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The Status of *Sabellaria spinulosa* Reef off the Moray Firth and Aberdeenshire Coasts and Guidance for Conservation of the Species off the Scottish East Coast

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This report presents the results of marine and freshwater scientific work carried out for Marine Scotland under external commission.

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Pelagica Limited

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This report was commissioned by the ScotMER Forum: Marion Harrald at Marine Scotland Science, Janelle Braithwaite and John Mouat at Marine Scotland, Fiona Manson and Flora Kent at Scottish Natural Heritage, and Becky Hitchin and Joey O'Connor at the Joint Nature Conservation Committee. The input of the Project Steering Group together with Ben James (SNH) to earlier drafts of this report have improved the text considerably and their assistance in the interpretation and application of the reefiness assessments, and wider policy implications of this work, have been invaluable.

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Executive summary

Sabellaria spinulosa is a gregarious tube-dwelling marine polychaete, which can form extensive reef habitats that have been identified as a priority for protection under the OSPAR Convention for the Protection of the Marine Environment of the North East Atlantic and Annex I of the Habitats Directive. Until recently there was little evidence that these habitats occurred in Scottish waters. However, *S. spinulosa* aggregations with reef-like properties have recently been observed in seabed imagery collected through a variety of sources from the east coast of Scotland. Video footage, still images and ROV clips collected from five such sites were analysed comprehensively to determine the status of the *S. spinulosa* habitats by applying existing 'reefiness' criteria. Four of the five sites were found to support significant areas of reef, with the best examples being located at the Rattray Head and Southern Trench study sites. A new and unique *S. spinulosa* reef habitat sub-type was identified at the fifth site surveyed during an Oceana research cruise, which supported a diverse reef community. *S. spinulosa* aggregations in this area are limited in their extent by the available substrate, with well-developed reef 'bommies' occurring on isolated cobbles and boulders in an otherwise fairly featureless soft bottom habitat. Recommendations regarding the conservation and management of *S. spinulosa* reefs in Scotland as well as more general modifications to existing reefiness assessment criteria are proposed.

Introduction

Sabellaria spinulosa reefs have been identified as a priority habitat for conservation at both a European and a National level, most notably through the OSPAR Convention for the Protection of the Marine Environment of the North East Atlantic, and the UK transpositions of the Habitats Directive (*Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora*). *S. spinulosa* reefs are afforded protection through their inclusion as features of Marine Protected Areas (MPAs) though that protection applies to the reefs that it creates, and not to the species itself. Despite the high conservation status of this reef habitat, the definition of what constitutes a ‘reef’ remains a topic of much discussion. Each policy or piece of legislation that identifies *S. spinulosa* reef as a conservation priority either has its own description of what constitutes a reef, or refers directly to those of preceding legislation, but these are all relatively imprecise, referring for example to ‘topographically distinct’ and ‘extensive’ structures.

In 2006, a scientific paper was published proposing a framework for assessing the relative ‘reefiness’ of structures formed by *Sabellaria spinulosa* in an effort to standardise the assessment and identification of reef features (Hendrick and Foster-Smith 2006). The framework proposed by the authors combined scores based on physical reef attributes (e.g. elevation, patchiness and extent) with biological reef attributes (e.g. worm density and supported biodiversity) as well as longevity and temporal stability, to produce an overall reefiness score. In 2007 this approach was refined further through an inter-agency workshop, where Statutory Nature Conservation Bodies (SNCBs) and invited experts discussed and decided upon thresholds for key physical reef attributes that could be used more widely for management purposes. In the resulting report a classification schema for *S. spinulosa* reefs was presented (Gubbay 2007), whereby *S. spinulosa* structures are classified as ‘Not Reef’ or as having ‘Low’, ‘Medium’ or ‘High’ reefiness based on their elevation, patchiness and extent. This schema has now been widely adopted into casework and protected site management throughout the UK. This schema was, however, developed based on what was known in 2007 about *S. spinulosa* reefs, primarily from the Wash, areas offshore of Norfolk and the eastern English Channel, and the applicability of the schema to Scottish *S. spinulosa* habitats has yet to be fully evaluated. The reefiness matrix was always intended to be a starting point from which to develop a robust reefiness classification following further research, but the classification has not so far been significantly updated or revisited.

The Scottish Government has set a target for the equivalent of 100% of the country's gross annual electricity consumption to be met from renewable energy sources by 2020 (SG 2017) and in order to meet this target new offshore renewable energy developments will be required. However, the targets for renewable energy must be met sustainably and with due consideration to the environment in which the developments will be placed. *Sabellaria spinulosa* favours turbid waters with a good supply of sand, and the reefs that it creates have a tendency to co-occur with areas suitable for renewable energy developments. It is imperative then, given Scottish Government targets, that the relative conservation importance of *S. spinulosa* reefs is assessed with specific reference to Scottish waters. *S. spinulosa* reefs are not known to be as prevalent, or at least have not been as well documented, in Scottish waters, and as Scottish waters appear to be at the northern extremity of the natural range of *S. spinulosa*, it is possible that any reefs present may differ somewhat from their English counterparts. Furthermore, since there has historically been less anthropogenic activity in areas suitable for *S. spinulosa* reef development in Scottish waters, the lack of data pertaining to their presence cannot be taken as proof of their historic extent or presence in Scottish waters as they are likely to have been under-recorded.

The ecological, and hence conservation, significance of any one *S. spinulosa* reef should be evaluated relative to other reefs known to occur in the same geographical region, as well as those occurring across the habitats range. Nevertheless, *S. spinulosa* settle preferentially on existing reefs (Pawlik 1992; Wilson 1970) and so the ecological significance of smaller or patchier reefs may be elevated in the absence of any nearby larger reefs, particularly where there is potential for the reefs to have been damaged historically by activities such as bottom trawling. Like other biogenic reefs, *S. spinulosa* support a diverse suite of marine life and are thought to play an important role in supporting marine food webs (Pearce 2008; Pearce, Hill *et al.* 2011b). It is likely therefore that these habitats provide important ecological functions that warrant protection from offshore development and other activities that may impact the habitat.

Policy background

The Scottish Energy Strategy (SG 2017) sets out the Scottish Government's vision for the energy sector up to 2050, with an interim goal of producing the equivalent of 50% of the energy required for the country's heat, transport and electricity from renewable sources. Scotland's electricity supply is already largely decarbonised and it is anticipated that 100% of its electricity demand will come from renewable sources by 2020. Legally-binding EU renewable energy and energy efficiency targets have played a defining role in stimulating the expansion of the renewable energy sector in Scotland, backed-up by the country's desire for sustainable economic growth, as highlighted in Scotland's National Performance Framework[1] and the Scottish Government's recent consultation on a new round of Offshore Wind Development. The UK's exit from the EU could have a significant bearing on the energy sector and the impacts are likely to be amplified in Scotland because of the important role that energy plays in the country's economy. It is likely therefore that in the coming months and years, there will be ever more pressure to increase onshore, inshore and offshore renewable energy production to meet Scotland's environmental commitments whilst also contributing to the energy and economic security of the country.

The environmental benefits of renewable energy are of considerable global importance, but there nevertheless exists a concurrent environmental cost, and the Scottish Government must ensure that growth in this sector does not compromise other environmental commitments. The interaction between development licensing and consenting, and European sites is carefully managed through the Habitats Regulations Assessment (HRA) process, but developers must also consider any species and habitats with potential conservation significance during the Environmental Impact Assessment (EIA) process. In Scotland, this includes all Priority Marine Features (PMFs) as well as any species or habitats included in the Birds and Habitats Directives and their transpositions, domestic legislation, Biodiversity Action Plans (BAPs) and the OSPAR list of threatened or declining habitats and species. Although it is imperative that the interaction between protected species and habitats and developments is managed carefully, it is also important to note that the interaction may not always be negative and can often be managed effectively. For example, the interaction

[1] https://nationalperformance.gov.scot/

between *S. spinulosa* reefs and aggregate extraction activities has been managed effectively in England for many years through the use of exclusion zones (see for example Pearce, Taylor *et al.* 2007). Micro siting wind turbines to avoid areas of core reef has also been shown to be an effective tool for managing the interaction between *S. spinulosa* reefs and offshore wind farms and the exclusion or reduction in some fishing practices mean that such developments may ultimately provide some protection for these habitats (Pearce, Fariñas-Franco *et al.* 2014).

Conservation designations

Sabellaria spinulosa reefs are not currently listed as a PMF in Scotland but they have been identified as a priority habitat of conservation interest or importance in legislative and policy instruments that are applicable to the whole of the UK as well as those that apply only to Scotland as summarised in **Table 1.**

European Habitats Directive (92/43/EEC)

Sabellaria spinulosa reefs qualify under Annex I of the Habitats Directive where they are a type of "1170 Reef" to be protected by a network of Special Areas of Conservation (SACs). The Interpretation Manual of European Union Habitats (EC 2013) specifically lists *Sabellaria* reefs of the sublittoral North Sea "*Sabellaria*-Riff des Sublittorals der Nordsee", though they may also be protected by virtue of their occurrence in broader physiographic habitats listed under the directive such as "Estuaries" and "Large Shallow Inlets and Bays".

OSPAR Convention

Sabellaria spinulosa reefs were added to the "OSPAR list of threatened and / or declining habitats" based on the Texel-Faial criteria for identification of species and habitats in need of protection (OSPAR 2003; OSPAR 2008). Sensitivity, rarity, ecological significance and decline were cited as reasons for the inclusion with information also provided on threat (OSPAR 2010; OSPAR 2013). The habitat is considered under threat and / or in decline in OSPAR Regions II (Greater North Sea) and III (Celtic Seas).

Table 1

Table summarising the main legislative/policy instruments that can be used to protect *Sabellaria spinulosa* reefs on a UK-wide basis and in Scotland specifically.

Legislative / Policy Instrument	Mechanism for Legal Protection	Inclusion in Strategies / Targets
UK-Wide		
UK transpositions of the European Habitats Directive 1992 (inshore and offshore; oil and gas)	Special Areas of Conservation (SACs)	
OSPAR Convention 1992	OSPAR Marine Protected Areas OSPAR Threatened and Declining Species list	
Marine Strategy Framework Directive 2008		"Good Environmental Status" (GES) targets (particularly under D1 and D6)
Marine and Coastal Access Act 2009	Marine Conservations Zones (MCZs)	
Scotland		
Nature Conservation (Scotland) Act 2004		Scotland's Biodiversity Strategy
Marine (Scotland) Act 2010	Nature Conservation Marine Protected Areas (NC MPAs)	

Marine Strategy Framework Directive (2008/56/EC)

As *S. spinulosa* reefs are identified under European legislation and policy (specifically the EU Habitats Directive and OSPAR), they are considered a Special Habitat as defined in Table 1 of Annex III of the Marine Strategy Framework Directive (MSFD). Biogenic reefs formed by *S. spinulosa* have also been identified as suitable Good Environmental Status (GES) targets for Descriptors 1 (Biological diversity) and 6 (D6 - Seafloor integrity) under the MSFD (Cochrane, Connor *et al.* 2010).

Marine and Coastal Access Act (2009)

The Marine and Coastal Access Act (2009) (MACA) commits the UK to an ambitious approach to managing the marine environment that includes MPA designation and protection through Marine Conservation Zones (MCZs) that will exist alongside European Marine Sites (SACs and SPAs), to form a UK marine protected areas network. *S. spinulosa* reef is identified as a priority habitat for protection in the "Ecological Network Guidance", both as the Broad Scale Habitat 'Subtidal biogenic reefs A5.6' and as the Habitat Feature of Conservation Importance (FOCI) 'Ross worm (*Sabellaria spinulosa*) reefs' (NE and JNCC 2009).

MACA also includes provisions for a Marine Planning system, inshore fisheries reform, streamlining of licensing, establishment of a Marine Management Organisation (for England and UK matters) and coastal access provisions. MACA provides executive devolution to Scottish Ministers of the new marine planning and conservation powers and as such MCZs will not be designated in Scottish waters but the UK and Scottish Ministers have interlocking responsibilities under MACA and both parties have contributed to the Marine Planning Statement (MPS) which aims to integrate marine management throughout the UK.

Nature Conservation (Scotland) Act 2004

Under the Nature Conservation (Scotland) Act 2004, public bodies in Scotland have a duty to further the conservation of biodiversity. This biodiversity duty applies to nature everywhere and not just in specific protected sites. The Scottish Biodiversity List (SW 2005) was published to satisfy Section 2(4) of The Nature

Conservation (Scotland) Act 2004. However, the list does not include *S. spinulosa*.

Marine (Scotland) Act 2010 and the National Marine Plan

The Marine (Scotland) Act 2010 gives Scotland devolved powers to manage their seas and the activities occurring within them, and introduces a duty to protect and enhance the marine environment. The Marine (Scotland) Act and the UK Marine and Coastal Access Act (MACA) include powers for Scottish Ministers to designate Nature Conservation Marine Protected Areas (NCMPAs) as part of a range of measures to manage and protect Scotland's inshore and offshore regions[2]. The process will also help Scotland meet its contribution to UK commitments under international conventions and legislation such as the Convention on Biological Diversity (CBD), and the OSPAR Convention for an ecologically coherent network of MPAs. The Scottish MPA network includes Special Areas of Conservation (SACs) and Special protection Areas (SPAs), collectively known as European Marine Sites (EMS), which were designated under the Habitats and Birds Directives, and now also includes NCMPAs.

To help create NCMPA designations in Scottish Seas, Scottish Natural Heritage (SNH) and the Joint Nature Conservation Committee (JNCC) identified a list of Priority Marine Features (PMFs) (Tyler-Walters, James *et al.* 2016), which included features identified in other conservation legislation, but which was refined to reflect the species and habitats that are of the greatest significance to Scotland in terms of their prevalence in Scottish seas, their ecological functions and their vulnerability to disturbance. Those PMFs for which NCMPAs were considered an appropriate conservation measure were then included in a list of MPA search features (Tyler-Walters, James *et al.* 2012), and it is this list of species and habitats that were considered for inclusion as designated features in Scotland's NCMPAs. PMFs also benefit from some protection out with the MPA network with the National Marine Plan stating that "Development and use of the marine environment must not result in significant impact on the national status of Priority Marine Features" (SG 2015). *S. spinulosa* reefs are not specifically listed as an MPA Search Feature or as a PMF (Tyler-Walters, James *et al.* 2016).

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2 http://marine.gov.scot/information/scottish-assessment-areas-scottish-marine-regions-and-offshore-marine-regions-scottish

Aims and objectives

Survey work carried out between 2011 and 2017 off the east coast of Scotland has revealed the presence of a number of areas supporting *Sabellaria spinulosa* aggregations that have features in common with reefs as defined by JNCC (Gubbay 2007).

The main objective of this research is to assess the status of the *S. spinulosa* aggregations observed on the east coast of Scotland and to establish whether or not they would be classified as reef using the JNCC reefiness criteria (Gubbay 2007). The suitability of the reefiness criteria for use in Scotland will be assessed and guidance will be given regarding the future conservation of this habitat in Scotland.

The aims of this project are as follows:

- Review current management guidance relating to *Sabellaria spinulosa* reefs throughout its European range.
- Assess the relative 'reefiness' of *S. spinulosa* aggregations recently discovered off the east coast of Scotland.
- Explore the influence that *S. spinulosa* reefs are having on epifaunal communities on the east coast of Scotland.
- Examine the suitability of existing 'reefiness' guidance for use in a Scottish context.
- Make recommendations for the future conservation of *S. spinulosa* reefs in Scottish waters.

Materials and methods

Literature and guidance review

A desk based review was carried out on guidance documents, protected site management and monitoring documents and scientific literature relating to *Sabellaria spinulosa* reefs in Scotland, the rest of the UK and Europe. The desk review was undertaken with a view to defining and comparing the ways in which *S. spinulosa* reefs are managed and protected throughout their known geographic extent. Information on individual reef characteristics were also extracted wherever possible, to provide some broader spatial context to Scottish *S. spinulosa* reefs.

In order to build a picture of the conservation status and process applied to *S. spinulosa* across Europe, individuals working with these habitats were contacted directly at the following organisations;

- IFREMER - The Institut Français de Recherche pour l'Exploitation de la Mer, France.
- Wageningen University and Research, Holland.
- DELTARES, Delft, Holland.
- Ecosub, Holland.
- North Sea Foundation, Holland.
- Marine Science Service, Dassendorf, Germany.
- Ghent University, Belgium.
- University of Rome Tor Vergata, Italy.
- ISPRA – Institute of Environmental protection and Research, Italy.

Site descriptions and management plans were obtained for each of the UK sites designated to protect *S. spinulosa* reefs, identified through the relevant authority websites and through direct consultations with the relevant authorities.

Study Sites

Five study sites were selected for inclusion in this study of *S. spinulosa* reefs on the east coast of Scotland. Two of the survey areas, the Southern Trench and an area south east of Peterhead (hereafter referred to as the Oceana site) were sampled during the course of two separate research cruises and the remaining three were sampled as part of the Environmental Impact Assessment (EIA) work associated with commercial developments (EMU 2012; NorthConnect 2018). In all cases *Sabellaria spinulosa* aggregations that possessed some features in common with the Annex I protected Reef habitat were detected during the course of the surveys. The locations of the five study sites and the sampling locations included in this investigation are summarised in **Figure 1**. The details of the surveys are further summarised overleaf in **Table 2.**

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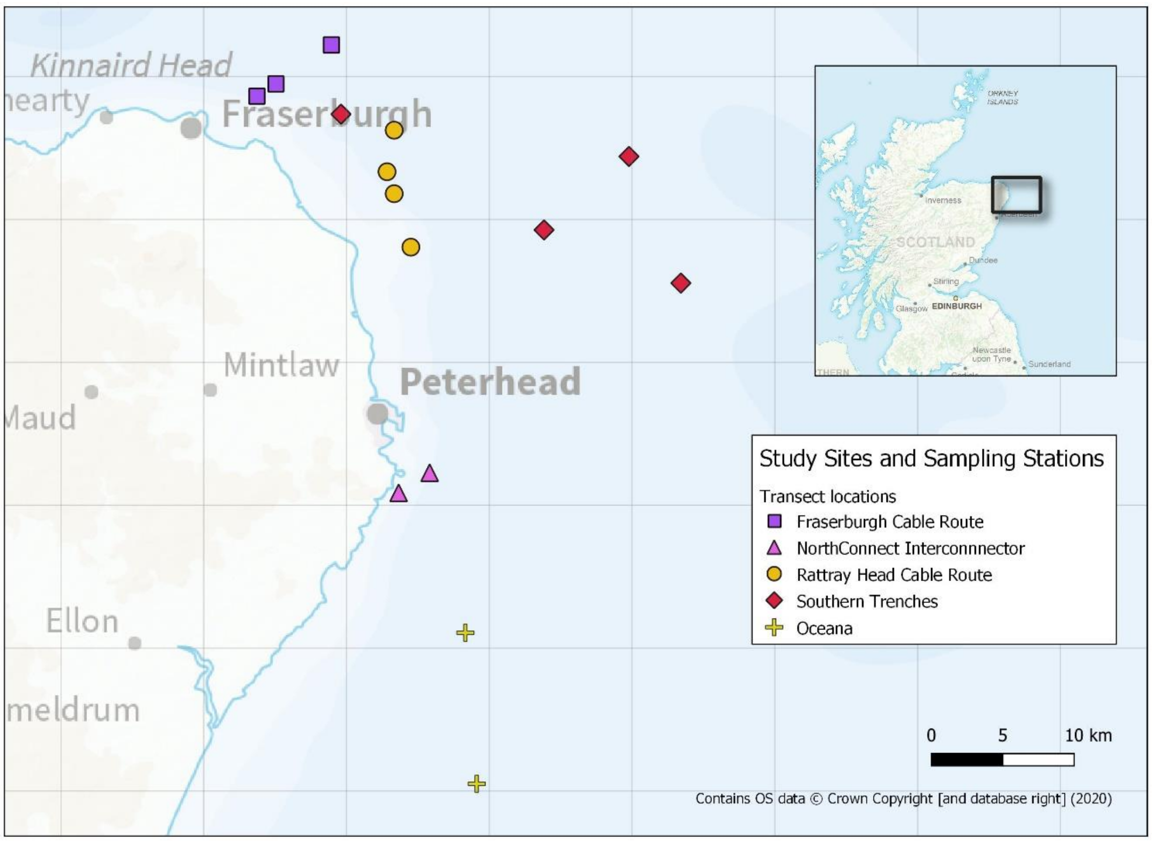

Figure 1: Distribution of study sites and sampling stations selected for use in the assessment of *Sabellaria spinulosa* reefs on the east coast of Scotland.

Table 2

Summary of the study sites and samples selected for use in the assessment of *Sabellaria spinulosa* reefs on the east coast of Scotland.

