route Benthic Macro-Invertebrate Survey Data Report, May 2008 *Robin Rigg* Monitoring. *Cable Route Benthic Macro Invertebrate Survey Data Report, June 2009*	March 2008 Mar 2009		• Comparison of natural variation and anthropogenic impact discussed intertidally • Comparison over the years of surveys conducted, however no comparison to historical non-project specific data assessed. **Methodology – cable route** • Multiple methodologies - physio-chemical data and PSA and TOC both physical and environmental data collected • Consistent methodology to pre-construction, with duplicates and similar locations. • Surveys undertaken at different times of the year. • Consistent labs were used to send samples throughout programme • Data from two years included in (one in each report) and compared to previous survey results. **Methodology – intertidal survey** • Consistent methodology to pre-construction, though this is later expanded on in 2011. No duplicated taken but this is consistent • Surveys undertaken at different times of the year however this is mentioned in some discussions to obtain more temporal data • No laboratory methods were required, however same surveyor was used who performed 2004 and 2008 surveys • Multiple methodologies were not used for these surveys, only visual • Data from two years included in (one in each report) and compared to previous survey results **Correlation** • No correlation assessments undertaken, no statistical analysis done **Power analysis** • No power analysis indicated	route to be laid without disturbing the reef. As a result of this survey the cable route was adjusted to avoid the Sabellaria and take advantage of this natural corridor thorough the reef. • Compared to the 2004 survey done, position of the corridor between the Sabellaria reefs has changed little, interpreted to be a result of seasonal effects.
Robin Rigg OWF Construction Site Surveys Year 1 and 2 Robin Rigg Monitoring Windfarm Site Benthic Macro Invertebrate Data Report, March 2008	March 2008 Jun 2009	Entec Holdings Ltd Technical notes summarising the methodology and results of their respective surveys. No data interpretation included.	**Survey design and statistical approach** • Distinction in results made between samples from the OWF and those at the reference (control) stations • No statistical analysis done • No assessment into underlying habitat or extent compared to previous years • No assessment into natural variability or anthropogenic impacts • Basic comparison done to previous surveys done as part of the licensing requirements. • No comparison to previous non-project specific historical or external data **Methodology**	• Although duplicate grab samples were taken at each sampling station, in accordance with the approved methodology invertebrate identification, PSA and TOC were only performed on the first sample taken, with the second sample being preserved for reference • Particle size distributions agree with the visual assessment that sediments in this area largely comprise medium to very fine sand. • In total 25 species of invertebrates were identified from the grab samples collected. • The invertebrate communities from this area are consistent with an impoverished sand associated community dominated by the

Robin Rigg Monitoring Windfarm Site Benthic Macro Invertebrate Data Report, June 2009			• Multiple methodologies - physio-chemical data and PSA and TOC both physical and environmental data collected • Consistent methodology to pre-construction and construction surveys • Duplicate samples taken at each station, however some variation in sample locations experienced due to difficulty sampling • Not consistent sampling seasons • Labs in which samples were sent were the same as pre and post-construction. Vessel and method of collection was the same • Data from one year assessed here **Correlation** • No correlation assessments undertaken, no statistical analysis done.	amphipod *Bathyporeia* spp. and the polychaete Nephtys cirrosa.
Robin Rigg OWF Post-construction Cable Route and Intertidal Surveys Years 1 and 2 **Cable route:** Robin Rigg Monitoring Cable Route Benthic Survey Data Report, May 2010 Robin Rigg Monitoring Cable Route Benthic Survey Data Report, April 2011	**Cable Route:** May 2010 April 2011 **Intertidal:** Sep 2009 Sep 2010 Dec 2010 Jan 2011 Feb 2011 Mar 2011 Dec 2011	AMEC Environment & Infrastructure UK Ltd (acquisitioned Entec Holdings Ltd) Technical notes summarising the methodology and results of their respective surveys. Some comparisons have been drawn from previous surveys but no data interpretation/statistical analysis has been undertaken.	**Survey design and statistical approach** • No distinction made between samples from the OWF and those at the reference (control) stations as no controls taken along cable route • Statistical analysis done on intertidal surveys to assess percentage cover and topographic changes • Habitat cover of sand inundation assessed and extent changes compared intertidally relating to scars and sand extent • Comparison of natural variation and anthropogenic effect discussed intertidally • Comparison over the years of surveys conducted, however no comparison to historical non-project specific data assessed **Methodology - cable route** • Multiple methodologies - physio-chemical data and PSA and TOC both physical and environmental data collected • No duplicates and some variation in sample locations experienced due to difficulty sampling • Not consistent sampling seasons • Labs in which samples were sent were the same as pre and post-construction. Vessel and method of collection was the same • Data from one year assessed here **Methodology - intertidal surveys (sand inundation study and reef mapping study)** • Consistent methodology to pre-construction and construction surveys and with same approximate locations to previous surveys, no duplicates though, however additions to methodology were implemented in 2011 related to sand inundation • Sampling was not carried out at the same time of year across the survey programme • Benthic analysis for percentage cover of sand along transects and the second using quadrants at regular intervals along the same transect lines was consistent using fixed transects., Methodology extended out from solely	• Samples used 0.1m2 Day grab. • Identichaete conducted taxonomic identification. • AES Labs did PSA and TOC analysis on sediment samples. • PSA agree with visual assessment for majority of samples taken. Majority of samples within the OWF are made up of fine sand. Some discrepancies in mud content and shell sometimes not picked up by PSA. • Site 3 (close to the OWF) was unique amongst samples, mixed sediment composition but it was not the most diverse, but had the highest number of individuals. • Communities identified consistent with an impoverished sand associated community dominated by amphipod *Bathypoeria* spp. and the polychaete *Nephytys cirrosa*. • Site 8 was rocky and so sediment samples could not be taken. • More sand inundation running perpendicular to the coast., • Size of sand area has doubled since track marks discovered in 2009, peaking a total area of 82,910 m2 in Jan 2011 (from 35,740 m2). Background natural change of sand cover increased by 36% between 2004 and 2008 in the absence of any cable work being done. • ANOVA found no significant difference in diversity of species recorded between the two sampling occasions, only T2 was statistically

			• mapping the extent of the *Sabellaria* reefs and this is discussed in Feb 2011 Reef Monitoring Data Analysis Report • Photographs alongside diversity and topography assessed. They are not however discussed together in interpreting results • Data over 5 years has been used **Correlation** • No correlation assessments undertaken **Power analysis** • No power analysis indicated	significant in the change of extent of sand cover. • Sabellaria reefs to north and south of central sandy area appear in good health and with good mound formations and re-colonisation • of the tracks, though tracks still visible. • No statistically significant impact on diversity of the survey shore as a whole in vicinity of cable route has been recorded however study carried out over short time phrase (less than 1 year). • Analysis of biological communities showed no differences between assemblage recover between Dec 2010 and Jan 2011. • Topographic survey found height of sand above scar ground was over 0.5 m deep, with an average of 2mm increased depth per sampling station.
Robin Rigg OWF Post-construction report - Year 2 Robin Rigg Monitoring Windfarm Site Benthic Data Report, April 2011	Apr 2011	Entec UK Limited Technical notes summarising the methodology and results of their respective surveys. No data interpretation has been undertaken.	**Survey design and statistical approach** • Distinction in results made between samples from the OWF and those at the reference (control) stations • No statistical analysis done • No assessment into underlying habitat or extent compared to previous years • No assessment into natural variability or anthropogenic impacts • Basic comparison done to previous surveys done as part of the licensing requirements. No comparison to previous non-project specific historical or external data **Methodology** • Multiple methodologies - physio-chemical data and PSA and TOC both physical and environmental data collected • Consistent methodology to pre-construction and construction surveys • Duplicate samples taken at each station, with same approximate locations to previous surveys • Not consistent sampling seasons • No information on whether lab methodologies have been consistent, however vessel and method of collection was the same • Data from one year assessed here **Correlation** • No correlation assessments undertaken, no statistical analysis done	• 12 species of invertebrate identified in grab samples. • Communities identified consistent with an impoverished sand associated community dominated by *amphipod Bathypoeria* spp. and the polychaete *Nephytys cirrosa*. The bivalve *Donax vittatus* found in high numbers, although only at one sampling station (control site 1 outside the OWF). • Species found consistent with previous benthic surveys, and overall diversity and productivity of sampling stations similar to that recorded in 2010. • PSA agree with visual assessment for majority of samples taken. Majority of samples within the OWF are made up of fine sand, or very fine sands, consistent with previous surveys.
Robin Rigg OWF Post-construction Comparison Reports:	April 2011 Mar 2012	Entec UK Limited Natural Power Consultants	**Survey design and statistical approach** • Sampling stations located within wind farm (primary) and outside wind farm (reference)	• Part of the Marine Environment Monitoring Programme (MEMP) and under the Food and Environmental Protection Act (FEPA) licence conditions. Results compared with similar Baseline (pre-consent) surveys undertaken as part of the EIA.

