A review of benthic ecological surveying for marine renewable developments in Scottish waters

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Acronyms

Acronym	Meaning
AG	After-Gradient
AC	Alternating Current
AI	Artificial Intelligence
ARIS	Adaptive Resolution Imaging Sonar
AUV	Autonomous Underwater Vehicle
BACI	Before-After-Control-Impact
BAG	Before-After-Gradient
BIIGLE	BioImage, Graphical Labelling and Exploration
BRUV	Baited Remote Underwater Video
BSH	Broadscale Habitat
CES	Crown Estate Scotland
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CNN	Convolutional Neural Networks
DC	Direct Current
DDC	Drop-Down Camera
DDV	Drop-Down Video
DsCI	Distance-Stratified Control Impact
DS BACI	Distance-Stratified BACI
DTM	Digital Terrain Model

Acronym	Meaning
eDNA	Environmental Deoxyribonucleic Acid
EFH	Essential Fish Habitats
EIA	Environmental Impact Assessment
EMEC	European Marine Energy Centre
EMF	Electromagnetic Field
EMODnet	European Marine Observation and Data Network
ENM	Ecological Niche Modelling
EPS	European Protected Species
EU	European Union
EUNIS	European Nature Information System
FeAST	Feature Activity Sensitivity Tool
GES	Good Environmental Status
GeMS	Geodatabase of Marine Features adjacent to Scotland
GIS	Geographical Information Systems
GPS	Global Positioning System
GW	Gigawatt
ha	Hectare
H-AUV	Hybrid Autonomous Underwater Vehicles
HRA	Habitats Regulations Assessment
HSM	Habitat Suitability Modelling

Acronym	Meaning
ID	Identification
IHO	International Hydrographic Organisation
INNS	Invasive Non-Native Species
INTOG	Innovation and Targeted Oil and Gas
JNCC	Joint Nature Conservation Committee
LAT	Lowest Astronomical Tide
kW	kilowatt
MarESA	Marine Evidence based Sensitivity Assessment
MarLIN	Marine Life Information Network
MaxN	Mean Relative Abundance
MBBS	Multi Beam Backscatter
MBES	Multi Beam Echosounder
MD	Marine Directorate
MD-LOT	Marine Directorate Licensing Operations Team
MEDIN	Marine Environmental Data and Information Network
MESH	Mapping European Seabed Habitats
MHC	Marine Habitat Classification
MLWS	Mean Low Water Springs
MNCR	Marine Nature Conservation Review
MP	Megapixels

Acronym	Meaning
MPA	Marine Protected Area
MRE	Marine Renewable Energy
MRED	Marine Renewable Energy Development
MW	MegaWatt
NBN Scotland	National Biodiversity Network Atlas Scotland
NCMPA	Nature Conservation Marine Protected Areas
NE	Natural England
NGO	Non-Governmental Organisation
NM	Nautical Miles
NMBAQC	NE Atlantic Biological Analytical Quality Control
NMP	National Marine Plan
NMPi	The Marine Scotland National Marine Plan Interactive
NPF4	National Marine Planning Framework 4
NRW	Natural Resource Wales
OGUK	Oil and Gas UK
OSPAR	Oslo and Paris Convention for the Protection of the Marine Environment of the North-East Atlantic
OPRED	Offshore Petroleum Regulator for Environment and Decommissioning
O&G	Oil and Gas
OWF	Offshore Wind Farm

Acronym	Meaning
OWIP	Offshore Wind Environmental Improvement Package
PEMP	Project Environmental Monitoring Plan
POSEIDON	Planning Offshore Wind Strategic Environmental Impact Decisions
PMF	Priority Marine Feature
PSA	Particle Size Analysis
PSD	Particle Size Distribution
PUF	Polyurethane Foam
QC	Quality Control
QGIS	Quantum Geographical Information Systems
RHIBs	Rigid Hull Inflatable Boats
ROV	Remotely Operated Vehicle
RSMP	Regional Seabed Monitoring Programme
SACs	Special Areas of Conservation
SBES	Single Beam Echosounder
SBP	Sub Bottom Profiling
SCM	Strategic Compensatory Measures
ScotMER	Scottish Marine Energy Research
SCUBA	Self-Contained Underwater Breathing Apparatus
SDM	Species Distribution Modelling
SMA2020	Scotland's Marine Assessments 2020

Acronym	Meaning
SNCB	Statutory Nature Conservation Bodies
SPA	Special Protection Areas
SPI	Sediment Profile Imaging
SSS	Side-Scan Sonar
SSSI	Sites of Special Scientific Interest
TOC	Total Organic Carbon
UAV	Uncrewed Aerial Vehicle
UKCS	United Kingdom Continental Shelf
UKOOA	UK Offshore Operators Association
USV	Uncrewed Surface Vehicle
VIAME	Video and Image Analytics for Marine Environments
VMS	Vessel Monitoring System
3D	Three-Dimensional

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Executive Summary

The pace of development in the offshore wind, wave, and tidal sectors in Scotland, referred to here as Marine Renewable Energy (MRE), has increased significantly recently. This is especially the case in the offshore wind sector with the ScotWind and Innovation and Targeted Oil and Gas (INTOG) leasing rounds now completed. Development in this sector is likely to continue to progress to meet Scottish and wider UK decarbonisation targets.

A variety of environmental assessments are needed as part of the MRE development process. Characterising the intertidal and seabed features within development areas is key to establish a baseline and can be useful during and post-construction to monitor any potential changes arising from development activity.

Scotland has a rich marine geodiversity and biodiversity that are intrinsically linked to the unique physical characteristics and processes that occur within the marine environment. These features and patterns have some similarities to the other parts of the UK but can also be distinctly different. The equipment and methods employed elsewhere for intertidal and seabed ecology surveys are therefore not necessarily suitable for the inshore and offshore waters around Scotland.

The Scottish Government aims to ensure that planning and consenting decisions are informed by sound evidence and makes reasonable efforts to address any gaps in knowledge in line with the National Marine Plan (Scottish Government, 2015). This report, commissioned by the Scottish Marine Energy Research (ScotMER) programme, provides a detailed appraisal of possible intertidal and seabed ecology surveying options. It also provides recommendations on planning and executing seabed ecology surveys for the characterisation and monitoring of Marine Renewable Energy Developments (MREDs) at each stage of activity.

At the heart of the project outputs is a tabular “tool, technology and technique evaluation matrix”, which is presented as an Appendix to the main report. This Evaluation Matrix and supporting commentary in the report provides users with a comprehensive option evaluation toolkit. The toolkit can be used to identify the technical solutions best suited for surveying benthic ecology features in the context of specific MRED project needs within Scottish waters.

The report evaluates the key issues and decisions linked to applying these tool, technology and technique options within an overall seabed survey planning and delivery framework.

The report highlights that:

- Topography, bathymetry, geophysical and geotechnical techniques can give initial insights about the type and extent of habitats likely to be present.
- Visual tools of skilled eye appraisal, video and photographs can provide confirmatory evidence of the key macro indicator species that are present and of the status of colonising communities. Repeated visual monitoring can give cost-effective information on community types, their distribution, abundance and dynamic trends.
- Physical samples recovered from the seabed provide tangible evidence of some of the smaller, cryptic and buried species present and more details regarding abundance, size, age structure, reproductive state. Such samples can also be used to characterise detailed physical and chemical conditions, as well as obtaining genetic material from environmental DNA (eDNA), for example.
- Increased intensity of sampling in terms of sample replication or more regular undertaking of surveys over time often gives a more comprehensive insight into the details of seabed ecosystem characteristics and dynamics.

Some of the underpinning principles applied to this evaluation of options for surveying tools, technologies and techniques, as well as survey strategy and design, were:

- Consideration of surveying approaches and strategies that are best aligned with the project type and purpose.
- The right survey method and level of sampling effort needs to be found to deal with the prevailing local conditions, and to help resolve key topics of concern and uncertainty.
- Anticipated sensitivity potential and likely project complexity can be determined from existing information. An appropriate level of survey intensity for a intertidal/seabed survey design can then be based upon these factors.
- The importance of taking into account any cumulative influences that may arise from nearby or co-located activities.
- The need to understand existing pressures on ecosystems, levels of natural change and the merits of suitable control stations to be incorporated into monitoring strategies.

Taking all these factors into account, an overall intertidal and seabed survey framework is presented based upon the level at which community details need to be described. The framework recognises and describes three levels of survey intensity: standard; enhanced; and comprehensive. The appropriate level of intensity is designed to be applied to each project element based upon location-specific sensitivity and complexity. This means that different intensities of surveying may be appropriate for different parts of a project's layout.

The approach and methods required to deliver such levels of survey intensity also vary. For 'standard' intensity surveys, for example, there is a greater reliance upon descriptions of physical habitats and key indicator species which can be easily seen in video footage; for 'enhanced' intensity surveys there is a greater emphasis placed upon the gathering of still photographs and physical samples from seabed grab devices; and for 'comprehensive' intensity surveys, there is even greater emphasis upon physical sampling and likely increased sample replication.

A key aim of this study has been to establish a staged process to help guide project developers, survey practitioners, regulators and advisors towards a consensual understanding of what might be an appropriate intertidal and seabed ecology survey strategy for a given set of circumstances. Consequently, a table of key actions to be followed when planning and executing any seabed survey has been prepared and is included (see Table 8.1). Within this table and other supporting materials there has been a strong focus upon generating the level of information required to undertake assessments involved in licensing and consenting applications at each project development stage. There is then an option to expand and extend that work scope as appropriate for added value.

This guidance is intended to be used to make recommendations for best practice only.

1 Introduction

1.1 Background

The pace of development in the offshore wind, wave, and tidal sectors in Scotland, referred to here as Marine Renewable Energy (MRE), has increased significantly in recent years. This is especially the case in the offshore wind sector with the ScotWind and Innovation and Targeted Oil and Gas (INTOG) leasing rounds now completed. This increased development activity is likely to continue to meet Scottish and wider UK decarbonisation targets. The Scottish Government's policy is to ensure that planning and consenting decisions are informed by sound evidence and make reasonable efforts to address any gaps in knowledge in line with the National Marine Plan (Scottish Government, 2015). This has led the Scottish Marine Energy Research (ScotMER) programme to commission a review of benthic baseline and monitoring survey tools, techniques and designs, in the context of marine and offshore renewables, and to provide recommendations for such surveying in Scottish waters.

Consequently, this report provides a detailed appraisal of possible seabed ecology surveying options. It also recommends how best to plan seabed ecology surveys for the overall sequence of characterisation and monitoring activities at each stage of Marine Renewable Energy Developments (MREDs). These recommendations are supported by descriptions and examples of good practice and tools which can be applied. The rational as to why these approaches have been adopted and showcased is also given.

Scotland has a rich marine geodiversity and biodiversity that are intrinsically linked to the unique physical characteristics and processes that occur within the marine environment. These features and patterns have some similarities to the other parts of the UK but are also distinctive and, in several cases, are quite different. The equipment and methods employed elsewhere are therefore not necessarily suitable for the inshore and offshore waters around Scotland.

To date there has been less offshore wind development around Scotland than elsewhere in the UK. Conversely, although at much smaller scale, there has been more wave and tidal development in Scotland. This situation is however rapidly changing, particularly for offshore wind, with the ScotWind and INTOG leasing rounds meaning an expansion of future offshore wind capacity in Scottish waters. Offshore wind has therefore already become the dominant MRE activity and will likely continue as the leading sector over the coming decades.

As this development process takes place much will be learned, further experience gained, and ambient conditions may will change. Consequently, the key issues of today may be different to those of the future. In addition, as well as the new, innovative techniques for monitoring benthic species and habitats that have recently become available, more new techniques may be developed in the future. Regular reviews of the recommendations and guidance provided will be necessary to ensure that the approaches remain appropriate and fit for purpose.

This guidance is intended to be used to make recommendations for best practice only.

1.2 Aims and objectives

The overarching goal of this report is to review possible seabed ecology surveying options and to recommend a standard approach to benthic monitoring at MRE sites in Scotland. This work will help ensure that benthic environmental assessments for planned and future offshore wind, wave and tidal developments, as well as linked infrastructure, can be based on agreed principles and recommendations using the best available evidence. This will be applicable to all stages and sectors of MREDs and is designed to be effective and adaptive to the diversity and uniqueness of Scotland's marine waters.

The specific objectives of this work were:

- To review existing benthic ecological survey guidance, peer reviewed literature, grey literature and survey techniques currently employed at MRE sites in the UK and internationally.
- To review and assess new and emerging survey technologies and analytical techniques that could be applied to MREDs, including an assessment of relative costs, limitations, data quality, survey efficiencies and logistics.
- To provide recommendations for scientifically robust, cost-effective monitoring approaches with appropriate powers to detect change.

The findings from these investigations were then considered in the context of certain specific priority surveying objectives to provide an assessment of the most effective methods and sampling designs to meet the different requirements. The priority surveying objectives addressed were:

- Determining the extent, distribution and condition of benthic species and habitats;
- Monitoring changes in diversity and community composition over time at different spatial scales;
- Measuring potential habitat recovery and enhancement at different stages of MRE development;

- Quantifying potential habitat enrichment from enhanced biomass growth on hard structures;
- Identifying metrics and strategies to combine approaches and address multiple objectives; and
- To identify opportunities for such approaches to contribute towards predictive habitat models and demonstrate how these can be applied to case studies in Scottish waters.

1.3 Approach

The approach taken in this study is set out below. There were three main stages: context and scoping; cataloguing; and strategic planning recommendations (See Figure 1.1).

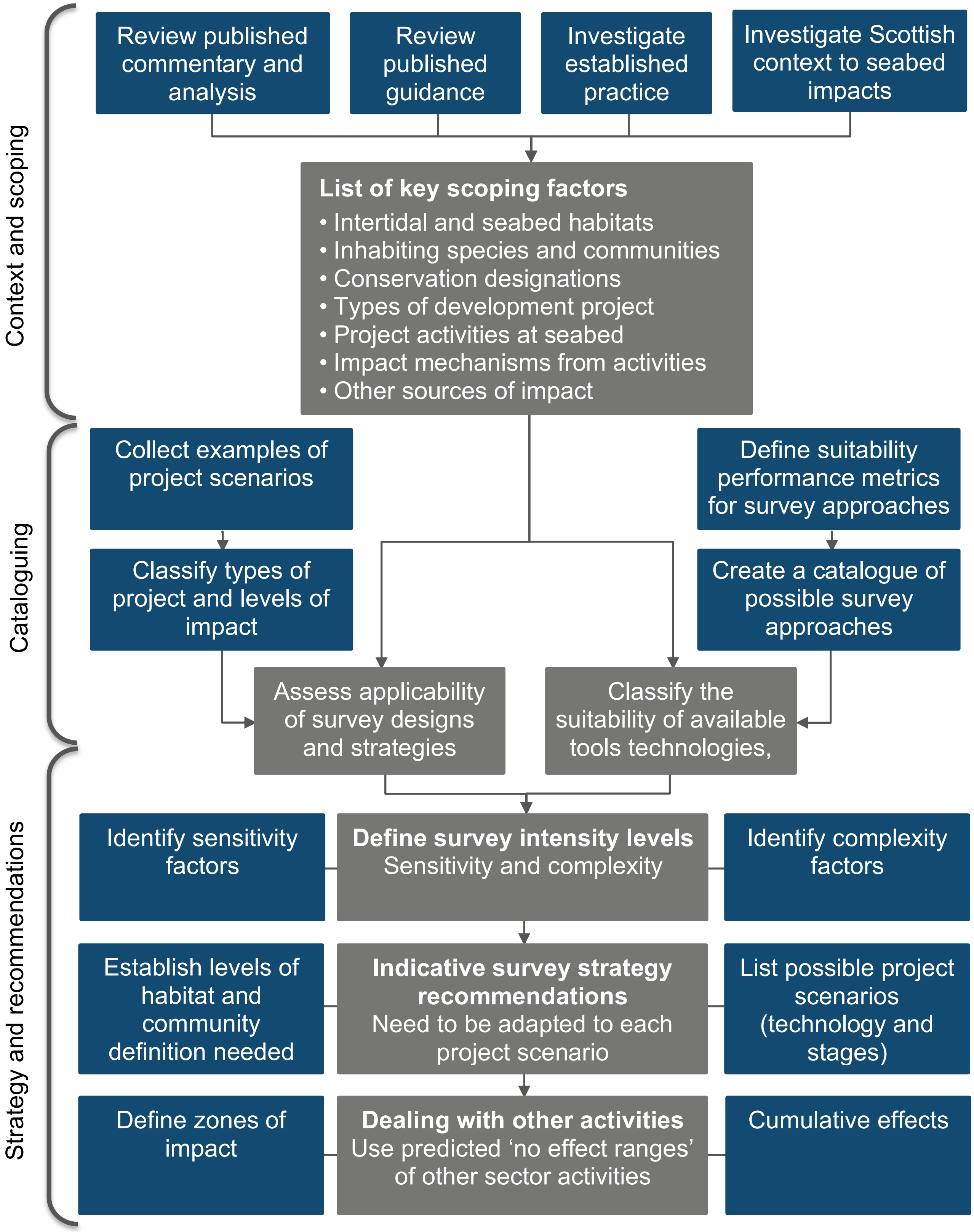
The context and scoping stage considered the key factors that could influence the planning and execution of seabed ecological survey work. The key context factors were the distinctive Scottish marine conditions, established practices and experience as well as published guidance and other literature. The key scoping factors included specification of the development, potential impacts, habitat presence and sensitivity, and the operational context.

The cataloguing stage consisted of two main streams. The first was associated with the various sampling tools, techniques and methods that can be applied to ecological surveying of the seabed. The second was associated with the characteristics of the different project activities.

The aim of the strategy planning and recommendations stage was to bring the scoping and cataloguing information together at both strategic and project-specific levels, creating an overall framework within which to decide upon the most appropriate surveying approach. The project-specific level considered how the various surveying tools and techniques could be collated into a coherent plan, which could be followed through each stage of the project lifecycle. These approaches generated a high-level set of recommendations about how to plan and implement a programme of seabed ecology surveys for MREDs.

In addition to the above, stakeholder engagement was employed to collate the views of developers, researchers, and Statutory Nature Conservation Bodies (SNCB).

Figure 1.1 Overview of the process followed during this study of intertidal and seabed ecology surveying tools and techniques appropriate for MREDs in Scottish waters. This shows the key context and scoping factors which feed into the assessment of applicability and suitability, along with examples of project scenarios and performance metrics. This then feeds into a definition of intensity levels and links to survey strategy recommendations as well as having to deal with nearby activities.



2 Scope of marine renewable energy developments (MREDs)

2.1 Current status of Marine Renewable Energy Developments in Scottish waters

Most of the activity related to MREDs in Scottish waters has been from offshore wind developments, starting with the Robin Rigg offshore wind farm in the Solway Firth, followed by a progressive build-out of offshore wind capacity in the Moray Firth and off the Aberdeenshire and Angus coasts. Existing offshore wind lease options will lead to further growth of the sector around eastern and northern Scotland as well as the Northern Isles and Outer Hebrides. There are generally two scales of offshore wind development: smaller scale demonstration projects of up to and around 100 Megawatt (MW) and large commercial scale Gigawatt (GW) projects. An Environmental Impact Assessment (EIA), backed by appropriate baseline characterisation, is required to accompany a licence application for all types of offshore wind development (Scottish Government, 2015, 2018, 2020, 2021).

In comparison to offshore wind, there has been less activity associated with wave and tidal energy, however, there has been extensive testing of technology in Orkney with European Marine Energy Centre (EMEC) test sites at Billia Croo, Scapa Flow, The String and the Fall of Warness. Demonstration scale deployments have been established in Bluemull Sound, Shetland, and south of Stroma in the Pentland Firth. Individual technologies have been installed for short term testing at a variety of other locations in Shetland, off Orkney, in the inner Moray Firth and down the west coast at the Falls of Lora, Islay and in the Corran Narrows. Tidal energy generation currently is most likely with small-scale projects (<10MW; 5-20 turbines) but there may be larger scale (~100 MW; 50-200 turbines) developments as operational confidence grows. The next technology deployment steps for wave energy will probably be single devices and small array deployments (<10 MW; 20 devices) associated with established test sites, or for specific niche markets such as powering remote offshore facilities.

Each form of renewable energy generation, outlined above, will also need to export the energy generated. This may involve an offshore substation and/or an energy conversion plant (e.g., electricity to hydrogen) and the export of energy is most likely to be achieved as electricity through an export cable. This may be alternating current (AC) electricity over shorter distances and direct current (DC) electricity where distances to the nearest onshore sub-station and associated grid connection point are greater. There may also be circumstances where the energy generated offshore is converted offshore into a liquid or gaseous energy carrier, such as hydrogen or ammonia, and then shipped by pipeline to shore.

Where cables or pipelines are used there are also seabed protection mechanisms that may need to be applied. These include covering with concrete mattresses, covering with placed rock materials, trenching with or without backfill, or direct slit burial into the seabed.

At the coastal landfall site, another set of protection mechanisms can be used such as beach burial on sandy and muddy shores through trenching and backfill, shoreline crossing with clam shell steel covers or concrete cover protection, or directional drilling under the shore.

The purpose of any MRED proposal, whether it be testing, demonstration or full commercial activity, will influence the scale and duration of development activity and therefore the extent, duration and intensity of any potential impacts arising. The novelty of the development in terms of technology or location will also influence the likelihood of there being existing data and understanding about possible impacts. These factors will collectively influence the type and intensity of seabed ecology survey needed.

2.2 Stages of MRE project development, locations and impact extent

A key consideration when developing a suitable surveying strategy is the specific stage of development and how surveying needs may alter through the lifetime of a project. The key stages of a project relevant to benthic surveying are site characterisation, pre-construction, post-construction/operational and decommissioning. Further detail on the aims and considerations at each stage are provided in section 4.5.1.

Wind, wave, and tidal energy developments and their associated energy export infrastructure can spread from a few kilometres (km) to over 100 km and can extend from the intertidal, to the nearshore (<12 nautical miles (NM)) and offshore (>12 NM) areas out to the continental shelf edge. Across these areas, MREDs are likely to intersect a diverse array of seabed habitats and associated communities of species so that any surveying strategy approach may require an appropriate variety of sampling and analysis tools.

Potential direct effects on intertidal and seabed habitats could manifest within a few metres to tens of metres from the devices and infrastructure with indirect effects going beyond this. To be able to examine such issues, close proximity and high accuracy of benthic ecology sampling methods are likely to be key factors underpinning survey success.

3 Review of seabed and intertidal biological survey approaches

3.1 Introduction

3.1.1 Scope of benthic survey activities to be considered

Benthic surveying, in the context of MREDs, includes the collection of geophysical/ geotechnical (remote sensing), biological, physical, and chemical information. This is conducted throughout the lifespan of a development, from pre-development (characterisation) to the monitoring stages (pre/post-construction/operation), and decommissioning.

The data gathered and information generated about the types and status of the seabed communities can inform key site and route selection decisions and determine the suitability of a proposed plan of works for licensing purposes. The data can also help a developer report potential effects with regard to licence conditions.

