Cyfoeth Naturiol Cymru
Natural Resources Wales

Guidance note

Benthic habitat assessment guidance for marine developments and activities

A guide to characterising and monitoring subtidal sediments

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1. Introduction and summary

This guidance document is one of a series of Benthic Habitat Assessment Chapters developed by Natural Resources Wales (NRW) for key habitats of conservation importance around Wales. It has been prepared by NRW with the initial document prepared under contract by APEM Ltd.

The guidance aims to assist developers in designing and undertaking robust benthic habitat characterisation surveys and monitoring of these habitats in the context of Ecological Impact Assessment, thereby helping streamline the regulatory review and consultation process.

This chapter will be relevant if you already have seabed habitat data and know that subtidal sediment habitats are present, and you need to carry out habitat characterisation and/or monitoring of these habitats.

If you are unsure about the seabed habitats present, you should refer to chapter GN030g[1] which covers characterisation of subtidal habitats.

This habitat chapter (GN030h) is not intended to be used alone and should always be used in conjunction with the NRW Guidance Note GN030 and the Introductory chapter (GN030-intro).

1.1. What are subtidal sediments and where are they found in Wales?

Subtidal sediments typically extend from the extreme lower shore down to the edge of the bathyal zone (200 m). They range from boulders and cobbles, to pebbles and shingle (gravel), coarse sands, sands, fine sands and muds, but are predominantly gravels, sands and muds. These sediment types can also be mixed, forming distinct habitats.

Subtidal sediments are the most widespread marine habitat in Wales and can be found in all subtidal areas in both inshore and offshore waters.

1.2. The conservation importance of subtidal sediments

Subtidal sediments have high ecosystem and biodiversity value and provide a wide range of ecosystem services (Defra, 2007) which can vary considerably between habitats (Balmford *et al.*, 2008). Subtidal sediments provide important feeding, nursery and spawning grounds for fish species and a habitat for commercially important shellfish such as brown shrimp and scallops. Species associated with subtidal sediments can also provide important food for mobile species such as seals, cetaceans and diving birds.

The value of subtidal sediments is recognised under a number of different pieces of national and international legislation, including:

- Habitats Directive
- Birds Directive
- Water Framework Directive

[1] This document is currently in preparation.

- Marine Strategy Framework Directive
- OSPAR Convention
- Environment (Wales) At 2016
- Wildlife and Countryside Act 1981 (as amended by the Countryside and Rights of Way (CROW) Act 2000)
- Marine and Coastal Access Act 2009

More information is provided in section 2.4.

1.3. What kind of developments and activities might affect subtidal sediments?

Developments and activities that could affect this habitat during construction and/or operational phases include those involving actions that could result in:

- changes to salinity regime and temperature
- changes to hydrodynamic regime (including current speed)
- changes to water quality (such as nutrient and organic enrichment; eutrophication of sediments; suspended solids, pollutants)
- loss of sediment within footprint (including scour), removal and disturbance of sediment
- changes to sediment transport dynamics, erosion/accretion regime and geomorphology
- introduction of invasive species
- pollution and other chemical changes
- eutrophication of sediments (for example, due to input of nutrients from aquaculture)

Further detail relating to potential pressures from developments and activities on subtidal sediments is provided in Section 2.5.

1.4. Existing data and guidance for surveying and monitoring subtidal habitats

A brief summary of available information is provided in section 3. Key sources of existing data and guidance for surveying and monitoring subtidal sediments are:

- Joint Nature Conservation Committee (JNCC): recent JNCC guidance for the monitoring of marine benthic habitats (Noble-James *et al.*, 2017)
- Common Standards Monitoring: developed for site monitoring and assessment of protected sites (JNCC, 2004). Specific habitat guidance relevant to subtidal sediments: Inshore Sublittoral Sediment Habitats (JNCC, 2004a), Estuaries (JNCC, 2004b), Inlets & Bays (JNCC, 2004c).
- Marine Monitoring Handbook (Davies *et al.*, 2001)
- Water Framework Directive (WFD) Monitoring approaches for Transitional and Coastal Water Assessment to assess the ecological health of the biological quality element ‘benthic invertebrate fauna in subtidal sediments’ for the WFD (WFD-UKTAG, 2014a).
- Mapping European Seabed Habitats (MESH) and MESH Atlantic recommended operating guidelines for:
    - swath bathymetry (Hopkins, 2007)
    - side scan sonar (Henriques *et al.*, 2012)
    - sediment profile imagery (Coggan & Birchenough, 2007)
    - underwater video and photographic imaging techniques (Coggan *et al.*, 2007)
    - grab sampling, sorting and treatment of samples (Guerra & Freitas, 2013)

- benthic monitoring survey design and planning (Ware & Kenny, 2011) – produced for work in relation to the aggregate industry but has wider application.
- Regional Seabed Monitoring Plan (Cooper & Mason, 2017) specifically developed for work in relation to the aggregate industry.
- North-East Atlantic Marine Biological Analytical Quality Control (NMBAQC):
    - Remote monitoring of epibiota using digital imagery (Hitchin *et al.*, 2015)
    - Analysis of remote underwater video footage and still images (Turner *et al.*, 2016)
    - Processing of sediment samples (Mason, 2016)
- NRW Guidance GN006: Marine Ecology Datasets for marine developments and activities (Natural Resources Wales, 2019). Identifies data sources for subtidal habitat maps and provides information on the marine ecology data sets we hold and routinely use and how you can access them.

1.5. Survey and monitoring design

The requirements for habitat characterisation survey and monitoring design are covered in section 4. The following provides a brief summary of key points:

- the aim of the habitat characterisation survey is to collate data to describe the subtidal sediments within the survey area, identify any habitats and/or species of conservation importance and provide an up-to-date ecological appraisal to inform Ecological Impact Assessment (EcIA)
- the aims of any monitoring required for a proposed development or activity will depend on the potential impacts as identified through the EcIA and any conditions set by the regulator
- a comprehensive desk-based review of all available existing data should be conducted prior to designing any habitat characterisation or monitoring programmes. This will help determine the scope of survey that may be required
- if there is little or no existing seabed habitat data or it is out of date or of poor quality, you may need to undertake a geophysical survey to determine the seabed habitats present and their distribution and extent in order to target habitat characterisation and monitoring surveys.
- a sampling window between early spring (February) and autumn (October) is preferable
- relevant ecological parameters need to be selected. The key parameters (section 4.2) to be assessed for subtidal sediments for habitat characterisation and monitoring in relation to Ecological Impact Assessment are:
    - extent and distribution of subtidal sediment habitats/biotopes
    - biological community composition (such as number of infauna/epifauna taxa in each habitat/biotope; presence/absence of species of conservation importance)
    - sediment characteristics (sediment type, composition, chemistry)
- the aims of the habitat characterisation survey and monitoring need to be clearly stated and the survey programmes tailored to deliver these requirements. This includes defining hypotheses and trigger levels for monitoring.
- sampling designs can involve grid-based (i.e. systematic) random sampling or stratified random sampling. Before-After-Control-Impact may need to be an integral part of monitoring programme design. The design will depend on the characteristics of the habitat, availability of existing data for the survey area and the aims of the survey.

- sampling effort for a characterisation survey should cover the range of habitat types within the area that may be affected by the proposed development or activity. More sampling stations will be required in areas of higher habitat heterogeneity.
- for a characterisation survey single biotic grab samples at a greater number of stratified sampling stations is generally preferable (as opposed to replicate samples at fewer stations). Samples for particle size analysis PSA should be collected at all sample stations.
- for monitoring, replicate samples are required in order to apply robust statistical techniques required to detect significant change in community characteristics. This may require up to five replicates at each sample station. A single PSA sample at each sample station is generally sufficient.
- other parameters of the wider environment that influence subtidal sediment habitat may need to be characterised and monitored; this will depend on the nature and location of a proposed development or activity and the associated pressures arising from this. This could include parameters such as: patterns of sediment transport, the hydrodynamic regime, water quality and sediment contaminants.

1.6. Survey and monitoring methods and analysis

There are various methods available for survey and monitoring of subtidal sediment habitats (section 5), each providing information for different aspects of the habitat. The main options include:

- Geophysical survey (such as side scan sonar and multibeam):
    - for large scale survey to identify physical features of subtidal sediments
    - for large developments with little or no seabed data both multibeam and side scan sonar would generally be required
    - can differentiate between hard and soft substrate to determine extent and distribution but cannot provide fine detail in terms of the subtidal sediment type
    - does not provide detail on the fauna and/or flora present but can be used to help characterise biogenic reef formations when data resolution and quality are sufficient
    - ground truthing using other survey methods is required to define seabed habitats
- Sediment Profile Imagery (SPI):
    - can determine changes in sediment type and condition across an area without the need for physical sample collection (for example, human induced/natural turbation, oxygen depletion, grain size distribution)
    - provides limited biological data
- underwater image survey (such as towed video, still images, ROVs and AUVs):
    - provides visual data on sediment type and conspicuous epibiota
    - can be used to help determine habitat distribution and extent
- physical sampling grabs and cores)
    - grabs and cores provide quantitative data on sediment characteristics and infauna
    - grabs and trawls can be damaging to some habitats (such as biogenic reef or seagrass beds), therefore sensitivity of the target habitats needs to be assessed beforehand to determine if this is an appropriate method
- physical sampling (trawls, dredges)
    - not advised for general benthic habitat characterisation surveys

- can have a specific application for some types of survey for certain epibenthic and mobile species
- trawls and dredges can be damaging to seabed habitats, so the sensitivity of the target habitats needs to be assessed to determine if this is an appropriate method.

Quality control measures for the field methods including species identification need to be clearly defined and implemented by field staff undertaking the survey work.

Not all methods will be required for a particular development or activity and proposed methods need to be defined on a project-specific basis. The JNCC Marine Monitoring Method Finder, a web-based information hub, has been developed to provide a single point of access to the numerous guidance documents and tools generated both within and outside the UK. It can be used in conjunction with this document to ensure a consistent approach to data collection and analysis.