Study Site	Year	Organisation	Samples	Survey Focus
Fraserburgh	2011	EMU / MORL[3]	4 video tows (two on reef and two off) and corresponding still images	EIA transmission infrastructure corridor, associated with the three proposed Moray Firth Round 3 wind farm sites
Rattray Head	2011	EMU/ MORL	4 video tows (two on reef and two off) and corresponding still images	EIA transmission infrastructure corridor, associated with the three proposed Moray Firth Round 3 wind farm sites
NorthConnect[4] Interconnector	2016	MMT / NorthConnect	2 x 250 m video tows and corresponding still images covering both reef and non-reef habitats	To inform cable routing and EIA for electricity interconnector cable between Scotland and Norway
Southern Trench	2015	MSS / SNH	4 video tows (two on reef and two off) and corresponding still images	Research cruise add-on making use of weather down-time
Oceana	2017	Oceana	ROV clips and corresponding screen grabs from 36 stations centered on discrete *S. spinulosa* aggregations	Research cruise

[3] Moray Offshore Renewables Limited (MORL) is now referred to as Moray Offshore Windfarm (East) Limited (MOWEL). Any reference in this report to MORL now refers to MOWEL".

[4] Areas of *Sabellaria spinulosa* reef were avoided by at least 50 m throughout the North Connect cable route.

Sample selection

A large number of video tows and still images were made available for use in this study and so an initial selection was made based on the quality of the footage (Turner, Hitchin *et al.* 2016) and the presence or absence of *Sabellaria spinulosa* reef-like aggregations. For most areas, it was possible to select two tows of moderate quality footage on and off areas identified as potentially being *S. spinulosa* reefs. Along the NorthConnect interconnector, only two longer tows were collected and both of these intersected areas of possible reef as well as non-reef habitats. In this case, comparisons were made between reef and non-reef areas within the same tow. At the Oceana site, only ROV clips were available, alongside screenshots taken from the same.

Underwater imagery analysis

Video tow analysis

All video and imagery analysis was undertaken in accordance with current National Marine Biological Analytical Quality Control Scheme (NMBAQC) guidance on remote monitoring of epibiota from digital imagery (Parry 2015; Turner, Hitchin *et al.* 2016) as well as, where feasible, methodologies recently devised by Cefas and JNCC specifically for the assessment of *Sabellaria spinulosa* habitats (Jenkins, Eggleton *et al.* 2015; Jenkins, Eggleton *et al.* 2018). Assessors used two high resolution screens in order to review video footage, any associated images and data sheets simultaneously. VLC Media Player software was used to review video footage, which permits fast forwarding, rewinding, pausing, advancing by frame and looping. An initial, quick run through of each video (at no more than four times normal viewing speed) was undertaken to confirm that they were of adequate quality to perform detailed analysis, taking into account camera distance from the seabed, angle of the field of view, speed of the camera over ground, turbidity, lighting quality and presence or absence of scale. The level of analysis undertaken on each video tow broadly followed the criteria set out by Turner, Hitchin *et al.* (2016)[5] (**Table 3**).

[5] Note there were some instances where the quality of the video footage fell short of that normally required for the analysis undertaken but in the interest of having sufficient data to compare methodologies, analysis was undertaken nonetheless.

Table 3

Summary of video quality criteria (Turner, Hitchin *et al.* 2016).

Quality Category	Proportion of Tow Negatively Affected	Organism Enumeration	Biotopes
Excellent	<5%	Quantitative	Level 5
Good	5-20%	Quantitative	Level 5
Poor	20-50%	Qualitative	Level 3
Very Poor	50-80%	Not Recommended	Level 2/3
Zero	>80%	Data Not Usable	Data Not Usable

The time taken for the camera to be towed approximately five meters was then estimated from the length of the transect (m) and duration of the video (minutes) and the video files were then split automatically into equal five metre segments using Bandicut software[6]. Segmenting the video footage to 5 m sections is recommended by both Turner, Hitchin *et al.* (2016) and Jenkins, Eggleton *et al.* (2018) as segments are considered to be approximately equal to an area of 5 m^2 which is the minimum area that should considered as a new biotope (Turner, Hitchin *et al.* 2016).

Segments were named and stored according the following convention

SITE_TRANSECT_1_of_41, SITE_TRANSECT_2_of_41 etc.

Each segment was then viewed and analysed as if it were a separate sample, pausing, looping and rewinding as many times as required, in order to record the following;

- Presence / absence of *S. spinulosa.*
- Percentage cover of *S. spinulosa.*
- Estimated maximum height of *S. spinulosa* aggregations.
- Abundance and identification of associated fauna.

An 8 x 10 grid was overlaid on the video to improve the accuracy of percentage cover estimates and to account for variations in the camera's field of view during

[6] Jenkins, Eggleton et al (2018) used five second video segments as a proxy for 5 metre segments but their recommendation is to use five metre segments (Chris Jenkins Personal Communication).

video tows. Where video quality allowed, percentage cover was calculated by taking the average for each new area of seabed observed within each segment (in accordance with the methodology proposed by Jenkins, Eggleton *et al.* 2018). Where the quality of video footage made this impossible, percentage cover was estimated for the entirety of each 5 m segment (in accordance with Turner, Hitchin *et al.* 2016).

Maximum tube elevation was estimated using laser scaling systems. Where no lasers had been used or were not visible, visual estimates were made using fauna as a guide. Even where laser scaling was visible, the estimation of maximum tube height proved to be very subjective, in-part because it was not always clear whether *S. spinulosa* was growing upwards from the seafloor, or whether it was growing up from a boulder or cobble. A visual guide to reef heights was therefore developed to improve consistency. This has been provided in **Appendix 1** for reference.

Epifauna were quantified according to the Marine Nature Conservation Review (MNCR) SACFOR abundance scale (S = Superabundant, A = Abundant, C = Common, F = Frequent, O = Occasional, R = Rare), in accordance with the list of example fauna for each category recommended by Turner, Hitchin *et al.* (2016). A full list of the taxa recorded during this analysis and the SACFOR category used is provided in **Appendix 2.** Biotope classifications were also assigned at this time to areas > 5 m at an appropriate level of detail, dependent upon video quality and sparsity of epifauna (Parry 2015). Biotopes were recorded using the MNCR classification scheme (Connor et al. 2004).

In contrast to the methodology proposed by Jenkins *et al.* (2018), all of the video footage was analysed to the highest level of detail possible, regardless of the presence or absence of *S. spinulosa*. This facilitated a direct quantitative comparison between habitats as required by this study.

Still image analysis

All of the still images collected along the length of a video tow included in this study were analysed to obtain the same data as was extracted from the video tows. In addition still images from three supplementary areas from the NorthConnect Interconnector site were also included.

Individual fauna were identified to as accurate a taxonomic level as possible and then enumerated, whilst colonial species were recorded using the SACFOR scale[7]. A 7 x 9 grid was overlaid on the still images to improve the accuracy of percentage cover estimates. Maximum tube elevation was estimated using laser scaling systems. Where lasers had not been used or were not visible, visual estimates were made using fauna as a guide.

ROV clips

The ROV clips and their associated screen grabs were all focused on discrete *S. spinulosa* aggregations but also covered the surrounding sedimentary habitats. To facilitate comparisons between the *S. spinulosa* aggregations and the surrounding substrates, the two habitats were analysed separately as sub-samples of the same image. The resulting data should therefore, be regarded as semi-quantitative. Analysis was otherwise comparable to that of still images and video tows.

Quality assurance

Quality assurance of the image analysis was undertaken by a senior marine ecologist and followed the NMBAQC recommendations (Turner, Hitchin *et al.* 2016). A minimum of 10% of the video tows and still images were re-analysed during quality checks, as well as the full digital reference collection. Species names were then checked and standardised against the World Register of Marine Species[8] (WoRMS).

Reefiness assessment at the Sample Level

Once all of the data had successfully passed QC checks, it was analysed for *S. spinulosa* reefiness. Percentage cover and tube height were combined to assign reef status for each segment, based upon the Gubbay reefiness matrix outlined in **Table 4**.

[7] *http://jncc.defra.gov.uk/page-2684*
[8] http://www.marinespecies.org/

Table 4

Gubbay *Sabellaria spinulosa* reef structure matrix (as modified by Collins (2010)).

Reef Structure Matrix			Elevation (cm) <2 Not a reef	2-5 Low	5-10 Medium	>10 High
% Cover	<10%	Not a reef	Not a reef	Not a reef	Not a reef	Not a 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

Percentage cover was then used to identify areas that would be considered reef using the broad reef definitions included in the OSPAR List of Threatened and / or Declining Species (OSPAR 2010; OSPAR 2013), which states 30% cover is considered reef in mixed sedimentary habitats and 50% cover on rock habitats. A reefiness assessment based on the scoring system proposed by Hendrick and Foster-Smith (2006) was also carried out using percentage cover, height and biotopes assigned to each video tow segment and still image as outlined in **Table 5**.

Table 5

Hendrick *Sabellaria spinulosa* reefiness assessment modified from the scoring system proposed by Hendrick and Foster-Smith (2006).

	Low (0)	Medium (50)	High (100)
Elevation (Height (cm))	0-12.5	12.6-17.5	≥17.6
Consolidation (% Cover)	0-37.5	37.6-52.5	≥52.6
Biotope	Other biotopes	CR.MCR.CSab.Sspi	SS.SBR.PoR.SspiMx
Average Score	0-25	26-75	≥76

Statistical analysis

Data transformation

As a means of facilitating statistical analysis of the data recorded from video tow segments, still images and ROV clips, data were first transformed from their SACFOR codes to an abundance based on the % Cover scale for crust/meadow species[9] (**Table 6**). This scale was chosen as it would not require further transformation prior to statistical analysis, and because it gave colonial species equal weighting with mobile fauna.

Table 6

Summary of the scale used to transform SACFOR data to abundances on a uniform scale to facilitate quantitative statistical analysis of the data. The abundance scale is based on the % cover scale for Crust/Meadow species[6].

SACFOR	Abundance
S	80
A	40
C	20
F	10
O	5
R	1

Multivariate analysis

Multivariate analyses were carried out using the PRIMER v7 software package (Clarke and Gorley 2015; Clarke, Gorley *et al.* 2014); the following routines were employed in this investigation:

Multidimensional scaling (MDS) ordination

This technique allows the construction of a 'map' or configuration of the samples in multidimensional space. This configuration attempts to position the samples as accurately as possible within a multidimensional space to reflect the similarity between the samples. For example, if sample one has a greater similarity to

[9] https://mhc.jncc.gov.uk/media/1009/sacfor.pdf

sample two than it does to sample three then sample one will be positioned more closely to sample two than it is to sample three. This ‘map’ of the relative similarities between samples is then plotted in two dimensions. It is important to remember that this two-dimensional plot is a representation of a multidimensional picture. When large numbers of samples are analysed, or datasets that include samples that are very different from one another, the accuracy of the two-dimensional plot may be reduced. A measure of the accuracy of the two-dimensional representation (stress) is given on the MDS plot. Stress values <0.1 correspond to a good ordination; values <0.2 give a useful two-dimensional picture but one should not place too much reliance on the fine details of the plot; stress values >0.3 indicates that the samples are close to being positioned in an arbitrary manner and should not be regarded as necessarily similar to one another, particularly in the upper half of this range.

The analysis of similarities (ANOSIM) routine

Analogous to a traditional ANOVA (analysis of variance) test, ANOSIM tests for differences between groups of samples, where the groups have been determined according to some a-priori factor such as substrate type, depth zone, biotope class etc. Variants include the 1-way and 2-way tests. A 1-way ANOSIM tests a single factor (e.g. depth zone OR substrate); a 2-way ANOSIM tests two factors (e.g. depth zone AND substrate). In this study 2-way ANOSIM tests were carried out using the factors study site and reefiness class to explore the correlation between the communities observed and the different *S. spinulosa* reef classes they were assigned to. The abundance of *S. spinulosa* itself was removed from all such analysis.

Similarity of percentages (SIMPER) routine

The SIMPER routine allows for comparisons to be made between groups of samples. Species responsible for the dissimilarity between the two groups are listed in decreasing order of importance in the discrimination between the two groups. This routine also provides information on which species are responsible for the within-group similarity and their relative contributions to the same.

Diversity indices

A number of community descriptors and diversity indices have been calculated as a means of investigating the influence of *Sabellaria spinulosa* reefs on marine fauna. These indices were calculated using the DIVERSE routine in the PRIMER v7 software package (Clarke and Gorley 2015; Clarke, Gorley *et al.* 2014) and included the number of taxa (S), abundance of taxa (N), Margalef's Richness (d'), Pielou's Evenness (J'), Shannon Wieners Index H(Loge) and Simpson's Diversity (1-λ).

Reefiness assessment at the site level

Patchiness scores

The observations of *S. spinulosa* in each video segment were used to assign a patchiness score in accordance with the methods proposed by Jenkins, Eggleton *et al.* (2018) using R[10]. Further details of the patchiness methodology are provided in **Appendix 3**, along with the R Script used.

Reef extent

Estimates of reef extent were obtained from habitat maps contained in the associated reports wherever these were available. An approximation of the reef extent observed in each video tow was also made based on an assumed tow width of 1 m and tow length of 5 m for each segment examined. The extents were then combined with sample level reefiness scores to present combined tow and site scores based on the Gubbay reefiness criteria (Gubbay 2007) as summarised in **Table 7**.

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[10] https://www.r-project.org/

Table 7

Sabellaria spinulosa reefiness criteria proposed by Gubbay (2007).

Characteristic	Not a Reef	Low	Medium	High
Elevation (height cm)	<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

No habitat maps or acoustic data were made available to the project for the Oceana cruise and since the ROV clips represent discrete observations rather than a continuous tow, a full reefiness assessment was not possible for this dataset.

Results 1: *Sabellaria spinulosa* reef assessment and management across the UK and Europe

The reef habitat created by *Sabellaria spinulosa* has been identified as a priority for conservation efforts in European and National legislation, but despite this, the definition of what constitutes a 'reef' remains somewhat uncertain. *S. spinulosa* is a gregarious polychaete, which is found in numerous different growth forms ranging from solitary individuals and small clumps to low level veneers and reef. However, the boundary between the different growth types, their ecological significance and the conditions which lead to the development of one growth type over another remains largely unknown.

S. spinulosa reefs fall under the broad 'Reef 1170' definition provided by the Habitats Directive as well as the more specific *S. spinulosa* reef definition provided by the OSPAR list of threatened and declining species as detailed in **Box 1**. These habitat definitions are relatively ambiguous and difficult to apply to standard survey data.

In 2006, a scientific paper was published proposing a framework for assessing the relative reefiness of structures formed by *S.spinulosa* in an effort to standardise the assessment and identification of reef features (Hendrick and Foster-Smith 2006). The framework proposed by the authors, combined scores based on physical reef attributes (e.g. elevation, patchiness and extent) with biological reef attributes (e.g. worm density and supported biodiversity) as well as longevity and temporal stability, to produce an overall reefiness score (**Box 2**). In 2007, this approach was refined further through an inter-agency workshop, where Statutory Nature Conservation Bodies (SNCBs) and invited experts discussed and decided upon, thresholds for key physical reef attributes that could be used more widely for management purposes. In the resulting report (Gubbay 2007) a classification schema for *S. spinulosa* reefs is presented. *S. spinulosa* structures are classified as 'Not Reef' or as having 'Low', 'Medium' or 'High' reefiness based on their elevation, patchiness and extent (**Box 2**). The comparative ease of applying these criteria to standard survey data has made it very popular and it is now widely applied in both commercial and research settings throughout the UK.

Box 1

Definitions encompassing *Sabellaria spinulosa* Reef.

Definition of 'reefs' from the revised Habitats Directive Interpretation Manual (CEC 2007)

"Reefs can be either **biogenic concretions** or of **geogenic origin**. They are **hard compact substrata** on solid and soft bottoms, which **arise from the sea floor** in the **sublittoral and littoral zone.** Reefs may support a zonation of benthic communities of algae and animal species as well as concretions and corallogenic concretions."

Definition of* S. spinulosa *reef from the OSPAR list of Threatened and Declining Species (OSPAR 2008)

"The tube-building polychaete *Sabellaria spinulosa* can form dense aggregations on mixed substrata and on rocky habitats. In mixed substrata habitats, comprised variously of sand, gravel, pebble and cobble, the *Sabellaria* covers 30% or more of the substrata and needs to be sufficiently thick and persistent to support an associated epibiota community which is distinct from surrounding habitats. On rocky habitats of bedrock, boulder and cobble, the *Sabellaria* covers 50% or more of the rock and may form a crust or be thicker in structure. In some areas, these two variations of reef type may grade into each other. *Sabellaria* reefs have been recorded in depths between 10-50 m Below Chart Datum (BCD) or more. The reef infauna typically comprises polychaete species such as *Protodorvillea kefersteini, Scoloplos armiger, Harmothoe* spp., *Mediomastus fragilis, Lanice conchilega* and cirratulids together with the bivalves *Abra alba* and *Nucula* spp. and tube-building amphipods such as *Ampelisca* spp. Epifauna comprise calcareous tubeworms, pycnogonids, hermit crabs, amphipods, hydroids, bryozoans, sponges and ascidians. *S. spinulosa* reefs are often found in areas with quite high levels of natural sediment disturbance; in some areas of reef, individual clumps of *Sabellaria* may periodically break down and rebuild following storm events. *S. spinulosa* reefs have been recorded from all European coasts except the Baltic Sea, Skagerrak and Kattegat. Areas of dead *Sabellaria* reef indicate the site supported reef habitat in the past and should be reported as this habitat type."

Box 2

Sabellaria spinulosa ‘Reefiness’ Assessment Frameworks.

Proposed scoring system for a variety of *Sabellaria spinulosa* reef characteristics (Hendrick and Foster-Smith 2006)

		Characteristic score		
		Low	Medium	High
		0	50	100
A.	*Elevation score.*			
	Average tube height	~10 cm	~15 cm	~20 cm
	Maximum tube height	~15 cm	~20 cm	~30 cm
	Indications from remote sensing	Undetectable	Colony produces an indistinct image	Colony produces a distinct image
B.	*Sediment consolidation score.*			
	Percentage cover of substratum by consolidated *Sabellaria* tubes	~30% cover	~45% cover	~60% cover
	Degree of consolidation	Consolidation of sediment primarily an encrusting veneer of *Sabellaria* tubes, little concretion of substratum	Sediment consolidation by upright *Sabellaria* tubes, some concretion of underlying substratum	Substratum well consolidated by intertwined matrix of *Sabellaria* tubes
C.	*Area score.*			
	Extent of total area	Area ~600 m^2	Area ~900 m^2	Area ~1200 m^2
	Extent of core area	Area ~200 m^2	Area ~350 m^2	Area ~500 m^2
	Extent of peripheral area	Area ~500 m^2	Area ~750 m^2	Area ~1000 m^2
D.	*Patchiness score.*			
	Percentage cover of consolidated tubes within overall spatial extent of reef	~10% cover	~20% cover	~30% cover
E.	Sabellaria spinulosa *density score.*			
	Average density of *S. spinulosa* (/m^2)	~800 individuals	~1500 individuals	~3000 individuals
	Maximum density (/m^2)	~500 individuals	~1700 individuals	~3500 individuals
F.	*Biodiversity score.*			
	Margalef’s species richness	~5.0	~6.5	~8.0
	Shannon diversity index	~2.5	~2.7	~3.0
	Simpson’s diversity index	~0.85	~0.87	~0.90
G.	*Biotope score.*			
	MNCR biotope code (see Table 3)	Other biotopes	CR.MCR.CSab.Sspi	SS.SBR.PoR.SspiMx
H.	*Longevity score.*	No evidence for longevity of colony	Evidence of dense *S. spinulosa* aggregations found *repeatedly* but not *persistently* over time	Evidence of dense *S. spinulosa* aggregations found *persistently* over time

Reefiness thresholds for *Sabellaria spinulosa* proposed by JNCC following an inter-agency workshop (Gubbay 2007)

Characteristic	Not a Reef	“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

Whilst the reefiness criteria proposed by Gubbay (2007) are now widely applied throughout the UK, the way in which the criteria are applied does differ subtly between organisations and individuals, highlighting the ambiguity that remains in this assessment method. In 2010, Paul Collins developed a reef structure matrix based on the reefiness criteria proposed by Gubbay (2007) as a means of standardising the way in which the reefiness characteristics are combined (**Table 4**). In contrast, the Eastern Inshore Fisheries and Conservation Authority (EIFCA) assign reefiness values based on the lowest 'reefiness' level across the three characteristics (Hormbrey 2018). There are also differences in the final interpretation of the reefiness categories with many considering that only reefs categorised as 'high' reefiness are of significant conservation value, or equivalent to the reef habitat covered by Annex I of the Habitats Directive. Others consider any reefs falling outside the 'Not a Reef' category as having potential conservation significance, as was initially intended by the workshop participants (Gubbay 2007). There is as yet no consensus of how to combine the overall reef extent with the other reefiness characteristics included in the criteria proposed by Gubbay (2007).