Baseline, Pre-construction and Construction Phase Analysis - Fish and Benthic Monitoring Analysis of MEMP Ecological Data (Pre-construction vs. Construction Years) Two Benthic Ecology Comparison Reports - Pre-construction and Construction Phase (Two years following construction)		(Canning et al) These reports present the assessment of the demersal fish, epibenthic, and benthic conditions at the site of the Robin Rigg during the pre-construction, construction and post-construction phase.	• Long term variability in benthos studied, looking at natural variability of the sand banks compared to changes relating to the any specific anthropogenic activity from construction. Discussion of results in relation to variation in fauna and sediment between surveys due to presence of OWF. Changes in species richness and abundance were identified between years • ANOSIM multivariate analysis done • Comparison into biotope classification conducted and mapped over the construction and operational years looking at extent • ES and historical datasets in the area (not project-specific) used to contextualise mobile and highly dynamic environment **Methodology** • Surveys followed using consistent methodology, however not as many stations as the original baseline, but same locations • MDS plots were constructed to provide a visual analysis of small and large scale changes in community structure. Univariate measures of diversity were calculated using DIVERSE (Primer6) and analysed with a Kruskal-Wallis test (XLSTAT) to test for effects of wind farm construction. Multivariate analysis using ANOSIM (analysis of similarity) (Primer6) was carried out to test for any variation in community assemblages caused by wind farm construction activity. • Data over several years included • No information on whether lab methodologies have been consistent **Correlation** • No RELATE or BioEnv test applied **Power analysis** • No power analysis indicated	• No species or habitats of conservation interest, as listed under the EU Habitats or Birds Directive (92/43/EEC), were identified in subtidal samples. *Sabelleria alveolata* reefs are present on the intertidal section of the cable route, however none occur sub tidally. • Benthic community assemblages did change over time, with significant changes being detected between the Baseline sampling period and the Pre-Construction and Construction sampling periods. Differences were independent of location i.e. inside or outside the wind farm and along the cable route. • Some seasonal variations in benthic community structure were also observed, with samples obtained in winter being significantly different to those taken in spring or summer. • Univariate measures of diversity revealed a significant increase in biodiversity of the benthos from the Baseline to the Pre-Construction period in species richness, number of individuals and evenness and a significant decrease in Shannon's and Simpson's indices from the Pre-Construction to the Construction period. • Significant changes observed in biodiversity and community structure cannot be linked to construction phase activity alone (baseline vs. construction) and are most probably a result of natural variability in this dynamic environment or are due to other pressures not considered within the scope of these works. • There is no evidence that the construction phase of the Robin Rigg offshore wind farm has had any effect on the demersal fauna and benthos in the immediate or surrounding area. Predictions made in the environmental statement relating to the potential impact of wind farm construction at the Robin Rigg site were supported by the data collected. • The addition of extra benthic sampling stations would improve the usefulness of the survey. • 3 reference stations for the entire OWF development (18% of sampling locations)
Robin Rigg OWF Post-construction - Year 1 and 2	Sep 2013	Natural Power Consultants (Rutherford and Lancaster) (Walls et al.)	**Survey design and statistical approach** • Sampling stations located within wind farm (primary) and outside wind farm (reference)	• During the EIA the biotope SS.SSa.IFiSa.NcirBat - *Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand was the only one identified at the site of the proposed Robin Rigg Wind Farm installation.

Analysis of Marine Environmental Monitoring Plan Data from the Robin Rigg Offshore Wind Farm, Scotland (Operational Year 1) Analysis of Marine Ecology Monitoring Plan Data from the Robin Rigg Offshore Wind Farm, Scotland (Operational Year 2)		These reports represent the analysis performed on data collected before construction, during construction and during operation.	• Several forms of statistical analysis undertaken both multivariate and univariate. Direct comparisons were made between the community structures throughout specific sampling periods using ANOVA • Comparison into biotope classification conducted and mapped over the construction and operational years looking at extent • Discussion of results in relation to variation in fauna and sediment between surveys due to presence of OWF. Changes in species richness and abundance were identified between years Discussion of results in relation to windfarm construction and concludes changes observed not due to anthropogenic activities • ES and historical datasets in the area (not project-specific) used to contextualise mobile and highly dynamic environment **Methodology** • Data over several years included and compared • Benthic surveys have been undertaken both offshore on the site and along the cable route, as well as intertidally at the cable landing point from baseline through to the operational phase of the offshore wind farm. Consistent methodology using many of the same locations just not as many of the original • There was a large degree of similarity between replicate samples obtained in terms of both sediment and benthos characteristics over the survey area. As a result, following consultation with the Robin Rigg Monitoring Group, only duplicate grab samples during pre-construction and construction phase monitoring were required • No information on whether lab methodologies have been consistent • All statistical analysis was undertaken using the statistical package PRIMER v6 and Microsoft Excel. Initially data were sorted and stored in Excel spread sheets with all species counts and physical data for all years. All species names were checked and revisions made for new taxonomic classifications. Data were sorted by abundance to enable simple observations to be made • Sampling throughout all years has not been consistent, there is an assessment into difference in the seasons of sampling • Multiple methodologies used across the post-monitoring period **Correlation** • No RELATE or BioEnv test applied	• In total the loss of habitat to for *N. cirrosa* and *Bathyporeia* spp. was only 0.4% of the total area inside the wind farm. In addition other habitats (biotopes) identified around the wind farm site were described as comprising of fauna which is characterised by the Presence of short lived benthic species tolerant to sediment disturbance. As a result the ES predicted that any impacts on the benthos in this area would not be significant and where any may occur they would be of a short duration. • The main impact predicted by laying the cable route was smothering from disturbed sediments, particularly through ploughing. However, this area is naturally highly disturbed and turbid, with strong tidal currents and wave disturbance. As a result the ES predicted that any sedimentation or disturbance suffered by fauna would be short in duration due to the highly dynamic nature of the area and therefore would not cause significant impacts on the benthos. According to the Robin Rigg ES the naturally highly dynamic nature of the seabed at the site of the proposed Robin Rigg Wind Farm led to predicted impacts during construction caused by minor habitat loss and sedimentation to be insignificant. Habitats in the area recover quickly from disturbance and the mobile and resistant nature of fauna result in rapid re-colonisation. • Encrusting fauna, such as bryozoans and hydroids, attached to boulders, have a high resistance and therefore low sensitivity to such disturbance.
Scroby Sands Offshore Wind Farm				
Scroby Sands OWF Benthic ecology of Scroby Sands windfarm site: results of July 2005 (post-construction)	Jul 2005	Unicomarine This report presents a comparison of sediment composition and benthic fauna assemblages pre- and post-construction	**Survey design and statistical approach** • Sampling stations OWF near monopiles (no. 20), cable route (no. 1) • Reference stations: 17 stations - 45% of sampling stations • Distinction between stations in Yarmouth Road (South of the development area) and within the development area – however, no stats to look at differences within and outside of development area.	• The area is subject to considerable wave action, sand banks generally comprise a well-sorted sediment of medium to fine sand. Away from the banks, pebbled and granules were more common, especially in Yarmouth Road, in which the seabed was generally hard. • Fauna found in 2005 generally less diverse than those found in 1998. Only five stations had

