Guidance note

Benthic habitat assessment guidance for marine developments and activities

A guide to characterising and monitoring intertidal sediment habitats

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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 need to characterise and/or monitor intertidal sediment habitats.

If you are unsure about the habitats present in the intertidal area you are interested in, you should consult existing information (see section 4.1), and/or you may need to carryout Phase 1 intertidal survey (section 5.1) to determine the habitats present before undertaking more focussed characterisation surveys.

This habitat chapter (GN030b) 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 intertidal sediments and where are they found in Wales?

Intertidal sediments can be highly variable and include habitats of shingle (mobile cobbles and pebbles), gravel, sand and mud, or any combination of these which occur in the intertidal zone. They are found throughout the intertidal area of Wales and may be particularly extensive within estuarine environments (see Section 2 for more details). They support an array of infaunal communities adapted to the specific conditions present in different sediment types.

Intertidal sediment often forms part of dynamic marine systems, frequently interacting with other adjacent marine and coastal habitats such as subtidal sandbanks, saltmarshes and sand dunes.

1.2. The conservation importance of intertidal sediments

Intertidal sediments have high ecosystem and biodiversity value and provide a wide range of ecosystem services (Defra, 2007). They can provide important habitats for other species, such as feeding grounds for mobile species such as fish and birds and can support commercially important shellfish such as cockles and brown shrimp. Intertidal sediments have a valuable role providing natural hazard protection and supporting nutrient cycling.

The value of intertidal sediment habitats is recognised under a number of different pieces of national and international legislation, including:

- Habitats Directive
- Birds Directive
- Ramsar Convention

- Water Framework Directive
- 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 intertidal 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 water flow, tidal inundation regime and exposure to wave action
- Changes to water quality (such as nutrient and organic enrichment, suspended solids, pollutants)
- Loss of sediment within footprint, removal and disturbance of sediment (including scour) and sediment compaction
- Changes to sediment transport dynamics, erosion/accretion regime, sedimentology and geomorphology
- Introduction of invasive species
- Pollution and other chemical changes

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

1.4. Existing data and guidance for surveying and monitoring intertidal sediment

A brief summary of available information is provided in section 3. Key sources of existing data and guidance for surveying and monitoring intertidal sediment habitats 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 intertidal sediment habitats: Littoral Sediment Habitats (JNCC, 2004a), Estuaries (JNCC, 2004b), and 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 invertebrates’. The monitoring data enables the calculation of an Infauna Quality Index that contributes to the assessment of water body status. Guidance on sampling methods for the monitoring is provided by the WFD UK Technical Advisory Group (WFD UKTAG, 2014a). An additional WFD tool is used to assess biomass and cover of opportunistic algae on intertidal sediments (WFD UKTAG, 2014b).
- Phase I intertidal habitat mapping handbook (Wyn *et al.*, 2006).
- Mapping European Seabed Habitats (MESH) and MESH Atlantic recommended operating guidelines for:
    - Aerial photography (Piel & Populus, 2007)

    - LiDAR (Piel *et al.*, 2012)
- the Royal Institute for Chartered Surveyors (RICS) guidelines for aerial survey
- North-East Atlantic Marine Biological Analytical Quality Control (NMBAQC):
    - Processing of sediment samples (Mason, 2016)
    - Processing microbenthic invertebrate samples (Worsfold *et al.*, 2010)
- NRW Guidance GN006: Marine Ecology Datasets for marine developments and activities (Natural Resources Wales, 2019). Identifies data sources for intertidal 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 intertidal sediment habitats 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 habitat data you may need to undertake a Phase 1 intertidal survey to determine the habitats present before undertaking more focussed characterisation surveys
- a sampling window between February to July is preferable for characterisation and monitoring of intertidal sediment habitats, but can be extended to late autumn (October) if necessary
- relevant ecological parameters need to be selected. The key parameters (section 4.2) to be assessed for intertidal sediment habitats in relation to Ecological Impact Assessment are:
    - extent and distribution of intertidal sediment habitats/biotopes
    - biological community composition (such as number of taxa (infauna and epifauna) in each habitat; diversity indices; semi-quantitative data for conspicuous species
    - presence/absence of any species of conservation or commercial importance, or non-native species
    - sediment characteristics (such as sediment composition, chemical concentrations, depth of redox layer; areas of erosion and accretion)
- 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
- a common approach for characterisation of intertidal sediment habitats is to sample along transects that run from the upper to lower shore, with sampling at one or more sample stations within the upper, mid and lower shore. One sample station in each zone is often sufficient for small-sale surveys and restricted intertidal zones. The number of transects along the shore should be sufficient to enable characterisation

of transitions from the upper to lower shore across the survey area. More variable habitats will generally require a greater number of sample stations.

- where habitats are more heterogenous with a wider range of intertidal substrates and/or uneven distribution, the sampling design may need to involve a more complex sample design (grid-based, random sampling or stratified random sampling with the choice depending on a number of factors including coverage or existing data.
- a grid-based survey design is usually applied to surveys of intertidal sediment habitats that aim to quantify the benthic invertebrate food resource available to birds
- replicate biotic core samples are beneficial for a habitat characterisation survey to improve understanding the small-scale variation in community composition and improve confidence when assigning a habitat/biotope, but they are not essential at the characterisation stage. 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 sample for particle size analysis (PSA) at each sample station is generally sufficient for habitat characterisation and monitoring surveys.
- monitoring programme design will be influenced by the specific hypotheses to be tested and the indicators to be measured. The approaches used will also be informed by the methods and outputs of the habitat characterisation survey. In areas with relatively homogenous substrates within the survey area, localised sampling, such as within transects, may be appropriate. In areas with more heterogenous intertidal sediment habitats a stratified monitoring design is more likely to be required. If the habitat characterisation survey was based on a stratified design, this would be expected to be applied to any monitoring programme.
- surveys should be planned to coincide with low spring tides in order to ensure that as full an area as possible of intertidal habitat is surveyed. This is particularly so for habitat characterisation and will also apply to monitoring programmes where lower shore intertidal sediment habitats need to be surveyed. Repeat monitoring surveys need to be conducted at the same time of year as the previous monitoring surveys.
- other parameters of the wider environment that influence intertidal sediment habitats may need to be characterised and monitoring. This will depend on the nature and location of the proposed development or activity and the associated pressures arising from this. This could include parameters such as: analysis of sediment transport regimes, patterns or erosion and accretion within the survey area, water and sediment quality parameters.

