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TR473 - Coralline Crag Characterisation

TR473 - Coralline Crag Characterisation

Damien Kirby and Jon Hawes

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Executive summary

Coralline Crag is an erosion resistant outcrop formed of bryozoan and mollusc microfossil debris that protrudes from the seabed in an area off the coast of Thorpeness, near to Sizewell in Suffolk. This bedrock provides an unusual area of hard substrate in an area where the coastal seabed is dominated by soft mobile sands. Acoustic image surveys were carried out around the Coralline Crag to assess whether *Sabellaria spinulosa* reef was present in this area. Reefs are listed under Annex I of The Habitats Directive (European Commission Council Directive EEC/92/43 on the Conservation of Natural Habitats and of Wild Fauna and Flora) as a marine habitat to be protected for their role in harbouring diversity.

Sabellaria spinulosa reef habitat is traditionally mapped using underwater photography (stills and video footage) in combination with samples collected by grabs, trawls and other sampling devices such as side-scan sonar. High turbidity levels in waters around Sizewell preclude the use of traditional light-based camera systems. Historic efforts to survey the area with dive surveys and with specialised cameras designed for use in low visibility have failed, however evidence from grab samples has suggested that if *Sabellaria* reef is present it is likely to be in the area of the Coralline Crag.

Three surveys were carried out between 2016 and 2018 using an ARIS 3000 acoustic imaging camera. This camera utilises 128 high frequency (3MHz) beams to provide high resolution surface imaging in highly turbid waters. An additional multibeam echosounder (MBES) survey was completed in September 2018 to achieve comprehensive benthic surface data for the extent of the Coralline Crag habitat.

Acoustic image survey footage identified 33 sites where reef-like *S. spinulosa* colonies were present. These structures were present in all surveys, spanning a period of 32 months, suggesting temporal persistence.

In accordance with guidance from Gubbay (2007), three physical characteristics were considered to assess whether these features were likely to qualify as 'reef': elevation; spatial extent; and patchiness.

Average worm tube elevation was considered to assess topographic distinctness of the biogenic structures. From these data it was determined that the *S. spinulosa* colonies meet the guidance criteria for low and medium quality reef. In order to assess whether these reef-like structures can be classified as 'reef' habitat it is necessary to determine spatial extent and coverage. The recorded observations of *S. spinulosa* colony presence and absence was analysed using eCognition modelling software to predict where reef structures were likely to occur. However, the model output confidence levels were insufficient for use in determining spatial extent or patchiness.

Footage from the acoustic imaging camera was assessed to determine what proportion of the observed area contained *S. spinulosa* at the minimum coverage to be considered reef. These calculations showed that surface coverage was greatest in the northern and central areas of the survey area.

In conclusion, acoustic imaging survey results represent the best available means for mapping reef habitat when water clarity is low. Evidence collected using this method indicate *S. spinulosa* reef structures are likely to be present upon and around the Coralline Crag outcrops off the coast of Thorpeness, and these formations show a degree of temporal persistence. There is insufficient evidence to say conclusively whether these reef structures meet the three criteria to be classed as Annex I Reef habitat. However, on the balance of evidence and based on the temporal persistence of the *S. spinulosa* structures at the Coralline Crag it is likely that biogenic reef habitats exist. Where evidence gaps mean quantification of the extent of the reef habitat is not possible adopting a precautionary stance is recommended. Therefore, examples of Annex I reef habitat are likely to be present, particularly within the north, central, west and south west regions of the Coralline Crag.

1. Introduction

1.1 Background

1.1.1 Ecological function and conservation

Sabellaria spinulosa is a tube building polychaete worm ubiquitous to large areas of UK subtidal and lower intertidal habitat (UKBAP 2008). It is most commonly found as solitary individuals (Hayward and Ryland 1990; Hendrick and Foster-Smith 2006), however when present in dense aggregations the collective structure of the amalgamated worm tubes creates reef structures.

Sabellaria reefs are listed under Annex I of The Habitats Directive (European Commission Council Directive EEC/92/43 on the Conservation of Natural Habitats and of Wild Fauna and Flora) as a marine habitat to be protected for their role in harbouring diversity.

Reefs created by Sabellariid polychaetes, including those built by *Sabellaria spinulosa*, enhance biodiversity by providing attachment surfaces and refuge or shelter for a variety of marine organisms (Chen and Dai 2009; Brown *et al.* 2001; Jones, Hiscock, and Connor 2000; Dubois, Retière, and Olivier 2002). Pearce *et al.* (2011) demonstrated that the diversity of benthic fauna associated with large reef structures in the North Sea was over five times that recorded from sedimentary habitats. Differences in faunal abundances and diversity between reef structures and surrounding habitats was greatest when *S. spinulosa* tube structures developed on sand deposits. The presence of complex irregular features performs multiple functions such as: attachment surfaces to facilitate colonisation; crevices in structure for refuge from predation; protection from erosion; and reduction in localised flow rate, causing increased deposition of biological material and other food sources (Holt et al. 1998; Steele 1999; Sheppard et al. 2005; Graham and Nash 2013; Johansen, Bellwood, and Fulton 2008).

1.2 Historical assessment of *Sabellaria* reef presence

Guidance for the classification of *Sabellaria* reef structures recommend the use of underwater photography (stills and video footage) in combination with samples collected by grabs, trawls and other sampling devices such as side-scan sonar (Gubbay 2007; Jenkins *et al*. 2018). The high turbidity environment in the waters off the coast of Sizewell preclude the use of underwater photography. Historical diver survey records of the area include no record of reef structures (Bamber and Moore 1995) and trials using a specialised low visibility underwater camera system with freshwater lens to image the benthic habitat have been unsuccessful (BEEMS Technical Report TR248). Side-scan sonar is commonly used to map substantial reef areas; however, this method can miss smaller reef features (Foster-Smith and White 2001).

Due to these difficulties precluding the use of traditional assessment techniques, evaluation of whether reefs are present has previously been based on data from benthic grab samples (BEEMS SPP079).

1.2.1 Summary of grab sample data

The likelihood of *Sabellaria* reef presence at Sizewell has previously been assessed using data from grab samples (BEEMS SPP079). Grab samples were collected from Sizewell coastal sites between 2008 and 2012 as part of the BEEMS benthic ecology characterisation programme. Data from these surveys was used to assess whether *S. spinulosa* densities exceeded the minimum threshold of 500 individuals.m^2 Hendrick and Foster-Smith (2006) associated with the presence of *Sabellaria* reef structures.

S. spinulosa was recovered from the grabs[1] at 22 BEEMS survey stations, but at only 5 of these were there more than 10 individuals over the whole survey series (Station 136, north of Thorpeness and 4 stations around Orford Ness) and only 2 of these were in the region of, or above, the 500 m^2 threshold (457 m^{-2} at station SZ136 in November 2011 and 1,117 m^{-2} at station SZ126 in March 2012).

Abundance recorded from grab samples was highly variable over the four-year series of surveys and there was little evidence of temporal persistence other than in some of the stations local to Thorpeness. Fragments or individuals were recovered from one station (station SZ126) on all four seasonal surveys (2011 – 2012). At another station (station SZ129) three annual surveys (non-consecutive) revealed individuals, and *Sabellaria* was found in two consecutive survey years at stations SZ128 and SZ136.

Various sources assert that *S. spinulosa* require hard substratum upon which to settle and become established (Holt *et al*. 1998; Jones, Hiscock, and Connor 2000; Jackson, A. & Hiscock 2008).

[1] Fragments were obtained from the beam trawls in 2008 and 2011

Despite this, *S. spinulosa* reefs have been recorded in association with large mobile sandbanks (e.g. George and Warwick 1985). It has been hypothesised that settlement is enhanced at the boundaries of rock aggregations, as the recirculation in such areas increases settlement due to the deposition of cells by eddies in the water (Simmons *et al*. 2005). Based on these factors it was hypothesised that if present, *S. spinulosa* would most likely be found on, or at the fringes of the Coralline Crag substrate.

1.2.2 Background on Coralline Crag

The Suffolk coastal seabed is dominated by sandy substrate with large coast-parallel sandbanks. Between Aldeburgh and Dunwich the nearshore coast is characterised by sands, muddy sands and gravels, with extensive areas of gravelly sands and sandy gravels further offshore (Sturt and Dix 2009). BEEMS Technical Report TR087 presents detailed descriptions of benthic substrates in the nearshore area local to Sizewell. Seabed substrate largely consists of a layer of fine sand with narrow stretches of more muddy sediments which run northwards from Sizewell, parallel to the coastline. An area of exposed Coralline Crag bedrock, approximately 4km^2, is present off the coast of Thorpeness, and an area of sand over mud/clay occurs to the east of this.

The Coralline Crag bedrock outcrops are a series of hard substrate ridges extending from below the surface north of Aldeburgh to the coastal headland of Thorpeness and continuing at the sea-bed in a SW-NE direction offshore, east of Sizewell (Lees 1983). These Pliocene Coralline Crag ridges are formed of bryozoan and mollusc microfossil debris, and sand and can be several hundreds of metres long, tens of metres wide, and protrude 1-2 m from the surrounding seabed (BEEMS Technical Reports TR087 and TR475; Lees 1983). The Coralline Crag habitat is a dynamic environment and the extent protruding from the seabed is affected by migration of adjacent sandwaves (BEEMS Technical Report TR457). This natural variation in the location of exposed Crag limit benthic communities to organisms capable of recovering from habitat loss and colonising newly available substrate.

1.3 Existence of Coralline Crag reef habitat

This report explores the likelihood that the *S. spinulosa* colonies off the Thorpeness coast meet the criteria that define biogenic reefs. However, Annex I reef habitats also encompasses bedrock reefs. Bedrock reefs are defined as “hard compact substrata on solid and soft bottoms, which arise from the sea floor in the sublittoral and littoral zone” (European-Comission 2013). The Coralline Crag formations are solid rock formations that protrude 1-2 m above the surrounding seabed (BEEMS Technical Reports TR087, TR475). The exposed area of Coralline Crag therefore qualifies under this subcategory.