survey and comparison with 1998 (pre-construction) survey First Post Construction Benthic Ecology Report (One year following construction)			• Statistical tests were not carried out • Comments on shifts in species composition and habitat distribution between survey years: comparisons of diversity, biotopes, biomass etc between stations inside and outside of main development area • Interpretations of the cause of observed changes in benthos between years were not definitive and suggested that there are multiple explanations for the change: natural variation in species/habitat presence, adverse effects from turbine presence, and changes in sampling methods between years causing variation in results • No comparison with historical or external data **Methodology** • Grab and trawl samples collected • Same stations sampled between surveys – however, from one survey to the next, Hamon grab was invented, which was used in the 2005 survey compared to Day Grab in 1998 survey. Also meant that in 1998, some stations were trawled instead of grab sampled due to stony ground. • Consistent methodology to analyse macrofauna and PSA data. Multiple methodologies used. • Surveys carried out at same time of year (July), ruling out any temporal effects • Data from two years (1998 and 2005) **Correlation** • Trends described but no analyses of correlation **Power analysis** • No power analysis indicated	similar Shannon Weiner Diversity values in 2005 compared to 1998, all of these were away from Scroby Sands. • Some species were more common in areas of mixed sediment, such as the sand mason worm Lanice conchilega and another sedentary worm called *Scoloplos armiger*. Both of these showed a sharp reduction in numbers in 2005. The Ross worm *Sabellaria spinulosa* was more common in post-construction survey. Different species were found on the clean sand of middle Scroby.
Sheringham Shoal Offshore Wind Farm				
Sheringham Shoal OWF Benthic Ecology and *Sabellaria* Study 2009 Pre-Construction Benthic Ecology Report	May 2010	Staloil and EMU Ltd. The principal objective of the survey was ascertain whether *Sabellaria spinulosa* reef had built up in the windfarm turbine areas, or in the associated cable route since previous surveys undertaken in 2008.	**Survey design and statistical approach** • Sampling stations OWF (no. 11), cable route (no. 1 grabs, no. 3 DDV only), • Reference stations: 8 stations - 35% of sampling stations • ANOSIM for temporal differences between pre-construction and post-construction, as well as between and primary and reference areas • Changes discussed at both site and habitat level • Results found no evidence to suggest Sabellaria spinulosa reef had built up post-construction of the OWF site, only small changes found in biotope presence were thought to be down to natural variability • Data compared with the previous 2008 survey only. No additional historical or external data/reports used **Methodology** • Multiple methodologies used and interpreted in context of one another (DDV and benthic grab)	• Surveys in 2009 (pre-construction) were compared with 2008 surveys (baseline/pre-construction). • Multiple stations were assigned to a different biotope in 2009 compared to the 2008 survey. As these surveys were undertaken before OWF installation, changes in habitat were associated with natural variability.

			• Similar methodology carried out as the previous 2008 baseline survey, however, as the 2009 survey was the first to target Sabellaria for the project, the sampling locations/methods have varied • Cannot compare survey times with previous surveys • Similar analysis of benthic data as 2008 surveys, however, analysis targeted more at Sabellaria • Compared with 2008 survey **Correlation** • Basic correlation (unspecified) between PSA and Faunal data; RELATE & Bio-Env were not used. Biotopes identified **Power analysis** • No power analysis indicated	
Sheringham Shoal OWF Post-construction Monitoring Benthic Survey First Post Construction Benthic Ecology Report (One year following construction)	July 2013	Fugro EMU Ltd. This report assessed the benthic community after the construction of the Sheringham Shoal wind farm.	**Survey design and statistical approach** • Sampling stations OWF (no. 7 grabs, no. 4 DDV only), within tidal extent (no. 6), cable route (no. 5 grabs, no. 3 DDV only), • Reference stations: 18 stations - 42% of sampling stations • ANOSIM for temporal differences between pre-construction and post-construction, as well as between and primary and reference areas • Changes discussed at both site and habitat level • Discussion of results in relation to windfarm construction and concludes no significant changes in habitat presence/extent other than small-scale natural variability • Data compared with pre-construction survey only. Other prior or interim surveys were not considered due to a difference in survey design **Methodology** • Faunal grabs, DDV, beam trawl (2012 post-construction only), and PSA data collected and compared • Survey repeats stations carried out for pre-construction survey. Additional stations were added for the post-construction survey and added beam trawl data was also collected • Post-construction survey undertaken in winter (December) but unclear if undertaken at same time of year at pre-construction survey, therefore, cannot eliminate potential seasonal effects • Consistent laboratory methodologies used for pre- and post- construction surveys • Data from two surveys compared **Correlation** • Basic correlation (unspecified) between PSA and Faunal data; RELATE & Bio-Env were not used. Biotopes identified	• The temporal comparison of the grab data highlighted some differences which resulted in being indistinguishable through statistical analysis. The majority of the stations were allocated the same biotopes as per previous studies. Some changes were observed; however the different biotopes which were allocated resulted in being transitional or impoverished variants of the main biotopes identified in the whole of the survey area. • The results were consistent with the findings from baseline and interim studies. No significant difference was highlighted by the temporal analysis of the benthic community and those observed are likely to be attributable to natural variations in a highly dynamic environment • In both the pre-construction and post-construction surveys, *Sabellaria* was present as thin crusts on pebbles and no reef formations were observed. These findings were consistent with previous studies in the area. • No significant changes occurred between the 2009 pre-construction and the 2012 post-construction surveys (ANOSIM test results: R=-0.005, p=49.9%).

Sheringham Shoal OWF Second Post-Construction Benthic Monitoring Survey Second Post Construction Benthic Ecology Report (Two years following construction)	Nov 2014	Marine Ecological Surveys Limited. This report presents the second post-construction survey of benthic resources undertaken at the Sheringham Shoal Offshore Wind Farm.	**Survey design and statistical approach** • Sampling stations located within footprint, near-field, outside tidal excursion • ANOSIM for temporal differences between pre-construction and post-construction, as well as between and primary and reference areas • Changes discussed at both site and habitat level • Discussion of results in relation to variation in biota and sediment between surveys due to presence of OWF. Interpretation suggests observed changes are related to natural variation. • Comparison with historical data, specifically for *Sabellaria* presence **Methodology** • Multiple methodologies used and interpreted in context of one another (DDV and benthic grab) • Similar methodology carried out as the previous baseline and yr 1 post-construction survey; however, appropriate modifications were made following the MMO and their scientific advisors • Surveys undertaken in Spring (April-May) whilst previous survey undertaken in Autum (September) therefore, seasonal effects cannot be ruled out • Same analysis of benthic data as previous surveys • Compared with 2009 and 2012 surveys **Correlation** • RELATE and Bio-Env testing for correlations were used for testing relationships between environmental variables (Sediment type) and faunal communities.	• Between the pre- and post-construction surveys (2009 – 2014), the primary impact zone showed an increase in the average percentage of gravel from 17.93% to 24.07%, which was coupled with a decrease in sandy sediments from 80.66% to 74.52%. Conversely, the secondary impact zone showed a decrease in the average percentage of gravel from 32.65% to 29.59%, coupled with a slight increase in sand percentage from 65.17% to 68.40%. • The identified physical impacts of the wind farm on the benthos were limited to the scour pits surrounding the monopiles, and the trenches for the subsea cabling. • ANOSIM did reveal a significant overall difference between the benthic assemblages sampled in 2009, 2012 and 2014. However, these differences were not large with a relatively high degree of overlap between years (low R value) • From 2009 to 2014, a decrease in the relative abundance of *Balanus crenatus* and *Dendrodoa grossularia* was recorded together with an increase in *Goodallia triangularis*, *Crepidula fornicata*, and Myidae (juv).
Thanet Coast Offshore Wind Farm				
Thanet OWF A Post-construction Monitoring Survey of Benthic Resources First Post Construction Benthic Ecology Report (Two years following construction)	Jan 2013	MES Ltd. This report presents the findings of the post-construction monitoring survey that was undertaken across the TOWF area during two sampling events in August & November 2012.	**Survey design and statistical approach** • Sampling stations OWF (no. 20), scour pit (no. 4) • Reference stations: 5 stations - 17% of sampling stations • Sampling stations located within wind farm (primary) and outside wind farm (reference) • ANOSIM for temporal differences • Changes discussed at both site and habitat level • Discussion of results in relation to windfarm construction and concludes changes observed not due to anthropogenic activities • No comparisons with historical data outside the current survey regime to contextualise natural variability **Methodology**	• Statistical analyses revealed a significant relationship between patterns observed in the particle size distribution data to those seen in the faunal communities. • Statistical analyses revealed significant overall differences between the benthic assemblages sampled during pre-construction compared to those sampled post-construction at TOWF. These differences contributed to an increase in the number of taxa that made up 90% of the population in 2012, in addition to a variation in the highest contributing taxa within the benthic communities. • Temporal comparisons of PSD data recorded pre- (2005 & 2007) and post-construction