2. Habitat introduction

2.1. Overview

Connor *et al.* (2004) define subtidal sediments as: 'Sediment habitats in the sublittoral near shore zone (i.e. covering the infralittoral and circalittoral zones), typically extending from the extreme lower shore down to the edge of the bathyal zone (200 m)'.

'Sediment' encompasses a broad range of particle (clast) sizes ranging from boulders and cobbles, to pebbles and shingle (gravel), coarse sands, fine sands, muds, and mixed sediments. Sediments are categorised using these terms, based on the distribution of particle sizes which, in any one area, can be either highly variable or dominated by one particular particle size range.

The sediment type present in any one area is determined by the source of the sediment supply and influence of physical processes in the locality (such as tidal currents and, particularly in shallower water, the influence of waves and storm events). There are generally transitions from one sediment habitat to another, potentially within relatively small areas, although single sediment habitat types can also be extensive in any given area.

Different types of sediment habitat support varying species assemblages. In sediments with predominantly smaller particle sizes species assemblages are dominated by infaunal species. When larger sediment particles are present (from gravel up to larger particle sizes), sediment habitat can also support epibiota (with algal species dominant in shallow water and faunal species dominant in deeper water).

2.2. Sub-habitats

The Introductory Chapter (GN030-intro, section 3.2.4) provides information on the Joint Nature Conservation Committee (JNCC) and European Nature Information System (EUNIS) classification systems for marine habitats and biotopes. We recommend the JNCC website as a reference point to determine the latest guidance documentation for habitat and biotope assignment. The information provided below is based on the latest available guidance at the time of writing.

Within the EUNIS classification system 'Sublittoral sediment' (EUNIS code A5) is one of six Level 2 broad scale marine habitats (see Table 1 for an example of the EUNIS classification hierarchy). This broad scale habitat includes seven Level 3 main habitats and three of these are covered by this protocol:

- Sublittoral coarse sediment (A5.1)
- Sublittoral sand (A5.2)
- Sublittoral mud (A5.3)

Two of the remaining main habitats are in part covered by other chapters in this guidance:

- *Sabellaria* spp. reefs GN030d and *Modiolus modiolus* beds GN030c (cover part of EUNIS A5.6 'Sublittoral biogenic reefs')
- Seagrass beds GN030f (covers part of EUNIS A5.5 'Sublittoral macrophyte-dominated sediment')

The other main habitat types. 'Sublittoral mixed sediments' EUNIS A5.4 (which includes muddy gravels) and 'Features of sublittoral sediments' EUNIS A5.7 are not yet covered by the guidance.

Table 1. The EUNIS habitat/biotope hierarchy for subtidal sediments using 'Sublittoral mud' as an example

Level	EUNIS code	Habitat	Example
Level 1	A	Marine Habitats	
Level 2	A5	Broad Habitat	Sublittoral sediment
Level 3	A5.3	Main Habitat	Sublittoral mud
Level 4	e.g. A5.35	Biotope complex	Circalittoral sandy mud
Level 5	e.g. A5.354	Biotope	*Virgularia mirablis* and *Ophiura* spp. with *Pecten maximus* on circalittoral sandy or shelly mud
Level 6	e.g. A5.3541	Sub-biotope	*Virgularia mirablis* and *Ophiura* spp. with *Pecten maximus*, hydroids and ascidians on circalittoral sandy or shelly mud with shells or stones

2.2.1. Sublittoral coarse sediment

This habitat is composed of coarse sand, gravel, pebbles, shingle and cobbles which are often unstable due to tidal currents and/or wave action. These habitats are generally found on the open coast or in tide-swept channels of marine inlets (Connor *et al.*, 2004). They typically have low silt content, and in shallow waters they lack a significant seaweed component. They are characterised by a robust fauna including venerid bivalves and most of the animals that live here are found buried in the seabed (Connor *et al.*, 2004).

- 4 biotope complexes (EUNIS level 4)
- 14 biotopes (EUNIS level 5), with no sub-biotopes

2.2.2. Sublittoral sand

This habitat consists of clean, medium to fine sands or non-cohesive slightly muddy sands on open coasts, offshore or in estuaries and marine inlets (Connor *et al.*, 2004). Such habitats are often subject to a degree of wave action or tidal currents which restrict the silt and clay content to less than 15%. The 'sublittoral sand' habitat is characterised by a range of animals including polychaete worms, bivalve molluscs and amphipod crustaceans (Connor *et al.*, 2004).

- 7 biotope complexes (EUNIS level 4)
- 17 biotopes (EUNIS level 5), with no sub-biotopes

2.2.3. Sublittoral mud

This habitat comprises sublittoral mud and cohesive sandy mud extending from the extreme lower shore to offshore, circalittoral habitats. It is predominantly found in sheltered harbours, sea lochs, bays, marine inlets and estuaries, and stable deeper/offshore areas where the reduced influence of wave action and/or tidal streams allow fine sediments to settle. Such habitats are often dominated by polychaetes and echinoderms, in particular brittlestars such as *Amphiura* spp. and sea pens such as *Virgularia mirabilis.* Burrowing megafauna, including Norway lobster (scampi) *Nephrops norvegicus*, are common in deeper muds. Estuarine muds tend to be characterised by infaunal polychaetes and oligochaetes (Connor *et al.*, 2004).

- 7 biotope complexes (EUNIS level 4)
- 33 biotopes (EUNIS level 5), including three with a single sub-biotope (EUNIS level 6)

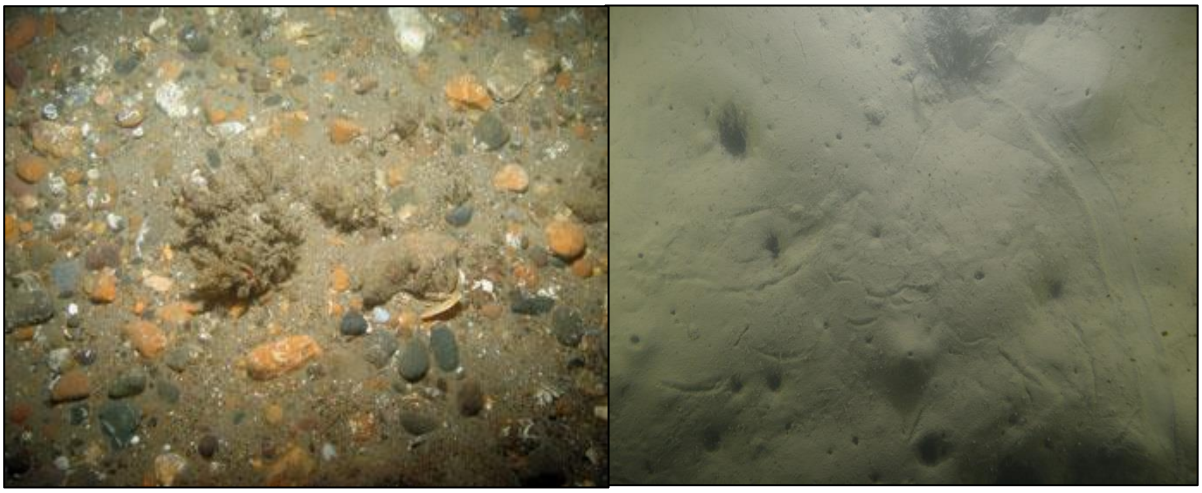

Figure 1. Example images of subtidal sediment habitats: Subtidal sands and gravels (left), image © JNCC; mud habitat in deep water (right), image © APEM Ltd

2.3. Extent/distribution in Wales

Subtidal sediments are the most widespread marine habitat in Welsh waters and can be found in all subtidal areas in both inshore and offshore areas.

2.4. Conservation importance

Subtidal sediments have high ecosystem and biodiversity value and provide a wide range of ecosystem services (Defra, 2007) which can vary considerably between habitats (Balmford *et al.* 2008). For example, subtidal sediments provide important feeding and nursery grounds for demersal fish such as sole *Solea solea*, plaice *Pleuronectes platessa*, cod *Gadus morhua* and rays, and provide spawning grounds for species including herring *Clupea harengus*. Several shellfish species of commercial importance live on or within subtidal sediments, including brown shrimp *Crangon crangon*, scallops *Pecten maximus* and *Aequipecten opercularis* and Norway lobster *Nephrops norvegicus*. They also provide supporting habitat for aquaculture, natural hazard protection/provision of environmental resilience, pollution regulation, nutrient cycling, tourism, recreation, aesthetic benefits, nature watching, research and education (Balmford *et al.*, 2008).

The Introductory Chapter (GN030-intro, section 3.2.2) provides more general information on conservation policies and legislation, but key aspects relevant to subtidal sediments habitats are highlighted below.

2.4.1. Habitats Directive

The Habitats Directive lists habitats and species of interest in Annex I and Annex II respectively. The following Annex I habitats are relevant to the subtidal sediments considered in this chapter:

- Estuaries (code 1130[2])
- Large shallow inlets and bays (code 1160)
- Sandbanks which are slightly covered by seawater all the time (code 1110)

Each of these Annex I habitats can encompass a variety of different sediment habitats and associated species assemblages.

Special Areas of Conservation (SACs) are protected sites designated under the Habitats Directive. The Annex I habitats listed above are features of seven SACs in Wales which are listed in Table 2 (not all features occur within each site).

Table 2. SACs in Wales with Annex I habitat features that include subtidal sediments

Special Area of Conservation	Estuaries	Large shallow inlets and bays	Sandbanks
Dee Estuary SAC / Aber Dyfyrdwy ACA	X		
Glannau Môn Cors Heli SAC / Anglesey Coast: Salt Marsh	X		
Y Fenai a Bae Conwy / Menai Strait and Conwy Bay		X	X
Pen Llŷn a'r Sarnau SAC / Lleyn Peninsula and the Sarnau	X	X	X
Bae Ceredigion / Cardigan Bay			X
Pembrokeshire Marine SAC / Sir Benfro Morol	X	X	X
Carmarthen Bay and Estuaries SAC / Bae Caerfyrddin ac Aberoedd	X	X	X
Severn Estuary SAC / Môr Hafren	X		X

Subtidal sediment habitats may form part of the essential habitat for some mobile marine species (such as fish and marine mammal species) listed under Annex II of the Habitats Directive.