It is important to differentiate between biogenic and bedrock reefs because they differ in sensitivity to external pressures such as chemical contamination or thermal variation. However, the presence of both types increases the conservation importance of the area.

2. Survey Methods

2.1 Data collection

Benthic mapping surveys were completed during four survey visits in 2016 and 2018 (Table 1). Seabed imagery was collected using a Seatronics ARIS 3000 acoustic imaging camera fitted with an ARIS Rotator AR2, to allow complete 360° imaging of the surrounding area. The imaging system operates through 128 beams at 3 MHz to provide image clarity in turbid waters. The camera is mounted within a 0.8 m^3 stainless-steel frame (Figure 1). At each station the camera unit was deployed whilst the vessel held station as far as possible. Camera rotation was directed in real time by survey crew to capture the surrounding seabed. In instances when seabed imagery was unclear, due to the orientation of the frame upon the seabed, the frame was raised and redeployed.

Table 1: Details of survey activities across all years.

Date	Survey type	Vessel
16th February 2016	ARIS acoustic imaging survey	Our Josie Grace (fishing vessel)
12-13th June 2016	ARIS acoustic imaging survey	Our Josie Grace (fishing vessel)
13-17th September 2018	Multibeam survey	FPV Morven (survey vessel)
3-4th October 2018	ARIS acoustic imaging survey	Seren Las (survey vessel)

The initial exploratory survey (16th February 2016) collected images from 24 sites, which were selected based on results of historical grab samples and bathymetric information of the area. Target locations incorporated soft sediment areas, areas on the hard substrate Coralline Crag outcrops and points where *Sabellaria* worms have been recorded in grab samples. A more extensive follow up survey was carried out in June 2016. Data from the February survey indicated that reef-like structures were present around the Coralline Crag outcrops. In accordance with this, in the July 2016 follow up survey a greater density of survey stations were located in areas where Coralline Crag was present (250 m spacing), than in the surrounding areas of soft substrate habitat (400 m spacing) (see Figure 2 for illustration of survey grid).

To contextualise survey images in relation to a known physical reference object, a model section of reef, 13 cm long, 7 cm wide and 7 cm high was built and recorded with the ARIS camera (Figure 4). The model reef was primarily made from plastic tubes to replicate the thin walled worm tubes and air chambers within. ARIS footage of the reef model also allowed verification of the inbuilt measurement tool in the image processing software. The software function calculates distance from the camera lens to observed objects and measured the model as 12 cm long and 7 cm wide from *in situ* underwater footage at a distance of 1.7 m. The close agreement between the calculated and measured dimensions support the use of this tool in image processing.

Figure 1: Frame and acoustic imaging camera setup used in field surveys. Frame is lowered to seabed and the camera rotated 360° and tilted up or downwards remotely by survey crew aboard the vessel.

In September 2018 a multibeam echosounder survey was carried out to provide detailed bathymetric and backscatter data for the area of seabed containing the exposed Coralline Crag. The resultant seabed imagery was used in the selection of targets for the October 2018 acoustic imaging survey (Figure 3). Survey sites targeted Coralline Crag edges, where the hard substrate transitioned to adjacent sandy substrate, as this was where reef-like structures had been primarily observed in the 2016 data. The presence of static fishing gear (pots) and drift nets precluded access to some target locations. On these occasions the target was relocated to the nearest site further along the Coralline Crag edge that could be accessed safely.

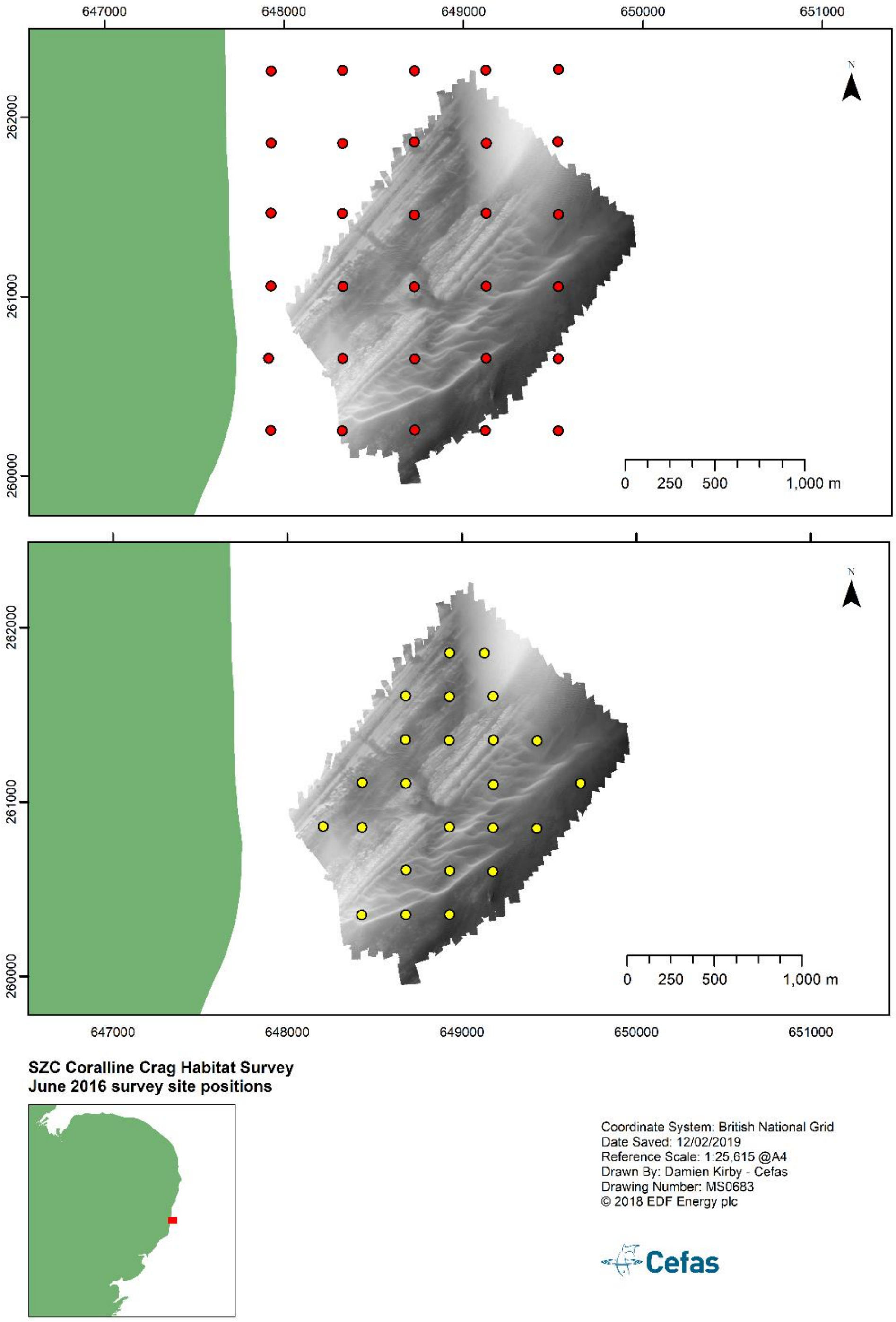


Figure 2: Location of sampling stations targeted in June 2016 acoustic imaging monitoring survey. Red dots (top) show 400 m spaced grid, and yellow dots (bottom) show additional higher density (250 m spaced) stations in areas where Coralline Crag was present.

