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North Norfolk Sandbank and Saturn Reef cSAC/SCI Management Investigation Report

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Summary

The North Norfolk Sandbanks and Saturn Reef candidate Special Area of Conservation (cSAC)/Site of Community Importance (SCI)[3] encloses the most-extensive example of offshore linear-ridge sandbank feature in UK waters and also encompasses an area, named Saturn Reef, where previous seabed surveys identified an extensive biogenic reef created by the Ross Worm (*Sabellaria spinulosa*). Both the North Norfolk Sandbanks and Saturn Reef features qualify as Annex I habitats under the European Commission Habitats Directive, listed as 'Sandbanks which are slightly covered by sea water all the time' and 'Reefs' (CEC 2007). However, the Annex I sandbank feature is dynamic and the Annex I biogenic reef feature is ephemeral with both also deemed sensitive to human activities present within the SCI boundary. Therefore in order to develop appropriate management advice for the site, a dedicated survey by the Joint Nature Conservation Committee (JNCC) in partnership with the Centre for Environment, Fisheries and Aquaculture Science (Cefas) was undertaken in 2013 with the aims of:

- characterising the infaunal communities across the sandbanks in order to better understand their sensitivities to human pressures; and
- confirming or identifying the existence of Annex I *S. spinulosa* reef and characterising the associated fauna.

Benthic community and sediment composition were assessed in the troughs, flanks and on the crests of three nearshore (i.e. the nearer to shore portion of site) sandbanks (Inner, Well and Leman) and across a group of offshore (i.e. the further from shore portion of site) sandbanks collectively known as the 'Indefatigables' within the SCI boundary. Prior to grab sampling, multibeam echosounder transects were run across the sandbanks to identify crest, flank and trough. This newly collected bathymetry data was compared with historical data to determine potential sandbank feature migration. Temporal changes in community composition were also investigated at a subset of banks using historical data collected in 2001.

Nearshore sandbanks appeared to be more pronounced, exhibiting shallower crests and deeper troughs, than the offshore banks. Sediment was comparable, fine sand, on the crests and flanks of the nearshore banks and on the crest of the offshore banks, while the troughs of both the nearshore and offshore banks were more heterogeneous. Species number and abundances were generally lower on the crests compared to the flanks and troughs for both near and offshore sandbanks. This is as expected in such an energetic environment. Slight differences were observed in community composition between the nearshore and offshore banks, and between crest, flank and trough at only the offshore banks. Temporal differences in community composition observed were due to differences in taxonomic occurrence, which may be an artefact of sampling device used or due to natural variability across the sandbanks over time. Temporal differences in bank elevation were also observed for the nearshore banks with reduced elevation at the southern edges and deposition at the northerly edges. Evidence suggests the nearshore banks are moving in a north easterly direction, as predicted by Cooper *et al* 2008.

For the Annex I reef assessment, six survey boxes (A-F), identified from historical data as having the most potential for containing *S. spinulosa* reef (for example, there were historic records of *Sabellaria spinulosa*), were investigated with high resolution multibeam echosounder and side-scan sonar. Confirmation of reef presence and quality was provided by targeted video transects following review of the acoustic data collected. Grab samples

[3] Reference URL: http://jncc.defra.gov.uk/protectedsites/sacselection/sac.asp?EUCode=UK0030358

were collected across a 1.5 km sampling grid within each survey box to provide information on benthic community composition and seabed sediment particle size.

Acoustic signatures, which appeared to be associated with patches of *S. spinulosa* identified in video data, were not consistent across the North Norfolk Sandbanks and Saturn Reef SCI. Only Box A demonstrated a truly distinct ‘mottled’ signature that could be considered strong evidence for reef delineation. Detailed analysis of the video segments revealed that the most established reef within Box A was located west of the area known as Saturn Reef. This box also contained the highest numbers of *S. spinulosa*. Box F also demonstrated a signature that allowed for areas of known and potential reef to be mapped, but was not as clear as that seen in Box A. A similar ‘mottled’ signature was observed in Box C, but appeared to be a reflection of the underlying coarse sediment rather than a reflection generated by reef features. Numbers of taxa and abundance were generally highest in this box, which again may reflect the predominance of coarse sediment rather than reef within this box.

This study has highlighted the challenges associated with monitoring ephemeral features such as sandbanks and reef habitats. Changes in *S. spinulosa* reef presence, as observed at the Saturn Reef location, poses the question as to the consistency and validity of mapping reef boundaries. Future monitoring and potential management decisions are likely to struggle with this issue. Combining mapped patches of *S. spinulosa* reef to create larger polygons may mitigate poor understanding of patch validity and connectivity, as well as uncertainty in establishing presence from remote techniques. Use of larger polygons, when combined with monitoring from video analysis, would allow reef extent at the North Norfolk Sandbanks and Saturn Reef SCI to be considered in light of the ephemeral nature of the feature. The new video analysis methodology developed under this project also has the potential to provide a consistent scoring system for monitoring changes in *S. spinulosa* reef quality within the North Norfolk Sandbanks and Saturn Reef SCI into the future.

Prior to publication this report was subject to JNCC’s Evidence Quality Assurance (EQA) process and peer reviewed by Jon Moore and Dr Pål Buhl-Mortensen. The JNCC EQA policy can be found on the JNCC website. http://jncc.defra.gov.uk/default.aspx?page=6675

Contents

1 Background and Introduction

The North Norfolk Sandbanks and Saturn Reef Site of Community Importance (SCI) is located in the southern North Sea, extending from about 40 km off the north east coast of Norfolk (Figure 1). The SCI encloses a series of ten main sandbanks (Leman, Inner, Ower, Well, Broken, Swarte and four sandbanks collectively known as the 'Indefatigables') and associated fragmented smaller banks, all of which together represent the most extensive example of offshore linear ridge sandbank feature in UK waters (Graham *et al* 2001). The SCI also includes areas of Ross Worm (*Sabellaria spinulosa*, hereafter referred to as *S. spinulosa*) biogenic reef, which qualify as Annex I habitat according to the European Commission (CEC 2007). Reefs formed by *S. spinulosa* allow the settlement of other species not found in adjacent habitats leading to a diverse community of epifaunal and infaunal species (MarLIN 2006a). The SCI boundary encloses the minimum area necessary to ensure protection of the Annex I habitats and takes into account potential movement of both the more naturally disturbed (nearshore) and more stable (offshore) sandbanks (JNCC 2010).

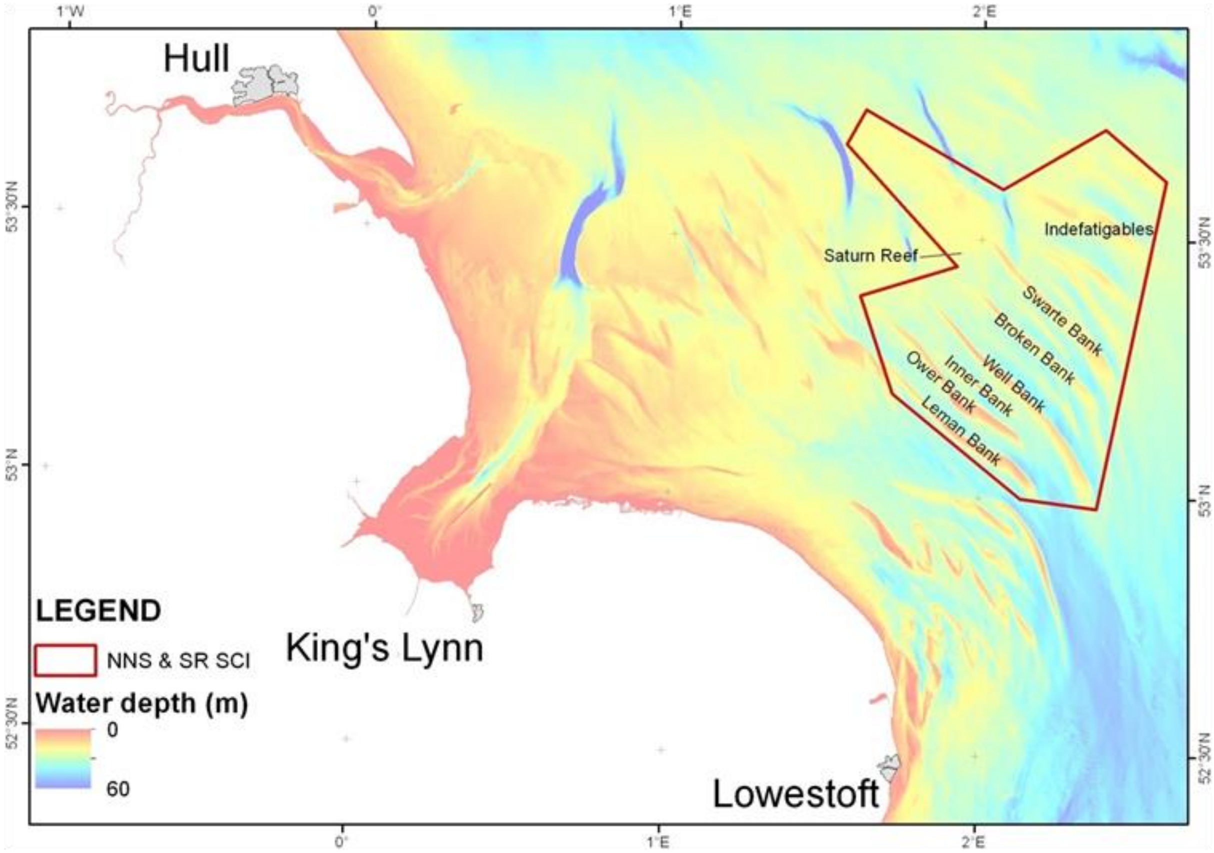

Figure 1. Location of the North Norfolk Sandbanks [NNS] and Saturn Reef [SR] SCI.

The banks are subject to a range of water current strengths, which are strongest on the banks closest to shore (the 'inner banks') and which reduce gradationally in strength with increasing distance offshore (Collins *et al* 1995). The outer banks are the best example of open sea, tidal sandbanks in a moderate current strength in UK waters. Sand waves are present, being best developed on the inner banks, indicating the sediment surface is regularly mobilised by tidal currents. The biological communities associated with the sandbanks are typical of the biotope 'infralittoral mobile clean sand with sparse fauna'. The sandbanks are active systems that are thought to be progressively, although very slowly, elongating in a north-easterly direction (Cooper *et al* 2008).

The most recent dedicated site level survey of the sandbanks was conducted in 2001 as part of the Department of Trade and Industry's Strategic Environmental Assessment (SEA2). Part of the site area was also surveyed by Entec/Envision on behalf of Natural England, as part of their Outer Wash Sandbank survey (Natural England 2008).

The Saturn Reef, located between Swarte and Broken banks, was first identified during a proposed gas pipeline route survey for the ConocoPhillips Saturn Development (BMT Cordah 2003). The reef consisted of thousands of consolidated sand tubes, made by *S. spinulosa*, creating a solid structure rising above the seabed. The extent of Saturn Reef was estimated to cover an area of 0.375km^2, with a core area (0.125km^2) of near continuous (90% coverage of the core area) and high elevation reef (>10cm high). Areas of patchy reef (<10-50% coverage of reef extent) were also observed which were either broken by various shaped 'holes' or comprised elongated strips, raised above surrounding seabed. Surrounding sediment included both tube debris and non-tube sediment (silty sand and stones). Damage to the reef structure, which may have been the result of bottom trawling, was also observed, particularly in the south western part of the area.

A more-recent survey of the Saturn Reef area was carried out by Cefas in 2006 (Limpenny *et al* 2010). No substantial reef structures were found, though it is not understood whether this absence is as a result of damage to the reef structures (e.g. by bottom trawling) or due to the apparent ephemeral nature of this feature (OSPAR 2013). However, formation of such a substantial reef of *S. spinulosa* in this area in 2003 indicates favourable conditions for reef formation. Despite the widespread occurrence of the species *S. spinulosa*, there are few known areas of well-developed *S. spinulosa* reef in UK and European waters.

Conservation objectives for the SCI are to *restore* the Annex I Sandbanks and Reef to favourable condition such that the natural environmental quality, natural environmental processes and extent are maintained and the physical structure, diversity, community structure and typical species representative of the Annex I habitats are restored (JNCC 2012). However, there is currently insufficient detailed information on the existing and preferred condition of features of interest for offshore sites (JNCC 2012).

The Annex I features within the North Norfolk Sandbanks and Saturn Reef SCI are dynamic (sandbanks) and ephemeral (biogenic reef); in order to develop appropriate management advice for the site it is vital to understand how the features change over time. Therefore in 2013, JNCC, in partnership with the Cefas, conducted a field survey to investigate the current condition of the Annex I habitat features within the North Norfolk and Saturn Reef SCI (see Vanstaen & Whomersley 2014).

This report describes the findings of the dedicated survey and provides the best-available evidence to aid development of future monitoring programmes.

Survey objectives

The objectives of the survey (listed in order of priority) were to:

1. survey areas where *S. spinulosa* reef has previously been found;
2. assess presence, and where possible, delineate the extent of Annex I biogenic reef feature and characterise associated fauna; and
3. survey areas of sandbank to characterise distribution of infaunal communities in order to better understand their sensitivities to demersal fishing pressures.

2 Survey Design and Methods

2.1 Planning, including sampling site selection

2.1.1 Annex I Reef

The Annex I Reef survey was based on six areas of search ('boxes' labelled A to F) owing to the size of the SCI and time available to complete the survey (Figure 2). These boxes were selected using a combination of historical evidence of *S. spinulosa* reef presence in these areas along with an analysis of potentially favourable habitat to explore new sites within the SCI (detailed planning information can be found in the cruise report, Vanstaen and Whomersley 2014).

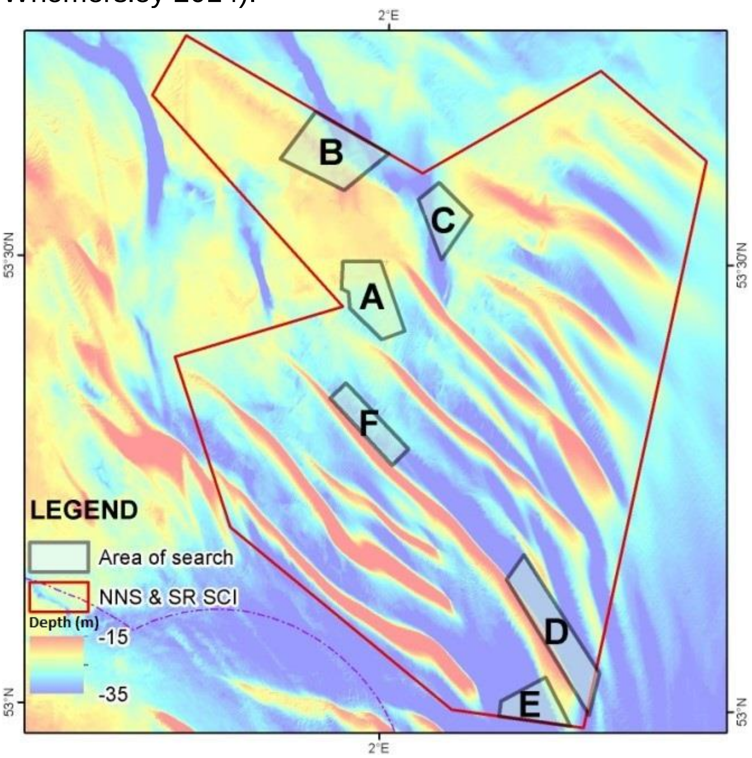

Figure 2. Survey boxes (A-F) for Annex I reef within the North Norfolk Sandbanks and Saturn Reef SCI.

Acoustic survey lines were planned at 200m line spacing to achieve full seafloor coverage in the study 'boxes' using a high resolution side-scan sonar system (SSS). Limpenny *et al* (2010) had investigated the various options for assessing and identifying presence of *Sabellaria* reef, wherein it was demonstrated that, although all methods had differing benefits, side-scan data provided the most reliable evidence, with deployment at low altitude above the seabed, low speed and at a small swathe range being critical to successful reef identification. Simultaneous collection of multibeam data was also planned, although it was recognised that full seafloor coverage would not be achieved with this type of gear, due to the reduced swathe from multibeam echosounder compared with SSS in these water depths.

Groundtruth sampling grids within each of the survey 'boxes', with a spacing of 1.5km between sampling points, were provided by JNCC. Two minute video tows were planned to supplement benthic sampling at all stations; these tows were completed to help contextualise understanding of each station beyond what a grab sample alone can provide and were not processed further as part of the faunal analysis. Following an on board review of the newly acquired acoustic data, further video and stills data were collected at locations based on potential *S. spinulosa* reef signatures identified.

2.1.2 Annex 1 Sandbanks

Sandbanks suitable for survey (> 13m water depth) on *RV Cefas Endeavour* were identified using the Defra Digital Elevation Model (Astrium 2011) bathymetry layer (Figure 3). A power analysis, using historical data from similar habitat types, was undertaken (Appendix 1) to determine the number of samples needed to detect a difference in species richness (i.e. number of taxa). Forty transects were planned based on this analysis. Multibeam echosounder lines were planned across each sandbank transect. These data were visualised in real time with an OLEX plotter display system to identify sandbank bathymetric profiles. Grab sampling points were then positioned across the sandbank to coincide with the trough, flank and crest (see Figure 4 for more detail).

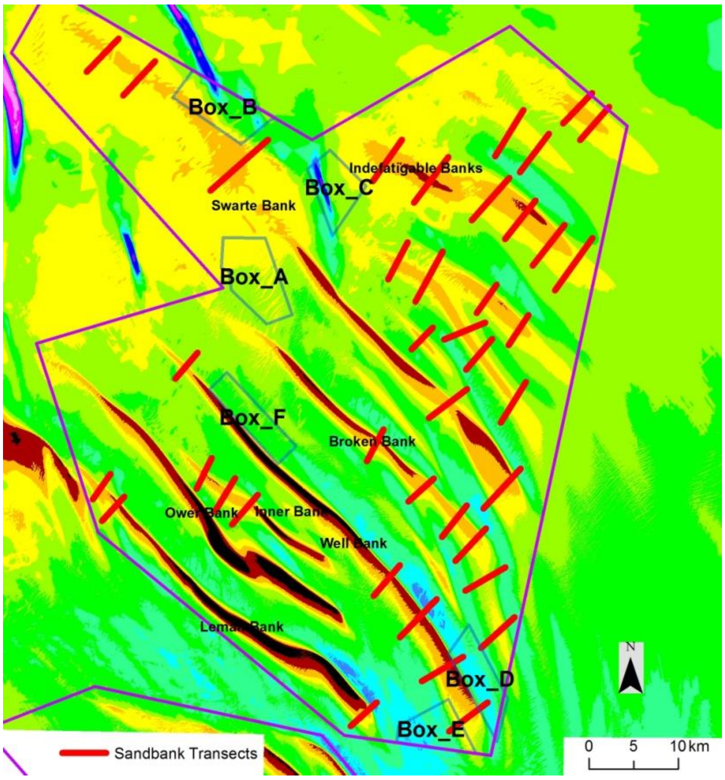

Figure 3. Map showing the location of proposed sandbank transects overlain on bathymetric data from the Defra DEM (Astrium 2011).

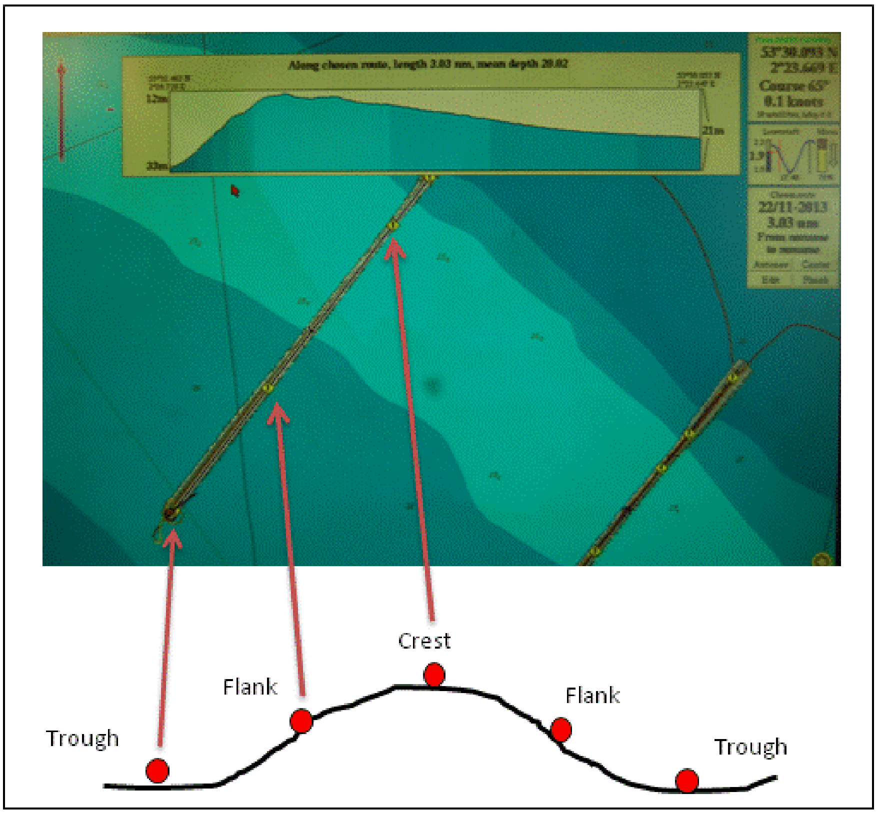

Figure 4. 'Screen grab' demonstrating the use of the seabed profiling tool in OLEX and how the multibeam echosounder transect line was used to plot the profile of the sandbank and then position sample stations in troughs, on flanks and on the crest of the sandbank.

2.2 Sample acquisition methods

2.2.1 Acoustic and geophysical

An Edgetech FS-4200 dual frequency (300/600 kHz) side-scan sonar was used in combination with Edgetech *Discovery* software for data recording. Data were recorded in XTF format and post-processed using the Triton Imaging software suite (Isis and TritonMap)[4].

Multibeam echosounder bathymetry and backscatter data were acquired using a Kongsberg EM2040 system operated at 200 kHz and deployed on the drop keel of RV *Cefas Endeavour*. Variations of sound velocity with water depth were determined using a CTD (conductivity-temperature-depth) probe and the sound velocity data acquired were applied to the multibeam echosounder data during multibeam echosounder data acquisition.

2.2.2 Underwater video and still photography

Underwater video footage and still photographs were acquired, within the potential Annex I reef boxes only (see Figure 2), using a Kongsberg 14-208 camera mounted in a rectangular drop-frame (DropCam). High power LED strip lights and a four point laser system (with lasers set 17cm apart, to provide scale) were also mounted on the DropCam. Set-up and operation followed the MESH 'Recommended Operating Guidelines (ROG) for underwater video and photographic imaging techniques'[5]. At each sampling site (Figure 5) the vessel's dynamic positioning (DP) system was used to set the course and speed of the tow (0.3 knots). Video was recorded simultaneously to a Sony GV-HD700 DV tape recorder and a computer hard drive. At each sampling station the drop camera was deployed to collect two

[4]Reference URL: http://www.tritonimaginginc.com

[5] Reference URL: http://www.emodnet-seabedhabitats.eu/pdf/GMHM3_Video_ROG.pdf

minutes of video data and three still images; these data were not to be processed further but gave contextual information to support the PSA analysis from grab sampling. Where *S. spinulosa* reef was observed along these tows, the tow was continued to assess the extent of the reef feature. Furthermore, side-scan sonar data was assessed to identify additional camera transects where the acoustic signature suggested the potential occurrence of *S. spinulosa* reef, as well as to explore the boundaries between reef and non-reef. At these stations, a minimum ten minute tow using the drop camera was undertaken, followed by a targeted $0.1m^2$ mini-Hamon grab sample. Stills images were captured at regular one minute intervals, and opportunistically if specific features of interest were encountered.

2.2.3 Sediment and faunal sample acquisition

A mini Hamon grab (sampling area: $0.1m^2$) was used to acquire sediment and infaunal samples following the guidance set out in Ware and Kenny (2011). Upon retrieval, each sample was assessed for suitability (i.e. sampled volume > 5 litres). A sediment subsample (approx. 500ml) was taken for particle size distribution analysis (PSA), the remaining sediment was washed over a 1mm mesh sieve, and the material stored in buffered 4% formalin solution.

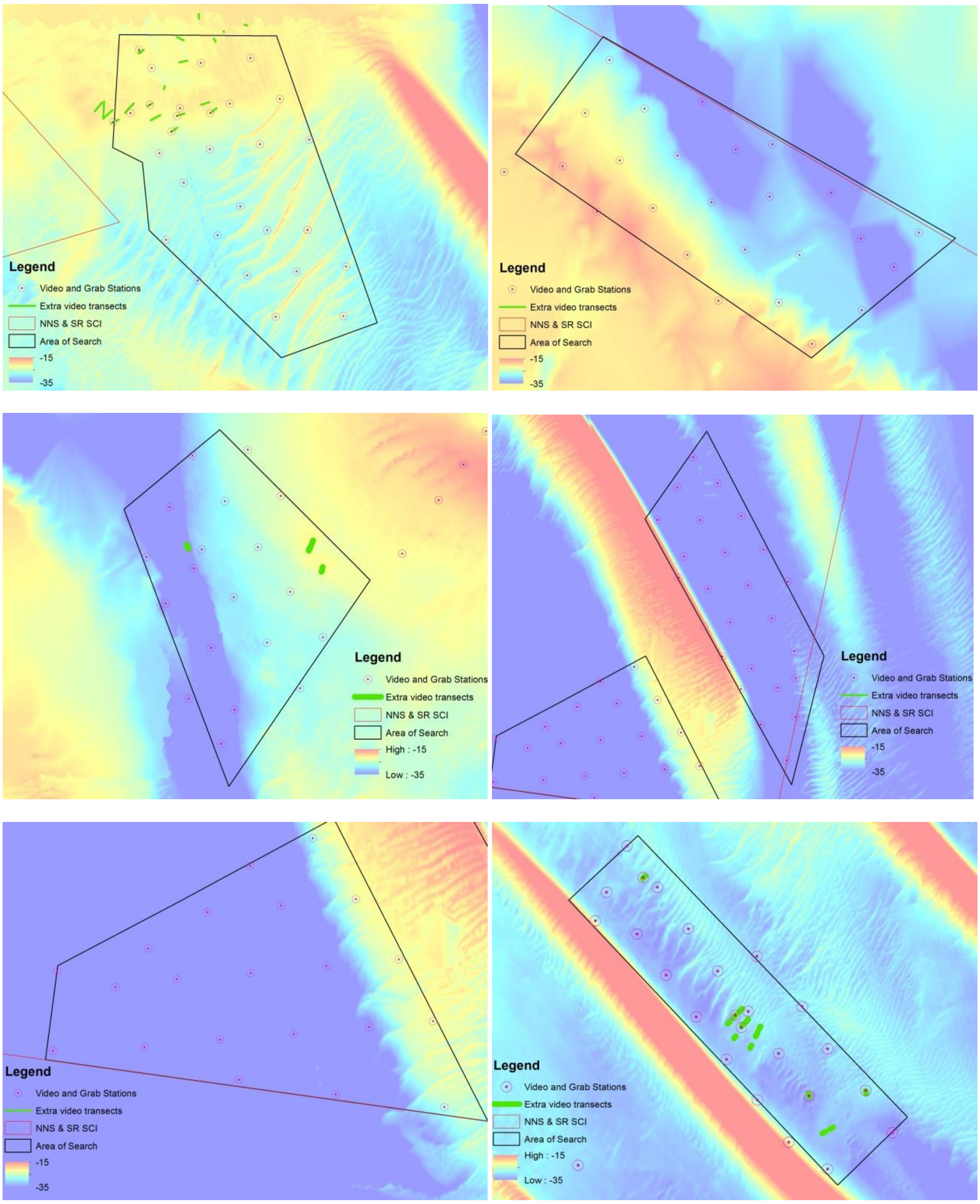

Figure 5. (Top left) Location of grab and video stations within survey Box A; (Top right) Location of grab and video stations within survey Box B; (Middle left) Location of grab and video stations within survey Box C; (Middle right) Location of grab and video stations within survey Box D; (Bottom left) Location of grab and video stations within survey Box E; (Bottom right) Location of grab and video stations within survey Box F.

2.3 Sample and data processing – analysis methodologies

2.3.1 Acoustic data processing

The raw multibeam echosounder bathymetry data were processed using CARIS *HIPS* and QPS Fledermaus. Tidal information was extracted from a high precision CNAV 3050 DGPS receiver. Tide-height data were smoothed and extracted to reduce the bathymetry data to

Chart Datum. The bathymetry soundings were cleaned by an experienced hydrographic surveyor using CARIS. Multibeam echosounder backscatter data were processed with the QPS *Fledermaus Geocoder Toolbox* (FMGT) software to produce floating point (FP) GeoTiff images. Multibeam echsounder data did not provide 100% coverage of the survey 'boxes' (see Figure 1). Though overlap was achieved, data quality and density was not sufficient to allow confidence and quality to be maintained and the outer beams were, therefore, heavily processed. This decision reduced the coverage but improved quality of the dataset and was deemed appropriate.

2.3.2 Primary video and stills analysis

Video and photographic still images acquired along each camera transect were analysed by RSS Marine (RSS Marine 2014).

In accordance with the guidance documents developed by Cefas and the JNCC for the acquisition and processing of video and stills data (Cefas & JNCC 2014), each video transect was viewed several times, first to detect and record any changes in biotope across the entire transect, and second, to describe physical features and quantify the epifauna characterising each biotope. All still images were analysed for sediment type and fauna present were documented. Additionally, patchiness (% cover) of *S. spinulosa* reef and estimated tube elevation were documented for both videos and still images following a reduced 'reefiness' scoring system[6] proposed by Gubbay (2007; see Table 1). Each video and still image was also assigned a biotope code according to the European Nature Information System (EUNIS)[7].

Table 1. *Sabellaria spinulosa* reefiness scoring system, adapted from Gubbay (2007) after exclusion of the 'extent' parameter

Measure of reefiness	Not a Reef	Low	Medium	High
Tube elevation (cm)	<2 cm	2 – <5 cm	5 – 10 cm	>10 cm
Patchiness (% cover)	<10%	10 - <20%	20 – 30%	>30%

2.3.3 Additional video analysis

During a joint JNCC and Cefas workshop it was agreed that patchiness and percentage cover were not synonymous. For example, a value of 20% cover of reef over a video tow could be the result of one continuous patch of reef or numerous smaller patches separated by large areas of sediment. The significance, in terms of biodiversity, may be completely different for these two scenarios. Videos identified as containing *S. spinulosa* reef habitat were therefore re-analysed in more detail by JNCC and Cefas to assess 'reefiness' components at an increased temporal and spatial resolution. This was to allow improved scoring of 'reefiness' criteria components (as outlined in Gubbay 2007), and to allow an assessment of true patchiness of *S. spinulosa* reef along a video transect to be carried out. The combination of this information gives an indication of the quality of the reef.
Video transects identified as containing *S. spinulosa* reef were split into 5-second segments using an automated script in VLC Video Player[8].

[6] Gubbay (2007) suggests including a further assessment parameter; feature 'extent'. This was not feasible in this study due to problems concerning confidence in *S. spinulosa* reef extent delineation using the side-scan sonar data collected (see Discussion in Section 4.5).

[7] Reference URL: http://eunis.eea.europa.eu/

[8] Reference URL: http://www.videolan.org/index.html

Data quality, presence/absence of *S. spinulosa* reef, percentage cover of reef and an estimate of tube height elevation (made using the laser pointer markers visible in the footage) were assessed by a video analyst for each five second segment (see Appendix 2 for more information).

Results of the five second video method analysis were converted into a spatial dataset and made available to Cefas.

2.3.4 Additional *Sabellaria spinulosa* reef assessment

A measure of 'reefiness' (High, Medium, Low, Not a reef) was determined for each five-second video segment using a *S. spinulosa* reef structure matrix (Table 2 below) modified from a table provided by Fugro (2010).

Scores were assigned to each five-second segment of each video transect to demonstrate the spatial variability of reef composition along each seabed video transect. Therefore, in this investigation, 'reefiness' is defined as a combination of *S. spinulosa* reef elevation and percentage cover at a given point along each video transect. This information was overlaid spatially onto the processed side-scan sonar data to provide a visual assessment of *S. spinulosa* patchiness and reefiness. The proportion of each video tow assigned to a given reefiness category was also calculated.

