Guidance note

Benthic habitat assessment guidance for marine developments and activities

A guide to characterising and monitoring *Sabellaria* reefs

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Contents

List of Tables

List of Figures

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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 Ocean Ecology Limited.

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 seashore / seabed habitat data and know that intertidal or subtidal *Sabellaria* reef habitats are present, and you need to carry out habitat characterisation and/or monitoring of these reefs.

If you are unsure about the habitats present, you should:

- for intertidal areas, consult existing information (see section 4.1) and/or you may need to carry out a Phase 1 intertidal survey (see section 5.1 in chapters GN030a and GN030b) to determine the habitats present before undertaking more focussed characterisation surveys
- for subtidal areas, refer to chapter GN030g[1] for guidance on characterisation of subtidal habitats

This habitat chapter (GN030d) 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 *Sabellaria* reefs and where are they found in Wales?

Sabellaria reefs are biogenic habitats formed by tube-forming polychaete worms. The two species found in Wales are generally, but not always, restricted to either the intertidal (*Sabellaria alveolata*) or subtidal (*S. spinulosa*), where they can form dense colonies of tubes built from sand-sized particles.

The reefs are thought to contribute to beneficial ecosystem processes as they can be topographically complex, providing microhabitats for an abundance of marine life.

The majority of known Welsh reefs are found in intertidal areas along parts of the south, west and north Wales coastlines, with concentrations along the Gwent and Glamorgan coastline and within Cardigan Bay. Subtidal reefs are less common but have been recorded off Anglesey and in the Severn Estuary (see sections 2.3).

Criteria have been developed to help determine when *Sabellaria* spp. should be considered as forming a reef, and also descriptions for different reef formations (see section 2.5 for more details).

[1] This document is currently in preparation.

1.2. The conservation important of *Sabellaria* reefs

Biogenic reefs formed by *Sabellaria* spp. provide topographically complex structures with varied microhabitats which can support high levels of biodiversity.

On the shore, *S. alveolata* reefs, whilst not generally supporting particularly diverse communities, do provide increased diversity of habitat. The reefs can cover large areas of mid and lower intertidal zone increasing the heterogeneity of the shore by forming hummocks and ridges which can trap water leading to the formation of pools. The reefs can have a stabilising function on otherwise mobile sand, shingle, cobbles and pebbles. Although the communities associated with these reefs are not necessarily particularly rich, the reefs provide attachment for a variety of macrophytes and epifaunal species, as well as a multi-faceted matrix of cavities for various faunal species.

Subtidal *S. spinulosa* reefs are of biodiversity importance as the complex reef structure provides attachment surfaces and crevices that enable a higher abundance (and biomass) of fauna to live than occurs in surrounding substrates where the reefs are not present.

Sabellaria reefs support a number of ecosystem services such as food provisioning for other species and through their role in filtering water and nutrients from the surrounding water.

More information is provided in section 2.4.

1.3. What kind of developments and activities might affect *Sabellaria* reefs?

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

- changes to temperature and salinity
- changes to emergence regime and wave exposure
- changes to, removal of, and disturbance of substrate surface and subsurface
- changes in suspended solids (water clarity)
- siltation rate changes (smothering)
- permanent habitat loss (change to another seabed type or to a freshwater or terrestrial habitat)
- introduction or spread of invasive non-native species (INNS)
- removal of non-target species

Further detail relating to potential pressures from developments and activities on *Sabellaria* reefs is provided in Section 2.6.

1.4. Existing data and guidance for surveying and monitoring *Sabellaria* reefs

A brief summary of available information is provided in section 3. Key sources of existing data and guidance for surveying and monitoring *Sabellaria* spp. reefs are:

- Joint Nature Conservation Committee (JNCC): recent JNCC guidance for the monitoring of marine benthic habitats (Noble-James *et al.*, 2017)
- feature condition monitoring reports from work in Wales and the rest of the UK (references provided in section 3 and other sections of the document)
- Marine Monitoring Handbook (Davies *et al.*, 2001)
- Phase I intertidal habitat mapping handbook (Wyn *et al.*, 2006)

- Mapping European Seabed Habitats (MESH) and MESH Atlantic recommended operating guidelines for:
    - swath bathymetry (Hopkins, 2007)
    - side scan sonar (Henriques *et al.*, 2012)
    - single beam echo sounder (Populus & Perrot, 2007)
    - sediment profile imagery (Coggan & Birchenough, 2007)
    - underwater video and photographic imaging techniques (Coggan *et al.*, 2007)
- benthic monitoring survey design and planning (Ware & Kenny, 2011) – produced for work in relation to the aggregate industry but has wider application.
- benthic habitat survey and monitoring in relation to marine renewables deployments (Saunders *et al.*, 2011) but has wider application
- 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)
- 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 *Sabellaria* spp. reefs within the survey area, identify any other 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 seashore or seabed habitat data or it is out of date or of poor quality, you may: for intertidal areas, need to undertake a Phase 1 intertidal survey or, for subtidal areas, need to undertake a geophysical survey, to determine the seashore / seabed habitats present and their distribution and extent in order to target habitat characterisation and monitoring surveys
- a sampling window between late summer to early autumn is recommended, following the main spring/summer settlement period to ensure sampling during peak biomass. Sampling from late October to March should be avoided. Within a monitoring programme, all reefs should be surveyed during the same month of the year, and repeat surveys should be in the same month as the baseline survey
- relevant ecological parameters need to be selected. As a minimum the following ‘broad-scale’ parameters should be established for each reef:
    - extent (essential to inform sampling design)
    - elevation
    - percentage cover

other fine-scale and environmental parameters may be relevant depending on the nature of the proposed development or activity and likely effects

- 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.
- all reefs in the survey area should be characterised using the broad-scale ecological parameters. Sample design for habitat characterisation can be relatively simple with a focus on mapping extent and distribution. The mapped data can inform any more detailed sampling that is required for characterisation, with a systematic grid of sample points overlain across each reef. Triangular grid patterns are advised to reduce the chance of bias. A stratified random sampling approach can be applied if the characteristics of the reef(s) require this.
- monitoring programme design will be influenced by the specific hypotheses to be tested and the indicators to be measured. An 'investigative' monitoring approach is often the most appropriate for *Sabellaria* reefs. The 'beyond-BACI' sample design should be implemented when possible. However, if no control reefs are available, a Before-After-Control-Impact Paired Series design should be considered.
- the degree of homogeneity of the area to be monitored and variability of the indicators to be measured will influence the sampling approach for monitoring. A systematic grid can be used or, alternatively, randomly positioned samples stratified based on specific parameters of the reef and/or surrounding environment. The key indicators will generally be the broad-scale ecological parameters, although it may be considered necessary to also monitor some of the fine-scale and/or environmental parameters.
- *Sabellaria* spp. reefs are sensitive to physical impacts and care should be taken to ensure that the methods used for characterisation and monitoring have as little impact as possible.
- other parameters of the wider environment that influence *Sabellaria* reefs 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 and the hydrodynamic regime and water quality.

1.6. Survey and monitoring methods and analysis

A range of survey methods can be appropriate for survey and monitoring of *Sabellaria* reef parameters/indicators (section 5). The main options include:

- Phase I walkover survey and habitat mapping (intertidal reef)
- aerial surveys / Unmanned Aerial Vehicle (UAV) (intertidal reef)
- geophysical survey (such as side scan sonar) for habitat mapping (subtidal reef)
- Digital Imaging Scanning Sonar and Sediment Profiling Imagery – application in turbid environments (subtidal reef)
- underwater image survey (such as towed video, still images, ROVs and AUVs) (subtidal reef)
- Phase II quantitative sampling (for example, quadrats) (intertidal and subtidal reef)
- dive survey for quantitative and semi-quantitative sampling (subtidal reef).
- other sampling approaches for specific fine scale or environmental parameters

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

Sabellaria reefs are biogenic habitats formed by sedentary filter-feeding polychaete worms belonging to the family Sabellariidae. Two species are found in the UK, the honeycomb worm (*Sabellaria alveolata*) and the Ross worm (*Sabellaria spinulosa*).

S. alveolata is most abundant on south and west coasts of the UK. It occurs primarily in the mid to lower parts of the intertidal and occasionally in sublittoral zones (Mettam *et al.*, 1989; Allen *et al.*, 1991; Grave & Whitaker, 1997). In contrast, *S. spinulosa* is found all around the UK. It normally occurs in the sublittoral zone, although significant aggregations have been identified in the intertidal zone in Harwich, the Wash and parts of Scotland (Mcintosh, 1992; Unicomarine, 1998; Hendrick, 2007).

Like other Sabellarid polychaetes, both species are adapted to and require sediment-laden water with a good supply of sand-sized particles (Kirtley & Tanner, 1968) which they glue together with a biomineralised cement secreted from specialised glands (Le Cam *et al.*, 2011) to build their tubes. Both are gregarious species and can form biogenic reef colonies that cover hundreds of thousands of square meters of seabed (Pearce *et al.*, 2007; Pearce *et al.*, 2011a; Pearce *et al.*, 2011b; Jenkins *et al.*, 2018) and similarly large areas of intertidal lower shore (Dubois *et al.*, 2002; Egerton, 2014; Ocean Ecology Limited, 2016a).

Figure 1. Micrograph of *S. alveolata* (top left); aerial image of *S. alveolata* reef (in centre of image) beginning to expose during an ebbing tide in the Severn Estuary (top right); 'platform' reef in Port Talbot, South Wales (bottom). All images © Ocean Ecology Limited

There is a high organisational level to the reef structures formed by *S. alveolata*. The tubes are so closely aggregated that they resemble a honeycomb, giving the species its common name 'honeycomb worm reef' (Figure 1). Each tube shares communal walls with its neighbours and has a fragile porch-like projection over the entrance to the tube (Wilson, 1974; Egerton, 2014) where the head and tentacles protrude when submerged. Despite its reef-forming capabilities, *S. alveolata* can also be found as single individuals or in small aggregations. A synopsis of the current understanding of the life history and ecology of *S. alveolata* is provided in section 2.2.1 and in Bush (2015).

The reef structures created by *S. spinulosa* lack the tube 'porches' and organisational structure of *S. alveolata* reefs and, consequently, the strength and consolidated appearance (Gruet, 1986; Vorberg, 2000). The seemingly fragile and haphazard nature of *S. spinulosa* reefs has led many authors to conclude that these structures are ephemeral in nature (Holt *et al.*, 1998; Hendrick, 2007; UKBAP, 2007; JNCC & NE, 2010; Jenkins *et al.*, 2018). However, this has not been fully evaluated in the absence of pressures from commercial fishing, so this assertion remains a subject of debate. A comprehensive account of the ecology of *S. spinulosa* reefs is provided by Hendrick (2007), Pearce *et al.*, (2011b) and Pearce (2014).

Figure 2. Micrograph of *S. spinulosa* (top left), image © Ocean Ecology Limited; clumps of *S. spinulosa* sampled with a 2m beam trawl (bottom left) (reproduced from Pearce *et al*., 2011b); an image of a *S. spinulosa* reef taken with a drop down camera trawl (right) (reproduced from Pearce *et al*. 2011b), Crown Copyright 2013

2.2. Sub-habitat types

There are a number of requirements that are essential for the development and persistence of *Sabellaria* reef. These include:

- an abundance of *Sabellaria* larvae in the water column for recruitment
- a supply of suspended sediment for tube construction
- a degree of wave exposure and/or water currents to transport sediment and provide particulate organic matter for feeding
- a suitably stable substratum for physical attachment (Gruet, 1971; 1972; 1986; Porras *et al.*, 1996)

It is the variability of these key requirements that is thought to govern the form of the various reef structures created by *S. spinulosa* and *S. alveolata* (La Porta & Nicoletti, 2009).

2.2.1. *Sabellaria alveolata* reef

S. alveolata reef is considered to undergo phases of development and decay over periods of up to five years (Gruet, 1986) whereby they prograde or retrograde either partially or totally through resettlement (Curd *et al.*, 2019). This cycling of different sub-habitat types is regarded as key in relation to the ecosystem services that the reefs provide, which in turn underpins their conservation status (see section 0).

The majority of *S. alveolata* reefs located around Wales are thought to be representative of the EUNIS[2] Level 5 biotope A2.711 '[*Sabellaria alveolata*] reefs on sand-abraded eulittoral rock', attached to either exposed intertidal bedrock or on cobble and boulder substrate. Some reefs are, however, found on mixed sediment substrates and form extensive low-lying sheets composed of fused clumps of tubes (R. Griffin, pers. obser.). These reefs are distinctly different from the hummock-shaped and platform colonies that form on cobble and boulder substrate and are thought to represent an alternative EUNIS Level 5 biotope (A2.71x '[*Sabellaria alveolata*] reefs on stable eulittoral mixed sediment') (Ocean Ecology Limited, 2015). The EUNIS biotopes for *Sabellaria* reefs are provided in Table 1.

Current understanding of the life history and ecology of *Sabellaria alveolata* reef

S. alveolata are ciliary suspension feeders (Dubois *et al.*, 2005), feeding when covered by the tide, extracting fine suspended matter and phytoplankton from the surrounding seawater (Allen *et al*., 2002). Grains that are too large to digest are diverted on intake to provide material for tube building (Wells, 1970). *S. alveolata* are well adapted to relatively high-energy environments.

S. alveolata has a complex life cycle with a planktonic larval stage followed by sessile bottom-dwelling juvenile and adult stages (Cazaux, 1964). The free-swimming larvae are thought to spend anything between six weeks and six months in the plankton (Wilson, 1968; Wilson, 1971) developing to a stage when they seek a suitable settlement site to begin tube construction during their sessile bottom-dwelling stage (Cazaux, 1964; Dubois et al., 2007; Slater, 2013).

Adults have separate sexes and produce gametes on a broadly seasonal basis or in response to physical disturbances (Pawlik, 1988). The periods of spawning seem to vary throughout its geographical distribution and have been shown to vary from year to year (Cunningham *et al*., 1984b; Gruet 1982). Both hydrodynamic and biological factors can affect the dispersal of larvae. Hydrodynamic factors can include both wave- and tidal-induced currents, coastal upwellings, river plumes and eddies (Bradbury & Snelgrove, 2001). Biological factors include spawning time, period and location, along with larval behaviour and recruitment (Ayata *et al*., 2009; 2011). A study by Bush *et al*. (2015) looking at larval dispersion and connectivity around the coast of the UK found that sites in south Wales at Dunraven, Porthcawl, Swansea Bay and Limeslade appeared to form a distinct

[2] EUNIS is a pan-European habitat classification system developed by the European Environment Agency to provide a comprehensive habitat classification for Europe. The Marine Habitat Classification for Britain and Ireland has been incorporated into the EUNIS classification. There is more information about these habitat classifications in the introductory chapter of this guidance (GN030-intro section 3.2.4.)

sub-population, showing interconnectivity, but displaying isolation from other sub-populations.

Table 1. EUNIS biotopes listed for *Sabellaria* reefs and the corresponding marine conventions, directives and legislation affording protection for each*

EUNIS Code	MNCR Code	Biotope Description	Section 7	Annex I	OSPAR	WFD
A2.7	LS.LBR	Littoral biogenic reefs	-	✓	-	-
A2.71	LS.LBR.Sab	Littoral [Sabellaria] reefs	-	✓	-	✓
A2.711	LS.LBR.Sab.Salv	[*Sabellaria alveolata*] reefs on sand abraded eulittoral rock	✓	✓	-	✓
A4.22	CR.MCR.Csab	[Sabellaria] reefs on circalittoral rock	-	✓	✓	✓
A4.221	CR.MCR.CSab.Sspi	[*Sabellaria spinulosa*] encrusted circalittoral rock	-	✓	✓	✓
A4.2211	CR.MCR.CSab.Sspi.ByB	[*Sabellaria spinulosa*] with a bryozoan turf and barnacles on silty turbid circalittoral rock	-	✓	✓	✓
A4.2212	CR.MCR.CSab.Sspi.As	[*Sabellaria spinulosa*], didemnid and small ascidians on tide-swept moderately wave-exposed circalittoral rock	-	✓	✓	✓
A5.6	SS.SBR	Sublittoral biogenic reefs	-	✓	-	-
A5.61	SS.SBR.PoR	Sublittoral polychaete worm reefs on sediment	-	✓	-	✓
A5.611	SS.SBR.PoR.SspiMx	[*Sabellaria spinulosa*] on stable circalittoral mixed sediment	-	✓	✓	✓
A5.612	SS.SBR.PoR.SalvMx	[*Sabellaria alveolata*] on variable salinity sublittoral mixed sediment	✓	✓	-	✓

* Section 7: Habitats of principle importance for the purpose of maintaining and enhancing biodiversity in relation to Wales (Section 7 Environment (Wales) Act 2016).
Annex I: Habitat: protected habitat within SACs under the European Habitats Directive (92/43/EEC).
OSPAR: listed as a threatened and/or declining priority habitat (OSPAR, 2008).
WFD: 'higher sensitivity' habitat which needs to be considered in any WFD assessment (see section 2.4.2)
It should be noted that not all occurrences of *S. spinulosa* biotopes are automatically protected under these conventions, directives and legislations as they first must be shown to be representative of reefs rather than veneers and/or crusts based on their extent and temporal stability.