Whilst the Gubbay criteria deals with the physical character of the *S. spinulosa* fairly well, it does not consider the persistence of the reef, which is explicitly mentioned in the OSPAR definition (OSPAR 2008). In 2007 work on the, then proposed, Thanet offshore windfarm site revealed a number of *S. spinulosa* reefs that presented a relatively unique management challenge, since the reefs were not afforded the protection of a Marine Protected Area (MPA). Working with Natural England, Pearce developed the concept of preserving a core area of reef, defined in this instance as a high quality area of reef that was present over the course of several baseline and pre-construction surveys, whilst allowing lower quality areas of reef to be damaged during the construction of the windfarm (MESL 2007; Pearce, Fariñas-Franco *et al.* 2014). It was postulated that by preserving a core area of reef, but allowing the windfarm to be constructed that the longevity of the reef might ultimately be enhanced through a reduction in bottom trawling effort. This management method proved to be successful and ultimately the reef extent increased in the years after the windfarm was constructed (Pearce, Fariñas-Franco *et al.* 2014) .

The concept of 'core reef' was developed and refined by Natural England and in 2016, they began to apply this approach to the management of the reefs in the

Wash and North Norfolk Coast SAC (Roberts, Edwards *et al.* 2016). This approach works particularly well in the Wash as it allows the regulators to identify the areas of reef from which bottom fishing activities should be excluded, whilst stopping short of banning all bottom fishing throughout the SAC. The core reef approach assigns a reef index value based on the ratio of the number of times an area has been surveyed compared to the number of times reef has been found, with areas where reef is consistently found receiving a higher reef index. For any given area to qualify as core reef it must have a reef index value >1. The application of this approach is, however, somewhat limited in most instances since it is entirely reliant on time-series data from the reef in question and also assumes a degree of confidence that the same areas of reef have been surveyed, which isn't always achievable.

The most recent development in *S. spinulosa* reef assessment comes from Cefas and JNCC, and was developed through the course of an investigation into the North Norfolk Sandbank and Saturn Reef SCI (Jenkins, Eggleton *et al.* 2015; Jenkins, Eggleton *et al.* 2018). The methods proposed by Jenkins, Eggleton *et al.* (2018) were designed to increase the accuracy and repeatability of standard NMBAQC video analysis methodologies (Turner, Hitchin *et al.* 2016); essentially requiring the analyst to consider each new area of seabed, within each video segment, separately, for *S. spinulosa* height and % cover, averaging the data for each segment at the end. The second aspect of the methodology proposed by Jenkins, Eggleton *et al.* (2018) is the development of a more complex measure of 'patchiness'. In their publication they define 'patchiness' as:

"*A value to represent the propensity of* S. *spinulosa reef to be clustered together rather than to grow uniformly and randomly everywhere"*"

The authors have developed a routine within the statistical software package 'R' that calculates patchiness based on the presence or absence of *S. spinulosa* within each video segment, taking into consideration the height of the reef. Therefore, if reef is observed in numerous adjacent segments the patchiness score will be higher than if there were fewer adjacent observations (Jenkins, Eggleton *et al.* 2018).

The aforementioned guidance and assessment methodologies have recently been used to develop a guidance document for characterising and monitoring *S.*

spinulosa reefs in Wales (NRW 2019). However, the guidance document itself does not present any new methods of assessment that have not already been considered. It does, however, suggest some additional reef indicators that could be included in condition monitoring surveys, including larval concentrations, concentrations of suspended particulate matter and measures of associated communities.

Sabellaria spinulosa reefs have been identified as a priority for conservation at a European level, but despite this, there exists no formal guidance or management documents for this habitat outside the UK. The reefiness scoring system proposed by Hendrick and Foster-Smith (2006) and the criteria proposed by Gubbay (2007) form the basis for investigations of reef habitats across Europe but neither is currently applied in a standardised way. Similarly, it is hoped that the core reef approach can be applied to the Brown Bank reefs in Holland and this is informing current data collection efforts (Garcia et al., 2019; van der Reijden et al., 2019).

Results 2: *Sabellaria spinulosa* reefiness assessments at the sample level

Video tow data

Analyses of the video tow data and subsequent analyses of reefiness using criteria proposed by Gubbay (2007), Hendrick and Foster-Smith (2006) and OSPAR (2013) revealed that the best examples of reef occurred in the study sites at Rattray Head and Southern Trench (**Table 8**). At both of these sites, the two transects that covered reef-like habitats were classified as reef along much of their length using all three reefiness criteria. The reefiness criteria were less consistent in their determination of reef in the tows incorporating reef-like habitats at the Fraserburgh and NorthConnect sites. Here, the proportion of the tow that was classified as reef ranged from 26% to 43% according to the Gubbay criteria and 0% to 4% according to the OSPAR criteria. All tows were identified as being reef along their full length using the Hendrick criteria since no criteria were proposed by the authors for what would not constitute reef, in essence this means that the ‘low reef’ class encompasses habitats that would not constitute reef or indeed contain any *S. spinulosa* at all.

Table 8

Summary of the *Sabellaria spinulosa* reefiness assessment carried out on 5 m video tow segments collected from four sites on the east coast of Scotland between 2011 and 2016. The reefiness assessment is based on the Gubbay (or JNCC) reefiness criteria as adapted by Collins (2010), the OSPAR reef criteria (30% coverage on mixed sediments and 50% coverage on rock) and the reefiness scoring system outlined by Hendrick and Foster-Smith (2006). Also shown is the presence or absence (P = 1, A = 0) of *S. spinulosa* in each tow. Tows highlighted in bold font were chosen because they intersect reef-like habitats.

Study Site	Tow	P/A	Gubbay Reefiness (% of Tow)				OSPAR (% of Tow)	Hendrick Reefiness (% of Tow)		
			Not a Reef	Low	Med	High	Reef	Low	Med	High
Fraserburgh	34	0	100	0	0	0	0	100	0	0
	36 (1)	**1**	**63**	**26**	**7**	**5**	**4**	**93**	**7**	**0**
	36 (2)	**1**	**68**	**21**	**4**	**7**	**4**	**88**	**9**	**4**
	37	0	100	0	0	0	0	100	0	0
Rattray Head	**43 (1)**	**1**	**0**	**58**	**43**	**0**	**100**	**0**	**100**	**0**
	45	**1**	**9**	**49**	**43**	**0**	**89**	**11**	**89**	**0**
	46	1	90	0	2	8	8	89	9	2
	48	1	92	0	8	0	3	100	0	0
NorthConnect	**T04**	**1**	**58**	**33**	**10**	**0**	**3**	**66**	**34**	**0**
	T05	**1**	**53**	**21**	**19**	**7**	**0**	**92**	**8**	**0**
Southern Trench	**STTR01**	**1**	**0**	**26**	**74**	**0**	**100**	**0**	**100**	**0**
	STTR04	**1**	**18**	**79**	**4**	**0**	**58**	**0**	**100**	**0**
	STTR06	1	100	0	0	0	0	100	0	0
	STTR10	1	100	0	0	0	0	100	0	0

Still image and ROV clip data

Analyses of the data extracted from still images and ROV clips, and subsequent analyses of reefiness using criteria proposed by Gubbay (2007), Hendrick and Foster-Smith (2006) and OSPAR (2013) confirmed the results of the video analysis. The best examples of reef again were identified in the study sites at Rattray Head and Southern Trench (**Table 9**), as well the Oceana site, with much lower proportions of reef being recorded at the Fraserburgh and NorthConnect sites.

Table 9

Summary of the *Sabellaria spinulosa* reefiness assessment carried out on still images and ROV clips collected from five sites on the east coast of Scotland between 2011 and 2017. The reefiness assessment is based on the Gubbay (or JNCC) reefiness criteria as adapted by Collins (2010), the OSPAR reef criteria (30% coverage on mixed sediments and 50% coverage on rock) and the reefiness scoring system outlined by Hendrick and Foster-Smith (2006). Also shown is the presence or absence (P/A) of *S. spinulosa* in each image. Stations highlighted in bold font were chosen because they intersect reef-like habitats.

Study Site	Station	n	P/A	Gubbay Reefiness (% of images)				OSPAR (% of images)	Hendrick Reefiness (% of images)		
				Not a Reef	Low	Med	High	Reef	Low	Med	High
Fraserburgh	34	10	1	100	0	0	0	0	100	0	0
	36 (1)	**13**	**1**	**54**	**31**	**8**	**8**	**23**	**92**	**8**	**0**
	36 (2)	**9**	**1**	**22**	**0**	**56**	**22**	**23**	**78**	**22**	**0**
	37	14	0	100	0	0	0	0	100	0	0
Rattray Head	**43 (1)**	**11**	**1**	**0**	**64**	**36**	**0**	**100**	**0**	**100**	**0**
	45	**14**	**1**	**0**	**50**	**50**	**0**	**100**	**0**	**100**	**0**
	46	9	1	89	0	0	11	11	100	0	0
	48	10	1	90	0	10	0	0	100	0	0
NorthConnect	**T04**	**11**	**1**	**55**	**36**	**9**	**0**	**9**	**91**	**9**	**0**
	T05	**11**	**1**	**82**	**9**	**9**	**0**	**0**	**100**	**0**	**0**
	S01	4	0	100	0	0	0	0	100	0	0
	S02	**4**	**1**	**0**	**100**	**0**	**0**	**100**	**0**	**100**	**0**
	S03	4	0	100	0	0	0	0	100	0	0
Southern Trench	**STTR01**	**14**	**1**	**7**	**29**	**50**	**14**	**79**	**21**	**79**	**0**
	STTR04	**15**	**1**	**40**	**60**	**0**	**0**	**53**	**100**	**0**	**0**
	STTR06	10	1	100	0	0	0	0	100	0	0
	STTR10	12	1	100	0	0	0	0	100	0	0
Oceana	Off Reef	29	0	100	0	0	0	0	~	~	~
	On Reef	**29**	**1**	**0**	**34**	**55**	**10**	**90**	**~**	**~**	**~**

Results 3: Influence of *Sabellaria spinulosa* on Epifaunal Communities on the East Coast of Scotland

Data extracted from video tows, still images and ROV snapshots were all analysed to explore the influence of *Sabellaria spinulosa* on epifaunal communities on the east coast of Scotland. In addition, the degree to which the reefiness classes assigned to each video segment, still or ROV clip, correlated with patterns in the epifaunal communities was investigated. *S. spinulosa* abundance was removed from the data for all statistical analyses that follow since it is the associated fauna that is the focus of the analysis rather than the reef building species itself. Individual video segments were treated as separate samples in the statistical tests which could lead to issues with pseudoreplication. However, within the limits imposed by the semi-quantitative nature and highly variable quality of the underlying data, this is not considered to significantly undermine the exploratory power of the tests.

Video Tow Data

A total of 506 video segments were analysed from four sites on the east coast of Scotland, of which 40 were found to be afaunal and were excluded from subsequent statistical analyses. Figure 2 shows a non-parametric Multidimentional Scaling (nMDS) ordination of the epifaunal communities identified in each of the video segments, and the 'reefiness' categories assigned to them. These plots show that there is little separation between the epifaunal communities based on their relative reefiness, and we can assume from this that there is significant overlap between the communities associated with *S. spinulosa* aggregations and the surrounding sedimentary habitats in these areas.

A series of two-way ANOSIM tests carried out on the data confirm that whilst there are significant differences between the communities recorded at each of the study sites, the different reef classes do not generally support significantly different epifaunal communities (Table 10). The only exception to this was the presence / absence of *Sabellaria spinulosa*.

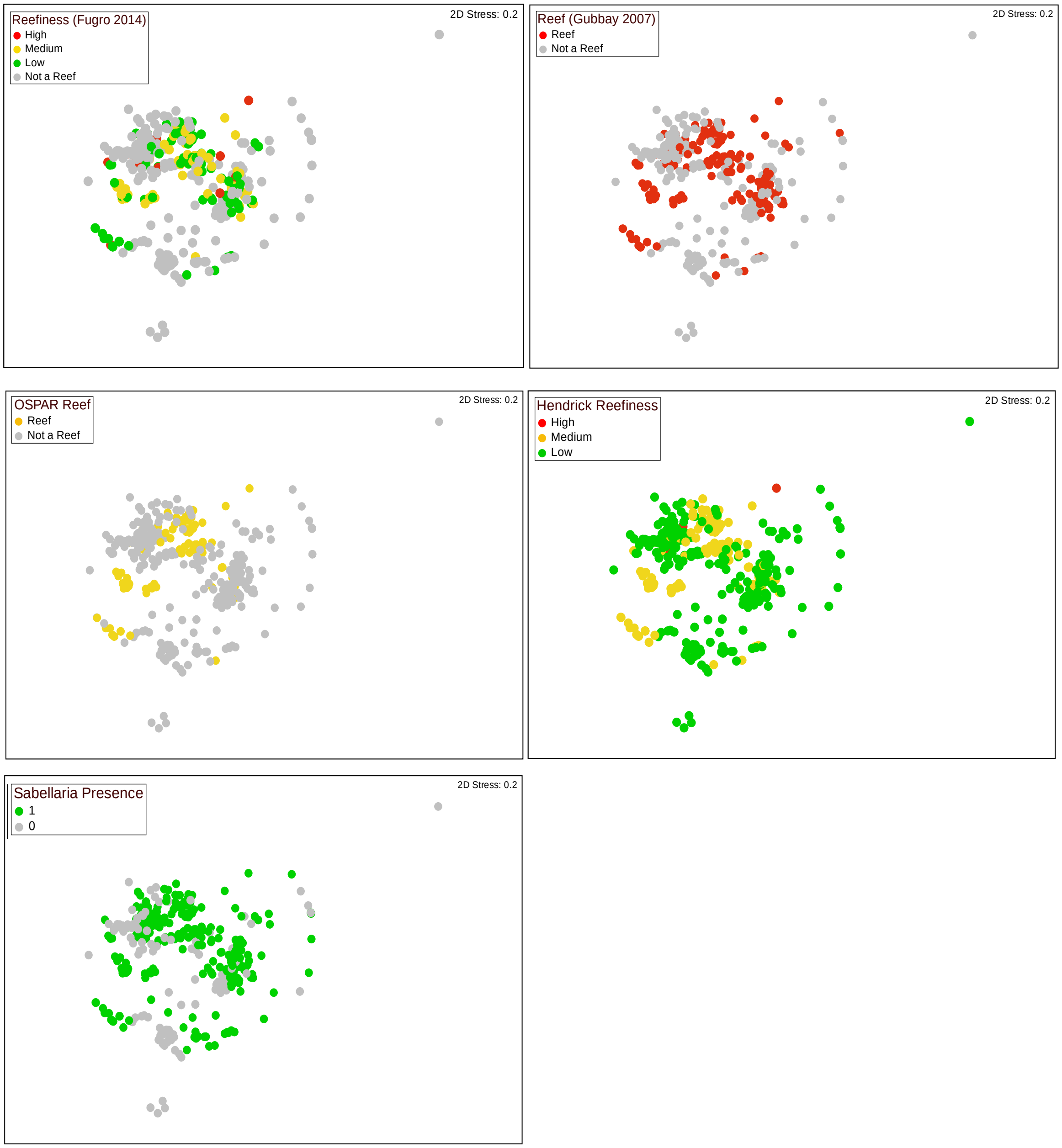

Figure 2:. A two-dimensional nMDS ordination based on the untransformed SACFOR abundance data (Table 6) extracted from video tow segments on the east coast of Scotland between 2011 and 2016. *Sabellaria spinulosa* abundance has been removed as well as any afaunal and outlying samples. The MDS plots are overlaid with the *Sabellaria spinulosa* reefiness classes as summarised in **Table 8** and presented in full in **Electronic Appendix 1**.

Table 10

Two-way crossed ANOSIM test results between study sites and the different *Sabellaria spinulosa* reefiness classes carried out on a Bray Curtis resemblance of untransformed, converted SACFOR abundance records from towed video footage collected from the east coast of Scotland between 2011 and 2016. Significant test results (at the 0.1% level) are highlighted in bold font.

	Study Sites (Across Reefiness Classes)		Reefiness Class (Across Study Sites)	
Reefiness Class	R	Sig Level	R	Sig Level
Gubbay Reefiness (Collins 2010)	**0.543**	**0.1**	-0.06	93.7
Reef vs Not Reef (Gubbay 2007)	**0.564**	**0.1**	0.059	0.6
OSPAR	**0.557**	**0.1**	0.096	9.6
Hendrick (2006)	**0.547**	**0.1**	-0.003	50
Sabellaria Presence	**0.509**	**0.1**	**0.382**	**0.1**

As the presence of *S. spinulosa* showed the only significant effect on the epifaunal communities, this relationship has been explored further by identifying the taxa that account for the dissimilarity between these communities at each of the study sites.

Table 11 shows that whilst the level of dissimilarity between communities associated with *S. spinulosa* and those not is consistently high, the effect on the epifauna is site specific.

An increase in the abundance of sea anemones (Order: Actiniaria) was observed in the presence of *S. spinulosa* at the Rattray Head and NorthConnect sites, whilst a reduction was observed in the presence of *S. spinulosa* at the Southern Trench site. It is likely that such differences are driven by the nature of the habitat in which the reefs have developed. Where *S. spinulosa* reefs develop on mixed sediments, they will invariably increase the abundance of sedentary epifauna by providing a hard surface for attachment that is otherwise not available. In areas with a ready supply of attachment surfaces, the reef itself may exclude some of these species, or simply be a less favourable site for attachment.

Table 11

Summary of taxa that contribute to the dissimilarity between epifaunal communities in which *Sabellaria spinulosa* was present and those in which it was absent at the four study sites examined on the east coast of Scotland. Also shown is the apparent effect of *S. spinulosa* presence on the abundance of individual taxa (reduction (-), increase (+), no change (~)). The SIMPER test was carried out on untransformed, converted SACFOR abundance records from video tow segments.

Fraserburgh

Average dissimilarity = 68.48

Taxon	Absent Av. Abund	Present Av. Abund	Effect	Contrib%	Cum.%
Spirobranchus	31.39	0	-	27.55	27.55
Ophiuroidea	26.46	25.92	-	22.09	49.64
Keel worms / barnacles	18.48	19.18	+	12.53	62.17
Echinus esculentus	8.86	7.76	-	8.53	70.70

Rattray Head

Average dissimilarity = 81.83

Taxon	Absent Av. Abund	Present Av. Abund	Effect	Contrib%	Cum.%
Keel worms / barnacles	3.08	17.14	+	18.12	18.12
Asterias rubens	16.92	8.57	-	17.83	35.95
Hydroid / bryozoan turf	0.21	9.63	+	10.64	46.60
Munida rugosa	0	8.45	+	9.60	56.20
Flustridae	7.18	2.40	-	7.37	63.56
Actiniaria	2.31	2.86	+	4.55	68.11
Phaeophyceae #2	3.59	0	-	3.63	71.74

NorthConnect

Average dissimilarity = 72.30

Taxon	Absent Av. Abund	Present. Av. Abund	Effect	Contrib%	Cum.%
Asterias rubens	9.09	28.65	+	29.37	29.37
Trisopterus luscus	7.27	7.03	-	12.79	42.15
Actiniaria	8.18	11.22	+	12.37	54.52
Asteroidea	5.45	3.11	-	7.51	62.03
Keel worms / barnacles	3.64	2.16	-	6.11	68.14
Flustra foliacea	2.91	1.04	-	5.63	73.77

Southern Trench

Average dissimilarity = 90.73

Taxon	Absent Av. Abund	Present. Av. Abund	Effect	Contrib%	Cum.%
Inachus	6.67	0.77	-	10.59	10.59
Spirobranchus	6.67	2.18	-	8.83	19.42
Actiniaria	6.67	1.92	-	7.88	27.31
Echinus esculentus	6.67	0.77	-	6.74	34.05
Ophiuroidea	0	9.87	+	6.66	40.71
Cancer pagurus	6.67	0.26	-	6.50	47.21
Chaetopterus variopedatus	3.33	1.67	-	6.45	53.66
Keel worms / barnacles	0	8.46	+	5.53	59.19
Galatheidae	3.33	0.38	-	5.37	64.57
Scaphopoda	1.67	1.09	-	5.10	69.67
Hydroid / bryozoan turf	1	0.42	-	4.15	73.82

Most taxa were observed both in the presence and absence of *S. spinulosa*, differing only in the relative abundance. However, one species, the rugose squat lobster, *Munida rugosa*, was only found in the presence of *S. spinulosa* at the Rattray Head site (at a mean abundance of ~ 0.5/m^2), where the best examples of reef were identified. This corresponds well with previous research undertaken by Pearce, Taylor *et al.* (2007), who found that the most developed reefs on the south coast of England were associated with high abundances of another small crevice dwelling crustacean, the porcelain crab, *Pisidia longicornis*. Noting that the abundance of small crevice dwelling fauna like *M. rugosa* is highly likely to be under-recorded in seabed imagery, compared to the grab samples that formed the basis of the study by Pearce, Taylor *et al.* (2007).