2.4.2. Birds Directive

This Directive aims to protect all European wild birds and the habitats of listed species, in particular through the designation of Special Protection Areas (SPAs), including all the most suitable territories for these species. SPAs can encompass areas of sea that are important for particular bird species for feeding, resting and other essential behaviours. The species associated with some sublittoral sediments in shallow water, such as molluscs, small crustaceans, worms and fish, are important food for some birds and may form part of the essential habitat for species protected under this Directive.

2.4.3. Water Framework Directive (WFD)

'Benthic invertebrates' is one of the biological quality elements (BQE) used to assess the status of Transitional and Coastal (TraC) waterbodies for the WFD (WFD-UKTAG, 2014a).

[2] The code assigned to the Annex I features is the Natura 2000 code which is a four digit code given in the Natura 2000 standard data-entry form. Natura 2000 is a network of nature protection sites in the territory of the European Union. It is made up of Special Areas of Conservation and Special Protection Areas.

2.4.4. Marine Strategy Framework Directive (MSFD)

Two of the 11 high level descriptors of Good Environmental Status (GES) in Annex I of the Directive (Defra, 2014) relate directly to sedimentary benthic habitats (D1 Biodiversity and D6 Seafloor integrity), with others relating to aspects of benthic ecology (for example, food webs and commercial fishing).

2.4.5. OSPAR list of threatened and/or declining species and habitats

This chapter covers two subtidal sediment habitats which appear on the OSPAR list of threatened and/or declining species and habitats:

- *Mytilus edulis* beds on sediment
- Sea pen and burrowing megafauna communities

Other subtidal sediment habitats on the OSPAR list covered by other chapters include:

- *Modiolus modiolus* (northern horse mussel) beds (GN030c)
- *Sabellaria spinulosa* reefs (GN030d)
- *Zostera* (seagrass) beds (GN030f)

Two OSPAR-listed marine invertebrates may be found on subtidal sediments:

- ocean quahog *Arctica islandica*
- native oyster *Ostrea edulis*

In addition, a number of OSPAR-listed fish may be supported by subtidal sediments including:

- Allis shad *Alosa alosa*
- European eel *Anguilla anguilla*
- common skate *Dipturus batis*
- spotted ray *Raja montagui*
- Atlantic cod *Gadus morhua*
- long-snouted seahorse *Hippocampus guttulatus*
- short-snouted seahorse *Hippocampus hippocampus*
- sea lamprey *Petromyzon marinus*
- thornback ray *Raja clavata*
- bottlenose skate *Rostroraja alba*
- Atlantic salmon *Salmo salar*
- angel shark *Squatina squatina*

2.4.6. Environment (Wales) Act 2016 Section 7 list of habitats and species of principal importance (previously BAP/NERC S42 lists)

The following Section 7 species may be found in subtidal sediments:

- burrowing anemone *Edwardsia timida*
- fan mussel *Atrina fragilis*
- maerl *Lithothamnion corallioides*
- native oyster *Ostrea edulis*
- ocean quahog *A. islandica*
- spiny lobster *Palinurus elephas*
- tentacled lagoon worm *Alkmaria romijni*

A range of fish species on the list may also be supported by subtidal sediments.

Section 7 priority habitats included under sublittoral sediment are:

- subtidal sands and gravels
- subtidal mixed muddy sediments
- mud habitats in deep water
- maerl beds
- *Musculus discors* beds
- blue mussel beds
- horse mussel beds
- saline lagoons

Of these, only ‘subtidal sands and gravels’ and ‘mud habitats in deep water’ are covered by this chapter.

2.4.7. The Wildlife and Countryside Act 1981 (amended by the Countryside and Rights of Way (CROW) Act 2000)

The Act provides for the designation of Sites of Special Scientific Interest (SSSIs). There are more than 1,000 SSSIs in Wales, covering about 12% of the country. The seaward limit of SSSIs in Wales does not extend into the subtidal but some estuarine areas within SSSIs will have permanently submerged channels with subtidal sediments. In SACs, SPAs and Ramsar sites, SSSI designations also underpin the terrestrial and intertidal components of these sites.

A range of marine species, some of which are relevant to subtidal sediments, are protected under Schedule 5 of the Act, which also prohibits interference with structures / places that are used by these species for shelter and protection.

2.4.8. Marine and Coastal Access Act 2009

The Act enables Marine Conservation Zones (MCZs) to be designated to conserve ‘nationally important’ features including marine flora, fauna, habitats and geological or geomorphological structures. Subtidal sediment habitats can be MCZ features; infaunal and epifaunal communities are features of Skomer MCZ, currently the only MCZ designated in Wales.

The Act also established the requirement for marine licences for developments and activities in the marine environment.

2.4.9. Welsh Marine Protected Area Network

Several subtidal sediment habitats are considered within the Marine Protected Area network feature list for Wales. (Carr *et al.*, 2016).

2.5. Key potential pressures

The potential pressures of marine developments and activities on subtidal sediments vary in relation to factors such as the nature of the development or activity, construction methods, mode of operation and scale of the project. In order to assess the significance of the effect of a given pressure on a specific receptor (such as a particular subtidal sediment habitat), you will need to identify the factors and pressures associated with your proposed development or activity. You will need to consider these, along with conservation value and sensitivity of the habitat/species present and the magnitude of effect, as part of the

Ecological Impact Assessment (EcIA) (CIEEM, 2018). The main potential pressures include, but are not restricted to, those indicated in Table 3.

Table 3. Key potential pressures of marine developments or activities on subtidal sediment (adapted from Tillin & Tyler-Walters, 2014)

Pressure	Examples
Salinity changes	Cooling water discharges, freshwater inputs or abstraction.
Temperature changes	Cooling water discharges.
Water flow (tidal current) changes; Wave exposure changes; Change in tidal inundation regime and/or water levels	Construction and operation of coastal/marine structures/developments (incl. tidal lagoons); Coastal defences (e.g. managed realignment); Extraction industry.
Nutrient (eutrophication) and organic enrichment; Presence of pollutants	Sewage effluent; Agricultural run-off; Marinas; Aquaculture; Spillage of contaminants during development construction/operation.
Changes to suspended solid levels (water clarity); Changes to siltation rates (smothering)	Dredging; Discharges to marine environment; Spoil disposal; Agricultural run-off; Extraction industry.
Loss of habitat in development footprint; Changes to, removal and disturbance of substrate surface and subsurface (including scour and sediment compaction)	Bait digging; Dredging; Trawling; Anchoring/mooring; Construction and operation of coastal/marine structures/developments; Extraction industry.
Changes to sediment transport and erosion/accretion regime; Changes to subtidal habitat structure/ sedimentology/ geomorphology	Dredging; Construction and operation of coastal/marine structures/developments; Coastal defences (e.g. managed realignment); Extraction industry
Introduction or spread of invasive non-native species (INNS)	Vessel activity; Discharges to marine environment; Marinas; Aquaculture; Spoil disposal; Construction and operation of coastal/marine structures/developments.
Removal of target and non-target species	Trawling
Biological pressures	Other anthropogenic influences e.g. Waste tipping; Recreational pressures; electromagnetic changes

2.6. Sensitivity (resistance/resilience to pressures)

For any species or habitat found in the Zone of Influence (ZoI)[3] of a development or activity, it is important to understand their sensitivity to each of the specific associated pressures arising from the proposed works.

[3] Zone of Influence (ZoI) - the area of the seabed or foreshore that could be affected by the proposed development or activity, during both construction and/or operation.

The different subtidal sediments covered by this guidance exhibit varying sensitivity to different anthropogenic pressures. The most sensitive biotopes are generally those from stable, deeper mud communities especially where large species are present, but all sediments are highly sensitive to certain pressures such as physical loss and change in sediment type. In addition, some biotopes have particular sensitivities to salinity or temperature changes, or to removal of species or introductions of invasive species.

The Marine Life Information Network (MarLIN) provides sensitivity reviews for a number of subtidal sediment biotopes. You can see what is available by using the expandable UK marine habitat classification list on the website.

It is important that you read the further information and considerations related to MarLIN assessments in the introductory chapter (GN030-intro, section 3.2.6.). It is also important to consider the sensitivities and traits of species found within these benthic habitats. These are discussed by Tillin & Tyler-Walters (2014) and incorporated into MarLIN and its Biological Traits Information Catalogue (BIOTIC) resource, with further information in the wider scientific literature.

3. Existing guidance and data

This section identifies information and guidance that may be useful in the context of survey and monitoring of subtidal sediments. Whilst some of the guidance (such as for Common Standards Monitoring and Water Framework Directive) is primarily for statutory monitoring work undertaken by ourselves and others, the documents and references may still provide useful contextual information and guidance on methods.

The JNCC has recently produced specific guidance for the monitoring of marine benthic habitats (Noble-James *et al.*, 2017) which is a useful reference document for many aspects of monitoring.

3.1. Common Standards Monitoring

Common standards monitoring (CSM) was developed in the context of SSSIs and SACs to set and assess conservation objectives to help staff undertake site monitoring and assessment (JNCC, 2004). A key use of this monitoring data is to satisfy the requirement to report on the status of protected habitats and species under Article 17 of the Habitats Directive (see 2.4.1).

CSM is based on monitoring a set of mandatory attributes with the objective of assessing whether a site feature is in a favourable condition. As an example, the attributes that might need to be monitored for ‘Sandbanks which are slightly covered by seawater all the time’ (code 1110) include:

- extent of the subtidal sandbank habitat
- distribution of subtidal sandbank habitat
- community composition
- sediment character
- topography

High level guidance for monitoring these attributes is provided in the relevant CSM Guidance: Inshore Sublittoral Sediment Habitats (JNCC, 2004a), Estuaries (JNCC, 2004b) and Inlets & Bays (JNCC, 2004c). The CSM documents provide broad guidance for feature-specific monitoring, indicating the background, targets and monitoring techniques for feature attributes. In terms of survey methods, the CSM guidance primarily directs the reader to the Marine Monitoring Handbook (Davies *et al.*, 2001). It should be noted that some of the technical details in the Marine Monitoring Handbook have been superseded due to advances in technology; however, it remains a comprehensive and widely used guidance document covering a diverse range of survey methods and survey and monitoring requirements.