The tools, technologies, and techniques employed for the purpose of surveying benthic habitats and species are diverse and vary from traditional and widely used to novel and emerging. Traditional methods such as grab sampling typically provide a strong evidence-based methodology that conforms to industry standards for application across diverse marine sectors. Over time, traditional methods may be replaced by those that are new or innovative which may currently be limited in operational and industrial application, but could provide wider benefits (i.e. refined approaches, reduced costs, low environmental impact etc.).

There may be additional factors to consider that influence the survey method selection process, for example survey and data continuity, availability and cost of equipment or site-specific conditions. The chosen tools, technologies and techniques must be effective at acquiring the required benthic data to fulfil the survey objectives, however, they should also be appropriate for use in Scottish waters, the sector, development stage, and local environmental conditions.

Four stages are examined within the following sections of the report:

- Section 3 describes the range of sampling platforms, sample gathering tools, technologies and techniques, the forms of analysis applied to the samples and the types of data applications, as well as uses and forms of presentation that may be applied to the data created.

- Section 4 presents a series of key considerations that need to be taken into account when planning an individual survey or a survey campaign over a number of locations or years.
- Section 5 describes the systematic analysis and comparison carried out on these candidate tools, technologies and techniques which is presented in full as an Evaluation Matrix in Appendix 1.
- Section 6 distils these comprehensive findings into a set of more descriptive pros and cons associated with the various tools, technologies and techniques.

Benthic sampling tools, technologies, and analytical techniques are summarised in Section 3.2 and critically analysed and compared within Appendix 1. Geotechnical data acquisition is included within Section 2 for completeness since it can help inform certain questions from a seabed ecology perspective. However, it is not discussed further within this report as its application relates more specifically to engineering aspects of MREDs.

3.1.2 Structure of seabed surveying tools, techniques and technologies adopted for this study

There are five key elements of benthic data acquisition that are applicable to the MRE sector:

- Existing data: Making full use of existing bathymetric, geological, hydrographic and ecological data to best understand the likely prevailing conditions in an area.
- Geophysical/geotechnical remote sensing: The collection of acoustic data and sub-surface sampling of the seabed.
- Biological: The collection of biological information relating to species, habitats, and biotopes.
- Physical: The collection of sediments to determine physical and morphological characteristics.
- Chemical: The collection of sediment and water samples to determine chemical composition.

For these five elements, the types of samples that can be collected and how they can be analysed and/or reported over a project cycle are presented in Table 3.1.

Table 3.1 Summary of main surveying categories and associated attributes linked to gathering existing data, gathering new data and gathering example/ representative specimens and materials

Category: Biological, chemical, physical
Main application: Gathering existing data

Criteria	Associated attributes
What type of material gathered	• Raw data, maps, photos, video, reports. • Stored samples and specimens. • Experience and local knowledge.
Tools used	• Previously published literature and data. • Data published within EIAs and other consenting documents. • Privately held data archives – consultancy, survey companies and NGOs. • Publicly held archives – regulators, agencies and national laboratories. • Other sector interests – fishing organisations, oil and gas companies. • GIS and other mapping/spatial analysis software. • Experienced marine science/activity experts familiar with specific locations of interest.
How is the material analysed	• Desk-based subject matter expert appraisal to establish understanding of present conditions, issues as well as past/future trends. • Data atlas. • Constraint and opportunity mapping.
How the data is reported	• Preliminary descriptions of features and condition. • Interpretive mapping. • Option evaluation, site and route selection processes and reports. • As appropriate in EIA, Habitats Regulations Assessments (HRA) reports and to inform any Project Environmental Monitoring Plan (PEMP).

Category: Geophysical
Main application: Gathering geophysical/geotechnical data

Criteria	Associated attributes
What type of material gathered	• Point water depths. • Swath water depths. • Surface texture. • Surface reflectivity. • Sediment and rock profiling.
Tools used	• Echo sounder, side-scan sonar, acoustic camera, magnetometer, sub bottom profiler, EMF detector.
How is the material analysed	• Bathymetry. • Large scale topography. • Surficial habitat description. • Subsea infrastructure catalogue. • Areas of disturbance.
How the data is reported	• Updated, improved, higher level details in reports/maps. • More definitive impact assessment and analysis. • Baseline and monitoring reports. • Data for sectoral/regional databases. • As appropriate in EIA, Habitats Regulations Assessments (HRA) reports and to inform any Project Environmental Monitoring Plan (PEMP).

Category: Physical
Main application: Gathering visual imagery

Criteria	Associated attributes
What type of material gathered	• Physical seabed description. • Topographical description. • Physical process understanding.
Tools used	• ROV. • Laser profiling.

How is the material analysed	• Visual interpretation. • Habitat classification at MHC/EUNIS Level 2/3. • Narrative description. • Photogrammetry.
How the data is reported	• Habitat mapping. • Habitat modelling. • As appropriate in EIA, Habitats Regulations Assessments (HRA) reports and to inform any Project Environmental Monitoring Plan (PEMP).

Category: Biological
Main application: Gathering visual imagery

Criteria	Associated attributes
What type of material gathered	• Seaweeds. • Mobile fauna. • Epifauna. • Surface signs of infauna. • Movement and behaviour. • Sediment profiling.
Tools used	• Drop camera. • ROV (tethered remote vehicle), autonomous underwater vehicle (AUV). • unmanned seabed vehicle (USV). • Manned submersible. • Baited video/photo trap (BRUV). • 360-degree camera. • Skilled eye assessment.
How is the material analysed	• Species identification. • Community classification at MHC/EUNIS Level 4/5. • Specimen counting. Abundance estimation. • Cover estimation. • Narrative description. • Photogrammetry.

How the data is reported	• Community indices (biomass, diversity, richness, similarity). • Determining change (indicator species, population change modelling, carrying capacity). • Mapping features of conservation interest. • As appropriate in EIA, Habitats Regulations Assessments (HRA) reports and to inform any Project Environmental Monitoring Plan (PEMP).

Category: Biological
Main application: Biological species/specimen sampling

Criteria	Associated attributes
What type of material gathered	• Seaweed specimens. • Mobile fauna specimens. • Epifauna and infauna specimens.
Tools used	• Grab. • Corer. • Trawl net. • Dredge. • Colonisation plate. • Trap.
How is the material analysed	• Key species identification. • Biomass. • Epifaunal. Taxonomic analysis. • Infaunal taxonomic analysis. • eDNA. • Habitat/community classification at MNCR/EUNIS Level 5/6.
How the data is reported	• Detailed community characterisation to MHC/EUNIS levels 5 and 6. • Species specific impact assessment. • Species population modelling. • Monitoring for introduction of non-native species.

	• As appropriate in EIA, Habitats Regulations Assessments (HRA) reports and to inform any Project Environmental Monitoring Plan (PEMP).

Category: Chemical
Main application: Sediment, rock, water, material sampling

Criteria	Associated attributes
What type of material gathered	• Sediment. • Interstitial water. • Organisms.
Tools used	• Grab, corer.
How is the material analysed	• Organic carbon. • Oxygen levels. • Organic materials. • Hydrocarbons. • Heavy metals. • Persistent compounds. Mineral composition.
How the data is reported	• Establishing REDOX status. • Establishing levels of any organic enrichment. • Determining contaminant levels in sediments and tissues. • Identifying possible impacting compounds. • Determining background levels of metals and minerals. • As appropriate in EIA, Habitats Regulations Assessments (HRA) reports and to inform any Project Environmental Monitoring Plan (PEMP).

Category: Geophysical
Main application: Geophysical/geotechnical material sampling

Criteria	Associated attributes
What type of material gathered	• Sediment. • Rocks.

Tools used	• Grab. • Corer. • Penetrometer.
How is the material analysed	• Particle size analysis (PSA). • Carbonate origin. • Geotechnical properties.
How the data is reported	• Sediment characterisation. • Geology characterisation. • Understanding habitat origins, stability and prospects. • As appropriate in EIA, Habitats Regulations Assessments (HRA) reports and to inform any Project Environmental Monitoring Plan (PEMP).

3.2 Review of seabed and intertidal sampling tools, technologies, and techniques

This section provides an overview of benthic sampling tools, technologies, and analytical techniques and their applicability for wind, wave, and tidal energy developments (MREDs). The first step consists of a review of the various platforms from which sample gathering activities are undertaken. This is followed by a review of the sample gathering approaches that can be used from these platforms. The final part of this section considers how the gathered samples might be analysed to create datasets and briefly considers how these data may be used and presented.

3.2.1 Types of sampling platform that can be used

Direct surveyor observation and specimen/sample collection

Cable landfall locations vary in complexity (from sand to rocky shore) and accessibility (easy access to remote). Walkover surveys are a common and inexpensive method of collecting intertidal data across MRED cable landfalls whereby a survey team is deployed on-foot with a Global Positioning System (GPS) to ground-truth the habitats/biotopes and species throughout a survey area. This can include the collection of samples using hand cores and quadrats. Walkovers are suitable for small scale surveys and rocky shores. A minimum of two persons per team is required for health and safety reasons. Data can be hand-written or logged digitally using in-field mapping software. Walkovers can provide wider site detail and precise biotope mapping and identification whilst causing low disturbance to sensitive animals and habitats.

There are safety implications to consider, as well as assessing if the size of the site and coverage can be achievable during a tidal ebb. Further, GPS accuracy and the battery life of electronic equipment needs to be carefully considered in remote and enclosed areas. Intertidal surveys are typically performed as walkover surveys, however, hovercrafts can be deployed for covering larger distances to collect hand cores and quadrats. Hovercrafts enable safe and efficient sampling over difficult and often vast and inaccessible intertidal terrain such as estuaries and mudflats where the tide can flood quickly. In remote locations, local knowledge may need to be sought to identify how best to approach a site (i.e., by land or sea).

Commercial diving teams using Self-Contained Underwater Breathing Apparatus (SCUBA) can be utilised to collect benthic data in shallow (<30 m) waters; however, SCUBA surveys are not a common approach in operational MREDs in the UK. Benthic surveys within wind developments typically occur deeper than recreational diving depths (>30 m) and alternatives for diving deeper incur greater expense. SCUBA is used more frequently in the wave and tidal MRE sectors to conduct photography surveys and epifaunal sample collection in otherwise difficult to sample areas (e.g., EMEC tidal test sites).

Sampling from crewed surface vessels

Crewed vessels are most often utilised to deploy benthic monitoring equipment in the shallow subtidal, nearshore, and offshore. The vessel provides transportation, accommodation and shelter as well as working platform in terms of storage, space and lifting capacity. The vessel is often selected based on the type of survey required, however the size and capacity of the individual vessel can influence the choice of sampling equipment and the methods employed to obtain the required data. Broadly, vessels can be split into two main categories, large offshore vessels (>12 m), and nearshore coastal vessels (<12 m) which include hard boats, Rigid Hull Inflatable Boats (RHIBs) and hovercraft. For MREDs in Scottish waters a combination of vessels may be required. Nearshore vessels must be powerful and nimble enough to withstand and safely navigate the inherent challenging local conditions at wind, wave and tidal development sites and along cable route approaches to shore, to ensure that sampling is effective.

The equipment available on the vessel is also critical. The specifications of winches, cranes, crew skills, deck space, position keeping capacity, accommodation, endurance, speed and motion control may all be important.

Vessel tethered Remotely Operated Vehicles (ROVs) are deployed to collect data during the characterisation, pre-operational, and operational stages of MREDs in UK waters. They are also used during decommissioning of the oil and gas sector which is likely to be cross comparable in methodology.

Sampling from autonomous craft and vehicles

The development and advancements in marine robotics have revolutionised the marine survey industry. Uncrewed vessels, which include all autonomous and semi-autonomous platforms, are now used widely in the global marine sector. As such, several guidelines have been produced for selecting and using uncrewed vessels for the purpose of benthic monitoring (Noble-James et al., 2018). Uncrewed Aerial Vehicles (UAVs) are also used extensively for surveying MREDs.

Uncrewed aerial vehicles

UAVs (more commonly known as drones) are used extensively by the wind farm sector for surveying landfall and potential landfall locations and for identifying sensitive habitats and species. They are not suitable for subtidal surveys in turbid UK waters but have high applicability for Scotland’s shallow subtidal where water depth is shallow with high clarity (Ahmed et al., 2022; Carpenter et al., 2022; Price et al., 2022).

Uncrewed sea surface vessels

The use of Uncrewed Surface Vehicles (USVs) has recently expanded in the wind farm sector. These small, low energy, remotely piloted vessels can conduct a variety of tasks in close proximity to surface and subsea infrastructure without the additional risks associated with larger vessels and tethered equipment.

Autonomous underwater vehicles

Autonomous Underwater Vehicles (AUVs) are most suitable for the characterisation stage of MREDs for surveying over simple seabed topography, or for conducting operational monitoring across export cables. Vertical subsea/subsurface structures that require a complex survey design can present collision risks. This risk is minimised by using a Hybrid AUV (H-AUV). This is an AUV that can be connected via a tether (like an ROV). These adaptations enable greater manoeuvrability than standard ROVs and more stability than AUVs. Local environmental conditions will dictate the suitability of untethered autonomous vessels as strong currents impact stability, with resulting data gaps from equipment moving off course or poor data outputs caused by increased turbulence.

Autonomous seabed vehicles

The surveying needs and capacity of tethered and remote underwater operations are expanding rapidly. Seabed vehicles (both tethered and autonomous) are widely used in marine industry specifically for cable and pipe laying and deep-sea mining. Conducting benthic activities in situ with vehicles that drive across the seabed reduces many of the inherent risks that can impact the collection of data using more traditional approaches (e.g., due to wind, tide, surface/midwater currents). Therefore, the applicability and suitability of seabed vehicles to the MRE sector has become a recent research and development focus, particularly within the tidal sector, where they are being increasingly used to deploy and install moorings at tidal energy sites. It is therefore likely that in the near future seabed vehicles will develop into key tools with wide applicability to the MRE sector, however further research and development is required to understand their effectiveness and suitability for benthic data collection, including direct and indirect impacts to marine habitats and species.

Remote sensing

Satellite and aerial sensing data can be used to help provide information on seabed and intertidal ecology, particularly for intertidal and nearshore habitat characterisation. Visible spectrum photography can show shoreline features and shallow water distribution of rocks and sediments. Radar/lidar type technology can display shoreline topography as a Digital Terrain Model (DTM) creating a DTM dataset. Offshore gravitational pull and sea level detection techniques can be used to map larger scale bathymetric features.

3.3 Methods of data gathering

3.3.1 Making use of existing data

The sources and availability of existing datasets are not a major focus of this present study. However, there are datasets available which can help scope any planned survey effort effectively and successfully. The types of data that can be accessed relevant to seabed ecology include:

- Historical species records,
- Navigational chart data – depth, seabed features, sediment type,
- Nationally held bathymetry – swath bathymetry at varying resolutions (1 m to 50 m),
- Geological information and geophysical data – sediment classification and distribution, rock types, bedforms, rocky reef structures (e.g., moraines),
- Previously gathered seabed photos and videos,
- Hydrographic information (currents, wave action, mixing zones, water chemistry),
- Fisheries data (e.g., spawning grounds, feeding areas),
- Species and habitat records and extent information including features of conservation interest,
- Data supporting previous project development in an area (baseline and monitoring surveys), and
- Previous research (widespread subject matter and sources).

3.3.2 Bathymetry and geophysical data gathering

Geophysical surveys (also referred to as acoustic approaches) can include a combination of: Multi Beam Echosounder (MBES), Single Beam Echosounder (SBES), Multi Beam Backscatter (MBBS), Side-Scan Sonar (SSS), Sub Bottom Profiling (SBP) and magnetometer. There is a general requirement that geophysical surveys for the purposes of benthic characterisation and temporal monitoring are designed to meet the International Hydrographic Organisation (IHO) 'Order 1a' standard as per IHO Special Publication S44 (Ed 6.1.0) (IHO, 2022). Key standards and guidance notes for the acquisition and processing of geophysical data for this purpose include Plets, Dix & Bates (2013) and Judd (2012).

The sensors can be hull mounted and vessel towed as well as mounted onto autonomous or semi-autonomous systems. Acoustic equipment can be deployed from a variety of vessel types, nearshore and offshore. In shallow waters (<10 m) USVs mounted with acoustic sensors are generally deemed to be suitable.

Geophysical approaches are widely used during all stages of a development and across all marine sectors to characterise the seabed, detect sub-surface features including man-made objects and obstructions such as wrecks, ordinance, and debris and geomagnetic anomalies within and around an area of influence. Geophysical data is also commonly used to delineate distinct boundaries between differing sediments and seabed features to provide a broad description of the seabed and assign benthic habitat types, it is usually applied in conjunction with traditional ground-truthing methods (e.g., Drop-Down Camera (DDC) and grab sampling).

Acoustic sonar systems coupled with ground-truthing are capable of detecting and distinguishing between fine scale changes and reflective signatures associated with ecological seabed features, that include biogenic reef (*Modiolus modiolus, Mytilus edulis,* and *Sabellaria spinulosa*) (e.g., see Sanderson et al., 2014 for *M. modiolus*), seagrass beds (Greene et al., 2018; Gumusay et al., 2019; MMT, 2021) and maerl beds (De Esteban et al., 2018; Noble-James et al., 2023).

Modes of acquisition have differing scales of influence on the marine environment depending on the sound source, exposure time, frequency, and depth of use. Therefore, the use of geophysical equipment may require licensing for disturbance of European Protected Species (EPS), particularly cetaceans, and basking sharks.

3.3.3 Seabed imagery

Seabed imagery is extensively employed in marine industries, including all MRED sectors. It is collected for multiple purposes, including ground-truthing and delineating habitat features in geophysical surveys, recording species and habitats (particularly those of conservation importance), monitoring collision risks (wave and tidal devices) and investigating potential subsea hazards prior to grab sampling.

Optical imaging systems (including freshwater chambers for use in turbid conditions) vary in style and design, therefore the aims of the survey and the environmental conditions that dominate the site should dictate the type of system used. Operational guidelines developed for remote monitoring of biota (Hitchin, Turner & Verling, 2015) and interpreting seabed imagery (Turner et al., 2016) are widely used and cited by industry but are now largely superseded by the work of the UK's Benthic Imagery Action Plan, (NMBAQC, 2023a) or Big Picture Imagery Analysis Working Group for the NE Atlantic Biological Analytical Quality Control (NMBAQC), and resulting quality assurance guidance (NMBAQC, 2023b).

The benefits of seabed imagery systems are that they are relatively inexpensive compared to other methods and can be adapted to a range of conditions. However, systems can be limited by operational depth, on-site subsea conditions (turbidity and currents) and weather.

ROV or vertical drop system video surveillance surveys are often one of the first on-site checks to be made on a prospective site or cable route in the wave and tidal sectors. This may be followed up by a stills camera survey or more systematic video survey once the habitats present have been confirmed.

Ocean underwater imaging sensors and laser profiling

Recent advances in ultra-high resolution digital imaging systems such as 'CathX' Ocean underwater imaging sensors and laser profiling are increasingly being used within MREDs. For example, in the wind sector, they can be attached to semi-autonomous equipment and used for conducting array and export cable route inspection surveys. They can be used to measure biological and physical impacts such as biofouling, introduction of Invasive Non-Native Species (INNS), habitat loss (e.g., Annex I/Priority Marine Feature (PMF)), scour, sedimentation, and structural integrity. The benefits are the collection of continuous ultra-high resolution imagery that can be used to produce photogrammetric models. Limitations include the overall expense of hiring equipment coupled with the associated platform requirements (Working Class ROV) and costs of hiring a large vessel. Further, large volumes of data are produced that require regular storage and processing. Recent advancements in affordable high-speed satellite internet connectivity have improved data transfer issues. However, there are additional costs associated with the storage and access of big data that may need consideration.

Baited Remote Underwater Video (BRUV)

Baited Remote Underwater Video (BRUVs) are video cameras deployed and left in situ for a determined period of time (soak time). The cameras are baited to attract species towards the camera's field of view. This method promotes a holistic view of species assemblages in situ, particularly fish (including commercial and priority species) and other mobile epibiota that are less likely to be recorded using traditional methods due to their behavioural reaction to disturbance.

BRUVs are commonly used as a benthic survey tool in Scotland by Non-Governmental Organisations (NGOs) involved in habitat restoration and species recovery. BRUVs are not widely deployed within MREDs, however the development and application of BRUVs and BRUV technology in MREDs has been driven forward in recent years through collaboration with researchers at Swansea University, specifically for the benthic characterisation and operational stages of wind developments in the UK (Griffin et al., 2016; Jones et al., 2019). Exclusion zones created by MREDs have the potential to create refuge areas for mobile species which could over time promote a "spillover" effect of species into commercial fishing grounds (Halouani et al., 2020). Deploying BRUVs could therefore enable the collection of data that promotes quantification of the spillover effect. Consideration is needed when planning and executing BRUV surveys to ensure sampling is representative to the life-history stages, feeding, and migratory patterns of mobile species. Survey parameters such a soak time and sampling time require standardisation to factor in the survey bias associated with bait use. Bait selection and preparation also requires careful consideration.

Timelapse and trigger imagery

Timelapse and trigger photography and/or video can also be used with stimulus sources such as light, bait, or sound or around structures to examine behaviour over time. This approach works for macro- and megafauna such as crustaceans, echinoderms, and bottom living/demersal fish. These techniques show movement and use of an area over time and can also be used to record more occasional/sporadic mobile faunal behaviour. Their advantage is that they are more energy and memory efficient than continuous monitoring and recording approaches.

Sediment Profile Imaging (SPI)

Novel and emerging methods used less commonly in MREDs include acoustic cameras and Sediment Profile Imaging (SPI). Acoustic cameras such as Adaptive Resolution Imaging Sonar (ARIS) and Gemini models are mounted on ROVs for the primary purpose of object detection/collision avoidance as they can detect hard features in turbid conditions when camera visibility is poor. They can be pivoted towards the seabed to capture hard sediment features such as bedrock, boulders, and biogenic reef. They have proven to be particularly useful in turbid conditions which are a favoured environmental condition of *S. spinulosa* which form reefs (Annex I biogenic reef) throughout the UK, but mainly the east coast of England and Wales, as well as the Moray to Aberdeenshire coast of Scotland (Pearce & Kimber 2020).

Whilst not widely used within MREDs, acoustic cameras offer an alternative sampling method during operational wind farm seabed remediation surveys and the benthic characterisation stage to confirm the presence and absence of biogenic reef (Griffin et al., 2020). The acoustic signature of the *S. spinulosa* differs from bedrock and stony structures and whilst not tested, this method could potentially be utilised on other biogenic reef habitats such as *M. modiolus, Ostrea edulis,* or *Lithothamnion* sp. to identify whether different biogenic structures present differing acoustic signatures.