			• Faunal grabs, DDV, and PSA data collected and compared • Survey repeats same stations as 2005 & 2008 pre-construction surveys • Sampling time of year not specified for 2005 & 2006 surveys • Consistent laboratory methodology used each year • Data from three surveys compared **Correlation** • Correlation (unspecified) between PSA and TOM; RELATE & Bio-Env between Fauna and PSA **Power analysis** • No power analysis indicated	(2012) indicated that there were no significant differences in sediment composition following the construction and operation of TOWF. • Temporal comparisons of faunal data recorded pre- and post-construction, revealed that there has been an increase in mean infaunal abundance, diversity and biomass across the TOWF site, although grouping 2005 and 2007 data together makes it difficult to assess natural variability at the site prior to construction • Scour pit assessment showed similar faunal composition to the other sampling stations but with a coarser substrate • *Sabellaria spinulosa* assessment showed slight changes in distribution and an increase in density of aggregations
Walney I & II Offshore Wind Farm				
Walney OWF Year 3 Post-construction Benthic Monitoring Surveys Third Post Construction Benthic Ecology Report (Three years following construction)	February 2015	CMACS Ltd. This report concentrates on grab and DDV surveys that were carried out in 2014, with comparison of these data against those collected in previous years.	**Survey design and statistical approach** • Sampling stations OWF (no. 17), near field (no. 5), cable route (no. 13) • Reference stations: 9 stations - 20% of sampling stations • ANOVA/Kruskal-Wallis and ANOSIM statistical tests used to compare results between primary, secondary and references zones, and between pre- and post-construction data • Comments on shifts in species composition and habitat distribution between survey years • Some comparison with historical or external data/reports **Methodology** • Grabs and DDV • Same sampling stations for year 1 and 2 post-construction surveys, which were matched the approach taken for the baseline survey (sampling protocol changes as requested by Licence Authority and explained in text) – 7 stations failed to be sampled • Sampling carried out in June-July, previous survey dates are not shown in report • Similar laboratory methods used across years • Pre-construction (2009) and post-construction year 1 (2013) and 2 (2014) surveys compared **Correlation** • BioEnv analysis used to correlate environmental parameters (mean particle size; % gravel; % sand; % mud; TOM; and depth) to faunal data **Power analysis**	• Minor changes detected for overall faunal community assemblages and diversity over time. • The detected changes in fauna were mostly minor reductions in species that tend to be associated with somewhat muddy sediments, however, there has been a general increase in muddier sediment in the site area overtime. As with the changes to sediment, it is possible that the changes are at least partly natural, with some observed reduction in burrowing macrofauna being superimposed on a wider scale natural reduction. • Cable Route survey stations show a great deal of variation in the sediments, as well as in water depth, and hence also in associated fauna. No widespread impacts on benthos have been reported, the report notes that localised changes associated with scour pits and decreased local current flow were found at Thornton bank OWF in Belgian waters, and cautions that longer term studies are needed to determine whether changes such as these may eventually have more widespread effects on both infauna and epifauna.

			• No power analysis indicated	
Westermost Rough Offshore Wind Farm				
Westermost Rough OWF Post Construction Benthic Survey 2015 First Post Construction Benthic Ecology Report (One year following construction)	April 2016	Precision Marine Survey LTD. The report aims to provide an assessment of the benthic habitats and associated assemblages within and adjacent to the areas of potential impact resulting from the construction and of the WMR OWF (year 1 post-construction)	**Survey design and statistical approach** • Sampling stations OWF (no. 8), secondary impact zone (no. 4), cable route (no. 3: primary impact zone; no. 1: secondary impact zone) • Reference stations: 5 stations - 24% of sampling stations • ANOSIM statistical tests used to compare results between primary, secondary and references zones, and between pre- and post- construction data • Comments that species composition were similar between 2013 and 2015: a similar range of assemblages/biotopes recorded and with some variation • Interpretation suggests that observed changes between 2013 and 2015 were a result of natural small scale spatial and temporal variability and unlikely due to OWF presence. • No comparison with historical or external data/reports **Methodology** • Grabs and DDV • The same areas were sampled for pre-construction (2013) and post-construction (2015) surveys, however, more stations were sampled in 2015 surveys due to failed sampling attempts in 2013. • Post-construction survey undertaken at similar time of year (June) as pre-construction survey (April/May) • Similar laboratory methods used – data standardisation used for 2013 data due to changes in nomenclature • Pre-construction (2013) and post-construction (2015) surveys compared **Correlation** • BEST analysis used to correlate environmental parameters (mean particle size; % gravel; % sand; % mud; and depth) to faunal data **Power analysis** • No power analysis indicated	• Due to sampling difficulties in 2013 only six stations were successfully sampled in full (stations 4, 7, 8, 15, 18 and 21) so these stations were used to assess changes in biological data. The mean values of biological parameters for the six survey stations sampled in both 2013 and 2015 along with 95% confidence limits. Relatively few differences were noted in relation to mean numbers of quantitative species with somewhat higher values recorded in 2015. • A comparison of infaunal data from 2013 and 2015 highlighted a number of differences although at a broader scale a similar range of assemblages/biotopes were recorded. Silt content was slightly higher at most stations in 2015 and a wider range of taxa were also recorded in the post-construction survey which had a much higher range of epifaunal taxa (hydroids and bryozoans but a lower contribution by polychaetes
Westermost Rough OWF Post Construction Benthic Survey	April 2020	Precision Marine Survey Ltd. / Orsted. The report aims to provide an assessment of the benthic	**Survey design and statistical approach** • Sampling stations OWF, secondary impact zone, cable route (primary impact zone; secondary impact zone), reference stations	• A comparison of infaunal data from 2013 to 2019 highlighted a number of differences between years although at the habitat/biotope complex level a similar range of assemblages/biotopes were recorded.

(2019). Technical Report Second Post Construction Benthic Ecology Report (Two year following construction)		habitats and associated assemblages within and adjacent to the areas of potential impact resulting from the construction of the WMR OWF. It provides a comparison with previous data collected at the development site during year 1 post-construction and pre-construction surveys.	• ANOSIM statistical tests used to compare results between primary, secondary and references zones, and between pre- and post- construction data • Comments on shifts in species composition and habitat distribution between survey years • Significant differences in species assemblages was identified between years, however, these differences were consistent for both reference and primary stations. Interpretation concludes differences primarily reflect effects of natural variation • No comparison with historical or external data/reports **Methodology** • Grabs and DDV • Same sampling stations for year 1 and 2 post-construction surveys, with some of the same stations from pre-construction survey sampled (due to failed sampling attempts in pre-construction only 6 stations sampled) • Year 2 Post-construction survey undertaken at similar time of year (July) as year 1 survey (June) and pre-construction survey (April/May) • Similar laboratory methods used – data standardisation used for 2013 data due to changes in nomenclature • Pre-construction (2013) and post-construction year 1 (2015) and 2 (2019) surveys compared **Correlation** • BEST analysis used to correlate environmental parameters parameters (mean particle size; % gravel; % sand; % mud; and depth) to faunal data	• Differences in both sediment parameters and biological parameters were evident both within stations and between years although such temporal differences were often rather small.

Annex 1c Observed trends in sediment and benthic fauna associated wth offshore wind farms

Grey shading indicates there was no consistent trend apparent.