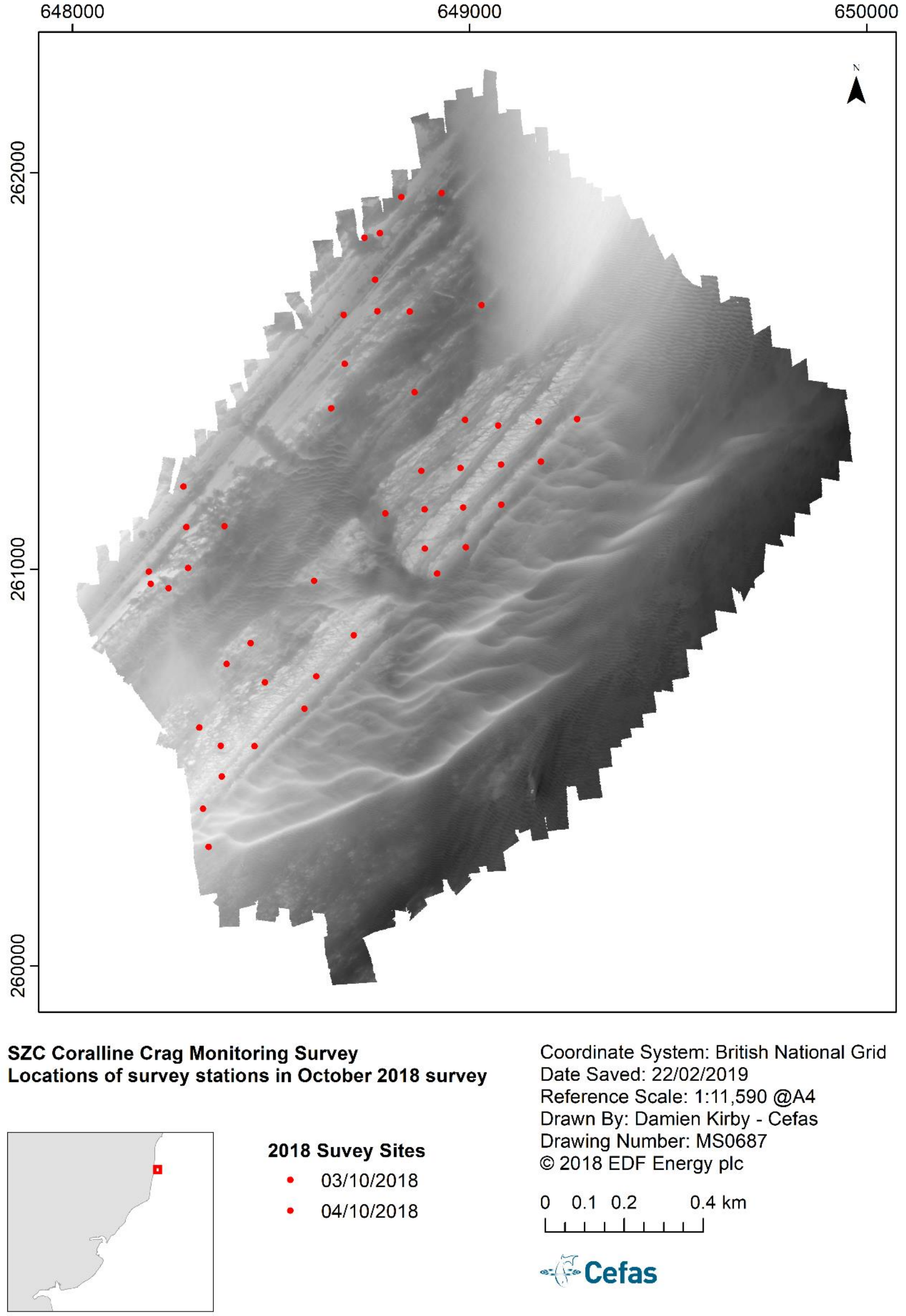


Figure 3: Location of sample stations surveyed in October 2018 acoustic imaging survey

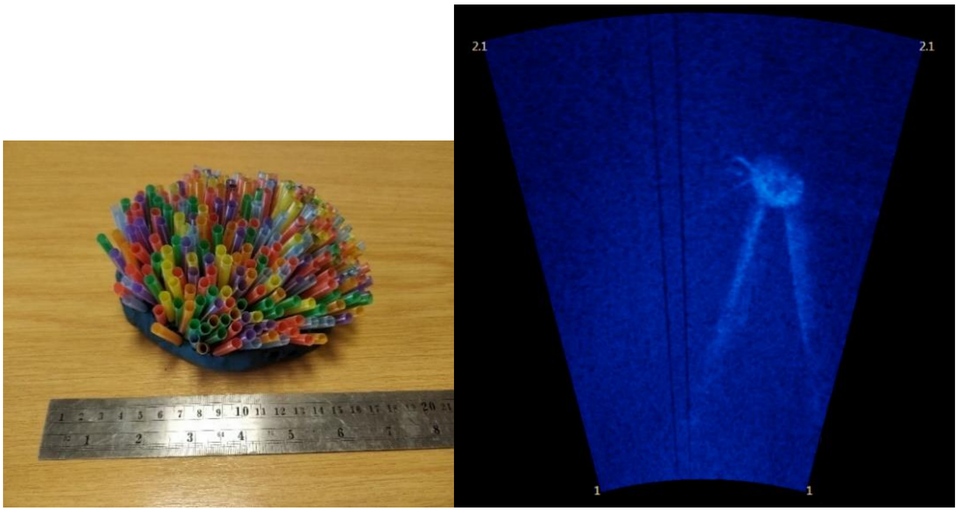


Figure 4: Section of model reef used to ground truth acoustic image footage and measurements (left) and *in situ* footage of the model recorded using the acoustic imaging camera (right).

2.2 Data processing

Sabellaria spinulosa elevation was estimated from acoustic image footage and used to categorise observed colonies by the average height of tube structures (Table 2).

To quantify the proportion of total survey area that contained *S. spinulosa* colonies at the minimum spatial coverage for classification as 'reef', the following metric was calculated for survey footage at each station:

$$\textbf{Proportional coverage} = \frac{\boldsymbol{S.spinulosa}\ \textbf{present in 10\% of the field of view X coverage or above (degrees)}}{\textbf{Total field of view extent (degrees)}\boldsymbol{a}}$$

Equation 1

Camera field of view was defined by the number of degrees the acoustic imaging camera rotated whilst S. spinulosa reef-like structures remained present in the image central axis at a sufficient coverage.

10% coverage represents the minimum threshold for classification as reef in guidance from Gubbay (2007)

Table 2: Categorisation of *S. spinulosa* into height classes in accordance with (Gubbay 2007). Average elevation height category was used for instances where a range of *S. spinulosa* elevations were observed. Data includes surveys carried out in February and June 2016 and in October 2018.

Survey	Total number of sites	Number of sites where *S. spinulosa* reef like structures was observed	Number of low elevation structures (2-5 cm)	Number of medium elevation structures (5-10 cm)	Number of high elevation structures (>10 cm)
February 2016	24	2	1	1	0
June 2016	59	10	8	3	0
October 2018	48	21	7	14	0
Total	**131**	**33**	**16**	**17**	**0**

High resolution multibeam echosounder (MBES) bathymetry data were collected and a backscatter (acoustic reflectance) image produced, derivatives of these bathymetry data were calculated. These data were all collected with reference to the WGS84 datum, projected to UTM Zone 31N. Predictive mapping of potential *S. spinulosa* habitat was undertaken using the acoustic data as detailed above, alongside the additional ground-truth data (ARIS sonar) as collected by several dedicated surveys (Table 1) (multiple ground truth points form single stationary deployments were aggregated into a single “Sabellaria” or “Not Sabellaria” class. The process is a combination of two approaches, statistical modelling and object-based image analysis (OBIA).

OBIA is a two-step approach consisting of segmentation and classification (Blaschke 2010), implemented in the software package eCognition® v9. The bathymetry data, backscatter image and topographic derivates (Topographic Roughness Index [TRI]; and mean negative openness thresholds) were fed into a segmentation algorithm, which partitions the data into objects (sections of the image with homogenous backscatter, bathymetry and topographic characteristics). For each object, mean values of the primary acoustic data layers and their derivatives were calculated and input into a conditional inference tree model, alongside the ground truthing data. This allowed for accurate selection of those metrics which best predict *Sabellaria* occurrence. The statistical analyses were carried out in the statistical programming environment R (R Development Core Team, 2012). A detailed methodology for production of the predictive habitat map is provided in Appendix A.

3. Results

3.1 Acoustic image data

Images collected during the February 2016 exploratory survey identified *S. spinulosa* structures in 2 of the 24 sample locations. These structures were located in the northern corner of the Coralline Crag outcrops, at the transitional edge from exposed bedrock to sandy substrate. In June 2016, *S. spinulosa* structures were identified in 10 of the 59 stations visited. The samples where *S. spinulosa* structures were present were similarly located at the edge of Coralline Crag outcrops, where the exposed bedrock transitioned to sandy substrate.

Accordingly, the 2018 survey targeted transitional edges of the Coralline Crag rock outcrops. Acoustic image data showed evidence of similar structures in 21 of the 47 sample stations. Mapping the locations of observed reef-like structures across all surveys (Figure 5) shows a degree of spatial grouping. Four geographical groups were identified and highlighted on the map. The locality of points within each group suggest they may comprise an extended area of reef.

Tube structures were reef-like and showed a variety of physical forms. In some cases, large extensive structures were present which formed topography highly distinct to the surrounding seabed (see Figure 6). These larger structures often occupied the full camera field of view (approximately 2.3 by 1 metres). Additional smaller formations were commonly found, ranging from smaller clumps (5-10 long by 5-10 cm wide) intermittently distributed within the field of view, to larger isolated hummocks (50-100 cm L by 50-100 cm W) (see Figure 7). *S. spinulosa* was also observed as a layer covering larger rocks or boulders. Although these were typically large and elevated from the surrounding seabed, the tube structures themselves only raised ≤5 cm in height from the rock surface (see Figure 8).

Geographical representation of these data illustrates how proportional coverage is greatest in the northern survey positions (Figure 9). A proportional coverage value of 1 (Equation 1) was recorded at six stations in the north and two in the central area, indicating patches approximately 4 m in diameter or larger.