SPI is a method for rapid assessment of the quality of seafloor habitats. Identified as a more cost and time efficient method than grab sampling, it works by inserting the flat viewport of a camera into the top 20 cm of seafloor sediments and taking images of the upper sediment structure and sediment/water interface to determine the chemical and biological characteristics of the sediment, including the percentage of oxic and anoxic sediments and presence of bioturbation features. SPI cameras produce both cross-sectional and surface imaging, they consist of a wedge-shaped prism with a Plexiglas faceplate and a back mirror mounted at a 45-degree angle. An internal strobe is used to provide light. The mirror reflects the image of the sediment profile to a digital camera mounted horizontally on top of the prism (NewFields, 2023).

SPI systems can be deployed down to 4000 m and have been widely used for decades to assess the anthropogenic impacts of aquaculture, trawling, sewage effluent and oil spills. They require specialised image analysis and interpretation software in order to measure multiple physical and biological parameters (sediment type/colour, prism penetration depth, grain size, surface boundary roughness, mud clasts, redox potential discontinuity depth, presence of oxygen/methane, presence of benthic organisms, faecal pellets, burrows, surface tubes, feeding mound/voids, infaunal succession stage, organism-sediment index, benthic habitat quality index and INNS).

The benefits of SPI systems include the ability to convey the ecological outputs in an easily understandable format to the end user. Limitations include a smaller field of view compared to other imaging techniques, and images of coarser heterogeneous sediments are less reliable and require more replicates than finer sediments (Smith et al., 2003; Blanpain et al., 2009). Additionally, ‘smearing’ (displacement of oxygen rich sediments to deeper layers) during camera penetration into sediments can result in sediments appearing healthier than they are (Moser et al., 2021). SPI has been trialled in cable routes and wind turbine sites assessments for offshore energy projects in North America to reduce the risks and costs for offshore wind projects. SPI imagery was integrated with plan view imagery and MBES acoustic data (‘forward scouting’) to optimise route selection, provide ground-truthing, and characterise benthic habitats and demonstrated a collaborative approach to cable routing and site characterisation (Carey, Doolittle & Smith, 2019).

3.3.4 Gathering physical seabed samples

Benthic sediments are sampled using a variety of tools to provide data on the physical, biological and chemical condition of the seabed. The type of sampling device selected will depend on the method of deployment (mechanical or by hand), water depth, and the known or predicted composition of the sediment. Sediment samplers come in a variety of sizes depending on how/where they will be deployed and typically collect the top 10 - 20 cm of sediment.

Sediment sampling is widely adopted within wind farm developments for the benthic characterisation and operational monitoring phases and currently adopted less across the wave and tidal industries. The most common and widely used subtidal sediment samplers applied to MREDs are Day Grab, Hamon Grab, Mini-Hamon Grab, Van Veen, Dual Van Veen, and Shipek Grab (Coggan & Birchenough, 2007; Judd, 2012; Bender et al., 2017; Hemery, Mackereth & Tugade, 2022). The main benefit of sediment sampling is the ability to conduct repeat quantitative sampling with high positional accuracy to obtain samples of suitable size for multiple analyses. However, sediment sampling is limited by the on-site subsea conditions (sediment type) and weather (wind/wave action during deployment and recovery).

Sediment cores are often collected during the benthic characterisation stage of wind farm developments to provide an undisturbed sample of sediment. These are commonly collected by mechanical means (e.g., Box Core, Vibrocore), however other methods such as Hand Cores and Push Cores can be collected by SCUBA divers and ROVs (Coggan & Birchenough, 2007; Judd, 2012; Bender, Francisco & Sundberg, 2017; Cochrane, Hemery & Henkel, 2017; Hemery, Mackereth & Tugade, 2022). The limitations of core sampling are the relatively small surface area of sample that can be obtained compared to a grab sampler.

Demersal trawl sampling

Remote sampling of mobile benthic epifauna (mainly fish, shellfish and highly mobile megafaunal species) is traditionally conducted subtidally using benthic trawls to provide quantitative and semi-quantitative estimates of abundance and diversity. There are a diverse variety of trawls used to sample benthic species. The choice of trawl is largely dependent on the nature of the seabed sediments, the environmental considerations of the site, and temporal scale cohesion with local fisheries management.

Recommendations and standards relating to benthic trawl use within MREDs is generally lacking, however, recommendations, considerations, and operating guidelines are available via;

- Mapping European Seabed Habitats (MESH) (Curtis & Coggan, 2006)
- Centre for Environment, Fisheries and Aquaculture Science (Cefas) Regional Seabed Monitoring Programme (RSMP) protocols for sample collection and processing (OneBenthic, 2020)
- Joint Nature Conservation Committee (JNCC) (Noble-James et al., 2018)

Further guidance documents are available in relation to aggregate dredging (Boyd, 2022). The use of benthic trawls poses some inherent impact on the seabed and species (Somerton, 2001; Hiddink et al., 2019; Jac et al., 2022; Noble-James et al., 2023). Additional considerations are required in Scottish waters to minimise bycatch of critically endangered PMFs such as the flapper skate, including its egg cases which are attached to the seabed or encrusting epifauna.

3.4 Methods of data analysis on seabed and intertidal samples

3.4.1 Bathymetry, geophysical and geotechnical analysis

The primary purposes of gathering bathymetry, geophysical and geotechnical data relate to the engineering design process, but this information can also help inform likely seabed habitat type and extent. The key factors that should be discernible from such data include:

- Accurate water depths, seabed slope and roughness/texture
- Defining areas of bedrock, broken rock, cobbles, or areas of sediment
- Defining the depth of sediments
- Identifying any shallow natural gas deposits or seepage/pockmark activity
- Defining the limits of mineralised biogenic reefs
- Defining dynamics of mobile sediment features

Making good use of the resources put into geophysical/geotechnical activities is therefore very useful and important for seabed ecological investigations.

3.4.2 Seabed imagery analysis

Stills and video imagery

Seabed imagery is typically analysed using standardised approaches and recommended guidelines (Jones et al., 2016; Golding et al., 2019; 2021) that align with best practice and Quality Control (QC) procedures (NMBAQC, 2016) and are endorsed by governance frameworks. This includes the use of image annotation techniques which utilise cloud-based annotation platforms such as BioImage, Graphical Labelling and Exploration (BIIGLE) (Langenkämper et al., 2017). Imagery can also be analysed for the purpose of assessing wildlife interactions with equipment operating on the seabed (i.e., subsea turbines) (Hutchison, Secor & Gill, 2020).

BRUVs

BRUV imagery undergoes quantitative analysis using dedicated open-source software such as SeaGIS EventMeasure (SeaGIS, 2023) to conduct fast, efficient analysis of movie sequences. The user can train the software to dynamically analyse recorded events and report on abundance measures such as Mean Relative Abundance (MaxN), cumulative MaxN and mean count (by species and stage). Whilst initial software training can take time, overall, it is a cost-effective method of analysing hours of video footage that requires a non-technically skilled user.

3.4.3 Biological seabed sample analysis

Directly gathered specimens

Samples of seaweed, shoreline and seabed animals including mobile, epifauna and even larger infauna can be gathered by hand, sometimes assisted by hand tools. Such samples can sometimes be inspected, photo recorded, notes and measurements taken and the samples then returned to the environment. In other cases, the specimens may need to be anaesthetised and, if appropriate, preserved in fixative. Then at a suitable time and location they may be photo recorded, measured and then restored or discarded. Where certain chemical analyses or DNA analyses are to be carried out, preservation through freezing or other defined means may be necessary.

Grab and box core sampling for biology

The treatment of a seabed sediment sample for biological analysis is relatively universal but has a number of subsequent analysis pathways that are commonly used. Firstly, the obtained sample may be processed whole or may be sub-sampled using a hand core placed into the intact recovered seabed sample. The resultant sample is then placed onto a suitable mesh size of sieve and seawater used to wash away the finer sediment leaving macrofauna and any stones. The latter may be discarded or retained separately to avoid abrasion of the biological specimens. The biological material will generally be anaesthetised/relaxed and then fixed in preservative for later sorting, identification and workup.

The suite of analytical techniques conducted on benthic grab samples depends on the purpose of sampling and the requirements (for example as part of a development licence). Traditional analytical methods such as infaunal and microbenthic identification and analysis (e.g., abundance and biomass) are widely used by marine industry to provide baseline data on the sediment and species composition. Samples are typically analysed by laboratories that participate in the NE Atlantic Marine Biological Analytical Quality Control (NMBAQC) (note this is not an accreditation) scheme, whereby the methods follow high quality control (QC) standards (Mason, 2022; Worsfold, 2023). The MRE sector has generally adopted these traditional analytical techniques, particularly the wind sector. In the UK the wind sector currently conducts sampling and analysis at the benthic characterisation stage to inform monitoring approaches adopted throughout the operational lifespan of a development and to inform assessment of development impacts, and appraisal of alternative and mitigation options.

eDNA analysis

eDNA sampling is a relatively new method of obtaining presence data on assemblages of species. Analysis of eDNA samples provides presence data on species that may be under-reported if traditional methods are used (e.g., mobile/cryptic/rare/invasive species) or at locations that are logistically difficult to sample (subsea/subsurface marine infrastructure). Samples can be collected from different media (predominantly water/sediment), to record the presence of pelagic, near benthic, and benthic species. For example, Matejusova et al. (2021) demonstrated the use of eDNA analytical techniques from water samples as a cost-effective way to detect the presence of the invasive sea squirt, *Didemnum vexillum*.

Methods of sampling eDNA to inform on the community composition on marine infrastructure have been trialled and compared by Alexander et al. (2023). Trials included ROV scrapes, water samples, a keel crab (underwater drone) scrapes, plankton tows and PUF tows (cylindrical polyurethane foam attached to a funnel). These methods may be of benefit to MRED benthic monitoring, particularly for describing community composition over time.

Other novel methods of eDNA sample collection have recently been researched and trialled using SCUBA divers and platforms of opportunity (BRUV frames) (Cai et al., 2022; Harper et al., 2023; Neave et al., 2023; Neave, Mariani & Meek, 2023). Water eDNA samples often require extensive sampling and filtration which may vary depending on water quality (turbidity/salinity/organic compounds). Sediment eDNA sampling is relatively cost and time efficient as samples can be collected during the standard suite obtained from grab samples and frozen until required. However, it is logistically more difficult to conduct repeat sediment sampling post-construction, i.e. in close proximity to subsea/ subsurface MRE infrastructure.

The persistence of eDNA molecules in the marine environment is relatively short (Collins et al., 2018), degrading rapidly (48 hours) due to many combined abiotic and biotic factors, therefore producing a snapshot of the species assemblages within the sediment/water column at a given point in time. Further, studies have shown that eDNA degrades faster inshore than offshore (Collins et al., 2018). Multi-collection methods may also be required to accurately represent diversity across benthic and epibenthic surfaces, and depths (Koziol et al., 2018; Antich et al., 2020; West et al., 2022; Alexander et al., 2023), increasing survey and analytical costs. eDNA results are heavily influenced by sampling method, substrate and assay selection (Wegleitner et al., 2015; Koziol et al., 2018; Sakata et al., 2020). Therefore, to be effective, a survey design should be driven by knowledge of the target assemblage, habitat and depth (Alexander et al., 2023). Novel field collection methods have only been trialled under a narrow range of environmental conditions, therefore further research is required into the costs and benefits for different eDNA sampling methods in Scottish waters and where used, repeat sampling should ensure consistent collection method(s) are applied when comparing sites or different time points.

Despite its limitations, eDNA is being widely adopted throughout the marine sector. The aquaculture industry has led the development of eDNA research and industry guidance (Jones et al., 2020; NatureMetrics, 2022; Wort et al., 2022; SEPA, 2023). Research conducted by Elliott et al. (2023) identified the usefulness of eDNA within the MRE sector, having completed a comparison study recently between eDNA and traditional techniques for monitoring around wind farms (Elliott et al., 2023). The research focussed on fish ecology; however initial invertebrate results have proved encouraging (Elliott et al., 2023).

Used alone or in conjunction with visual surveys, eDNA can reduce the need for taxonomic expertise and the costs/logistical limitations associated with traditional methods. At inshore MREDs, eDNA water sampling could be co-located with Water Framework Directive (2000/60/EC) sampling stations (if collected) but will likely incur additional sampling requirements and associated time/monetary costs for sampling and analysis by a dedicated laboratory.

3.4.4 Geophysical and chemical sediment sample analysis

Common geophysical parameters derived from benthic samples include sediment composition via Particle Size Distribution (PSD) analysis. Chemical analysis of samples includes contaminant analysis (heavy metal and hydrocarbon concentrations), Total Organic Carbon (TOC), Redox, other water chemistry measures (pH, temperature), and mineral composition.

It is critical that the handling of samples and sub-samples required for multiple purposes does not undermine the integrity of the planned analyses, particularly where the methods employed for one analysis pathway may be contrary to that required for another pathway.

A detailed description of environmental sedimentology and chemistry procedures is beyond the scope of this present study. Suffice to say that it needs to be clear from the outset of survey planning what is envisaged for the end point analyses and appropriate resources and sample capacity need to be made available to:

- ensure an appropriate chain of custody for each sample type
- ensure sufficient representative samples are obtained
- ensure that sufficient replicates are collected for initial analysis and any follow-up verification
- ensure suitable long-term storage of reference samples if needed
- ensure consistent and compatible analyses through laboratory continuity where critical

3.5 Data interpretation, use and presentation of results

3.5.1 Habitat/biotope classification

The combined results of PSD and macrobenthic analyses plus seabed imagery and acoustic data are collectively used to produce standardised hierarchical seabed classifications (i.e. Broadscale Habitats (BSH), or biotopes). In the UK two main habitat classification systems are used – European Nature Information System (EUNIS) and the Marine Habitat Classification for Britain and Ireland (MHC). EUNIS is a Europe-wide classification system whilst the MHC is a UK-wide classification system. The MHC is cross-transferable to the EUNIS system. Guidance on assigning benthic biotopes using both habitat classification systems has been produced by JNCC (Parry, 2019).

3.5.2 Habitat mapping

Habitat classifications assigned from ground-truthed samples are used alongside geophysical acoustic data to delineate boundaries between habitat types to produce digitised maps and spatial datasets of the seabed. The same method is used to identify potential reef areas as it is evident that different geogenic (stony/bedrock) and biogenic reef structures produce differing acoustic signatures (Brown et al., 2011; McGonigle & Collier, 2014; Jenkins et al., 2018; Griffin et al., 2020). Habitat mapping utilises Geographical Information Systems (GIS) software from developers such as ESRI which ranges from free open-source software (e.g. Quantum Geographical Information Systems (QGIS)/Grass) to expensive programs that require licences to use (e.g. ArcGIS/ArcPro). There is freely available guidance online for utilising these software packages. This method can be subjective and influenced by the experience of a habitat mapping specialist and therefore should be contextualised with the relative level of confidence in the data and outputs. Habitat mapping is a widely used and accepted method of producing digitised maps and sharing spatial data.

3.5.3 Predictive habitat modelling

Predictive habitat modelling is a broadscale statistical approach used to predict the likelihood that an area of unknown habitat is similar/dissimilar to an area of known habitat. It utilises data including acoustic (geophysical) sources, physical, and environmental variables coupled with ground-truthed classifications. There are numerous methods available, and no unified approach is adopted. Popular predictive mapping techniques utilise either a supervised (classes are assigned – Maximum Likelihood Classification, Random Forest) or unsupervised (classes are unassigned – Iso Cluster analysis) approach. A pixel or object-based analysis is then performed on the data layers to assign classes. The EU SeaMap 2021 (Vasquez et al., 2021) is an example of a Europe-wide predictive map used widely by marine industry during survey planning/design and monitoring in order to identify the range of habitats likely to occur within the given area. Local-scale predictive maps may be of benefit throughout MREDs to refine broad-scale predictive maps if sufficient data and coverage of ground-truthed habitat is available. The methods of Boswarva et al. (2018) have been used to conduct predictive mapping outputs for MREDs in England, further guidance is also available and the method in general is widely researched and applied (Miller et al., 2017).

3.5.4 Predictive biotope modelling

The predictive power of biotope scale modelling is inherently lower than BSH modelling as the biological information that informs a biotope is not represented visually within acoustic (geophysical) data utilised to produce predictive maps. Species Distribution Modelling (SDM) and Habitat Suitability Modelling (HSM) (also called Ecological Niche Modelling (ENM)) provide alternative methods of capturing species level information. SDM is a similar concept to predictive habitat modelling, whereby specialised statistical software is used (e.g., R/MatLab/ArcMap/ArcPro) to produce a predicted output of a species current distribution utilising occurrence data. Software packages range from open source and free to requiring expensive licences and expertise. HSM/ENM combines observed species data with environmental factors to predict the potential distribution of a species given its suitable habitat within a realised niche (Brown & Griscom, 2022). This is not a widely adopted method in the MRED sectors, however, JNCC have produced a framework that utilises an ensemble modelling approach to predict suitable habitat for *Zostera marina* beds, *M. modiolus* beds and *S. spinulosa* reefs in the UK (Castle et al., 2022).

3.5.5 Novel analytical techniques

Throughout the UK marine sector, novel approaches for recording species assemblages have recently developed from being largely research-based to being increasingly used for commercial application. In MREDs data from eDNA and BRUVs is increasingly being collected and analysed as an alternative to benthic trawl surveys, particularly within the wind sector.

All of the data gathered and analysed needs to be processed, assessed and interpreted. There are a number of tools that can help with this and increasingly these are likely to draw upon AI approaches to make them more effective.

Artificial intelligence and machine learning

Artificial Intelligence (AI) is the intelligence of machines that perform extensive computational tasks and machine learning is the statistical process in which the machine is trained to automate a task, removing the need for human supervision. However, the translation of data into programming scripts and algorithms remains challenging (Blowers et al., 2021). In the marine sector AI and machine learning are used as novel methods of analysing expansive datasets, particularly seabed imagery and video to automatically detect marine life. There are numerous algorithms created that target object and feature detection, the prominent being Neural Networks, which loosely simulate the human brain (Blowers et al., 2021).

An extensive review of the current methods and applications of use was conducted by the Marine Directorate (MD) (Blowers, Evans & McNally, 2020). The leading platforms include Google Object Detection API, Coral Net, BIIGLE, FishTick and Video and Image Analytics for Marine Environments (VIAME). VIAME is a Convolutional Neural Networks (CNN) detector used to produce object detectors, full frame classifiers, image mosaics, rapid model generation, search image and video, and perform stereo measurements. In Scotland it has been applied as a novel method of conducting shellfish stock assessments (Ovchinnikova et al., 2021).

The major limitation of machine learning is the challenge of training a programme to detect and assign the required features automatically. Studies are limited but have shown that the accuracy of detection is dependent on the feature in question with some features (such as burrows) requiring greater processing and annotation steps than others (such as fish or sea pens) (Blowers et al., 2020). Many of the existing platforms are in varying stages of development and require training and expertise to execute.

Substantial training datasets are required which take time to develop, however once developed could act as a resource to facilitate future development. Portals used for standard image annotation such as BIIGLE and VIAME could act as suitable platforms to develop a standardised training dataset, facilitated by imagery data obtained from strategic sampling regimes.

3D Photogrammetric modelling

Three-Dimensional (3D) photogrammetric modelling is a relatively new analytical tool. Its primary use originally was for monitoring damage to tropical coral reefs caused by climate-induced bleaching. In recent years the technique has been utilised in temperate seas and marine industry primarily for monitoring the structural integrity of subsea infrastructure, including the biomass of marine growth in the operational (e.g., cables) and decommissioning stages (e.g., for oil and gas platforms). The process involves the collection of high-quality digital stills of which there is sufficient overlap between imagery (>60 %) to create a mosaic, and the presence of scaling tools. Specialist processing software is required, most commonly Agisoft which ranges from free to expensive depending on requirements and use. 3D photogrammetry can therefore be a relatively low-cost method of visualising habitats and subsurface structures that has global applications. For example, citizen science groups and NGOs can conduct 3D photogrammetry surveys in shallow waters relatively inexpensively using a GoPro and lighting system attached to a hand-held frame. At the opposite end of the scale, 3D photogrammetry can be conducted in deeper and more challenging waters by utilising ROVs mounted with skids that contain multiple cameras and lighting systems.

3D photogrammetry techniques are widely applicable within the MRE sector, methods are under development for modelling the extent and quality of biogenic reef structures on the seabed and subsea infrastructure. Recent advances in geo-referenced photogrammetry aim to incorporate 3D photogrammetry into a bespoke geospatial data portal to improve visualisation and promote effective decision making by government agencies and stakeholder groups.

3.5.6 Overall assessment of analysis options

The analytical techniques discussed here range from traditional and widely used to novel and infrequently applied. The techniques also vary in their suitability and are likely to be required at different stages of a development’s lifespan rather than selected by sector, spatial scale of a development, or site complexity. The likelihood that a particular analytical technique is applied to a given development stage is summarised in Table 3.2.

Likelihood is based on the technique’s current use and applicability to each major stage within the MRE sector and in the case of novel methods the likelihood of it being applied in the future;

Likely = The technique is widely applied and applicable to the specified development stage/a novel technique that will likely be applied.
Possible = The technique is identified as applicable to MRE and the specified development stage but it may not be a requirement.

Unlikely = The technique is identified as applicable to the sector but it is unlikely to be used at the specified development stage.

Table 3.2 Likelihood of analytical techniques being applied within Scottish MREDs at each major development stage.

Analytical Techniques	Benthic Characterisation	Operational	Decommissioning
PSD	Likely	Likely	Likely
Macrobenthic	Likely	Likely	Likely
Physiochemical	Likely	Possible	Likely
Seabed Imagery	Likely	Likely	Likely
eDNA	Likely	Possible	Possible
BRUVs	Possible	Possible	Possible
3D Photogrammetry	Unlikely	Possible	Possible
Laser Profiling	Unlikely	Possible	Possible
BSH Classification	Likely	Possible	Possible
Biotope Classification	Likely	Possible	Possible
Conservation Features Mapping	Likely	Likely	Likely
Habitat/Biotope Mapping	Likely	Unlikely	Likely
Predictive Habitat Mapping	Possible	Unlikely	Unlikely
Species Distribution Modelling	Possible	Unlikely	Unlikely

4 Considerations for planning survey strategies and campaigns

4.1 Existing guidance for benthic survey activity

4.1.1 Background

Benthic sampling regimes (sampling and survey design principles) adopted by MRE developers are commonly determined on a site-by-site basis through discussion between the MRED developer, survey contractors, and advisory bodies, and therefore vary both regionally and internationally. However, to help standardise the process there have been several key guidance documents produced or adopted by the MRE sectors in different parts of the UK.

The seabed surveying recommendations produced by NatureScot (Saunders et al., 2011) are relevant for the Scottish renewables industry, but were not formally published. However, these mainly focus on the wave and tidal sectors, which were considered the most pressing development pressure at that time. With offshore wind now much more to the fore, and with the learning achieved since 2010, these recommendations are regarded as out of date and need to be refreshed.

There have also been seabed survey guidance documents produced for English and Welsh waters as well as internationally, which provide recommendations for surveying benthic ecology traits within MRED areas as well as for other sectoral interests and research (see Boyd, 2002; Ware & Kenny, 2011; Reach et al., 2013a; Oil and Gas UK, 2019). Existing seabed survey guidance documents relevant to MREDs for England and Wales are summarised below as well as other national guidance.