1.6. Survey and monitoring methods and analysis

There are various methods available for survey and monitoring of intertidal sediments (section 5). The main options include:

- Remote sensing (for example, aerial imagery and LiDAR) with ground-truthing to determine extent and distribution of sediment types
- Walkover surveys and habitat mapping
- Physical sediment sampling (usually via hand cores or, in some circumstance, grabs) to target observed habitat types across the site, provide localised quantitative data for biotic communities and samples for particle size analysis (PSA)

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

Intertidal, or littoral[1] sediment includes habitats of shingle (mobile cobbles and pebbles), gravel, sand and mud or any combination of these which occur in the intertidal zone (Connor *et al*., 2004). Intertidal sediment is defined further using descriptions of particle sizes, with sub-categories of the three main groupings (gravel (8-2 mm), sand (2 mm-0.063 mm), and mud (less than 0.063 mm)), and various mixtures of these including coarser grades, for example, muddy sand, sandy mud and mixed sediment (i.e. cobbles, gravel, sand and mud together).

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 exposure to wave action). There is often a transition from one sediment habitat to another, or zoning of different sediment habitats on a shore depending on the relative influence of prevailing conditions.

The physical properties of intertidal sediments is highly dependent on the particle size composition and can be very variable. Intertidal sediment habitats can support communities which are tolerant to a degree of drainage at low tide, variation in air temperature, and changes in salinity. Different types of sediment habitat support varying species assemblages which are generally dominated by infaunal species:

- very coarse sediments tend to support few macrofaunal species because these sediments tend to be mobile and dry out when exposed at low tide.
- medium and fine sand shores usually support a range of oligochaetes, polychaetes, and burrowing crustaceans, and muddy sand shores which are more stable also support a range of bivalves.
- finer sediments (such as those within mudflats) tend to be more stable and retain some water between high tides, and therefore support a greater diversity of species. However, in areas with very fine and cohesive sediment with a black anoxic layer of sediment close to the survey, the species diversity tends to be lower because oxygen cannot penetrate very far below the sediment surface.

2.2. Sub-habitats

The Introductory Chapter of this guidance (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.

The EUNIS classification system refers to intertidal sediment as 'Littoral sediment' (EUNIS code A2 - see Table 1 for an example of the EUNIS classification hierarchy). This broad scale habitat includes eight main habitats, three of which are covered by this chapter[2]:

- Littoral coarse sediment (A2.1)

[1] The terms 'intertidal' and 'littoral' are often used inter-changeably. 'Intertidal' pertains to the part of the shore between high and low water, while 'littoral' is of or relating to the shore.

[2] The terms 'intertidal sediment' or 'littoral sediment' in the rest of the documents refer collectively to the 3 EUNIS Level 3 main habitats that are the focus of this chapter.

- Littoral sand and muddy sand (A2.2)
- Littoral mud (A2.3)

Three of the remaining main habitats will be covered by other chapters of this guidance:

- Salt marsh GN030e (covers EUNIS A2.5: Coastal saltmarshes and saline reedbeds)
- Seagrass beds GN030f (covers EUNIS A2.6: Littoral sediments dominated by aquatic angiosperms)
- *Sabellaria* spp. reefs GN030d (EUNIS A2.7: covers the *Sabellaria* component of 'Littoral biogenic reefs')

Of the remaining two main habitats, it is intended that the littoral mixed sediments habitat (A2.4) will be addressed in a future chapter of the guidance.

Table 1. The EUNIS habitat/biotope hierarchy for intertidal sediments, using 'Littoral mud' as an example

Level	EUNIS code	Habitat	Definition
Level 1	A	Marine Habitats	
Level 2	A2	Broad Habitat	Littoral sediment
Level 3	A2.3	Main Habitat	Littoral mud
Level 4	e.g. A2.32	Biotope complex	Polychaete/oligochaete-dominated upper estuarine mud shores
Level 5	e.g. A2.322	Biotope	*Hediste diversicolor* in littoral mud
Level 6	e.g. A2.3221	Sub-biotope	*Hediste diversicolor* and *Streblospia shrubsolii* in sandy mud

2.2.1. Littoral coarse sediment

This habitat is defined in Connor *et al*. (2004) as including shores of mobile pebbles, cobbles and gravel, sometimes with varying amounts of coarse sand. The sediment is highly mobile and subject to high degrees of drying between tides. As a result, few species can survive in this environment. Beaches of mobile cobbles and pebbles tend to be devoid of infauna, while gravelly shores may support limited numbers of crustaceans.

- 1 biotope complex (EUNIS Level 4)
- 2 biotopes (EUNIS Level 5) with no sub-biotopes

2.2.2. Littoral sand and muddy sand

This habitat consists of shores comprising clean sands (coarse, medium or fine-grained) and muddy sands with up to 25% silt and clay fraction. Shells and stones may occasionally be present on the surface. The sand may be duned or rippled as a result of wave action or tidal currents. Littoral sands exhibit varying degrees of drying at low tide depending on the steepness of the shore, the sediment grade, and the height on the shore. The more mobile sand shores are relatively impoverished; more species-rich communities of amphipods, polychaetes and, on the lower shore, bivalves, develop with increasing stability in finer sand habitats. Muddy sands, the most stable within this habitat complex, contain the highest proportion of bivalves.