Table 2. *Sabellaria spinulosa* reef structure matrix, modified from table provided by Fugro (2014), used to assign reefiness scores to each five second segment.

Reef Structure matrix			**Elevation (cm)**			
			<2	**2 to 5**	**5 to 10**	**>10**
			Not a reef	**Low**	**Medium**	**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

A calculation of true reef patchiness was also determined using the presence (1) or absence (0) information ascertained from the five- second assessments following methods described in Appendix 3. This methodology calculates the extent, in terms of number of five-second segments in succession classified as *S. spinulosa* reef present. Each group of consecutive segments with reef is termed a 'patch'. This information, along with the number of reef 'patches' observed, gives an indication of the consolidation of the reef along a video tow. Information on tube elevation and % cover for each patch was used to calculate the magnitude of each *S. spinulosa* reef patch. A mean value (with standard deviation) for patchiness and magnitude was calculated for each video tow (see Appendix 3).

2.3.5 Faunal sample analysis

All infaunal samples were sent to a specialist sub-contractor (Thomson Unicomarine) for processing. Sample processing followed standard laboratory practices, and results checked following the recommendations of the National Marine Biological Analytical Quality Control (NMBAQC) scheme (Worsfold *et al* 2010). Fauna were identified to lowest taxonomic resolution, enumerated and weighed. *S. spinulosa* reef fragments in the grab samples were assessed for tube occupancy by counting the holes on all undisturbed surfaces of the reef patches. The volume of biogenic 'reef' from each grab sample was calculated by water displacement in a measuring cylinder. Any stones or pebbles on which the *S. spinulosa* were growing were removed prior to calculation of volume. The volume of reef rubble (broken tubes) was also measured using this methodology and recorded separately.

After inspection, the resulting taxon-by-sample matrices were subjected to standard univariate and multivariate analyses using the PRIMER software package (Clarke & Gorley, 2006). Metrics calculated per sample included number of species, abundance, diversity (H'), evenness (J) and total biomass. Multivariate analyses were performed to investigate patterns in benthic community structure and to compare assemblage composition between the different sampling treatments. Links between community structure and particle size distributions were explored using the RELATE and BEST routines in PRIMER. Correlation analyses were performed using Minitab 15.

2.3.6 Particle size distribution analysis

PSA was carried out by Cefas following standard laboratory practice, and results were checked by Cefas specialist staff following the recommendations of the NMBAQC scheme (Mason 2011). Samples were analysed at half phi intervals using a combination of laser diffraction (<1mm fraction) and dry sieving techniques (>1mm). Gradistat software (Blott and Pye 2001) was used to produce all sediment statistics (e.g. mean, mode, sorting, skewness). Each sample was also assigned to one of the four EUNIS sediment classes defined by Long (2006), namely coarse sediment, sand, mud and mixed sediment.

2.3.7 EUNIS Level 3 habitat mapping

All new habitat maps and their derivatives have been projected to WGS 1984 UTM Zone 31N datum. A new habitat map for the six potential Annex I reef 'boxes' (Figure 1) of acoustic data acquisition was produced by analysing and interpreting the available acoustic data (as detailed above) and the groundtruth data collected by the 2013 dedicated survey.

A semi-automated object-based image analysis (OBIA) was performed to produce each habitat map. A flow chart of the overarching process is shown in Figure 6. OBIA is a two-step approach consisting of segmentation and classification (Blaschke 2010), implemented in the software package *eCognition v8.7.2*. The backscatter image (Figure 8) is segmented into objects (sections of the image with homogenous backscatter characteristics). For each of these objects, mean values of the acoustic data layers were calculated.

Each stage in the process is described in detail below.

Data Preparation

Prior to analysis, bathymetry and backscatter data were re-sampled onto a grid at 2m resolution. Default 'no data' values in the Floating Point GeoTiff files were transformed to null values within *ArcGIS v10.1*.

Segmentation

Segmentation divides an image into meaningful objects based on their spectral and spatial characteristics. The resulting objects can be characterised by features such as layer values (mean, standard deviation, skewness, etc.), geometry (extent, shape, etc.), texture and many others.

The input layers used were the acoustic data layers bathymetry and backscatter strength.

Segmentation was carried out using the multi-resolution segmentation algorithm in *eCognition v8.7.2*. This is an optimisation procedure that starts with an individual pixel and merges it consecutively with neighbouring pixels to form an object. The process continues until a threshold value for a scale is reached. The threshold is set by the operator, who determines the variability allowed in the objects.

The goal of segmentation is to create meaningful objects that represent areas of homogenous values in the map image. The size of the objects is influenced by the scale parameter and the heterogeneity of the image. For a fixed value of the scale parameter, a homogeneous area of seabed will have larger objects than a heterogeneous area. Likewise, for a fixed seabed heterogeneity, larger values of the scale parameter produce larger objects than smaller values. The scale parameter was selected using the Estimation of Scale Parameters (ESP) tool. The tool calculates local variance (LV) of object heterogeneity within a scene for increasing scale parameters at user-defined intervals. The threshold for rate of change of LV relative to the data properties in the entire image, can be used to indicate the scale level at which the image can be segmented in the most appropriate manner (Drăguţ *et al* 2010). The final segmentation was carried out at pixel level on backscatter strength and bathymetry with the scale parameter set at 10.

Classification

For each of the objects created, mean values of the primary acoustic data layers and their derivatives were calculated (e.g., the mean backscatter value for the grid cells lying within the object) for further statistical analysis and modelling. Objects and associated feature mean values were exported as a GIS shapefile for further use in assigning their corresponding sediment class and producing a broadscale habitat map. Across the SCI survey area, two grab sample stations were found (in a localised region of the survey area) to be comprised of the EUNIS level 3 habitat ‘Sublittoral Mud’. These two mud samples were excluded from the automated classification process and displayed on the final Broad-scale Habitat (BSH) map as point occurrences to demonstrate only their presence and localisation.

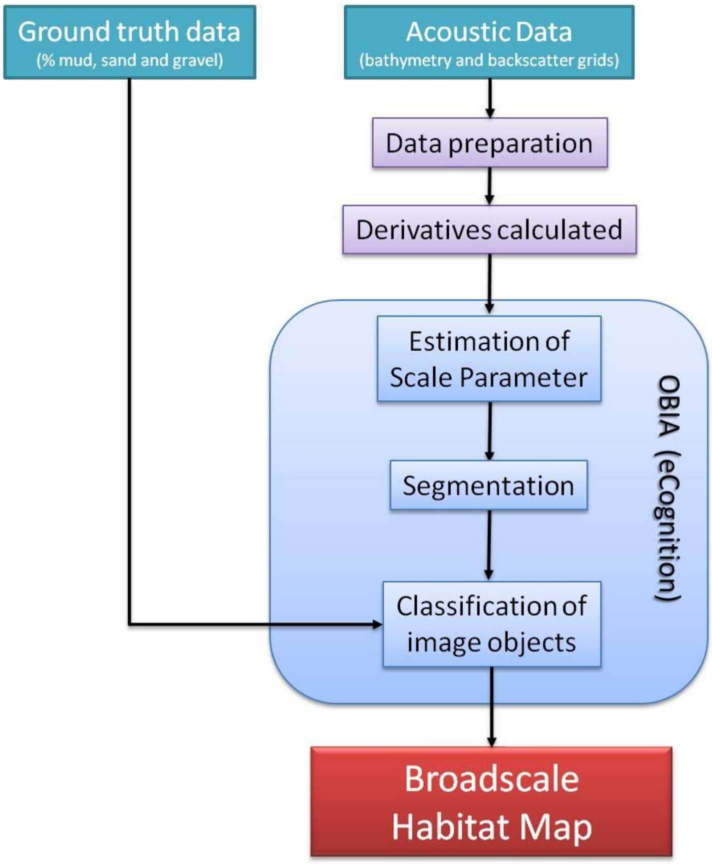

Figure 6. Flowchart outlining the process of producing the broadscale habitat map.

2.3.8 Historical sandbank comparison

Historical faunal abundance data (collected as part of the SEA2 programme in 2001) from the sandbanks were acquired from JNCC for qualitative comparison with data collected in 2013. Two replicate 0.1m^2 Van Veen samples were taken at each SEA2 sample location across the sandbanks and sieved through nested 5mm, 1mm and 0.5mm mesh. For comparison with the newly acquired 2013 data that sieved samples through 5mm and 1mm mesh, only the 5mm and 1mm fractions were selected for further analysis. Data from the two fractions were summed for each taxa and replicate, then averaged for each sample location. The SEA2 data were then merged with the 2013 sandbank data. The data were checked for species name changes between the years and truncated to alleviate problems in taxonomic resolution between the datasets. Data were selected from both datasets that corresponded with the same sandbanks (Indefatigables, Inner, Well and Leman Banks). Standard univariate and multivariate analyses were conducted on presence absence data using *PRIMER v.6* (Clarke & Gorley 2006).

Acoustic data were collected in corridor transects across some North Norfolk Sandbanks as part of the sandbank assessment objective. These data were predominantly collected to guide the survey sampling, where it was crucial to demonstrate good confidence in sample location (in relation to crest, flank and trough of the sandbank transects). However, bathymetric data collected along these transects was also assessed against historical data in an attempt to make a low resolution (see below) assessment of potential bank movement.

Publicly available bathymetric data was downloaded from the United Kingdom Hydrographic Office (UKHO) Inspire Portal and Bathymetry DAC website[9], where it related to the relevant

[9] Reference URL: http://aws2.caris.com/ukho/mapViewer/map.action

survey regions. SEA2 multibeam echosounder data did not coincide with the survey areas, and was not used as part of the analysis described herein. Downloaded data includes that obtained from surveys commissioned by the Maritime and Coastguard Agency (MCA) on several vessels. All data are derived from single beam echosounder bathymetric data acquisition. It was not possible to establish comprehensive data analysis methodologies for historical data sets, and should be noted as a potential source of error when comparing with present data. Due to the resolution of historical data sets both present and historical data were regridded at a resolution of 35m in the QPS *Fledermaus* software package before exporting as a FP Tiff for visualisation in *ArcGIS 10.1*.

Historical bathymetry layers were clipped to the collected multibeam echosounder data corridor extents. Current and previous values were then compared using the raster subtraction tool in *ArcGIS 10.1*. Comparison between these data sets, though appearing quantitative, should be viewed as a qualitative interpretation due to the potential errors introduced by acquisition and processing techniques coupled with poor and degraded data resolution.

Results of raster subtraction have been categorised into four groups based on the natural breaks within the dataset using Jenks Natural Breaks for map demonstration purposes. Grouping in this way affords the opportunity for the data to dictate how best to separate itself and cluster the processing discrepancy as much as possible. This technique cannot remove all discrepancies but allows for some confidence to be associated where large decreases or increases in bank elevation are identified.

2.4 Data QA/QC

2.4.1 Survey

All activities in the field were performed according to the recommendations in the following documents:

- Biological Monitoring: General Guidelines for Quality Assurance document[10];
- Quality Assurance in Marine Biological Monitoring[11];
- Recommended operating guidelines for underwater video and photographic imaging techniques[12].

2.4.2 Faunal and sediment samples

Faunal and sediment samples have been processed and results checked following the recommendations of the NMBAQC Scheme. A taxonomic reference collection has been prepared for archive.

2.4.3 Primary video and stills analysis

For quality assurance purposes, 10% of the videos and stills were re-analysed by different personnel and the name and any findings recorded in the *pro forma* (RSS Marine Ltd 2014).

2.4.4 Additional video analysis

For the additional video analysis undertaken by JNCC, initial analyst training was undertaken, whereby the analyst reviewed a number of seabed video transects alongside a staff member experienced with using the guidance provided in Gubbay (2007) for assessing the 'reefiness' of *S. spinulosa* reef occurrences. This was in order to ensure the analyst had a good understanding of the guidelines, and how they should be interpreted.

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[10] Reference URL: http://www.marbef.org/qa/documents/PKG85.pdf

[11] Reference URL: http://www.nmbaqcs.org/media/1325/quality-assurance-in-marine-biological-monitoring_rev2014.pdf

[12] Reference URL: http://www.emodnet-seabedhabitats.eu/pdf/GMHM3_Video_ROG.pdf

Following the analysis, 10% of the video transects were independently reanalysed by a different analyst, and the results compared with those of the original analysts (see Appendix 2, Annex A).

3 Data Analysis and Results

3.1 Multibeam echosounder bathymetry and backscatter

Within the surveyed area, water depth varied between 13 and 65 m below Chart Datum, the shallowest depths occurring towards the eastern side (Box C) of the SCI boundary (Figure 7). However, these measured depths may not be the limits of the bathymetric range of the site; survey ‘boxes’ were selected for their potential *S. spinulosa* presence rather than to explore the SCIs bathymetric features. Sand waves were present within all boxes. Further bathymetric transects were collected over selected sandbanks across the SCI and are discussed further in Section 3.5.

Backscatter values were relatively high across the survey site, indicative of a coarse, mixed and sandy substrate (Figure 8). Deeper regions within Boxes B and C appear to be associated with lower backscatter reflectivity. This association was not, however, consistent across the surveyed regions.

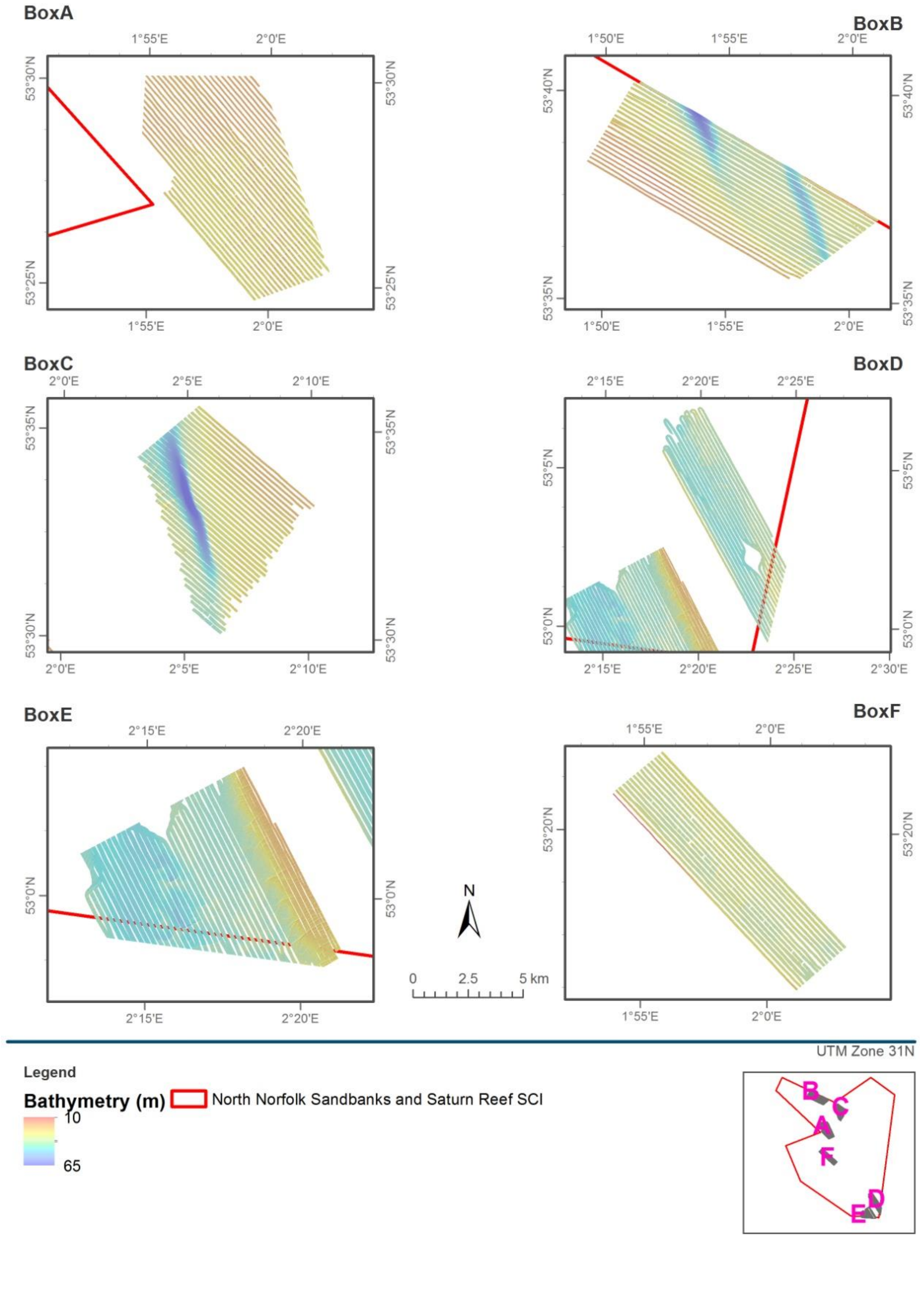


Figure 7. Multibeam echosounder bathymetry for the six potential Annex I reef survey 'boxes' (A-F) at North Norfolk Sandbanks and Saturn Reef SCI. The data gap evident in Box D results from a static gas platform at the centre of the surveyed region.

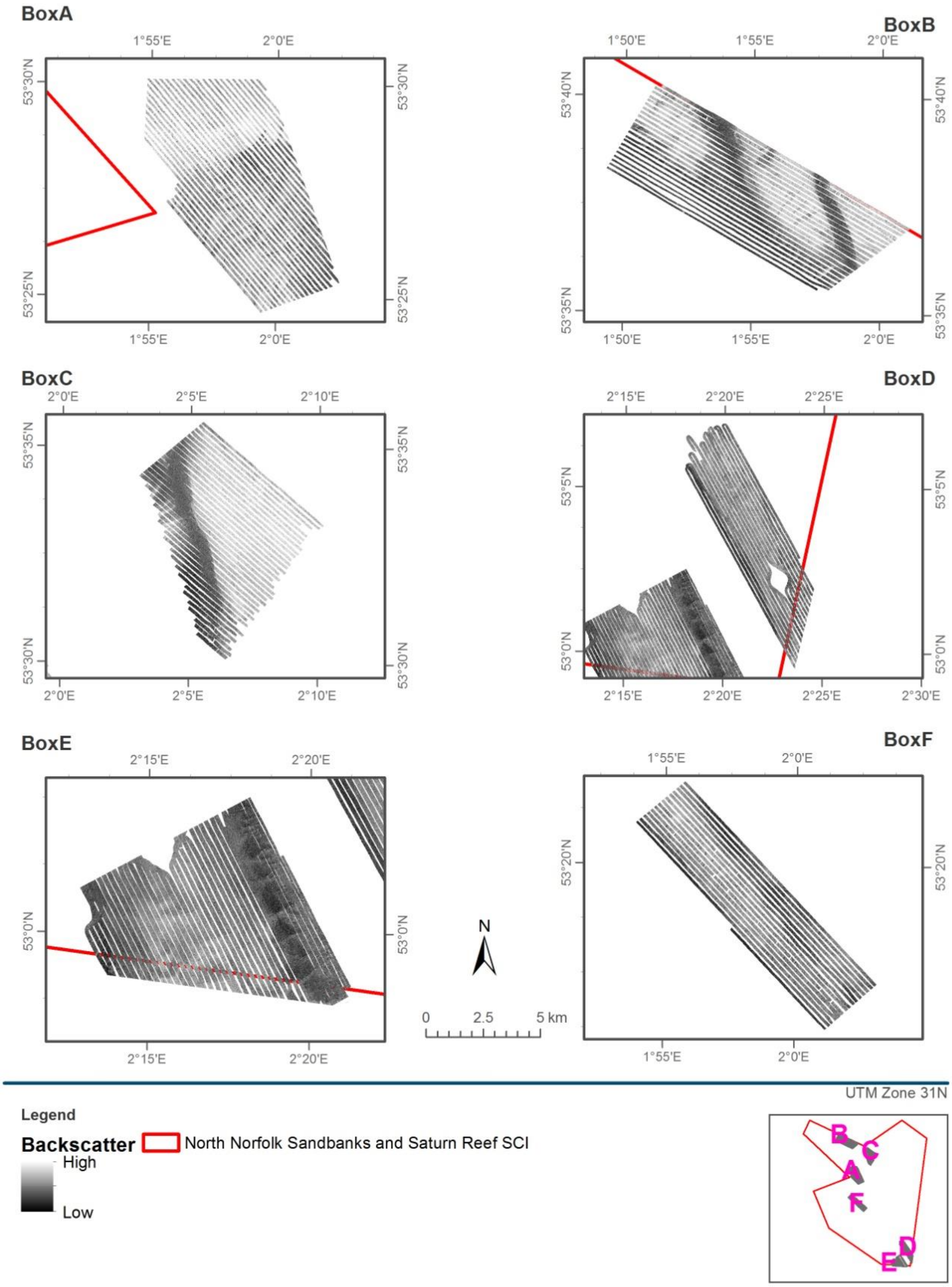


Figure 8. Multibeam echosounder backscatter for the six potential Annex I reef 'boxes' (A-F) at North Norfolk Sandbanks and Saturn Reef SCI. The data gap evident in Box D results from a static gas platform at the centre of the surveyed region.

3.2 EUNIS Level 3 habitat maps

Results of the Object Based Image Analysis (OBIA) suggest that areas surveyed within the North Norfolk Sandbanks and Saturn Reef SCI predominantly comprise three EUNIS Level 3 habitat types: Sublittoral Sands, Sublittoral Mixed Sediments and Sublittoral Coarse Sediments (Figure 9-14). However, two grab samples, at Box D, were allocated the EUNIS classification A5.3 – Sublittoral mud. It was not possible to predict this habitat within the OBIA process. These two samples were not supported by a strong region of acoustic differentiation. When a classification was run with these two samples remaining, large regions of the mapped area were predicted to be interspersed with 'Sublittoral Mud'. Acoustics in these regions, and physical sampling, did not support these predictions. It is likely in these areas that the decision tree process was unable to adequately distinguish between backscatter signatures equating to either 'Sublittoral Sand' or 'Sublittoral Mud'. Removal of these samples was deemed appropriate due to the poor evidence for 'Sublittoral Mud', and allowed for more confident predictions to be made across the SCI. These samples are presented in Figure 12 as point locations to provide evidence for their presence, though not extent.

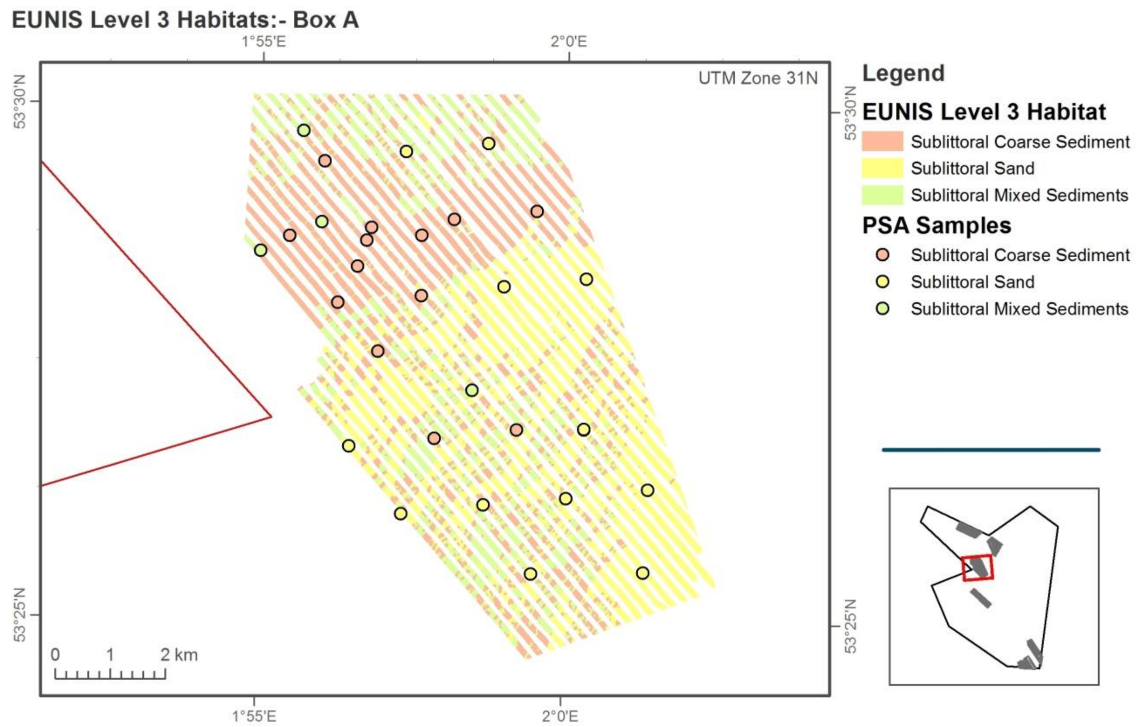


Figure 9. EUNIS level 3 habitat map, overlaid with PSA results, for Box A, at North Norfolk Sandbanks and Saturn Reef SCI.

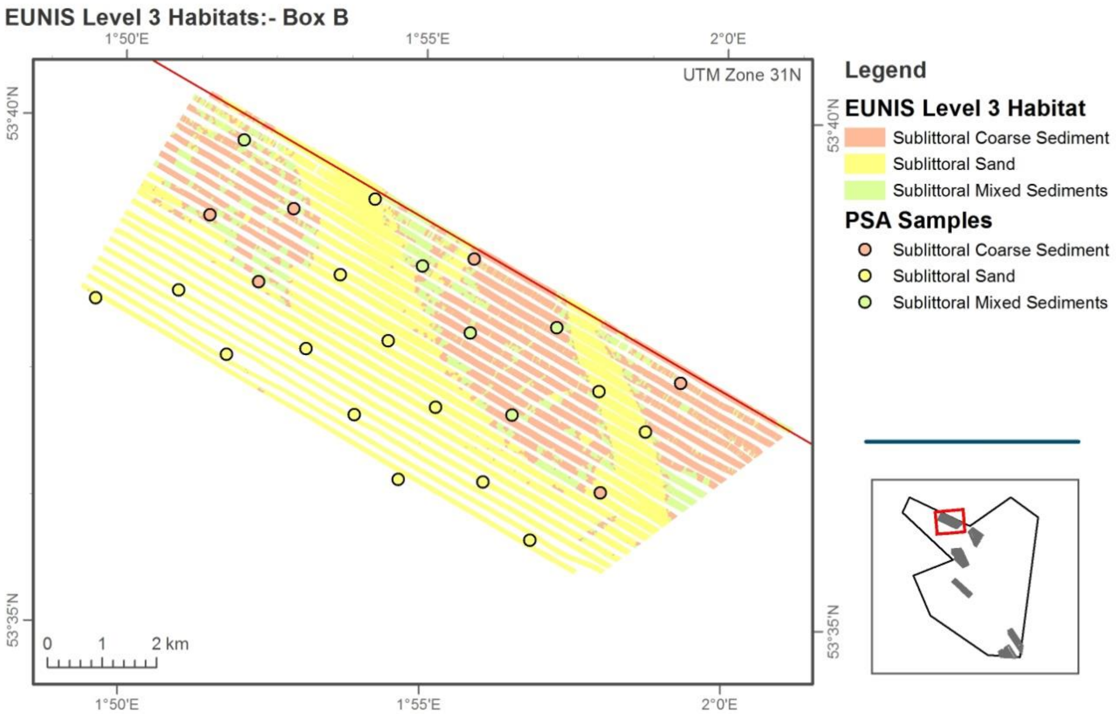


Figure 10. EUNIS level 3 habitat map, overlaid with PSA results, for Box B, at North Norfolk Sandbanks and Saturn Reef SCI.

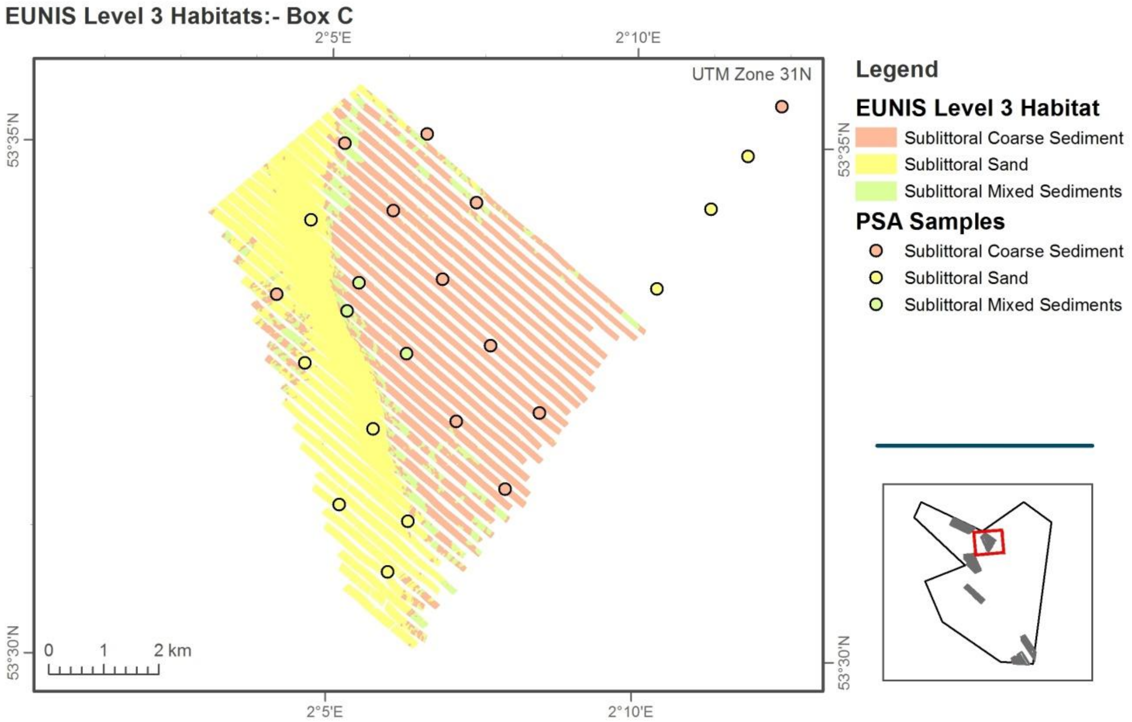


Figure 11. EUNIS level 3 habitat map, overlaid with PSA results, for Box C, at North Norfolk Sandbanks and Saturn Reef SCI.

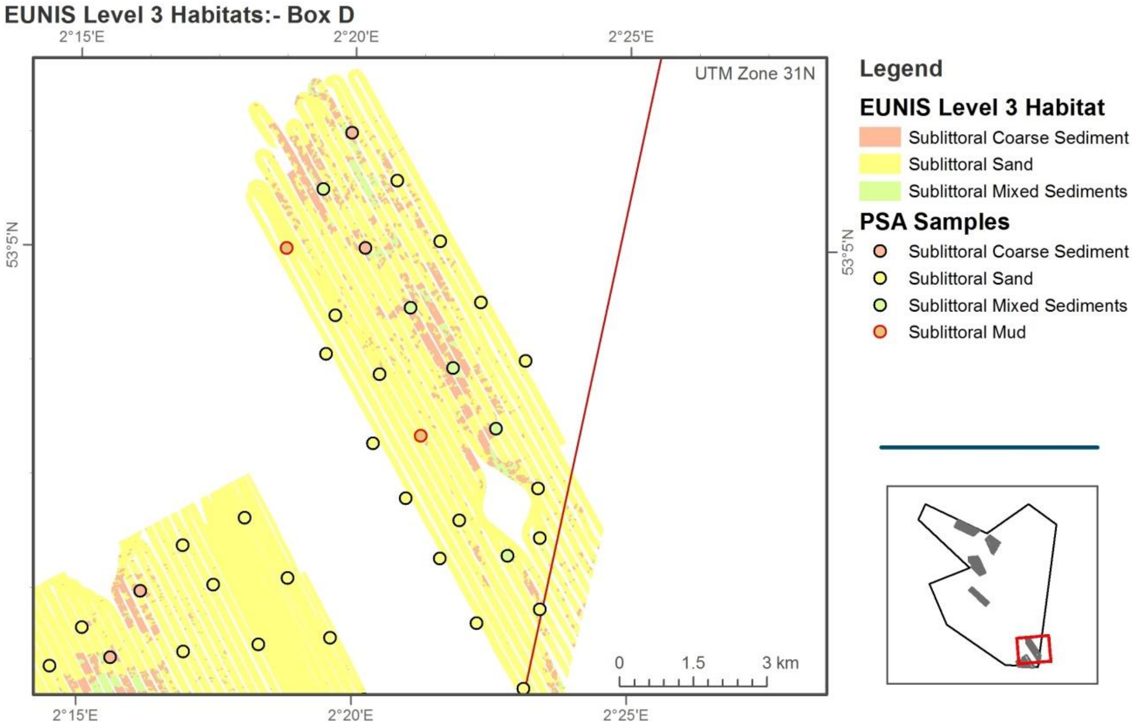


Figure 12. EUNIS level 3 habitat map, overlaid with PSA results, for Box D, at North Norfolk Sandbanks and Saturn Reef SCI.