The settlement of *S. alveolata* can be stimulated by the presence of adult tubes or tube remnants (Cunningham *et al*., 1984a; Quian, 1999; Wilson, 1971), most likely due to chemical cues that stimulate the larvae to settle and metamorphose (Wilson, 1968). Intensity of settlement is extremely variable from year to year and between locations but has been observed in all months except July (Ayata *et al*., 2009; Hill *et al*., 2010). Some studies in south Wales have shown that the greatest densities of settlement stage larvae occur between June and August. (R. Griffin, Ocean Ecology Ltd, 2016, pers. obser.).

2.2.2. *Sabellaria spinulosa* reef

S. spinulosa reefs exist in a range of formations from isolated patches to extensive reefs extending 20+ km^2 (Pearce *et al.*, 2011a). However, unlike *S. alveolata*, *S. spinulosa* reefs are thought to have fewer defined sub-habitat types, as the developmental cycle described by Gruet (1986) has not been documented for *S. spinulosa* (primarily due to the difficultly of observing them in subtidal environments and in what are often low visibility conditions). There are references to 'crusts' or 'veneers' where *S. spinulosa* occurs in high densities but does not form topographically distinct features (Gubbay, 2007; Limpenny *et al.*, 2010; Jenkins *et al.*, 2018). However, it is unclear at this time whether these low-lying structures constitute a separate or sub-habitat type, a phase in the development of a reef, or a reef which is developmentally moderated by one or more environmental or anthropogenic stressors.

Both 'crusts' and topographically distinct reef structures formed by *S. spinulosa* have been observed on a variety of substrates ranging from rock to fine sand (Wilson, 1970; Pearce *et al.*, 2011a; Pearce *et al.*, 2014; Jenkins *et al.*, 2018), although biotopes in which *S. spinulosa* are either common or abundant are limited to circalittoral rock and mixed sediments (Table 1). Given the wide variety of substrata upon which *S. spinulosa* aggregations have been reported, including some that occur in the eulittoral zone, it is likely that *S. spinulosa* reef habitats are currently under-represented in the EUNIS classification scheme

2.3 Extent and distribution in Wales

2.3.1. *Sabellaria alveolata* reef

As a warm water species, *S. alveolata* has a relatively restricted distribution in Britain with greatest abundance on south and west coasts. Its extent and distribution are thought to be increasing in Wales (Mercer, 2016). This may be related to factors such as increasing sea water temperature due to climate change, improvements to water quality, periods of good recruitment, and increases in the availability of habitats such as those provided by coastal defence structures (Frost, 2004).

A notable density of the *S. alveolata* reefs in Wales is located along the Gwent and Glamorgan coastline, particularly in the Severn Estuary where they extend into the subtidal zone and represent some of the only known subtidal reefs formed by this species in the UK (NE & CCW, 2009). In south Wales, reefs are known to occur all along the coast from Goldcliff to the Gower Peninsula. In west Wales reefs are located on cobble and boulder substrate along stretches of coastline in Cardigan Bay (Boyes *et al.*, 2008; Moore, 2010) and the Llŷn Peninsula (Mercer, 2013; 2016), and are thought to represent some of the best UK examples of *S. alveolata* reef.

In north Wales the distribution is limited to individual reefs at Llanddulas and Rhyl, with more extensive reef and crusts on the English side of the Dee estuary at Hilbre Island. There are records of *S. alveolata* crusts on Anglesey between Beaumaris and Penmon Point and other isolated records but to date no observations of reef formations on the island.

2.3.2. *Sabellaria spinulosa* reef

S. spinulosa is found all around the UK and is most commonly encountered as solitary tubes, small clumps or crust-like aggregations (Wilson, 1971; Holt *et al.*, 1998).

Consolidated reef features that fall under the Annex I reef description are thought to be relatively rare, with perhaps the best documented examples occurring in the Wash (Foster-Smith & White, 2001), the Severn Estuary (George & Warwick, 1985), and off the North Norfolk coast (BMT Cordah, 2003; Limpenny *et al.*, 2010; Pearce *et al.*, 2011a; Jenkins *et al.*, 2018). However, new *S. spinulosa* reefs are being discovered on a relatively frequent basis (Pearce *et al.*, 2007; Pearce *et al.* 2014; Jenkins *et al.*, 2018) and it is possible that the full extent and distribution of these features has been underestimated due to a paucity of relevant subtidal survey data.

S. spinulosa occurs from the sublittoral fringe to the circalittoral, with many records from 15-30 m, and seems to be capable of growing on a variety of substrata, including kelp holdfasts, rock and unconsolidated sediments such as stony sand or gravel. It can often be present as a crust which is commonly found in areas off west Wales. In the north west of Anglesey, and in other tide-swept sites near sediment plains, *S. spinulosa* forms an underlying thin crust often covered by ascidians and the erect bryozoan *Flustra foliacea*.

More recently, the presence of *S. spinulosa* reef was recorded in north and west Anglesey during benthic characterisation surveys conducted to inform the EIA for the proposed Wylfa Newydd nuclear power station. Subsequent follow-up surveys conducted by NRW (Baldock & Goudge, 2017) confirmed the presence of *S. spinulosa* reef in this area. There is, however, ongoing discussion, as it is thought that the reefs found here may be partially formed by, or be present in conjunction with, *S. alveolata.* This is based on the appearance of the tube formations observed and the presence of tube 'porches', which are not thought to be formed by *S. spinulosa*.

2.4. Conservation importance

Biogenic reefs formed by *Sabellaria* spp. are thought to benefit wider ecosystem functioning. Their structures are topographically complex, with features such as standing water, crevices and consolidated fine sediments providing microhabitats for other organisms and high levels of biodiversity (Limpenny *et al.*, 2010; Pearce *et al.*, 2011b). The associated communities can vary according to local conditions of salinity, water movement, depth and turbidity (NE & CCW, 2009). Most of the research into ecosystem services provided by *Sabellaria* reefs has been on the predominantly subtidal reefs formed by *S. spinulosa* (Pearce *et al.*, 2011b), with less work on intertidal *S. alveolata* reefs (Davies & Newstead, 2013).

Sabellaria alveolata reef

In general, *S. alveolata* reefs are not thought to support especially diverse communities. However, they do provide increased diversity of habitat which varies depending on the age and formation of the reef. When growing actively as sheets or hummocks *S. alveolata* reef can cover entire areas of the lower and mid-eulittoral zone. It can stabilise otherwise mobile sand, shingle, pebbles and cobbles and increase habitat heterogeneity by forming hummocks and ridges that can trap water and form pools (Cunningham *et al.*, 1984a; Holt *et al.*, 1998). Greater habitat diversity and species diversity are found as reefs begin to break up, when the emergence of cracks and crevices produces a greater variety of available surfaces, resulting in a more complex habitat (Porras *et al.*, 1996; Dubois *et al.*, 2002).

S. alveolata reefs in the UK provide attachment for a variety of macrophytes and epifaunal taxa (Wilson, 1971; Hill *et al.*, 2010; Tillin & Jackson, 2015) and a multi-faceted matrix of cavities for various crevice-dwelling crustaceans and errant polychaetes. Larger fauna such as crabs and small fish, have been observed using gaps in *S. alveolata* reefs and also predate on the worms themselves (Bamber & Irving, 1997; Holt *et al.*, 1997; Hill *et al.*, 2010). The reefs offer food provisioning services to a number of commercial finfish and shellfish species (Dubois *et al.*, 2002) and are thought to influence foraging behaviours of wading birds (Ware, 2015). *S. alveolata* reefs are likely to play similar ecological roles as *S. spinulosa* during periods of inundation. As a primary consumer of phytoplankton, the reefs also provide a key ecosystem service by filtering large volumes of water (Dubois *et al.*, 2006).

In its 'reef' form, *S. alveolata* is protected by a variety of conservation legislation and policies (see Table 1, sections 2.4.1 – 2.4.8 and Figure 3). However, there is no existing guidance setting out the qualifying characteristics required for a colony to be classified as a 'reef' in the context of these policies (unlike for *S. spinulosa*, see section 2.5.2). Further discussion around defining what classifies a *S. alveolata* 'reef' is provided in section 2.5.1.

***Sabellaria spinulosa* reef**

S. spinulosa reefs are identified as a priority for protection through both national and European conservation legislation and policies (see Table 1, sections 2.4.1– 2.4.8 and Figure 3). Most notably through the Habitats Directive (as an Annex I feature), OSPAR and as a benthic indicator habitat under Descriptor 1 and Descriptor 6 of the Marine Strategy Framework Directive (Cochrane *et al.*, 2010).

The inclusion of *S. spinulosa* reefs as a priority habitat for conservation is due to their historic losses, sensitivity to anthropogenic disturbance, and their role in enhancing biodiversity (OSPAR, 2003; 2008; 2013; EC, 2013), although studies are ongoing to fully understand the communities associated with the reefs. *S. spinulosa* reefs are thought to increase habitat complexity, providing attachment surfaces and crevices which allow a faunal complement to exist in areas which otherwise would be unsuitable. More recent studies suggest that the main ecological value of *S. spinulosa* reefs lies in their propensity to support a higher abundance (and biomass) of fauna that occur more sporadically in surrounding substrates (Pearce, 2014). There is evidence that *S. spinulosa* reefs can influence prey choices made by some demersal fish species (Pearce *et al.*, 2011b) by providing a direct food source (i.e. the worms themselves) and an abundance of other small fauna living on the reef.

Conservation legislation and policies relevant to *Sabellaria* reefs

The Introductory Chapter (GN030-intro, section 3.2.2) provides more general information on conservation policies and legislation, but key aspects relevant to *Sabellaria* reefs are highlighted below. Figure 3 provides a stepwise framework of the key considerations and actions to be taken if *Sabellaria* reef is known to be present within the Zone of Influence (ZoI)[3] of a proposed development or activity.

2.4.1. Habitats Directive

The Habitats Directive lists habitats and species of interest in Annex I and Annex II respectively. Both *S. alveolata* and *S. spinulosa* reefs can be considered as biogenic reefs

[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.

(see section 2.5 for reef definitions), and are encompassed by the following Annex I habitats:

- Reef (code 1170[4])
- Estuaries (code 1130)
- Large shallow inlets and bays (code 1160)

Special Areas of Conservation (SACs) are protected sites designated under the Habitats Directive. In Wales, *S. alveolata* reef is part of the Annex I reef feature of the Pen Llŷn a'r Sarnau SAC, Cardigan Bay SAC and part of the reef and estuary Annex I features for the Severn Estuary SAC.

S. alveolata reef is also a notable community of the Annex I estuary feature of the Dee Estuary SAC but only around the shores of Hilbre Island in the English part of the site.

S. spinulosa reef is an interest feature in several SACs around the UK, although none of the sites are located within Wales.

2.4.2. Water Framework Directive (WFD)

'Polychaete reef' is identified as one of several higher sensitivity habitats that specifically need to be considered if a proposed development of activity needs to be subject to a WFD assessment (see the Guidance Note GN030 section 2.2).

2.4.3. 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 benthic habitats (D1 Biodiversity and D6 Seafloor integrity), with others relating to aspects of benthic ecology (for example, food webs and commercial fishing).

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

S. spinulosa reef is listed on the OSPAR List of Threatened and/or Declining Species and Habitats. A background document for this habitat is available from OSPAR (2013).

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

Sabellaria alveolata reef is listed as a Priority Habitat under Section 7 of the Act within the category of 'Littoral Rock'.

2.4.6. 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 does encompass intertidal areas. *S. alveolata* reefs are a designated feature of a number of SSSIs in Wales. In SACs, SPAs and Ramsar sites, SSSI designations also underpin the terrestrial and intertidal components of these sites.

[4] 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.

2.4.7. 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. *Sabellaria* reefs can be MCZ features but, at present, the only MCZ currently designated in Wales is the Skomer MCZ which does not have *Sabellaria* reef within it.

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

2.4.8. Welsh Marine Protected Area Network

Sabellaria alveolata and *Sabellaria spinulosa* reefs are considered within the Marine Protected Area network feature list for Wales (Carr *et al.*, 2016).

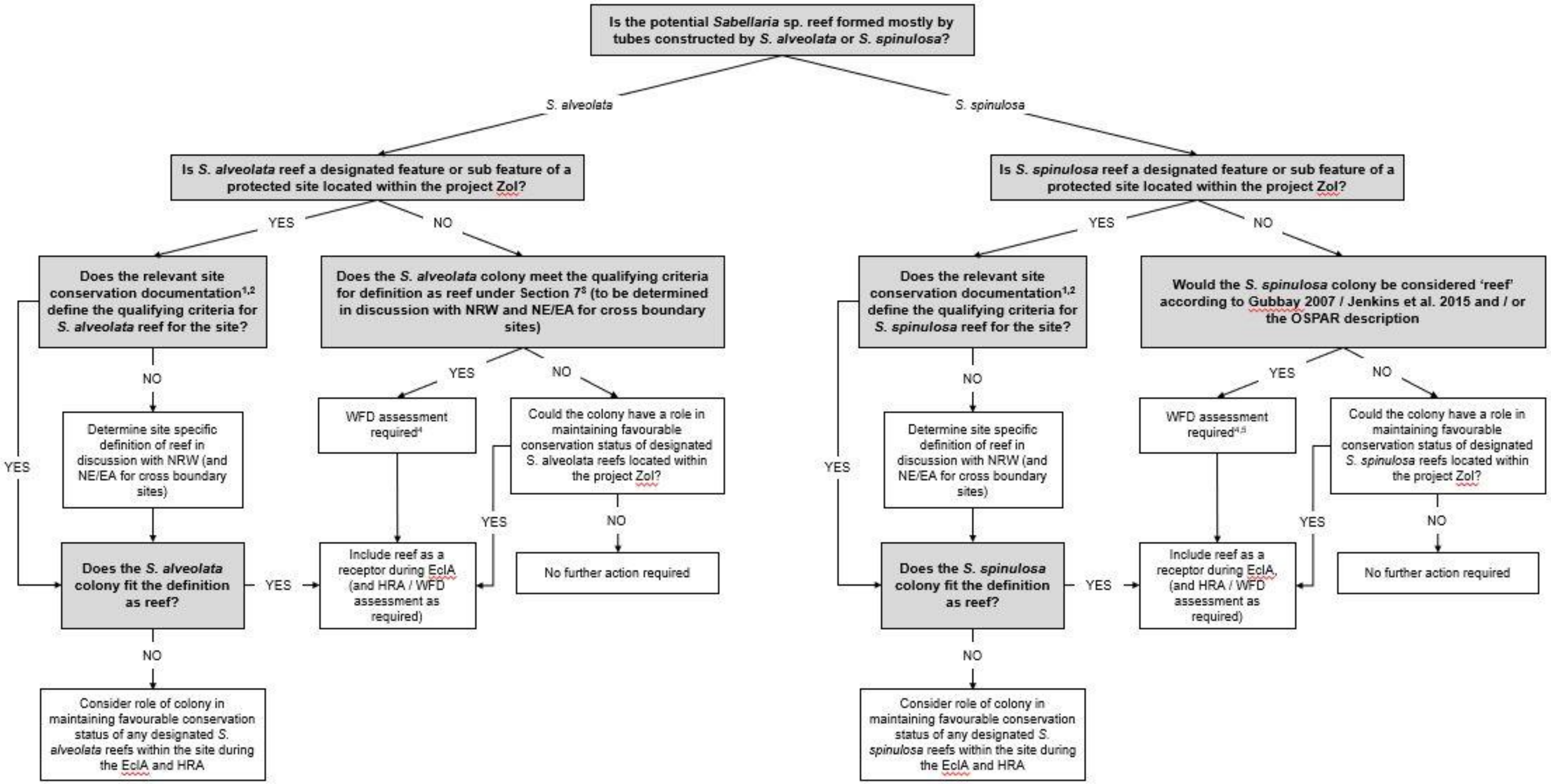

Figure 3. Key considerations and actions if potential *Sabellaria* spp. reef is known to be present within the ZoI of a proposed development or activity (figure developed by Ross Griffin and Bryony Pearce)

[1] For SAC check the conservation objectives, feature description and maps in Reg 37 document (see section 3.4 on how you can access this information).