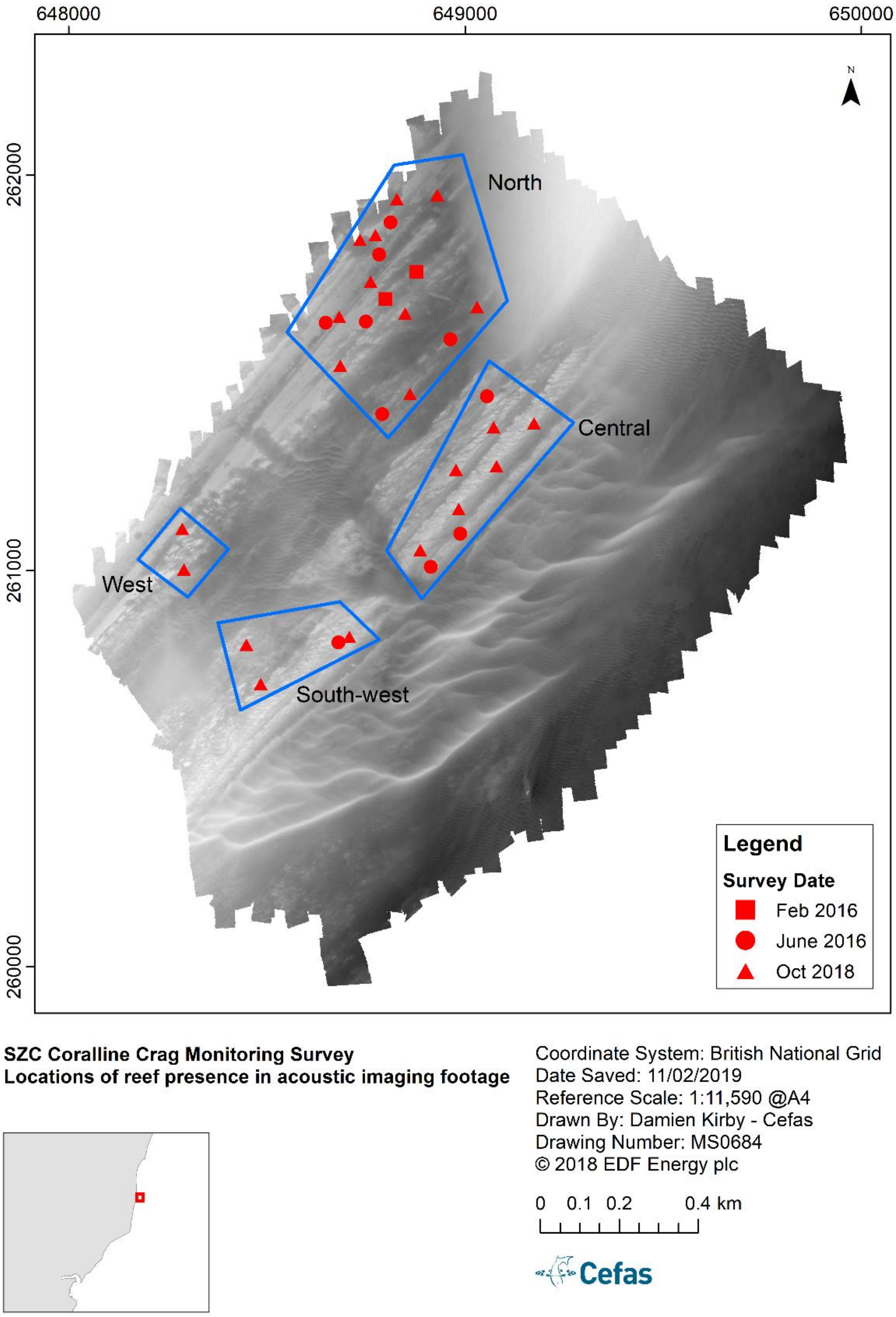


Figure 5: Map showing the location of survey sites for monitoring surveys in February 2016, June 2016 and October 2018. Blue polygons show four areas of reef presence identified in results.

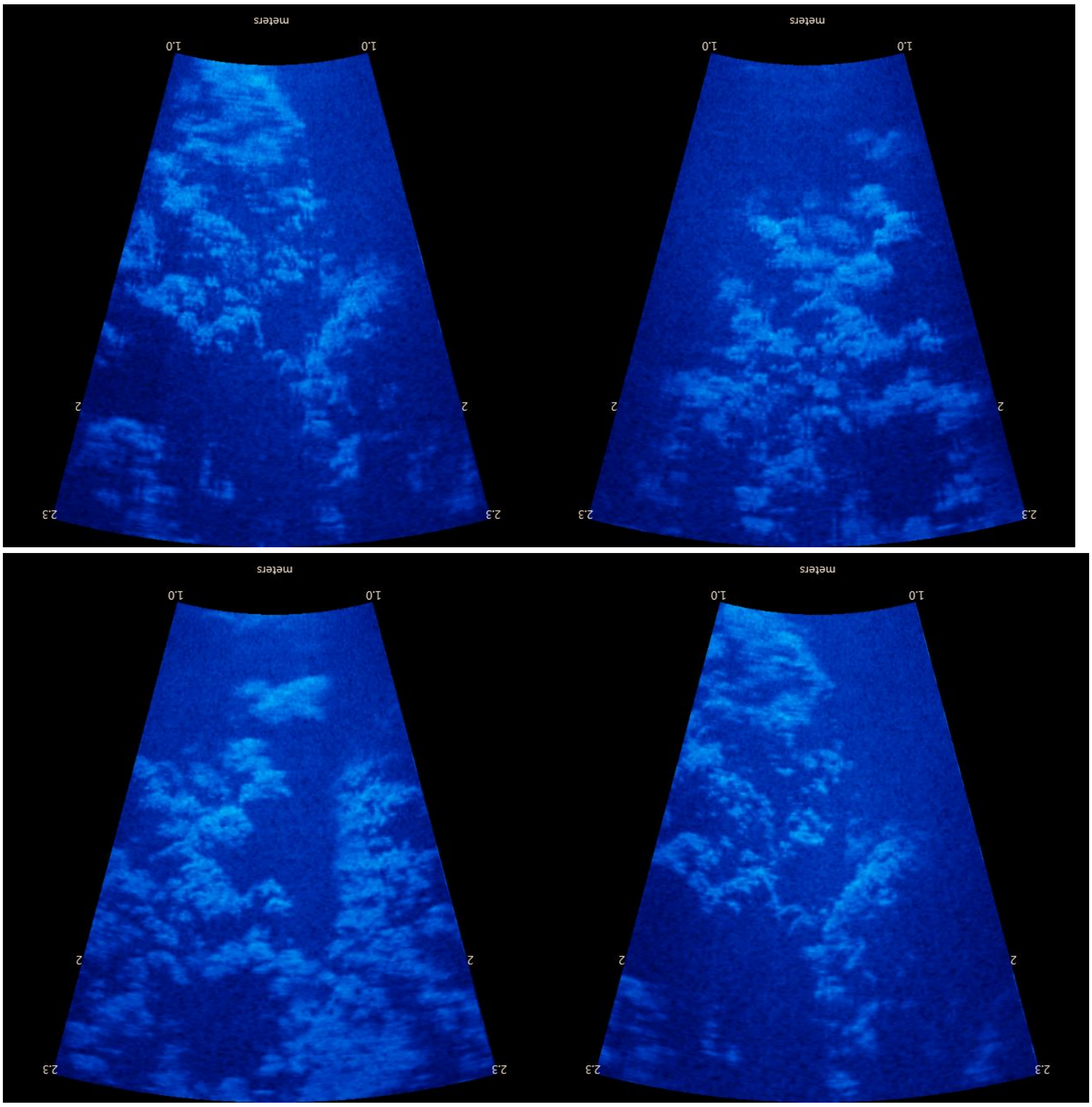


Figure 6: Example images of large *Sabellaria spinulosa* aggregations identified in acoustic imaging footage.

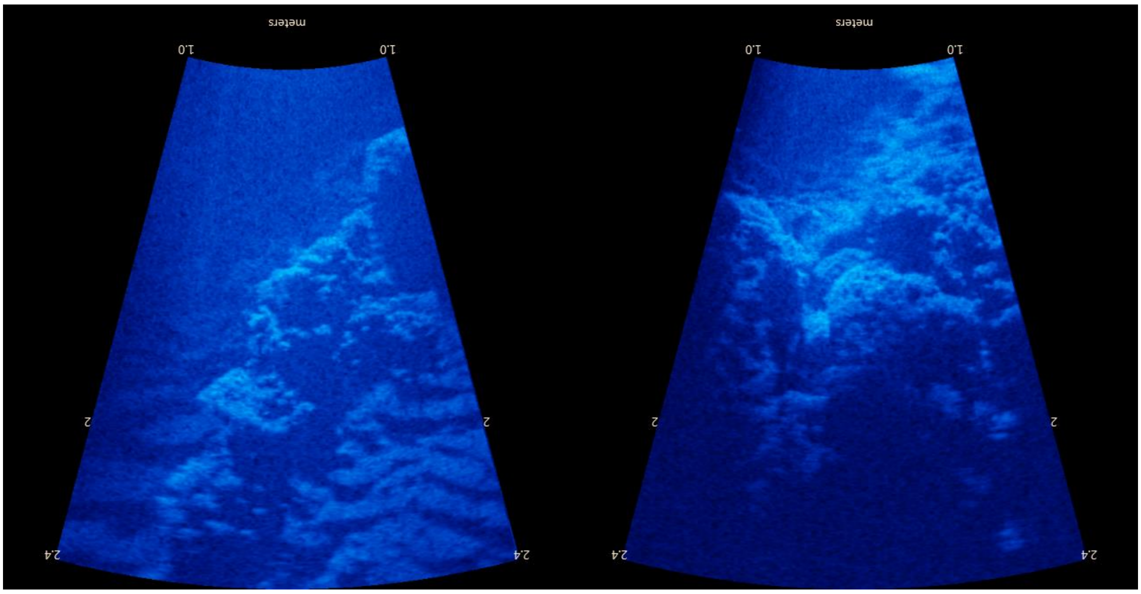


Figure 6 cont.: Example images of large Sabellaria spinulosa aggregations identified in acoustic imaging footage.