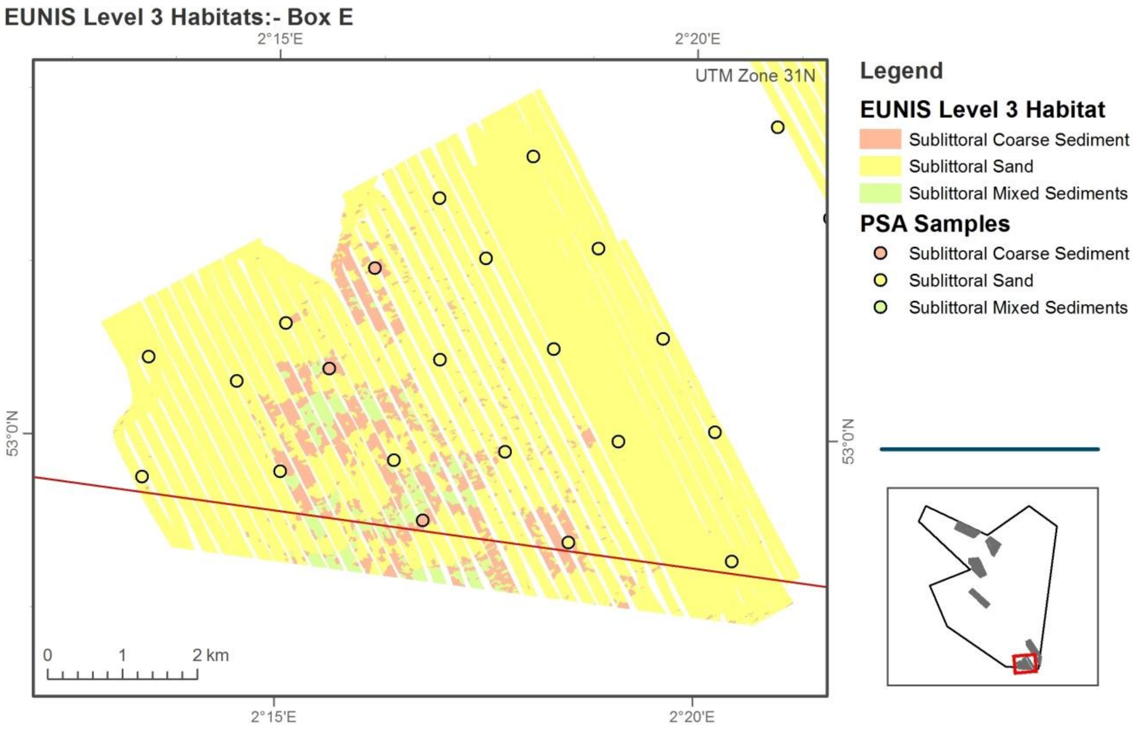


Figure 13. EUNIS level 3 habitat map, overlaid with PSA results, for Box E, at North Norfolk Sandbanks and Saturn Reef SCI.

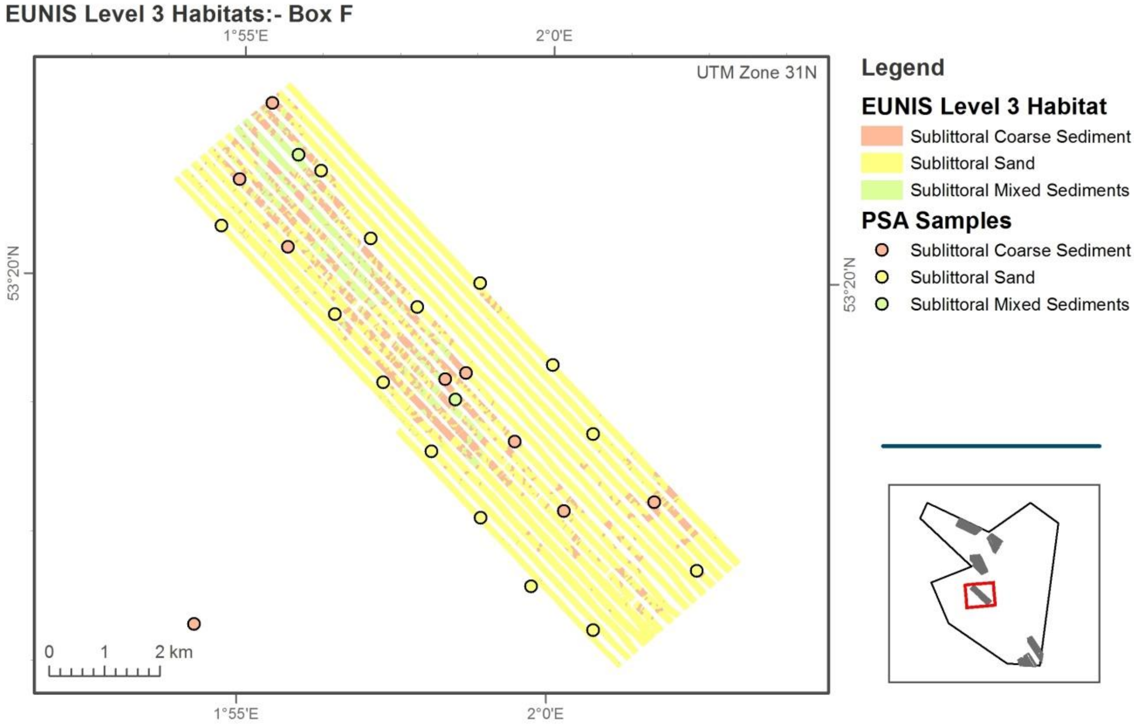


Figure 14. EUNIS level 3 habitat map, overlaid with PSA results, for Box F, at North Norfolk Sandbanks and Saturn Reef SCI.

3.3 Infaunal community analysis

Infaunal community analyses were performed on 363 taxa and 53,194 individuals. Numbers of taxa and abundance were highly variable between sampling 'boxes' (Figure 15) and were generally highest in Box C and lowest in Box E. Samples containing high abundances (thousands) of *S. spinulosa* were found at five sampling stations, although the species was found in all sampling boxes in low numbers (Figure 16).

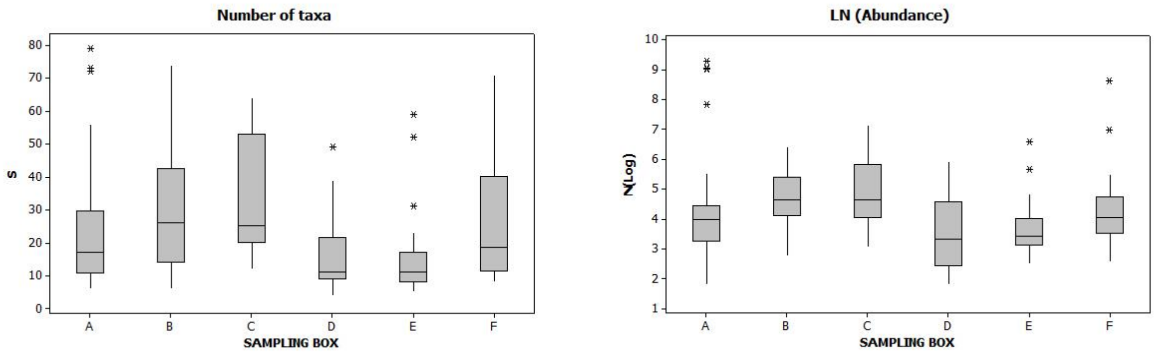


Figure 15. Box and whisker plots of (left) number of taxa and (right) abundance (natural log) within each sampling box. Boxes in the plots represent the interquartile range (middle 50% of the data), horizontal line represents the median, the vertical lines (whiskers) represent the data range and the asterisks (*) are outliers.

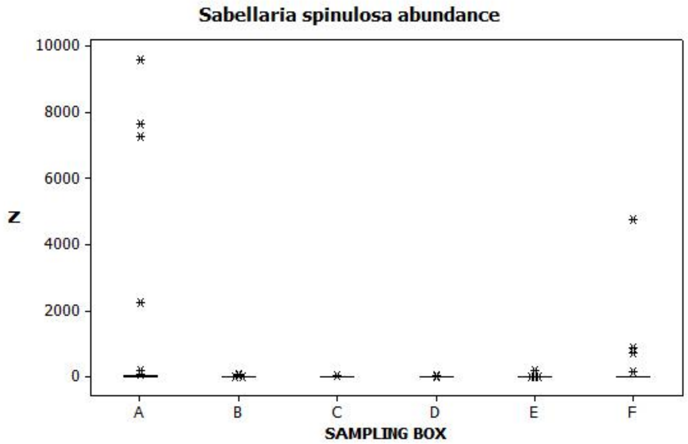


Figure 16. Abundances of *S. spinulosa* within each potential Annex I reef sampling 'box' (see Figure 2).

A multivariate comparison of biological assemblages between sampling 'boxes' revealed a significant result, however the R value is low, suggesting the communities barely differ (global R = 0.147, p<0.01). Pairwise comparisons indicate greatest differences are found between communities within Boxes C and E (R = 0.358, p<0.01). Characterising species (species contributing most to the similarity between the samples) of the boxes were similar and generally included the polychaetes *Ophelia borealis, Polycirrus, Lagis koreni, Scoloplos armiger* and *Nephtys cirrosa,* and the amphipod *Bathyporeia guilliamsoniana. S. spinulosa* contributed to the similarity between samples in Boxes A and C and F (see Appendix 4). Further multivariate analysis of community structure within the North Norfolk Sandbanks and Saturn Reef SCI identified 23 significantly different groups, with a further seven samples classed as outliers (Figure 17 and Figure 18), suggesting the whole area was faunally heterogeneous on a small spatial scale. Five of the groups were characterised by *S. spinulosa*. Group i, represented by three samples within Box A, contained the highest abundances of *S. spinulosa* (>9000). High abundances of *S. spinulosa* were also found in group c and g (two samples in each group), located in Boxes E and F. Lower abundances of *S. spinulosa* were found in groups e (in Boxes A, B and C) and d (Boxes A, B, D, E, F). The five groups characterised by *S. spinulosa* were located in areas of mixed or coarse sediment (Figure 19). Those with highest abundances of *S. spinulosa* (Figure 16 and Figure 20) were associated with mixed sediments. See Appendix 5 for characterising species of each SIMPROF group.

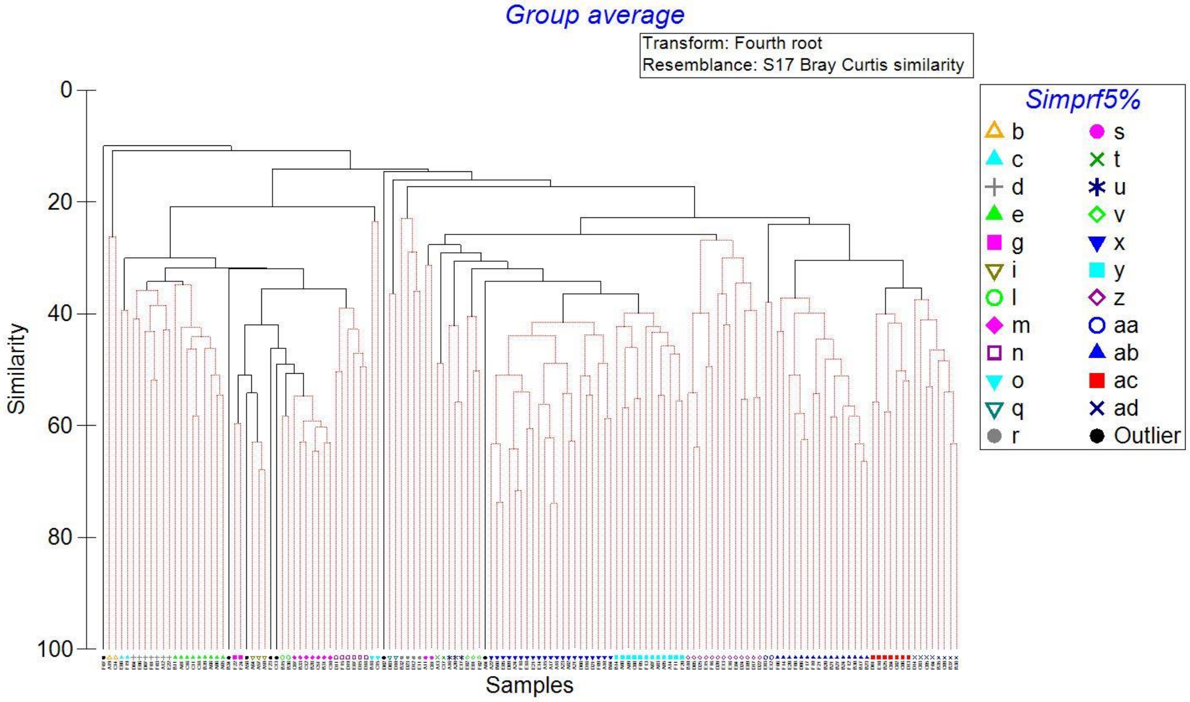


Figure 17. Dendrogram of fourth root transformed infaunal abundance data from all *S. spinulosa* potential Annex I reef sample 'boxes'. Symbols represent the SIMPROF (5% significance) groups and labelled according to sampling box.

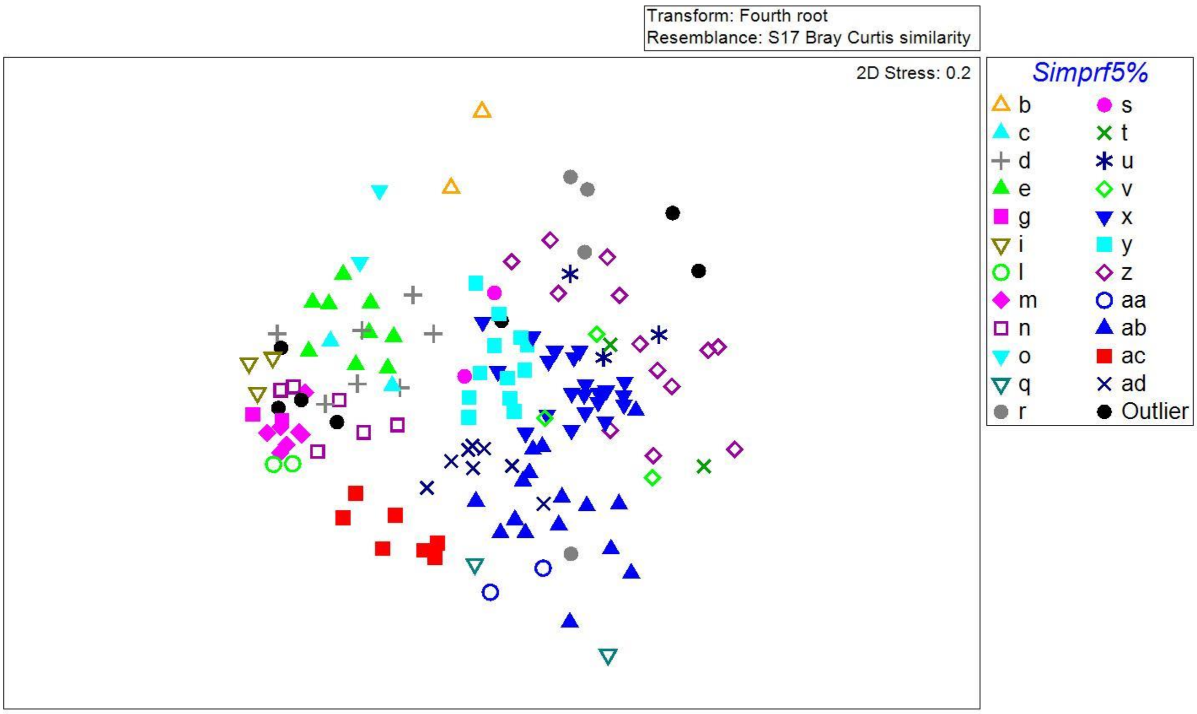


Figure 18. nMDS ordination of fourth root transformed infaunal abundance data from the *Sabellaria spinulosa* potential Annex I reef sample 'boxes', displayed according to SIMPROF groups.

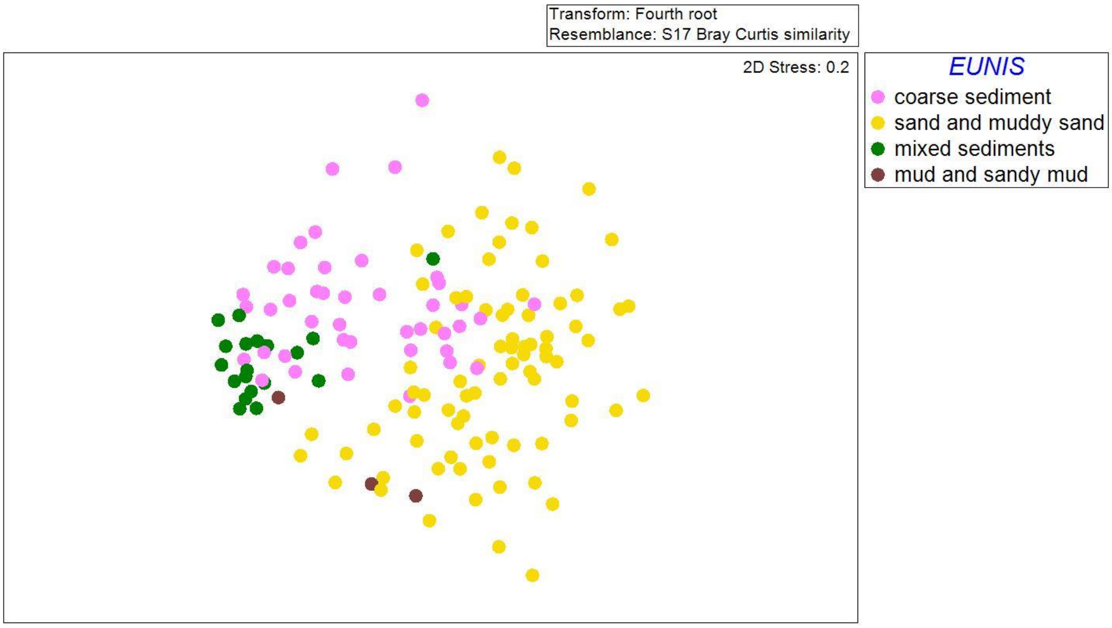


Figure 19. nMDS ordination of fourth root transformed infaunal abundance data from the *Sabellaria spinulosa* potential Annex I reef sample 'boxes', displayed according to EUNIS sediment group.

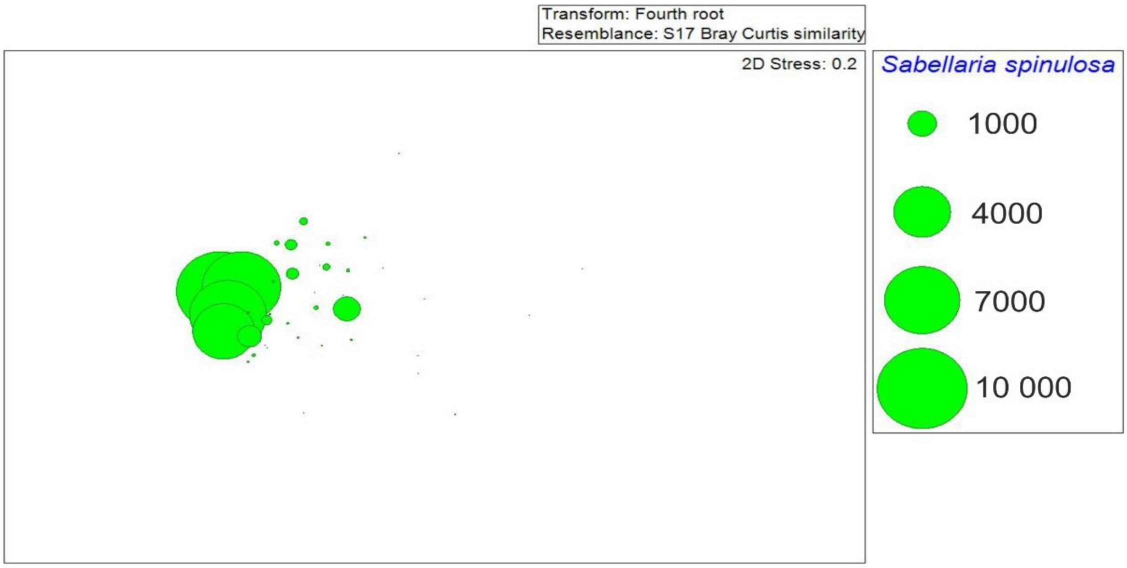


Figure 20. nMDS ordination (as shown in Figure 19) with superimposed *Sabellaria spinulosa* abundance.

Correlation analyses between *S. spinulosa* abundance and number of taxa indicated a significant positive association (0.482), although the relationship between *S. spinulosa* and taxon abundance (excluding *S. spinulosa*) was stronger (0.684). Correlations between *S. spinulosa* and taxa characteristic of faunal groups i, e and g revealed varying strengths of association. Strongest positive correlations were found for the scaleworm family Polynoidae (0.946), the squat lobster *Galathea intermedia* (0.967), the edible crab *Cancer pagurus* (0.931) and the porcelain crab *Pisidia longicornis* (0.819). Positive relationships were also found for the polychaetes *Eteone longa* (0.798), *Phyllodoce mucosa* (0.769), *Eunereis longissima* (0.710), *Sthenelais boa* (0.687) and *Glycinde nordmanii* (0.634), the amphipod *Abludomelita obtusata* (0.740) and the brittlestar *Amphipolis squamata* (0.630). All correlations were significant at p<0.001. Relationships were less apparent for Actiniaria, (0.441), Nemertea (0.437), *Pholoe baltica* (0.463), but no clear relationship was found between abundances of *Abra alba* and *S. spinulosa* (0.183). Relationships between sediment sorting (a measure of spread of grain sizes around the average) with the number and abundance of recorded taxa (excluding *S. spinulosa*), abundance of *S. spinulosa* and abundances of the characteristic taxa were also explored. Abundance of *S. spinulosa* was weakly correlated with sediment sorting (0.34) whilst a stronger positive correlation was found between sediment sorting and taxon abundance (excluding *S. spinulosa*) (0.55) and sediment sorting with the number of taxa (0.67). Significant weak to moderate relationships with sediment sorting were observed for all characteristic taxa, with the strongest observed for *P. baltica* (0.589). Correlation analyses were also performed between the abundance of *S. spinulosa,* number of taxa, total abundance (excluding *S. spinulosa*) and abundances of the characteristic taxa with volume of reef measured. A strong positive association (0.758) was found, although not perfect, between *S. spinulosa* abundance and reef volume. Further investigation revealed reef fragments present but no *S. spinulosa* in two samples (located in Box D) and high abundances of *S. spinulosa* but no reef fragments in one further sample (located in Box F). No significant relationships were observed between reef volume and number of taxa (0.439, P=0.153) and total abundance (0.509, p=0.091), although abundances of Nemertea, *G. intermedia*, *A. squamata* and *A. alba* were positively correlated with reef volume (0.591, 0.71, 0.695 and 0.894 respectively at p<0.05).

3.4 *S. spinulosa* reef delineation

3.4.1 Sabellaria 'Reefiness' (video)

Video analysis, using the five-second assessment method, and subsequent analysis of reef patchiness and magnitude revealed best examples of *S. spinulosa* reef in Box A (Table 3). High reefiness was infrequently observed in any of the video tows. The tow (A68) with the most continuous patches of reef was mainly classed as low reefiness. The full table can be found in Appendix 6.

Table 3. Example summary table of *S. spinulosa* reefiness (% cover and elevation) and associated patchiness per video tow ordered according to tows with largest patches of reef. Average patch length = the average number of five-second segments that *Sabellaria spinulosa* was observed. Average magnitude = Average combined value of percent cover and height. SD = Standard Deviation.

	% of Tow							
Tow Name	No Reef	Not Reef	Low Reef	Medium Reef	High Reef	No. of patches	Ave. Patch length (SD)	Ave. Magnitude per patch (SD)
A68	21.39	5.28	65.83	7.50	0.00	28	10.07 (10.56)	157 (86.86)
A69	42.59	9.60	41.92	5.89	0.00	47	7.28 (7.41)	114.08(83.73)
A67	44.87	8.97	39.32	6.62	0.21	56	4.54 (5.35)	147.57(124.57)
A63	65.53	17.96	11.65	3.88	0.97	19	3.74 (4.33)	87.89 (109)

Each potential Annex I reef survey 'box' was explored using side-scan sonar. These data were explored visually in an attempt to discern regions of potential *S. spinulosa* reef. It was not possible to assign a uniform *S. spinulosa* reflectivity 'signature' across all of the boxes.

Each box, where S. spinulosa was demonstrated to be present from groundtruthing, was independently assessed and described. Where boundaries have been drawn it is important to recognise these represent areas of known and potential S. spinulosa reef presence identifiable from remote data, and do not exclusively delineate Annex I reef extent within the North Norfolk Sandbanks and Saturn Reef SCI. These areas represent observed reef from video analysis and potential reef from side-scan sonar interrogation, where signature and imagery coincide with reef presence.

Automated processes, such as segmentation or clustering, were not feasible owing to the nature of the side-scan sonar data. In any given side-scan line a central nadir is present where no data is collected due to the beam angle of the transducer. When loaded into *ArcGIS 10.1* for further processing these 'no data' regions have the same value as real 'contacts'. Subsequently, it is not possible to clean sonar data for these nadir areas. Attempts to segment or cluster side-scan sonar data will, therefore, aggregate the nadir as if it were an object. Furthermore, side-scan sonar data lose power when emitted over greater distances. This means returns from beams at the edge of a side-scan sonar swathe will be weaker, and visually less defined, than those closer to the nadir, where the strength is greatest. This data artefact means that visualisation of data in *ArcGIS 10.1* will appear as though data at the edges of the swathe are of a softer texture than that in the centre. Automatic segmentation and classification rely on data values being representative of habitat types to enable effective clustering. This was not possible for side-scan sonar data collected here, where raster values varied with distances from the transducers. Visual interpretation of side-scan sonar data by expert judgement can be used in the delineation process. Data collected as part of this survey varied in mapping potential across the site. Within Box A there was a demonstrably stronger signature associated with *S. spinulosa* reef presence that was not found at other surveyed areas within the SCI. This is potentially due to the relative reflectivity of the *S. spinulosa* reef against the predominant habitat, that is, where the two are more distinct from one another it is possible to make higher confidence predictions of reef presence.

Box A

Interpretation of data acquired at Box A demonstrated an identifiable signature for *S. spinulosa* reef presence. Figure 21 shows the results from this interpretation. Though areas of *S. spinulosa* have been mapped, and presence confirmed by video analysis (Figure 22), boundaries should be considered as a coarse demarcation rather than a sharp cut off. Mapping at a finer spatial resolution was not feasible due the nature of the acquired side-scan sonar data. The presence of the nadir at the centre of each line meant that these portions of the survey area could not be interpreted. As such, confidence in *S. spinulosa* extent was inferred from its presence either side of the nadir. Also, as described for the potential to automate reef delineation, signal degradation at the outer beams decreased expert judgement accuracy when interpreting acoustic boundaries.

Results here demonstrate the potential migration of the Saturn Reef feature in a westerly direction, or the loss of the feature and development of subsequent reef structures. It is currently not possible to state whether there are positional discrepancies between datasets due to historical data not being available at the time of writing. Further work would be required to investigate potential causes for reef movement to distinguish between natural or anthropogenic environmental drivers. Figure 23 shows results for video tows and acoustics directly over the area previously reported to encompass the Saturn reef feature and demonstrates the recent absence of *S. spinulosa* reef from within this area.

Patch sizes in Box A varied between 0.004km^2 and 1.5km^2. These values would represent 'not reef' to 'high reef' areas according to the Gubbay (2007) criteria. Areas of known and potential reef were mapped with a precautionary approach to ensure that potential reef areas were captured. For this reason area calculations are likely an over estimation of *S. spinulosa* reef. It was not possible to draw together scores for elevation, percentage cover and area due to the variable nature, and patchiness, of the reef structures.

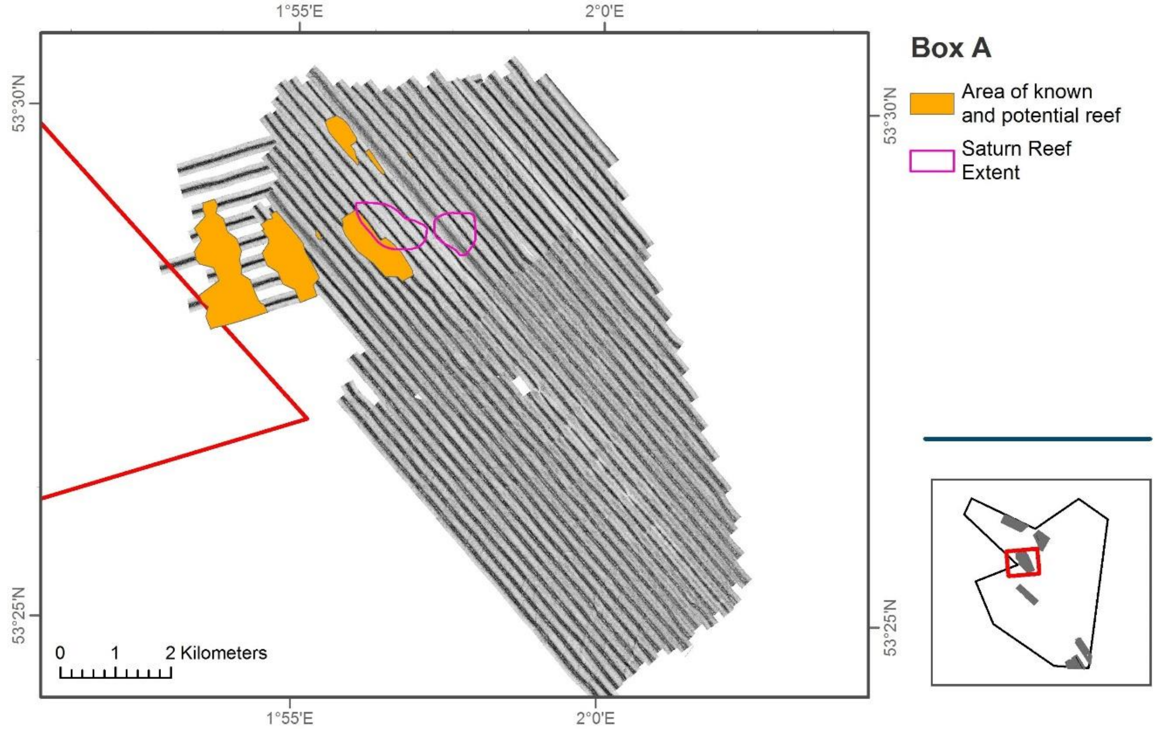


Figure 21. Identified areas of known and potential *Sabellaria spinulosa* reef extent from side-scan sonar at Box A and historical location of Saturn reef (see Section 1).