- 4 biotope complexes (EUNIS Level 4)

- 11 biotopes (EUNIS Level 5), with 8 sub-biotopes (EUNIS Level 6) between three of them

2.2.3. Littoral mud

Most muddy shores are subject to some freshwater influence, as most of them occur along the shores of estuaries. Mudflats on sheltered lower estuarine shores can support a rich infauna, whereas muddy shores at the extreme upper end of estuaries, which are subject to very low salinity, often support very little infauna.

- 2 biotope complexes (EUNIS Level 4)
- 6 biotopes (excluding the two saltmarsh biotopes) (EUNIS Level 5); one these biotopes has three sub-biotopes (EUNIS Level 6)

There are numerous littoral sediment habitats to be considered when designing benthic habitat characterisation and monitoring surveys. However, any monitoring programmes required for marine developments or activities will generally be focussed on habitats or biotopes of conservation importance and/or those that have a high sensitivity to particular anthropogenic pressures (see sections 2.4 to 2.6).

Figure 1. Extensive mudflats in the Burry Inlet, Carmarthen Bay (left) and close-up of muddy sand habitat with *Corophium* sp. holes (right). Images © APEM Ltd

2.3. Extent and distribution in Wales

Intertidal sediments are found around the whole of the coast of Wales (Figure 2). They are most extensive in the larger sheltered Welsh estuaries (Dee, Dyfi, Dysynni, Dwyryd, Mawddach, Milford Haven/ Daugleddau, Burry Inlet/Loughor, Taf-Tywi-Gwendraeth (Three Rivers estuaries), Severn, Usk, Wye), and bays (Red Wharf Bay, Traeth Lafan, Swansea Bay). They are also present in many smaller estuaries, inlets and embayments and along substantial stretches of the Welsh coast. Some lagoon areas have intertidal sediment, but these are not considered here as lagoons will be addressed through a future chapter of the guidance.

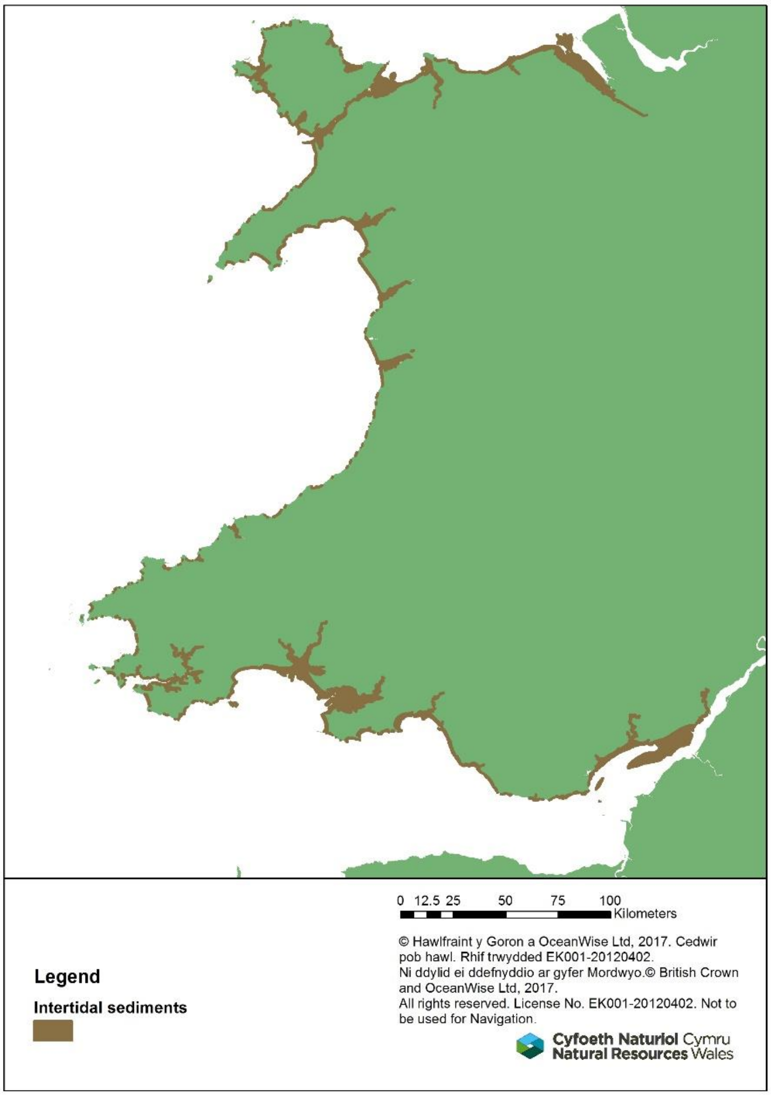

Figure 2. Indicative map of intertidal sediment habitat in Wales

2.4. Conservation importance

Intertidal sediments have high ecosystem and biodiversity value and provide a wide range of ecosystem services (Defra, 2007). Such services can vary considerably between habitats (Balmford *et al.*, 2008). For example, littoral sediments provide important feeding and nursery grounds for commercially exploited fish (such as sole *Solea solea*), several important shellfish species that live on or within intertidal sediments (including brown shrimp *Crangon crangon* and cockles *Cerastoderma edule*), as well as important bait species (for example, lugworms *Arenicola* spp. and ragworms *Hediste diversicolor*).

Intertidal sediments are particularly important for supporting coastal bird populations, providing a rich invertebrate food source for birds that are overwintering, on passage and breeding. Consequently, they are a key feature of many coastal Special Protection Areas (SPAs) and Ramsar sites around the UK such as the Dee Estuary that support bird populations of international importance.

