JNCC/Cefas Partnership Report Series

Report No. 38

North Norfolk Sandbanks and Saturn Reef, Haisborough, Hammond and Winterton, Inner Dowsing, Race Bank and North Ridge Special Areas of Conservation (SAC) Monitoring Report 2016

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December 2020

ISSN 2051-6711

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This report should be cited as:

Eggleton, J., Bolam, S., Benson, L., Archer-Rand, S., Mason, C., Noble-James, T., Jones, L., McBreen, F. & Roberts, G. (2020). North Norfolk Sandbanks and Saturn Reef SAC, Haisborough, Hammond and Winterton SAC, and Inner Dowsing, Race Bank and North Ridge SAC Monitoring Report 2016. JNCC/Cefas Partnership Report No. 38. JNCC, Peterborough, ISSN 2051-6711, Crown Copyright.

Acknowledgements

We thank the Marine Protected Areas Survey Coordination and Evidence Delivery Group (MPAG) representatives for reviewing earlier drafts of this report.

Funded by:

Department for Environment, Food & Rural Affairs (Defra)
Marine and Fisheries
Seacole Block
2 Marsham Street
London SW1P 4DF

Please Note:

This work was delivered by Cefas and JNCC on behalf of the Marine Protected Areas Survey Coordination & Evidence Delivery Group (MPAG) and sponsored by Defra. MPAG was established in November 2012 and continued until March 2020. MPAG, was originally established to deliver evidence for Marine Conservation Zones (MCZs) recommended for designation. In 2016, the programme of work was refocused towards delivering the evolving requirements for Marine Protected Area (MPA) data and evidence gathering to inform the assessment of the condition of designated sites and features by SNCBs, in order to inform Secretary of State reporting to Parliament. MPAG was primarily comprised of members from Defra and its delivery bodies which have MPA evidence and monitoring budgets and/or survey capability. Members included representatives from Defra, JNCC, Natural England, Cefas, the Environment Agency, the Inshore Fisheries Conservation Authorities (IFCAs) and the Marine Management Organisation (MMO)).

Since 2010, offshore MPA surveys and associated reporting have been delivered by JNCC and Cefas through a JNCC\Cefas Partnership Agreement (which remained the vehicle for delivering the offshore survey work funded by MPAG between 2012 and 2020).

Contents

Abbreviations

ANOSIM	Analysis of Similarity
ANOVA	Analysis of Variance
BSH	Broadscale Habitats
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CHP	Civil Hydrography Programme
CP2	Charting Progress 2
CSA	Case Study Area
Defra	Department for Environment, Food and Rural Affairs
DIVERSE	Diversity routine
DKSH	Docking Shoal
EA	Environment Agency
EC	European Commission
ESVP	East of Silver Pit
EUNIS	European Nature Information System
FOCI	Feature of Conservation Interest
GES	Good Environmental Status
HHW	Haisborough, Hammond and Winterton (Special Area of Conservation)
HWNC	Haisborough, Hammond and Winterton Northern Closure
HWSC	HHW Southern Closure
IDFB	Indefatigable Bank
IDRBNR	Inner Dowsing, Race Bank and North Ridge (Special Area of Conservation)
IFCA	Inshore Fisheries and Conservation Authority
INND	Inner Dowsing
JNCC	Joint Nature Conservation Committee
LMBK	Leman Bank
LYNK	Lynn Knock
MBES	Multibeam echosounder
MCZ	Marine Conservation Zone
MESH	Mapping European Seabed Habitats
MPA	Marine Protected Area
MPAG	Marine Protected Areas Survey Coordination and Evidence Group
MSFD	Marine Strategy Framework Directive

MV	Motor Vessel
NE	Natural England
NIS	Non-Indigenous Species
NMBAQC	North East Atlantic Marine Biological Analytical Quality Control Scheme
nMDS	Non-metric Multidimensional Scaling
NNSSR	North Norfolk Sandbanks and Saturn Reef (Special Area of Conservation)
NRRD	North Ridge
NSWB	North of Swarte Bank
NWBK	North of Well Bank
OSPAR	The Convention for the Protection of the Marine Environment of the North East Atlantic
PCA	Principal Components Analysis
PRIMER	Plymouth Routines in Multivariate Ecological Research
PSA	Particle Size Analysis
PSD	Particle Size Distribution
REC	Regional Environmental Characterisation
RV	Research Vessel
SAC	Special Area of Conservation
SACFOR	Superabundant-Abundant-Common-Frequent-Occasional-Rare scale
SACO	Supplementary Advice on Conservation Objectives
SAD	Site Assessment Document
SBES	Singlebeam echosounder
SDB	Satellite-derived bathymetry
SIMPER	Similarity Percentages analysis
SIMPROF	Similarity Profile analysis
SIS	Seabed Information System
SNCB	Statutory Nature Conservation Body
SSS	Sidescan sonar
STR	Subsea Technology and Rentals
STRN	Saturn Reef
SVPS	Silver Pit South
VMS	Vessel Monitoring System
WCT	Wider Characterising Transect
WMCS	West of Middle Cross Sand

Glossary

Definitions signified by an asterisk (*) have been sourced from Natural England and JNCC Ecological Network Guidance (NE & JNCC 2010).

Annex I Habitat	A habitat for which a Special Area of Conservation (SAC) can be designated under the Habitats Directive.
Anthropogenic	Caused by humans or human activities; usually used in reference to environmental degradation.*
Assemblage	A collection of plants and/or animals characteristically associated with a particular environment that can be used as an indicator of that environment. The term has a neutral connotation and does not imply any specific relationship between the component organisms, whereas terms such as ‘community’ imply interactions (Allaby 2015).
Benthic	A description for animals, plants and habitats associated with the seabed. All plants and animals that live in, on or near the seabed are benthos (e.g. sponges, crabs, seagrass beds).*
‘Beyond sandbank’	Sampling stations located beyond the areas defined as Annex I Sandbank (including the 500m margin).
Biotope	A biotope is an area of uniform environmental conditions providing a living place for a specific assemblage of plants and animals.
Case Study Area (CSA)	Areas selected from each MPA for investigation of the structural and functional ecology of communities inhabiting different topographical zones of the same sandbank. CSAs were selected to be representative of the range of sandbank types within the three MPAs.
Chart Datum	Chart datum is the water level that depths displayed on a nautical chart are measured from.
Community	A general term applied to any grouping of populations of different organisms found living together in a particular environment, essentially the biotic component of an ecosystem. The organisms interact and give the community a structure (Allaby 2015).
Conservation Objective	A statement that sets out the broad ecological aims of a site. These can be written at feature level providing a target for individual attributes.
Entropy	A non-hierarchical clustering method that groups large matrices of PSD datasets into a finite number of groups (see Stewart *et al.* 2009).
Epifauna	Fauna living on the seabed surface.

EUNIS	A European habitat classification system, covering all types of habitats from natural to artificial, terrestrial to freshwater and marine.*
Feature	Term used to describe the habitat / species / geological / geomorphological / large-scale feature which is designated within an MPA.
Feature Attributes	Ecological characteristics of the habitat or species which together describe the desired condition or state of the feature. Attributes for conservation advice include: • Extent & Distribution • Structure & Function • Supporting Processes
Inshore Fisheries and Conservation Authorities	The public bodies responsible for managing the marine environment and fisheries in the inshore area (out to 6 nm).
Infauna	Fauna living within the seabed sediment.
Impact	The consequence of pressures (e.g. habitat degradation) where a change occurs that is different to that expected under natural conditions (Robinson *et al*. 2008).*
Joint Nature Conservation Committee (JNCC)	The statutory adviser to Government on UK and international nature conservation. Its specific remit in the marine environment ranges from 12 - 200 nautical miles offshore.
Marine Management Organisation (MMO)	The public body responsible for licensing, regulating and planning activities in the seas around England.
Marine Protected Area (MPA)	A generic term to cover all marine areas that are ‘A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values’ (Dudley 2008). *
Marine Strategy Framework Directive (MSFD)	The MSFD (EC Directive 2008/56/EC) aims to achieve Good Environmental Status (GES) of EU marine waters and to protect the resource base upon which marine-related economic and social activities depend.
Natural England	The statutory conservation adviser to Government, with a remit for England out to 12 nautical miles offshore.
Non-indigenous Species	A species that has been introduced directly or indirectly by human agency (deliberately or otherwise) to an area where it has not occurred in historical times and which is separate from and lies outside the area where natural range extension could be expected (Eno *et al*. 1997). *
Pressure	The mechanism through which an activity has an effect on any part of the ecosystem (e.g. physical abrasion caused by

	trawling). Pressures can be physical, chemical or biological, and the same pressure can be caused by a number of different activities (Robinson *et al*. 2008). *
Special Areas of Conservation	Protected sites designated under the European Habitats Directive for species and habitats of European importance, as listed in Annex I and II of the Directive. *
Supplementary Advice on Conservation Objectives (SACO)	Site specific advice providing more detailed information on the ecological characteristics or ‘attributes’ of the site’s designated feature(s). This advice is issued by Natural England and/or JNCC.
Topographical Zones	Topographical areas of the sandbank that were targeted for investigation: crest, mid-flank, trough and ‘beyond sandbank’.
Wider Characterising Transects (WCT)	Transects conducted to investigate whether Case Study Areas (CSA)

Executive summary

This report presents the findings of the first dedicated monitoring survey of the Inner Dowsing, Race Bank and North Ridge (IDRBNR) SAC, Haisborough, Hammond and Winterton (HHW) SAC and the North Norfolk Sandbanks and Saturn Reef (NNSSR) SAC, which will form the initial point in a monitoring time series against which feature condition can be assessed in the future. The monitoring survey was conducted between 31st May and 27th June 2016, aboard three survey vessels: Environment Agency (EA) vessels the MV *Humber Guardian* and the MV *Solent Guardian*, and the RV *Cefas Endeavour*.

SACs are designated under the Habitats Directive for a range of species and habitats. Under Article 17 of the Directive, every six years progress must be reported on the implementation of the Directive. In order to inform this reporting, Statutory Nature Conservation Bodies (SNCBs) undertake a programme of SAC monitoring. Where possible, this monitoring will also inform assessment of the status of the wider UK marine environment; for example, assessment of whether Good Environmental Status (GES) has been achieved, as required under Article 11 of the MSFD.

The SNCB responsible for nature conservation of English inshore waters (between 0 and 12 nm from the coast) is Natural England (NE) and the SNCB responsible offshore (between 12 nm and 200 nm from the coast) is the JNCC. The SNCBs utilise evidence gathered by targeted environmental and ecological surveys and site specific MPA reports in conjunction with other available evidence (e.g. activities, pressures, historical data, survey data collected from other organisations or data collected to meet different obligations). These data are collectively used by SNCBs to make assessments of the condition of designated features within sites, to inform and maintain up to date site specific conservation advice and produce advice on operations and management measures for anthropogenic activities occurring within the site. This report, as a stand-alone document, **does not** therefore aim to assess the condition of the designated features or provide advice on management of anthropogenic activities occurring within the site.

The IDRBNR, HHW and NNSSR SACs are located in the Southern North Sea and all contain examples of the Annex I Habitats 'Sandbanks which are slightly covered by sea water all the time' and 'Reefs' created by the Ross Worm, *Sabellaria spinulosa*. The primary aim of this monitoring report is to explore and describe the attributes of the Annex I feature within the IDRBNR, HHW and NNSSR SACs, in relation to specific questions to enable future assessments of feature condition.

Temporal comparison of multibeam echosounder (MBES) data for five sandbanks across the three sites revealed differences in the temporal stability of broad morphology between sandbanks. While the Indefatigable Bank sandbank within the NNSSR was regarded as having remained more-or-less stable between 2013 and 2016, the Leman Bank (also within NNSSR) was estimated to have migrated 30m north west in the same timeframe. Meanwhile, the two profiles studied for the sandbank within the HHW site indicated no discernible shift between 2014 and 2016, while the shoreward flank of the Inner Dowsing sandbank within IDRBNR site has shifted by *circa* 40m. Clearly, therefore, temporal changes in sandbank morphology and distribution is very bank-specific making generalities in, or predictions of, movement difficult to make.

Sediment and faunal composition on the sandbank topographical zones (crest, flank, trough, 'beyond sandbank' i.e. areas beyond the sandbank edge and 500m buffer) within and between SACs generally reflect the hydrodynamic conditions of the sites and their proximity to the coast. Fauna inhabiting areas/topographical zones subject to high tidal current velocities (e.g. crests and flanks) were depauperate and showed little variability in sediment composition in comparison with troughs and 'beyond sandbank' areas. Species common to the infralittoral were observed on the crests and flanks of the nearshore banks, whilst the troughs of some sandbanks (near and offshore) provided conditions suitable for the settlement and formation of *Sabellaria spinulosa* reef. Secondary production estimates provided some insights into the functional variability between infauna communities inhabiting the sandbank topographical zones and the potential of energy transfer to the next trophic level.

Annex I *S. spinulosa* reef was observed in all three SACs, although the habitat varied considerably in quality. Reef was found to persist within the MMO Marine Conservation Byelaw areas and areas previously surveyed within HHW during the East Coast Regional Environmental Characterisation in 2009, where the highest quality reef from all three sites was observed. Reef and underlying habitat suitable for reef formation was observed within NNSSR in the vicinity of Saturn Reef but was significantly reduced in quality in comparison with previous surveys of the area. More extensive areas of reef were, however, observed in the trough of the Leman Bank sandbank. A previous assessment of the fishing effort across the NNSSR SAC (based on data from 2009 to 2013) indicated that parts of the site are not fished at all and large areas trawled less than once per year. Fishing activity was shown to be concentrated in the troughs of the sandbanks. Further study is therefore required to help understand why reefs are persisting in troughs which are subject to high fishing activity and are declining from other areas of the SAC.

Fauna associated with reef features generally resembled fauna inhabiting the surrounding coarse and mixed sediments, due to the presence of certain sessile epifauna and mobile predators. Some subtle differences were, however, observed between reef and non-reef areas at some sites.

The data collected from infauna and epifaunal samples were also assessed for the presence of non-indigenous species (NIS) and litter. Three species were identified: The Slipper limpet, *Crepidula fornicata*, the bivalve mollusc, *Mya arenaria* and the polychaete, *Goniadella gracilis*. The expansion of *C. fornicata* within IDRBNR is of concern in relation to Annex I *S. spinulosa* reef due to the competitive nature of the species and should be monitored. Marine litter was ubiquitous across the three sites with microplastics (<5mm) the most numerous and widespread. The impact of microplastics on the function and integrity of the SACs is currently unknown therefore further study is recommended.

The report includes recommendations which inform continual improvement and development of sample acquisition, analysis and data interpretation for future surveys and reporting. Site and feature specific indicator metrics are not currently defined for this site. The design of any future monitoring should be based on the specific aims and objectives which are likely to be formulated over the coming years. Further, potential indicators which are shown to be suitable for such monitoring are yet to be currently decided. The data acquired here may, in future, be used to assess the variability of such indicators and hence represent an important component in the design of future surveys for the North Norfolk Sandbanks.

1. Introduction

The North Norfolk Sandbanks and Saturn Reef SAC (hereafter NNSSR), the Haisborough, Hammond & Winterton SAC (hereafter HHW), and the Inner Dowsing, Race Bank & North Ridge SAC (hereafter IDRBNR) are part of a network of Natura 2000 sites designed to meet conservation objectives under the Habitats Directive. These sites also contribute to an ecologically coherent network of MPAs across the north east Atlantic agreed under the Oslo-Paris (OSPAR) Convention and other international commitments to which the UK is a signatory. These particular sites are located in the Southern North Sea and are all designated for examples of the Annex I Habitats ‘Sandbanks which are slightly covered by sea water all the time’ and ‘Reefs’ created by the Ross Worm, *Sabellaria spinulosa.*

Under Article 17 of the EC Habitats Directive, Defra is required to produce a report to Parliament every six years that includes an assessment of the degree to which the conservation objectives set for SACs are being achieved. In order to inform this reporting, SNCBs undertake a programme of SAC monitoring. The SNCB responsible for nature conservation inshore (between 0 nm and 12 nm from the coast) is NE and the SNCB responsible for nature conservation offshore (between 12 nm and 200 nm from the coast) is the JNCC. Where possible, this monitoring will also inform assessment of the status of the wider UK marine environment; for example, assessment of whether Good Environmental Status (GES) has been achieved, as required under Article 11 of the MSFD. Two of the three sites considered in this report (IDRBNR & HHW) intersect the 12 nm inshore-offshore boundary, therefore this report has been produced as a part of a monitoring collaboration between NE and JNCC.

The report primarily explores data from the first dedicated monitoring survey of the NNSSR, HHW and IDRBNR SACs, conducted between 31st May and 27th June 2016, which will form the initial point in a monitoring time series against which feature condition can be assessed in the future. The specific aims and objectives of the report are discussed in detail in Section 1.4.

1.1 Feature descriptions

The features for which the three sites are designated sites are described in the following sections.

1.1.1 Sandbanks slightly covered by sea water all the time

As stated in the Interpretation Manual of European Union Habitats (European Commission 2013) which provides standard descriptions for Annex I Habitats:

‘Sandbanks are elevated, elongated, rounded or irregular topographic features, permanently submerged and predominantly surrounded by deeper water. They consist mainly of sandy sediments, but larger grain sizes, including boulders and cobbles, or smaller grain sizes including mud may also be present on a sandbank. Banks where sandy sediments occur in a layer over hard substrata are classed as sandbanks if the associated biota are dependent on the sand rather than on the underlying hard substrata. “Slightly covered by sea water all the time” means that water depth seldomly exceeds 20m (chart datum) although some sandbanks are located in deeper water. It can, therefore, be appropriate to include in designations such areas where they are part of the feature and host its biological assemblages.’

Annex I Sandbank features are composed of a number of finer scale habitats. These include (but are not limited to); 'A5.2 Sublittoral sand', 'A5.1 Sublittoral coarse sediment' and 'A5.4 Sublittoral mixed sediments', as per the EUNIS classification[1]. These EUNIS level 3 habitats are equivalent to the sub-features used by NE in their conservation advice for the sites[2].

Sublittoral sand is the dominant habitat type within the Annex I Sandbanks feature, comprising clean medium to fine sands or non-cohesive slightly muddy sands. Sublittoral coarse sediment is a combination of sand and gravel increasing to pure gravel. Coarse sediments are often unstable due to tidal currents and/or wave action. Sublittoral mixed sediments are composed of a range of different sediment types, from muddy gravelly sands to mosaics of cobbles and pebbles embedded in or lying on sand, gravel or mud. Mixed sediment habitats also include seabeds where waves or ribbons of sand form on the surface of a gravel bed (EUNIS habitat classification 2016).

1.1.2 Reefs

As stated in the Interpretation Manual of European Union Habitats (European Commission 2013):

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

'Biogenic concretions' are defined as: 'concretions, encrustations, corallogenic concretions and bivalve mussel beds originating from dead or living animals, i.e. biogenic hard bottoms which supply habitats for epibiotic species. These include reefs formed by large aggregations of the Ross Worm, *Sabellaria spinulosa'* (such as those found at NNSSR, HHW and IDRBNR). *S. spinulosa* reefs consist of thousands of fragile sand tubes which have consolidated to create a solid structure rising above the seabed. Reefs formed by *S. spinulosa* are colonised by other species not found in adjacent habitats, leading to a diverse community of epifaunal and infaunal species.

For management purposes, JNCC and NE provide advice on a defined 'Area to be managed as Annex I Reef'. This area includes a 500m margin around any point or line data where reef (low-high Gubbay Reefiness score; Gubbay 2007) has been recorded. The margin has been applied to point or line records of *S. spinulosa* reef to reflect uncertainty in its extent and distribution within the site. The margin is set at 500m and is a consistent approach based on expert judgement in the absence of any evidence to support a margin of specific size.

1.2 Site descriptions

1.2.1 North Norfolk Sandbanks and Saturn Reef (NNSSR) SAC

Located exclusively in offshore waters (beyond 12 nm), NNSSR extends from approximately 22 nm to 60 nm from the north east coast of Norfolk (Figure 1). The North Norfolk Sandbanks are the most extensive example of the offshore linear ridge sandbank type in UK waters. At this site, the Annex I Sandbank feature is considered to cover the full extent of the designated site area, encompassing the whole linear sandbank system. The sandbank structures are maintained through offshore sediment transport processes, with each

[1] http://eunis.eea.europa.eu/habitats-code-browser.jsp
[2] https://www.gov.uk/guidance/conservation-advice-for-marine-protected-areas-how-to-use-site-advice-packages

sandbank acting as a 'steppingstone', and the development of new sandbanks between existing banks. They are subject to a range of current strengths, which are strongest on the sandbanks closest to shore and are weakest at the offshore sandbanks. The outer sandbanks (i.e. those furthest offshore) are the best example of "open sea, tidal sandbanks in a moderate current strength" in UK waters (JNCC 2010).

The sandbanks have a north west to south east orientation and are thought to be progressively, although very slowly, elongating in a north easterly direction. Sandwaves are present, being best developed on the inner banks. The outer banks have small or no associated sandwaves. The crests of the banks are in water shallower than 20m, and the flanks of the banks extend into waters up to 40m deep. Sand is the dominant sediment type across the site. Patches of coarse and mixed sediment are also found, which may also be associated with *S. spinulosa* reef in places.

The biological communities associated with Annex I Sandbanks (as defined by the Habitats Directive) have been recorded across the site, including adjacent areas where the seabed is much deeper than 20m (Parry *et al.* 2015). This further validates the notion of the entire SAC being designated as a representative functioning example of the Annex I Sandbanks feature, not just the immediate vicinity of sandbank itself. The series of sandbanks within the site are similar in terms of the biological communities present. However, fewer species have been recorded on the inner and eastern-most ends of the outer banks (Parry *et al*. 2015). Increasing numbers of species have been recorded on the outer-most (offshore) sandbanks, particularly on the Indefatigable Bank and the western-most end of the Swarte Bank.
When first discovered in 2002 using a remotely operated vehicle (BMT Cordah Ltd. 2003), the Saturn Reef covered an area approximately 750m by 500m just to the south of Swarte Bank, with *S. spinulosa* tube density varying over this area. In follow up surveys in 2006 (Limpenny *et al.* 2010) and in 2013 (Vanstaen & Whomersley 2015) no substantial reef structures were found in the Saturn Reef area. However, a 2013 survey identified reef to the west of Saturn Reef and observed areas of low reef structure in the north and south of the site, with more extensive reef delineated in the centre of the site (Jenkins *et al*. 2015). The previous extent of Saturn Reef (in 2002), in comparison to the more recently collected data, highlights the ephemeral nature of this feature. It also indicates that favourable conditions for *S. spinulosa* formation have persisted within the site.

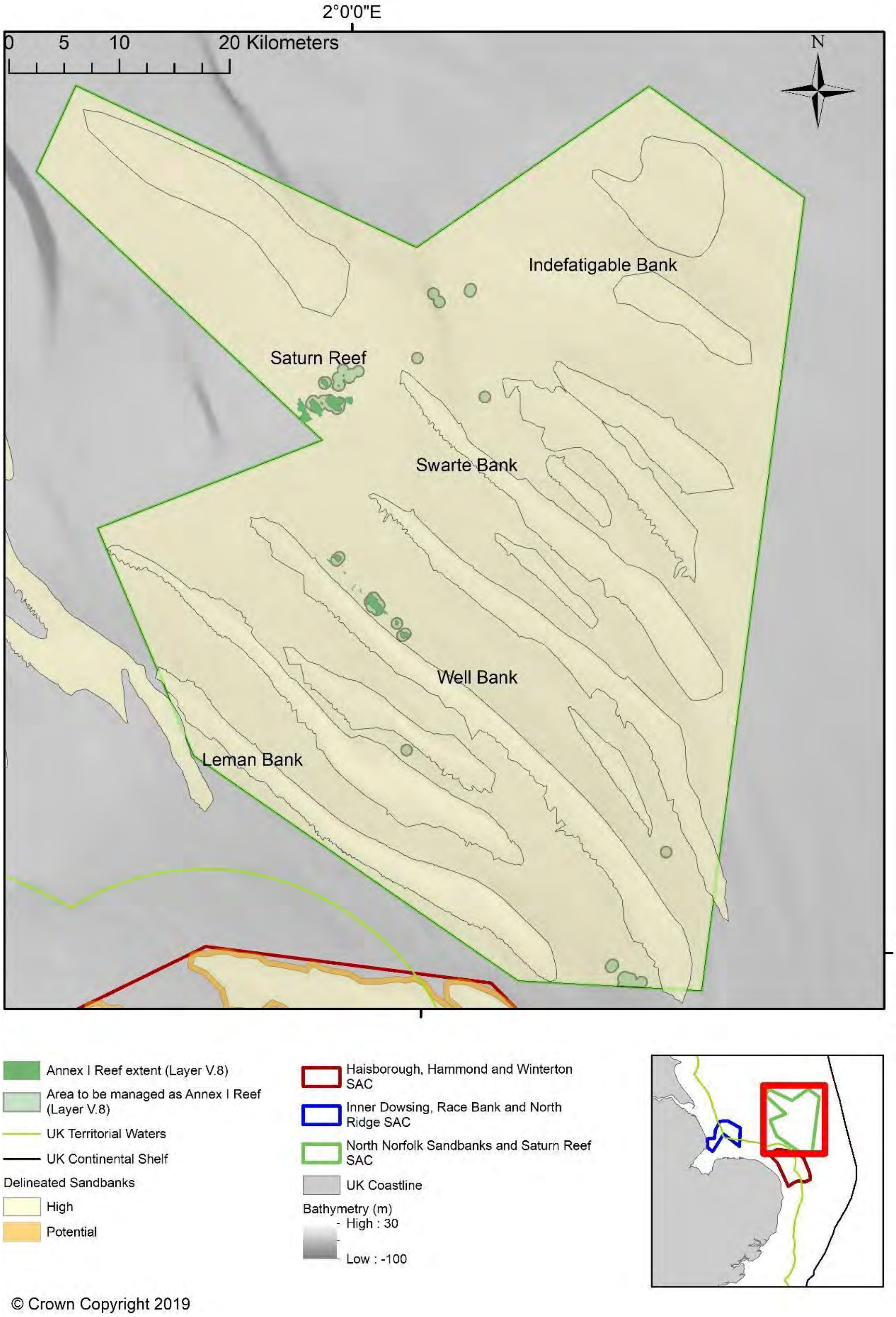

Figure 1. Annex I Sandbank and Biogenic Reef extent within the North Norfolk Sandbanks and Saturn Reef (NNSSR) SAC at the time of survey in 2016. Annex I Reef layers are from JNCC's Interactive Mapper.

1.2.2 Haisborough, Hammond & Winterton (HHW) SAC

The HHW SAC lies off the north east coast of Norfolk (Figure 2) and contains a series of sandbanks which range in depth from 52m (below chart datum) to almost breaching the sea surface. The central sandbank ridge in the site is composed of headland associated sandbanks with alternating ridges (Dyer & Huntley 1999). The sandbank system consists of Haisborough Sand, Haisborough Tail, Hammond Knoll, Winterton Ridge and Hearty Knoll sandbanks. The sandbanks known as Hewett Ridge and Smiths Knoll are located along the outer site boundary, and Newarp Banks and North and Middle Cross Sands sandbanks lie on the south west corner of the site.

The sandy sediments within this site are very mobile due to the strong tidal currents which characterise the area. Large-scale sandbank migration appears to be slow, but within the sandbank system sediment movement around, and across, the sandbanks occurs. This is evidenced by megaripple and sandwave formations on the banks (Barrio-Froján *et al*. 2013).

Unlike NNSSR, the entire area of the site is not considered to comprise Annex I Sandbank. Margins (~500m width) around the immediate periphery of sandbanks are included within the Annex I Sandbanks designated feature to account for uncertainty in feature extent on sandbanks that are known to be mobile. The margins can be viewed in the Annex I Sandbank layer provided on the JNCC MPA mapper[3].

Due to the dynamic nature of the environment, infaunal communities of the sandbank crests are low in biodiversity, characterised by polychaetes and amphipods which can rapidly re-bury into the sediment. Along the flanks of the sandbanks, and towards the troughs between the banks, the sediments tend to be slightly more stable with gravels exposed in areas. In these regions, infaunal and epifaunal communities are much more diverse. There are several areas of reduced sediment movement which support an abundance of attached bryozoans, hydrozoans and sea anemones. Other tube-building worms such as keel worms (*Pomatoceros* sp.) and sand mason worms (*Lanice conchilega*) are also found in these areas, along with bivalves and crustaceans.

S. spinulosa reefs are also a designated feature of the site and have been found at Haisborough Tail, Haisborough Gat and between Winterton Ridge and Hewett Ridge. They arise from the surrounding coarse sandy seabed to heights of between 5cm to 10cm. The reefs are consolidated structures of sand tubes showing seafloor coverage of between 30 to 100% of the sediment (JNCC & Natural England 2010).

Specific inshore areas of HHW are subject to a byelaw which restricts bottom towed fishing gear to protect *S. spinulosa* reef[4].

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[3] https://jncc.gov.uk/mpa-mapper/
[4] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/308567/byelaw-hhw.pdf

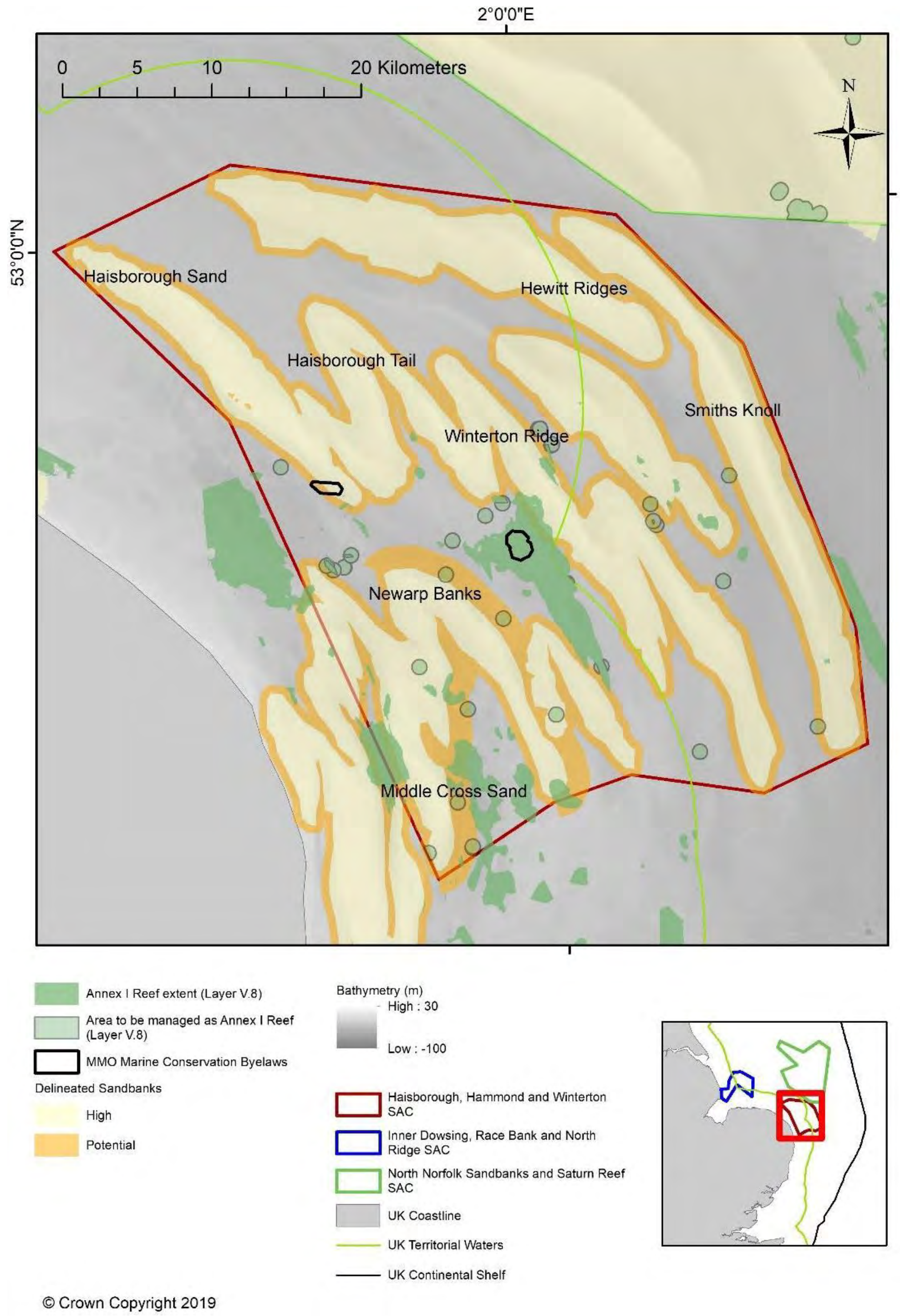

Figure 2. Annex I Sandbank and Biogenic Reef extent within the Haisborough, Hammond and Winterton (HHW) SAC. Annex I Reef layers are from JNCC's Interactive Mapper.

1.2.3 Inner Dowsing, Race Bank & North Ridge (IDRBNR) SAC

The IDRBNR SAC extends eastwards off the south Lincolnshire coast and northwards off the North Norfolk coast. The site lies within the Wash Approaches and intersects the 12 nm inshore-offshore boundary (Figure 3). Water depths are generally shallow, mostly less than 30m. The area encompasses a range of sandbank types and biogenic *S. spinulosa* reefs. The group of sandbanks within the Wash Approaches are made up of fine to medium sands derived from coastal erosion processes. The Inner Dowsing sandbank in the west of the site comprises coarse sand with some areas of gravel, and a distinctive elongate shape maintained by tidal currents. The Race Bank-North Ridge-Dudgeon Shoal sandbank system, within which the Race Bank and North Ridge sandbanks lie, is a sinusoidal sandbank that also has a complex pattern of smaller sandbanks associated with it. Together, this site and the HHW SAC (Section 1.2.2) provide the only protection to offshore, headland associated sandbank systems in the Southern North Sea.

As with the HHW site, 500m wide margins are included within the Annex I Sandbanks feature, to account for uncertainty in feature extent of sandbanks that are known to be mobile.

The crests and flanks of the IDRBNR sandbanks are characterised by low diversity communities dominated by polychaete worms and mobile amphipod crustaceans. The trough areas between these sandbank features are composed of mixed and gravelly sands, predominantly as veneers over glacial tills (Cooper *et al*. 2008). In these areas diverse mosaics of biotopes occur, which are dominated by the ascidian *Molgula* sp. along with nemertean worms and polychaetes.

Abundant *S. spinulosa* agglomerations have consistently been recorded within the site (ENTEC UK 2008; Barrio Froján *et al*. 2013). For areas of reef within the 6 nm limit, the core reef approach has been used (Roberts *et al*. 2016). This is the same approach used for the Wash area where the existence of high-quality data allows a more accurate delineation of the reef features. Areas of high *S. spinulosa* density support attached epifauna such as bryozoans, hydrozoans, sponges and anemones. Additional fauna also includes polychaetes, squat lobsters, crabs, the common lobster (*Homarus gammarus)* and notably the commercially important pink shrimp **(***Pandalus montagui).* The sandbanks provide an ideal spawning and nursery ground for commercially important fish such as sandeel (*Ammodytes* sp.) and Atlantic herring (*Clupea harengus*), whilst also providing important feeding grounds for lemon sole (*Microstomus kitt*) and European plaice (*Pleuronectes platessa*)[5].

Specific inshore areas of IDRBNR are also subject to a byelaw which restricts bottom towed fishing gear to protect *S. spinulosa* reef[6].

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[5] https://hub.jncc.gov.uk/assets/a29c186f-6241-47dd-8077-58bbb0819522#IDRBNR-SAC-selection-assessment-v5-0.pdf
[6] https://www.gov.uk/government/publications/inner-dowsing-race-bank-and-north-ridge-european-marine-site-specified-areas-bottom-towed-fishing-gear-byelaw

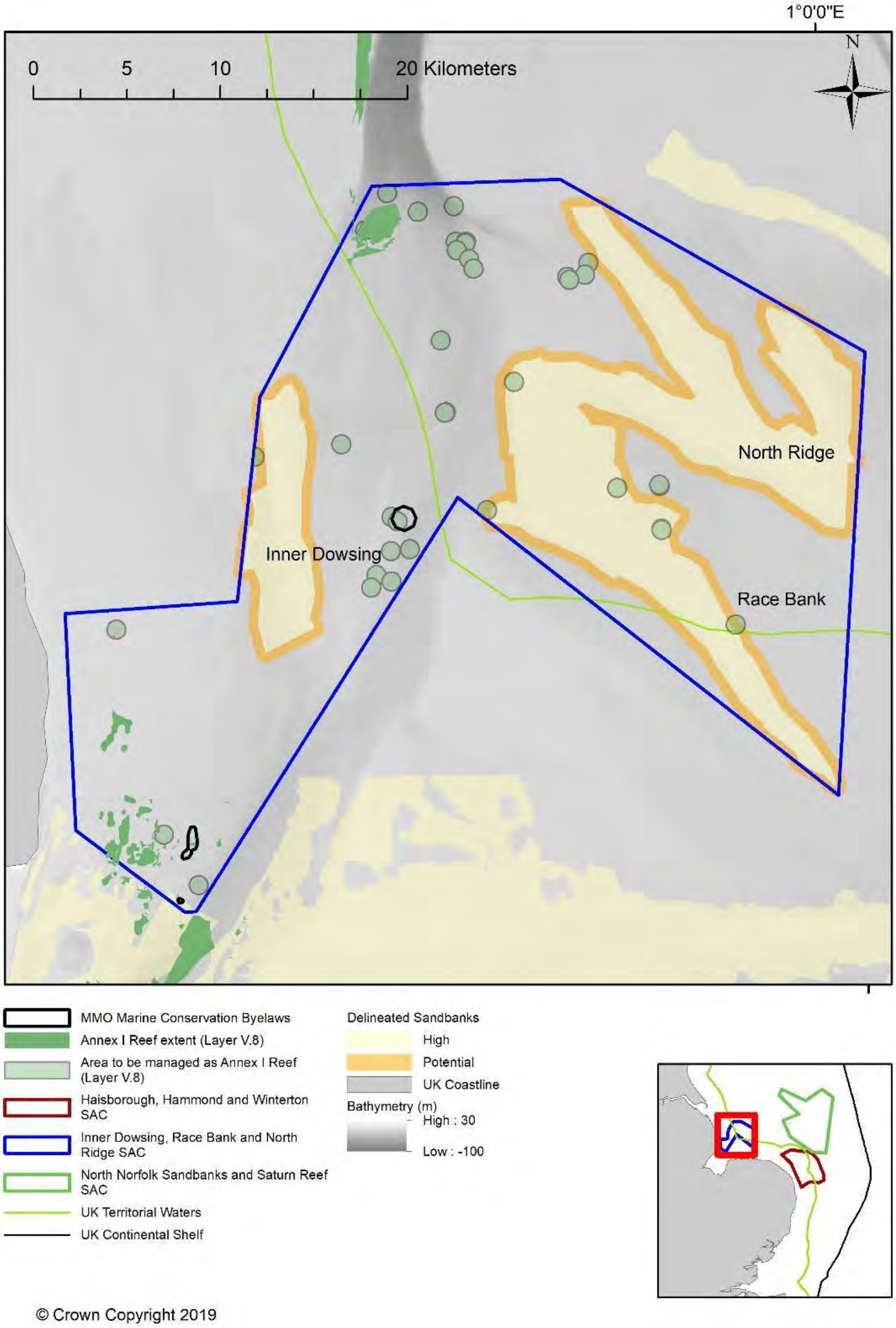


Figure 3. Annex I Sandbank and Biogenic Reef extent within the Inner Dowsing, Race Bank and North Ridge (IDRBNR) SAC at the time of survey in 2016. Annex I Reef layers are from JNCC's Interactive Mapper.

1.3 Human activities and management measures

A summary of human activities occurring within each of the sites is presented in Table 1 and Table 2, along with the measures proposed to manage these activities.

Table 1. Overview of human activities and management measures in North Norfolk Sandbanks & Saturn Reef SAC.

	North Norfolk Sandbanks & Saturn Reef (NNSSR)
Human activities and pressures	There is evidence of mobile demersal, static and pelagic fishing effort within the site. UK and non-UK registered vessels have been active in the area. A large amount of oil and gas activity takes place within the SAC, including many fields, pipelines, wells, surface and subsurface infrastructure. Extensive oil and gas decommissioning are also taking place within the SAC. Two aggregate licence areas overlap with the SAC, one of which has been licensed at the time of writing. Two dredge disposal sites are located on the Ower and Leman Banks, however, these are classed as 'disused sites' and have not received material since 1986. Three telecommunication cables overlap the SAC boundary. Commercial shipping activities take place within the site, however, the associated pressures are not considered likely to impact the protected features. Further information regarding activities occurring in the site can be found on the Activities and Management tab in the Site Information Centre. Details of current advice on sensitivities of features to pressures associated with activities are provided in the Advice on Operations workbook.
Current and proposed management measures	The entire site falls outside the 12 nm limit and is to be exclusively managed under the EU Common Fisheries Policy (CFP). Joint recommendations for fisheries management are currently under review. These include proposed areas with restrictions on all demersal towed gears and on demersal trawls and dredges within the site. Licensed activities continue to be managed through the existing licensed activities processes.

Table 2. Overview of human activities and management measures in Inner Dowsing, Race Bank & North Ridge SAC and Haisborough, Hammond & Winterton SAC.

	Inner Dowsing, Race Bank & North Ridge (IDRBNR)	**Haisborough, Hammond & Winterton (HHW)**
Human activities and pressures	The south west of the site overlaps with moderate levels of dredging and bottom trawling which occurs over Lynn Knock reef. There are low levels of bottom trawling and static fishing gear also occurring across the site and both UK and non-UK vessels have been recorded. There are two abandoned oil wells within the site and four pipelines cross the north of the MPA. There is substantial windfarm activity with operational windfarms (including Inner Dowsing, Lincs and Lynn) located within the Inner Dowsing and Lynn Knock area with associated energy cables connecting to the shore. The Race Bank offshore windfarm was commissioned in 2018. There is low to moderate levels of commercial and recreational shipping activity taking place within the site, however the associated pressures are not considered likely to impact the protected features. Approximately 31 wrecks have been recorded within the site. Further information can be found on the Activities and Management tab in the Site Information Centre. The Advice on Operations matrix available on Natural England's Designated Sites System provides details of the sensitivities of both features to pressures associated with activities.	The south eastern corner of the site is heavily fished by trawlers. UK and non-UK registered vessels have been active in the area. There is a considerable number of oil and gas developments within the site and aggregate extraction takes place along the site boundary. There is a moderate level of commercial and recreational shipping activity taking place within the site, however the associated pressures are not considered likely to impact the protected features. Telecommunication cables pass through the site and there are over 100 wrecks which have been identified within the site boundary. Further information can be found on the Activities and Management tab in the Site Information Centre. The Advice on Operations matrix available on Natural England's Designated Sites System provides details of the sensitivities of both features to pressures associated with activities.
Current and proposed management measures	As both of these sites straddle the 6-12 nm limit, fisheries operating within the offshore portions are subject to regulation under the EU Common Fisheries Policy (CFP). The MMO has created a byelaw in each of the sites to protect biogenic reef (*Sabellaria spinulosa*) in the inshore portions by prohibiting the use of bottom towed fishing gear in specified areas within the 12 nm limit. Please see byelaws for IDRBNR and HHW for more information. Joint recommendations for fisheries management are currently under review. These include proposed areas with restrictions on all demersal towed gears in both sites. Fisheries management within 6 nm is the responsibility of Eastern IFCA and will be implemented in due course. Licensable activities such as oil and gas development are managed in accordance with the clauses set out under Section 127 of the Marine & Coastal Access Act (2009).	

1.4 Aims and objectives

1.4.1 High-level conservation objectives

High-level site-specific conservation objectives serve as benchmarks against which to monitor and assess the efficacy of management measures in maintaining a designated feature in, or restoring it to, 'Favourable Conservation Status'.

For NNSSR, the site conservation Objective[7] (set by JNCC) is for features to be in favourable condition thus ensuring site integrity in the long-term and contribution to Favourable Conservation Status of 'Annex I Sandbanks which are slightly covered by sea water all of the time' and Annex I 'Reefs'. This contribution would be achieved by maintaining or restoring, subject to natural change:

- the extent and distribution of the qualifying habitats in the site;
- the structure and function of the qualifying habitats in the site, and;
- the supporting processes on which the qualifying habitats rely.

For HHW and IDRBNR the site conservation objectives[8,9] (set by NE) are to ensure that, subject to natural change, the integrity of the site is maintained or restored as appropriate, and that the site contributes to achieving the Favourable Conservation Status of its qualifying features, by maintaining or restoring:

- the extent and distribution of qualifying natural habitats and habitats of the qualifying species;
- the structure and function (including typical species) of qualifying natural habitats;
- the structure and function of the habitats of the qualifying species;
- the supporting processes on which qualifying natural habitats and the habitats of qualifying species rely;
- the populations of qualifying species;
- the distribution of qualifying species within the site.

1.4.2 Feature attributes

The condition of Annex I features is assessed against high-level feature attribute themes; **extent and distribution**, **structure and function**, and **supporting processes**.

The extent of a habitat feature refers to the total area in the site occupied by the qualifying feature and must also include consideration of its distribution. A reduction in feature extent has the potential to alter the physical and biological functioning of sediment habitat types (Elliott *et al.* 1998). The distribution of a habitat feature influences the component communities present and can contribute to the condition and resilience of the feature (JNCC 2004).

Structure encompasses the physical components of a habitat type and the key and influential species present. Physical structure refers to topography, sediment composition and distribution. Physical structure can have a significant influence on the hydrodynamic

[7] https://hub.jncc.gov.uk/assets/d4c43bd4-a38d-439e-a93f-95d29636cb17#NNSSR-2-Conservation-Objectives-v1.0.pdf
[8] https://designatedsites.naturalengland.org.uk/Marine/MarineSiteDetail.aspx?SiteCode=UK0030369&SiteName=hais&countyCode=&responsiblePerson=&SeaArea=&IFCAArea=#hlco
[9] https://designatedsites.naturalengland.org.uk/Marine/MarineSiteDetail.aspx?SiteCode=UK0030370&SiteName=inner%20dows&countyCode=&responsiblePerson=&SeaArea=&IFCAArea

regime operating at varying spatial scales in the marine environment, as well as influencing the presence and distribution of associated biological communities (Elliott *et al*. 1998). The function of habitat features includes processes such as: sediment reworking (e.g. through bioturbation) and habitat modification, primary and secondary production and recruitment dynamics. Habitat features rely on a range of supporting processes (e.g. hydrodynamic regime, water quality and sediment quality) which act to support their functioning as well as their resilience (e.g. the ability to recover following impact).

Further information on the feature attributes can be found in Supplementary Advice on Conservation Objectives (SACOs) for NNSSR[10] HHW[11] and IDRBNR[12].

1.4.3 Report aims and objectives

The primary aim of this monitoring report is to explore and describe the attributes of the Annex I feature within NNSSR, HHW and IDRBNR to assist future assessments of feature condition. The results presented will additionally be used to propose recommendations for future monitoring whereby each feature will subsequently be evaluated to determine whether its condition has been maintained, restored or declined. The secondary aim of the report is to present evidence relating to MSFD Descriptors of GES.

The specific objectives of this monitoring report are provided in Table 3, with high-level feature attributes in bold. Table 3 also lists the key questions which will be addressed within the report to improve understanding of the features and facilitate attainment of the report objectives.

Table 3. Report objectives and key questions posed.

Objective	Questions
1. Describe the extent and distribution of the Annex I feature 'Sandbanks which are slightly covered by seawater all the time' within the three sites.	Have the sandbank topographical zones (crest, flank, trough) changed over time in comparison to previous acoustic datasets e.g. 2011 (survey CEND 05/11) and 2013 (survey CEND 22/13)?
2. Describe the **structure and function** of the Annex I feature 'Sandbanks which are slightly covered by seawater all the time' within the three sites.	How are sediment types (EUNIS level 3 and entropy approaches) distributed across the three SACs, and across the topographical zones of individual sandbanks?
	How do infaunal and epifaunal communities vary across the three SACs, and, at a local sandbank scale, are the communities influenced by environmental factors and orientation (e.g. seaward or shoreward sides of banks)?
	How similar are the biological communities inside and outside of the delineated Annex I Sandbank features?

[10]https://hub.jncc.gov.uk/assets/d4c43bd4-a38d-439e-a93f-95d29636cb17#NNSSR-3-SACO-v1.0.pdf
[11]https://designatedsites.naturalengland.org.uk/Marine/SupAdvice.aspx?SiteCode=UK0030369&SiteName=hais&SiteNameDisplay=Haisborough%2c+Hammond+and+Winterton+SAC&countyCode=&responsiblePerson=&SeaArea=&IFCAArea=
[12]https://designatedsites.naturalengland.org.uk/Marine/SupAdvice.aspx?SiteCode=UK0030370&SiteName=inner+dows&SiteNameDisplay=Inner+Dowsing%2c+Race+Bank+and+North+Ridge+SAC&countyCode=&responsiblePerson=&SeaArea=&IFCAArea=

Objective	Questions
	This question pertains only to HHW and IDRBNR as the boundary of the feature corresponds to the site boundary at NNSSR.
	Which biotopes exist, and how do they vary across the sites, features and at the scale of individual sandbanks?
3. Describe the **extent and distribution** of the Annex I feature ‘Reefs’ within the three sites.	What is the current distribution of Annex I Reef across the sites, as delineated using side scan sonar and video data?
	Has Annex I Reef persisted in areas where it had previously been identified from survey data?
	Is Annex I Reef present in areas of ‘potential reef’ modelled from ‘The East Coast Regional Environmental Characterisation’ (Limpenny *et al.* 2011; Pearce *et al*. 2011) acoustic data?
	Has Annex I Reef persisted within the MMO byelaw closure areas?
4. Describe the **structure** of the Annex I feature ‘Reefs’ within the three sites.	How does the quality of Annex I Reef vary across and within the three sites?
	Does epifaunal community composition and abundance of conspicuous fauna (e.g. *Asterias rubens*) differ between Annex I Reef and non-reef areas?
5. Present any evidence of non-indigenous species (MSFD Descriptor 2) and marine litter (MSFD Descriptor 10) within the three sites.	Are non-indigenous species present within the site, and if so, how are they distributed in terms of abundance?
	Which types of marine litter are present (if any)?
6. Recommend future monitoring approaches for the three sites, and other sites containing comparable Annex I features.	How can the monitoring data presented in this report be used to inform future monitoring in terms of survey design and operations, and analysis and interpretation of resultant data? For example; which sampling techniques should be used, which types of data should be acquired, how should sampling locations be distributed, and which parameters should be focused on to indicate a change in condition?

1.4.4 What is not covered by this report

The report **does not** aim to assess the condition of the designated features. SNCBs use evidence from MPA monitoring reports in conjunction with other available evidence (e.g. activities, pressures, sensitivities, historical data, survey data collected from other organisations or collected to address different drivers) to make assessments on the condition of designated features within an MPA.

2. Methods

2.1 Survey design

The sampling design selected for the three SACs ('sites' hereafter) was 'Sentinel monitoring' of long-term trends (Type 1 monitoring). This type of monitoring provides the basis upon which to distinguish directional trends from short-scale variability in space and time (Kröger & Johnston 2016).

2.1.1 Annex I Sandbanks

In order to characterise the morphology and associated benthic communities of the sandbanks, two survey themes were developed:

- intensive sampling at a subset of sandbank CSAs hereafter);
- lower intensity sampling along a number of Wider Characterising Transects (WCTs hereafter) distributed across the sites. These were included to allow an assessment of whether communities of other sandbanks were similar to those observed for the CSAs and, in turn, whether the observed spatial patterns may be extrapolated to other sandbanks across the three sites.

This approach provided a relatively detailed assessment of the CSAs whilst allowing a broad characterisation of the features across the sites.

Two CSAs were adopted for each of the three sites to provide empirical data from which to understand the structural and functional features of faunal (infauna and epifauna) communities inhabiting different topographical zones of both sides of each sandbank. The six CSAs were selected to be representative of the range of sandbank types at the three sites. A number of criteria were considered when selecting the CSAs, including:

- general geomorphology and bathymetry of sandbanks (using crest depth, trough depth either side of sandbank and bank width);
- energy regime of the sandbank (using current speed as a proxy for energy/exposure);
- whether data (acoustic, abiotic and biological) had previously been collected at the sandbank;
- whether proposed fisheries management areas were located at the sandbank;
- whether commercial fishing pressure had been recorded at the sandbank;
- relative proximity to shore, and;
- logistical considerations (ease of access for sampling with beam trawl and minimum clearance for survey vessels).

As part of the CSA selection process, a principal component analysis with k-means clustering of environmental parameters (including bathymetry and associated derivatives, modelled currents data, distance from shore and vessel monitoring system (VMS) fishing data) was conducted to partition the area of interest into potentially ecologically distinct zones. This analysis was used to ensure that data were collected at areas representative of the range of environmental conditions present across the three sites.

The outcomes of this CSA selection procedure are presented in Table 4, and the locations of the CSAs are mapped in Figure 4.

Table 4. Sandbanks selected as CSAs within North Norfolk Sandbanks and Saturn Reef (NNSSR), Haisborough, Hammond and Winterton (HHW) and Inner Dowsing, Race Bank and North Ridge (IDRBNR), with selection rationale.