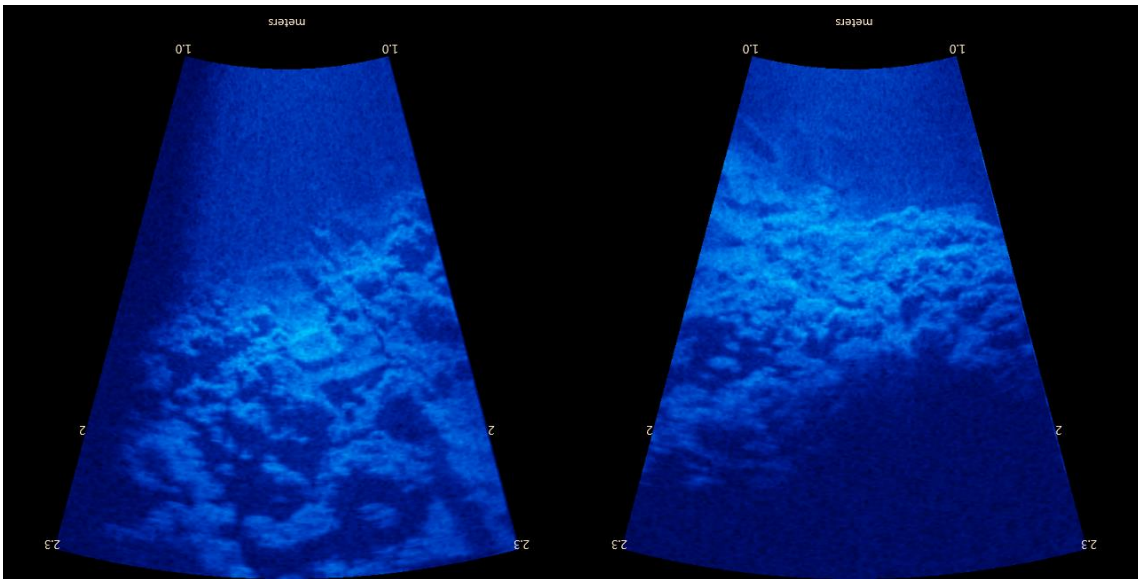
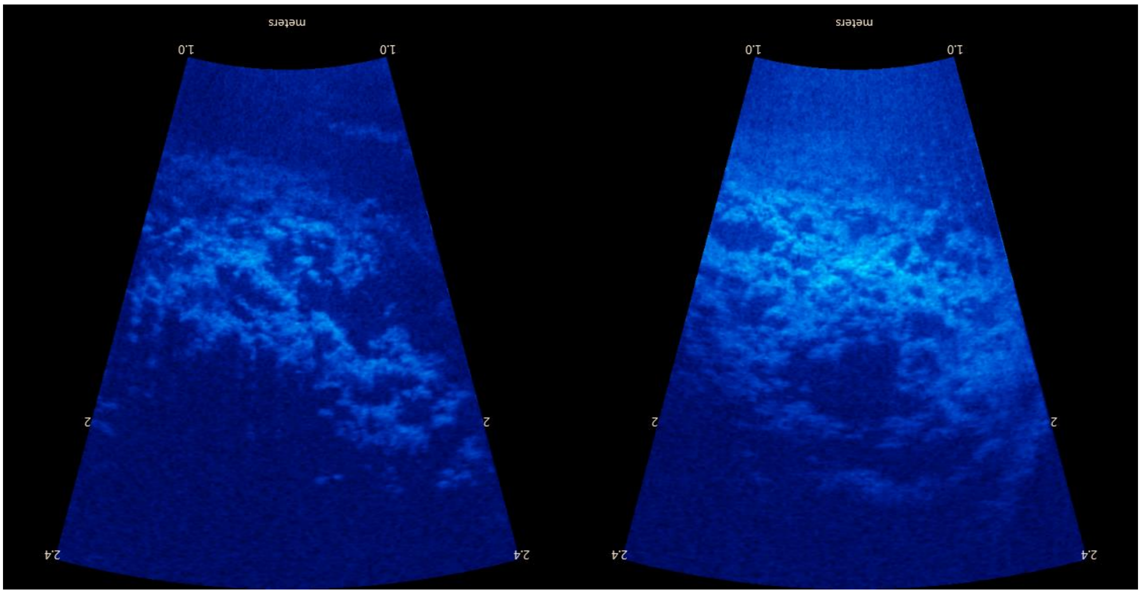


Figure 7: Example images of smaller *Sabellaria spinulosa* clumps and hummocks identified in acoustic imaging footage.



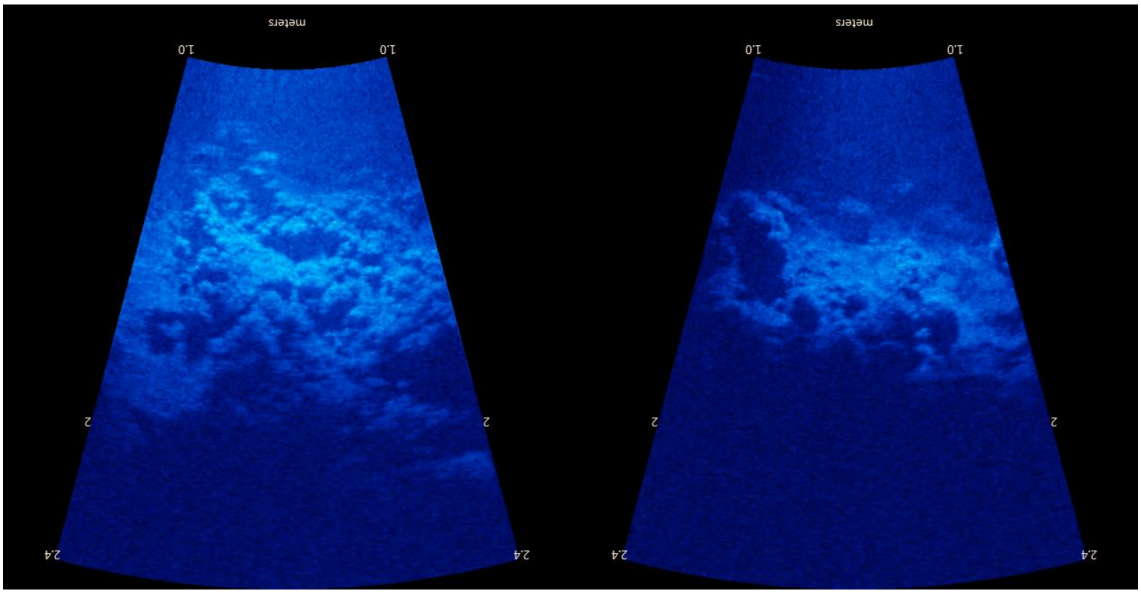
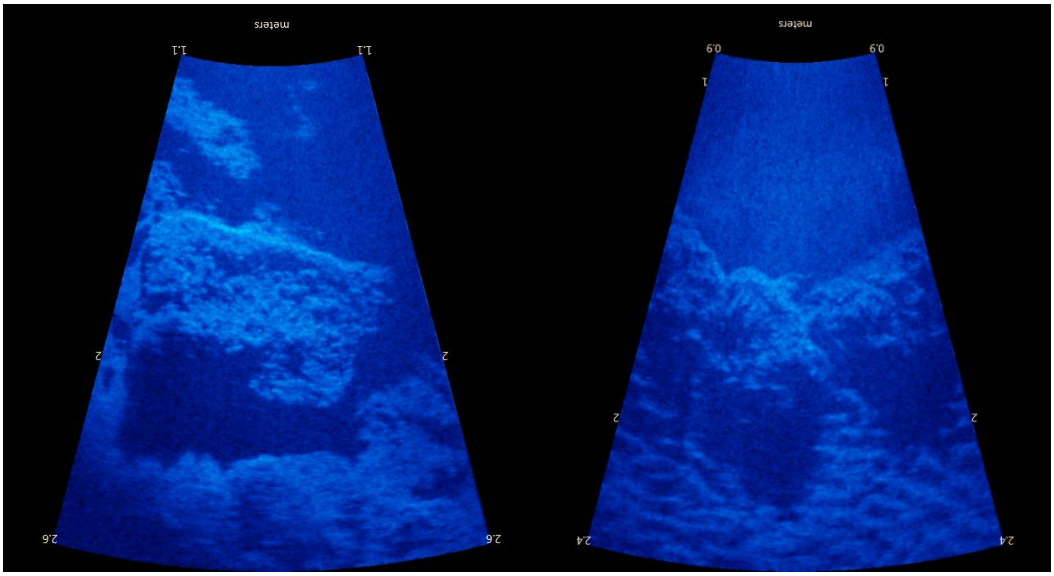


Figure 7 cont.: Example images of smaller Sabellaria spinulosa clumps and hummocks identified in acoustic imaging footage.



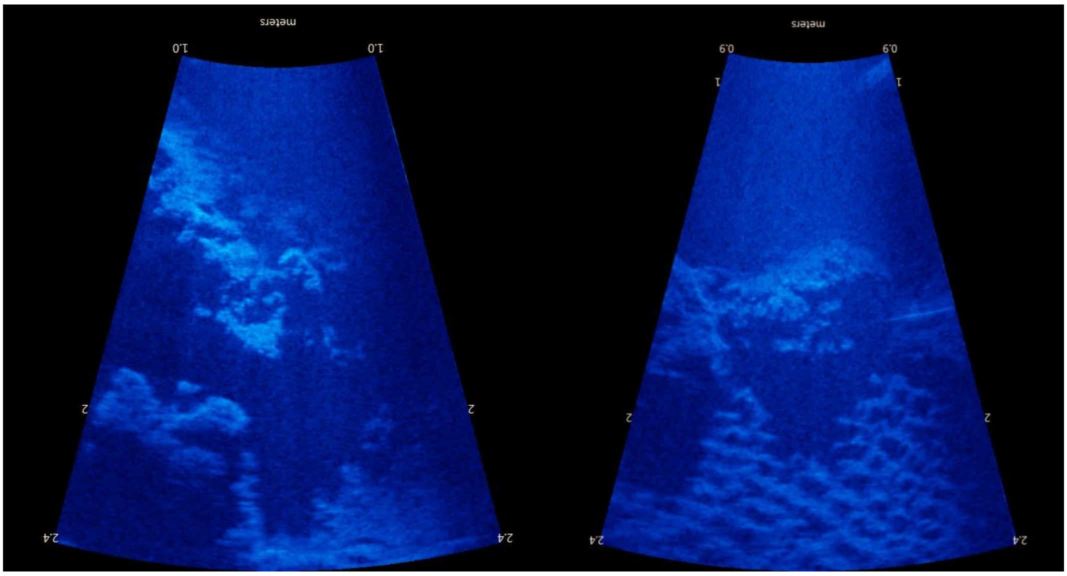


Figure 8: Example images from acoustic image footage of *Sabellaria spinulosa* forming thin covering layer on rocks or boulders present on the seabed.