[2] For SSSI check the features of interest sheet, citation and operations likely to damage for the site.

[3] See UK Biodiversity Action Plan Priority Habitat Description for *Sabellaria alveolata* reefs

[4] will be considered a higher sensitivity habitat in relation to WFD assessment requirements (see section 2.4.2).

[5] *Sabellaria spinulosa* is not currently on the Section 7 list but it is on the OSPAR list of threatened and/or declining species and habitats and would therefore be expected to be included in a WFD assessment.

2.5. Defining *Sabellaria* reefs

2.5.1. Defining *Sabellaria alveolata* reef

For the purposes of the Habitats Directive, the Interpretation Manual of European Union Habitats (CEC, 1999) defines a 'reef' as being: "*submarine or exposed at low tide, rocky substrates and biogenic concretions, which arise from the sea floor in the sublittoral zone where there is an interrupted zonation of plant and animal communities".*

This was revised in 2007 to clarify the meaning of 'biogenic concretions' (CEC, 2007) which was defined as: *"concretions, encrustations, corallogenic concretions and bivalve mussel beds originating from dead or living animals, i.e. biogenic hard bottoms which supply habitats for epibiotic species"*

At a UK level, definitions are similar and there is no indication of the lower limits of size to be considered a reef other than the stipulation that the reef "*must be large enough to maintain its structure and functions*".

Holt *et al.*, (1988) provided an interpretation for biogenic reef in coastal waters as part of the UK Marine SAC Project and argued that aggregations of reef-forming species should be given a minimum size in order to be classified as an Annex I 'reef'. The definition includes the criteria that: *"[A reef] should be substantial in size (generally in the order of a metre or two across as a minimum, and somewhat raised)* [and] *should create a substratum which is reasonably discrete and substantially different to the underlying or surrounding substratum, usually with much more hard surfaces and crevices on and in which other flora and fauna can grow*. "

Gruet (1982) divided *S. alveolata* aggregations ('colonies') into three types of formation: veneers, hummocks and reefs. These formation types were further subdivided and classified (Allen *et al.,* 2002; Moore, 2009) and a photographic guide to the classification of *S. alveolata* reef incorporating 'health' categories was developed (Egerton, 2014). Mercer (2016) commissioned by CCW/NRW and Dubois *et al*. (2002) have established criteria for quality and age assessments, whilst others have developed empirical measures for assessing health status (Desroy, *et al.*, 2011).

Some of these formation classifications have been found to be somewhat ambiguous[5] and not necessarily suitable for monitoring reef formation in all locations. To address this, further work undertook to define a series of reef formation categories in order to provide a structure for monitoring the formation of reefs located within the ZoI of the proposed Tidal Lagoon Swansea Bay (TLSB) development (Table 2) (TLSB, 2017). This was based on specific knowledge of the reefs that occur within the Bristol Channel and was adapted from the categories proposed by Gruet (1982) and Egertopn (2014), providing an alternative method for classifying *S. alveolata* reef in such environments.

Building on the recommendations provided by Holt *et al.*, (1998) and the 'reefiness' classification proposed by Gubbay (2007) for *S. spinulosa* reefs, a series of definitions have been developed as part of the Tidal Lagoon Swansea Bay Adaptive Environmental Management Plan (AEMP) (TLSB, 2017) to standardise the terminology used when developing the programme of monitoring for *S. alveolata* reefs to be impacted by the

[5] This refers to the inclusion of 'reef' as one of the categories proposed by Egerton (2014), which is confusing when considering all of the categories are treated as sub-habitats of reef. This is likely to be a result of the lack of existing guidance in what qualifies as an Annex I *S. alveolata* reef.

proposed development. These set out a series of attributes that a colony or agglomeration of colonies of *S. alveolata* must exhibit in order to qualify as 'reef', including thresholds for extent, elevation and percentage cover (Table 2):

- Colony: An aggregation of *S. alveolata* tubes (dead or alive)
- Reef: A colony of *S. alveolata* elevated by at least 2 cm from the underlying substrate covering at least 10 % of an area of 25 m^2 or more

For broadscale SAC monitoring of *S. alveolata* reef, NRW uses a combination of descriptors for reef age and condition.

Reef formations vary depending on local conditions, but the approaches described here are the kinds of definitions that you should consider, and which should be clearly set out prior to the onset of development-related habitat characterisation or monitoring of *S. alveolata* reefs around Wales.

Figure 4. Examples of *Sabellaria alveolata* reef formations at Llandanwg, Gwynedd (north east Cardigan Bay): a veneer (left), image © NRW/Ben Wray; a hummock (right), image © NRW/Tom Mercer

Table 2. ***S. alveolata*** **colony formation categories defined for monitoring related to the proposed Tidal Lagoon Swansea Bay by Ocean Ecology Limited, adapted from Gruet (1982) and Egerton (2014)**

Colony Formation	Coalescence	Stage	Elevation	Description	Examples in Wales
Veneers	-----	Newly Settled, Live*, Dead** ***or*** Combination	<2 cm	Encrusting low-lying colonies with overlapping tubes that lie at an acute angle often opposing the direction of prevailing wave action. These colonies can cover large expanses of rocky shore (often beneath a canopy of fucoid cover) and can completely outcompete other sessile fauna. **Does not qualify as 'reef'*** due to <2 cm elevation regardless of area.**	Mid-upper shore on bedrock on Newton Beach (Porthcawl).
Clumps	Isolated ***or*** Coalesced	Newly Settled, Live*, Dead** ***or*** Combination	>2 cm	Colonies formed by aggregations of tubes (~100) growing vertically that, when coalesced, can form patchy but continuous sheets covering large expanses of mixed, gravel, pebble and cobbles. The crevices and gaps between the colonies consolidate fine sediments often supporting numerous infaunal taxa and creating small intertidal pools. Faecal pellets excreted by the worms aggregate between the colonies, forming mounds of silt that on mixed sediments further consolidate the matrix of clumps and pebbles/gravel. On mixed sediments clump growth seems to be restricted by the size of the substrate particles that the clumps are attached to. **Qualifies as 'reef'*** if continuous area >25 m^2.**	On lower shore bedrock platform at Lavernock (near Cardiff) and on extreme lower shore mixed sediments east of Goldcliff (Severn Estuary).
Hummocks	Isolated ***or*** Coalesced	Newly Settled, Live*, Dead** ***or*** Combination	>2 cm	Ball-shaped colonies consisting of tubes that radiate out from the initial settlement point. Always found attached to large cobbles/boulders, frequently covering the entire upper surface and growing larger than the cobble/boulder itself. These colonies form intertidal pools when partially coalesced and form the continuous platform formation when fully coalesced. Faecal pellets excreted by the worms also aggregate between the colonies forming mounds of silt. **Qualifies as 'reef'*** if continuous area >25 m^2.**	On lower shore glacial till at Llanddulas, North Wales coast.
Platforms	-----	Newly Settled, Live*, Dead** ***or*** Combination	>2 cm	Continuous relatively flat colonies formed by numerous fully coalesced hummocks commonly 50 cm+ in thickness. These colonies are often found on rugose rock or stable consolidated cobbles and/or boulders on which they completely outcompete other sessile fauna. **Qualifies as 'reef'*** if continuous area >25 m^2.**	On consolidated matrix of boulders and cobbles. Aberaeron and Cei Bach, Cardigan Bay.

* Live: *S. alveolata* with crisp tube apertures and/or presence of faecal pellets in tube porches or on substrate surface between tube aggregations

** *S. alveolata* without crisp tube apertures and devoid of faecal pellets in tube porches or on substrate surface between colonies

*** References to 'reef' are only referring to *Sabellaria* reef. Even if *Sabellaria* reef is not present, there could still be rocky reef habitat present that may be part of a protected feature in its own right

2.5.2. Defining *Sabellaria spinulosa* reef

Elevation, extent, percentage cover and patchiness are the characteristics currently used by the statutory nature conservation bodies of the UK to describe physical reef habitat. Other attributes which are considered when assessing condition of a *Sabellaria spinulosa* reef in the context of SAC feature monitoring in the UK are described in JNCC (2017). The widely accepted working definition of *S. spinulosa* reef in the UK is based on outputs from an expert workshop and attributes originally put forward by Hendrick and Foster-Smith (2006) which is set out in Table 3. Examples of the application of the definition are provided in EMU (2008) and Jenkins *et al.* (2018).

When considering impact of a proposed development or activity on *S. spinulosa*, the presence of this species should be considered to form a reef when its characteristics meet the thresholds for low, medium or high 'reefiness'.

Table 3. Threshold ranges of *S. spinulosa* reef characteristics proposed by workshop participants (Gubbay, 2007)

Characteristic	Not a *Sabellaria* Reef	*Sabellaria* 'Reefiness'		
		Low	Medium	High
Elevation (cm) Average tube height	<2	2-5	5-10	>10
Extent (m^2)	<25	25 – 10,000	10,000 – 1,000,000	>1,000,000
Patchiness (% Cover)	<10	10-20	20-30	>30

The easiest and most commonly measured attribute of *S. spinulosa* reefs is the total extent, although this is often complimented by point measures of patchiness and elevation. A key requirement for a *Sabellaria spinulosa* colony to be considered as a 'reef' in line with Gubbay (2007) is for it to be elevated by more than 2 cm. This relates to the tendency of colonies with an upright (and therefore more elevated) morphology to consolidate and 'coalesce' underlying substrates, which has not been observed for horizontally growing tube 'crusts' (see consolidation scale in Limpenny *et al.* (2010)). This important function stabilises sediment and allows other epibenthic and crevice-dwelling species to become established and is indicated in the Habitats Directive definition of 'reef' as 'biogenic concretion'. The physical structure of *S. spinulosa* reefs is naturally highly variable. Elevation is considered to be a particularly important attribute for conservation value, but crusts and areas of high density can be considered stages in reef development and should be considered in relation to assessment of proposed developments or activities.

The original guidance document upon which most judgements of 'reefiness' have been made to date (Gubbay 2007) did not give any recommendations for how the different 'reefiness' scores might be combined. A method has since been developed to combine the 'reefiness' characteristics of elevation and patchiness (Table 4) (Jenkins *et al.*, 2018). Whilst this has now been adopted by Cefas, JNCC and others, it should be noted that it is not always possible to confidently ascertain estimates of patchiness depending on the survey methods used, and therefore it is often left to expert judgement whether *Sabellaria* colonies qualify as reef in these circumstances. More specialised sampling methods (such as Digital Imaging Scanning Sonar) can provide this information in some circumstances as described in Section 5.1.1.

Table 4. ***S. spinulosa*** **reef structure matrix used to assign 'reefiness' scores (in accordance with Gubbay (2007)) to seabed images and video footage (Jenkins *et al.*, 2018). Extent of >25m^2 is assumed**

Sabellaria **reef structure matrix**			**Elevation (cm)**			
			<2	**2 - 5**	**5 - 10**	**>10**
			Not a Reef	**Low**	**Medium**	**High**
Patchiness (% Cover)	**<10**	**Not a *Sabellaria* reef**	Not a *Sabellaria* reef	Not a *Sabellaria* reef	Not a *Sabellaria* reef	Not a *Sabellaria* reef
	10 - 20	**Low**	Not a Reef	**Low**	**Low**	**Low**
	20 - 30	**Medium**	Not a Reef	**Low**	**Medium**	**Medium**
	>30	**High**	Not a Reef	**Low**	**Medium**	**High**

2.6. Key potential pressures

The key potential impacts of marine developments and activities on *Sabellaria* reefs 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 *Sabellaria* reef), 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 5.

Table 5. Key potential pressures of marine developments/activities on *Sabellaria* reefs (adapted from Tillin & Walters, 2014)

Pressure	Examples
Changes to temperature and salinity	Cooling water discharges, freshwater inputs or construction of coastal structures (lagoons, ports etc.) resulting in changes in coastal processes.
Changes to emergence regime and wave exposure	Construction and operation of coastal structures, managed realignment.
Changes to, removal and disturbance of substrate surface and subsurface	Dredging, trawling, anchoring/mooring, cable burying, construction and operation of offshore structures.
Changes in suspended solids (water clarity)	Dredging, construction, operation of coastal structures
Siltation rates changes (smothering)	Dredging, managed realignment, cable and pipeline laying, mariculture, disposal at sea, construction and operation of offshore structures.
Permanent habitat loss (change to another seabed type or to a freshwater or terrestrial habitat)	Dredging, managed realignment, cable and pipeline laying, installation of infrastructure, scour protection, mariculture.
Introduction or spread of invasive non-native species (INNS)	Vessel activity, anchoring/mooring, marinas, aquaculture, construction activities.
Removal of non-target species	Trawling, bait digging.

2.7. Sensitivity (resistance/resilience to pressures)

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

The Marine Life Information Network (MarLIN) provides sensitivity reviews for *Sabellaria* reefs considering various hydrological, chemical, physical and biological pressures associated with marine activities. Reviews are available for the six *Sabellaria* reef biotopes identified in Table 1:

- *Sabellaria alveolata* reefs on sand abraded eulittoral rock (EUNIS A2.711) (MNCR CR.MCR.CSab.Sspi)
- *Sabellaria alveolata* on variable salinity sublittoral mixed sediment (EUNIS A5.612) (MNCR SS.SBR.PoR.SalvMx)
- *Sabellaria spinulosa*] encrusted circalittoral rock (EUNIS A4.221)
- *Sabellaria spinulosa* with a bryozoan turf and barnacles on silty turbid circalittoral rock (EUNIS A4.2211) (MNCR CR.MCR.CSab.Sspi.ByB)
- *Sabellaria spinulosa*, didemnid and small ascidians on tide-swept moderately wave-exposed circalittoral rock (EUNIS A4.2212) (MNCR CR.MCR.CSab.Sspi.As)
- *Sabellaria spinulosa* on stable circalittoral mixed sediment (EUNIS A5.611) (MNCR SS.SBR.PoR.SspiMx)

The assessments conclude that *Sabellaria* reefs have a medium to high sensitivity to the defined benchmark intensities set for the pressures assessed.

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).

Additional information for *Sabellaria spinulosa* is provided in Gibb *et al.* (2014).

3. Existing guidance and data

The JNCC has recently produced specific guidance for the monitoring of marine benthic habitats (Noble-James *et al.*, 2017). In relation to *Sabellaria* reefs, monitoring requirements and approaches have tended to be developed for feature condition monitoring as part of marine protected area management. The following sections summarise this work and identify key references.

3.1. Monitoring guidance

3.1.1. *Sabellaria alveolata* reef

Feature condition monitoring of intertidal *S. alveolata* reefs to ensure that the conservation objectives for SACs are achieved has been carried out in the Pen Llŷn a'r Sarnau and Cardigan Bay SACs over the past 12 years (Boyes *et al.*, 2008; Mercer, 2013; 2016). The monitoring techniques have been underpinned by the Marine Monitoring Handbook (Davies *et al.*, 2001) with adaptations developed over time (Mercer, 2016). For example, adopting a reduced quadrat sampling size so presence/absence data of visible fauna and flora is undertaken with a 0.25 m^2 (0.5 m x 0.5 m) quadrat instead of a 1m^2 quadrat.

To date, all CCW/NRW condition assessment surveys mapping *S. alveolata* reef boundaries have involved perimeter walking, using the tracking function of a hand-held GPS as recommended by Wyn *et al.* (2006). However, this method can lead to surveyor bias and overestimation of extent (Moore, 2010; Brazier, 2013; Ocean Ecology Limited, 2016a), and efforts have been made to employ alternative remote sensing techniques such as Unmanned Aerial Vehicles (UAVs) (Davies & Newstead, 2013; Ocean Ecology Limited, 2016b). The use of UAVs for mapping intertidal habitats is in its infancy (Jaud *et al.*, 2016), particularly for mapping intertidal *S. alveolata* reefs. However, the rapid development of the systems and the post-processing software means that they are quickly becoming a viable monitoring tool. The use of UAVs for *Sabellaria* reef mapping is discussed in more detail in section 5.1.1 and 5.1.2.

3.1.2. *Sabellaria spinulosa* reef

There has been limited reef condition monitoring in SACs around the UK where *S. spinulosa* reefs are listed as an interest feature (McIlwaine *et al.*, 2017; Roberts *et al.*, 2016). Other monitoring has been undertaken as part of EcIA-related monitoring associated with some offshore developments (see for example: MESL, 2012; Pearce *et al.*, 2014) and other studies aimed at developing suitable surveying techniques and monitoring protocols for *S. spinulosa* reefs (Foster-Smith & Hendrick, 2003; Limpenny *et al.*, 2010; Fariñas-Franco *et al.*, 2014; Jenkins *et al.*, 2018). It is likely that the methods used for monitoring *S. spinulosa* reefs will develop over the coming years as our understanding of this habitat increases, and as methods currently recommended are applied more extensively. Technological advances are also likely to be significant in the development of monitoring programmes, given the inherent difficulties in surveying subtidal habitats and the dependence on remote observations.