SAC	CSA Sandbank name	Selection rationale
NNSSR	Indefatigable Bank (IDFB)	Offshore MPA, deep bank, low energy, no proposed fisheries management area, previous sampling, north east edge of entire sandbank system
	Leman Bank (LMBK)	Offshore MPA, deep bank, proposed fisheries management area, low energy, previous sampling undertaken
HHW	South West Haisborough Tail (SWHT)	Inshore-offshore MPA, fisheries management area, higher energy, area suitable for deployment of scientific trawling gear
	Smith's Knoll (SMKN)	Inshore-offshore MPA, previous sampling undertaken, assumed fishing pressure, relatively steep bank
IDRBNR	North Ridge (NRRD)	Inshore-offshore MPA, shallow bank, relatively wide bank, low energy, fisheries management area
	Inner Dowsing (INND)	Inshore-offshore MPA, shallow bank, low energy, relatively steep bank, likely to be no fisheries management area, previous sampling undertaken

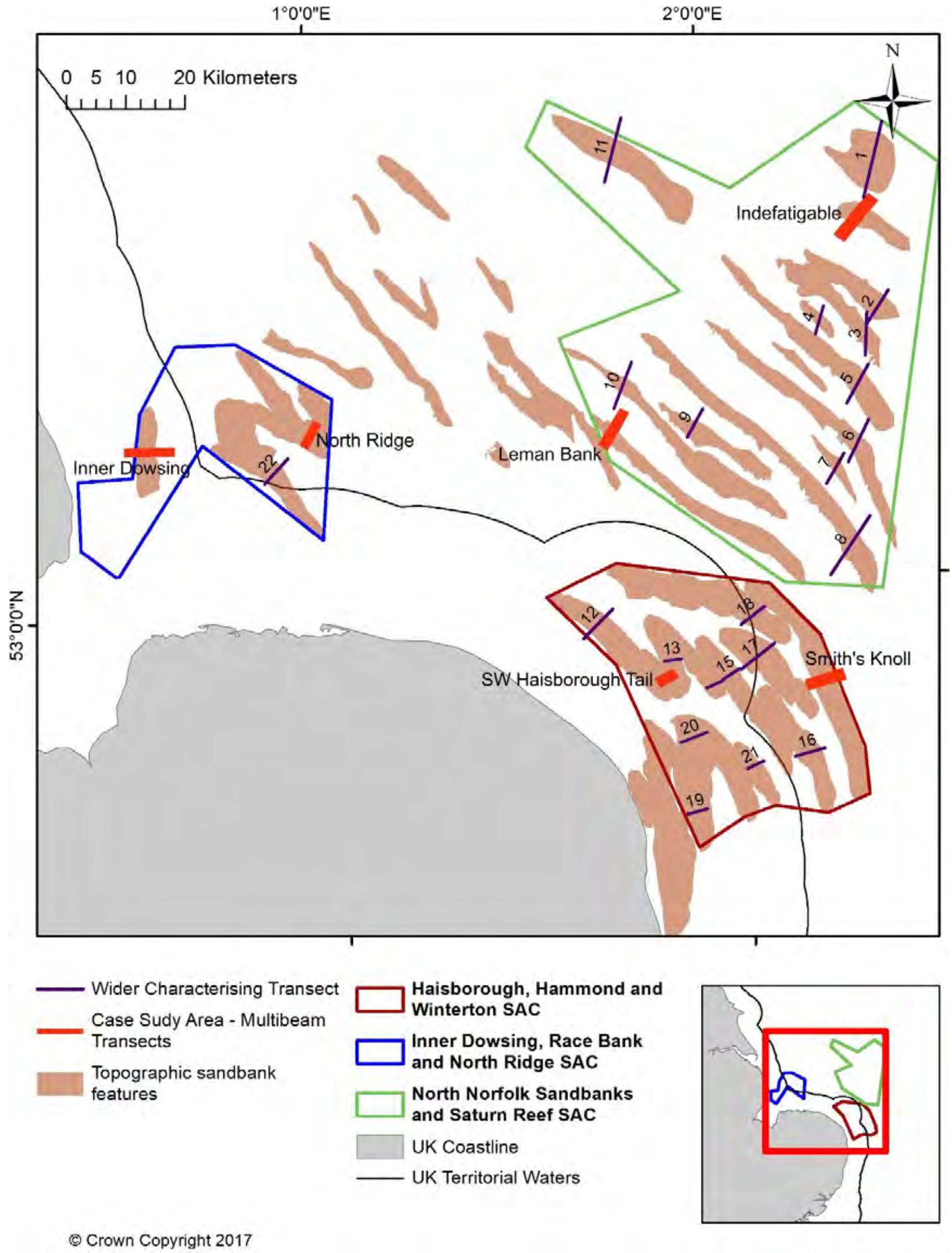


Figure 4. Locations of CSAs and WCTs within the three SACs.

Sampling effort across each CSA sandbank was stratified between three sandbank topographical zones; crest, mid-flank and trough (Figure 5). For two of the CSAs (Inner Dowsing within IDRBNR and Smiths Knoll within HHW), sampling stations were also positioned beyond the sandbank feature (and 500m margin) to characterise the areas in between the sandbanks. The sandbank topographical zones were identified using acoustic data acquired along corridors intersecting each sandbank. The topographical zones are described as follows:

- **Crest:** The shallowest point/area of the sandbank topographic feature.
- **Flank:** The flanks occur along the sides of the sandbanks, i.e. along the slope down from the crest to the trough. Approximately halfway between these points is the ‘mid-flank’. Data were acquired from shoreward facing and seaward facing flanks.
- **Trough:** Where the seabed slope extending from a flank has a slope angle of <5º. This is generally considered to be the base of the sandbank. Coarse sediments, identified using acoustic backscatter techniques (Jenkins *et al*. 2015), collect in this area and the area outward from the sandbank. For the purposes of the 2016 survey, the trough is considered to extend to at least 100m outwards from the sandbank edge. Data were acquired from shoreward facing and seaward facing troughs.
- **‘Beyond sandbank’:** This area extends outwards from the trough, away from the sandbank (and 500m margin). In areas where multiple sandbanks occur parallel to one another, the ‘beyond sandbank areas’ are represented by the region between the sandbanks. Otherwise, the ‘beyond sandbank’ regions may continue indefinitely. For the purposes of the 2016 survey, two rows of five ‘beyond sandbank’ sampling stations were positioned in 500m increments outward from either side of the sandbank trough edge. Data were acquired from shoreward facing and seaward facing ‘beyond sandbank’ areas.

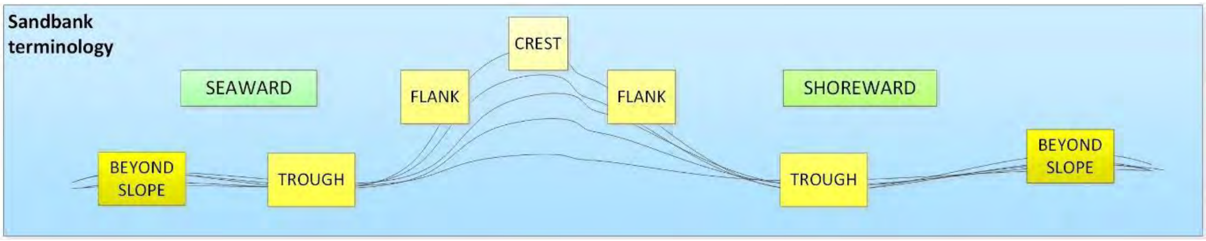


Figure 5. Sandbank terminology used in sampling designs. Slopes may be either north or east facing (seaward) or south or west facing shoreward facing).

In lieu of appropriate indicator metrics upon which to perform meaningful power analyses, the number of required samples was based on expert judgement within JNCC, NE and Cefas taking logistical, financial and scientific/statistical considerations into account. The resulting design was:

- ten grab stations were positioned on each of the crests, flanks and troughs (each side) on and between the acoustic lines for collection of sediment and infauna samples.
- ten grab stations were positioned in the area beyond the delineated sandbanks at one CSA within HHW and one in IDRBNR on and between the acoustic lines (‘beyond sandbank’ herein) for collection of sediment and infauna samples.
- three ground truthing stations were also targeted for sampling with a 2-metre beam trawl to collect epifauna and small fish from each of the topographical zones.

Where possible, MBES lines were positioned to coincide with historic acoustic corridors, to enable any change in topography (e.g. the locations of the crest, flank and trough) to be measured.

In addition to the six CSAs, 22 single MBES lines were positioned over a range of sandbanks (WCTs) across the three sites (Figure 4 and Table 5). The MBES corridors were used to guide the positioning of single grab stations on each of the topographical zones (crest, flank and trough) for collection of sediment and fauna. Only one WCT was placed within IDRBNR due to there being fewer sandbank features (two of which were already represented by the CSAs).

Table 5. List of WCTs within North Norfolk Sandbanks & Saturn Reef (NNSSR), Haisborough, Hammond & Winterton (HHW) and Inner Dowsing, Race Bank & North Ridge (IDRBNR) SACs.

SAC	Transect Number	WCT Sandbank
NNSSR	1	North of Indefatigable
	2	North of Viking Field Bank
	3	South of Viking Field Bank
	4	North of Swarte Bank
	5	Swarte Bank
	6	Broken Bank
	7	North of Leman Field Bank
	8	Well Bank
	9	Vulcan Field Bank
	10	Ower Bank
	11	North of Saturn Reef
HHW	12	Haisborough Sand
	13	Haisborough Tail
	14	Hammond Knoll
	15	Winterton Ridge
	16	Hearty Knoll
	17	Middle Ground
	18	Hewitt Ridges
	19	Middle Cross Sand
	20	Newarp Banks
	21	East of Middle Cross Sand
IDRBNR	22	Race Bank

2.1.2 Annex I Sabellaria spinulosa reef

Potential *S. spinulosa* reef areas were selected in each of the three sites (Table 6 and Figure 6) using a variety of selection criteria, including:

- 'Core reef' areas: areas where extensive monitoring survey work has previously been undertaken, resulting in high confidence in the occurrence of *S. spinulosa* reef (Roberts *et al*. 2016);
- whether areas of potential *S. spinulosa* reef overlap with proposed or existing fisheries management areas;

- whether data (acoustic, abiotic and biological) had previously been collected at the *S. spinulosa* reef areas; and
- logistical considerations (ease of access for sampling with a drop-down camera and navigable depths for survey vessels).

A combination of sidescan sonar (SSS) and seabed imagery techniques were used to inform the presence and condition of *S. spinulosa* reef within each of the areas. The SSS data were used to better inform the placement of video transects on the *S. spinulosa* reefs and provide the potential for extrapolating the ground truthed data over larger areas of seabed. Acoustic coverage of 50%, along with 5-10 video transects of approximately 100m in length, was planned at each *S. spinulosa* survey site.

Table 6. Summary of potential *Sabellaria spinulosa* reef areas selected for survey.

SAC	Potential *S. spinulosa* reef area	Key attributes for selection
North Norfolk Sandbanks and Saturn Reef (NNSSR)	North of Well Bank (NWBK)	Proposed fisheries closure / presence of *S. spinulosa* data.
	Saturn Reef (STRN)	Proposed fisheries closure / presence of *S. spinulosa* data.
	North of Swarte Bank (NSWB)	Proposed fisheries closure / presence of *S. spinulosa* data.
Haisborough, Hammond and Winterton (HHW)	HHW Northern Closure (HWNC)	Area of extensive potential *S. spinulosa* reef determined from 'The East Coast Regional Environmental Characterisation' (Limpenny *et al.* 2011) acoustic data. Incorporates the MMO Marine Conservation Byelaw area 'Haisborough Tail Reef', which is closed to fishing.
	HHW Southern Closure (HWSC)	Area of potential *S. spinulosa* reef determined from 'The East Coast Regional Environmental Characterisation' (Limpenny *et al*. 2011) acoustic data. Incorporates the MMO Marine Conservation Byelaw area 'Gat Reef', which is closed to fishing.
	West of Middle Cross Sand (WMCS)	Area of potential *S. spinulosa* reef determined from The East Coast Regional Environmental Characterisation' (Limpenny *et al.* 2011) acoustic data.
Inner Dowsing, Race Bank and North Ridge (IDRBNR)	Docking Shoal (DKSH)	MMO fisheries closure / presence of *S. spinulosa* data.
	Lynn Knock (LYKN)	MMO fisheries closure / presence of *S. spinulosa* data.
	Silver Pit South (SVPS)	Proposed fisheries closure / presence of *S. spinulosa* data.
	East of Silver Pit (ESVP)	Proposed fisheries closure / presence of *S. spinulosa* data.

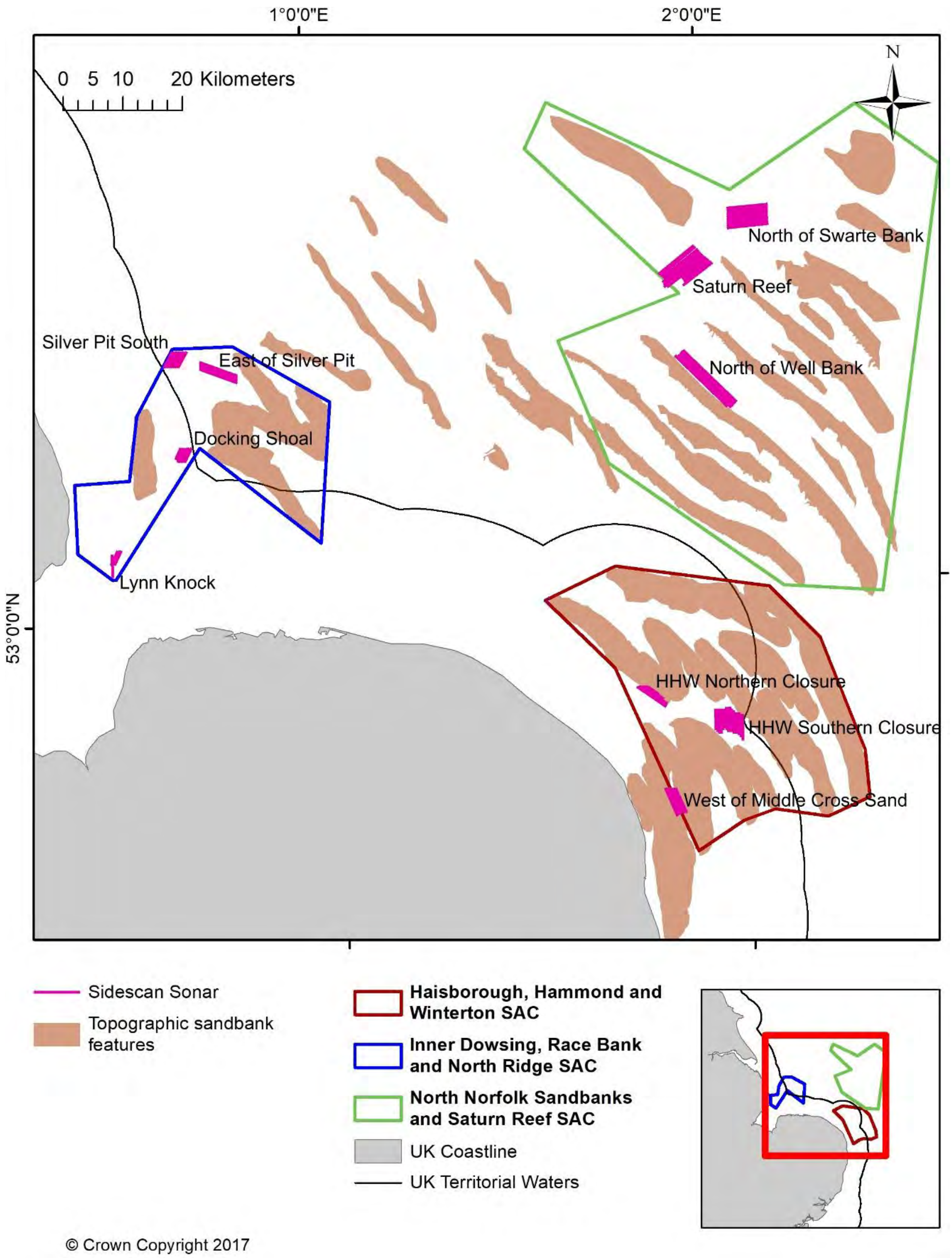


Figure 6. Location of Annex I *S. spinulosa* reef survey areas within the three SACs.

3. Data acquisition and processing

The 2016 dedicated monitoring surveys were conducted aboard three survey vessels: Environment Agency (EA) vessels the MV *Humber Guardian* and the MV *Solent Guardian*, and the RV *Cefas Endeavour*. The EA vessels were used to survey the two inshore-offshore sites (IDRBNR and HHW), while the RV *Cefas Endeavour* was largely restricted to survey the offshore site (NNSSR) due to its deeper draft (operations restricted to depths >15m). However, all SSS acquisition and ground truth sampling at some of the more accessible (deeper) sites within IDRBNR and HHW was also undertaken using the RV *Cefas Endeavour*. All data were collected between 31st May and 27th June 2016. Further details of survey planning, operations, data acquisition and onboard processing can be found in McIlwaine *et al*. (2017) and Fraser *et al*. (in press).

3.1 Acoustic data

3.1.1 Annex I Sandbanks

MBES data were acquired using a Kongsberg EM2040 single head transducer on the RV *Cefas Endeavour* and a Kongsberg EM3002 dual head transducer on the EA vessels. Singlebeam echosounder (SBES) data were also acquired using the *Humber Guardian*'s Kongsberg echosounder unit. MBES data were acquired at all CSAs and WCTs within NNSSR, and SBES data were acquired at all planned CSAs and WCTs within IDRBNR and HHW (with exception of Haisborough Sand where a MBES was used) to aid positioning of the grab samples. All data were recorded using Kongsberg Seabed Information System (SIS) software (v4.1.3). Bathymetric data were processed by Cefas to 1m resolution and exported as a floating point GeoTIFF for analysis.

3.1.2 Annex I Reef

All SSS data collected for the *S. spinulosa* reef survey were acquired by the RV *Cefas Endeavour* using the EdgeTech 4200 Multi Pulse (300/600kHz) tow-fish and acquisition software EdgeTech Discover v 35.01.104. High and low frequency data were processed and exported at 0.3m resolution. Simultaneous MBES data were also acquired at each SSS survey area.

3.2 Seabed imagery

Video and still images were collected using a Seabed Technology and Rentals (STR) SeaSpyder 'Telemetry' drop camera system, following Mapping European Seabed Habitats (MESH) recommended operating guidelines (Coggan *et al*. 2007). Seabed imagery was acquired for three purposes during the 2016 surveys:

- to mitigate for any potential impact to *S. spinulosa* reef during beam trawling of the flanks and troughs of the sandbanks,
- to determine the presence and condition of *S. spinulosa* reef in 'high' and 'low' confidence' in areas surveyed using SSS, and
- to identify the presence of any anthropogenic material (see Annex 5).

A number of camera transects were conducted within each specified *S. spinulosa* reef survey area, as detailed in Table 7.

Table 7. Number of camera transects undertaken at each of the areas targeted for *S. spinulosa* reef assessment.

SAC	Area name	No. of transects
North Norfolk Sandbanks and Saturn Reef (NNSSR)	North of Swarte Bank (NSWB)	15
	North of Well Bank (NWBK)	14
	Saturn Reef (STRN)	15
Haisborough, Hammond and Winterton (HHW)	HHW Southern Closure (HWSC)	4
	HHW Northern Closure (HWNC)	6
	West of Middle Cross Sand (WMCS)	8
Inner Dowsing, Race Bank and North Ridge (IDRBNR)	Docking Shoal (DKSH)	6
	East of Silver Pit (ESVP)	14
	Silver Pit South (SVPS)	10
	Lynn Knock (LYNK)	2

Mitigation transects were also undertaken on the flanks, troughs and 'beyond sandbank' zones of Smiths Knoll and South West Haisborough Tail CSAs in HHW, on the flanks and troughs of North Ridge CSA in IDRBNR and in the troughs of Leman Bank and Indefatigable Bank CSAs in NNSSR.

Video and still images, to determine the presence and condition of *S. spinulosa* reef in 'high' and 'low' confidence areas, were processed in accordance with National Marine Biological Analytical Quality Control (NMBAQC) epibiota interpretation guidelines (Turner *et al*. 2016). The physical habitat and biological assemblages were recorded for each substrate type encountered on the video. Changes in habitat covering less than 5m were considered incidental patches and recorded as part of the overall habitat description for that segment. Each recorded habitat was assigned a EUNIS habitat classification code as per guidance provided by Parry *et al*. (2015). Identifiable taxa within each habitat were recorded according to their abundance (solitary taxa) or percentage cover (colonial taxa) and a semi-quantitative Superabundant-Abundant-Common-Frequent-Occasional-Rare scale (SACFOR) abundance score[13] was applied. The abundance of *S. spinulosa* in each image was recorded as percentage of live and dead tubes, where live tubes were considered as erect tubes with visible crisp apertures. Degraded tubes or reef rubble were considered to reflect dead *S. spinulosa*. The percentages of *S. spinulosa* (live and dead) were also converted to the SACFOR scale.

Where *S. spinulosa* reef was observed, percentage cover and an estimate of tube elevation were recorded for each 5m video segment. These criteria were used to assign a *S. spinulosa* reefiness category for each 5m segment, using the matrix in Table 8 (as used by Jenkins *et al*. 2018).

Still images were also assigned EUNIS classification codes, and epifaunal taxa and *S. spinulosa* reef characteristics were recorded as per the video data.

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

Table 8. *Sabellaria spinulosa* reef structure matrix (Jenkins *et al.* 2018) used to assign reefiness categories (as per Gubbay 2007) to each 5m video segment.

<table>
<tr><th colspan="3" rowspan="3">Reef Structure Matrix</th><th colspan="4">Elevation (cm)</th></tr>
<tr><td><2</td><td>2 to 5</td><td>5 to 10</td><td>>10</td></tr>
<tr><td>Not a reef</td><td>Low</td><td>Medium</td><td>High</td></tr>
<tr><td rowspan="4">% cover</td><td><10%</td><td>Not a reef</td><td>NOT A REEF</td><td>NOT A REEF</td><td>NOT A REEF</td><td>NOT A REEF</td></tr>
<tr><td>10-20%</td><td>Low</td><td>NOT A REEF</td><td>LOW</td><td>LOW</td><td>LOW</td></tr>
<tr><td>20-30%</td><td>Medium</td><td>NOT A REEF</td><td>LOW</td><td>MEDIUM</td><td>MEDIUM</td></tr>
<tr><td>>30%</td><td>High</td><td>NOT A REEF</td><td>LOW</td><td>MEDIUM</td><td>HIGH</td></tr>
</table>

3.3 Grab sampling

Seabed sediment samples for particle size assessment Particle Size Analysis (PSA) and benthic infauna analyses were collected using a 0.1m^2 Hamon grab (also known as a 'mini' Hamon grab) (Table 9). Repeat sampling was undertaken where small samples (<5L) were collected in line with Ware and Kenny (2011). However, in some cases smaller samples were accepted where there was difficulty obtaining a volume greater than 5L. This was particularly evident for the Indefatigable CSA, where samples were generally between 3 and 4.5L.

A 500ml sub-sample of sediment was taken from each grab sample and stored at minus 20°C. These sediment samples were later processed using the PSA methodology recommended by the NMBAQC scheme (Mason 2016). The remaining sediment from each grab was used for infaunal assessment by sieving over a 1mm mesh, then fixing in buffered 4% formaldehyde after the sample had been photographed. Infaunal samples were later processed to extract and identify all fauna present in each sample. All infauna were identified to the lowest taxonomic level possible, enumerated and weighed (blotted wet weight) to the nearest 0.0001g, following the NMBAQC recommendations (Worsfold *et al.* 2010).

Marine litter was also extracted from the faunal samples and categorised into:

- Wire coated with plastic
- Plastic >5mm
- Plastic <5mm

Table 9. The number of successful 0.1m^2 Hamon grab samples taken within each CSA sandbank and WCT. N.B.: No samples were collected from WCT013 (Haisborough Tail) in HHW, due to its proximity to the South West Haisborough Tail CSA.

SAC	CSA Sandbank / WCT	Crest	Shoreward Flank	Seaward Flank	Shoreward Trough	Seaward Trough	Shoreward 'Beyond Sandbank'	Seaward 'Beyond Sandbank'
North Norfolk Sandbanks and Saturn Reef (NNSSR)	Indefatigable Bank (IDFB)	10	10	10	10	10	-	-
	Leman Bank (LMBK)	10	10	10	10	10	-	-
	WCT x 11	11	11	11	11	11	-	-
Haisborough, Hammond and Winterton (HHW)	Smiths Knoll (SMKN)	10	10	10	10	10	10	10
	South West Haisborough Tail (SWHT)	10	10	10	10	10	-	-
	WCT x 9	9	9	9	9	9	-	-
Inner Dowsing, Race Bank and North Ridge (IDRBNR)	Inner Dowsing (INND)	10	10	7	10	10	10	10
	North Ridge (NRRD)	10	10	10	8	10	-	-
	WCT x 1	1	1	1	1	-	-	-

3.4 Epifaunal sampling

A scientific (Jennings) 2m beam trawl with chain mat and 4mm knotless mesh liner in the cod end was used by both Cefas and the EA to sample epifauna and small demersal fish. All tows were undertaken against the tide, over approximately 150m of seabed (5min at 1kn). The catch from each tow was photographed and rinsed over a 5mm mesh. Taxa were identified to the lowest possible taxonomic level and biomass (wet weight in grams) was recorded for each individual. A combined weight was recorded for colonial organisms. All fish species collected were also identified and measured. A reference collection was retained of species that proved difficult to identify in the field with confidence.

Two tows were planned at each epifaunal station on each of the six CSA sandbanks. However, despite mitigation camera transects being undertaken, one station in the seaward trough of Leman Bank CSA in the NNSSR site was not trawled due to the presence of *S. spinulosa* ‘reef’ in the first trawl sample collected at that topographical zone. Similarly, although six trawl samples were successfully collected from the North Ridge shoreward flank, no further trawling was undertaken after the first sample collected on the seaward flank also revealed the presence of *S. spinulosa* ‘reef’. Inclement weather and sea conditions also resulted in only one of the CSAs within each of HHW and IDRBNR being sampled for epifauna (Table 10).

Table 10. Number of successful 2m beam trawls at each topographical zone and CSA sandbank within North Norfolk Sandbanks and Saturn Reef (NNSSR), Haisborough, Hammond and Winterton (HHW), and Inner Dowsing, Race Bank and North Ridge (IDRBNR).

SAC	Bank	Crest	Seaward Flank	Shoreward Flank	Seaward Trough	Shoreward Trough
NNSSR	Indefatigable Bank (IDFB)	6	6	6	6	6
	Leman Bank (LMBK)	6	6	6	5	6
HHW	South West Haisborough Tail (SWHT)	5	6	5	4	4
IDRBNR	North Ridge (NRRD)	6	-	6	5	6

The epifaunal reference specimens collected from each survey were quality checked in the Cefas laboratory by a qualified taxonomist. Any taxonomic differences were highlighted and changed in the matrix where only one individual was encountered in the sample. Further decisions were made during the data rationalisation stage for those species where more than one individual was collected (see Section 3.5.8 and Annex 1).

Litter found in any of the beam trawls was categorised[14] measured and recorded.

[14] https://mcc.jrc.ec.europa.eu/documents/201702074014.pdf

3.5 Data preparation, rationalisation and analysis

3.5.1 Existing data for temporal comparison

A number of sandbanks within the three sites have been the subject of targeted survey efforts in recent years. The data acquired from these surveys were instrumental not only in planning the 2016 surveys, but for acting as a basis from which the 2016 data could be compared to assist in assessments of temporal changes.

Historic bathymetric and backscatter data for IDRBNR and HHW were sourced from a 2011 survey (CEND 05/11; Barrio Froján *et al*. 2013) onboard the RV *Cefas Endeavour* and the MV *Humber Guardian*. Lines of data collected by the RV *Cefas Endeavour* focused on the boundaries of the sandbanks within the SACs, limited by the operational capabilities of the vessel. Bathymetric data were processed by Cefas to 1m resolution and exported as a floating point GeoTIFF for analysis.

Bathymetric data for IDRBNR and HHW were collected as part of the UK's Civil Hydrography Programme (CHP) managed by the Maritime and Coastguard Agency (MCA). The data covering IDRBNR were collected between December 2013 and May 2014 while the data for HHW were collected between April 2014 and September 2014. The data are archived by the United Kingdom Hydrographic Office (UKHO) and were provided to Cefas as fully processed and cleaned bathymetry data at 1m resolution.

To characterise the known and potential *S. spinulosa* reefs of the nearshore and offshore sandbanks within NNSSR, data from a survey conducted in 2013 (Vanstaen & Whomersley 2015) were used. The survey collected MBES and SSS data from six blocks within the SAC. Characterisation of the sandbanks, which were within the operational capabilities of the vessel, was undertaken through the running of MBES transects perpendicular to the sandbanks (Vanstaen & Whomersley 2015). Bathymetric data were processed by Cefas to 2m resolution and exported as a floating point GeoTIFF for analysis.

3.5.2 Sandbank profile temporal comparison

Where MBES data from the 2016 survey intersected those from previous surveys, a virtual 'slice' was taken through the two datasets and the profiles of the slices compared in ArcGIS V10.1. Slices were created along the longest axis of the intersecting data and the profiles presented with the MBES layers. Lateral movement of the banks was assessed by comparing the location of the crest and flank features along lines of equal bathymetry between years. It should be noted that such a comparison can only provide an indication of movement for the particular section of sandbank and this may not be indicative of the movement of the entire sandbank feature.

3.5.3 Mapping suspected *Sabellaria spinulosa* reef

SSS data were collected from 10 areas within the three SACs for the assessment of suspected areas of *S. spinulosa* reef (see Figure 6). This included three areas within NNSSR, three areas within HHW, and four areas within IDRBNR. The three areas within NNSSR were also previously surveyed for the presence and extent of *S. spinulosa* reef as part of the characterisation survey carried out in 2013 (CEND2213; Jenkins *et al*. 2015).

Full SSS mosaics of each *S. spinulosa* survey area were processed and exported into ArcGIS V10.1. Areas of *S. spinulosa* reef and the supporting sediments produce a mottled acoustic backscatter return which is distinguishable from unconsolidated finer sediments and rocks. Such areas were manually delineated from SSS data using expert judgement, in addition to areas of *S. spinulosa* reef which had been positively identified by ground truth data.

3.5.4 Seabed imagery

For video segments where reef was observed, *S. spinulosa* reefiness scores were assigned to each 5m segment of a given camera transect and were mapped using ArcGIS V10.1 to demonstrate the variability of reef composition along each transect. This information was used to ground truth the acoustic transects, to aid classification and mapping of reef areas, and to determine reef quality within and between areas and SACs. Where available, imagery data from the 2013 survey of NNSSR were used to allow assessments of temporal changes in *S. spinulosa* reefs (Jenkins *et al*. 2015).

The biological data from all video segments (reef and non-reef areas) were analysed using the SACFOR scores. This allowed the inclusion of all taxa observed in a standardised form (i.e. including both solitary (counts) and colonial taxa (percentages)). SACFOR scores were then converted to a numerical scale, to enable multivariate analyses, where: Superabundant = 6; Abundant = 5; Common = 4; Frequent = 3; Occasional = 2; and Rare = 1 (as per Burrows *et al.* 2008 and Parry *et al.* 2015). PRIMER v7 was used to combine the taxon matrices derived for each site to enable between site comparisons to be undertaken. Factors imported with the matrices included site name, *S. spinulosa* reef area name (as per Table 6) and video quality category. Video data gathered solely for *S. spinulosa* reef mitigation purposes were removed from the dataset prior to analyses, as were data determined as having poor, very poor or zero visibility (according to Turner *et al*. 2016). Taxonomic data were truncated in accordance with the protocol presented in Annex 1. Faunal data were only recorded per EUNIS broadscale habitat (BSH) segment and not for each 5m segment. Analyses was therefore undertaken to determine if there were significant differences in faunal composition, and characteristic species, between reef and non-reef communities using similarity profile (SIMPROF) permutation tests and the similarity percentages (SIMPER) routine. Prior to multivariate analyses, 'Live' and 'dead' *S. spinulosa* reef variables were removed to avoid influencing the similarity of the cluster groups. These data were, however, included as an overlay in the non-metric multidimensional scaling (nMDS) ordination to aid in interpretation of the results.

3.5.5 Particle size analysis (PSA) and distribution (PSD)

Sediment samples were analysed using a combination of laser diffraction (<1mm fraction) and dry sieving techniques (>1mm). Gradistat software (Blott & Pye 2001) was used to produce all sediment statistics (e.g. mean, mode, skewness). Each sample was also assigned to one of four EUNIS sediment classes (level 3) as defined by Long (2006).
In addition, the full resolution PSD data were grouped using EntropyMax, a non-hierarchical clustering method that summarises large matrices of PSD datasets into a finite number of groups (Stewart *et al*. 2009), using the Calinski–Harabasz statistic (Orpin & Kostylev 2006).

3.5.6 Infaunal data

The infaunal dataset was checked to ensure consistent nomenclature using the World Register of Marine Species (WoRMS) taxon match tool. Discrepancies were resolved using expert judgement following the truncation steps presented in Annex 1. All samples were retained for analysis despite the volume of the majority of samples from the Indefatigable Bank CSA being less than 5L.

The infaunal species list was cross-referenced against a list of 49 non-indigenous target species which have been selected for assessment of GES in United Kingdom waters under

MSFD Descriptor 2 (Stebbing *et al.* 2014; Annex 4). The list includes two categories; species which are already known to be present within the assessment area (present) and those which are not yet thought to be present but have a perceived risk of introduction and impact (horizon). An additional list of taxa, which were identified as invasive in the 'Non-native marine species in British waters: a review and directory' (Eno *et al.* 1997) was also used to cross-reference against the recorded taxa (Annex 4).

3.5.7 Infaunal function: Secondary productivity

Secondary productivity estimates Production: Biomass (P:B) ratio (yr^{-1}) and total production P ($kJm^{-2}yr^{-1}$) were derived from the raw abundance and biomass data using a stepwise approach. First, taxa with a total wet mass of <0.001g across all stations (total mass = 1779.16g) were removed as their contribution was considered negligible. Measured (wet) biomass values were then converted to energy values using published conversion factors (Brey *et al*. 2010). For taxa with shells, the relevant conversions were used to ensure estimates related only to the metabolically active tissue of the taxa. Energy values were then converted to production values using a multi-parameter P:B model on a freely available spreadsheet (Brey 2001). This empirical relationship method unifies all previous habitat-specific approaches into a multiple regression model estimating annual production of macrobenthos. This model was found to be one of the most reliable and robust models available during critical appraisals of such methods (Cusson & Bourget 2005; Dolbeth *et al*. 2005). The model is represented below:

$$\log_{10} P/B = 7.947(-2.294 \log_{10} M - 2409.856 \times (1/(T+273)) + 0.168 \times (1/D) + 0.194SubT + 0.180InEpi + 0.277MoEpi + 0.174Taxon1 - 0.188Taxon2 + 0.33Taxon3 - 0.062Habitat1 + 582.851 \times (\log_{10} M \times (1/T(273)))$$

where P= production; B = mean biomass; M = mean individual body mass; T = mean annual bottom water temperature (°C) for each station; D = depth (m) for each station; SubT = subtidal (SubT=1) or intertidal (SubT=0); InFau = infauna (InFau=1) or epifauna (InFau=0); MoEpi = motile epifauna (MoEpi=1) or not (MoEpi=0); Taxon1, Annelida or Crustacea (Taxon1=1) or other taxon (Taxon1=0); Taxon2, if Echinodermata (Taxon2=1) or other taxon (Taxon2=0); Taxon3, if Insecta (Taxon3=1) or other taxon (Taxon3=0); Habitat1, lake (Habitat1=1) or other habitat (Habitat1=0).

For deriving estimates for each station, the mean biomass (kJm^{-2}), mean abundance (number per m^{-2}) and individual mass (kJ) of each taxon, along with station-specific depths and mean annual bottom water temperatures were entered into the empirical model. Additionally, each taxon was determined as sub/intertidal, in/epifauna, whether it was motile or sedentary and to which main taxonomic group it belonged. Using the entered data, the model calculated the estimated P:B ratio and total production values for each data row, together with 95% CI estimates. These error values indicate the errors associated with the estimates of P:B and P for each data row; such errors are generally very high and Brey (2001) emphasised a need for great caution when using such estimates based on single data rows (commonly populations). In the present study we have derived and based all subsequent analyses on estimates at the community level. As we have no indication of the prediction error associated with such community level estimates, we need to use caution in the absolute values presented. However, the large prediction errors associated with estimates for individual populations are greatly reduced when the estimates are pooled to the community level (Brey 2001).

The Brey model requires mean annual abundance and biomass data for each taxon, however, the input values used here were based only on the data acquired during the June 2016 surveys. As benthic abundance and biomass data collected in June would be expected to exceed the annual average, it is likely that secondary production estimates for the sites are overestimated. Total production in this study was estimated by summing the values of total production from the model for each taxon. Values represent the amount of energy produced per m^2 by the assemblage per year.

3.5.8 Epifaunal trawl data

The epifaunal trawl datasets collected during the Cefas and EA 2016 surveys were checked to ensure consistent nomenclature using the WoRMS taxon match tool. The datasets were then combined in Microsoft Excel for rationalisation. During this stage the two replicate trawls at each station were combined, resulting in a sampling area of approximately $600m^2$ for most stations[15]. Discrepancies between the datasets were resolved using expert judgement following the truncation steps presented in Annex 1.

While estimated secondary production for the infauna served as a proxy for the amount and variability of energy to the next trophic level, such as the epifauna and bottom-feeding fish, derivation of such estimates for the epifaunal component has less functional relevance. Thus, secondary production was not calculated for the epifaunal data.

3.5.9 Biotopes

Biotopes for infaunal sandbank communities were determined using SIMPER analysis. Characteristic fauna from SIMPER groups were used to match each infaunal sample to the most appropriate biotope using the JNCC online Marine Habitat Classification system v15.03 (JNCC 2015) and the EUNIS[16], with additional information on sediment type and water depth used to validate final assignments. All samples were assigned to a level 4 or 5 biotope code where possible, using the EUNIS naming convention. It should be noted that some samples from the Indefatigable CSA were <5L.

Biotopes for *S. spinulosa* reef areas were determined for each video segment (EUNIS BSH) using characteristic fauna from SIMPER analyses, along with substrate information provided by the video processing contractor.

3.6 Statistical analyses

3.6.1 Annex I Sandbanks: structure and function

Analyses to determine differences in infaunal and epifaunal communities between sandbank topographical zones and between sites were undertaken using PRIMER v7 (Clarke & Gorley 2015). The truncated infaunal datasets, which included both CSA and WCT data, were assigned a number of different groups or factors prior to analysis according to site, sandbank, CSA/WCT, topographical zone, orientation (seaward/shoreward), entropy group and EUNIS level 3 habitat. Structural metrics (number of taxa (S), total abundance of individuals (N), Margalef's species richness (d) and diversity (Hill's N1)) were calculated using the DIVERSE function in PRIMER. The average values for each metric, along with 95% confidence intervals, were calculated for each CSA.

[15] N.B. Four stations were only represented by one trawl and had a resulting sampling area of $300m^2$.
[16] https://eunis.eea.europa.eu/habitats.jsp

Multivariate analyses were undertaken using PRIMER to compare infaunal community composition within and between sandbanks. For IDRBNR and HHW where 'beyond sandbank' samples were collected, infaunal data from troughs and 'beyond sandbank' zones were also compared. Data for the WCTs were analysed in combination with the respective CSA data for each site to determine whether the CSA communities were representative of the wider communities within each site.

Following a square root transformation, a Bray-Curtis resemblance matrix was used for non-metric multidimensional scaling ordination (nMDS). Analysis of Similarity (ANOSIM) and SIMPER routines were conducted to explore differences and connectivity between topographical zones between sandbank communities.

Univariate testing for differences in infaunal secondary productivity between sandbank topographical zones was conducted using either t-tests or one-way Analysis of Variation (ANOVA) in Minitab v13. Where a one-way ANOVA test was used, a Tukey multiple comparison test was simultaneously conducted to test for pairwise differences at the 95% significance level. For all tests, data were checked for normality of variance using an Anderson-Darling test and the data transformed, if necessary. Secondary production estimates were analysed in further detail using PRIMER, to quantify the similarities between areas with respect to the types of taxa contributing to total production. The results, based on relative contribution to total production of each individual taxon as well as the major taxonomic phyla, were presented as Principal Components Analysis (PCA) plots for each CSA. These plots were used to assess the relative variability in taxonomic contribution to secondary productivity to provide an indication of the functional variability of a system. For example, greater variability in taxonomic contribution to production may be regarded as indicative of greater functional variability in a system.

To determine epifaunal community composition between topographical zones, abundance and biomass data were similarly analysed using PRIMER v7. A Bray-Curtis similarity measure was applied to square root transformed (abundance) and fourth root transformed (biomass) data prior to analysis. nMDS plots and SIMPER were used to investigate patterns in epibenthic community composition within CSAs as per the infaunal analyses. ANOSIM was not performed on these data due to the limited number of trawls and the semi-quantitative nature of the sampling technique.

3.6.2 Annex I *Sabellaria spinulosa* Reef: structure and function

The epifaunal data collected from within the *S. spinulosa* reef investigation areas were analysed in PRIMER to determine community composition within and between reefs. A Bray-Curtis similarity measure was applied to untransformed data prior to analysis. SIMPROF testing was used to divide the data into statistically significant ($p \leq 0.05$) groups. An nMDS ordination was produced using all data and displayed according to SIMPROF group, *S. spinulosa* reef area name and presence of 'live' *S. spinulosa* reef. SIMPER was used to determine community differences and whether certain characteristic or conspicuous species were strongly associated with the presence of reef.

3.7 Hydrodynamic conditions

To provide some background regarding the hydrodynamic conditions across the site, and to ascertain whether any differences within and/or between sites exist, mean and maximum tidal current velocities (ms^{-1}) at the seabed and mean tidal direction data were obtained from a tidal model built for the study area. The depth-averaged model of the North Norfolk coast was developed using an unstructured triangular mesh using the hydrodynamic software Telemac2D (v7p1). The mesh has a resolution of approximately 6km along the open boundary with a refined resolution to approximately 50m for the present study area. Bathymetry for the model was sourced from the Defra Digital Elevation Model (DEM) (Astrium Oceanwise 2011). The resolution of the dataset is 1 arc second (~30m). The hydrodynamics are forced along the open boundaries using 11 tidal constituents (M2, S2, N2, K2, K1, O1, P1, Q1, M4, MS4 and MN4) from the Oregon State University TOPEX/Poseidon Global Inverse Solution tidal regional model for the European Shelf 1/30°. After a spin-up period of five days, the model was run for 30 days to cover a full spring-neap cycle.

The model revealed that the three sites are exposed to peak flood flows from a north west or north-north west direction (Figure 7). This is most apparent for HHW. The three sites exhibit varying bottom current velocities, the strongest maximum currents (0.5 – 1.5 up to 2.0ms^{-1}) being observed at HHW, particularly in the most inshore areas of this site. The weakest mean currents, of less than 1.0ms^{-1} maximum velocity, are observed at the deeper and further offshore NNSSR site. This information will be used to aid interpretations of the results.

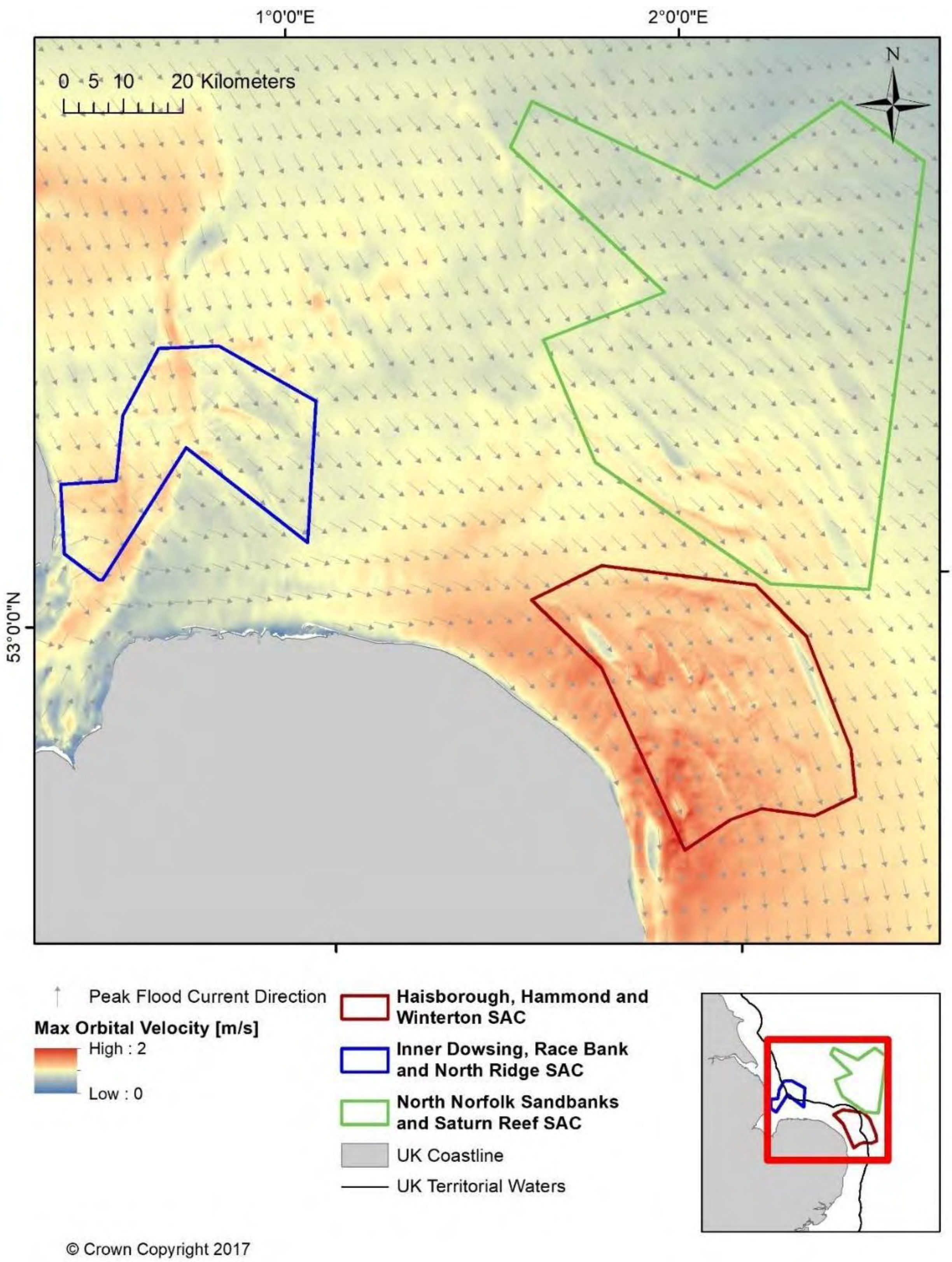


Figure 7. Peak flood tidal trajectories and maximum orbital velocity currents for the three SACs.

4. Results

4.1 Objective 1. Annex I Sandbanks: extent and distribution

This section meets the requirements of Objective 1 by addressing the following question:

Question 1: Have the sandbank topographical zones (crest, flank, trough) changed over time in comparison to previous acoustic datasets (e.g. CEND 22/13 & CEND 05/11)?

Acoustic data from the 2016 survey spatially overlapped with those previously acquired for two locations within the NNSSR and HHW sites and one location in IDRBNR. A comparison of the bathymetric profiles over time was conducted, and the outcomes are presented for each site in turn below.

4.1.1 North Norfolk Sandbanks and Saturn Reef SAC

Two profile comparisons were conducted using intersecting data collected within NNSSR in 2013 and 2016. Data from the Indefatigable Bank are shown in Figure 8, revealing a north east facing slope deepening from 20m depth in the south west, to a depth of 37m in the north east. Some minor differences are visible between the two datasets, however, no movement of the bank in the direction of the slice is apparent. The apparent differences seen in the number of sandwaves both on the flank and on the crest are likely an artefact of the differences in the resolution of the datasets and are unlikely to reflect a change in small-scale topography.

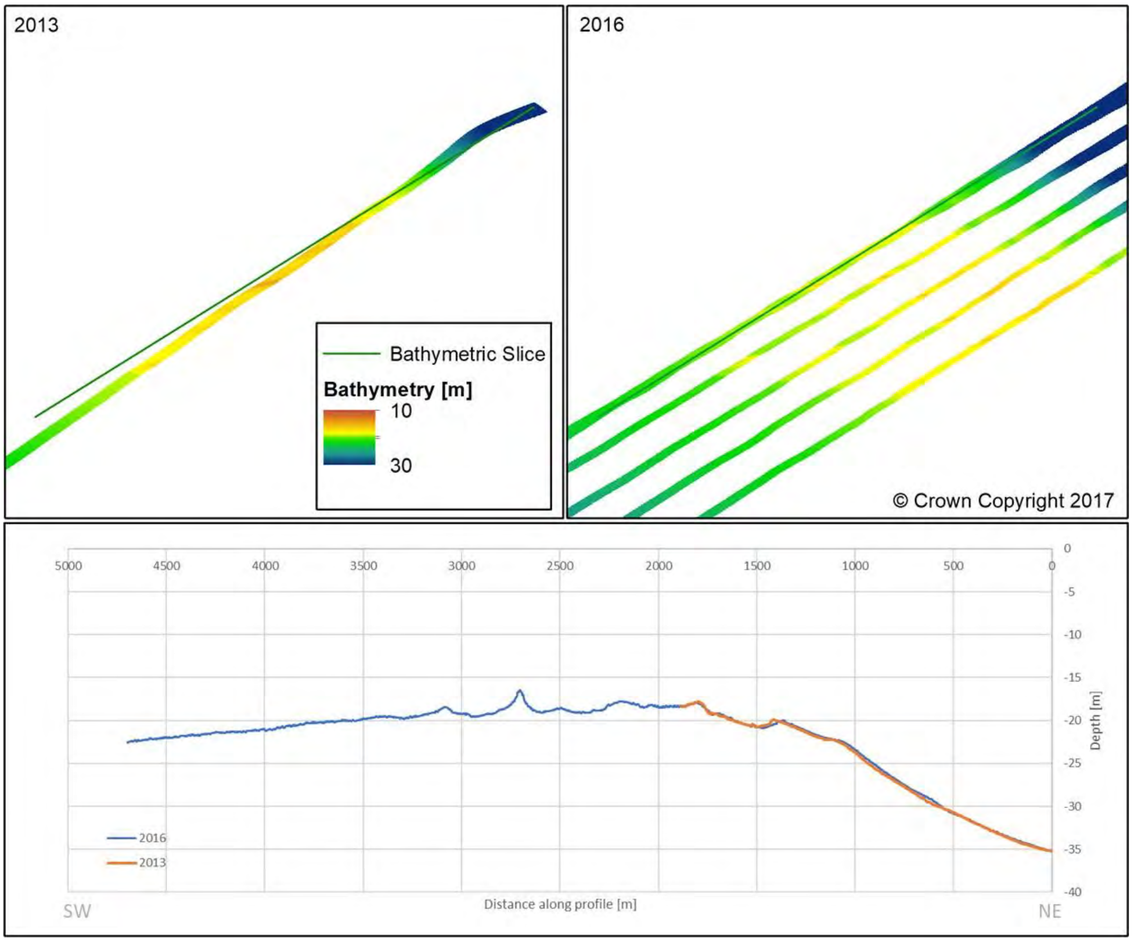


Figure 8. Bathymetric profiles from the Indefatigable Bank CSA sandbank within the North Norfolk Sandbanks and Saturn Reef (NNSSR) SAC showing the changes in profile between 2013 and 2016.

The second profile comparison at NNSSR corresponds with the Leman Bank in the south west of the site. Following the direction of the slice, 42° True, the bank gently slopes up, shallowing from a depth of 27m to approximately 18m at its crest (Figure 9). The bank then steeply drops to a depth of 25m before a shallower slope continues in a north west direction to a depth of 34m. The shallower and flatter regions of the profile show very little difference between 2013 and 2016. Some small-scale topographical variation representing sandwaves and ripples, typical of a moderate to high energy environment, can be observed. An obvious shift can be observed in the shape of the main sandbank feature between 2013 and 2016. The most notable difference occurs on the north west slope of the bank between 1900m and 2200m along the profile (Figure 9) wherein the slope has shifted approximately 30m north west.

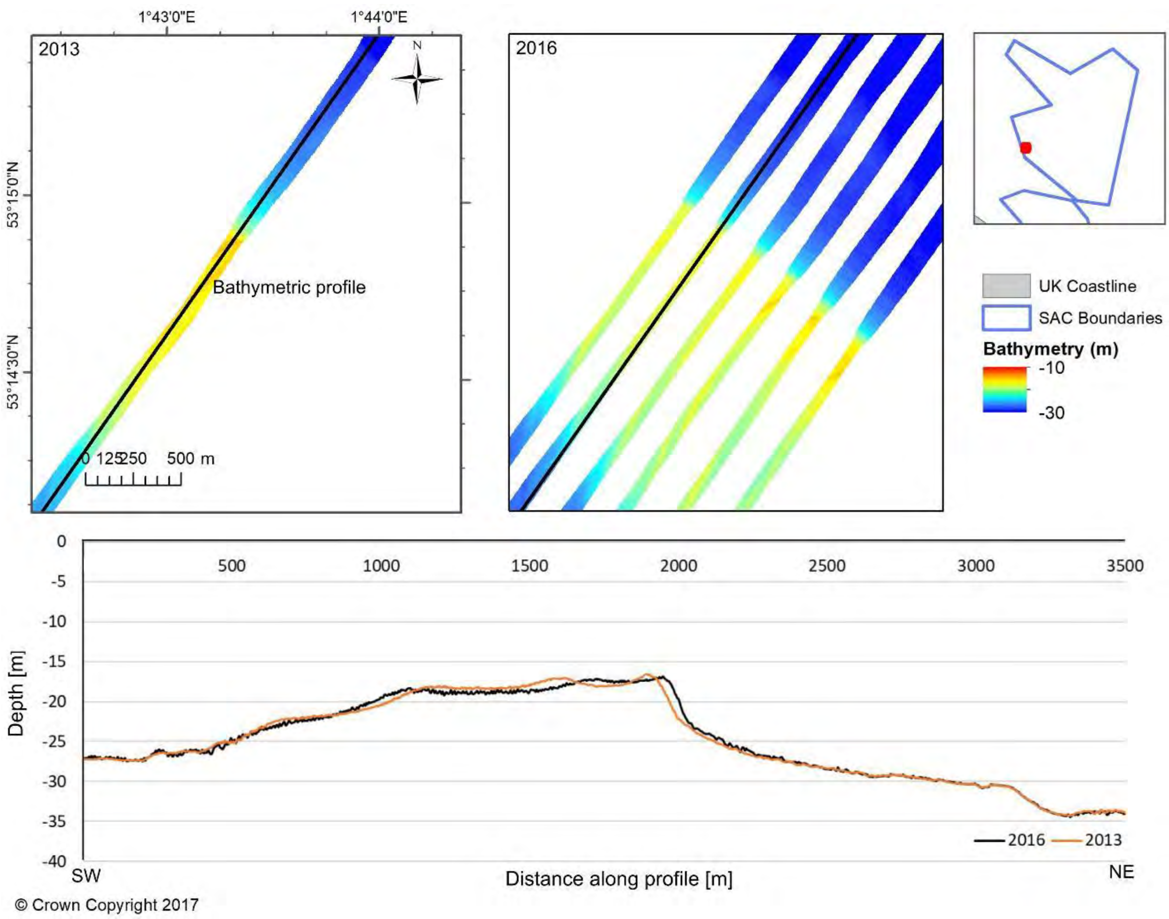


Figure 9. Bathymetric profiles from the Leman Bank CSA sandbank in the south west of North Norfolk Sandbanks and Saturn Reef (NNSSR) SAC showing the changes in profile between 2013 and 2016.

4.1.2 Haisborough, Hammond & Winterton SAC

For HHW, MBES data collected in 2016 were compared to the 2014 CHP data for two acoustic transects (347° True) measuring approximately 260m (transect 1) and 290m (transect 2) long respectively. This area corresponds with the HHW Southern Closure area surveyed for *S. spinulosa* reef. The seabed topography from both 2014 and 2016 is dominated by sandwaves and ripples in both transects (Figure 10). Two large, similar features to sandbanks were identified within both profiles, each rising between 6-10m above the surrounding seabed.

The profile of transect 1 displayed a similar pattern between the two years, with the larger sandwaves moving in both directions of the transect. The two large sandbank features did not display any distinct movement within the context of the transect direction. These two profiles infer that while smaller sandwaves appear to move, the main sandbank feature has showed no sign of lateral shifts between 2014 and 2016.

At transect 2, the bathymetry data indicated that many of the larger sandwaves have moved between 2014 and 2016 (Figure 10). However, the movement has not been consistent in direction or distance, with sandwaves moving in both directions with relation to the transect. The larger sandbank feature, however, did not show any distinct movement in either direction of the transect.