Further investigation of the influence of *S. spinulosa* on the epifaunal community revealed that the effects on diversity are also site specific (**Table 12**). For the most part, the presence of *S. spinulosa* was associated with an increase in the abundance and diversity of epifauna. At the Fraserburgh site, however, the reverse was true with a decrease in the abundance and diversity of epifauna. At this site the only community descriptors that increased (Pielou’s J’ and Simpson’s Diversity Index (1-λ)) are measures of the evenness or equitability of species within a community. This is, therefore, likely to be a reflection of the numerical dominance of the keel worm *Spirobranchus* in areas where *S. spinulosa* is absent as noted in the dissimilarity table for this site (**Table 11**).

Table 12

Summary of the average number of taxa (S), abundance of taxa (N), Margalef's Species Richness (d'), Pielou's Evenness (J'), Shannon's Diversity (H'(loge)) and Simpson's Diversity Index (1-λ) recorded from video tows at each of the four study sites where *Sabellaria spinulosa* was present (P) or absent (A). Also shown is the apparent effect of *S. spinulosa* presence on each of the community descriptors (reduction (-), increase (+), no change (~)).

		Fraserburgh	Rattray Head	NorthConnect	Southern Trench
S	A	5.49	4.1	5.36	4.0
	P	4.11	6.24	6.24	4.19
	Effect	-	+	+	+
N	A	115.59	42.85	43.63	43.0
	P	64.59	66.33	73.38	48.8
	Effect	-	+	+	+
d	A	0.95	0.82	1.22	1.09
	P	0.75	1.38	1.34	1.02
	Effect	-	+	+	+
J'	A	0.67	0.69	0.77	0.83
	P	0.82	0.86	0.72	0.76
	Effect	+	+	+	+
H'(loge)	A	1.13	0.86	1.14	0.94
	P	1.13	1.52	1.18	0.94
	Effect	~	+	+	~
1-λ	A	0.56	0.46	0.58	0.49
	P	0.63	0.75	0.62	0.49
	Effect	+	+	+	~

Data from the still images

A total of 175 still images were analysed from four sites on the east coast of Scotland, of which 15 were found to be afaunal and were excluded from subsequent statistical analyses.

Figure 3 shows an nMDS ordination of the epifaunal communities identified in each still image, and the 'reefiness' categories assigned to them. These plots show that there is little separation between the epifaunal communities based on their relative reefiness and, as was observed in the video data, there is likely to

be significant overlap between the communities associated with *S. spinulosa* aggregations and the surrounding sedimentary habitats in these areas.
In contrast to the communities recorded from the video footage, communities recorded from still images showed a significant degree of concordance with the different reef classes (**Table 13**), albeit with the coarser reef definitions driven mostly by % coverage.

Figure 3: A two-dimensional nMDS ordination for the untransformed SACFOR abundance data (Table 6) extracted from still images taken on the east coast of Scotland between 2011 and 2016. *Sabellaria spinulosa* abundance has been removed as well as any afaunal and outlying samples,

and samples have been grouped according to their *S. spinulosa* reefiness classes as summarised in **Table 9** and presented in full in **Electronic Appendix 2.**

Table 13

Two-way crossed ANOSIM test results between study sites and the different reefiness classes carried out on a Bray Curtis resemblance of untransformed, converted SACFOR abundance records from still images collected from the east coast of Scotland between 2011 and 2016. Significant test results (at the 0.1% level) are highlighted in bold font.

	Study Sites (Across Reefiness Classes)		Reefiness Class (Across Study Sites)	
Reefiness Class	R	Sig Level	R	Sig Level
Gubbay Reefiness (Collins 2010)	**0.651**	**0.1**	0.126	1
Reef vs Not Reef (Gubbay 2007)	**0.647**	**0.1**	**0.327**	**0.1**
OSPAR	**0.637**	**0.1**	**0.214**	**0.1**
Hendrick (2006)	**0.659**	**0.1**	**0.238**	**0.1**
Sabellaria Presence	**0.459**	**0.1**	0.157	3.4

In keeping with the video data, the still images show that the influence of *S. spinulosa* on community composition is site specific (**Table 14**). The reefs at Fraserburgh appear to have a slightly different influence on epifaunal communities to those studied at the other three sites with as many taxa occurring in reduced abundances as occur in increased abundance in the presence of the reef. At all three of the other sites, the taxa are generally present in higher abundances in association with the reef than they are in surrounding sediments.

Although there is significant overlap in the community compositions, a small number of taxa are present on the reefs that are not present in the surrounding substrates, including the rugose squat lobster, *M. rugosa* (present at a mean abundance of ~6 m^{-2} at Rattray Head and ~2 m^{-2} at Southern Trench), in keeping with the video results. Other taxa that appear to be exclusive to the reefs include the pink shrimp, *Pandalus montagui* (present at a mean abundance of ~6 m^{-2} at Rattray Head and ~12 m^{-2} at Southern Trench), erect bushy hydroids and the small ophiuroid, *Ophiactis balli*[11] (present at a mean abundance of ~6 m^{-2} at Southern Trench).

[11] Note that the identification of this species is not certain in the absence of a physical specimen or many clear images showing the brittle star test.

Table 14

Summary of taxa that contribute to the dissimilarity between epifaunal communities classified as 'Reef' (high, medium or low) and 'Not a Reef' in accordance with the criteria proposed by Gubbay (2007) at the four study sites examined on the east coast of Scotland. Also shown is the apparent effect of *S. spinulosa* reef presence on the abundance of individual taxa (reduction (-), increase (+), no change (~)). The SIMPER test was carried out on untransformed, converted SACFOR abundance records from still images.

Fraserburgh

Average dissimilarity = 65.85

Taxon	Not a Reef Av.Abund	Reef Av.Abund	Effect	Contrib%	Cum.%
Spirobranchus	47.58	14.62	+	22.25	22.25
Ophiocomina nigra	30.3	37.69	+	16.69	38.94
Hydroid / bryozoan turf	13.7	3.54	-	8.54	47.48
Echinus esculentus	4.24	9.23	+	7.3	54.79
Asteroidea	8.48	3.08	-	5.42	60.21
Ophiothrix fragilis	10.91	0	-	5.29	65.5
Alcyonium digitatum	4.24	6.92	+	3.72	69.22
Encrusting organism #3	5.79	2.08	-	3.71	72.93

Rattray Head

Average dissimilarity = 87.66

Taxon	Not a Reef Av.Abund	Reef Av.Abund	Effect	Contrib%	Cum.%
Asterias rubens	40	5.93	-	14.81	14.81
Spirobranchus	2.5	27.04	+	10.79	25.61
Erect bushy hydroid	0	17.78	+	6.97	32.57
Munida rugosa	0	15.56	+	6.61	39.18
Pandalus montagui	0	12.59	+	4.80	43.98
Asteroidea	8.33	2.96	-	3.97	47.95
Flustra foliacea	11.33	3.67	-	3.94	51.89
Gadidae	6.67	0	-	3.28	55.16
Erect branched hydroid	3.33	5.93	+	3.19	58.35
Gibbula	1.67	7.41	+	3.12	61.47
Actiniaria	2.5	5.93	+	2.83	64.30
Hydroid / bryozoan turf	5.92	10.37	+	2.62	66.91
Alcyonidium diaphanum	1.67	5.19	+	2.53	69.44
Chaetopterus variopedatus	0	6.67	+	2.51	71.95

NorthConnect

Average dissimilarity = 89.33

Taxon	Not a Reef Av.Abund	Reef Av.Abund	Effect	Contrib%	Cum.%
Asterias rubens	2.86	25.45	+	31.81	31.81
Actiniaria	5	10.91	+	18.67	50.48
Asteroidea	4.29	9.09	+	9.65	72.93
Gastropoda	2.86	6.36	+	12.8	63.28

Southern Trench

Average dissimilarity = 78.75

Taxon	Not a Reef Av.Abund	Reef Av.Abund	Effect	Contrib%	Cum.%
Pandalus montagui	2.14	16.36	+	9.14	9.14
Ophiocomina nigra	1.43	19.09	+	8.23	17.37
Spirobranchus	14.29	23.64	+	5.82	23.19
Solitary sea squirts	7.5	14.55	+	5.56	28.75
Chaetopterus variopedatus	9.29	5.45	-	5.48	34.23
Gastropoda	3.57	10	+	4.47	38.70
Ophiothrix fragilis	0	9.09	+	3.76	42.45
Munida rugosa	0	8.18	+	3.31	45.76
Pectinidae	5.71	2.73	-	3.10	48.86
Decapoda	2.86	5.45	+	3.07	51.93
Sabellidae	2.14	4.55	+	3.01	54.94
Ophiactis balli	0	6.36	+	2.99	57.93
Erect branched hydroid	2.14	4.55	+	2.64	60.57
Caridea	1.43	2.73	+	2.33	62.90
Actiniaria	0.71	5	+	2.23	65.13
Ophiura albida	0.71	4.55	+	2.14	67.27
Gibbula	0.71	4.55	+	2.09	69.36
Scaphopoda	2.50	2.27	-	2.07	71.43

Again reflecting the results of the video analysis, more detailed investigation of the influence of *S. spinulosa* on the epifaunal community observed in still images revealed that the effects on diversity are site specific (**Table 15**). For the most part, the presence of *S. spinulosa* was associated with an increase in the abundance and diversity of epifauna. At the Fraserburgh site, however, the reverse was true with a decrease in the abundance and diversity of epifauna. At this site the only community descriptors that increased (Pielou's J' and Simpson's Diversity Index (1-λ)) are measures of the evenness or equitability of species within a community. This is, therefore, likely to be a reflection of the numerical dominance of the keel worm *Spirobranchus* in areas where *S. spinulosa* is absent, as noted in the dissimilarity table for this site (**Table 14**).

Table 15

Summary of the average number of taxa (S), abundance of taxa (N), Margalef's Species Richness (d'), Pielou's Evenness (J'), Shannon's Diversity (H'(loge)) and Simpson's Diversity Index (1-λ) recorded from still images taken at each of the four study sites where *Sabellaria spinulosa* Reef (of high, medium or low quality as defined by Gubbay (2007) was present (Reef) or absent (Not a Reef). Also shown is the apparent effect of *S. spinulosa* reef presence on each of the community descriptors (- = reduction, + = increase, ~ = no change).

		Fraserburgh	Rattray Head	NorthConnect	Southern Trench
S	Not a Reef	9.24	7.67	2.43	5.57
	Reef	5.15	13.67	5.91	12.95
	Effect	-	+	+	+
N	Not a Reef	163.94	113.25	28	74.18
	Reef	85.54	175.63	62	199.41
	Effect	-	+	+	+
d	Not a Reef	1.62	1.51	0.8	1.2
	Reef	0.91	2.45	1.19	2.25
	Effect	-	+	+	+
J'	Not a Reef	0.71	0.67	0.72	0.78
	Reef	0.76	0.81	0.57	0.88
	Effect	+	+	-	+
H'(loge)	Not a Reef	1.51	1.18	0.55	1.22
	Reef	1.15	2.11	0.97	2.22
	Effect	-	+	+	+
1-λ	Not a Reef	0.71	0.56	0.5	0.69
	Reef	0.56	0.84	0.52	0.88
	Effect	+	+	+	+

Oceana ROV footage

The ROV clips collected as part of the Oceana research cruise revealed a very different habitat to those seen in the other four study sites. The area was characterised by discrete aggregations of *S. spinulosa,* which appeared to have developed on large cobbles and boulders amongst an otherwise relatively featureless, fine sediment habitat (**Plate 1A**). That *S. spinulosa* aggregations have developed on isolated cobbles and boulders was confirmed by the presence of *S. spinulosa* attached to cobbles in corresponding grab samples (**Plate 1B**).

An nMDS plot presented in **Figure 4** shows that there is some separation between the faunal communities associated with *S. spinulosa* aggregations and those associated with the surrounding sediments, but that there is some overlap between the three reef groups. Because of the nature of this dataset, there was a strong concordance between the different classification schemes (e.g. Reef (Gubbay 2007), Hendrick (2006), OSPAR and *Sabellaria* presence) and the vast majority of the samples were given the same classification using all of the different schemes. To avoid unnecessary repetition only the Gubbay (2007) reef classification has been explored in relation to the ROV clips but the results can be assumed to apply to all of the reef presence/absence classification schemes.

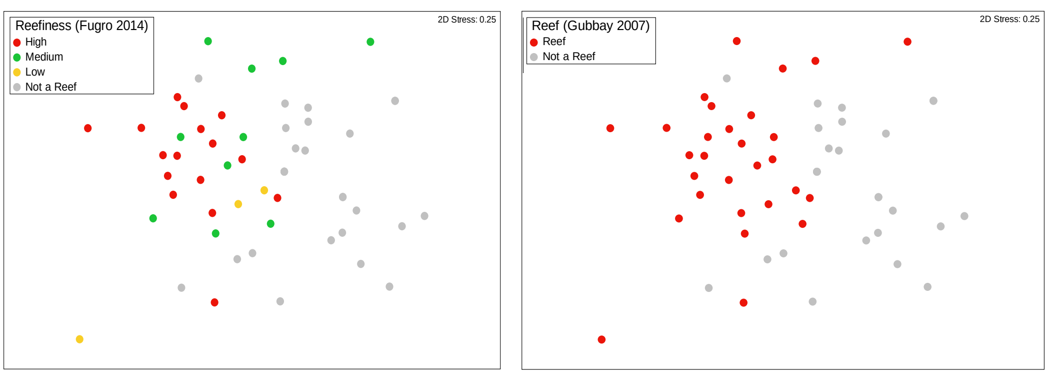

Figure 4: A two-dimensional nMDS ordination for the untransformed SACFOR abundance data (**Table 6**) extracted from ROV clips taken during the Oceana research cruise on the east coast of Scotland in 2017. *Sabellaria spinulosa* abundance has been removed as well as any afaunal and outlying samples, and samples have been grouped according to their *S. spinulosa* reefiness classes as summarised in **Table 9** and presented in full in **Electronic Appendix 3**.

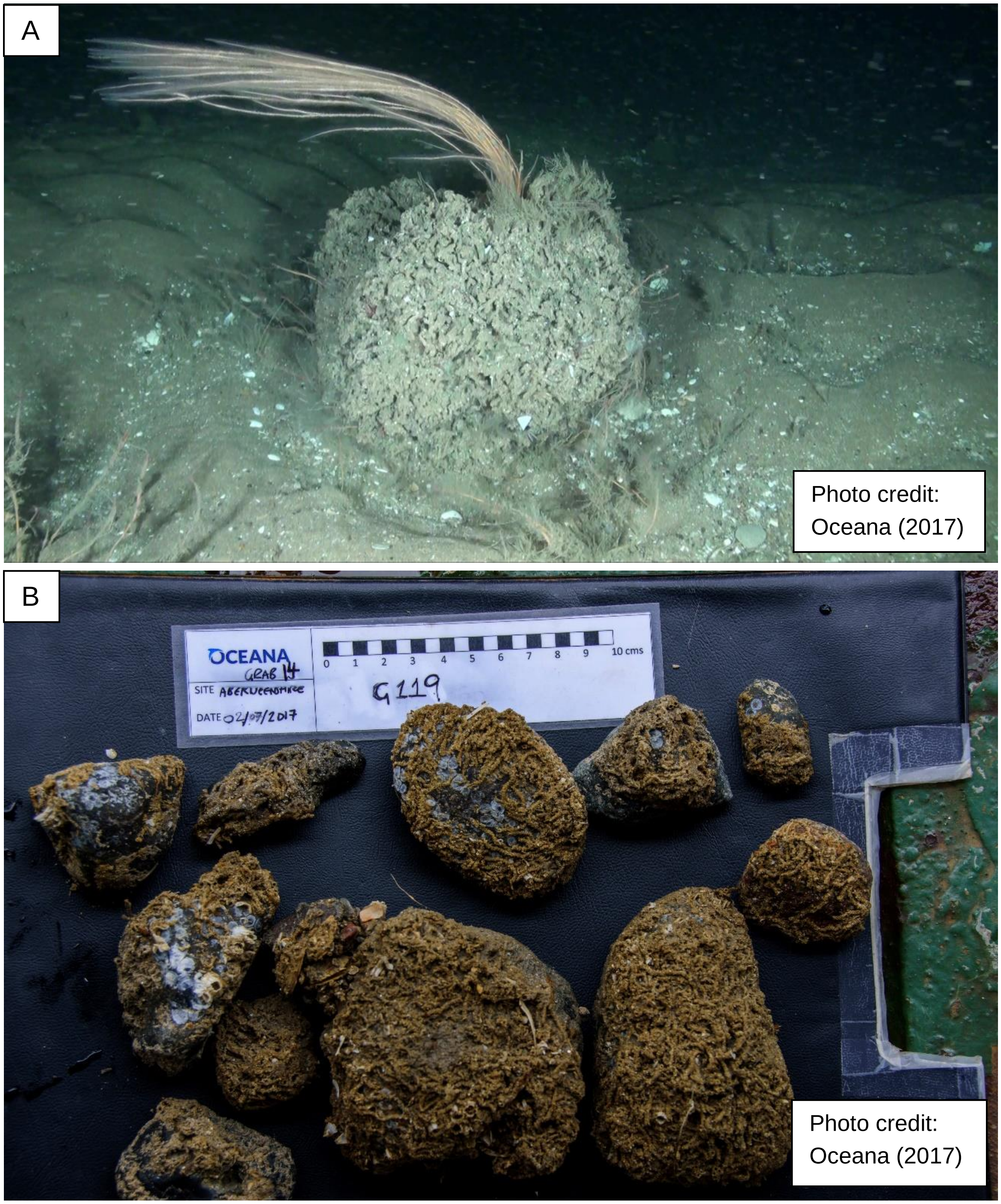

Plate 1: A) Screengrab from the ROV footage collected as part of the Oceana research cruise showing a discrete aggregation of *Sabellaria spinulosa* amidst an otherwise relatively featureless fine sedimentary habitat. **B)** Photograph of cobbles sampled during the Oceana cruise with encrusting *S. spinulosa* tubes.

The relationships between reef classes and epifaunal communities observed in **Figure 4** were confirmed by ANOSIM tests (**Table 16**). The test results show that whilst the full reefiness classification shows a significant level of concordance with the epifaunal communities the level of concordance with the coarser ‘Reef’ vs ‘Not a Reef’ classification was stronger.

Table 16

One-way ANOSIM test results between the different reefiness classes carried out on a Bray Curtis resemblance of untransformed, converted SACFOR abundance records from ROV snapshots collected during the Oceana research cruise from the east coast of Scotland in 2017. Significant test results (at the 0.1% level) are highlighted in bold font. Note that in this instance Reef Vs Not Reef is synonymous with *S. spinulosa* presence/absence and samples taken on and off *S. spinulosa* clumps.

	Reefiness Class	
Reefiness Class	R	Sig Level
Gubbay Reefiness (Collins 2010)	**0.294**	**0.1**
Reef vs Not Reef (Gubbay 2007)	**0.333**	**0.1**

Closer examination of the faunal dissimilarities between the *S. spinulosa* reefs and the surrounding sediments observed in the ROV footage reveals that fish species, including the dab *Limanda limanda,* were more abundant on nearby sediments whilst all other fauna were more abundant on the aggregations themselves. The *S. spinulosa* aggregations support a diverse array of epifaunal species, including hydroids, soft coral and fan worms as well as crevice dwelling crustaceans and brittle stars. A number of the species found to be characteristic of the *S. spinulosa* aggregations in the Oceana survey area, were not recorded at all on the nearby sedimentary habitat indicating that these structures support a faunal compliment that would otherwise not exist in this area.

Table 17

Summary of taxa that contribute to the dissimilarity between epifaunal communities classified as 'Reef' (high, medium or low) and 'Not a Reef' in accordance with the criteria proposed by Gubbay (2007) at the Oceana site on the east coast of Scotland. Also shown is the apparent effect of *S. spinulosa* reef presence on the abundance of individual taxa (reduction (-), increase (+), no change (~)). The SIMPER test was carried out on untransformed, converted SACFOR abundance records from ROV clips and associated screen grabs.

