Shell Flat and Lune Deep Special Area of Conservation (SAC) Monitoring Report 2017

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Shell Flat and Lune Deep Special Area of Conservation (SAC) Monitoring Report 2017

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Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Background

Following designation, Natural England started a baseline monitoring programme across all marine protected areas.

This report was commissioned as part of an inshore benthic marine survey of Shell Flat and Lune Deep SAC.

Acknowledgements

We thank the Marine Protected Areas Group (MPAG) representatives for reviewing earlier drafts of this report. We gratefully appreciate the efforts undertaken by Simeon Archer-Rand and Riccardo Arosio (Cefas) for producing the various maps within this report.

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Abbreviations

ANOSIM	Analysis of Similarities
BAC	Background Assessment Concentration
BSH	Broadscale Habitats
Cefas	Centre for Environment, Fisheries and Aquaculture Science
Defra	Department for Environment, Food and Rural Affairs
DG	Day Grab
DW	Dry Weight
EA	Environment Agency
EC	European Commission
EUNIS	European Nature Information System
ERL	Effects Range Low
ERM	Effects Range Median
GES	Good Environmental Status
HMW	High Molecular Weight
JNCC	Joint Nature Conservation Committee
LMW	Low Molecular Weight
MCZ	Marine Conservation Zone
MHM	Mini-Hamon Grab
MPA	Marine Protected Area
MPAG	Marine Protected Areas Survey Coordination and Evidence Delivery Group
MSFD	Marine Strategy Framework Directive
NE	Natural England
NIS	Non-Indigenous Species
nMDS	Non-metric 2D Multidimensional scaling plot
NMBAQC	North East Atlantic Marine Biological Analytical Quality Control Scheme
OSPAR	The Oslo Paris Convention for the Protection of the Marine Environment of the North-East Atlantic
PAH	Polycyclic Aromatic Hydrocarbon
PREMIAM	Pollution Response in Emergencies Marine Impact Assessment and Monitoring

PSA	Particle Size Analysis
PSD	Particle Size Distribution
RV	Research Vessel
SAC	Special Area of Conservation
SACO	Supplementary Advice on Conservation Objectives
SCI	Site of Community Importance
SIMPER	Similarity Percentages Routine
SIMPROF	Similarity Profile Analysis
SNCB	Statutory Nature Conservation Body
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest

Glossary

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

Annex I Habitats	Habitats of conservation importance listed in Annex I of the EC Habitats Directive, for which Special Areas of Conservation (SAC) are designated.
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).
BEST	A procedure in the statistical package PRIMER which finds the best match between the multivariate among-sample patterns of an assemblage and that from environmental variables associated with those samples.
Biotope	The physical habitat with its associated, distinctive biological communities. A biotope is the smallest unit of a habitat that can be delineated conveniently and is characterised by the community of plants and animals living there.*
Broadscale Habitats	Habitats which have been broadly categorised based on a shared set of ecological requirements, aligning with level 3 of the EUNIS habitat classification. Examples of Broadscale Habitats are protected across the MCZ network.
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 of the nature conservation aspirations for the feature(s) of interest within a site, and an assessment of those human pressures likely to affect the feature(s).*
EC Habitats Directive	The EC Habitats Directive (Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora) requires Member States to take measures to maintain natural habitats and wild species of European importance at, or restore them to, favourable conservation status.

Entropy	A non-hierarchical clustering method that groups large matrices of particle size distribution (PSD) datasets into a finite number of groups (Stewart *et al.,* 2009).
EUNIS	A European habitat classification system, covering all types of habitats from natural to artificial, terrestrial to freshwater and marine.*
Favourable Conservation Status	The conservation status of a natural habitat will be taken as 'favourable' when; its natural range and areas it covers within that range are stable or increasing, and the specific structure and functions which are necessary for its long-term maintenance exist and are likely to continue to exist for the foreseeable future (Council Directive 92/43/EEC).
Feature	A species, habitat, geological or geomorphological entity for which an MPA is identified and managed.*
Feature Attributes	Ecological characteristics defined for each feature within site-specific Supplementary Advice on Conservation Objectives (SACO). Feature Attributes are monitored to determine whether condition is favourable.
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).*
Infauna	Fauna living within the seabed sediment.
Joint Nature Conservation Committee (JNCC)	The statutory advisor to Government on UK and international nature conservation. Its specific remit in the marine environment ranges from 12 - 200 nautical miles offshore.
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.
Marine Conservation Zone (MCZ)	MPAs designated under the Marine and Coastal Access Act (2009). MCZs protect nationally important marine wildlife, habitats, geology and geomorphology, and can be designated anywhere in English and Welsh inshore and UK offshore waters.*
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).*

Natura 2000	The EU network of nature protection areas (classified as Special Areas of Conservation and Special Protection Areas), established under the 1992 EC Habitats Directive.*
Natural England	The statutory conservation advisor 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.

Executive Summary

Special Areas of Conservation (SACs) are designated under the EU Habitats Directive for a range of species and habitats. Under Article 17 of the Directive, every six years Statutory Nature Conservation Bodies (SNCBs) must report on the implementation of the Directive. In order to inform this, SNCBs undertake a programme of SAC monitoring. Where possible, this monitoring will also inform assessment of the status of the wider UK marine environment, in line with UK Marine Strategy (Defra, 2014).

The SNCB responsible for nature conservation inshore (up to 12 nm from the coast) is Natural England. Natural England utilises 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.

This report primarily explores data acquired from a dedicated monitoring survey of the Shell Flat and Lune Deep SAC in 2017, intended to serve as first sampling point in a monitoring time series. Anthropogenic pressures and their interactions with the data reported on here are considered by SNCBs at a later stage as part of condition assessment and management advice for this site.

This 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. Potential indicators, where identified, will be evaluated and considered for inclusion in recommendations for future reporting.

Shell Flat and Lune Deep SAC is located between three and 20 km off the Lancashire coast, at the mouth of Morecambe Bay. The site is designated for the Annex I Habitat ‘Sandbanks which are slightly covered by seawater all the time’. This report describes the extent and distribution of this feature within the SAC, and its sediment composition, infaunal structural and functional attributes based on data acquired during the dedicated 2017 survey. Furthermore, this report presents the outcomes of numerical analyses designed to address a wider suite of site-specific objectives including the importance of the site for providing food resources for the Common scoter (*Melanitta nigra*), a designated feature of the Liverpool Bay Special Protection Area (SPA), investigating the effects of the 2017 Douglas Field oil spill and making recommendations regarding sieve mesh size for subsequent infaunal monitoring.