All of the existing *S. spinulosa* monitoring surveys have recorded a change in the location and/or size and shape of the reefs between years, leading many authors to conclude that these features are naturally ephemeral. However, it should be noted that the majority of the reefs surveyed in the UK have been, and continue to be, the target of commercial fishing activities to which they are thought to be moderately sensitive (Gibb *et al.*, 2014). It is not therefore possible at this time to determine the true stability of these features in the absence of any anthropogenic activity, but the possibility of some natural change in reef extent and distribution does need to be considered in the planning stages of future monitoring programmes.

3.2. MESH guidance

The Mapping European Seabed Habitats (MESH)[6] project produced 'Recommended operating guidelines' (ROGs) for marine habitat mapping survey methods and these are hosted in the MESH archive on the EMODnet[7] website. A number of these ROGs are relevant to survey and monitoring of *Sabellaria* reefs.

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.

3.3. NMBAQC guidance

Operational guidelines for remote monitoring of epibiota using digital imagery and analysis of that data are presented within the following North-East Atlantic Marine Biological Analytical Quality Control (NMBAQC) guidance documents:

- Operational guidelines for remote monitoring of epibiota using 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)

3.4. Data sources

Distribution data for intertidal and subtidal 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 and 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.

Distribution data for *Sabellaria* spp. in the UK are available on the National Biodiversity Network (NBN) Gateway where searches can be conducted based on species distribution data by either site or species.

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[6] The MESH project, conducted between 2004 and 2008, was a consortium of twelve partners from five European countries led by the UK's JNCC.

[7] EMODnet is an EU network of organisations that collate and make available data relevant to Europe's marine environment.

3.5. *Sabellaria* spp. information for Wales

3.5.1. *Sabellaria alveolata* reef

Information on *S. alveolata* reefs around Wales was collected as part of the Countryside Council for Wales Phase I intertidal habitat mapping carried out between 1996 and 2005 (Wyn *et al.*, 2006; Brazier *et al.*, 2007). This data provides complete coverage of the distribution and extent of *S. alveolata* reefs around the entire Welsh coast at the time of the survey. More recent survey data is available where the reefs are monitored as part of the designated features of Welsh SACs or where there has been survey and monitoring associated with proposed developments such as the Swansea Bay Tidal Lagoon.

Data on epibiota (fauna and flora) is collected as part of the SAC monitoring of *S. alveolata* reefs in Wales providing a substantial data set for the surveyed reefs at Afon Dwyfor, Llandanwg, Cei Back and Aberaeron. Fewer studies have been undertaken on the infauna associated with Welsh *S. alveolata* reefs.

A number of studies have been undertaken on Welsh *Sabellaria alveolata* reefs. Davies and Newstead (2013) investigated aspects of the influence of the reef on the local environment. Bush *et al.* (2015) studied larval source and dispersal for a number of sites in north, mid and south Wales (Llanddulas, Aberarth, Dunraven respectively). More recently, information relating to larval abundance around the Welsh coast has been collected for monthly surveys in Swansea Bay as part of site characterisation studies for the proposed Tidal Lagoon Swansea Bay (TLSB) development.

3.5.2. *Sabellaria spinulosa* reef

There are currently no *S. spinulosa* reefs designated for protection in Wales. Data on the extent and condition of this habitat around the Welsh coast is limited to ad-hoc observations made during routine baseline and monitoring surveys associated with marine developments (for example the Anglesey Skerries Tidal Stream Array and the TLSB developments), and a limited number of seabed mapping projects (Mackie, *et al.*, 2003; Robinson *et al.*, 2007).

Quantitative information relating to the fauna associated with Welsh *S. spinulosa* reefs is limited to a study conducted by NRW (Baldock and Goudge, 2017), which confirmed the presence of reef in north and west Anglesey. There is, however, ongoing discussion, as it is thought that the reefs found here may be formed by *S. alveolata* in conjunction with *S. spinulosa* (views based on the appearance of the tube formations and the presence of tube ‘porches’ which are not normally observed on the tubes built by *S. spinulosa*).

Information relating to larval abundance around the Welsh coast is limited to incidental records from monthly surveys aimed at identifying the settlement period of *S. spinulosa* larvae throughout Swansea Bay. No surveys aimed at assessing other *S. spinulosa* reef supporting processes (such as the supply of suitable suspended sediments) have, to the best of our knowledge, been conducted in Wales, or indeed the UK However, some experimental laboratory-based studies have been conducted (see Davies *et al.*, 2009).

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[8]. 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 *Sabellaria* reefs in the area to be surveyed based on available ecological data and/or habitat surveys. For subtidal areas, 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. For intertidal areas where you have no recent habitat data refer to chapters GN030a or GN030b for guidance on undertaking intertidal Phase I survey to determine the habitats present.

4.1. Existing Data

Where possible, and where timeframes allow, a comprehensive desk-based review of all available data relevant to *Sabellaria* reefs within the area of interest should be conducted prior to designing any habitat 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 *Sabellaria* reefs are set out in Table 6. In the absence of a relevant Conceptual Ecological Model (CEM), these were short-listed based on a critical review of relevant literature and the findings of a recent study which aimed to define and validate Marine Strategy Framework Directive (MSFD) indicators for a number of biogenic reef habitats including *S. spinulosa* reefs (Fariñas-Franco *et al.*, 2014).

It is recommended that, as a minimum, the following ‘broad-scale’ parameters are established for each reef within the ZoI of a proposed development or activity and any control reefs being used as part of a monitoring programme:

- extent
- elevation
- patchiness (percentage cover)

[8] 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.

Depending on the pressures arising from a proposed development or activity, it may be necessary to survey some of the 'fine-scale' and environmental parameters indicated in Table 6. The requirements for this and the selection of any other indicators for monitoring will need to be determined on a project-specific basis. Sampling for the 'fine-scale' parameters may require destructive sampling and the necessity for this and likely impacts of the sampling should be fully assessed before proceeding.

Table 6. *Sabellaria* reef ecological parameters/indicators to be considered for habitat characterisation and/or monitoring programmes

'Broad-scale'	'Fine-scale'	Environmental
Reef extent	**Associated communities**	**Larval concentration**
i. Total area	i. Species composition*	i. Larval density
	ii. Diversity	ii. Larval development stage
Reef structural composition	**Worm metrics**	**Suspended Particulate Matter (SPM) concentrations**
i. Elevation ii. Patchiness (% cover)	i. Number of tubes ii. Number of live worms iii. Tube aperture iv. Worm length v. Worm biomass and energy content vi. Sex ratio vii. Biochemical indicators	i. Suspended Organic Matter (SOM) concentrations (food) ii. Suspended Inorganic Matter (SIM) concentrations (suspended sediments for tube building)

* Some limited work has been undertaken to look at whether the long-clawed porcelain crab *Pisidia longicornis* could be used as a proxy for total associated diversity (Fariñas-Franco *et al*., 2014) negating the requirement of assessing all macrofaunal taxa. However, this association has not been fully investigated.

4.3. Habitat characterisation

4.3.1. Aims of habitat characterisation surveys for Sabellaria reefs

The aim of habitat characterisation survey is to collate data to describe any *Sabellaria* reefs within the survey area, identify any other 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 *Sabellaria* reefs

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).

The range of available survey methods for habitat characterisation of *Sabellaria* reefs 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; Noble-James *et al.*, 2017).

4.3.2.1. Survey design options

In most cases, habitat characterisation surveys of *Sabellaria* reefs will involve a single sampling event to provide a snap shot of the condition of the reefs. As an assessment of the influence of background spatial and temporal variance is not required, these sampling designs can be relatively simple, unlike designs for *Sabellaria* reef monitoring programmes (see section 4.4.3).

All reefs located within the predicted ZoI should be characterised. If monitoring will be required, reefs located outside the ZoI that are to be used as control reefs in any monitoring programme should also be characterised.

As a minimum, the 'broad-scale' parameters of extent, elevation and percentage cover should be established for each reef. Depending on the potential pressures arising from a proposed development or activity on *Sabellaria* reefs it may be necessary to also sample other of the ecological parameters set out in Table 6.

Knowledge of reef extent is essential to inform the sampling design. If there are no suitable existing data on reef extent, this is an essential first step to provide the framework for appropriately locating sampling positions across the reef(s).

The most appropriate method for determining reef extent will depend on a number of factors such as biological zone (i.e. intertidal or subtidal) and the size and accessibility of the reef. All extent mapping surveys should aim to achieve at least 100 % coverage[9] to ensure that all areas of reef within the ZoI have been surveyed. Where the survey area is more localised in extent it is important to make sure that the whole area of any reef is mapped and that the survey has extended some way beyond the reef edge to make sure there is no additional reef nearby. Any patches extending beyond the main areas of reef should also be mapped.

4.3.2.2. Timing of characterisation surveys

See section 4.4.5.1.

4.3.2.3. Location of sampling stations

If sampling is deemed necessary at the habitat characterisation stage, a systematic grid of sample points should be overlain across each reef with sample points determined based on the mapped extent data. Where possible, triangular grid patterns should be used, as this reduces the chance of bias towards a regularly spaced reef feature or condition (Barry & Nicholson, 1993; Byrnes, 2000).

The sampling interval (i.e. grid size) should be back-calculated by considering the maximum possible number of sampling stations that could be sampled given the size, variability and accessibility of the reef.

If environmental indicators such as concentrations of *Sabellaria* larvae, food and suspended sediments present in the water column are deemed necessary at the habitat characterisation stage, they will not need to be measured at every sampling station but either at a reef scale or at points within a gradient (for example, depth). A 'judgement sampling' approach (see Noble-James *et al.*, 2017) may therefore be adopted, whereby a targeted single sampling station may be positioned in the centre of the reef(s), or elsewhere within the reef when there is a desire to target a particular feature or existing pressures.

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[9] A higher proportion is required for side scan sonar where complete seabed coverage is required (see section 5.1.2)

Alternatively, a stratified random approach may be adopted whereby the reefs(s) are delineated into distinct areas (for example, reef formation type (see Table 2) or 'reefiness' categories (see Table 3 and Table 4), within which sampling stations may be randomly positioned.

4.4. Monitoring

4.4.1. Aims of monitoring programmes for *Sabellaria* reefs

The aims of the monitoring need to be clearly defined and will depend on the potential impacts of a development or activity as identified through the EcIA process, relevant assessments as required (such as Habitats Regulations Assessment, Water Framework Directive assessment), and any licence 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.

For *Sabellaria* reefs an 'investigative' monitoring approach will, in most cases, be the most appropriate (see Kröger & Johnstone, 2016). The guidance provided here is therefore based around 'investigative' monitoring principles. However, 'sentinel' and/or 'operational' approaches may need to be considered when the requirement for complex sampling designs makes 'investigative' monitoring unfeasible (see Noble-James *et al.*, 2017).

4.4.2. Defining hypotheses and trigger levels

Hypotheses to inform ecological monitoring are generally framed to detect change in an 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 *Sabellaria* reefs

4.4.3.1. Sampling design

Noble-James *et al.* (2017) and the Introductory Chapter GN030-intro (section 4.2.5) give a background to the variety of survey designs that can be employed to monitor impacts of developments and activities on marine habitats.

The 'beyond-BACI' design (Underwood, 1992) is considered as best practice for *Sabellaria* and should be implemented when possible. A true beyond-BACI design needs to include a minimum of two control reefs. When multiple control reefs are not available, a Before-After-Control-Impact Paired Series (BACIPS) (Stewart-Oaten *et al.*, 1986) design should be considered. The control reefs should be carefully selected to minimise the likelihood that monitoring is confounded by natural variation or changes arising from the impact itself by considering the key principles of control site selection set out in Noble-James *et al.* (2017). In practice, it may be difficult to fully adhere to these recommendations due to limited availability of suitable control reefs; mitigative measures are therefore suggested and should be applied if necessary/possible.

4.4.3.2. Locating sampling stations

The process outlined for habitat characterisation survey design in section 4.3.2 may, in some cases, be followed to locate sampling stations on a systematic grid across each impact and control reef. The grid size should be determined by back-calculating the number of sampling stations required to confidently detect the desired magnitude of effect derived by *a priori* power analysis (see section 4.4.4). In other cases, samples may be positioned randomly within areas of the impact and control reef(s) stratified based on formation type, height on the shore (intertidal) / depth (subtidal) and/or underlying substrate type. The approach taken will largely depend on the homogeneity of the site and the inherent variability of the indicators that will be measured.

The final positioning of sampling stations should aim to minimize the effects of pseudo-replication resulting from correlations within the indicators to be monitored (i.e. the response variables), in space (spatial autocorrelation) and/or time (serial correlation) (see Noble-James *et al.* (2017) for further explanation). There are conflicting opinions on whether sampling stations should remain fixed or be re-randomised during each monitoring event in order to reduce the influence of dependency issues (Jon Barry, Cefas, pers. comm. (2015) cited in Noble-James *et al.* (2017); Schultz *et al.* (2015)). This should be decided on a project-by-project basis and by carefully considering the aims of the monitoring and the feasibility of accurately resampling fixed locations (especially in subtidal environments).

The following sampling approaches may be adopted:

- ‘Judgement sampling’ approach – a targeted single sampling station may be positioned in the centre of the reef(s), or elsewhere within the reef when there is a desire to target a particular feature or existing pressures.
- Stratified random approach – the reef(s) are delineated into distinct areas (e.g. reef formation type) within which sampling stations may be positioned either systematically (systematic stratified design) or randomly, using a ‘pseudo-randomisation’ approach where necessary (see Noble-James *et al.*, 2017)

If it is considered necessary to measure environmental indicators such as concentrations of *Sabellaria* larvae, food and suspended sediments present in the water column they will not need to be measured at every sampling station. Whether or not these need to be monitored should be identified on a case by case basis.

4.4.4. Determining appropriate sampling effort and sampling units for *Sabellaria* reefs

The Introductory Chapter GN030-intro (section 4.2.4) provides information about identifying appropriate sampling effort to detect change in a statistically robust manner.

In the case of *Sabellaria* reefs, it will not always be necessary to conduct power analysis for determining the appropriate sampling effort for all indicators. For example, it would not be necessary to determine the required sampling effort for monitoring reef extent, whereas it may be necessary to establish how many sampling stations are needed to monitor patchiness or the number of ground-truthing locations required for confidently classifying areas of reef (see Schultz *et al.*, 2015). Determining a feasible sampling effort for appropriately measuring these indicators should be conducted in line with the guidance set out in the Introductory Chapter and further discussed in Noble-James *et al.* (2017).

The level of sampling effort also needs to consider the implications of sampling on the reef. If sampling has the potential to damage the reef, this needs to be assessed and the least impacting approach determined.

After generating a statistically robust sample size through power analysis, it is important to ensure that the sampling units provide accurate observations of the indicator(s) in question (for example, quadrat size for associated community assessment or number of cm per pixel for UAV and/or acoustic mapping). The design process must consider a number of factors which can determine the effectiveness of sampling units. The most influential of these are the size and type of the sampling unit (Eleftheriou, 2013) and the amount of replication required within each.

Ideally, the precision and accuracy of different sampling unit sizes should be investigated in a pilot study assessing retention of *Sabellaria* reef and considering spatial autocorrelation (Noble-James *et al*., 2017). If resources do not allow this, the life history and ecology of the *Sabellaria* species, or a similar proxy species, should be researched to inform decisions on the sampling unit to be used (Sutherland, 1996; Underwood & Chapman, 2013).

4.4.5. Timing, frequency and duration of monitoring

4.4.5.1. Timing

Currently there is no set guidance on the most appropriate time of year for sampling *Sabellaria* reef for monitoring purposes. The seasonal timing of much of the historic condition assessment monitoring of *Sabellaria* reefs around Wales varies from May (Moore *et al.*, 2010) to October (Boyes *et al.*, 2008).

Intertidal and shallow subtidal reefs in particular can suffer significant damage from increased wave action during winter storms. The resulting loss of reef extent and structural complexity (R. Griffin, pers. obser.) leaves many surfaces available for settlement of larvae.