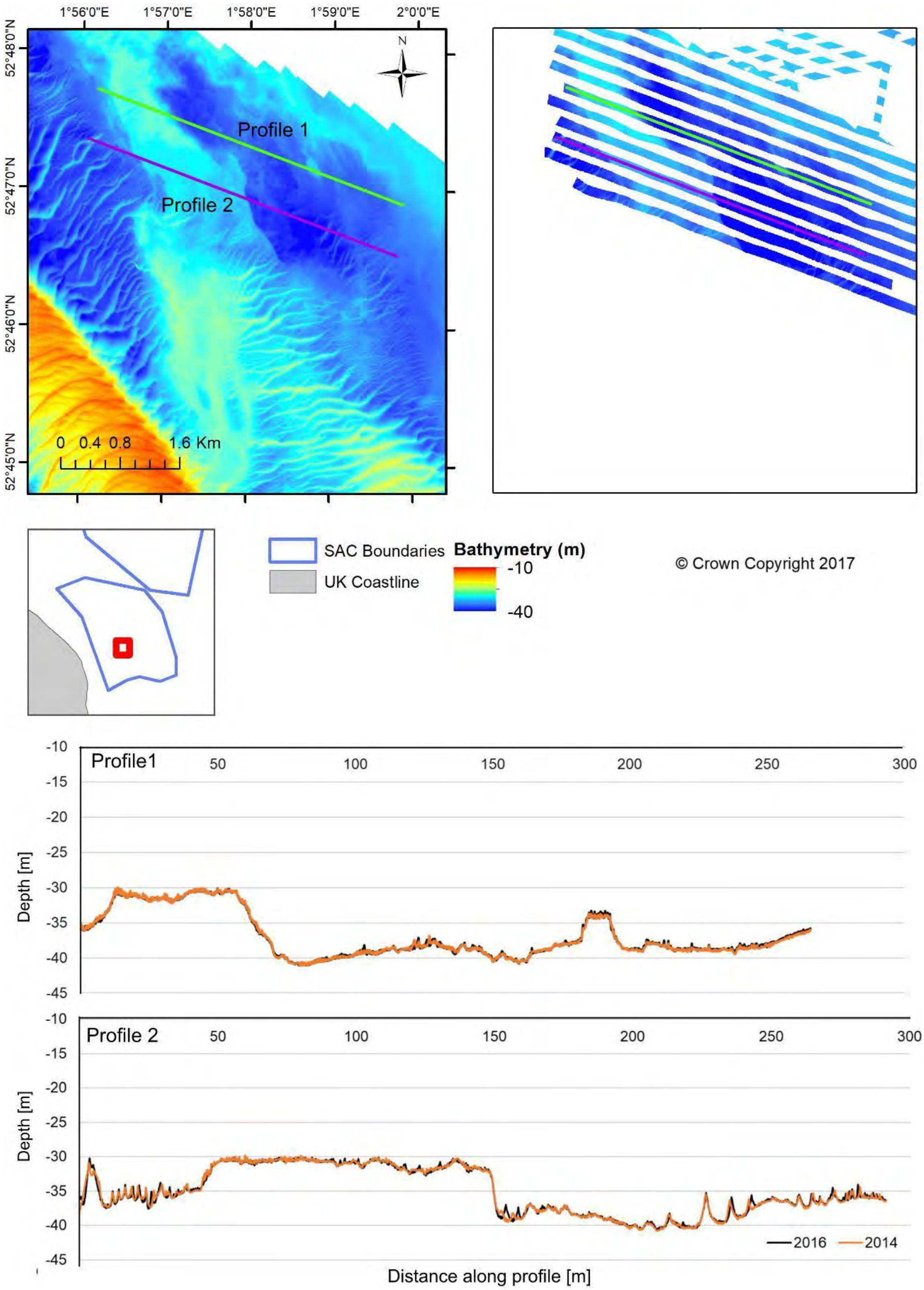


Figure 10. Bathymetric profiles from the Haisborough, Hammond and Winterton (HHW) SAC, showing the changes in profile between 2014 and 2016.

4.1.3 Inner Dowsing, Race Bank & North Ridge SAC

One 600m bathymetric profile was created for Inner Dowsing within IDRBNR from the 2016 data, allowing data to be compared with those collected in 2011. The profile was created along the longest axis of overlapping data in a direction of 357° True. The transect crosses approximately 270m of relatively flat seabed before leading up the flank of the sandbank (Figure 11). This section of the profile has remained stable from 2011 to 2016. From thereon, the two profiles differ with an increased number of sandwaves being present in the 2016 data compared to 2011. A large divergence of the profiles occurs from around 400m along the transect, with a sudden decrease in bathymetry occurring in the 2016 profile compared to the 2011 profile. The profiles once again become comparable for the remainder of the flank to the end of the 600m transect. The movement of the slope in the direction of the transect ranged from 39.9m to 79.9m with the base of the bank moving further than the upper slopes of the bank. These data, albeit limited, imply that between 2011 and 2016 there was a marked shift in the location of the shoreward flank of the Inner Dowsing sandbank. As this assessment is based on two sampling events only, it is not possible to ascertain whether this shift is occurring at a constant rate over time, or whether this resulted from a short-term acute movement episode. Further temporal data will allow such understanding to be achieved. Furthermore, as the overlapping profiles did not transect the crest nor the seaward facing flank or trough, it is not possible to quantify the movement of the whole cross-section of the sandbank at this location.

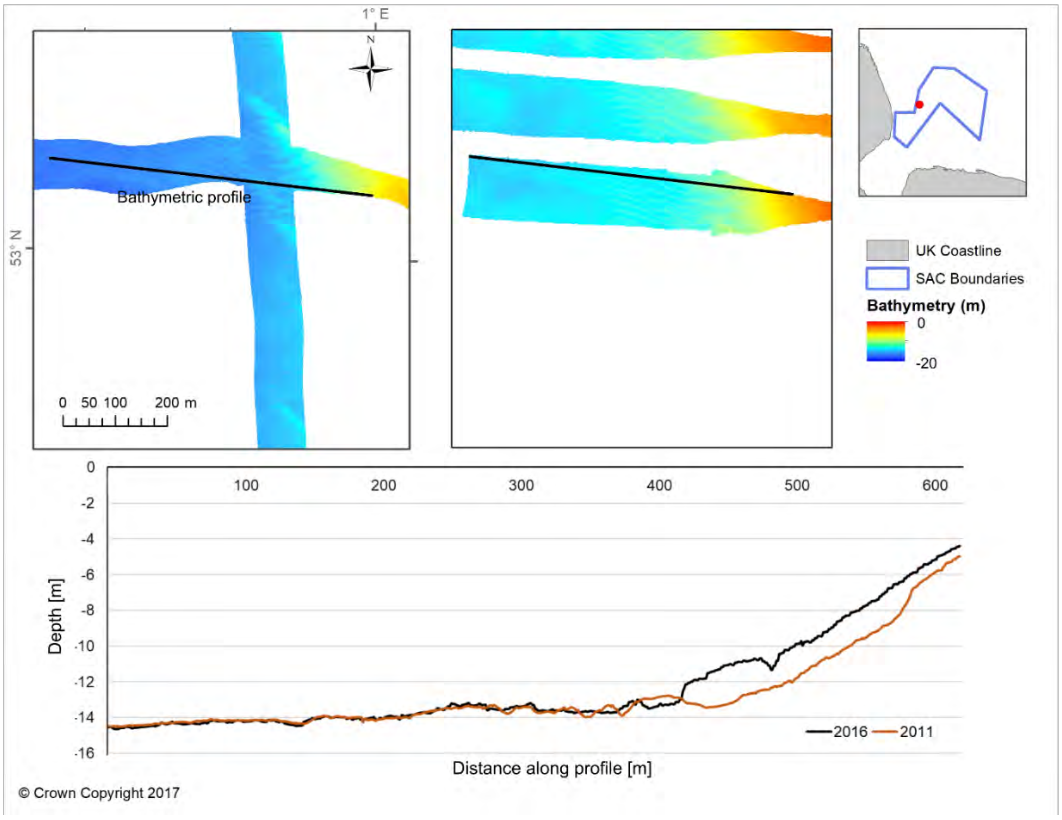


Figure 11. Bathymetric profiles from Inner Dowsing CSA within Inner Dowsing, Race Bank and North Ridge (IDRBNR) SAC showing changes in profile between 2011 and 2016.

4.2 Objective 2. Annex I Sandbanks: structure and function

This section meets Objective 2 by addressing four questions:

Question 1. How are sediment types (EUNIS level 3 and entropy approaches) distributed across the three sites, and across the topographical zones of individual sandbanks?

Question 2. How do infaunal and epifaunal communities vary across the three sites, and, at a local sandbank scale, are the communities influenced by environmental factors and orientation (e.g. seaward or shoreward sides of banks)?

Question 3. How similar are the biological communities inside and outside of the delineated Annex I Sandbank features? This question pertains only to HHW and IDRBNR as the boundary of the feature corresponds to the site boundary at NNSSR.

Question 4. Which biotopes exist, and how do they vary across the sites, features and at the scale of individual sandbanks?

In advance of the questions being addressed, this section firstly presents the results of the sediment entropy analysis for all sites.

4.2.1 Sediment entropy analysis

Entropy analysis revealed that five distinct sediment groups were present across the data (Table 11). As entropy groups are derived using the full resolution PSD, more subtle differences in sediment composition are observed in comparison to the EUNIS classification scale, which is based on gravel, sand and mud ratios (Long 2006). In particular, the different sand fractions show considerable variation between entropy groups, which is not visible when classified by EUNIS level 3. Groups ‘1a’, ‘4a’ and ‘5a’ are slightly gravelly sands (‘1a’ dominated by medium sand, ‘4a’ by fine sand and ‘5a’ fine and medium sands), while group ‘2a’ represents gravelly sands dominated by coarse sand, and group ‘3a’ reflects a mixed sediment containing gravel, sand and mud. In the following sections, sediments have been categorised using both entropy analysis and EUNIS classes, along with hydrodynamic conditions to assist in explaining variability in faunal distributions.

Table 11. Sediment characteristics of the five groups derived following entropy analysis, produced using the average Particle Size Distribution (PSD) for each sediment group, calculated using Gradistat (Blott & Pye 2001).

Sediment group	Number of samples	Sample Type	Folk Sediment description	MODE 1 (µm):	MODE 2 (µm):	MODE 3 (µm):	Sorting : Methods of moments Logarithmic (ϕ)	Gravel (%)	Sand (%)	Silt/clay (%)	Very coarse sand (%)	Coarse sand (%)	Medium sand (%)	Fine sand (%)	Very fine sand (%)
1a	118	Unimodal, Moderately Well Sorted	Slightly Gravelly Sand	301.8			0.60	0.68	96.97	2.35	0.61	11.39	66.62	17.29	1.05
2a	93	Unimodal, Poorly Sorted	Gravelly Sand	426.8			1.04	7.04	90.68	2.28	7.06	36.05	39.71	7.07	0.79
3a	72	Polymodal, Very Poorly Sorted	Gravelly Muddy Sand	301.8	4800	26950	3.90	23.40	54.67	21.93	5.41	7.57	19.19	17.65	4.86
4a	66	Unimodal, Moderately Sorted	Slightly Gravelly Sand	213.4			0.96	0.84	91.60	7.56	0.25	1.36	14.51	68.20	7.28
5a	90	Unimodal, Moderately Well Sorted	Slightly Gravelly Sand	213.4			0.62	2.46	95.21	2.33	0.81	3.42	44.86	44.42	1.70

4.2.2 North Norfolk Sandbank and Saturn Reef SAC

Sediment types

Within NNSSR, sediment composition on the CSA sandbanks generally reflected the strength of the prevailing tidal currents (Figure 7). Where the strongest currents prevailed, the most inshore crest (Leman Bank) was characterised by sediments associated with entropy group ‘1a’ (medium sand). Medium sands also dominated the seaward flank (although some samples contained up to 14% gravel), with finer sands characterising the shoreward flank of this CSA. Within the troughs, sediment was more variable due to the additional presence of gravel and silt/clay.

Sediments on the further offshore CSA (Indefatigable Bank) were less variable between topographical zones. The crest sediments were composed of mainly medium and fine sand (entropy group ‘5a’) with flanks and troughs comprising almost entirely entropy group ‘4a’ (fine, slightly silty sands).

The WCTs for NNSSR show a similar pattern in sediment grain size to those of the CSAs. The crests of the WCT sandbanks nearer to shore, Well Bank (WCT008) and Ower Bank (WCT010), showed sediments associated with entropy group ‘1a’ (medium sand), which is also found on the crest of the most north westerly WCT sandbank (North of Saturn Reef). The crests of sandbanks further offshore comprised finer sediments typical of entropy group ‘5a’ (medium and fine sand). Greater variability was seen in the sediment composition of the troughs within the NNSSR SAC. Swarte Bank (WCT005) shoreward trough and both troughs at Broken Bank (WCT006) comprised >49% mud, which was most noticeable when the EUNIS classification was applied (Figure 12).

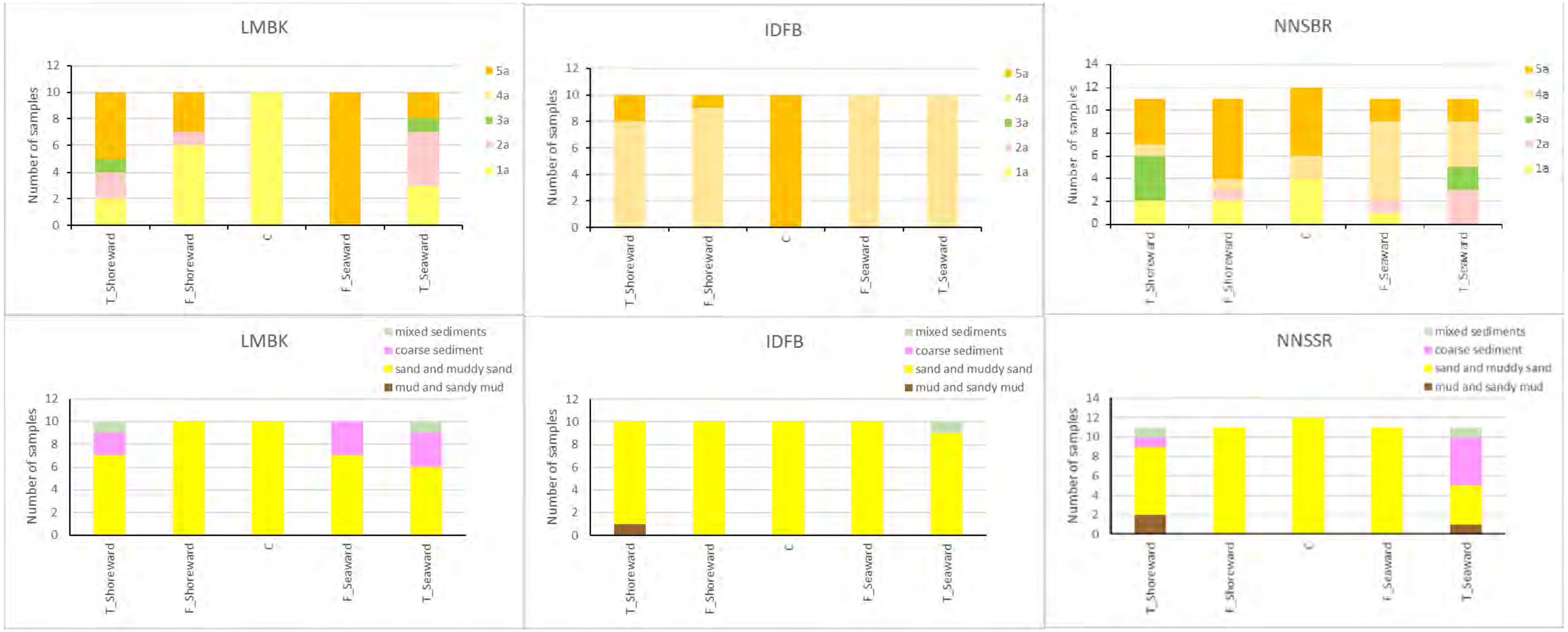


Figure 12. Stacked histograms showing number of samples from each topographical zone that fell into each entropy sediment groups (top) and EUNIS broad sediment classification (bottom) at Leman Bank (LMBK), Indefatigable Bank (IDFB) and 11 wide characterising transects combined (NNSSR; WCT001 to WCT011) in the North Norfolk Sandbanks and Saturn Reef (NNSSR) SAC. T = trough, F = flank, C = crest.

Case Study Areas: Community structure

Infauna

Infaunal univariate metrics show a general decline from trough to crest at the Indefatigable Bank CSA (Table 12). Numbers of species, Margalef's species richness and Hill's diversity values were slightly higher on the seaward flank and trough compared to the shoreward, whilst numbers of individuals were only slightly higher in the seaward trough compared to the shoreward.

At Leman Bank CSA, all metrics showed a decline from trough to crest with the exception of numbers of individuals, where higher abundances were observed on the crests than on the flanks and troughs (Table 12). The exception to this was for the seaward trough where there were significantly higher abundances than all other topographical zones.

Table 12. Mean (per 0.1m^2, ±95% confidence) diversity measures at each topographical zone on Indefatigable Bank (IDFB) and Leman Bank (LMBK) within the North Norfolk Sandbanks and Saturn Reef (NNSSR) SAC*.

Bank	Topographical zone	Number of species (S)		Number of individuals (N)		Species richness Margalef's (d)		Species diversity Hill's (N1)	
IDFB	T(shore)	9.80	(±0.56)	18.60	(±1.57)	3.05	(±0.15)	8.30	(±0.48)
	F(shore)	8.10	(±0.37)	19.00	(±1.28)	2.47	(±0.13)	5.97	(±0.46)
	C	5.40	(±0.27)	12.80	(±1.33)	1.79	(±0.09)	4.49	(±0.24)
	F(sea)	10.60	(±0.47)	19.00	(±1.37)	3.32	(±0.12)	9.00	(±0.41)
	T(sea)	13.10	(±0.62)	22.10	(±1.51)	3.94	(±0.13)	10.84	(±0.44)
LMBK	T(shore)	13.40	(±0.91)	34.60	(±2.36)	3.52	(±0.22)	8.94	(±0.69)
	F(shore)	9.80	(±0.61)	35.50	(±4.00)	2.54	(±0.14)	6.43	(±0.41)
	C	7.90	(±0.41)	37.20	(±3.75)	1.99	(±0.14)	4.67	(±0.36)
	F(sea)	10.00	(±0.54)	27.50	(±1.86)	2.77	(±0.15)	7.40	(±0.38)
	T(sea)	34.60	(±2.86)	131.70	(±15.34)	6.91	(±0.47)	17.38	(±1.41)

* T = trough; F = flank; C = crest; sea = seaward facing; shore = shoreward facing.

The nMDS ordination of Indefatigable Bank infauna samples shows crest samples generally clustering away from all other topographical zones (Figure 13). Shoreward flank communities show greatest similarity with the crest communities although they exhibit high variability and overlap with shoreward troughs and seaward flanks. A gradient in community composition, from crest to trough, is apparent for the shoreward facing side. This is less apparent between the crest communities and seaward facing communities, although there is some overlap in community composition between seaward flanks and troughs.

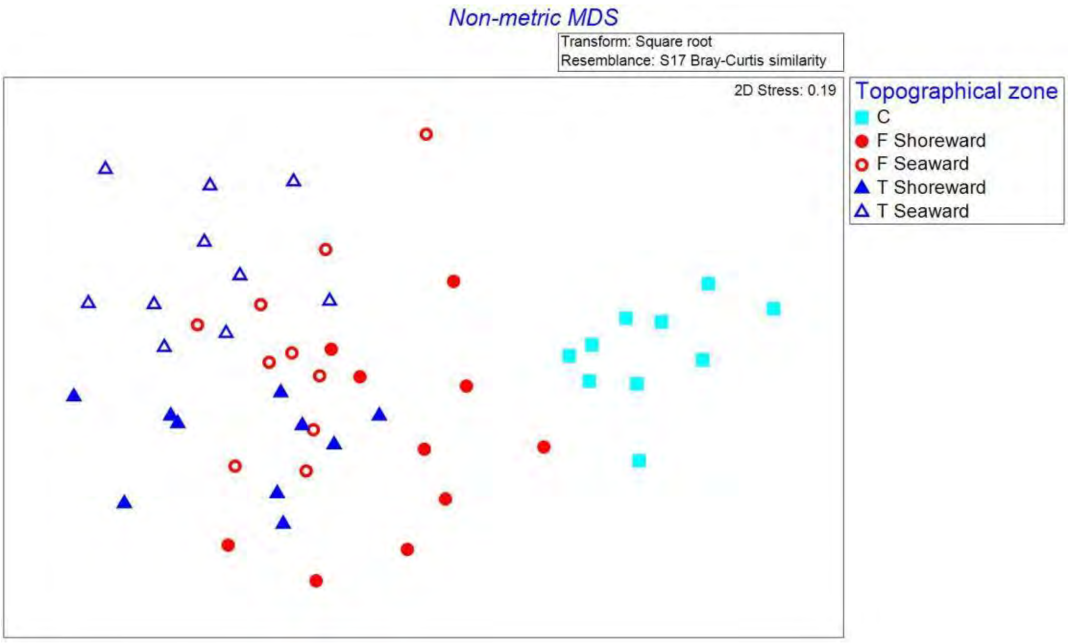


Figure 13. nMDS ordination of infaunal community composition at Indefatigable Bank within the North Norfolk Sandbanks and Saturn Reef (NNSSR) SAC, displayed according to topographical zone (crest, flank, trough) and seaward/shoreward orientation.

ANOSIM pairwise comparisons (Table 13) confirms that crest communities are significantly different from all topographical zones. Differences between seaward and shoreward flank communities and between seaward flank and shoreward trough communities appear slight (significant at the 5% level) although the nMDS suggests high within zone variability.

Table 13. ANOSIM pairwise tests between topographical zones at Indefatigable Bank.

Pairwise Tests Groups	R Statistic	Significance Level %
Crest, F Shoreward	0.658	0.1
Crest, F Seaward	0.967	0.1
Crest, T Shoreward	0.969	0.1
Crest, T Seaward	0.985	0.1
F Shoreward, F Seaward	0.161	2.5
F Shoreward, T Shoreward	0.201	1
F Shoreward, T Seaward	0.576	0.1
F Seaward, T Shoreward	0.164	0.8
F Seaward, T Seaward	0.295	0.1
T Shoreward, T Seaward	0.507	0.1

Multivariate analyses (nMDS) of the Leman Bank infauna data show the seaward trough communities most notably separated from the other topographical zones, with high within group variability (Figure 14). Crest communities show strong overlap with shoreward flank communities but show distinct separation from seaward flanks. As with Indefatigable Bank, there appears to be a gradual change in community composition from crest to trough on the shoreward side, but less so on the seaward side.

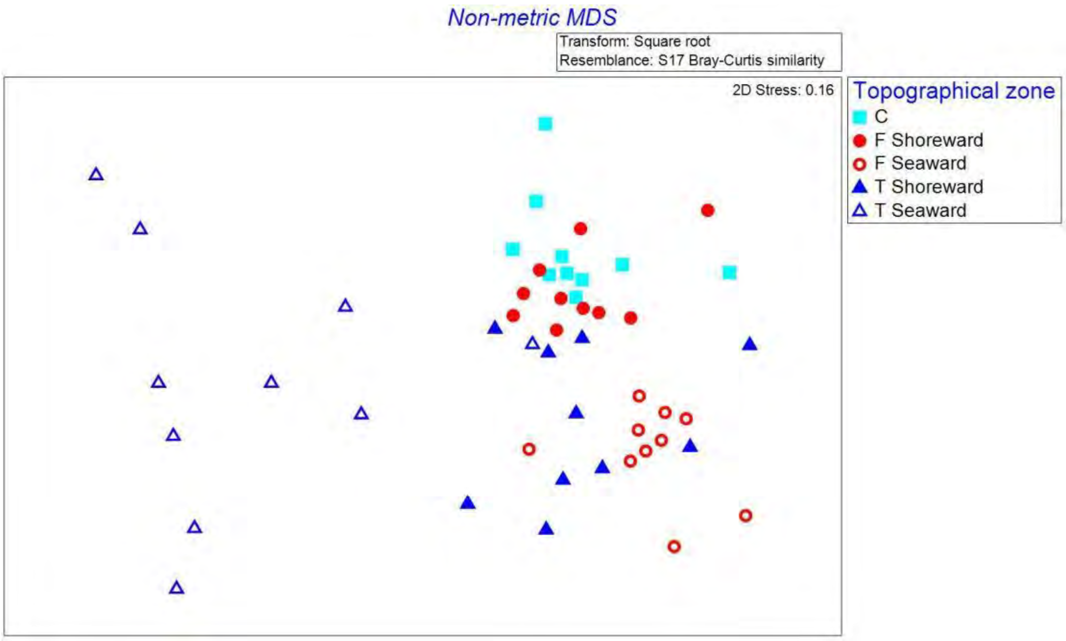


Figure 14. nMDS ordination of infaunal community composition at Leman Bank within the North Norfolk Sandbanks and Saturn Reef (NNSSR) SAC, displayed according to topographical zone (crest, flank, trough) and seaward/shoreward orientation.

ANOSIM confirms the seaward trough topographical zone to be most significantly different from all others (Table 14). Seaward flank communities were also significantly different to crest and shoreward flank communities. As suggest by the nMDS, crest and shoreward flank communities are not significantly different. The seaward flank and shoreward trough samples also exhibited some similarities in community composition. Figure 18 shows the location of topographical zones according to the bathymetry of the sandbanks. The shoreward trough samples appear to be partially located on the seaward flank of the adjacent sandbank, which may explain the similarity in community composition observed.

Table 14. ANOSIM pairwise tests between topographical zones at Leman Bank.

Pairwise Tests Groups	R Statistic	Significance Level %
Crest, F Shoreward	0.029	24.1
Crest, F Seaward	0.82	0.1
Crest, T Shoreward	0.5	0.1
Crest, T Seaward	0.716	0.1
F Shoreward, F Seaward	0.731	0.1
F Shoreward, T Shoreward	0.373	0.1
F Shoreward, T Seaward	0.698	0.1
F Seaward, T Shoreward	0.38	0.1
F Seaward, T Seaward	0.8	0.1
T Shoreward, T Seaward	0.732	0.1

Epifauna

Univariate metrics for epifauna show similar trends of increasing species and individuals from crest to trough for both CSAs. The only exception for this is the shoreward flank of Leman Bank (LMBK) which shows reduced number of individuals in comparison with the crest. As with the infauna, the number of species and individuals are elevated on the seaward zones of LMBK.

Biomass shows similar trends (increasing volumes from crest to trough) for Indefatigable Bank (IDFB) on the shoreward side but not for the seaward facing side. Biomass on the LMBK crest resembled those of the shoreward and seaward troughs. Biomass on the seaward facing flank was significantly elevated due to the presence of large hydrozoan and bryozoan species. These taxonomic groups were responsible for the elevated biomass values on all topographical zones (except the seaward trough) at LMBK in comparison with IDFB. LMBK seaward trough comprised less hydrozoa and bryozoa than the other topographical zones but a high biomass of *S. spinulosa* tubes. The sediments collected at LMBK were generally composed of sandy sediments, although gravel was present in generally low percentages on the seaward flanks. Trough sediments were far more variable with the percentage of gravel contributing to 25% of the total sediment composition. This suggests that there was sufficient attachment surface for the hydroids, bryozoans and *S. spinulosa* to colonise.

Table 15. Mean (per 600m^2**, ±95% confidence) diversity measures and biomass at each topographical zone* on Indefatigable Bank (IDFB) and Leman Bank (LMBK) CSAs within the North Norfolk Sandbank and Saturn Reef (NNSSR) SAC.

Bank	Topographical Zone	Number of Species (s)		Number of Individuals (N)		Biomass (g)	
IDFB	T(shore)	18.67	(± 0.88)	177.33	(± 50.23)	1941	(± 683)
	F(shore)	15.00	(± 0.58)	106.00	(± 10.69)	1048	(± 164)
	C	14.33	(± 0.88)	80.33	(± 4.10)	779	(± 118)
	F(sea)	15.67	(± 1.20)	172.67	(± 17.57)	2003	(± 182)
	T(sea)	19.67	(± 1.76)	161.00	(± 15.70)	1958	(± 145)
LMBK	T(shore)	19.67	(± 1.76)	111.67	(± 29.63)	4043	(± 1729)
	F(shore)	15.33	(± 0.33)	41.33	(± 4.84)	6294	(± 2065)
	C	13.67	(± 0.67)	45.33	(± 5.24)	4557	(± 785)
	F(sea)	20.00	(± 1.00)	219.00	(± 65.04)	19553	(± 7207)
	T(sea)	30.00	(± 4.04)	342.33	(± 66.89)	4531	(± 784)

* T = trough; F = flank; C = crest; sea = seaward facing; shore = shoreward facing.
** The seaward trough dataset for Leman Bank (LMBK contained one less replicate of 300m^2).

Multivariate analyses of the epifaunal communities show greater within zone variability at IDFB in comparison LMBK. As with the univariate metrics, a graduating trend from crest to trough (both seaward and shoreward) is observed for IDFB. This is also apparent for the shoreward side of LMBK but not for the seaward side. The communities inhabiting each of the topographical zones at LMBK appear as separate clusters on the nMDS, suggesting distinctly different communities inhabit the topographical zones (with exception of the shoreward flank communities which are highly similar to those inhabiting the crest).

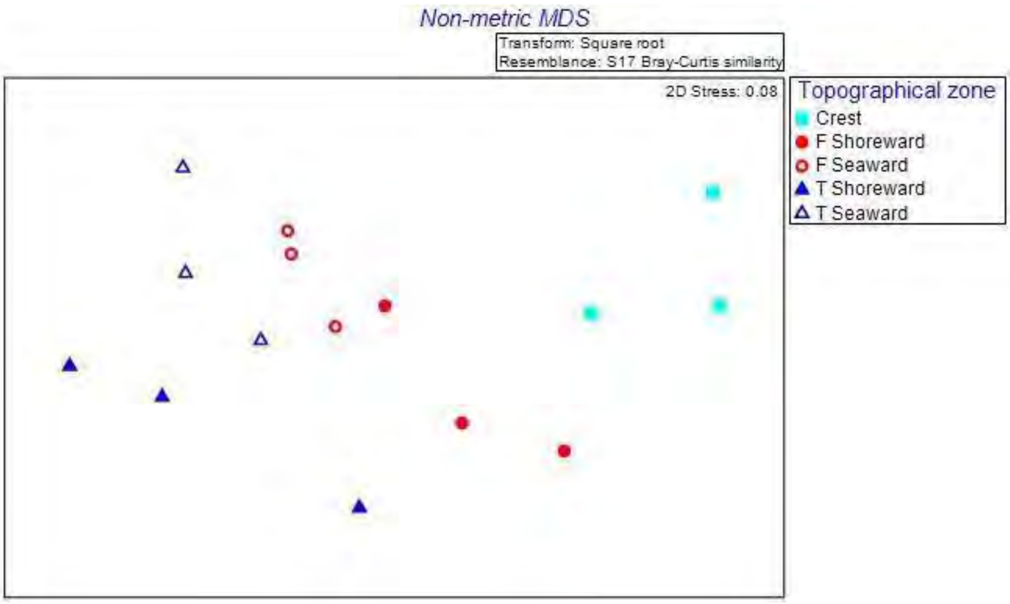


Figure 15. nMDS ordination of epifaunal community composition at Indefatigable Bank within the North Norfolk Sandbanks and Saturn Reef (NNSSR) SAC, displayed according to topographical zone (crest, flank, trough) and seaward/shoreward orientation.

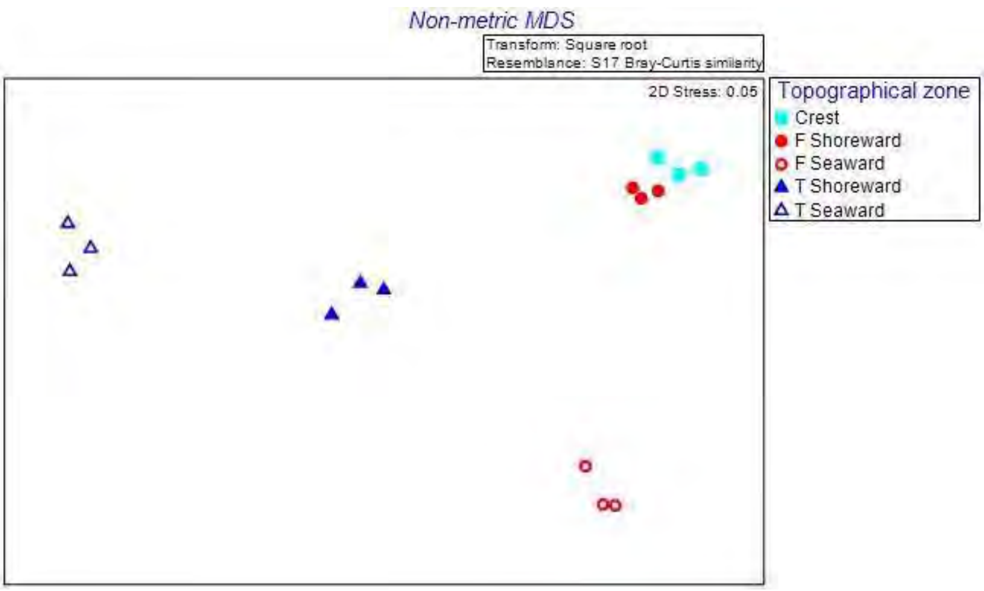


Figure 16. nMDS ordination of epifaunal community composition at Leman Bank within the North Norfolk Sandbanks and Saturn Reef (NNSSR) SAC, displayed according to topographical zone (crest, flank, trough) and seaward/shoreward orientation.

Biotopes

Indefatigable Bank

Differences in the infaunal community composition between topographical zones at the Indefatigable Bank are largely due to higher abundances of *Ophelia borealis* and *Nephtys cirrosa* and the absence of, primarily, *Fabulina fabula* on the crest (SIMPER results presented in Annex 2). Epifaunal communities on all topographical zones of the Indefatigable Bank were dominated by abundances of the solenette (*Buglossidium luteum*) and to a lesser extent scaldfish (*Arnoglossus laterna*) and the crab, *Corystes cassivelaunus*. The lesser weaver fish, *Echiichthys vipera*, was characteristic of the crest and flanks communities, whilst the starfish, *Asterias rubens* was only characteristic of the troughs and seaward flank communities. Other species were only characteristic of one topographical zone; Dab (*Limanda limanda*) was most consistently caught in the troughs, whilst sandeels (*Ammodytes* spp. and *Hyperoplus lanceolatus*) showed the highest abundances on the shoreward flank (see SIMPER results in Annex 2).

Crest communities resemble the EUNIS biotope 'A5.231: Infralittoral clean sand with sparse fauna', due to the low numbers of infaunal species and individuals. Communities on the flanks and troughs resemble the EUNIS biotope 'A5.242: *Fabulina fabula* and *Magelona mirabilis* with venerid bivalves and amphipods in infralittoral compacted fine muddy sand' (Figure 17). This corresponds with the sediment classification for these samples, entropy group '4a' (fine muddy sand). A full list of biotopes for all three SACs is found in Annex 3.

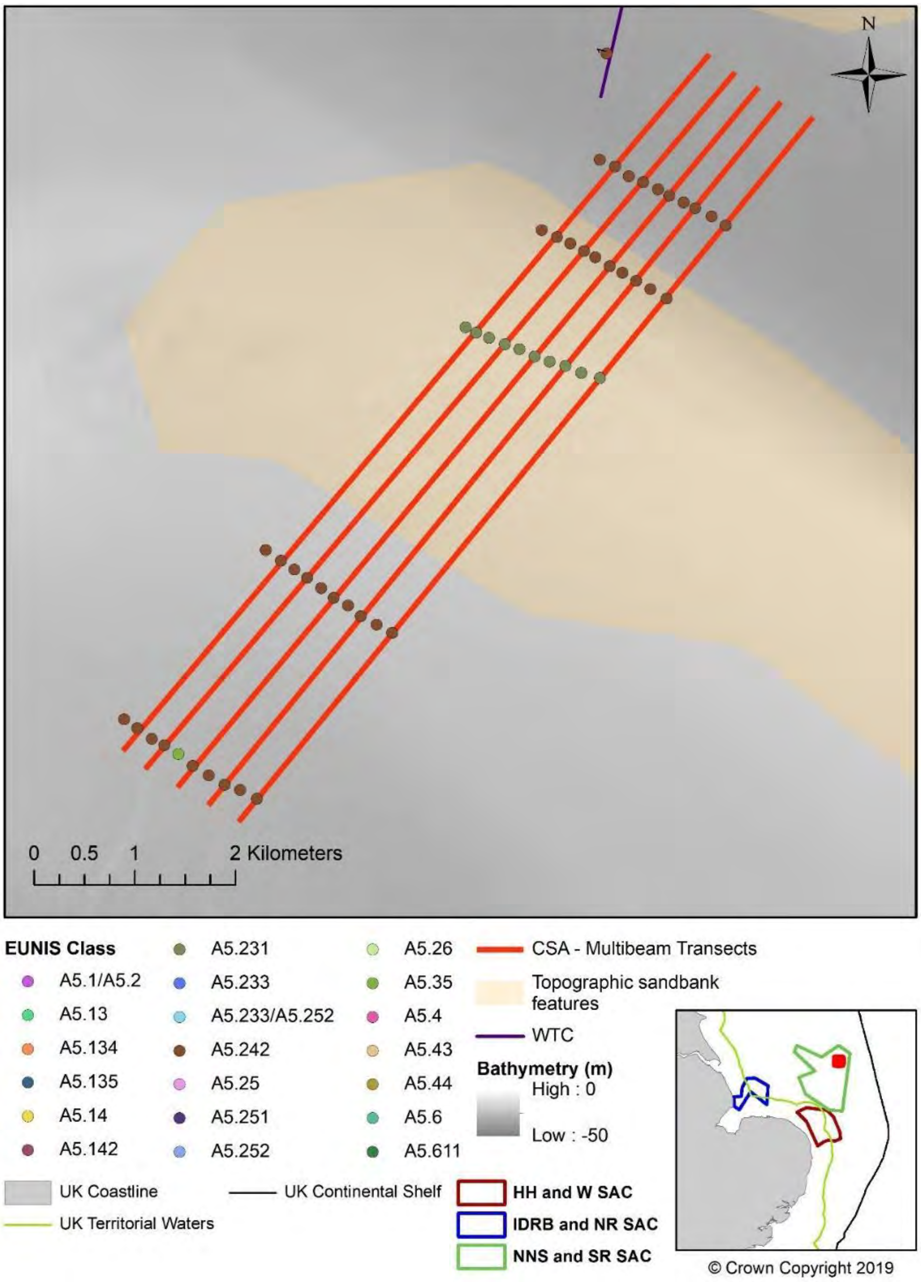


Figure 17. Biotopes determined for infaunal communities inhabiting topographical zones of the Indefatigable CSA.

Leman Bank

SIMPER analyses show the similarity in infaunal species composition between crest and shoreward flank to be relatively high (>50%). The characterising species for both these topographical zones were the polychaetes *Ophelia borealis, Nephtys cirrosa* and *Scoloplos armiger and the amphipod, Bathyporeia elegans*. The isopod, *Eurydice spinigera* (characteristic of littoral habitats) was also present on the crest (although did not feature in the taxa contributing 70% to within group similarity) but was absent on the flanks or troughs**.** Solenette*, Buglossidium luteum* was the only epifaunal species which was consistently characteristic of all topographical zones at Leman Bank. High abundances of brittlestars (*Ophiura* spp.) also dominated the trough communities, whilst *Ammodytes* spp. showed greater preference for the seaward flank and *H. lanceolatus* was only observed on the crest. *E. vipera* was (as per IDFB) more abundant on the crest than flanks and troughs, contributing the most to the shoreward community similarities. Reflecting the patterns seen for infauna, the seaward trough was associated with the highest epifaunal richness.

Although, similar in species composition to Indefatigable Bank crest, abundances of Leman Bank crest communities were higher and therefore show greater resemblance to the biotopes ‘A5.233: *Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand’ and also to ‘A5.252: *Abra prismatica, Bathyporeia elegans* and polychaetes in circalittoral fine sand’, due to the higher presence of *O. borealis*.

The seaward flank and shoreward trough samples were also characterised by *N. cirrosa, B. elegans, S. armiger* and *O. borealis*, although *O. borealis* was present in considerably lower abundances. These samples were therefore assigned solely to the biotope ‘A5.233: *Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand’.

The seaward trough communities were highly variable (only 30% within zone similarity) and were more diverse than at any other topographical location within NNSSR. The majority of samples from this topographical zone were tentatively assigned as ‘A5.252: *Abra prismatica, Bathyporeia elegans* and polychaetes in circalittoral fine sand’, however this biotope does not fully represent the epifaunal community present.

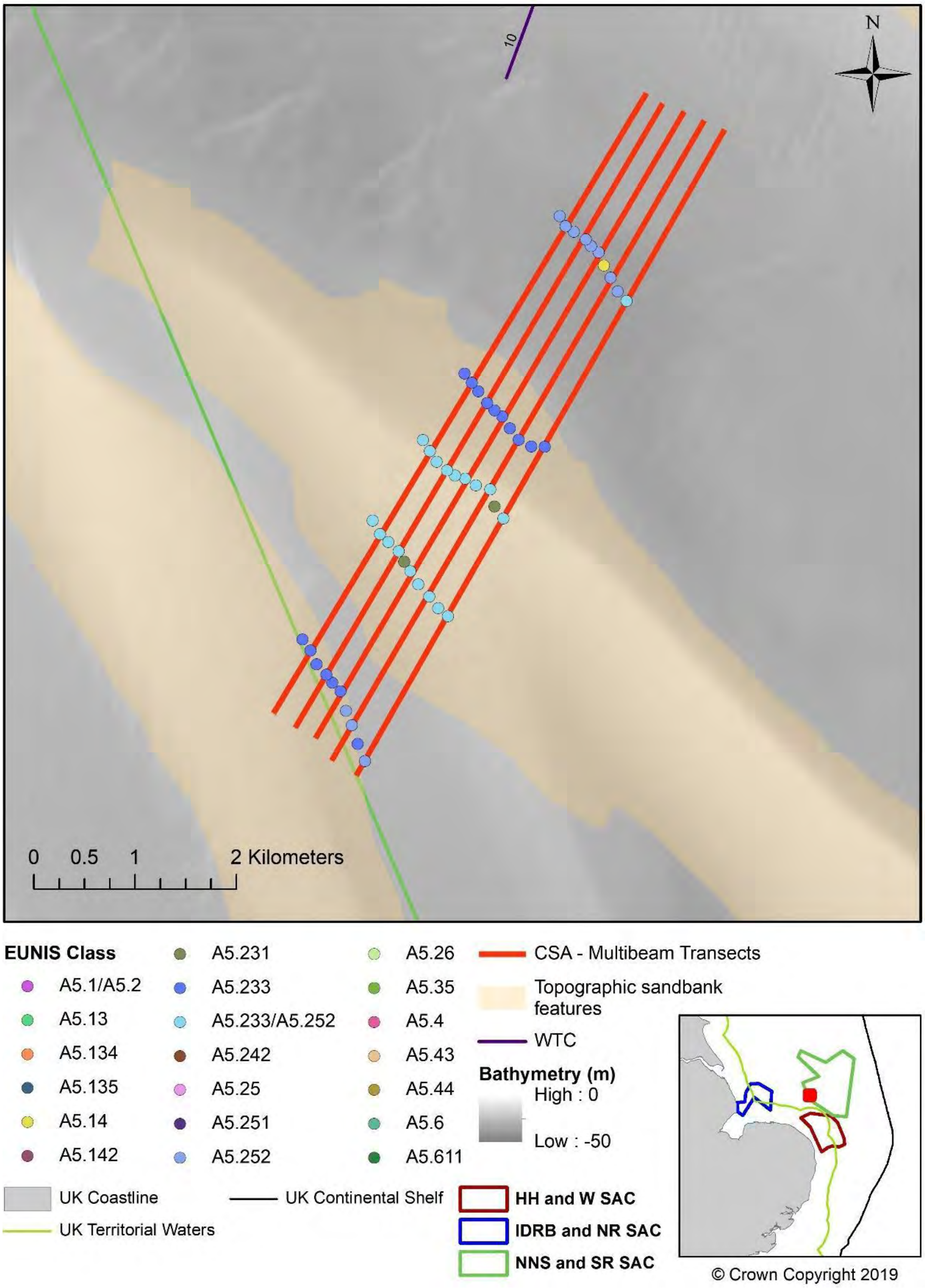
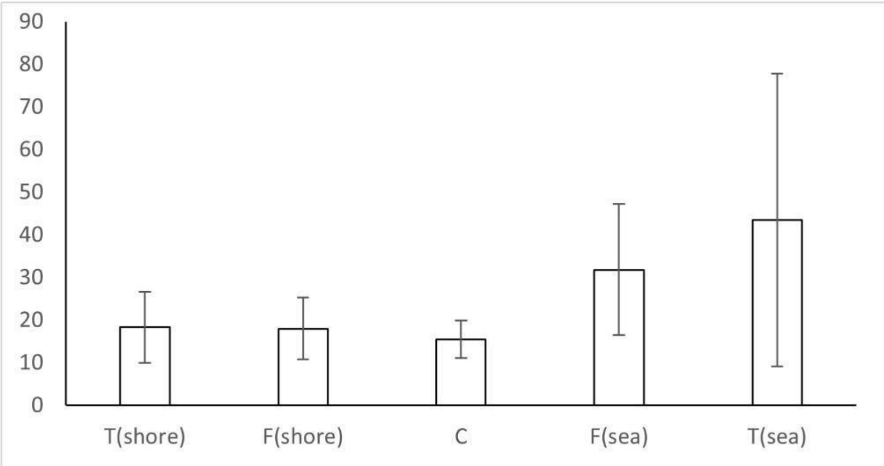


Figure 18. Biotopes determined for infaunal communities inhabiting topographical zones of the Leman Bank CSA.

Case Study Areas: Secondary productivity

Secondary productivity estimates across both Indefatigable Bank and Leman Bank were less than 100kJm^{-2}y^{-1} (from 15.5 to 87.0kJm^{-2}y^{-1}) (Figure 19). Secondary production estimates for crest assemblages at Indefatigable Bank were the lowest of all topographical zones across the bank. Secondary productivity estimates for crest assemblages on Leman Bank were significantly higher than crest estimates for Indefatigable Bank and those of all other CSAs (ANOVA, $F = 21.93$, $p<0.001$). Both seaward topographical zones at Indefatigable Bank showed the highest mean estimates of secondary production, however, with high variability across samples no significant differences were found between the seaward and shoreward flanks or between seaward and shoreward troughs. Similarly, estimates were highest and most variable at seaward trough locations at Leman Bank. However, unlike at Indefatigable Bank, the difference between trough orientations (seaward and shoreward) was found to be significant (t-test, $T = 2.35$, $p = 0.04$).

a) Indefatigable Bank



b) Leman Bank

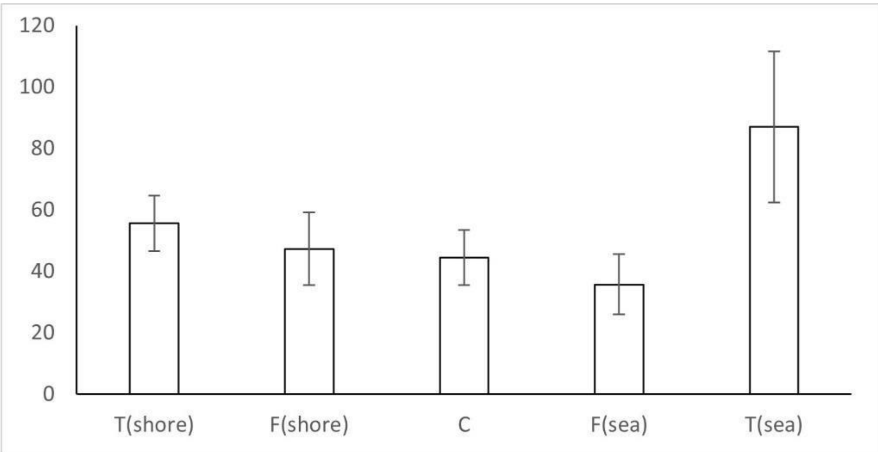


Figure 19. Mean total annual secondary production (kJm^{-2}y^{-1}) of the macrofaunal assemblages of a) Indefatigable Bank and b) Leman Bank within the North Norfolk Sandbanks and Saturn Reef (NNSSR) SAC*.
* Error bars represent 95% confidence intervals. T = trough; F = flank; C = crest; sea = seaward facing; shore = shoreward facing.

At Indefatigable Bank, the taxa contributing to total secondary production on the crests were different from those on the other topographical zones (Figure 20(a)). There was a large amount of overlap observed for all other topographical zones, regardless of seaward or shoreward orientation. In comparison, assemblages at Leman Bank (Figure 20(b)) exhibited greater functional variability (i.e. a wider taxonomic contribution to total production) at all topographical zones across the bank.

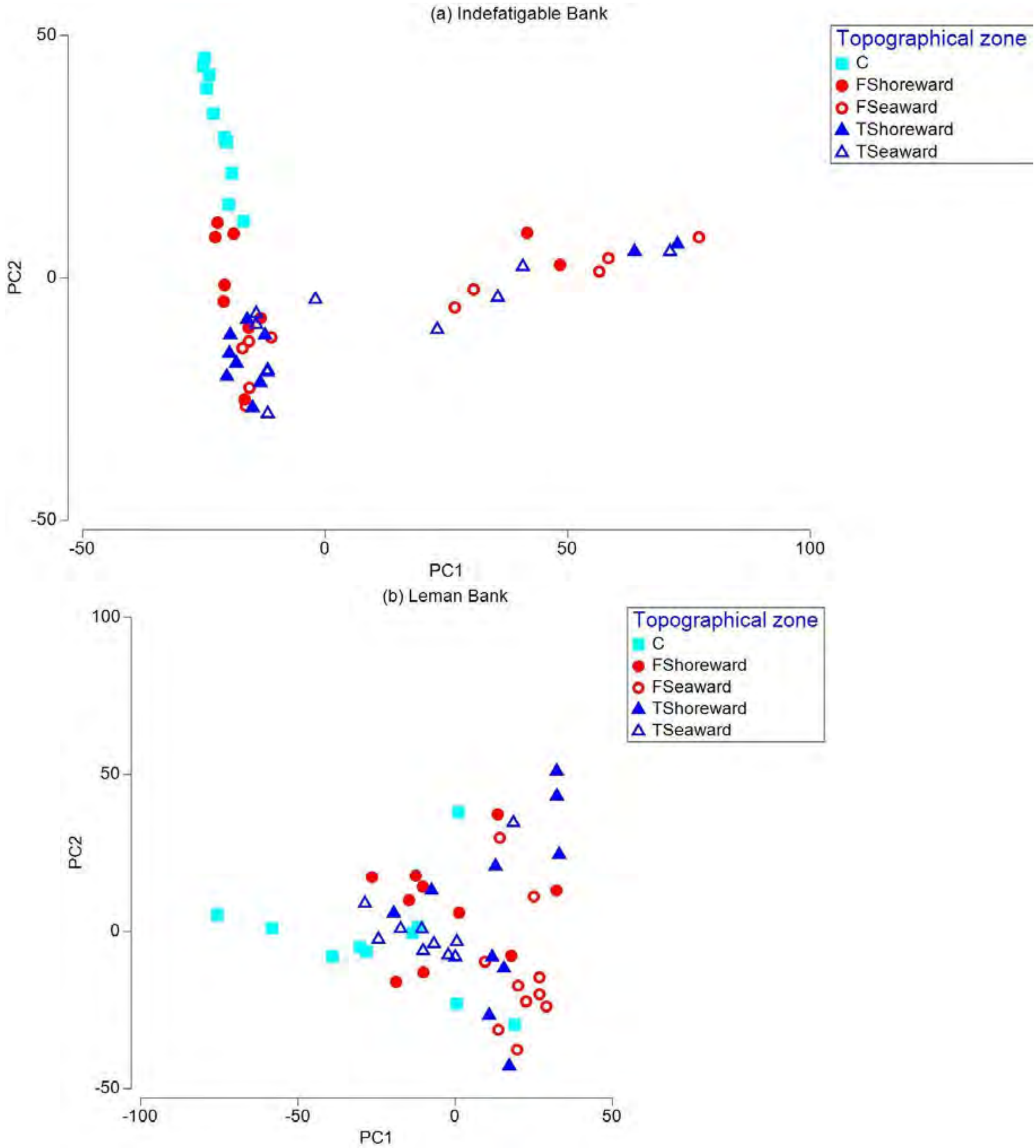


Figure 20. PCA plot of taxonomic contribution to total production at a) Indefatigable Bank and b) Leman Bank within North Norfolk Sandbanks and Saturn Reef (NNSSR) SAC***.**
*T = trough; F = flank; C = crest.

Secondary production at both CSA sandbanks within NNSSR, generally irrespective of topographical zone or orientation, is predominantly governed by annelid worms (P) (Figure 21). Echinoderms (ZB) and crustaceans (S) were also observed to contribute towards secondary production in a number of samples across all topographical zones and orientations at Indefatigable Bank except for at the crest of the bank. At Leman Bank the contribution of other phyla to secondary production estimates appeared lower, with the exception of a small number of samples that were highly influenced by the presence of echinoderms (ZB) (one seaward flank and one shoreward trough sample) and a number of seaward trough communities that were more heavily influenced by crustaceans than at other topographical zones.

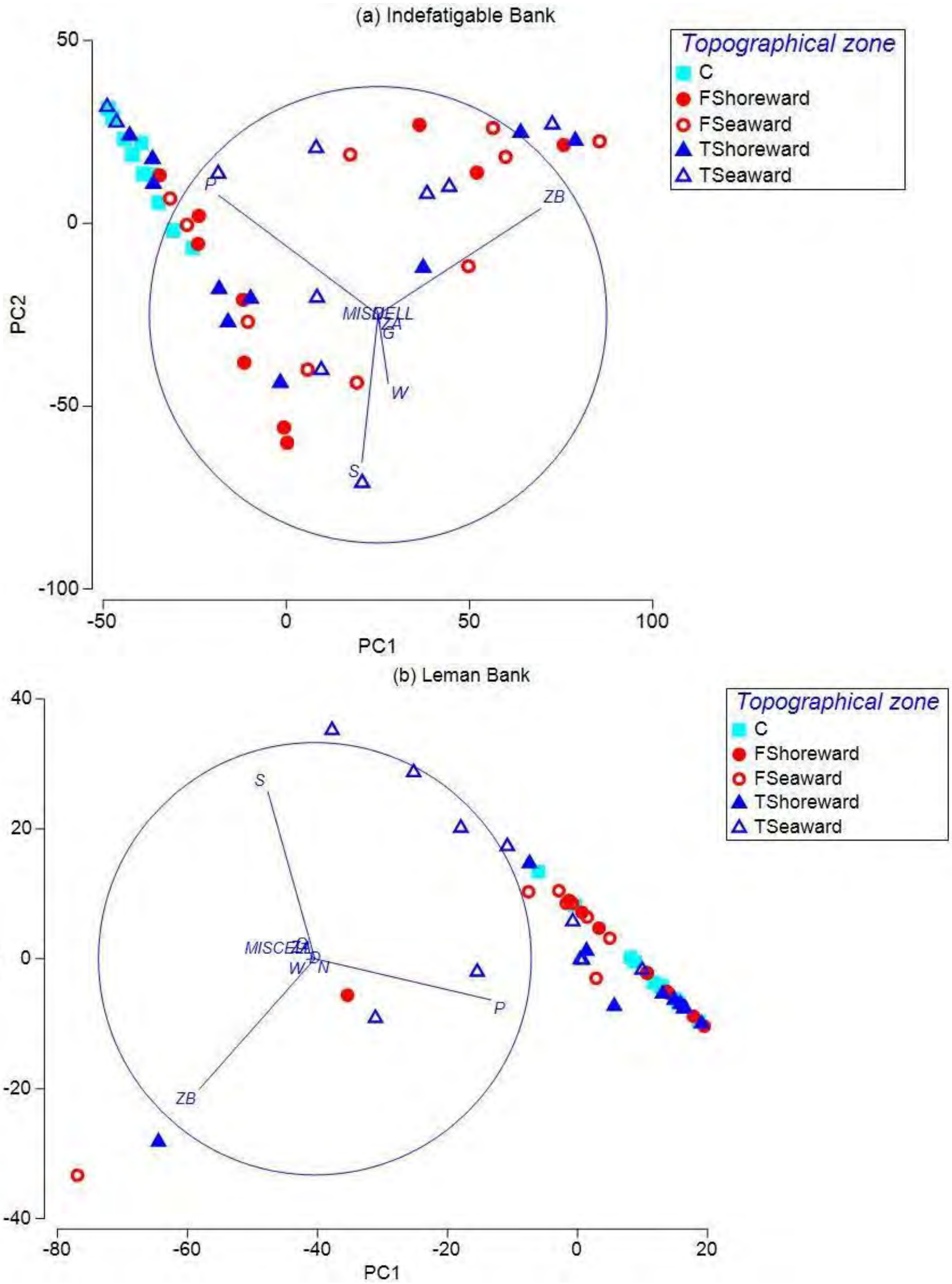


Figure 21. PCA plot based on the relative contribution to total production of the major taxonomic phyla at a) Indefatigable Bank and b) Leman Bank within North Norfolk Sandbanks and Saturn Reef (NNSSR) SAC*.