The 2017 survey targeted the Shell Flat region of the Shell Flat and Lune Deep SAC, and this report therefore does not present data pertaining to the Lune Deep area of the SAC. The 37 stations sampled for infauna and sediment granulometric properties revealed that Shell Flat is predominantly represented by 'A5.2 Subtidal sand' (28 stations), although sediments classified as 'A5.3 Subtidal mud' (seven stations) and 'A5.4 Subtidal mixed sediments' (two stations) were also present. Multivariate analyses and clustering of the infaunal data revealed the existence of seven statistically different assemblages across Shell Flat. However, many of these were numerically dominated by shared taxa implying that these clusters differed only in the relative density of these dominant taxa. Total secondary production estimates across the site were principally governed by a small number of annelid and mollusc species, although echinoderms contributed disproportionately to total production along the southern flank of the sandbank and some central regions.

Based on the data acquired in 2017, the Shell Flat assemblages most closely resemble the biotope '*Abra alba* and *Nucula nitidosa* in circalittoral muddy sand or slightly mixed sediment' (SS.SSa.CMuSa.AalbNuc), with *Fabulina fabula* substituting *A. abra* as the numerical dominant. The biotope '*Fabulina fabula* and *Magelona mirabilis* with venerid bivalves and amphipods in infralittoral compacted fine muddy sand' (SS.SSa.IMuSa.FfabMag) is also an apposite biotope class as *Magelona filiformis* (as opposed to *M. mirabilis*) was also an abundant taxon across the site. The data for six stations inferred the potential presence of the '*Mysella* [*Kurtiella*] *bidentata* and *Abra* spp. in infralittoral sandy mud' (SS.SMu.ISaMu.MysAbr) biotope. It should be noted that these biotope assessments were made from single grab samples and that none of the biotope definitions available were a perfect match for the community found at Shell Flat.

Comparisons of the 2017 data with those from 2012 revealed a significant decrease in the total number of individual infauna for both 'A5.2 Subtidal sand' and 'A5.3 Subtidal mud' and in the number of species (for 'A5.2 Subtidal sand' only) over this five-year timespan. Multivariate assemblage structure was also identified to have altered, mainly due to the decreased numbers of the key discriminatory taxa (e.g., *Mytilus edulis* and *M. filiformis* for 'A5.2 Subtidal sand' and Mactridae and *Kurtiella bidentata* for 'A5.3 Subtidal mud'). However, this temporal shift must be interpreted with a degree of caution, due to the smaller grab volumes acquired in the 2017 survey relative to those in 2012.

Sediment concentrations of polycyclic aromatic hydrocarbons (PAHs) in 2017 were low across Shell Flat, both inside and outside the Shell Flat boundary. Furthermore, no significant difference in PAH concentrations between the 2012 and 2017 surveys was discernible. These data indicate no evidence of sediment contamination from the Douglas Field oil spill, which occurred shortly before the acquisition of the 2017 sediment samples at Shell Flat. The 2017 survey was not specifically designed based

on a spill dispersion model and these results should, therefore, be regarded as a basic measurement of any signs of elevated PAHs in the SAC in 2017 compared to 2012.

Abundance and biomass data pertaining to the dominant taxa within Shell Flat (e.g. the bivalves *A. alba*, *Chamelea striatula* and *Mactra stultorum*; the annelids *Lagis koreni* and *Nephtys hombergii*; and the echinoderms *Ophiura ophiura* and *Echinocardium cordatum*) were analysed to assess the prevalence of, and temporal differences in, food resources of the Common scoter across the site. While some taxa exhibited greater abundance or biomass inside the Shell Flat site, others were more notable outside. Likewise, each taxon showed independent temporal changes, with some increasing since 2012 and others displaying a decreasing presence. These data indicate that while Shell Flat harbours a rich potential food resource for Common scoter, prey are also available in the wider environs. The small grab volumes acquired during the 2017 survey may, however, have contributed to any temporal differences.

A comparison of the data obtained when the samples were processed using a 1.0 mm mesh sieve with those using a 0.5 mm sieve revealed mesh size significantly altered multivariate community structure. A large proportion of the numerically dominant taxa at Shell Flat were retained on a 0.5 mm sieve but pass through a 1.0 mm sieve. Furthermore, these taxa are those considered to be important in characterising the infaunal cluster groups. Thus, sieve mesh size clearly affects the capacity to delineate between different assemblage types at Shell Flat. Of the 11 taxa included in the Common scoter food resource analysis, seven were within the top 20 taxa characterising the dissimilarity between mesh sizes, indicating the mesh size directly affects assessments of food resource availability to Common scoter. We conclude that the choice of sieve mesh size adopted during subsequent monitoring surveys must be given careful consideration.

One juvenile ocean quahog (*Arctica islandica*), an Oslo Paris Convention (OSPAR) threatened and/or declining species, was observed in the grab samples acquired during the 2017 survey. No items of litter were found to be present in the grab sediments from the 40 stations sampled (including three which were processed for sediment particle size only) within Shell Flat nor from the 16 stations sampled outside.

Operational and analytical recommendations for future monitoring within the Shell Flat and Lune Deep SAC (and comparable sites) are provided. These include ensuring future surveys are designed with a specific capacity to fully address all survey objectives, resolving issues associated with small grab sample volumes and, as is the case for other sites, controlling for seasonal variations in infaunal assemblages.

1 Introduction

The Shell Flat and Lune Deep Special Area of Conservation (SAC) is part of a network of sites designed to meet conservation objectives under the European Commission (EC) Habitats Directive (92/43/EEC). These sites will also contribute to an ecologically coherent network of Marine Protected Areas (MPAs) across the North-East Atlantic, as agreed under the Oslo Paris Convention (OSPAR) and other international commitments to which the UK is a signatory.

SACs exist alongside other Marine Protected Areas (MPAs), including Special Protection Areas (SPAs), Marine Conservation Zones (MCZs), Sites of Special Scientific Interest (SSSIs) and Ramsar sites to conserve marine biodiversity with a particular focus on the most valuable and threatened species and habitats of European and national importance.

Under Article 17 of the Habitats Directive, Defra is required to provide 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. To fulfil its obligations, Defra has directed the Statutory Nature Conservation Bodies (SNCBs) to carry out a programme of MPA monitoring. Where possible, this monitoring will also inform assessment of the status of the wider UK marine environment, in line with the UK Marine Strategy (Defra, 2014).

This report primarily explores data acquired from the first dedicated monitoring survey of the Shell Flat and Lune Deep SAC, conducted in 2017. This dataset will allow a detailed characterisation of the SAC and will form the second point in a monitoring time series (being compared to previous data acquired in 2012), against which site and feature condition can be assessed in the future. The specific aims and objectives of the report are discussed further in Section 1.5.