In addition, intertidal sediments provide supporting habitat for aquaculture, natural hazard protection and provision of environmental resilience, nutrient cycling, tourism, recreation, aesthetic benefits, nature watching, research and education (Balmford *et al.*, 2008).

The Introductory Chapter GN030-intro of this guidance (section 3.2.2) provides more general information on conservation policies and legislation, but key aspects relevant to intertidal sediments 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 littoral sediments considered within this chapter:

- Estuaries (code[3] 1130)
- Mudflats and sandflats not covered by seawater at low tide (code 1140)
- Large shallow inlets and bays (code 1160)

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. Special Areas of Conservation in Wales where Annex I habitats estuaries, mudflats and sandflats and large shallow inlets and bays are designated features

Special Area of Conservation	Estuaries	Mudflats and sandflats	Large shallow inlets and bays
Dee Estuary SAC / Aber Dyfyrdwy ACA	X	X	
Glannau Môn Cors Heli SAC / Anglesey Coast: Salt Marsh	X	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
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	

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. Intertidal sediments, particularly mudflats, support an important invertebrate food resource for SPA bird features.

[3] 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.

2.4.3. Ramsar Convention on Wetlands

The adoption of the Ramsar Convention on Wetlands of International Importance in 1971 committed the UK to conserve and sustainably use intertidal mudflats and salt marshes. Intertidal sediments can be supporting habitats for birds within Ramsar sites. Welsh coastal Ramsar sites include the Burry Inlet, Cors Fochno and Dyfi Estuary.

2.4.4. Water Framework Directive

Benthic invertebrates, opportunistic macroalgae and seagrass beds on intertidal sediment habitats are all indicators used for Water Framework Directive (WFD) Biological Quality Elements (BQEs) (WFD-UKTAG, 2014a). These BQEs are used to assess the status of Transitional and Coastal (TraC) waterbodies for the WFD. Intertidal macroalgae and seagrass are covered in more detail in chapters GN030a and GN030f of this guidance.

2.4.5. Marine Strategy Framework Directive

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).

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

'Intertidal mudflats' is on the OSPAR list of threatened and/or declining species and habitats. Other intertidal sediment habitats on the list are covered by other chapters of this guidance: GN030d: *Sabellaria spinulosa* reefs and GN030f *Zostera* (seagrass) beds.

A number of OSPAR-listed fish may be supported by littoral sediments including allis shad *Alosa alosa*, European eel *Anguilla anguilla*, sea lamprey *Petromyzon marinus*, thornback ray *Raja clavata* and salmon *Salmo salar*.

Two OSPAR-listed species (native oyster *Ostrea edulis* and ocean quahog *Arctica islandica*) can occasionally be found at the extreme low water level of intertidal sediments but are predominantly subtidal species.

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

The following marine invertebrate species are listed on section 7 of the Environment (Wales) Act 2016 and can be found in intertidal sediments in Wales:

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

In addition, a range of fish and bird species on the Section 7 list may be supported by intertidal sediment habitats.

The following habitats are included under 'intertidal sediments' on the list of Section 7 habitats:

- intertidal mudflats
- coastal saltmarsh
- seagrass beds
- sheltered muddy gravels
- peat and clay exposures

Of these habitats, only 'Intertidal mudflats' are covered by this chapter of the guidance (other littoral sediment habitats will be covered by other chapters as noted in section 2.2.). Peat and clay exposures are intermediate habitats (between sediment and rock) and are listed under Littoral rock in the EUNIS classification, as opposed to the Littoral Sediment classification under Section 7 of the Environment (Wales) Act 2016).

2.4.8. 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 with many having intertidal sediment habitats of one sort or another as a designated feature. In SACs, SPAs and Ramsar sites, SSSI designations also underpin the terrestrial components of these sites.

2.4.9. 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. Intertidal sediment habitats can be MCZ features but, at present, the only MCZ currently designated in Wales (Skomer MCZ) does not have intertidal sediments as a designated feature of interest.

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

2.4.10. Welsh Marine Protected Area Network

Several intertidal 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 or activities on intertidal 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 intertidal 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 Table3.

Table 3. Key potential pressures of marine developments/activities on intertidal 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	Construction and operation of coastal structures (ports, pilings, jetties, coastal defences, tidal

Pressure	Examples
tidal inundation regime and/or water levels	lagoons etc.); Coastal defences (e.g. managed realignment); Extraction industry.
Nutrient (eutrophication) and organic enrichment; Presence of pollutants	Sewage effluent; Agricultural runoff; 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 runoff; 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; Vehicle use; Construction and operation of coastal structures/developments; Coastal defences (e.g. managed realignment); Extraction industry; Recreation.
Changes to sediment transport and erosion/accretion regime; Changes to intertidal habitat structure/ sedimentology/ geomorphology	Dredging; Construction and operation of coastal 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 structures/developments.
Removal of target and non-target species	Bait digging; cockling; trawling
Biological pressures	Other anthropogenic influences e.g. Waste tipping; Recreational pressures.

2.6. Sensitivity (resistance/resilience to pressures)

For any species or habitat in the Zone of Influence (ZoI)[4] of a development or activity, it is important to understand their sensitivity to each of the specific associated pressures arising from the development or activity.

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

As an illustration of the kind of information that can be obtained from the MarLIN sensitivity reviews, some examples are provided below. Whilst different habitats can show different sensitivity to particular pressures, for some pressures the sensitivity of all or many habitats can be the same, for example all the intertidal sediment biotopes are highly sensitive to physical loss of habitat or change to another seabed type. Also, not all pressures are

[4] 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.

assessed in all cases and reference needs to be made to the individual sensitivity review for each habitat.