4.1.2 Regional guidance - Wales

Natural Resources Wales (NRW) developed a suite of guidance on methods and approaches for survey and monitoring of benthic marine habitats in 2019 which undergo regular review and updates (latest update was 2021). Its aim is to assist developers in designing and planning benthic marine habitat surveys and monitoring, where this is required for EIA in support of proposed developments and activities in or near Welsh waters. The guidance (Natural Resources Wales, 2023) is split into nine separate documents with an overarching document setting out the main principles and methods which links with a series of guidance notes specific to key benthic habitats. It is based on an extensive review of marine conservation legislation, peer reviewed and grey literature, and provides very detailed recommendations in relation to designing, conducting, and reporting on benthic assessment surveys in general and for included habitats. It draws heavily and builds upon the recommendations of Noble-James et al. (2018) (described in section 4.1.4) in relation to sampling design and statistical analysis.

4.1.3 Regional guidance - England

Natural England (NE) produced a series of documents providing best practice advice on the use of data and evidence to support offshore wind farm development in English waters (Natural England, 2021a, 2021b, 2022a, 2022b). The advice ranges from baseline characterisation surveys and pre-application engagement, through to expectations at application and post-consent monitoring. Whilst they cover all receptors there are chapters focussed specifically on benthic habitats. As with the NRW guidance, it draws heavily on the recommendations of Noble-James et al. (2018).

4.1.4 National guidance – Offshore UK

Noble-James et al. (2018) provide JNCC's best practice guidance for monitoring marine habitats, with a focus on sampling design. Although largely focussed on benthic monitoring of Marine Protected Areas (MPAs), it is applicable to the design of benthic surveys related to MREDs. It sets out a comprehensive framework for survey design and statistical analysis which is widely cited by regulatory authorities and MREDs and forms the basis of much of the key NRW and NE guidance.

In 2019 Oil and Gas UK (OGUK) produced guidance which provided an overview of the different categories and types of seabed surveys. The guidance outlined the recommended good practice for considering when to undertake a survey and designing seabed surveys for use within EIAs by the offshore Oil and Gas (O&G) industry on the United Kingdom Continental Shelf (UKCS) (Oil and Gas UK, 2019). This guidance is used extensively by those commissioning O&G operators, survey contractors, the regulator Offshore Petroleum Regulator for Environment and Decommissioning (OPRED) and SNCBs as a set of industry wide standards. Whilst they are specific to the O&G sector, many of the approaches and methods are relevant to MREDs and have been developed and refined based on the lessons learned from decades of benthic monitoring.

4.1.5 Other guidance – Offshore UK

There is a wider series of best practice, guidance, and review documents that, in the context of MRED benthic studies, have largely been superseded by the those summarised in previous sections. Some however remain at least partially relevant and are frequently referred to by the MRE industry (e.g., Davies et al., 2001; Boyd, 2002; JNCC, 2004a, 2004b, 2004c, 2004d; Curtis & Coggan, 2006a, 2006b; Coggan & Birchenough, 2007; White et al., 2007; Ware & Kenny, 2011; Judd, 2012; Piel et al., 2012; Henriques et al., 2013; Marine Management Organisation, 2014; K. Cooper & Mason, 2014; Cooper & Barry, 2017 and POSEIDON, n.d.). Therefore, consideration is required particularly when following historical scopes of work to ensure that sampling approaches follow appropriate guidance that is based on the most recent available literature.

4.2 Considerations for Scotland-specific survey and sampling regimes

The collection of robust baseline information is key for comparing the pre- and post-construction condition and patterns of change within benthic communities at MRED sites (Methratta, 2021). In addition, it is important that data from different surveys can be easily collated and compared for wider research on the potential large scale or cumulative impacts of MREDs. Scottish MREDs (particularly the wind sector) currently adopt benthic sampling regimes that draw upon appropriate guidance from various sectors (e.g., Saunders et al. 2011; Noble-James et al., 2018; Natural Resources Wales 2019a, 2019b; Oil and Gas UK, 2019; Natural England 2021a, 2021b, 2022a, 2022b; Parker et al., 2022), and utilise historical data entered into regional and international data portals such as:

- European Marine Observation and Data Network (EMODnet) Broad-scale Seabed Habitat Map for Europe (European Commission, 2024)

  (EUSeaMap 2021 Broad-Scale Predictive Habitat Map for Europe (ices.dk))
- OneBenthic Portal.
- Marine Recorder (JNCC, 2022).
- UK Atlas of Marine Renewable Energy Resources meso-scale model (ABPmer, 2008).

Additionally, there are several key Scotland-specific data portals, datasets, and reports that are consulted to inform the benthic sampling and survey design process, which include:

- Marine Scotland Maps National Marine Plan Interactive (NMPi),
- NatureScot – Open data hub
- Crown Estate Scotland (CES)
- Geodatabase of Marine Features adjacent to Scotland (GeMS)
- The NBN Atlas
- Feature Activity Sensitivity Tool (FeAST)
- Descriptions of Scottish PMFs (Tyler-Walters et al., 2016).
- Scotland's Marine Assessment 2020 (Moffat et al., 2020).
- The benthic environment of the North and West of Scotland and the Northern and Western Isles: sources of information and overview (Wilding et al., 2005).
- Sectoral Marine Plan: Regional Local Guidance Offshore Wind Energy in Scottish Waters: Regional Locational Guidance (Scottish Government, 2021).

Historically, Scotland's marine area is largely under-sampled. Therefore, dedicated benthic surveys are often required to inform the characterisation stage of MRE development, particularly within offshore regions where there is a lack of survey effort. These surveys aim to provide suitable coverage of the area, whilst considering any historical data gaps (e.g., Xodus, 2023). Targeting and identifying the presence and distribution of cryptic benthic habitats and species (e.g., flame shell beds, *Arctica islandica*) throughout a site can be difficult when using traditional sampling techniques alone (e.g., geophysical, grab, drop-down video and still imagery). The utilisation of predictive approaches such as SDM and HSM during the sampling design process may be of benefit (e.g., *A. islandica* (Reiss et al., 2011), horse mussel beds, flame shell beds (Millar et al., 2019)) if historical data is available. Alternate sampling regimes that can detect the presence of benthic species such as eDNA (e.g., Wort et al., 2022) may be required.

Sampling regimes should occur within suitable buffered areas that can account for site-specific indirect impacts such as sediment suspension resettlement, and the potential introduction of Invasive Non-Native Species (INNS). Where the monitoring of recovery and loss to intertidal or subtidal species and habitat is required post-construction, it is expected that sampling regimes will include grab sampling and seabed photography in both disturbed and undisturbed areas, using methods compatible with those used in the benthic characterisation survey. Benthic sampling regimes should also consider the life-history stages of PMFs associated with benthic habitats, such as the eggs of flapper skate which are laid on cobble/boulder habitat in 20 – 50 m but may lay in shallower or deeper water (Thorburn et al., 2022) and have long gestation periods (Benjamins et al., 2021). There are habitat-specific guidance resources available with regional and site-specific context for defining and assessing a variety of biogenic reef structures recorded in proposed development areas, these are discussed in Section 4.4.

Benthic surveys of MREDs in Scottish waters utilise seabed imagery as a multi-faceted approach: to ground-truth acoustic data prior to grab sampling, delineate boundaries between habitats and biotopes, and inform on the presence and distribution of protected features throughout the surveyed area. Two main methods are used, point samples (multiple images from within a buffer of a target location), and transects (images taken at intervals along a set line). Point samples are used to ground-truth potential sediments prior to grab sampling to ensure the area is clear of obstruction, and that visible protected features are absent prior to grab sampling. Transects are used pre-construction to delineate features of interest and/or potential boundaries between sediment types interpreted from acoustic data sources. Post-construction transects can be used to target specific areas of an MRED to inform the seabed condition and infrastructure (biofouling) prior to activities that could impact the benthos such as cable replacements.

Grab sampling provides vital background information on the composition and quality of benthic sediments and associated fauna. Data is assessed against background standards of acceptable heavy metal and chemical concentration levels (Oslo and Paris Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR)) (Larsen & Hjermann, 2022); UK Offshore Operators Association (UKOOA) (Sheahan et al., 2001), upholding Scotland's commitments under various regional, national, and international policies and legislations. It is used to inform on the condition of sediments pre- and post-construction, which has particular importance where energy industries have amalgamated or evolved (i.e., decommissioning of O&G and replacement with MRE, e.g., Beatrice Offshore Wind Farm (OWF)). Sampling for hydrocarbons, chemicals, and heavy metal provides data on the persistence of historical loading and potential resuspension of contaminated sediments during construction and decommissioning. Grab sampling for macrobenthic analysis can be used to inform sediment biotopes of high importance, which may require repeat sampling during post-construction surveys to monitor the recovery or loss of such features identified during pre-construction.

4.2.1 Examples of MRED survey strategies in Scotland

There have been many intertidal and seabed ecology surveys already completed for MREDs around Scotland. These have had to take into account the local issues, needs and constraints outlined in the previous section. The surveys have been associated with the established Solway, North Sea and Moray Firth offshore wind farms, the EMEC tidal and wave test centre sites in Orkney and a number of other tidal and wave technology deployment and development sites around the country. More recently ScotWind and INTOG seabed leasing rounds have also led to burgeoning survey activity. Examples of the surveying strategies adopted for some of these developments are listed in Table 4.1.

4.3 Spatial approaches to planning benthic surveys and sampling

4.3.1 Survey designs to detect change

The Before-After-Control-Impact (BACI) approach and the Before-After-Gradient (BAG) approach are two methodological sampling approaches used in marine surveys. BACI is a survey design that can be used to examine the effects of anthropogenic activities in the context of natural changes. This involves monitoring both impact and reference/control sites before (pre-construction) and after (post-construction) an expected impact has occurred. Control or reference sites are chosen in similar yet unaffected areas with a view to attribute changes at the impact site to the activity in question rather than natural variation or other potential factors. Parker et al. (2022) and Noble-James et al. (2018) provide guidance on selecting suitable control sites, reducing sample-induced variability, and improving robustness in the BACI approach.

The BAG approach (Ellis & Schneider, 1997; Methratta, 2021) involves sampling along a gradient with increasing distance from infrastructure (e.g., turbines) and includes sampling both inside and outside the MRED boundary before and after impact has occurred. BAG promotes the detection of effects over a spatial scale (distance independent variable) and does not require control sites.

Table 4.1 Examples of benthic sampling approaches listed by development project including techniques at different stages of development.

MRED	Benthic Sampling Plan
West of Orkney Wind Farm (Characterisation stage) (Xodus, 2023)	• Geophysical Survey • Drop-Down Video (DDV)/grabs (sediments) • DDV only (rock) • Transects (features) • Macrobenthos, PSD, Physio-chemical • Offshore: Dual Van Veen/Hamon grab (sediments) • Nearshore: Hamon grab (fauna), Shipek grab (PSD/physiochemical) • Intertidal: UAV imagery/Phase I walkover • eDNA (water)

Beatrice Offshore Wind Farm	• Pre-construction stage (BOWL, 2015)
	  ○ Benthic survey, Annex I habitat survey, and archaeological survey
	• Post-construction repeat monitoring (Markham Hubble, 2022)
	  ○ Benthic survey, Annex I habitat survey, and archaeological survey
	    ▪ Hamon grab (sediments)
	    ▪ PSD/Macrofauna
	    ▪ OWF site x 10
	    ▪ Reference stations x 2
	  ○ eDNA (water) – for INNS, fish, and invertebrates

MeyGen Inner Sound Tidal Energy Project	• DDV only • Grabs (in nearshore sediments)
EMEC wave test site	• Bathymetry and geophysical survey • DDV/DDC survey
EMEC tidal test site	• Bathymetry and geophysical survey • DDV/DDC survey • SCUBA photographic/sample collection survey • Biofouling survey of recovered equipment items

Sampling design approaches should be established at the earliest possible stage, whilst considering the location of proposed infrastructure to ensure samples do not overlap inaccessible areas post-construction (Parker et al., 2022). No standard approach has been adopted in Scottish waters thus far.

Methratta, (2021) proposes a combined approach, owing to empirical evidence that impact gradients towards fisheries resources occur at wind farms, whereby larger effects close to turbine foundations attenuate with increasing distance. Therefore, combining BACI with distance-based methods can promote a powerful approach enabling characterisation of both the spatial and temporal variance associated with wind farms. Several enhanced BACI and BAG approaches include Distance-Stratified BACI (DS BACI), Distance-Stratified Control Impact (DsCI) and After-Gradient (AG). An appraisal of the benefits and limitations of these approaches for surveying fish communities can be found in Methratta (2020). A summary of the pros and cons of these approaches in the context of benthic monitoring are summarised in Table 4.2. Such methods should be accompanied by appropriate statistical models to account for pseudoreplication, for example.

4.3.2 Distance-based sampling approaches

Distance-based sampling approaches are commonly applied by the Oil and Gas and aggregates industries to sample sediments from the point source of an impact or potential contaminant (e.g., a well head). Several distance-based sampling approaches have been used to identify spatial patterns in benthic invertebrates arising from the physical presence of turbine foundations (e.g., benthic community and sediment enrichment (Coates et al., 2014; Braeckman & Moens, 2018; Lefaible, Colson, Braeckman & Moens 2019; Lu et al., 2019; HDR, 2019, 2020; Braeckman et al., 2020). Distance based sampling approaches have also been used to identify spatial patterns in fish and macroinvertebrates at offshore wind farm developments (Griffin et al., 2016). The results of the studies showed that in general, sediment grain size increases with increased distance from turbine structures whilst conversely abundance, density, richness of benthic species, and organic content decrease. Changes in sediment characteristics and community composition along spatial gradients are therefore attributed to sediment enrichment close to the subsurface infrastructure (Coates 2014; De Mesel et al, 2015).

There is no uniform incremental distance or design currently applied in benthic sampling approaches, however, sampling distances from turbines typically range from 90 – 200 m with controls placed 500 – 4000 m away. Comparison studies between BAG and BACI designs highlight the importance of sampling at an appropriate spatial scale. In the case of marine energy structures there may be an emphasis upon sampling station placement within 100 m of subsea structures due to the limited extent of any disturbance.

A meta-analysis conducted on several major offshore wind farm monitoring programs in the North Sea identified distance to structure as one of the key diversity indicators of long-term changes in soft-sediment communities (Coolen et al., 2022). Coolen et al. (2022) collated data from a variety of sources with distance ranging 1 m to 9761 m from nearest structures and identified that in using meta-analysis it was possible to detect long-term small changes, that are not detected in small, localised surveys. However, they advise on producing a set of standardised parameters to enhance generalization of effects and exchange of knowledge. The results also showed that the sampling requirements dictated the required scale, with fewer BRUV stations required in comparison to benthic characterisation stations (camera and grabs) (Methratta 2021).

Table 4.2 Pros and cons for different spatial sampling approaches for benthic surveys where the aim is to describe cause and effect.

Sampling Approaches	Pros	Cons
BACI	Useful for answering questions about effects that are expected to occur over a limited spatial and temporal extent, particularly for sessile or slow-moving species. Emphasis on baseline data collection to identify patterns pre- and post-impact.	Does not always account for spatial heterogeneity. Difficult to find suitable controls.
DS BACI	Promotes the incorporation of spatial heterogeneity and scale. Comparisons can be made between baseline and post-impact.	Requires robust baseline data. Difficult to find suitable controls.
BAG	Promotes the incorporation of spatial and temporal heterogeneity and scale. Does not require control sites.	Requires knowing the exact location of the turbines prior to construction with enough time to collect baseline gradient data.
DsCI	Promotes the incorporation of spatial heterogeneity and scale. Characterises spatial patterns and effects post-impact. Assesses post-construction temporal variation if repeat sampling conducted through time.	Samples collected after the impact only. Baseline data is lacking. No comparisons can be made between pre- and post-impact. Report weak/inconsistent effects on commercial fish species. Relies on control to assess impacts.
AG	Promotes the incorporation of spatial heterogeneity and scale. Does not require control sites. Post-impact spatio-temporal changes can be identified if multiple time points are sampled post-impact.	Samples collected after the impact only. No comparisons can be made between pre- and post-impact.

4.3.3 Other spatial factors when choosing sampling approaches

There are numerous factors that require consideration when selecting the appropriate sampling approach. These are summarised in Table 4.3.

Table 4.3 Consideration factors for designing sampling approaches (adapted from Methratta, 2021).

Factor	Summary
Distance interval size	There is a need to match the spatial extent and resolution with ecological responses to detect impact gradients. Requires robust baseline information to understand the mobility of study animals and habitat distribution to understand how they may interact. Requires a hypothesis into the underlying mechanisms believed to be driving potential changes at varying levels (aggregate and targeted effects). Effects of large-scale hydrodynamic changes (e.g., wind wakes causing vertical stratification) may require much larger and wider distance intervals.
Distance bands	Narrow = species with low motility/sessile. Wider = species with higher motility.
Direction of transects	Identify oceanographic and environmental conditions on site. Current flow is known to change around subsurface structures.
Distance from subsurface structures	For some impact pathways there may be an assumption that the effect is reduced with distance from subsea structure and that species composition changes with distance.

4.4 Considerations for targeting features of conservation importance

Benthic surveys are often conducted to identify and monitor the occurrence (presence/absence) and spatial extent of benthic receptors relevant to an MRE development and associated activities. Features of conservation interest are of particular relevance for such surveys and therefore the sampling design will normally reflect any known or expected features, such as Annex I habitats, OSPAR threatened and/or declining habitats and PMFs.

4.4.1 Annex I Features

Annex I habitats refers to the list of habitats afforded protection under the European Union (EU) Habitats Directive (transposed since EU Exit into UK law) within Special Areas of Conservation (SACs). Examples of Annex I habitats are provided below.

Reefs – these are rocky marine habitats or biological concretions that rise from the seabed. This feature therefore includes bedrock and stony reefs (Irving, 2009; Golding, Albrecht & Mcbreen, 2020) as well as biogenic reefs. Biogenic reefs include those habitats formed by the ross worm (*Sabellaria spinulosa*), the horse mussel *Modiolus modiolus*, the blue mussel *Mytilus* sp. and the organ-pipe worm (*Serpula vermicularis*) for example. The ross worm (Gubbay, 2007; Jenkins et al., 2018; Natural Resource Wales, 2019a) has a smaller distribution around Scotland compared to England and Wales, however Scottish records are predicted to increase as survey effort associated with the development of the offshore energy sector increases (Pearce & Kimber, 2020). Horse mussels (*Modiolus modiolus*) (OSPAR Commission, 2009a; Morris, 2015; Natural Resource Wales, 2019b) are long lived biogenic structures which occur in sea lochs and off Noss Head on the north east coast of Scotland. Blue mussel (*Mytilus* sp.), and the organ-pipe worm (*S. vermicularis*) (Moore et al., 2006) also occur in Scottish waters.

Other Annex I habitats include sandbanks slightly covered by water all the time (JNCC, 2019; Pinder, 2020; Natural Resources Wales, 2021c), mudflats and sandflats (Elliott et al., 1998; Curtis, 2015), estuaries, coastal lagoons, and large shallow inlets and bays.

4.4.2 Priority Marine Features

PMFs relate specifically to 81 species and habitats identified as a conservation priority throughout Scotland's sea area. All PMFs receive a degree of protection whether within or outside the MPA network through the National Marine Plan general policies which state *'development and use of the marine environment must not result in significant impact on the national status of Priority Marine Features'* (Scottish Government, 2015).

A review of the PMF list was conducted by NatureScot in 2020 identifying eleven PMFs within 6 NM considered most vulnerable to the impacts associated with bottom-contact towed fishing and required additional protective measures that extended beyond the MPA network. The eleven PMFs were blue mussels, cold water coral reefs, fan mussel aggregations, flame shell beds, horse mussel beds, maerl beds, maerl or coarse shell gravel with burrowing sea cucumbers, native oysters, northern sea fan and sponge communities, seagrass beds and serpulid aggregations. Information sheets have been produced for each feature and can be found on the Marine Directorate website on PMFs.

Based on the location of current lease sites, it is possible that MRED boundaries will both intersect and be within the vicinity of the MPA network, Annex I habitats, and PMFs.

Therefore, consideration of such features and knowledge of their distribution and quality is required pre-construction to inform the sampling approach, post-construction monitoring (where appropriate) and decommissioning.

A series of documents, listed below (see Table 4.4 and Table 4.5), are available which provide guidance on appropriate assessment techniques for benthic features of conservation interest. Some are specific to Scotland, whilst others are applicable UK-wide and have been to some extent used by the wind MRE sector. A key step will be applying these assessment techniques to species and habitats identified across Scotland's wind, wave and tidal MRE sectors. However, for many target conservation features (species and habitats) within Scottish waters there remains no standardised guidance for surveying and assessing their abundance, distribution, and quality.

Table 4.4 Guidance for the surveying of intertidal features of conservation importance.

Guidance	Reference	Description	Limitations
Phase I Intertidal habitat mapping handbook	Wyn et al., 2006	Guidance for conducting intertidal surveys	None noted
The Marine Monitoring Handbook	Davies et al., 2001	Widely used and cited handbook for conducting intertidal surveys	None noted
Common Standards Monitoring Guidance for Marine Features	JNCC, 2004e	High level, standard monitoring guidance and techniques for protected sites	None noted
Littoral sediments	JNCC, 2004d	High level, standard monitoring guidance and techniques for protected sites	None noted
Estuaries	JNCC, 2004f	High level, standard monitoring guidance and techniques for protected sites	None noted
Large shallow inlets and bays	JNCC, 2004a	Includes component species, *Ostrea edulis* and *Zostera* beds	None noted
Intertidal sediments;	NRW, 2021a	Guidance specific to marine developments	None noted

Guidance	Reference	Description	Limitations
Rocky shores and rockpools;	NRW, 2021b	Guidance specific to marine developments	None noted
Seagrass	*Zostera noltii*; Kent et al., 2021	Handbook and guidance for assessing and monitoring seagrass in Scotland. Focus is on restoration	Document focusses on seagrass restoration and citizen science.
Native Oyster (*Ostrea edulis*)	University Marine Biological Station Millport, 2007; Beck et al., 2011; zu Ermgassen et al., 2021	Guidance for assessing native oyster (*Ostrea edulis*) Oyster reef condition indices Handbook designed for oyster restoration purposes but provides sampling techniques and metrics for monitoring	No published standardised guidance for conducting native oyster surveys and analysing data obtained in Scottish waters

Table 4.5 Guidance for the surveying of subtidal features of conservation importance.