The limited work that has been carried out on the spawning behaviour of *S. spinulosa* suggests that, although capable of spawning throughout much of the year, a main spawning event occurs around February (Pearce *et al.*, 2011a). The intensity of larval settlement is extremely variable from year to year and at different locations but has been observed in all months (Ayata *et al.*, 2009; Hill *et al.*, 2010; Davies & Newstead, 2013). Surveys undertaken during 2016-2017 for the TLSB development have shown that the greatest densities of settlement stage *S. alveolata* larvae (see Dubois *et al.*, 2007) occur between June and August. This is corroborated by observations of heavy settlement (evidenced by high densities of newly settled tubes) on reefs in Swansea Bay during and shortly after this period (R. Griffin, 2016, pers. obser.).

It is therefore recommended that surveys are undertaken in late summer to early autumn following the main spring/summer settlement period, to ensure *Sabellaria* reefs are sampled during periods of the likely peak biomass. Sampling from late October to March should be avoided because of the influence of storm events on the reef and the fact that the communities associated with intertidal reefs can also be depleted by overwintering birds foraging during this period (Ware, 2015). All reefs within a monitoring programme (including control reefs) should be surveyed during the same month of the year to minimise potential differences relating to the timing of larval settlement at different reefs. Monitoring surveys should always be undertaken in the same month as the baseline monitoring survey.

4.4.5.2. Frequency and duration

The frequency and duration of monitoring will depend on the nature and scale of the proposed development or activity, the timescale for the works and any potential impacts arising from the operational phase. An annual assessment of ‘broad-scale’ and ‘fine-scale’ indicators will generally be sufficient for habitat characterisation and monitoring purposes.

If more variable indicators (such as supply of larvae and food) or environmental factors (such as SPM concentrations) are part of the monitoring programme, monthly or seasonal sampling should be considered, in order to capture the spatio-temporal variations of these indicators.

‘Real-time’ monitoring

During periods of suspected heavy stress on *Sabellaria* reefs due to a development or activity (for example, during a dredging campaign), it may be necessary to assess particular environmental indicators (such as suspended sediments) in real time in order to detect exceedance of potential lethal thresholds and instigate mitigation procedures. The Introductory Chapter GN030-intro (section 4.2.3) provides more information about setting threshold (or trigger) levels. In such cases sampling frequency of the monitoring programme may need to be increased, but this needs to be balanced against the potential impact of such sampling on the reefs.

Monitoring duration

There is very limited evidence on recovery rates of *Sabellaria* reefs from different levels of impact, and whether these rates are similar or not between the different *Sabellaria* reef biotopes. Recovery rates will be determined by a range of factors such as degree of impact, season of impact, larval supply and local environmental factors including hydrodynamics and sediment supply. The required monitoring duration will therefore need to be determined on a project-by-project basis.

4.4.6. Supporting environment

Any monitoring programme for *Sabellaria* reefs needs to consider other parameters of the wider environment that may influence the presence of reefs 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. Some relevant environmental parameters are identified in Table 6 but could also include elements such as patterns of sediment transport or the hydrodynamic regime (for example, 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 can be appropriate for survey and monitoring of *Sabellaria* reef parameters/indicators although in general there is a paucity of literature relating to the methods for this purpose. Those presented below should be treated as a general guide and should not be seen as exhaustive. The main options include:

- Phase I walkover survey and habitat mapping (intertidal reef)
- aerial surveys / Unmanned Aerial Vehicle (UAV) (intertidal reef)
- geophysical survey (such as side scan sonar) for habitat mapping (subtidal reef)
- Digital Imaging Scanning Sonar (DISS) and Sediment Profiling Imagery (SPI) – application in turbid environments (subtidal reef)
- underwater image survey (such as towed video, still images, ROVs and AUVs) (subtidal reef)
- Phase II quantitative sampling (for example, quadrats) (intertidal and subtidal reef)
- dive survey for quantitative and semi-quantitative sampling (subtidal reef).
- other sampling for fine scale or environmental parameters/indicators (Table 6)

These methods are discussed in further detail below, with respect to the parameters/indicators that can be surveyed using these approaches. In practice, the suitability of each of the methods will depend on the specific *Sabellaria* reef(s) to be assessed, the project scale, and the predicted impacts. You might want to consult an established expert in *Sabellaria* reef ecology to help you with the selection of methods to be employed. If the reefs are located within marine protected areas, using the same methods as those used in the statutory feature condition monitoring will enable comparison with existing data sets.

Grabs, trawls or dredges are not recommended for sampling *Sabellaria* reefs due to the damage these methods can cause to the biogenic reef habitat. The use of grabs might be approved in exceptional circumstances, where it can clearly be shown that such sampling is essential and that it is not possible to deploy less-damaging methods.

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. *Sabellaria* reef parameters

5.1.1.1. Reef extent

Intertidal reefs

Most intertidal *Sabellaria* reefs can be mapped using established Phase I habitat mapping methods, using a hand-held GPS to track the perimeter of reefs on foot (Wyn *et al.*, 2006). This is the most appropriate method where canopies of fucoid algae attached to underlying rock cover significant proportions of the reef and reduce the effectiveness of more remote methods to survey extent.

Survey methods using Unmanned Aerial Vehicles (UAV) can give greater accuracy and are very useful for less accessible locations or where this level of accuracy is required.

However, if canopies of fucoid algae attached to underlying rock are covering the intertidal *Sabellaria* reef at low water, UAV mapping is not suitable.

For UAV surveys ground-truthing observations will be required to check and confirm remote measurements.

UAV mapping

Developments in Unmanned Aerial Vehicle (UAV) technology now means that remotely sensed imagery can be easily obtained at high temporal frequencies and substantially lower cost than aircraft or satellite derived imagery. UAVs are not subject to the same regulations as aircraft and can be flown at low altitude, which is crucial to improve the resolution and accuracy of the data (Jaud *et al.*, 2016). The use of UAVs means that mapping surveys can be more flexible and undertaken at shorter notice than with aircraft or satellite.

UAV mapping methods have proved to be an effective and low cost option for rapidly mapping the extent of intertidal *Sabellaria* reefs (Ocean Ecology Limited, 2016a). Most UAV platforms are capable of collecting elevation data alongside high-resolution photographs and so offer the potential for topographic monitoring of intertidal areas (Jaud *et al.*, 2016; Ocean Ecology Limited, 2016c), including *Sabellaria* reefs potentially subject to sedimentation and/or erosion. UAV mapping outputs need to be ground-truthed by direct field observations, but the ground-truthing effort can be much reduced due to the greater resolution of the outputs.

General guidance on UAV mapping techniques is provided in Kakaes *et al.* (2015). Specific UAV methodologies and the challenges with mapping intertidal habitats are detailed in Jaud *et al.* (2016), Duffy *et al.* (2017) and Pratt (2016).

Subtidal reefs

It is recommended that acoustic mapping techniques (chiefly high resolution side scan sonar mapping), combined with ground-truthing observations, are employed to measure extent of subtidal *Sabellaria* reefs whenever possible.

The most rapid and cost-effective method of producing an initial predictive mapping of areas thought to represent reef is to collect high resolution acoustic data using side scan sonar (SSS), complimented with multibeam echosounder bathymetry (MBES) and/or acoustic ground discrimination systems (ADGS) (Foster-Smith & White, 2001; Limpenny *et al.*, 2010).

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).

SSS returns an irregular or mottled signature in the presence of *Sabellaria* reef (see Figure 5), which is thought to be caused by the heterogeneous nature of the structures at a small-scale (Pearce *et al.*, 2014).

It should be noted that the signature detected can look very different depending on the underlying sediments and the physical structure of the reef, and it is not currently possible to differentiate between *Sabellaria* reefs and other biogenic reefs (such as *Mytilus edulis* beds), or even heterogeneous gravel and cobble sediments, with any degree of certainty (Limpenny *et al.*, 2010; Fariñas-Franco *et al.*, 2014; Pearce *et al.*, 2014). It is therefore essential that the acoustic data are appropriately ground-truthed to confirm the presence or absence of reef[10] and reef extent. This can be done using seabed imagery (such as video footage and/or digital stills) and/or direct sampling if necessary (such as grabs). Seabed imagery is the preferred method of ground-truthing as a large area can be covered in a shorter period and the results can be seen immediately on the survey vessel. The cost of subsequent analyses of underwater imagery may be lower than that for grab samples.

Grab sampling can be useful to confirm that the reef is composed of living worms and to facilitate investigations into the associated ‘infaunal’ communities and fine-scale parameters. However, in general, NRW advise against the use of grab sampling on *Sabellaria* reef because of the potential damage to the reef, unless there is an over-riding reason why grab sampling needs to be deployed. If this is the case, the likely impact of a grab would need to be assessed and its use justified in the survey or monitoring plan, including how the chosen survey design minimised impact on the reef.

Drop-down and towed video systems can also damage reefs and care needs to be taken in their deployment to avoid this impact.

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

[10] Meeting the EC Habitats Directive Annex I definition i.e. the criteria set out by Gubbay (2007).

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, for example, 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).

High resolution backscatter data collected with MBES have been used to successfully delineate *S. spinulosa* reefs (Limpenny *et al.*, 2010; Pearce *et al.*, 2011b), providing a similar acoustic signature as that shown in high resolution SSS data. However, backscatter data from MBES has not been widely tested and it is recommended that it is only collected in conjunction with SSS data until this method is more comprehensively proven.

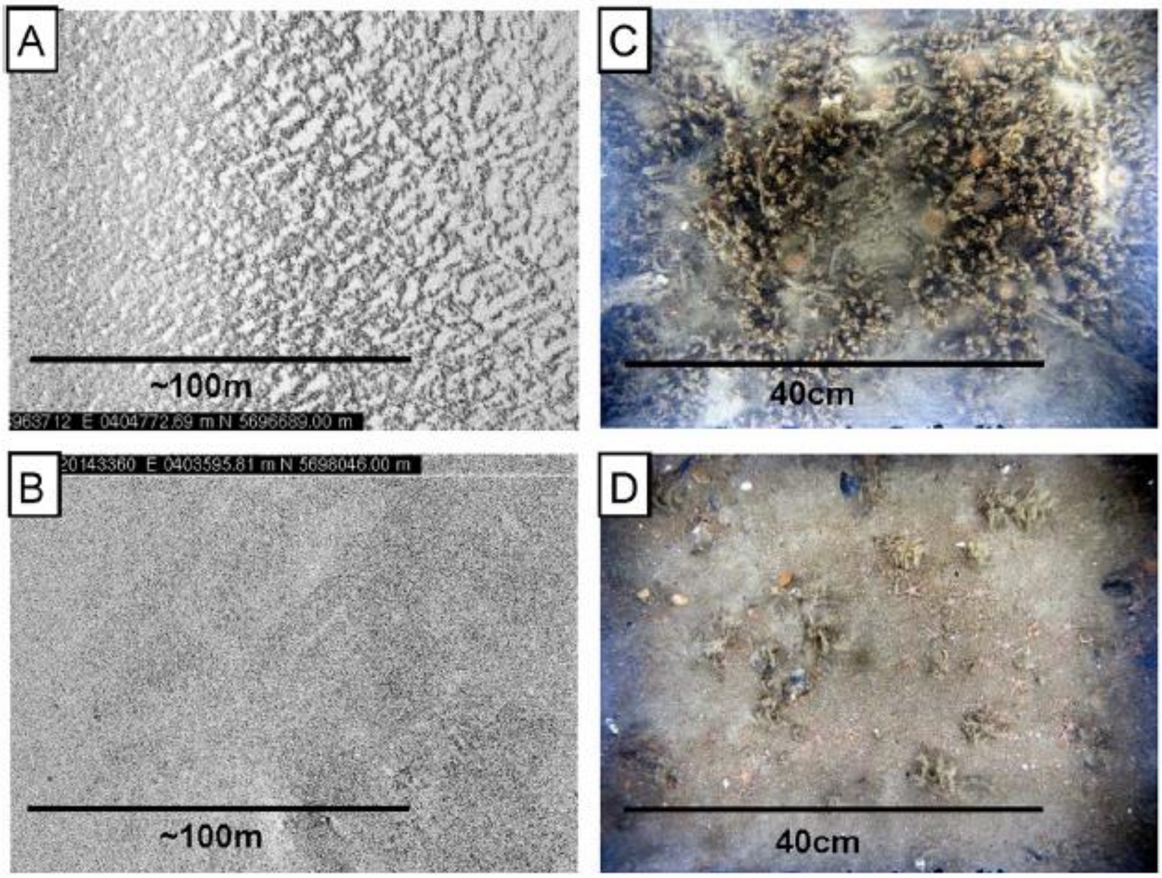

Figure 5. High resolution (410kHz) side scan sonar snap shot images (EdgeTech 4200FS) of (A) S. spinulosa reef; (B) flat sedimentary habitats; (C) seabed image taken at the same location as A; and (D) seabed image taken at the same location as B (from Pearce *et al*., 2014)

Digital Imaging Scanning Sonar, LiDAR, Sediment Profiling Imagery
In highly turbid environments such as the Severn Estuary, where obtaining seabed imagery is not possible, Digital Imaging Scanning Sonar (DISS) and Sediment Profiling Imagery (SPI) (see Germano *et al.*, 2011) can be considered as an alternative means of validating the initial predictive mapping.

Where *Sabellaria* reefs occur in very shallow waters, making SSS mapping surveys unfeasible in some cases, the use of DISS and/or LiDAR should be considered for the initial predictive mapping (Wang & Philpot, 2007; Limpenny *et al.*, 2010; Noernberg *et al.*, 2010) although the latter will not be appropriate in areas of turbid waters (such as the Bristol Channel).

Digital Image Scanning Sonar[11] (DISS) is an established technology based on side scan sonar theory that is used for ROV navigation and collision avoidance as well as for monitoring migratory fish in low visibility riverine environments (Martignac *et al.*, 2015). DISS systems can produce a video-like visualisation of far higher resolution than ordinary towed SSS as they can be held very close to the sea floor on seabed frames.

The use of Digital Image Scanning Sonar (DISS) for assessing *Sabellaria* reefs has been demonstrated by the Eastern Inshore Fisheries and Conservation Authority (IFCA) using an ARIS 3000 sonar DISS system to map areas of subtidal *S. spinulosa* reef in the Wash (Stephen Thompson, Eastern IFCA, pers. comm.).

The high resolution achieved by DISS systems comes at the cost of spatial coverage, so these systems have not been widely applied in monitoring the extent of subtidal *Sabellaria* reefs. A very similar ARIS system has, however, been trialled in 2016 and 2017 as part of an ongoing research project being conducted by a research consortium made up of regulatory, academic and industry partners[12]. The aim of this project is to fine-tune the methods for collecting and analysing DISS data in order to enable condition assessments of the subtidal *Sabellaria* reef features of the Severn Estuary SAC which, to date, have never been mapped. The preliminary results have demonstrated that video-like visualisations of *Sabellaria* reef can be achieved in shallow turbid waters by mounting the DISS head on a pole similar to MBES setups.

DISS systems are therefore emerging as viable options for both small-scale mapping and ground-truthing of predictive subtidal reef mapping and should therefore be given due consideration particularly when planning to assess reefs in highly turbid environments.

Sediment Profile Imagery uses a camera system that penetrates the upper surface of the seafloor sediments to provide detailed images of the sediment profile (see Solan *et al.*, 2003; Germano *et al.*, 2011); 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).

[11] Also known as imaging sonars, acoustic cameras or dual-frequency identification sonar (DIDSON).
[12] Including NRW, Natural England, the Environment Agency, Eastern IFCA, Devon and Severn IFCA, Ocean Ecology Limited and Swansea University.

Sediment Profiling Imagery (SPI) has been successfully tested as a means of assessing the vertical structure (elevation) of *Sabellaria* reefs in turbid conditions in the North Sea (Limpenny *et al.*, 2010). SPI also provides an insight into the substrate upon which the reef has developed. SPI imagery does not, however, assess patchiness (as % cover) as required when classifying *Sabellaria* colonies as 'reef' or 'not reef'[13], and is not suitable to assess *Sabellaria* colonies occurring on hard impenetrable substrates. As such, SPI systems should only be considered when all other ground-truthing methods are unfeasible.

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. In the intertidal a digital camera is used. For underwater imagery 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 could be used for visual characterisation of subtidal *Sabellaria* reefs but drop down and towed video systems are most commonly employed. Imagery can include video and still photography and can be analysed *in situ* on the vessel or post-survey.

Underwater imagery survey methods can provide visual data on the reefs and imagery taken along transects can provide extent data.

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 identification of the associated epifauna).

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, 2001), 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. Reef structural composition

Reef elevation

- **Intertidal reefs:** elevation should be sampled within quadrats positioned according to the sampling grid for the survey. Measurements can be easily taken using a ruler which is the method used in NRW's monitoring. Alternative approaches are to use a wire probe gently pushed vertically through the reef structure until it meets the substrate, or to use callipers for low reef structures. Averaging a number of

[13] as per the EC Habitats Directive Annex I definition i.e. the criteria set out by (Gubbay (2007))

measurements within a quadrat or within the habitat will ensure meaningful values across a reef, or sections of reef, as a whole.