- there is a tendency for the more mobile sandy biotopes to be less sensitive than other sediment habitats to hydrological or chemical pressures, and to certain physical pressures. For example, 'Barren littoral coarse sand' (code A2.221) is considered to have low sensitivity to all pressures apart from physical change to, or physical loss of, substratum.
- the biotope 'Polychaetes in littoral fine sand' (code A2.231), is indicated as having high or medium sensitivity to four of the physical pressures and three of the biological pressures.
- the most sensitive biotopes are generally those from stable mud and muddy sand communities, especially where large species are present. For example, '*Cerastoderma edule* and polychaetes in littoral muddy sand' (code: A2.242) is indicated as having medium sensitivity to three hydrological pressures, and high to medium sensitivity to the majority of physical and biological pressures that are relevant to this habitat.
- some biotopes have particular sensitivities to salinity or temperature changes, or to removal of species or introductions of invasive species.

It is important that you to 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 intertidal 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 Section 2.4.1).

CSM is based on monitoring a set of mandatory attributes with the objective of assessing whether the feature is in a favourable condition. As an example, the attributes that might need to be monitored for the Annex I habitat ‘Mudflats and sandflats not covered by seawater at low tide’ (code 1140) include:

- extent of the mudflat/sandflat habitat
- distribution of the mudflat/sandflat habitat
- community composition
- sediment character
- topography

High level guidance for monitoring these attributes is provided in the relevant CSM Guidance: Littoral 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

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 intertidal 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

The IQI contributes to calculation of the Ecological Quality Ratio (EQR) value which is then used to allocate one 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.

There is also a WFD tool to assess biomass and cover of opportunist algae on intertidal sediments (WFD-UKTAG, 2014b). These may be considered a problem where they are exceptionally abundant or persistent due to elevated nutrient levels. The results for the opportunistic algae water quality element of WFD monitoring also contribute to the overall assessment of waterbody status.

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 Intertidal habitat mapping handbook

The Countryside Council for Wales (CCW) guide to mapping of intertidal habitats (Wyn *et al*., 2006), provides detailed guidance for the 'Phase I' method for intertidal survey and mapping. This approach focusses on rapid survey of intertidal habitats/biotopes across large areas and provides habitat/biotope mapping outputs, as opposed to localised collection of quantitative data ('Phase II' survey). More detail is provided in section 5.

3.4 Aerial survey guidance

The Mapping European Seabed Habitats (MESH)[5] project produced a number of 'Recommended operating guidelines' (ROGs) for marine habitat mapping survey methods and these are hosted in the MESH archive on the EMODnet[6] website.

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.

The aerial photography ROG (Piel & Populus, 2007) and the updated LiDAR ROG (Piel *et al.*, 2012) are relevant to intertidal sediment survey and monitoring.

In addition, aerial imagery should be captured according to the Royal Institute for Chartered Surveyors (RICS) guidelines for aerial survey.

3.5. NMBAQC guidance

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

- Guidance on the processing of sediment samples is provided in Mason (2016)
- Guidance on processing macrobenthic invertebrate samples (Worsfold *et al.*, 2010)

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

3.6. Data sources

Distribution data for 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 intertidal habitat maps, intertidal species and other relevant data. 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.

Distribution data for intertidal sediment species in the UK are available on the National Biodiversity Network's (NBN) Gateway. Searches can be conducted based on species distribution data by either site or species.

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 development proposals and activities and over-arching principles for both of these[7]. It is important to understand the differences between characterisation surveys and monitoring when designing project-specific survey programmes.

4.1. Existing data

Where possible, and where timeframes allow, a comprehensive desk-based review of all available data relevant to intertidal 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) summarises 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 intertidal sediments include:

- extent and distribution of intertidal 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)
    - semi-quantitative data such as, number of large bivalves (for example, cockles *Cerastoderma edule*, sand gaper *Mya arenaria* or peppery furrow shell per *Scrobicularia plana* m^2, of number of lug worm *Arenicol*a marina casts per m^2)
    - presence/absence of any species of conservation importance or non-native species
- sediment characteristics
    - sediment type/composition/chemistry (e.g. granulometry, chemical concentrations, interstitial salinity, depth of redox layer)
    - rapid assessment of sediment characteristics (firmness, stability, sorting, surface relief)
    - areas of notable accretion/erosion

[7] Note that 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.

4.3 Habitat characterisation

4.3.1. Aims of benthic characterisation surveys for intertidal sediments

The aim of the habitat characterisation survey is to collate data to describe the intertidal 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 intertidal sediments

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

The range of available survey methods for intertidal sediment habitat characterisation 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).

4.3.2.1. Survey design options

A common approach for intertidal sediment surveys, especially for smaller scale surveys, is to sample along transects running from the upper to lower shore. Sampling is usually conducted at one or more sample stations within the upper, mid and lower shore, often with stations equidistant from each other. One station in each zone is often sufficient for small-scale surveys and restricted intertidal zones. A sufficient number of transects along the shore should be selected with the aim of characterising transitions from the upper to lower shore across the survey area. The transect approach is useful for surveying large areas of open coast, or small-scale sites, where intertidal sediments are relatively homogeneous (for example, APEM, 2013; 2014; Allen *et al.*, 2008).

Sampling design for benthic habitat characterisation surveys can be more complex where more heterogeneous environments, with a range of potential intertidal substrates, are distributed unevenly across a wide area. In this situation, sampling design can involve grid-based (i.e. systematic grid sampling), random sampling, or stratified random sampling. 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.