Guidance	Reference	Description	Limitations
Annex I Stony Reef	Golding, Albrecht & Mcbreen, 2020	Determines the characteristics of stony reef, in particular 'low reef' classification	None noted
Annex I Stony Reef	Irving, 2009	Determines the characteristics of stony reef	None noted
Annex I Biogenic Reef	Gubbay, 2007	Determines the characteristics of *Sabellaria spinulosa* reef	None noted
Annex I Biogenic Reef	Jenkins et al., 2018	Provides guidance for assessing *S. spinulosa* reef for ongoing monitoring	None noted
Annex I Sandbanks	Tillin et al., 2010	An assessment of sensitivity which displays the likely effects of a given	No standardised guidance for conducting surveys or assessing the quality

Guidance	Reference	Description	Limitations
		pressure on a species and/or habitat in the form of a matrix	and recovery/loss of sandbanks
Seagrass *Zostera marina*	Kent et al., 2021	Seagrass restoration in Scotland handbook and guidance. Addresses assessing and monitoring seagrass. Document focusses on seagrass restoration and citizen science.	No published standardised guidance for conducting seagrass surveys and analysing data obtained specifically in Scottish waters
Seagrass *Zostera marina*	NRW, 2019	Guidance for analysing seagrass imagery	None noted
Maerl and maerl gravel	Axelsson, 2023	Recently adopted maerl classification system produced by NE for assessing and analysing seabed imagery of maerl and maerl gravel	Not currently publicly accessible and requires permission from NE to use and reference
Burrowed mud and sea pen communities	Robson, 2014	UK-wide guidance on defining mud habitats in deep water and sea pen and burrowing megafauna communities	No published standardised guidance for conducting burrowed mud and sea pen communities surveys and analysing data obtained specifically in Scottish waters
Flame shell beds	Moore et al., 2018	As a cryptic species, flame shells are difficult to measure population size from seabed imagery alone. Grab sampling has been used to produce semi-qualitative assessment of population size, combined with SCUBA and DDC to quantify damage/loss and monitor recovery	No published standardised guidance for conducting flame shell surveys and analysing data obtained in Scottish waters
Horse mussel beds	None	N/A	No published standardised guidance for conducting horse

Guidance	Reference	Description	Limitations
			mussel surveys and analysing data obtained in Scottish waters
Fan mussels	Howson et al., 2012	Details combined SCUBA and drop camera surveys conducted by NatureScot to establish the distribution and status of fan mussels and other MPA search features	No published standardised guidance for conducting fan mussel surveys and analysing data obtained in Scottish waters
Subtidal native oyster reefs	Beck et al., 2011	Discusses oyster reef condition indices	None noted
Subtidal native oyster reefs	University Marine Biological Station Millport, 2007	Advice on the conservation management of the native oyster in Scotland including detailed population studies	None noted
Subtidal native oyster reefs	zu Ermgassen et al., 2021	Handbook designed for oyster restoration purposes but provides sampling techniques and metrics for monitoring	No published standardised guidance for conducting native oyster surveys and analysing data obtained in Scottish waters
Northern sea fan and sponge communities	None	N/A	No published standardised guidance for conducting northern sea fan and sponge communities surveys and analysing data obtained in Scottish waters. However, northern sea fan and sponge communities are identified as a component species of Annex I reefs
Ocean Quahog (*Arctica islandica*)	OSPAR Commission, 2009b	Contains information on data collection and reporting in terms of	None noted

Guidance	Reference	Description	Limitations
		determining the conservation status	
Ocean Quahog (*Arctica islandica*)	O'Connor, 2016	Details the survey methodology conducted to gather baseline data on the abundance and distribution of *Arctica islandica* that will track long term rate and direction of change	No published standardised guidance for collecting or analysing Ocean quahog data obtained in Scottish waters

4.4.3 Fish surveys

Fish spawning habitat assessments

Fisheries surveys are usually treated as a separate assessment entity, however, there are certain conditions where benthic surveys may be required to help understand the possible importance of habitats for commercially important fish species such as sandeels (Ellis et al., 2012). Fish spawning habitat assessments indicate whether the seabed consists of ecologically important habitat spawning/nursery grounds for fish species such as herring (Reach et al., 2013b).

Sandeel population surveys

Guidance for conducting sandeel assessments for Scottish MREDs is provided within Latto et al. (2013). The Beatrice OWF post-construction sandeel survey technical report (BOWL, 2021) provides an example of a sandeel survey and follows methodologies designed in consultation with the MD and MD Licensing Operations Team (MD-LOT).

Essential fish habitats

Essential Fish Habitats (EFH) are identified as waters and substrate around Scotland necessary for the spawning, breeding, feeding, growth, and maturity of fish and shellfish species. A series of spatial outputs from Franco et al. (2022) have been published for 29 species (20 fish including three elasmobranchs and nine shellfish) and can be used as an evidence base to inform future planning and project level assessments.

4.5 Overview of other factors for consideration for MRED benthic surveying

There are numerous factors to consider throughout the lifespan of an MRED which could influence the methods of benthic surveying that are chosen. These can be broadly categorised into scoping, location, and operating factors. Scoping factors relates to the

MRE sector in question (i.e., wind, wave, tidal), and the primary aim of the project, whether that be for research and development purposes (i.e., test/demonstration sites) or full-scale commercial deployment, and the stage of the MRED. Location factors considers geographical, site-specific factors relating to the environmental, biological, and physical condition of the site and the availability of suitable baseline data. Operating factors consider the feasibility (practicalities and cost) and jurisdictional limitations associated with the type of benthic survey.

4.5.1 Consideration of scoping factors

The choice of surveying method will depend on the stage and type of development (See Table 4.6). The benthic survey protocols adopted for test, demonstration, and pre-commercial stages of wave and tidal developments have historically differed from those adopted for commercial scale wind developments. In addition, to date in Scottish waters, the benthic survey requirements for wave, tidal and wind sectors have largely been selected and implemented on a case-by-case basis, however a more systemic sector-wide approach for each and possibly all marine energy sectors may be of benefit.

Table 4.6 Key aims and considerations when determining benthic survey type for the different stages of an MRE development.

Development Stage	Aims	Considerations
Scoping (inc. benthic characterisation)	Verify the baseline information (physical/ biological/geological) of the MRED.	Ensure data collection is suitable to the sector and area including the availability of suitable historic data.
Monitoring	An assessment of potential impacts at regular intervals throughout the operational lifespan of the MRED. Assess for the presence or absence of features of conservation importance (PMFs/Annex I).	Ensure length between monitoring periods is suitable and that data collection is practical and capable of assessing the likelihood that a change has occurred. May be used to monitor change prior to site maintenance.
Decommissioning (Pre)	An assessment of the MRED prior to removal of infrastructure at end of operational lifespan. Assess for the presence or absence of features of conservation importance (PMFs/Annex I) in proximity to the MRED infrastructure.	Ensure that data collection is practical. Effective temporal monitoring should have flagged potential features of conservation importance that would require assessment prior to decommissioning.

Development Stage	Aims	Considerations
Decommissioning (Post)	An assessment of the MRED development area following the removal of infrastructure at the end of operational lifespan.	May be sector-specific and dependent on the presence of remaining subsea infrastructure following decommissioning.

The identification of suitable benthic sampling techniques is required at each key development stage to ensure sampling effort is maximised to the benefit of both the environment and the MRE industry. The collation of historically relevant data is vital during the benthic characterisation stage to identify data gaps and therefore where survey effort should be maximised. In England and Wales, data repositories such as OneBenthic and Regional Seabed Monitoring Programme (RSMP) are utilised whilst in Scotland historical seabed data can be obtained from a combination of OneBenthic, Marine Recorder (biotopes/species), the NMPi (PMFs/protected features) and EMODnet data portal (Vasquez et al., 2021).

4.5.2 Considerations for a strategic surveying approach

Benthic sampling is most commonly conducted on a site-by-site basis, which provides some evidence on species and habitat distribution and abundance. However, benthic communities can often be disparate and patchy over quite short distances. This can lead to difficulties producing reliable and replicable results from small sample numbers and can also make the use of wider-scale habitat/community models less applicable.

Strategic sampling at a local level aims to minimise time and monetary effort in acquiring new sample data. Such sampling regimes rely on the availability of suitable existing data in order to identify gaps in a survey area that would benefit from additional data collection.

Strategic sampling at a region-wide level is conducted using sampling approaches such as the RSMP. The RSMP is a big data approach to macrofaunal baseline assessment and monitoring of the seabed (Cooper & Barry, 2017). The dataset comprises over 33,000 macrofauna samples with 83% containing associated sediment PSD data, from a combination of historical and targeted sample data collected during dedicated regional surveys, to fill gaps in spatial coverage within each region.

Strategic sampling strategies like RSMP promotes the use of data that already exists within a lease area. Surveys can then fill spatial data gaps whilst targeting habitats or species which may pose the greatest environmental consenting risk, or where more information is required to fully assess the potential impacts of the developments.
The POSEIDON (Planning Offshore Wind Strategic Environmental Impact Decisions) project facilitates regional-scale strategic sampling approaches. The POSEIDON project is

adopted throughout England and Wales to collect environmental baseline data and produce updated spatial models for key species (receptors), assemblages, and a suite of ecological metrics (diversity, functional traits). These models will be used to identify regions that are most vulnerable to potential offshore wind impacts. Mapping environmental risk using this approach will help guide future offshore wind development rounds and wider marine planning by demonstrating regional scale changes in biodiversity (including positive and negative change). The POSEIDON project has built upon previous benthic sampling protocols (e.g., that of Ware & Kenny (2011) and the RSMP) and provides a protocol for sample collection (including grab and eDNA samples) and processing likely to be applicable throughout Scotland. Adopting a regional-scale sampling approach in Scottish waters would be of benefit across marine sectors and a single unified method of collecting and displaying benthic data would synergise data collection effort throughout the UK (Cooper, Mason & Lozach, 2021).

4.5.3 Considerations of cross boundary issues

MRED programmes can span local and regional boundaries as well as national boundaries. Consideration should be given to any potential boundaries encompassed within MRED areas to ensure that the benthic survey techniques adopted are systemic and effective across jurisdictional boundaries. Strategic sampling approaches such as those adopted in England (Cooper et al., 2021) promote regional-scale sampling over project-specific sampling plans resulting in effective and appropriate temporal data collection. If a regional-scale strategic benthic sampling approach was adopted for Scotland, a suitable division of regions is required to ensure sampling is locally relevant. The Scottish marine area is divided into eleven regions for regional marine planning purposes (The Scottish Marine Regions Order, 2015). These divisions are largely based on physical characteristics and therefore could be suitable boundaries for regional-scale benthic sampling approaches. However, some sampling techniques may only be appropriate at a local scale rather than regional-scale due to the spatial resolution of the acquired data and the time/monetary constraints associated with up-scaling a survey area (e.g., AUV surveys).

4.5.4 Utilising existing data for survey planning

The type of benthic data required at each development stage is largely determined by the quality of historically available data. Typically, the greatest scale of data collection is conducted at the pre-production stage to fully characterise the seabed.
The broad-scale habitat type coupled with further geophysical (depth), morphological (features) and biological (flora/fauna) considerations largely determine the methods of benthic sampling and analyses that are most appropriate. The EU SeaMap predictive BSH habitat map (Vasquez et al., 2021) is an effective precursory tool used for visualising potential seabed habitats during data collation exercises and for selecting target sample locations across representative substrates during the characterisation stage.

4.5.5 Considering the potential impacts arising from surveying activity itself

Benthic survey activities may produce a footprint that require mitigation to reduce impact to sensitive habitats and species. Some methods such as trawling lead to mortality of the sampled fauna and leave damaged organisms behind. Features that may be impacted by benthic surveys are summarised in
Table 4.7. Fragile seabed habitats, rare/protected seabed habitats and species such as sponges and corals, biogenic reefs, burrowed mud and sea pen habitats can be directly impacted by the benthic survey methods chosen, whilst those categorised by physical and noise disturbance are indirectly impacted and mitigation is implemented through specific licensing requirements.

4.5.6 Consideration of other sectoral activities in survey planning

Scotland’s marine area is shared by multiple sectors which have the potential to exert multiple pressures and may increase the likelihood of a net negative impact to the marine environment. This may compound impacts evident within an MRED and influence the benthic sampling requirements. The sectors which require consideration and example impacts are summarised in Table 4.8.

Where other sea user activity is prevalent within or near to an MRE development scheme, a redistribution of sampling may be required to stratify sampling effort according to differing activities and pressures or select suitable control sites. The likely zone of influence of such issues should be considered in survey designs. Certain classes of the other maritime and coastal activities have the potential to lead to chemical contamination as well as physical disturbance, others are limited simply to potential physical disturbance.

Table 4.7 Environment sensitivities that may influence survey approaches.

Feature	Where found	Response
Sessile epifauna	Rocky and biogenic reefs Mud	Avoid or reduce dragging, bumping, dropping objects and lines
PMFs	Widespread in various habitat types	Avoid or reduce dragging, bumping, dropping objects and lines
Seal pupping	Haul outs and isolated shores	Seasonal avoidance of known haul outs Buffer zones, visual watches during survey activities to monitor for disturbance
Otter holts	Shorelines	Buffer zones, visual watches during survey activities to monitor for disturbance

Feature	Where found	Response
Birds nesting	Upper shorelines, hinterland, cliffs	Buffer zones, seasonal avoidance, visual watches during survey activities to monitor for disturbance
Birds key life stages (feeding/over wintering sites)	Open sea area	Seasonal avoidance, visual watches during survey activities to monitor for disturbance
Basking sharks	Open sea area	Seasonal avoidance, visual watches during survey activities to monitor for disturbance
All cetaceans	Open sea area	Buffer zones, seasonal avoidance, visual watches during survey activities to monitor for disturbance

Table 4.8 Summary of potential impacts attributed to adjoining sectors in Scottish waters.

Sector	Potential Impacts
Oil and gas	• Localised chemical contamination of seabed • Increased hydrocarbon concentrations • Physical disturbance • Surface/subsurface infrastructure • Noise pollution and vibration • Increased seabed debris • Exclusion zones providing suitable refuge for habitats and species
Shipping	• Physical seabed damage caused by anchoring • Increased seabed debris • Noise pollution
Fishing	• Physical damage caused by trawling/dredging/creeling • Ghost gear • Noise pollution
Aquaculture	• Localised chemical contamination • Nutrient enrichment from feed and metabolic waste • Physical seabed damage caused by anchoring • Biofouling • Increased seabed debris

Sector	Potential Impacts
	• Noise pollution • Exclusion zones providing suitable refuge for habitats and species
Sewage/intertidal pipelines	• Localised chemical contamination of seabed • Localised chemical contamination of water column • Litter • Localised temperature changes
Cables	• Subsurface infrastructure • Electromagnetic Field (EMF) • Localised temperature changes • Exclusion zones providing suitable refuge for habitats and species
Aggregate extraction, dredging and waste disposal	• Excavation and removal of materials • Resuspension and redissolution of chemical contaminants • Physical disturbance • Sediment turbidity plumes
Harbour works/ intertidal engineering	• Physical disturbance • Noise pollution and vibration
Other renewables	• Surface/subsurface infrastructure • Physical disturbance • Noise pollution • Localised changes to environment
Military	• Physical disturbance • Noise pollution and vibration • Increased seabed debris

4.5.7 Consideration of on-the-coast or at sea operating factors

Benthic sampling tools and technologies vary in size, complexity and therefore usability, which can then compromise their suitability and impact the time and monetary costs involved. As such, there are operating factors to consider that will influence the benthic survey tools and technologies that are employed throughout MREDs. The benthic survey tools and technologies employed in MREDs globally tend to vary by sector and country therefore, equipment and sampling vessels should be selected that are both suitable for the sampling purpose and local conditions of Scottish waters. Conditions that may impact operating and sampling success in Scottish waters include tidal cycles (springs vs neaps effect on current flow and sea levels), short-term (weather) and temporal meteorological patterns (e.g., seasonal storms, cyclic weather events (i.e. North Atlantic Oscillation)). MREDs require effective sampling throughout their operational lifespan. The predicted increase in severity and longevity of weather events may hinder operational success, exacerbating conditions at sites located in exposed and remote marine areas with prevalent wind directions and strong tidal conditions.

5 Benthic tools and technologies – comparative review of performance

5.1 Method used for assessing appropriate tools and technologies

A tabular evaluation framework for analysing and comparing seabed surveying tools and technologies has been produced (See Appendix 1: Evaluation Matrix, for details including instruction for use in the first tab). This matrix provides users with a comprehensive option evaluation toolkit for identifying the technical solution best suited for surveying benthic ecology features in the context of MREDs within Scottish waters.

The Evaluation Matrix is the product of a comprehensive review conducted on the various tools and technologies available. It comprises of an extensive list of traditional, novel, and newly emerging tools and technologies displayed in a format that easily identifies the most effective tools and methods for a wide range of survey purposes as well as in relation to a range of performance criteria.

The tools and technologies displayed within the matrix were selected based on a broad review of the current available guidance, research, and grey literature as well as expert knowledge and experience. The list was refined following further discussions with stakeholders on their applicability and likelihood/frequency of current use within the MRED sectors.

Within the Evaluation Matrix, the various options have been organised under three broad classifications: biological, physical and chemical; and main themes (Main Role): geophysical/geotechnical; visual imagery; specimen sampling; and sediment, rock, water, specimen sampling. Some of the approaches investigated perform multiple roles and functions, and therefore were assessed under more than one of the main categories in the matrix.

Within each row of the evaluation tab there are three sets of information presented:

- The first set provide factual information/specifications under **generic categories** about the approach which it is not relevant to scoring.
- The second is a set of performance metrics that are linked to the **sampling process** only. These tend to be associated with at sea and shoreline activities.
- The third set of parameters are again performance metrics, but they could apply to both **sampling and sample analysis**. These tend to be factors linked to land and lab-based activities.

Although the Evaluation Matrix is comprehensive, it is intended as an aid to decision making and option evaluation rather than it being a definitive standard to be followed. It is intended that the information within each output provides the user with the flexibility to select the tools and technologies they deem best suited to a particular development whilst also offering a comparison and alternatives.

Further details on the context for and the individual criteria in each of these sets are provided the following sub-sections as well as in the evaluation matrix itself in Appendix 1.

5.1.1 Generic Categories - Basic characterising features of candidate sampling tools and techniques

This first set of factors provide a simple description of a particular tool or technique without providing a judgement as to suitability. In a few cases some specific sub-definitions have been provided to help with consistency in classification.

Other characterising information and some of the background statement materials from the latter two sets of performance metric criteria in the master evaluation matrix can also be considered as background descriptors to be considered. The basic descriptors are set out in Table 5.1.

5.1.2 Performance metrics linked to sample acquisition.

These initial performance metrics focus upon the challenges and opportunities associated with gathering of samples whilst at sea or on the coast. Each tool/technology has been assessed for their suitability against the list of performance metrics presented in Table 5.2. There are three levels of classification for each criterion. These levels are backed up by clarifying definitions that allow users to understand and ascribe levels of suitability to any seabed or intertidal surveying activity consistently and reliably. In addition to the details provided in Table 5.2, further expressions of the reasons for a given classification are embedded as hidden but available cells in the Evaluation Matrix (Appendix 1), in the final Evaluation of Performance tab.

Where multiple suitability factors for characterising a tool are considered applicable in a given category, the lowest scoring suitability statement should be used as a reference. In this way the assessment presents a worst-case scenario where uncertainty, or lack of information, is relevant.

Table 5.1 Definition and description of the generic categories used in the Tools and Technologies Evaluation Matrix (see Appendix 1)

Category	Definition
Classification	The type of feature being investigated – geotechnical, geophysical, biological, chemical or physical.
Main Role	The key role of the activity in terms of gathering existing or new data or collecting physical samples of species or materials.
Function	The data related purpose that the technology, tool or technique is applied for.
Technology/Tool/Technique	A high-level description of the equipment being used (e.g., grab sampler).
Equipment	The specific type of tool or technology (e.g., drop camera).
Sub-category	If required to provide further detail (e.g., freshwater lens).
Depth Zone	Refers to the water depth zone that the tool or technology can be applied within. This could be: **Subtidal:** >5 m water depth at Lowest Astronomical Tide (LAT) (chart datum). **Shallow subtidal:** 0.5 – 5 m water depth at Mean Low Water Springs (MLWS) (larger vessels may have restricted access and movement). **Intertidal:** shore area down to <0.5 m below LAT (including rockpools).
Guidelines and approaches	References are provided to any literature that outlines the published guidelines for using the tool/technology or other supporting information.
Project development stage	The stages of the development in which the tool/technology can be used. **Benthic characterisation:** This encompasses all pre-placement and pre-operational stages where baseline line data is required. **(Pre)operational:** surveys designed to establish a baseline for any future monitoring activities. **Operational** This encompasses the operational lifespan of the MRED (25-30 years).

Category	Definition
	Decommissioning This encompasses the pre-decommissioning pre-removal and post-removal and any subsequent legacy monitoring.
Tethered/Untethered	**Tethered:** The tool or technology is attached in some way either to the vessel or the seabed. **Untethered:** The tool or technology is controlled remotely or is autonomous.

Table 5.2 Performance metric definitions applied to sample gathering tools and techniques within the evaluation matrix presented in Appendix 1.