Offshore Wind Farm	Owner	Completion Date	Pre-construction report (year)	Post-construction reports (survey year)	Sediment type			Abundance and Taxon Richness		
					Was there a change between pre-construction survey and the first post construction survey? (OWF)	Is there a consistent change in sediment type? (OWF)	Is there a consistent change in sediment type at the reference stations?	Was there a change between pre-construction survey and the first post construction survey? (OWF)	Is there a consistent change in abundance/taxa? (OWF)	Is there a consistent change in abundance/taxa at the reference stations?
Barrow	Ørsted	2006	2004-2006	2007, 2009	**YES** - there was an INCREASE in grain size from PRE (2004) to POST (2007) *Appendix 4 (Benthic & Sediment Survey: Comparative Analysis of Pre and Post Construction Benthic and Sedimentological Data). Section 3.1, page 9*	**NO** - there was no consistent trend or pattern observed between PRE (2004) and POST (2007, 2009) *Appendix 3 (Benthos & Sediment Survey: Comparative Analysis of Pre and Post Construction Benthic and Sedimentological Data). Section 4.1.1, page 10*	**NO** - there was an INCREASE in grain size from PRE (2004) to POST (2007), but there is no consistent trend or pattern observed between PRE (2004) and POST (2007, 2009) *Appendix 3 (Benthos & Sediment Survey: Comparative Analysis of Pre and Post Construction Benthic and Sedimentological Data). Section 4.1.1, page 10*	**ABUNDANCE** - **YES** - there was a general INCREASE in total abundance between PRE (2004) and POST (2007) *Appendix 4 (Benthic & Sediment Survey: Comparative Analysis of Pre and Post Construction Benthic and Sedimentological Data). Table 9, page 19* **TAXON RICHNESS** - **NO** - there was no consistent trend or pattern observed in taxon richness from PRE (2004) to POST (2007) *2009 Appendix 3 (Benthos & Sediment Survey: Comparative Analysis of Pre & PostConstruction Data. Table 4, page 15*	**ABUNDANCE** - **YES** - there was a general INCREASE in total abundance between PRE (2004) and POST (2007) *Appendix 3 (Benthos & Sediment Survey: Comparative Analysis of Pre & Post Construction Data. Table 4, page 15* **TAXON RICHNESS** - **NO** - there was no consistent trend or pattern observed in taxon richness from PRE (2004) to POST (2007, POST (2009) *Appendix 3 (Benthos & Sediment Survey: Comparative Analysis of Pre & Post Construction Data. Table 4, page 15*	**ABUNDANCE** - **YES** - there was a general INCREASE in total abundance between PRE (2004) and POST (2007) *Appendix 3 (Benthos & Sediment Survey: Comparative Analysis of Pre & Post Construction Data. Table 4, page 15* **TAXON RICHNESS** - **NO** - there was no consistent trend or pattern observed in taxon richness from PRE (2004) to POST (2007, 2009) *Appendix 3 (Benthos & Sediment Survey: Comparative Analysis of Pre & PostConstruction Data. Table 4, page 15*
Beatrice	SSE Renewables	2019	2015	2020, 2021	**YES** - there was a slight INCREASE in grain size from PRE (2015) to POST (2020).	**NO** - there was a slight INCREASE from PRE (2015) to POST (2020, but no	**NO** - there was a slight INCREASE from PRE (2015) to POST (2020) but then similar to 2021.	**ABUNDANCE** - **YES** - there was an INCREASE between PRE (2015) and POST (2020) *2015: Table 5, page 24* *2020: Table 6, page 27*	**ABUNDANCE** - **NO** - total abundance INCREASED from PRE (2015) to POST (2020), then DECREASED in POST (2021) *2015: Table 5, page 24*	**ABUNDANCE** - **NO** - total abundance RELATIVELY CONSISTENT from PRE (2015) to POST (2020, 2021) *2015: Table 5, page 24*

					Section 3.1.1, page 16 Section 4.1, page 41	consistent trend or pattern observed between PRE (2015) and POST (2020, 2021) *2020: Table 4, page 17* *2021: Table 4, page 14*	*Section 4.1, page 38*	**TAXON RICHNESS** - **YES** - there was an INCREASE between PRE (2015) and POST (2020) *2015: Table 5, page 24* *2020: Table 6, page 27*	*2020: Table 6, page 27* *2021: Table 6: page 24* **TAXON RICHNESS** - **NO** - taxon richness INCREASED from PRE (2015) to POST (2020), then DECREASED in POST (2021) *2015: Table 5, page 24* *2020: Table 6, page 27* *2021: Table 6: page 24*	*2020: Table 6, page 27* *2021: Table 6: page 24* **TAXON RICHNESS** - **NO** - there was a general INCREASE in taxon richness from PRE (2015) to POST (2020) then a DECREASE in POST (2021) *2015: Table 5, page 24* *2020: Table 6, page 27* *2021: Table 6: page 24*
Blyth Demo Phase 1	EDF Renewables	2018	2016	2018	**YES** - there was a general INCREASE in mean grain size between PRE (2016) and POST (2018). *Section 4.2.3.2, page 33* *2016: Table B2, page 50* *2018: Table D2, page 79-80*	Only one POST (2019) available	**NO** - no consistent trend or pattern observed between PRE (2016) and POST (2018) *2016: Table B2, page 50* *2018: Table D2, page 79-80*	**ABUNDANCE** - **YES** - there was an INCREASE in total abundance between PRE (2016) and POST (2019) *2016: Figure 5.7, page 30* *2019: Figure 4.9, page 29* **overall community was significantly different between years* **TAXON RICHNESS** - **YES** - there was an INCREASE in taxon richness from PRE (2016) to POST (2019) *2016: Figure 5.7, page 30* *2019: Figure 4.9, page 29* **overall community was significantly different between years*	Only one POST (2019) available	**ABUNDANCE** - **YES** - there was a general INCREASE in total abundance between PRE (2016) and POST (2019) *2016: Figure 5.7, page 30* *2019: Figure 4.9, page 29* **overall community was not significantly different between years* **TAXON RICHNESS** - **YES** - there was a general INCREASE in taxon richness from PRE (2016) to POST (2019) *2016: Figure 5.7, page 30* *2019: Figure 4.9, page 29* **overall community was not significantly different between years*
Burbo Bank	Ørsted A/S	2007	2005	2007, 2009	**NO** - there was no change in grain size from PRE (2005) to POST (2007)	**NO** - grain size was RELATIVELY CONSISTENT between PRE (2005) and	**NO** - there was no consistent trend between PRE (2005) and POST (2007, 2009)	**ABUNDANCE** - **NO** – abundance was RELATIVELY CONSISTENT from PRE (2005) to POST (2007)	**ABUNDANCE** - **NO** – no consistent trend in total abundance between PRE (2005) and POST (2007, 2009) *Table 9, page 31* *Figure 10, page 32*	**ABUNDANCE** - **NO** – no consistent trend in total abundance between PRE (2005) and POST (2007, 2009) Table 9, page 31

					Section 4.1, page 13-14 *Figure 6, page 19*	POST (2007), then there was a DECREASE in grain size from POST (2007) to POST (2009) *Section 4.1 page 13*	*Figure 6, page 20*	*Section 4.2.1, page 25-27* *Table 8, page 29* *Figure 10, page 30*	**significant difference in the communities between years and between OWF and REF; however, differences are small*	Figure 10, page 32 **significant diffrence in the communities between years and between OWF and REF; however, differences are small*
								TAXON RICHNESS - **NO** - taxon richness was RELATIVELY CONSISTENT from PRE (2005) to POST (2007) *Section 4.2.1, page 25-27* *Table 8, page 29* *Figure 11, page 31*	**TAXON RICHNESS** - **NO** - there was no consistent trend in taxon richness. Fluctuations between PRE (2005) and POST (2007, 2009) *Table 9, page 31* *Figure 10, page 32* **significant difference in the communities between years and between OWF and REF; however, differences are small*	**TAXON RICHNESS** - **NO** - there was no consistent trend in taxon richness. Fluctuations between PRE (2005, 2006) to POST (2007, 2009) *Table 9, page 31* *Figure 10, page 32* **significant difference in the communities between years and between OWF and REF; however, differences are small*
Greater Gabbard	SSE; RWE Npower Renewables	2012	2009	2013, 2017, 2023	**NO** - there was no change in sediment composition from PRE (2009) to POST (2013) *Section 6.3.1 page 121*	**NO** - there was no consistent trend or pattern observed between PRE (2009) and POST (2013, 2017, 2022) *Section 5.1.4, page 63*	**YES** - there was a general trend INCREASE in grain size between PRE (2009) and POST (2013, 2017, 2022) *Section 5.1.4, page 63*	**ABUNDANCE** - **YES** - there was an INCREASE in total abundance between PRE (2009) and POST (2013) *Section 6.3.1 page 121*	**ABUNDANCE** - **YES** -there was an INCREASE in total abundance between PRE (2009) and POST (2013, 2017, 2022) *Section 5.3.4, page 85* **Pairwise comparisons suggest a high degree of difference in faunal community that was statistically significant between 2009 and each post development year.*	**ABUNDANCE** - **NO** - there was no consistent trend in abundance between PRE (2009) and POST (2013, 2017, 2022) *Section 5.3.4, page 85*
								TAXON RICHNESS - **YES** - there was an INCREASE in taxon richness from PRE (2009) to POST (2013) *Section 5.1.2 and Table 15, page 92*	**TAXON RICHNESS** - **YES** - there was an INCREASE in taxon richness from PRE (2009) to POST (2014, 2020, 2023) *Section 5.3.4, page 85* **Pairwise comparisons suggest a high degree of difference in faunal community that was statistically significant between*	**TAXON RICHNESS** - **YES** - there was a general INCREASE in taxon richness between PRE (2009) to POST (2014, 2020, 2023) *Figure 5.9, page 88*