3.2. Water Framework Directive monitoring (WFD)

Water Framework Directive monitoring, encompassing a number of waterbody quality elements, is undertaken to assess the ecological status of waterbodies. The biological elements include benthic invertebrate fauna in subtidal sediments, for which the WFD assessment is based on consideration of an Infaunal Quality Index (IQI) calculated from:

- invertebrate abundance and diversity data
- the presence and/or absence of pollution-tolerant and disturbance-sensitive taxa
- habitat characteristics such as salinity and substratum information

The IQI contributes to calculation of the Ecological Quality Ratio (EQR) value which contributes to the allocation of one out of the five ecological status classes to a waterbody.

Guidance from the WFD UK Technical Advisory Group (WFD-UKTAG, 2014a) provides some details of the sampling methods used for the monitoring. Further information about WFD ecological monitoring and waterbody status assessments for Wales and how you can access this information is provided in our guidance note GN006 Marine ecology datasets for marine developments and activities (Natural Resources Wales, 2019).

3.3. MESH guidance

The Mapping European Seabed Habitats (MESH)[4] project produced 'Recommended operating guidelines' (ROGs) for marine habitat mapping survey methods and these are hosted in the MESH archive on the EMODnet[5] website. A number of these ROGs are relevant to survey and monitoring of subtidal sediments.

The MESH Atlantic Project updated the ROGs for LiDAR and side scan sonar and produced a new ROG for grab sampling. These documents will become available through the MESH archive but in the interim they need to be requested from one of the project partners who are listed on the project page of the keep.eu website.

Survey and monitoring work in relation to proposed developments and activities should have regard to the guidance provided in the ROGs. Specific ROGs are referenced where relevant in other sections of this guidance.

3.4. Aggregates industry

Specific guidance on surveying and monitoring subtidal habitats is available for the aggregates industry, and the information and approaches in the guidance may have relevance for other marine developments or activities. For example, the Marine Aggregate Levy Sustainability Fund (MALSF) 'Guidelines for benthic studies at marine aggregate extraction sites' (Ware & Kenny, 2011) includes advice for benthic monitoring survey design and planning, and appropriate survey equipment and methods. Ware & Kenny (2011) supersedes the previous guidelines (Boyd, 2002), though some details in the original guidance remain valid. Newell & Woodcock (2013) also cover a wide range of considerations for the aggregate industry, including sampling methods and survey approaches.

In addition, Cooper & Mason (2017) produced methods for the Regional Seabed Monitoring Plan (RSMP). This is a major initiative by the marine aggregates industry to provide evidence of the physical and biological characteristics of the seabed in support of marine aggregate dredging licence applications and renewals. The methods were pioneered by Keith Cooper (Cefas) following research on seabed recovery following dredging activity (Cooper 2012; 2013a; 2013b). The methods are currently being developed and refined during direct application in monitoring surveys by the marine aggregate industry.

3.5. NMBAQC guidance

A number of North-East Atlantic Marine Biological Analytical Quality Control (NMBAQC) guidance documents are relevant to subtidal sediments:

[4] The MESH project, conducted between 2004 and 2008, was a consortium of twelve partners from five European countries led by the UK's JNCC.
[5] EMODnet is an EU network of organisations that collate and make available data relevant to Europe's marine environment.

- Operational guidelines for remote monitoring of epibiota using underwater digital imagery are presented in Hitchin *et al.* (2015). The guidance covers the approaches, available equipment and methods for a variety of camera systems, including towed camera sledges, drop down cameras and towed camera platforms, as well as remote-operated vehicles (ROVs) and the use of freshwater lens camera systems. It also provides information on quality control of imagery and analysis and a recommended approach for data review.
- Guidance on the analysis of remote underwater video footage and still images is provided in the epibiota remote monitoring interpretation guidelines (Turner *et al.*, 2016)
- Guidance on the processing of sediment samples is provided in Mason (2016)
- Guidance on processing macrobenthic invertebrate samples (Worsfold *et al.*, 2010)

3.6. Data sources

Distribution data for subtidal sediment habitats in Wales and the UK are available from a number of sources. Our Guidance Note GN006 Marine ecology datasets for marine developments and activities (Natural Resources Wales, 2019) identifies data sources for subtidal habitat maps. It also explains how you can access information about Marine Protected Areas in Wales including maps and supporting documentation on protected features, as well as data and maps on protected marine habitats and species in Welsh waters.

4. Survey and monitoring design

The Guidance Note GN030 and Introductory Chapter GN030-intro explain when and why habitat characterisation and monitoring may be required in relation to proposed developments and activities and the over-arching principles for both of these[6]. It is important to understand the differences between characterisation surveys and monitoring when designing project-specific survey programmes.

The information provided in the following sections presumes an existing knowledge of the presence of subtidal sediment habitats in the area to be surveyed based on available ecological data and/or subtidal habitat surveys. If you have little or no seabed habitat data, a general benthic survey will be needed to record the habitats present and determine their extent and distribution which may require a geophysical survey. Information about geophysical survey is provided in this chapter but you should also refer to chapter GN030g of the guidance which addresses subtidal habitat characterisation surveys.

4.1. Existing data

Where possible, and where timeframes allow, a comprehensive desk-based review of all available data relevant to subtidal sediment habitats within the area of interest should be conducted prior to designing any characterisation surveys or monitoring programmes. Our Guidance Note GN006 (Natural Resources Wales, 2019) provides information on the marine ecology data sets we hold and routinely use and how you can access them. Further information relating to sourcing and using data is also provided in the Introductory Chapter GN030-intro (section 3.2.3) and Noble-James *et al*. (2017).

4.2. Selecting ecological parameters

The Introductory Chapter GN030-intro (sections 3.2.7. and 4.2.1) addresses the importance of selecting suitable ecological parameters for survey (known as 'indicators' for monitoring programmes) and the process to determine the effectiveness, appropriateness and validity of parameters.

The main ecological parameters that can be measured for subtidal sediments include:

- extent and distribution of subtidal sediment habitats/biotopes across the potential ZoI of a proposed development/activity (potentially in the form of a habitat/biotope map where applicable)
- biological community composition:
    - number of taxa present in each habitat/biotope (infauna and epifauna)
    - number of individuals of different taxa (abundance/density) (infauna and epifauna)
    - benthic assemblage composition (e.g. dominant species, notable species)
    - biomass (potentially required to taxon level or major taxonomic group)
    - other assemblage summary statistics (e.g. diversity indices)
    - presence/absence of any species of conservation importance or non-native species
- sediment characteristics:
    - sediment type, composition, chemistry

[6] Note: The Guidance Note and Introductory Chapter apply to all of the specific habitat chapters of this guidance; consequently, some parts may not be directly relevant to a specific marine habitat, and information should be evaluated as appropriate.

The survey / monitoring methods discussed in section 5 are presented in relation to their relevance for measuring these parameters.

4.3. Habitat characterisation

4.3.1. Aims of habitat characterisation surveys for subtidal sediments

The aim of habitat characterisation survey is to collate data to describe the subtidal sediments within the survey area, identify any habitats and/or species of conservation importance and provide an up-to-date ecological appraisal to inform EcIA.

4.3.2. Design of habitat characterisation surveys for subtidal sediments

Development- and activity-specific information should inform the design of habitat characterisation surveys which will also be influenced by the scale of the proposed development or activity (see Introductory Chapter GN030-intro, section 3).

The range of available survey methods for habitat characterisation of subtidal sediments is indicated in Section 5.1. The methods to be used should be determined on a project-by-project basis prior to survey.

Guidance for habitat characterisation survey design is provided in a range of sources including the Marine Monitoring Handbook (Davies, 2001), Ware & Kenny (2011) and Noble-James *et al.* (2017). Cooper & Mason (2017) indicates the characterisation approach taken during RSMP sampling specifically for aggregate licence areas.

4.3.2.1. Survey design options

There are two main options for habitat characterisation sampling design for subtidal habitats. These are:

- Systematic grid sampling. This is more appropriate where existing data are sparse for a site, as it provides a broad coverage across the ZoI.
- Stratified random sampling. This is applicable to where more robust historic biological data or geophysical data are available indicating variation in sediment type and the distribution of habitat is known to be heterogeneous. This design can be applied with stations targeted to different types of subtidal sediments across the ZoI. Stratifying sampling in this way will account for natural spatial variability in sediment types, and ensure data are collected for the range of communities expected to be present within the project ZoI.

Each of these approaches is discussed in more detail in Ware & Kenny (2011) and Noble-James *et al.* (2017), including when each approach would usually be required and what is involved. A third sampling design option, random sampling, is rarely used

There is an option to select ‘representative’ station locations across known sediment types (i.e. judgement sampling). However, this requires a high confidence in the habitat mapping forming the basis of the allocations and the risk of bias can be high (Noble-James *et al.*, 2017).

4.3.2.2. Timing

See section 4.4.4.1.

4.3.2.3. Number of stations (sampling effort)
The number of stations to be sampled should be sufficient to cover the range of habitat types within the potential ZoI of a development or activity, with sufficient replication of sample stations to cover all the areas of interest. The number of samples will depend in part on the variability of the habitats to be surveyed; an increased number of stations is recommended for more variable habitats (Ware & Kenny, 2011).

4.3.2.4. Within-station replication
Within-station replication of samples can provide a better understanding of small-scale variability within a habitat or species community. This is relevant if such information is a requirement of the survey or if the sampling sites are likely to be used in any future monitoring programme (but see Introductory Chapter GN030-intro section 3.2.9).

For a characterisation survey NRW's advice in general is to collect single grab samples at a greater number of stations rather than collect replicate samples at fewer stations. Consequently, it is recommended that a single biotic grab sample is collected at each station which would preferentially be stratified following interpretation of geophysical survey data.

For particle size analysis (PSA) and chemical analysis, single sediment samples at each sample station should be sufficient. If inorganic and organic chemical analyses are required a separate core for each of these should be collected at each station.

4.4. Monitoring
4.4.1. Aims of monitoring programmes for subtidal sediments
The aims of the monitoring need to be clearly defined and will depend on the potential impacts of a proposed development or activity as identified through the EcIA process. The monitoring methodology, including experimental design, needs to provide sufficient information to satisfy the relevant environment assessment processes and any conditions set by the regulator.