- **Subtidal reefs:** the approach taken to determine elevation is less straightforward and will depend on the remote sampling methodology.
    - when drop-down or towed seabed cameras are used elevation will need to be estimated based on expert judgement and interpretation of the reef and substrate visible in the field of view and/or using laser scaling pointers and/or line projected from the camera frame onto the seabed (Hitchin *et al.*, 2015; Jenkins *et al.*, 2018)
    - grab sampling: in general, NRW advise against the use of grab sampling on *Sabellaria* reef because of the damage it can cause to the reef. If there is an essential reason why grab sampling has to be deployed, the likely impact of a grab should be assessed, and its use justified in the survey or monitoring plan, including how the chosen survey design minimises its impact on the reef. If an aggregation of *Sabellaria* is collected in a grab, physical measurements can be made using callipers (or similar) whilst it is in the grab if this is feasible or when released from the grab if the reef structures remain intact.

Elevation measurements or estimates should be recorded for multiple points randomly positioned within the quadrat (intertidal) or field of view (subtidal) in order to calculate a mean elevation. For *S. spinolusa* the elevation can then be assigned to one of the elevation categories set out in Table 3 and Table 4 and, in combination with information on extent and patchiness, be used to establish if the *Sabellaria* colony meets the EC Habitats Directive Annex I definition (Gubbay, 2007). For *S. alveolata* the elevation data can assist in assigning a reef formation category (Table 2) for each sampling station.

Patchiness (% cover)
Sabellaria reef cover should be determined through *in situ* estimation of % cover:

- **Intertidal:** reef cover should be determined through *in* situ estimation either of % cover within quadrats deployed by surveyors or a visual assessment across the habitat. UAV imagery can also be used to assess patchiness.

- **Subtidal:** reef cover can be determined based on drop-down camera imagery positioned on either a systematic grid or a random stratified design (see section 4.4.3). True patchiness along transects can also be derived from drop-down camera imagery as outlined in Jenkins *et al.*, (2018). Alternatively, % cover can be estimated from plan-view quadrat photos of the seabed using image analysis software packages (see section 5.2.4). When subtidal reefs occur in areas of high turbidity, alternative methods of establishing % cover should be considered such as Digital Image Scanning Sonar (DISS)). Grab sampling is not advised as it is damaging to the reefs and is not considered to be suitable for establishing % cover.

5.1.1.3. Associated species composition and diversity

Benthos
The information that is required about the fauna and flora associated with *Sabellaria* reefs will depend on the requirements of the survey or monitoring associated with a proposed development or activity. In most instances, NRW would advise that this should focus on the epibiota attached to a reef and would not advocate coring or destructive sampling of

the reef. Under exceptional circumstances destructive sampling may be required, but the method needs to be determined and agreed on a case by case basis and the impact of such sampling fully assessed before any survey work is undertaken.

Epibenthos

The composition and diversity of epibenthic taxa associated with *Sabellaria* reefs should be assessed at sampling stations across each reef positioned on the selected sampling grid for the survey programme.

- **Intertidal reefs:** this should be achieved by using standard methodologies for *in situ* recording (Davies *et al.*, 2001).

- **Subtidal reefs:** data on epibenthic species can be determined from high resolution seabed imagery (section 5.1.1.1). If conditions are unsuitable for use of underwater imagery (such as high turbidity) this parameter should not be surveyed as other techniques such as physical collection of samples are destructive to the reef.

Motile fauna

Motile faunal assemblages associated with *Sabellaria* reefs (such as fish, large mobile crustaceans, cephalopods) are rarely studied, despite being thought to largely benefit from the increased habitat complexity and availability of food that the reef structures can provide. This is mostly due to the destructive nature of sampling methods that would traditionally have been used to assess motile communities (such as trawls). As a result, potential impacts on motile fauna associated with *Sabellaria* reefs are frequently ignored during monitoring programmes.

If motile fauna need to be assessed this should be undertaken using methods that do not damage or have much impact on the reef itself. These include baited remote underwater video (BRUV) systems (intertidal and/or subtidal) (see Unsworth *et al.*, 2014; Peters *et al.*, 2015; Hinder *et al.*, 2013; Griffin *et al.*, 2016); static nets that can be set at low tide and revisited after one tidal cycle (such as fyke and gill nets) (intertidal); and/or frame-deployed DISS systems modified for assessing fish communities in highly turbid environments (Martignac *et al.*, 2015).

Assessing the motile fauna that *Sabellaria* reefs support can be important if proposed developments or activities are predicted to have adverse impacts on commercial fisheries.

5.1.1.4. Worm metrics

If information about the individual *Sabellaria* worms are required, most of the relevant indicators relating to them can be measured using information and samples collected for assessing the other parameters/indicators covered in the sections above. As already noted in previous sections, any use of destructive sampling methods would need to be assessed and agreed on a case by case basis.

The number of tubes and tube apertures should be calculated as a mean from a selection of tubes. This can be determined by using image processing software such as ImageJ (Schneider *et al.*, 2012; Fariñas-Franco *et al.*, 2014; Pearce *et al.*, 2014) (see section 5.2.4) to analyse plan-view quadrats (intertidal) or seabed imagery (subtidal). If required, the numbers of live worms and their corresponding biometric measurements (length, biomass, energy content and sex ratio) could be derived from core (intertidal) and grab (subtidal) samples if such samples need to be collected.

5.1.1.5. Environmental indicators

Larval density and development stage

Sabellaria larval density and corresponding ratios of each larval development stage should be monitored by plankton tows sampled in line with methods set out by Bush *et al.* (2015). At each pre-determined sampling station, single plankton samples should be taken at three depths (lower, mid and upper water column) using a 50 μm mesh plankton net with an aperture of 50 cm. The net should be towed at a speed of two knots for approximately 200 m. The volume of water passing through the net should be measured with a calibrated flowmeter. Time, length and GPS position of each tow should be noted. The samples should then be condensed by filtering through a 50 μm mesh sieve and preserved in 10% formalin solution.

Suspended Particulate Matter concentrations

Water samples should be collected using a suitable water sampler (such as a Van Dorn water sampler or similar) to investigate the concentration of Suspended Particulate Matter (SPM). The sampling should be concurrent with the plankton larvae sampling and at the same three water depths (lower, mid and upper water column) at a position approximately mid-way along each plankton tow.

5.1.2. Fieldwork Quality control

All fieldwork should be carried out by experienced field scientists with knowledge of *Sabellaria* reefs and training in the 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
- detailed field notes for the sampling procedures and robust sample labelling
- a full physical and digital voucher/reference collection of all taxa identified during analysis of all imagery and samples taken
- sample collection and handling during surveys must conform to the requirements of subsequent analytical analyses
- 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. Unmanned Aerial Vehicle (UAV) mapping – intertidal reefs

UAV surveys should be conducted by qualified UAV Pilots operating under the current CAA rules (for example see Cunliffe *et al.*, 2017) and any other legislation and requirements. If mapping a particular *Sabellaria* reef requires the UAV to fly beyond Visual Line of Sight (VLOS) (such as when mapping extensive reefs), care needs to be taken to comply with current CAA requirements for such work (Extended Visual Line of Sight (EVLOS) operations). Alternatively, extensive reefs may need to be mapped during two or more flights.

Images captured by the UAV should have sufficient forward and lateral overlap so that post-processing software can identify common points between each image (Table 7) and flight transect plans should allow for this. Higher or lower overlap may be appropriate for different *Sabellaria* reefs. In practice the chosen overlap will be site- and reef-specific. For example, heterogeneous reefs will require less overlap, whereas relatively featureless reefs will need greater overlap.

The highest possible resolution[14] and accuracy[15] should be aimed for in order to delineate reefs as precisely as possible. As with overlap, this will be constrained by reef size and may need to be balanced against ensuring that entire reefs can be surveyed within the project resource and tidal constraints. Accuracy requirements will also be governed by the survey objectives. For example, habitat characterisation surveys are not likely to require high vertical accuracy, whereas monitoring surveys aiming to assess deposition or erosion will need to be able to detect fine scale changes in elevation (i.e. several centimetres) and require the use of Real Time Kinematic (RTK) derived Ground Control Points (GCPs).

Flights should preferably be carried out in early morning or late evening during cloudy weather, if compatible with tide times (Jaud *et al.*, 2016; Duffy *et al.*, 2017). This will avoid sun glints and the effects of brightly illuminated water-saturated sediments. Surveys should be undertaken when the maximum extent of the reef has drained which can be achieved by starting close to the time of low water and working up the shore ahead of the flooding tide. Survey dates should be selected for when the low tide level is sufficient to exposure as much as possible of the *Sabellaria* present on the shore. When repeat survey events are undertaken, differences in low tide height can lead to differences in extent measurements. Subsequent analysis of repeat surveys needs to standardise the seaward extent to the least low tide.

Table 7. Summary of recommended quality standards for UAV mapping of *Sabellaria* reefs based on recommendations in Kakaes *et al.* (2015)

Requirements	Forward overlap	Lateral overlap	Resolution (GSD)	Accuracy (RMSE)
CAA PfCO and UAV pilot qualification (RPQ). Further CAA permission for EVLOS operations.	70-80%	60-80%	<5cm / pixel	5-10m or <5cm*

* High accuracy will be required when monitoring reef elevation requiring use of RTK derived GCPs to georeference orthomosaic outputs.

5.1.2.2. Acoustic mapping

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.

[14] Measured as Ground-Sampling Distance (GSD).
[15] Measured as Root Mean Square Errors (RMSE).

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.

5.1.2.3. 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 need 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).

Quality standards for seabed imagery collected on subtidal *Sabellaria* reefs using drop-down and/or towed camera systems should align with those set out in the NE Atlantic Marine Biological Quality Control (NMBAQC) scheme Operational Guidelines for Epibiota Remote Monitoring (Hitchin *et al.*, 2015).

5.2. Analytical methods

5.2.1. GPS tracks and fixes
Positional fixes collected during reef perimeter tracking and at ground-truthing and sampling stations should be downloaded and plotted immediately after each survey. The resulting files should be imported into a Geographical Information System (GIS) and converted to relevant mapping formats (such as .shp, .tab) for sense checking against available base maps (for example aerial imagery and admiralty charts).

5.2.2. UAV data

Imagery from UAV extent mapping surveys should be 'stitched' together to generate orthomosaic outputs for each reef surveyed. This can be achieved using widely available processing software packages, for example Pix4D.

For small reefs these orthomosaics, when combined with ground-truthing information from quadrats, may be sufficient for rapidly establishing the areas that classify as 'reef' or 'not a reef' (see section 2.5) and/or delineating areas of different reef formation categories.

For large patchy reefs, manual delineation in GIS is unpractical. Instead, the orthomosaic output can be autonomously 'zoned' (Figure 6) using a variety of image classification methods that use red, green and blue (RGB) values collected in standard three-band imagery (such as the Vegetation Adjusted Reflectance Index (VARI) – see Gitelson *et al.* (2002).

It is sometimes difficult to distinguish between *Sabellaria* reef and other substrates found on the shore so, regardless of the method used, the ground-truthing data collected across each reef should be interpreted appropriately to fine-tune the classification of each reef (Ocean Ecology Limited, 2016a). In most cases, quadrat imagery, collected for measuring particular ecological parameters, will provide the information required to appropriately ground-truth the broad-scale habitat maps. If these parameters are not being measured as part of a survey or monitoring programme, then additional targeted sampling may be required to provide appropriate ground-truthing.

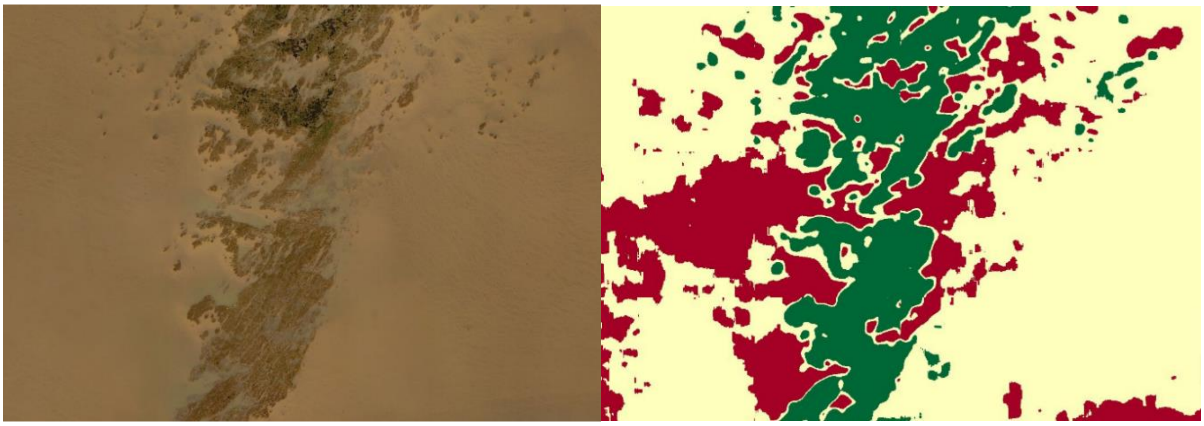

Figure 6. Example of orthomosaic output derived from a UAV extent mapping survey of a *S. alveolata* reef in Swansea Bay (left); the corresponding 'zoned' output derived from RGB values of the same reef: *S. alveolata* reef ground-truthed by quadrat sampling is shown in green (right) (Ocean Ecology Limited, 2016a)

With the rapid advance of UAV mapping technology and processing software, it is likely that methods for delineating *Sabellaria* reefs from UAV-derived imagery will be continually improved and updated. Where possible, the equipment, methods and 'rules' used for mapping and classifying reefs should be kept consistent throughout entire monitoring programmes. A repeatable method and rationale for classifying the reefs should be agreed on a project-by-project basis.

5.2.3. Acoustic data

Processing of acoustic data can be complex and will vary markedly depending on the method of collection. A variety of guidance is available (Populus & Perrot, 2007; 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 (SSS) data

Raw side scan data needs to be processed through proprietary software. SSS 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 *Sabellaria* reef extent (Henriques *et al.*, 2012; Plets *et al.*, 2013).

Using side scan imagery interpretation in the context of seabed habitat mapping is a complex task. In general, image interpretation is an open subject of research and there is no clearly defined 'best practice' (Blondel, 2009), particularly for *Sabellaria* reefs (although see Pearce *et al.*, 2014; Meadows *et al.*, 2006). Clear methods and 'rules' for mapping and classifying reefs should therefore be defined and agreed prior to any survey or monitoring and you may find it useful to consult an established expert in *Sabellaria* reef ecology to help with this

MBES data

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 GIS. Once applied, continuous DTMs can be interrogated in GIS alongside ground-truthing information, to classify areas of *Sabellaria* reefs. 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.

5.2.4 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.

Estimations of % cover taken in the field can vary substantially between surveyors (Wells, 2013). This observer bias can either be controlled using training exercises and reference cards or by using image analysis tools. Percentage *Sabellaria* reef cover within quadrats can be derived through post-survey analysis of plan view quadrat photographs, collected by field surveyors and/or drop-down cameras. This 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; Koedsin *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. The categories can be defined for specific *Sabellaria* reefs and percentage cover can then be estimated by assigning the categories to a set of points randomly overlain across each quadrat image. This provides a repeatable method for detecting change in percentage cover over time.

The minimum number of points necessary to ensure accurate % cover estimation per image (the Optimal Point Count (OPC)) should be determined by undertaking a preliminary precision analysis on a subset of representative images from each reef surveyed (see Pante & Dustan, 2012). After completing the analysis, the CPCe software can be used to produce a data matrix suitable for statistical analysis. Photo-interpretation of percentage cover should be carried out by trained CPCe operators and overseen by experienced scientists. All CPCe analysts should be trained using photographic reference images. Photo interpretation and counts should be verified by a second experienced scientist on 10 % of images. Where an error rate exceeds 10%, all images within that batch should be re-analysed.

Epibenthic species

Epibenthic communities should be assessed through a detailed analysis of the seabed imagery collected using drop-down and/or towed camera systems. All analysis should follow the NMBAQC / JNCC epibiota remote monitoring interpretation guidelines (Turner *et al.*, 2016) and methods specific to *Sabellaria* reef detailed in Jenkins *et al.* (2018)

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.

5.2.5 Grab and core samples

If core or grab samples are collected, they are generally preserved in buffered 4% formaldehyde solution in the field and are sent to a benthic analysis laboratory, fixed and labelled. The mesh size for the sieving process will be project-specific; the most common recommendations are 0.5 mm for fine sediments and 1.0 mm for coarser sediments. Subsampling may be carried out for particularly rich samples (as expected on *Sabellaria* reefs) or high volumes.