The Shell Flat and Lune Deep SAC is an inshore MPA designated to protect the Annex I Habitat features ‘Sandbanks which are slightly covered by seawater all the time’ (including the subfeatures ‘A5.2 Subtidal sand’, ‘A5.3 Subtidal mud’ and ‘A5.4 Subtidal Mixed Sediments’) and Reefs (including the subfeatures ‘Circalittoral rock’ and ‘Subtidal stony reef’) (Table 1)[1]. The survey focussed on the Shell Flat Annex I Habitat ‘Sandbanks which are slightly covered by seawater all the time’ and not on the Lune Deep region of the SAC.

[1] https://designatedsites.naturalengland.org.uk/Marine/MarineSiteDetail.aspx?SiteCode=UK0030376&SiteName=shell%20flat&countyCode=&responsiblePerson=&SeaArea=&IFCAArea=&HasCA=1&NumMarineSeasonality=0&SiteNameDisplay=Shell%20Flat%20and%20Lune%20Deep%20SAC#SiteInfo [accessed 10/06/20]

Table 1. Subtidal Annex I habitat features designated for protection within the Shell Flat and Lune Deep SAC (Natural England, 2018) (© Natural England and Cefas 2022). This report pertains solely to the Sandbanks feature at Shell Flat and does not include subfeatures associated with Reefs which are associated with Lune Deep.

Subfeature	**Annex I Feature**	
	H1110 Sandbanks which are slightly covered by sea water all the time (Subtidal Sandbanks)	H1170 Reefs
A5.2 Subtidal sand	✓	
A5.3 Subtidal mud	✓	
A5.4 Subtidal mixed sediments	✓	
Circalittoral rock		✓
Subtidal stony reef		✓

1.1 Feature description

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.”

Annex I Sandbank features are composed of several finer scale habitats. These include (but are not limited to) ‘A5.2 Subtidal sand’, ‘A5.1 Subtidal coarse sediment’ and ‘A5.4 Subtidal mixed sediments’, as per the EUNIS classification. Subtidal sand is the dominant habitat type within the Annex I Sandbank feature, comprised of clean medium to fine sands or non-cohesive slightly muddy sands. ‘Subtidal coarse sediment’ is a combination of sand and gravel through to pure gravel. Coarse sediments are often unstable due to tidal currents and/or wave action. ‘Subtidal 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.

1.2 Site overview

The SAC is located between 3 km and 20 km off the Lancashire coast, at the mouth of Morecambe Bay (**Error! Reference source not found.**). The SAC is characterised b y a deep-water channel (Lune Deep) and a large sandbank feature (Shell Flat) surrounded by shallow areas to the north and south. The depth of the seabed within the site ranges from 6 m on Shell Flat to 44 m in Lune Deep. As this report focuses solely on the Shell Flat region of the SAC, background material and further reference to Lune Deep will not be considered further within this report.

Shell Flat is an example of a Banner Bank, which are generally only a few kilometres in length with an elongated pear-shaped form, located in water depths less than 20 m (Envision Mapping Ltd., 2014). It is considered an important example of a sandbank habitat as other sandbank features in the Irish Sea are either associated with estuaries or headlands (EA, unpublished report). The area of sandbank habitat within the SAC is 89 km^2, equivalent to 0.52% of the UK total resource (Natural England, 2012). However, the sandbank extends beyond the site boundaries and its extent totals approximately 97 km^2 (Envision Mapping Ltd., 2014).

The hydrodynamic regime of Shell Flat is mostly influenced by tidal current and wave movement. Flood tidal currents on Shell Flat mostly flow from south-west to north-east, while ebb tides flow in the opposite direction, in and out of Morecambe Bay. Modelled tidal speed is between 0.5 and 0.75 m s^{-1}. Modelled yearly potential sediment transport (for 2010) for the area is between 100 and 500 m^3 m^{-1} y^{-1} in an approximately west to east direction.

The ‘A5.2 Subtidal sand’ subfeature of Shell Flat is mostly composed of slightly gravelly sand on the top of the sandbank with muddy sand in the northern part of the bank and slightly gravelly muddy sands in the deeper areas (Envision Mapping Ltd., 2014). The biotopes recorded were ‘*Fabulina fabula* and *Magelona mirabilis* with venerid bivalves and amphipods in infralittoral compacted fine muddy sand’ (SS.SSa.IMuSa.FfabMag) in the fine shallower sediments of the bank, with ‘*Abra alba* and *Nucula nitidosa* in circalittoral muddy sand or slightly mixed sediment*’* (SS.SSa.CMuSa.AalbNuc) occurring in the slightly muddier sediments found on the slopes and in deeper areas of the bank. Envision Mapping Ltd. (2014) concluded that the spatial distribution of infaunal communities in the ‘A5.2 Subtidal sand’ had remained consistent between 2002 and 2012.