									2009 and each post development year.	
Gunfleet Sands I & 2	Ørsted A/S	2010	2007	2010, 2011, 2012	**YES** - there was a change in sediment composition from PRE (2007) to POST (2010) *Section 4.1, page 34* *Figure 22, page 35*	**NO** - there was no consistent trend or pattern observed between PRE (2007) and POST (2010, 2011, 2012) *Section 4.1.1, page 43-45* *Figure 25, page 48*	**NO** - there was no consistent trend or pattern observed between PRE (2007) and POST (2010, 2011, 2012) *Section 4.1.1, page 43-45* *Figure 25, page 48*	**ABUNDANCE** - **YES** - there was an INCREASE in total abundance between PRE (2007) and POST (2010) *Section 4.2.3, page 41* *Figure 28, page 43*	**ABUNDANCE** - **YES** - there was an INCREASE in total abundance between PRE (2007) and POST (2010, 2011, 2012) *Section 4.2.3, page 54-55* *Figure 31, page 56* **no significant difference in the fauna of the wind farmbetween years.*	**ABUNDANCE** - **NO** - there was no consistent trend or pattern in abundance between PRE (2007) and POST (2010, 2011, 2012) *Section 4.2.3, page 54-55* *Figure 31, page 56*
								TAXON RICHNESS - **YES** - there was an INCREASE in taxon richness from PRE (2007) to POST (2010) *Section 4.2.1, page 38-39* *Figure 26, page 40*	**TAXON RICHNESS** - **NO** - there was no consistent trend or pattern from PRE (2007) to POST (2010, 2011, 2012) *Section 4.2.2, page 52* *Figure 29, page 53* **no significant difference in the fauna of the wind farm between years.*	**TAXON RICHNESS** - **NO** - there was no consistent trend or pattern in taxon richness from PRE (2007) to POST (2010, 2011, 2012) *Section 4.2.2, page 52* *Figure 29, page 53*
Kentish Flats	Vattenfall	2005	2002	2005, 2006, 2007	**NO** - there was no change in sediment composition from PRE (2002) to POST (2005) *Section 4.1 pages 48 - 51*	**NO** - there was no consistent change in sediment composition from PRE (2002) and POST (2005, 2006, 2007) *Section 4.2.1 pages 44-48* **significant differences identified between years*	**NO** - there was no consistent trend or pattern observed between PRE (2002) and POST (2005, 2006, 2007) *Section 4.2.1 pages 44-48* **no significant differences identified between years*	**ABUNDANCE** - **YES** - there was an INCREASE in total abundance between PRE (2002) and POST (2005) *Section 4.2, page 59-64* *Figure 61, page 61*	**ABUNDANCE** - **YES** -there was a general INCREASE in total abundance between PRE (2002) and POST (2005, 2006, 2007) *Figure 4.12, page 59* **significant differences in fauna community identified between years*	**ABUNDANCE** - **YES** - there was a general INCREASE in total abundance between PRE (2002) and POST (2005, 2006, 2007) *Figure 4.12, page 59* **significant differences in fauna community identified between years*
								TAXON RICHNESS - **YES** - there was an INCREASE in taxon richness from PRE (2002) to POST (2005) *Section 4.2, page 59-64* *Figure 61, page 61*	**TAXON RICHNESS** - **YES** - there was a general INCREASE in taxon richness from PRE (2002) to POST (2005, 2006, 2007) *Figure 4.11, page 58*	**TAXON RICHNESS** - **YES** - there was a general INCREASE in taxon richness from PRE (2002) to POST (2005, 2006, 2007) *Figure 4.11, page 58*

									**significant differences in fauna community identified between years*	**significant differences in fauna community identified between years*
London Array		2013	2010	2015	**NO** - there was no change in sediment composition from PRE (2010) to POST (2015) *Section 3.8.3, page 3.11*	Only one POST (2015) available	Not enough information to determine trends at reference stations	**ABUNDANCE** - **YES** - differences observed in abundance between PRE (2010) and POST (2015) (INCREASE/DECREASE not specified) *Section 3.4.1, page 3.5-3.6* **TAXON RICHNESS** – NO - RELATIVELY CONSISTENT from PRE (2010) to POST (2015) *Section 3.4.1, page 3.5-3.6*	Only one POST (2015) available	Not enough information to determine trends at reference stations
Lynn and Inner Dowsing OWF	Macquarie Asset Management	2009	2002	2010, 2011	**YES** - there was a change in sediment composition from PRE (2005) to POST (2010) *Section 3.2.1, page 33* *Appendix IX, page 160* **small but significant changes between survey years*	**NO** - there was no consistent trend or pattern observed between PRE (2005) and POST (2010, 2011) *Section 9.2, page 81*	**NO** - there was no consistent trend or pattern observed between PRE (2005) and POST (2010, 2011) *Section 9.2, page 81*	**ABUNDANCE** - **YES** - there was an INCREASE in abundance between PRE (2005) and POST (2010) *Appendix IX, page 163* **TAXON RICHNESS** - **YES** - there was an INCREASE in taxon richness from PRE (2005) to POST (2010) *Appendix IX, page 163*	**ABUNDANCE** - **NO** - there no consistent trend or pattern observed between PRE (2005) and POST (2010, 2011) *Section 9.5, page 84* *Section 1, page 15* *Figure 24, page 66* **TAXON RICHNESS** - **NO** - there was no consistent trend or pattern observed between PRE (2005) and POST (2010,2011) *Section 9.5, page 84*	**ABUNDANCE** - **NO** - there was no consistent trend between PRE (2005) and POST (2010, 2011) *Section 9.5, page 84* *Section 1, page 15* **TAXON RICHNESS** - **NO** - there was no consistent trend between PRE (2005) and POST (2010, 2011) *Section 9.5, page 84*
North Hoyle	Greencoat UK Wind	2004	2002-2003	2004-2005 2005-2006	**YES** - there was a change in sediment composition from PRE (2002-2003) to POST (2004-2005) *Section 4.1.3, page 17*	**NO** - there was no consistent trend or pattern observed between PRE (2002-2003) and POST (2004-2005, 2005-2006)	**NO** - there was no consistent trend or pattern observed between PRE (2002-2003) and POST (2004-2005, 2005-2006) *Section 4.2.1.3, page 15*	**ABUNDANCE** - **YES** - there was a DECREASE in abundance between PRE (2002-2003) and POST (2004-2005) *Section 5.1.3.1.2, page 33*	**ABUNDANCE** - **NO** - there was no consistent trend between PRE (2002-2003) and POST (2004-2005, 2005-2006) - DECREASE followed by INCREASE *Section 5.1.3.1.1, page 29-33* *Figure 5.4 page 30* *Figure 5.5 page 31*	**ABUNDANCE** - **NO** - there was no consistent trend between PRE (2002-2003) and POST (2004-2005, 2005-2006) *Section 5.1.3.1.1, page 29-33* *Figure 5.4 page 30* *Figure 5.5 page 31*