All biota should then be identified and enumerated from each sample (including *Sabellaria* spp.), by a laboratory participating in the macrobenthic component of the NMBAQC scheme following industry standard guidance (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 density (i.e. per m^2), if required for comparative purposes. Blotted wet weight biomass should also be measured, either at major taxonomic group or at each taxon level, using calibrated scales.

If an assessment of the energy content provided by particular *Sabellaria* reefs is required (for example, for Individual Based Models (IBMs) for predicting potential impacts of a development or activity on coastal birds), individual lengths should be measured for a subset of specimens from each taxon using calibrated microscope cameras and associated software (µm accuracy). Ash Free Dry Mass (AFDM) should also be determined to establish length-weight relationships for input into the IBMs (see methods described in West *et al.*, 2004; 2006; Ocean Ecology Limited, 2016c).

5.2.6. Environmental indicators

Larval samples

Larval samples should be analysed following the methods described by Bush *et al.* (2015). Where possible, *S. spinulosa* and *S. alveolata* larvae should be differentiated using a high powered stereo-microscope (with phase contrast functionality if available) to inspect the provisional bristles that are either asymmetrically (*S. alveolata*) or symmetrically (*S. spinulosa*) ringed (Pearce, 2014).

Water samples

Water samples should be analysed to determine Particulate Organic Matter (POM) and Particulate inorganic Matter (PIM) concentration in line with methods set out in Dubois *et al.* (2009). Particle Size Distribution (PSD) analysis of the PIM fraction should be undertaken by a laboratory participating in the PSA component of the NMBAQC scheme and should follow the methods described in industry standard guidance (Mason, 2016).

5.2.7. Analytical Quality control

5.2.7.1. Acoustic 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.

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.

5.2.7.2. 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.

5.2.7.3. Benthic sample analysis (macrobiota)
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).

If benthic samples are collected, it is strongly advised that their 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 macrobenthic samples. A check of benthic invertebrate reference collection identifications should also be included.

5.2.7.4. 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 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).

Noble-James *et al.* (2017) sets out a detailed description of the main analytical methods and procedures that can be employed for analysing data relating to marine habitats. These should be employed when analysing data as part of *Sabellaria* reef assessments. In practice, the routines employed will be reef-specific and should be developed in consultation with an experienced statistician and agreed on a project-by-project basis.

5.3.1. Habitat Characterisation and mapping

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 *Sabellaria* reefs will include production of spatial maps of reefs within the ZoI with details any other sampling outputs and photographs. Spatial data is often most usefully presented as detailed survey maps, typically using GIS software packages.

It will generally not be necessary to undertake in-depth analysis of *Sabellaria* reef indicator data collected for habitat characterisation purposes. In most cases, simple interpretation using univariate statistics will be sufficient. Most importantly, any analysis should aim to present the data in the most suitable manner for assessing the likely impacts of the project/activity on *Sabellaria* reefs within the ZoI.

5.3.2. Monitoring

For monitoring, the statistical framework should be established at the survey design stage as this will inform decisions on matters such as appropriate effect sizes and sampling effort (see section 4).

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.

6. References

Allen, J.H., Billings, I., Cutts, N. & Elliott, M. 2002. Mapping, Condition and Conservation Assessment of Honeycomb Worm Sabellaria alveolate reefs on the Eastern Irish Sea Coast.

Allen, J., Wilkinson, S., Hawkins, S.J., Hartnoll, R. & Russell, G. 1991. Baseline survey of the Cumbrian shores from St. Bees head to Maryport, Final Report.

Ayata, S.D., Ellien, C., Dumas, F., Dubois, S, & Theibaut, E. 2009. Modelling larval dispersal and settlement of the reef-building polychaete Sabellaria alveolate: Role of hydroclimatic processes on the sustainability of biogenic reefs. Cont Shelf Res 29:1605-1623

Ayata, S. D., Stolba, R., Comtet, T. & Thiébaut, É. 2011. Meroplankton distribution and its relationship to coastal mesoscale hydrological structure in the northern Bay of Biscay (NE Atlantic). Journal of Plankton Research.

Baldock, L. & Goudge, H. 2017. North Anglesey INNS and *Sabellaria* video and still image analysis. NRW Evidence Report Series. Report No: 206, 61pp. Natural Resources Wales, Bangor

Bamber, R. & Irving, P. 1997. The differential growth of Sabellaria spinulosa (L.) reefs at a power station outfall. Polychaete Research 17, 9-14.

Barry, J. & Nicholson, M. 1993. Measuring the probability of patch detection for four spatial sampling designs. J Appl Stat 20:353-362

Blondell, P. 2009. Shallow-water environments. In: The Handbook of Sidescan Sonar. Springer-Verlag Berlin Heidelberg, p 185-199

BMT Cordah. 2003. Ross-worm non-technical report. Report to Subsea 7 as part of contract for ConocoPhillips

Boyes, S., Mazik, K & Burdon, D. 2008. Intertidal Monitoring of Sabellaria alveolata in Cardigan Bay SAC in 2004. CCW Marine Monitoring Report no. 43. Countryside Council for Wales, Bangor.

Bradbury, I. R., & Snelgrove, P. V. 2001. Contrasting larval transport in demersal fish and benthic invertebrates: the roles of behaviour and advective processes in determining spatial pattern. Canadian Journal of Fisheries and Aquatic Sciences, 58(4), 811-823

Brazier, P., Birch, K., Brunstrom, A., Bunker, A., Jones, M., Lough, N., Salmon, L. & Wyn, G. 2007. When the tide goes out: the biodiversity and conservation of the shores of Wales – results from a 10 year intertidal survey of Wales. Countryside Council for Wales. ISBM: 1 86961 152 1

Brazier, P. 2013. Evaluating intertidal seagrass Zostera noltii beds – field surveys vs remote sensing. CCW Marine Monitoring Report no. 103. Countryside Council for Wales, Bangor

Brooks, A.J., Whitehead, P.A. & Lambkin, D.O. 2018. Guidance on Best Practice for Marine and Coastal Physical Processes Baseline Survey and Monitoring Requirements to inform EIA of Major Development Projects. NRW Report No: 243, 119 pp, Natural Resources Wales, Cardiff

Bush, L.E. 2015. Stability and variability of the ecosystem engineer Sabellaria alveolata on differing temporal and spatial scales. Bangor University.

Bush, L.E., Balestrini, S.J. & Robins, P.E. 2015. The reproduction and connectivity of Sabellaria alveolate reefs in Wales. NRW Evidence Report No. 049 – The reproduction and connectivity of Sabellaria alveolate reefs in Wales – MAR4REF Bangor University

Byrnes, M. 2000. Sampling and surveying radiological environments. In: Sampling and Surveying Radiological Environments. CRC press, p440

Cam, J.B. Le, Fournier, J. Etienne, S. & Couden, J. 2011. The strength of biogenic sand reefs: Visco-elastic behaviour of cement secreted by the tube building polychaete Sabellaria alveolate, Linnaeus, 1767. Estuar. Coast Shelf Sci 91:333-339

Cardno. 2013. Seagrass monitoring programme baseline report – Ichthys Nearshore Environmental Monitoring Program

Carr, H., Wright, H., Cornthwaite, A. & Davies, J. 2016. Assessing the contribution of Welsh MPAs towards and ecologically coherent MPA network in 2016. Joint Nature Conservation Committee.

Cazaux, C. 1964. Développement larvaire de *Sabellaria alveolata* (Linné). Bulletin de l'Institut Océanographique de Monaco, 62, 1-15

CEC. 1999. Interpretation Manual – EUR 15

CEC. 2007. Interpretation Manual of European Union Habitats

CIEEM. 2018. Guidelines for Ecological Impact Assessment in the UK and Ireland: Terrestrial, Freshwater, Coastal and Marine. Chartered Institute of Ecology and Environmental Management, Winchester.

Cochrane, S.K.J, Connor, D.W., Nilsson, P., Mitchell, I., Reker, J., Franco, J., Valavanis, V., Moncheva, S., Ekebom, J., Nygaard, K., Serrão Santos, R., Naberhaus, I., Packeiser, T., van de Bund, W., Cardoso, A.C. 2010. Marine Strategy Framework Directive. Guidance on the interpretation and application of Descriptor 1: Biological diversity. Rep by Task Gr 1 Biol Divers Eur Comm Jt Res Cent Ispra, Italy

Coggan, R. & Birchenough, S. 2007. MESH Recommended operating guidelines (ROG) for sediment profile imagery (SPI) ver. 3

Coggan R., Mitchell A., White J. & Golding N. 2007. MESH Recommended operating guidelines (ROG) for underwater video and photographic imaging techniques

Cunliffe, A.M, Anderson, K., DeBell, L. & Duffy, J.P. 2017. A UK Civil Aviation Authority (CAA)-approved operations manual for safe deployment of lightweight drones in research. Int J Remote Sens 38, Issue 8–10

Cunningham P., Hawkins S., Jones H., Burrows M. (1984a) The biogeography and ecology of Sabellaria alveolata. Nature Conservancy Council CSD Report

Cunningham, P. N., Hawkins, S. J., Jones, H. D., & Burrows, M. T. 1984b. The geographical distribution of Sabellaria alveolata (L.) in England, Wales and Scotland, with investigations into the community structure of, and the effects of trampling on *Sabellaria alveolata* colonies. Report to the Nature Conservancy Council from the Department of Zoology, Manchester University, Manchester, 1-38.

Curd, A., Pernet, F., Corporeau, C., Delisle, L., Firth, L.B., Nunes, F.L.D. & Dubois, S.F. 2019. Connecting organic to mineral : How the physiological state of an ecosystem- engineer is linked to its habitat structure. Ecol. Indic. **98**: 49–60

Davies, J., Baxter, J., Bradley, M., Connor, D., Khan, J., Murray, E., Sanderson, W., Turnbull, C. & Vincent, M. 2001. Marine Monitoring Handbook March 2001 (Jon Davies, J Baxter, M Bradley, D Connor, J Khan, E Murray, W Sanderson, C Turnbull, and M Vincent, Eds.).

Davies, A.J., Last, K.S., Attard, K. & Hendrick, V.J. 2009. Maintaining turbidity and current flow in laboratory aquarium studies, a case study using Sabellaria spinulosa. J Exp Mar Bio Ecol 370:35–40

Davies. A.J., Newstead, S.J. 2013. The function and restoration of biogenic reefs formed by Sabellaria alveolata. CCW Sci Rep No 1022:45pp

Defra. 2014. Marine Strategy Part Two: UK Marine Monitoring Programmes

Desroy, N., Dubois, S.F., Fournier, J., Ricquiers, L., Mao, P. Le, Guerin, L., Gerla, D., Rougerie, M. & Legendre, A. 2011. The conservation status of Sabellaria alveolata (L.) (Polychaeta: Sabellariidae) reefs in the bay of mont-saint-michel. Aquat Conserv Mar Freshw Ecosyst 21:462–471

Dubois, S., Barillé, L. & Cognie, B. 2009. Feeding response of the polychaete Sabellaria alveolata (Sabellariidae) to changes in seston concentration the particular case of the bay of Mont-Saint-Michel , where the cultivation of oysters (Le Mao *et al*., 2004), the question of the carrying capac. J Exp Mar Bio Ecol 376:94–101

Dubois, S., Barillé, L., Cognie, B. & Beninger, P.G. 2005. Particle capture and processing mechanisms in Sabellaria alveolata (Polychaeta: Sabellariidae). Marine Ecology Progress Series, 301, 159-171

Dubois, S., Commito, J.A., Olivier, F. & Retière C. 2006. Effects of epibionts on Sabellaria alveolata (L.) biogenic reefs and their associated fauna in the Bay of Mont Saint-Michel. Estuar Coast Shelf Sci 68:635–646

Dubois, S., Comtet, T., Retiere, C & Theibaut, E. 2007. Distribution and retention of Sabellaria alveolata larvae (Polychaeta: Sabellariidae) in the Bay of Mont-Saint-Michel, France. Mar Ecol Prog Ser 346:243–254

Dubois, S., Retiere, C. & Olivier, F. 2002. Biodiversity associated with Sabellaria alveolata (Polychaeta: Sabellariidae) reefs: effects of human disturbances. J Mar Biol Assoc UK 82:817–826

Duffy, J., Cunliffe, A., DeBell, L., Sandbrook, C., Wich, S.A., Shutler, J.D., Myers-Smith, .IH., Varela, M. & Anderson, K. 2017. Location, location, location: considerations when using lightweight drones in challenging environments. Remote Sens Ecol Conserv:1–13

EC. 2013. Interpretation Manual of European Union Habitats EUR28

Egerton, S. 2014. Distribution mapping and health assessment of honeycomb worm Sabellaria alveolata reefs on Heysham Flat, Lancashire.

Eleftheriou, A. 2013. Methods for the Study of Marine Benthos - Fourth Edition

EMU. 2008. Area 401/2 Lowestoft extension Sabellaria spinulosa survey, Southampton

Fariñas-Franco, J.M., Pearce, B., Porter, J.S., Harries, D.B., Mair, J.M., Woolmer, A.S. & Sanderson, W.G. 2014. Marine Strategy Framework Directive Indicators for Biogenic Reefs formed by Modiolus modiolus, Mytilus edulis and Sabellaria spinulosa Part 1 : Defining and validating the indicators.

Foster-Smith, R. & Hendrick, V. 2003. Sabellaria spinulosa reef in the Wash and North Norfolk cSAC and its approaches: Part III summary of kowledge, reccomended monitoring strategies and outstanding research requirments

Foster-Smith, R. & White, W. 2001. Sabellaria spinulosa reef in the Wash and North Norfolk Coast cSAC and its approaches: Part I, mapping techniques and ecological assessment

Frost, M. 2004. Recovery of a biodiversity action plan species in Northwest England: possible role of climate change, artificial habitat, and water quality amelioration. Mar Biol Assoc United Kingdom 16:57

George, C. & Warwick, R. 1985. Annual macrofauna production in a hard-bottom reef community. J Mar Biol Assoc UK 65

Germano, J.D., Rhoads, D.C., Valente, R.M., Carey, D. & Solan, M. 2011. The Use of Sediment Profile Imaging (Spi) for Environmental Impact Assessments and Monitoring Studies: Lessons Learned From the Past Four Decades. Oceanogr Mar Biol An Annu Rev 49:235–298

Gibb, N., Tillin, H., Pearce, B. & Tyler-Walters, H. 2014. Assessing the sensitivity of Sabellaria spinulosa reef biotopes to pressures associated with marine activities. JNCC Rep No 504:67. Joint Nature Conservation Committee (JNCC) Peterborough

Gitelson, A.A., Kaufman, Y.J., Stark, R. & Rundquist, D. 2002. Novel algorithms for remote estimation of vegetation fraction. Remote Sens Environ 80:76–87

Grave, S. de & Whitaker, A. 1997. The Occurrence of a Subtidal Sabellaria alveolata (L.) Reef off Wicklow Head, Irish Sea. Irish Nat J 25:416–418

Griffin, R., Robinson, G., West, A., Gloyne-Phillips, I. & Unsworth, R.F. 2016. Assessing Fish and Motile Fauna around Offshore Windfarms Using Stereo Baited Video (V Magar, Ed.). PLoS One 11:e0149701

Gruet, Y. 1971. Morphologie, croissance et faune associée des récifs de Sabellaria alveolata (Linné) de la Bernerie-en-Retz (Loire Atlantique). Tethys 3:321–380

Gruet, Y. 1972. Aspects morphologiques et dynamiques de constructions de l’Annelide polychete Sabellaria alveolata (Linne). Rev des Trav l’Institut des Pêches Marit 36:131–161

Gruet, Y. 1982. Recherches sur l'écologie des "récifs" d'Hermelles édifiés par l'Annélide Polychète Sabellaria alveolata (LINNE). Diss.