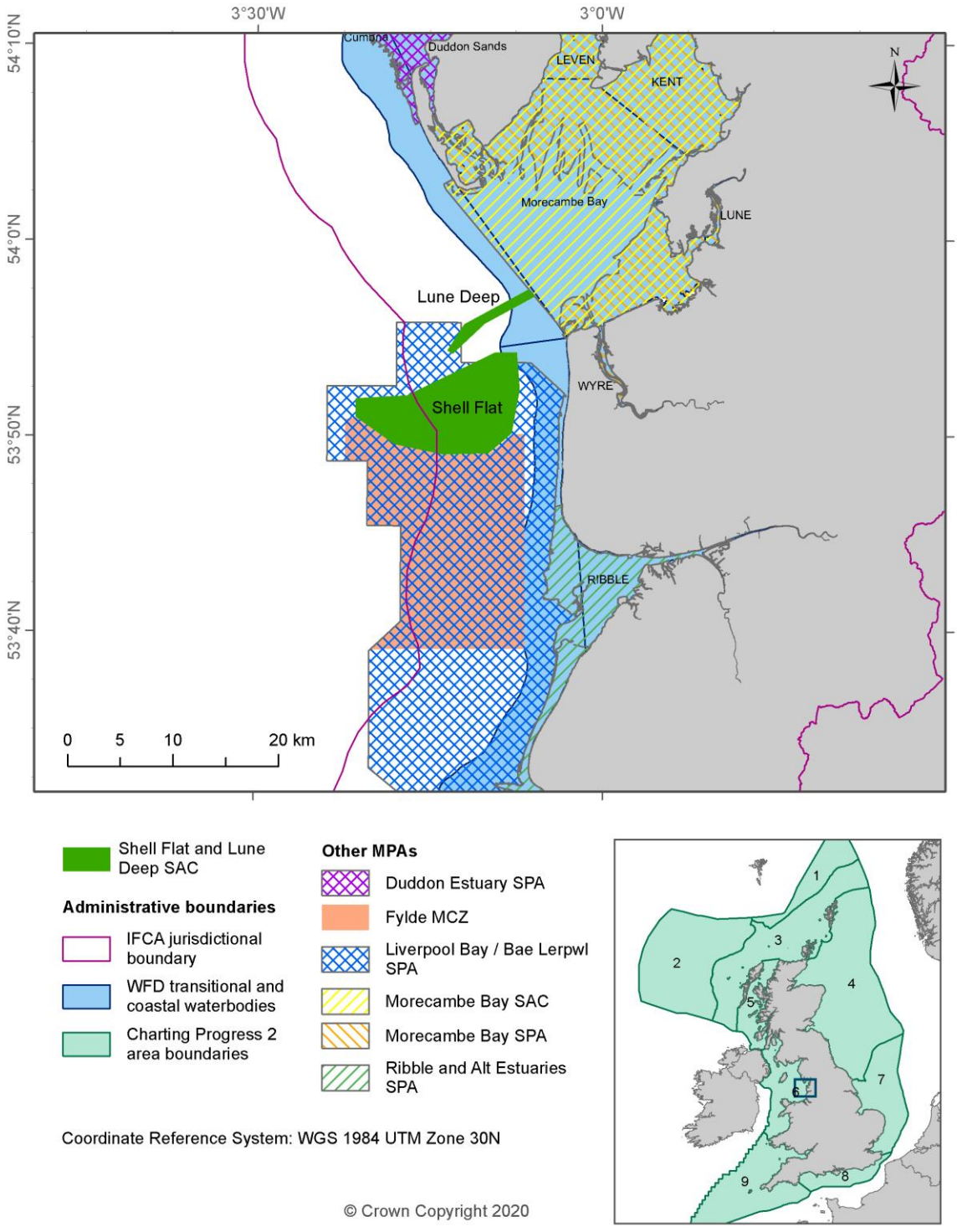

Figure 1. Location of the Shell Flat and Lune Deep SAC in the context of Marine Protected Areas and management jurisdictions proximal to the site (© Natural England and Cefas 2022).

Detailed site information can be found in the Shell Flat and Lune Deep SAC conservation advice (Natural England, 2012). The designated subtidal Annex I features and subfeatures within the Shell Flat and Lune Deep SAC are shown in **Error! R eference source not found.**.

The Shell Flat sandbank supports 50,000 wintering Common scoter (*Melanitta nigra*) that feed there on infauna inhabiting the sediment surface or within surficial sediments, particularly bivalve molluscs (Kaiser *et al.*, 2006). Shell Flat significantly contributes to the Liverpool Bay area being the most important site in the UK for this species (Kaiser *et al.*, 2006) as its infaunal assemblages play a vital role as a food source.

The only non-native infaunal species recorded in a 2012 survey was *Mya arenaria*. This bivalve mollusc was introduced in the 16th or 17th century and is now widespread in all British waters (Eno *et al*., 1997).

1.3 SAC management and human activities

Shell Flat and Lune Deep SAC overlaps with the Liverpool Bay SPA and is adjacent to the Fylde Marine Conservation Zone (Figure 1). The Shell Flat SAC was formally submitted by the UK Government to the European Commission (EC) in 2010. Lune Deep SAC was submitted in 2011 after new evidence led Natural England to propose a revised boundary. The site changed status from a Site of Community Importance (SCI) to a SAC in 2017. The joint site (i.e. the Shell Flat and Lune Deep SAC; the 'SAC' hereafter) now forms part of the Natura 2000 network of protected sites.

On 10th July 2017, oil leaked from an oil storage tanker located 16 km from the Douglas Complex, 24 km off the coast of North Wales. Subsequently, oil and tar balls washed up along the coast from Cleveleys to Fleetwood, at Knott End and in Blackpool. A survey was undertaken, specifically aimed at acquiring evidence for the presence of any residual oil contamination in sediments, shellfish and the water in September 2017, following the clean-up operations (Xodus, 2017). The survey focussed on the intertidal and shallow subtidal areas of the affected regions and did not include sediments within either Shell Flat nor within the wider Shell Flat and Lune Deep SAC.

1.4 Existing data and habitat maps

The Shell Flat area of the SAC has been the focus of sampling for a range of specific objectives over recent years. These various surveys have acquired data (e.g. video imagery, grabs for infauna and sediment particle size, acoustic data) using a variety of approaches governed by the specific objectives of each survey. These data were compiled and reported during 2014 (Envision Mapping Ltd., 2014) to produce topographical and habitat maps of the area as a basis for long-term monitoring of feature condition. Maps of the predictive distribution of sediment types revealed Shell Flat to be dominated by slightly gravelly sand on the top of the sandbank with slightly gravelly muddy sands in the deeper areas (Envision Mapping, 2014).

To allow several objectives of the present report to be addressed, infaunal and sediment data for 20 stations from a spatial survey conducted by the Environment Agency (EA) during 2012 have been analysed and compared with those from the dedicated 2017 monitoring survey. Sampling in both years took place in August.

1.5 Aims and objectives

1.5.1 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'.

As detailed in conservation advice for the Shell Flat to Lune Deep SAC (Natural England, 2018)[2], the conservation objective for the site is to:

Ensure that the integrity of the site is maintained or restored as appropriate, and ensure 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;
- the structure and function (including typical species) of qualifying natural habitats; and
- the supporting processes on which the qualifying natural habitats rely.

The Supplementary Advice for the Conservation Objectives (SACO)[3] for this site provides more detailed conservation objectives for Feature Attributes of 'Sandbanks which are slightly covered by sea water all the time' within the Shell Flat to Lune Deep SAC (Natural England, 2019).

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 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

[2] https://designatedsites.naturalengland.org.uk/Marine/MarineSiteDetail.aspx?SiteCode=UK0030376&SiteName=shell%20flat&SiteNameDisplay=Shell%20Flat%20and%20Lune%20Deep%20SAC&countyCode=&responsiblePerson=&SeaArea=&IFCAArea=&NumMarineSeasonality=&HasCA=1 [accessed 10/06/20]

[3] https://designatedsites.naturalengland.org.uk/Marine/SupAdvice.aspx?SiteCode=UK0030376&SiteName=shell%20flat&SiteNameDisplay=Shell+Flat+and+Lune+Deep+SAC&countyCode=&responsiblePerson=&SeaArea=&IFCAArea=&NumMarineSeasonality= [accessed 10/06/20]

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).