Performance metrics	Definitions
Ease of Deployment	This refers to the ease with which a tool or technology can be deployed from a vessel or on the shore. It includes practical considerations such as the nature of the lifting or winching needs if any, the size and weight of a given tool or technology and also the complexity and vulnerability in terms of the number and types of connections needed (lifting, communications, power etc). The definitions are: **High (easy to deploy):** hand-held, small scale (10s kg), minimum take-off and landing restrictions, **Medium (some difficulties to deploy):** mechanically aided, moderate scale (10s-100 kg), **Low (hard to deploy):** dedicated lifting technique, with multiple tethers, larger scale (100-1000 kg), restricted take-off and landing requirements
Capacity for simultaneous operations on vessel	This refers to the ability of the technique to be applied alongside or to dovetail into other work tasks. This may link to the degree of co-location and co-timing with engineering, design, inspection, maintenance and repair work/surveys. It also links to the way in which any deployment vessel or platform can carry out other tasks during surveying activity. For example, underwater noise monitoring will most likely require effective operational silence from other activities. **High, multiple operations possible:** good capacity for simultaneous activities **Moderate, dual operations possible:** moderate capacity for simultaneous activities **Low, sole use only:** no or limited capacity for simultaneous activities

Performance metrics	Definitions
Skills and training	This refers to the skills and competence levels required from personnel to successfully and safely deploy the tool, technology or technique. This may include instrumentation and system set-up skills, deployment and recovery skills, as well as sample acquisition and QC skills. **High:** low level skills needed. **Moderate:** some training and core competency needed. **Low:** specialist training and good experience needed.
Survey Cost (Time/ Monetary)	The relative costs associated with the survey including the capital in order to purchase or hire the equipment, and to mobilise or use it, the survey personnel and whether they need to be skilled/trained or novice/trainable, and the time associated with the data collection. **Cost effective:** Fast, easy to mobilise and collect data. Minimum skilled work. Requires a small survey vessel with a davit/small winch (£1000's). **Moderate cost:** Takes a significant amount of time and effort to mobilise and collect data. Crew require additional skills or qualifications. Requires a work boat with crane/winch (£10,000's). **High cost:** Expensive/time consuming to mobilise and collect data, highly skilled or specialist personnel required, requires a large vessel with Dynamic Positioning and A-frame (£100,000's).
Physical Operating Constraints Upon Deployment	This refers to the number of sensitivities that the approach has with regards to local operating conditions such as weather, sea state, and communities present (e.g., kelp) regards possible propeller fouling or equipment entanglement. **High suitability:** No occasional operating constraints **Moderate suitability:** Some regular operating constraints **Low suitability:** Many consistent operating constraints or constraints unknown
Spatial/ Temporal Restrictions	This refers to methods of sampling that may be sensitive to the specific location sampled or to the timing of samples. For example, if a sample is too spatially restricted and the feature being sampled is very variable at that scale, many samples would be needed to gather a representative sample (e.g., sampling *Arctica islandica* molluscs with a small grab sampler). Likewise a factor that has strong seasonal trends may need to be sampled at the same time of year to be representative (e.g., large populations of juveniles that do not survive to adulthood), similarly a feature which is known to vary strongly year by year (e.g., species prone to population explosions) may need a

Performance metrics	Definitions
	longer time series of samples to get a true picture of what is happening than for something more stable. **Low risk of spatial/temporal restrictions:** sampling strategy/method deals well with scale, and timeliness (large scale and easy/cheap to mobilise/replicate). **Moderate risk of spatial/temporal restrictions:** sampling scale moderately appropriate, and timeliness moderately achievable. **High risk of spatial/temporal restrictions:** sampling strategy may be too restricted in terms of scale and timeliness (too small and difficult/costly to mobilise/replicate).
Potential impact to other marine users	The level of consideration required regarding the potential impact of other marine users includes stakeholder engagement, environmental valuation, cost-benefit analysis, licensing, notice to mariners, and further research requirements to identify socio-economic impacts of using a particular tool/technology. The score for this metric is a combination of the considerations required on the factors above and the risk to other marine users. The risk to co-located marine activities (buffer zones/exclusion zones): **Low potential impact**: The use/misuse of tool/technology is not likely to negatively impact other marine users, or it may impact users but over a short time frame with no lasting impact. **Medium potential impact**: The use/misuse of tool/technology is more likely to negatively impact other marine users in the short but not the long-term. **High potential impact**: The use/misuse of tool/ technology will likely negatively impact other marine users in the longer term.
Environmental Sensitivity Considerations	The capacity of a tool/technology to be used on habitats and biotopes found throughout Scottish waters, including those of conservation importance and those sensitive to disturbance. This includes the risk of a net negative impact and disturbance arising from the use of a tool/technology (e.g., pollution (light/noise), release of materials, excavation). Includes whether more environmentally friendly alternatives are available. Risk of a net-negative impact from use of the tool/technology: **Low**: Impact to the environment is low or short-lived and covers a small area over a short period of time, habitat type goes back to normal function fast (weeks to months).

Performance metrics	Definitions
	Medium: Impact to the environment is low to moderate over a short to moderate time frame across a larger area and longer period of time, habitat type may take longer to recover (months to years). **High**: Impact to environment is moderate to high over a large area over a long or prolonged period of time, habitat type takes a long time to recover (years to decades).

5.1.3 Performance metrics linked to sample gathering and analysis.

Having considered the factors only associated with the various approaches to sample gathering, a second set of performance factors includes those linked to sample analysis as well as sample gathering and is presented below (Table 5.3). A similar definition and classification system as used previously has been applied.

Table 5.3 Performance metric definitions as applied to both sample gathering and analysis tools and techniques within the evaluation matrix presented in Appendix 1.

Performance Metric	Definitions
Strengths of the Method	Strengths are described as traits of the sampling tool or technique that make it widely applicable in terms of habitats and species that can be sampled, without losing definition or detail, where it is reliability and robustness in sample acquisition. Such traits which are applicable to each tool/technique option are listed in the body of the evaluation matrix. **High suitability: **Many inherent strengths**.** **Moderate suitability:** Some inherent strengths. **Low suitability:** No, or very few inherent strengths.
Limitations of the Method	Limitations are described as traits of the sampling tool or technique that make it only narrowly applicable in terms of habitats and species that can be sampled. There being inherent issues over accuracy, detail, reliability and/or robustness. Such traits which are applicable to each tool/technique option are listed in the body of the evaluation matrix. **High suitability:** No inherent limitations**.** **Moderate suitability:** Some inherent limitations. **Low suitability:** Many inherent limitations.

Performance Metric	Definitions
Secondary Use	A tool or technology may be suitable for collecting additional samples/data that are not its original intended purpose. For example, it may serve as a platform for additional sensor deployment, or the primary data may be analysed for additional purposes other than its original intent. **High suitability**: Many secondary applications and uses. **Moderate suitability**: Some secondary applications and uses. **Low suitability**: No secondary applications and uses.
Frequency of current use in MREDs	The number of times that the approach is used across the sector as a proportion of the total opportunities. **High suitability:** Widely used throughout the sector on the majority of developments within the majority of marine areas globally. **Moderate suitability**: Moderately used throughout the sector on some developments mostly UK but also used outside UK waters. **Low suitability:** Limited use throughout the sector – single or sporadic use within the sector at a local/national scale.
Operational Experience	The timespan over which the approach has been utilised **High - widely adopted;** Used extensively throughout industry for a minimum of 5 years. **Moderate - some industry use;** 3–5 years of industry use. **Low - little industry use (novel);** 0–3 years, R&D stage with little experience in an industry setting.
Spatial Scale of Application	This considered the degree of geographical territory over which a particular approach has been used. This helps to define the applicability across different conditions and the potential for national and international standardisation. **High: Global;** A tool/technology or technique that is widely used by multiple users in MRE developments worldwide. **Medium: Regional;** A tool/technology or technique that does not have global application but has been used extensively by a specific user in a global or multi-regional context. **Low: Local;** A bespoke tool/technology or technique used on an MRE development by a specific user within a specific area.
QC (Availability of Robust and	The availability and level of methodological standardisation upon which a robust and repeatable approach can be based.

Performance Metric	Definitions
Reliable Procedures)	**High: Available and strong standards;** suitable published guidance is available, current, and widely applied across the MRE sector or is an applicable and widely used and accepted method with strict samplings standards and procedures in place. History of inclusion in QC schemes. **Moderate: Limited availability and some inconsistencies with standards;** standards may not be published but are widely used and accepted, sampling standards and procedure have been produced, but the method is new and not widely used or not used across a breadth survey activities or sectors. Some inclusion in QC schemes. **Low: No recognised standards;** New or novel approach with little application to MRE or industry in general. Methodology is created in house and not widely shared or deviates with each application. Little to no inclusion in QC schemes.
QC (Ability to Replicate)	The likelihood that the method associated with the tool/technology delivers repeatable and accurate results. **High:** The method is well used, strong and reliable. The data obtained using the tool/technology is suitable to answer the required questions. No significant data gaps or uncertainties exist. **Moderate:** The data obtained using the tool/technology is mostly suitable for answering the required questions. A few knowledge gaps may be present, but the balance of understanding is strong. **Low:** The method has not been applied widely enough to identify its reliability spatially and/or on a temporal scale. There are still knowledge gaps which reduce confidence in results. More robust methods may be easily available in the marketplace.
Analytical Cost (Time/Monetary)	The relative costs associated with processing and analysing data. This includes the capital, time and skill level required. **Cost effective:** Fast, easy to process and analyse data. Minimum skilled work (£100s). **Moderate cost:** Takes a significant amount of time and effort to process and analyse data. Data analysts require additional skills or qualifications (£1,000s). **High cost:** Expensive/time consuming to process and analyse data, highly skilled or specialist personnel required (£10,000s).
Added Value	The potential for the approach to generate opportunities for added value contributions of data and associated metadata for purposes such as data bases, timeseries, models and inclusion in data repositories such as Marine Environmental Data and Information

Performance Metric	Definitions
	Network (MEDIN). Also, approaches that promote regional/national global data sharing. **High suitability:** good potential for added value data to be created. **Moderate suitability:** some potential for added value data to be created. **Low suitability:** little or no potential for added value data to be created.

5.2 Results and discussion arising from the evaluation matrix

For each tool and technique option, a collation of the various performance metrics has been provided to show the overall number of high suitability, moderate suitability and low suitability categorisations ascribed. This spectrum of performance can be used to help identify the better and worse performing approaches given a particular purpose.

To help present an overview of these collated performance spectrums they have been presented in Appendix 1 Evaluation Matrix within the 'Overall performance rankings' Tab. The combined total was determined by the following calculation:

(2 x number of green) + (1 x number of amber) - (1 x number of red).

The wider Evaluation Matrix also represents a summary of current knowledge and understanding about the various techniques, technologies and tools that are available with appropriate references where available. Over time this matrix will benefit from updating due to advances in innovative technology and research, and progression of the MRE sector itself and the as accumulated experience of benthic surveying activity grows.

As technology and research advances some of the traditional tools and technologies may become less favourable, whilst some of those that are currently novel or innovative may become more favourable as their merits and benefits become more fully developed and understood. However, certain well proven approaches are likely to remain suitable for the foreseeable future and certain novel approaches may prove to be less useful.

The Evaluation Matrix can further be used to identify possible gaps and areas of weakness in present provisions as well as areas of performance uncertainty, which could be addressed through further specific studies and investigations as resources allow.

The Evaluation Matrix can also act as a selection guide to users, that forms part of the decision-making process. However, the matrix should not be considered as directly deterministic. Ultimately the final decision on what are the most appropriate tools and technologies to be used, in a particular situation, will depend on a combination of factors, including the nature and size of the site, costs and funds available, timescales needed, alongside advice from the statutory bodies which uphold legislative and leasing requirements and other consulted stakeholders.

6 Overview of pros and cons of different sampling, analytical and data handling approaches

6.1 Introduction

The comprehensive seabed surveying Evaluation Matrix and the description presented in the previous chapter provide a detailed overview of suitability metrics for different seabed surveying tools and techniques applied to different purposes. This section provides a high-level overview of some of the key benefits and limitations arising from this comprehensive review combined with observations gained from direct surveying experience. The issues presented are indicative and not exhaustive. In addition, project specific circumstances and local conditions may alter, enhance or diminish certain issues.

6.2 Assessment of sampling approaches

This sub-section provides an evaluation of the benefits and limitations of the major sample gathering techniques (see Table 6.2). The sample acquisition method may be by in situ visual inspection by eye, via acoustic or visual signals, or in the form of a physical sample obtained by hand or mechanical recovery.

Table 6.1 Examples of the benefits and limitations of different seabed and intertidal sampling gathering tools, technologies and techniques.

Classification and example	Benefits	Limitations
Physical habitat characterisation - bathymetry	Almost universally available as single beam data and widely available as multibeam, swath data. Useful for showing pinnacles, shoals, banks, troughs, canyons, kettle holes etc. Vast majority of water depth features and conditions in Scottish waters are stable over time so data has long utilisation window. May help demark extent of mineralised biogenic reefs on the seabed, if high resolution data is collected.	Main issues are extent of coverage and resolution of data. Care needs to be taken to ensure that the right benchmarks are used such as LAT and global projections. Need to take account of long-term sea-level rise. Usually, no ecological information arising.

Classification and example	Benefits	Limitations
Physical habitat characterisation – geophysical (acoustic) remote sensing	Provides indication of the density and structure of seabed materials enabling better differentiation of rocks and sediment types. May help demark extent and depth of mineralised biogenic reefs on the seabed.	Requires skilled interpretation. Potential for wider ecological interactions from sound emissions with sound sensitive species such as Cetaceans Usually, no ecological information arising.
Physical habitat characterisation – seabed physical sample recovery (e.g., via grabs or cores, manipulators)	Verifies remote sensing methods. Enables further analysis to take place (see Section 6.3 and Table 6.2). *[Plus - see also below for biological and chemical sampling].*	Small spatial extent with all vertical samplers, low accuracy and precision with drag samplers. Grab and box cores often fail where stones are mixed into sediments. *[Plus - see also below for biological and chemical sampling].*
Physical habitat characterisation – video surveillance of seabed or coastline	Provides generally good resolution data over a wide area, enabling local variation to be better understood. Generally greater detail than most geophysical data. Data can be easily shared digitally.	Through water visibility in seabed use may be variable. Can be time consuming to review.
Physical habitat characterisation – eyeball surveys: walkover survey of coastline; diver survey of seabed	Intertidal walkover surveys are one of the easiest surveys to undertake, they provide a wide mix of useful data and insights as soon as it is undertaken and can adapt to finding immediately. Diver surveys in shallow waters can provide quick, insightful and adaptable survey capacity, especially where conditions are too shallow or complex for vessel navigation, where there	Intertidal walkovers may be more difficult to undertake along cliff-backed shorelines and around remote islands. In such locations close inspection from a small boat or aerial drone surveillance may be options. Diver based surveys, are more complex in terms of mobilisation and back-up safety resources needed.

Classification and example	Benefits	Limitations
	are thick kelp beds, rocky seabed areas and where site or route finding may be enhanced by an adaptable survey strategy.	
Biological – video images	Time-effective to gain good visual insights over a relatively wide area. When deployed on ROV platform with direct feedback to surface then dynamic search strategies can be employed for seeking out and characterising seabed features, habitats and even particular species or assemblages. Can be combined with manually triggered or timelapse high resolution still photography and or some sample recovered using ROV manipulator arms. With enough power and data storage there is no limit to duration and coverage. If camera is flown or held above the seabed then low impact.	Under turbid conditions or with high plankton concentrations visibility can be impaired and reflected light from suspended particulates can be an issue in deeper, darker waters. The resolution of video images is often less than still images. High data storage capacity required. Sledge or seabed rover-based systems will damage sensitive habitats.
Biological – still photos	When set-up well and with high (>10 megapixels (MP)) and ultra-high resolution (>20 MP); still photos can give very good images for mobile and epifaunal ID. Some signs of infauna (siphons, shell edges, burrows, faecal deposits etc.) can also be seen. Vertical shots can be useful for counting and coverage area estimation where lasers are used.	Still camera set-ups often do not have surface feedback, so shot set-up can be more random. Combining stills with a video feed is likely the best combination.

Classification and example	Benefits	Limitations
	Oblique landscapes and seascapes can be very effective for understanding context. A non-intrusive method of sample generation. Still images are more memory efficient than video. May be used for stakeholder engagement (e.g., public, fishers, NGOs, regulators).	
Biological sampling – seabed or intertidal sample recovery	*As above for physical habitat characterisation – plus:* Enables subsequent taxonomic identification, morphological measurement, fecundity assessment, food/stomach item analysis, biochemical, chemical and DNA analysis. Reduces some uncertainties linked to remote sampling methods and can verify assumptions and judgements made.	*As above for physical habitat characterisation – plus:* Careful treatment needed to preserve specimens for later analysis. Care needed to avoid damaging specimens. Sieving techniques select a certain size restriction of the fauna for the analysis. Tends to focus on infauna using grabs and does not deal with mobile, widely spaced or rarely occurring species, where trawls may be more appropriate. Number of samples obtained and area sampled generally lower than for imagery methods.
Chemical sampling - seabed or intertidal sample recovery	*As above for habitat characterisation and biology – plus:* Fills gaps linked to remote sampling methods and can verify assumptions and judgements made regarding why certain species may be present/absent such as organic material status, oxygen levels, any toxicant levels etc.	*As above for habitat characterisation and biology – plus:* Sample gathering needs to adopt strict QC standards from the outset specifically relevant to any subsequent analysis being planned to avoid contamination.

6.3 Assessing analytical techniques

There are many analytical techniques undertaken and applied to physical and digital samples of the seabed which can be used in the context of Scottish MREDs. Such techniques provide data suitable for informing on the primary objectives for planning and licensing at each key development stage.

Some of the traditional methods of analysing seabed data such as PSA or PSD, taxonomic macrobenthic analysis and physio-chemical techniques are likely to continue to be used in the future since they are quantitative, well-established, work well and are conducted under strict quality control standards in laboratory conditions. Any new additional or replacement techniques would need to demonstrate similar compliance and alignment with standards. However, as novel techniques such as eDNA and BRUVs develop and our understanding of their accuracy and precision increase, there is potential for this additional information to be of benefit to survey outcomes by augmenting the established approaches.

In identifying the suite of analytical techniques available, the user may choose to identify the techniques best suited to the stage of a development whilst factoring in site specific conditions and characteristics. Table 6.2 summarises the benefits and limitations of traditional analytical techniques whilst Table 6.3 summarises the benefits and limitations of novel analytical techniques that may be used to inform various stages of project development and seabed ecology assessment.

Table 6.2 The benefits and limitations of traditional approaches that may be used for benthic surveying within MREDs.

Purpose and sample analysis technique	Benefits	Limitations
Physical habitat characterisation – skilled eye interpretation	The utilisation of either direct observations, remotely gathered images and/or other supporting data by experienced subject experts provides an insightful approach to habitat characterisation. The ability to contextualise any determinations is particularly useful. It is also likely that a more nuanced insight into the conditions and any pressures or	Getting specialists for direct observations to all locations can be challenging, particularly in deep and/or turbid waters, areas with strong currents, large waves, beaches with cliff backdrops and steep shorelines and across multiple locations in archipelagic geography. The availability of suitably competent and experienced surveyors may be limited. Outputs can be subjective and

Purpose and sample analysis technique	Benefits	Limitations
	trends can be considered and provided as well.	lack a quantitative element to provide easy scaling or performance/suitability metrics.
Physical habitat characterisation – slope and texture mapping	A relatively simple data analysis tool which gives insights into seabed morphology and dynamics, as well as geological structure and can inform physical habitat extent estimations for rocky and possibly biogenic reefs, dynamic sediment features etc.	Needs high resolution bathymetry data to be most useful.
Physical habitat characterisation-sediment PSD	Accepted standardised, quantitative and robust methodologies for sediment characterisation.	Limited in application within tidal MRE industry. Cannot be conducted on hard seabed features.
Biological analysis - Taxonomic identification of macrobenthic specimens	Accepted, standardised, quantitative and robust methodologies for identifying macrobenthic assemblages. Outputs include cluster analysis, diversity, richness and evenness which can indicate habitat condition.	Species identification (ID) and sample work up efficiency needs to be consistent and at a high level of accuracy. High level of taxonomy skills required.
Biological analysis - seabed imagery analysis	Accepted, standardised and robust methodologies for conducting seabed imagery analysis. Camera and lighting technology is constantly improving. Imaging reference catalogues (such as BIIGLE) are open source and widely available/adaptable to the requirements of the imagery.	Large datasets are time consuming to analyse. Image quality affected by environmental conditions on site can lead to difficulties when analysing and determining species/habitats. Analyst bias when recording taxonomic and habitat information. Cryptic and mobile/transient/ infaunal species are typically under-recorded.

Purpose and sample analysis technique	Benefits	Limitations
Chemical analysis - laboratory based	Accepted standardised and relatively robust methodologies for identifying concentrations of chemical parameters.	Quality control for environmental chemistry is challenging and the handling of samples once gathered can vary between laboratories leading to inconsistent results. Spatial variability can be quite high at typical sampling scales (e.g., grab based)

Table 6.3 The benefits and limitations of novel analytical techniques that may be used for benthic surveying within MREDs.

Purpose and sample analysis technique	Benefits	Limitations
Physical habitat characterisation - laser profiling	Real-time profiling, measuring and quantification of biomass on subsea structure. Useful for helping to understand the distribution of species across complex hard structures. Less dependent upon good visibility for gathering data. Due to dynamic model building, less dependent upon platform stability, increasing weather window options.	Requires training and experience. High level of skilled personnel required both at sea and on land. Fine scale detailing may be lost compared to high resolution photography. Onsite time needed to gather data longer than other techniques, may increase vessel costs. False colour output from sensor.
Biological and habitats analysis - 3D photogrammetry	Various modelling software packages available. Very useful for helping to understand the distribution of species across complex hard structures. Possible application for establishing detailed understanding of seabed	Data intensive with long processing times. Typically conducted post survey. Requires training and experience. Moderate level of skilled personnel required. Needs good water column visibility.

Purpose and sample analysis technique	Benefits	Limitations
	coverage mosaics over a larger survey area (e.g., 10 m^2).	Works best where there are strong visual indicators of community composition on/at the surface. Onsite time needed to gather data longer than other techniques, may increase vessel costs.
Biological analysis - eDNA	Provides evidence on occurrence of cryptic, rare, and transient/mobile species and benthic species that are difficult to detect and sample using traditional methods. Non-disruptive method. Adaptive to sediment and water column assemblages. Applicable for validating whether previously unrecorded invasive/introduced species have migrated to or colonised a location. As the catalogue of DNA profiled species grows it could provide a relatively rapid check over time of biodiversity within an overall area or from a particular habitat type. Dedicated laboratories are increasing, and industry standards have recently been produced.	Detects occurrence only. Cannot be used to quantify abundance reliably. Skilled and experienced personnel required to interpret results. Requires training and laboratory experience. Attribution of a positive result to a particular location varies depending upon how/where sample is taken (water vs sediment; duration of DNA in environment).
Biological analysis - BRUVs	Provide evidence on transient/mobile species that may be under-sampled using traditional methods. Non-intrusive method.	No standardisation. Not suitable in strong currents. Bias to scavenger and opportunistic species. No standardised analytical methodology.

Purpose and sample analysis technique	Benefits	Limitations
	Open-source statistical software to conduct maximum entropy (Maxent) modelling. Requires some training. Low skill level required. Sample new or under-represented cohort of demersal/benthic species in terms of mobile predators and scavengers. Timelapse may help give insight into surface seabed processes such as burrowing, sediment turnover, rates of specimen movement. Could be applied to monitoring of deposited biofouling impacts.	Area over which observed species are recorded is unclear. Does not sample non-predatory mobile fauna. Requires a return to the site after a period of time to recover the system and data. This can lead to extra cost and challenging logistics. Recovery of untethered seabed equipment can be unreliable.

6.4 Assessing the pros and cons of various data handling techniques

Once a particular type of analysis has been completed, the data often needs to be further processed or contextualised in order to make it usable, or more easily understood. There are several post-analysis tools and frameworks that are used and some of these are considered below in the contexts of their benefits and limitations (see Table 6.4).

Table 6.4 Assessment of the benefits and limitations of different data outputs arising from the analysis options.

Type of data outputs and presentation	Benefits	Limitations
BSH Classifications	Broad classification of the key habitats based on the physical nature of the seabed. Can be displayed visually on mapping software. Widely used and standardised classification schemes are used	Does not factor in the biology. Mixed and coarse sediments can be difficult to differentiate. Relies on the quality of the imagery and the analysts' experience.