						Section 4.2.1.3, page 15		**TAXON RICHNESS** - **YES** - there was a DECREASE in taxon richness from PRE (2002-2003) to POST (2004-2005) *Section 5.1.3.1.2, page 33*	**TAXON RICHNESS** - **NO** - there was no consistent trend between PRE (2002-2003) and POST (2004-2005, 2005-2006) - DECREASE followed by INCREASE *Section 5.1.3.1.1, page 29-33* *Figure 5.7 and 5.8, page 33*	**TAXON RICHNESS** - **NO** - there was no consistent trend between PRE (2002-2003) and POST (2004-2005, 2005-2006) - DECREASE followed by INCREASE *5.1.3.1.1, page 29-33* *Figure 5.7 and 5.8, page 33*
Ormonde	Vattenfall	2012	2009	2012, 2013	**YES** - there was DECREASE in grain size from PRE (2009) to POST (2012) *Section 3.1.2, page 15*	**YES** - a general trend to a DECREASE in mean grain size between PRE (2009) and POST (2012, 2013) *2012: section 3.1.1 and table 5, page 14* *2013: section 3.3.1 and table 3.2, page 15*	**NO** - there was no consistent trend or pattern observed between PRE (2009) and POST (2012, 2013) *2012: section 3.1.1 and table 5, page 14* *2013: section 3.3.1 and table 3.2, page 15*	**ABUNDANCE** - **YES** - there was a DECREASE in abundance between PRE (2009) and POST (2012) *Section 3.1.6 and figure 28, page 42-44*	**ABUNDANCE** - **YES** - there was a general DECREASE in abundance between PRE (2009) and POST (2012,2013) *Section 3.6 page 37* **significant difference in the faunal community between 'years'.*	**ABUNDANCE** - **YES** - there was a general DECREASE in abundance between PRE (2009) and POST (2012,2013) *2012: Table 6, page 21* *2013: table 3.3, page 21*
								TAXON RICHNESS - **YES** - there was a DECREASE in taxon richness from PRE (2005) to POST (2012) *Section 3.1.6 and figure 28, page 42-44*	**TAXON RICHNESS** - **YES** - there was a general DECREASE in taxon richness from PRE (2005) to POST (2012, 2013) *2012: Table 6, page 21* *2013: table 3.3, page 21* **significant difference in the faunal community between 'years'.*	**TAXON RICHNESS** - **NO** - there was no consistent trend between PRE (2005) and POST (2012, 2013) - DECREASE followed by INCREASE *2012: Table 6, page 21* *2013: table 3.3, page 21*
Princess Amalia Windfarm	Eneco	2008	2003	2012, 2013, 2017, 2022	**YES** - there was a DECREASE in mean grain size from PRE (2003) to POST (2012) *Section 4.3, page 44* **stated to be significantly lower - no statistical information provided*	**NO** - no consistent trend or pattern observed between PRE (2003) and POST (2012, 2013) *2012: Table 2, page 26* *2013: Table 2, page 26*	**NO** - there is no consistent trend or pattern observed between PRE (2003) and POST (2012, 2013) *2012: Table 2, page 26* *2013: Table 2, page 26*	**ABUNDANCE** - **NO** - there was no consistent trend or pattern observed between PRE (2003) and POST (2012) *2022: Figure 4.12, page 18*	**ABUNDANCE** - **YES** - there was a general INCREASE in total abundance between PRE (2003) and POST (2012, 2013, 2017, 2022) *Figure 4.12, page 18*	**ABUNDANCE** - **YES** - there was a general INCREASE in total abundance between PRE (2003) and POST (2012, 2013, 2017, 2022) *Figure 4.12, page 18*
								TAXON RICHNESS - **NO** - there was no consistent trend of pattern observed between PRE (2003) to POST (2012) *2022: Figure 4.17, page 21*	**TAXON RICHNESS** - **YES** -there was a general INCREASE in taxon richness from PRE (2003) to POST (2012, 2013, 2017, 2022) *Figure 4.17, page 21*	**TAXON RICHNESS** – **YES** - there was a general INCREASE in taxon richness from PRE (2004) to POST (2003, 2012, 2013, 2017, 2022) *Figure 4.17, page 21*

Robin Rigg	RWE Renewables	2010	2007-2011	2011 -2013	**NO** - there was no change in sediment composition from PRE (2007-2011) to POST (2011) *Section 3, page 1-2*	Only one POST (2011) available for PSA	**NO** - there was no change in sediment composition between PRE (2007-2011) and POST (2011) *Section 3, page 1-2*	**ABUNDANCE - YES** - there was a general DECREASE in abundance between PRE-CONSTRUCTION, CONSTRUCTION, OPERATIONAL periods (2007-2011) and POST (2013) *2012: Table 3.10, page 28*	**ABUNDANCE -YES** - there was a general DECREASE in abundance between PRE-CONSTRUCTION, CONSTRUCTION, OPERATIONAL periods (2007-2011) and POST (2013) *Section 3.4.2, page 27-30* *Table 3.10* **significant difference in the faunal community between 'years'.*	**ABUNDANCE – YES** – no significant difference indicated between OWF site and control stations *Site benthic survey reports (Jul 2007, Mar 2008, Jun 2009 and Apr 2011), section 3*
								TAXON RICHNESS – YES - there was a general DECREASE in taxon richness from PRE-CONSTRUCTION, CONSTRUCTION, OPERATIONAL periods (2007-2011) to POST (2013) *2012: Table 3.10, page 28*	**TAXON RICHNESS – YES** - there was a general DECREASE in taxon richness from PRE-CONSTRUCTION, CONSTRUCTION, OPERATIONAL periods (2007-2011) to POST (2013) *Section 3.4.2, page 27-30* *Table 3.10* **significant difference in the faunal community between 'years'.*	**TAXON RICHNESS – YES** – no significant difference indicated between OWF site and control stations. *Site benthic survey reports (Jul 2007, Mar 2008, Jun 2009 and Apr 2011), section 3*
Scroby Sands	RWE Renewables	2004	1998	2005	**YES** - there was a change in sediment composition from PRE (1998) to POST (2005) *Section 4.2, page 5-6*	Only one POST (2005) available	Unable to determine trend or pattern *Section 4.2, page 5-6* *Figure 2 and 3, PDF page 63-64*	**ABUNDANCE - YES** - there was a DECREASE in abundance between PRE (1998) and POST (2005) *Section 4.3.2, page 6-7* *Figure 6 and 7, PDF page 67-68*	Only one POST (2005) available	**ABUNDANCE - YES** - there was a general DECREASE in abundance between PRE (1998) and POST (2005) *Section 4.3.2, page 6-7* *Figure 6 and 7, PDF page 67-68*
								TAXON RICHNESS – YES - there was a DECREASE in taxon richness from PRE (1998) to POST (2005)		**TAXON RICHNESS - YES -** there was a general DECREASE between PRE (1998) and POST (2005)

								Section 4.3.2, page 6-7 *Figure 6 and 7, PDF page 67-68*		*Section 4.3.2, page 6-7* *Figure 6 and 7, PDF page 67-68*
Sheringham Shoal	Equinor	2012	2009	2012, 2014	**YES** - there was a change in sediment composition from PRE (2009) to POST (2012) *Section 6.2, page 76-80* **changes not significant*	**YES** - a general trend towards an INCREASE in grain size between PRE (2009) and POST (2012, 2014) *Section D.1, page 35-37* **changes not significant*	**NO** - no consistent trend or pattern observed between PRE (2009) and POST (2012,2014) *Section D.1, page 35-37* **changes not significant*	**ABUNDANCE** - **YES** - there was an INCREASE in abundance between PRE (2009) and POST (2012) *Section: 6.2.3, page 81* **changes not significant*	**ABUNDANCE** - **NO** - there was no consistent trend between PRE (2005) and POST (2013, 2014) *Section D.2, page 38-40* **significant difference in communities between OWF and Ref*	Unable to determine trend. 2014 survey report lacks discussion on temporal variance at reference stations.
								TAXON RICHNESS - **YES** - there was a general INCREASE in taxon richness from PRE (2005) to POST (2013) *Section D.2, page 38-40* *Section: 6.2.3, page 81* **changes not significant*	**TAXON RICHNESS** - **NO** - there was no consistent trend between PRE (2005) and POST (2013, 2014) *Section D.2, page 38-40* **significant difference in communities between OWF and Ref*	Unable to determine trend. 2014 survey report lacks discussion on temporal variance at reference stations.
Thanet	Vattenfall	2010	2005, 2007	2012	**NO** - there was no change in sediment composition from PRE (2005, 2007) to POST (2012) *Section D.4, page 35* *Figures 17 and 18, page 30-31* **no significant differences between years*	Only one POST (2012) available	**NO** - no consistent trend or pattern observed between PRE (2005, 2007) and POST (2012) *Section D.4, page 35* *Figures 17 and 18, page 30-31* **no significant differences between years*	**ABUNDANCE** -**YES** - there was a general INCREASE in total abundance between PRE (2005, 2007) and POST (2012) *Section D.2, page 32* **significant overall differences between years*	Only one POST (2012) available	**ABUNDANCE** - **NO** - there was no consistent trend or pattern between PRE (2005, 2007) and POST (2012) *Section D.3, page 35*
								TAXON RICHNESS – **YES** - there was an INCREASE in taxon richness from PRE (2005, 2007) to POST (2012) *Section D.2, page 32* **significant overall differences between years*		**TAXON RICHNESS** - **NO** - there was no consistent trend or pattern between PRE (2005,2007) to POST (2012) *Section D.3, page 35*
Walney	Ørsted; Greencoat UK; PGGM	2011	2009 *report was not available,	2012, 2013,2014 *2012 and 2013 reports were not	**NO** - there was no change in sediment composition from	**YES** - a general trend towards a DECREASE in grain size	**YES** - a general trend towards a DECREASE in grain size between PRE	**ABUNDANCE** - **NO** - abundance was relatively consistent between PRE (2002) and POST (2014)	**ABUNDANCE** - **NO** - abundance was relatively consistent between PRE (2002) and POST (2014)	**ABUNDANCE** - **NO** - abundance was relatively consistent between PRE (2002) and POST (2014)