1.5.2 Report aims and objectives

The primary aim of this monitoring report is to explore and describe the attributes of the designated Sandbank feature ('Shell Flat' hereafter) within the Shell Flat and Lune Deep SAC, to enable future assessment and monitoring of feature condition. The results presented will be used to develop recommendations for future monitoring, including the operational testing of specific metrics which may indicate whether the condition of the feature has been maintained, has recovered or is in decline.

The objectives of this monitoring report are provided below:

Objective 1: Provide a description of the extent, distribution, structural and (where possible) functional attributes of the designated Annex I Sandbank feature using 2017 data (see Table 2 for more detail), to enable subsequent condition monitoring and assessment;

Objective 2: Assign biotopes (where possible) to the infaunal communities inside and outside the SAC, based on 2017 data;

Objective 3: Conduct a temporal comparison of sediment composition and infaunal assemblages, and specified univariate metrics, inside the SAC between 2012 and 2017;

Objective 4: Conduct a temporal comparison of contaminant levels inside the site between 2012 and 2017 and describe their relationships with those outside the site for 2017 data to explore signs of any impact of the 2017 Douglas Field oil spill;

Objective 5: Compare abundance of and size class distributions of Common scoter food resource species between 2012 and 2017 inside and outside the site;

Objective 6: Conduct a comparison of infaunal community data between 0.5 mm and 1.0 mm sieve mesh sizes to assess whether a 1.0 mm sieve is appropriate for future use at this SAC;

Objective 7: Note observations of OSPAR Threatened and/or Declining Species and Habitats;

Objective 8: Present evidence relating to the presence of non-indigenous species (NIS) and marine litter; and

Objective 9: Provide practical recommendations for appropriate future monitoring approaches for the sandbank feature and its natural supporting processes (e.g., metric selection, survey design, data collection approaches) with a discussion of their requirements.

1.5.3 Reporting sub-objectives (Objective 1)

To achieve Objective 1, several reporting sub-objectives will be addressed to provide evidence for Feature Attributes and supporting processes (as defined in the SACO; Natural England, 2019). The list of reporting sub-objectives for selected Feature Attributes (and supporting processes) of the designated features is presented in Table 2.

Table 2. Annex I Sandbank Feature Attributes and sub-objectives addressed to achieve report Objective 1 (© Natural England and Cefas 2022).

Feature Attributes	Sub-objectives
Extent and distribution	Conduct Particle Size Analysis, generate Entropy sediment clusters and conduct point distribution comparison with previous habitat map.
Structure: sediment composition and distribution	Generate Entropy clusters and create spatial distribution maps.
Distribution: presence and spatial distribution of biological communities	Conduct biotope analysis, univariate and multivariate community analysis.
Structure and function: presence and abundance of key structural and influential species	Conduct biological community analysis and biotopes.
***Structure**: non-native species and pathogens	Report presence, abundance and distribution of MSFD and UK listed non-native species.
Structure: species composition of component communities	Conduct multivariate community analysis.

* this sub-objective is addressed under Objective 8.

1.5.4 Report limitations

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

A dedicated monitoring survey was conducted at the Shell Flat and Lune Deep SAC onboard the RV *Mersey Guardian* in August 2017 (Green and Godsell, unpublished).

The survey consisted of subtidal sampling at 60 stations using sediment grabs, 56 of which were successful in obtaining a sample (Figure 2). Forty of these stations were within the Shell Flat area, two within the Lune Deep area, while the remaining 14 were located outside the SAC boundary (generally between Shell Flat and Lune Deep with a small number in the more inshore areas to the east) (Figure 2). Of the 40 stations in Shell Flat, 37 were sampled for infaunal assemblages while three were only sampled for particle size distribution (PSD) due to small amounts of sediment captured. Thirty of the 40 stations sampled within the Shell Flat area were previously surveyed in August 2012, allowing temporal comparisons to be made. Additionally, ten new stations within the SAC were added in areas not previously targeted. Nine (four within the SAC boundary and five outside) of the 56 stations were selected for sediment contaminants (polycyclic aromatic hydrocarbons ('PAHs' hereafter), total hydrocarbons and total organic carbon) sampling. These stations were selected based on the outcomes of previous sampling, targeting specifically the muddier habitats for contaminants assessment (EA, unpublished). The PAH data are used to provide an assessment regarding whether the sediments within and outside Shell Flat show signs of contamination from the Douglas Field oil spill, which occurred two weeks prior to the survey (Objective 5). PAH data from 2012, where six stations from within Shell Flat were sampled, are used to aid this assessment.

The 2017 infaunal samples were sieved over a 0.5 mm mesh in the field, making them comparable to those acquired 2012 which were processed using a 0.5 mm mesh. To allow the 2017 data to address Objective 6 (and to aid comparability with data from other MPAs), the 2017 samples were re-sieved in the laboratory on both a 1.0 mm and a 0.5 mm sieves to provide data to allow both fractions (i.e. >1.0 mm, >0.5 mm) to be compared.