Taxon	Off Reef Av.Abund	On Reef Av.Abund	Effect	Contrib%	Cum.%
Alcyonium digitatum	0.03	16.1	+	9.92	9.92
Kirchenpaueria pinnata	1.38	9.66	+	9.31	19.23
Limanda limanda	11.72	0	-	9.17	28.39
Actiniaria	1.72	6.55	+	5.96	34.36
Spirobranchus	0	5.86	+	4.97	39.32
Tubularia indivisa	1.45	4.93	+	4.62	43.95
Ophiactis balli	0	7.59	+	4.39	48.34
Pisces	5.52	0.69	-	4.28	52.63
Hydrallmania falcata	0	3.45	+	3.88	56.51
Encrusting organism #3	3.28	5.45	+	3.85	60.36
Gastropoda	0.34	4.83	+	3.77	64.14
Cancer pagurus	2.76	2.76	~	2.93	67.07
Asterias rubens	0	4.14	+	2.83	69.9
Munida rugosa	0	4.83	+	2.78	72.69

Species that were recorded exclusively in association with the *S. spinulosa* aggregations included keel worms belonging to the genus *Spirobranchus*, which need a hard surface upon which to build their calcareous tubes, and the branching hydroid, *Hydrallmania falcata,* which also needs a hard surface upon which to attach. The rugose squat lobster, *M. rugosa,* was observed sheltering in crevices of the *S. spinulosa* aggregations and common starfish, *Asterias rubens*, were observed crawling over the aggregation, possibly feeding on its inhabitants. Arguably the most noteworthy species identified in association with this unique habitat was the brittle star *Ophiactis balli,* which was observed to be living within the aggregation itself, with only its arms visible (**Plate 2**).

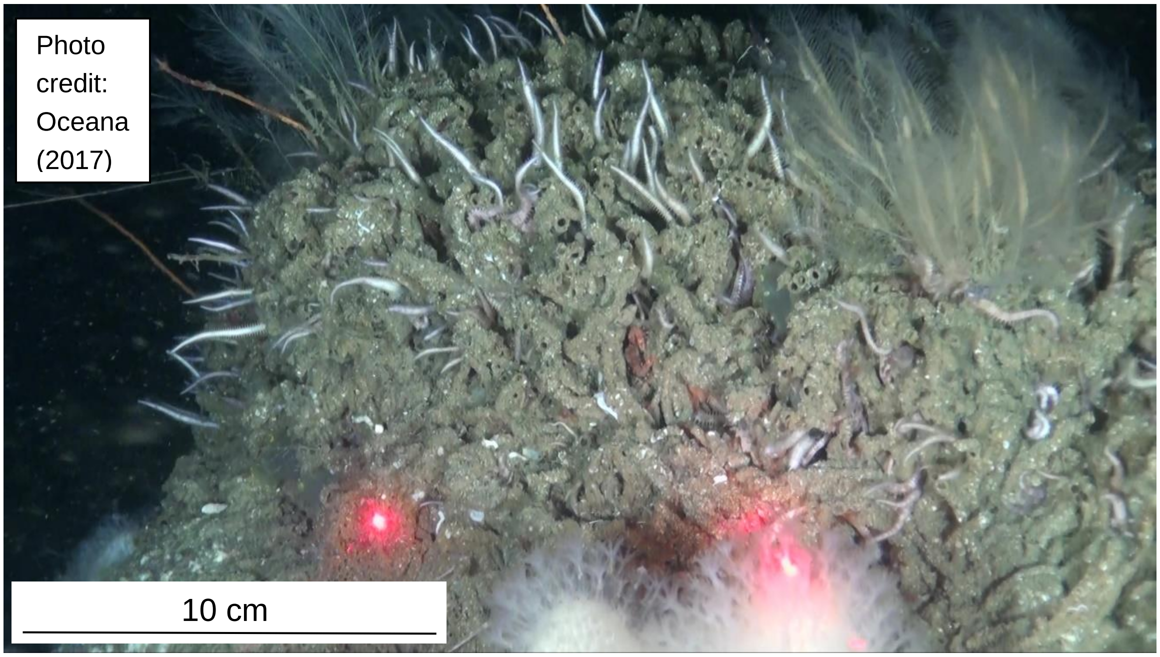

Plate 2

Screengrab from the ROV footage collected as part of the Oceana research cruise showing a close-up section of a *Sabellaria spinulosa* aggregation and fauna typically associated with this habitat.

Ophiactis balli is a small brittle star with widely spaced and conspicuous banding on its legs. It is generally found in crevices or amongst sessile invertebrates, or in the calises of the dead cold water coral, *Lophelia pertusa*, where the body is typically concealed and only the arms extend out into the water (Jensen and Frederiksen 1992; Picton 1993). This species is characteristic of exposed rocky habitats, but this is to the best of our knowledge the first record of its association with *S. spinulosa* aggregations. This species was also identified in association with the reefs at the Southern Trench site (**Table 14**).

Examination of the taxa contributing most to the internal similarity of the different reef classes shows that *Ophiactis balli* is only characteristic of the reef clumps classed as having high reefiness according to the criteria set out by Gubbay (2007) (**Table 18**). The similarity tables also indicate that there may be a continuum in the communities associated with habitats in this area moving from the sparsely populated non-reef habitats through to a more diverse and abundant faunal compliment associated with the best examples of reef in the area.

Table 18

Summary of taxa that contribute to the similarity within epifaunal communities classified as High, Medium or Low reef or Not a Reef in accordance with the criteria proposed by Gubbay (2007) at the Oceana site on the east coast of Scotland. The SIMPER test was carried out on untransformed, converted SACFOR abundance records from ROV clips and associated screen grabs.

High Reefiness

Average similarity: 22.64

Taxon	Av.Abund	Contrib%	Cum.%
Alcyonium digitatum	24.13	21.49	21.49
Encrusting organism #3	4.69	14.24	35.72
Tubularia indivisa	5.13	10.44	46.17
Ophiactis balli	10	9.67	55.84
Actiniaria	6.88	7.53	63.37
Gastropoda #1	5.63	7.05	70.42

Medium Reefiness

Average similarity: 14.06

Taxon	Av.Abund	Contrib%	Cum.%
Encrusting organism #3	7.3	24.14	24.14
Spirobranchus	8	23.73	47.87
Tubularia indivisa	5	14.86	62.73
Hydrallmania falcata	8	12.21	74.95

Low Reefiness

Average similarity: 26.16

Taxon	Av.Abund	Contrib%	Cum.%
Kirchenpaueria pinnata	26.67	77.81	77.81

Not a Reef

Average similarity: 17.95

Taxon	Av.Abund	Contrib%	Cum.%
Encrusting organism #3	3.28	46.59	46.59
Limanda limanda	11.72	35.07	81.66

The patterns observed in the dissimilarity and similarity matrices for the Oceana reef habitats were confirmed in the community descriptors summarised in **Table 19**. The abundance, richness and equitability of species are all higher in the presence of the reef habitat and furthermore show a continual increase with increasing ‘reefiness’ classes.

Table 19

Summary number of taxa (S), abundance of taxa (N), Margalef’s Species Richness (d’), Pielou’s Evenness (J’), Shannon’s Diversity (H’(loge)) and Simpson’s Diversity Index (1-λ) recorded from ROV clips taken during the Oceana research cruise on the east coast of Scotland in 2017. The data has been averaged by the *S. spinulosa* reefiness classes proposed by Gubbay (2007).

	S	N	d'	J'	H'(loge)	1-λ
Reef	6.4	108.5	1.1	0.8	1.4	0.7
Not a Reef	2.6	35.2	0.6	0.6	0.5	0.4
High	7.6	126.4	1.4	0.8	1.6	0.8
Medium	5.2	87.1	0.9	0.7	1.2	0.6
Low	4.3	84.3	0.8	0.6	0.9	0.5
Not a Reef	2.6	35.2	0.6	0.6	0.5	0.4

Results 4: Whole-site reefiness assessment

Thus far, the focus of this study has been on the finer detail of the nature of *Sabellaria spinulosa* growth in individual video segments, images and ROV clips as well as the associated fauna. However, to fully assess the conservation value of the reef habitats studied off the east coast of Scotland, it is necessary to examine the reefiness at the video tow level and where possible, to extrapolate those results to give some measure of the ‘reefiness’ at each site. An important component of whole-site reefiness is the extent of the reef habitat. At some of the sites included in this study, high resolution acoustic data has been collected and interpreted for benthic habitats and it is therefore possible to determine the maximum extent of the reef habitats identified. This data is only available for two of the sites and so it was necessary to estimate the reef extent in each tow based on the assumption that each segment represents 5 m^2. Both the interpreted polygon extents and the estimated extents from the video tows are summarised below in **Table 20**.

Table 20

Summary of the extent of *Sabellaria spinulosa* reefs on the east coast of Scotland, observed in towed video footage. Also shown are the associated habitat polygon extents, where these were available, and the adjusted extent based on an extrapolation of the proportion of reef (as defined by Gubbay (2007)) observed in video tow footage collected from within the habitat polygons.

Study Site	Stn.	Reef Polygons: Extent (m^2)	Reef Polygons: Description	Area of Video Tow: Not Reef (m^2)	Area of Video Tow: Reef (m^2)	Area of Video Tow: Reef (%)	Adjusted Reef Polygon Extent (m^2)
Fraserburgh	36 (1)	1,800,000	Area identified as 'High Potential Reef' based on high resolution acoustic data.	135	80	37	619,094
	36 (2)			195	90	32	
Rattray Head	43 (1)	~		0	200	100	
	45	~		15	160	91	
NorthConnect	T04	19,000	Biotope: A5.611 *Sabellaria spinulosa* on stable circalittoral mixed sediment. Based on high resolution acoustic data interpreted in conjunction with seabed video footage, still images and grab samples (including PSA).	115	85	43	8,456
	T05	23,000	Biotope Matrix: A4.213 *Urticina felina* and sand-tolerant fauna on sand-scoured or covered circalittoral rock /A4.2211 *Sabellaria spinulosa* with a bryozoan turf and barnacles on silty turbid circalittoral rock. Based on high resolution acoustic data interpreted in conjunction with seabed video footage, still images and grab samples (including PSA).	115	100	47	16,849
Southern Trench	STTR01	~	~	0	95	100	~
	STTR04	~	~	25	110	81	~

Recent advances in methods to assess *S. spinulosa* reefs have included the development of a more sophisticated measure of patchiness proposed by Jenkins, Eggleton *et al.* (2018). This method was applied to the video footage interpretation arising from this study and the results are summarised in **Table 21**. K values greater than one are larger than could be achieved if reef segment occupations were assigned at random and therefore these values are considered indicative of reef. Three video tows were found to have a patchiness score considered indicative of reef although none of these tows had previously been identified as being the best examples of reef using other reefiness criteria. Conversely, none of the tows that were identified as being the best examples of reef in this study had a K value >1. This is because *S. spinulosa* was present along the entirety of these tows and this method is not able to identify clumping of *S. spinulosa* in the absence of a start or end point.

Table 21

Summary of the patchiness calculated for each video tow in accordance with methods outlined by Jenkins, Eggleton *et al.* (2018) and provided in detail in **Appendix 3**. Tows with K values >1 are considered to be indicative of reef and these are highlighted in bold font.

Study Site	Tow	Patchiness			
		No. Patches	Mean Patch Length	Mean Magnitude	K (p_o/p_r)
Fraserburgh	34	0	0	0	~
	36 (1)	1	42	25.42	1.00
	36 (2)	1	54	98.66	1.00
	37	0	0	0	~
Rattray Head	43 (1)	1	41	401.04	1.00
	45	1	32	406.48	1.00
	46	**1**	**5**	**571.5**	**4.29**
	48	**1**	**2**	**206.25**	**1.85**
NorthConnect	T04	3	13.7	45.3	0.93
	T05	**7**	**4.3**	**48.92**	**1.37**
Southern Trench	STTR01	1	19	259.12	1.00
	STTR04	1	28	68.95	1.00
	STTR06	1	15	8.33	1.00
	STTR10	3	5.3	0.88	0.84

Combining all of the reefiness attributes for each of the four sites (**Table 22**) demonstrates that all of the four survey areas support *S. spinulosa* aggregations that would qualify as reefs using the reefiness criteria proposed by Gubbay (2007). The best examples of reef were identified at the Rattray Head and the Southern Trench sites, although the overall extent of these reefs is as yet unknown. A complete reefiness assessment was not possible for the Oceana data since there was no means of estimating patchiness or extent from the discrete observations made using an ROV. Because of the nature of the *S. spinulosa* aggregations in this habitat, it is considered unlikely that the habitat would score highly on either of these reef attributes.

Table 22

Whole-site *Sabellaria spinulosa* reefiness assessments based on the criteria proposed by Gubbay (2007) and the scores are colour coded using the same criteria (red = high, orange = medium, yellow = low). Study sites are ordered based on the scores for each reefiness attribute. Also shown is the patchiness score (K p_o/p_r) calculated using methods developed by Jenkins, Eggleton *et al.* (2018) as detailed in **Appendix 3**.

Study Site	Stn.	Extent		Elevation		Patchiness		
		Adj. Polygon (m^2)	Video (m^2)	Avg (cm)	Max (cm)	Avg (%)	Max (%)	K (p_o/p_r)
Rattray Head	43 (1)	~	200	5	5 to 10	78	90	1
	45	~	160	5	5 to 10	74	90	1
Southern Trench	STTR01	~	95	6	>10	75	87	1
	STTR04	~	110	3	5 to 10	31	43	1
Fraserburgh	36 (1)	619,094	80	5	>10	11	61	1
	36 (2)		90	7	>10	10	66	1
NorthConnect	T04	8,456	85	3	5 to 10	10	45	0.93
	T05	16,848	100	10	>10	17	50	**1.37**

Results 5: Broader context of the *Sabellaria spinulosa* reefs on the East Coast of Scotland

In order to assess the true conservation value of the *S. spinulosa* reefs identified off the east coast of Scotland during the course of this study, it is useful to consider these habitats in a broader geographical context.

Sabellaria spinulosa is known to occur on all UK coasts but there are a great many more records from English waters than there are from Scotland. A total of 119 *S. spinulosa* species records were identified in Marine Recorder in Scottish waters, a comparatively small number when compared to the 9,000+ species records from England. The *S. spinulosa* species records from Scottish waters have been mapped alongside the 15 *S. spinulosa* biotope records extracted from Marine Recorder in **Figure 5**. Biotope records in Scotland are limited to Luce Bay and the Solway Firth and the North Sea off Rattray Head.

Historically, there are records of *S. spinulosa* reefs off the shores of St Andrews (McIntosh 1922) and *S. spinulosa* reefs have previously been observed in Luce Bay (David Connor EC, Personal Comms).

That there are very few records of *S. spinulosa* from Scotland and even fewer extant records of reefs, is the main reason that *S. spinulosa* reefs were not assessed for potential inclusion on the list of Priority Marine Features (PMFs) for Scotland. The new observations reported here, however, indicate that the lack of records may in-part be due to the lower levels of effort allocated to surveying Scottish waters in comparison to the rest of the UK where surveys are undertaken more regularly in support of established industries such as aggregate extraction and offshore renewable energy. As the offshore energy sector develops in Scotland, it is highly likely that more *S. spinulosa* reef habitats will be identified.

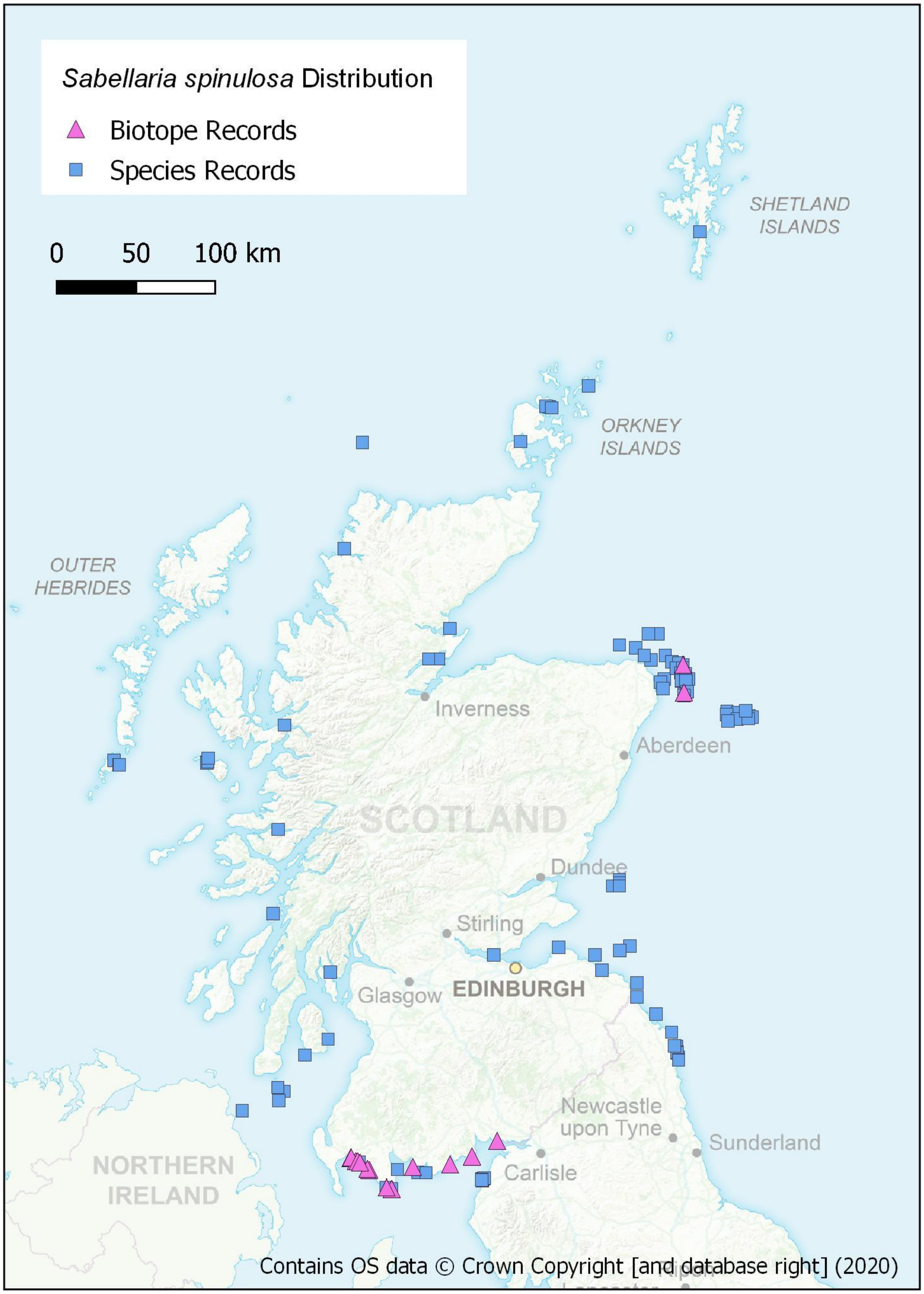

Figure 5: Chart showing the distribution of *Sabellaria spinulosa* species records held within Marine Recorder (Data extracted in September 2019).

Although it is widely accepted that *S. spinulosa* reefs occur throughout Europe, there are relatively few published records from outside of the UK (Bertocci, Badalamenti *et al.* 2017; Gravina, Cardone *et al.* 2018; van der Reijden, Koop *et al.* 2019). To date, there are only two *S. spinulosa* reefs designated for protection outside of the UK, and both of these are in Italy. The first site, MPA Torres del Cerrano, is in the central Adriatic and the second, SCI Torres Mileto, is in the southern Adriatic. The Klaverbank in Holland is designated for the protection of reef habitats, and although the designation is for the protection of a reef habitat formed by coralline algae, there are areas of *S. spinulosa* reef within the site. In recent years, there have also been attempts to get the newly discovered reef on the Dutch side of the Brown Bank designated as an a Natura 2000 site and work is ongoing to collect more data on the status of this reef (Garcia, Alvarez *et al.* 2019).

The scarcity of reefs protected, or otherwise, across Europe further emphasizes the importance of protecting this habitat in UK waters. This is especially true since the decline of this habitat in areas like the Wadden Sea (Reise and Schubert 1987; Riesen and Reise 1982; Wolff 2000) contributed to its inclusion on the OSPAR list of Threatened and Endangered Species, and in the Habitats Directive under Annex I.

Table 23 summarises the attributes of the *S. spinulosa* reefs that are currently protected or that have been put forward for protection across Europe. It is interesting to note that all of these reefs fall short of the high reefiness classification in at least one reef parameter. It also demonstrates that the newly discovered reefs from the east coast of Scotland sit well within the range considered suitable for protection in England, Italy and Holland. For example, the reefs at the Fraserburgh site have an estimated total extent of 619,094 m^2 with maximum elevations exceeding 10 cm and maximum patchiness (% cover) exceeding 60 % (**Table 22**).