Type of data outputs and presentation	Benefits	Limitations
	which are interchangeable (MHC/EUNIS).	
Biotope Classifications	Fine scale classification of the key habitats based on both the physical and biological nature of the seabed. Can be displayed visually on mapping software. Widely used and standardised classification schemes are used which are interchangeable (MHC/EUNIS).	Relies on the quality of the imagery and the analysts' taxonomic experience. Assumption that every sample will fit into a specific classification. Subjective and outputs can differ between analysts. Moderate skill and training are required.
Conservation Features Mapping	Identification of all features (species and habitats) of conservation interest, e.g., Annex I, PMF and OSPAR features. Some well-established and standardised guidance and methods for categorising/ quantifying the distribution and quality of features. Utilises mapping software that ranges from freely available to expensive.	Subjective and outputs can differ between analysts. Moderate skill and training are required. Relies on in-house or nationally established methods for analysing features that may draw upon available applicable guidance. Relies on the availability and quality of the data to provide confidence scores.
Habitat/Biotope Mapping	The drawing of digital maps can visually display the extent and heterogeneity of habitats and biotopes throughout an area. Digital maps are drawn in mapping software that ranges from freely available to expensive.	Subjective and outputs can differ between analysts. Moderate skill and training are required. Relies on the availability and quality of the data to provide confidence scores. Can be a time-consuming process for intensive sampling regimes.
Predictive Habitat Mapping/Modelling	A faster alternative to digitally drawn maps.	Requires enough data to run and validate the model.

Type of data outputs and presentation	Benefits	Limitations
	More suitable over expansive areas.	Requires enough of each type of BSH observed to provide statistically significant results. Lack of standardisation. Many methods are available and accepted. Less suitable for predicting biological information (biotopes). Moderate skill and training are required.
AI	Many applications for sourcing and organising existing and new data, searching data, calculating key parameters, presentation of results and generating useful outputs. Feedback of good data back into AI-based systems to help with decision making (e.g., route and site finding; carbon accounting; biodiversity net gain assessments).	Concerns that quality control systems for AI are not yet well developed. In most cases major investment needed to set-up a reliable AI system in terms of coding, testing, and quality assurance. Danger of losing key skills such as taxonomic identification if AI used indiscriminately.

7 Benthic surveying – recommendations

7.1 Introduction

Building upon the previous materials presented, this section outlines the recommendations for how to establish the right intensity of benthic ecological survey for MRE activities. In any particular project scenario, the site, technology and purpose of the development will vary. This will lead to distinctive needs, as well as pressures and opportunities that may need to be considered. Consequently, there is no “one size fits all” solution to apply to benthic surveys for MREDs. These recommendations set out the general principles to be applied. Examples and mechanisms for how this might be best achieved have been provided.

Follow on work by a project developer and/or regulator can take these recommendations forward to create more fixed action plans for project-specific outcomes and sets of site conditions. Flexibility in the specifics of what is done and used, adaptability in terms of what is achievable and a high degree of data literacy to handle available data will all be essential.

The basic approach involves:

- Recognising that the right survey solution needs to be found for the prevailing local conditions – any existing knowledge about conditions will influence that need, with greater uncertainty likely leading to greater survey intensity and higher levels of existing knowledge reducing the intensity or providing more focus of work needed.
- Establishing anticipated sensitivity potential and likely project complexity based upon existing information.
- Determining appropriate sampling intensity level for survey design.
- Considering surveying techniques and strategies that are best aligned with the project type, likely habitat types, local sensitivities, and prevailing local conditions.

7.2 Determining sensitivity potential and likely project complexity in a prospective development area

It is clear from the previous sections of this report that objectives and strategies for surveying will vary from place to place based upon the habitats and species present, the logistical challenges of the area, the number of samples needed to characterise a habitat type, the level of environmental sensitivity of the development area and linked routes, as well as the complexity of the proposed project. The combination of these features in any development scenario may lead to different survey intensities being most appropriate.

For relatively small scale and simple projects taking place across low sensitivity habitat areas with a sufficient level of data available, a less intense surveying strategy may be appropriate. However, larger and more complex projects taking place across more sensitive areas will require a higher level of survey intensity to be applied.

This section therefore applies this principle by recommending a level of survey intensity that might be most appropriate taking into account the two core drivers: the potential for environmentally sensitive communities of species to be present (ecological sensitivity); and the likely complexity of a development project in terms of seabed impacts (development complexity). To achieve this, a scheme has been devised to differentiate and define each of the levels of ecological sensitivity (Table 7.1) and development complexity (see Table 7.2).

The ecological sensitivity is based upon three “topic areas”: the likelihood that conservation features will be present; the uniformity of conditions across the area (heterogeneity); and the availability of existing data. The development complexity is also linked to three separate topic areas: the size or scale of activities; the range and types of impact that might arise; and the levels of any existing pressures from other sea user activity (see Table 7.2). Once the level of ecological sensitivity and development complexity have been scored (low, medium or high/complex), these scores can feed into the Survey Intensity Matrix (Table 7.3) to determine the recommended survey approach (Standard, Enhanced or Comprehensive).

Within each of the topic areas in Table 7.1 and Table 7.2, examples have been established to describe different sensitivity and complexity levels. The definitions provided should be seen as examples or guiding principles rather than as prescriptive standards.

These classifications of sensitivity potential should not be conflated with assessments and actual community sensitivity as defined under the Marine Life Information Network (MarLIN), FeAST and Marine Evidence based Sensitivity Assessment (MarESA) schemes. Those schemes deal with the character and sensitivity of a habitat, community or species once detected rather than seeking to identify potential for such types of habitats, community or species to be found in an area.

7.2.1 Classifying environmental sensitivity

To appropriately classify a certain level of sensitivity for a given area, route (or section thereof), existing data, knowledge and understanding should be used to consider which levels the particular site or route correlates to (with reference to Table 7.1).

If the levels of sensitivity score differently for each topic area for a given place (site or route) then the highest, most sensitive ranking is used. However, where the level of sensitivity varies between places within a development site, or along a development corridor, then the level of most appropriate sensitivity should be applied on an area by area, section by section basis. The scale at which such sensitivity classification may be most appropriate is at a hectare (ha) by hectare or 100 m by 100 m level in most instances. The resultant level(s) of sensitivity indicated for the whole development or for individual parts of the development will then be used to cross reference to the right level of survey intensity in the different parts of the overall development area, as described in Section 7.3.

Table 7.1 Classification reference table for core factors of environmental sensitivity potential.

Topic area	Low	Moderate	High
Level of expectation that seabed character has the potential to have conservation features associated with it	Outside designated area. Presence of features of conservation interest unlikely (<0.1% occurrence)	Partially within or crossing designated seabed area. Presence of features of conservation interest likely (0.1-1% occurrence)	Fully or partially within or crossing designated seabed area. Expected that features of conservation interest are present (>1% occurrence)
Heterogeneity across development area	Uniform and stable seabed with little differentiation Sedimentary coastline	Dynamic or slightly varied seabed. Simple rocky coastline with few features, scattered rocks on sedimentary shore	Complex, dynamic and varied seabed in composition and relief. Coastline with many complex features such as rock pools, overhangs etc.
Data availability	High resolution (<5 m) swath bathymetry Seabed video and photos plus some physical seabed sampling results of key features	Moderate resolution (<20 m) swath bathymetry Some seabed video and photos of key features A few existing seabed samples	Low resolution (<50 m) or no swath bathymetry, little other data No existing physical samples of seabed

7.2.2 Classifying development complexity

To classify levels of project complexity, this scheme takes account of impact intensity, scale of facilities and the degree of co-development. These factors are determined by taking into account existing project design, operational plans and information about other activities in the area of interest. These sources would be used to inform the classification of the project in terms of impact intensity, scale and the presence of other nearby or co-located activities as set out in Table 7.2. As with sensitivity, a project may be most appropriately classified as a mix of complexity- the core array and the export cables being classified differently or where a project utilises different technology or operational solutions in different parts of the development. Again, when assigning complexity at a site or to a place, the topic area with the highest level of complexity ascribed is deemed to be dominant.

Table 7.2 Classification reference table for core factors to determine development complexity.

Topic area	Low	Moderate	Complex
Impact intensity of different technology options or planned activities.	Site development approaches with a small seabed footprint <1 ha, no or low level of excavation. Surface laid cables.	Site development approaches with a moderate footprint 1-10 ha, limited excavation and/or sediment resuspension. Cables buried by specialised wand burial system.	Site development approaches with a larger footprint >10 ha widespread sediment resuspension. Trench and fill or rock protection of cables.
Scale of planned activities (number, area, length, size, mass)	Smaller scale development, <10 devices and one export cable.	Moderate scale development with 10-100 devices and two or three export cables.	Large scale development with >100 devices and three or more export cables.
Existing pressures from other activities	No or few co-located activities with the potential for cumulative effects.	Co-location of activity or activities with some potential for cumulative effects.	Nearby or co-located activities that have a significant potential for cumulative effects.

The resultant level of complexity indicated for the whole project or for individual parts of the projects will then be used to cross reference to the right level of survey intensity as described in Section 7.3.

This scheme provides an indicative framework for ascribing sensitivity and complexity levels. On a site/project-specific basis there may also be additional features or issues that suggest it might be appropriate to alter the classification up or down accordingly. Diversion from this generalised framework can be discussed with the relevant regulators and stakeholders.

7.3 Establishing appropriate surveying intensity levels

Having established a mechanism for classifying the level of sensitivity potential and development complexity for a prospective MRED, the next step is to integrate these two factors to indicate an appropriate level of survey intensity to apply to such an area. The approach is to use a simple interaction framework as shown below (Table 7.3.). This framework indicates the given level of survey intensity that is appropriate for each combination of sensitivity potential and project complexity. Three levels of intensity are used: Standard; Enhanced; and Comprehensive.

Table 7.3 Survey Intensity Framework illustrating the relationships between complexity and sensitivity and how they should be applied to determine a survey intensity approach (escalating environmental sensitivity factors derived from Table 7.1 and development complexity levels (derived from Table 7.2).

	Escalating complexity factors - **Low**	Escalating complexity factors - **Moderate**	Escalating complexity factors - **Complex**
Habitat sensitivity levels - Low	Standard	Standard	Enhanced
Habitat sensitivity levels - Moderate	Standard	Enhanced	Enhanced
Habitat sensitivity levels - High	Enhanced	Comprehensive	Comprehensive

Further explanation of the likely survey strategies associated with each intensity level is provided in the following paragraphs.

- **Standard** – The minimum sampling required to collect at a site, including metadata and QC standards. Aimed at confirming presence/absence of indicator species in different identified habitat types implied from topographical/bathymetry data and existing/established knowledge and understanding.
- **Enhanced** – It may be necessary to collect additional data beyond the standard approach. For example, if more sensitive or vulnerable species or habitats are expected or detected. Additional benthic data can also be collected that enhances the value of the data at a local level that is compatible with a secondary purpose such as

legacy creation, incorporation into regional or national models, data sharing with nearby projects and/or supporting research initiatives. This level of activity may also demonstrate enhanced corporate responsibility.

- **Comprehensive** – It may be beneficial to undertake a broad suite of benthic surveying techniques where key issues and concerns are shown to be active and dynamic, either due to ongoing nearby activities or where known pressures exist or where particularly vulnerable species and/or communities exist. Additional benthic data can be collected that greatly enhances the value of the data spatially and temporally, at a regional/national level that is widely compatible with secondary purposes (legacy/data sharing). Demonstrating a high level of corporate responsibility including marine net gain/nature positive approaches.

The classification of such survey intensity levels can provide two kinds of direction to any survey plan. Firstly, it can help ensure that the appropriate level of survey is undertaken for the conditions and circumstances that prevail. Secondly, the potential to increase survey intensity strategies can create an opportunity for wider social, science, or reputational benefits.

Whilst it might be easiest to apply this scheme where the development area is characterised by one level of sensitivity potential and one level of project complexity, the reality of MREDs around Scotland may not be that simple. There will be cases where the energy generation area, the cable/pipeline export route and the landfall for a project all have different levels of sensitivity potential and complexity. There may also be variation in such parameters along a cable/pipeline route or in different parts of generation device deployment area. A project itself may therefore have a mosaic of intensity levels that are appropriate.

This may lead to a surveying approach that has different sample numbers and indeed sample types gathered within each area of different sensitivity/complexity. The resultant targeting of effort to where it is most needed and best applied will help maintain survey effectiveness and efficiency at the same time and gives overall coherency and understanding for consenting and monitoring purposes.

To achieve this outcome, the exact configuration of survey effort in any particular place, at any time and for any particular purpose, will need to be agreed between the regulator, key stakeholders, the developer and wherever possible, the survey and consenting contractors, or similarly experienced advisors.

7.4 Applying specific surveying tools and techniques within the suggested survey intensity scheme

Building on from the Survey Intensity Framework, it is possible to align specific surveying tools to each level of seabed community investigation based on the required outputs for assigning samples or areas to the MHC and EUNIS classification systems. These classifications of seafloor habitats are organised in a hierarchy whereby each level introduces more detail. For example, the MHC starts at Level 1 “Marine” and in the EUNIS hierarchy, the first three levels describe the habitats (i.e. the abiotic part) while the last three describe the biotopes (i.e. habitats and benthic communities that occupy them). The first major division in the benthic marine part of the EUNIS classification is based on major biological zones (related to depth) and substrate type. As the hierarchical levels progress in resolution, more information is included in the descriptions. At level 4 the MHC describes a “Biotope Complex”, and at a high-resolution, records include typical prominent species (level 5: Biotopes). In some cases, these biotopes can be split into sub-biotopes where distinct sub-habitats can be described, and these generally describe a wider range of macrofaunal species.

These classification hierarchies are also aligned with a progression of data types and acquisition tools needed to provide the data used for community characterisation with increasing precision at the higher MHC/EUNIS levels. At the broad habitat level, remote sensing geophysical techniques are often used, at the next level visual video confirmation is often employed. At the third level, still photos can be very helpful and for the fourth and fifth levels increasing numbers of samples, or applying multiple techniques to get a fuller picture of the habitat may be used (e.g., grab and video). This scheme can be augmented by additional chemical and geotechnical analysis of samples where required as well as by other more detailed ecological studies.

An indication of the survey approaches and examples of tools used to obtain the required outputs at each level of the habitat classification hierarchies has been provided in Table 7.4. The EUNIS hierarchy and associated survey approaches can be applied to different stages of MRE developments. Table 7.5, 7.6 and 7.7 outline the surveying strategies that might be most appropriate for development projects of different types, with different intensity needs (based upon sensitivity and complexity) and at the various stages of the development cycle. Table 7.5 presents the anticipated surveying strategies expressed by the levels of habitat description likely to be required for **Standard** survey intensity, Table 7.6 for **Enhanced** survey intensity and Table 7.7 for **Comprehensive** survey intensity.

Table 7.4 Progression of the seabed community characterisation hierarchy and the surveying approaches applied based upon MHC and EUNIS classification systems. Example tools/techniques are usually additive, including information from the higher levels while adding information with more descriptive techniques at each level.

MHC classification	EUNIS classification	Description	Example tools/techniques
Broad habitats	EUNIS habitat level 2	Predicted habitat type	Existing data Geophysical surveys EUSeamap data
Main habitats	EUNIS habitat level 3	Visually observed habitat type	Video transects Oblique stills imagery PSD
Biotope complexes	EUNIS community level 4	Observed indicator species	Video and stills imagery
Biotopes	EUNIS community level 5	Sampled key species	Minimal replicate grab samples or core samples
Sub biotopes	EUNIS community level 6	Sampled wider species assemblage	More replicate samples from grabs and corers Specimen collection via SCUBA/ROV
Additional	Research (level R)	Sampled full species catalogue and investigation of other factors or interactions	BRUV, eDNA, photogrammetry, isotope tracking, settlement trays, colonisation trays, autonomous vehicles

Table 7.5 Overview of applicable surveying types for different development stages of a project across different technologies **for standard survey intensity**. Numbers are based on the EUNIS classification system displayed in Table 7.4.

Stage of development		Small wind	Large wind	Small tidal	Large tidal	Small wave	Large wave	Cable	Landfall
Characterisation	Option evaluation	2-3	2-3	2-3	2-3	2-3	2-3	2	2
Characterisation	Scoping	4-5	4-5	2-3	3	2-3	3	2-3	3
Characterisation	EIA	5	5	3	3-4	3	3-4	3	3-4
Pre-operations	Pre-operation baseline	5	5	3	4	3	4-5	3	3
Operations	Monitoring	5	5	3	4	3-4	4-5	3	3
Decommissioning	Pre-decommissioning	5	5	3	4	3-4	4-5	4	3
Decommissioning	Post-decommissioning	4-5	5	3	4	3-4	4	3	3

Table 7.6 Overview of applicable surveying types for different development stages of a project across different technologies **for enhanced survey intensity**. Numbers are based on the EUNIS classification system displayed in Table 7.4.

Stage of development		Small wind	Large wind	Small tidal	Large tidal	Small wave	Large wave	Cable	Landfall
Characterisation	Option evaluation	2-3	2-3	2-3	2-3	2-3	2-3	2	2
Characterisation	Scoping	4-5	4-5	2-3	3	2-3	3	2-3	3
Characterisation	EIA	5	5	3	3-4	3	3-4	3-5	4-5
Pre-operations	Pre-operation baseline	5	5-6	3-4	4	3-4	4-5	3-5	3-4
Operations	Monitoring	5	5-6	3-4	4	3-4	4-5	3-5	3-4
Decommissioning	Pre-decommissioning	5	5-6	3	4	3-4	4-5	3-5	3-4
Decommissioning	Post-decommissioning	4-5	5-6	3	4	3-4	4	3	3

Table 7.7 Overview of applicable surveying types for different development stages of a project across different technologies **for comprehensive survey intensity**. Numbers are based on the EUNIS classification system displayed in Table 7.4.

Stage of development		Small wind	Large wind	Small tidal	Large tidal	Small wave	Large wave	Cable	Landfall
Characterisation	Option evaluation	2-3	2-3	2-3	2-3	2-3	2-3	2-3	2-3
Characterisation	Scoping	4-5	4-5	2-3	4-5	2-3	4-5	2-3	3-4
Characterisation	EIA	5	5	3-4	4-5	3-4	5	4-5	4-5
Pre-operations	Pre-operation baseline	5-R	5-R	4	4-R	4	5-R	4-5	4-5
Operations	Monitoring	5-R	5-R	4	4-R	4	5-R	4-5	4-5
Decommissioning	Pre-decommissioning	5	5-6	3-4	4-5	4	5-6	4	4-5
Decommissioning	Post-decommissioning	4-5	5-6	3	4-5	3-4	5-6	3	4-5

8 Stakeholder engagement, survey process flow chart and stakeholder of roles

A key aim of this study has been to establish a staged process that helps guide project developers, survey practitioners, regulators and advisors towards a consensual understanding of what might be an appropriate seabed ecology survey strategy for a given set of circumstances.

8.1 Stakeholder views on benthic survey techniques and designs

The project undertook a variety of stakeholder engagement approaches to collate views on benthic survey techniques and sampling designs from a range of different groups. One approach was to convene a steering group comprising representatives with expertise relevant to MREDs in Scotland. A second was to ask for feedback on preliminary findings from a group of sector and surveying specialists.

The questionnaire respondents were Consultants, Government Researcher, Nature Intelligence Provider, Contractor, Stakeholder Consultee, Commercial Researcher, Academic Researcher and Lecturer.

The respondents who are active in sampling projects work globally across many sectors. Nationally, the focus of roles was on offshore wind with half of the respondents involved in this sector, with wave and tidal technology sectors having less representation. Only one respondent said they worked wholly in non-renewables sectors.

The conclusions drawn from these engagements were as follows:

- Most stakeholders agreed with the study scoping assumptions made, although some useful small additions were made with regards to effects of nature enhancement, assessing residual impacts, implementation of certain novel sampling approaches and the addition of further impact mechanisms to consider.
- The importance of establishing clear objectives during the design of benthic monitoring surveys was highlighted. Further questions to be considered at this stage were highlighted as:
    - What is the purpose (what is the survey trying to achieve)?
    - What are the thresholds for significant impacts?
    - What is the baseline?
    - Could the baseline be shifting?

- It was also raised that it is important to consider the cost implications of different survey approaches and analysis and that it could be useful to stratify sampling based on habitat heterogeneity and sensitivity. Cost was considered in the evaluation matrix and habitat heterogeneity was incorporated into the recommendations for sampling approach (see Section 6) to take account for these comments.
- The use of existing datasets can be of value and importance. For example, it is possible to use existing data to make assumptions at the scoping stage of the likely significance of possible impact pathways. As such, not all pathways may necessarily need to be investigated further and surveyed.
- Data collection should be carried out in a way that ensures it can be used in ecosystem models; this would have genuine value and not just be a 'tick-box' exercise.
- Collecting the survey data in a way that it is MEDIN compatible would add value to the data captured and make it reusable.

There were divergent opinions across the stakeholder spectrum about the level of survey intensity needed to adequately address MRED consenting and monitoring issues. This helped to inform the three-level approach covered by standard, enhanced and comprehensive survey intensity levels based upon categorisation of environmental sensitivity and project complexity.

The 'standard' approach to surveys and data gathering will hopefully provide the highest priority data cost effectively and can create a foundation for a more detailed follow-up survey. Where there is a key sensitivity, a priority knowledge gap, or to meet wider goals, additional control reference sites, greater survey effort and wider scope can be undertaken when required or desired.

8.2 Process list for survey planning processes and stakeholder roles

At the start of the investigation process for this project, it was anticipated that a single surveying model approach might be possible to achieve. However, it became clear that the diversity of development types, scale of arising issues, and variety of operating conditions would mean that a more flexible approach was needed.

Since the projects being catered for in this study vary from prototype testing of small new technology of a few hundred kilowatts (kW) capacity, through to large-scale commercial farms of multi-GW capacity, there is likely to be a range of survey implementation strategies adopted.

The process envisaged for that progression for a surveyor or survey planner is laid out in Table 8.1. By going through the table and checking that all the listed planning and executing practices are being undertaken, the project will have the best opportunity to handle any seabed ecology issues associated with the project.

Table 8.1 Task flow for planning and undertaking seabed survey for MRE projects around Scotland. Follow the list of factors to consider throughout the survey planning process, under 'context; scoping; assessment and results'. There are 32 action areas defined.

Stage 1. Context

Sub-stages	Factors to consider	User actions to be completed	Examples that could be covered
Objective setting and priority setting	Primary objectives	Identify the stage of the project, the associated regulatory needs and key project objectives	Characterisation Baseline Monitoring Decommissioning regulatory requirements
Objective setting and priority setting	Secondary objectives	Identify secondary objectives, e.g., research and data gaps that aren't the key focus, but which need to be considered	Use of local resources Early liaison with fishers Enhancement and recovery Biofouling enrichment Predator and foraging links
Objective setting and priority setting	Priorities	Provide resource to deliver the objectives in order of priority	List key actions and resources allocated
Objective setting and priority setting	Standards	Identify the minimum standards that to be followed and upheld	Statutory and advisory Lab analysis standards
Existing knowledge of operating environment	Habitats and species	Collate information on seabed habitats/species across and near to the survey area.	Mobile megafauna, epifauna, infauna (diversity, community composition, and/or abundance).
Existing knowledge of operating environment	Physical	Collate information on physical aspects of the survey area.	Seabed/subsea composition Hydrodynamics Weather

Sub-stages	Factors to consider	User actions to be completed	Examples that could be covered
Existing knowledge of operating environment	Chemical	Collate information on baseline chemical composition of the seabed within the survey area.	Baseline information e.g., heavy metals, hydrocarbons, organic carbon.
Existing knowledge of operating environment	Co-located activities	Collate information on occurrence, extent, or proximity of co-located activities or historical activities from other marine sectors.	Cables, pipelines, oil and gas installation, oil and gas wells, disposal sites, military ranges, fish farm sites, outfalls, fishing areas, aggregate extraction areas.
Existing knowledge of operating environment	Operating conditions	Collate information about and experience of operational conditions for surveying.	Normal, extreme, patterns of change, weather windows, safe haven proximity, particular hazards etc.
Existing data and research	Data quality	Identify if the quality of existing data is suitable for the purpose of the current survey.	Type, accuracy, timeliness, coverage (extent and density).
Existing data and research	Data availability	Determine if the data is accessible and able to be used.	Data format Intellectual property and ownership

Stage 2: Scoping

Once the user has satisfied all the objectives of Stage 1, using the data gathered move on to Stage 2.