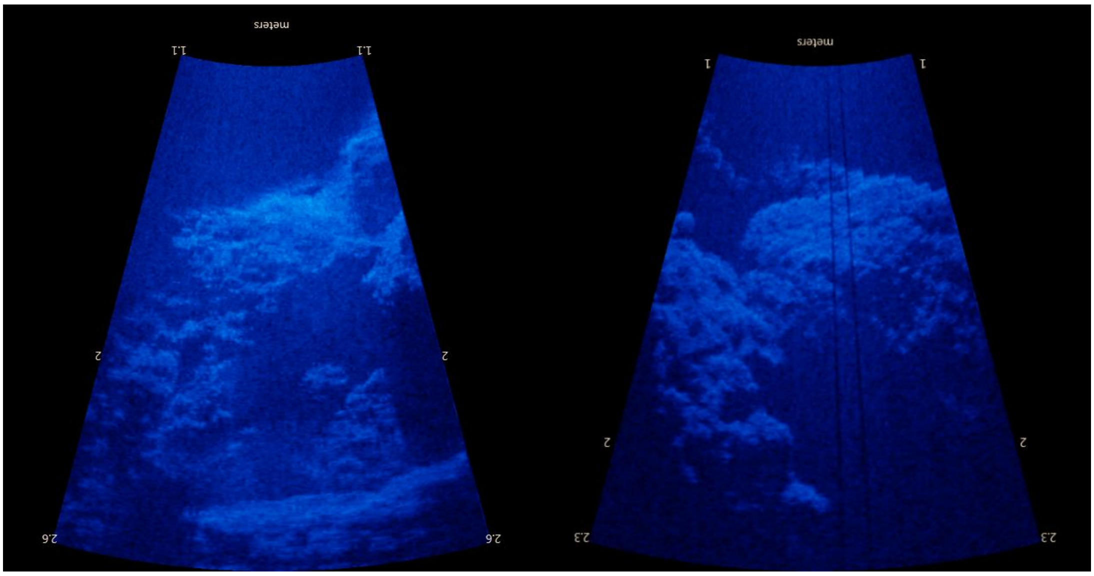


Figure 8 cont.: Example images from acoustic image footage of Sabellaria spinulosa forming thin covering layer on rocks or boulders present on the seabed.

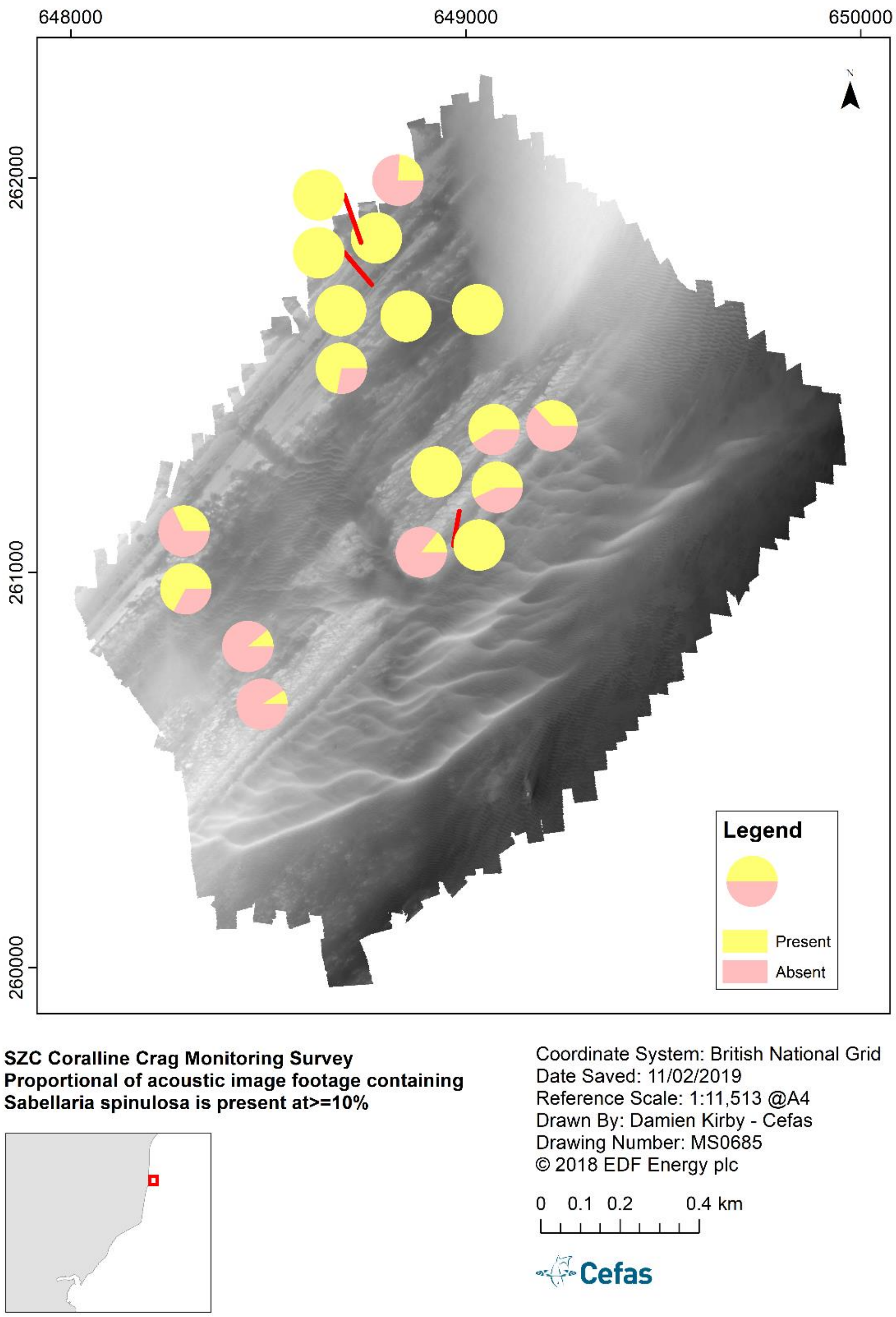


Figure 9: Proportion of acoustic image footage containing *Sabellaria spinulosa* reef at a spatial coverage ≥10% of the field of view. Red lines are leader lines showing the sample location when charts overlap.

3.2 eCognition modelling

Bathymetric derivatives from the multibeam echosounder (MBES) data were input into eCognition to produce a predictive model for *S. spinulosa* presence. Backscatter intensity was found not to be a good indicator of *Sabellaria* presence / absence. As such, the best predictor was a fine scale derivative of the bathymetry data (Topographic Roughness Index (TRI)), specifically the mean TRI at 10 pixels. The threshold for using this metric as a predictor provided by the conditional inference tree was >0.064.

When this threshold was used applied, it allowed for a good discrimination between the areas likely to have no *Sabellaria*, and those likely to contain *Sabellaria*. Further delineation was achieved using a manually derived slope thresholds of < 0.095, primarily to remove those larger sand wave features which can be confidently ruled out as potential *Sabellaria* habitat. This produced the "*Sabellaria* Reef - Moderate Probability" class. The "*Sabellaria* Reef- High Probability" class took the Moderate class polygons and ran a further threshold using the derivative "Mean Negative Openness" at a threshold of ≤ 1.51. This derivative was the second most correlated predictor to be outputted from the conditional inference tree model, and was thought therefore to add a further degree of discriminative power to the prediction. The remaining polygons were considered to be "Uncertain".

The distribution of the "High Probability" class polygons indicates and increased likelihood of *Sabellaria* presence within these areas. It does not provide a definitive extent. The 'Moderate Probability' class indicated a lower probability of *Sabellaria* presence therein.

Validation of the map was undertaken using the ground truth data, overlain onto the predictive shapefile within Arc Map 10. Class values form the map were then extracted and compared with the ground truth data classes. The map was found to have a predictive accuracy of ~67%. Although this value demonstrates that the model provides good assessment of areas where Sabellaria is likely to be found, a 33% error rate is too high to allow accurate estimation of spatial extent.

The eCognition analysis model produced a map illustrating likely *S. spinulosa* reef habitat (Figure 10). The map output illustrates that *S. spinulosa* reef is most likely to be found in hard substrate areas where the Coralline Crag bedrock is exposed. The areas where reef presence is predicted with a high confidence largely corresponds with sites where reef was observed in survey images. However, additional sites have been identified from seabed topographical data that were not targeted with acoustic imagery drops. Whilst the uncertainty of model did not allow quantification of *S. spinulosa* spatial extent it did allow an indicative estimate of the extent of potentially viable habitat for reef colonisation. 13 % of the total area (279,568 m^2) was classified as having a high probability of supporting *S. spinulosa*, 11 % was classified as moderate probability (244,830 m^2) and 10 % was classified as having an uncertain probability of containing *S. spinulosa*. The remaining 66 % was classified as unlikely to contain *S. spinulosa*.