Table 23

Summary of the reefiness attributes of *Sabellaria spinulosa* reefs that are either protected or have been recommended for protection across Europe. The reef metrics have been coloured in accordance with the reefiness criteria proposed by Gubbay (2007) where red = High reefiness, Orange = Medium reefiness and Yellow = Low reefiness. Extents marked with an asterisk denote the combined extent of multiple reefs.

Reef / MPA	Designation	Area (m^2)	Height (cm)	Patchiness (% Cover)	Source
Torre Mileto	SCI	89000	5-6	20	TRC (2019)
Brown Bank	Recommended for designation	1016	≤50	>30	van der Reijden, Koop *et al.* (2019)
Saturn Reef	SCI	375000	10	80-90 (in places)	BMT (2003)
Haisborough, Hammond and Winterton	SCI	880600*	5-10	30-100	JNCC and NE (2010) JNCC (2017a)
Inner Dowsing, Race Bank and North Ridge sandbanks	SCI	15043500*	3.5-8.5		Woo (2008) JNCC (2017b)
The Wash and North Norfolk	SCI	15750000*	1-6.5	25-100	Jessop and Soutt (2006)

Conclusions and recommendations

The status of *S. spinulosa* reefs on the East Coast of Scotland

This study has identified *S. spinulosa* aggregations at four sites on the east coast of Scotland that would qualify as reef based on the criteria proposed by Gubbay (2007). The best examples of reef were found at the Rattray Head and Southern Trench sites, although the total extent of these features has yet to be established. The initial discovery of *S. spinulosa* aggregations with reef-like qualities at Rattray Head led to this area being discarded as a potential route for the export cables associated with the Moray Firth Offshore Wind Farm (EMU 2011). Because this area was ruled out for development at an early stage, geophysical data collected from the area were never analysed and the habitats never mapped. There may, therefore, be potential to map the extent of this reef feature, using existing data, should it be considered as a candidate for protection in the future. No such data was ever collected from the Southern Trench site (Moore 2017), so additional surveys would be required to establish the reef extent in this area.

It was only possible to assess the reefiness of *S. spinulosa* aggregations identified from the east coast of Scotland during the Oceana research cruise at the sample level. Further analysis was not possible because ROV clips collected from this site were very short and focused on the discrete *S. spinulosa* aggregations at a face-on angle. Whilst this method of data collection resulted in very high quality imagery, it made it impossible to assess the proportion of the habitat covered by the *S. spinulosa* aggregations, or how far apart the aggregations were from one another, preventing any meaningful estimate of the area occupied by this habitat.

The sample level reefiness assessments applied to the Oceana data were also carried out on individual clumps, treating the surrounding sediments as off-reef sub-samples. This means that the true ‘reefiness’ at the sample level is likely to be slightly inflated. That said, the habitat identified here is quite unique and is clearly influencing biodiversity. The discrete clumps of *S. spinulosa* were well-established with a rich associated fauna and their extent appeared to be limited by the substrata. *S. spinulosa* are able to colonize a wide variety of substrata, but some stability does seem to be essential. This area appears to be characterised by fine mobile sediments, with occasional cobbles and boulders upon which *S. spinulosa* has been able to establish itself and the resulting habitat could be considered analogous with discrete coral reef 'bommies' in Australia. Additional towed video footage and high resolution acoustic data would help determine the reefiness of this habitat according to the criteria set-out by Gubbay (2007), but it is very unlikely that it would score highly for patchiness or overall extent.

The influence of *S. spinulosa* reef on epifaunal communities on the East Coast of Scotland

The influence of *S. spinulosa* reefs on epifaunal communities was found to be quite site specific, with the same species seemingly being excluded at one site whilst being more prevalent at another in the presence of *S. spinulosa* reef. It is likely that the patterns observed are driven largely by the nature of the surrounding sediments. At sites where the reefs are surrounded by rock habitats, epilithic species may show a preference for the surrounding habitat. Conversely, where the reef is surrounded by mobile sediments, the reef structure itself may be the only available space for settlement.

The diversity and abundance of epifauna generally exhibited a small increase where *S. spinulosa* reefs were present, with the exception of the Fraserburgh site, where as many species were negatively impacted by the presence of reef as were enhanced by it. The most marked and positive influence on epifauna was observed at the Oceana site, demonstrating that whilst this habitat may not conform strictly to the definition of reef, it is nevertheless playing an important structuring role in the marine community.

For the most part, the faunal compliment supported by *S. spinulosa* reefs reflected those of the surrounding substrates with slight differences in relative abundance. There were, however, a small number of species that were only found on the reefs. These included the rugose squat lobster, *Munida rugosa*, the pink shrimp *Pandalus montagui* and the brittle star *Ophiactis balli*. All of these species were found to be inhabiting the crevices or internal structure of the reefs and were most frequently associated with the best examples of reef. High numbers of crevice dwelling custaceans, including the porcelain crab *Pisidia longicornis* have been reported in association with well-developed reef structures in other areas (Pearce 2008; Pearce, Fariñas-Franco *et al.* 2014; Pearce, Taylor *et al.* 2007; TRC 2019). It has even been suggested that such species may make useful indicators for monitoring reef health (Fariñas-Franco, Pearce *et al.* 2014). Although the species were different in this area, they share some ecological functions and are occupying the same ecological niche, and hence they may also have some potential as reef health indicators.

The suitability of existing 'reefiness' guidance for use in a Scottish context

The existing reefiness guidance performed well on the data collected from the east coast of Scotland, in as much as it identified areas of reef, where the reef-like habitats had been noted by those collecting the seabed imagery and not in footage chosen to represent areas of contrasting habitats. That said, the simpler reefiness measures such as the OSPAR reef classification (based solely on % cover), the presence or absence of reef (regardless of whether it was classed as high medium or low) and in some cases simply the presence of the species itself showed the strongest concordance with the associated fauna. This indicates that whilst the finer grade reef classifications may have benefits from a management perspective they do not necessarily correlate with the ecological value of the reef. This shows good agreement with the findings of Pearce, Hill *et al.* (2011) who also found no relationship between the height, patchiness and worm density of *S. spinulosa* reefs on the Norfolk coast and the associated macrofaunal diversity.

Estimating the elevation of *S. spinulosa* aggregations proved to be quite inaccurate, with different assessors often assigning different height classes to the same image or video segment. This led to the development of a reefiness height guide (**Appendix 1**), which did improve consistency, although it did not remove subjectivity completely. Since height was only ever included in the Gubbay criteria because of the need for the feature to be topographically distinct as defined by OSPAR (2008) and studies (including this one) have now demonstrated that there is no relationship between reef height and ecological function (Pearce, Hill *et al.* 2011), there is perhaps an argument for simplifying the reefiness classification and only using height to differentiate between reef and non-reef habitats. Reef height also seems to be heavily influenced by the prevailing hydrodynamic regime, with offshore reefs rarely exceeding 10 cm, in contrast to reefs in the comparatively sheltered Wash which have been reported to exceed 30 cm in height. Therefore, the conditions under which the reefs have developed should also be considered. The question of elevation is further complicated by the nature of the underlying and surrounding sediments. It is often impossible to tell from seabed imagery alone whether a clump of *S. spinulosa* is growing over a boulder or from a relatively flat seabed. Where *S. spinulosa* reefs develop in a predominantly sandy area, they may also frequently become inundated (Limpenny, Barrio Frojan *et al.* 2011; Pearce, Hill *et al.* 2011) and so the part of the reef visible in a seabed image may vary dramatically from one day to the next.

The percentage cover of *S. spinulosa* at the sample level seemed to correspond well with patterns observed in the associated fauna. This measure of 'reefiness' is also very simple to record with a reasonable degree of accuracy and consistency when using gird overlays on both video footage and still images. Accuracy could be further increased through the use of automated image processing software such as ImageJ as demonstrated by Fariñas-Franco, Pearce *et al.* (2014).

A new measure of patchiness was proposed recently by Jenkins, Eggleton *et al.* (2018) based on the perceived need to differentiate between areas where *S. spinulosa* grows uniformly and randomly everywhere and areas where it clusters together to form distinct areas of reef. The method is theoretically sound and it did score discrete clumps of *S. spinulosa* surrounded by areas with no *S. spinulosa* more highly than areas where the *S. spin*ulosa occurred more intermittently. The method falls down though, where the video tow shows *S. spinulosa* reef throughout its entirety, as there is no start and end point to the 'patch'. Effectively this meant that the best examples of reef in this study were not identified as reef using this method (See **Table 21** and **Table 22**). Furthermore, most of the reefs studied here, and indeed those previously studied from offshore environments do seem to be inherently patchy in nature, with pockets of bare substrate intermingled with areas of *S. spinulosa* aggregations of different heights (**Plate 3**). In this study many of the habitats were assigned to a mosaic of biotopes to reflect this small-scale patchiness. It is unclear whether the apparent propensity of the species to create patchy reefs, as opposed to being more tightly clustered, is its natural growth form, a reflection of the underlying seabed and its suitability for settlement, or a result of many years of intermittent damage by bottom trawling and storm events. Establishing the nature of *S. spinulosa* reefs, in the absence of fishing or other anthropogenic pressures, is, therefore, considered an essential step in determining the applicability of the new ‘patchiness’ statistic to this habitat.

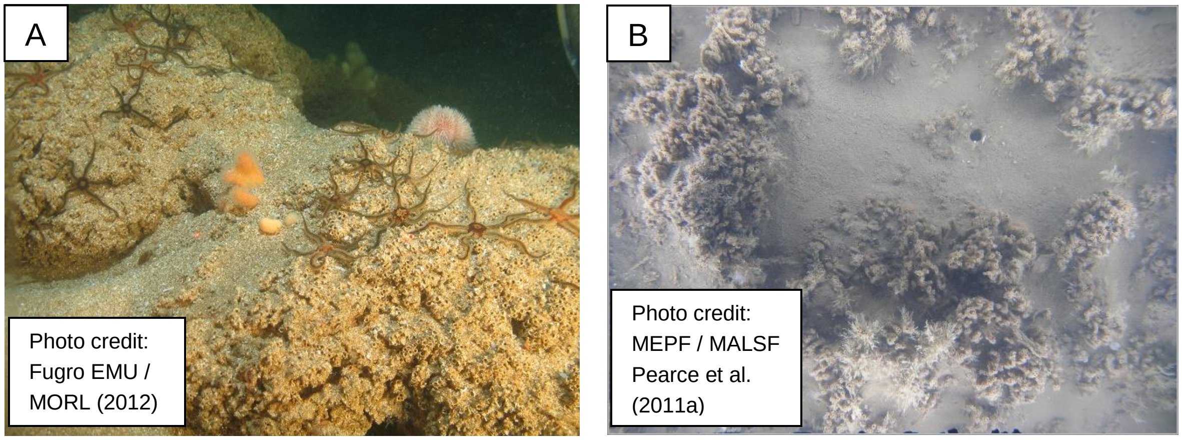

Plate 3

Images of *S. spinulosa* reef from **A)** the Fraserburgh study site and **B)** the Thanet offshore windfarm demonstrating the discontinuous nature of this reef habitats in these areas.

As well as exploring the applicability of the *S. spinulosa* reefiness criteria to the data collected from the east coast of Scotland, the present study also explored *S. spinulosa* reefiness parameters for reefs already protected as part of a Site of Community Interest, or that have been proposed for designation as such, across Europe. The total extents of individual *S. spinulosa* reefs are not reported on the Natura Standard Data Forms and hence extents appear inflated where there are several reefs within one MPA, as is the case for the Haisborough, Hammond and Winterton SCI, the Inner Dowsing, Race Bank and North Ridge Sandbanks SCI and the Wash and North Norfolk SCI. Of these, only the latter two scored highly based on the reefiness criteria proposed by Gubbay (2007). The largest reef extent comes from the Wash and North Norfolk SCI, where there are not only multiple reefs included in the one extent, but the extents themselves have been calculated based on the extrapolation of point data and hence are likely to be an overestimate of the true reef extent.

The reefiness criteria proposed by Gubbay (2007) was never intended to be an accepted and fully agreed set of thresholds, but rather the starting point for wider discussions and further research. Given that the criteria have not been revisited or updated since 2007, and a considerable volume of reef data has been collected across the UK in that time, now may be a good time to revisit and update the criteria. Adjusting the extent categories to better reflect the extents of known and protected reefs would be one amendment that we would recommend. Improved guidance on how the criteria should be applied would also be beneficial, as there is a real danger as the criteria stand, that where only 'high' reefiness is assumed to be synonymous with reefs of conservation potential, reefs of better quality than those that we are currently protecting are down-graded or even excluded from the HRA process.

Recommendations for the future conservation of *S. spinulosa* reefs in Scottish Waters

Sabellaria spinulosa reefs are not currently listed as PMFs in Scotland despite their high conservation status at a European level. There was little to no evidence of any such habitats occurring in Scottish waters when the PMF list was produced (Howson, Steel *et al.* 2012; Tyler-Walters, James *et al.* 2016). Evidence presented in this study, and additional records from the east coast (Moore 2019), suggest that there are in fact *S. spinulosa* reefs in Scottish waters, and it is likely that as survey effort associated with the blossoming offshore renewable energy sector increases, that more will be found. Should *S. spinulosa* reefs be deemed to qualify as a PMF following future assessment against the relevant criteria, there would be an increased impetus on regulatory bodies to ensure that this habitat was protected nationally. The habitats importance level during the EIA and HRA process may also increase, although their conservation status should already be clearly recognised as an Annex I habitat and a habitat listed on the OSPAR threatened and / or declining habitats list. That *S. spinulosa* reefs are apparently rare outside of the UK makes it all the more important that these habitats are protected in UK waters. All of the habitat examples reviewed as part of this study lie within the Southern Trench possible MPA[12].

The reefiness criteria proposed by Gubbay (2007) performed well on the Scottish reefs but it should be noted that, as in reefs elsewhere in the UK, the relative reefiness (high, medium and low) does not correspond well with the ecological value of the reefs and so areas of 'low' reef should not be discounted as having no conservation value, especially in Scotland where examples of this habitat are less common.

[12] https://www.nature.scot/possible-nature-conservation-mpa-advice-documents-southern-trench

The *S. spinulosa* habitat detected during the Oceana cruise is likely to fall short of the minimum % cover and extent to qualify as a reef under the Gubbay criteria. However, more data would be required to confirm this. Regardless of its apparent 'reefiness' score, the *S. spinulosa* colonies were clearly well established and support a faunal compliment that would otherwise not be able to exist in this area. The *S. spinulosa* 'bommies' were also topographically distinct and so meet many of the broader criteria for reef detailed in the Habitats Directive and OSPAR reef definitions (**Box 1**). This habitat certainly warrants further investigation and is perhaps best described as a new reef subtype, which as far as we know is unique to Scotland. An alternative mechanism for protection should also be explored to ensure that this habitat is given due consideration during the EIA process and that its potential conservation value is not overlooked on the basis of extent or patchiness.

The video tow data used in this study was of varying quality and often fell below the quality level that is strictly useful for this type of analysis (Turner, Hitchin *et al.* 2016). Developing minimum video quality standards for offshore surveys would therefore be beneficial for future work of this nature. Owing to the variable and often low quality of the data there were inconsistencies in the taxonomic resolution of the data. The use of standardised terminology such as the Collaborative Automated Tools for Analysis of Marine Imagery and Video (CATAMI) classification scheme (Althaus, Hill *et al.* 2015) would help produce more standardised datasets that could then be compared between sites. The data obtained from still images and ROV clips was of a much higher resolution and proved invaluable to this study so this should always be a required component of surveys on this habitat.

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Appendices

Appendix 1

***Sabellaria spinulosa* reef height guide**

Measuring the height of *Sabellaria spinulosa* aggregations from seabed images and video footage is a difficult and subjective task. Although most underwater imagery has some sort of scaling, usually laser points, from which distances can be calculated with some accuracy, these are usually in a different plane (most often horizontal) to the worm growth (usually vertical) and may be some distance from the aggregation you are trying to measure. Because underwater cameras are often angled, heights can also appear very different toward the front and back of the image. To further complicate matters, *S. spinulosa* often grows on top of hard substrata, which may or may not be visible. It is often, therefore, impossible to determine the extent to which the elevation above seabed is being influenced by the underlying rock as opposed to the reef itself. The reef structure formed by *S. spinulosa* also traps fine sediment, which can make the visible portion of the tube appear significantly shorter than it is, and, since *S. spinulosa* preferentially settles on areas of existing reef, the visible parts of the tubes rarely represent the full height of the reef itself (see **Plate 1**).

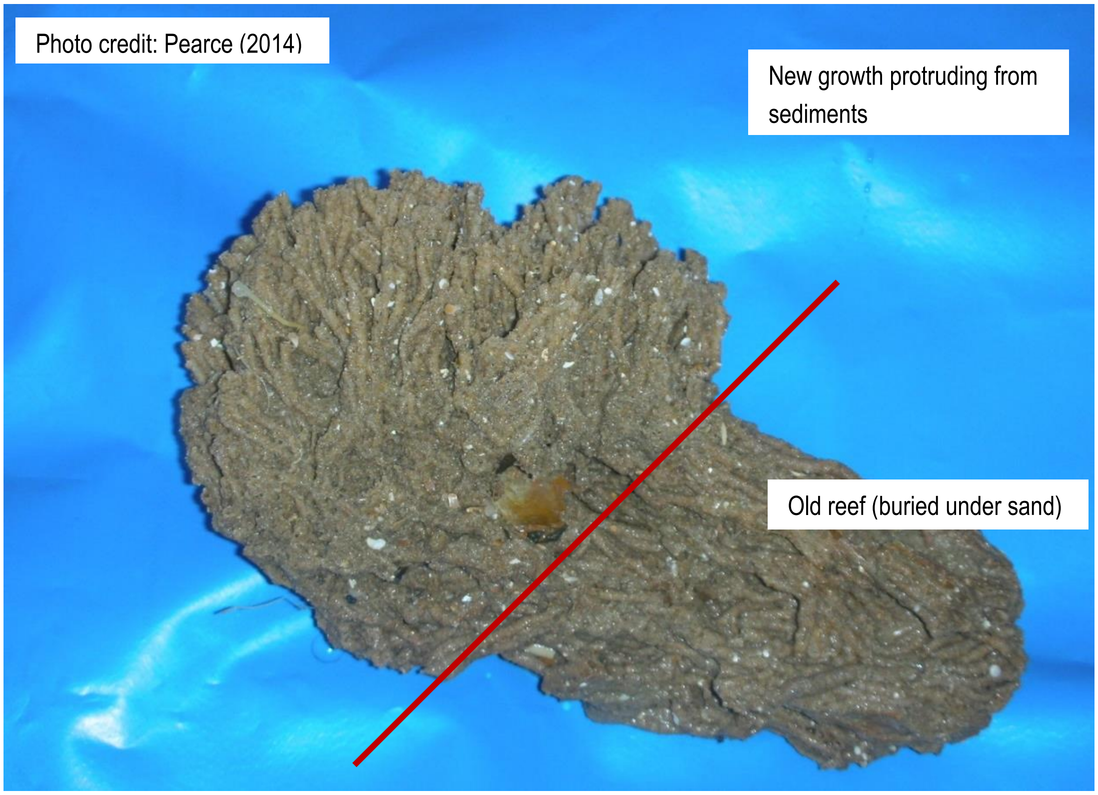


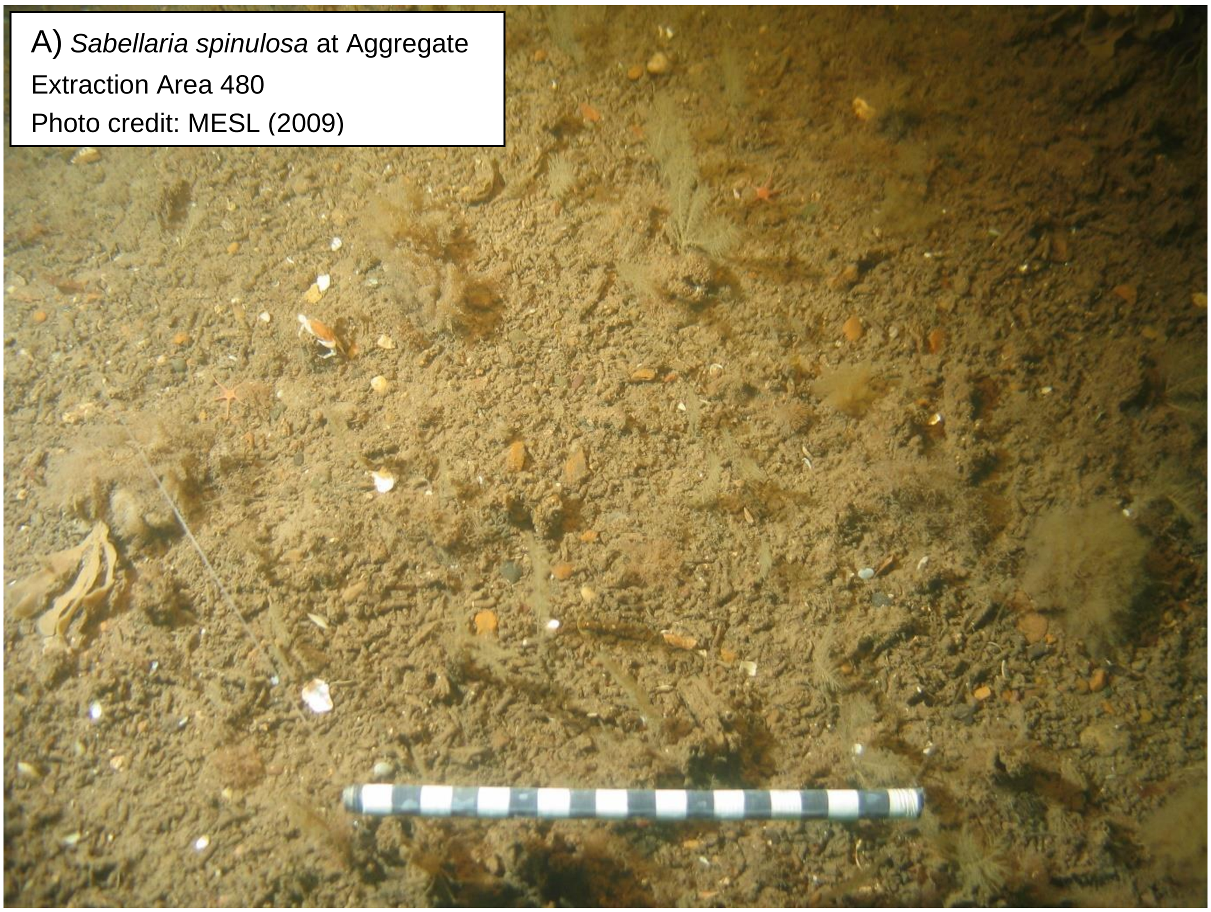
Plate 1

Photograph of a *Sabellaria spinulosa* aggregation extracted from an undisturbed day grab sample. The red line highlights the transition from old reef to new settlement and the approximate position of the surrounding sand, demonstrating the portion of the reef that would be visible in a seabed image. Image reproduced from (Pearce 2014).