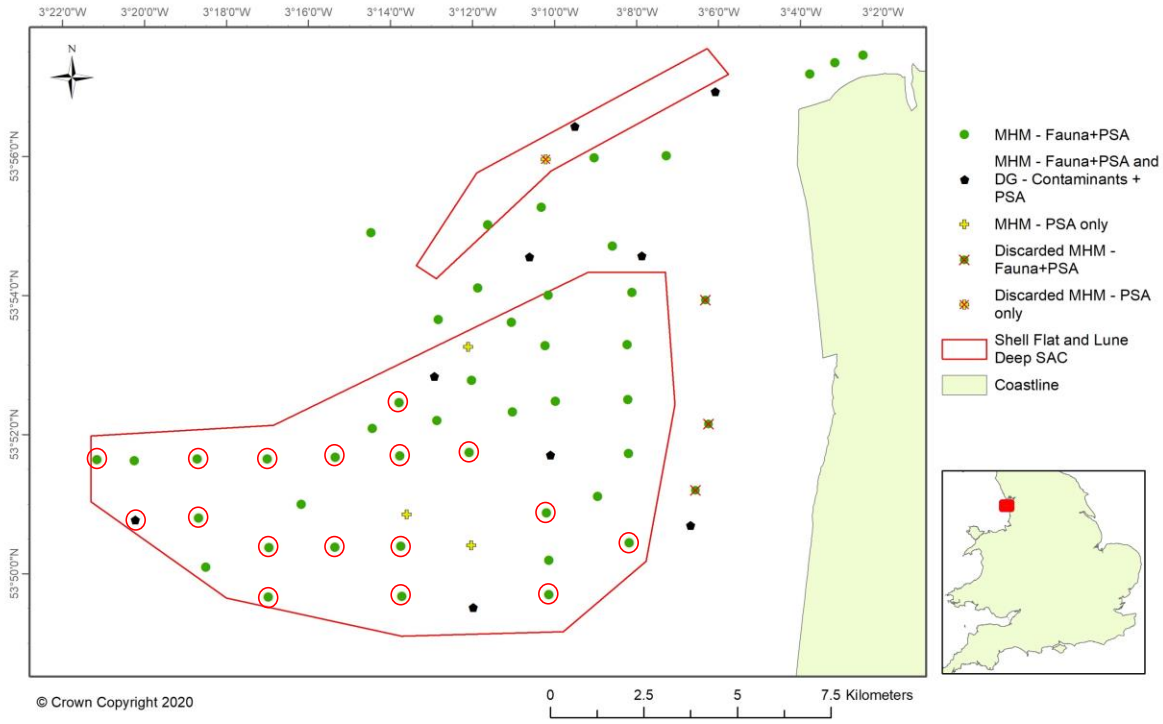

Figure 2. Location of the grab samples collected at the Shell Flat and Lune Deep SAC in 2017. Samples taken for different parameters (fauna, particle size analysis (PSA), contaminants) or using different gear types (MHM = Mini-Hamon Grab; DG = Day Grab) are given different symbols (© Natural England and Cefas 2022). Stations highlighted with red circles are repeat stations from 2012.

2.2 Data acquisition and processing

2.2.1 Grab sampling

A Mini-Hamon Grab, with a sampling area of 0.1 m^2, was deployed from the stern gantry of the vessel to collect sediment from the seabed, as described by Ware and Kenny (2011). Sampling positions were recorded (fixed) using Hydropro data acquisition software when the gear contacted the seabed, with the mid-point of the vessel's stern gantry being used as the default offset for position fixing.

Once recovered, the sample was emptied into a suitable container, photographed, and the sample volume measured. A minimum of three attempts were made at each station to obtain a valid grab sample before the station was abandoned. A sample volume of 5 L was required to qualify as a valid sample. Samples of <5 L were ordinarily discarded. However, when it was difficult to obtain a valid sample (i.e., all three attempts were <5 L), a sample with <5 L of material was retained at the discretion of the lead scientist. For accepted samples, a small scoop was used to remove a sub-sample (approx. 0.5 L) of sediment for particle size analysis (PSA) which was immediately frozen at -20 °C for storage. The remaining sample was washed over a 0.5 mm sieve to retain the infaunal fraction, photographed and preserved with a

buffered 4% formaldehyde solution for transfer ashore to a specialist laboratory for analysis.

Where the volume of sediment collected was insufficient for infaunal analysis in each grab, a photograph was taken and, if possible, material removed for PSA (i.e. a 'PSA only' station, the case at three stations). If an insufficient volume of suitable material was retrieved following all three attempts for any of the analyses, the station was abandoned (the case at four stations).

At a subset of stations, a 0.1 m^2 Day Grab was deployed from the stern gantry of the survey vessel to recover sediment for contaminant analyses, following the methodology detailed in EA (2007). Surface scrapes (i.e. the recently deposited sediment) were removed from each grab to a maximum depth of 1 cm (avoiding the anoxic layer). A metal scoop was used to collect material for contaminant analyses and a small corer for the associated particle size samples. The remaining material was then discarded. Between stations, the Day Grab and scoops were rinsed with a solvent to prevent cross-contamination of samples, as detailed in the Pollution Response in Emergencies Marine Impact Assessment and Monitoring (PREMIAM) guidelines (Law *et al*., 2011).

Sediment PSA samples were processed following the recommended methodology of the North East Atlantic Marine Biological Analytical Quality Control (NMBAQC) scheme (Mason, 2011). The <1.0 mm sediment fraction was analysed using laser diffraction and the >1 mm fraction was dried, sieved and weighed at 0.5 phi (ϕ) intervals. The resulting PSD data from the <1.0 mm and >1.0 mm fractions were then merged. Organisms within the infaunal samples were identified to the lowest taxonomic level possible, enumerated and weighed (blotted wet weight) to the nearest 0.0001 g, following the recommendations of the NMBAQC scheme (Worsfold *et al*. 2010).

2.2.2 Biological data truncation

Infaunal taxa recorded from the mini-Hamon Grab samples were checked for the application of consistent and up to date nomenclature using the WoRMS match taxa tool[4]. Any taxa not considered as sediment infauna (e.g. fish, mysids, nematodes) were removed from the dataset. The truncation steps taken depended on the needs of the various report objectives (see Annex 1 for a full description). For the analyses used for Objective 1 (wherein only the 2017 data are used), the resolution of the records was maintained where possible. For example, by removing juveniles at genus level while keeping adults for a corresponding species (*sensu* Downie *et al*., 2018). For the comparison of 2012 and 2017 data (Objective 3), the truncation was optimised for comparison between data sets which were processed by different companies. This

[4] http://www.marinespecies.org/aphia.php?p=match [accessed 10/06/20]

led to some loss of resolution by merging to higher taxonomic levels, thus ensuring that apparent differences between years were not due to different taxonomic identification guidelines. The same truncation method was maintained for the comparison between mesh sizes (Objective 6) whereby the final dataset represented the highest possible level of taxonomic information, while ensuring a correct merging of the two independent datasets. Although sample analyses for both mesh sizes were conducted by the same contractor using common guidelines, the comparison still required some merging to higher levels when species level was not found in the smaller mesh size. Small colonial taxa had been recorded as 'P' since the number of individuals is hard to determine. These 'P's were replaced by an abundance of '1' (*sensu* Downie *et al*., 2018) prior to numerical analyses.

2.3 Data analysis

2.3.1 Physical structure

To assess the extent and distribution of the Annex I Sandbank feature (Objective 1), sediment PSD data (0.5 ϕ classes) derived from mini-Hamon Grab samples were grouped into the percentage contribution of gravel (> 2 mm diameter), sand (0.063–2 mm) and mud (<0.063 mm) based on a modified version (Long, 2006) of the classification system proposed by Folk (1954). To be classified as 'Sandbanks which are slightly covered by seawater all the time', sediment must consist primarily of sand and contain less than 30% gravel (Duncan, 2016).