Monitoring requires repeat sampling to detect change over time in one or more indicators (i.e. selected ecological parameters). In relation to regulatory development control, monitoring usually consists of pre-construction monitoring (the 'baseline'), monitoring during construction and operational monitoring (see Introductory Chapter GN030-intro section 4.1).

As noted in section 4.2 of the Introductory Chapter, it may be beneficial to make any development-related monitoring compatible with data from existing, ongoing monitoring programmes, such as those undertaken by NRW.

4.4.2. Defining hypotheses and trigger levels
Hypotheses to inform ecological monitoring are generally framed to detect change in a selected indicator over time, and to determine if any change observed is outside normal expectations. In the context of regulatory development control and EcIA, key thresholds known as 'trigger levels' are generally set to help assess whether impacts are evident on a given indicator over the course of a monitoring programme, along with management action(s) to be implemented if trigger levels are exceeded. The Introductory Chapter GN030-intro (sections 4.2.2 and 4.2.3) provides further detail relating to hypotheses testing and considerations associated with the potential use of trigger levels.

4.4.3. Design of monitoring programmes for subtidal sediments

Sampling designs can involve grid-based (i.e. systematic) sampling, random sampling, or stratified random sampling, depending on the characteristics of the habitat to be sampled, available data for the survey area, the aims of the survey and the type and level of impact. In addition, a Before-After-Control-Impact (BACI) design can be applied which involves identifying suitable control stations (see Introductory Chapter GN030-intro, section 4.2.5.).

Sample stations are typically selected to encompass as much of the range of subtidal sediment habitat and biological community variation as possible. The location of sample stations will be influenced by the specific hypotheses being tested, habitat variation and the areas of greatest anticipated change. If the development or activity results in a gradient of pressure from high to low from, for example a point source discharge, then additional sampling stations should be located at set distances from the discharge point along the anticipated gradient of the output.

4.4.3.1. Monitoring programme design options

Monitoring design needs to be determined on a case by case basis as it will be influenced by the hypotheses to be tested and the indicators to be measured. A range of considerations for the design of monitoring programmes is provided in the Introductory Chapter GN030-intro (section 4).

Design options include grid based, simple random sampling and stratified random sampling (Noble-James *et al.*, 2017) (see the Introductory Chapter). The approach can also involve transect sampling if, for example, the habitats being surveyed are linear, or if habitat is being sampled across a gradient of change such as across a subtidal sandbank.

The monitoring approach will depend on whether broad scale monitoring is required to monitor change across the full ZoI, or whether monitoring is focussed on one or more specific habitats of interest within the ZoI.

4.4.3.2. Number of stations (sampling effort) and BACI design

To be able to detect change in the benthic environment due to a development or activity sufficient stations need to be incorporated into the monitoring programme design. You can find more information about this, the selection of control sites and Before-After-Control-Impact (BACI) monitoring designs in sections 4.2.4. and 4.2.5. of the Introductory Chapter GN030-intro.

4.4.3.3. Within-station replication

The amount of sample replication within each station is a key consideration in any monitoring programme. This needs to be determined on a case by case basis in relation to the specific monitoring requirements (see Introductory Chapter GN030-intro section 4.2.5.3).

Determining the statistical analyses that will be applied to the data is an essential aspect of the monitoring programme design, as replicate samples will be required to enable application of the robust statistical techniques required to detect significant change in community characteristics across stations. This may require up to five replicates at each sample station.

For PSA, a single sample at each station is generally sufficient and can usually also be used for samples for inorganic and organic chemical analyses (if required). If samples for chemical analyses are being collected, they may not be required at all biotic sample stations.

4.4.4. Sampling timing, frequency & duration

4.4.4.1. Timing

Existing guidance indicates that a sampling window between early spring and autumn is preferable (Table 4):

- WFD guidance for benthic invertebrates indicates that sampling should ideally be conducted between February and June, inclusive (WFD-UKTAG, 2014).
- CSM guidance for inshore sublittoral sediment habitats suggests a sampling window of April to July, with possible sampling in August to October (JNCC, 2004a)

Depending on the aim and selected indicators for the monitoring it may be that sampling outside of this window would be acceptable but would need to be agreed on a case by case basis.

Repeat monitoring surveys need to be conducted at the same time of year as the previous monitoring surveys.

Many marine organisms have seasonal reproductive patterns that can significantly alter the number of individuals present at different times of the year (JNCC, 2004a). Larval settlement and recruitment of juveniles to the population can result in a massive increase in the population size at certain times of the year. The presence and number of juveniles should be enumerated separately to the adults in all samples.

Table 4. Recommended times of year for survey of subtidal sediments based on Water Framework Directive and Common Standards Monitoring guidance

Guidance	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Water Framework Directive												
Common Standards Monitoring												

Recommended timeframes   Possible window

4.4.4.2. Frequency and duration

There is no set guidance on the frequency of sampling of subtidal sediment for monitoring purposes. Relevant considerations when determining potential frequency and duration of monitoring are provided in the Introductory Chapter GN030-intro (section 4.3).

4.4.5. Supporting environment

Any monitoring programme for subtidal sediments needs to consider other parameters of the wider environment that that may influence the presence of subtidal sediments and the nature and quality of their associated species communities. Depending on the nature, scale and location of a proposed development or activity and its associated environmental pressures, these other environmental parameters may also require monitoring.

These requirements should be determined through assessment of the likely impact pathways from a proposed development or activity. For example, analysis of contaminants within sediment, measurement of water quality, or on-going monitoring of patterns of sediment transport or hydrodynamic regime (e.g. bed shear stress, current speed) within the survey area. These requirements are outside the scope of this guidance document but are identified here as they may need to be incorporated into a monitoring programme.
If you need to undertake any survey or monitoring work in relation to physical processes, you may find it useful to refer to Brooks *et al.* (2018) which provides guidance on survey and monitoring requirements in relation to Environmental Impact Assessment for major development projects.

Any requirements for the monitoring of the supporting environment should be described in the monitoring plan.

5. Survey and monitoring methods and analysis

5.1. Field methods

A range of survey methods are appropriate for survey and monitoring of subtidal sediments depending on the type of sediments to be surveyed and the specific parameters or indicators being measured or assessed. The main options include:

- geophysical survey (for example, side scan sonar and multibeam echosounder) for large scale survey to identify physical features of subtidal sediments
- Sediment Profile Imagery (SPI) for large scale survey to characterise subtidal sediments
- underwater image survey (such as towed video, still images, ROVs and AUVs) for acquisition of data for sediment type (visual) and conspicuous biota
- physical sampling (such as grabs, cores, beam trawl) for acquisition of data for sediment type and biota (quantitative or qualitative data)
- dive survey for acquisition of data for sediment type and conspicuous biota (visual data) and targeted collection of sediment cores

These methods are discussed in further detail below, with respect to the parameters that can be surveyed using these approaches. The types of methods that are appropriate will vary in relation to both the scale and nature of the proposed marine development/activity. Standard protocols are available for the most commonly used field methods and are indicated where applicable.

The JNCC Marine Monitoring Method Finder, a web-based information hub, has been developed to provide a single point of access to the numerous guidance documents and tools generated both within and outside the UK. It can be used in conjunction with this document to assure a consistent approach to data collection and analysis.

5.1.1. Subtidal sediment parameters

5.1.1.1. Extent & distribution of habitat

Geophysical survey

Geophysical surveys are an efficient and effective approach to assist with mapping the extent and distribution of subtidal sediment habitats based on sediment topographic features (such as sand waves, sand banks, ridges, bars) and topographic complexity (for example, presence of biogenic reefs). Typically, geophysical surveys allow sediments to be assigned to broad categories such as sands, cobbles and boulders, or bedrock, especially where the boundaries of these substrates is distinct.

For a large development, NRW would generally expect both multibeam and side scan data to be collected. Ideally this should conform to International Hydrographic Organisation (IHO) standards (S44 and S57) and have regard for the guidance provided in the relevant MESH ROGs. As well as detecting any biogenic habitats present, the acoustic data should also be used to create a map of sediment facies, which then needs to be appropriately ground-truthed with biological surveys to confirm the habitats/biotopes present and their extent and distribution. The biological survey results should be cross-checked with the initial sediment map to see whether the seabed types found in the biological survey are consistent. Further information can be found in Ware & Kenny (2011).

Guidance on geophysical survey and methods is provided in a number of sources including Ware & Kenny (2011), Saunders *et al*. (2011) and a number of MESH guidelines for seabed mapping including Hopkins (2007) and Henriques *et al*. (2012). See also chapter GN030g for general guidance on geophysical and ground-truthing surveys.

***Side scan* sonar**

Side scan is particularly effective at discriminating features on the surface of the seafloor. Analysis of the sonar data allows prominent seafloor features to be determined and helps to discriminate between different substrates, depending on the quality and resolution of the sonar data. However, it cannot necessarily differentiate between fine and coarse sands.

Harder areas (such as coarser substrates like boulders and bedrock reef) are areas of high reflectivity. They reflect more energy (high backscatter) and usually appear as a lighter signal on the image. Areas of low reflectivity (for example, softer substrates such as fine substrates) reflect less energy (low backscatter) and appear as a darker signal. Very dark areas normally mean the absence of backscattered sound, indicating a shadow behind objects. Further information related to the interpretation of backscatter is provided in Henriques *et al*. (2012).

Side scan sonars are characterised by a beam which is narrow in the horizontal plane and wide in the vertical plane. This creates a narrow acoustic sweep across the sea bed at right angles to the track of the towfish (the unit holding the sonar). Side scan sonars are available with frequencies ranging from about 5 kHz to 1 mHz. Lower frequencies provide a longer range with lower resolution whilst the higher frequencies have a higher resolution but a shorter range (e.g. 5 kHz system can have range of >50 km, while for 1 mHz system the range may be just 50 m) (Henriques *et al*., 2012).

For habitat mapping, side scan sonar should be deployed within a suite of complimentary survey methods including multibeam echo sounders to provide a georeferenced morphology over which high-resolution side scan mosaics can be draped (Henriques *et al*., 2012).