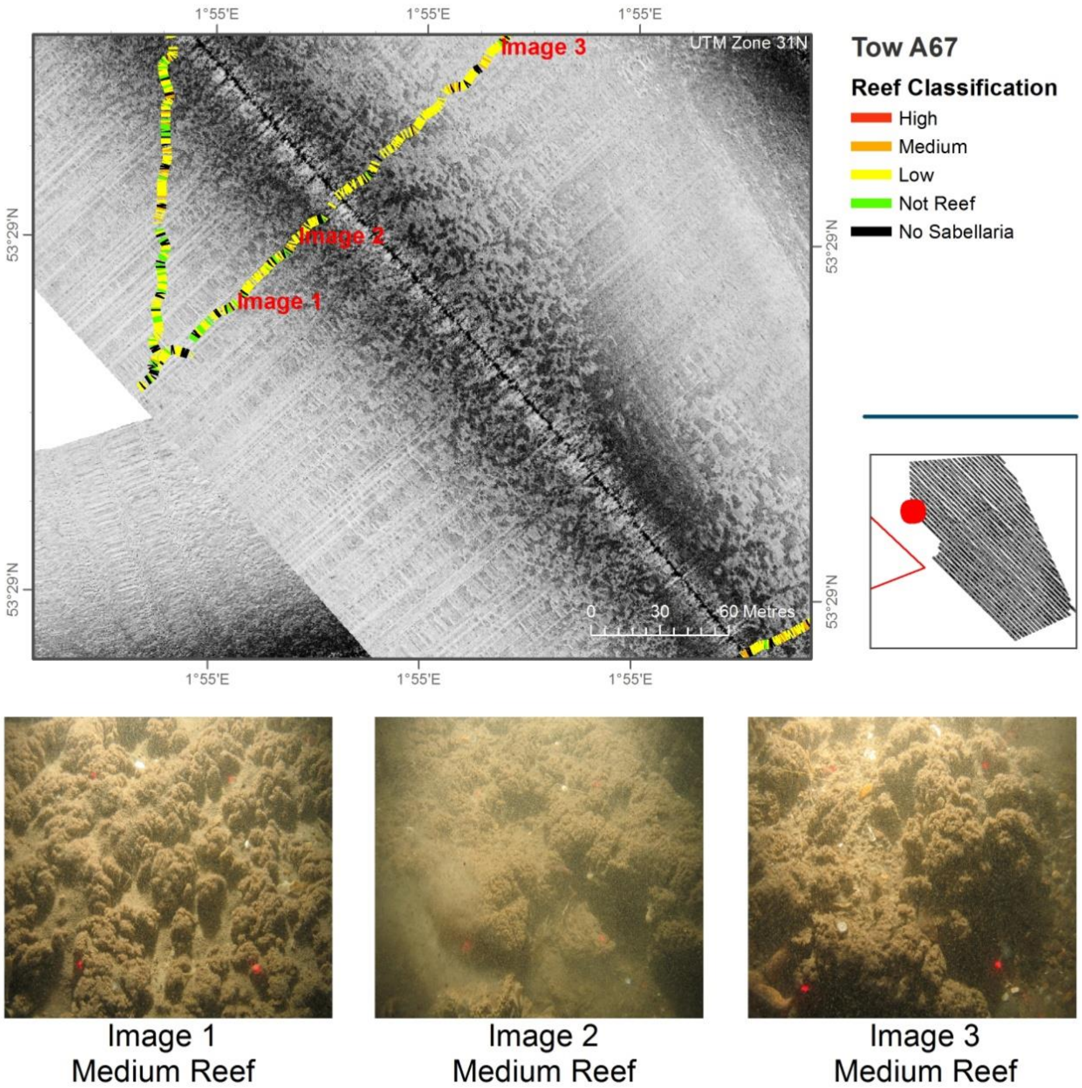


Figure 22. Single side-scan sonar line acquired at Box A (showing the characteristic *S. spinulosa* reef acoustic signature for this box) and overlain by video tow analysis. Video tow broken down into five-second points and assigned reef classification as per Table 2.

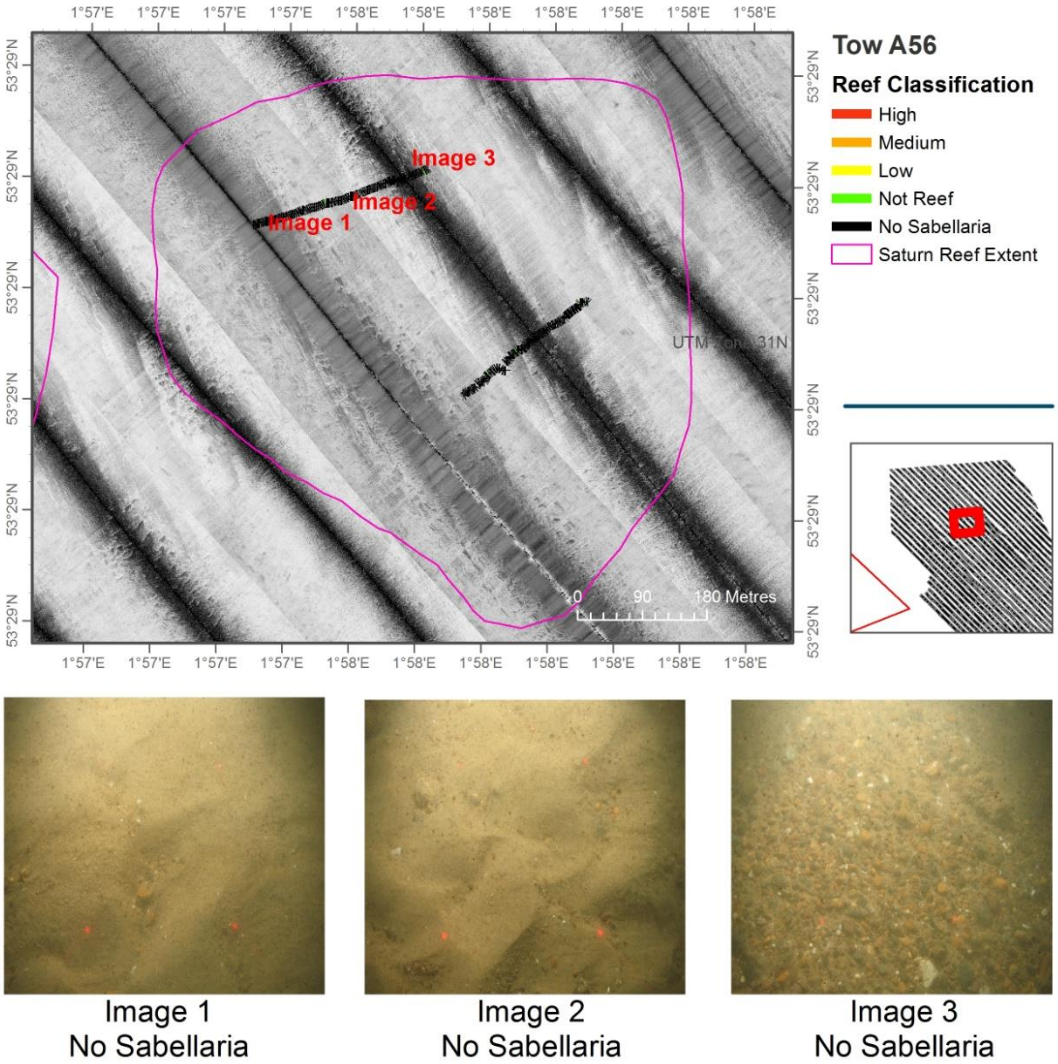


Figure 23. Side-scan sonar and video analysis of the previously reported location of Saturn Reef, overlain by video tow analysis. Video tow broken down into five-second points and assigned reef classification as per Table 2.

Figure 24 highlights a further limitation in mapping the spatial extent of *S. spinulosa* presence. The overlaid camera tow demonstrates that video analysis demarcating areas of reef (such as areas associated Image 1 of Figure 24) intersect regions of both high and low reflectivity. Similarly, areas of 'No Sabellaria' (such as Image 3 of Figure 24) also traverse high and low reflectivity patches. These fine-scale discrepancies are potentially introduced due to positional errors inherent in data acquisition, both for side-scan sonar and for video transects. There is also potential that the nature of the drop camera, being downward facing, means that regions of reef and or habitat either side of the field of view cannot be investigated for a wider analysis of the towed region.

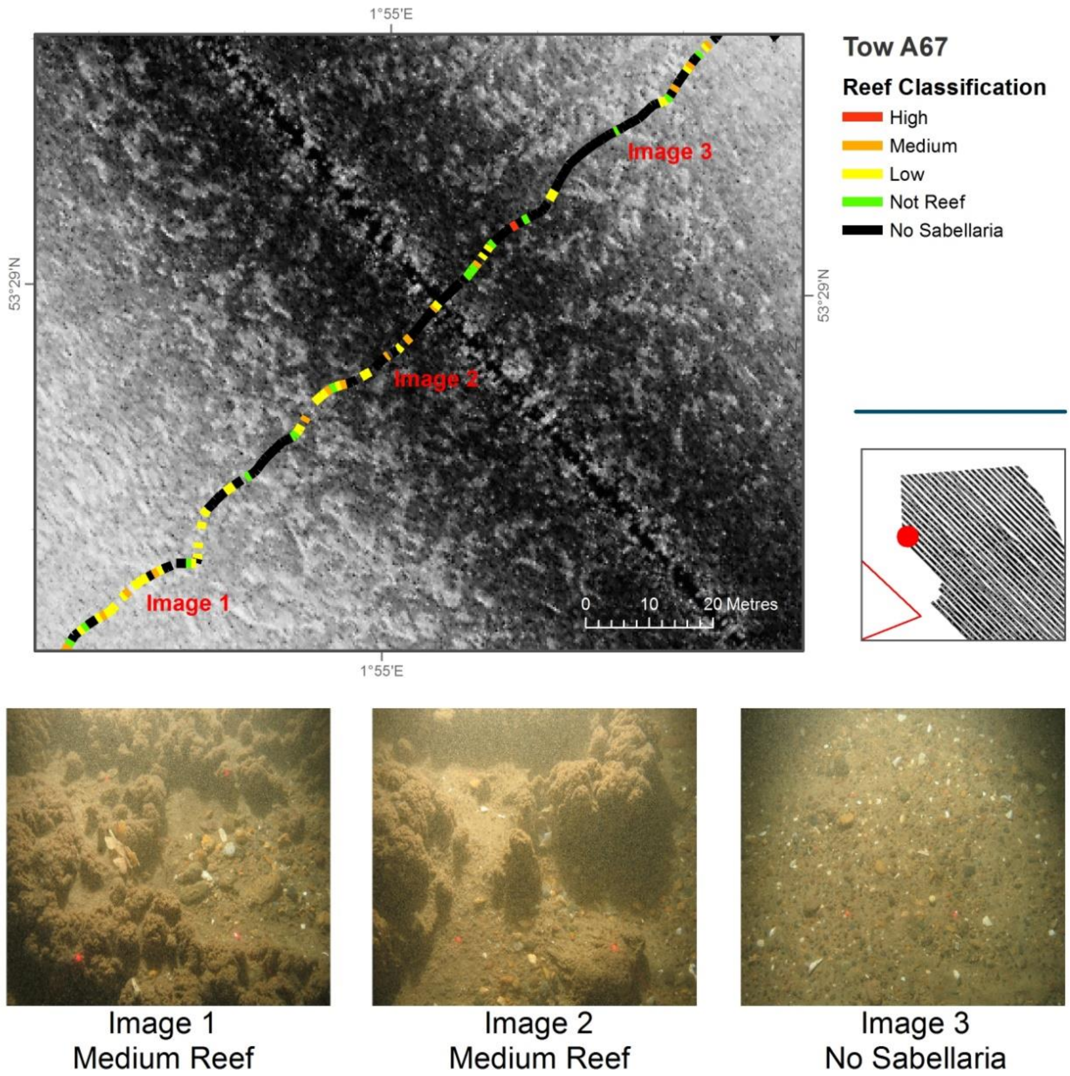


Figure 24. Single side-scan sonar line acquired at Box A and overlain by video tow analysis. Video tow broken down into 5 second points and assigned reef classification as per Table 2.

Box B

Analysis of side-scan sonar and groundtruthing data sets demonstrated no evidence of *S. spinulosa* reef within Box B.

Box C

Results from video and stills analysis demonstrated the presence of low reef structures within Box C. Figure 25 suggests an area of *S. spinulosa* reef presence with an associated 'mottled' signature. This signature was not as clear, and or pronounced, as that seen at Box A, but was investigated to see whether it was a suitably demonstrative signature for reef presence. However, further investigation of other tows within Box C, Figure 26, demonstrated a similar signature where no *S. spinulosa* reef structures were identifiable. Stills image and video analyses of these tow locations demonstrated that predominant substrata identified were a mixture of coarse sediments interspersed with patches of sand. It is highly probable that the acoustic signature seen at Box C is a reflection of these harder substrata against areas of softer sand. Therefore, the acoustic signatures which correlated with *S. spinulosa* presence in groundtruthing data are most likely a reflection from underlying coarse substrata rather than a reflection generated by reef features.

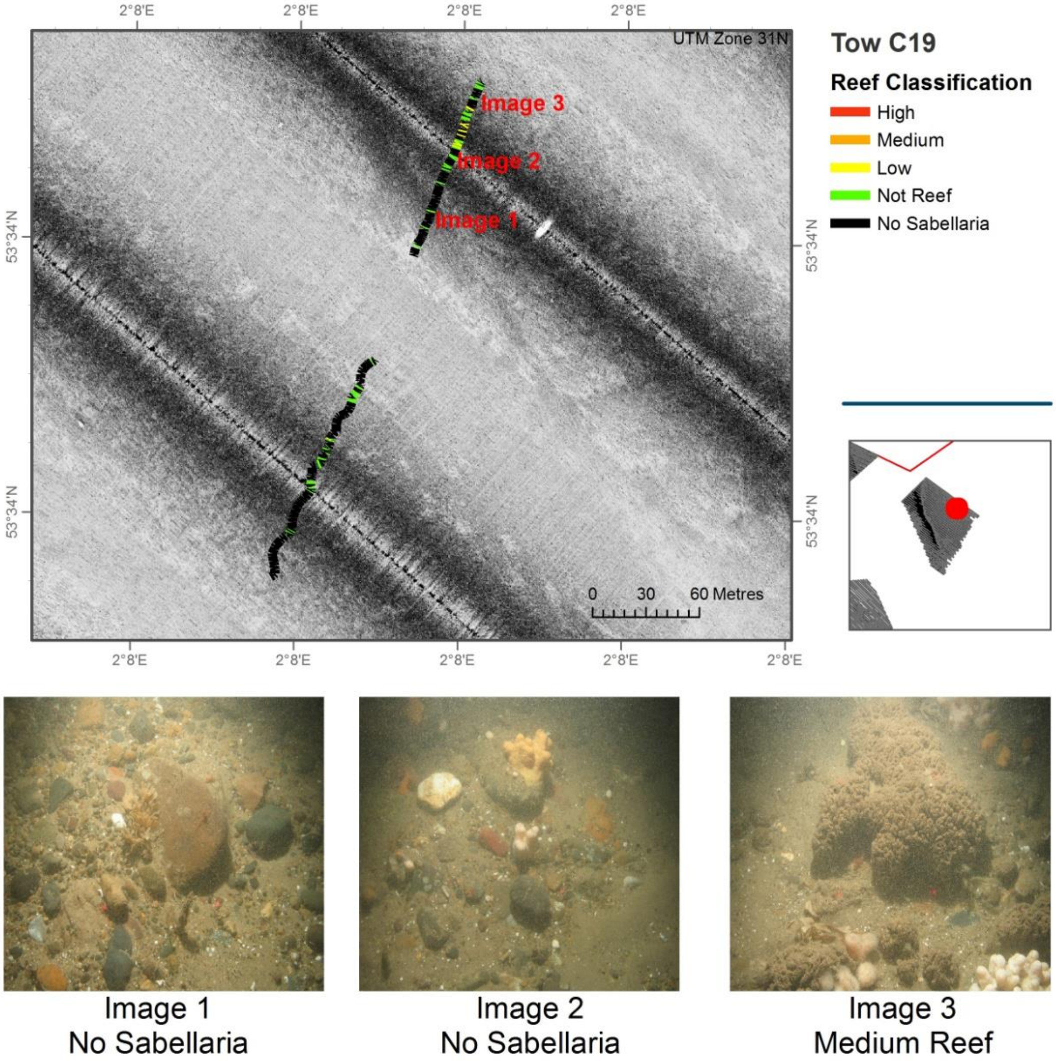


Figure 25. Side-scan sonar data acquired at Box C and overlain by video tow analysis. Video tow broken down into five-second points and assigned reef classification as per Table 2.

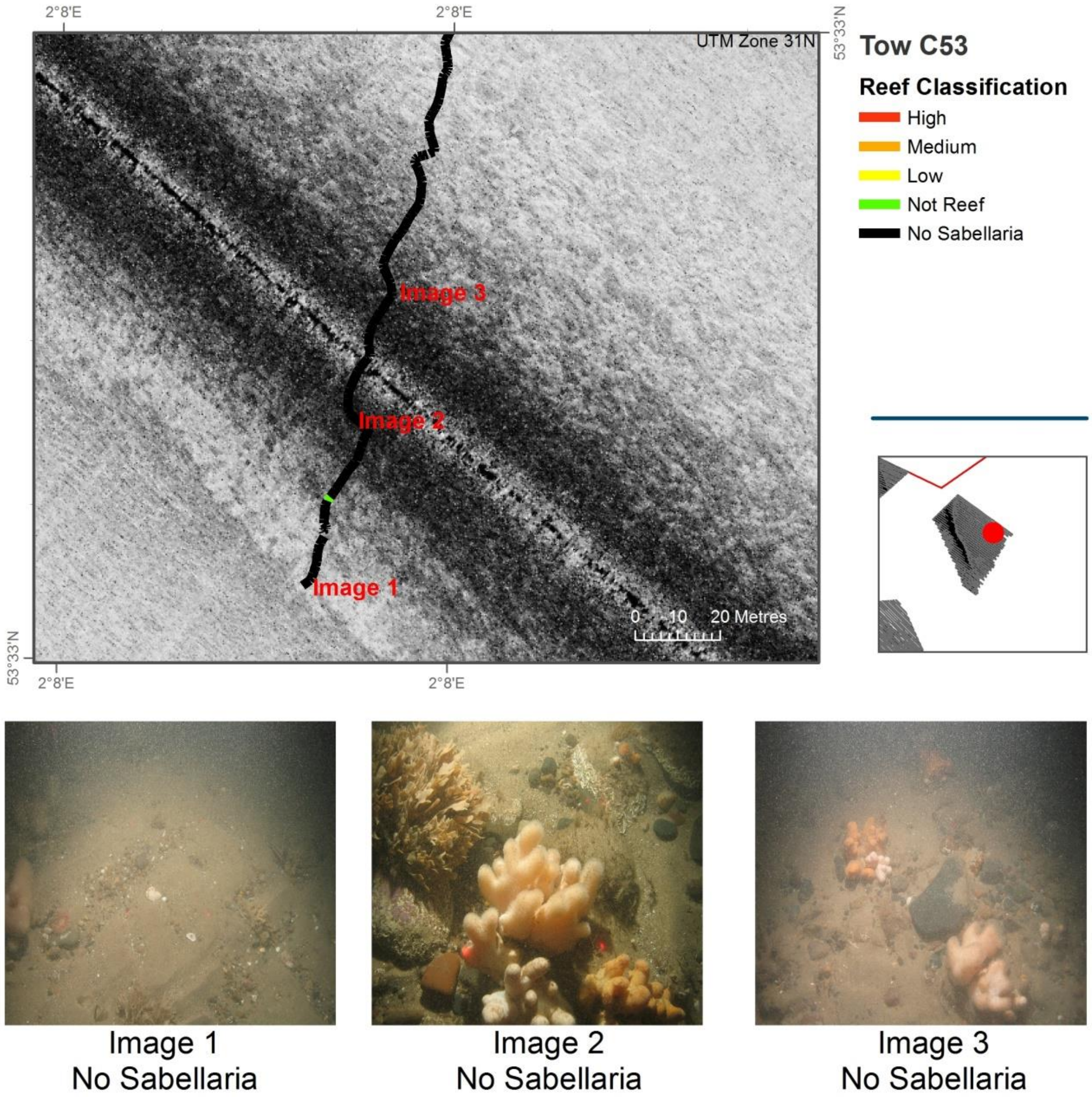


Figure 26. Side-scan sonar data acquired at Box C and overlain by video tow analysis. Video tow broken down into five-second points and assigned reef classification as per Table 2.

Box D

Analysis of side-scan sonar and groundtruthing datasets demonstrated no evidence of *S. spinulosa* reef at Box D. A single video tow at this site demonstrated *S. spinulosa* presence, but was not assessed as a reef structure. Further acoustic interpretation was not feasible due a large number of artefacts in the data record, produced by poor weather conditions at time of acquisition, reducing confidence in identifying distinct habitat signatures.

Box E

Regions of *S. spinulosa* reef were identified from video analysis at Box E, an example of which can be found in Figure 27. Mapping of potential *S. spinulosa* reef extent was not possible due to the texture and topographic nature of the seabed. Figure 27 demonstrates the variability of the textured return of side-scan sonar data collected at Box E. This variability prevented the isolation of any discernible signature related to potential *S. spinulosa* presence. Therefore, high confidence delineation and mapping of potential *S. spinulosa* presence was not possible.

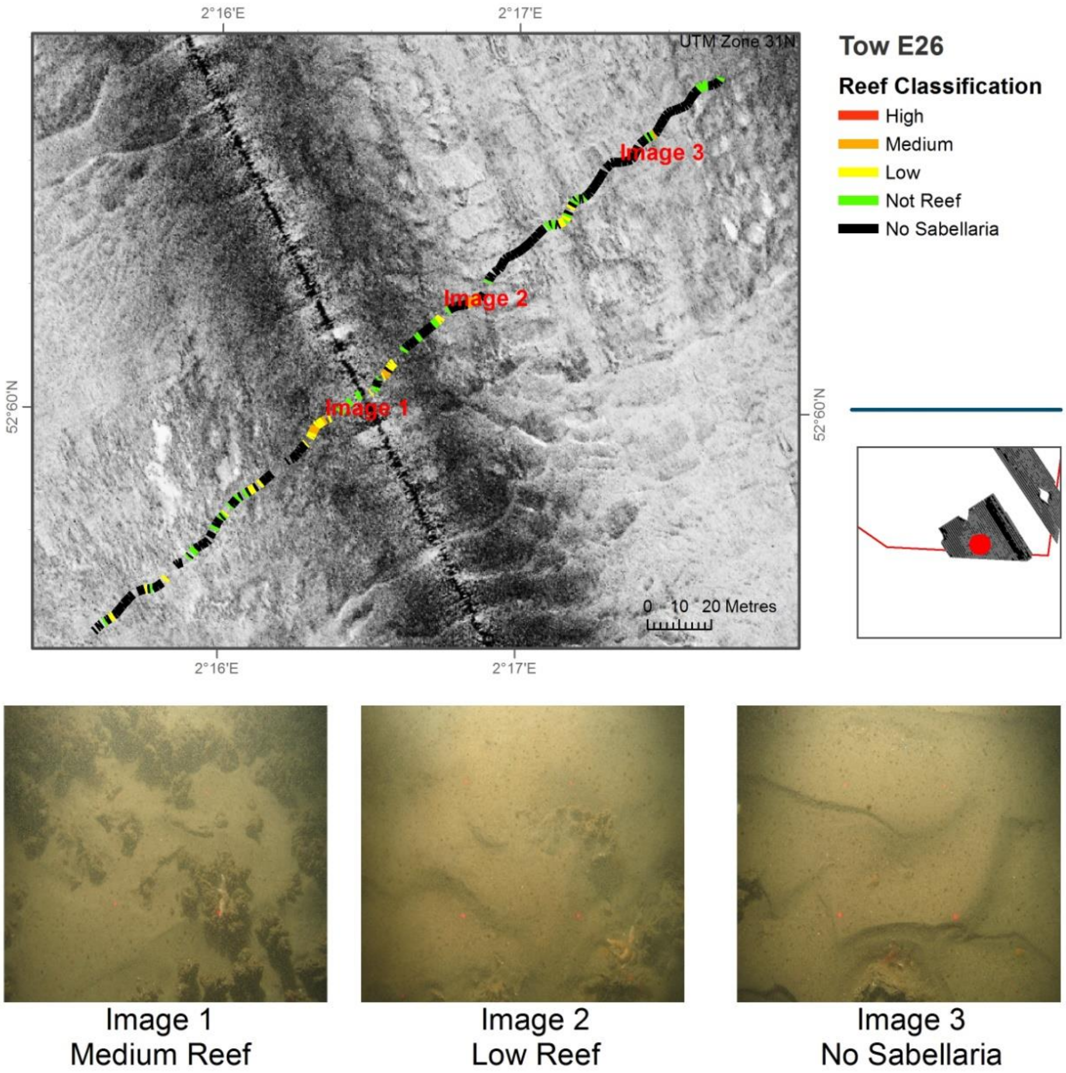


Figure 27. Side-scan sonar data acquired at Box E and overlain by video tow analysis. Video tow broken down into five-second points and assigned reef classification as per Table 2.

Box F

Side-scan sonar data acquired at Box F enabled coarse mapping of potential *S. spinulosa* presence (Figure 28). The mapped signature used here was not as clear as that identified at Box A due to poorer quality data caused by poor weather conditions at time of acquisition (Figure 29 and Figure 30). In this instance the combination of side-scan sonar signature and video analysis provided some confidence in mapping patches of potential *S. spinulosa* reef presence, but lower than that for mapping of signatures in Box A. As above, boundaries cannot be considered as strict demarcations of reef features. Figure 29 illustrates *S. spinulosa* reef presence from video overlaid on SSS data and Figure 30 demonstrates results of video tows where *S. spinulosa* reef was not observed overlain on side-scan sonar data.

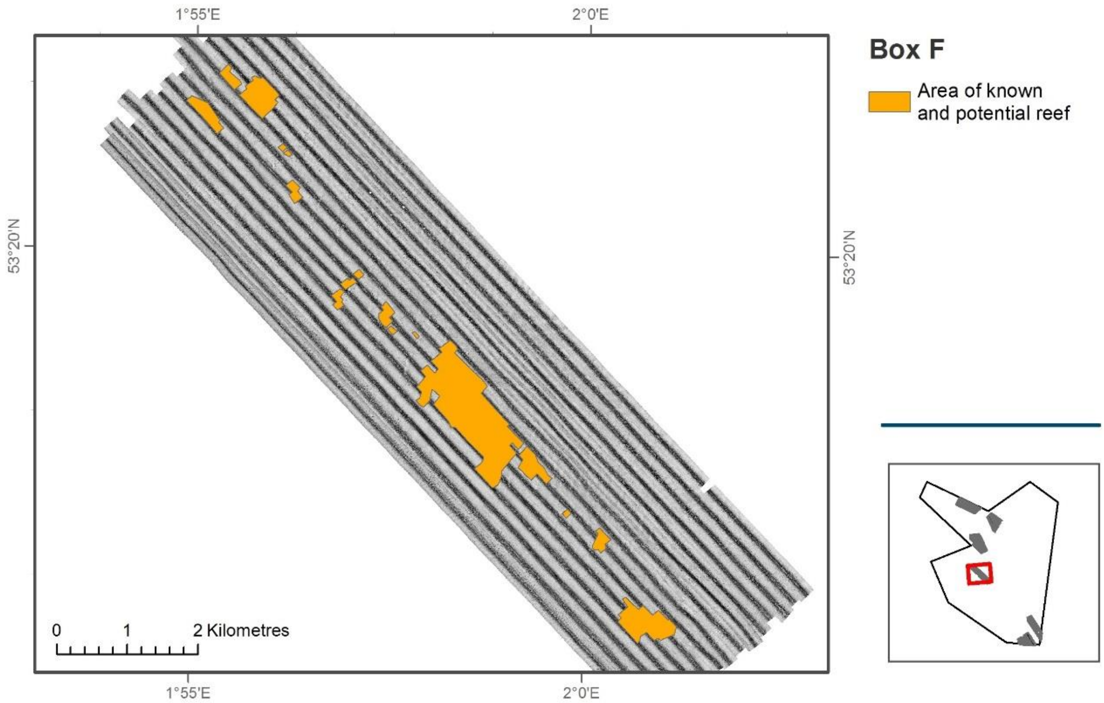


Figure 28. Identified areas of known and potential Sabellaria reef habitat from side-scan sonar at Box F.

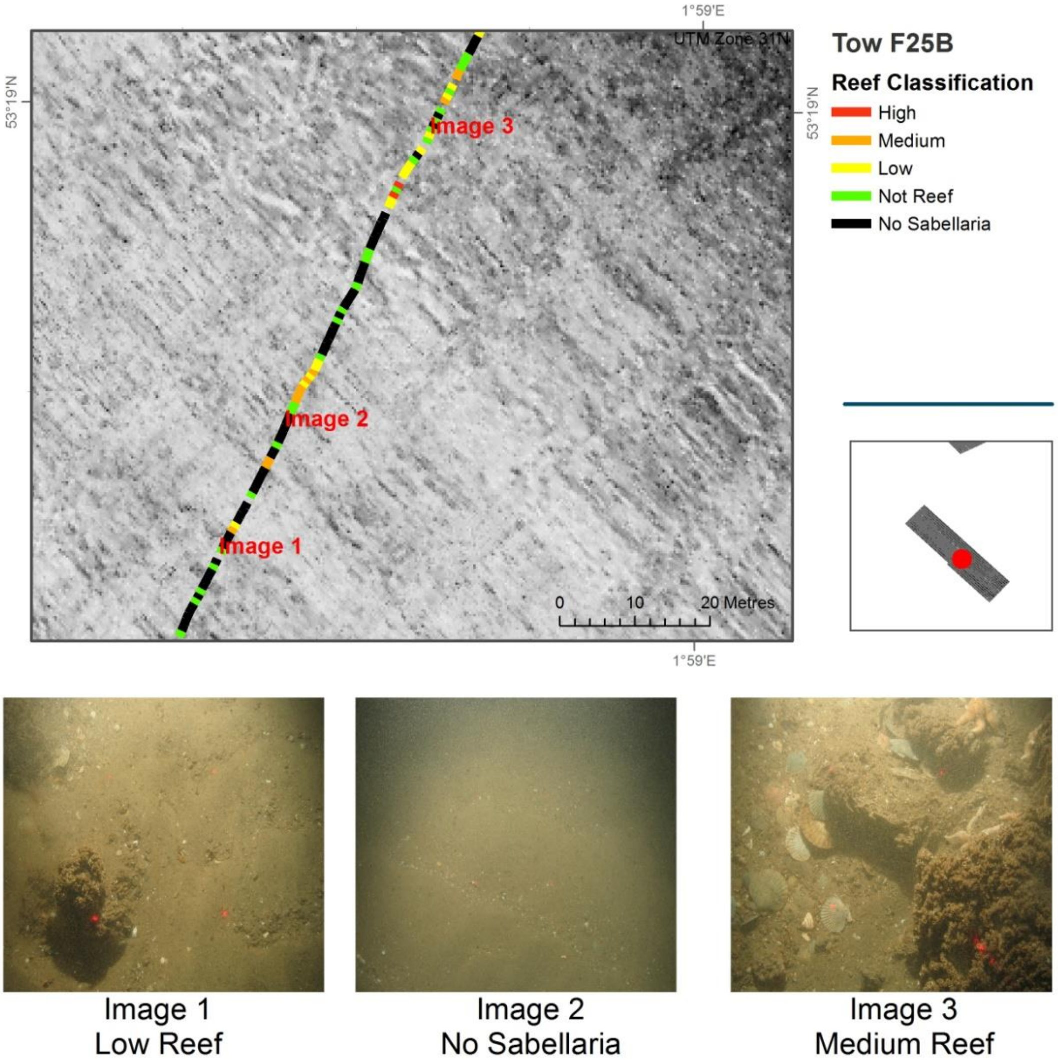


Figure 29. Side-scan sonar data acquired at Box F and overlain by video tow analysis. Video tow broken down into five-second points and assigned reef classification as per Table 2.