The composition and distribution of sediments associated with the Annex I Sandbank feature was further explored by assigning each sediment sample to EUNIS Level 3 Broadscale Habitats ('subfeatures' hereafter) based on the contents of gravel, sand and mud using the BGS-modified version of the Folk classification (Long, 2006). Subfeature type of sampled stations were plotted to produce a high-level overview of habitat types throughout Shell Flat.

In addition, the full-resolution PSD data (at 0.5 ϕ intervals) were grouped using Entropy, a non-hierarchical clustering method that groups large matrices of PSD datasets into a finite number of groups (Stewart *et al*., 2009). The notable difference between categorising sediments using this approach as opposed to the Folk (1954) approach is that it uses data regarding all size distribution classes as opposed to the composition of gravel, sand and mud. The optimum number of sediment clusters was achieved when the Calinski–Harabasz (C–H) statistic is at its maximum (Orpin and Kostylev, 2006). As the clustering approach produces more robust groups when based on a larger number of samples, the PSD data from all samples acquired within the SAC in both 2012 and 2017 were included.

2.3.2 Biological structure

Biological assemblages were analysed with respect to the composition, density and diversity of infauna (Objective 1). To analyse community composition, infaunal taxa abundance and biomass datasets for 0.5 – 1.0 mm and >1.0 mm were combined in Microsoft Excel and formatted for subsequent importation into the statistical package PRIMER (version 7; Clarke and Gorley, 2015). After comparing transformation methods using shade plots, taxa abundances were transformed by $\log_e (x+1)$ to downweigh the influence of numerically dominant taxa and allow variation in less abundant taxa to be detected. Subsequently, a resemblance matrix was created from the Bray-Curtis similarities of each pair of stations. Hierarchical cluster analysis (with group average linking) was then performed in association with similarity profile analysis (SIMPROF) to identify sets of stations with significantly distinct infaunal assemblages (p <0.05). From the Bray-Curtis similarity matrix, non-metric 2D Multidimensional scaling plots (nMDS) were produced with symbols or labels identifying subfeatures, Entropy clusters and SIMPROF clusters, in addition to nMDS bubble plots to visualise the differences in PSD percentages between sites. Subfeatures, Entropy clusters and SIMPROF clusters were plotted in ArcMap to present spatial distributions of these groupings. An analysis of similarities (ANOSIM) was performed to test for differences between subfeature groups and similarity percentages (SIMPER) routines were performed to identify the main taxa contributing to similarity within (and dissimilarity between) the groupings. A BEST analysis was performed on percentages of sand, mud, and gravel as well as water depth at which the grab was taken and volume of the grab sample to quantify correlations between these environmental and sampling parameters with patterns in the infaunal community data. Finally, a set of univariate biotic indices were calculated in PRIMER that may be useful for monitoring: total abundance, total number of species (i.e. 'species richness'), the Margalef Diversity Index (Margalef, 1958; hereafter 'Margalef index') and the Shannon Diversity Index (Shannon, 1948; hereafter 'Shannon Index'). Total abundance and species richness were used as they are fundamental and commonly used measures of faunal density and diversity. The Margalef index (species richness relative to the log of total abundance) was selected because there is evidence that it may represent a good general indicator of physical, organic and chemical disturbance (van Loon *et al*., 2018) and therefore be responsive to a range of anthropogenic pressures. The Shannon Index is an integrated measure of both species richness and evenness (i.e. how evenly total abundance is distributed across species) and was included for its ability to respond to changes in either aspect of biodiversity. Mean values and 95% confidence intervals for these univariate indices were determined for each subfeature.

To undertake the temporal comparison of infaunal assemblages between 2012 and 2017 (Objective 3), density and diversity values and multivariate structure between the two years were compared. To give a complete picture, two sets of analyses were done: one where 17 stations were analysed, which were sampled in both years, and one

where all stations within Shell Flat (20 in 2012 and 37 in 2017) were used to assimilate as much data as possible. Stations in both years covered the extent of the Shell Flat area. For both datasets, nMDS plots were created based on Bray-Curtis similarity matrices from $\log_e (x+1)$ transformed data. Of the stations sampled in both years, five differed in their subfeature classification. These changes, due to differing PSD percentages, were depicted in a Folk triangle, after which these stations were removed from further analyses which were based on subfeature groupings. The remaining subfeatures were 'A5.2 Subtidal sand' and 'A5.3 Subtidal mud'. ANOSIM analyses were performed per subfeature on both datasets, followed by SIMPER to determine which taxa were responsible for any observed temporal changes in community structure ($p < 0.05$).

The comparison between mesh sizes based on the 2017 infauna data (n = 37) again used very similar analyses as described above. An nMDS plot was created based on a Bray-Curtis similarity matrix from the $\log_e (x+1)$ transformed dataset, followed by an ANOSIM and a SIMPER routine to determine the taxa characterising the differences between the communities retained by the two mesh sizes. Additionally, taxa that were present in the 0.5 mm mesh size data but absent in the 1.0 mm mesh size data were identified. Species accumulation curves were calculated in R using the Vegan package (Oksanen *et al.*, 2018) with 1000 random permutations.

2.3.3 Ecological function

Infaunal secondary production (KJ m^{-2} yr^{-1}) were estimated indirectly for each station using abundance and biomass data (Objective 1). First, any taxa that could not be both enumerated and weighed were removed from the datasets. Measured (wet) biomass values were then converted to energy values, using published conversion factors (Brey *et al*., 2010), and converted to annual production values using a multi-parameter empirical model (Brey, 2001). This method unifies previous habitat-specific approaches into a multiple regression model and is one of the most reliable and robust methods for estimating secondary production (Cusson and Bourget, 2005; Dolbeth *et al*., 2005).

To derive estimates for each station, the mean biomass (kJ m^{-2}), mean abundance (individuals m^{-2}) and individual body mass (kJ) of each taxon were entered into the empirical model along with station-specific depths (recorded during the survey) and modelled mean annual bottom water temperatures. Production by each taxon was calculated and these values summed to estimate the total secondary production at each station.

As the model prediction error associated with community-level production values is unknown, caution must be applied when interpreting model results. That said, the large prediction errors typically associated with population-level estimates are greatly reduced when pooled to the community-level (Brey, 2001). It should also be noted that the model requires mean annual abundance and biomass data for each taxon,

whereas the available community data in 2017 are from a single survey conducted in August. As the abundance and biomass of a taxon typically varies throughout the year, an under- or overestimation of total production is possible. The degree to which this influences results will depend on how closely abundance and biomass in August resemble annual values.

2.3.4 Food availability for Common scoter

Differences in food availability for Common scoter were analysed for both temporal changes and spatial changes (Objective 5). As the 2012 survey only acquired infaunal data from within Shell Flat, the temporal comparison of the changes in the food resources of the Common scoter was conducted separately from the assessment of difference between prey inside the site and outside the site, as this was limited to data from 2017.