Multibeam echo sounders

Multibeam data provides a detailed bathymetric dataset for the survey area, allowing features such as undulations and sand ripples to be detected. Multibeam echo sounders (MBES) determine depth by accurately measuring the angles of emission, reception and two-way travel time for a pulse of sound energy from the emitting instrument (transducer) to the seabed and back.

A key benefit of MBES is its ability to simultaneously collect bathymetry and backscatter information in a single survey. The images obtained can be used to map the different acoustic characteristics of the seafloor, which can then be used to characterise seabed material when accompanied with ground-truthing from grab samples, seafloor photography and video, and/or following input to acoustic classification software. MBES systems can achieve full bottom coverage with beam swath widths of four to seven times the depth of water being surveyed. Guidance for the use of multibeam is provided in the MESH swathe bathymetry ROG (Hopkins, 2007).

Sediment Profile Imagery (SPI)
This method uses a camera system that penetrates the upper surface of the seafloor sediments to provide detailed images of the sediment profile; most systems also take a simultaneous plan view image of the sediment surface. Guidance for use of SPI is provided in the MESH SPI ROG (Coggan & Birchenough, 2007). This method enables changes in sediment characteristics to be identified accurately across spatial scales and allows sediment boundaries within a given survey area to be identified. If required, several replicate images can be acquired at each location (Coggan & Birchenough, 2007).

Underwater imagery
Various image survey methods are available to collect video or stills imagery. The selection of any particular approach will depend on the aims of the habitat characterisation survey and the area and nature of the seabed to be surveyed. The main options include:

- Drop Down Video (DDV)
- towed video (with option for additional stills camera)
- Remote Operated Vehicle (ROV)
- Autonomous Underwater Vehicle (AUV)

All of these approaches can be used for visual characterisation of subtidal sediments (Holt & Sanderson, 2001a; Hitchin *et al.*, 2015). Imagery can include video and still photography and can be analysed *in situ* on the vessel or post-survey. Targeted image surveys can also be undertaken by divers, see section 5.1.1.2 – Diver survey.

Underwater imagery survey methods can provide visual data on sediment type. Underwater imagery taken along transects can provide habitat/biotope extent data and can enable the identification of any small-scale habitats such as rock outcrops.

Underwater imagery is particularly effective when combined with the more broad-scale data from geophysical survey, as it complements and ground-truths the geophysical outputs and allows the underwater video to target habitats of interest. Underwater imagery is also very useful when trying to identify a transition of one sediment type to another, or the boundary of a seabed feature.

With sled-mounted camera systems the optimum arrangement is to mount both a video camera and a separate still camera on the same frame, with the video facing obliquely forward and the still camera facing directly downward. The video footage provides an overview of the presence or continuity of the seabed habitats, plus an impression of the unevenness of the bed (while the still camera produces a series of higher resolution images that allow accurate identification of the associated fauna (OSPAR, 2009)). Video outputs can be of varying resolutions with a preference for high definition video cameras.

A MESH ROG is available for ‘Underwater Video and photographic imagery’ (Coggan *et al*., 2007). Guidelines are also provided in Procedural Guideline 3-5 of the Marine Monitoring Handbook (Holt & Sanderson, 2001a), and more recent guidance is available in a North-East Atlantic Marine Biological Analytical Quality Control (NMBAQC) scheme Operational Guideline (Hitchin *et al.*, 2015).

5.1.1.2. Biological community composition

Quantitative sampling (grabs and cores)
Most biota in subtidal sediments are usually below the sediment surface (infauna) and will not be recorded in image surveys. Grabs and cores are the most common methods for obtaining quantitative data from sediment habitats on infauna (quantitative and qualitative data) and also on sediment type for particle size analysis (see section 5.1.1.3).

Ware and Kenny (2011) outline types and sizes of grab that could be considered. The two most commonly used are:

- Day grab ($0.1m^2$): recommended for use in soft sediment (such as mud and sand)
- Mini-Hamon ($0.1m^2$): recommended where a significant gravel component is expected

For some specific sediment features where a grab is not suitable, diver-operated cores or suction samplers may be used – see section on diver survey below.

Cores tend to be less commonly used but may have application in certain situations. Core sampling can be undertake from a vessel using a box corer (procedural guidelines on this method are provided in Hopkins, 2007). Samples are generally sieved and preserved in the field (see 5.1.2.3).

Grabs in particular can be damaging to some habitats (such as biogenic reef or seagrass beds), therefore sensitivity of the target habitats needs to be assessed beforehand to determine if this is an appropriate method. NRW would generally advise against taking grab samples in any areas where it is thought there is biogenic reef such as *Sabellaria* reefs or horse mussel *Modiolus modiolus* reefs. If live *Modiolus* or aggregations of *Sabellaria* are collected in the grab, this may indicate the presence of these biogenic reef habitats, and underwater imagery techniques should be used at these locations to determine if this is the case before proceeding with further grab samples in the area.

There is a MESH ROG for ‘Grab sampling and sorting and treatment of samples’ (Guerra & Freitas, 2013) and further information is available in Ware & Kenny (2011) and Procedural Guideline 3-9 of the Marine Monitoring Handbook (Thomas, 2001) which covers the use of grabs. Cooper & Mason (2017) provides a specifically developed protocol for RSMP sampling at aggregate sites.

Underwater imagery
Underwater imagery methods are described in section 5.1.1.1. In relation to community composition ecological parameters for subtidal sediments. Underwater image techniques are only suitable for collection of data on conspicuous epibiota because the majority of the faunal communitiy is buried within the sediment. However, esimates of % cover of conspicuous epibiota can be made from plan-view photography for images of known spatial area.

Diver survey
Diver survey can be used to obtain quantitative data for epibiota using quadrat-based survey approaches or semi-quantitative samples following the Marine Nature Conservation Review survey methods and the Superabundant-Abundant-Common-Frequent-Occasional-Rare (SACFOR) scale (Hiscock, 1996).

Divers can be also used for targeted ground-truthing sampling within habitats, for example to collect video footage and stills images or collect infaunal samples using cores or suction samplers. Diver survey can be a useful approach if finer detail needs to be recorded that would be difficult to determine from remotely deployed underwater imagery or to sample in areas where other methods would not be effective or difficult to deploy.

Guidelines for dive survey are provided in Procedural Guideline 3-3 of the Marine Monitoring Handbook (Holt & Sanderson, 2001b). Guidance on diver-operated cores is provided in Brazier (2001) and for diver-operated suction samplers in Rostron (2001).

Dredges and trawls
In general, trawls and dredges are unlikely to provide useful information for characterisation of benthic habitat and we do not advise them for these types of survey. However, there are some circumstances under which they can be useful, for example in surveying for certain epibenthic invasive non-native species of specific local concern (for example the slipper limpet *Crepidula fornicata*).

Where they are used, dredges and trawls can provide semi-quantitative data; non-countable biota can be recorded on the Superabundant-Abundant-Common-Frequent-Occasional-Rare (SACFOR) scale (Hiscock, 1996).

Trawls and dredges can also be useful for characterising populations of fish and mobile epifauna, although this has several limitations, and is outside the scope of this document.

Different trawl types and methods are discussed in Ware & Kenny (2011). The most common specification for coastal waters is a 2 m beam trawl, with a smaller 1.5 m beam trawl often used in estuaries in line with Water Framework Directive guidance (WFD-UKTAG, 2014b).

Trawls and dredges can damage some seabed habitats, so it is important to assess the sensitivity of the target habitats beforehand to determine if this is an appropriate method to use.

5.1.1.3. Sediment characteristics

Quantitative sampling (grabs and cores)
Grab or core samples can be used to collect samples for particle size analysis (PSA).

The volume of sediment required for a representative PSA depends on the particle size of sediment at the sample site: for muddy sediment a relatively small volume is required but for coarse and more gravelly sediments a greater volume is needed (Mason, 2016). A single PSA sub-sample at each station of about 500ml is usually sufficient (Ware & Kenny, 2011) but taking a greater quantity of material helps improve the estimate of particle size composition, and a larger sample of up to 1kg may be needed for some coarse sediments. For RSMP sampling following the Cooper & Mason (2017) method for sediment-only stations, the volume of sediment for the PSA sub-sample should be greater than 500ml.

There is differing advice in guidance documents about whether PSA samples should be collected as separate sediment samples in order to avoid loss of material from the biotic sample (for example for WFD monitoring (WFD-UKTAG, 2014a), or whether the PSA samples should be collected as a sub-sample of the biotic sample (for example, Ware & Kenny, 2011; Cooper & Mason, 2017). Depending on the purpose of the survey it may be necessary to follow a particular procedure. If this is not the case, NRW's advice is that for characterisation surveys it is acceptable to collect the PSA sample from the biotic sample as long as there is sufficient volume of sediment in the grab not to compromise the biotic sample by doing this. However, for monitoring, a separate PSA sample is likely to be required.

If additional samples also need to be collected for chemical analysis, then it is more likely that an additional grab for PSA and chemical samples will be required so as not to deplete the biotic sample.

PSA samples must be stored in sealed containers without sieving and kept cool until they are analysed.

Diver-operated core samples (instead of grab samples) are equally effective for providing quantitative sediment data (such as percentage composition of different particle size fractions).

If chemical analyses are required, a stainless-steel grab must be used, with sub-samples collected for different chemical analyses. Sample containers will generally be supplied by the analysing laboratory. A plastic scoop should be used to remove samples for metal analysis samples, while a stainless steel or aluminium scoop should be used to remove samples for analysis of organic compounds. The analysing laboratory can advise on the amount of sediment required based on the analyses to be conducted.