Where only sparse existing data are available for a site, systematic grid sampling may be most effective as it provides a broad coverage across the ZoI. Where more robust historic biological data are available (or aerial imagery is of sufficient resolution to indicate variation in broad sediment type, such as mud or sand), and the distribution of habitat is known to be heterogeneous, a random stratified sampling design would be preferential, with stations targeted to different types of intertidal sediments across the ZoI. Stratifying sampling in this way can account for natural spatial variability in sediment types, and ensure data are collected for the range of communities expected to be present within the ZoI (Ware & Kenny, 2011; Noble-James *et al.*, 2017). Design can include consideration of stratification across sediment types, WFD water bodies and varying distance from the immediate footprint of the development or activity (for example, APEM & Ocean Ecology, 2015; Ocean Ecology, 2016).

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).

It should be noted, however, that where a development or activity could potentially impact on estuarine SPA / Ramsar site bird features, there may be additional specific survey requirements to effectively quantify the benthic invertebrate food resource available to the birds, to allow Individual-Based Modelling (IBM) of protected coastal bird species to be applied. A key requirement for IBM is to understand the level of invertebrate bird prey depletion over winter (Wright *et al*., 2015). For this type of survey, a grid-based design is usually applied, with methods largely based on sampling protocols set out in West *et al*. (2004; 2006). The IBM survey should be designed to incorporate each of the relevant elements of the benthic ecological survey (i.e. a sub-set of the IBM stations will be sampled for the ecological survey). This will improve time and cost efficiencies.

4.3.2.2. Timing

See section 4.4.4.1.

4.3.2.3. Number of stations (sampling effort)

The number of samples will depend in part on variability of the habitats to be surveyed, with an increased number of stations recommended for more variable habitats (Ware & Kenny, 2011).

For surveys informing IBM (Section 4.3.2.1), a 750 m to 1 km spacing between grid points is recommended (Wright *et al*., 2015; West *et al.*, 2004). However, the exact spacing will depend on the size of the area in question and will need to be proportionate to the area covered.

4.3.2.4. Within-station replication

Where infauna are being sampled for intertidal sediment habitat characterisation using a core or grab (see section 5), replicate samples at each sample station are usually needed; this is mainly due to the relatively small surface area sampled by a corer for each individual sample and the sometimes low faunal abundance in some sediments).

Collecting more than one sample core at a station can benefit EcIA by providing an understanding of small-scale variation in community composition and increasing the chances of sampling species of conservation interest, if present. In addition, having within-station replication increases confidence when assigning a habitat/biotope to a specific station based on the analysis of core samples. But replicate samples are not essential for habitat characterisation.

The suggested amount of within-station replication at each intertidal sediment sample station can vary:

- WFD guidance (WFD-UKTAG, 2014a) is based on collection of three biota core samples at each station which are pooled together
- For CSM for Habitats Directive monitoring, the Marine Monitoring Handbook recommends collecting five separate biotic cores at each station (Common Operation Required Element (CORE) methodology), (Davies *et al.*, 2001).

- When surveying to characterise the available invertebrate food resource for birds to inform IBM (Section 4.3.2.1), the preference is to cover a larger area with fewer replicates (Wright *et al*., 2015). Consequently, for this type of survey a single core is taken at each station (supplemented by a dig-over of an area 0.25 m by 0.25 m), (see Section 5.1.1.2).

For particle size analysis (PSA) and chemical analysis a single sediment sample at each sample station should be sufficient. Separate samples should be taken for inorganic and organic chemical analyses if required.

4.4. Monitoring

4.4.1. Aims of monitoring programmes for intertidal 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.

As part of the EcIA process, measures may also be proposed to enhance existing or created habitats to mitigate impacts or to offset predicted biodiversity loss (Cook & Clay, 2013; Defra & Natural England, 2012).

4.4.3. Design of monitoring programmes for intertidal 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 intertidal sediment habitat (and community) variation as possible. The location of sample stations will be influenced by the specific hypotheses being tested, habitat variation and the location of 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 will need 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. The survey approach used for benthic habitat characterisation will also influence the monitoring programme design. For example, if transects were used for the habitat characterisation survey and indicated relatively homogeneous substrates within the survey area, repeat survey along the same transects may be considered appropriate for ongoing monitoring. On the other hand, if the transect approach and any associated Phase I mapping (see Section 5) revealed a heterogeneous distribution of sediments, then the design may be revised for monitoring purposes to a stratified design. Where the habitat characterisation survey was based on a stratified design, this would be expected to be continued throughout the monitoring phase.

A range of considerations for the design of monitoring programmes is provided in the Introductory Chapter GN030-intro (section 4).

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 at each sample station is a key consideration in any monitoring programme. This needs to be determined 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 any change in community characteristics across stations.

As explained in section 4.3.2.4, CSM guidance recommends collecting five replicate cores for Habitats Directive monitoring, whereas if samples need to be collected in accordance with WFD monitoring guidance, then three within-station biotic cores, which are then pooled, is recommended.

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 and chemical analyses, a single sample at each station is generally sufficient (with separate samples for inorganic and organic chemical analyses if required). Where samples for chemical analyses are being collected, they may not be required at all biotic sample stations.

4.4.4. Sampling timing, frequency and 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, 2014a)
- CSM guidance for inshore littoral 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.

For habitat characterisation, surveys should be planned to coincide with low spring tides in order to ensure that as full an area as possible of intertidal habitat is surveyed. This will also apply to monitoring programmes where lower shore intertidal sediment habitats need to be surveyed. 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. In some areas in Wales at particular times of year, the infaunal community in intertidal sediments can be overwhelmingly dominated by cockle spatfall which may be relevant if monitoring non-cockle fauna. Reference to existing information should help to identify when this is likely to occur.

For surveys designed to determine the available bird food resource to inform IBM, sampling should be conducted prior to the bird overwintering period (i.e. sampling in September and continuing into October if necessary), (West *et al*., 2004). Ideally, this would be followed by sampling after the overwintering period (for example, in February to April) at a reduced number of stations in order to assess declines in the abundance and biomass of the invertebrate prey (Wright *et al*., 2015). If the post-winter survey cannot be conducted, potential declines in abundance/biomass would need to be derived from other studies (Wright *et al*., 2015).