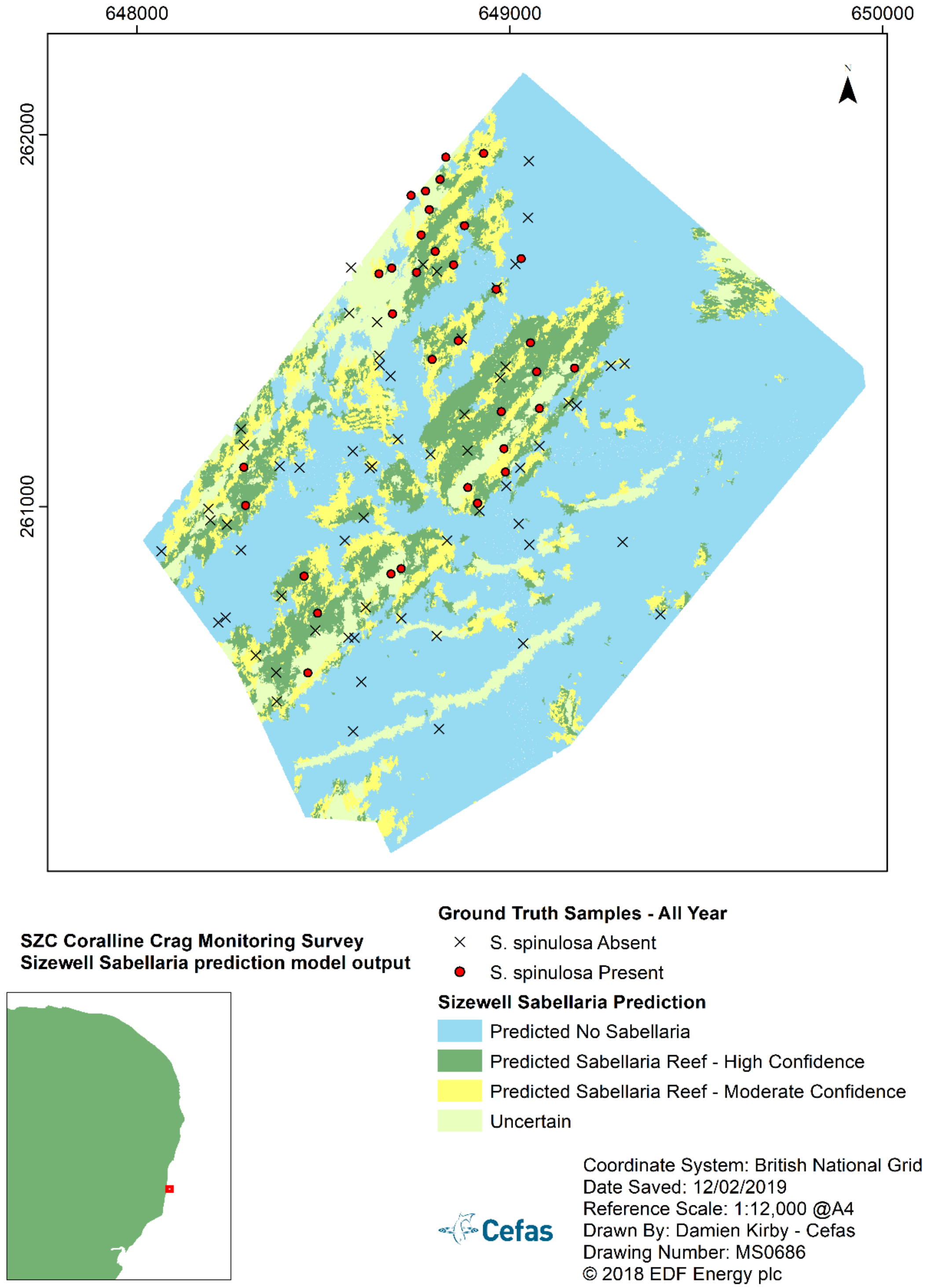


Figure 10: Output from eCognition model of predicted *Sabellaria spinulosa* habitat.

4. Discussion and Conclusions

Analysis of ARIS footages identified *S. spinulosa* aggregations in each of the three monitoring surveys. These have taken place over a period of 32 months, indicating temporal persistence. Worm tube aggregations ranged from small clumps and hummocks arising a few centimetres from the seabed, to large reef-like structures extending over tens of square metres.

Gubbay (2007) presented criteria to define *S. spinulosa* reef habitat within the context of Annex I listed habitats that qualify for conservation designation under The Habitats Directive. This guidance defined *S. spinulosa* reef as "an area of *Sabellaria spinulosa* which is elevated from the seabed and has a large spatial extent. Colonies may be patchy within an area defined as reef and show a range of elevations". The definition is expanded to identify the three physical characteristics as primary means to define a reef habitat (Table 3).

Table 3: Criteria proposed by Gubbay (2007) for the classification of reef habitats in accordance Annex I of The Habitats Directive. Table includes thresholds for qualification as reef and for each of the 'low', 'medium', 'high' subdivisions therein.

Measure of 'reefiness'	Not a reef	Low	Medium	High
Elevation (cm) (*Average tube height*)	<2	2-5	5-10	>10
Spatial extent (m^2)	<25	25-10,000	10,000-100,000	>1,000,000
Patchiness (% of overall spatial extent occupied by worm tube aggregations)	<10	10-20	20-30	>30

4.1 Elevation

EU guidance for interpretation of The Habitats Directive states that reefs are concretions that "arise from the seafloor". This topographical distinctness is a key mechanism through which reefs impart beneficial characteristics on the local environment, and tube height is used as a quantitative proxy for this. Gubbay (2007) recommended the consideration of average tube height rather than maximum height when characterising reef features and provides the cut-off points to differentiate between low, medium and high reefs (Table 3).

The *Sabellaria* observed in acoustic image footage was evenly divided between 'medium' (17 survey stations) and 'low' (16 survey stations) elevation categories. Isolated areas of 'high' *Sabellaria* reef was recorded on three occasions, however the guidance advises the use of average tube heights rather than maximum, and therefore these small areas of 'high' reef could not be considered representative of the site as a whole.

The scarcity of 'high' elevation structures offers explanation why these have not been recognised in previous lower resolution MBES or side-scan surveys. Although the observed *S. spinulosa* tube aggregations do not qualify as 'high' quality reef under this criterion, the additional topographic complexity offers valuable shelter and refuge for benthic communities.

4.2 Spatial extent

The present report recognised four areas within which *S. spinulosa* reef is found (north, central, south-west and west). Hendrick and Foster-Smith (2006) consider how the indistinct boundaries between *Sabellaria* reefs present difficulties in determining spatial extent and suggest that a variety of sampling and detection techniques are required for successful differentiation. For this reason modelling approaches were undertaken to augment the stationary deployments of the acoustic imaging camera.

The *Sabellaria* habitat map was produced using a classification model in eCognition, the ground truth data from ARIS footage was used to determine which data layers and their corresponding threshold values were most correlated with *S. spinulosa* presence (see Appendix A for detailed description of methodology). In addition to thresholds for derivatives as output by the predictive model, the habitat map also incorporated a manually derived slope threshold. This threshold was applied to discount large sandbanks predicted as potential habitat. *Sabellaria spinulosa* aggregations have not been found in any sandy substrate stations captured during the 2016 or 2018 surveys (59 survey stations) and therefore it is considered likely that reefs are not present in these areas. The prediction of *S. spinulosa* aggregations on large sandbanks, where these structures are not thought to occur, demonstrates that the autonomous selection of derivatives requires further refinement to identify suitable habitat more accurately. Validation of the model results showed a predictive accuracy to be 67%. The model made both type I and type II errors[2] in as far as *Sabellaria* was predicted to be absent in one third of the locations that it was identified in ground truth data and was predicted to be found in areas where *in-situ* sampling suggests it was not present.

Although spatial extent cannot be accurately quantified, there is evidence that *S. spinulosa* reef-like structures are present over a substantial area. Density of worm tube structures was greatest in four regions (north, central, south-west and west), the largest of which (in the north of the survey area) extends over approximately 600 x 400 m. Within this area *S. spinulosa* structures of low or medium elevation were recorded at 18 of 24 survey sites. The central region measured approximately 550 x 200 m and 9 of 18 stations contained low or medium elevation reef. Guidance on reef classification (Gubbay 2007) stipulates that a spatial extent of 25-10,000 m^2 qualifies as 'low reef' and 10,000-100,000 m^2 qualifies as 'medium reef' (Table 3). Although the four described regions may not be distinct uninterrupted areas of *S. spinulosa*, the density of survey observations provide confidence that tube structures are present over areas at least equal to low spatial extent reef and potentially sufficient for classification as 'medium'.

4.3 Patchiness

Sabellaria spinulosa coverage is not 100% even within large high-quality reefs and a degree of patchiness should always be expected (Gubbay 2007; Hendrick and Foster-Smith 2006). Patchiness is an important attribute to measure, as it allows differentiation between a large reef or a series of smaller reefs.

The uncertainties in inferring reef coverage from the eCognition model output precludes determination of patchiness. The modelled prediction of *S. spinulosa* reef coverage is a good representation of the areas where reef structures are likely to be found. However, the model is limited in its capacity for differentiating areas of exposed Coralline Crag from *S. spinulosa*, and it is not possible to establish what proportion of the wider reef extent is occupied by actual reef structures. As such, the area recognised as reef is likely to be an overestimation. The limitations in predictive accuracy for this region results from a shortage of 'no reef' observations within the Coralline Crag footprint. In order to improve the model's capacity to distinguish between reef and bedrock it would be necessary to collect additional survey images of rock locations where reef was not present.

A further potential means for determining patchiness would be to collect imaging data from a series of closely distributed points along a transect within the area identified in the model as having a 'high' likelihood of containing *S. spinulosa* reef structures. This would provide additional training data for the model but also provide data to quantify patchiness independently from the model: where a transect is situated within a known area of *Sabellaria* reef, the proportion of sample sites containing reef structures can be used as a measure of overall patchiness.

Although the reef habitat predictive model does not effectively differentiate between reef patches and adjacent interstitial spaces, footage from acoustic imaging camera does allow quantification of patchiness on a localised scale. In instances where reef-like structures were present, the proportion of footage in which they were observed was calculated to provide a proxy of patchiness. As discussed in Section 4.2, locations where *S. spinulosa* reef-like structures were present can be divided between four areas (Figure 5). A higher proportion of survey footage contained reef-like structures at stations in the north and central regions (Figure 9), indicating that reef-like patches are larger in these regions. *S. spinulosa* colonies were registered in more samples in the north and central regions and as such the greater degree of patchiness in the west and south west regions suggest that reef-like structures are less abundant in these areas.

Footage from the ARIS acoustic imaging camera demonstrate that *S. spinulosa* coverage is sufficient to qualify as 'reef' within the camera field of view, particularly at sites in the north and central regions. At these sites patchiness is sufficient to qualify as reef under the guidance stipulated in Table 3. However, acoustic imaging data are localised. The weight of available evidence allows reasonable conclusion that reef habitat exists, patchiness cannot be quantified for the wider Coralline Crag extent.

[2] Type I and type II errors are statistical terms to describe false positive and false negative results. A type I error is to falsely conclude the existence of something that is not there; a type II error is to falsely infer the absence of something that is present.

4.4 Conclusions

Survey evidence indicate *Sabellaria spinulosa* structures are likely to be present upon and around the Coralline Crag rock outcrops off the coast of Thorpeness. These formations show a degree of temporal stability, having been observed in monitoring surveys in both 2016 and 2018.