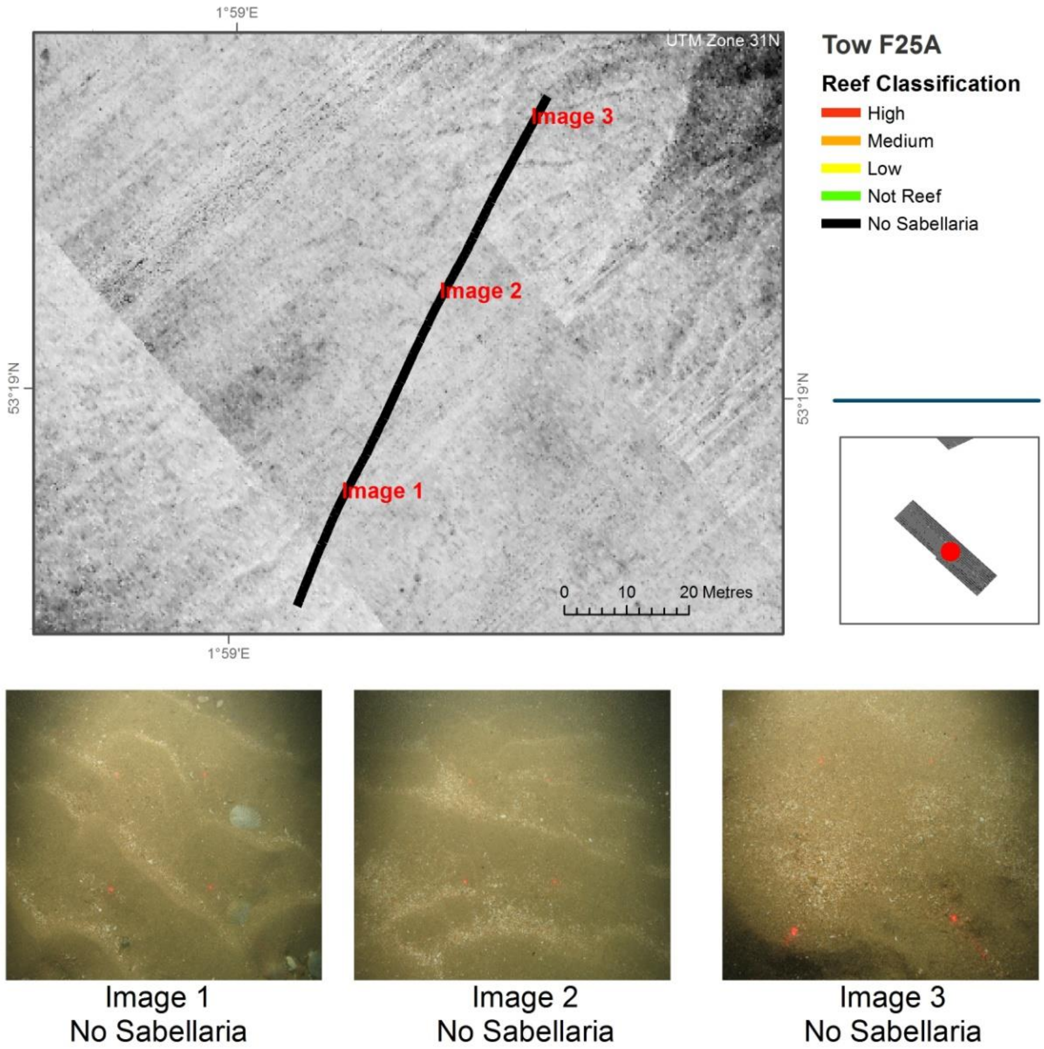


Figure 30. Side-scan sonar data acquired at Box F and overlain by video tow analysis. Video tow broken down into five-second points and assigned reef classification as per Table 2.

3.5 Sandbank Assessment

Multibeam echosounder transects were carried out across the profile of the sandbanks (providing bathymetry and backscatter data) prior to sampling with the Hamon grab. Locations of transects are presented in Figure 31. In total, 17 transects were sampled. The number of transects was considerably less than the planned 40 due to time restrictions. Transects were, however, spaced to incorporate a number of different sandbanks.

Eighty-five samples were collected for PSA and infauna representing three treatments (crest, flank and trough).

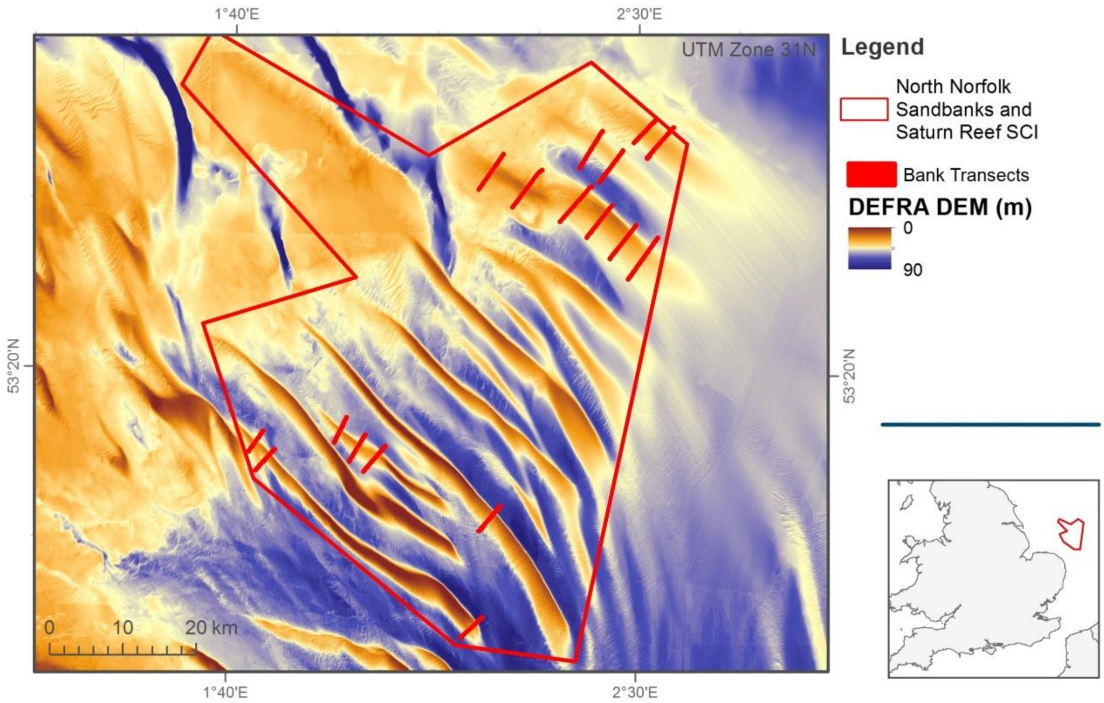


Figure 31. Location of multibeam transects at the North Norfolk Sandbanks and Saturn Reef SCI, underlying bathymetry layer is taken from the DEFRA digital elevation model (Astrium 2011).

3.5.1 Environmental data analysis: Depth and particle size distribution

An investigation of depth, according to sandbank and position on the bank, revealed that the crests of the Indefatigable Banks were generally deeper than those of nearshore banks; Inner, Leman and Well (Figure 32). However the troughs of the nearshore banks were comparable with and occasionally deeper than the troughs of the Indefatigables. The median depths for the flanks of the nearshore banks (Inner, Well and Leman) and the troughs of the Indefatigables were fairly similar, although the depths at Inner Bank were less variable.

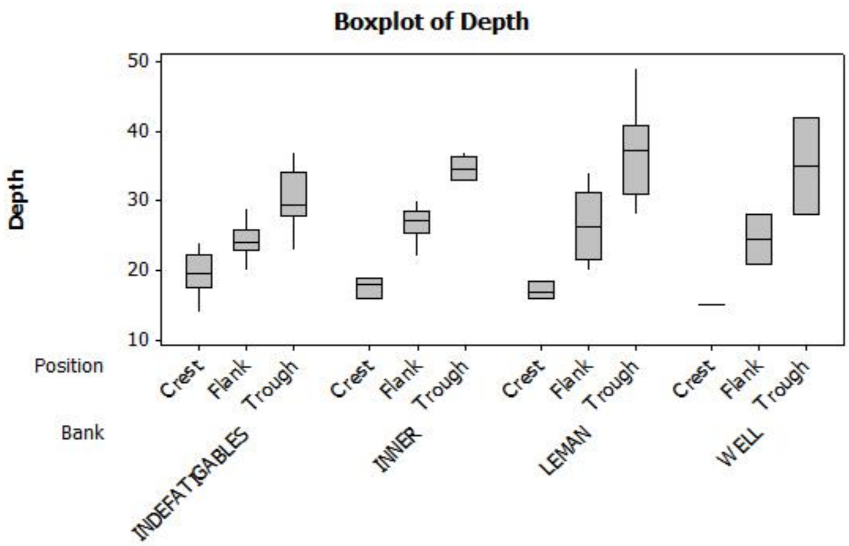


Figure 32. Depth range of the crests, flanks and troughs according to sandbank. Horizontal line represents the median, the box for each group represents the interquartile range (middle 50%) of the data and vertical lines (whiskers) represent the upper and lower 25% of the distribution (excluding outliers).

Particle size distributions (grouped according to position on bank; crest, flank and trough) showed greatest variability within the troughs of the sandbanks in comparison with the crests and flanks (Table 4 and Figure 33). Significant (but small) differences were found between particle size distribution found on the nearshore and offshore banks (ANOSIM Global R = 0.198, p = 0.1%).

Table 4. Example summary statistics for particle size distributions (µm) on the crest, flank and trough of near and offshore sandbanks

Nearshore	Mean (±SD)	Sorting (±SD)
Crest	279.92 (± 43.83)	1.36 (± 0.03)
Flank	261.91 (± 42.68)	1.46 (± 0.22)
Trough	428.70 (± 367.32)	2.89 (± 2.23)
Offshore		
Crest	275.46 (± 142.12)	1.54 (± 0.26)
Flank	305.94 (± 258.47)	1.90 (± 0.98)
Trough	477.14 (± 692.59)	2.29 (± 1.03)

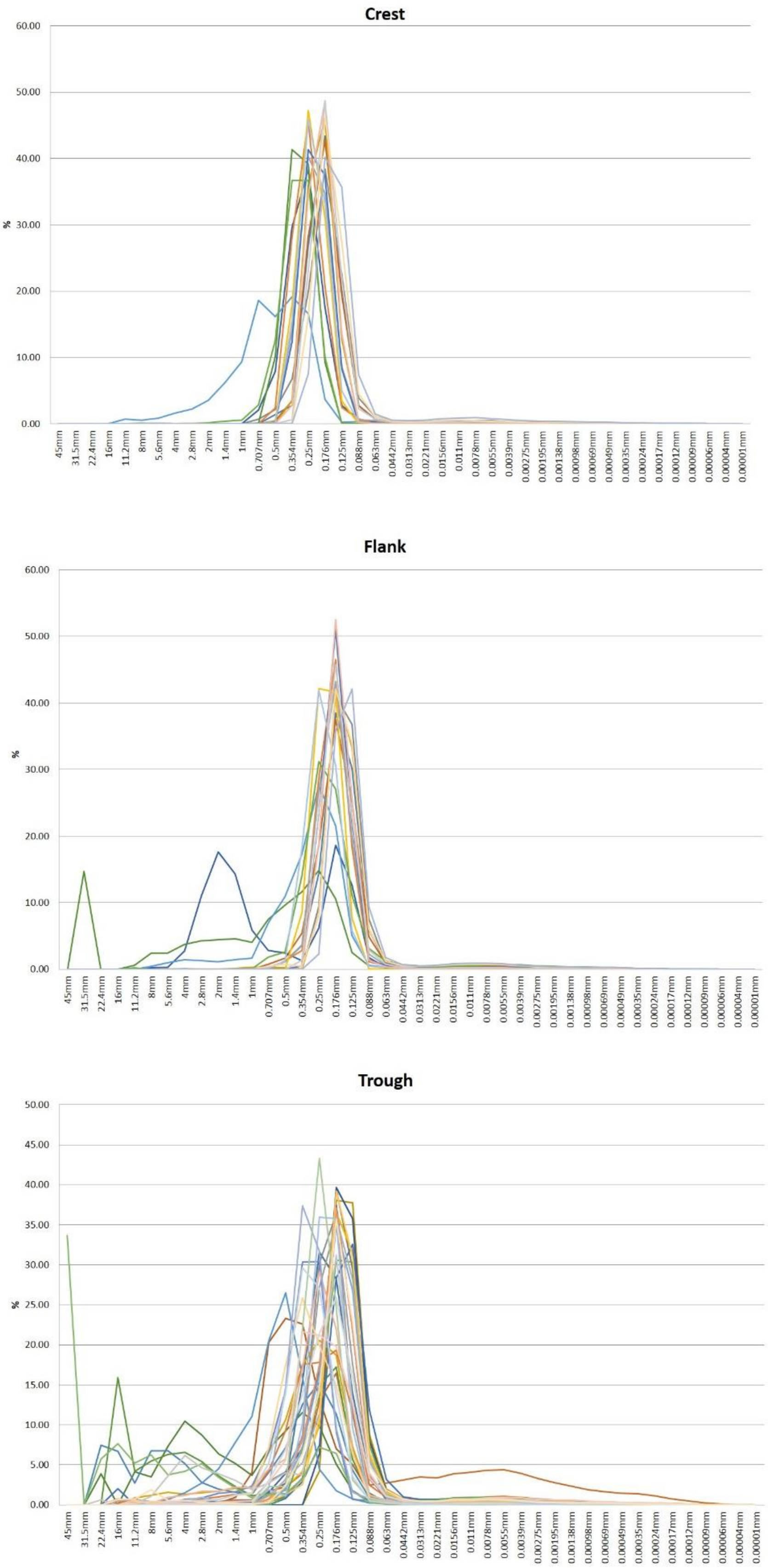


Figure 33. Particle size distribution (mm) on all banks according to position on the bank: Crest, flank, trough.

Further testing revealed that no significant differences could be found between the sediments on the crests, flanks and troughs of the offshore banks, but slight differences were found between nearshore crests and troughs, and between troughs and flanks (Table 5).

Table 5. Results of one-way ANOSIM tests between sediment samples taken from crest, flank and trough according to nearshore and offshore location.

	Nearshore		Offshore	
	R Statistic	**Significance Level %**	**R Statistic**	**Significance Level %**
Global Test	0.129	1.4	0.039	14.7
Pairwise Tests				
Trough vs. Flank	0.184	0.8	0.009	26.6
Trough vs. Crest	0.227	2.2	0.116	7.4
Flank vs. Crest	-0.052	65.9	0.028	26.9

Comparison of the sediment composition of the crests, flanks and troughs between nearshore and offshore banks revealed greatest differences between the flanks. No significant differences in sediment composition were found between crests of nearshore and offshore banks.

3.5.2 Infaunal community analysis

Infaunal community analyses were performed using 173 taxa and 2,843 individual records. Numbers of taxa, abundance and species diversity generally increased with increasing depth in both nearshore and offshore samples. Samples taken from the nearshore crests contained fewer taxa, but similar abundances compared to the offshore sandbanks. Samples representing the troughs of the nearshore sandbanks showed greatest variability in the number of taxa, abundance and diversity (Figure 34). The median value suggests that the majority of samples contained a low number of taxa and abundances comparable with the offshore troughs. Outlying samples in the nearshore data corresponded with a muddy area north of the Leman bank and a sandy south-westerly facing flank, with high abundances but low numbers of taxa, off Inner Bank.

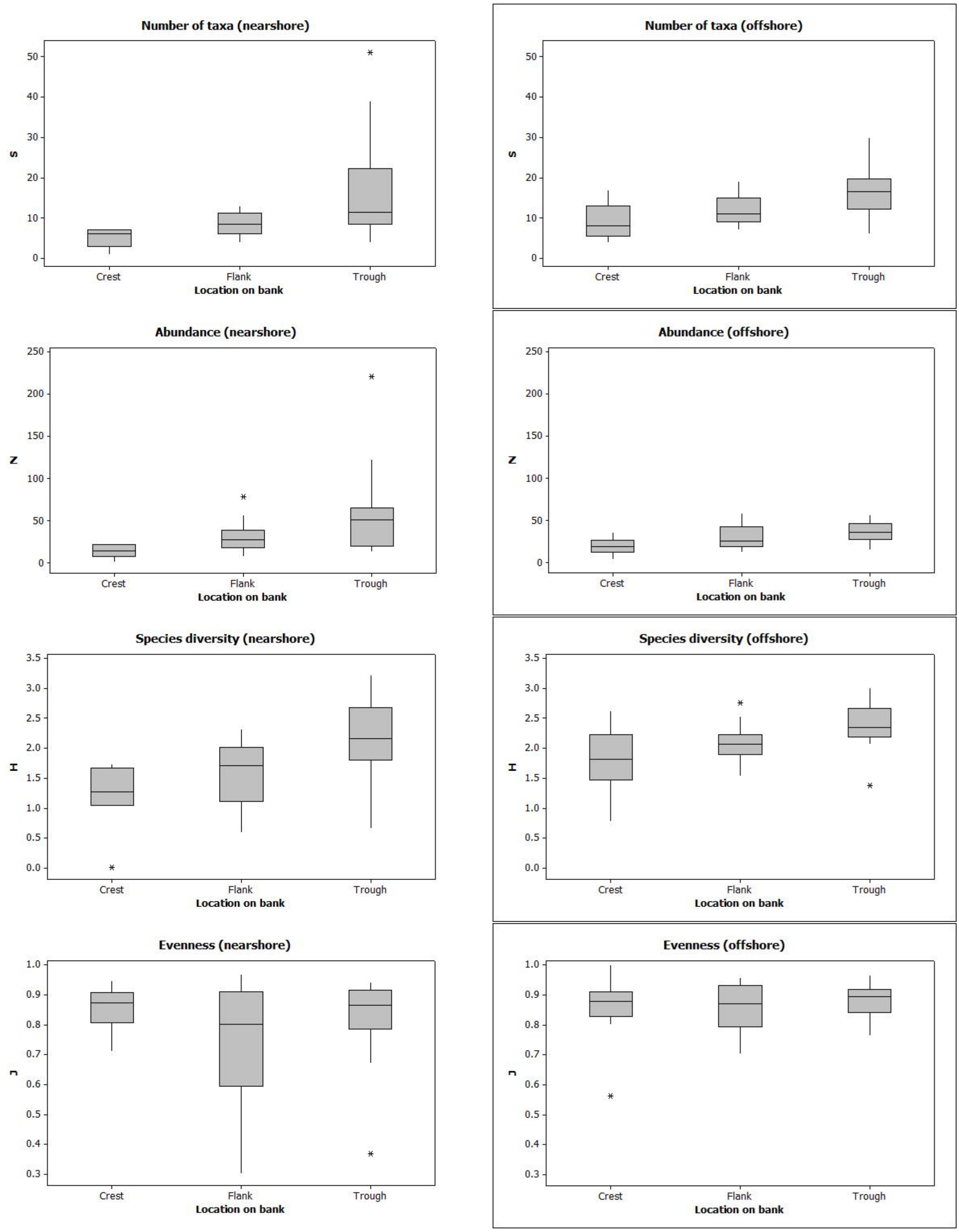


Figure 34. Box and whisker plots of all univariate metrics across sampling treatments (crest, flank, trough) according to location (nearshore/offshore). Boxes represent the interquartile range (middle 50% of the data), horizontal line represents the median, the vertical lines (whiskers) represent the data range and the asterisks (*) are outliers.

The non-metric multidimensional scaling (nMDS) plots in Figure 35 show high overlap in samples representing offshore and nearshore (left) communities and location on the banks (crests, flanks and troughs) (right).

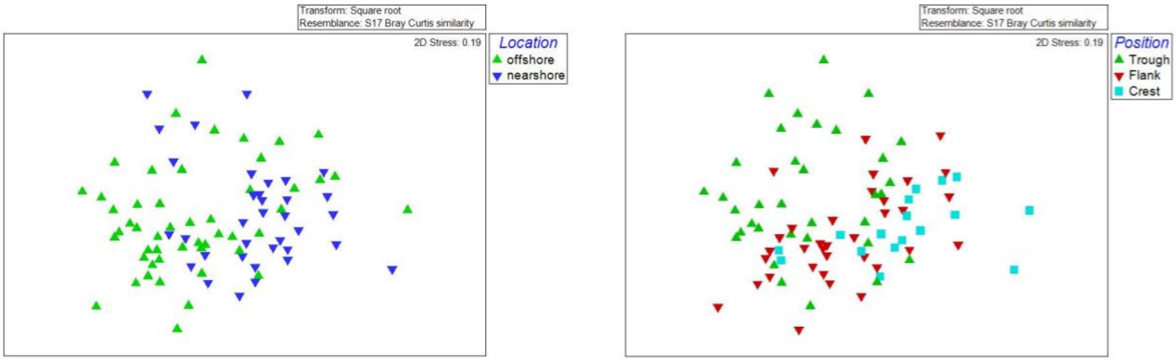


Figure 35. Sandbank benthic communities displayed according to (left) nearshore/offshore and (right) location on the bank (crest, flank, trough).

Comparisons between offshore and nearshore assemblages revealed a difference in assemblage composition (ANOSIM sample statistic (Global R) = 0.197, significance level = 0.1%), although the R value is low, suggesting considerable overlap in community composition. Small but significant differences in overall community composition were also revealed between crest, flank and trough (Global R = 0.142, significance level = 0.1%). Pairwise comparison testing revealed greatest differences between communities in the troughs and on the crests, although the R statistic was again low (R = 0.261, significance level = 0.1%).

Comparison between locations on the bank for each area (nearshore/offshore) revealed that communities inhabiting the nearshore banks were statistically indistinguishable, whereas small but significant differences were observed between crest, flank and troughs located on the offshore banks (Table 6).

Table 6. Results of one-way ANOSIM tests between samples representing crest, flank and trough according to nearshore and offshore location.

	Nearshore		**Offshore**	
	R Statistic	**Significance Level %**	**R Statistic**	**Significance Level %**
Global Test	0.057	14.7	0.135	0.1
Pairwise Tests				
Trough vs. Flank	0.067	6.5	0.125	0.2
Trough vs. Crest	0.153	8.8	0.272	0.1
Flank vs. Crest	-0.071	70.9	0.226	2.9

SIMPROF analysis revealed ten significant different community groups (Figure 36). Only three of the groups (each containing two samples) corresponded with a single position of the bank; Group a (crest) and Group n and k (trough), only one of which consisted of a single sediment type (Group k = sand). The largest groups (c,f and g) contained samples from both offshore and nearshore banks and from crests, flanks and troughs but were mostly composed of sand (one sample was classed as coarse sediment). Summary information for each group can be found in Appendix 7. Information on the sediment type and species composition was used to determine EUNIS level 5 biotopes.

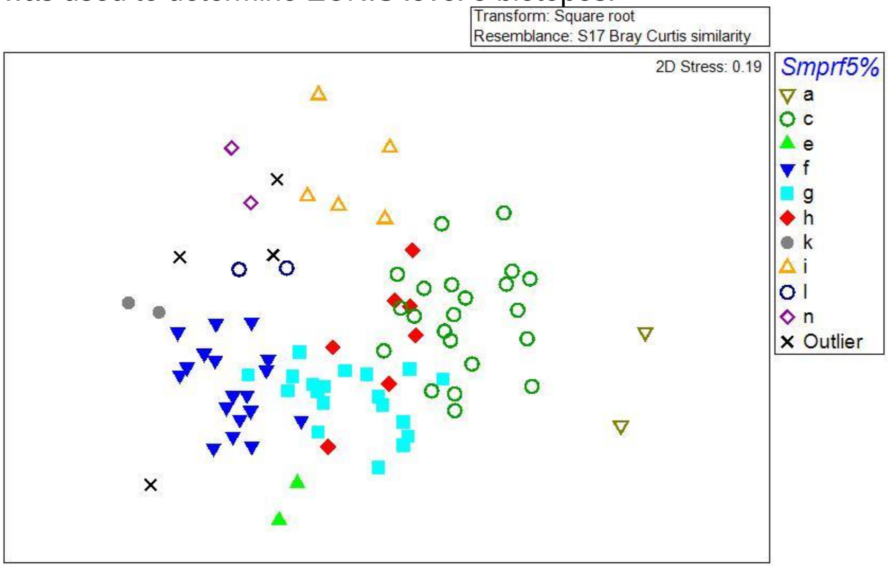


Figure 36. Significantly different sand bank communities according to SIMPROF analysis (5%) See Appendix 7 for full explanation of symbology.

3.5.3 Historical sandbank comparison

Fauna

Average numbers of taxa and abundances were comparable between 2001 and 2013. Multivariate patterns in community composition displayed using nMDS suggest some community similarities.

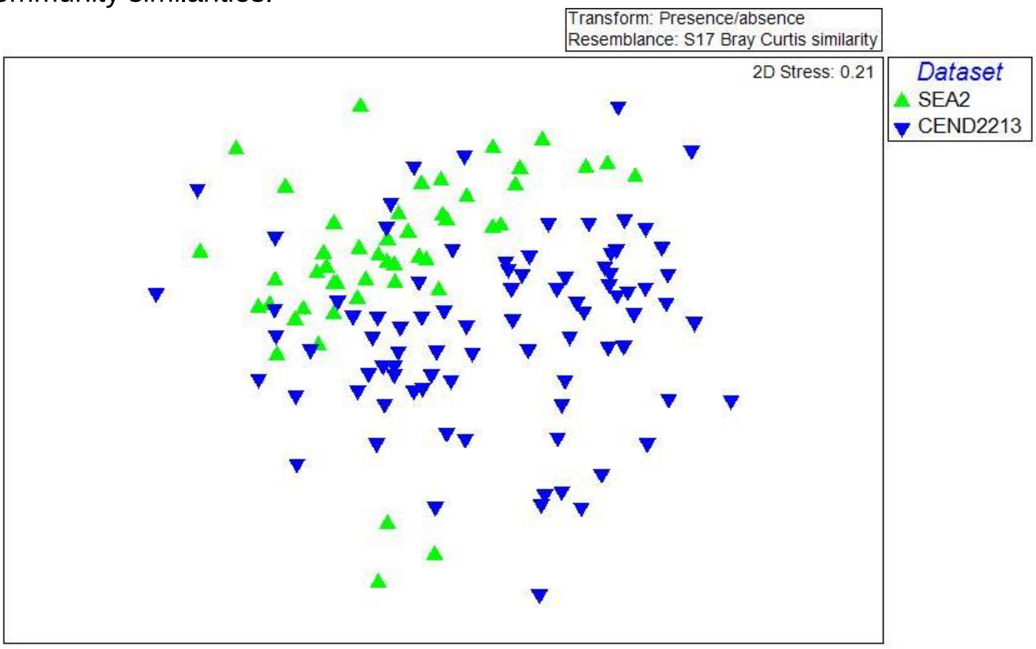


Figure 37. nMDS ordination of community composition of presence absence data from 2001 and 2013 from comparable sandbanks.

Comparisons between the two datasets revealed significant, although small, differences (Global R: 0.239, significance level = 0.1%). Both datasets were highly variable in species composition (low similarity between samples within years) and both were highly characterised (top 50%) by *Nephtys cirrosa* and *Bathyporeia* sp. However, the dominant *Bathyporeia* species differed between years; *Bathyporeia elegans* in 2001 and *Bathyporeia guilliamsoniana* in 2013 (*Bathyporeia elegans* was absent from the 2013 samples). The absence of *Bathyporeia elegans* from the 2013 dataset contributed only to 5% of the difference in species composition between the datasets. Further differences were caused by the level of taxonomic resolution; e.g. in 2013 a large number of *Nephtys* individuals were damaged and could not be identified further than genus level whilst in 2001 all *Nephtys* individuals were identified to species level. However, most of the dissimilarity between surveys was due to the differences in taxa occurrence (see SIMPER output in Appendix 8). These differences may be due to the sampling techniques used during the two surveys (Van Veen in 2001 vs Hamon grab in 2013), different sample processor used, numbers of sandbanks compared (six in 2001 compared to 17 in 2013) or be due to the natural variability present across the sandbanks.

Acoustic

Although the primary reason for acquiring multibeam echosounder data was to add confidence to sample allocations of crest, flank and trough of the sandbanks, this newly collected bathymetry also allowed for comparison with historical data to interrogate potential sandbank feature migration.

Historical and newly collected bathymetry data were aggregated to 35m grid resolution to allow for reasonable comparison be made. The raster subtraction tool was utilised in the *ArcGIS 10.1* software and used to represent differences between datasets. Figure 38 presents results for ten transects collected in the north east of the North Norfolk Sandbanks and Saturn Reef SCI. Results in this area demonstrated a consistent and low level of difference along transects. The difference in elevation between datasets was predominantly of a magnitude between 0.5m and 1.5m. The consistency of this difference (approximately a 1m vertical elevation increase across each tow) suggests a moderate amount of discrepancy between the two datasets.

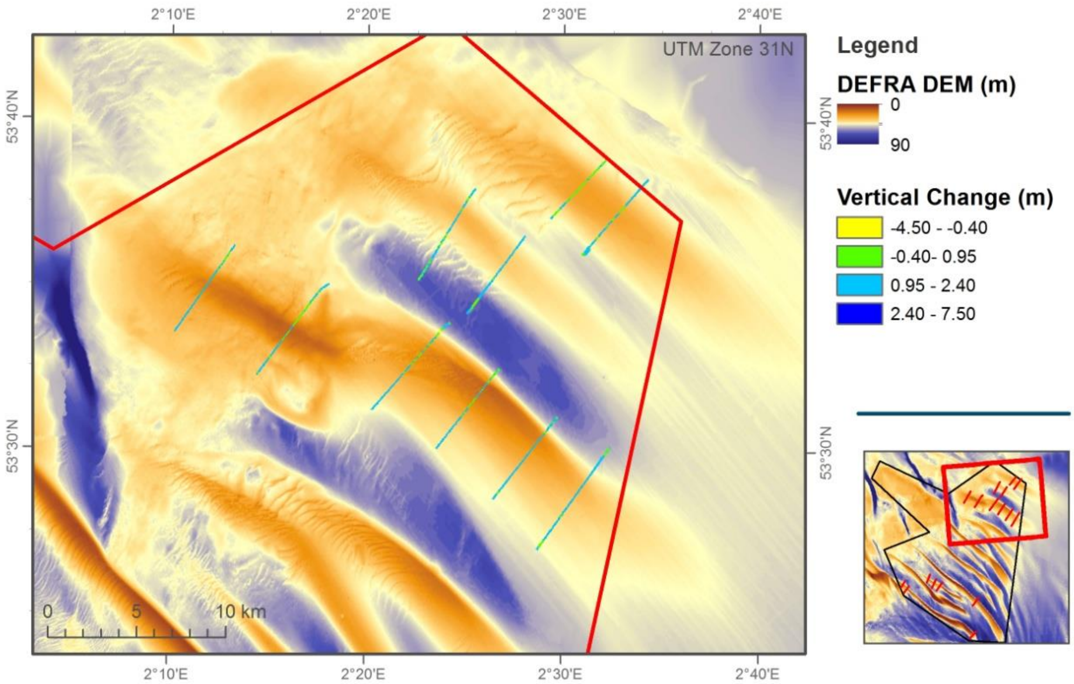


Figure 38. Results from raster subtraction between newly acquired and historical bathymetry transects to the north east of the North Norfolk Sandbanks and Saturn Reef SCI. Transects are overlaid on the DEFRA DEM (Astrium 2011).

Investigation of bathymetric transects in the south west of the site also showed fairly consistent difference across the banks (Figure 39). In the case of those transects closest to the southern boundary (Figure 39b) this difference suggests sediment deposition to the north side of the bank. This sedimentation appears to be of a magnitude of 3-7 for the northern transect, and 3-5m for the more southerly. In both cases there is slight evidence for bank reduction on the southern edge of the bank, though of a magnitude of less than a metre.