Table 4. Recommended times of year for survey of intertidal 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 intertidal 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 intertidal sediments needs to consider other parameters of the wider environment that may influence the presence of intertidal sediments and the nature and quality of their associated benthic 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 sediment transport or accretion and erosion regime within the survey area, or chemical concentrations in the water column or within intertidal sediments.

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.

As good practice, any anthropogenic impacts observed during intertidal surveys should be recorded including the nature of the impact and coordinates where possible.

5. Survey and monitoring methods and analysis

5.1. Field methods

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

- remote sensing (for example, LiDAR, aerial imagery)
- field-based habitat and biotope mapping
- physical sampling (for example using cores and, in some circumstances, grabs) for quantitative data on biota and also sediment characteristics (such as particle size analysis or chemical concentrations)

These methods are discussed in further detail below with respect to the parameters or indicators 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 development or 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 and can be used in conjunction with this document to assure a consistent approach to data collection and analysis.

5.1.1. Intertidal sediment ecological parameters

5.1.1.1. Extent & distribution of habitat

Remote sensing

Remote sensing can be an extremely effective way of collecting data quickly and efficiently in intertidal areas. It may be particularly useful where other ground-based survey methods are not possible due to access or health and safety reasons.

Low and medium resolution data can be obtained via satellite data, although availability of data is often a problem for intertidal areas as it relies on the overhead passing of the satellite on a clear day at low water.

Airborne imagery is therefore more commonly used to collect data for intertidal areas, and this can be done with high resolution imagery, LiDAR or a combination of both. Where possible, bespoke flights should be conducted at low water on a spring tide.

- For image surveys, data should be collected at a resolution that is typically between 5 and 15 cm (depending on the level of detail required) and with stereo overlaps to allow orthomosaics and height models to be generated using photogrammetric software. Imagery should be captured according to RICS guidelines for aerial survey (section 3.4)
- LiDAR data are typically captured at a point density of between 1 and 16 points per m^2 depending on the level of detail required

Both imagery and LiDAR surveys are typically paired with ground control data to improve upon positional and height accuracy. Broad-scale habitat boundaries can be identified based on the imagery obtained; field survey is then required to ground-truth the boundaries, identify other sediment transitions not evident from the aerial imagery, and collect qualitative and quantitative data for assessment.

Guidance on aerial photography and LiDAR is provided in MESH and MESH Atlantic recommended operating guidelines (Piel & Populus, 2007; Piel *et al.*, 2012).

Habitat/biotope mapping and Phase 1 survey
Littoral sediment habitat and biotope distribution can be mapped on foot or by boat or hovercraft, using a hand-held GPS.

Phase I *in situ* biotope mapping should follow best practice guidance including the Countryside Council for Wales (CCW) Handbook for Marine Intertidal Phase I mapping surveys (Wyn *et al*., 2006), Marine Monitoring Handbook (Davies *et al*., 2001) and CSM guidance (JNCC, 2004a).

Typically, a ‘wire-frame’ map of expected biotopes will be prepared from aerial photographs and taken on the shore survey (Wyn *et al*. 2006). Boundaries and features are then be marked in the field using GPS and noted on the map, along with conspicuous biota and obvious anthropogenic impacts. Any noticeable changes in sediment type or surface features should be recorded, and a GPS reading for each boundary should be taken.

Within each distinct sediment type, stations should be sampled periodically *in situ,* where possible, by digging sediment and sieving through a 0.5 mm to look for conspicuous characterising species. It is not essential to count invertebrates in the sieve but this information (or rapid SACFOR assessment) can provide further qualitative information to inform habitat/biotope allocation and Quality Assurance (QA) for biotope allocation post survey, with a slight increase to the time required to process each Phase I survey station. In addition, at each *in situ* sieve site the following information should be recorded:

- sediment characteristics including sorting, firmness, stability, surface relief, and depth of redox layer
- the numbers of *Arenicola marina* casts and *Lanice conchilega* worm tubes per m^2
- the number of *Scrobicularia plana* marks and the presence of any other conspicuous species such as lug worm *Arenicol*a marina casts and macroalgae (with estimate of abundance/cover when present)

The main aim of this *in situ* sampling is to provide some qualitative data to inform habitat/biotope assignment (Wyn *et al*., 2006). Such Phase I sampling can also be conducted along transects to provide additional information for sediment transitions while supplementing any quantitative data obtained.

Biotopes can be assigned according to the JNCC Marine Habitat Classification Scheme. This has been incorporated into the European Nature Information System (EUNIS) classification (EEA, 2017), within which each habitat/biotope type has been allocated a EUNIS code. JNCC provides correlation tables between the two systems and the EUNIS system is now more commonly applied to biotope mapping.

5.1.1.2. Biological community composition

Quantitative sampling (e.g. cores) – Phase II survey
Most of the biota in intertidal sediments is usually below the sediment surface and generally too small for photographic assessment. Phase II survey involves quantitative sampling techniques to gather samples for analyses to assess abundance and diversity of taxa present. Phase II surveys provide robust quantitative data which usually supplements the Phase I survey.

The most common method for obtaining quantitative data for benthic organisms within sediment is to use cores (for example, Dalkin & Barnett, 2001). The most common core type is a plastic or metal cylinder with an area of 0.01 m^2 (a cylinder of diameter 11.28cm), which is usually inserted into the sediment to a depth of 15 cm. Where a significant gravel component is expected, a metal corer with a toothed rim may be needed. Other core diameters may be used but 0.01 m^2 is a standard size and is the most likely to provide data comparable to historic surveys. It may be necessary to conduct subsampling for particularly rich samples or where invertebrate abundance is particularly high.