Guidance for the classification of reefs in accordance with The Habitats Directive stipulate minimum thresholds in three categories: elevation; spatial extent; and patchiness within this spatial extent. Acoustic imaging video footage show that where reef structures are present they can be classified as 'low' or 'medium' reef in terms of elevation and as such topographic distinctness. At 33 sample locations within the Coralline Crag site *S. spinolosa* structures were observed that met the reef criteria for topographic elevation (21 of 47 in 2018). Whilst, it is not possible to directly quantify the spatial extent or patchiness of the structures it is likely that they achieve qualifying criteria for a reef.

On the balance of evidence and based on the temporal persistence of the *S. spinulosa* structures at the Coralline Crag it is likely that biogenic reef habitat exists. Where evidence gaps mean quantification of the extent of the reef habitat is not possible adopting a precautionary stance is recommended. Therefore, it is likely that Annex I reef habitat *is* present on the Coralline Crag formation, particularly within the north, central, west and south west regions identified in Section 4.2 (Figure 5).

The uncertainty associated with habitat classification reflects the difficulties in mapping benthic environments to high resolution where water clarity is particularly low. High turbidity levels preclude the use of traditional light-based imaging systems (Foster-Smith and White 2001) and historical surveys using divers have not distinguished reef structures in this area (Bamber and Moore 1995). Additional trials with specialised underwater light-based cameras, designed for highly turbid waters, have failed to produce any useful images of the seabed (BEEMS Technical Report TR248). The survey methods presented herein represent the best available techniques for detection of *S. spinulosa* in the turbid waters off the Sizewell coast. The use of novel survey techniques identified elevated tube aggregations that were previously unknown and these reef-like structures could be classified as reef subject to acceptable spatial characteristics.

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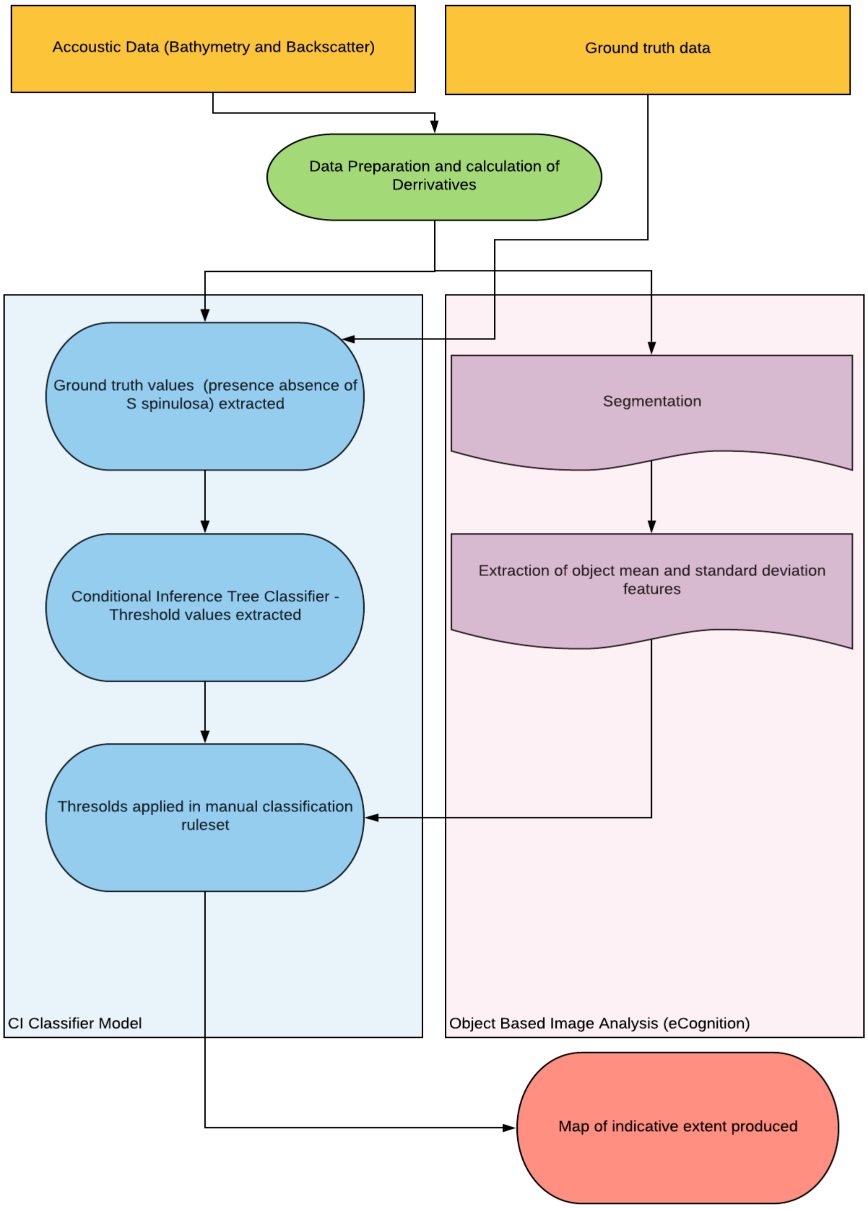
Appendix A

Methodology for Production of *Sabellaria spinulosa* Predictive Habitat Map
High resolution multibeam (MBES) bathymetry data were collected and a backscatter (acoustic reflectance) image produced, derivatives of these bathymetry data were then calculated. These data were all collected with reference to the WGS84 datum, projected to UTM Zone 31N. Predictive mapping of potential *Sabellaria spinulosa* habitat was undertaken using the acoustic data as detailed above, alongside the additional ground-truth data (ARIS sonar) as collected by several dedicated surveys (multiple ground truth points form single stationary deployments were aggregated into a single “Sabellaria” or “Not Sabellaria” class. The process is a combination of two approaches, statistical modelling and object-based image analysis (OBIA).



Derivatives were calculated from the bathymetric data created using the SAGA package in QGIS v3.2, and incorporated into the eCognition project (not used within the segmentation). The derivatives layers (are detailed below:

Derivative	Description
Slope	The slope in degrees using the maximum change in elevation of each cell and its 8 neighbours
Relative Slope Position	indicates the relative position of any cell from the lowest point that water from it would flow to. It is represented as a proportion above the lowest point, which is at 0. A value of 1 indicates a top of a ridge
Positive and Negative Openness	These metrics express 'the degree of dominance or enclosure of a location on an irregular surface'. A lower Negative Openness infers a more dominant position of the cell (i.e. less enclosed by surrounding bathymetric features)
BPI (25)	Bathymetric position index (Lundblad *et al*., 2006); radius of 25 cells
TRI*	Terrain ruggedness index (Wilson *et al*., 2007); radius of 10 cells
Aspect	Expressed as eastness and northness (Wilson *et al*., 2007)
Closed Depressions	This metric scales the extent to which cells form sinks surrounded by cells higher than them on all sides.

The object-based image analysis is a two-step approach consisting of segmentation and classification (OBIA; Blaschke, 2010), implemented in the software package eCognition® v9. The bathymetry data, backscatter image were fed into a segmentation algorithm, which partitions the data into objects (sections of the image with homogenous backscatter and bathymetry) using the following parameters:

Layer	Value (weighting within eCognition)
Bathymetry	0.5
Backscatter	1

Segmentation algorithm parameters

Parameter	Value
Scale	50
Shape	0
Compactness	0.9

For each object, mean and standard deviation values, of both the primary acoustic data layers and their derivatives, were calculated and input into a conditional inference (CI) tree model, alongside the ground truthing data (presence or absence of Sabellaria). This regression tree-based classification model outputted the parameters (i.e. those data layers and their corresponding threshold values) which best explain the presence of *Sabellaria*. This is achieved using recursive, univariate splitting of the dependent variable (presence or absence) alongside the covariates (data layer values), and testing for statistical significance using permutation testing and resulting in the selection of those predictors with the highest significant correlation the Sabellaria "presence" variable. This then allows for use of these threshold values in developing a manual classification ruleset. The statistical analyses were carried out in the statistical programming environment R (R Development Core Team, 2012).

Results

Backscatter intensity was not found by the CI model to be a good indicator of Sabellaria presence / absence. As such, the best predictor was a fine scale derivative of the bathymetry data; Terrain ruggedness Index (TRI), specifically the mean TRI at 10 pixels. The threshold for using this metric as a predictor provided by the conditional inference tree to be >0.064.

When this threshold was used to classify objects, it allowed for a good discrimination between the areas likely to have no Sabellaria, and those likely to contain Sabellaria. Further delineation (a second tier in the rule set hierarchy) was achieved using a manually derived slope thresholds of < 0.095, primarily to remove those larger sand wave features which can be confidently ruled out as potential Sabellaria habitat. This produced the “Sabellaria Reef - Moderate Probability” class. The “Sabellaria Reef- High Probability” class took the Moderate class polygons and ran a further threshold (a third tier in the ruleset hierarchy) using the derivative “Mean Negative openness” at a threshold of <= 1.51. This derivative was the second most correlated predictor to be outputted from the conditional Inference tree model, and was found to be associated with the elevated sections of rocky reef. It is thought therefore to add a further degree of discriminative power to the prediction. The remaining polygons were considered to be “Uncertain” in their classification.

The distribution of the High probability class polygons indicates the elevated likelihood of Sabellaria presence within these areas, and not a definitive extent. As so with the Moderate probability class, indicative of a lower probability of Sabellaria presence therein.

As a fully predictive model was not used, no data were withheld from the CI tree model. Validation of the map was undertaken using the full ground truth dataset, overlain onto the manually classified (using the derived thresholds) shapefile within Arc Map 10. Class values from the map were then extracted and compared with the ground truth data classes. The predicted high, moderate and uncertain probability classes were all counted as “Sabellaria presence”, and thus scored positively if any ground truth station with Sabellaria present was located within that object. The map was found to have a predictive accuracy of 67%.