* The vector trajectories reflect the influence of each phyla group to each of the first two principal component axes. D = actinarians; G = sipunculids; N = nemerteans; P = annelids; S = crustaceans; W = molluscs; ZA = phoronids; ZB = echinoderms; MISCELL = miscellaneous phyla (e.g. sea spiders, turbellarians). T = trough; F = flank; C = crest.

Wider Characterising Transects (WCTs)

Eleven WCTs were sampled for infauna across the NNSSR SAC to make qualitative comparisons with data collected from each of the CSAs. Figure 22 and Figure 23 suggest there is high variation in the infaunal community composition across the SAC. Similarities are apparent between the topographical zones of the CSAs and WCTs. Crest communities of the WCTs largely resemble those of IDFB as opposed to LMBK. WCT flanks and troughs also exhibit greater similarity with IDFB (Figure 23). Similar patterns are observed between the SIMPROF groups and sediment entropy groups. No clear patterns were visible when displayed according to EUNIS sediment classes (figure not shown).

Biotopes were assigned to each of the WCT samples to compare against those assigned to the CSAs within each site (Figure 25). Figure 25 suggests that the communities observed in the northern WCTs (1-6) strongly resemble communities observed at the Indefatigable CSA, while those in the south of the site share some similarity with Leman Bank CSA, although there are a wider variety of biotopes present.

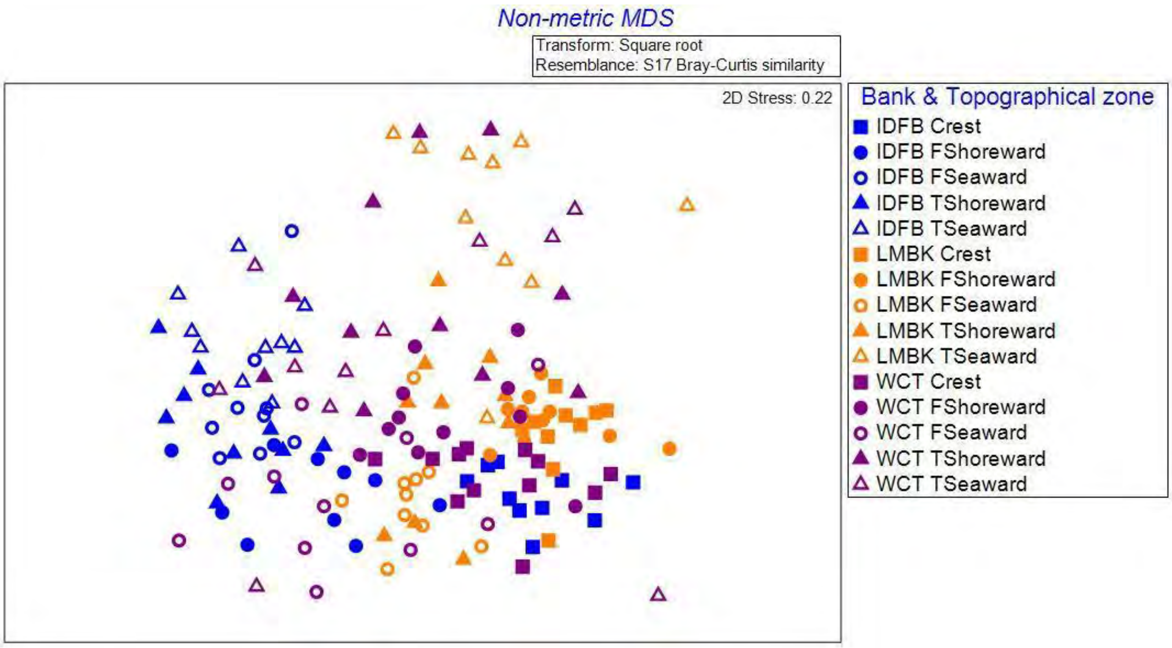


Figure 22. **n**MDS ordination of WCT and CSA infauna within NNSSR SAC.
* WCT = Wider Characterising Transect, IDFB = Indefatigable Bank, LMBK = Leman Bank, T = trough; F = flank; C = crest.

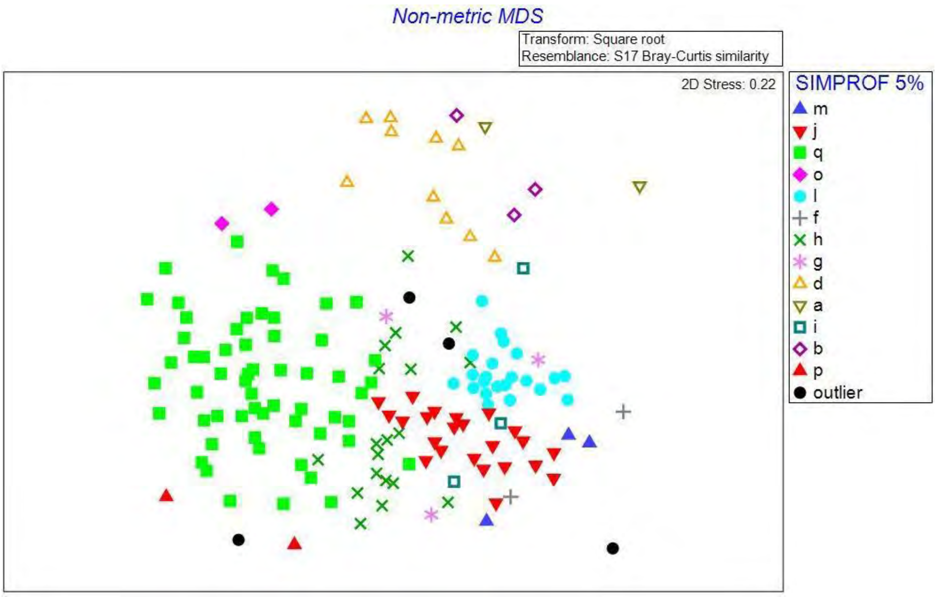


Figure 23. nMDS ordination of WCT and CSA infauna within NNSSR SAC, displayed according to SIMPROF groups.

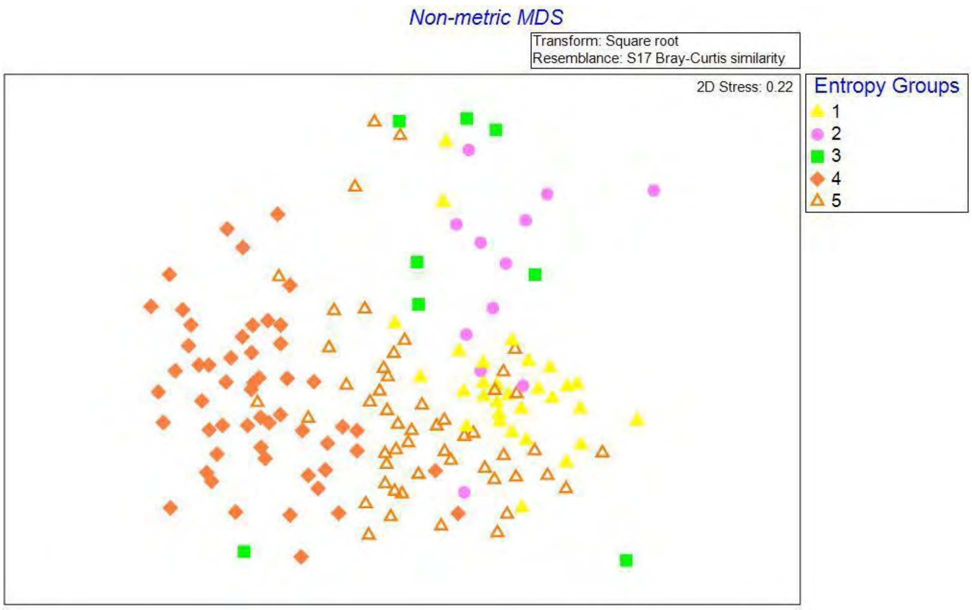


Figure 24. nMDS ordination of WCT and CSA infauna within NNSSR SAC, displayed according to sediment entropy groups.

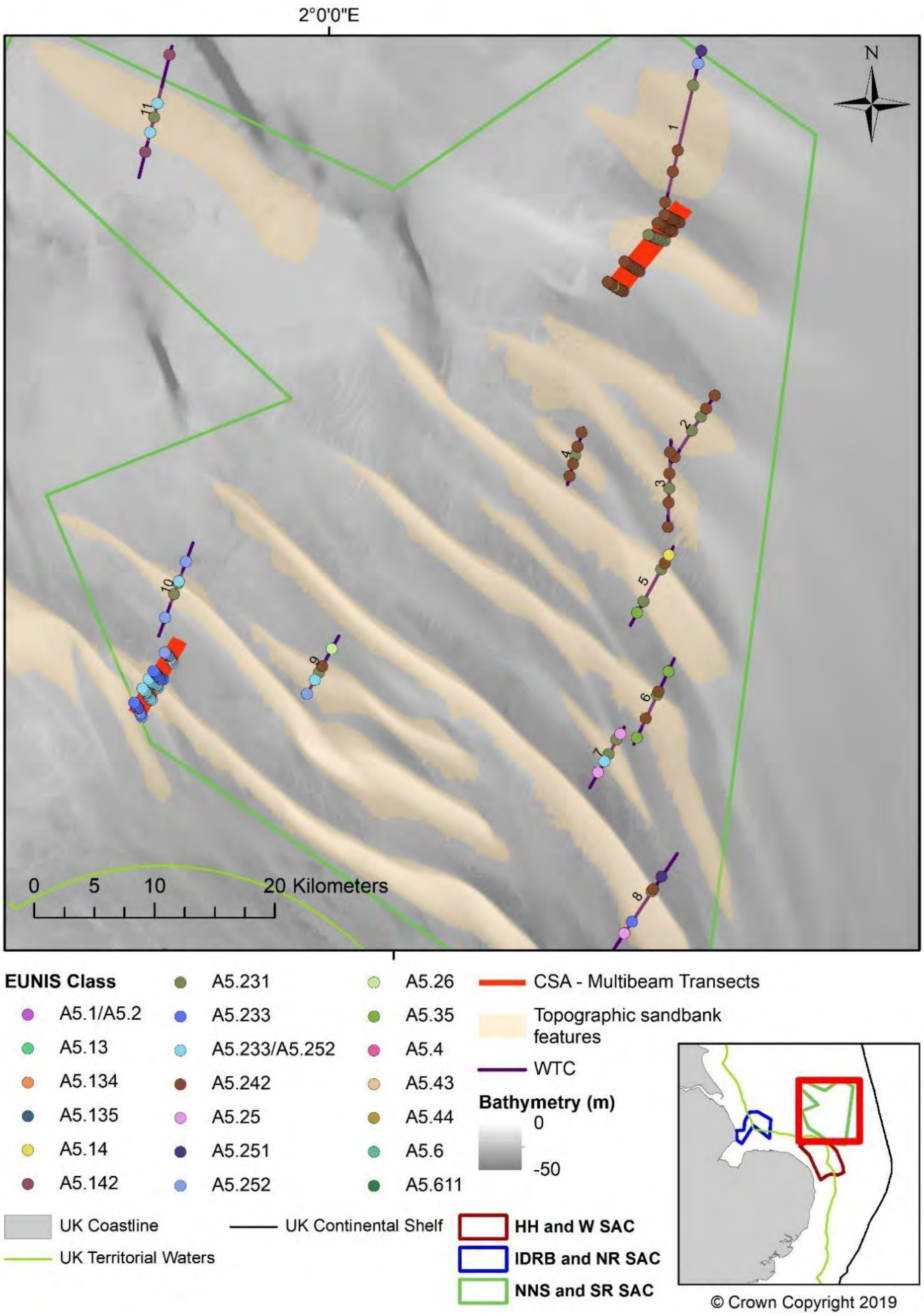


Figure 25. Biotopes determined for infaunal communities inhabiting topographical zones of the North Norfolk Sandbanks and Saturn Reef SAC Wider Characterising Transects.

4.2.3 Haisborough, Hammond and Winterton SAC

Sediment composition

The sediments of the sandbanks within HHW are coarser relative to those of the other SACs (Figure 26). Sediments of all topographical zones of South West Haisborough Tail (in the west of the site) are composed mainly of medium to very coarse sand and gravel (entropy groups ‘1a’ and ‘2a’).

Smith’s Knoll in the eastern part of the SAC comprises medium and fine sand (entropy group 5a) on the crest, with fine sand (entropy group ‘4a’) on the seaward flank and mainly medium sand (entropy group ‘1a’) on the shoreward flank. The seaward trough and both ‘beyond sandbank’ zones contain some areas of gravelly sands, mixed sediments and muds.

Mixed sediments were observed at the WCTs of both Winterton Ridge (WCT015) and Middle Ground (WCT017), although this may be associated with the presence of *S. spinulosa*[17].The WCTs show a similar pattern in sediment type to the CSAs which implies the observations based on the latter may be regarded as being representative of the whole SAC (Figure 26).

[17] Any *S. spinulosa* tubes present in a sediment sample are processed as part of the sediment within the PSA method, and, as a result, these sediments become integrated with the sample being analysed. Resultingly, intact tubes will be represented in the gravel fraction, while those that break down will be represented as finer sediment.

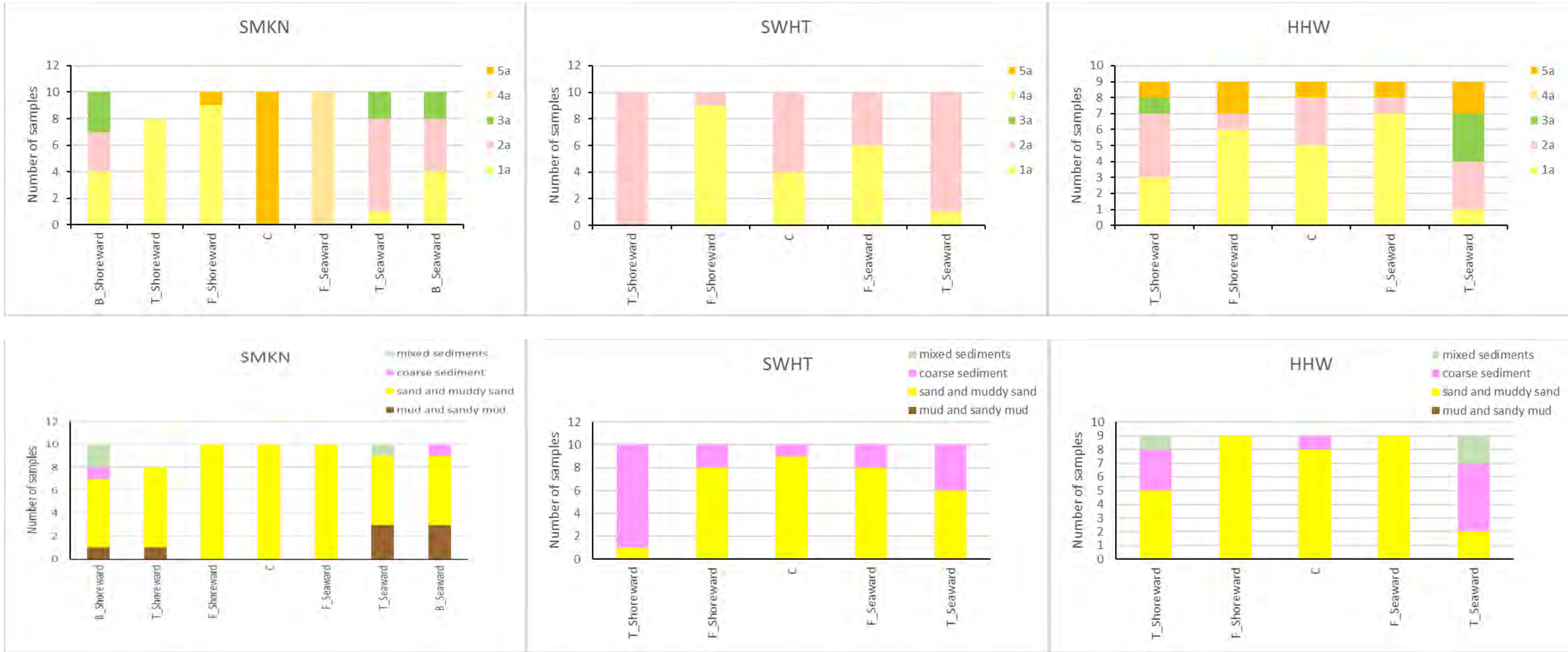


Figure 26. Stacked histograms showing number of samples in each form for entropy sediment groups (top) and EUNIS broad sediment classification (bottom) at Smiths Knoll (SMKN), South West Haisborough Tail (SWHT) and the nine Wider Characterising Transects (HHW) in Haisborough, Hammond and Winterton SAC. * T = trough; F = flank; C = crest.

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Case Study Areas: Community structure

Infauna

At Smiths Knoll, numbers of species on the seaward topographical zones were twice as numerous than found on the shoreward zones (Table 16). Abundances on the seaward flanks and troughs were also significantly greater than the shoreward zones. Margalef's richness and Hill's diversity values were low for the shoreward zones, with trough and beyond sandbank zones exhibiting lower values than for the crest.

The number of species at South West Haisborough Tail showed the lowest variation between crest, flank and trough. However, abundances on both seaward and shoreward flanks were significantly greater than in the troughs (due to the relatively higher abundances of the polychaete *O. borealis)*. Margalef's species richness index (d) and Hill's species diversity (N1) were low at all topographical locations, with crests and flanks representing the lowest values for all CSAs studied (Table 16).

Table 16. Mean (per $0.1m^2$, ±95% confidence) diversity measures at each topographical zone on Smiths Knoll (SMKN) and South West Haisborough Tail (SWHT) CSAs within Haisborough, Hammond and Winterton (HHW) SAC*.

Bank	Topographical zone	Number of species (S)	Number of individuals (N)	Species richness Margalef's (d)	Species diversity Hill's (N1)
SMKN	B(shore)	7.10 (±0.41)	48.80 (±9.01)	1.70 (±0.10)	3.64 (±0.23)
	T(shore)	5.50 (±0.52)	15.00 (±1.56)	1.73 (±0.15)	4.32 (±0.46)
	F(shore)	6.80 (±0.46)	22.40 (±1.86)	1.89 (±0.13)	4.95 (±0.30)
	C	5.20 (±0.35)	9.50 (±0.75)	1.87 (±0.11)	4.53 (±0.30)
	F(sea)	14.20 (±0.81)	83.40 (±7.09)	3.01 (±0.16)	7.68 (±0.39)
	T(sea)	12.00 (±0.73)	75.60 (±9.77)	2.66 (±0.20)	5.32 (±0.61)
	B(sea)	13.50 (±0.66)	59.00 (±5.95)	3.11 (±0.13)	6.79 (±0.44)
SWHT	T(shore)	5.10 (±0.53)	9.10 (±1.03)	1.88 (±0.16)	4.33 (±0.40)
	F(shore)	5.20 (±0.26)	36.80 (±9.74)	1.42 (±0.08)	3.32 (±0.21)
	C	2.60 (±0.32)	5.50 (±0.76)	1.21 (±0.13)	2.39 (±0.26)
	F(sea)	3.90 (±0.37)	13.10 (±2.49)	1.26 (±0.10)	2.80 (±0.26)
	T(sea)	4.90 (±0.54)	9.00 (±0.88)	1.93 (±0.19)	4.20 (±0.54)

* B = 'beyond sandbank'; T = trough; F = flank; C = crest; sea = seaward facing; shore = shoreward facing.

Multivariate analyses shows that the most notable difference in infaunal community composition between topographical zones on Smiths Knoll is the separation between the seaward flank, trough and 'beyond sandbank' samples from those of the crests, shoreward flanks, troughs and 'beyond sandbanks' (Figure 27). The seaward trough samples also cluster away from the crest and the shoreward flank and trough samples but do appear to cluster more closely with the 'beyond sandbank' samples.

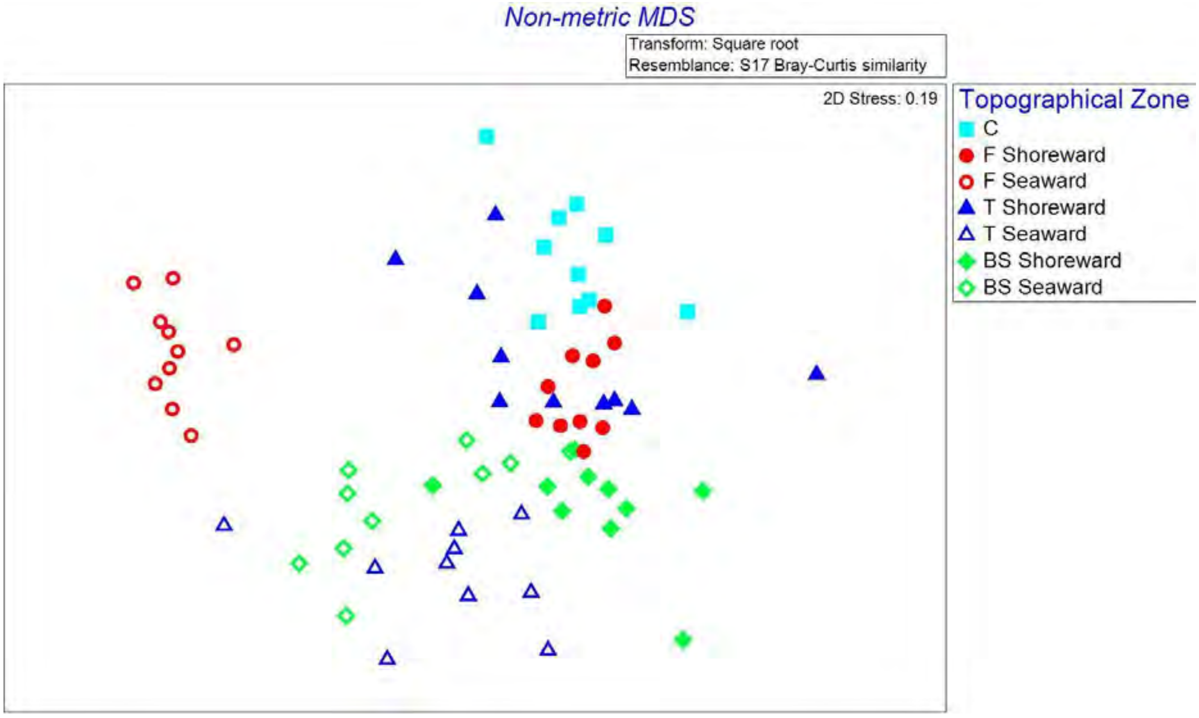


Figure 27. nMDS ordination of infaunal community composition of Smiths Knoll within the Haisborough Hammond and Winterton (HHW) SAC, displayed according to topographical zone (C = crest, F = flank, T = trough, BS = beyond sandbanks) and seaward/shoreward orientation.

ANOSIM pairwise tests confirm the differences observed in the nMDS (Table 17) suggesting that communities inhabiting the seaward flank are highly different to all other topographical zones. ANOSIM also suggests some overlap in community composition between crest and shoreward flank and trough, although significant differences were also observed. Seaward trough and 'beyond sandbank' samples show greatest community similarity with the ANOSIM test suggesting the communities are not significantly different. Differences are observed between shoreward trough and 'beyond sandbank' samples, although the R statistic suggests the communities strongly overlap in composition.

Table 17. ANOSIM pairwise tests between topographical zones at Smiths Knoll.

Pairwise Tests Groups	**R Statistic**	**Significance Level %**
Crest, F Shoreward	0.384	0.1
Crest, F Seaward	0.996	0.1
Crest, T Shoreward	0.263	0.4
Crest, T Seaward	0.872	0.1
F Shoreward, F Seaward	1	0.1
F Shoreward, T Shoreward	0.196	0.8
F Shoreward, T Seaward	0.65	0.1
F Seaward, T Shoreward	0.942	0.1
F Seaward, T Seaward	0.924	0.1
T Shoreward, T Seaward	0.509	0.1

Pairwise Tests Groups	R Statistic	Significance Level %
BS Shoreward, BS Seaward	0.431	0.1
BS Shoreward, C	0.656	0.2
BS Shoreward, F Shoreward	0.242	0.1
BS Shoreward, F Seaward	0.972	0.1
BS Shoreward, T Shoreward	0.28	0.2
BS Shoreward, T Seaward	0.303	0.2
BS Seaward, C	0.785	0.1
BS Seaward, F Shoreward	0.572	0.2
BS Seaward, F Seaward	0.93	0.1
BS Seaward, T Shoreward	0.49	0.1
BS Seaward, T Seaward	0.071	15.4

Multivariate analyses of the South West Haisborough Tail infaunal communities show high variability within groups, with some overlap in species composition between locations on the bank (Figure 28). A gradient from crest to trough is apparent for both seaward and shoreward side of the bank.

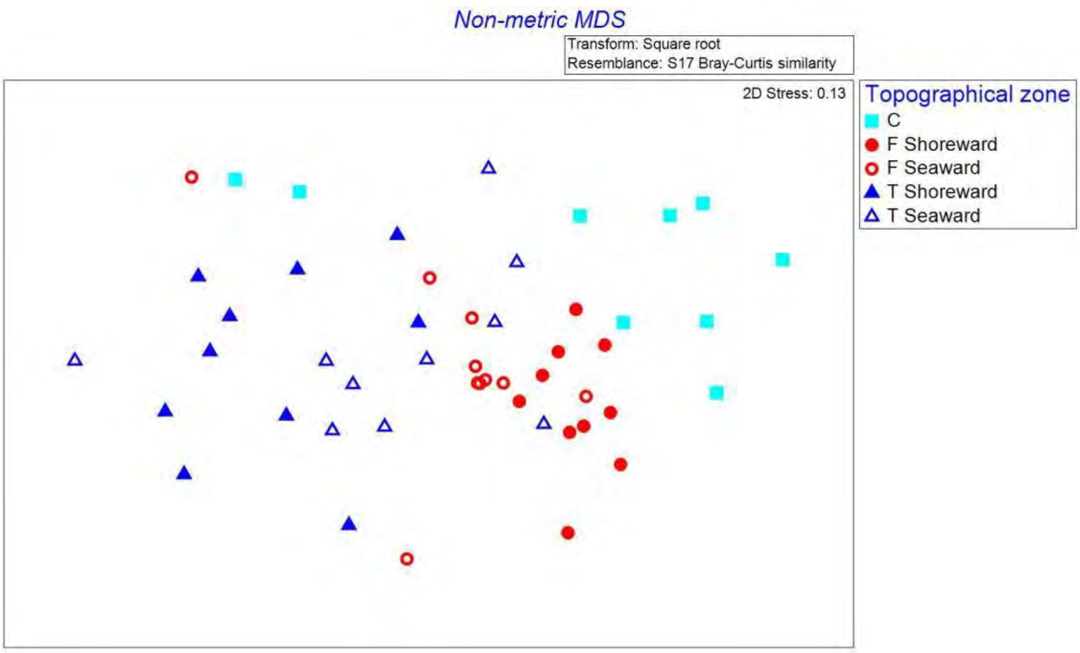


Figure 28. nMDS ordinations of infaunal community composition at South West Haisborough Tail within the Haisborough Hammond and Winterton (HHW) SAC, displayed according to topographical zone (crest, flank, trough) and seaward/shoreward orientation.

ANOSIM analysis showed this CSA to be one of the least different, in terms of infaunal community composition, between topographical zones (R = 0.428, p<0.001). The greatest differences were observed between shoreward flank and trough communities, whilst seaward trough and flank were not significantly different.

Table 18. ANOSIM pairwise tests between topographical zones at South West Haisborough Tail.

Pairwise Tests Groups	R Statistic	Significance Level %
Crest, Flank (Shore)	0.373	0.1
Crest, Flank (Sea)	0.438	0.1
Crest, Trough (Shore)	0.508	0.2
Crest, Trough (Sea)	0.397	0.1
Flank (Shore), Flank (Sea)	0.317	0.1
Flank (Shore), Trough (Shore)	0.834	0.1
Flank (Shore), Trough (Sea)	0.448	0.1
Flank (Sea), Trough (Shore)	0.55	0.2
Flank (Sea), Trough (Sea)	0.041	18.2
Trough (Shore), Trough (Sea)	0.275	0.9

Epifauna

Epifauna were sampled only from the South West Haisborough Tail CSA in HHW. Univariate metrics show increases in number of species, individuals and biomass between crest and flanks (seaward and shoreward), but with decreases from flank to trough, reflecting the patterns observed in the infauna. Lowest metrics are observed for the shoreward trough, where numbers of species, individuals and biomass values are lower than found on the crest.

Table 19. Mean (per 600m^{2*}, ±95% confidence) diversity measures and biomass at each topographical zone on South West Haisborough Tail CSA within HHW SAC**.

Bank	Topographical Zone	Number of Species (s)		Number of Individuals (N)		Biomass (g)	
SWHT	T(shore)	7.50	(± 1.50)	8.00	(± 2.00)	57	(± 7)
	F(shore)	13.67	(± 0.88)	55.67	(± 3.67)	369	(± 120)
	C	8.00	(± 2.08)	25.67	(± 13.69)	214	(± 103)
	F(sea)	11.67	(± 2.33)	106.00	(± 49.52)	513	(± 197)
	T(sea)	11.50	(± 0.50)	50.50	(± 14.50)	147	(± 68)

* The crest and shoreward flank datasets contained one less replicate of 300m^2. The shoreward and seaward trough datasets both consisted only 2 sampling locations representing 600m^2.
** T = trough; F = flank; C = crest; sea = seaward facing; shore = shoreward facing.

Multivariate analyses of the epifaunal communities at SWHT show low within zone variability of the shoreward flank and seaward trough samples (and to a lesser extent for the shoreward trough) (Figure 29). Whilst similarities are observed for two of the samples for both crest and seaward flank, one sample from each zone is spatially separated, suggesting different communities may exist.

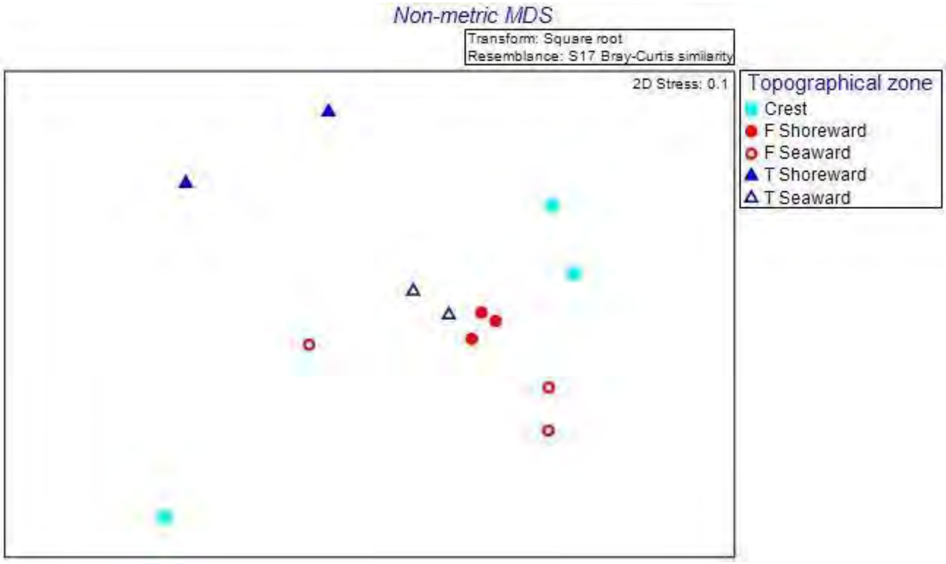


Figure 29. nMDS ordination of epifaunal community composition at South West Haisborough Tail within HHW SAC, displayed according to topographical zone (crest, flank, trough) and seaward/shoreward orientation.

Biotopes

Smiths Knoll

Differences observed between the seaward flank and other topographical zones at Smiths Knoll are largely due to the presence of relatively high abundances of the bivalve species *Fabulina fabula* (7 to 50 individuals per grab) and *Abra alba* (7 to 19 individuals per grab) on the seaward flank, all of which were absent from all other topographical zones (with the exception of 23 individuals of *A. alba* present within one seaward trough sample). The sediment type on the seaward flank was also different to all other topographical zones (entropy group '4a'), being characterised by higher proportions of fine sands and slightly higher mud content than was found on the crest and shoreward flank and trough. This sediment type is favoured by both *F. fabula* and *A. alba,* and as such the community resembles the biotope 'A5.242: *Fabulina fabula* and *Magelona mirabilis* with venerid bivalves and amphipods in infralittoral compacted fine muddy sand'.

The seaward trough samples of Smiths Knoll also separated away from the main cluster due to the higher abundances of the polychaetes *O. borealis* and *Scalibregma inflatum* although the within-station similarity in species composition at this topographical zone was low (~36%). Sediment composition was more variable between samples from the seaward trough and 'beyond sandbank' samples, hence the biotopes assigned represent several different broadscale habitats (at EUNIS level 3).

The crest samples of Smiths Knoll are dominated by low abundances of the polychaetes *Nephtys cirrosa* and *Magelona johnstoni* along with the amphipod *Urothoe brevicornis* and resemble the biotope 'A5.231: Infralittoral mobile clean sand with sparse fauna'. These three species, along with *Lanice conchilega* and *Bathyporeia elegans,* were also found in the shoreward flank and trough samples, and were therefore also assigned to 'A5.231: Infralittoral mobile clean sand with sparse fauna' due to the low abundances of all species present (Figure 30).

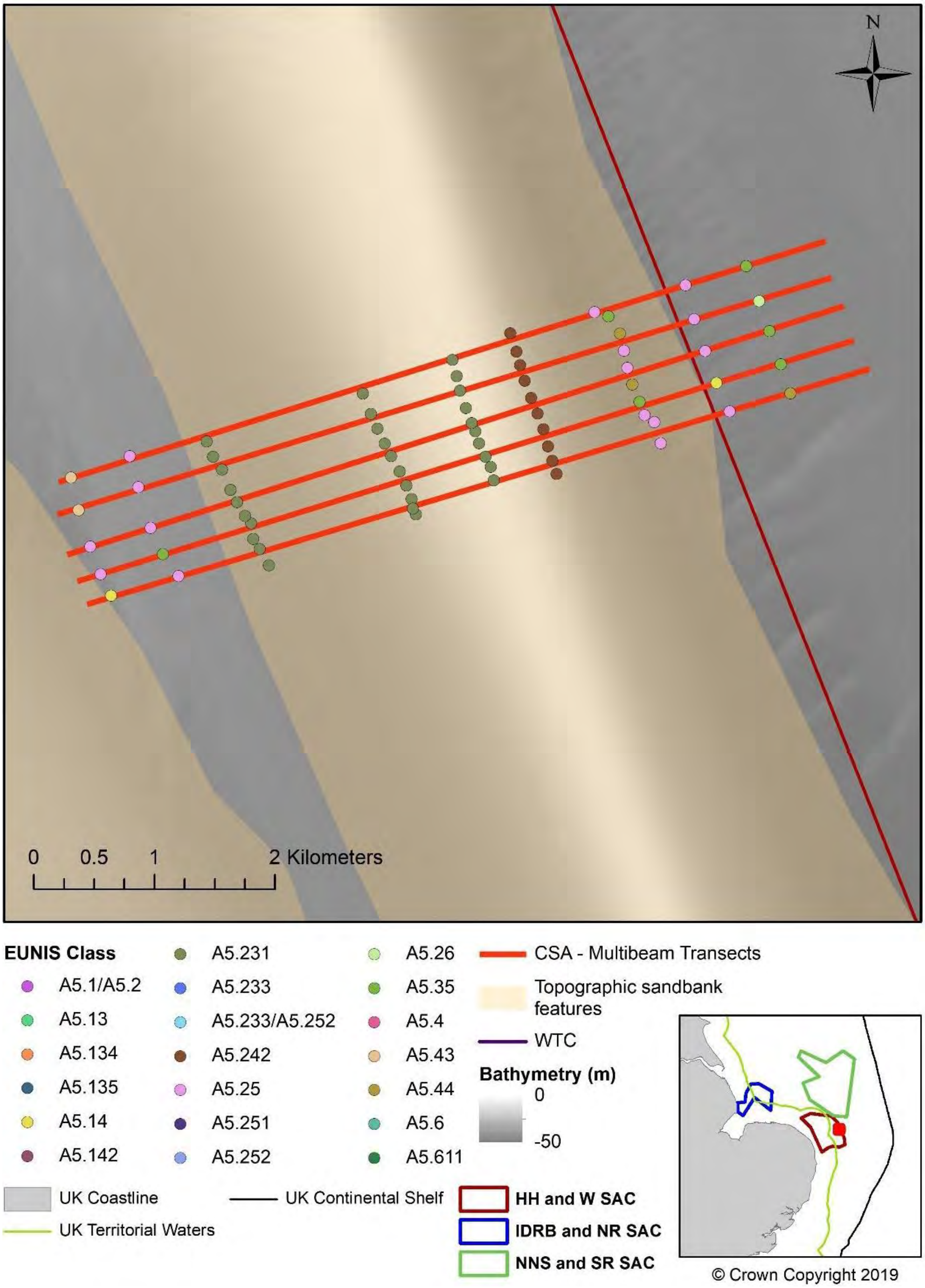


Figure 30. Biotopes determined for infaunal communities inhabiting topographical zones of the Smiths Knoll CSA (including 'Beyond Sandbank' samples).

South West Haisborough Tail

Infaunal crest communities at South West Haisborough Tail were characterised by low abundances of the amphipod *Haustorius arenarius* and mysid *Gastrosaccus spinifer*. Both species were also present on the seaward and shoreward flanks, although *H. arenarius* was absent from both troughs. This amphipod species is common in the intertidal up to the high-water mark and therefore may be at its depth limit on this sandbank. This species, along with the amphipods *Pontocrates arenarius* and *Bathyporeia pelagica* (also present on the crests) are characteristic of the EUNIS littoral biotope 'A2.2233: *Pontocrates arenarius* in littoral mobile sand'. However, as the samples were collected from the subtidal, the biotope 'A5.231: Infralittoral mobile clean sand with sparse fauna' was assigned. *O. borealis* was also present in low numbers on the crest, with slight increases in density on the flanks and troughs. Seaward and shoreward trough samples were characterised by low abundances of the polychaetes *Glycera lapidum*, *Spio goniocephala* and *Nephtys cirrosa* and the phylum Nemertea and resemble the coarse sediment biotope 'A5.135 *Glycera lapidum* in impoverished infralittoral mobile gravel and sand' (Figure 31). All trough samples were classified as entropy group '2a' which comprised ~7% gravel and were equivalent to the EUNIS 'A5.1 Sublittoral coarse sediment' habitat.

For the epifauna, crangonidae was the most characteristic taxon for all topographical zones, with highest abundances on the shoreward flank and seaward trough. The lesser weever, *E. vipera*, was characteristic of all topographical zones, with exception of the shoreward trough. Low abundances of few epifaunal taxa (Crangonidae, and *Nemertesia*) were characteristic of the shoreward trough. Overall numbers of epifaunal taxa were low, potentially due to the stronger tidal conditions experienced at this CSA (see Figure 7).

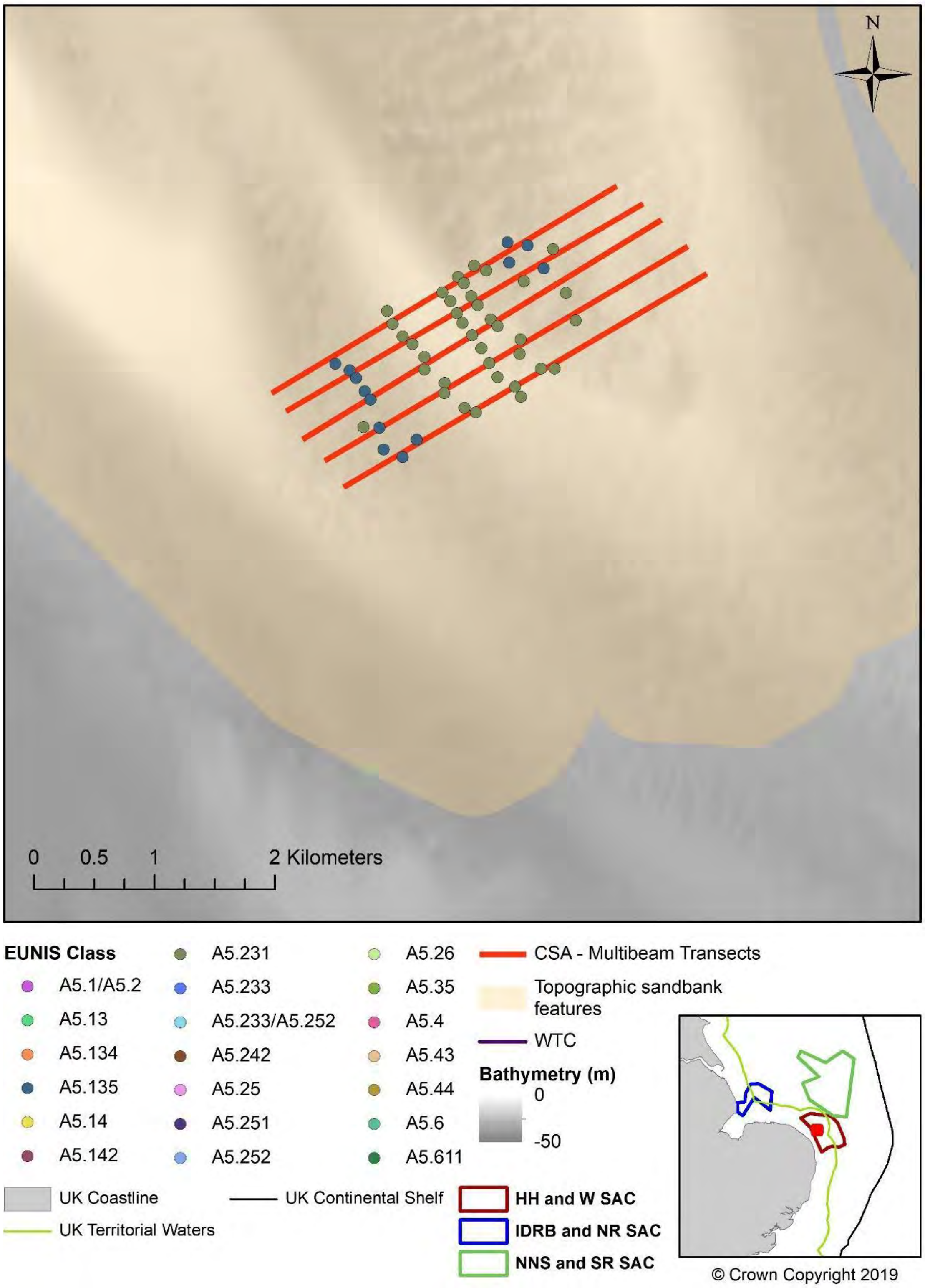


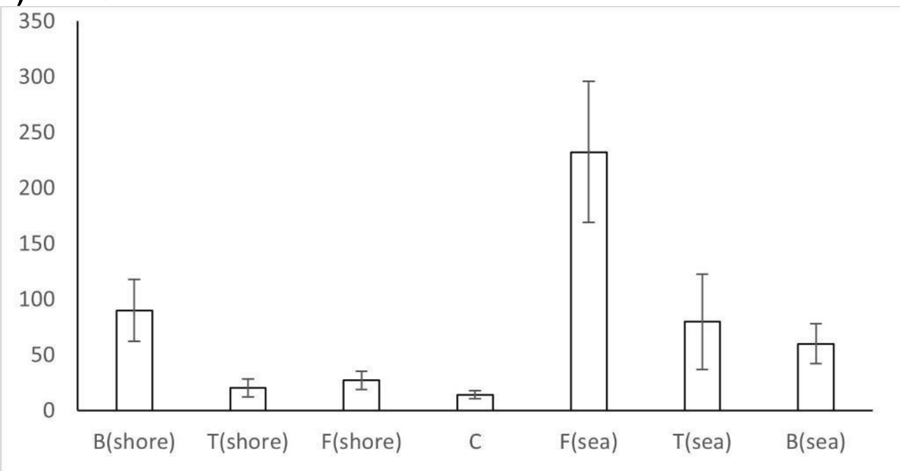
Figure 31. Biotopes determined for infaunal communities inhabiting topographical zones of the South West Haisborough Tail CSA.

Case Study Areas: Secondary productivity

Secondary production estimates for the HHW site generally fell under 100kJm^{-2}y^{-1} (i.e. 8.4 – 90.9kJm^{-2}y^{-1}), with the exception of the seaward flank of Smiths Knoll where secondary production was estimated at 232.41 (±63.54) kJm^{-2}y^{-1} (Figure 32).

Smiths Knoll was the only CSA that showed significant differences in productivity between seaward and shoreward flanks (t-test; T = -6.38, p<0.001). There was also a significantly higher secondary production estimate recorded on the seaward trough compared to the shoreward trough at Smiths Knoll (t-test; T = -2.68, p = 0.03). As was the case at Smiths Knoll, the seaward flank of South West Haisborough Tail was also the most productive topographical zone of the CSA. The crests of both CSAs within HHW followed the general trend of other surveyed CSAs in being the least productive zone on the bank.

a) Smiths Knoll



b) South West Haisborough Tail

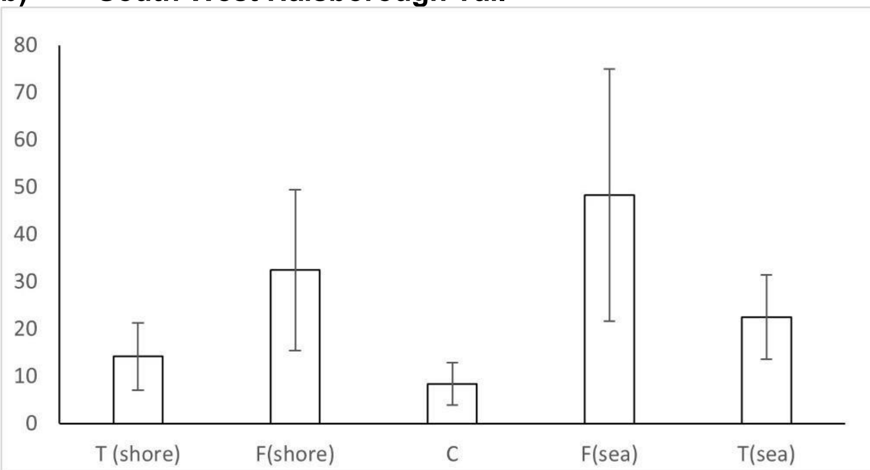


Figure 32. Mean total annual secondary production (kJm^{-2}y^{-1}) of the macrofaunal assemblages of a) Smiths Knoll and b) South West Haisborough Tail within Haisborough Hammond and Winterton (HHW) SAC*.
* Error bars represent 95% confidence intervals. T = trough; F = flank; C = crest; B = 'beyond sandbank'; sea = seaward facing; shore = shoreward facing.

At Smiths Knoll, shoreward trough assemblages appear to show greater functional variability than those on the seaward trough (Figure 33). At 'beyond sandbank' locations, of both orientations, functional variability appears indistinguishable. The greatest functional separation at Smiths Knoll appears at the seaward flank, which coincides with the area of greatest productivity within the CSA. At South West Haisborough Tail trough, assemblages show large variability regardless of orientation, whilst there is a certain level of overlap in a number of seaward flank assemblages.

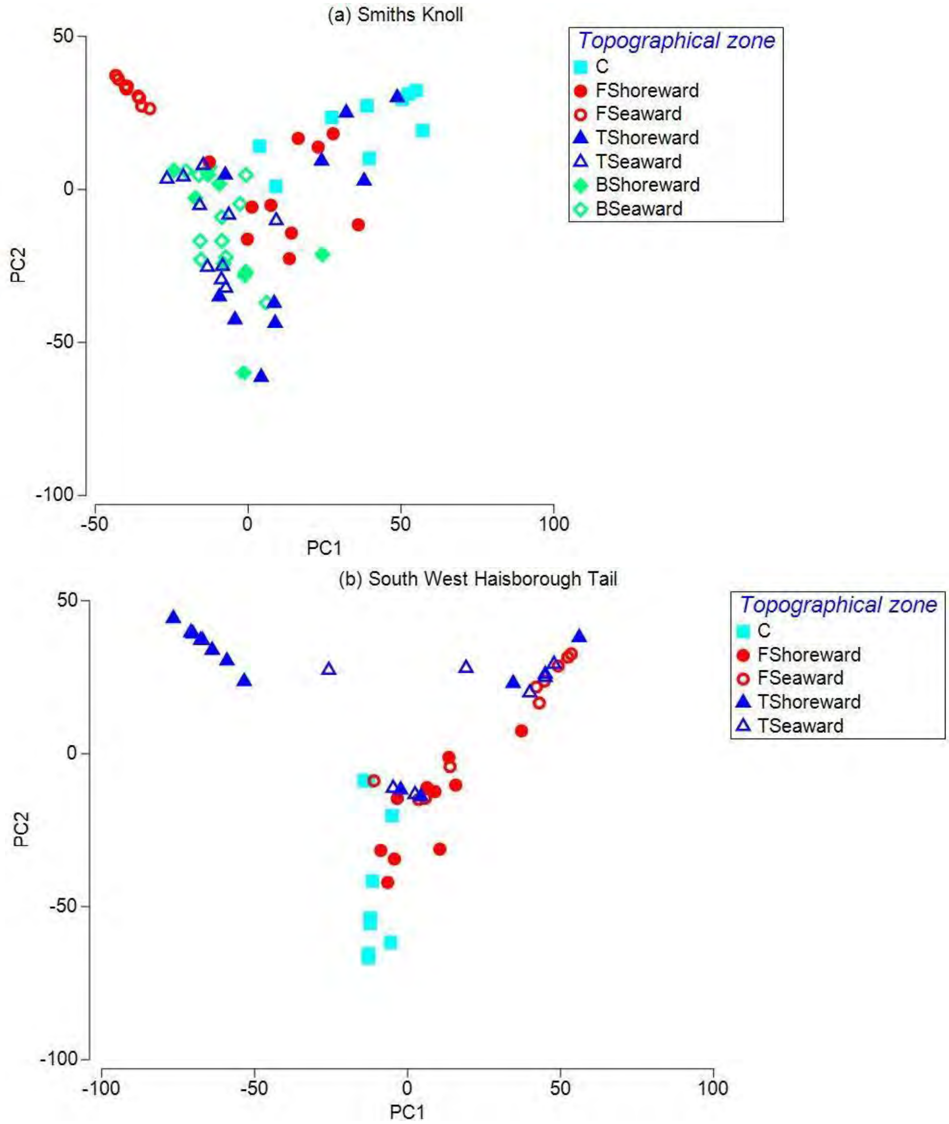


Figure 33. PCA plot of taxonomic contribution to total production at a) Smiths Knoll and b) South West Haisborough Tail within Haisborough Hammond and Winterton (HHW) SAC*.
* B = 'beyond sandbank'; T = trough; F = flank; C = crest.

As observed at other CSAs, secondary production at Smiths Knoll and South West Haisborough Tail was greatly influenced by annelid worms (P) (Figure 34).

At Smiths Knoll the exception to this was the seaward flank where only molluscs (W) notably contributed towards secondary production. For the majority of other topographical zones (across both orientations) crustaceans (S) also contributed towards production estimates. The exception at South West Haisborough Tail was crest assemblages, where secondary production was not heavily influenced by annelid worms but more so by crustaceans and in the case of two samples, sipunculids (G).

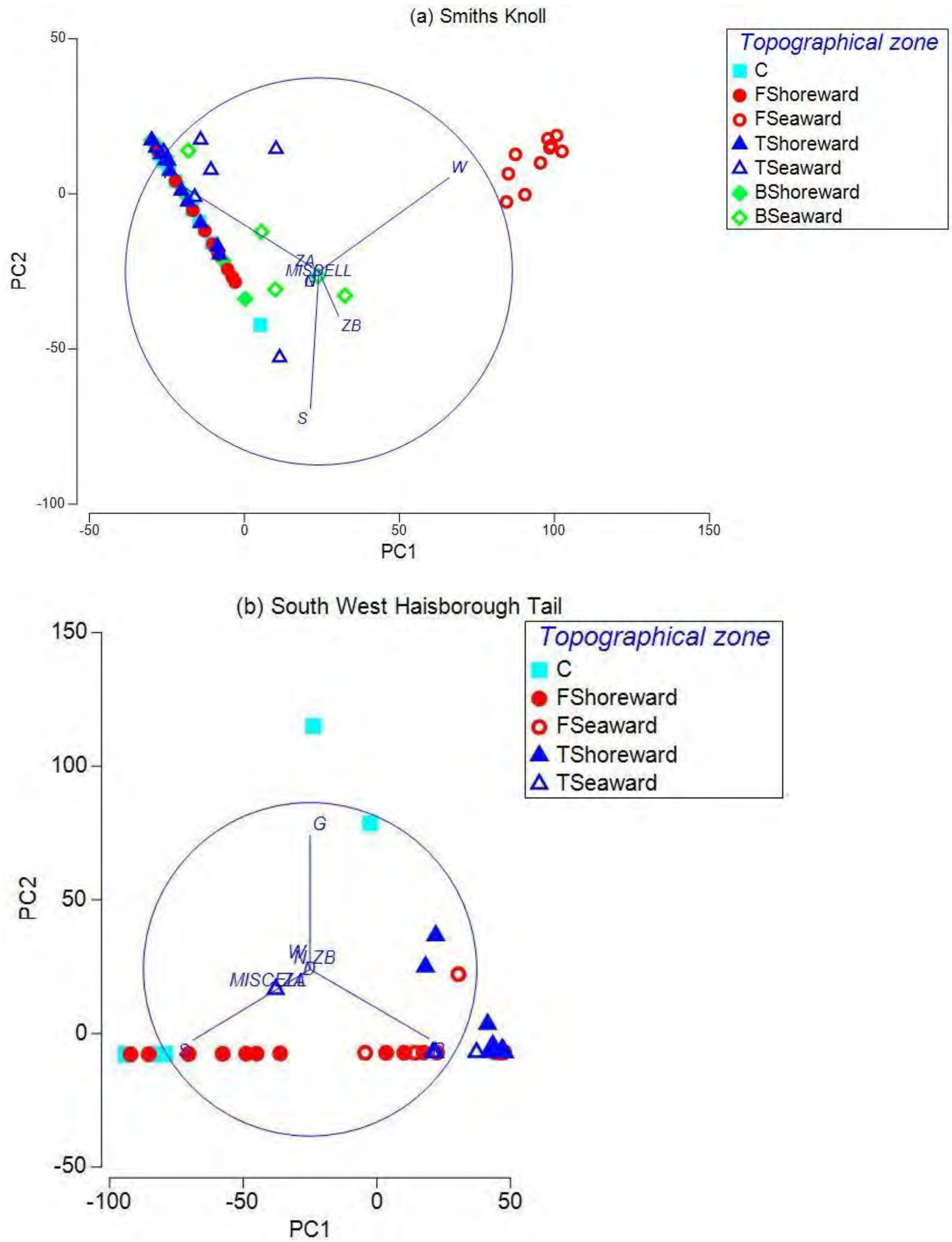


Figure 34. PCA plot based on the relative contribution to total production of the major taxonomic phyla at a) Smiths Knoll and b) South West Haisborough Tail within Haisborough Hammond and Winterton SAC*.