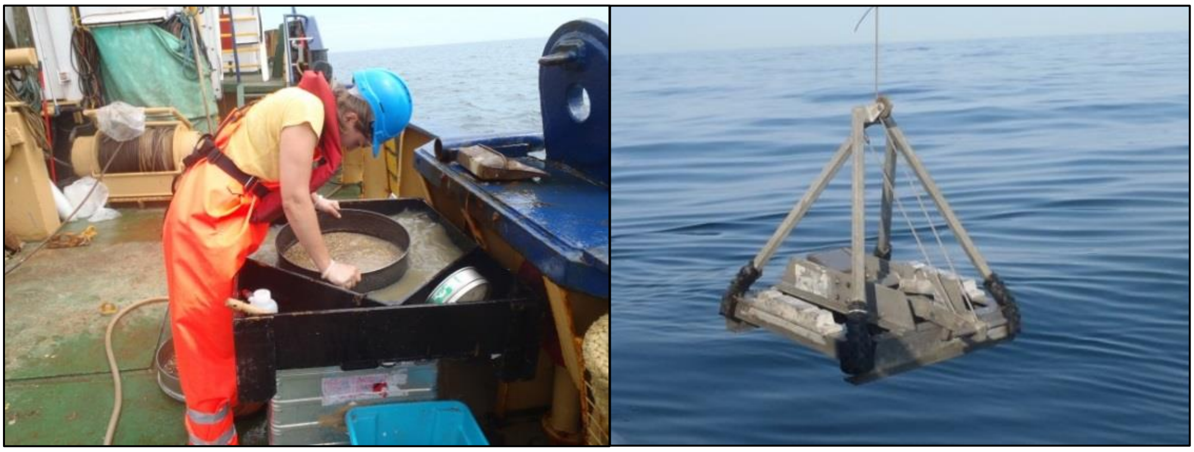

Figure 2. Sieving a grab sample on board (left); deploying a Hamon grab (right). Images © APEM Ltd

Underwater imagery
Still photographs and video can provide descriptive information for sediment type based on visual assessment, but this will only provide an initial high-level characterisation of the surface sediments. The methods are described in section 5.1.1.1 - Underwater imagery.

Diver survey
Observations during a dive survey can provide descriptive information for sediment type based on visual assessment. Divers can also be used for collection of core samples which

can enable more targeted sampling within a habitat. Guidelines for dive survey are provided in Procedural Guideline 3-3 of the Marine Monitoring Handbook (Holt & Sanderson, 2001b).

Sediment Profile Imaging
This technique is an effective method of studying the physical characteristics of the sediments (see Section 5.1.1.1 - Sediment profile imagery).

5.1.2. Fieldwork Quality Control

All fieldwork should be carried out by experienced field scientists, with necessary health and safety provisions, and should observe the following points:

- there should be full sample tracking documentation and field notes for the sampling procedures
- sample collection and handling during surveys must conform to the requirements of subsequent analytical analyses
- macrobenthic samples should be processed in line with the NMBAQC Scheme Processing Requirements Protocol (PRP) (Worsfold *et al.*, 2010).
- particle size samples should be processed in line with NMBAQC Scheme guidance (Mason, 2016).
- all processes should be witnessed and documented, with documentation retained after the surveys are completed

Across all methods it is important to obtain accurate, detailed records and to retain records/data for quality control/assurance procedures.

5.1.2.1 Geophysical survey

Acoustic data collection requires advanced survey instruments which require regular calibration to obtain high quality data and a sound technical knowledge of their operation. These surveys should therefore be undertaken by appropriately qualified and experienced personnel, preferably recognised by a professional institute (International Hydrographic Organization (IHO)) in line with relevant guidance. Amongst other things, attention needs to be given to accurately georeferencing the sounding footprint on the seafloor.

Side scan sonar
The height of the towfish above the seabed should be between 5 and 10% of the horizontal range setting. This usually allows a good level of seabed feature discrimination, including detection of some biogenic reef features. The overlap between tracks should be at least 50% and include appropriate cross tracks. Where complete seabed coverage is required for detailed feature or habitat mapping, ≥200% coverage is recommended.

Multibeam echo sounders
When collecting multibeam data, it’s important to maintain an appropriate overlap to ensure that 100% coverage is achieved without any data gaps or holes. Appropriate statistical analysis of cross line/main line intersections should be undertaken to assess the quality of the data.

5.1.2.2 Underwater imagery

The quality of underwater image data can be significantly limited by environmental conditions at the time of the survey as well as the deployment technique. For towed video systems the tow speed should be constant and suitable to allow seabed features to be observed; the towing vessel should head into the tide and speed over ground of the camera system should be ≈ 0.5 knot (Coggan *et al.*, 2007). If the camera system is towed too quickly the video is difficult to analyse and it reduces the information that can be extracted from the imagery. Also, the camera system can end up being lifted off the seabed so that no usable imagery is obtained. Particular care needs to be taken if deploying towed camera systems in areas of potentially strong tidal currents.

For underwater video to be effective there needs to be adequate underwater visibility, and it cannot be used effectively in highly turbid areas (such as the Severn Estuary). In some instances, addition of a freshwater lens can improve the imagery obtained when underwater visibility is low (for example, Moore & Mercer, in prep).

Video and stills images can be rendered entirely useless for mapping purposes if they cannot be adequately georeferenced. Remote underwater video imagery equipment requires accurate timing and positions, which should be matched between on-screen data and actual times. Ultra-short Baseline (USBL) positioning should be employed where possible. Care must be taken to ensure that images are not obscured by equipment and to avoid disturbance to the seabed (to avoid turbidity and damage).

5.1.2.3. Grabs and cores

There are specific requirements for handling the sediment samples that should be followed:

- all sampling activity must be noted in a field log
- there are protocols for determining the suitability of a sample (such as required volumes) and the field treatment of samples. For example, to approve a sample from a 0.1m^2 grab, Guerra & Freitas (2013) advise that a grab should contain the upper layer of sediment and this surface layer should be undisturbed; it should have a bite depth of at least 5 cm for sand and 7 cm for mud or, alternatively, a volume of at least 5l with sand and 10 l with mud. Further guidance is provided in Ware & Kenny (2011)
- samples are generally sieved in the field immediately after collection, using the same mesh size that will be used in the laboratory when the samples are analysed.
  The sieve size to be used will be specified for a project and the most common recommendations are:
  - 0.5 mm mesh for fine sediments
  - 1.0 mm mesh for coarser sediments

  Choice of sieve size will depend on the objectives of the study as well the sediment type (for example, Rumohr (2009) cited in Guerra & Freitas, 2013). For characterisation surveys NRW advise that a 1mm mesh sieve will generally be sufficient although for muddy sediment or in certain situations it may be necessary to use a 0.5mm mesh sieve. For monitoring, consideration needs to be given to the most appropriate sieve size for the survey.

  If the samples need to be collected in accordance with WFD guidance (as part of a WFD monitoring programme) the sieve sizes required are 0.5 mm for transitional waters, and 1.0 mm in coastal waters (WFD-UKTAG, 2014a). If grab sampling at aggregate sites needs to comply with the RSMP protocol, then a 1 mm mesh sieve should be used, and samples analysed following guidance in Cooper & Mason (2017).
- macrobenthic samples should be processed in line with the NMBAQC Scheme Processing Requirements Protocol (PRP) (Worsfold *et al.*, 2010)

- particle size samples should be processed in line with NMBAQC Scheme guidance (Mason, 2016)
- all samples must be clearly labelled inside and out with codes that link to details in the sampling log
- samples must be preserved and stored in sealed containers as soon as possible. Grab and core samples are generally preserved in buffered 4% formaldehyde solution in the field and are then sent to a benthic analysis laboratory. Other preservation methods may be considered for specialised purposes, such as use of ethanol for molecular studies.

Sub-sampling may be carried out for particularly rich samples or high volumes.

Samples should be discarded if the grab has not closed properly and spillage occurs during transfer of the samples. In situations where a sample fails, for example where a stone is caught in the jaws of the grab NRW's advice is to repeat the sample up to 3 times but, if no satisfactory sample has been secured, to then move approximately 100m from the sample location and try again. If grab samples continually fail, you will need to consider alternative survey methods such as underwater imagery.

Attention should be given to the proportion of cobbles (>64mm) in samples, as this could indicate the presence of Annex I reef habitat (Irving, 2009) and image survey methods may need to be used to determine if reef habitat is present.

5.2. Analytical methods

5.2.1. Geophysical data

Processing of acoustic data can be complex and will vary markedly depending on the method of collection. A variety of guidance is available (Henriques *et al.*, 2012; Plets *et al.*, 2013; IMCA, 2015) and should be followed where possible. All processing should meet International Hydrographic Organisation 1A standard (IHO, 2008).

The scale at which the data is examined appears to be important. If the multibeam bathymetry or side scan data is viewed at too small a scale, then biogenic features may be missed. It is therefore important to view the data at a range of scales; for example, scales of between 1:4,000 and 1:2,000 have previously been found to be appropriate for delineating biogenic *Modiolus modiolus* reefs from side scan data depending on their distinctiveness from the surrounding seabed. A scale of 1:2,000 allows a 300m square to be displayed comfortably on an average computer screen. It is advisable to look at the data at more than one scale, for example at a scale of both 1:4,000 and 1:2,000.

Side scan sonar

Raw side scan data needs to be processed through proprietary software. Side scan sonar data can be processed in real-time to provide field surveyors with composite mosaics. This is suitable for initial quality control and preliminary on-board interpretation. However, like MBES-derived data, side scan sonars are susceptible to interferences from a number of sources (e.g. vessel noise), so the recorded raw data should be post-processed before attempting to classify seabed habitats.

Multibeam echo sounders

The data collected from MBES systems are complex given that they can provide full bottom coverage and require a great deal of post-processing to apply positional, tidal and sound velocity corrections before meaningful interpretations can be made (see IMCA,

2015) Tidal information must be incorporated at the post-processing stage in order to correct all soundings to a standard water level. Additional data cleaning and checking may be required in regard to vessel navigation data.

Standard data-processing for MBES data can involve building a digital terrain model (DTM). This can be visualized in a variety of software packages and imported into Geographic Information Systems (GIS) where it can be integrated with additional biological and geophysical datasets. Unlike data derived from single beam echo sounders, the DTM outputs are normally continuous (as long as 100 % coverage is achieved), meaning interpolation is not required.