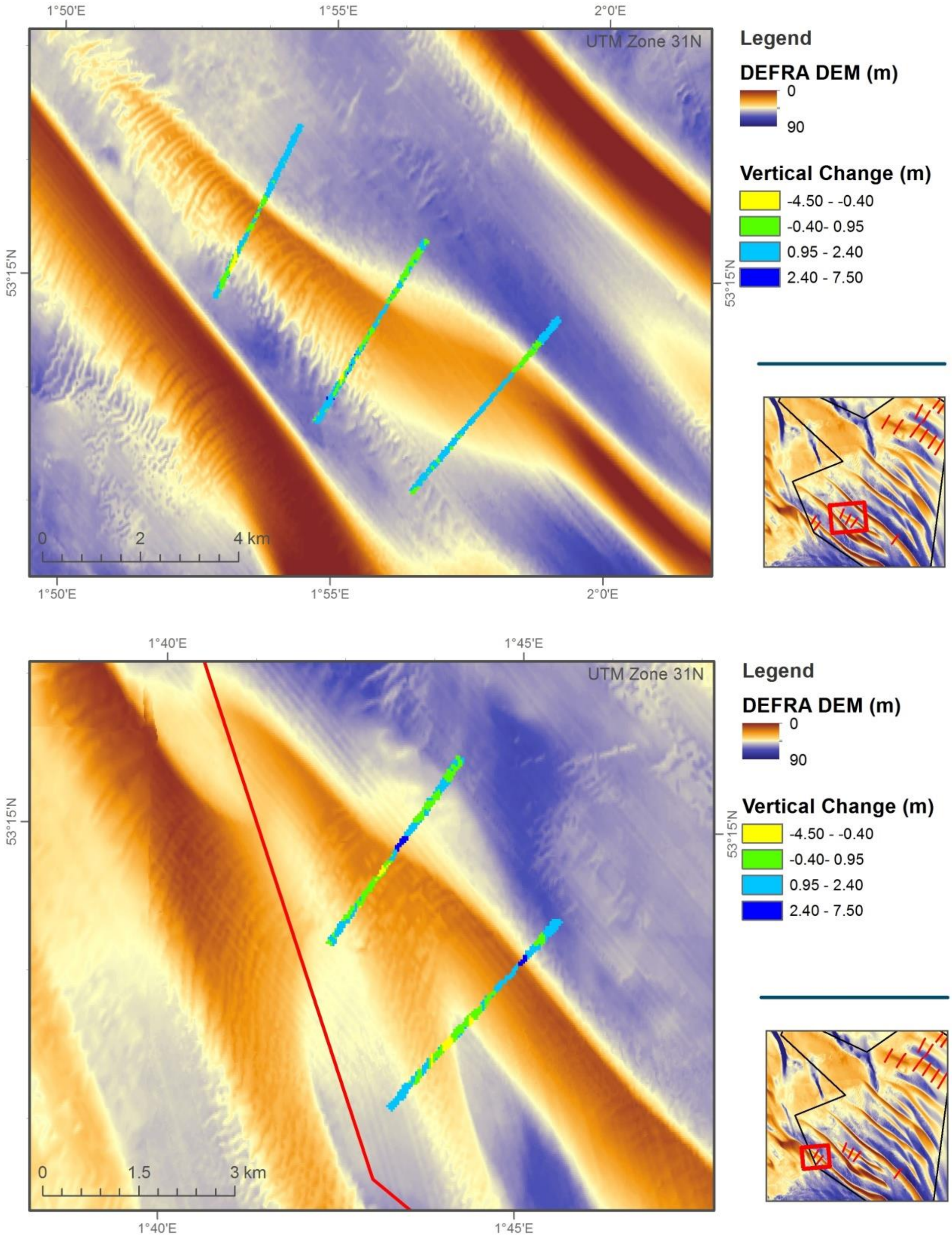
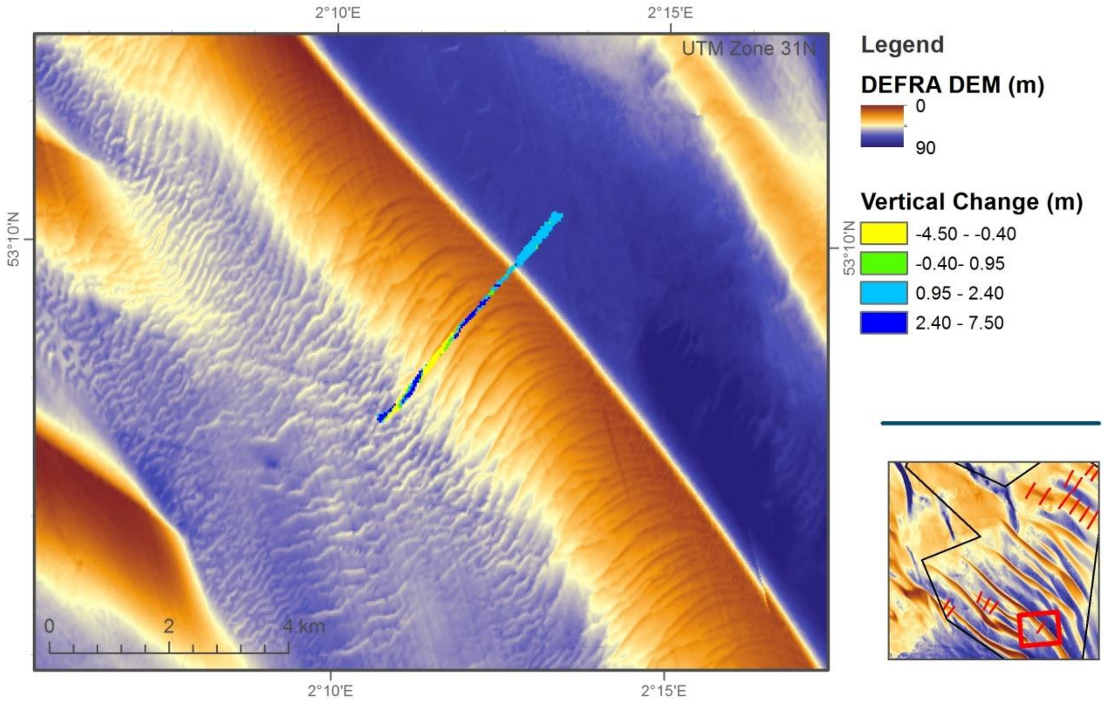


Figure 39a and b (a top; b, bottom). Results from raster subtraction between newly acquired and historical bathymetry transects in the south west of the North Norfolk Sandbanks and Saturn Reef SCI. Transects are overlaid on the DEFRA DEM (Astrium 2011).

Figure 40a demonstrates differences in elevation that may be indicative of deposition of sediment at the centre of the sandbank feature. This deposition appears to be of a magnitude between 2m and 4.7m. Closer investigation of the underlying DEFRA DEM layer provides evidence for sand wave sub-features running along, and in the same orientation as, the sandbank. At a 35m grid resolution results from transect analysis must be considered in the context of these sub features where bathymetric change will occur at a much finer spatial scale. This has repercussions for analysing change at this particular location as bathymetric change of sand waves will occur at a much finer scale than the bathymetric grid used for transect analysis. It is possible to envisage that sand waves on sandbanks are prone to high levels of spatial change in dynamic environments, it is, however, not possible to discern potential bank change from sand wave change at the resolution of this current study.

Figure 40b, however, demonstrates a result similar to that of the banks presented in Figure 39 (a and b) where the northern side of the bank appears to be showing deposition of sediments (approximately 2m to 4.5m) and mild amounts of reduction on the southern edge(approximately 0.5m to 2.0m).



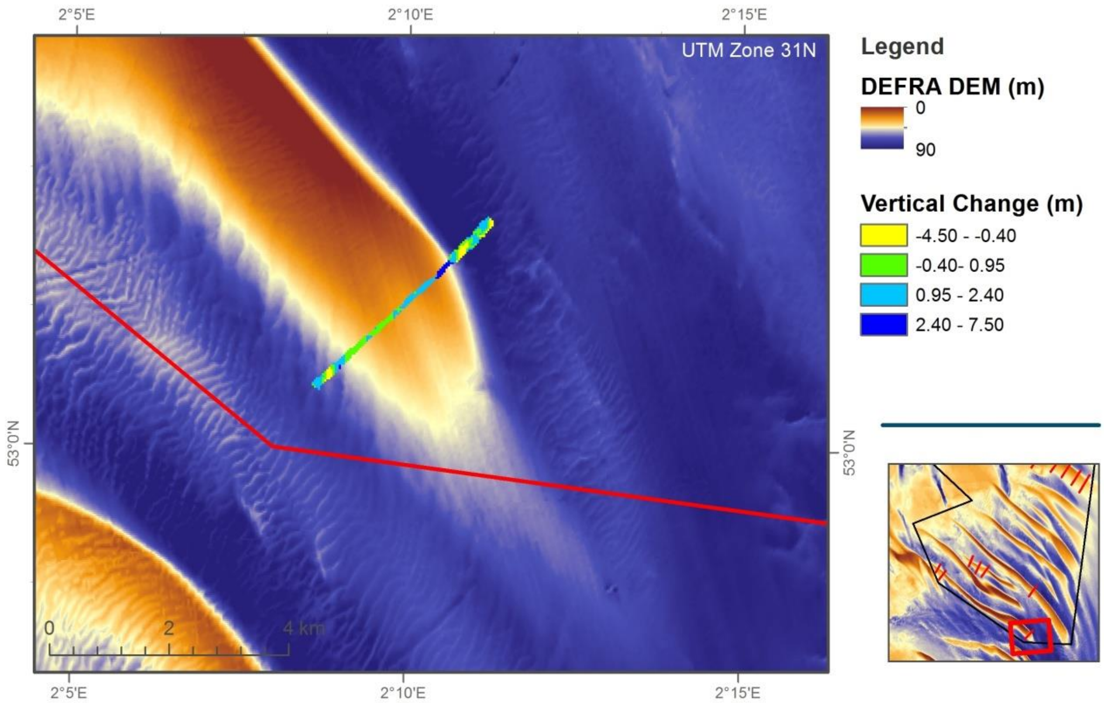


Figure 40 (a (top) and b (bottom)). Results from raster subtraction between newly acquired and historical bathymetry transects to the south east of the North Norfolk Sandbanks. Transects are overlaid on the DEFRA DEM (Astrium 2011).

3.6 Potential EUNIS Level 5 biotopes

Each of the SIMPROF cluster groups was assigned to a potential biotope based on sediment type and species present/characteristic of the group (Figure 41). The only EUNIS biotope that could confidently be assigned to grab and video samples was A5.611: *S. spinulosa* on stable circalittoral mixed sediment[13].

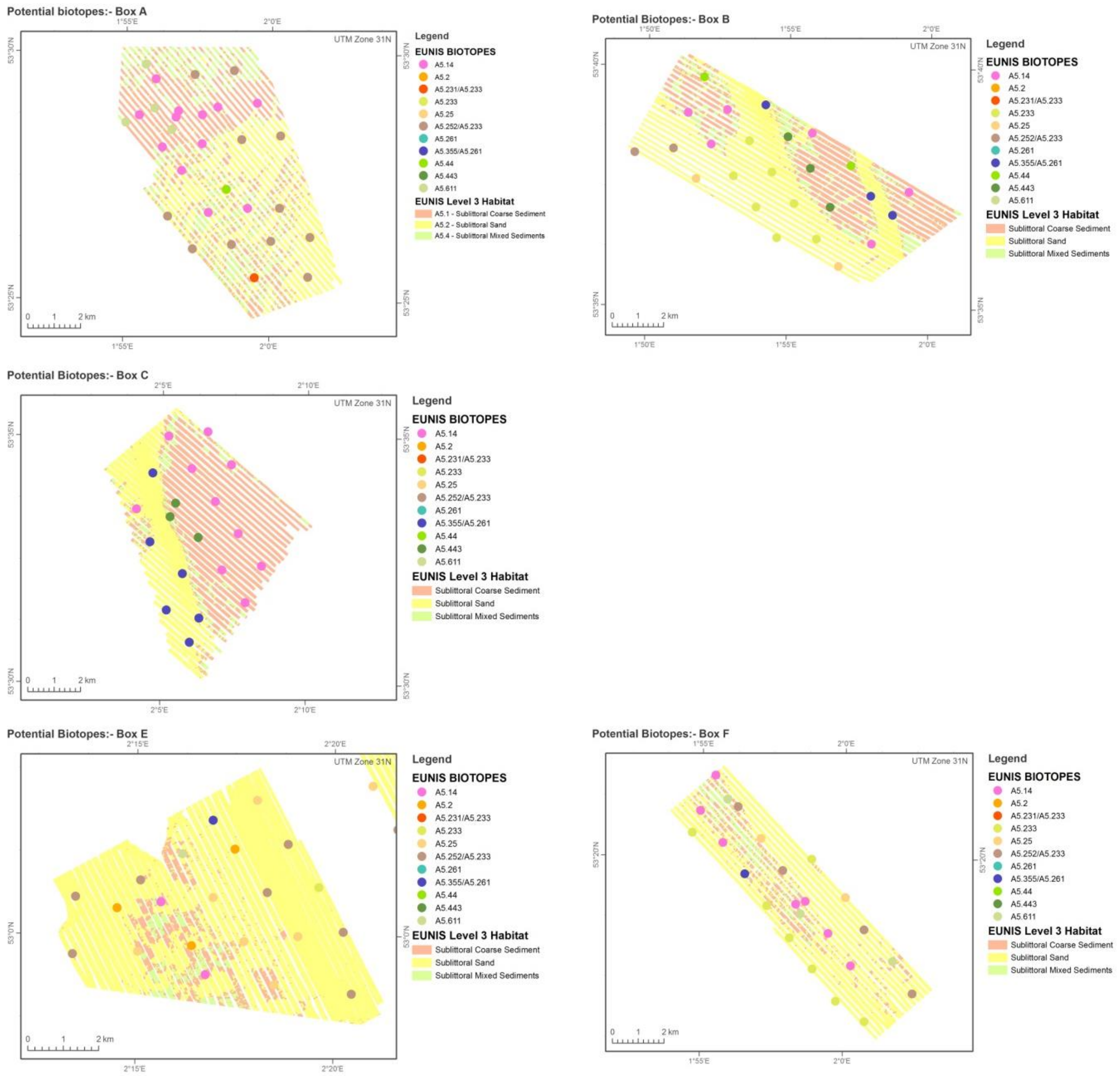


Figure 41. Potential EUNIS biotopes assigned to grab data within each of the sampling 'boxes' (see Figure 2).

[13] Reference URL: http://eunis.eea.europa.eu/habitats/1693

Table 7. EUNIS biotopes assigned to data collected by grab: numbers of biotope records per sampling station and 'box'

EUNIS Biotope	Biotope description	A	B	C	D	E	F	Total
A5.14	Circalittoral coarse sediment	12	6	9	2	2	7	**38**
A5.2	Sublittoral sand					3		**3**
A5.231/A5.233	Infralittoral mobile clean sand with sparse fauna/*Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand	1						**1**
A5.252/A5.233	*Abra prismatica, Bathyporeia elegans* and polychaetes in circalittoral fine sand/*Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand	12	2		3	7	4	**28**
A5.233	*Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand		7		1	1	7	**16**
A5.25	Circalittoral fine sand		2		9	6	2	**19**
A5.261	*Abra alba* and *Nucula nitidosa* in circalittoral muddy sand or slightly mixed sediment				2			**2**
A5.355/A5.261	*Lagis koreni* and *Phaxas pellucidus* in circalittoral sandy mud/*Abra alba and Nucula nitidosa* in circalittoral muddy sand or slightly mixed sediment		3	6	3	1	1	**14**
A5.44	Circalittoral mixed sediment		2		5			**7**
A5.443	*Mysella bidentata* and *Thyasira* spp. in circalittoral muddy mixed sediment		3	4				**7**
A5.611	*Sabellaria spinulosa* on stable circalittoral mixed sediment	4				1	3	**8**

Biotopes present on the sandbanks generally matched either A5.233: *Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand or A5.231: Infralittoral mobile clean sand with sparse fauna.

3.7 Anthropogenic activities

There was some evidence of anthropogenic benthic disturbance across the surveyed areas of the SCI. Potential seabed structures, such as pipelines, were observed from acoustic datasets, as well as trawl scars, as in Figure 42.

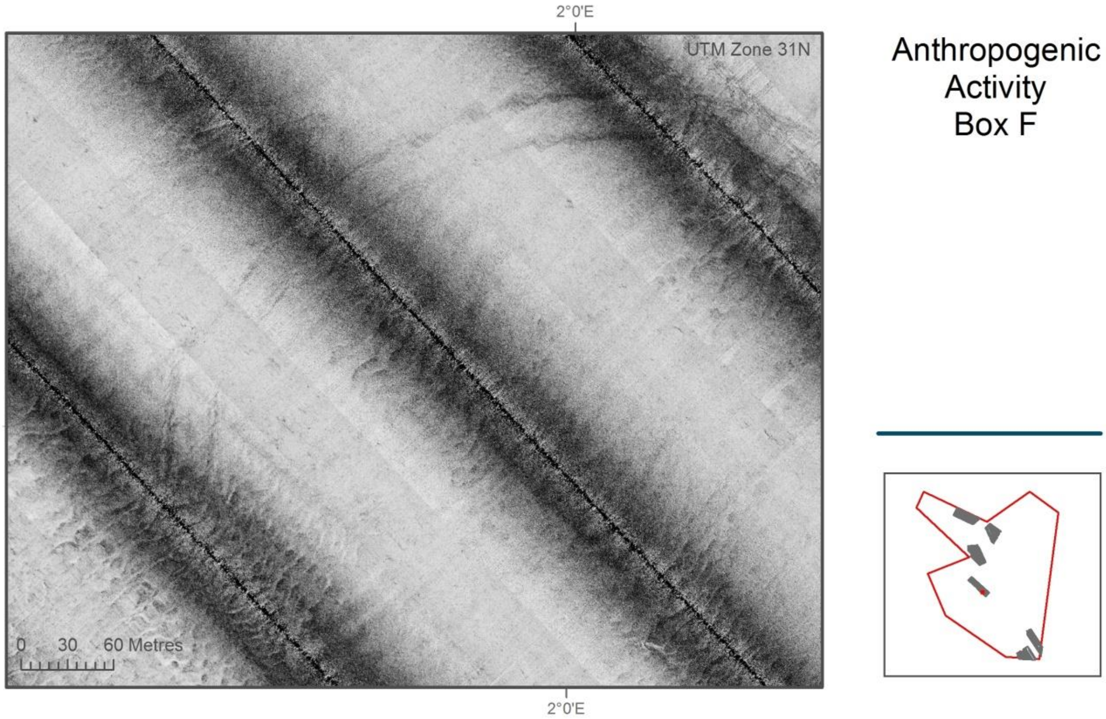


Figure 42. Side-scan sonar image at Box F showing trawl scarring of the seabed.

4 Discussion

4.1 Summary of habitats and features recorded

Predominant EUNIS[14] Level 3 habitats found at the North Norfolk and Saturn Reef SCI were:

- A5.1: Sublittoral Coarse Sediment;
- A5.2: Sublittoral Sand;
- A5.3: Sublittoral Mud; and
- A5.4: Sublittoral Mixed Sediments.

The presence of the Annex I habitats S. spinulosa reef and Sandbanks which are slightly covered by seawater all the time were confirmed within the SCI.

4.2 Sabellaria spinulosa reef assessment

The North Norfolk Sandbanks and Saturn Reef SCI incorporates the Saturn Reef *S. spinulosa* biogenic reef (JNCC 2010). This reef structure qualified for Annex I status under the European Commission's interpretation of *S. spinulosa* reef (CEC 2007). Since its first identification in 2002, evidence (Limpenny *et al* 2010) suggests that the Saturn Reef feature has decreased in extent and condition. The reasons for this decline have not yet been established. However, the presence of such a reef structure demonstrates that favourable conditions for *S. spinulosa* reef establishment exist within the area and reinforce the rationale for targeting this area for study.

Six areas of search were identified as potential locations for reef presence from previously acquired data, and were investigated with high resolution multibeam echosounder and side-scan sonar. From previous work by Limpenny *et al* (2010) it is well established that reef identification from remote data is a challenging undertaking, and heavily reliant on the presence of prominent reef habitat, conducive environmental conditions (weather, surrounding habitat etc.) and a combination of appropriate techniques including groundtruthing. Pearce *et al* (2014) have attempted to demonstrate consistent reef mapping from acoustic data sets, whereby newly acquired data from a previously surveyed region have been directly compared. Evidence at the North Norfolk Sandbanks and Saturn Reef SCI demonstrates the difficulties involved in consistently mapping reef habitats, using remote data acquisition methods, against a broadscale habitat backdrop with a similar, or dominating, acoustic return. Data acquisition is also likely to vary between replications, with weather, line orientation and processing methods all incorporating potential variability into the final maps being used for comparison.

Acoustic signatures that appeared to be associated with patches of *S. spinulosa* identified in video data were not consistent across the North Norfolk Sandbanks and Saturn Reef SCI. Only Box A demonstrated a truly unique 'mottled' signature that could be considered strong evidence for reef delineation. Box F also demonstrated a signature that allowed for areas of known and potential reef to be mapped, but was not as clear as that seen in Box A, potentially due to poor weather conditions impacting quality of data acquired. Expert judgement is a key component of any such analysis and introduces a large level of subjectivity when drawing boundaries. Caution should be advised when considering features mapped above as a baseline for *S. spinulosa* reef spatial extent at the North Norfolk Sandbanks and Saturn Reef SCI. Mapped regions may best be considered as areas of known and potential reef where video transects have provided strong evidence for reef presence and reef boundaries have been interpolated from acoustics.

Best examples of *S. spinulosa* reef were found to the west of the Saturn Reef boundary, in Box A. This Box also contained the highest numbers of *S. spinulosa* worms compared to

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[14] Reference URL: http://eunis.eea.europa.eu/index.jsp

other sampling 'boxes'. The reef quality was determined as low using video observations, although there were a few small patches of moderate and high reef quality present. Species richness and total abundance were positively related to *S. spinulosa* worm abundance but were less related to volume of reef fragments. Species richness showed a stronger relationship with sediment sorting than with *S. spinulosa* presence i.e. higher numbers of species tended to be associated with poorly sorted (mixed) sediments, suggesting the relationship between species richness and *S. spinulosa* is not necessarily causal. However abundances of certain characteristic taxa showed stronger relationships with both *S. spinulosa* abundance and reef volume. This could indicate that certain species are relying on *S. spinulosa* as a food source and also highlights the importance of the reef as a habitat and refuge.

Tube occupancy has been suggested as an additional indicator of reef quality. However the samples, collected by grab, need to be relatively undisturbed for this method to be of value. In the current study, the grab used (mini-Hamon grab) tended to mix the sample, resulting in broken reef fragments. However, it was necessary to use this gear type due to the coarse nature of the sediment within the study area. Results therefore may not give a true indication of tube occupancy.

As demonstrated by the changes at the Saturn Reef location, there is potential that *S. spinulosa* reef patches are highly ephemeral. This being the case there will be high levels of natural variability beyond any anthropogenic impacts. Understanding this poses the question as to the consistency, and validity, of mapping reef boundaries. Future monitoring and potential management decisions are likely to struggle with this issue. From a pragmatic perspective, establishment of those regions with high environmental suitability may be best mapped at a very coarse scale to reflect *S. spinulosa* reef presence. Combining mapped patches of *S. spinulosa* reef to create larger polygons may mitigate poor understanding of patch validity and connectivity, as well as uncertainty in establishing presence from remote techniques. These larger polygons, when combined with monitoring from video analysis, would allow reef extent at the site to be considered in light of the ephemeral nature of the feature. The new methodology for assessing *S. spinulosa* reefiness and patchiness using video developed under this project has the potential to provide a consistent scoring system for monitoring changes in *S. spinulosa* reef quality within the North Norfolk Sandbanks and Saturn Reef SCI in the future.

4.3 Sandbank assessment

Differences were observed between the sediment composition on the crests and flanks in comparison with the troughs. The crests and flanks of the banks were composed mainly of fine sand while the troughs were more heterogeneous. In general, the troughs contained coarser sediment and slightly higher mud content than the flanks and crests. One sample, from a nearshore trough, contained over 40% mud and was characterised by relatively high numbers of the mud shrimp *Callianassa subterranea*. Overall, infaunal communities only differed slightly between the nearshore and offshore sandbank groups and between crest, flanks and trough. Temporal differences were slight and were mainly due to switching in dominance of *Bathyporeia species*. *Bathyporeia* is one of the most problematic taxa concerning species identification (d'Udekem d'Acoz 2004). However, without further temporal information, it cannot be concluded whether this change is natural or due to misidentification.

Historical geophysical data were not available at a spatial resolution comparable with those collected by the present study. For comparison purposes it was, therefore, necessary to match resolutions of datasets at the coarser scale. Re-gridding at 35m resolution drastically reduced the ability of the study to identify marginal change in bank movements. In the case of one bank transect (Figure 40a) this was further compounded by the presence of large sand waves running perpendicular to the sand bank. Presence of these sand waves introduces uncertainty when attempting to ascertain true sandbank movement, i.e. the vertical difference observed may be due to the overriding feature increasing/decreasing or may be an artefact of more minor sand wave movements.

It was, however, possible to identify moderate trends at the North Norfolk Sandbank site. Those banks at the north east extent of the site appeared to have no changes outside of those associated with processing artefacts introduced from different multibeam echosounder systems and/or varying processing techniques. Banks at the more southern reaches, in contrast, appear to demonstrate reductions in bank elevation at the southern edges, whilst also showing deposition at the more northerly edge. Therefore, there is some evidence these more southern banks are moving in a northerly direction and when coupled with the Defra DEM (Astrium 2011) evidence for general bank orientation more likely in a north easterly direction. Due to the coarse resolution of the data it was not possible to make an assessment of horizontal distances moved. Without being able to accurately ascertain a reference point for comparison between data sets (such as the bottom of the bank) any quantitative value could be misleading.

For future investigations, there would be value in making further observations of bottom sheer stresses not only between sandbanks but also either side of individual banks. The present assessment has demonstrated evidence that banks closer to the UK coast are moving in a north westerly direction whilst those banks further offshore appear to be more stable. This stability can only be measured over the timescale of the data sets used as part of this assessment (approximately 12 years). Further measurements would allow dominant prevailing environmental conditions to be considered and further explore the natural progression of the North Norfolk Sandbank features. This assessment reflects the findings of Collins *et al* (1995) who report decreasing strength in currents across the North Norfolk area as the distance from shore increases.

4.4 Survey Limitations

The original survey design for this investigation was suitable to address the objectives of this report. However, due to time constraints exacerbated by poor weather conditions at site, it was not possible to collect the full sampling complement. The survey was carried out in November and poor weather conditions in the North Sea will often be a problem at that time of year. Mitigation for weather down time is only really possible through allocation of more-dedicated survey time. However, even this cannot guarantee completion of the survey objectives. The survey design did not allow for direct comparison between reef and adjacent non reef communities.

4.5 Data Limitations

Overall, the data quality collected by *RV Cefas Endeavour* was good. However, some acoustic data was significantly affected by poor weather and compromised the potential for mapping of features. Similarly strong tidal currents were experienced to the south of the North Norfolk Sandbanks and Saturn Reef SCI which increased suspended sediments at several video sampling locations. This poor visibility affected the data quality and interpretation of video for *S. spinulosa* presence.

Side-scan sonar acquisition did not include adequate overlap to remove the effects of the nadir at the data interpretation stage. Ensuring complete overlap could help mitigate the need to interpolate across this data gap in the future. Side-scan sonar on these habitats was unable to consistently delineate *S. spinulosa* patches. Increasing the resolution of acquired acoustic data may better resolve these fine-scale objects, though could still not guarantee identification of small, low lying, reef against a predominantly coarse sediment background. Further investigation of higher resolution systems across a variety of habitat types would be required to better understand the benefits of such a suggestion.

5 Acknowledgements

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Appendices

Appendix 1. Power analysis of grab samples from sandy sediments

The aim of the power analysis was to compare the diversity of communities in a sandy area (ON) with those in a non-sandy area (OFF). Abundance and richness (number of species) per grab as parameters of diversity were chosen as measures of community.

There were 45 grab sample stations ON the sand and 45 OFF the sand. The means and standard deviations for the data are:

	Mean Richness	Standard Deviation Richness		Mean Abundance	Standard Deviation Abundance
ON	32.4	32.5		130	191
OFF	52.1	31.7		518	592

Histograms of the data are shown in Figure 43. The spread of the data for richness is similar ON and OFF the sandbank but much more widely spread for abundance for OFF the sandbank.

The observed differences in means are around 20 (richness) and 400 (abundance).
To calculate the power of detecting differences in abundance or richness between the sandy area (ON) and the non-sandy (OFF) area, it is assumed that data from the OFF area would be increased / decreased by some amount of ‘difference’, but that the shapes of the distribution for the ON and OFF area would be the same apart from this.
The power is calculated as follows (note abundance has been used for illustration, though the same procedure applies for richness). The power calculations are done by simulation, which is an increasingly used method. However, rather than simulate from some distribution, simulations are taken from the observed data in a procedure similar to bootstrapping (see Manly, 1998).

Firstly, the OFF data is reduced by an amount equal to the difference between the OFF and ON means (i.e. so that the ON and OFF data now have the same mean).
A random sample with replacement of sample size N (N varies between 5 and 40) is then taken from the abundance per grab data for the ON data. A second random sample of size N with replacement is then taken from the OFF, but a value ‘difference’ is added to each of these observations. The two samples are then compared using a Wilcoxon non-parametric test using the function *wilcox.test* in the statistical package R. This whole procedure is repeated 1000 times. The power is the proportion of times that the Wilcoxon test is statistically significant at the 5% level (two-sided test).

A Wilcoxon test was used because both sets of data had a skewed distribution and so a non-parametric test rather than one based on, say, a theoretical distribution (e.g. Gaussian distribution) was identified as probably safest to use.

Figure 44 and Figure 45 show power plots for richness and abundance per grab as a function of sample size (this is the number of grabs taken from each area – e.g. six from one area and six from the other); there are separate lines for different values of the difference between the means of the two distributions.

Figure 44 shows the power plots for richness. Assuming the mean difference required is the same as in this one (i.e. about 20) then just over 40 samples would be needed so that the power was around 0.9. That is, if we took 40 samples, we would expect to statistically detect a difference 90% of the time. This makes sense because if we compare the ON vs OFF data for this experiment for richness we get a p-value of 0.002. That is, the sample size of 45 here is just more than adequate to detect the difference at the 0.05 level.

Figure 45 shows the power plots for abundance. If we assume that the difference in the new experiment will be 400 then a sample size of about 15 would be needed.

The powers that were calculated were as powerful as previously as approximately 40 samples are required to detect a difference in richness. For richness, these had a standard deviation of 21.8, which was used for both the ON and the OFF datasets before. During the present analysis, the standard deviations were 32.5 and 31.7. Thus, the actual data seems to be more variable than the data used before. The implication of this is the reduced power for given sample size for richness.

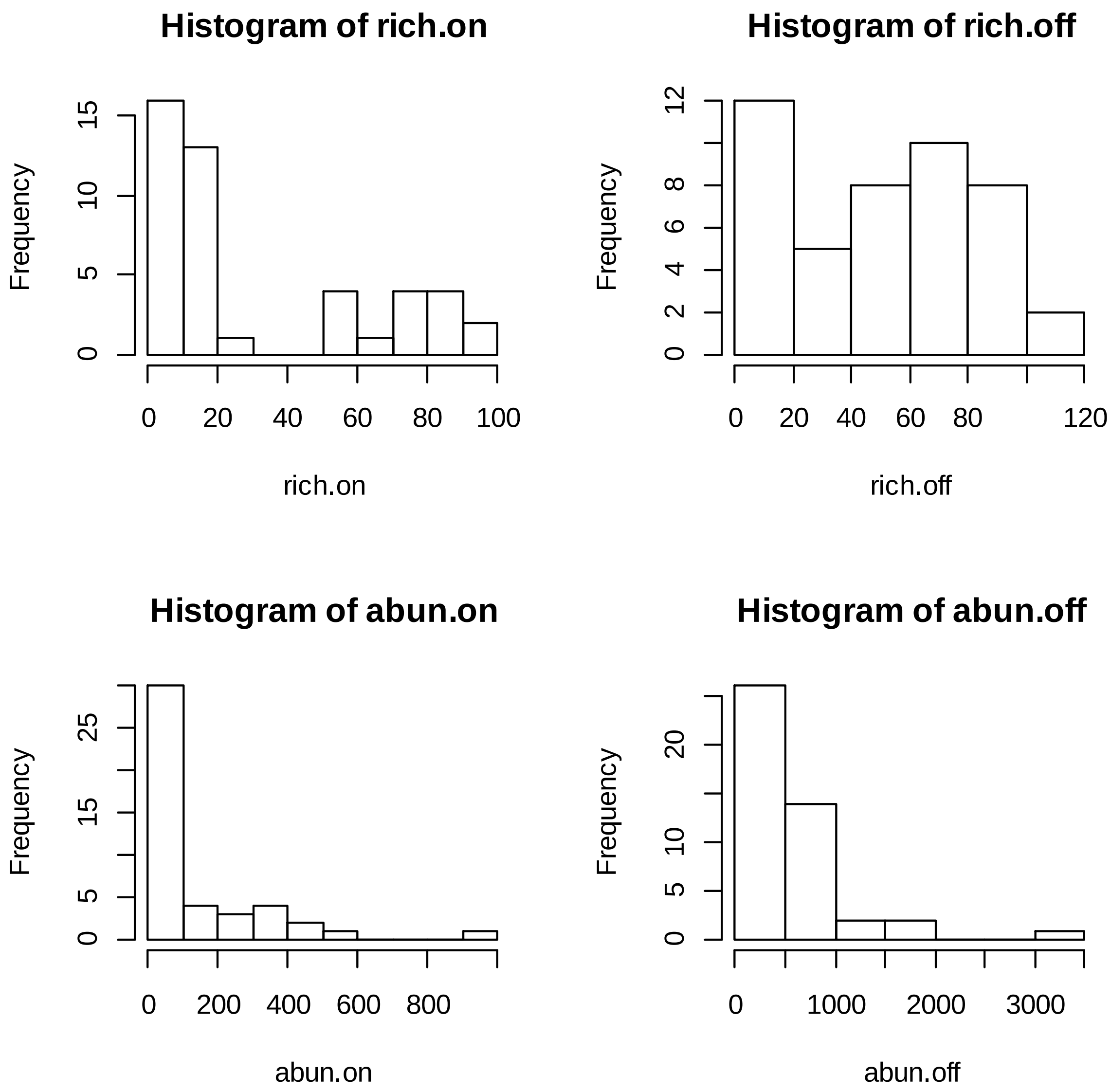

Figure 43. Histograms of abundance and richness both ON and OFF the sandbank.