* The vector trajectories reflect the influence of each phyla group to each of the first two principal component axes. D = actinarians; G = sipunculids; N = nemerteans; P = annelids; S = crustaceans; W = molluscs; ZA = phoronids; ZB = echinoderms; MISCELL = miscellaneous phyla (e.g. sea spiders, turbellarians). B = 'beyond sandbank'; T = trough; F = flank; C = crest; seaward = seaward facing; shoreward = shoreward facing.

Wider Characterising Transects (WCTs)

Nine WCTs were sampled for infauna across the HHW SAC to make qualitative comparisons with data collected from each of the CSAs. Figure 35 and Figure 36 suggest there is high variation in the infaunal community composition across the SAC, although less so than for NNSSR. The WCTs exhibit greater affinity with samples from SWHT than with those from SMKN, although Figure 36 shows some similarity in community composition between both CSAs and WCTs (SIMPROF group n). SMKN seaward flank communities are significantly different to all other zones and are the only zone classified as entropy group 4 (Figure 37). Similar patterns are observed between the SIMPROF groups and sediment entropy groups, although several sediment types are apparent with the main faunal cluster group (n). Differences in sediment type according to the faunal clusters are less apparent when displayed according to EUNIS sediment classes (figure not shown).

Biotopes within HHW SAC (Figure 38), are broadly similar between WCTs and CSAs, with most topographical zones classified as A5.231: Infralittoral mobile clean sand with sparse fauna.'

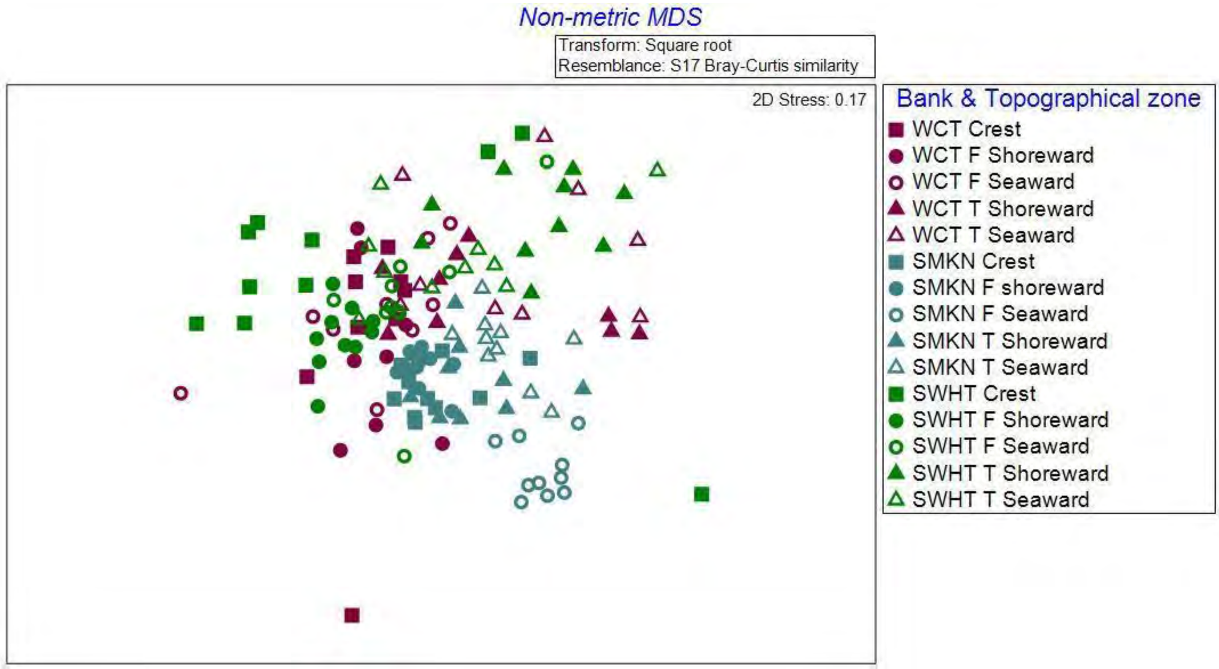


Figure 35. nMDS ordination of WCT and CSA infauna within HHW SAC.
*WCT = Wider Characterising Transect, SMKN = Smiths Knoll, SWHT = South West Haisborough Tail. T = trough; F = flank; C = crest.

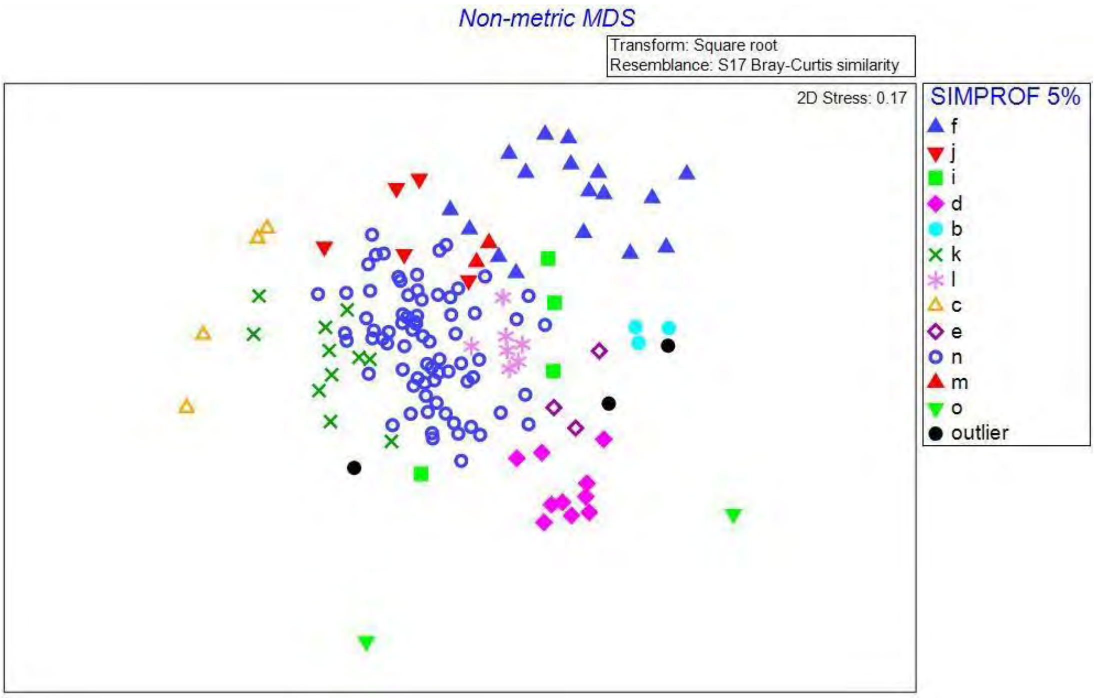


Figure 36. nMDS ordination of WCT and CSA infauna within HHW SAC, displayed according to SIMPROF groups.

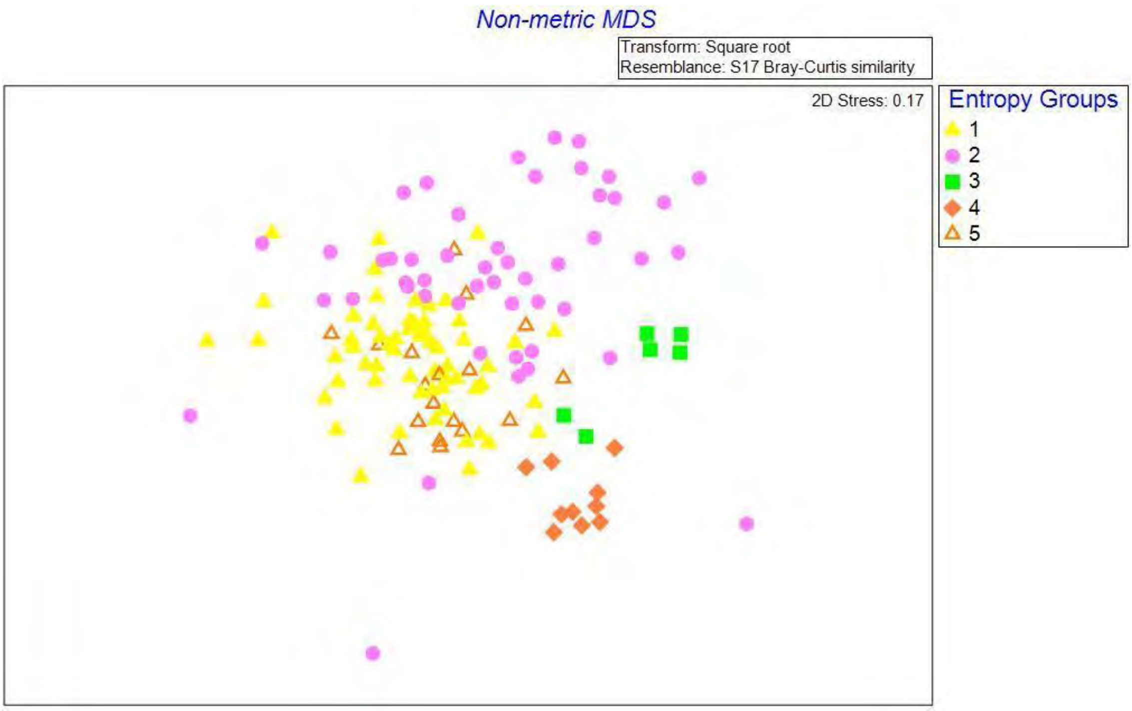


Figure 37. nMDS ordination of WCT and CSA infauna within HHW SAC, displayed according to sediment entropy groups.

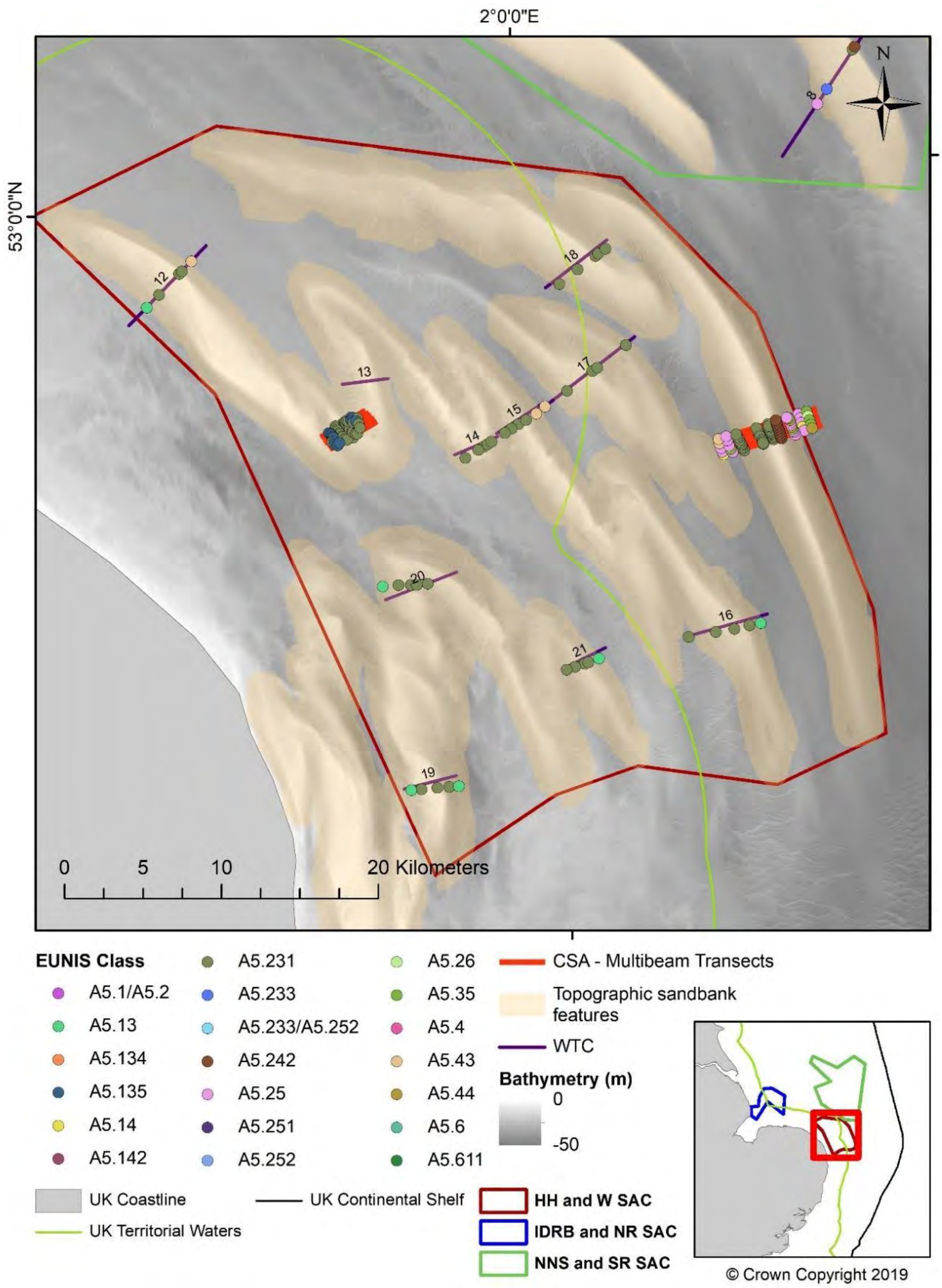


Figure 38. Biotopes determined for infaunal communities inhabiting topographical zones of the Haisborough Hammond and Winterton SAC Wider Characterising Transects.

4.2.4 Inner Dowsing, Race Bank and North Ridge SAC

Sediment types

The sediments within IDRBNR SAC, were more variable than those at NNSSR and HHW (Figure 39). This is particularly evident at Inner Dowsing, where mixed and coarse sand sediments were observed. However, as was the case for HHW, this may be associated with the presence of *S. spinulosa* tubes within the samples analysed. Inner Dowsing's crest and some flank samples were composed of medium to coarse sand, whilst the majority of shoreward flank, trough and beyond sandbank topographical zones at this sandbank were composed of mixed sediment with an average of 21% silt/clay and 23% gravel.

North Ridge crest and shoreward trough samples were dominated by medium and fine sands (entropy group '5a'), whilst medium and coarse sands (entropy groups '1a' and '2a') became more dominant from flank to trough on the seaward side of the bank and on the shoreward flank.

The single WCT shows a similar pattern in sediment grain size to those of the CSAs. This supports the notion that the CSAs at this site may be regarded as being representative of the site.

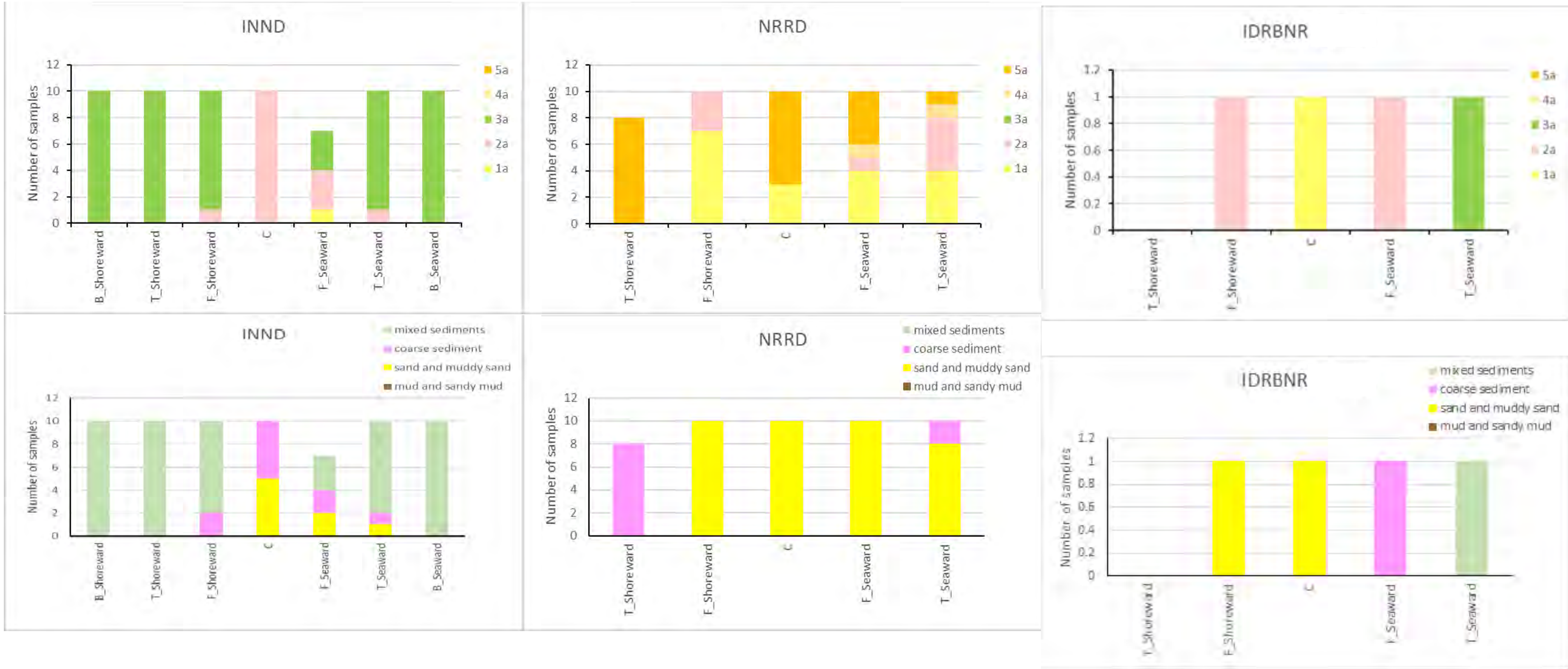


Figure 39. Stacked histograms showing number of samples in each entropy sediment groups (top) and EUNIS classification (bottom) at Inner Dowsing (INND) and North Ridge (NRRD) CSAs and Race Bank (RCBK) WCT, in the Inner Dowsing, Race Bank and North Ridge (IDRBNR) SAC*.
* T = trough; F = flank; C = crest; B ='beyond sandbank'.

Case Study Areas: Community structure

Infauna

Infaunal univariate metrics at Inner Dowsing generally followed similar trends (decline from trough to crest) observed at the other CSAs within NNSSR and HHW SACs. However, the values of all metrics were significantly higher on the flanks, troughs and 'beyond sandbank' zones than the crest at Inner Dowsing (Table 20). These values were also the highest observed across all CSAs. Conversely the number of species and individuals inhabiting the crests were some of the lowest values (along with North Ridge) of all the CSAs.

Margalef's species richness index (d) was highest for samples located in the troughs and 'beyond sandbank' locations at Inner Dowsing. Hill's species diversity (N1) was also highest at these locations at Inner Dowsing.

All topographical zones of North Ridge, with exception of the shoreward trough, were low in species number and abundance (Table 20). The amphipod *A. diadema* was dominant (485 individuals per grab) at just one station located on the seaward flank, causing an increase in overall abundance at this topographical zone. High abundances of this species in both the seaward and shoreward trough samples were also partly responsible for the elevated overall abundances at this sandbank, along with high abundances of *S. spinulosa*.

Table 20. Mean (±95% confidence) diversity measures 0.1m^2 at each topographical zone on Inner Dowsing (INND) and North Ridge (NRRD) CSAs surveyed within Inner Dowsing, Race Bank and North Ridge (IDRBNR) SAC*.

Bank	Position	Number of species (S)	Number of individuals (N)	Species richness Margalef's (d)	Species diversity Hill's (N1)
INND	B(shore)	83.40 (±3.92)	1021.50 (±117.84)	12.11 (±0.39)	18.28 (±1.62)
	T(shore)	80.60 (±2.89)	864.80 (±53.96)	11.80 (±0.36)	18.14 (±0.74)
	F(shore)	31.90 (±2.04)	95.20 (±9.82)	6.83 (±0.33)	20.13 (±1.24)
	C	2.60 (±0.30)	4.60 (±0.49)	1.19 (±0.15)	2.47 (±0.26)
	F(sea)	29.86 (±9.00)	259.86 (±125.08)	5.45 (±1.18)	12.20 (±2.54)
	T(sea)	50.70 (±3.19)	530.80 (±101.07)	8.43 (±0.51)	15.07 (±1.90)
	B(sea)	59.30 (±2.05)	401.40 (±64.73)	10.03 (±0.24)	26.62 (±1.00)
NRRD	T(shore)	53.13 (±3.78)	181.38 (±18.61)	10.11 (±0.63)	23.81 (±2.25)
	F(shore)	4.50 (±0.53)	6.50 (±1.13)	2.15 (±0.13)	4.10 (±0.41)
	C	2.10 (±0.27)	3.20 (±0.36)	1.13 (±0.15)	2.10 (±0.23)
	F(sea)	4.50 (±0.83)	10.20 (±1.84)	1.56 (±0.26)	3.42 (±0.59)
	T(sea)	7.30 (±0.47)	24.80 (±3.42)	2.19 (±0.19)	5.06 (±0.51)

* B = 'beyond sandbank'; T = trough; F = flank; C = crest; sea = seaward facing; shore = shoreward facing.

Multivariate analyses of the communities inhabiting the crest and seaward flank of Inner Dowsing (Figure 40) showed high variability, in comparison with the shoreward flanks and both troughs at this site. ANOSIM analysis showed significant overall differences between topographical zones (Global R = 0.579, $p<0.001$). Slight differences were observed (at the 5% significance level) between crest and seaward flank communities, however both were highly variable. The most significant differences were observed between the shoreward flank and trough communities. This was due to the high average abundances of *S. spinulosa* and other species such as the bivalve mollusc *Nucula nitidosa*, the suspension-feeding worm *Jasmineira elegans* and the tube-building, amphipod crustacean *Ampelisca diadema* within the shoreward trough. These species were either absent or significantly reduced on the shoreward flank.

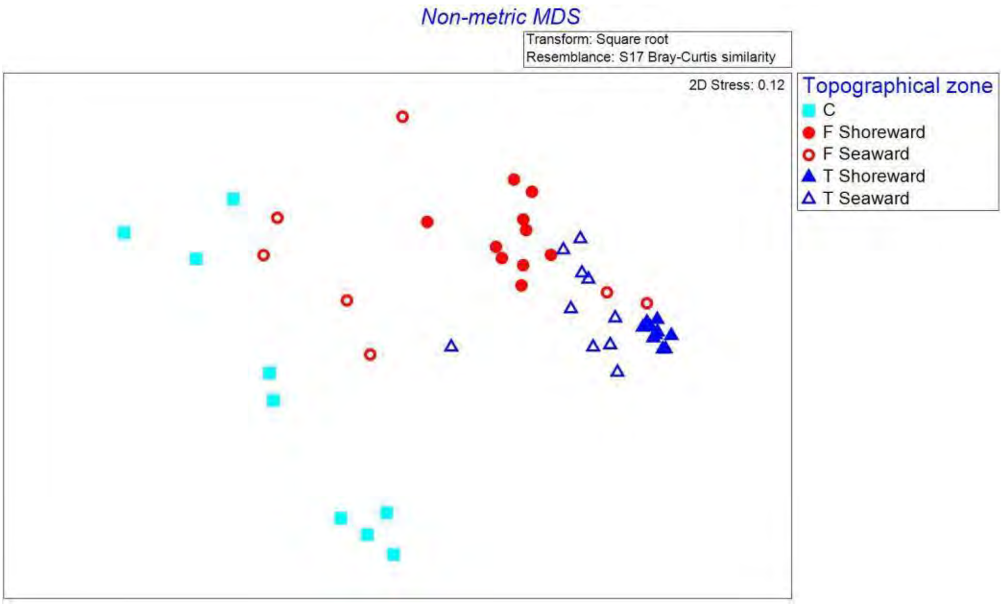


Figure 40. nMDS ordinations of infaunal community composition of Inner Dowsing within the Inner Dowsing, Race Bank and North Ridge (IDRBNR) SAC, displayed according to topographical zone (crest, flank, trough) and seaward/shoreward orientation.

Table 21. ANOSIM pairwise tests between topographical zones at INND.

Pairwise Tests Groups	R Statistic	Significance Level %
Crest, F Seaward	0.17	6.1
Crest, F Shoreward	0.58	0.1
Crest, T Seaward	0.589	0.1
Crest, T Shoreward	0.604	0.1
F Seaward, F Shoreward	0.642	0.1
F Seaward, T Seaward	0.416	0.4
F Seaward, T Shoreward	0.731	0.1
F Shoreward, T Seaward	0.573	0.1
F Shoreward, T Shoreward	0.999	0.1
T Seaward, T Shoreward	0.567	0.1

Following the exclusion of a small number of samples with no or very few fauna, multivariate analysis of the North Ridge data revealed that the assemblages of the shoreward trough were notably different from all others (Figure 41). Apart from a single seaward flank sample which was an outlier, differences between all remaining topographical zones were relatively minor. Global ANOSIM test between topographical zones was the lowest of all CSAs across the North Norfolk SACs (0.327, p<0.001). The most significant differences revealed by ANOSIM pairwise comparisons were between the seaward and shoreward trough communities, between shoreward flank and trough communities and between crest and shoreward trough. No significant differences in community composition were observed between crest and shoreward flank and between crest and seaward flank. Although significant at the 5% level, differences between seaward and shoreward flank, shoreward flank and seaward trough, and seaward flank and seaward trough were minimal.

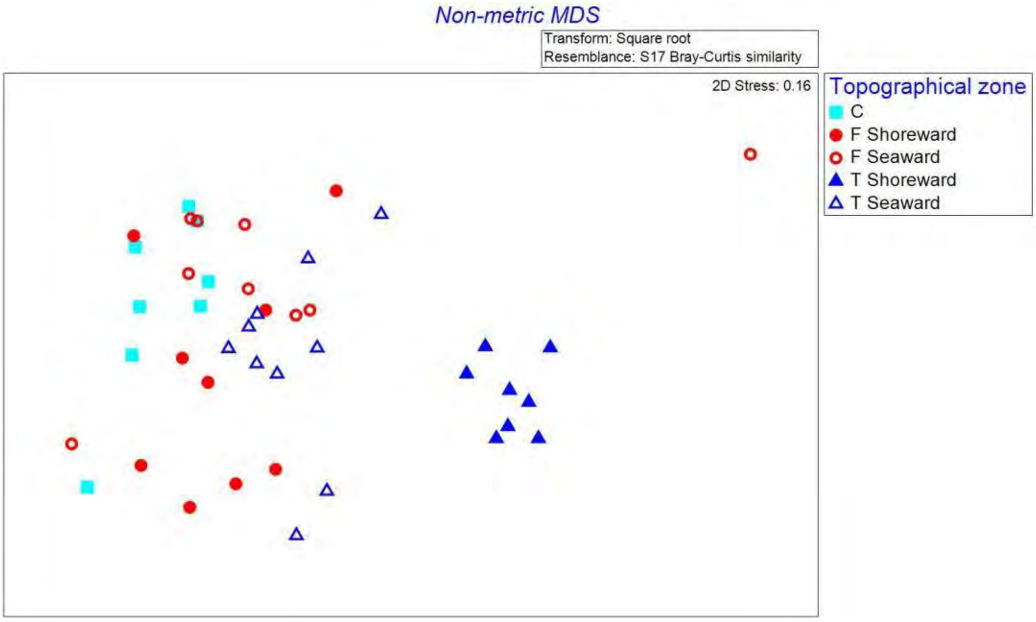


Figure 41. nMDS ordinations of infaunal community composition of North Ridge within the Inner Dowsing, Race Bank and North Ridge (IDRBNR) SAC, displayed according to topographical zone (crest, flank, trough) and seaward/shoreward orientation.

Table 22. ANOSIM pairwise tests between topographical zones at NRRD.

Pairwise Tests **Groups**	**R Statistic**	**Significance Level %**
Crest, F Shoreward	0.041	21.5
Crest, F Seaward	0.005	39.4
Crest, T Shoreward	0.627	0.1
Crest, T Seaward	0.289	0.1
F Shoreward, F Seaward	0.106	5.9
F Shoreward, T Shoreward	0.616	0.1
F Shoreward, T Seaward	0.143	2
F Seaward, T Shoreward	0.57	0.1
F Seaward, T Seaward	0.122	2.2
T Shoreward, T Seaward	0.946	0.1

Epifauna

North Ridge was the only CSA within IDRBNR where epifauna was collected. All metrics increased from crest to trough on the shoreward side, with highest values overall observed for the shoreward trough. Seaward trough metrics were similar to the crest with exception of biomass which was double that found on the crest.

Table 23. Mean (per 600m^{2*}, ±95% confidence) diversity measures and biomass at each topographical zone on North Ridge CSA within IDRBNR SAC**.

Bank	Topographical Zone	Number of Species (s)	Number of Individuals (N)	Biomass (g)
NRRD	T(shore)	39.67 (± 3.84)	207.33 (± 32.20)	15831 (± 4527)
	F(shore)	18.33 (± 0.67)	55.67 (± 7.69)	610 (± 169)
	C	10.67 (± 0.88)	38.67 (± 3.18)	316 (± 49)
	F(sea)	-	-	-
	T(sea)	13.67 (± 5.36)	29.67 (± 14.78)	602.00 (± 280)

* The seaward trough dataset contained one less replicate of 300m^2. No data was collected from the seaward flank.
** T = trough; F = flank; C = crest; sea = seaward facing; shore = shoreward facing.

Multivariate analyses show high community similarity between crest, shoreward flank and two seaward trough samples (Figure 42). The shoreward trough samples cluster away from the main group (as per the infaunal analyses) suggesting different epifaunal communities are present.

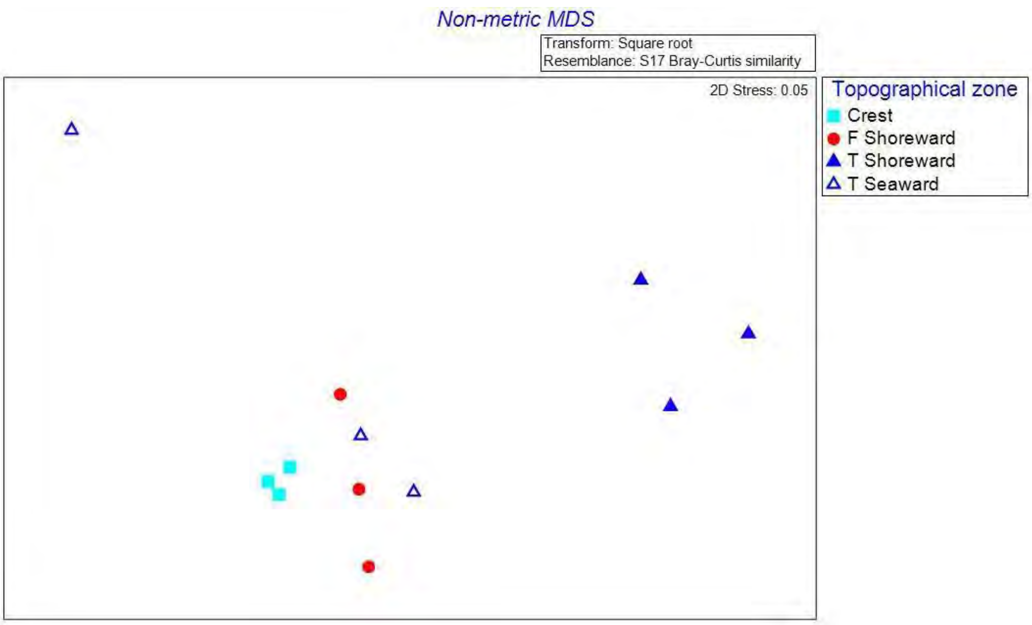


Figure 42. nMDS ordination of epifaunal community composition at North Ridge within IDRBNR SAC, displayed according to topographical zone (crest, flank, trough) and seaward/shoreward orientation.

Biotopes

Inner Dowsing

The crest and seaward flank communities of Inner Dowsing resembled those characteristic of the biotope 'A5.135: *Glycera lapidum* in impoverished infralittoral mobile gravel and sand'. Most samples from these locations were classified as entropy group '2a' (gravelly sand).

Two seaward flank samples also clustered with the troughs and shoreward flanks and were mainly dominated by the reef-building polychaete *S. spinulosa* and/or the tube-building amphipod *A. diadema*. Sediment at these locations were classified as entropy group '3a' (gravelly muddy sand).

'Beyond sandbank' communities on both the seaward and shoreward sides of the bank were also characterised by *S. spinulosa* and/or *A. diadema*. Communities at locations where *S. spinulosa* was dominant strongly resembled and were assigned to the biotope 'A5.611: *S. spinulosa* on stable circalittoral mixed sediment', whilst those dominated by *A. diadema* were assigned 'A5.4: Subtidal mixed sediment', as reefs created by this species are not currently considered as Annex I Reef under the Habitats Directive and EUNIS Classification system. Locations in the troughs and on the flanks not characterised by either reef-building species were assigned to biotopes reflecting their characteristic species and sediment composition; INNDT04, located between the seaward flank and trough samples in the nMDS, was assigned to 'A5.134: *Hesionura elongata* and *Microphthalmus similis* with other interstitial polychaetes in infralittoral mobile coarse sand', and INNDF20, which clustered away from the other shoreward flank samples, was assigned to 'A5.135: *Glycera lapidum* in impoverished infralittoral mobile gravel and sand'.

The remaining samples were assigned to the higher sediment clasification of 'A5.4: Subtidal mixed sediment' due to the absence of species characteristic of specific biotopes (Figure 43).

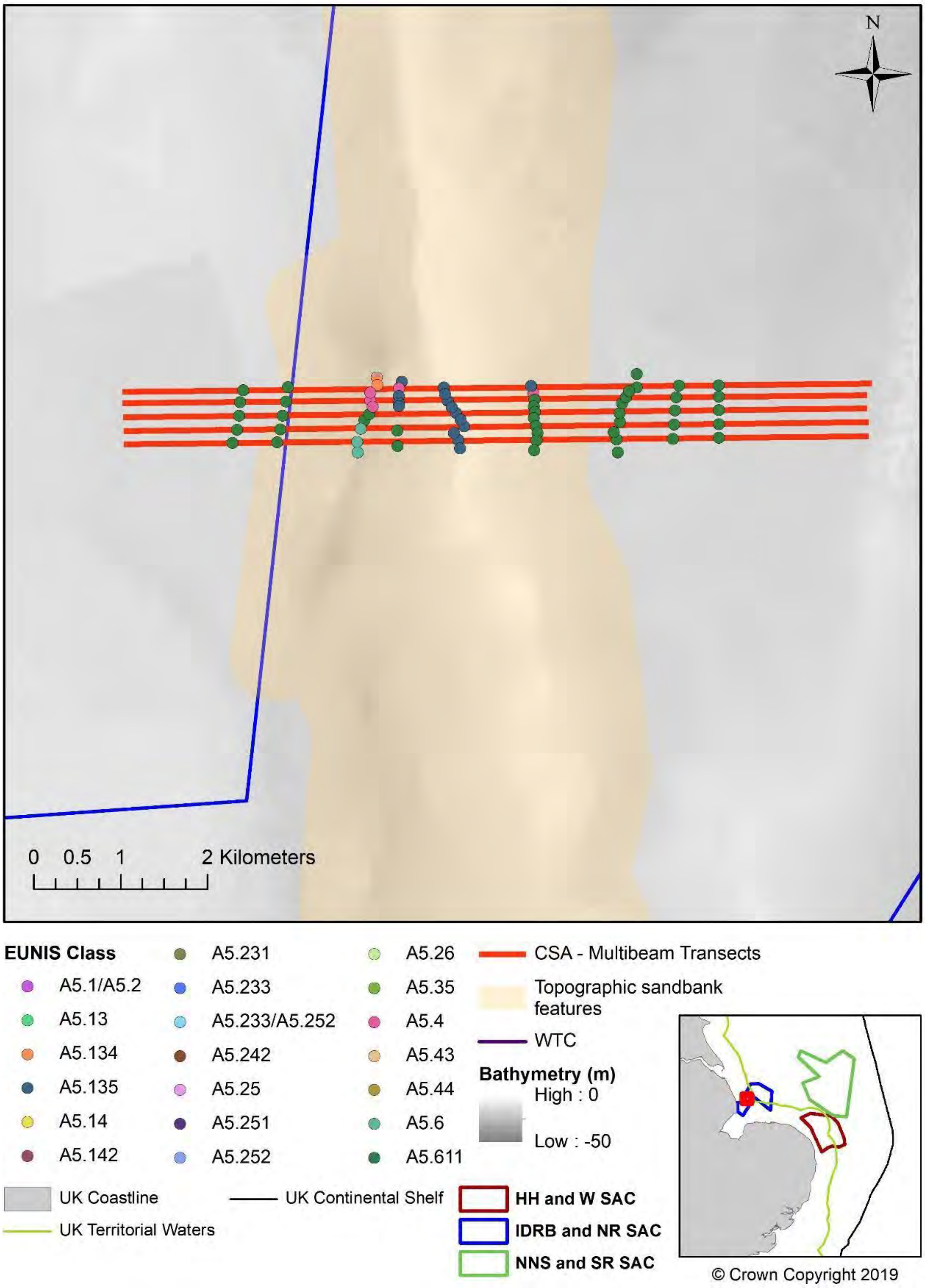


Figure 43. Biotopes determined for infaunal communities inhabiting topographical zones of the Inner Dowsing CSA (including 'beyond sandbank' samples).

North Ridge

At North Ridge shoreward trough samples were characterised by species typical of both gravelly (e.g. the Ross Worm, *S. spinulosa* and barnacle, *Balanus crenatus,* along with several colonial species*)* and finer sediments (e.g. the amphipod crustacean *Urothoe elegans*, and the sedentary worms *Polycirrus* sp. and *Lanice conchilega)*. The epifaunal community at this location was equally as diverse with high abundances of small spider crabs belonging to the genus *Macropodia* spp., brown shrimp crangonidae spp., the common sunstar *Crossaster papposus*, the swimming crab *Liocarcinus depurator* and the sea slug *Doris pseudoargus* were also highly abundant, with numerous other epifaunal species present. The shoreward trough communities therefore represent a mosaic of ‘A5.1: Subtidal coarse sediment’ and ‘A5.2: Subtidal sand’ habitats.

Crangonidae spp. was abundant at all topographical zones, with the lesser weever *Echiichthys vipera*, common dab *Limanda* and the large bryozoan *Alcyonidium diaphanum* characterising the crest and shoreward flank.

The bivalve *Goodallia triangularis* was common to crest, flanks and seaward trough, along with polychaetes *O. borealis* and low abundances of *N. cirrosa* and *Glycera oxycephala*. The amphipod *Pontocrates arenarius* was also present but only on the crests. Due to the species-poor infauna communities of these topographical zones they were all assigned to ‘A5.231: Infralittoral clean sand with sparse fauna’ (Figure 44).

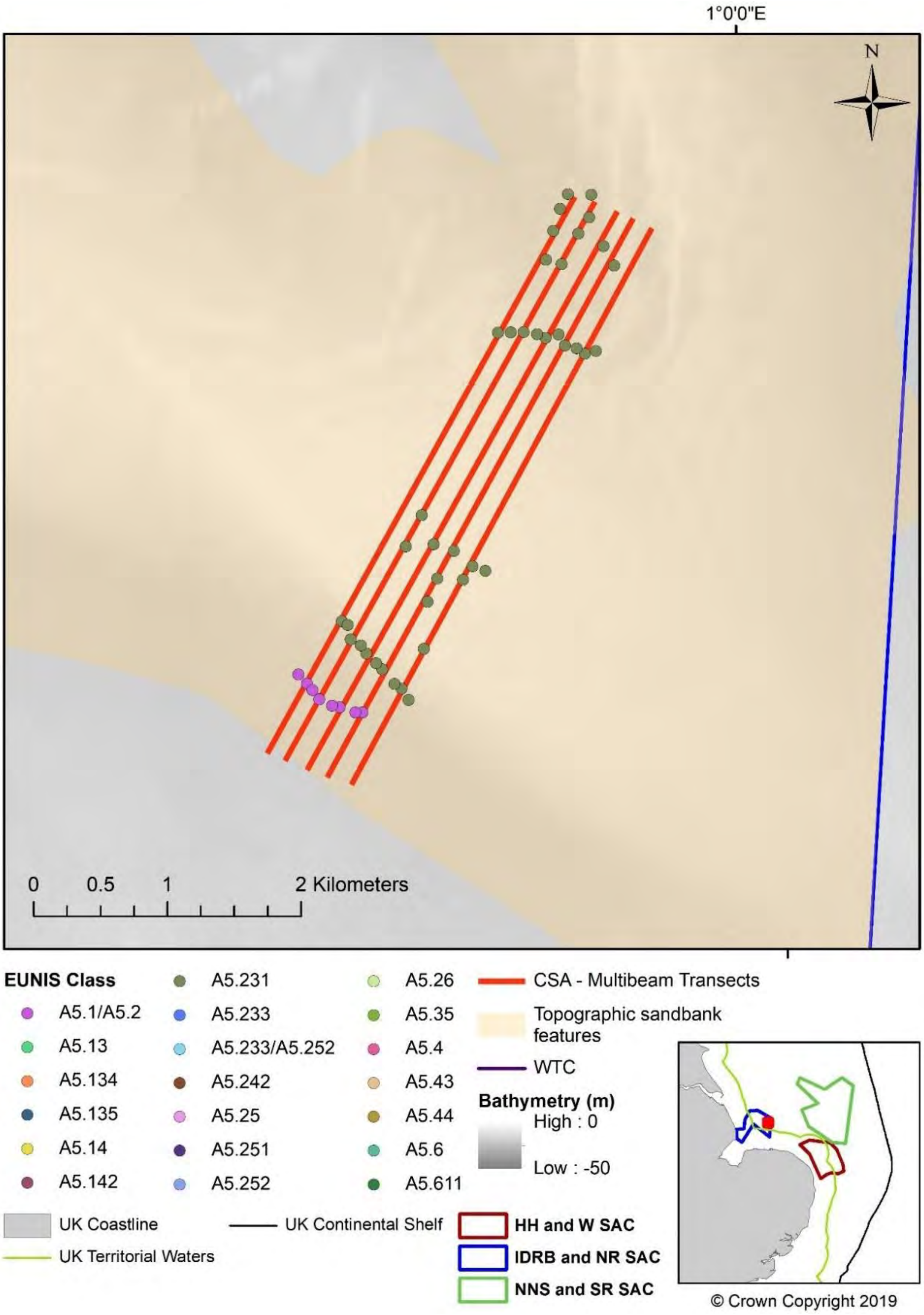


Figure 44. Biotopes determined for infaunal communities inhabiting topographical zones of the North Ridge CSA.

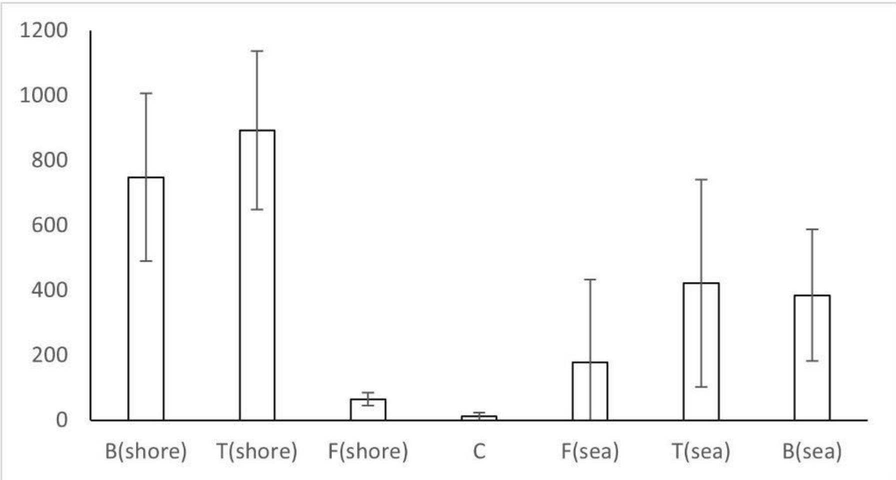
Case Study Areas: Secondary productivity

Inner Dowsing was the only CSA where secondary productivity exceeded 100kJ^{2}y^{-1} at more than one topographical zone (Figure 45).

Inner Dowsing represents a highly productive region, as secondary productivity exceeded 400kJm^{-2}y^{-1} for both shoreward and seaward facing troughs and 'beyond sandbanks'. Akin to those of other CSAs, crest assemblages represented the least productive topographical zone at Inner Dowsing, whereas this was found to be the shoreward flank at North Ridge.

At both CSAs within IDRBNR secondary productivity was found to be significantly higher at shoreward troughs compared to seaward troughs (t-test; $T = -3.16$, $p = 0.01$ and $T = -4.74$, $p = 0.001$ for Inner Dowsing and North Ridge, respectively).

a) Inner Dowsing



b) North Ridge

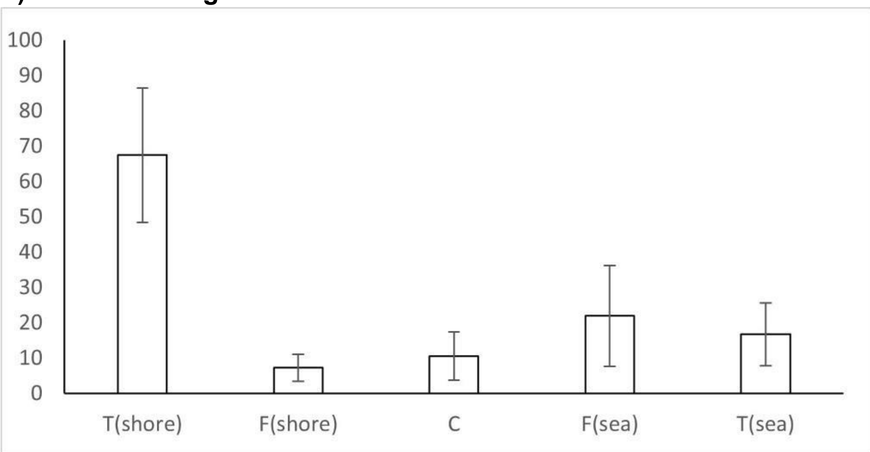


Figure 45. Mean total annual secondary production (kJm^{-2}y^{-1}) of the macrofaunal assemblages of a) Inner Dowsing and b) North Ridge within Inner Dowsing, Race Bank and North Ridge (IDRBNR) SAC*.
* Error bars represent 95% confidence intervals. B = 'beyond sandbank'; T = trough; F = flank; C = crest; sea = seaward facing; shore = shoreward facing.

At Inner Dowsing, shoreward flank assemblages appeared to show lower functional variability than seaward flank and crest assemblages (Figure 46). Seaward facing trough assemblages exhibited notably higher functional variability compared to the corresponding seaward facing 'beyond sandbank' assemblages, whilst the shoreward facing trough and 'beyond sandbank' assemblages of this bank appeared indistinguishable. At North Ridge there was a high-level of functional variability between most topographical zones and orientations, with the exception of shoreward trough assemblages.

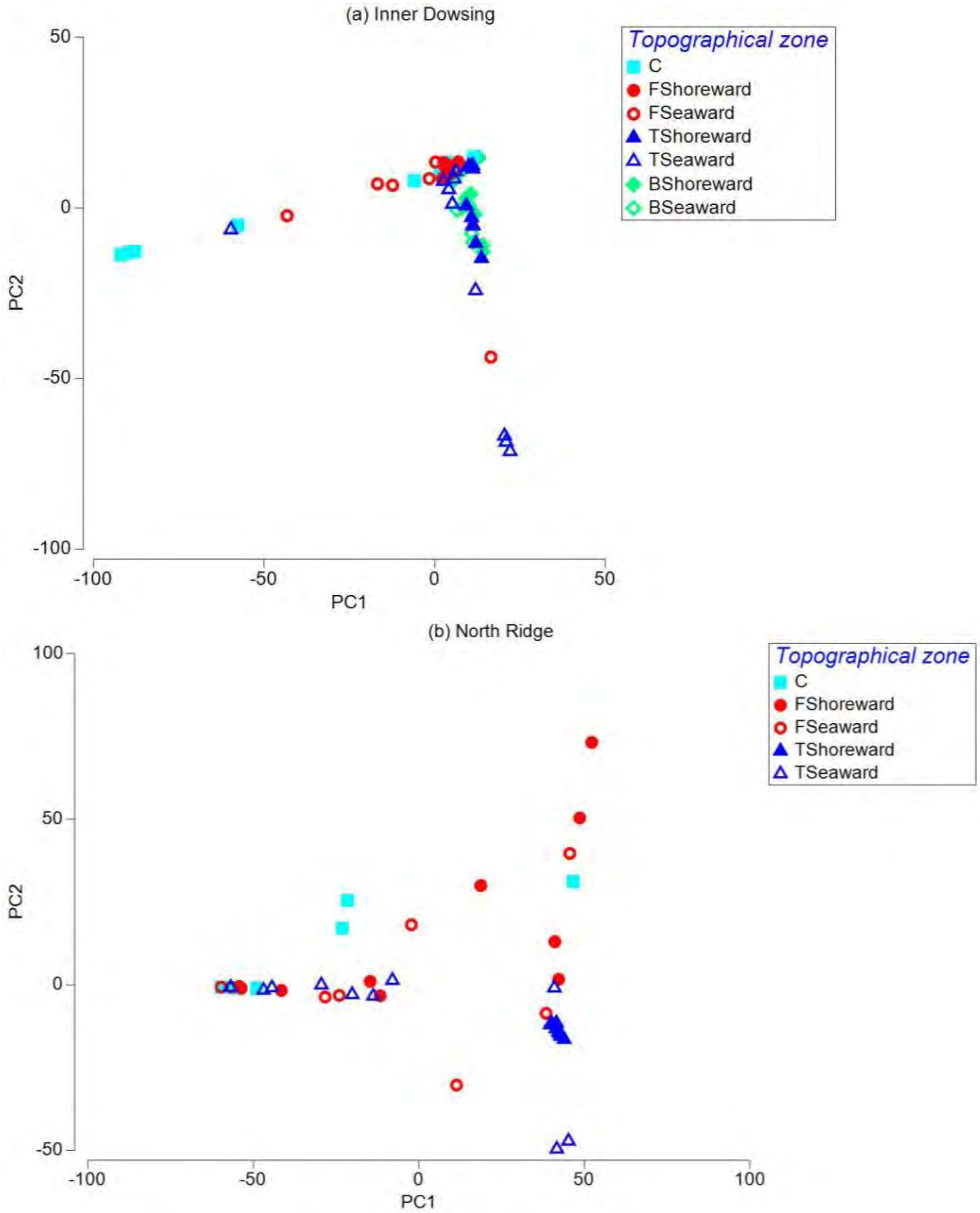


Figure 46. PCA plot based on the taxonomic contribution to total production at a) Inner Dowsing and b) North Ridge within Inner Dowsing, Race Bank and North Ridge (IDRBNR) SAC*.
* B = 'beyond sandbank'; T = trough; F = flank; C = crest.

As observed at other CSAs, secondary production at Inner Dowsing and North Ridge was largely influenced by annelid worms (P) (Figure 47).

At North Ridge, although still annelid-dominated, there was evidence that crustaceans (S) and molluscs (W) notably contributed to secondary production along the seaward flank. At Inner Dowsing the contribution of crustaceans and annelid worms was observed across all topographical zones and orientations.

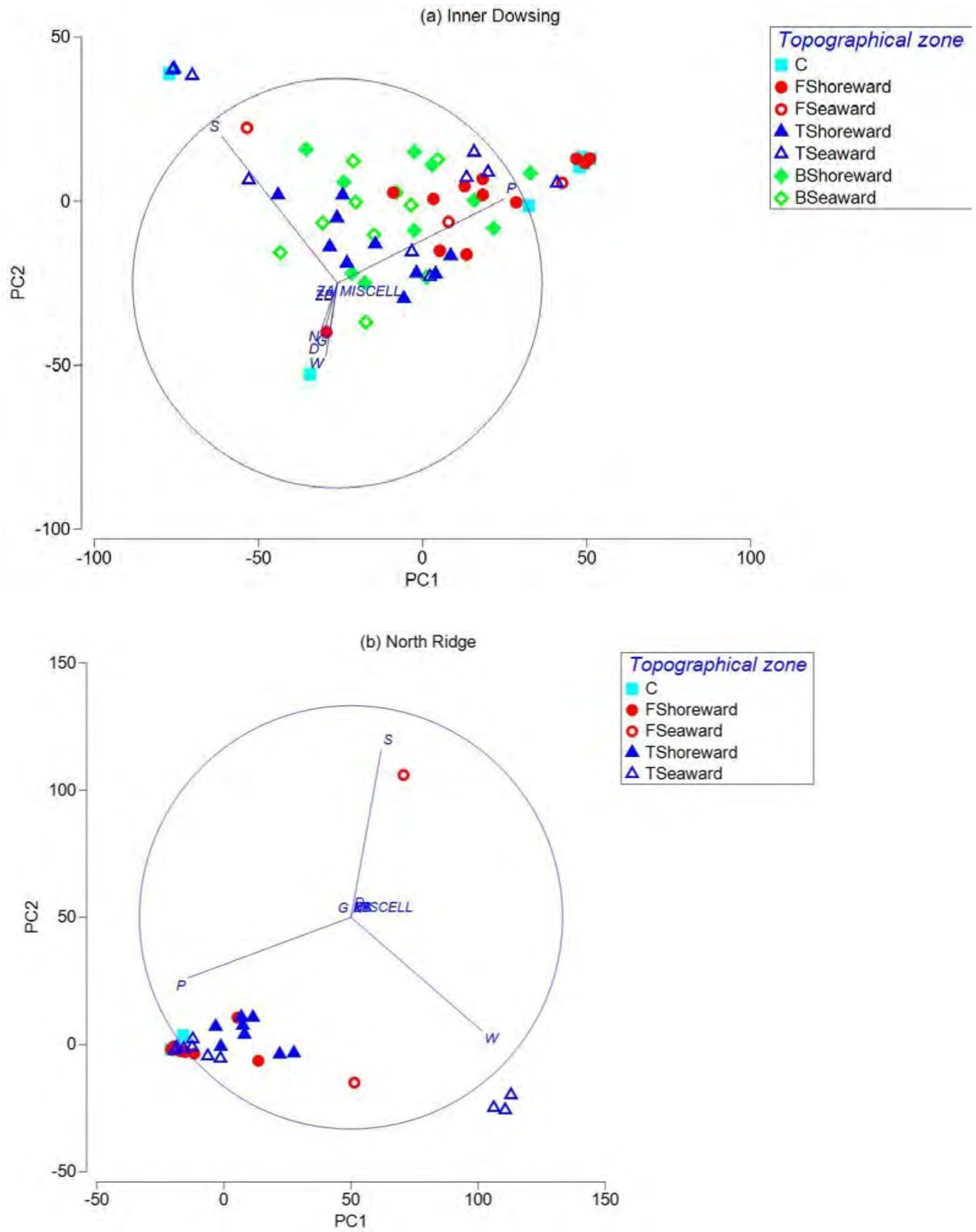


Figure 47. PCA plot based on the relative contribution to total production of the major taxonomic phyla* at a) Inner Dowsing and b) North Ridge within Inner Dowsing, Race Bank and North Ridge (IDRBNR) SAC.