In light of the subjectivity and inaccuracy inherent in estimating reef height, **maximum** heights have been recorded using the categories outlined by Gubbay (2007). To limit the subjectivity further, the following reference images and notes were provided to the analysts to help inform their assessments. To ensure broad consistency across other studies, these images have been taken from reefs around the UK and have been analysed by a number of different analysts.

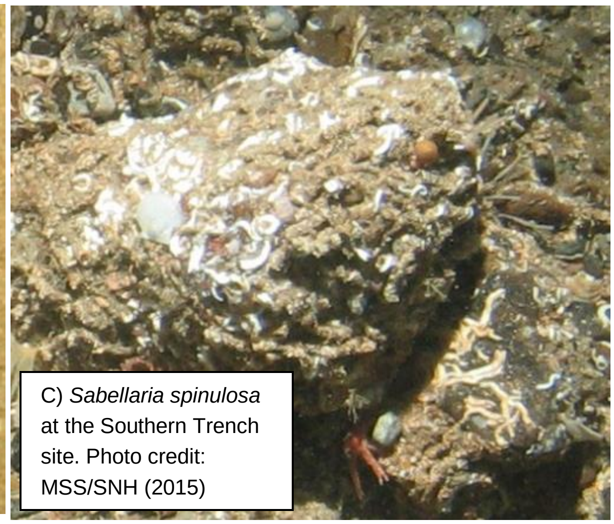
<2 cm (not reef)

Where *Sabellaria spinulosa* aggregations are elevated by less than 2 cm, they are not considered to fall within any existing definitions of reef, i.e. they are not considered to be topographically distinct seabed features. Typically, this class of aggregation includes loose moribund tubes (A) and (B) and areas where *S. spinulosa* is encrusting or growing horizontally on rocks or other seabed surfaces (C). Once the worms form aggregations of vertical tubes arising from the seabed it is rare that their height will not be equal to, or exceed 2 cm.



A) *Sabellaria spinulosa* at Aggregate Extraction Area 480
Photo credit: MESL (2009)

B) *Sabellaria spinulosa* at the Southern Trench site
Photo credit: MSS/SNH (2015)

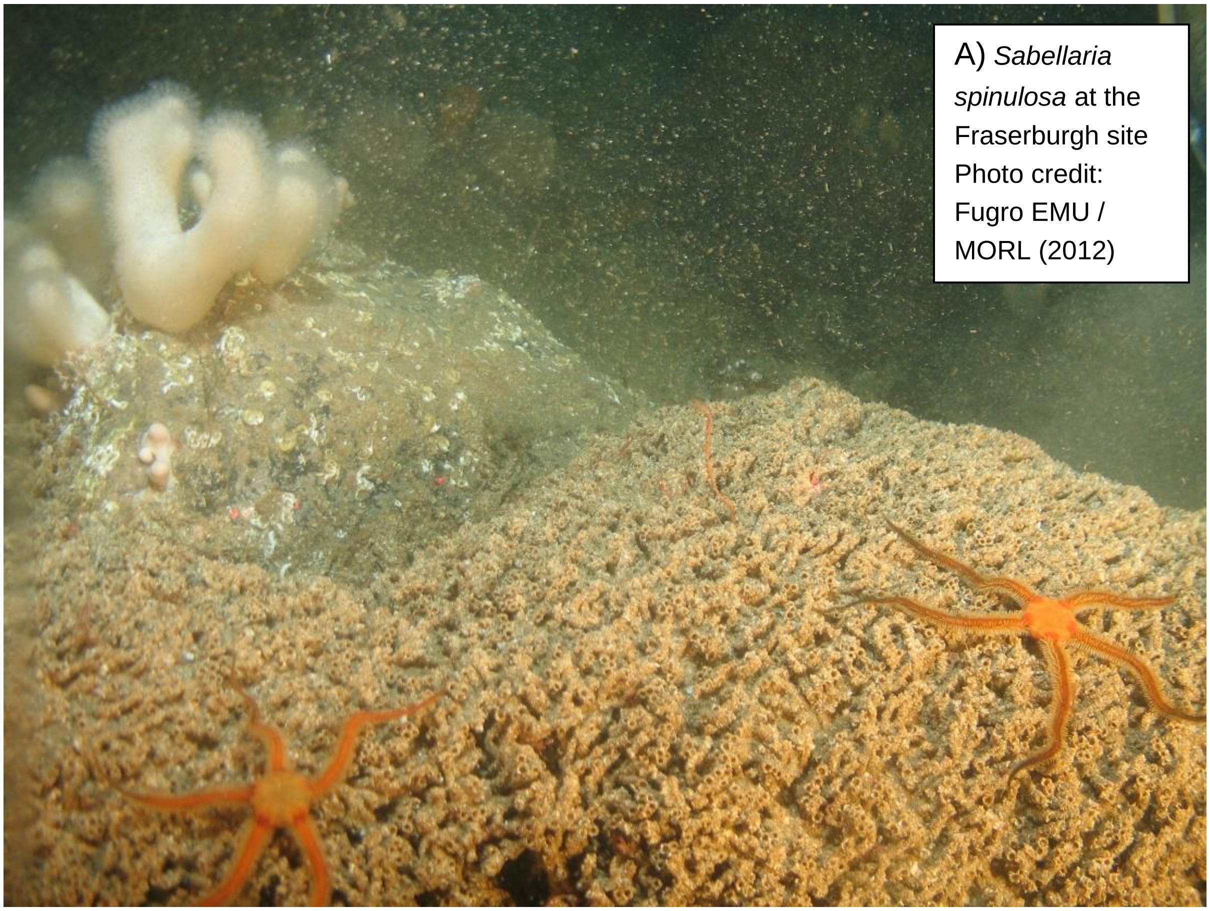


C) *Sabellaria spinulosa* at the Southern Trench site. Photo credit: MSS/SNH (2015)

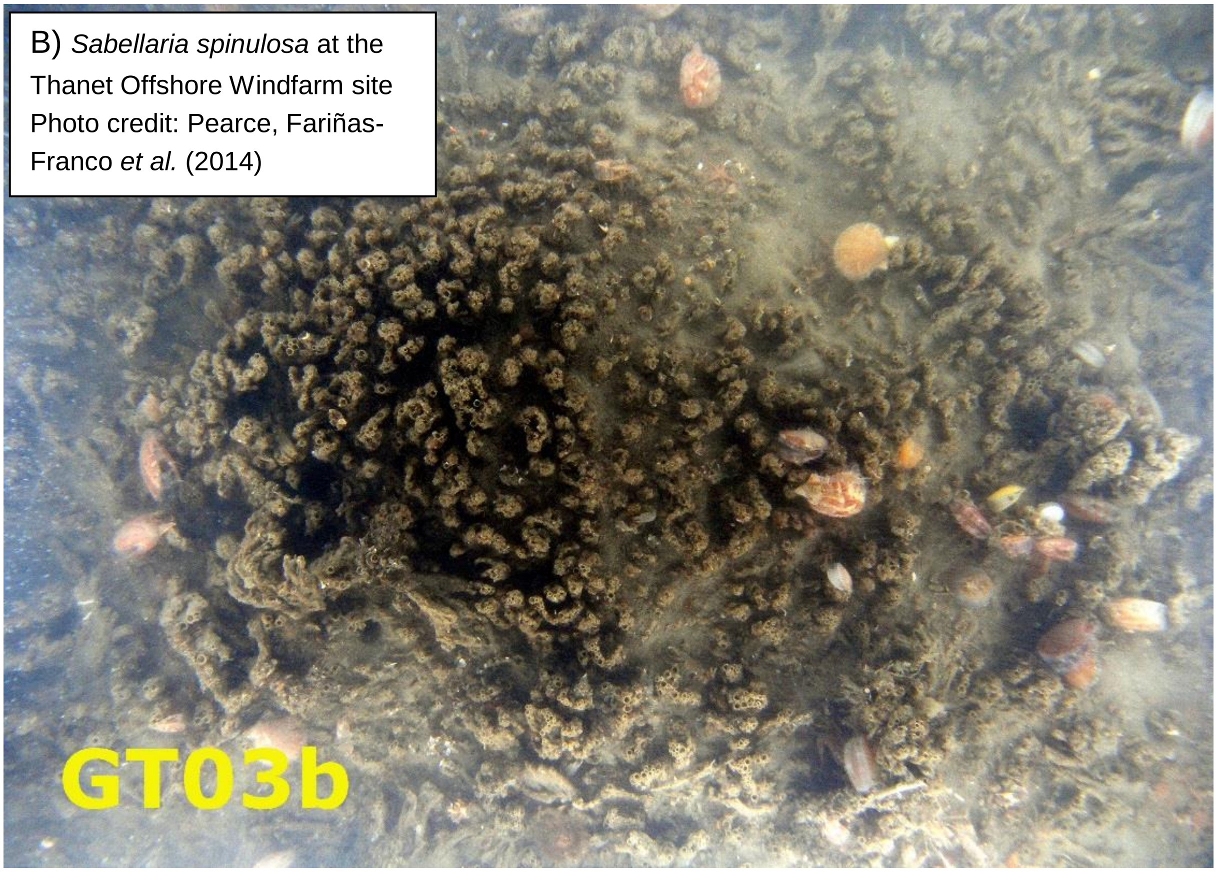
2-5 cm

Where *Sabellaria spinulosa* has become established and adult worms are growing vertically, it is rare that the height of the aggregation will not exceed 2 cm since the median adult body length is 9 mm (Pearce 2014) and the tube in which they reside is typically very much longer (personal observations) to allow the worm to retract and hide from predators and also to allow space for the exchange and expulsion of gametes and waste products. The size of associated fauna can act as a useful reference where this is known. For example, the test of an adult *Ophiocomina nigra* (A) is 2.5 cm in diameter and their arms can reach up to 12.5 cm in length (Picton 1993).

Some examples of *S. spinulosa* reef classified as being 2-5 cm in elevation are provided in images A-C.



A) *Sabellaria spinulosa* at the Fraserburgh site Photo credit: Fugro EMU / MORL (2012)

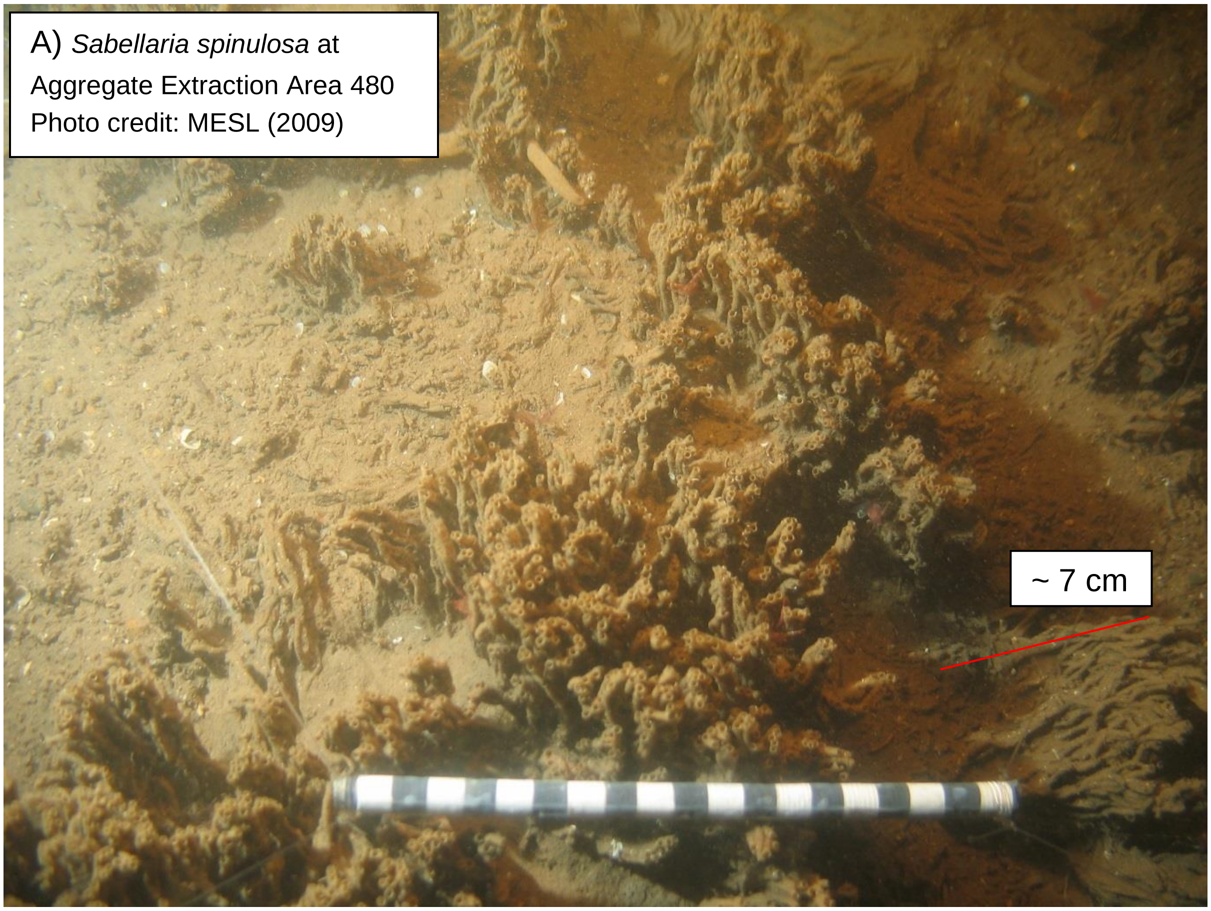


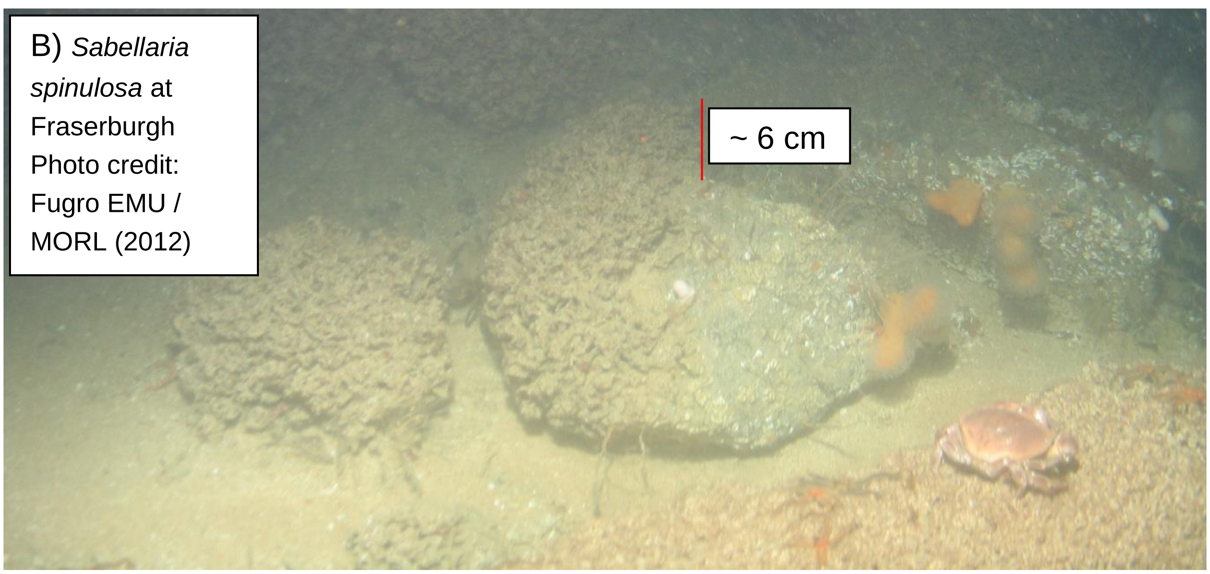
B) *Sabellaria spinulosa* at the Thanet Offshore Windfarm site Photo credit: Pearce, Fariñas-Franco *et al.* (2014)

C) *Sabellaria spinulosa* at Aggregate Extraction Area 480
Photo credit: MESL (2009)

5-10 cm

By this stage *S. spinulosa* have usually developed into a well-developed reef structure. In some images there will be gaps in the reef, or broken sections that allow for relatively accurate measurements of elevation using a scale bar or lasers (A). Most often though, the reef growth will be continuous and estimating height in these instances requires an informed judgement to be made. Looking for areas where the aggregation extends up from a rock (B) or crevices/gaps in the reef structure are often helpful in determining maximum height.