Sub-stages	Factors to consider	User actions to be completed	Examples that could be covered
Habitats	PMF, Annex I	Identify the likely presence and distribution habitats of conservation importance in/near the survey area.	Sandbanks Reefs
Species/communities	PMF, Annex I,	Identify the likely presence and distribution of species/communities of conservation importance in/near the survey area.	Maerl, horse mussels, ocean quahog.

Sub-stages	Factors to consider	User actions to be completed	Examples that could be covered
Conservation designation	Protected sites network	Identify the conservation designations within or in proximity to the survey area.	SAC Nature Conservation Marine Protected Areas (NCMPA) Sites of Special Scientific Interest (SSSI) PMFs
Impacting activities	Direct impacts	Identify potential pressures on habitats and species.	Habitat loss, surface abrasion, INNS
Impacting activities	Indirect impacts	Identify the pressures that may cause secondary impacts to habitats and species or co-located/nearby.	Changing climate-linked conditions, dispersed pollutants, fishing
Survey tools and techniques available	Survey requirements	Identify the suitable methods given the objectives and conditions.	Explain why and how factors match objectives and conditions.
Survey tools and techniques available	Robustness	Identify key factors determining robustness scientifically robust, sector appropriate, and MEDIN compliant.	Explain why each factor has been chosen and how they match objectives and conditions.
Survey tools and techniques available	Replicability and limitations	If novel methods are utilised, consider their robustness/longevity/suitability over lifespan of a project.	Outline key limits on any techniques considered.
Survey tools and techniques available	Replicability and limitations	Consider the feasibility of repeat application over lifespan of a project.	Outline reasoning.
Tools and technology	Availability	Identify which tools and technologies are available to use in a particular location and take positive steps to broaden availability where needed.	Consider progressive partnership type procurement strategies which encourage capacity building locally.

Sub-stages	Factors to consider	User actions to be completed	Examples that could be covered
Tools and technology	Suitability	With reference to the Annex I: Identify which tools and technologies are most suitable for your project and the stage it is at. Consider how to best maintain consistency across multiple project stages.	Identify best tools from matrix regards reliability, synergy, complementarity, and novelty. Seek approaches which reduce impact, footprint, mortality, noise, fuel use, carbon emissions, obstacle or obstruction to others.

Stage 3. Survey assessment

Once the user has satisfied all the objectives of Stage 2, move on to Stage 3.

Sub-stages	Factors to consider	User actions to be completed	Examples that could be covered
Survey intensity	Project complexity and environmental sensitivity factors	Referring to Tables 6.1 and 6.2 and the results of Stage 1 and Stage 2 identify whether your survey area is categorised as "High", "Medium", or "Low." sensitivity and complexity.	Establish the intensity of survey suggested, either 'standard'; 'enhanced'; or 'comprehensive'.
Level of community classification	EUNIS or MHC investigation levels	Based on the results of "Survey Intensity" and the survey objectives, identify the scale at which habitats will be classified as indicated in Table 6.4.	Broadscale – remote sensed, physical habitat Main habitat – observed, physical habitat Biotope complexes – indicator species present. Biotope – list of dominant species. Sub-biotope – comprehensive species list. Additional research areas.
Survey design	Survey design and approach	Referring to Sections 3.6.3 - 3.6.5, and the results of Stage 1 and Stage 2 identify which survey design approach is most suitable (gradient or stratified).	Consider habitat and feature targets for sampling at pre-operational stage and to identify suitable control sites. Consider which development facilities to

Sub-stages	Factors to consider	User actions to be completed	Examples that could be covered
			target as locations for future monitoring operations and ensure baseline surveys are completed.
Survey design	Co-located or historical activity	Identify whether additional samples within survey area and reference/control sites are required to verify the influence or otherwise of nearby activities.	Add sampling locations as needed.
Sampling procedure	Quantity	From results of Stage 1 and Stage 2, and if needed power analysis calculations, identify how many samples at each site/habitat type are required from each category?	Minimally, 150 m video Minimally, 10-20 photos Minimally, 1-3 grabs (sediment) Minimally, 3-5 grabs (ecological) Minimally, 1-3 grabs (chemical)
Sampling procedure	Location	Sample placement throughout the survey area, including control site(s).	Minimally, 3 per broadscale habitat (BSH) Minimally, 1 out of every 10 facility locations (generators/ sub stations) <50 m from device <5 m from cable/pipeline
Sampling procedure	Timing	Based on results of Stage 1 and Stage 2 identify appropriate timings to conduct surveys that reduce temporal bias and promote the collection of high-quality data.	Consider: weather, tidal cycle, seasonality, residual swell regime, water currents etc.

Stage 4. Survey results

Once the user has satisfied all the objectives of Stage 3, move on to Stage 4.

Sub-stages	Factors to consider	User actions to be completed	Examples that could be covered
Analytical	Biodiversity metrics	Will the results of Stage 1 though to Stage 3 provide you with data suitable to establish/calculate the desired biodiversity metrics? If no, identify why and return to relevant row above to rectify.	Species biodiversity metric Species richness Species biomass
Data transparency	MEDIN	Will the obtained data and corresponding metadata be suitable to submit to MEDIN? If no identify why and return to relevant row above.	Change data to be MEDIN compliant
Data transparency	Data sharing/data repositories	Will the data obtained be suitable to share on a data repository (e.g., NMPi/GeMS) or wider strategic survey programme.	Prepare to share data with others.

9 Study discussion and conclusions

This study has undertaken a structured process of context building; scoping; evaluating survey techniques available and strategies required; and then formulating a framework of recommendations about what surveys can be implemented, most appropriately, at various stages of development and for various development types. Building from those survey framework recommendations, the following sections provide additional reflections, recommendations and conclusions in the key topic areas defined for this study.

9.1 Review of existing benthic ecology survey guidance, survey techniques, and data flows currently employed at offshore renewables sites in the UK and internationally

A significant volume of guidance and recommendations have been published about practices for surveying seabed ecology, but to date they have been prepared for geographies other than Scotland and to meet different sets of objectives, purposes and policies. Consequently, although most of the materials are generally coherent, and provide useful insights and findings, they are not necessarily consistent nor particularly relevant to the permitting and monitoring of MREDs in Scottish waters. For example, many documents have been developed for reference and theoretical validation rather than for practical use.

Therefore, the conclusion reached was that although certain principles and approaches could be harvested from existing guidance and study results, the application of this previous work to Scotland's and MRED's needs would require some adaptation.

The key areas of differentiation were:

- Recognising that there is a need to achieve a balance between the detail/volume of data gathered and its functional use or purpose. More data does not necessarily provide greater understanding or insight into an issue.
- Considering the likely extent of any impact mechanisms and the levels of feature sensitivity should feed into the survey design at an early stage to enable survey activity to focus on priority impact pathways.
- Adopting the MHC/EUNIS levels of marine habitat and community classification as a core descriptor of needed survey intensity and delivered survey capacity.
- Recognising that sea and seabed conditions are different to those encountered in other parts of the UK and Europe and contribute as a major factor to planning and undertaking seabed surveys in Scotland. Typical conditions include greater water

depths, wider prevalence of rock, more exposed areas, different daylight patterns, greater transit times, etc.

- MREDs, and particularly offshore wind farms in Scotland, will be installed at a larger scale than in many other places. This could mean that they interact with many different habitats, leading to a greater range of survey techniques being needed on any given project.
- The close proximity of a number of likely development sites to each other may heighten the need for cumulative effects to be considered.
- Acknowledging that a different pathway to sectoral development has taken place in Scotland, in comparison to the rest of UK, with earlier implementation of wave and tidal testing and demonstration, but later expansion of offshore wind – enabling more established learning to be applied.
- If a regional-scale strategic benthic sampling approach was adopted for Scotland, a suitable division of regions would be required to ensure sampling is locally relevant. At present the Scottish marine area is divided into eleven regions for regional marine planning purposes. These may provide a suitable basis for regional survey management.
- Recognising that under a standard level of community sensitivity and project complexity, the evaluation and assessment of seabed impacts takes place at a descriptive level equivalent to Levels 3 and 4 on the MHC/EUNIS scale.
- Appreciating that there is existing data and established understanding about Scottish waters in various locations and organisations that to date have not been uploaded to present data sharing platforms. The data sources include survey contractor records, academic research records, ecological advisors, fishing organisation, fishers themselves, scuba divers etc.
- Acknowledging that surveying is not always necessary for reaching a clear and robust conclusion for certain objectives or questions being asked. There are times where modelling, detailed analysis and sometimes conceptual analysis of a situation can lead to the required clarity and help to determine the best next steps.

9.2 Review and assessment of new, emerging survey technologies and analytical techniques that could be applied to MREDs

Within the range of seabed ecology surveying tools and techniques reviewed for this project, there were a number that were considered to be new and/or emerging. The new and emerging techniques reviewed were primarily relevant to the analysis stage of a sampling approach. As such, these are described in section 3.5.3 which reviews the literature relevant to these techniques as well as further information in the dedicated section on Novel Analytical Techniques (3.6.1). Some of the methods (e.g., eDNA) were assessed in the Evaluation Matrix and associated results in section 6.4. Of these tools and techniques, a few were considered to be potentially relevant to supporting MREDs consenting processes. However, during the assessment it became clear that at present, these should be viewed as being optional additions to the existing suite of tools and techniques rather than being replacements.

A short commentary of each of the options considered and their possible pathway to greater use is provided below:

- Reconfiguring BRUV timelapse photo/video surveillance to record movement and behaviour across an area of seabed surface - this might illuminate the movement of macrofauna (crustaceans, echinoderms, molluscs, small fish) through the area, for example. The data could also show the behaviour of tentacles, siphons, burrows and other feeding/foraging mechanisms of infauna and the behaviour of any epifauna present. Such outputs could be applied to assessments on potential organic enrichment effects from biofouling deposits, for example, or used for establishing new ecosystem function measures of community health linked to defining recovery from impacts such as excavation or sediment deposition.
- Enhanced imaging techniques clearly add new dimensions to imaging and expand what can be seen and understood, but they are unlikely to replace ROV/sledge video or high-resolution drop-down photography since these techniques provide alternative or additional real colour visual capacity at relatively low costs. A possible new development could be to integrate this technology with autonomous survey drones that could operate untethered, but which could still send back real-time imagery to an offshore or onshore control centre.
- Two clear uses for eDNA are to check for any INNS (where DNA has already been catalogued) and/or to confirm the presence of species that are too sporadic, cryptic, or hidden to be effectively sampled by existing video, photo, grab and coring techniques. For both purposes, improving the DNA genetic sequence databases to include sequences for more seabed species will be key for the development of this technique. Further research is also required to calibrate the method to be confident that a positive DNA result is representative of a particular locality within a given range. Linked to that is the significance of an absence result. Present techniques are accepted as useful despite rogue absence of species in some samples due to the species being too thinly spread or located too deep in the sediment for example. There is a question therefore about how an absence of eDNA result should be interpreted given the longevity of eDNA, how much it might get re-distributed and at what levels it becomes detectable. However, these limitations should be considered in the context of limitations of existing methods where species may be too difficult to detect or identify.

- The application of AI is already taking place at some level within the seabed surveys to help surveyors, taxonomists and seabed survey experts. The key question is perhaps whether AI will open-up or majorly advance certain approaches which traditionally use non or limited AI processes. Some possible examples of AI applications include:
  - Shape/pattern recognition: developing suitable recognition protocols to stimulate a camera or sensor to take video, stills image or a sample when something specific has happened.
  - Shape/pattern recognition: analysis of captured video clips and stills to recognise specimens, species, behavioural traits in sequences and shots.
  - Rapid quantification/counting: Real-time tallying of identifiable features in acoustic, laser or visual spectrum data sets.
  - 3D scanning: recognition of taxonomic specimens or features on surface of seabed.
- Seabed tractor technology is already used to assist in the laying of cables and pipelines as well in checking their status and condition. A key next step is to enable such vehicles to manoeuvre untethered over the seabed. This could be especially useful in areas where tethered craft are difficult to control such as in strong currents or heavy seas. They could also be used to cover transects repeatedly over time, perhaps servicing a cluster of sampling stations with one vehicle.

9.3 An assessment of the most effective methods and sampling designs for different monitoring requirements and objectives

This study has shown that there are a large array of potential tools and approaches that could be applied to surveying seabed ecology in Scotland around MRE projects. However, when the context for this surveying activity is considered, including the purpose; the type of habitats present; the communities and species found; the ambient operating conditions; and the quality and utility of the data gathered, there are nine core tools/techniques (summarised below).

This suite of selected tools creates a gradient of increasingly detailed insight into ecological conditions and status. This gradient can be broadly structured into three categories as follows:

- The geophysical remote sensing techniques give insights about the ecology present.
- The visual tools start to provide evidence of the key indicator species present.
- The physical biological material samples recovered by divers, grabs or box cores provide tangible evidence of the species present and increasing intensity of sampling

gives increasingly comprehensive insights into the details of seabed ecosystem character.

The recommended tools/techniques are listed below:

- Swath bathymetry which reveals the depth and shape of the seabed, and from that some key seabed forms and textures. These can infer certain seabed types, objects and/or bedforms (e.g., relict rocks, faults, sandbanks, sand waves, debris, wrecks, cables, pipelines, trawl scars).
- Geophysical surveying techniques which reveal the near surface structure of the seabed confirming certain seabed types (e.g., bedrock, broken rock, gravel, sand, mud) and depths of these features.
- Video transects along pre-defined seabed routes or exploring new territory (e.g., smaller scale surface features such as ripples, sediment veneers on rock, larger epifaunal and surface living fauna and flora). These videos obtained by cameras deployed by towed sledge, tethered ROV, diver and possibly untethered AUV.
- Still images of seabed communities, taken vertically or obliquely, giving high resolution and wide depth of field images. These enable a greater range of smaller and quicker moving species to be more easily identified as well as finer scale detail of underlying habitat type to be described. The choice of vertical or oblique views will link to the specific purpose and target features of interest, with horizontal detection and quantitative use needing vertical orientation and more vertical target features and background context suiting a more oblique orientation.
- Diver observations of seabed conditions along with photography or specimen collection – this is particularly useful in shallow, and tide swept areas where other forms of sampling may be more difficult to deploy.
- ROV recovery of seabed rocks, sediment and sea life specimens – again, this is particularly useful in shallow, and tide swept areas where other forms of sampling may be more difficult to deploy.
- Grab sampling of seabed sediments and biota – undertaken across a wide range of sediment habitat types but becomes limited in coarser gravels and areas with many stones present. Both conditions stop the grab system closing, leading to sample wash out.
- Box core sampling of seabed sediments and biota – particularly for medium to finer sediments where a larger sample is beneficial.
- Sediment coring – used where relatively undisturbed samples need to be taken.

These tools are also not necessarily applicable ‘en masse’ to every surveying task. There are key differences over the data needed for projects of different scales, the MRE technology types deployed and the location and therefore ambient conditions encountered. The right tool needs to be applied in the right circumstance.

This study has not specifically defined the relationship between condition and technology since there are so many variables to consider. The principles and options underlying that choice have been set out in the previous sections and particularly in the accompanying Appendix 1 Evaluation Matrix for tools and technologies, which reviews the suitability of all tools and techniques. However, the following sections discuss how different surveying approaches may be applied to address different objectives, including to assess feature extent, distribution and condition and monitoring changes over time.

9.4 How can the proposed scheme be used to describe the extent, distribution and condition of benthic species and habitats?

The marine environment comprises a mosaic of species and communities that transition continually from one to another. The extent and distribution of habitats can be determined through physical surveying techniques such as bathymetry and geophysical acoustic surveys. Almost all of the physical features and many of the indicator species for particular habitats are visible in video and photographic images. However, the spatial scale of a baseline or monitoring approach is dependent on the type and diversity species and/or habitats in question and also the heterogeneity of the conditions.

For seabed communities, their extent, distribution and condition can be assessed at different levels using different techniques. The extent of a reef habitat might best be confirmed through ground-truthed geophysical data, the abundance and distribution of indicator species by video or still image records, and the presence or absence of a wider range of macrofaunal species may require samples to be taken and analysed. While direct biological samples (e.g., via grab sampling) can provide a high level of detail on the species composition and diversity which may indicate condition, the small surface area of such samples means that the habitat between samples is unknown and extrapolation or predictive mapping is required to assess other metrics such as extent.

9.5 How can the proposed scheme be used to monitor changes in seabed diversity and community composition over time at different spatial scales?

The capacity for the scheme to meet this objective depends critically upon the scale of spatial and temporal change that is anticipated. At key visual indicator species level and 10s to 100s m resolution the task can be relatively simple; at a full species list level and individual metre by metre level or at an even more localised range it will be much harder, time consuming and expensive.

To address a monitoring objective to detect change, it is necessary to understand what levels and types of changes are typical or happening elsewhere outside the influence of any project (e.g., natural variation), as well as ascertaining what factors may be contributing to any change. This is where control site monitoring may be very helpful or indeed critical (see section 3.6.3 and 3.6.4 for a comparison of different sampling designs including BACI – Before After Control Impact and BAG – Before After Gradient designs).

The length of time and intensity of seabed sampling needed to build an understanding of seabed community changes could also be impractical in the context of the pre-operational consenting process but may be more feasible over the lifetime of a project.

9.6 How can the proposed scheme be used to measure potential habitat recovery and enhancement at different stages of MREDs?

The applicability of a particular tool or technique to assess habitat recovery or enhancement has been included in the Evaluation Matrix in the Evaluation of Performance tab in Appendix 1, where it is considered under the secondary use category.

All the shortlisted and recommended sampling techniques suggested in this study and listed in Section 8.1.3 are able to support a seabed habitat enhancement programme linked to an MRED if desired. The specific tool(s) and approach(es) used will be dictated by the level of community definition required to detect the anticipated level of change. It is expected that a higher level of survey intensity will be required to draw conclusions on habitat enhancement or positive effects. Hence the inclusion of nature positive effects in the “comprehensive” survey option in section 6.2. For example, underwater video can be used to confirm general community habitat type, 2-dimensional imagery can help identify surface living species and grab sampling can give before and after details on actual seabed community type.

In addition, novel techniques can play their role alongside older techniques. 3D Photogrammetry can be used to detect positive changes in biomass, eDNA can be used as a relative measure of diversity or species richness over time, while BRUVs can illustrate relative changes in abundance of mobile species or macrofauna. Therefore, a combination of metrics could be used depending on the species present and expected level of change, whilst considering natural variation and any influences from other anthropogenic sources or activities such as climate change and demersal fishing.

It would be of value to design surveys that consider the collection of data for reporting on the recovery and enhancement of species and habitats within MRED areas. If considered from the outset, the appropriate tools and technologies that score highly given the particular habitats and species of interest can be used, and the techniques must be quantifiable so that the output data can be compared over time. For example, macrofaunal data derived from repeated grab samples can be compared as they are obtained from a known volume, likewise for vertical still images with lasers where the seabed area surveyed can be quantified.

Survey planners could also consider the colonisation of new species onto hard substrates that were not present at the characterisation stage (artificial subsea infrastructure), as wells as those that are offered shelter and protection from physical pressures (e.g., fishing) and environmental influences (e.g., changes in sediment mobility caused by artificial obstructions).

One critical factor with regards to detecting and interpreting change is the need to have suitable control sites away from the influence of MREDs activities and restrictions on other sea users. The need for and resourcing of control sampling needs to be carefully considered in any survey plan targeting a 'change' processes.

9.7 How can the proposed scheme be used to quantify potential habitat enrichment from enhanced biomass growing on hard structures?

As reported in a review of offshore wind reef effects by Degraer et al. (2020), there have been various studies undertaken around offshore wind turbines that have shown an increase in fine sediments and associated colonisation by species within 50 m or so of the turbine. There are also indications from these studies that jacket type foundation structures may lead to a greater effect than monopile structures.

Biofouling communities may ‘coalesce’ or ‘condense’ production into a smaller more compact area, and where there are no growth limitations (e.g., nutrients) then enhanced productivity in a localised area may occur. The various mechanisms for localised enrichment of sediments are explored by Degraer et al. (2020) with a key focus upon biofouling community production. However, it may not be possible to disentangle this cause-and-effect relationship with other drivers such as physical changes to current regimes, reduced fishing effort and the behaviour of aggregating fish which may all play a part alongside the production of the colonising biofouling itself.

The findings of Dannheim et al. (2020) agree that the reasons for any such changes are still uncertain. They also point out that the consequences of any such changes could be interpreted as ecologically beneficial, by adding to ecosystem diversity.

Whilst the investigation of nutrient pathways and sediment deposition processes are likely to be rather complex and challenging, designing a benthic survey to assess the consequential impact upon seabed species is a viable option. The sampling of seabed sediments to detect any signals of organic enrichment has been well practised around municipal outfalls, offshore drilling cuttings piles and fin-fish aquaculture sites. In these circumstances grab sampling has been used to gather samples for both biological and chemical analysis in the laboratory and therefore could be applied to an MRED scenario.

However, in these other sectors the enrichment effects have been linked to added direct organic inputs from the sewage, drilling mud or fish feed, and the zones of consequential effect have often extended to more than 100 m in radius. In the offshore wind case, where there are no artificially added nutrient inputs, the greatest challenge is likely to be getting the grab sampler close enough to the wind turbine, given the nominal 50 m range of effect detected so far (Degraer et al., 2020).

To help signal appropriate tools for these types of survey, a “biomass on hard structures” secondary use category is included in the tool Evaluation Matrix. The tools and technologies that score highest for quantifying seabed habitat enrichment are the grab samplers (such as Van Veen and Day grabs), with the tools for detecting enhanced biomass growing on hard structures include ROVs, high resolution imagery and laser profiling that can be used to produce 3D models (this is also discussed further in Section 6).

9.8 Strategic Sampling

Regional-scale strategic sampling approaches have recently been adopted across England and Wales to collect benthic baseline data and produce updated spatial models for key species (receptors), assemblages, and a suite of ecological metrics (diversity, functional traits). These models will be used to identify regions that are most vulnerable to potential offshore wind impact in the context of other activities and potential natural or global changes.

No such sampling strategy exists in Scottish waters, yet data gaps exist (e.g., outside MRED sites and MPAs). A recommended next step would be to improve data coverage to put site-specific assessments into context and improve understanding of broadscale environmental shifts.

10 References

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