* The vector trajectories reflect the influence of each phyla group to each of the first two principal component axes. D = actiniarians; G = sipunculids; N = nemerteans; P = annelids; S = crustaceans; W = molluscs; ZA = phoronids; ZB = echinoderms; MISCELL = miscellaneous phyla (e.g. sea spiders, turbellarians). B = 'beyond sandbank'; T = trough; F = flank; C = crest.

Wider Characterising Transects (WCTs)

Only one WCT was sampled within IDRBNR SAC. Figure 48 shows similarity between the topographical zones of both CSAs between the WCT zones. The WCT crest sample clusters with the crests from INND and some seaward trough and shorward flank samples from NRRD. The WCT shoreward trough clusters well with the shoreward flanks and troughs, and seaward troughs of INND, along with the shoreward troughs of NRRD. These samples appear to be characterised by significantly different communities despite the clustering (Figure 49) with sediments classified as entropy group 3 (mixed sediments) (Figure 50). The

WCT seaward flank sample clusters well with the seaward flanks of both CSAs forming the main cluster, along with the crests (group v). Sediments are highly variable within this cluster group, classifed into entropy groups 1, 2 and 5.

Biotopes present on the WCT are also represented on the CSAs within this SAC (Figure 51).

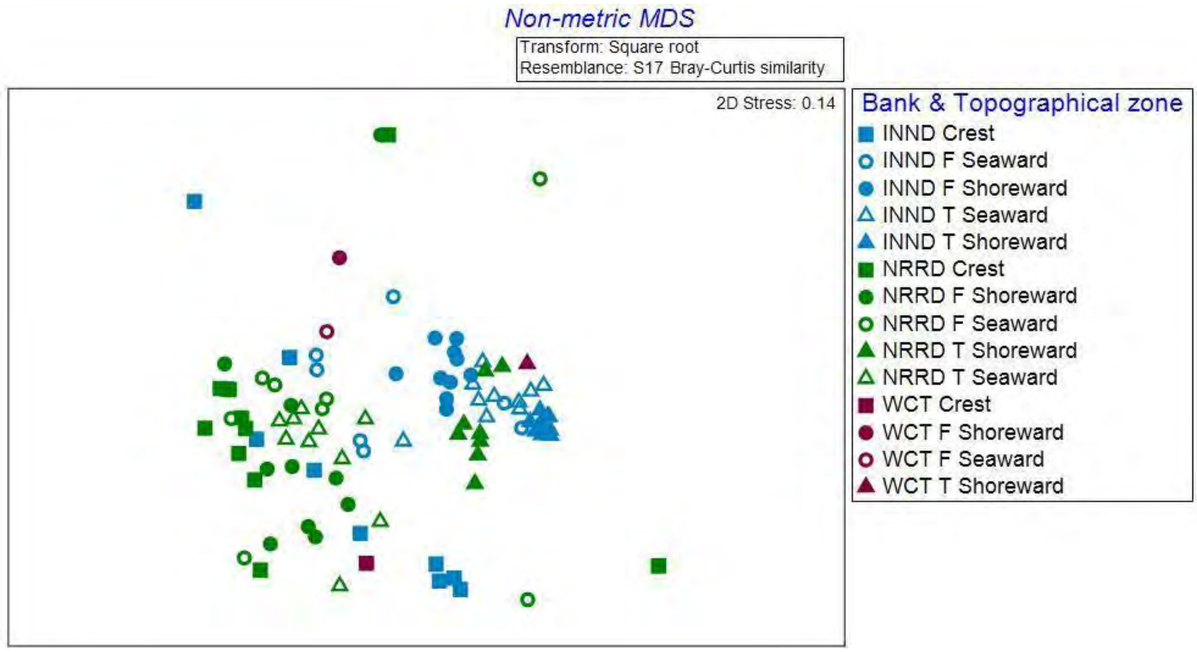


Figure 48. nMDS ordination of WCT and CSA infauna within IDRBNR SAC.
*WCT = Wider Characterising Transect, INND = Inner Dowsing, NRRD = North Ridge, T = trough; F = flank; C = crest.

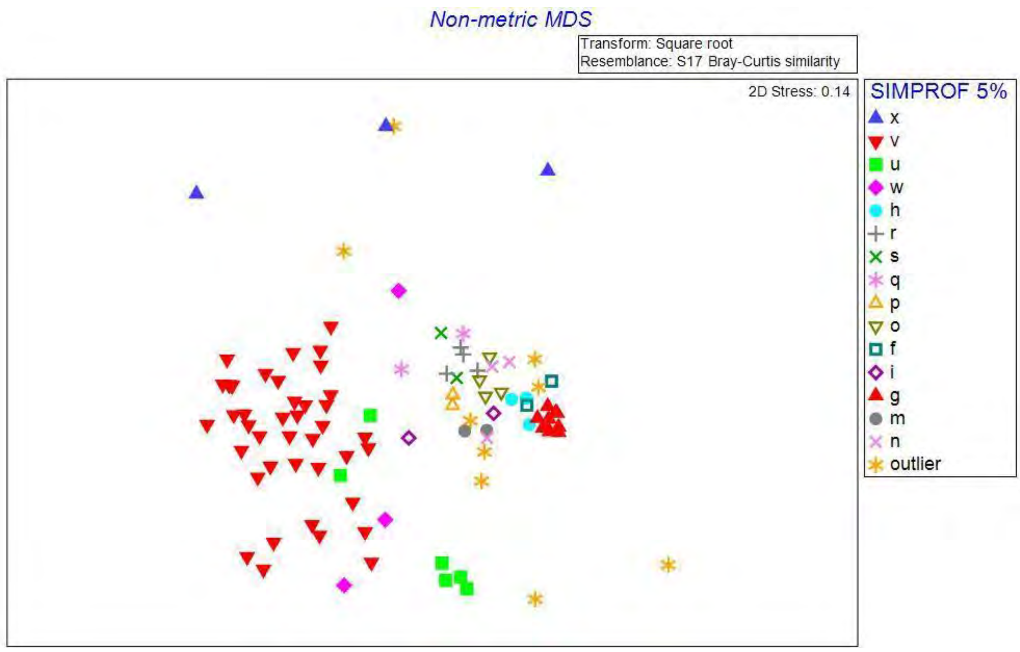


Figure 49. nMDS ordination of WCT and CSA infauna within IDRBNR SAC, displayed according to SIMPROF groups.

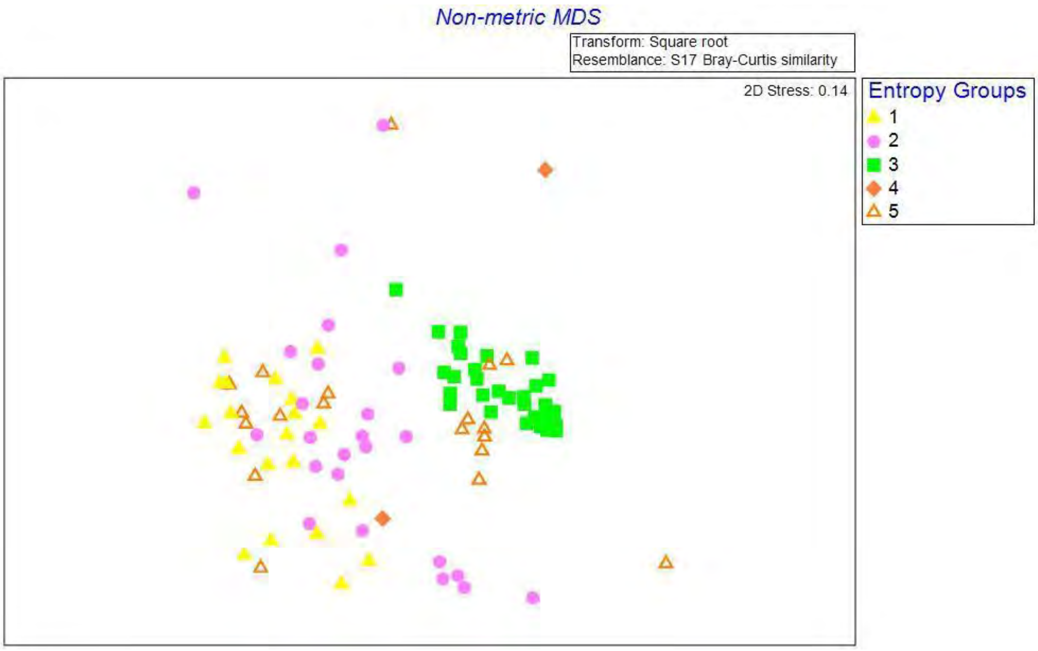


Figure 50. nMDS ordination of WCT and CSA infauna within IDRBNR SAC, displayed according to sediment entropy groups.

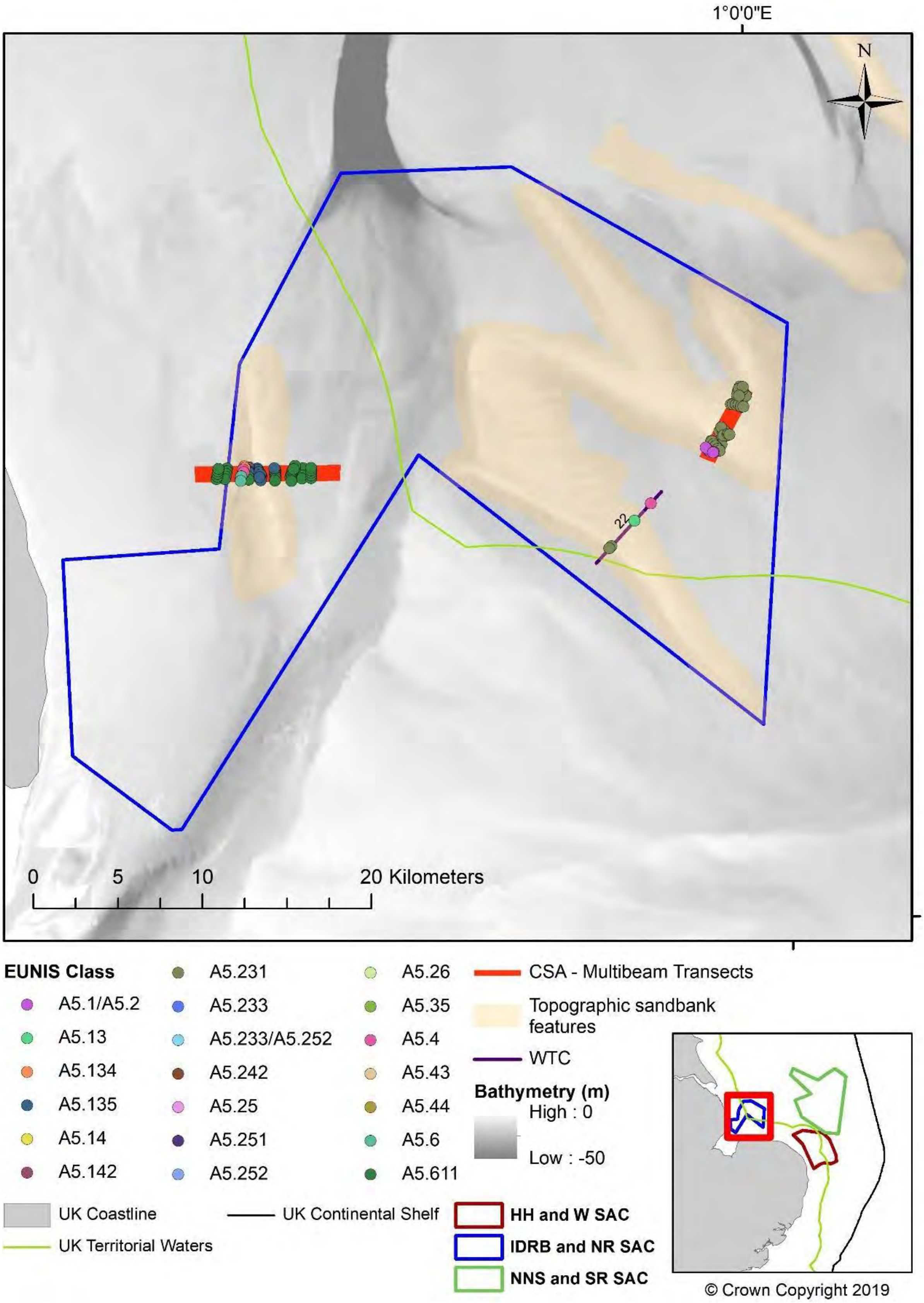


Figure 51. Biotopes determined for infaunal communities inhabiting topographical zones of the Inner Dowsing, Race Bank and North Ridge SAC Wider Characterising Transects.

4.3 Objective 3: Annex I *S. spinulosa* Reefs: extent and distribution

This section meets the requirements of Objective 3 by addressing the following questions:

Question 1. Has Annex I Reef persisted in areas where it had previously been identified from survey data?

Question 2. Is Annex I Reef present in areas of 'potential reef' modelled from 'The East Coast Regional Environmental Characterisation' (Limpenny *et al*. 2011) acoustic data?

Question 3. Has Annex I Reef persisted within the MMO byelaw closure areas?

The extent and distribution of potential *S. spinulosa* reefs were assessed from the SSS data in conjunction with the video and stills data. Areas of potential reef and habitat suitable for reef formation were delineated through manual interpretation of the acoustic data and the interpretation of the ground truthing video data collected in the same area. Any potential reef observed from video was assessed and classified into 'high', 'medium', 'low' or 'not a reef' according to the reef matrix presented in Jenkins *et al*. (2015). In the following sub-section, an interpretation of the data for each of the reef areas is given, along with responses to each of the questions. Figures are only presented where videos were assessed for *S. spinulosa* reefiness.

4.3.1 North Norfolk Sandbank and Saturn Reef SAC

Leman Bank

Although such habitats were not targeted by the grab sampling, *S. spinulosa* reef was observed in the grab samples taken from the northern trough of Leman Bank, therefore this area was targeted for additional SSS and camera survey. From the single track of acoustic data acquired at Leman Bank, an area of coarser sediment was observed along the eastern side surrounded by areas of more mobile, finer sediments (Figure 52). Camera transects within the acoustic track confirmed the presence of 'low' reefiness *S. spinulosa* in the north of the acoustically surveyed area, whilst the central area was determined to comprise 'A5.2: Subtidal sand'. Further to the east (in the area not targeted by SSS) the substrate was assigned as 'A5.1: Subtidal coarse sediment'.

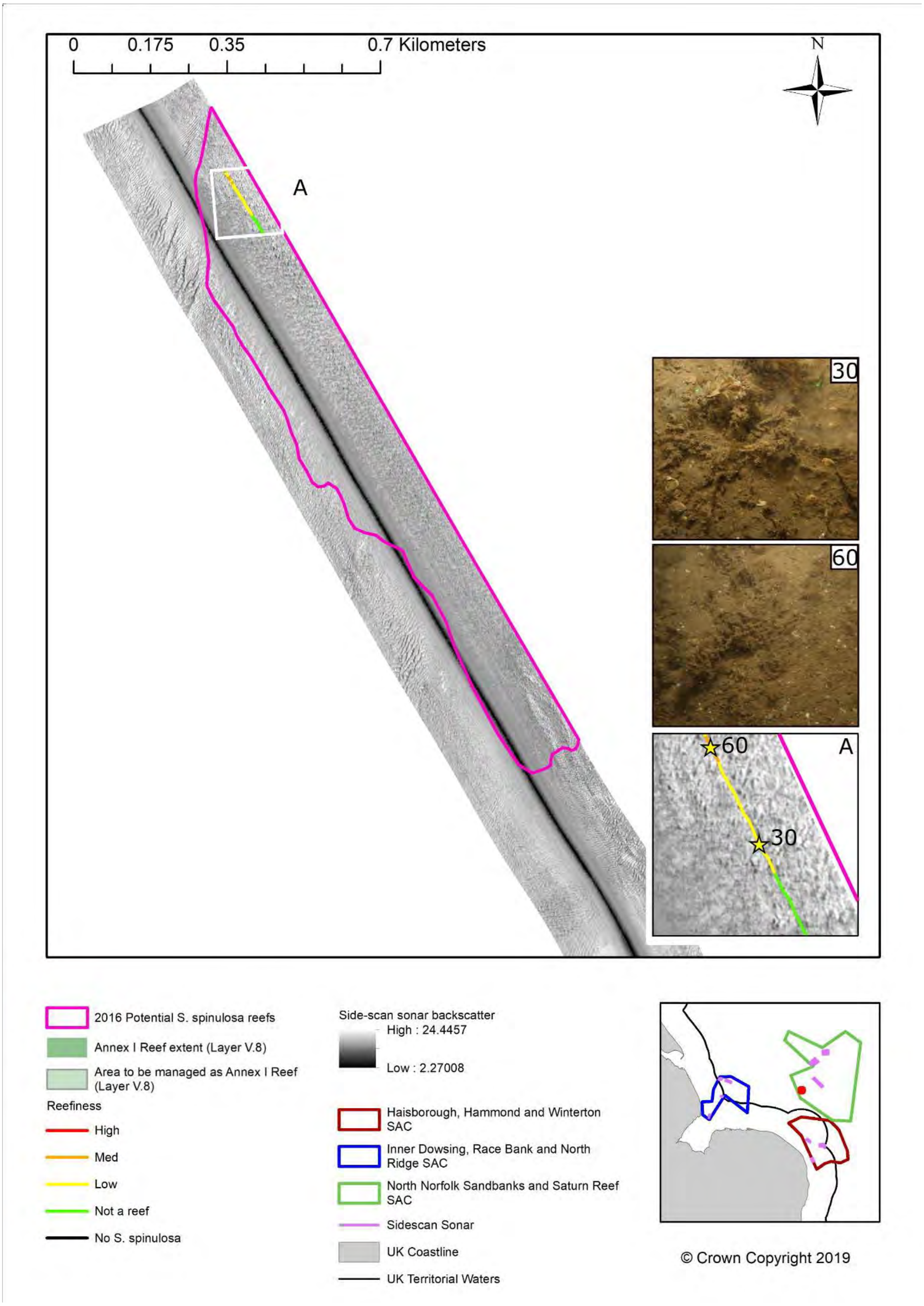


Figure 52. Side scan sonar data collected from Leman Bank northern trough with the area of potential *S. spinulosa* reef delineated. Insets show a close-up of the acoustic signature and seabed images (video station LMBKADD02, stills 30 and 60) from two sections classified as having ‘low-medium’ reefiness.

North of Swarte Bank

The acoustic data acquired at North of Swarte Bank indicated the presence of a large sandbank feature with a crest running north to south. To the west of the sandbank crest was an area of small sandwaves and ripples, with crests running in a south west to north east direction. To the east of the crest, an area of relatively flat seabed with a mosaic of coarse and fine sediments was evident. SSS backscatter signals indicative of *S. spinulosa* reefs and/or sediment types which they commonly colonise were evident from the acoustic data. Video analysis confirmed the presence of mixed and coarse sediments, however there was no evidence of *S. spinulosa* reef. A total area of potential reef and/or supporting habitat of 2.67km^2 was delineated.

Data collected from this area during the previous survey in 2013 (CEND2213) found very little evidence of *S. spinulosa* reefs with the areas of mottled acoustic backscatter identified as patches of mixed and/or coarse sediments.

North of Well Bank

This area of North of Well Bank was previously surveyed in 2013 (CEND2213) using SSS and video transects. The 2013 video survey identified several patches of potential *S. spinulosa* reef with distinctive acoustic signatures. The acoustic data collected as part of the 2016 survey, however, found no evidence of *S. spinulosa* or reef-suitable substrate in this area. Moreover, the acquired SSS acoustic signatures were found to be more representative of a sandy substrate forming waves and ripples. Video data collected within this area in 2016 confirmed the presence of mixed, coarse and sandy sediments and the absence of Annex I Reef.

Saturn Reef

The central part of the area surveyed in the vicinity of Saturn Reef displayed a backscatter signal indicative of *S. spinulosa* reef or substrate which potentially support such reefs. The mottled ‘cauliflower’ appearance of this backscatter return was observed across all of the acoustic survey lines up to the area of sandwaves and ripples in the east (Figure 53). Of the 15 video transects undertaken, only three were identified with potential *S. spinulosa* reef and taken forward for reefiness assessments. Within these three transects the majority of 5m segments were assessed as either ‘no *S. spinulosa’* or ‘not a reef’, confirming that the acoustic signatures here depict consolidated sediments and small patches of *S. spinulosa*. One small section of the video transect, in the west of the acoustically surveyed site, was classified as ‘medium’ reef. However, no difference in the underlying acoustic signal could be discerned between this area and that of the areas classed as ‘not a reef’. All three transects were located in areas previously identified as potential Annex I Reef (Jenkins *et al*. 2015; JNCC 2019).

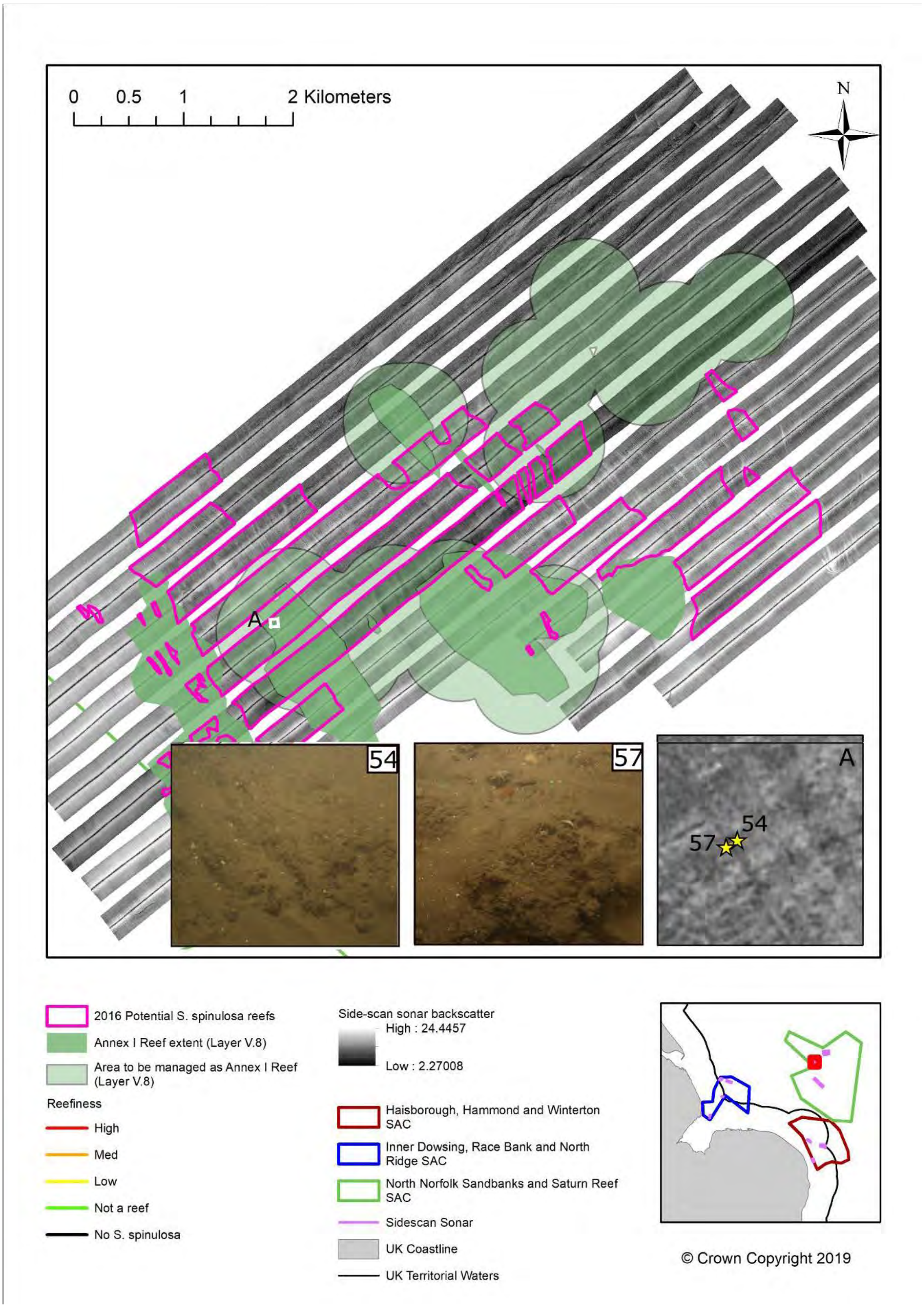


Figure 53. Side scan sonar data collected from around Saturn Reef with the area of potential *S. spinulosa* reef delineated. Insets show a close-up of the acoustic signature (A) and seabed images (video station STRN15, stills 54 and 57) from two areas classified as 'not a reef'.

Comparisons with previous data collected at Saturn Reef

There is very little spatial overlap between the areas of seabed surveyed for potential *S. spinulosa* reef between 2013 and 2016 (Figure 54). This makes inferences regarding temporal shifts in reefiness difficult. However, what is evident is that where present, the quality of *S. spinulosa* reef in 2013 was generally regarded to have been of low and, occasionally, medium quality while in 2016 where *S. spinulosa* was observed it was not classed as a reef. Medium quality reef was only evident from a single region of a transect in 2016, while this quality of reef was found relatively frequently in 2013 (Figure 54). Given the spatial differences, it would be questionable to speculate the reasons why differences in reef quality between the two survey years are evidenced.

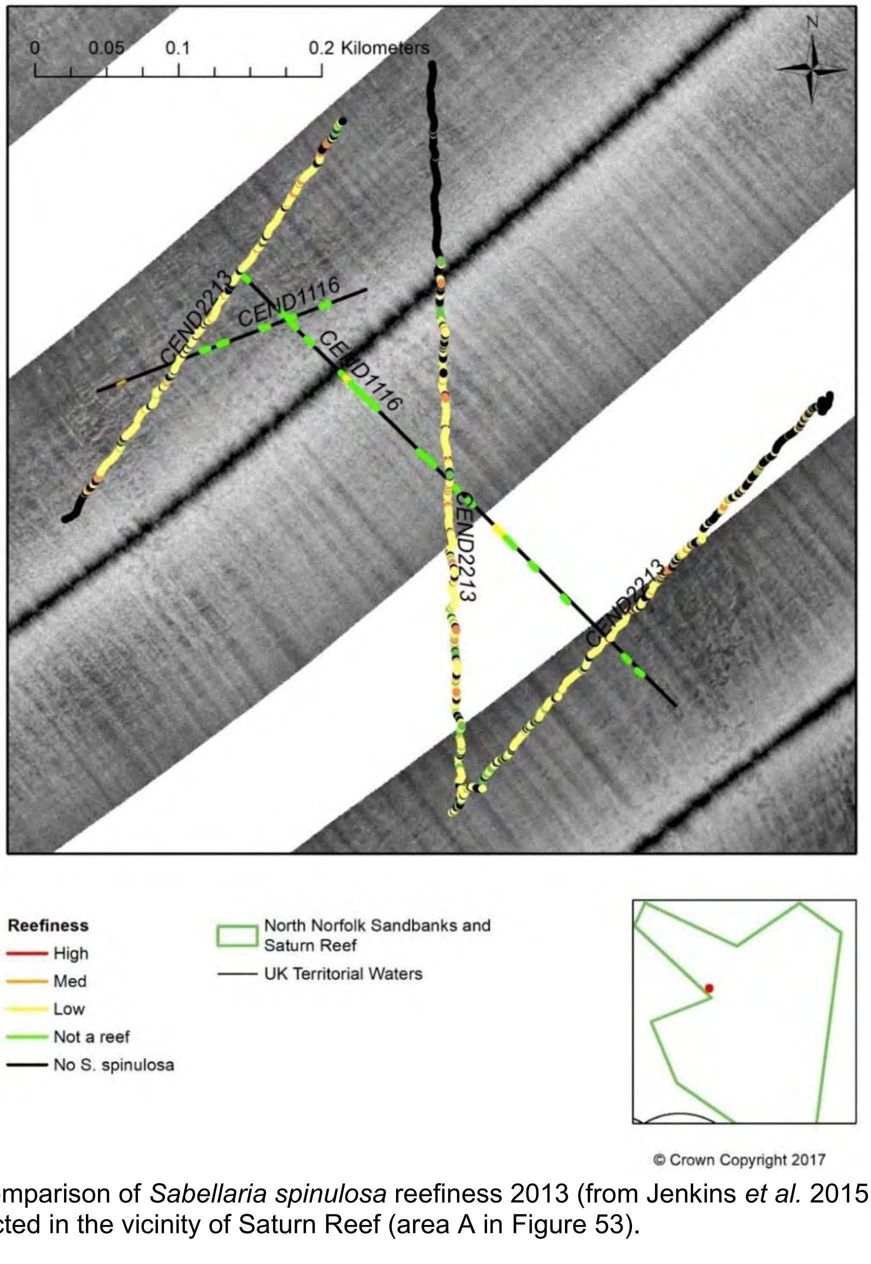


Figure 54. Comparison of *Sabellaria spinulosa* reefiness 2013 (from Jenkins *et al.* 2015) and 2016 imagery collected in the vicinity of Saturn Reef (area A in Figure 53).

4.3.2 Haisborough, Hammond and Winterton SAC

HHW Northern Closure

A total seabed area of 6.97km^2 was acoustically surveyed at HHW Northern Closure. The resulting acoustic data display a complex seabed with mottled areas interspersed with patches of sandwaves (Figure 55). Larger crests and troughs run across the surveyed area, running predominantly along a north east to south west trajectory.

Five video transects within the surveyed area were assessed for *S. spinulosa* reefiness; two of these comprised areas of ‘medium’ and ‘high’ reefiness (one of which was located within the eastern part of ‘Haisborough Tail Reef’, an MMO Marine Conservation Byelaw area which is closed to fishing, and one in an area previously identified as high potential Annex I Reef extent during the East Coast Regional Environmental Characterisation (East Coast REC) survey in 2009 (Limpenny *et al*. 2011) (which is now included in the Annex I Reef layer V.8, JNCC 2019)).

Due to the complexity of the seabed the areas of potential *S. spinulosa* reefs could not be delineated from the areas of sand. However, due to the relatively small sizes of the sandy patches and the highly mobile nature of the substrate in this area, it may not be appropriate to map these patches even if that were possible.

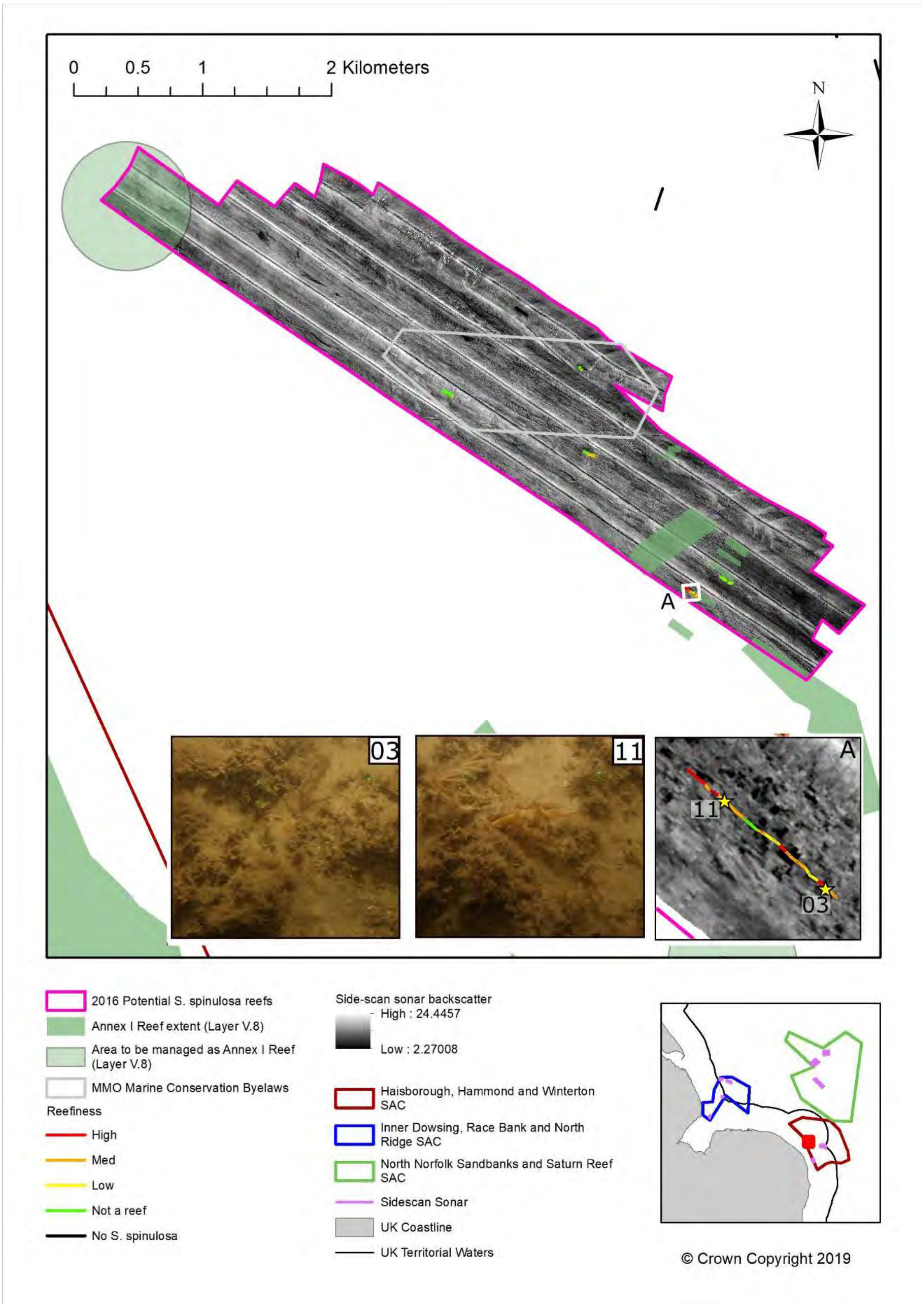


Figure 55. Side scan sonar data collected from HHW Northern Closure. Insets show a close-up of the acoustic signature and seabed images (video station HWNC01, stills 03 and 11) from two areas classified as having ‘medium’ reefiness.

HHW Southern Closure

The acoustic data for the HHW Southern Closure area show a seabed signature indicative of a highly mobile substrate with a large number of sandwaves with the peaks running predominantly north east to south west (Figure 56). These sandwaves generally had a wavelength of ~60m (peak to peak).

Two patches (one to the east and one to the west) had a similar signature to the patches of reef identified from other areas. The flat, mottled seabed from these two areas was similar to the coarse consolidated sediments preferentially colonised by *S. spinulosa*. Four video transects were assessed for *S. spinulosa* reefiness. Two videos, located within ‘Gat Reef’ (an MMO Marine Conservation Byelaw area closed to fishing), were classified as predominately ‘medium’ to ‘high’ reefiness. Videos taken outside the byelaw area (but within the high potential Annex I Reef area identified during the East Coast REC survey in 2009 (Limpenny *et al*. 2011)) were generally classified as ‘low’ to ‘medium’ reefiness, with the northern transect also containing small areas classified as ‘high’ reefiness.

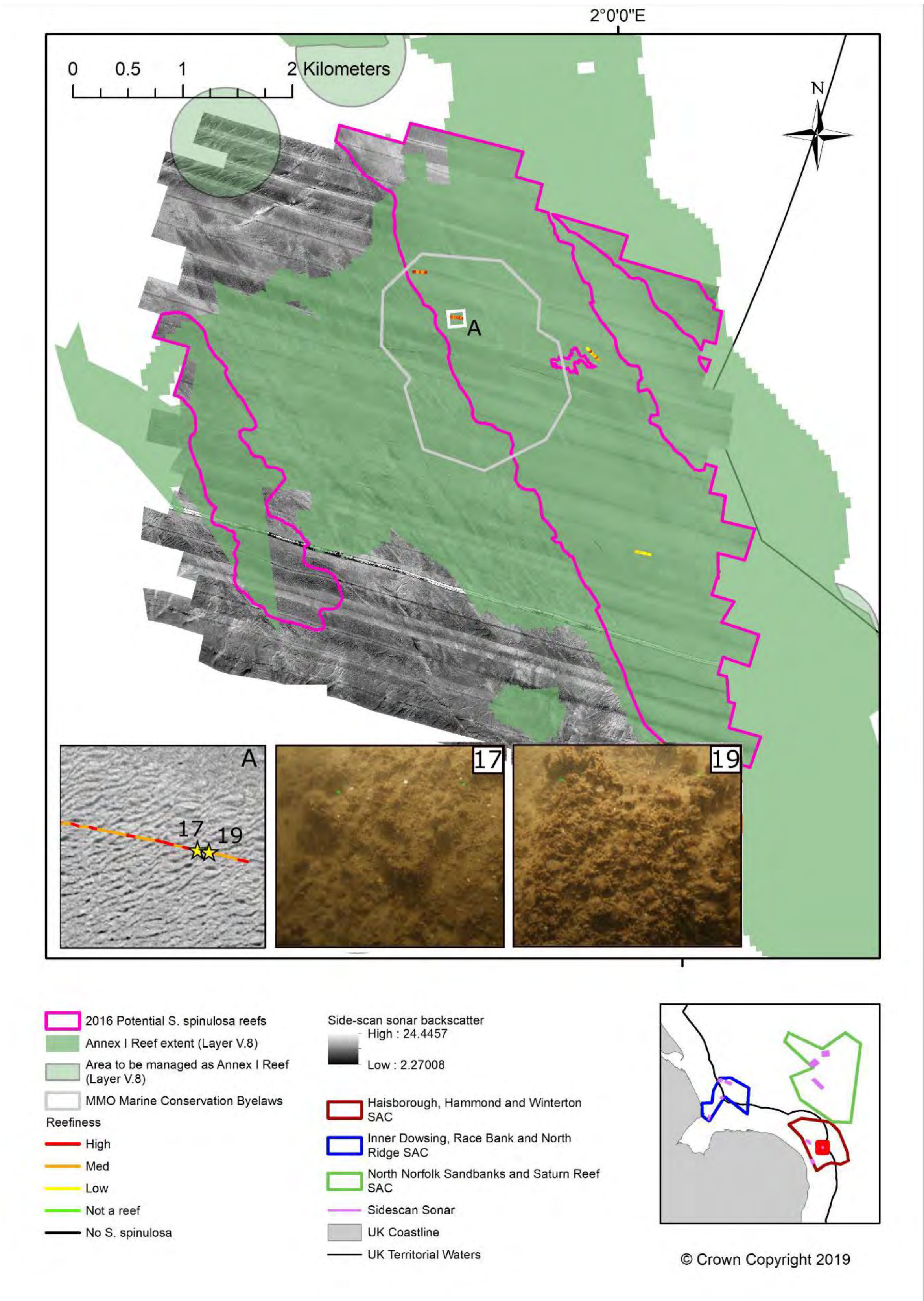


Figure 56. Side scan sonar data collected from HHW Southern Closure with the area of potential *S. spinulosa* reef delineated. Insets show a close-up of the acoustic signature and seabed images (video station HWSC05, stills 17 and 19) from two areas classified as having 'medium-high' reefiness.

West of Middle Cross Sand

The acoustic data collected from West of Middle Cross Sand show a complex array of features ranging from sediment waves and ripples, areas of flat coarse sediment and patches of outcropping rock and boulders. Several of the video transects which were spatially coincident with the SSS data were classified as having ‘high’ and ‘medium’ reefiness (Figure 57). The areas of ‘high’ reefiness may be associated with several raised features observed from the acoustic data. The areas where ‘high’ and ‘medium’ reefiness were identified from the video data had very similar acoustic signatures to those identified as having ‘low’ or ‘no reefiness’. The surveyed area is coincident with the high potential Annex I Reef extent identified during the East Coast REC survey in 2009 (Limpenny *et al*. 2011).

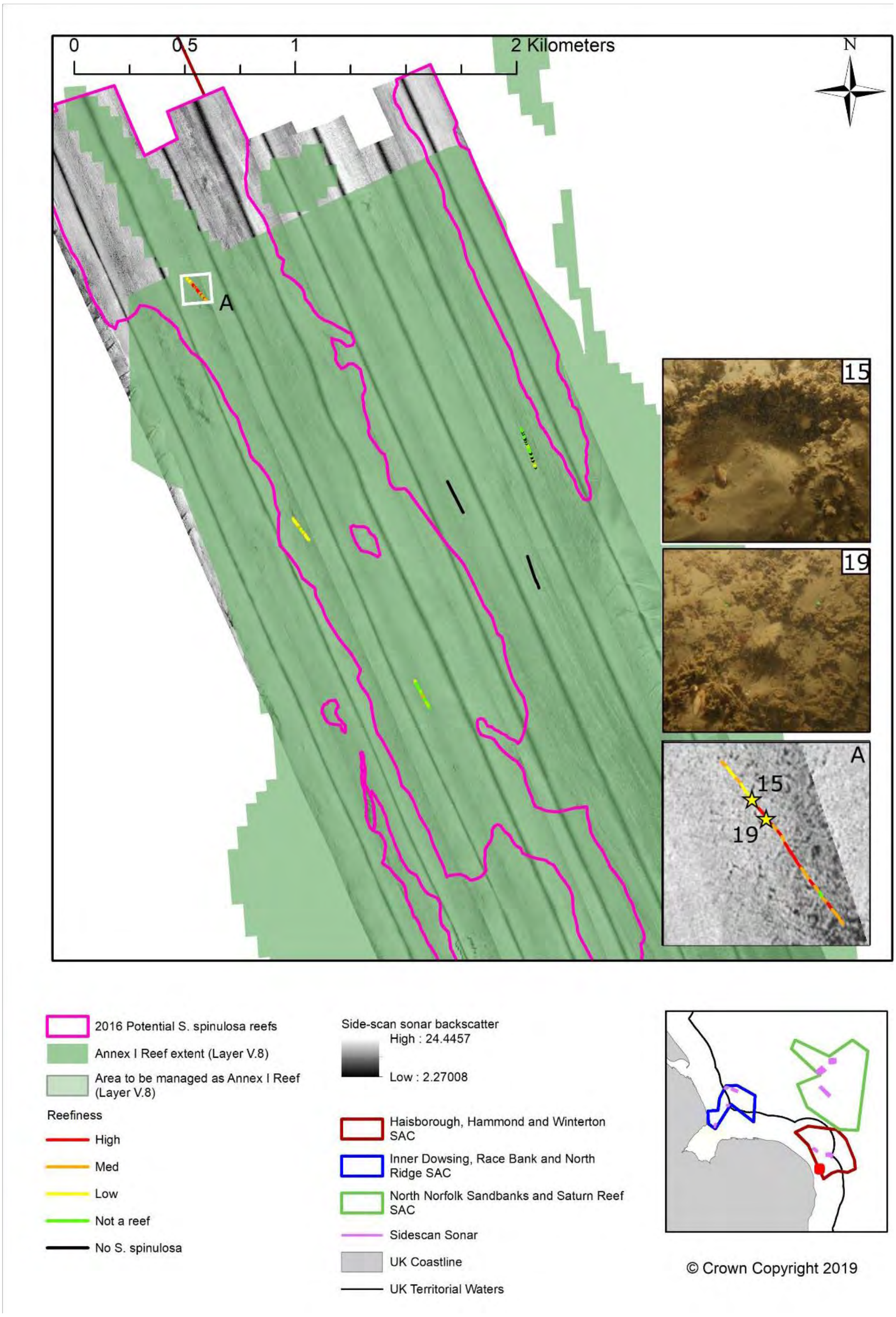


Figure 57. Side scan sonar data collected at West of Middle Cross Sand, with potential Annex I biogenic reef delineated. Insets show a close-up example of the acoustic signature overlain with a video transect (WMCS05) classified as predominately 'medium-high' reefiness and example seabed images from the areas of 'medium' (still no.15) and 'high' reefiness (still no.19).

4.3.3 Inner Dowsing, Race Bank and North Ridge SAC

Docking Shoal

The SSS data for Docking Shoal covered 5.95km^2 of seabed. The data indicated areas of flat sediment with small patches of sandwaves to the north east and south west of the site. Within Docking Shoal all six video transects were analysed for *S. spinulosa* reefiness and ranged from ‘not a reef’ to ‘medium’ reef (Figure 58). The highest reefiness scores were recorded in the south east of the site (outside the ‘Area to be managed as Annex I Reef’ (JNCC 2019)). Two video transects are coincident with the ‘Area to be managed as Annex I Reef’ (JNCC 2019), however only one was classified as (low) Annex I Reef.

Analysis of the acoustic data within the area of highest reefiness identified a seabed signature typically observed in association with *S. spinulosa* aggregations. This acoustic signature occurred across much of Docking Shoal, including areas which were identified as ‘not a reef’ from video data, with no discernible boundaries between different areas of sediment type and was therefore delineated as potential reef. The video footage obtained here showed *S. spinulosa* aggregations, but much lower percentage cover than those required for classification as Annex I Reef. The acoustic signature observed may therefore be more related to the reflectivity of the underlying sediments at this site rather than the reef itself.

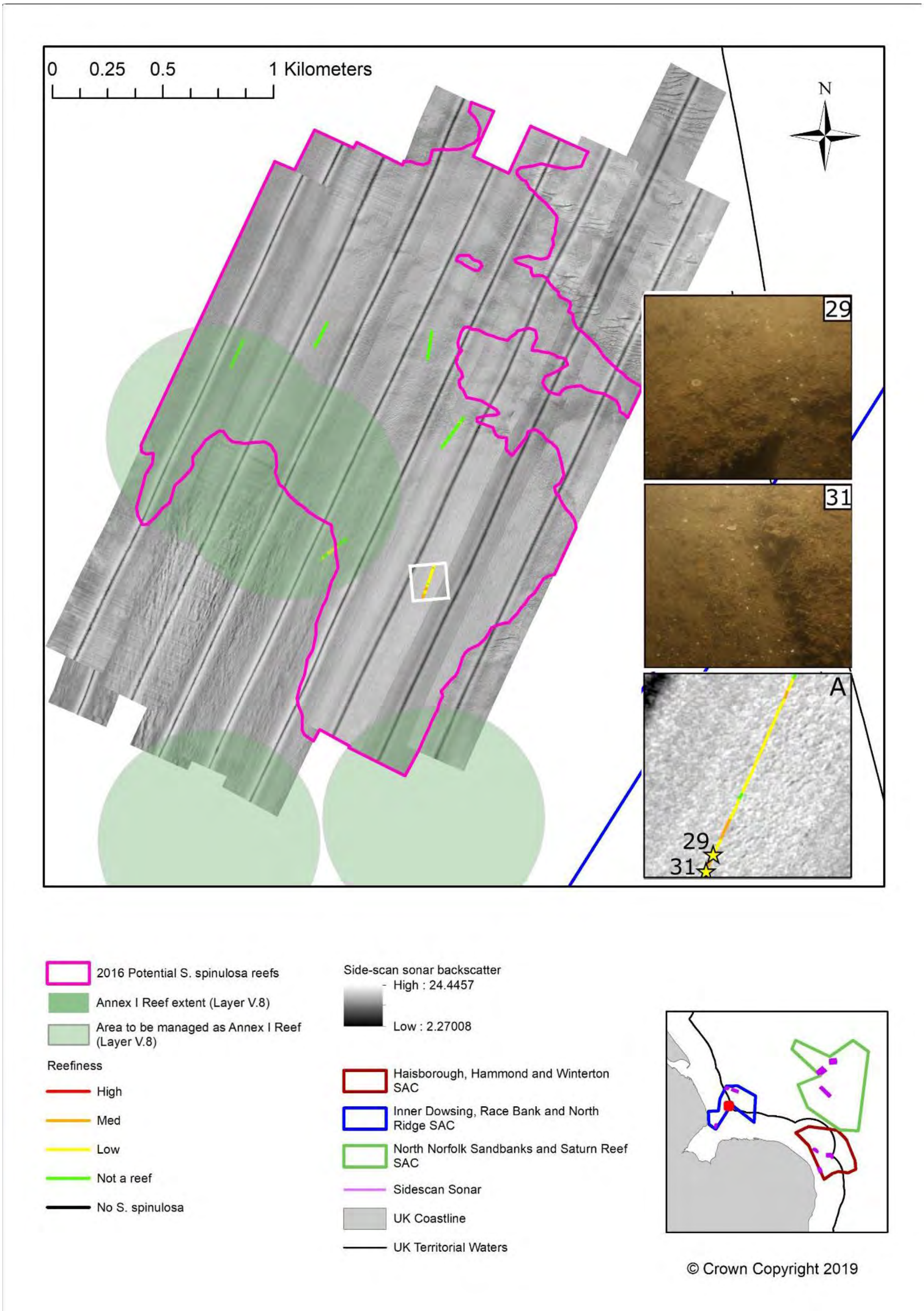


Figure 58. Side scan sonar data collected from the Docking Shoal with the area of potential *S. spinulosa* reef delineated. Insets show a close-up of the acoustic signature and seabed images (video station DKSH02, stills 29 and 31) from two locations classified as having 'low-medium' reefiness.

East of Silver Pit

The acoustically surveyed area ESVP was dominated by a large central sediment feature consisting of large sandwaves with peaks running from the north east to the south west (Figure 59). To the west of this large sediment feature was an area of mottled backscatter return, which is generally attributed to coarse or consolidated sediments.

The presence of *S. spinulosa* in this area was confirmed by the video transects and delineated as potential reef. Areas of 'high' reefiness were identified from several video transects, along with patches of 'medium' and 'low' reefiness. Four video transects, located in the west of the survey area, coincide with 'Area to be managed as Annex I Reef' (JNCC 2019), three of which contain areas of 'high' reefiness. It was not possible to discern the different reefiness categories from the acoustic data, as much of the *S. spinulosa* reefs are interspersed with patches of coarse sediment which exhibit very similar acoustic signals.

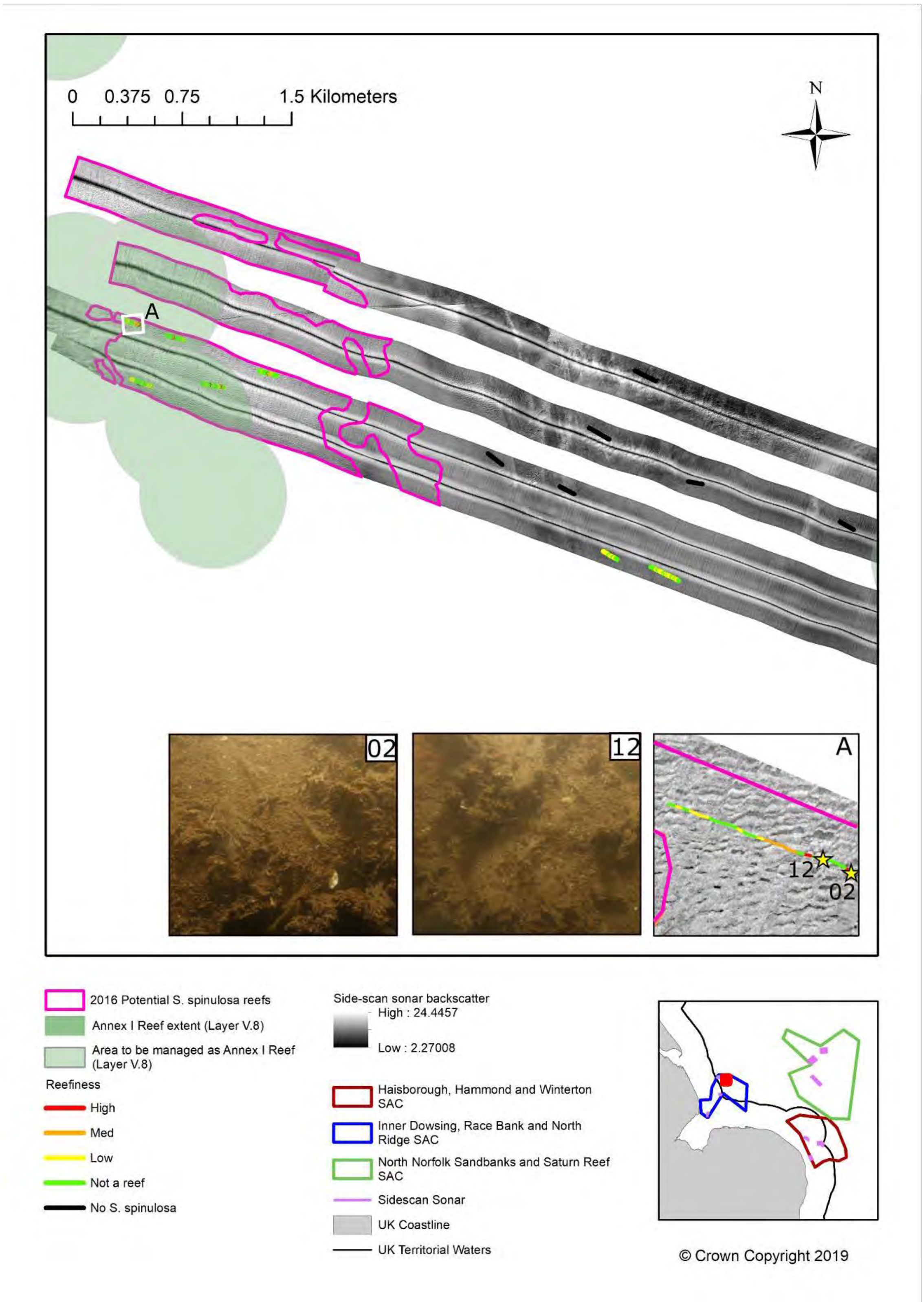


Figure 59. Side scan sonar data collected from East of Silver Pit with the area of potential *S. spinulosa* reef delineated. Insets show a close-up of the acoustic signature and seabed images (video station ESVP53, stills 02 and 12) from two areas classified as having 'high' reefiness.

Lynn Knock

No evidence of *S. spinulosa* or suitable substrate was observed from the acoustic data. The two camera transects undertaken at Lynn Knock within IDRBNR recorded no *S. spinulosa* reef.

Silver Pit South

A total of ten video transects were assessed for the presence and reefiness of *S. spinulosa* within Silver Pit South. All, but one, are located in areas previously identified as Annex I Reef or within the 'Area to be managed as Annex I Reef' (JNCC 2019). While the majority of the transect segments were classified as having a 'low' reefiness, some areas were categorised as 'medium' reefiness (Figure 60). In the northern region of the area surveyed in Silver Pit South, several locations along one video transect (i.e. SVPS06_STN220) were assigned as 'high' reefiness. These 'high' reefiness areas may be associated with several raised seabed features. The acoustic signatures of the 'low' and 'medium' reefiness regions could not be distinguished from those of the surrounding, coarse sediments. However, the areas of reef and areas of coarse sediment (where reefs could potentially form) could be distinguished from fine sediment areas in the east of the site, wherein distinctive sandwaves and ripples could be differentiated.