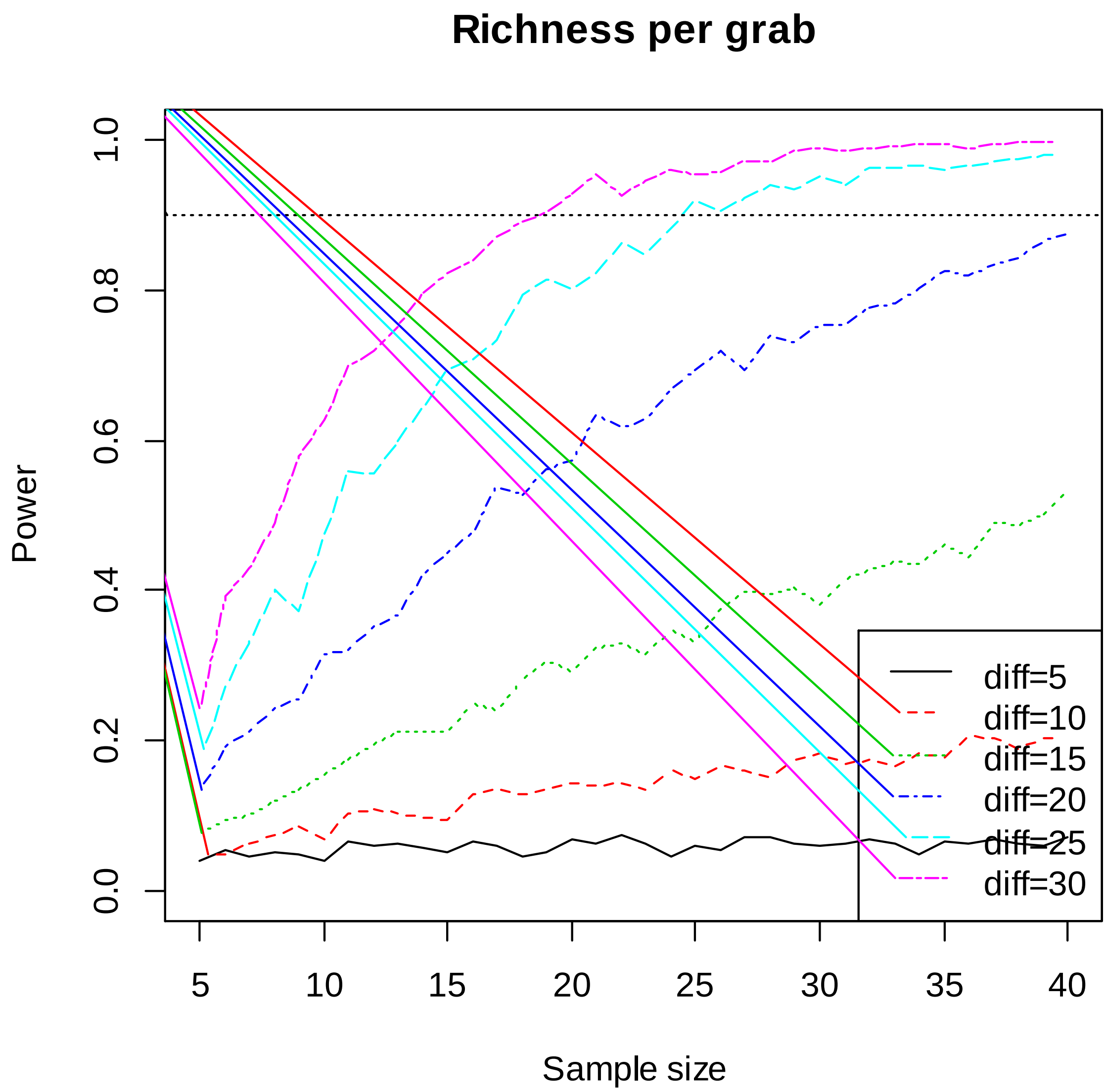

Figure 44. Power probabilities as a function of levels of mean difference (diff) and sample size for richness per grab. The observed difference previously was 20.

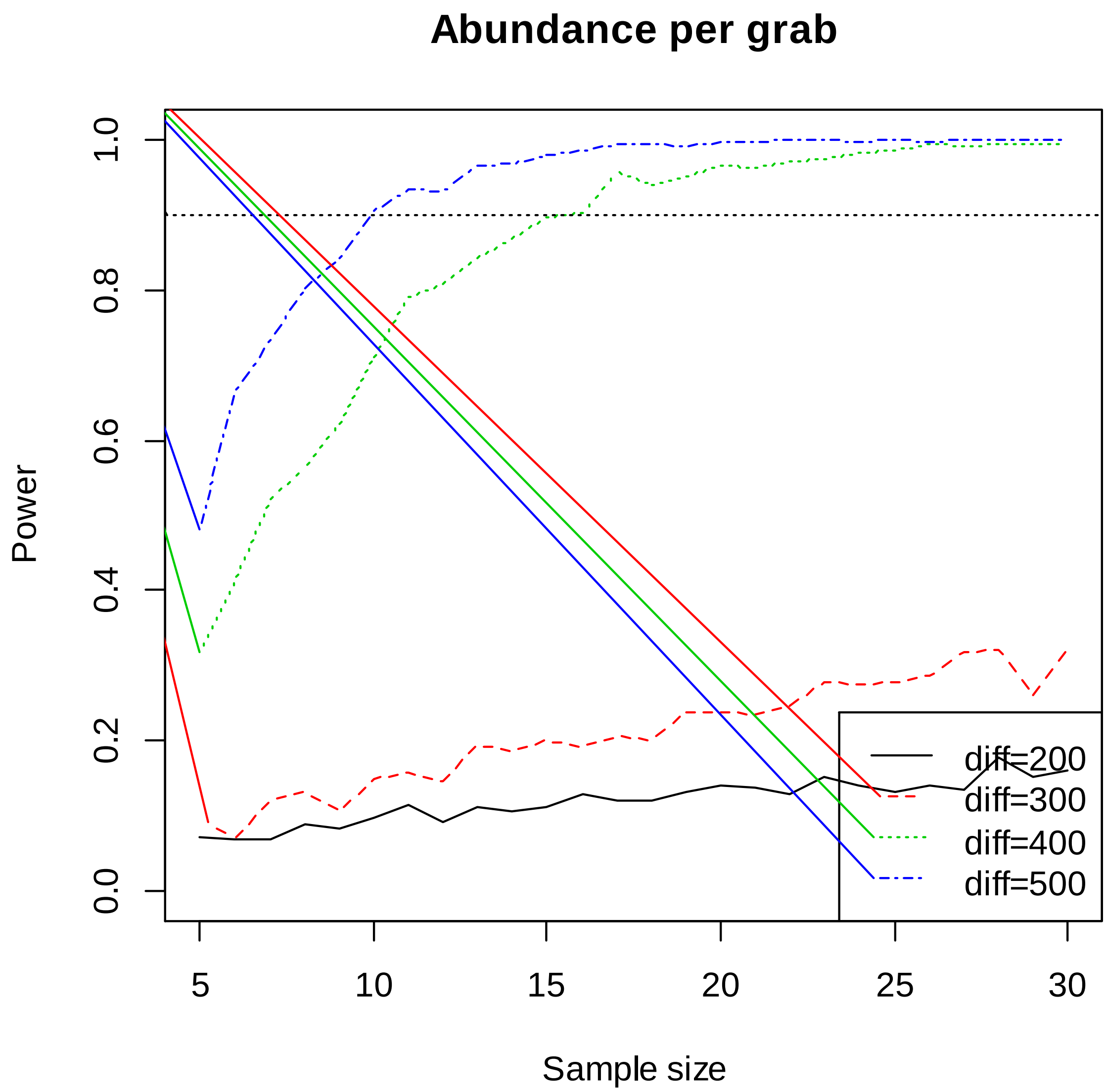

Figure 45. Power probabilities as a function of levels of mean difference (diff) and sample size for abundance per grab (soft substrate). The observed difference previously was around 400.

Appendix 2 Seabed video analysis methodology trials for assessing 'reefiness' of *Sabellaria spinulosa* reef

A2.1 A composite approach to assessing *Sabellaria spinulosa* 'reefiness' from seabed video imagery

A2.1.1 Introduction

The Joint Nature Conservation Committee (JNCC) is the statutory adviser to the UK Government and devolved administrations on UK and international nature conservation. Its work contributes to maintaining and enriching biological diversity, conserving geological features and sustaining natural systems.

JNCC is responsible for the identification of Marine Protected Areas (MPAs) in UK offshore waters. This role includes providing advice to UK Government and the devolved administrations on the selection of Special Areas of Conservation (SACs), Special Protection Areas (SPAs), Marine Conservation Zones (MCZs) and Nature Conservation MPAs.

A number of Special Areas of Conservation (SACs) are designated for bedrock, stony and biogenic reef habitats, where these qualify as Annex I habitat according to the Habitats Directive (CEC 2007). This Appendix specifically deals with the Annex I biogenic reef habitat formed by Sabellaria spinulosa. The Ross worm (S. spinulosa) is widely distributed and common in UK waters, occurring as individuals but also forming 'crusts' or 'reefs' of many individuals on sandy and mixed/coarse sediments (Gubbay 2007).

The North Norfolk Sandbanks and Saturn Reef Site of Community Importance (SCI)15 comprise a series of ten main sandbanks and associated fragmented smaller banks formed as a result of tidal processes. In addition, there are areas of S. spinulosa biogenic reef. JNCC and Centre for Environment, Fisheries and Aquaculture Science (Cefas) undertook a seabed survey (CEND 22/13 & 23/13) at the North Norfolk Sandbanks and Saturn Reef SCI between 4 November and 25 November 2013 on the RV Cefas Endeavour (Vanstaen and Whomersley 2014).

The aim was to gather additional seabed data to assist with the development of management advice for the site. Locations of known S. spinulosa reef, along with historic records where reef had been previously observed, were surveyed to assess presence, and where possible, delineate the Annex I biogenic reef feature and characterise associated fauna.

A2.1.2 Sabellaria spinulosa 'reefiness'

In 2007, JNCC invited representatives from a range of organisations working on Sabellaria spinulosa to an 'Inter-agency workshop on defining and managing S. spinulosa reefs'. The results from this workshop are presented in a report (Gubbay 2007). The main focus of the workshop was seeking agreement on a definition of S. spinulosa reefs. The simplest definition of S. spinulosa reef in the context of the Habitats Directive was considered to be:

"an area of S. 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. In UK waters elevations created by worm tubes of up to 30cm have been recorded and spatial extents of more than 1km^2"

[15] http://jncc.defra.gov.uk/pdf/NNSandbanksandSaturnReef_ConservationObjectives_AdviceonOperations_6.0.pdf

From the report (Gubbay 2007), Table A.1 below provides a range of metrics proposed by participants which could be used together as a measure of ‘reefiness’. Note that the metrics and thresholds were considered a starting point for wider discussion, rather than accepted and fully agreed thresholds for S. spinulosa reef identification.

Table A.1. Range of figures proposed by Gubbay workshop participants which could be used together as a measure of ‘reefiness’ (from Gubbay 2007).

Measure of 'reefiness'	NOT a reef	LOW	MEDIUM	HIGH
Elevation (**cm**) (average tube height)	<2	2-5	5-10	>10
Area (**m^2**)	<25	25-10,000	10,000-1,000,000	>1,000,000
Patchiness (**% cover**)	<10%	10-20	20-30	>30

JNCC in partnership with Cefas completed a survey (CEND 22/13 & 23/13) in November 2013 to investigate *S. spinulosa* reef presence as well as to investigate the sandbank community variability at the North Norfolk Sandbanks and Saturn Reef cSAC/SCI. Areas of currently existing *S. spinulosa* reef along with areas where it had previously been found were surveyed using side-scan sonar and seabed drop-down camera imagery to assess presence, characterise the associated fauna and, where possible, delineate the extent of the Annex I biogenic reef feature (Vanstaen and Whomersley, 2014).

The seabed imagery was initially analysed by segmenting the video into habitat ‘sections’ typically with a minimum length of one minute. Estimates of *S. spinulosa* reef patchiness and elevation (if present) were made. However, following review and concerns over the subjectivity of making estimates of patchiness for extended time periods, a series of novel, repeatable, objective methods were trialled, focusing on analysing sections of video of shorter duration. The methodologies and results from these trials is reporting below.

A2.1.3 Outline of the seabed video imagery analysis pilot for *Sabellaria spinulosa* reef

This document outlines three methodologies that were trialled to provide a robust, repeatable methodology for the analysis of seabed video imagery for areas of *S. spinulosa* reef. Following review, only one approach was progressed, and developed to allow JNCC to objectively assess the ‘reefiness’ components of *S. spinulosa* reef.

For all three methods, the seabed imagery was assessed for data quality (see Table A.2), presence/absence of *S. spinulosa* reef, percentage cover of reef and an estimate of tube height elevation. The results were then quality checked. All methods were carried out using VideoLAN media player 2.0.2 Twoflower (© VideoLAN 1996-2012), hereafter referred to as ‘VLC’.

Table A.2. Quality scores assigned to video segments/images

Quality	Score
Completely unusable segment (e.g. extremely low visibility throughout or where the camera did not move during the segment)	0
Good quality imagery: high confidence in assessment of criteria (i.e. % cover, tube elevation)	1
Image coincides with taking of a still photograph (which resulted in no image). This only applies to methods 2 and 3 above	2
Low quality image: Low confidence in one or more assessment criteria recorded (i.e. % cover, tube elevation) and independent verification required – for example, partially obscured due to sediment	3

The three methods were:

1. ‘5 second video’ method
2. ‘Equal interval Frame grab’ method
3. ‘Paused Video Frames’ method

Four video transects where *S. spinulosa* reef had been identified as potentially present were chosen to trial the above methods. Advantages and disadvantages of each method are outlined in Table 3 below.

A2.1.4 ‘5 second video’ Method

- For each video transect, a 5x5 transparent grid (saved as a .png file), with each grid square equating to 4% cover, was overlaid on top of the video feed window using VLC’s ‘Overlay/Add logo’ video effect.
- The video transect was viewed using VLC in five-second segments using an automated script, which segmented the video into individual files, each five seconds in length.
- Percentage cover was estimated over the 5-second period using the overlay grid as an aid, and the resulting value recorded along with a binary value for presence/absence against the timecode of the segment’s start (i.e. 1 for present or 0 for absent).
- A quality score was assigned to each video segment record (see Table A.2 above)
- Where a segment showed evidence of *Sabellaria* presence but a coverage score could not be assigned with confidence, the value for coverage was left blank and the segment given a quality assurance (QA) score of 3. Segments with a QA score of 3 are to be verified before being given a score of either 1 or 0.

A2.1.5 ‘Equal interval Frame grab’ method

- For each video transect, the video file was loaded into VLC and equal-interval frame-grabs extracted using VLC’s “Scene” filter.
- The filter was set to save 1 frame out of every 125 where the video was encoded at 25fps.
- This extracted one frame grab every 5 seconds. A 5x5 transparent grid, with each grid square equating to 4% cover, was overlaid over the top of each image using Adobe Photoshop’s batch-processing tools.
- For each video frame, percentage cover was assigned using the 5x5 grid to enumerate percentage whilst presence/absence was recorded as a binary value.
- A quality score was assigned to each video segment record (see Table A.2 above).

A2.1.6 'Paused Video Frames' method

- For each video transect, a 5x5 transparent grid (saved as a .png file), with each grid square equating to 4% cover, was overlain on top of the feed using VLC's ''Overlay/Add logo' video effect.
- The video imagery was viewed using VLC, pausing every five seconds. If the paused frame was obscured (for example by the blank screen associated with a still photograph being taken), the footage could be advanced to the next closest viewable frame.
- Percentage cover was estimated from the paused video frame using the overlay grid as an aid, and the resulting value recorded along with a binary value for presence/absence against the timecode of the segment's start (i.e. 1 for present or 0 for absent).
- A QA score was assigned to each video segment record (see Table A.2 above).

Table A.3. Advantages and disadvantages of the three video analysis methods

Method	Advantages	Disadvantages
'5 second video' method	• Should get more representative data on patchiness, as far fewer "QA=0" values than the other methods trialled. • Less likely to miss occurrences of *Sabellaria spinulosa* reef, especially when highly patchy as constant visual of the transect is achieved. • A lot easier to identify *S. spinulosa* reef on a moving image, especially with low-resolution video.	• More reliant on 'expert' judgment. Less objective than the other two methods trialled as estimation of coverage over time rather than a single view (frame grab that is easily quantified). • More time consuming than frame grab technique
'Equal interval Frame grab' method	• Relatively quick • Highly objective coverage values obtained from frame grabs when using transparent grid overlay	• Increased risk of missing *Sabellaria* reef occurrences, especially if highly patchy (can be mitigated by increasing sufficiently high number of frame grabs). • High occurrence of "QA=0" frames
'Paused Video Frames' method	• Similar to Frame Grab technique. • Frame-by-frame advancing reduces the number of "QA=0" frames, allowing the selection of nearest usable frame.	• A lot slower than Frame Grabs especially when frame advancing a high proportion of the time. • Increased risk of missing *Sabellaria* reef occurrences, especially if highly patchy (can be mitigated by increasing sufficiently high number of frame grabs). • High occurrence of "QA=0" frames

Following a review of the results from all three approaches, the '5 second video' method was identified as the most appropriate (with respect to advantages and disadvantages) out of the three approaches trialled to determine 'reefiness' scores (including 'patchiness') of *Sabellaria spinulosa* reef occurrence.

A2.1.7 Application of '5 second video method' to full seabed video dataset

The '5 second video' method was applied to the full suite of seabed video transect data from the CEND 22/13 & 23/13 (North Norfolk Sandbanks and Saturn Reef SCI) survey. In addition, an estimate of average elevation (a proxy for average tube height in Table 1) was recorded, based on an examination of reef height vs the vertical distance between two of the laser spots.

The following steps were undertaken.

A2.1.8 Splitting video transect files into 5-second segments

Each video transect was split into 5-second segments using VirtualDub (http://www.virtualdub.org/) through the following process:

- Video files to be analysed were consolidated into a single temporary holding directory prior to splitting. Once copied, the videos were split automatically into 125 frame long segments using the combination of a Windows batch file and VirtualDub. As videos from the survey were recorded at 25 frames per second this created segments of five seconds length.
- The Virtualdub process was controlled by an automated script file, ensuring objective and repeatable segmentation of videos.
- Segments were output into folders specific to their original video to enable clear distinction between tows, and were sequentially numbered.

A2.1.9 Analysis of video segments

- Once split, the segmented videos were loaded into a playlist within VLC media player.
- The 'play and pause' option was enabled for playback to ensure that the tow was automatically paused at the end of each segment.
- For each segment, presence/absence of *S. spinulosa*, percentage cover, estimation of average tube elevation and video quality were scored. A transparent .png 5x5 grid (with each grid cell representing 4%) was overlaid over the video footage using VLC's 'Add logo' video effect to aid in the estimation of percentage cover (see Figure A.1 below).
- To account for the cameras field of view changing over a segment, percentage cover was estimated over the entire 5-second segment and divided by the approximate number of times a new area of seabed was visible in the camera's field of view, thereby giving a value of the average percentage cover for the full 5-second video segment.
- Average elevation was estimated using the four-spot (red) laser-scaling device, projecting the corners of a 17 cm x 17cm square along the axis of the lens onto the seabed in the video footage, to estimate the height of the reef from its base. Elevation scores were assigned using the ranges proposed in Gubbay (2007) (see Table A.4)

Table A.4. Elevation categories recorded by analyser

	Not a Reef	Low	Med	High
Elevation (Average tube height in cm)	<2	2-5	5-10	>10
Score	0	1	2	3

- When duplication of footage occurred (i.e. due to camera frame not moving across the seabed) the QA score was lowered to 3 (for further checking) or 0.

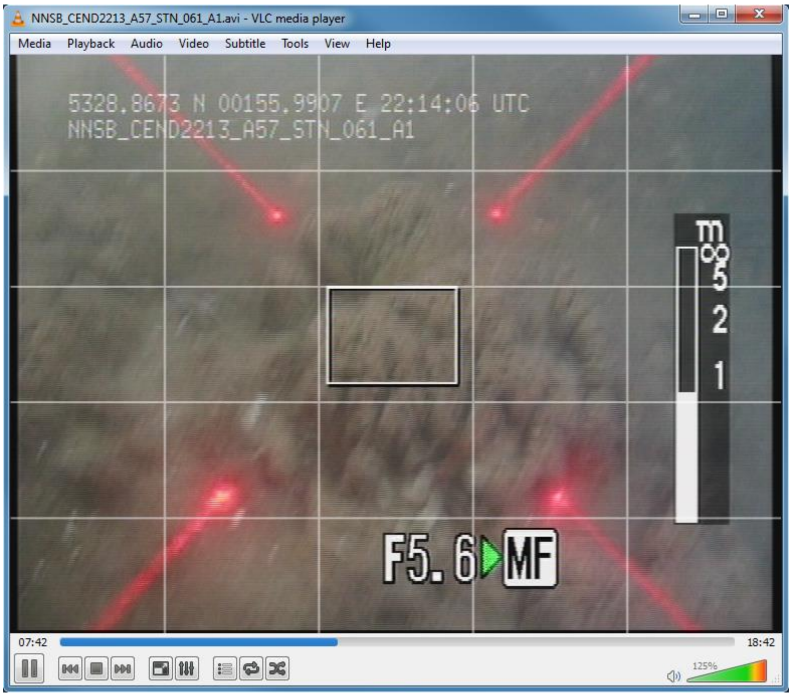

Figure A.1. Example of a transparent 5x5 grid composited over a video tow using VLC media player. Each grid cell represents 4% of the image.

A2.1.10 Quality Assurance

Training was carried out initially, with Vanstaen, K. and Whomersley an analyst reviewing a number of seabed video transects alongside a staff member experienced with using the guidelines in Gubbay (2007) for assessing the 'reefiness' of *S. spinulosa* reef occurrences. This was in order to ensure that analyst had a good understanding of the guidelines, and how they should be interpreted.

Following the analysis, 10% of the video transects were reanalysed by a different analyst, and the results compared with the original analyst (see Annex A).

A2.1.11 Results

Results of the '5 second video' method analysis were converted into a spatial dataset and made available to Cefas for further interpretation and integration into reporting.

A2.1.12 Recommendations

- Please note distance covered and percentage of 'usable' video per five-second section is not consistent between five-second sections owing to vertical and horizontal movements of the drop camera and variable turbidity caused by vessel movements and currents encountered. It is suggested that splitting video tows into sections using distance travelled along a tow instead of time would allow for a more quantitative assessment be undertaken; this was not feasible within the timescales available for this study.

- Further work is required to account for relationship between changing field of view and recording of percentage cover during each five-second section.
- Due to the partially oblique camera angle, further work needs to be undertaken looking at percentage cover estimates – using a flat grid does not account for how the field of view increases with increased distance away from the bottom of the image.
- It is suggested that the quality score set out in Table A.2 above is revised as follows in Table A.5.

Table A.5. Recommendation for revised quality scores assigned to video segments/images.

Quality	Score
Completely unusable segment (e.g. extremely low visibility throughout or camera did not move during the segment)	0
Low quality image: Low confidence in one or more criteria recorded (i.e. % cover, tube elevation) and independent verification required – for example, partially obscured due to sediment	1
Good quality imagery: high confidence in assessment of criteria	2

A2.2 References

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Annex A Additional video analysis quality assurance

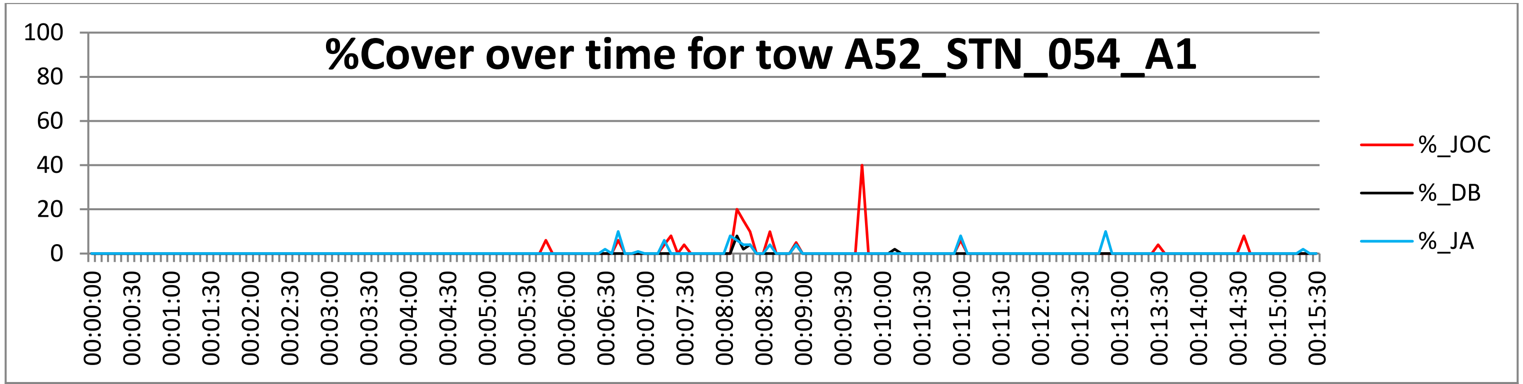
10% (five tows) of the video transects analysed were reanalysed by a different analyst, and the results compared with the original analyst.

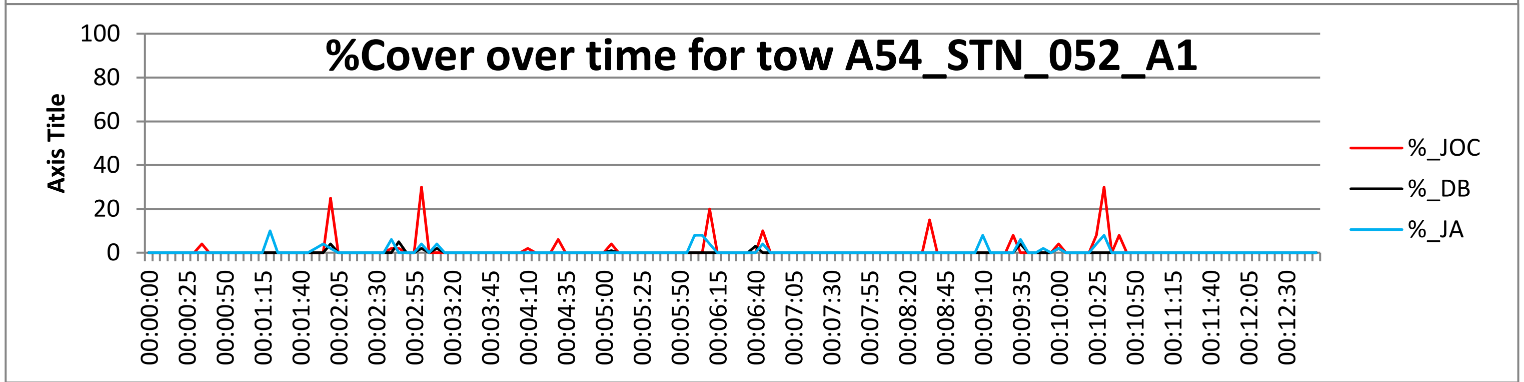
To select the videos for reanalysis, videos analysed were categorised as long (>40 minute), medium (40m<>15m) and short (< 15m) to ensure representative videos were selected. A random number generator was then run to give an unbiased selection, which resulted in the following video transects being selected.

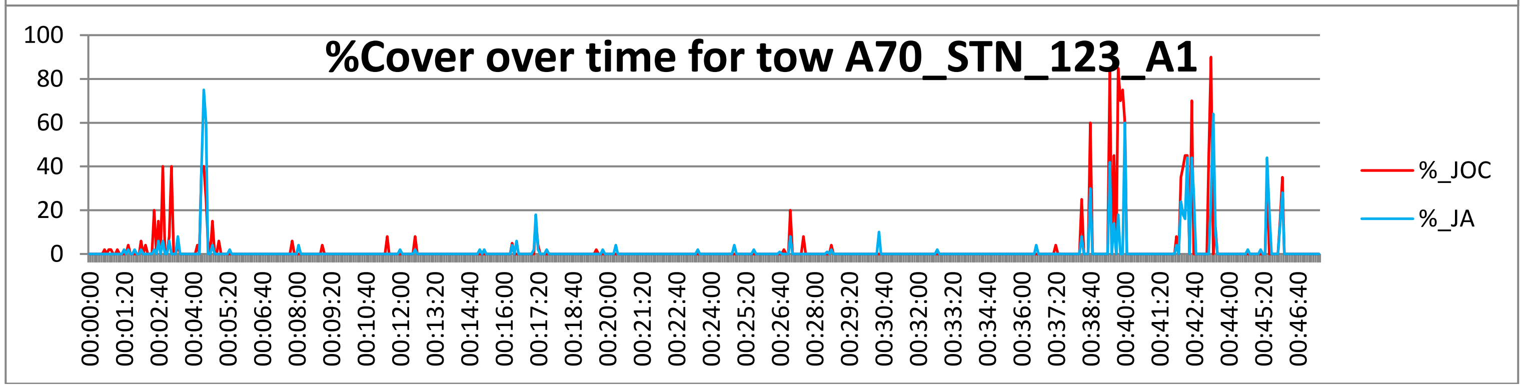
Results of the reanalysis have been averaged for each transect and can be seen in Table A.6 below. Large differences observed between analyst percentage cover scores have been further investigated; it is thought that these differences are a result of the subjective method used to determine percentage cover, which relies on expert judgement to account for the changing field of view within each 5 second section, as in most cases both analysts have agreed on presence/absence of *Sabellaria spinulosa* reef (see Figure A.2).