Developments in multibeam echo sounder backscatter processing – specifically an integrated suite of processing algorithms called Geocoder – allow end-users to produce properly corrected backscatter mosaics and add more robust qualitative and quantitative discrimination of seabed materials to their seafloor characterisations. Fully corrected backscatter data increases confidence in interpretations of these data to assign seabed features/habitats. MBES data should be gridded at a suitable resolution that will enable accurate bathymetric mapping. Where appropriate, shaded relief models may be created based upon the bathymetric outputs and the two can be overlain to provide additional information.

The MBES outputs should be compared alongside the side scan sonar to identify sediment type and other features of interest where possible, and to confirm seabed morphologies, which can include identification of boulders and boulder fields, sand waves and geogenic reef and bedrock.

5.2.2. Macrobiota samples

Following sieving, all biota should be identified from each sample, following standard NMBAQC guidelines (Worsfold *et al.*, 2010). Identifications should be to species level, but there will always be some taxa for which higher taxonomic levels are used, due to identification difficulties. The data are typically presented as a matrix of taxon counts for each sample. These can be converted to numbers per m^2 if required. Taxonomic nomenclature should follow the World Register of Marine Species (WoRMS).

Blotted wet-weight biomass could be required at different taxonomic levels, (such as taxon level or major taxonomic group), depending on the requirements of the habitat characterisation survey or monitoring. These values can be converted to Ash Free Dry weight using standard conversion factors (see Cooper & Mason, 2017).

Laboratories should retain biological sample residues and extracted biota and produce a reference collection of recorded taxa from each survey.

5.2.3. PSA samples

Analysis of PSA samples should be carried out by a suitable laboratory following NMBAQC standard procedures (Mason, 2016). Typically, coarse fractions are separated dry through a series of standard (certified mesh sizes) sieves. The finest fractions are subjected to laser analysis.

Results are presented as percentages of each particle size fraction, usually divided by Phi fractions (Wentworth, 1922). These can then be converted to sediment categories using either the classification according to Wentworth (1922) or Folk (1954). If the Folk classification is being applied, the modified Folk diagram should be used (see Figure 1 in McBreen & Askew, 2011). The proportion of larger sediment (cobbles (>64mm) and bigger) within the samples should be noted as this is relevant to identify potential stony reef habitat (Irving, 2009).

Particle size samples should be retained until external Analytical Quality Control (AQC) procedures are completed.

5.2.4. Underwater imagery

All analysis of remote underwater video footage and still images should follow the NMBAQC / JNCC epibiota remote monitoring interpretation guidelines (Turner *et al.*, 2016) and be undertaken by a suitably qualified marine ecologist.

Typically, video footage should be divided into broad habitat types and records made separately for each. The records would include an assessment of video quality, percentages of the different sediment types, SACFOR abundances of non-countable biota, and counts of easily recognisable large animals.

Taxa should, wherever possible, be identified to the lowest taxonomic level practicable. It is recognised that due to the limitations of seabed imagery not all taxa can be identified to species level and that identification also depends on the quality of the digital images and footage.

Still photographs can be used to undertake counts and accurate identifications for a higher proportion of species and potentially provide density data (numbers of individuals per m^2), if required. Non-countable taxa can be recorded as percentage cover.

Estimations of % cover for certain biota from plan view quadrat photographs can be undertaken rapidly using open source image analysis software packages such as CPCe software (Kohler & Gill, 2006) or ImageJ (Schneider *et al.*, 2012). CPCe in particular is widely used for monitoring seabed habitats throughout the world (Cardno, 2013; Koedsein *et al.*, 2016; Tabugo *et al.*, 2016) and provides an accurate and repeatable methodology for determining percentage cover from plan-view photography based on a standardised set of categories defined by the user. This substantially reduces the inherent subjectivity of analyst-derived estimates or estimates made by field surveyors.

5.2.5. Analytical Quality control

5.2.5.1. Geophysical data

It is important that the multibeam and side scan data are analysed by someone experienced in interpretation of such data in relation to biological habitats and particular attention needs to be given to the possible presence of biogenic habitats. Refer to chapters GN030c (*Modiolus*), GN030d (*Sabellaria*) and GN030g (subtidal habitats) for more information about acoustic signals associated with biogenic reef structures.

The data processing routines of converting the raw sounding data to the final smooth sounding values are critical in producing quality bathymetric data from which biological habitats can be discriminated. Any methods used to derive final depths such as cleaning filters, sounding suppression/data decimation, binning parameters should be done so sensitively, bearing in mind the importance of the sediment surface features.

Side scan sonar
Problems with detecting the sea bottom in a side scan sonar survey can be corrected during the post-processing stage. Selecting a suitable pixel size for production of the side scan mosaic must consider the resolution of the original acquisition frequency, the detail required, and size of the file that will be produced. It is important that adjacent survey lines are co-registered so that linear features such as sand wave crests join accurately across the survey lines.

Multibeam echo sounders
Tidal information must be incorporated at the post-processing stage for multibeam surveys in order to correct all soundings to a standard water level. Additional data cleaning and checking may be required in regard to vessel navigation and attitude (roll, pitch, and heave) data.

5.2.5.2. Sediment Profile Imagery
Interpreting sediment profile images requires a skilled analyst. Ideally, data should be interpreted either by an experienced marine ecologist or a geotechnical specialist. who is knowledgeable about the processes at work on the seafloor and the patterns created by these processes (Germano *et al.*, 2011). As with any dataset, it is important that all interpretations are subjected to rigorous quality assurance protocols to ensure consistent and reliable results.

5.2.5.3. Benthic sample analysis (macrobiota and PSA)
Benthic sample analysis is quality controlled through the NMBAQC Scheme. Benthic analysis laboratories should be selected by considering their membership and performance in this or similar schemes (Statement of Performance documents can be requested for the NMBAQC Scheme components from participating laboratories).

It is strongly advised that benthic sample analysis for any important project be audited by a third-party laboratory through a nationally recognized QC scheme. The NMBAQC Scheme recommends the audit of 5% of samples for both macrobenthic and particle size samples. A check of benthic invertebrate reference collection identifications should also be included.

Following external auditing, all remedial actions must be completed to ensure data consistency and quality prior to data analysis and interpretation. It is recommended that potential requirements for external analytical quality control for both macrobenthic and particle size analyses following NMBAQC scheme protocols is considered, with recommended remedial actions to quality assure data (for macrobenthos: Milner & Hall 2016; Hall 2016).

5.2.5.4. Underwater imagery
Underwater video and digital stills analysis should be undertaken by a suitably qualified marine ecologist. For small-scale surveys it is recommended that, wherever possible, all digital stills are subjected to quality control and review by a senior marine scientist. For larger projects this is not always practical, given time and cost restraints, in which case 10% of images should be subject to internal audit. If notable discrepancies are identified, it is recommended that all images are re-checked. If errors are identified that relate only to specific taxa, it may be feasible to just re-analyse the relevant images. Creation of a digital

reference collection for each taxon is recommended for Analytical Quality Control (AQC) and to maintain consistency in identification.

5.3. Data analysis and interpretation

The Introductory Chapter GN030-intro (section 4.4) outlines approaches which are available for data analysis. The most suitable approach for each habitat should consider a variety of factors such as whether data are being analysed for a habitat characterisation or monitoring survey and the survey design. Further detail is provided in a wide range of published and grey literature such as Noble-James *et al*. (2017).

5.3.1. Habitat Characterisation and Monitoring

The key aim of the habitat characterisation data analysis is to provide the data outputs necessary to enable the subsequent interpretation required for EcIA and any associated assessments that are required such as Habitats Regulations Assessment and Water Framework assessment (see Guidance Note GN030, section 2.2).

Key outputs of habitat characterisation surveys for subtidal sediments will include production of spatial habitat maps with details of core or other sampling outputs and photographs. Statistical analysis can be applied to the data to describe and distinguish trends in the infaunal and epifaunal communities. The range of statistical analyses to be applied are within the 'identifying patterns in multivariate community data' grouping of statistical approaches (Noble-James *et al*., 2017).

Monitoring data should be subject to in-depth statistical analysis and interpretation to test the hypotheses set out at the design stage. A wide range of suitable univariate and multivariate analysis and mapping techniques are available to achieve this and as a result those chosen are likely to vary markedly between projects. The proposed statistical tests to be used should be described at the monitoring programme design stage.

5.3.1.1. Biota

Data analyses need to calculate a range of appropriate metrics to characterise the biotic communities/assemblages within the subtidal sediments (see Introductory Chapter GN030-intro section 4.4.1).

Multivariate analyses can determine variation in communities/assemblages, such as cluster analysis (usually run with a Similarity Profile (SIMPROF) test) and multi-dimensional scaling (MDS), which allows creation of a 'map' of samples indicating how closely related they are to each other (Noble-James *et al*., 2017). Variation across samples can be analysed further using Similarity Percentages (SIMPER) analysis, which calculates within-cluster similarity, and identifies the most influential taxa within each cluster by ranking average abundances and similarity contributions (Noble-James *et al*., 2017). Further analyses can be used to assess potential relationships between biotic data and environmental data.

5.3.1.2. Particle Size Analysis

The particle size data from all survey replicates can be combined as consistent size fractions and entered into software such as GRADISTAT (Blott & Pye, 2001) to produce sediment classifications, following Wentworth (1922) and Folk (1954). If the Folk classification is being applied, the modified Folk diagram should be used (see Figure 1 in

McBreen & Askew, 2011). Summary statistics should be calculated including mean (Phi), sorting, skewness and kurtosis (following Blott & Pye, 2001).

5.3.1.3. Habitat mapping

Subtidal sediment survey data is most usefully presented as detailed survey maps, typically using GIS software packages. For habitat characterisation we would expect to see a seabed habitat map based on the results of the survey that identifies the different habitats and species assemblages recorded (generally using the JNCC/EUNIS classification). This should identify any protected habitats and/or species recorded (such as Annex I habitats and epibiotic and infaunal species (such as those listed under Section 7 of the Environment (Wales) Act 2016 and OSPAR)). The Introductory Chapter provides further information relating to the types of classification systems that can be used to map benthic habitats and the inclusion of point sampling data within the mapping outputs.

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Cambria House
29 Newport Road
Cardiff
CF24 0TP
0300 065 3000 (Mon-Fri 8am-6pm)
enquiries@naturalresourceswales.gov.uk
www.naturalresourceswales.gov.uk
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