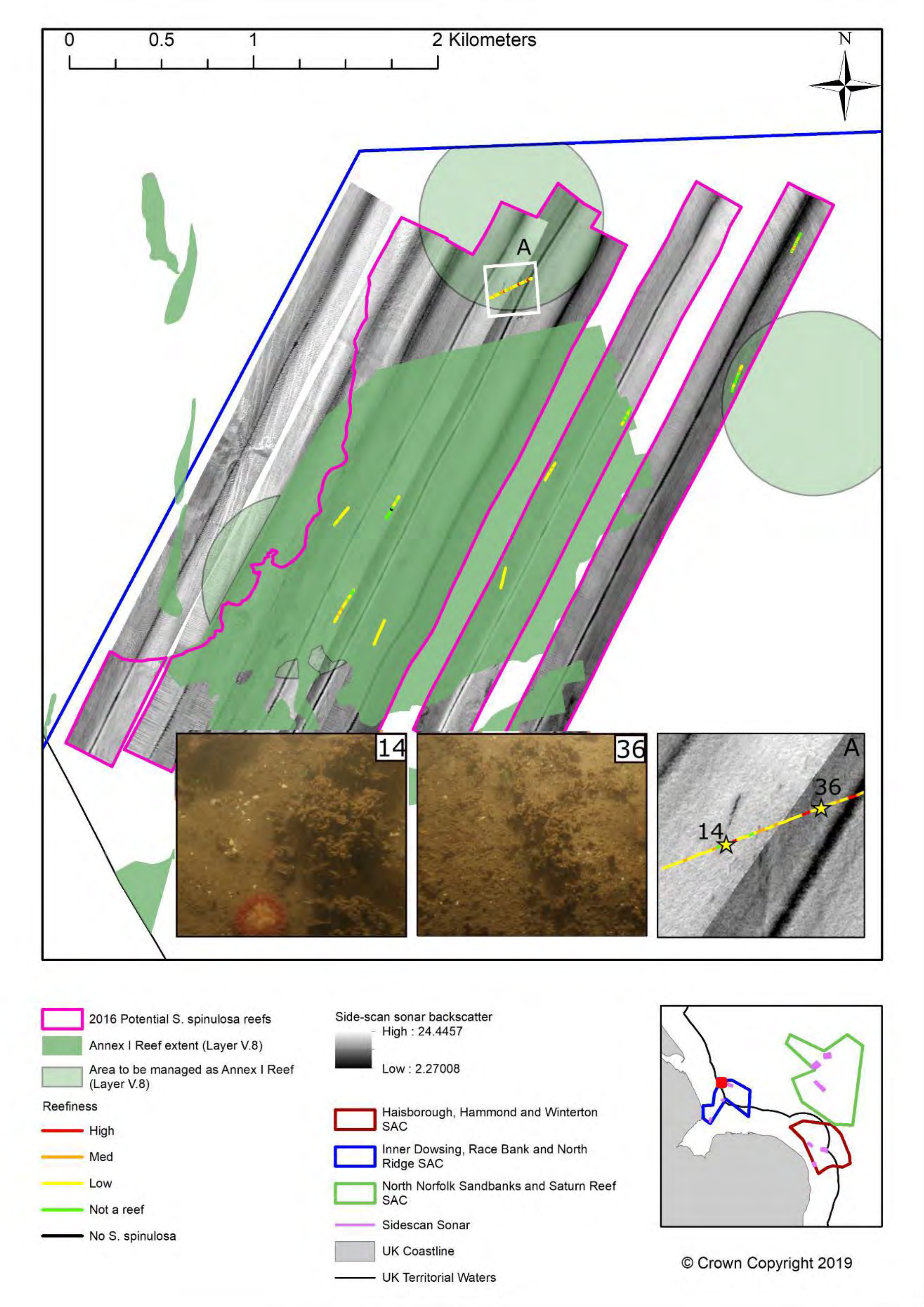


Figure 60. Side scan sonar data collected from Silver Pit South with the area of potential *S. spinulosa* reef delineated. Insets show a close-up of the acoustic signature and seabed images (video station SVPS06, stills 14 and 36) from two areas classified as having 'medium' reefiness.

4.4 Objective 4: Annex I *S. spinulosa* Reef quality and epifaunal communities

This section meets the requirements of Objective 3 by addressing the following question:

Question 1. How does the quality of Annex I Reef vary across and within the three SACs?

Question 2. Does abundance of conspicuous fauna (e.g. *Asterias rubens*) vary according to the quality of the Annex I Reef?

To answer question 1, Annex I Reef quality (i.e. high, medium, low, not a reef, no reef) in this study was assessed by quantifying the percentage of the different reef categories based on the results of the 5m video segments for each of the surveyed areas. This was undertaken for seven areas across the three SACs (Table 24).

Differences in epifaunal communities and characteristic (or conspicuous) species were assessed using data from both reef and non-reef areas. Whilst these analyses provide some information to aid in addressing question 2, community differences according to reef quality (low, medium or high) could not be undertaken using the data provided.

The outcomes are presented in the sub-sections below for each of the SACs. The assessments are confined to the structural features of epifaunal communities as there are currently no robust methods that allow the functional features of epifaunal communities to be described based on video-derived data.

Table 24. Percentages of video (5 m segments) identified as containing *S. spinulosa* aggregations within the North Norfolk Sandbanks and Saturn Reef (NNSSR), Haisborough, Hammond and Winterton (HHW) and Inner Dowsing, Race Bank and North Ridge (IDRBNR) SACs, categorised according to reefiness (as per Table 8). Two additional transects were undertaken in the Leman Bank CSA trough.

SAC	Area*	No. of transects undertaken	No. of transects for reefiness assessment	No reef	Not a reef	Low	Medium	High
NNSSR	NSWB	15	0	-	-	-	-	-
	NWBK	14	0	-	-	-	-	-
	STRN	15	3	0	84.38	12.50	3.13	0
	LMBK (ADD)	2	1	0	31.43	57.14	11.43	0
HHW	HWNC	6	5	1.18	50.59	16.47	22.35	9.41
	HWSC	4	4	0	1.02	28.57	47.96	22.45
	WMCS	8	6	8.64	40.74	24.69	18.52	7.41
IDRBNR	DKSH	6	6	0	74.25	22.16	3.59	0
	ESVP	14	7	0.51	57.58	33.84	5.05	3.03
	SVPS	10	10	0.71	25.36	64.64	7.50	1.79
	LYNK	2	0	-	-	-	-	-

* NSWB = North of Swarte Bank; NWBK = North of Well Bank; STRN = Saturn Reef; LMBK (ADD) = Leman Bank CSA trough additional transects; HWNC = HHW Northern Closure; HWSC = HHW Southern Closure; WMCS = West of Middle Cross Sand; DKSH = Docking Shoal; ESVP = East of Silver Pit; SVPS = Silver Pit South; LYNK = Lynn Knock.

4.4.1 North Norfolk Sandbanks and Saturn Reef SAC

The assessment of Annex I Reef quality ('reefiness') within NNSSR was undertaken at Saturn Reef and the Leman Bank trough areas. No reef was observed in any of the video transects from North of Swarte Bank and North of Well Bank within NNSSR. For Saturn Reef, the majority of the 5m video sections assessed for reefiness were classified as 'not a reef' (Table 24). Of the three videos taken forward for reefiness assessment, approximately 15% were classified as 'low to medium' reef. Annex I reef was confirmed at one of the two video transects undertaken at Leman Bank. Approximately 57% of the transect was classified as 'low' reef, with a further 11% classified as medium reef.

Analyses of the epifaunal communities from all reef and non-reef areas surveyed at NNSSR was conducted on a reduced number of transects due to naturally turbid conditions at the site affecting the visual quality of the video.

Cluster analysis (at SIMPROF similarity of 5%) revealed seven significantly different epifaunal groups and one outlier ('d') (Figure 61 and Figure 63). Groups 'a' and 'h' separated from the main faunal cluster, with 'a' representing Leman Bank (seven segments from one transect) and 'h' representing North of Swarte Bank. Group 'a' was characterised by taxa such as the edible crab *Cancer pagurus*, and hermit crabs from the family Paguridae, hydrozoans; *Nemertesia sp.*, Sertulariidae and *Turbularia sp.*, bryozoan turf and erect bryozoans such as *Vesicularia spinosa* and from the family Flustridae, and the sea anemone *Sagartia* sp. The common starfish, *Asterias rubens*, was frequently observed in three of the seven video segments at Leman Bank but was not a characteristic species of group a, whilst it was the main characterising species in groups 'b' - 'h' (Figure 62). When *S. spinulosa* reef SACFOR abundances were overlain on the nMDS ordination, Leman Bank was the only area in NNSSR (included in the analyses) where 'live' reef (upstanding, with visible apertures) was observed (Figure 63). Reef rubble was also observed STRN01 (group 'e'), however the associated fauna resembled areas without reef (see Annex 2). The broadscale habitats (BSH) A5.1: Subtidal Coarse Sediment and A5.2: Subtidal Sand, predominated groups 'b' – 'h'. The Subtidal Mixed Sediment BSH (A5.4) was also observed in groups 'e', 'f' and 'g', along with group 'a' (Figure 64).

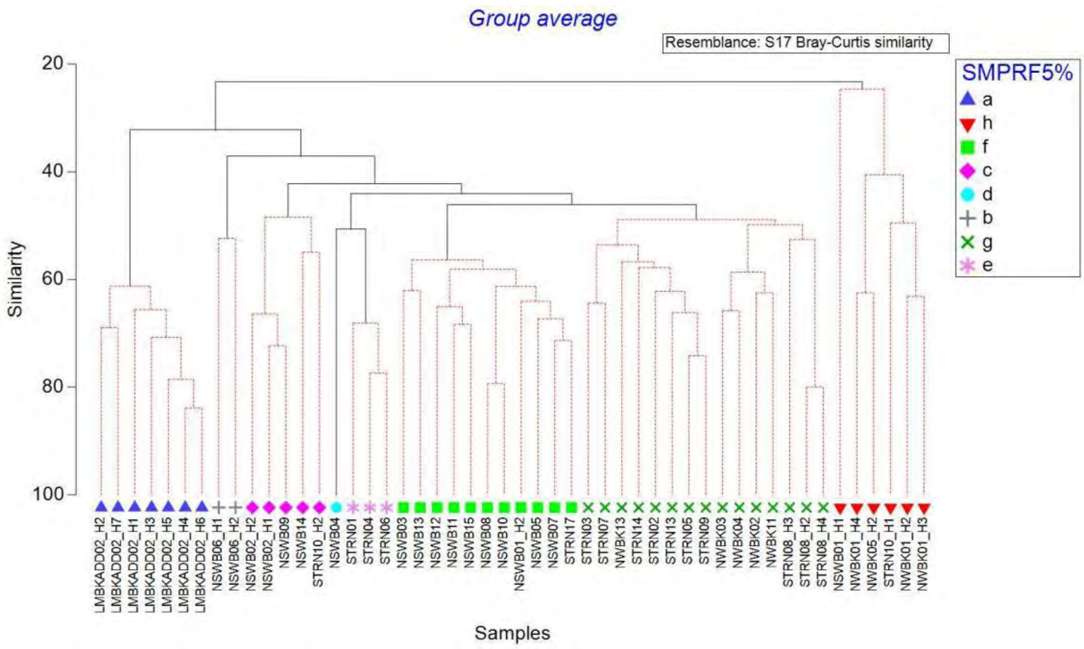


Figure 61. Cluster analysis (SIMPROF 5%) of epifaunal communities observed in video transects collected within North of Swarte Bank (NSWB), North of Well Bank (NWBK), Saturn (STRN) and Leman Bank (LMBKADD) within North Norfolk Sandbanks and Saturn Reef (NNSSR) SAC.

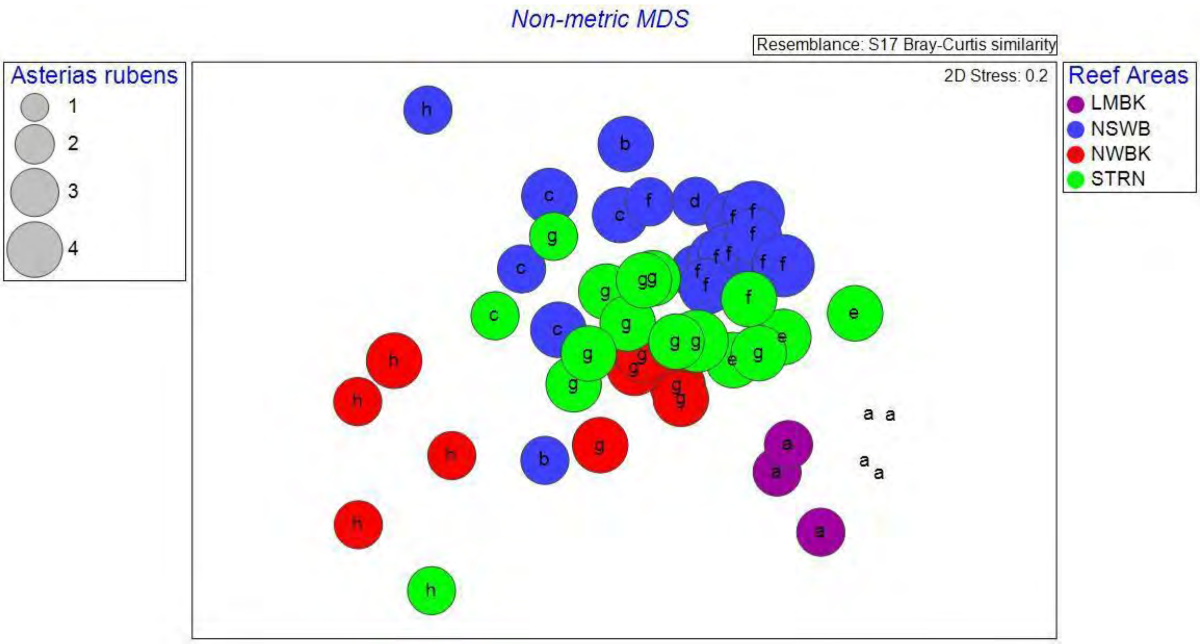


Figure 62. nMDS ordination of epifaunal communities at North of Swarte Bank (NSWB), North of Well Bank (NWBK), Saturn (STRN) and Leman Bank (LMBKADD) in North Norfolk Sandbanks and Saturn Reef (NNSSR) SAC, displayed according to SIMPROF group (5% significance), displayed according to SACFOR abundance of the common starfish, *Asterias rubens* (1 = Rare, 2 = Occasional, 3 = Frequent, 4 = Common).

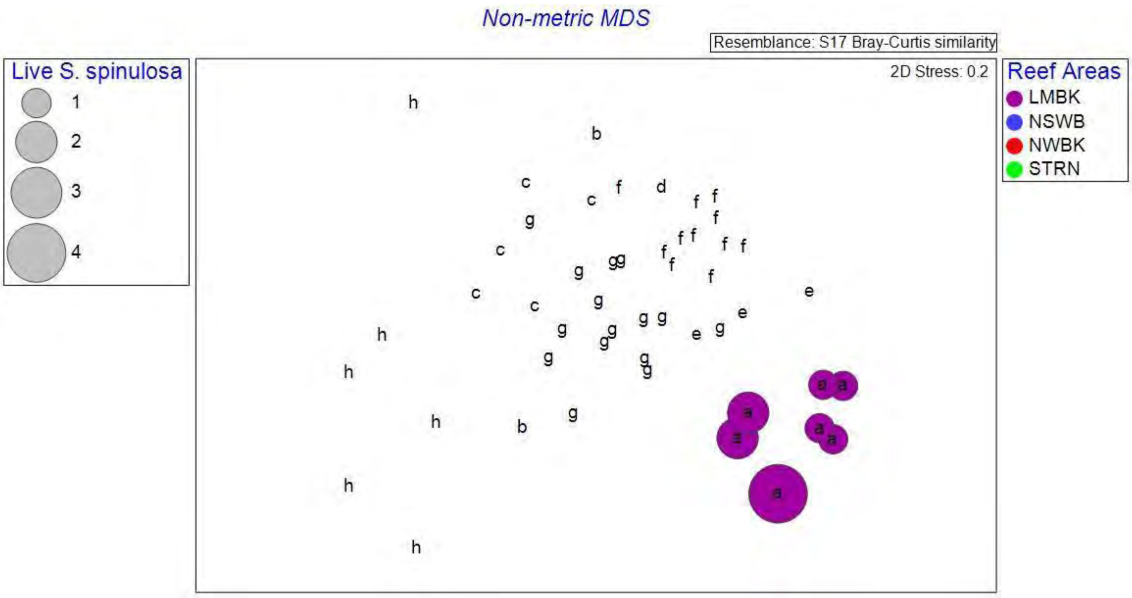


Figure 63. nMDS ordination of epifaunal communities at North of Swarte Bank (NSWB), North of Well Bank (NWBK), Saturn (STRN) and Leman Bank (LMBKADD) in North Norfolk Sandbanks and Saturn Reef (NNSSR) SAC, displayed according to SIMPROF group (5% significance) and overlain with 'live' *S. spinulosa* reef SACFOR values (1 = Rare, 2 = Occasional, 3 = Frequent, 4 = Common).

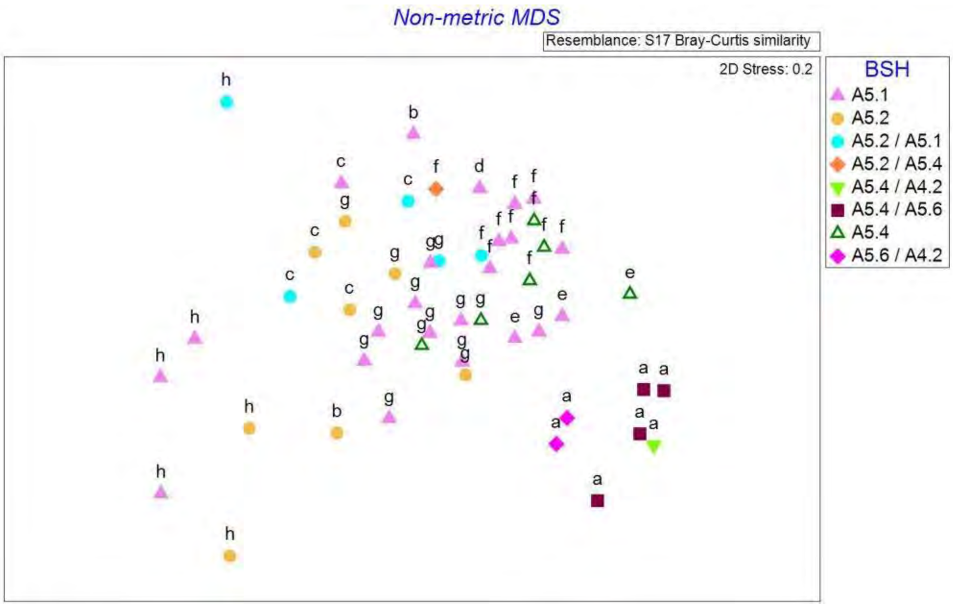


Figure 64. nMDS ordination of epifaunal communities observed at NNSSR, displayed according to SIMPROF group (5% significance) and broadscale habitat (BSH).

4.4.2 Haisborough Hammond and Winterton SAC

HHW Southern Closure contained the greatest proportion of ‘high’ and ‘medium’ Annex I Reef of all the SACs (Table 24). Overall, all areas targeted within the HHW site contained the highest quality reef (‘medium-high’ reefiness).

The poor quality of videos collected from within HHW Southern Closure resulted in the complete exclusion of these data from epifaunal community analysis. The biological data from two of the six videos collected from within HHW Northern Closure, and four of the eight from West Middle Cross Sands were also excluded due to poor visual quality. The analysed data therefore consisted of two main groups (‘b’ and ‘c’), consisting of three and four video segments respectively (one of which comprised two segments from the same transect) and one outlier (group ‘a’) (Figure 65 and Figure 67). Group ‘b’ was characterised by abundant common starfish, *A. rubens*, along with Ceriantharia (tube-dwelling anemones), the bryozoans such as *Alcyonidium* sp. and Flustridae. Group ‘c’ was characterised by the edible crab *C. pagurus*, erect hydrozoans/bryozoans and small anthozoans (1–3cm). Only one species was observed in group ‘a’: the erect bryozoan *V. spinosa*. Differences between the two main groups were mainly due to greater occurrences of *A. rubens* (Figure 66), the hydrozoan*, Nemertesia*, Ceriantharia, the polychaete family Sabellidae and the sunstar, *C. papposus* in group ‘b’. *S. spinulosa* reef (‘live’ and rubble) was observed in both main groups (Figure 67). Sediments within both main groups were classified as A5.1: Subtidal Coarse Sediment, A5.4: Subtidal Mixed Sediments (including pebbles, cobbles and boulders), A5.6: Subtidal Biogenic Reef or a mosaic of two of these habitats. Bedrock (A4.2) was also observed at WMC09 (Figure 68).

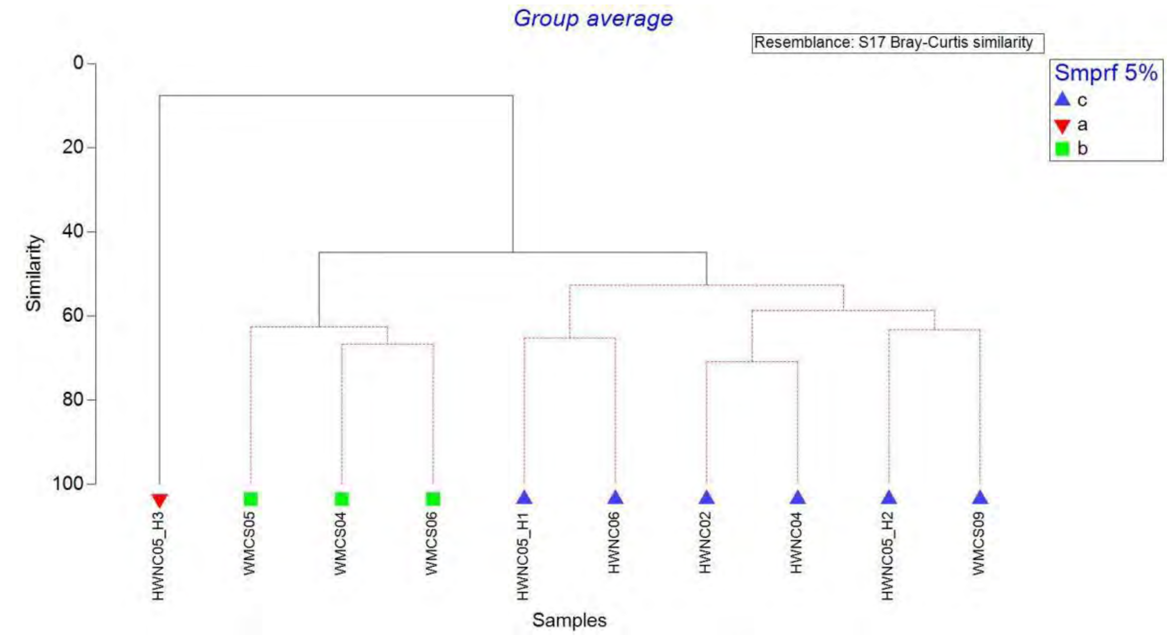


Figure 65. Cluster analysis (SIMPROF 5%) of epifaunal communities observed in video transects from HHW Northern Closure (HWNC) and West Middle Cross Sand (WMCS) within Haisborough, Hammond and Winterton (HHW) SAC.

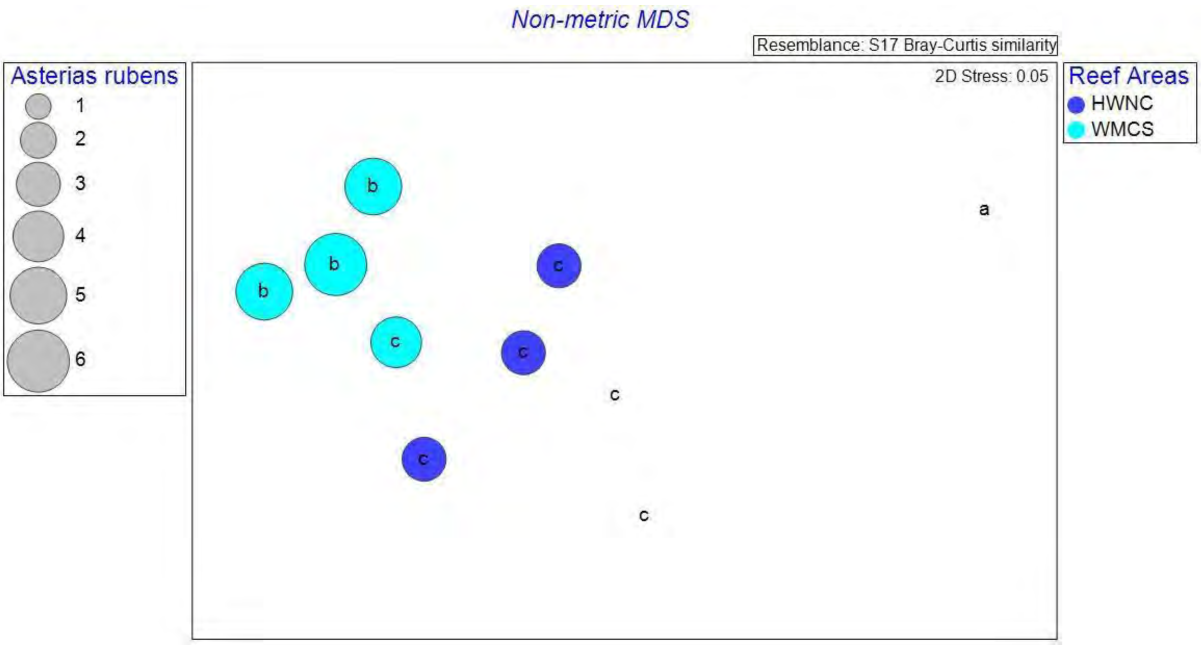


Figure 66. nMDS ordination of epifaunal communities at HHW Northern Closure (HWNC) and West Middle Cross Sand (WMCS) within Haisborough, Hammond and Winterton (HHW) SAC, displayed according to SIMPROF group (5% significance) and overlain with SACFOR abundances of the common starfish, *Asterias rubens* (1 = Rare, 2 = Occasional, 3 = Frequent, 4 = Common, 5 = Abundant, 6 = Superabundant).

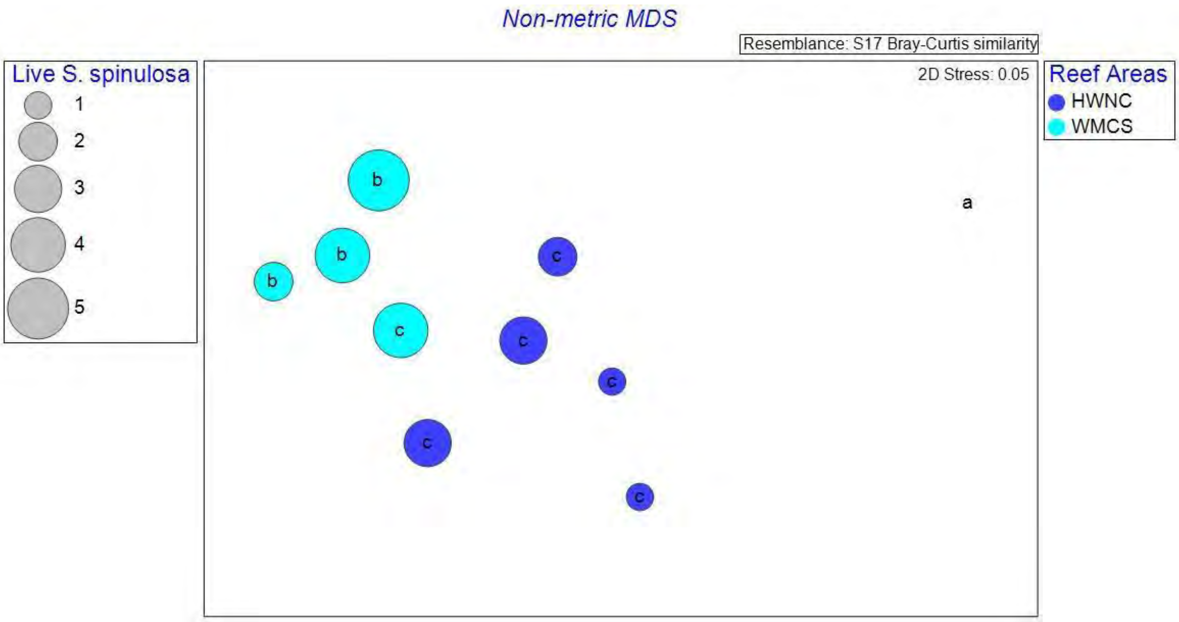


Figure 67. nMDS ordination of epifaunal communities at HHW Northern Closure (HWNC) and West Middle Cross Sand (WMCS) within Haisborough, Hammond and Winterton (HHW) SAC, displayed according to SIMPROF group (5% significance) and overlain with 'live' *S. spinulosa* reef SACFOR values (1 = Rare, 2 = Occasional, 3 = Frequent, 4 = Common, 5 = Abundant).

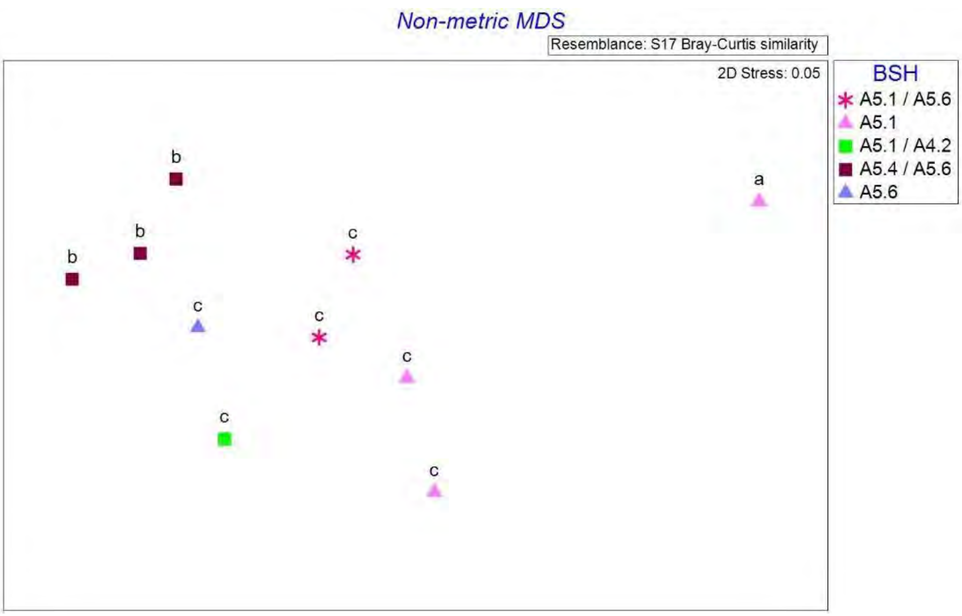


Figure 68. nMDS ordination of epifaunal communities observed at HHW, displayed according to SIMPROF group (5% significance) and broadscale habitat (BSH).

4.4.3 Inner Dowsing, Race Bank and North Ridge SAC

Three of the four areas targeted for Annex I Reef survey within IDRBNR, contained low and medium Annex I Reef. ESVP and Silver Pit South in the north of the site also contained small patches of high *S. spinulosa* reef. No reef was observed at Lynn Knock.

The visual quality of videos collected from with IDRBNR was lower than those acquired from other SACs. For Docking Shoal and ESVP, only one video was excluded from analysis, whereas four videos were excluded from Silver Pit South and all videos were excluded from Lynn Knock. Cluster analysis (SIMPROF) identified two distinct groups: 'a' and 'b' (Figure

69). SIMPER analysis showed that both groups were similarly characterised by the anemone, *Urticina* sp., which accounted for approximately 20% of the within group similarity for both groups. The hydrozoan, Sertulariidae, bryozoan, Flustridae, and edible crab, *C. pagurus* were the next characteristic taxa for group ‘a’, whilst Caridea (shrimps), Flustridae and the hydrozoans Plumulariidae were characteristic of group ‘b’. The common starfish was only observed in six of the video segments but was present in the three reef areas within IDRBNR included in the analyses (Figure 70). ‘Live’ *S. spinulosa* and *S. spinulosa* rubble were observed within both groups, although seven videos within group ‘a’ (ESVP) contained no ‘live’ reef or rubble. Further examination of the differences between this subgroup and the other two main subgroups within group ‘a’ revealed an absence of taxa such as large anthozoans (including *Sagartia* sp. 3-15cm), Caridean shrimps, the lobster *Homarus Gammarus,* and the tube-building polychaete *Lanice conchilega*. The broadscale habitat associated within this subgroup was A5.1: Subtidal Coarse Sediment. Examination of the habitat notes for the non-reef transects (subgroup within ‘a’) revealed that the sediments were composed of cobbles and pebbles in addition to sand, gravel and shell. The larger surface area of the cobbles and pebbles provide an attachment surface for sedentary species, such as found in areas of *S. spinulosa* reef, which accounts for the similarity in species composition within reef and non-reef areas. Sediments associated with reef/rubble in the remainder of group ‘a’ and group ‘b’ were generally classified as A5.4: Subtidal Mixed Sediments or a mosaic of A5.1 or A5.4 with the BSH A5.6: Subtidal Biogenic Reef (Figure 72).

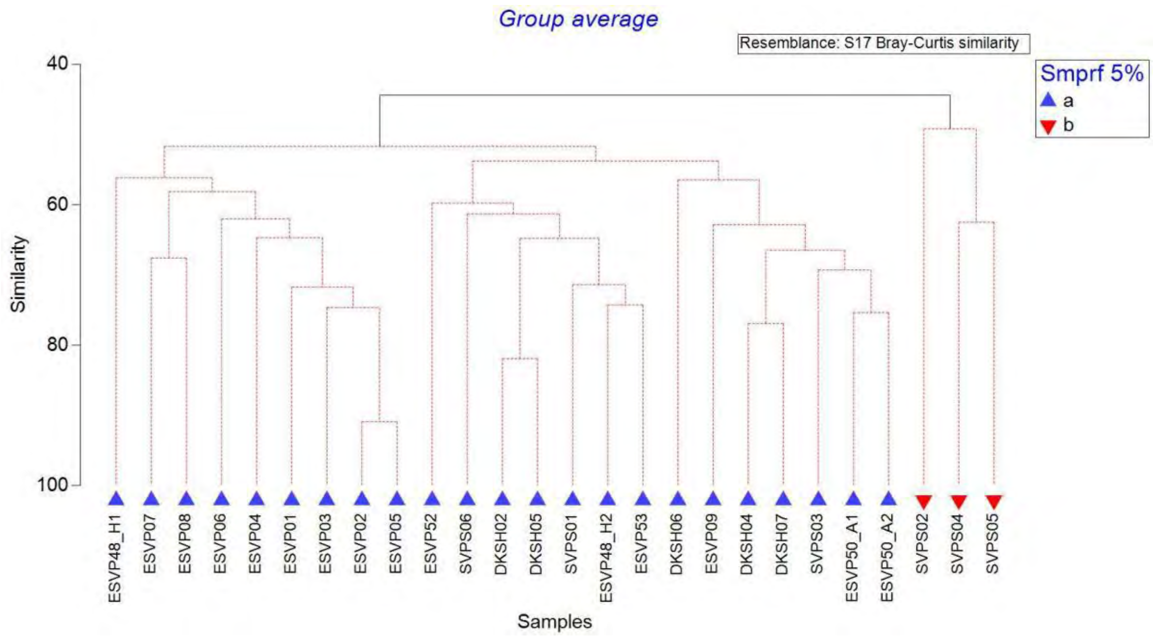


Figure 69. Cluster analysis (SIMPROF 5%) of epifaunal communities observed in video transects from ESVP, Docking Shoal (DKSH) and Silver Pit South (SVPS) CSA within Inner Dowsing, Race Bank and North Ridge (IDRBNR) SAC.

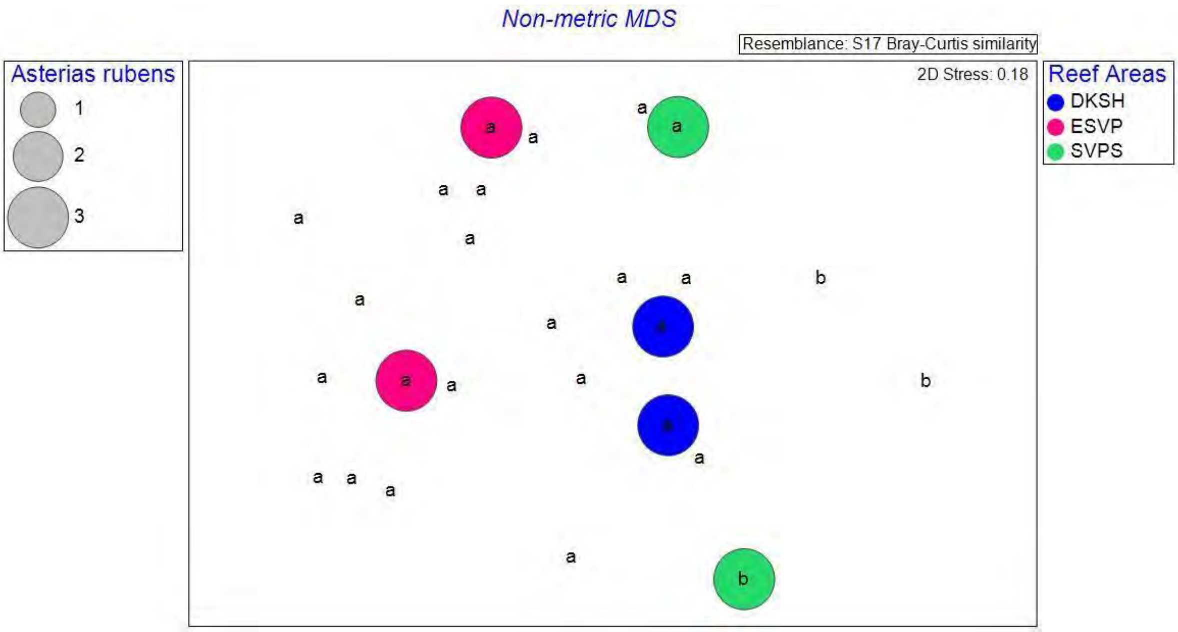


Figure 70. nMDS ordination of epifaunal communities from ESVP, Docking Shoal (DKSH) and Silver Pit South (SVPS) within Inner Dowsing, Race Bank and North Ridge (IDRBNR) SAC, displayed according to SIMPROF groups (5% significance) and overlain with SACFOR abundances of the common starfish, *Asterias rubens* (1 = Rare, 2 = Occasional, 3 = Frequent).

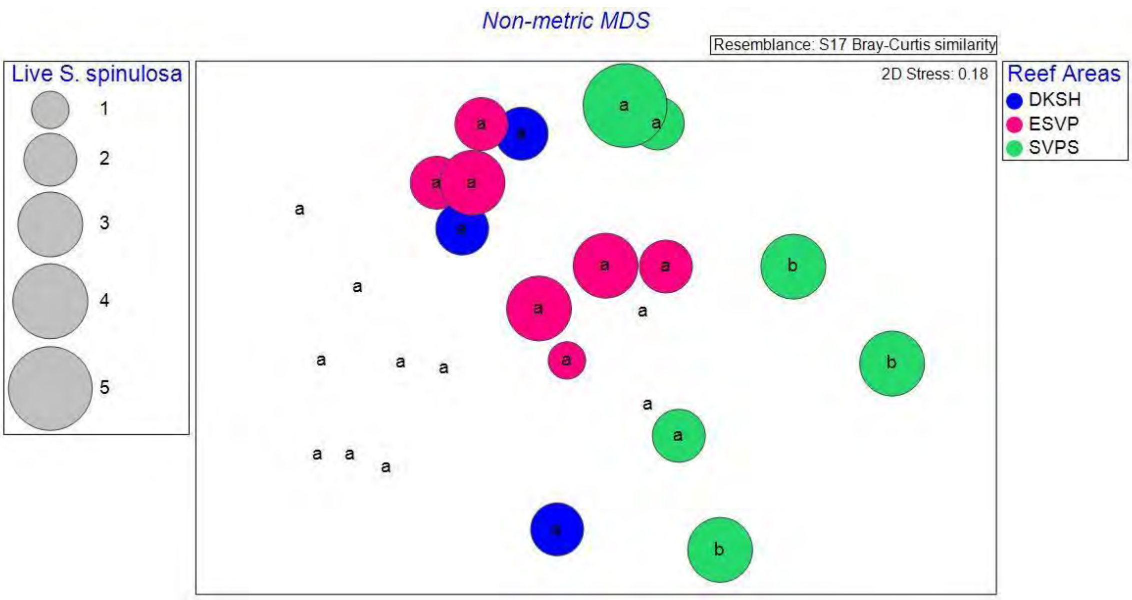


Figure 71. nMDS ordination of epifaunal communities from ESVP, Docking Shoal (DKSH) and Silver Pit South (SVPS) within Inner Dowsing, Race Bank and North Ridge (IDRBNR) SAC, displayed according to SIMPROF groups (5% significance) and overlain with 'live' *S. spinulosa* reef SACFOR values (1 = Rare, 2 = Occasional, 3 = Frequent, 4 = Common, 5 = Abundant).

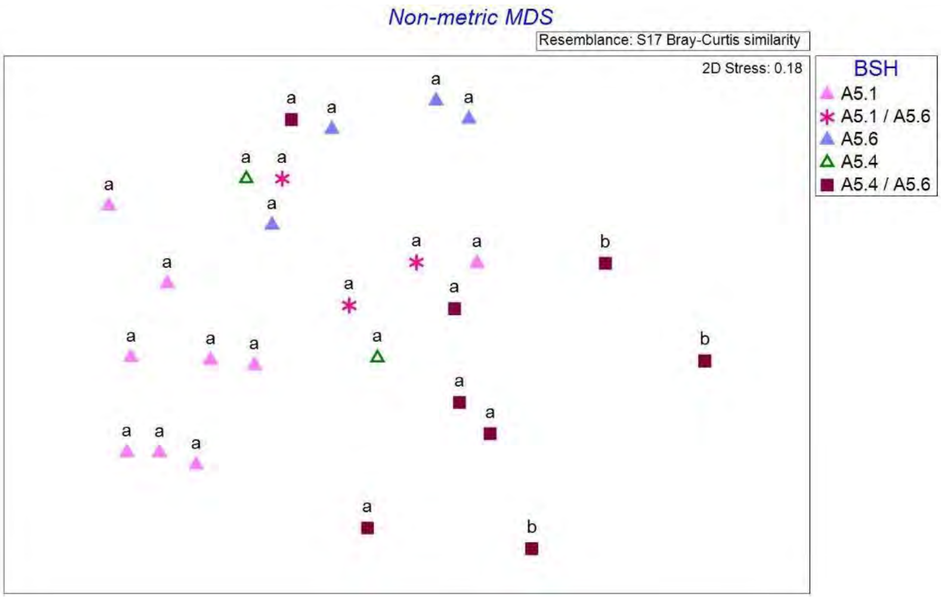


Figure 72. nMDS ordination of epifaunal communities observed at IDRBNR, displayed according to SIMPROF group (5% significance) and broadscale habitat (BSH).

4.5 Objective 5: Non-indigenous species and Marine litter (MSFD Descriptors D2 and D10)

This section meets the requirements of Objective 5 by addressing the following questions:

Question 1. Are non-indigenous species present within the site, and if so, how are they distributed in terms of abundance?

Question 2. Which types of marine litter are present (if any)?

4.5.1 Non-indigenous species (MSFD Descriptor D2)

Three NIS were identified from the 440 grab samples (Figure 73). A total of 74 individuals of the slipper limpet (*Crepidula fornicata*) were identified from 6% (27 out of 440) of the grab samples. One of these samples was located within HHW while the remaining 26 samples were located within IDRBNR. In addition, 21 *Mya arenaria* (a bivalve mollusc) were collected from nine Inner Dowsing trough and 'beyond sandbank' samples within IDRBNR. One WCT trough sample (located just outside the NNSSR SAC boundary) contained one individual of the polychaete *Goniadella gracilis*.

C. fornicata was the only NIS observed in beam trawls; two individuals were collected from the Leman Bank trough within NNSSR, three from within North Ridge trough and one from the flank of Inner Dowsing within IDRBNR. *C. fornicata* was also the only NIS observed in video and still images. Four individuals were observed in one still image at Docking Shoal within IDRBNR.

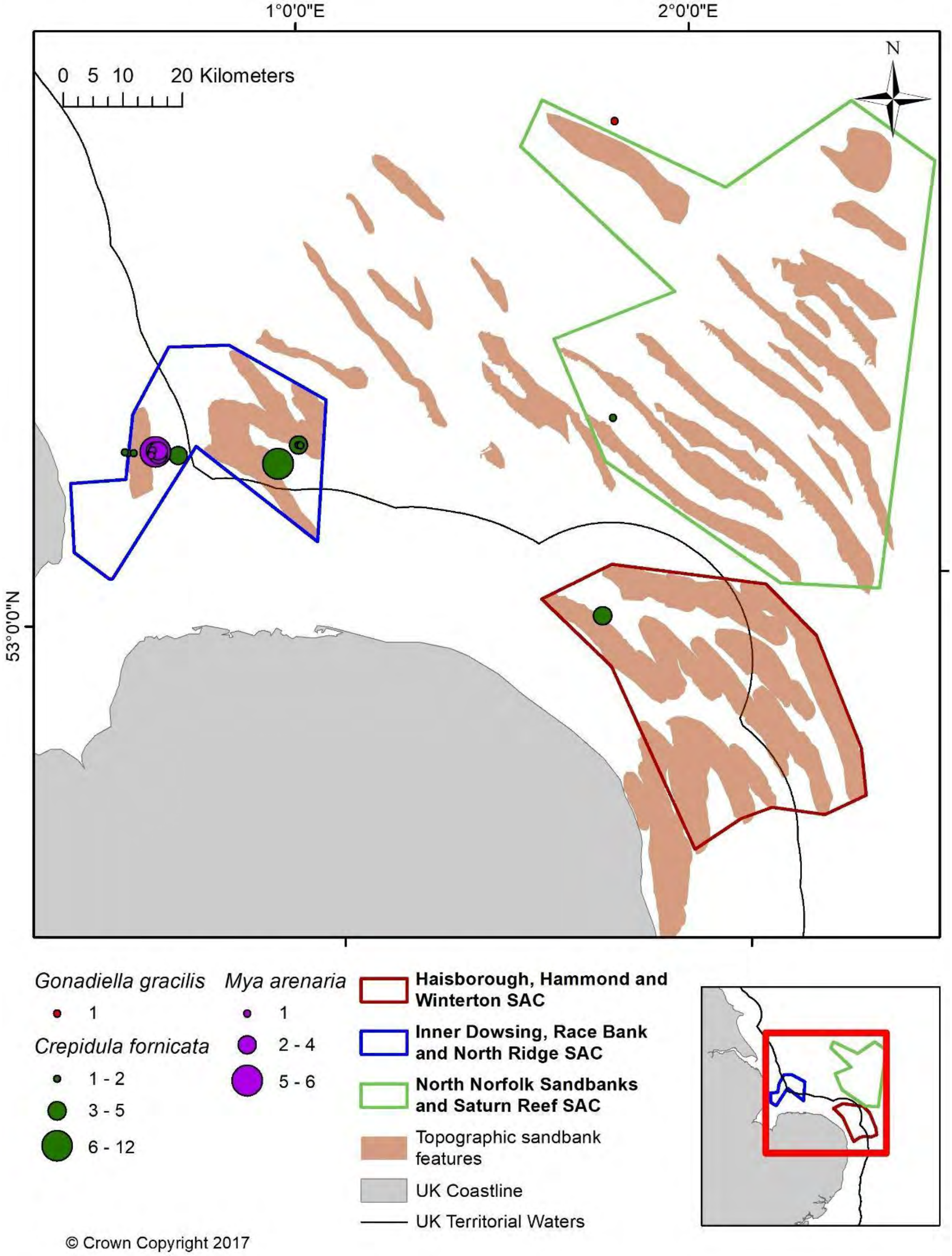


Figure 73. Locations where non-indigenous species were recorded across the three SACs.

4.5.2 Marine litter (MSFD Descriptor D10)

Plastic was found in 45% (199 out of 440) of grab samples across all three SACs (Figure 74). Of a total of 732 pieces of plastic, 299 were >5mm and 433 were <5mm in size. Plastic was also observed in beam trawls from IDRBNR (station NRRDT02) and HHW (station SWHTF21). Fishing line was also found at station NRRDT02. No litter was recorded from beam trawls undertaken at NNSSR.

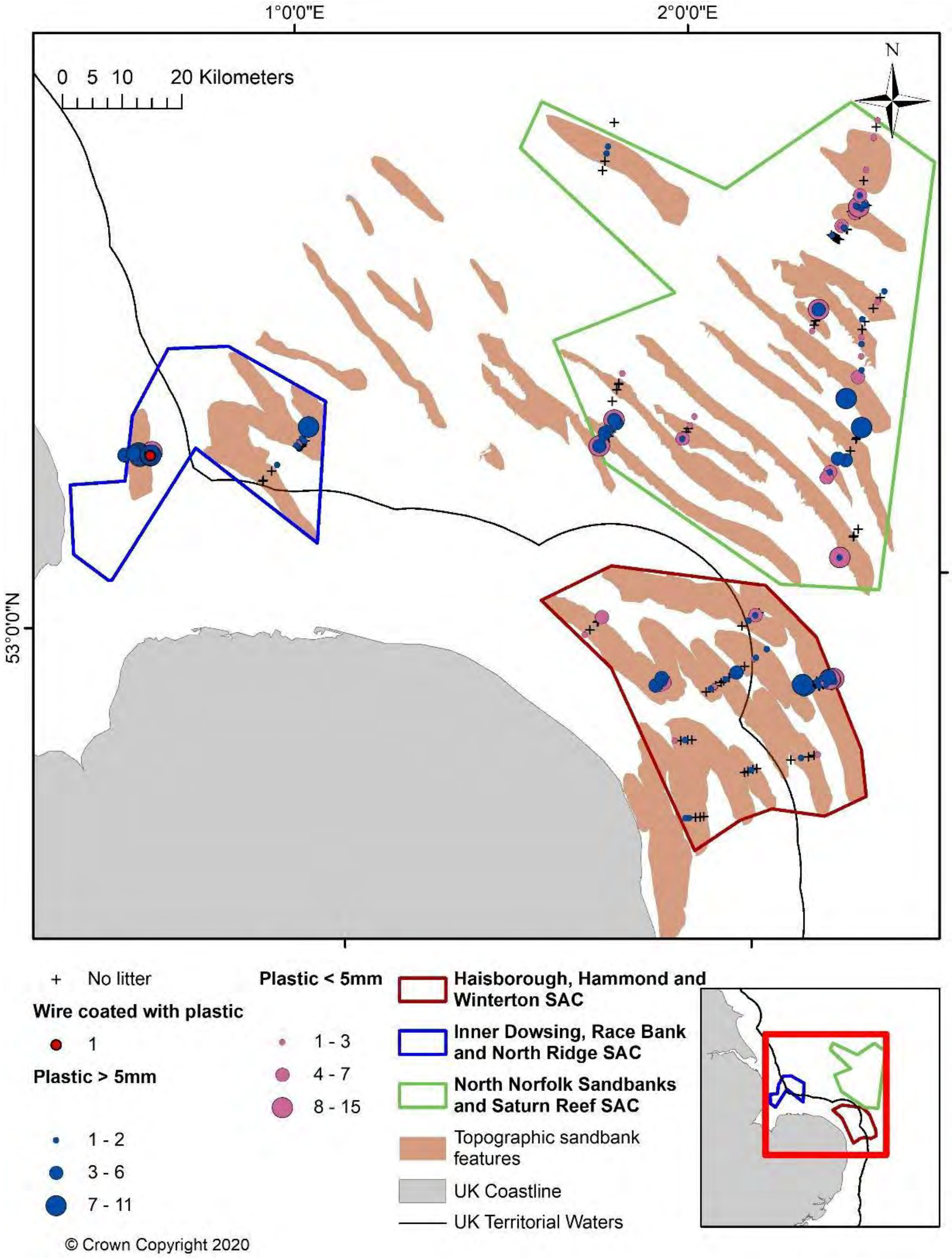
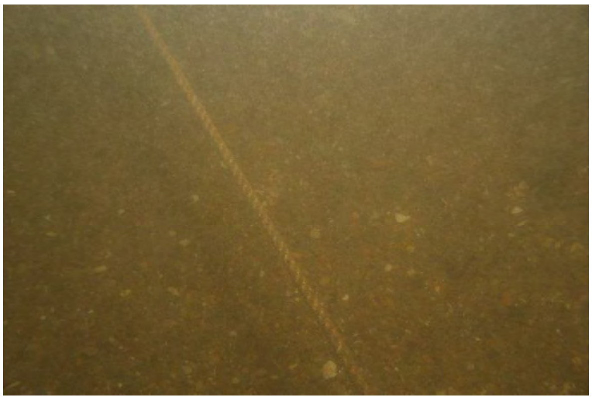
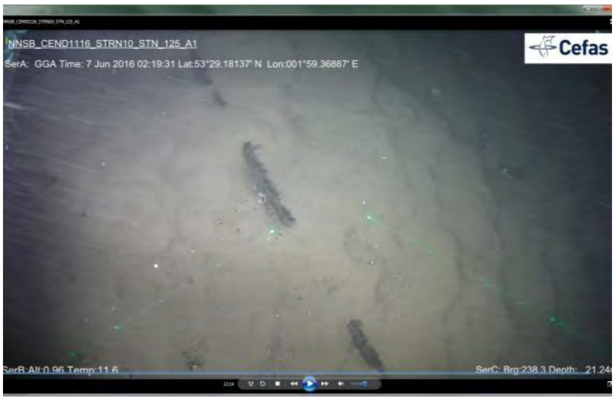


Figure 74. Litter observed in 2016 grab samples collected across the three SACs.

Anthropogenic material was also observed in video footage collected at three of the ten *S. spinulosa* reef investigation areas. Fishing gear in the form of rope and twine was observed within East of Silver pit (IDRBNR) and Saturn (NNSSR). An exposed cable was also observed within the Saturn survey area. A black bin bag wrapped around a boulder and wreckage were observed within HHW Northern Closure (HHW) (Figure 75, see also Figure 6 for reef area locations).


Rope: East of Silver Pit (IDRBNR) still image no.49

Blue Twine: Saturn (NNSSR) still image no. 01



Exposed cable: Saturn (NNSSR) still image no.10


Black bin bag: HHW Northern Closure (HHW) still image no. 06

Wreckage: HHW Northern Closure (HHW) still image no. 04

Figure 75. Images of anthropogenic material observed in video and still images within the *S. spinulosa* reef investigation areas during 2016.

5. Discussion

The successful, collaborative surveys of the NNSSR, HHW and IDRBNR SACs during 2016 acquired a significant quantity of targeted, empirical data pertaining to the sediments and biological features of a number of Annex I Sandbanks and *S. spinulosa* reefs within each site. For the Annex I Sandbanks, data are analysed and interpreted here with the aim of assessing the spatial (and in some cases temporal) variability of the structure and function of their biological attributes and how these vary spatially within different topographical zones. Morphological and sediment granulometric properties variability of sandbanks are also described. This assessment has not been restricted solely to the sandbanks themselves, but data from areas beyond the sandbank feature and from areas representing the wider seabed characteristics have also been included within this appraisal. It is in this respect that arguably the 2016 surveys have, hitherto, resulted in the acquisition of the most comprehensive and holistic dataset of the ecological characteristics of sandbanks in the Southern North Sea. For Annex I *S. spinulosa* reefs, this study has focused on assessing their distribution, quality, persistence and biological characteristics. The data are presented here to address a number of objectives to aid the relevant SNCBs to more effectively manage the designated Annex I features within the three SACs. While the detailed outcomes of the data are presented within the results section, the broader implications of the findings are discussed in the sub-sections below for each Annex I feature attribute. Finally, recommendations to facilitate the future monitoring of the three sites, based on what has been learnt from the data presented herein, are discussed. In doing so, the latter sub-section explicitly meets the requirements of Objective 6.