Table A.6. Video transects reanalysed for quality assurance purposes

Tow	***Length***	**%Cover JA**	%Cover JOC	**Pres/abs JA**	Pres/abs JOC	**QA JA**	QA JOC	**Elevation JA**	Elevation JOC
A52_STN_054_A1	*15:30*	**0.369**	0.781	**0.070**	0.075	**0.989**	1.262	**0.070**	0.064
A54_STN_052_A1	*12:52*	**0.555**	1.148	**0.110**	0.103	**0.897**	1.419	**0.135**	0.123
A70_STN_123_A1	*47:34*	**1.515**	2.375	**0.105**	0.093	**0.897**	1.475	**0.131**	0.102
E23_STN_389_B1	*19:44*	**0.456**	2.359	**0.059**	0.093	**1.156**	1.532	**0.059**	0.093
_F26_STN_238_A1	*10:32*	**1.402**	5.622	**0.236**	0.425	**0.961**	1.126	**0.276**	0.339


%Cover over time for tow A52_STN_054_A1
100
80
60
40
20
0
00:00:00
00:00:30
00:01:00
00:01:30
00:02:00
00:02:30
00:03:00
00:03:30
00:04:00
00:04:30
00:05:00
00:05:30
00:06:00
00:06:30
00:07:00
00:07:30
00:08:00
00:08:30
00:09:00
00:09:30
00:10:00
00:10:30
00:11:00
00:11:30
00:12:00
00:12:30
00:13:00
00:13:30
00:14:00
00:14:30
00:15:00
00:15:30
%_JOC
%_DB
%_JA


%Cover over time for tow A54_STN_052_A1
Axis Title
100
80
60
40
20
0
00:00:00
00:00:25
00:00:50
00:01:15
00:01:40
00:02:05
00:02:30
00:02:55
00:03:20
00:03:45
00:04:10
00:04:35
00:05:00
00:05:25
00:05:50
00:06:15
00:06:40
00:07:05
00:07:30
00:07:55
00:08:20
00:08:45
00:09:10
00:09:35
00:10:00
00:10:25
00:10:50
00:11:15
00:11:40
00:12:05
00:12:30
%_JOC
%_DB
%_JA


%Cover over time for tow A70_STN_123_A1
100
80
60
40
20
0
00:00:00
00:01:20
00:02:40
00:04:00
00:05:20
00:06:40
00:08:00
00:09:20
00:10:40
00:12:00
00:13:20
00:14:40
00:16:00
00:17:20
00:18:40
00:20:00
00:21:20
00:22:40
00:24:00
00:25:20
00:26:40
00:28:00
00:29:20
00:30:40
00:32:00
00:33:20
00:34:40
00:36:00
00:37:20
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00:46:40
%_JOC
%_JA

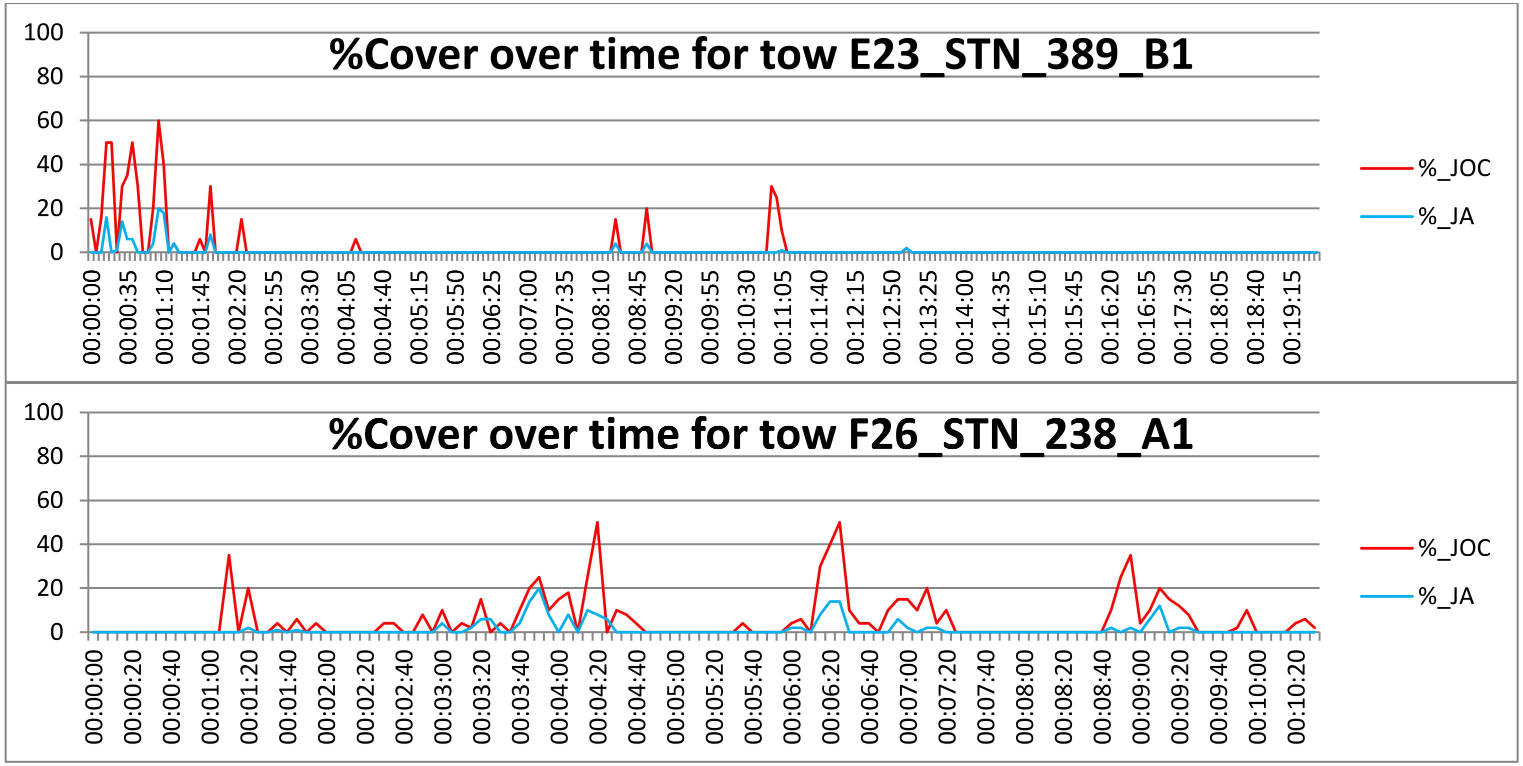

Figure A.2. Quality assurance results for percentage cover scores recorded

Appendix 3 Patchiness methodology

This Appendix describes work on 'patchiness' of *S. spinulosa* reef based on presence or absence of reef during a 5 second segment of video tow. Note that 'patchiness' means the propensity of *S. spinulosa* reef to be clustered together rather than to, say, grow uniformly everywhere.

Elsewhere in this report the authors have defined and used a measure relating to the magnitude of S. *spinulosa* (this measure is a function of the product of elevation and percent cover). However, in this Appendix, patchiness is defined as whether S. *spinulosa* is present or absent.

There are various statistics to define patchiness for spatial data. These include statistics suggested by Clark and Evans (1954), and the G statistic of Brown and Rothery (1978) - also used by Dare and Barry (1990). These statistics are based on nearest neighbour distances between points. The G statistic of Brown and Rothery was introduced to get around the problem of non-independence of the nearest neighbours – for example, if the nearest neighbour to point X is point Y, then there is a high probability that the nearest neighbour to point Y will be point X.

The authors have chosen to use a method based on mean patch size. This has the desirable property that it gives a readily understandable measure of patchiness. However, as mentioned below, this definition is only a relative measure between surveys using the same length of video segment (5 seconds here).

The method used here works by calculating the size of each patch seen in the video tow. For this, a *presence* variable (defined to be 0 if coverage = 0 and 1 if coverage > 0) was created. A patch is defined as a continuous sequence of 1s; it is ended by a 0. So, if our data for a series of segments is;

1 0 0 1 1 1 0 0 1 1 0,

then there would be patches of size 1, 3 and 2.

Missing values derived from unusable data (i.e. because of poor quality video) give no information about whether a patch continues or not, therefore they have been excluded. This means that there are sometimes five seconds or more gaps in the data. So, for example (missing segment defined by *), if a series of segment presences was

0 1 * 1 1 0

then this would be counted as a single patch of length 3.

Because our analysis is based on five-second (or more) segments, there could be gaps in the reef within a segment. Thus, the definition of patchiness is dependent on the duration of segments. The shorter the segments, the finer our measurement of patchiness will be.

The value of mean patchiness depends on how many segments are occupied by reef. If there is lots of reef, the mean patchiness will be higher than if there is less reef. This will cause problems when comparing reefs because apparent differences in mean patch size may be caused by different overall levels of reef rather than differences in inherent clumping together of the reef between the areas. To try to standardise patchiness measurements between reefs, the statistic K was calculated:

$K = P_o / P_r$

where P_o is the mean patch size observed and P_r is the mean patch size if the presence of reef observations in the data string were random. P_r was calculated by randomising the data

1000 times, calculating the mean patch size each time and then calculating the mean of these 1000 values.

Calculation of K also allows the calculation of a p-value to test the null hypothesis that the segments occupied by *S. spinulosa* reef are 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).

In terms of calculating mean patch size, there is a minor problem at the beginning and at the end of the tows. That is, the sizes at each end will be underestimated because the patch could have been part of one that either starts before the beginning of the video or continues after the end of the video. This problem is resolved by wrapping the video sequence around on itself. Thus, if there is reef present in the first and last segments then the sizes of these two patches are added together to form one patch.

A3.1 Results

Table A7. Observed mean patch sizes (P_o), mean patch sizes if segment presence was random (P_r), number of patches and the p-value under the null hypothesis that segment presence was random.

Video tow	P_o	P_r	$K = P_o/P_r$	No of patches	p-value
F23	1.53	1.27	1.21	15	0.001
A64	4.25	1.61	2.63	8	0.001
A57	1.89	1.25	1.52	18	0.001
F25	2.3	1.82	1.27	20	0.001

Table A7 gives results for the four video tows considered in this Appendix. In all examples, the patchiness is more patchy than random. A64 contains the most continuous patches of reef (mean patch size 4.25) compared to the other areas within this example.

The magnitude of each patch of *S. spinulosa* reef was also calculated. To do this, the elevation of the patch was defined to be either 3.5 cm (where the elevation was scored as Low '1'), 7.5 cm (where the elevation was scored as Medium '2') or 15 cm (where the elevation was scored as High '3'). These elevation integers represent the medium value from the Gubbay (2007) elevation scoring system. So for a particular patch with *nsegs* segments, mean magnitude is defined as

$$\overline{M} = \frac{1}{nsegs}\sum_{j=1}^{nsegs} E_j C_j$$

where E_j is the elevation of the jth segment and C_j is the percentage cover of the jth segment.

Appendix 4 Species contributing to the similarity within sampling boxes (fourth root transformed abundance data)

Taxa	A	B	C	D	E	F
NEMERTEA	1.16	1.32	1.29	0.82	0.56	0.97
Ophelia borealis	1.31	0.63	0.9	0.91	0.93	0.81
Ophiuridae	0.95	1.06	1.23	0.47	0.76	0.95
Bathyporeia guilliamsoniana	1.15	1.2	0.26	0.46	0.52	1.16
Abra alba		1.08	1.38	0.48	0.52	0.81
Sabellaria spinulosa	1.61		0.93			1.19
Polycirrus	0.88	0.46	0.85	0.37	0.31	0.75
Nephtys cirrosa	0.58	0.61	0.37	0.44	0.63	0.83
Lagis koreni	0.36	0.74	0.7	0.58	0.53	0.42
Scoloplos armiger	0.43	0.48	0.35	0.58	0.85	0.55
Scalibregma inflatum	0.37	0.86	0.96	0.55		0.49
Glycinde nordmanni	0.64	0.69	1.04	0.38		0.45
Pholoe baltica (sensu Petersen)	0.52	0.72	0.8	0.57		0.56
Abra		0.94	1.67			0.51
Nephtys	0.37	0.52	0.38	0.39	0.35	0.77
Eteone longa	0.75	0.57	0.65		0.26	0.53
Urothoe brevicornis	0.21	0.32		0.49	0.92	0.38
Spiophanes bombyx		0.68	0.41	0.25	0.49	0.48
Galathowenia oculata		1.12	0.52			0.43
Chaetozone christiei	0.66	0.55	0.41			0.36
Goniada maculata		0.44	0.42	0.66		0.38
Aonides paucibranchiata	0.47		0.53	0.39		0.34
Poecilochaetus serpens		0.67	0.51			0.53
Magelona johnstoni		0.51		0.36	0.26	0.4
Mediomastus fragilis		0.51	0.86			
Notomastus		0.48	0.86			
Eunereis longissima	0.5		0.51	0.3		
Anobothrus gracilis		0.68	0.58			
Owenia fusiformis		0.52	0.68			
SPATANGOIDA	0.2	0.3			0.2	0.43
Fabulina fabula		0.44	0.32			0.26
Anaitides groenlandica		0.45	0.36	0.2		
Scolelepis bonnieri	0.35	0.33				0.31
Glycera lapidum	0.38		0.38			
Abludomelita obtusata				0.24	0.48	
Abra prismatica		0.36				0.32
Ampharete lindstroemi (agg)			0.67			
Aglaophamus agilis				0.29	0.31	
ACTINIARIA			0.54			
Ampharetidae		0.53				
Ampelisca tenuicornis			0.49			
Glycera alba			0.47			
Ampelisca spinipes			0.44			
Kurtiella bidentata		0.44				
Lumbrineris cingulata	0.43					
Urothoe poseidonis						0.43
Iphinoe trispinosa			0.37			
Phoronis				0.35		
Euspira nitida			0.33			
Laonice			0.32			
TEREBELLIDA			0.32			
Clymenura			0.31			
Campanulariidae						0.29
Ophiura albida	0.28					
TURBELLARIA				0.27		
Spionidae				0.2		

Appendix 5 *Sabellaria spinulosa* boxes SIMPROF groups (fourth root transformed abundance data)

Taxa	aa	ab	ac	ad	b	c	d	e	g	i	l	m	n	o	q	r	s	t	u	v	x	y	z
Sabellaria spinulosa						4.58	1.4	2.17	6.73	9.49													
NEMERTEA			1.28			1.69	1.65	1.46	1.97	2.11	2.13	1.66	1.98				1.16	1.09				1.21	
Abra alba			2.83	1.44					2.6	3.05	2.35	1.93			1.3								
Ophelia borealis				1.12			1.26	1.22								0.95	2.01		1.24		1.42	1.63	1.22
Abra			2.06						1.98	2.45	2.54	2.66											
Pisidia longicornis						2.63			3.19	4.23													
Lagis koreni	1.09		1.49	1.4			1.5				1.87		1.56										
Scalibregma inflatum							1.33		1.6		2.27	2.34	1.35										
Ophiuridae			1.54	1.78			1.34		2.54				1.45										
ACTINIARIA						2.68	1.25			2.92		1.69											
Glycinde nordmanni								1.3		1.98	1.65	1.55		1.25									
Pholoe baltica (sensu Petersen)									2.1		2.16		2.02	1									
Galathowenia oculata									1.75		2.94	1.82											
Polycirrus								1.64	1.76			1.47	1.64										
Bathyporeia guilliamsoniana		1.73		1.35																	1.54	1.62	
Abludomelita obtusata						2.75				2.92													
Nephtys cirrosa		1.1		0.9														1.19		1.24	1.16		
Anobothrus gracilis											2.81	2.67											
Lumbrineris cingulata									1.71		1.6	1.91											
Chaetozone christiei					1.09													1.25	1.17			1.18	
Eteone longa						1.25				1.95	1.41												
Mediomastus fragilis									2			2.13											
Ampharete lindstroemi (agg)									1.79			2.17											
Amphipholis squamata						1.63				1.95													
Eunereis longissima										1.92			1.31										
Notomastus								1.45				1.57											
Spiophanes bombyx											1.76									1.23			
Aonides paucibranchiata							1.27	1.29															
Cancer pagurus										2.38													
Urothoe brevicornis																				1.25			1.13
Polynoidae										2.37													
Goniada maculata													1.25		1.09								
Scoloplos armiger	1.09																					1.13	
Scolelepis bonnieri		0.93																	1.14				
Nephtys	1	1.02																					
Galathea intermedia										1.98													
Phoronis											1.73												
Praxillella affinis									1.7														
Ampelisca tenuicornis											1.61												
Urothoe marina														1.59									
Fabulina fabula			1.5																				
Ampelisca spinipes												1.48											
Ophiura albida																	1.47						
Poecilochaetus serpens									1.41														
TURBELLARIA											1.41												
Amphictene auricoma											1.34												
Glycera alba											1.3												
Magelona johnstoni		1.15																					
Spionidae																1							
Travisia forbesii					1																		

Appendix 6 Reefiness scores

	% of Tow							
Tow	No Reef	Not Reef	Low Reef	Medium Reef	High Reef	No. of patches	Ave. Patch length (SD)	Ave. Magnitude per patch (SD)
A68	21.39	5.28	65.83	7.50	0.00	28	10.07 (10.56)	157 (86.86)
A69	42.59	9.60	41.92	5.89	0.00	47	7.28 (7.41)	114.08(83.73)
A67	44.87	8.97	39.32	6.62	0.21	56	4.54 (5.35)	147.57(124.57)
A63	65.53	17.96	11.65	3.88	0.97	19	3.74 (4.33)	87.89 (109.46)
F24_C 1	44.68	29.08	17.02	9.22	0.00	21	3.71 (3.5)	60.52 (72.61)
F24_B 1	52.50	13.33	25.00	9.17	0.00	16	3.56 (2.28)	93.47 (74.74)
F22_A 1	35.92	30.28	30.28	3.52	0.00	27	3.37 (2.76)	59.72 (50.08)
A64	63.56	11.02	16.95	8.47	0.00	13	3.31 (2.86)	115.05 (72.96)
E24	87.36	5.34	7.02	0.28	0.00	15	3 (2.64)	54.94 (43.25)
F25_B 1	48.21	22.62	17.86	10.12	1.19	29	3 (3.12)	105.33 (43.25)
F25_C 1	44.68	29.08	17.02	9.22	0.00	22	2.95 (2.57)	85.82 (144.06)
A59	61.36	15.93	15.59	6.78	0.34	39	2.92 (4.28)	80.13 (91.58)
E27	85.95	6.61	6.61	0.83	0.00	6	2.83 (1.83)	47.77 (116.80)
F23_B 1	57.75	14.79	26.06	1.41	0.00	22	2.73 (1.96)	58.84 (33.4)
A57	74.18	9.86	5.16	9.86	0.94	21	2.62 (2.38)	137.11 (47.53)
E25	91.03	5.54	2.11	1.32	0.00	13	2.62 (2.43)	54.93 (120.52)
E26	69.89	15.99	10.41	3.72	0.00	32	2.56 (3.36)	56.40 (77.56)
F22_B 1	69.72	15.49	14.08	0.70	0.00	17	2.53 (2.8)	32.12 (69.9)
E28	81.33	13.30	4.09	1.02	0.26	29	2.52 (2.37)	36.51 (33)
C50	56.52	41.30	2.17	0.00	0.00	25	2.4 (1.66)	2.91 (44.72)
F23_A 1	60.14	26.81	6.52	6.52	0.00	25	2.2 (2.24)	49.93 (12.16)
A71	64.86	18.18	9.34	5.65	1.97	67	2.13 (1.39)	122.42 (74.35)
A66	91.38	7.59	1.03	0.00	0.00	12	2.08 (1.24)	12.98 (196.08)
A58	81.51	9.59	6.16	2.74	0.00	26	2.08 (1.44)	61.41 (8.9)

E23_A1	81.90	14.29	1.90	1.90	0.00	10	1.9 (1.2)	20.9 (74.35)
C19	75.19	18.60	6.20	0.00	0.00	17	1.88 (1.5)	24.71 (31.53)
F23_C1	80.83	15.83	3.33	0.00	0.00	13	1.77 (1.09)	15.75 (32.03)
A60	90.16	6.89	0.66	2.30	0.00	17	1.76 (2.19)	42.76 (33.31)
F26_238_B1	88.11	6.99	3.50	1.40	0.00	10	1.7 (0.82)	52.38 (65.12)
F26_238_A1	78.69	16.39	4.92	0.00	0.00	16	1.63 (0.72)	28.27 (46.32)
E23_B1	93.86	4.39	1.75	0.00	0.00	9	1.56 (1.13)	24.13 (33.13)
A54	87.59	11.68	0.73	0.00	0.00	11	1.55 (0.82)	24 (17.94)
F24_A1	92.50	5.00	2.50	0.00	0.00	6	1.5 (0.55)	29.33 (17.87)
F15	94.39	4.67	0.93	0.00	0.00	4	1.5 (0.58)	31.5 (35.35)
C52	87.01	12.43	0.56	0.00	0.00	16	1.44 (0.82)	11.08 (23.25)
A70	85.92	9.22	2.67	0.97	1.21	41	1.41 (1.12)	74.84 (16.51)
A61	97.20	1.60	0.80	0.40	0.00	5	1.4 (0.55)	53.8 (175)
F26_A1	78.69	16.39	4.92	0.00	0.00	10	1.3 (0.48)	26.95 (72.37)
A52	92.57	6.86	0.57	0.00	0.00	10	1.3 (0.95)	21.83 (16.47)
A51	95.50	3.60	0.90	0.00	0.00	4	1.25 (0.5)	57.75 (65.84)
A50	93.41	5.49	1.10	0.00	0.00	5	1.2 (0.45)	20.8 (38.84)
A56	99.41	0.59	0.00	0.00	0.00	2	1.00	10.5 (4.95)
F19	96.55	3.45	0.00	0.00	0.00	4	1.00	14.75 (9.9)
A62	98.37	1.63	0.00	0.00	0.00	2	1.00	7 (13.25)
A65	98.54	1.46	0.00	0.00	0.00	4	1.00	8.75
C53	99.43	0.57	0.00	0.00	0.00	1	1.00	0.00
D12	99.00	0.00	1.00	0.00	0.00	1	1.00	35 (20.23)

Appendix 7 Sandbanks SIMPROF groups (square root transformed abundance data)

					Group					
Taxa	**a**	**c**	**e**	**f**	**g**	**h**	**i**	**k**	**l**	**n**
Bathyporeia guilliamsoniana			2	1.78	3.99	2.67	1.49		2.8	
Abra alba								3.93	2.34	2.34
Ophelia borealis		1.62					3.09			
Fabulina fabula				2.08				2.28		
NEMERTEA							1.32			2.98
Ophiuridae										4.1
Urothoe elegans										3.99
Nephtys cirrosa	1	1.31			1.52					
Poecilochaetus serpens										3
Kurtiella bidentata										2.99
Pholoe baltica (sensu Petersen)										2.81
Lagis koreni								1.98		
Magelona johnstoni				1.92						
Urothoe brevicornis		1.81								
Glycinde nordmanni										1.73
Scoloplos armiger						1.55				
Urothoe marina							1.43			

Appendix 8 Historical sandbank comparison; SIMPER output (presence/absence data)

Group SEA2

Average similarity: 36.28

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Nephtys cirrosa	0.92	8.68	1.75	23.91	23.91
Bathyporeia elegans	0.88	6.85	1.52	18.87	42.79
Urothoe brevicornis	0.67	4.78	0.84	13.17	55.95
Ophelia borealis	0.63	3.69	0.74	10.17	66.12
Bathyporeia guilliamsoniana	0.63	3.49	0.75	9.62	75.75
Magelona johnstoni	0.52	2.28	0.57	6.29	82.03
Scoloplos armiger	0.35	1.03	0.36	2.83	84.86
Scolelepis bonnieri	0.27	0.67	0.26	1.84	86.7
Echinocardium cordatum	0.31	0.64	0.31	1.75	88.45
Euspira nitida	0.25	0.35	0.24	0.96	89.42
Chaetozone christiei	0.25	0.34	0.24	0.93	90.34

Group CEND2213

Average similarity: 27.45

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Bathyporeia guilliamsoniana	0.8	5.46	1.15	19.89	19.89
Nephtys cirrosa	0.58	3.91	0.62	14.23	34.11
Nephtys	0.59	2.99	0.67	10.89	45.01
Ophelia borealis	0.47	2.1	0.47	7.66	52.67
Magelona johnstoni	0.45	1.55	0.47	5.66	58.33
Urothoe brevicornis	0.31	1.14	0.3	4.15	62.48
Fabulina fabula	0.4	1.13	0.42	4.12	66.61
Chaetozone christiei	0.4	1.1	0.41	4	70.61
Abra alba	0.4	1.06	0.41	3.87	74.48
NEMERTEA	0.4	1.05	0.4	3.82	78.3
Scoloplos armiger	0.33	0.76	0.33	2.76	81.06

Scolelepis bonnieri	0.27	0.59	0.27	2.16	83.22	
Ophiuridae	0.31	0.59	0.3	2.14	85.36	
Goniada maculata	0.27	0.53	0.26	1.95	87.31	
SPATANGOIDA	0.24	0.44	0.22	1.62	88.92	
Spiophanes bombyx	0.24	0.3	0.23	1.11	90.03	

Groups SEA2 &
CEND2213

Average dissimilarity = 77.24

	Group SEA2	Group CEND2213				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib %	Cum. %
Bathyporeia elegans	0.88	0	4.04	1.83	5.23	5.23
Nephtys	0	0.59	2.72	1.05	3.52	8.74
Urothoe brevicornis	0.67	0.31	2.7	0.98	3.49	12.23
Ophelia borealis	0.63	0.47	2.44	0.88	3.16	15.4
Magelona johnstoni	0.52	0.45	2.38	0.89	3.08	18.48
Bathyporeia guilliamsoniana	0.63	0.8	2.14	0.76	2.78	21.25
Scoloplos armiger	0.35	0.33	2.04	0.83	2.64	23.89
Chaetozone christiei	0.25	0.4	1.89	0.84	2.45	26.34
Fabulina fabula	0.21	0.4	1.87	0.84	2.42	28.76
Scolelepis bonnieri	0.27	0.27	1.86	0.74	2.41	31.17
Nephtys cirrosa	0.92	0.58	1.8	0.81	2.33	33.49
Abra alba	0.1	0.4	1.75	0.78	2.27	35.76

NEMERTEA	0.13	0.4	1.75	0.78	2.26	38.03
Urothoe poseidonis	0.21	0.21	1.44	0.64	1.87	39.89
Goniada maculata	0.15	0.27	1.4	0.66	1.81	41.71
Euspira nitida	0.25	0.18	1.33	0.63	1.73	43.43
Spiophanes bombyx	0.19	0.24	1.32	0.66	1.71	45.14
Echinocardium cordatum	0.31	0.02	1.28	0.65	1.65	46.79
Ophiuridae	0	0.31	1.2	0.61	1.55	48.34
SPATANGOIDA	0	0.24	1.06	0.51	1.38	49.72
Sthenelais limicola	0.17	0.12	0.92	0.55	1.19	50.91
Bathyporeia pelagica	0.15	0.01	0.87	0.4	1.12	52.03
Phialella quadrata	0.23	0	0.86	0.52	1.11	53.14
Tellimya ferruginosa	0.19	0.05	0.84	0.5	1.08	54.22
Spio goniocephala	0	0.15	0.78	0.4	1.01	55.23
Gastrosaccus spinifer	0.13	0.01	0.78	0.36	1.01	56.24
Donax vittatus	0	0.18	0.76	0.44	0.98	57.22
Scalibregma inflatum	0.1	0.06	0.73	0.38	0.94	58.16
Eteone	0.04	0.15	0.71	0.43	0.92	59.08
Travisia forbesii	0.15	0.01	0.67	0.38	0.87	59.95
Nephtys longosetosa	0.04	0.12	0.66	0.39	0.86	60.81
Pontocrates arenarius	0.17	0	0.66	0.41	0.86	61.67
Glycinde nordmanni	0.02	0.18	0.65	0.45	0.85	62.51
Abra prismatica	0.02	0.14	0.65	0.41	0.84	63.35
Portumnus latipes	0.1	0.02	0.62	0.35	0.81	64.15
Sigalion mathildae	0.06	0.11	0.59	0.41	0.76	64.91
Polycirrus	0.1	0.08	0.58	0.41	0.76	65.67
Nephtys caeca	0.1	0.01	0.58	0.33	0.75	66.42
Ophiura ophiura	0.02	0.11	0.55	0.35	0.72	67.14
Poecilochaetus serpens	0	0.16	0.53	0.42	0.68	67.82
Nephtys hombergii	0.04	0.11	0.53	0.38	0.68	68.5
Nucula nitidosa	0.02	0.12	0.51	0.38	0.66	69.16
Haustorius arenarius	0.08	0.01	0.49	0.3	0.64	69.8
Lagis koreni	0	0.15	0.47	0.41	0.61	70.41

Lagotia viridis	0.08	0.01	0.46	0.29	0.6	71.01
Ophiura albida	0.08	0.06	0.45	0.36	0.58	71.59
Mediomastus fragilis	0	0.12	0.44	0.32	0.57	72.16
HYDROZOA	0	0.12	0.43	0.35	0.56	72.72
Magelona filiformis	0.04	0.07	0.4	0.33	0.52	73.24
Perioculodes longimanus	0.08	0.02	0.4	0.31	0.52	73.76
Paraonis fulgens	0.08	0	0.4	0.29	0.51	74.27
Sigalionidae	0	0.09	0.4	0.31	0.51	74.78
Sabellaria spinulosa	0.06	0.06	0.39	0.33	0.51	75.29
Synchelidium maculatum	0.08	0	0.39	0.28	0.5	75.79
Iphinoe trispinosa	0.06	0.06	0.39	0.34	0.5	76.29
Spio martinensis	0.08	0	0.38	0.29	0.49	76.78
Notomastus	0.04	0.07	0.36	0.32	0.46	77.24
Scolelepis squamata	0	0.07	0.36	0.26	0.46	77.7
Megaluropus agilis	0.08	0	0.34	0.28	0.44	78.14
Pholoe baltica (sensu Petersen)	0.02	0.08	0.32	0.31	0.42	78.56
Abra	0.06	0.04	0.31	0.3	0.4	78.96
Flustra foliacea	0.04	0.06	0.3	0.31	0.39	79.35
Pseudocuma similis	0.06	0	0.3	0.25	0.39	79.74
Magelona minuta	0.08	0	0.3	0.29	0.39	80.13
Sertularia	0.02	0.06	0.29	0.26	0.37	80.5
Aonides paucibranchiata	0.06	0.04	0.28	0.31	0.37	80.86
Nephtys kersivalensis	0.06	0.02	0.27	0.3	0.35	81.21
Spio filicornis	0.04	0.06	0.26	0.31	0.34	81.55
Spio armata (agg.)	0.06	0	0.26	0.25	0.34	81.89
Protodorvillea kefersteini	0.06	0.02	0.25	0.28	0.33	82.22
Anoplodactylus	0.02	0.05	0.25	0.23	0.33	82.55
Nephtys assimilis	0.06	0.01	0.25	0.27	0.32	82.87
Pseudocuma longicornis	0.06	0	0.24	0.25	0.32	83.19
Diastylis bradyi	0.06	0	0.24	0.24	0.32	83.5
Pontocrates altamarinus	0.06	0	0.24	0.25	0.31	83.82
Calycella syringa	0.06	0	0.23	0.24	0.3	84.12

OPHIUROIDEA	0	0.06	0.23	0.24	0.3	84.42
Glycera lapidum (agg.)	0.04	0.04	0.23	0.26	0.3	84.71
Urothoe marina	0	0.06	0.21	0.24	0.27	84.99
Campanulariidae	0	0.05	0.2	0.21	0.26	85.24
Thracia phaseolina	0	0.06	0.2	0.24	0.25	85.5
Diastylis rugosa	0.04	0.01	0.2	0.23	0.25	85.75
Liocarcinus	0	0.04	0.19	0.18	0.25	86
Owenia fusiformis	0	0.07	0.19	0.26	0.25	86.25
TEREBELLIDA	0	0.06	0.19	0.23	0.25	86.49
Spionidae	0	0.06	0.18	0.23	0.23	86.73
Goniadidae	0	0.05	0.18	0.22	0.23	86.96
Eurydice spinigera	0.04	0	0.18	0.2	0.23	87.19
Glycera alba	0	0.05	0.18	0.22	0.23	87.42
Hypereteone foliosa	0.02	0.02	0.17	0.19	0.22	87.64
Magelona	0	0.05	0.17	0.2	0.22	87.87
Spisula elliptica	0.02	0.02	0.17	0.2	0.22	88.08
Kurtiella bidentata	0.02	0.04	0.16	0.22	0.21	88.29
Scrupocellaria	0.02	0.02	0.16	0.21	0.2	88.5
Mactra stultorum	0	0.04	0.16	0.18	0.2	88.7
Alcyonidium diaphanum	0	0.04	0.15	0.18	0.2	88.9
Goodallia triangularis	0.04	0.01	0.15	0.23	0.2	89.1
Scolelepis	0	0.04	0.15	0.19	0.2	89.3
Sagitta	0.02	0.01	0.15	0.17	0.19	89.49
Diphasia	0.04	0	0.15	0.2	0.19	89.68
Pisione remota	0.04	0.01	0.14	0.23	0.19	89.87
Polygordius	0.04	0.01	0.14	0.23	0.19	90.06

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