Larger and/or deeper-burrowing species might not be sampled in the cores, and where they are also of interest (for example, taxa that are known to provide a bird food resource), a dig-over can be conducted (Dalkin & Barnett, 2001). For this approach a 1 m^2 area is marked out using a quadrat in an undisturbed section of the site, and the abundance of obvious mounds and casts and any algal cover are recorded. The area is then excavated to a depth of 20–30 cm and examined in the field for larger macrofaunal species. As for the Phase I survey, further detail relating to sediment characteristics, any macroalgae present, and any conspicuous fauna should also be recorded at each station.

Samples are generally sieved in the field, using the same sieve mesh size that will be used in the laboratory (usually a 0.5 mm mesh sieve, Dalkin & Barnett (2001)). 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. Buffered formaldehyde solution is the most usual preservative, while other preservation methods may be considered for specialised purposes (e.g. ethanol for molecular studies).

It should be noted that some specific approaches are applied when collecting data to inform IBM which are variations of those indicated above. Specific considerations and methods for invertebrate sampling for IBM, including analytical approaches, are indicated in Wright *et al*. (2015).

5.1.1.3. Sediment characteristics

Quantitative sampling (grabs and cores)
When replicate biological cores are collected at a sample station, a further core should be collected directly adjacent to the biological sample for particle size analysis (PSA) to provide quantitative sediment data, such as percentages of different particle size fractions within the sediment.

To ensure that the PSA sample is representative of the biota sample, it must include a cross section of the sediment sampled for biology, not just the surface (i.e. a core usually taken to a depth of 15 cm). A sample of about 500 ml is usually required for analysis but a larger sample may be needed in coarse sediments. PSA samples must be stored in sealed containers without sieving and kept cool until analysis can be conducted (section 5.3.1.2).

If chemical analyses are required, subsamples should be collected, usually taken using a scoop from the sediment surface. Separate samples should be collected for the different analyses required. 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 would be used to remove samples for organic matter analysis.

Figure 3. Deploying a hand corer (left) and a sediment core after collection (right) Images © APEM Ltd

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 completion of surveys.

Across all methods it is important to obtain accurate detailed records and to retain records and data for quality control and quality assurance procedures. Where there is more than one survey team it can be useful to conduct a pre-survey sampling session with all of the surveyors together, or to sample the first station together, to ensure consistency.

5.2. Analytical methods

5.2.1. Aerial imagery

Specialist image processing software should be used to perform the following functions:

- geometric image correction
- radiometric image correction

- quality control image data before, during and after download

The pre-processing functions above are used to create colour-balanced, distortion-free aerial imagery. The processed imagery and associated flight log data are imported into specialist proprietary photogrammetric software, to be mosaiced and orthorectified to generate seamless high resolution georeferenced orthomosaics.

The imagery should be aligned using pixel-matching algorithms which identify common features between each image pair. The post-processed GPS data from the aircraft flight log is then used to triangulate the block, creating a continuous model of the site. Once the initial triangulation is complete, any Ground Control Point (GCP) data captured in the field can be imported into the block to enhance the accuracy of the model. A final seamless, accurately georeferenced image mosaic is then produced.

5.2.2. Macrobiota samples

Core samples are generally fixed in buffered formaldehyde solution in the field and are sent to a benthic analysis laboratory. Other preservation methods may be considered for specialised purposes, such as use of ethanol for molecular studies).

In most instances the sieve size to use for mudflats and other intertidal sediments is 0.5 mm (Dalkin & Barnett, 2001) which is WFD compliant for intertidal sediment sampling. There may be project specific reasons where different sieve sizes may need to be considered but this will need to be justified on a project by project basis.

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 may be required at different taxonomic levels (such as taxon level or major taxonomic group) depending on the requirements of the habitat characterisation survey and monitoring. An alternative method to record biomass is to calculate Ash Free Dry Weight (AFDW) (for example, Wright *et al*., 2015). For assessments of bird prey availability, measurements of biomass and size of invertebrates can focus on the main invertebrate bird prey species.

5.2.3. PSA samples

Analysis of granulometry or PSA should be carried out by a suitable laboratory following standard procedures (Mason, 2016). Typically, coarse fractions are separated dry through a series of standard sieves (certified mesh sizes). 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 according to Folk (1954) or Wentworth (1922).

5.2.4. Analytical Quality Control

5.2.4.1. Benthic sample analysis (macrobiota and PSA)

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

PSA should be undertaken by laboratories which operate through a nationally recognised Quality Control (QC) scheme such as the NMBAQC Scheme. Dry sieving should be performed in accordance with recognised technical requirements and testing e.g. ISO 3310 (2000).

Laboratories should retain biological sample residues and extracted biota and produce a reference collection of recorded taxa from each survey. Particle size samples should also be retained until external Analytical Quality Control (AQC) procedures are completed.

It is also strongly advised that 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. Benthic invertebrate reference collection identifications should also be checked. Following external auditing, all remedial actions must be completed to ensure data consistency and quality prior to data analysis/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 see Worsfold & Hall, 2017).

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 main purpose of habitat characterisation in the context of proposed developments and activities is to provide the data outputs necessary for the EcIA process and to provide evidence in support of any associated assessments as required (see the Guidance Note GN030 and Introductory Chapter GN030-intro).

Key outputs of habitat characterisation surveys for intertidal sediments will include production of spatial habitat maps with details of core or other sampling and photographs. Statistical analysis can be applied to the data to describe and distinguish trends in the infaunal 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 intertidal 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. 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 Distribution
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). Summary statistics should be calculated including mean (Phi), sorting, skewness and kurtosis (following Blott & Pye, 2001).

5.3.1.3. Habitat mapping
Mapped intertidal sediment survey data may be most usefully presented as detailed survey maps, typically using GIS software packages. 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 is provided in the Introductory Chapter.

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