Gruet, Y. 1986. Spatio-temporal Changes of Sabellarian Reefs Built by the Sedentary Polychaete Sabellaria alveolata (Linne). Mar Ecol 7:303–319

Gubbay, S. 2007. Defining and managing Sabellaria spinulosa reefs: Report of an inter-agency workshop 1-2 May, 2007. JNCC Rep No 405 44:22. Joint Nature Conservation

Committee (JNCC), Peterborough

Hendrick, V. 2007. An appraisal of Sabellaria spinulosa reefs in relation to their management and conservation. University of Newcastle Upon Tyne, Newcastle Upon Tyne

Hendrick, V.J. & Foster-Smith, R.L. 2006. *Sabellaria spinulosa* reef: a scoring system for evaluating “reefiness” in the context of the Habitats Directive. J Mar Biol Assoc UK 86:665

Henriques, V., Mendes, B., Pinheiro, L.M., Gonçalves, D. & Long, D. 2012. Recommended Operating Guidelines (ROG) for sidescan sonars. MESH Atlantic

Hill, J., Pearce, B., Georgiou, L., Pinnion, J. & Gallyot, J. 2010. Meeting the MPA Network Principle of Viability: feature specific recommendations for species and habitats of conservation importance. Natural England Commissioned Reports, Number 043

Hinder, S., Peters, J., Mccloskey, R., Callaway, R. & Unsworth, R. 2013. Investigating sensitive marine habitats around Wales using Stereo Baited Remote Underwater Video Systems (BRUVs)

Hitchin, R., Turner, J.A. & Verling, E. 2015. Epibiota Remote Monitoring from Digital Imagery: Operational Guidelines.

Holt, T.J., Rees, E.I., Hawkins, S.J. & Seed, R. 1998. An overview of dynamic and sensitivity characteristics for conservation management of marine SACs.

Holt, R. & Sanderson, B. 2001. Procedural Guideline No. 3-5. *Identifying biotopes using video recordings*. *In*: Marine Monitoring Handbook, ed. by J. Davies, J. Baxter, M. Bradley, D. Connor, J. Khan, E. Murray, W. Sanderson, C. Turnbull and M. Vincent, 241-251. Joint Nature Conservation Committee, Peterborough.

Hopkins, A. 2007. MESH Recommended operating guidelines (ROG) for swath bathymetry

IHO. 2008. IHO standards for hydrographic surveys

IMCA. 2015. Guidelines for the use of multibeam echosounders for offshore surveys

Jaud, M., Grasso, F., Dantec, N. Le, Verney, R., Delacourt, C., Ammann. J,, Deloffre. J, & Grandjean, P. 2016. Potential of UAVs for Monitoring Mudflat Morphodynamics (Application to the Seine Estuary, France). ISPRS Int J Geo-Information 5:50

Jenkins, C., Eggleton, J., Barry, J. & O'Conner, J. 2018. Advances in assessing *Sabellaria spinulosa* reefs for ongoing monitoring. Ecology and Evolution 2019:1-15.

Jenkins, C., Eggleton, J.D., Albrecht, J., Barry, J., Duncan, G., Golding, N. & O’Connor, J. 2015. North Norfolk Sandbank and Saturn Reef cSAC/SCI Management Investigation Report. JNCC/Cefas Partnersh Rep Ser Rep No 7:92

JNCC & NE. 2010. Special Area of Conservation (SAC): Haisborough , Hammond and Winterton SAC Selection Assessment.

JNCC. 2017. Supplementary advice on conservation objectives for North Norfold Sandbanks and Saturn Reef Special Area of Conservation. December 2017. JNCC.

Kakaes, K., Greenwood, F., Lippincott, M., Meier, P. & Wich, S. 2015. Drones and Aerial Observation : New Technologies for Property Rights, Human Rights, and Global Development

Kirtley, D. & Tanner, W. 1968. Sabellariid worms: builders of a major reef type. J Sediment Petrol 38:73–78

Koedsin, W., Intararuang, W., Ritchie, R.J. & Huete, A. 2016. An integrated field and remote sensing method for mapping seagrass species, cover, and biomass in Southern Thailand. Remote Sens 8

Kohler, K.E. & Gill, S.M. 2006. Coral Point Count with Excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology. Comput Geosci 32:1259–1269

Kröger, K. & Johnston, C. 2016. The UK Marine Biodiversity Monitoring Strategy

La Porta, B. & Nicoletti, L. 2009. Sabellaria alveolata (Linnaeus) reefs in the central Tyrrhenian Sea (Italy) and associated polychaete fauna. Zoosymposia2 2:527–536

Limpenny, D.S., Foster-Smith, R.L., Edwards, T.M., Hendrick, V.J., Diesing, M., Eggleton, J.D., Meadows, W.J., Crutchfield, Z., Pfeifer, S. & Reach, I,S, 2010. Best methods for identifying and evaluating Sabellaria spinulosa and cobble reef. Aggregate Levy Sustainability Fund (ALSF) Project Ref No MAL0008:149, Peterborough

Mackie, A.S.Y., James, C.J.W., Rees, E.I.S., Darbyshire, T., Philpott, S.L., Mortimer, K., Jenkins, G.O. & Morando, A. 2003. Outer Bristol Channel Marine Habitat Study. The National Museum of Wales & NERC (British Geological Survey)

Martignac, F., Daroux, A., Bagliniere, J., Ombredane, D. & Guillard, J. 2015. The use of acoustic cameras in shallow waters: New hydroacoustic tools for monitoring migratory fish population. A review of DIDSON technology. Fish Fish 16:486–510

Mason, C. 2016. NMBAQC's Best Practice Guidance – Particle Size Analysis (PSA) for Supporting Biological Analysis

Mcintosh, W.C. 1922. A Monograph Of The British Marine Annelids. Ray Soc 4:170–209

McIlwaine, P., Brown, L. & Eggett, A. 013 – 2017. No. 13 – CEND11/16 Cruise Report: North Norfolk Sandbanks and Saturn Reef, Inner Dowsing, Race Bank and North Ridge and Haisborough, Hammond and Winterton cSAC/SCI Monitoring Survey 2016 Cruise Report, ISSN 2051-6711

Meadows, B., Limpenny, D., Eggleton, J. & Foster-Smith, B. 2006. Case Study: Optimal detection and identification of biogenic structures using side scan sonar. MESH Case history on the application of habitat mapping.

Mercer, T. 2013. Intertidal SAC monitoring Pen Llŷn a'r Sarnau SAC July 2012

Mercer, T. 2016. Intertidal monitoring, Pen Llŷn a ' r Sarnau SAC August 2013

MESL. 2012. Thanet offshore wind farm: A post-construction monitoring survey of benthic resources. Marine Ecological Surveys Limited, Peterborough, Haskoning UK Ltd acting on behalf of Vattenfall

Mettam, C., Connelly, M. & White, S. 1989. Distribution of subtidal benthos associated with sediments.

Moore, J. 2009. Intertidal SAC monitoring, Cardigan Bay SAC, May 2007

Moore, J. 2010. Intertidal SAC monitoring Cardigan Bay SAC May 2008NE & CCW. 2009. The Severn Estuary / Môr Hafren European Marine Site

Noble-James, T., Jesus, A. & Fionnuala, M. 2017. Monitoring guidance for marine benthic habitats. JNCC Rep No: 598:119

Noernberg, M.A., Fournier, J., Dubois, S. & Populus, J. 2010. Using airborne laser altimetry to estimate Sabellaria alveolata (Polychaeta: Sabellariidae) reefs vo lume in tidal flat environments. Estuar Coast Shelf Sci 90:93–102

Natural Resources Wales. 2019. Marine ecology datasets for marine developments and activities: Marine ecology data owned or recommended by NRW and how to access it. Natural Resources Wales, Bangor

Ocean Ecology Limited. 2015. Intertidal Characterisation and WFD Sampling Report Tidal Lagoon Cardiff – 2016.

Ocean Ecology Limited. 2016a. Sabellaria alveolata site characterisation surveys: Port and Newton Beach reefs UAV extent mapping.

Ocean Ecology Limited (2016b) Invertebrate Bird Prey Sampling to Inform Individual-Based Modelling of Protected Bird Species – Autumn 2015 & Spring 2016

Ocean Ecology Limited (2016c) Review of the suitability of UAV survey methods for detection of accretion of fine sediments – Tidal Lagoon Swansea Bay

OSPAR. 2003. Criteria for the Identification of Species and Habitats in need of Protection and their Method of Application (The Texel-Faial Criteria).

OSPAR. 2008. Case reports for the OSPAR list of threatened and/or declining species and habitats.

OSPAR. 2013. Background document on Sabellaria spinulosa reefs. OSPAR Comm:1–25

Pante, E. & Dustan, P. 2012. Getting to the Point: Accuracy of Point Count in Monitoring Ecosystem Change. J Mar Biol 2012:1–7

Pawlik, J.R. 1988. Larval settlement and metamorphosis of sabellariid polychaetes, with special reference *to Phragmatopoma lapidosa*, a reef-building species, and *Sabellaria floridensis*, a non-gregarious species. Bulletin of Marine Science, 43(1), pp.41-60

Pearce, B. 2014. The ecology of Sabellaria spinulosa reefs. Plymouth University

Pearce, B., Fariñas-Franco, J.M., Wilson, C., Pitts, J., DeBurgh, A. & Somerfield, .PJ. 2014. Repeated mapping of reefs constructed by Sabellaria spinulosa Leuckart 1849 at an offshore wind farm site. Cont Shelf Res 83:3–13

Pearce, B., Hil,l J., Grubb, L., & Harper, G. 2011a. Impacts of Marine Aggregate Dredging on Adjacent Sabellaria spinulosa Aggregations and other benthic fauna.

Pearce, B., Hill, J.M., Wilson, C., Griffin, R., Earnshaw, S. & Pitts, J. 2011b. Sabellaria spinulosa Reef Ecology and Ecosystem Services. The Crown Estate

Pearce, B., Taylor, J., Seiderer, L. 2007. Recoverability of Sabellaria spinulosa Following Aggregate Extraction. Project No. MAL0027. Marine Ecological Surveys Ltd, Bath

Peters, J.R., McCloskey, R.M., Hinder, S.L. & Unsworth, R.K.F. 2015. Motile fauna of sub-tidal Zostera marina meadows in England and Wales. Mar Biodivers 45:647–654

Plets, R., Dix, J. & Bates, R. 2013. Marine Geophysics Data Acquisition, Processing and Interpretation: Guidance Notes.

Populus, J. & Perrot, T. 2007. MESH Recommended operating guidelines (ROG) for single-beam echosounder surveying.

Porras, R., Bataller, J. V., Murgui, E. & Torregrosa, M.T. 1996. Trophic structure and community composition of polychaetes inhabiting some Sabellaria alveolata (L.) reefs along the Valencia Gulf Coast, Western Mediterranean. Mar Ecol 17:583–602

Pratt, L. 2016. To what extent is the distribution of Zostera noltii in South and West Wales changing ? Proj Seagrass, Sustain Places Res Inst:1–79

Quian, P.Y. 1999. Larval settlement of polychaetes. Reproductive Strategies and Developmental Patterns in Annelids. Springer Netherlands., pp. 239-253

Roberts, G., Edwards, N., Neachtain, A., Richardson, H. & Watt, C. 2016. Core reef approach to Sabellaria spinulosa reef management in The Wash and North Norfolk Coast SAC and The Wash approaches. Natural England Research Reports, Number 065.

Robinson, K., Ramsay, K., Wilson, J., Mackie, A., Wheeler, A., O'Beirn, F., Lindenbaum, C., van Landeghem, K., McBreen, F. & Mitchell, N. 2007. Habmap : habitat mapping for conservation and management of the southern Irish Sea. Countryside Council for Wales (CCW), Bangor

Saunders, G., Bedford, G.S., Trendall, J. R. & Sotheran, I. 2011. Guidance on survey and monitoring in relation to marine renewables deployments in Scotland. Volume 5. Benthic Habitats. Unpublished draft report to Scottish Natural Heritage and Marine Scotland (Chapter 9).

Schneider, C.A., Rasband, W.S. & Eliceiri, K.W. 2012. NIH Image to ImageJ: 25 years of image analysis. Nat Methods 9:671–675

Schultz, S.T., Kruschel, C., Bakran-Petricioli, T. & Petricioli, D. 2015. Error, power, and blind sentinels: The statistics of seagrass monitoring. PLoS One 10:1–32

Slater, E.J. 2013. Resilience of Sabellaria alveolata reefs. Bangor University Masters Thesis, 61 pp.

Solan, M., Germano, J.D., Rhoads, D.C., Smith, C., Michaud, E., Parry, D., Wenzhöfer, F., Kennedy, B., Henriques, C., Battle, E., Carey, D., Iocco, L., Valente, R., Watson, J. & Rosenberg, R. 2003. Towards a greater understanding of pattern, scale and process in marine benthic systems: A picture is worth a thousand worms. J Exp Mar Bio Ecol 285–286:313–338

Stewart-Oaten, A., Murdoch, W. & Parker, K. 1986. Environmental impact assessment:

“Pseudoreplication” in time? Ecology 67:929–940

Sutherland, W. 1996. Ecological Census Techniques a handbook, Second

Tabugo, S.R.M., Manzanares, D.L. & Malawani, A.D. 2016. Coral reef assessment and monitoring made easy using Coral Point Count with Excel extensions (CPCe) software in Calangahan , Lugait , Misamis Oriental , Philippines. 6:21–30

Tillin, H. & Jackson, A. 2015. Sabellaria alveolata reefs on sand-abraded eulittoral rock. In Tyler-Walters, H. and Hiscock, K. (eds). Marine Life Information Network: Biology and Sensitivity Key Information Reviews

Tillin, H. & Tyler-Walters, H. 2014. Assessing the sensitivity of subtidal sedimentary habitats to pressures associated with marine activities. Phase 2 Report – Literature review and sensitivity assessments for ecological groups for circalittoral and offshore Level 5 biotopes. JNCC Report No. 512B, 260 pp

TLSB. 2017. Tidal Lagoon Swansea Bay Adaptive Environmental Management Plan

Turner, J.A., Hitchin, R., Verling, E. & van Rein, H. 2016. Epibiota remote monitoring from digital imagery: Interpretation guidelines. NMBAQC

UKBAP. 2007. Habitat Action Plan: Sabellaria spinulosa Reefs.

Underwood, A.J. 1992. Beyond BACI - The detection of einvornmental impacts on poulations in the real, but variable, world. J Exp Mar Bio Ecol 161:145–178

Underwood, A.J. & Chapman, M.G. 2013. Design and Analysis in Benthic Surveys in Environmental Sampling. In: Methods for the Study of Marine Benthos, Fourth. John Wiley & Sons, Ltd, p 1–45

Unicomarine. 1998. Results of the biological sampling of the areas around the deep water approach channel to Harwich and Felixtowe Docks: 1992 and 1996.

Unsworth, R.K.F., Peters, J.R., McCloskey, R.M. & Hinder, S.L. 2014. Optimising stereo baited underwater video for sampling fish and invertebrates in temperate coastal habitats. Estuar Coast Shelf Sci 150:281–287

Vorberg, R. 2000. Effects of shrimp fisheries on reefs of Sabellaria spinulosa (Polychaeta). ICES J Mar Sci 57:1416–1420

Wang, C-K. & Philpot, W.D. 2007. Using airborne bathymetric lidar to detect bottom type variation in shallow waters. Remote Sensing of the Environment 106:123–135

Ware, J. 2015. A study of the physical and biological characteristics of Sabellaria alveolata reefs in Swansea Bay; does varying “reefiness” and benthic diversity influence bird activity? Swansea University

Ware, S.J. & Kenny, A.J. 2011. Guidelines for the Conduct of Benthic Studies at Marine Aggregate Extraction Sites (2nd Edition). Marine Aggregate Levy Sustainability Fund, 82pp. ISBN: 978 0 907545 70 5

Wells, E. 2013. The National Marine Biological Analytical Quality Control Scheme Macroalgae and Seagrass % Cover Component Report

Wells, R.M.G. 1970. The feeding biology of *Sabellaria*. Tane, 16, 131-134

West, A., Durell, S. & Gray, C. 2006. Severn Estuary Bird Food Monitoring. Phase 1

West, A., McGrorty, S., Caldow, R., Durell, S., Yates, M., Stillman, R., CEH. 2004. Sampling Macro-Invertebrates On Intertidal Flats To Determine The Potential Food Supply For Waders. NERC/Centre Ecolgy Hydrol Rep:19

Wilson, D. P., 1968. The settlement behaviour of the larvae of *Sabellaria alveolata* (L.). Journal of the Marine Biological Association of the United Kingdom, 48(02), 387-435

Wilson, D.P. 1970. Larvae of *Sabellaria spinulosa* and their settlement behaviour. J Mar Biol Assoc UK 50: 33-52

Wilson D. 1971. Sabellaria colonies at Duckpool, North Cornwall, 1961-1970. J Mar Biol Assoc UK 51(03):509–580

Wilson, D.P. 1974. Sabellaria colonies at Duckpool, North Cornwall, 1971–1972, with a note for May 1973. J Mar Biol Assoc United Kingdom 54:393

Wyn, G., Brazier, P., Birch, K., Bunker, A., Cooke, A., Jones, M. & Lough, N. 2006. CCW Handbook for Marine Intertidal Phase 1 Biotope Mapping Survey

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