			but data was included in 2014 Post construction report, allowing comparison	available, but data was included in 2014 Post construction report, allowing comparison	PRE (2002) to POST (2012) *Year 3 Post-construction Benthic Monitoring Surveys. Figure 10, Page 25*	between PRE (2009) and POST (2012, 2013, 2014) *Year 3 Post-construction Benthic Monitoring Surveys. Section 3.1.3, Page 18* **Significant difference between years*	(2009) and POST (2012, 2013, 2014) *Year 3 Post-construction Benthic Monitoring Surveys. Figure 10, Page 25. See comment* **no significant differences between years*	*Year 3 Post-construction Benthic Monitoring Surveys. Figure 25, Page 48.*	*Year 3 Post-construction Benthic Monitoring Surveys. Figure 25, Page 48.* **no significant difference in community structure between years*	*Year 3 Post-construction Benthic Monitoring Surveys. Figure 25, Page 48.* **significant difference in community structure between years, but small effect*
								TAXON RICHNESS - **YES** - there was a DECREASE in Taxon Richness between PRE (2002) and POST (2012) *Year 3 Post-construction Benthic Monitoring Surveys. Figure 25, Page 48.*	**TAXON RICHNESS** - **NO** - there was no consistent trend between PRE (2002) and POST (2012, 2013, 2014) *Year 3 Post-construction Benthic Monitoring Surveys. Figure 25, Page 48.* **no significant difference in community structure between years*	**TAXON RICHNESS** - **NO** - there was a DECREASE followed by general INCREASE towards PRE (2002) levels. *Year 3 Post-construction Benthic Monitoring Surveys. Figure 25, Page 48.* **significant difference in community structure between years, but small effect*
Westermost Rough	Orsted A/S	2015	2013	2015, 2019	**YES** - there was variable change in sediment type from PRE (2013) to POST (2015) *Section 9.1, page 75* *Figure 20, page 76-77*	**NO** - no consistent trend or pattern observed between PRE (2013) and POST (2015, 2019) *Section 9.1, page 89* *Figure 21, page 91-92* **no significant difference between years*	**NO** - no consistent trend or pattern observed between PRE (2013) and POST (2015, 2019) *Section 9.1, page 89* *Figure 21, page 91-92* **no significant difference between years*	**ABUNDANCE** - **NO** - relatively consistent abundance between PRE (2013) and POST (2015) *Section 9.2.1, page 79* *Figure 21, page 80*	**ABUNDANCE** - **NO** - relatively consistent abundance between PRE (2013) and POST (2015, 2019) *Section 9.2.1, page 94* *Figure 22, page 95*	**ABUNDANCE** - **NO** - there was no consistent trend or pattern observed between PRE (2013) and POST (2015, 2019) *Section 9.2.1, page 94* *Figure 22, page 95*
								TAXON RICHNESS - **YES** - there was an INCREASE in taxon richness from PRE (2013) to POST (2015) *Section 10, page 90*	**TAXON RICHNESS** – **YES** - there was a general INCREASE in taxon richness from PRE (2013) to POST (2015, 2019) *Section 10, page 110* **significant difference between years*	**TAXON RICHNESS** - **NO** - there was no consistent trend observed between PRE (2013) and POST (2015, 2019) *Figure 22, page 95*

Annex 1d Project phase and spatial scales for different potential impact pathways associated with offshore wind farms

Understanding and managing these effects requires long-term, regionally coordinated monitoring efforts to assess impacts across relevant ecological scales and over time. Implementing adaptive management practices can help mitigate negative impacts, while integrated planning could potentially optimise the ecological benefits of offshore wind farms in the UK (van Berkel *et al*., 2020).

Project Stage/Activity	Factors to be considered	Potential Effects and Comments
Construction	Introduction of artificial structures	**Local:** Increased habitat complexity through introduction of hard structures/substrates (artificial reef effect); provision of new substrata for species such as gastropods, bivalves, crustaceans, and polychaetes (Wilhelmsson & Malm, 2008; Zupan et al., 2023).
Construction	Sediment disturbance	**Local:** Temporary disturbance from sediment displacement and suspension; recovery within 1.5 to 2 years (SEER, 2022; Coates *et al*., 2015). **Regional:** Changes in turbidity may affect broader sediment dynamics. Opportunistic species like *Spiophanes bombyx* can increase in abundance during construction (Coates *et al*., 2015).
Construction	Sediment composition changes	**Local:** Pre-construction dredging creates sediment plumes, it can shift species dominance to species certain species with quick recovery periods (Coates *et al*., 2015).
Construction	Non-native species colonisation	**Local:** Artificial substrata has the potential to promote non-native species colonisation (barnacles, amphipods, crabs, oysters, limpets) (Sheehy & Vik, 2010; Bulleri & Airoldi, 2005; De Mesel *et al*., 2015). **Regional:** Substrata may act as stepping stones and connect previously isolated populations facilitating further dispersal of non-native species (Bulleri & Airoldi, 2005; Glasby *et al*., 2007; Adams at al., 2014).
Construction	Underwater noise and vibration	**Local:** Pile driving noise up to 200 dB re 1μPa at 300 m from source for 5 m piles. Scallops can exhibit valve closure within 50 m, increasing predation risk (Jézéquel *et al*., 2023). **Regional:** Acoustic disturbance may

		propagate into adjacent marine zones (Zhou *et al.*, 2023).
Construction	Substrate-borne vibrations	**Local:** Potential disruption of feeding and burrowing in bivalves, could impact sediment bioturbation and nutrient cycling (Roberts *et al.*, 2016).
Construction	Chemical contaminants	**Local:** Release of synthetic polymers and hydrocarbons may affect benthic macrofauna (Coates *et al.*, 2015).
Operation	Biofouling and habitat changes	**Local:** Increased species richness and biomass (e.g., *Mytilus edulis*, *Metridium senile*) with biofouling stages from pioneer to climax (Vanagt *et al.*, 2013). **Regional:** Enhanced habitat connectivity between turbine structures (Causon *et al.*, 2018).
Operation	Organic matter accumulation	**Local:** Deposition from biofouling organisms increases Total Organic Carbon (TOC) near monopiles, enriching sediments (Ivanov *et al.*, 2021). **Regional:** Higher trophic levels can be attracted, including fish and scavengers (Draeger *et al.*, 2020).
Operation	Connectivity and dispersal of species	**Local:** Turbines act as stepping stones for species dispersal (Bulleri & Airoldi, 2005; De Mesel *et al.*, 2015). **Regional:** Can promote broader connectivity between benthic populations, including non-native species (Langhamer, 2012).
Operation	Hydrodynamic changes and sediment transport	**Local:** Wake flows increase bed shear stress near monopiles, potentially causing erosion, deposition, and grain redistribution (Nielsen *et al.*, 2010). Turbulence-driven substrate changes around monopiles (Van Landeghem *et al.*, 2023). **Regional:** Altered sediment transport patterns up to hundreds of meters away from source (Austin *et al.*, 2025; Unsworth *et al.*, 2022).
Operation	Organic enrichment	**Local:** Wake flows contribute to organic enrichment, altering benthic habitat structure (Donadi *et al.*, 2015). **Regional:** Redistribution of organic material may impact adjacent seabed areas (Ivanov *et al.*, 2021).
Operation	Electromagnetic fields (EMFs)	**Local:** Influences movement and feeding in benthic species. Lab studies found larval development impacts in *Cancer pagurus* and

		Homarus gammarus, but no significant effect on *Asterias rubens* (Scott *et al*., 2018; Chapman *et al*., 2023).
Operation	Long-term EMF exposure effects	**Local:** Disrupted circadian rhythms and stress responses in crustaceans observed in lab settings (Scott *et al*., 2020). **Regional:** Population-level impacts remain unclear (Boehlert & Gill, 2010).
Operation	Noise and vibration emissions and cumulative impact	**Local:** Turbine noise (80-150 dB re 1µPa) may disturb benthic organisms (Betke *et al*., 2004). **Regional:** Repair-related shipping adds acoustic disturbance (Bailey *et al*., 2014).
Operation	Seabed habitat changes	**Local:** Harmonic vibrations may alter benthic community structures (Betke *et al*., 2004). **Regional:** ECOWind BOWIE and POSEIDON projects study covering wider potential seabed biodiversity impacts.
Operation	Community composition changes	**Local:** Colonisation of artificial substrata by biota due to reduced competition and empty niches (Mineur *et al*., 2012; Airoldi *et al*., 2015). Potentially including non-native species.
Decommissioning	Specific processes not yet defined, but anticipated to encompass range of factors to be considered above. In particular, those for Construction. Habitat loss and removal of benthic communities if infrastructure is removed.	Encompassed by information provided above

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