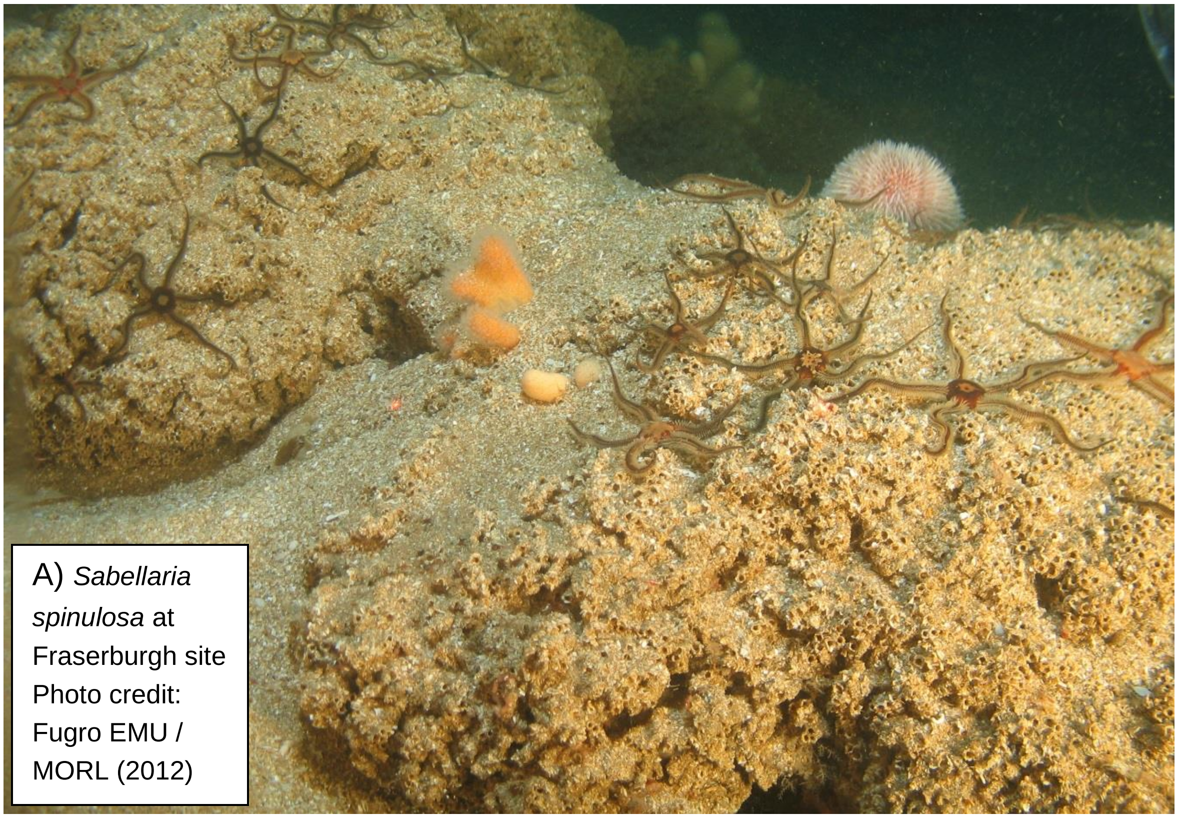

A) *Sabellaria spinulosa* at Aggregate Extraction Area 480 Photo credit: MESL (2009)
~ 7 cm


B) *Sabellaria spinulosa* at Fraserburgh Photo credit: Fugro EMU / MORL (2012)
~ 6 cm

C) *Sabellaria spinulosa* at the Southern Trench site
Photo credit: MSS / SNH (2015)

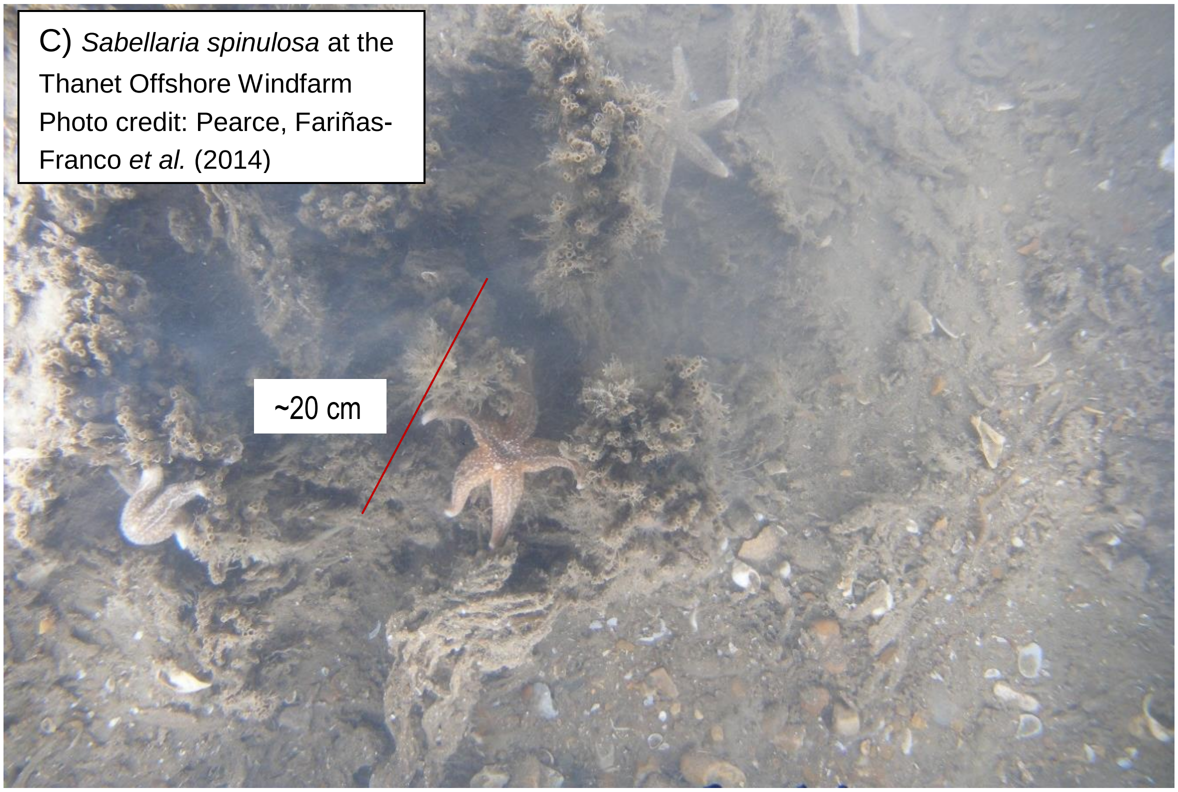
>10 cm

Reef heights exceeding 10 cm can often be the easiest to discern as normally by this stage, there is a well-developed reef structure with obvious elevation (A) and (B). However, in other instances, damaged horizontal sections of reef may reveal a greater height than might otherwise have been assumed (C).



A) *Sabellaria spinulosa* at Fraserburgh site
Photo credit: Fugro EMU / MORL (2012)

B) *Sabellaria spinulosa* at Rattray Head
Photo credit: Fugro EMU / MORL (2012)



C) *Sabellaria spinulosa* at the Thanet Offshore Windfarm Photo credit: Pearce, Fariñas-Franco *et al.* (2014)

Acknowledgements

Thanks go to Hanson Aggregates Marine Limited for allowing the use of *Sabellaria spinulosa* images collected for their site assessment work at Licence Area 480 to be included in this reef height guide.

Appendix 2

Summary of the SACFOR[13] scales applied to marine taxa identified in still images, video tows and ROV clips collected from the east coast of Scotland between 2011 and 2017. Scales specified by Turner, Hitchin et al. (2016) have been used where available and otherwise scales have been chosen based on growth form and / or adult body size.

Scientific Name	Common Name	SACFOR Scale
Actiniaria	Anemones	3 to 15 cm
Aglaophenia	A hydroid	1 to 3 cm
Agonus cataphractus	Hooknose / Pogge	3 to 15 cm
Alcyonidium diaphanum	Sea chervil	3 to 15 cm
Alcyonium digitatum	Dead man's fingers	Massive / turf
Ammodytidae	Sandeel	> 15 cm
Amphipoda	Sand hoppers	<1 cm
Animalia #1	Beige encrusting colonial organism	Crust / meadow
Animalia #2	Brown encrusting colonial organism	Crust / meadow
Animalia #3	Grey encrusting colonial organism	Crust / meadow
Animalia #4	Orange massive colonial organism	Massive / turf
Animalia #5	Orange encrusting organism	Crust / meadow
Animalia #6	Pink massive colonical organism	Massive / turf
Animalia #7	Red massive colonical organism	Massive / turf
Animalia #8	Red translucent organism	Massive / turf
Animalia #9	White translucent organism	Massive / turf
Animalia #10	White massive organism	Massive / turf
Animalia #11	Pink encrusting organism	Crust / meadow
Animalia #12	Yellow massive organism	Massive / turf
Animalia #13	Pink flabellate organism	Massive / turf
Animalia #14	Red encrusting organism	Crust / meadow
Animalia #15	Keel worms and / or barnacles	1 to 3 cm
Animalia #16	Mollusc or nudibranch eggs	Crust / meadow
Animalia #17	Hydroid / bryozoan turf	Massive / turf
Antedon bifida	Feather star	3 to 15 cm
Aphroditiformia	Scale worms	1 to 3 cm
Ascidiacea #1	Colonial sea squirt	1 to 3 cm
Ascidiacea #2	Solitary sea squirt	1 to 3 cm
Asterias rubens	Common starfish	>15 cm
Asteroidea	Starfish	>15 cm
Bivalvia	Bivalve molluscs	1 to 3 cm
Brachyura	Crabs	3 to 15 cm
Buccinidae	Whelks	3 to 15 cm
Bugulina flabellata	A bryozoan	Massive / turf

13 https://mhc.jncc.gov.uk/media/1009/sacfor.pdf

Scientific Name	Common Name	SACFOR Scale
Calliostoma zizyphinum	Painted top shell	1 to 3 cm
Cancer pagurus	Edible crab	> 15 cm
Caridea	Shrimps	3 to 15 cm
Cellaria fistulosa	A branching bryozoan	3 to 15 cm
Chaetopterus variopedatus	A parchment worm	3 to 15 cm
Corallinales	Encrusting coraline algae	Crust / meadow
Crossaster papposus	Common sun star	>15 cm
Decapoda	Squat lobster or crabs	3 to 15 cm
Ebalia	Nut crab	1 to 3 cm
Ebalia tuberosa	Nut crab	1 to 3 cm
Echinus esculentus	Edible sea urchin	>15 cm
Filograna implexa	Coral worm	Crust / meadow
Flustra foliacea	Hornwrack	Massive / turf
Flustridae	A bryozoan	Massive / turf
Gadidae	Juvenile gadoid fish	>15 cm
Galatheidae	A squat lobster	3 to 15 cm
Gastropoda	Marine snail	1 to 3 cm
Gastropoda ?	Marine snail / large foraminifera	< 1 cm
Gibbula	Top shells	1 to 3 cm
Haliclona (Haliclona) oculata	Mermaids glove	Massive/ turf
Henricia	Starfish	3 to 15 cm
Holothuroidea	Sea cucumber	> 15 cm
Hydrallmania falcata	A hydroid	3 to 15 cm
Hydrozoa #1	Erect branched hydroids	3 to 15 cm
Hydrozoa #2	Erect bushy hydroids	3 to 15 cm
Inachus	A spider crab	3 to 15 cm
Kirchenpaueria pinnata	A hydroid	3 to 15 cm
Lanice conchilega	Sand mason worm	3 to 15 cm
Limanda limanda	Dab	> 15 cm
Liocarcinus	Swimming crabs	3 to 15 cm
Luidia ciliaris	Seven-armed starfish	> 15 cm
Macropodia	A spider crab	3 to 15 cm
Melanogrammus aeglefinus	Haddock	>15 cm
Modiolus modiolus	Horse mussel	3 to 15 cm
Munida rugosa	Rugose squat lobster	3 to 15 cm
Mysida	Mysid shrimps	1 to 3 cm
Nemertea	Ribbon worm	3 to 15 cm
Nemertesia antennina	Sea beard	3 to 15 cm
Nemertesia ramosa	A hydroid	3 to 15 cm
Nudibranchia #1	White and yellow sea slug	1 to 3 cm
Nudibranchia #2	Blue sea slug	1 to 3 cm
Nudibranchia #3	White sea slug	1 to 3 cm
Nudibranchia #4	White and brown seaslug	1 to 3 cm
Nudibranchia #5	Pink sea slug	1 to 3 cm
Ophiactis balli	Small banded brittlestar	3 to 15 cm
Ophiocomina nigra	Black brittlestar	3 to 15 cm
Ophiothrix fragilis	Common brittlestar	3 to 15 cm
Ophiura albida	Sepent's table brittlestar	3 to 15 cm
Ophiuroidea	Brittlestars	3 to 15 cm

Paguridae	Hermit crabs	3 to 15 cm
Pandalus montagui	Pink shrimp	3 to 15 cm
Pectinidae	Scallops	3 to 15 cm

Scientific Name	Common Name	SACFOR Scale
Phaeophyceae #1	Brown seaweed	Massive / turf
Phaeophyceae #2	Kelp	>15 cm
Pholis gunnellus	Butterfish	>15 cm
Phrynorhombus norvegicus	Norwegian topknot	>15 cm
Pisces #1	Fish	> 15 cm
Pisces #2	Flatfish	> 15 cm
Pisces #3	Dragonette / flatfish/.	> 15 cm
Pisces #4	Pouting?	> 15 cm
Pisces #5	Dragonette?	>15 cm
Plantae	Brown or red seaweed	Massive / turf
Platyhelminthes	Flat worms	1 to 3 cm
Polymastia boletiformis	A sponge	Massive / turf
Polyplacophora	Chitons	1 to 3 cm
Porifera #1	Branching orange / beige sponge	Massive / turf
Porifera #2	Branching orange sponge	Massive / turf
Porifera #3	Yellow repent sponge	Massive / turf
Porifera #4	Brown branching sponge	Massive / turf
Porifera #5	White branching sponge	Massive / turf
Rhodophyta	Red seaweed	Massive / turf
Sabellaria spinulosa	Ross worm	Crust / meadow
Sabellidae	Fan worms	3 to 15 cm
Scaphopoda	Tusk shells	1 to 3 cm
Scyphozoa	Jellyfish	3 to 15 cm
Securiflustra securifrons	A bryozoan	Massive / turf
Sertularia cupressina	Whiteweed	Massive / turf
Spirobranchus	Keel worm	1 to 3 cm
Tethya aurantium	Golf ball sponge	3 to 15 cm
Thoracica	Barnacles	Crust / meadow
Thuiaria thuja	Bottlebrush hydroid	3 to 15 cm
Triglidae	Gurnard	>15 cm
Trisopterus luscus	Pouting	>15 cm
Tubularia indivisa	Oaten pipes hydroid	Massive / turf

Appendix 3

Sabellaria spinulosa patchiness assessments

Overview

Underwater video tow footage collected from the east coast of Scotland was initially split into five meter segments (based on the total tow length and tow duration) using Bandicut[14] software. This resulted in 518 five-meter segments. Data quality, presence/absence of *Sabellaria spinulosa*, % cover and an estimate of elevation (height) were recorded.

To account for the variation in the camera's field of view along any given video segment, percentage cover and elevation were estimated for each new area of seabed encountered, and then this data was averaged across each segment. This data was then used to determine reef patchiness using the methods developed by Jenkins, Eggleton *et al.* (2018), who define "true patchiness" as:

"a value to represent the propensity of *S. spinulosa* reef to be clustered together rather than to grow uniformly and randomly everywhere"

Applying the Jenkins definition, the size of each patch of *S. spinulosa* observed in a video tow can be calculated by creating a presence variable (defined as 0 if coverage= 0 and 1 if coverage >0). A patch is defined as a continuous series of values of 1 that is ended by a value of 0. For example, for the segment sequence 1 0 0 1 1 1 0 0 1 1 0, the patch sizes will be one, three and two. Any missing values (owing for example to poor video quality) are excluded. Mean patchiness can then be calculated and standardised using the equation, below:

$K = p_o/p_r$

Where p_o is the mean patch size observed and p_r is the mean patch size if the reef presence observations were random (by randomising the data one thousand times and then averaging the 1,000 values). Values of $K > 1$ indicate patchiness considered to be indicative of *S. spinulosa* reef. A *p*-value may be calculated to

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[14] https://www.bandicam.com/bandicut-video-cutter/

test the null hypothesis that the segments in which *S. spinulosa* was observed is random. The *p*-value is calculated from the proportion of times that the mean patch size under randomisation is greater than the observed value (Manly 1998).

Practical application

Step 1. Format data as CSV files

Data recorded from each video segment were summarised in a CSV files as follows;

Segment start	Segment number	%Cover	Pres/abs	QA	elevation
13:55:56	1	40.2	1	1	2.4
13:56:05	2	27.67	1	1	2.2
13:56:17	3	61.33	1	1	2.33
13:56:28	4	52.67	1	1	2.33
13:56:39	5	19.33	1	1	1.6
13:56:50	6	16.5	1	1	2.25
13:57:00	7	19.33	1	1	1.67

% Cover is the average percentage cover of *S. spinulosa* recorded across the segment.

Pres/abs is based on % cover (0 = 0% Cover and 1 = >0 % Cover).

QA is a measure of the video quality and any segments marked as 0 will be stripped out during the patchiness assessment. In this case all segments were assigned a value of one, except those that were noted as being 'Very Poor' in accordance with quality criteria set-out by Turner, Hitchin *et al.* (2016).

Elevation is the average elevation category recorded across a video segment based on the height categories proposed by Gubbay (2007), where 1 = "2-5 cm", 2 = "5-10 cm" and 3 = ">10 cm". *S. spinulosa* height data for each new area of seabed was first categorised and then averaged across the segment.

Separate CSV files were created for each video tow and they were re-named according to the tow number e.g. MF 36 1.

Step 2. Edit *R* Script[15]

Next the following *R* Script was adjusted (in Microsoft Word) to reflect the CSV files that were to be analysed.

Only the text highlighted in yellow needs to be changed each time to direct the programme to the CSV files to be analysed. In the example below two CSV files (NC TO4 and NC T05) are to be selected. More files can be analysed by copying and editing the final section of the *R* Script.

```
patch.score = function(y, cov, el) {
#************************************************************
# Calculates patch lengths and then mean patch score
# Doesn't work if just one patch
#************************************************************
# convert elevation to a height

#y = c(1,0,1,1,1,0)
#cov = c(10,0,20,30,0,40)
#el = c(1,0,2,2,0,1)

el = ifelse(el==1, 3.5, el)
el = ifelse(el==2, 7.5, el)
el = ifelse(el==3, 15, el)

# To get round glitch where doesn't work if all positive
allpos = F
if (sum(y)==length(y)) allpos = T

leny = length(y)
patch = rep(0,leny)
index = rep(0,leny)
```

15 https://www.r-project.org/

```
count = 0; p = 1
for (k in 1:leny) {
if (y[k]==1) {count = count+1; index[k]=p}
if (y[k]==0 & count!=0) {patch[p] = count; count = 0; p = p + 1}
}
if (count!=0) patch[p] = count
patch = patch[patch!=0]
# allow for 'edge' effects at the beginning and end
lenp = length(patch)
if (y[1]==1 & y[leny]==1 & allpos==F)
{patch[1] = patch[1] + patch[lenp]
patch = patch[1:(lenp-1)]
index[index==p] = 1
}
# Calculate magnitude of each patch
# ind identifies the patches

cov = cov[index!=0]; el = el[index!=0]; ind = index[index!=0]
mag = cov * el
mag.patch.mean = tapply(mag, ind, mean)
mag.mean = mean(mag.patch.mean)
score = mean(patch)
list(patch=patch, score=score, mag.mean=mag.mean, mag.patch.mean=mag.patch.mean)
}

elev.pres = c(1,0,2,2,0,1)
pres.pres = c(1,0,1,1,1,0)
cover.pres = c(10,0,20,30,0,40)

patch.score(pres.pres, cover.pres, elev.pres)

patch.stat = function(y, cov, el, nreps=999) {
```

```
#******************************************************************
# Mean patch score divided by mean patch score assuming randomness
#******************************************************************
observed = patch.score(y, cov, el)
score.mean = rep(0, nreps)
for (j in 1:nreps) {
y.ran = sample(y)
score.mean[j] = patch.score(y.ran, cov, el)$score
}
mean.ran = mean(score.mean)
stat = observed$score / mean.ran
bigger = mean.ran[mean.ran >= observed$sc]
pvalue = (length(bigger)+1)/(nreps+1)
list(stat=stat, p.val=pvalue)
}

# ************* NC T04 ******************
data = read.csv("NC T04.csv")

seg = data$Segment.number
cover = data$X.Cover
pres = data$Pres.abs
QA = data$QA
elev = data$elevation

# Patchiness statistic is the mean patchiness score divided by the mean
# score under randomness

# Use QA=0 to strip out rubbish values

arse = !QA==0
pres.pres = pres[arse]
```

```
cover.pres = cover[arse]
elev.pres = elev[arse]

patch.score(pres.pres, cover.pres, elev.pres)
patch.stat(pres.pres, cover.pres, elev.pres)

# ************* NC T05 *****************
data = read.csv("NC T05.csv")

seg = data$Segment.number
cover = data$X.Cover
pres = data$Pres.abs
QA = data$QA
elev = data$elevation

# Patchiness statistic is the mean patchiness score divided by the mean
# score under randomness

# Use QA=0 to strip out rubbish values

arse = !QA==0
pres.pres = pres[arse]
cover.pres = cover[arse]
elev.pres = elev[arse]
patch.score(pres.pres, cover.pres, elev.pres)
patch.stat(pres.pres, cover.pres, elev.pres)
```

Step 3. Run patchiness calculations in *R*.

Once the *R* software is open it is necessary to change the working directory to the file containing your CSV files. Then the edited *R* script can simply be pasted in and the patchiness calculations will run.

R will then output the following values:

$patch
[1] 1 2 1 1
In this example there are four patches which occupy 1, 2, 1 and 1 segments respectively.

$score
[1] 1.25
This is the mean patch size i.e. the average of the 4 numbers listed under $patch.

$mag.mean
[1] 57.75
This is the mean size (elevation x % cover) of the four patches i.e. the average of the 4 numbers listed under **$mag.patch.mean**

$mag.patch.mean

1	2	3	4
150	7	14	60

This is the mean size of each patch per segment (elevation x % cover)

$stat
[1] 1.191461
This is the K statistic which is the mean patch size divided by the mean patch size if the presence of patches was random.

$p.val
[1] 0.001
This is a p-value obtained from the randomisations above. It is the proportion of times that the observed mean patch size is greater than the patch size under the randomisations.

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