5.1 Annex I Sandbanks: extent and distribution

Temporal comparison of MBES data for five sandbanks across the three sites revealed differences in the temporal stability of broad morphology between sandbanks. While the Indefatigable Bank sandbank within the NNSSR was regarded as having remained more-or-less stable between 2013 and 2016, the Leman Bank (also within NNSSR) was estimated to have migrated 30m north west in the same timeframe. Meanwhile, the two profiles studied for the sandbank within the HHW site indicated no discernible shift between 2014 and 2016, while the shoreward flank of the Inner Dowsing sandbank within IDRBNR site has shifted by *circa* 40m. Clearly, therefore, temporal changes in sandbank morphology and distribution are very bank-specific making generalities in, or predictions of, movement difficult. The observed geographical progression of a designated feature has inherent management implications, and significant consequences for the design and conduct of any subsequent monitoring programme which relies on point samples over limited spatial scales (e.g. grab sampling for biotic community structure or function). As has been demonstrated for at least one sandbank here, a sample taken on a flank in one year may possibly be located within a sandbank trough at the time of the next sampling event (based on a 6-yearly monitoring timeframe). This would imply that monitoring changes in sandbank morphology and/or position is indispensable as part of any program in which seabed samples are taken.

The extent and distribution of Annex I Sandbanks here was addressed based on limited acoustic data from six CSA sandbanks. Data were restricted to one location (i.e. a ‘slice’ through) on each sandbank which is insufficiently comprehensive to allow scaling up to the entire sandbank. Future monitoring of sandbank extent and distribution using acoustic approaches clearly needs to be more spatially comprehensive. Coverage of each sandbank needs to allow a greater number of slices to be morphologically analysed, and a larger number of sandbanks (within and across SACs) need to be targeted. Such an extensive monitoring programme would have cost implications and the financial viability would need to be assessed. An alternative approach to acoustic-based monitoring in this respect is described later in the recommendations for monitoring sub-section.

5.2 Annex I Sandbanks: structure and function

Several numerical approaches were applied to the particle size data to explore the variability in sediments between topographical zones and CSAs/WCTs within each of the SACs. EUNIS provided a broad overview of the sediment types and indicated that sandy sediments dominated at all CSAs and WCTs within the three sites with coarse, mixed and muddier sediment fractions being present in localised regions. However, more subtle differences in sediment composition could be discerned using additional approaches. Entropy enabled an examination of changes in sediment granulometry which were not apparent when grouped according to EUNIS. Unlike EUNIS, which uses the percentages of sand, gravel and mud, entropy derives groups based on the composition of the full phi breakdown. For this study area, differences in the composition of the various sand fractions, which are merged in formulating the EUNIS groups, were influential in distinguishing between entropy groups. Furthermore, the sediment groups derived from entropy analysis also proved to be particularly suitable for the basis of biotope classification. Inclusion of entropy analysis to support future assessments of sediment groups for these SACs and potentially other MPAs is therefore recommended.

Differences in sediment type were observed between the topographical zones, with the crests and flanks generally sharing more similarities with each other than with the troughs and ‘beyond sandbank’ zones. Sediment differences were also observed between seaward and shoreward flanks at some CSAs which may be due to the morphology of the sandbanks. For example, Leman Bank shows a steady incline from trough to crest on the shoreward side of the bank and sharply declines on the seaward side, with observed differences in shoreward and seaward flank sediment types (Figure 9). However, Indefatigable Bank shows a steady decline on the seaward side, with very little differences observed for both flanks and troughs. Differential slope gradients between shoreward- and seaward facing flanks are likely to reflect differences in the prevailing local hydrodynamic conditions and these are likely to manifest in the observed sediment granulometric differences.

The faunal assemblages inhabiting the sandbanks were also assessed for differences and similarities with respect to topographical zones. This allowed us to gain a better understanding of the potential faunal connectivity within and between banks. At the scale of a sandbank, the infaunal data demonstrated that crests were generally less speciose than flanks and troughs and the crest taxa that were observed were also commonly observed on flanks and troughs. These infaunal taxa (generally a small number of polychaete worms and amphipods) vary with respect to their larval, post-larval or adult dispersive capabilities. However, given the hydrodynamic nature of the sandbanks, faunal recolonisation potential is likely to be high even for the taxa with relatively poor dispersal potentials (e.g. amphipods which brood their young). Indeed, while amphipods may possess relatively poor egg and larval dispersal capabilities, they are relatively mobile as adults and movement between topographical zones or even between sandbanks in such hydrodynamic areas is certainly plausible. This is supported by the fact that many of the infaunal taxa observed are ubiquitous and have been found associated with sandbanks further offshore, e.g. Dogger Bank (Ellis *et al*. 2011). At the larger scale, however, the sandbanks closer to shore showed a certain degree of distinction in their infaunal assemblages. Amphipod species such as *Pontocrates arenarius* and *Haustorius arenarius,* more commonly found in intertidal and littoral habitats, were found on the crests and flanks of these near shore sandbanks. For these less ubiquitous taxa, it is likely the source of recruits will be restricted to assemblages inhabiting inshore waters as opposed to those offshore. Similarly, differences between inshore and offshore SACs were observed for the epifaunal assemblages.

There was a degree of variability in the epifaunal communities inhabiting the different topographical zones both within and between SACs. Not surprisingly the more mobile species were found to be ubiquitous and widely distributed across sandbank topographical zones, whilst less-mobile species were restricted to flanks and troughs. Attached epifauna are generally more sensitive to trawling impacts, their presence across all topographical zones at Leman Bank implies that trawling impacts are, therefore, not evident at the CSA.

Currently, the entire NNSSR SAC is delineated as Annex I Sandbank, whereas within the nearshore SACs, IDRBNR and HHW, only the sandbank features themselves are delineated as Annex I habitat. In this study, a comparison of the sediments and infaunal assemblages of the Annex I Sandbank troughs and the 'beyond sandbank' regions (outside the delineated Annex I Sandbanks) were compared for two CSAs within HHW and IDRBNR. Although the assemblages differed between the two CSAs, no significant differences in community structure were apparent between trough and 'beyond sandbank' areas at both CSAs. However, at Smiths Knoll, estimated total secondary production of the 'beyond sandbank' assemblage was significantly higher than of the trough assemblage for the sea-facing area but not for the shore-facing assemblages. As secondary production is seasonally variable, and estimates can be inflated by the presence of larger, less-abundance taxa, further data should be acquired to ascertain whether this is an inherent difference between these two topographical zones.

Macrofaunal assemblages are functionally important in fine sediment (mud) habitats as their bioturbative activities significantly alter the oxidative state and subsequent biogeochemical status of the sediment matrix (Mermollid-Blondin & Rosenberg 2006). In coarser sediments (typically where mud content <8%), however, the sediments are more advective and sediment oxidative processes are more governed by physical forces (van Oevelen *et al*. 2009). Thus, one may postulate that the predominant functional role of the infauna within the advective sediments of sandbanks is that of provision of food/prey for the next trophic level (bottom-feeding predatory or scavenging fish). Secondary production, the estimate of incorporation of organic matter or energy per unit of time and area (Cusson & Bourget 2005), has assumed a fundamental role in the quantification of ecosystem dynamics as they quantify one of the major pathways of energy flow (Tumbiolo & Downing 1994). Estimates were derived for the infaunal assemblages inhabiting the various topographical zones for the sandbanks sampled and provided insights into functional variability than would not have been possible hitherto. However, the input of abundance and biomass data from a single survey, as opposed to mean annual values, to the Brey algorithm during secondary production estimates ultimately limits the confidence that may be placed on the resulting values. Further work needs to focus on obtaining empirical data regarding the seasonal variability of infaunal abundance and biomass estimates for these or comparable sandbanks. This would potentially allow adjustment factors to be applied to abundance and biomass data from samples acquired at different times of the year.

Future assessments of infaunal assemblage functioning should, additionally, embrace the outcomes of current approaches using functional traits, however the capacity of these approaches to aid assessment of benthic function is currently untested. Aside from secondary production, there are presently limited functional metrics that can be used to act as proxies for different benthic functions. While biological traits are currently being developed to offer some advancement in this respect, approaches are currently not able to provide quantifiable metrics that unequivocally act as proxies for function. Changes in the proportional composition of various traits (e.g. feeding and bioturbation mode, motility) are currently being applied to infer differences in potential functioning of infaunal assemblages (Bolam *et al*. 2016; van Denderen *et al*. 2016), but these have yet to be applied in a monitoring context. There are a number of approaches which are currently being developed which use traits, longevity in particular, to model impacts of trawling on benthic assemblages at the EUNIS level 3 habitat (e.g. Rijnsdorp *et al*. 2016; Rijnsdorp *et al*. 2018). These approaches, which are currently undergoing further evaluation, represent potential future trait-based models which could be applied to the data here.

5.3 Annex I *S. spinulosa* Reef: extent and distribution

In this study the extent and distribution of Annex I reefs was undertaken using a two-step approach. Large areas of seabed were first appraised acoustically allowing for more targeted video approaches in areas identified as potential reef. The delineation of the *S. spinulosa* reefs using SSS data was found to be extremely challenging, as areas of 'medium' and 'high' reefiness displayed similar acoustic properties to the areas of 'not a reef'. This is an inherent issue when acoustic approaches are used to identify *S. spinulosa* reefs in such coarse habitats. Areas of coarse and mixed sediments create a mottled, cauliflower-like, SSS backscatter akin to that associated with *S. spinulosa* reefs. Discernible differences in backscatter signals only occur where a reef structure has formed with sufficient elevation and extent to be evidenced by the acoustic data. In such circumstances, the edges of the reef are discerned within the SSS data as areas of very high backscatter intensity and areas of shadow. Unfortunately, due to the dynamic nature of the seabed where *S. spinulosa* often occurs, the sides of the reefs are often filled with moving sediment preventing clean 'cut-offs' of reef edges being seen on the acoustic data. Additionally, in highly dynamic habitats the erosive capability of bottom flows and associated sediment movement lead to scouring on one side of the reef. This infers that acoustic data should not be solely used to assess reef presence, but they do have merit in targeting areas for follow up assessment, as they can be used to identify where *S. spinulosa* reef is unlikely to occur.

5.4 Annex I *S. spinulosa* Reef: Reef quality and epifaunal communities

The 2016 video data revealed that *S. spinulosa* reefs within the SACs are localised and very patchy. Within NNSSR, low-medium reef was observed within the northern trough of Leman Bank, to a lesser extent at Saturn Reef and was absent from data collected from North of Swarte Bank and North of Well Bank. The greatest threat to *S. spinulosa* reefs in the North Sea is considered to be abrasion by physical disturbance (e.g. aggregate extraction, offshore constructions e.g. oil and gas pipelines and renewable energy infrastructure, and fishing), with fishing implicated as the main reason for its demise (OSPAR Commission 2013). In a recent study (van der Reijden *et al*. 2019) of the sandbank troughs in the Dutch Brown Bank area, which are subject to high demersal fishing intensities (fished >5 times a year), reefs were found, and appeared to persist, despite the high fishing intensity. The study deduced that most of the *S. spinulosa* reefs were located within 'small-scale wave valleys' within the larger scale troughs. It was hypothesised that the demersal fishing gear 'jumped' from top to top of each sand wave without physically impacting the valleys, as had been observed in a previous study by Houziaux *et al*. (2008), in the Belgian Hinder Banks. In NNSSR, the frequency of impact from VMS data indicates that parts of the site are not fished at all, and large areas may be trawled less than once per year with fishing activity more concentrated in the channels between the sandbanks (ABPmer & Ichthys Marine 2015). It is therefore unlikely that any decline in *S. spinulosa* at this particular site is due to anthropogenic abrasion.

Within HHW, reef persisted in two areas of potential reef, previously identified and modelled using the East Coast Regional Environmental Characterisation (ECREC) data (Limpenny *et al*. 2011). HHW Northern Closure is situated in a sandbank trough and coincides with the Haisborough Tail Reef' an MMO Marine Conservation Byelaw area closed to fishing. HHW Southern Closure also coincides with an MMO Marine Conservation Byelaw area, 'Gat Reef'.

Reef also persisted in all IDRBNR surveyed areas but was not observed at Lynn Knock in this survey and was observed both within and outside of the currently defined 'Area to be managed as Annex I Reef'. For Saturn Reef, in NNSSR, low reef was infrequently observed in areas where it had previously occurred more extensively.

Further information on the distribution and intensity of anthropogenic activities, occurring in the SACs, would enable a better understanding of why reef is persisting and is of higher quality (e.g. medium – high reefiness) in some, but not all, areas surveyed.

Epifaunal community data acquired reflected the species composition at the video segment level (defined according to change in habitat). In coarse and mixed sediment areas, where reef was also patchily distributed, determining whether communities were specifically associated reef or non-reef habitats was difficult as the epifaunal species inhabiting both habitat types were found to be similar (sedentary attached fauna and mobile predators). However, broad differences in taxa could be discerned within some areas. In IDRBNR, the lobster *Homarus gammarus*, and caridean shrimp were present in areas containing reef and absent for non-reef areas. In NNSSR, the starfish *Asterias rubens* was the most characteristic species of the coarse and mixed sediment habitats, where reef was not observed, but was less abundant in areas classified as reef. The species has been commonly found across the North Sea over the past 100 years but has increased its presence off the North Norfolk coast at least since 1982 (Callaway *et al*. 2007). *Asterias rubens* is a predator of a range of species, including molluscs, polychaetes and echinoderms (Budd 2008), large aggregations of which have been known to clear mussel (*Mytilus edulis*) beds (Dare 1982). *S. spinulosa* reef provides habitat to many species, and therefore attracts predators such as *A. rubens*. Equally *A. rubens* may prey on fauna exposed following reef damage and therefore may not necessarily be a threat to reef existence: *Asterias rubens* was, however, abundant in an area of medium to high reef at Middle Cross Sands in HHW.

5.5 Non-indigenous species and marine litter

The increase in presence and distribution of NIS and litter in the marine environment in recent years has raised cause for concern for the health of species and restoration of habitats already impacted by other anthropogenic activities[18] [19]. Non-indigenous species can become invasive and have long lasting effects on the environment, whilst marine litter (plastics in particular) can negatively affect the feeding ability of certain species (Cole *et al*. 2013).

We identified three NIS which were mainly found within IDRBNR; the slipper limpet, *Crepidula fornicata*, the bivalve mollusc, *Mya arenaria* and the polychaete, *Goniadella gracilis,* all thought to originate from North America. Of these, *C. fornicata* is the only species thought to pose a threat to the habitats and species present within the SACs (Eno *et al*. 1997). The slipper limpet can have a devastating impact on mussel and oyster fisheries and may prevent other species from settling on hard sediments[20]. High numbers of the species may therefore impact on the formation and ongoing survival of *S. spinulosa* reefs as has been shown oysters and mussels (Thieltges *et al*. 2006).

Marine litter collected in grabs and trawls and observed in seabed images mainly comprised of plastic. Plastics measuring less than 5mm (microplastics) were the most commonly found size class across the three sites. Due to their small size, microplastics are available to ingest by a wide range of species and are therefore of most concern in the marine environment

[18] https://ec.europa.eu/environment/marine/good-environmental-status/descriptor-2/index_en.htm
[19] https://www.ospar.org/work-areas/eiha/marine-litter
[20] http://www.nonnativespecies.org/factsheet/factsheet.cfm?speciesId=1028

(Cole *et al*. 2013). The impact of microplastics in relation to the integrity of the designated features of the SAC's is currently unknown, therefore further study is recommended.

5.6 Recommendations for future monitoring (Objective 6)

While the specific approaches to adopt during any subsequent monitoring at these SACs should inherently be established based on the objectives that are deemed important at that time, there are a number of outcomes based on the findings of this report that may be used to help guide the formulation of such methods and approaches. Several generic recommendations for future monitoring are presented in this sub-section, followed by several monitoring recommendations that pertain specifically to the monitoring of each Annex I feature attribute.

5.6.1 Generic recommendations

1. The data presented here reveal that each SAC represents an ecologically distinct region displaying its own biological communities and unique spatial separations between topographical zones. This would imply that future survey designs should be tailored for each SAC as opposed to imposing a blanket approach to surveying all SACs.
2. A fixed-station sampling approach, whereby stations are repeatedly sampled over time to quantify change, needs to embrace intelligence of sandbank movement. As sandbanks may move, the topographical zone of any geographical location may change in accordance, particularly when sandbank movement is lateral as opposed to linear. As such, a station reflecting a sandbank crest at one point in time may, in theory, represent a sandbank flank at some other point in time. Sampling designs need to be flexible and updated based on the best knowledge of such sandbank movement.
3. Non-statistical approaches to monitoring specific feature attributes need to be considered in the absence of a specific metric that responds to change in sandbank habitats. For example, assessing broad changes in species or functional composition.
4. Prior to any future surveys, a thorough literature review of suitable metrics to indicate anthropogenic change in sandbank habitats should be undertaken. Findings can then be used to conduct a post-hoc power analysis to inform sampling.
5. The 2016 data revealed that some fish species were consistently present at certain locations on the banks. However, it was not possible to ascertain the precise nature of their relationship with these topographical zones, whether they were acting as nursery or feeding grounds for example. Future monitoring should consider incorporation of fish stomach content analyses, and assessment of the reproductive status and life history stages of fish sampled, to provide data to augment our understanding of the functional role sandbanks fulfil for such epifaunal species. This could be undertaken using data collected for other programmes, if available.
6. Further monitoring of litter (microplastics) found in sediment and faunal species would improve our understanding of the potential impacts to the functional integrity of the Annex I feature of the SACs.
7. Monitoring of the *Crepidula fornicata* populations should be undertaken within IDRBNR as a priority. Further data regarding the spatial and temporal changes in the presence of this species would augment our understanding as to whether it directly and/or indirectly affects Annex I *S. spinulosa* reefs.

5.6.2 Annex I Sandbanks: extent and distribution

1. Monitoring sandbank extent and distribution can be undertaken using acoustic approaches, but the spatial cover of the data would need to be substantially greater than that acquired in 2016. Should a spatially extensive acoustic approach to monitor sandbank extent and distribution across the SACs be deemed unviable, other options should be considered. Satellite-derived bathymetry (SDB) potentially offers one alternative for monitoring the morphology of the North Norfolk Sandbanks. This relatively new technique utilises colour satellite images to calculate bathymetry based on the ratios of the different colour bands. Since the technique quantifies light reflected from the seabed, its suitability is reduced in regions of high suspended sediment or turbidity. Furthermore, this method is generally limited to depths of approximately 15m – 20m. Given such constraints, it is likely that SDB could not be used to detect whole banks across this particular region, where troughs extend to water depths at least 40m (Figure 10). The technique should, however, be appropriate to monitor the locations of sandbank crests and potentially some flanks, particularly for the more nearshore SACs. Open source Earth Observation data that could indicate the movement of the crests of the sandbanks over time are available at a suitable resolution (e.g. 10m for SENTINEL-2). This approach, and the resulting data, may be used to address Objective 1 to a certain extent i.e. the method will not provide data on the complete morphology of a sandbank. Moreover, whether this could help inform a suitable monitoring survey design to fulfil other objectives needs to be considered.

5.6.3 Annex I Sandbanks: structure

1. Future monitoring should continue to be stratified by topographical zone and include ‘beyond sandbank’ zones outside the Annex I Sandbank boundary within IDRBNR and HHW. This would ensure that data are acquired to allow an appraisal of the topographical zone differences and similarities for the various sediment and faunal features remain temporally consistent.
2. The acquisition of additional environmental parameters, such as seabed slope angle and mean depth, would allow analyses to be conducted to better understand the potential drivers of spatial variability observed for infaunal and epifaunal assemblages.
3. Epibenthic trawls provide important information on the epifauna and fish communities, according to the different topographical zones of the sandbanks, however the benefits of such bottom-contacting methods must be assessed against the potential for damage to the designated features.
4. Monitoring should be conducted at the same time of year to that undertaken during 2016 to enhance comparability of infaunal and epifaunal abundance and biomass estimates.
5. All CSAs should be considered for revisiting (with consideration of sandbank movement) as they are each representative of a different type of sandbank within the North Norfolk coast sandbank network. However, the presence of potential *S. spinulosa* reef on the flanks and troughs of Inner Dowsing within IDRBNR and Leman Bank trough within NNSSR may preclude these topographical zones from further monitoring. The location of the shoreward trough of Leman Bank also requires repositioning due to its current position on the adjacent sandbank flank.
6. There is currently no adopted metric for detecting structural or functional change in sandbank communities. A review of scientific research on suitable metrics is recommended. Any suitable metrics identified before the next survey should be used in power analyses. Furthermore, future approaches and gears to acquire data must

be selected with due regard to ensure that those adopted can acquire data suitable for the derivation of any formally accepted metrics.

7. The data acquired have demonstrated that variability, and thus number of samples needed in future monitoring, widely varies between both topographical zones and, at larger spatial scales, between banks. Greater replicate variability was particularly evident at some topographical zones implying that monitoring these areas in future might be financially unfeasible.

5.6.4 Annex I *S. spinulosa* reefs: extent and distribution

1. The assessment of the extent and distribution of *S. spinulosa* reef in the present study was conducted based on SSS data. However, this approach proved difficult to clearly assess reef presence. For the SSS to detect reef edges in these areas, the direction of the beam needs to be roughly perpendicular to the feature to create the bright/shadow signatures. The likelihood of reef detection in this situation is directly correlated with the number of passes of the acoustic sensor. By passing the feature twice at different directions, the chance of detecting any reef-associated elevational change is much more likely (Figure 76).

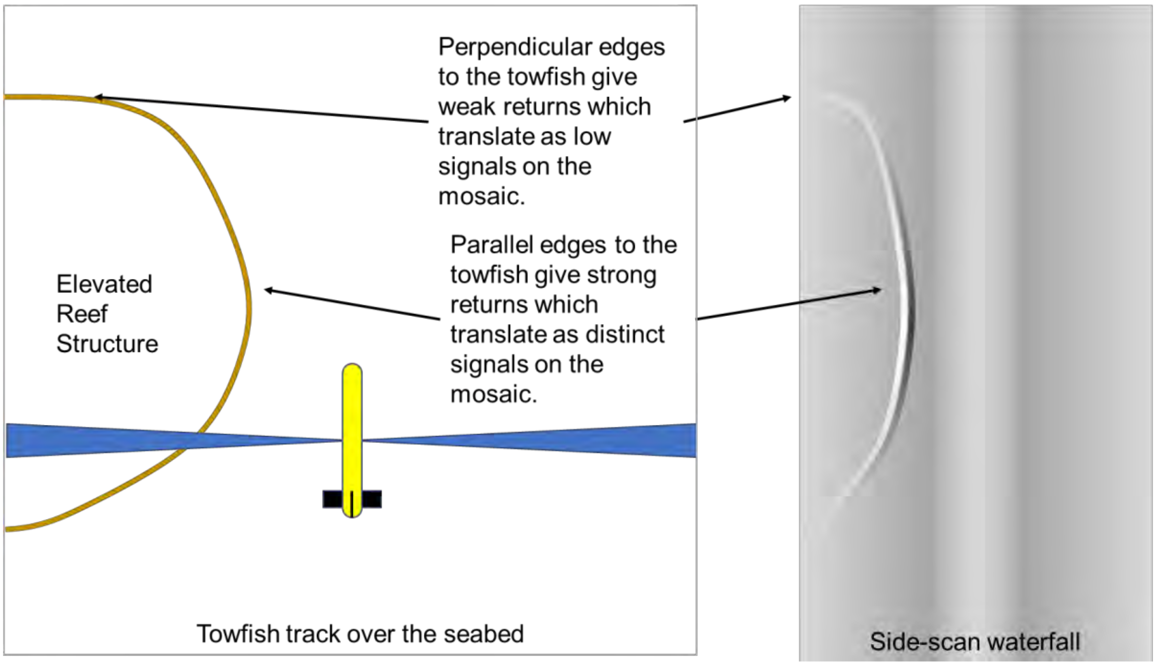


Figure 76. Demonstrating the differences between return signals from parallel and perpendicular features.

Studies have been carried out on the use of very high frequency SSS for the identification of biogenic reefs with some success (Degraer *et al*. 2008). Unfortunately, due to the very high frequency of these units, only a small area of the seabed is surveyed with each pass due to the increased levels of signal attenuation compared to standard systems. This makes these systems unsuitable for covering large areas of seabed.

2. Areas of known or suspected reefs should be monitored using a 200% coverage SSS survey (Figure 77). This allows multiple passes over any seabed feature resulting in an improved ability to detect textural and elevational.
3. Future monitoring should ensure that 2016 survey areas should be revisited to assess change and ensuring that camera transects are positioned based on acquired SSS interpretation.

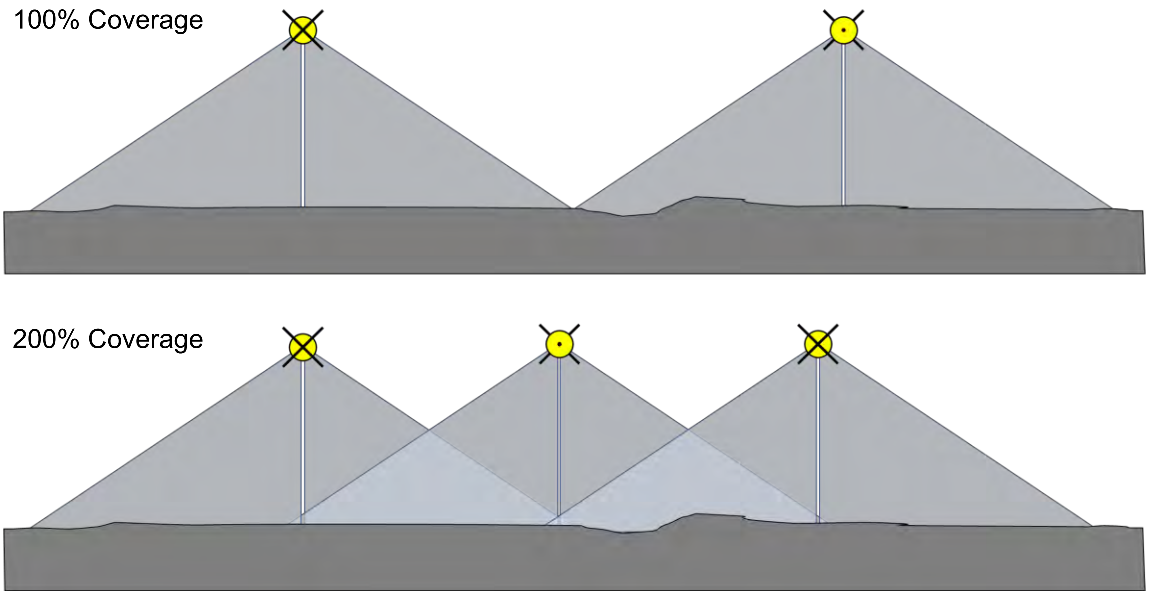


Figure 77. Different survey designs for SSS surveys showing 100% and 200% coverage.

4. Rugosity measurements should be considered to aid in reef height measurements.
5. Novel approaches and gear types, e.g. sonar camera, should be considered for incorporation in future surveys. Sonar cameras, for example, can be used in low visibility environments and the data can be analysed for additional metrics such as rugosity and roughness which can help in the identification of features such as *S. spinulosa* reefs.

5.6.5 Annex I *S. spinulosa* reefs: Reef quality and epifaunal communities

1. Epifaunal data should be acquired for every 5m camera segment to allow robust comparisons in community composition and presence of conspicuous fauna between different reefiness categories. This would offer a solution to the mismatch in scales encountered in the present study which only allowed for general differences to be assessed for reef and non-reef areas.
2. As fishing has previously been attributed to the demise of *S. spinulosa* reef within the NNSSR sites (OSPAR Commission 2013), any future monitoring should consider contemporary human activities that are likely to affect (either directly or indirectly) the ability of the reefs to re-establish.
3. The acquired video data were processed in a manner that precluded comparisons between the epifaunal communities associated with different quality reefs to be undertaken. This omission had implications for addressing Objective 4 in the present report. We advocate that the processing of subsequently acquired video data of *S. spinulosa* reefs for the three SACs are processed ensuring that this assessment can be subsequently undertaken.
4. It is inherently critical to the successful detection and delineation of reef features to collect the highest quality and resolution of acoustic and video data. It is evident that the video data collected during the 2016 surveys were of quality which limited, to varying degrees, the ability of the data to delineate reef boundaries in some areas. As many of the issues which affect the resultant quality of such data are currently being addressed by a number of government-led initiatives, it is imperative that future monitoring approaches capitalise on the recommendations obtained. Generic, site specific practices may include ensuring video surveys are conducted during periods of relatively minimal tidal flows, or during periods of high primary productivity if this is known to affect resulting imagery quality.

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Annex 1: Data truncation protocol and excluded taxa

A number of decisions applied during the data truncation process are described here, in the hope that by following such decisions, a greater degree of consistency in truncation exercises across different studies may be achieved. Annex 1: Data truncation protocol and excluded taxa

Raw taxon-by-sample matrices can often contain entries that include the same taxa recorded differently, erroneously or differentiated according to unorthodox, subjective criteria. For example, each row should represent a legitimate taxon to be used in analytical software packages as a unit for the calculation of diversity indices and of similarity amongst groups of samples. An artificially inflated taxon list (i.e. one that has not had spurious entries removed) risks distorting the interpretation of pattern contained within the sampled assemblage. The truncation exercise aims to identify and neutralise such entries to reduce the risk of them supporting an artificial pattern in the assemblage.

It is often the case that to overcome uncertainty and to avoid the introduction of unsupported certainty, some taxa have to be merged to a level in the taxonomic hierarchy that is higher than the level at which they were identified. In such situations, a compromise must be reached between the level of information lost by discarding recorded detail on a taxon's identity, and the potential for error in analyses, results and interpretation if that detail is retained.

Where there were records of one named species together with records of members of the same genus, but the latter not identified to species level, the entries were merged and the resulting entry retains only the name of the genus (i.e. species level information is forfeited).

In this way, the entries identified only to genus are not assigned to a level that is unsupported by the evidence, and the resulting single entry is representative of both original entries, albeit with a little less information, but a loss that will not affect the pattern in the assemblage as a whole.

Additionally, taxa are often assigned as 'juveniles' during the identification stage with little evidence for their actual reproductive natural history (with the exception of some well-studied molluscs and commercial species). Many truncation methods involve the removal of all 'juveniles'. However, a decision must be made on how to avoid the issues discussed above while retaining valuable information within the multivariate data set. The term 'juvenile' is often used to refer to individuals which do not exhibit the morphological features to resolve them to species level. In this case, these records were removed from the analysis rather than lowering the taxonomic resolution of other species level identifications. When a species level identification was labelled 'juvenile' the record was combined with the associated species level identification, when present or the 'juvenile' label removed.

Invalid taxa and fragments of countable taxa were removed from the infaunal datasets while colonial taxa only recorded as 'Present' were changed to a numeric value of one.

Epifaunal identification differences were resolved by combining taxa to a lower taxonomic resolution. For example, *Spisula subtruncata, Spisula solida* and *Spisula elliptica* were combined to *Spisula* sp., and *Philocheras trispinosa, Crangon crangon* and *Crangon allmanni* were resolved to Crangonidae.

Annex 2: SIMPER results (70% similarity)

Colour scale is representative of square root transformed average abundance values: Red = highest average abundance, green = lowest average abundances.

Indefatigable Bank CSA Infauna

Taxa	T(shore)	F(shore)	C	F(sea)	T(sea)
Fabulina fabula	1.79	1.41		1.63	1.01
Bathyporeia elegans		2.17	1.25	1.35	
Lovenella clausa	1	0.6		0.8	1
Magelona johnstoni	1.36	0.9		1.1	
Ophelia borealis			2.12		
Sigalion mathildae	0.78			1.1	
Bathyporeia guilliamsoniana	0.9	0.72			
Nephtys cirrosa			1.39		
Chaetozone christiei					1.33
Bathyporeia tenuipes					1.08
Spiophanes bombyx					1.06
Notomastus latericeus					0.93
Euspira nitida				0.88	
Bougainvilliidae					0.8

Indefatigable Bank CSA Epifauna

Taxa	T(Shore)	F(Shore)	C	F(Sea)	T(Sea)
Buglossidium luteum	9.32	7.72	4.78	9.59	8.12
Echiichthys vipera		2.75	5.41	3.3	
Asterias rubens	4.26			3.95	4.96
Pagurus bernhardus					3.15
Corystes cassivelaunus	4.14	2.24	1.9	4.06	4.29
Arnoglossus laterna	2.67	2.47	2.84	2.34	2.43
Ammodytes		2.41			
Echinocardium		1.47		4.17	2.51
Limanda limanda	2.52				2.05
Ascidiacea	3.15	1.47	1.76		

Leman Bank CSA Infauna

Taxa	T(shore)	F(shore)	C	F(sea)	T(sea)
Ophelia borealis	1.57	3.22	4.11		2.67
Scoloplos armiger	2.51	2.1	1.66	1.58	2.13
Nephtys cirrosa	2.03	1.82	1.55	2.21	
Bathyporeia elegans		1.76	1.77	1.77	0.97
Magelona johnstoni	1.08			1.82	
Bathyporeia guilliamsoniana				1.22	1.67
Nemertea					2.54
Polycirrus					2.24
Spiophanes bombyx					2.13
Urothoe marina					1.96
Aonides paucibranchiata					1.64
Mediomastus fragilis					1.53
Glycera lapidum					1.1
Urothoe brevicornis					0.97
Lovenella clausa	0.9				
Chaetozone christiei	0.87				
Lanice conchilega					0.81
Vesicularia spinosa					0.7
Euspira nitida					0.67

Leman Bank CSA Epifauna

Taxa	T(shore)	F(shore)	C	F(sea)	T(sea)
Buglossidium luteum	5.61	2.61	2.37	5.78	3.13
Ophiura	4.48				13.46
Ammodytes		1.14		11.61	
Pagurus bernhardus	3.53	1.88		1.49	4.78
Echiichthys vipera	1.52	3.94	4.49		
Asterias rubens	2.72			1.38	2.76
Spisula					5.32
Callionymus	1.58				3.11
Arnoglossus laterna	1.28	1.55			
Crangonidae					2.42
Liocarcinus holsatus					2.36
Macropodia					2.2
Alcyonidium diaphanum		1	1		
Idotea				1.76	
Echinocardium	1.75				

Taxa	T(shore)	F(shore)	C	F(sea)	T(sea)
Limanda			1.69		
Ascidiacea				1.41	
Corystes cassivelaunus		1.14			
Flustra foliacea			1		

Inner Dowsing CSA Infauna

Taxa	B(shore)	T(shore)	F(shore)	C	F(sea)	T(sea)	B(sea)
Sabellaria spinulosa	14.88	14.93					5.86
Ampelisca diadema	5.93	7.51				10.14	4.26
Lumbrineris cingulata	4.35	4.35	2.55		1.86	3.36	3.35
Jasmineira elegans	11.83	7.88					
Polycirrus	4.89	4.05	1.85		1.96	3.75	2.82
Nucula nucleus	4.01	9.88					4.17
Pholoe inornata (sensu Petersen)	5.42	5.83				2.43	3.27
Nemertea	3.94	3.68	1.26	0.93		2.74	2.31
Kurtiella bidentata	4.17	4.88				1.69	3.5
Notomastus latericeus	2.63	3.91			2.17	1.69	2.45
Ampelisca		3.58				4.43	3.14
Lanice conchilega	2.06	1.88	1.85			2.19	2.98
Abra alba	3.79	4.7					1.42
Golfingia elongata	3.56	4.47					
Spiophanes bombyx			2.58			2.67	2.12
Urothoe elegans			1.67			2.59	2.92
Spirobranchus lamarcki	7.03						
Scoloplos armiger			1.6		1.52	2.44	1.47
Epilepton clarkiae	3.09	3.5					
Actiniaria		3.34					2.77
Protodorvillea kefersteini	2.07					2.19	1.65
Amphicteis	2.48	2.63					
Amphipholis squamata	2.8	2.1					
Eumida	2.32	2.06					
Pseudopolydora pulchra	1.95	2.4					
Pholoe baltica (sensu Petersen)	2.01	2.28					
Ophiura albida						1.49	2.59
Scalibregma inflatum	1.85	1.75					
Dipolydora caulleryi	2.45		1.05				

Serpulidae	3.24					
Aonides paucibranchiata		1.66			1.54	
Glycera lapidum					1.46	1.16
Spio goniocephala		1.26		1.26		
Rissoa parva						2.39
Spio armata						2.22
Leptocheirus hirsutimanus		2.11				
Polynoidae	2.07					
Conopeum reticulum		0.9				1
Pisidia longicornis	1.87					
Eulalia bilineata	1.72					
Poecilochaetus serpens		1.58				
Mediomastus fragilis		1.54				
Ampelisca spinipes						1.54
Ophelia borealis			0.56	0.92		
Eucratea loricata					0.9	
Vesicularia spinosa					0.9	
Flustra foliacea					0.9	
Caulleriella alata					0.84	
Glycera oxycephala				0.68		

North Ridge CSA Infauna

Taxa	T(shore)	F(shore)	C	F(sea)	T(sea)
Ophelia borealis		0.58	1.03	1.85	1.9
Sabellaria spinulosa	5.06				
Balanus crenatus	5.06				
Goodallia triangularis		1.01			2.8
Urothoe elegans	3.56				
Scoloplos armiger	3.03				
Polycirrus	2.42				
Nemertea	1.78				
Spiophanes bombyx	1.73				
Achelia echinata	1.71				
Actiniaria	1.6				
Nymphon brevirostre	1.45				
Dipolydora coeca (agg)	1.38				
Dipolydora caulleryi	1.34				
Lanice conchilega	1.19				

Poecilochaetus serpens	1.18	
Conopeum reticulum	1	
Sertularia	1	
Alcyonidium diaphanum	0.88	
Eucratea loricata	0.75	
Amathia sp. 2	0.75	
Glycera oxycephala		0.44

North Ridge CSA Epifauna

Taxa	T(shore)	F(shore)	C	T(sea)
Crangonidae	3.09	5.21	4.27	2.4
Macropodia	6.61			
Echiichthys vipera		2.35	2.9	
Crossaster papposus	4.18			
Doris pseudoargus	3.87			
Liocarcinus depurator	3.33			
Callionymus	3.01			
Alcyonidium diaphanum		1	1	1
Limanda		1.28	1.52	
Gibbula	2.78			
Pomatoschistus pictus	2.23			
Flustra foliacea		1		1
Hydrozoa		1		1
Agonus cataphractus	1.87			
Aeolidiidae	1.82			
Pleuronectes platessa	1.73			
Pisidia longicornis	1.66			
Pleuronectiformes juv	1.61			
Spisula				1.47
Botryllus				0.67

Smiths Knoll CSA Infauna

Taxa	B(shore)	T(shore)	F(shore)	C	F(sea)	T(sea)	B(sea)
Scoloplos armiger	2.96	1.88			1.98	2.84	2.47
Scalibregma inflatum	4.14					4.13	
Ophelia borealis	1.42					3.2	3.39
Nephtys cirrosa		1.13		1.52	1.49		1.2
Magelona johnstoni			3.86	0.81			

Fabulina fabula			4.49		
Urothoe brevicornis				1.19	2.51
Urothoe poseidonis			3.31		
Abra alba			3.28		
Spiophanes bombyx	1.64				
Diastylis bradyi	1.47				
Lanice conchilega		1.03			

South West Haisborough Tail CSA Infauna

Taxa	**T(shore)**	**F(shore)**	**C**	**F(sea)**	**T(sea)**
Ophelia borealis	1.25	2.33		1.63	
Urothoe brevicornis				3.51	
Haustorius arenarius			0.89	1.64	
Nephtys cirrosa	0.72	1.2			
Pseudonotomastus southerni	0.66				1.01
Glycera lapidum					1.05
Nemertea					0.96
Gastrosaccus spinifer			0.5		

South West Haisborough Tail CSA Epifauna

Taxa	T(shore)	F(shore)	C	F(sea)	T(sea)
Crangonidae	1.21	4.64	1.33	3.4	5.7
Echiichthys vipera		3.17	2.89	4.04	1.41
Ammodytidae		2.05		4.92	1.21
Pagurus bernhardus		2.51			1.98
Mysida		1.41		1.28	
Alcyonidium diaphanum				1	1
Flustra foliacea			1		
Nemertesia	1				
Alcyonidium			0.67		

All CSAs Infauna

	NNSSR		IDRBNR		HHW	
Taxa	**IDFB**	**LMBK**	**INND**	**NRRD**	**SMKN**	**SWHT**
Ophelia borealis	0.55	2.36	0.27	1.16	1.49	1.17
Sabellaria spinulosa			5.97			
Scoloplos armiger		2	1.1		1.77	
Ampelisca diadema			4.51			
Jasmineira elegans			3.43			
Nucula nucleus			3.29			
Nephtys cirrosa		1.65			1.06	0.53
Lumbrineris cingulata			2.89			
Pholoe inornata (sensu Petersen)			2.81			
Polycirrus			2.8			
Bathyporeia elegans	1.35	1.44				
Nemertea			2.39			0.38
Ampelisca			2.34			
Kurtiella bidentata			2.26			
Magelona johnstoni	0.96				0.98	
Notomastus latericeus			1.86			
Abra alba			1.78			
Golfingia elongata			1.74			
Lanice conchilega			1.73			
Actiniaria			1.32			
Mediomastus fragilis			1.26			
Urothoe brevicornis					1.26	
Spiophanes bombyx			1.22			
Urothoe elegans			1.22			
Dipolydora caulleryi			1.2			
Ophiura albida			1.2			
Fabulina fabula	1.17					
Protodorvillea kefersteini			1.07			
Pholoe baltica (sensu Petersen)			1.01			
Goodallia triangularis				0.93		
Glycera lapidum			0.88			
Spio armata			0.88			
Lovenella clausa	0.7					
Conopeum reticulum			0.67			
Euspira nitida	0.55					
Haustorius arenarius						0.55

Sigalion mathildae	0.54		
Spio goniocephala		0.42	
Glycera oxycephala			0.25

All CSAs Epifauna abundance

	NNSSR		IDRBNR	HHW
Taxa	**IDFB**	**LMBK**	**NRRD**	**SWHT**
Buglossidium luteum	7.91	3.9		
Echiichthys vipera	2.78	2.27	1.51	2.63
Crangonidae			3.74	3.23
Pagurus bernhardus	1.84	2.47		
Arnoglossus laterna	2.55	1.03		
Corystes cassivelaunus	3.33			
Ammodytes		3.06		
Flustra foliacea		1	1	0.92
Asterias rubens	2.85			
Hydrozoa		1	1	0.77
Limanda limanda		1.06	1.24	
Alcyonidium diaphanum		1	1	
Ascidiacea	1.84			
Nemertesia			0.92	0.77
Mysida				0.96

All CSAs Epifauna biomass

	NNSSR		IDRBNR	HHW
Taxa	**IDFB**	**LMBK**	**NRRD**	**SWHT**
Alcyonidium diaphanum		7.08	4.65	1.19
Hydrozoa	2.22	6.28	3.01	1.33
Flustra foliacea	3.55	2.62	3.72	1.68
Echiichthys vipera	3.02	2.2	1.42	2.48
Buglossidium luteum	4.05	3.01		
Limanda limanda		2.14	2.47	
Pagurus bernhardus		2.11		1.26
Corystes cassivelaunus	3.26			
Crangonidae			1.67	1.43
Asterias rubens	2.76			
Ascidiacea	2.57			

Arnoglossus laterna	2.36

Annex I *Sabellaria spinulosa* Reef areas (Epifauna)

NNSSR SAC

Taxa	a	b	c	e	f	g	h
Asterias rubens		3.5	3.6	4	4.18	4	3.17
Flustridae	1.71	2	2.2		2.55	2	
Alcyonium digitatum		2.5			3.73	2.8	
Paguridae	2.43			2	1.64	1.73	
Cancer pagurus	3				3		
Alcyonidium			1.6	2	1.91		
Urticina sp.					2.82	2.53	
ASTEROIDEA 3-15cm			2.2	3			
BRYOZOA Turf	2.86			2			
Nemertesia sp.	2			2			
Sertulariidae	2			2			
Serpulidae 1-3cm Tube				2	1.91		
BRYOZOA Plumose			2		1.82		
ASCIDIACEA 3-15cm Solitary				3			
Gadidae >15cm				3			
PLEURONECTIFORMES >15cm				3			
Metridium senile					2.27		
BRACHYURA 3-15cm				2			
Hydrozoan/Bryozoan Turf		2					
Sagartia sp. 3-15cm	2						
Tubularia sp.	2						
PLEURONECTIFORMES 3-15cm	1.71						
Vesicularia spinosa	1.71						
PORIFERA Massive					1.64		
BRYOZOA Dendroid						1.6	

HHW SAC

Taxa	b	c
Asterias rubens	5.33	2.17
CERIANTHARIA 3-15cm	4	
Alcyonidium	2	1.67
Flustridae	2	1.67
Cancer pagurus		3

BRYOZOA Turf		2.67
Lanice conchilega Tube		2.33
Nemertesia sp.	2.33	
Sabellidae Tube	2.33	
Sertulariidae	2	
Vesicularia spinosa		2
ANTHOZOA 1-3cm		1.67
Serpulidae 1-3cm Tube		1.67
Tubularia sp.		1.67

IDRBNR SAC

Taxa	**a**	**b**
Urticina sp.	3.7	3.33
Flustridae	2.3	2
Cancer pagurus	2.35	
Crossaster papposus	2.22	
Sertulariidae	2.17	
Caridea		2
Plumulariidae		2
BRYOZOA Plumose	1.7	
Nemertesia sp.	1.65	
BRACHYURA 3-15cm		1.33
ACTINIARIA 3-15cm		1
ANTHOZOA 3-15cm		1

Annex 3: Biotopes

Biotope	SAC	Bank	Topographical zone
A5.1: Sublittoral coarse sediment	IDRBNR	INND	Trough
A5.13: Infralittoral coarse sediment	HHW IDRBNR	WCTs (EMCS, HBSD, HRKN, NWBK) RCBK	Trough Flank
A5.134: *Hesionura elongata* and *Microphthalmus similis* with other interstitial polychaetes in infralittoral mobile coarse sand	IDRBNR	INND	Trough
A5.135: *Glycera lapidum* in impoverished infralittoral mobile gravel and sand	IDRBNR HHW	INND SWHT	Crest, Flank Trough
A5.14: Circalittoral coarse sediment	NNSSR HHW NNSSR	LMBK SMKN WCT (5)	Trough Beyond sandbanks Trough
A5.142: *Mediomastus fragilis*, *Lumbrineris* spp. and venerid bivalves in circalittoral coarse sand or gravel	NNSSR	WCT (11)	Trough
A5.2: Sublittoral sand	IDRBNR	INND	Trough
A5.231: Infralittoral mobile clean sand with sparse fauna	NNSSR NNSSR NNSSR HHW HHW HHW IDRBNR IDRBNR	IDFB LMBK WCTs (All) SMKN SWHT WCTs (All) NRRD WCT (RCBK)	Crest Crest,Flank Crest/Flank Crest, Flank, Trough Crest, Flank, Trough Crest, Flank, Trough Crest, Flank, Trough Crest,Flank
A5.233: *Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand	NNSSR NNSSR	LMBK WCT (7-11)	Crest, Flank, Trough Flank
A5.242: *Fabulina fabula* and *Magelona mirabilis* with venerid bivalves and amphipods in infralittoral compacted fine muddy sand	NNSSR NNSSR	IDFB WCT (1-6, 8,9)	Flank, Trough Crest, Flank, Trough

Biotope	SAC	Bank	Topographical zone
	HHW	SMKN	Flank
A5.25: Circalittoral fine sand	HHW NNSSR	SMKN WCT (7,8)	Trough, Beyond sandbanks Trough
A5.251: *Echinocyamus pusillus, Ophelia borealis* and *Abra prismatica* in circalittoral fine sand	NNSSR	WCT (1,8)	Trough
A5.252: *Abra prismatica, Bathyporeia elegans* and polychaetes in circalittoral fine sand	NNSSR NNSSR	LMBK WCT (1,7, 9-11)	Crest, Flank, Trough Flank, Trough
A5.26: Circalittoral muddy sand	HHW NNSSR	SMKN WCT (9)	Beyond sandbanks Trough
A5.35: Circalittoral sandy mud	NNSSR NNSSR HHW	IDFB WCT (5,6) SMKN	Trough Trough Trough, Beyond sandbanks
A5.4: Sublittoral mixed sediments	IDRBNR IDRBNR	INND WCT (RCBK)	Flank, Trough Trough
A5.43: Infralittoral mixed sediments	HHW HHW	SMKN WCT (MDGR, HBSD, WNRD)	Beyond sandbanks Trough
A5.44: Circalittoral mixed sediments	HHW	SMKN	Trough, Beyond sandbanks
A5.6: Sublittoral biogenic reefs	IDRBNR	INND	Trough
A5.611: *Sabellaria spinulosa* on stable circalittoral mixed sediment	IDRBNR	INND	Flank, Trough, Beyond sandbanks

Annex 4: Non-indigenous Species (NIS)

Taxa listed as non-indigenous species which have been selected for assessment of GES in GB waters under MSFD Descriptor 2 (Stebbing *et al*. 2014) (present = already present in UK waters, horizon = not currently present but of concern).

Species name	List	Species name	List
Acartia (Acanthacartia) tonsa	Present	*Alexandrium catenella*	Horizon
Amphibalanus amphitrite	Present	*Amphibalanus reticulatus*	Horizon
Asterocarpa humilis	Present	*Asterias amurensis*	Horizon
Bonnemaisonia hamifera	Present	*Caulerpa racemosa*	Horizon
Caprella mutica	Present	*Caulerpa taxifolia*	Horizon
Crassostrea angulata	Present	*Celtodoryx ciocalyptoides*	Horizon
Crassostrea gigas	Present	*Chama sp.*	Horizon
Crepidula fornicata	Present	*Dendostrea frons*	Horizon
Diadumene lineata	Present	*Gracilaria vermiculophylla*	Horizon
Didemnum vexillum	Present	*Hemigrapsus penicillatus*	Horizon
Dyspanopeus sayi	Present	*Hemigrapsus sanguineus*	Horizon
Ensis directus	Present	*Hemigrapsus takanoi*	Horizon
Eriocheir sinensis	Present	*Megabalanus coccopoma*	Horizon
Ficopomatus enigmaticus	Present	*Megabalanus zebra*	Horizon
Grateloupia doryphora	Present	*Mizuhopecten yessoensis*	Horizon
Grateloupia turuturu	Present	*Mnemiopsis leidyi*	Horizon
Hesperibalanus fallax	Present	*Ocenebra inornata*	Horizon
Heterosigma akashiwo	Present	*Paralithodes camtschaticus*	Horizon
Homarus americanus	Present	*Polysiphonia subtilissima*	Horizon
Rapana venosa	Present	*Pseudochattonella verruculosa*	Horizon
Sargassum muticum	Present	*Rhopilema nomadica*	Horizon
Schizoporella japonica	Present	*Telmatogeton japonicus*	Horizon
Spartina townsendii var.anglica	Present		
Styela clava	Present		
Undaria pinnatifida	Present		
Urosalpinx cinerea	Present		
Watersipora subatra	Present		

Annex 5: Marine litter

Categories and sub-categories of litter items for sea floor from the OSPAR/ICES/IBTS for North East Atlantic and Baltic. Guidance on Monitoring of Marine Litter in European Seas, a guidance document within the Common Implementation Strategy for the Marine Strategy Framework Directive, MSFD Technical Subgroup on Marine Litter, 2013[21].

A: Plastic	B: Metals	C: Rubber	D: Glass/ Ceramics	E: Natural Products/ Clothes	F: Miscellaneous
A1. Bottle	B1. Cans (food)	C1. Boots	D1. Jar	E1. Clothing/ rags	F1. Wood (processed)
A2. Sheet	B2. Cans (beverage)	C2. Balloons	D2. Bottle	E2. Shoes	F2. Rope
A3. Bag	B3. Fishing related	C3. Bobbins (fishing)	D3. Piece	E3. Other	F3. Paper/ cardboard
A4. Caps/ lids	B4. Drums	C4. Tyre	D4. Other		F4. Pallets
A5. Fishing line (monofilament)	B5. Appliances	C5. Other			F5. Other
A6. Fishing line (entangled)	B6. Car parts				
A7. Synthetic rope	B7. Cables				
A8. Fishing net	B8. Other				
A9. Cable ties					
A10. Strapping band					
A11. Crates and containers					
A12. Plastic diapers					
A13. Sanitary towels/ tampons					
A14. Other					

Related size categories

A: ≤5*5cm = 25cm^2

B: ≤10*10cm = 100cm^2

C: ≤20*20cm = 400cm^2

D: ≤50*50cm = 2500 m^2

E: ≤100*100cm = 10000cm^2

F: ≥100*100cm = 10000cm^2

[21] https://mcc.jrc.ec.europa.eu/documents/201702074014.pdf

Annex 6: Figures and Tables

6.1 Figures

6.2 Tables

Annex 7: Acknowledgement

North Norfolk Sandbanks and Saturn Reef, Haisborough, Hammond and Winterton, Inner Dowsing, Race Bank and North Ridge Special Areas of Conservation (SAC)

Monitoring Report 2016

Marine Protected Area (MPA) Monitoring Programme

Report Number 15

Version 4

November 2020

Association of IFCA

Cefas

Department for Environment Food & Rural Affairs

Environment Agency

JNCC Joint Nature Conservation Committee

Marine Management Organisation

NATURAL ENGLAND

Marine Protected Areas Survey Coordination & Evidence Delivery Group

This work was delivered by Cefas and JNCC on behalf of the Marine Protected Areas Survey Coordination & Evidence Delivery Group (MPAG) and sponsored by Defra. MPAG was established in November 2012 and continued until March 2020. MPAG, was originally established to deliver evidence for Marine Conservation Zones (MCZs) recommended for designation. In 2016, the programme of work was refocused towards delivering the evolving requirements for Marine Protected Area (MPA) data and evidence gathering to inform the assessment of the condition of designated sites and features by SNCBs, in order to inform Secretary of State reporting to Parliament. MPAG was primarily comprised of members from Defra and its delivery bodies which have MPA evidence and monitoring budgets and/or survey capability. Members included representatives from Defra, JNCC, Natural England, Cefas, the Environment Agency, the Inshore Fisheries Conservation Authorities (IFCAs) and the Marine Management Organisation (MMO)).

Since 2010, offshore MPA surveys and associated reporting have been delivered by JNCC and Cefas through a JNCC\Cefas Partnership Agreement (which remained the vehicle for delivering the offshore survey work funded by MPAG between 2012 and 2020).

Eggleton, J., Bolam, S., Benson, L., Archer-Rand, S., Mason, C., Noble-James, T., Jones, L., McBreen, F. & Roberts, G. (2020). North Norfolk Sandbanks and Saturn Reef, Haisborough, Hammond and Winterton, Inner Dowsing, Race Bank and North Ridge Special Areas of Conservation (SAC) Monitoring Report 2016. JNCC/Cefas Partnership Report No. 38. JNCC, Peterborough, ISSN 2051-6711, Crown Copyright.