Bivalve molluscs are thought to be the main prey species for the Common scoter (Kaiser *et al*., 2006), although there is evidence that it may be a non-selective feeder with other invertebrates (e.g. gastropods, echinoderms, crustaceans) found to be predated. Given this, it may be postulated that changes in the abundance and/or biomass of the biomass dominants act as a proxy for changes in prey availability. Taxa considered in the analyses were therefore selected based on their relative dominant contribution to total biomass in both sampling years (the selected taxa comprised >86 % of the total biomass across both years).

All samples from inside Shell Flat were used for the temporal comparison (n = 20 in 2012 and n = 37 in 2017) as opposed to restricting the assessment to those stations sampled in both years. We assume that the additional 17 stations in 2017 do not bias the temporal comparisons but provide a more robust estimate of the prey availability compared to that based on 20 stations.

The spatial assessment (inside versus outside of Shell Flat) was based on all stations sampled during 2017 (n = 37, n = 16; inside and outside respectively). For several taxa, the 2017 dataset contained abundance and biomass broken down into several size classes. The number of size categories (between three and five) varied between taxa.

2.3.5 Other OSPAR threatened and/or declining habitats or species

The infaunal data from the mini-Hamon Grabs were inspected for any OSPAR threatened and/or declining species and any species indicative of OSPAR threatened and/or habitats, and the results were mapped (Objective 7).

2.3.6 Non-indigenous species (NIS) and marine litter

The raw infaunal data were cross-referenced against a list of 49 target species which has been developed under the Marine Strategy Framework Directive (MSFD) for assessment of Descriptor 2: Non-indigenous species (Stebbing *et al*., 2014; Annex 2). The list includes two categories; species which are already known to be present within the assessment area (present) and species 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 observed taxa (Annex 2).

Items of litter found in the 2017 grab samples were identified according to the categories in Annex 3 (Objective 8).

3 Results

3.1 Extent, distribution, structure and function of Annex I Sandbank habitat

Objective 1: *Provide a description of the extent, distribution, structural and (where possible) functional attributes of the designated Annex I Sandbank feature using 2017 data to enable subsequent condition monitoring and assessment*.

3.1.1 Sediment composition

The PSD of the 40 stations sampled inside Shell Flat in 2017 confirm the dominance of sand, with varying amounts of silt/clay (Figure 3). The central region of Shell Flat is generally comprised of sand, and the stations within increased proportions of silt/clay are found along the northern and southern limits of Shell Flat. One station to the western edge is noteworthy, being composed almost exclusively of silt/clay (97.8%). Increased fractions of gravel occur in a small number of stations along the southern edge of Shell Flat.

When the sediments of the 37 stations for which infaunal data were attained are categorised according to EUNIS Broadscale Habitats (BSHs), three BSHs were evident ('A5.2 Subtidal sand' (28 stations), 'A5.3 Subtidal mud' (7 stations), and 'A5.4 Subtidal mixed sediment' (2 stations)) (Figure 4). These BSHs define the subfeatures to which each station belongs. Stations representing 'A5.2 Subtidal sand', the most widespread subfeature, are found across the whole of Shell Flat, except the southern flank where the two stations classed as 'A5.4 Subtidal mixed sediments' are located. The seven stations classed as subfeature 'A5.3 Subtidal mud' occur across Shell Flat, although two clusters of two neighbouring stations occur. It is important to note that the sediment composition of 'A5.4 Subtidal mixed sediment' is not markedly

different from that of ‘A5.2 Subtidal sand’ or ‘A5.3 Subtidal mud’, as they lie close to the delineations between the BSH (see Figure 5).

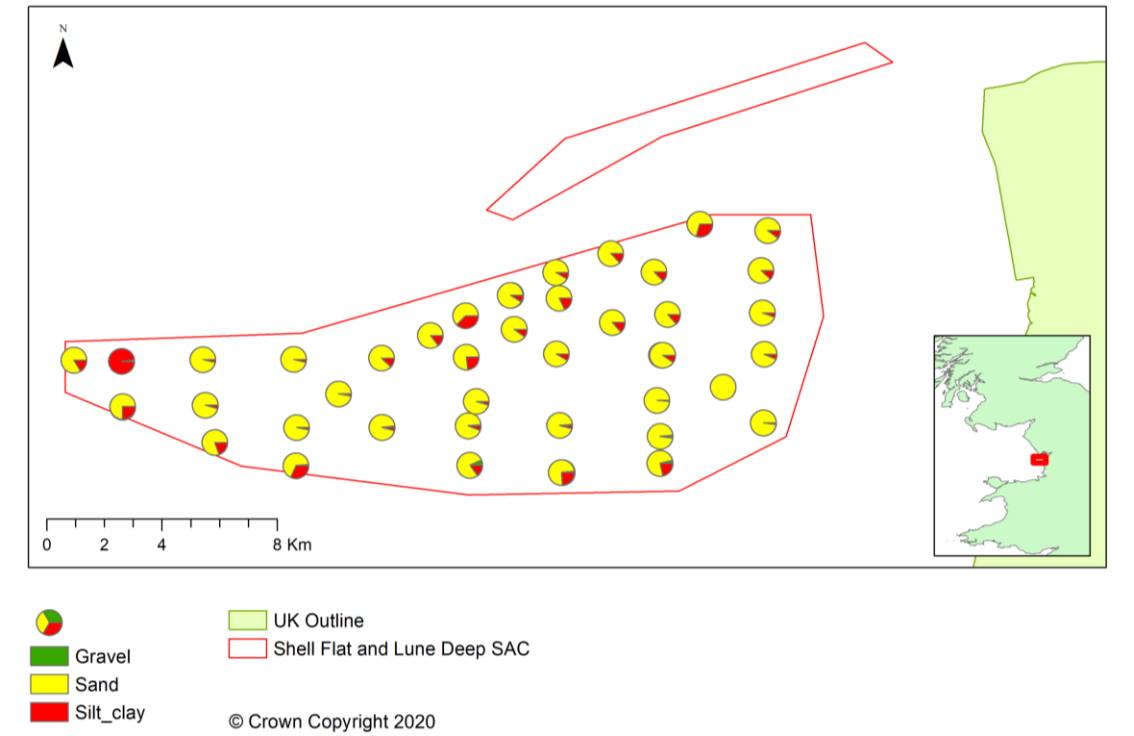

Figure 3. Pie charts of the proportional composition of gravel, sand and silt/clay of the sediments sampled within Shell Flat 2017.

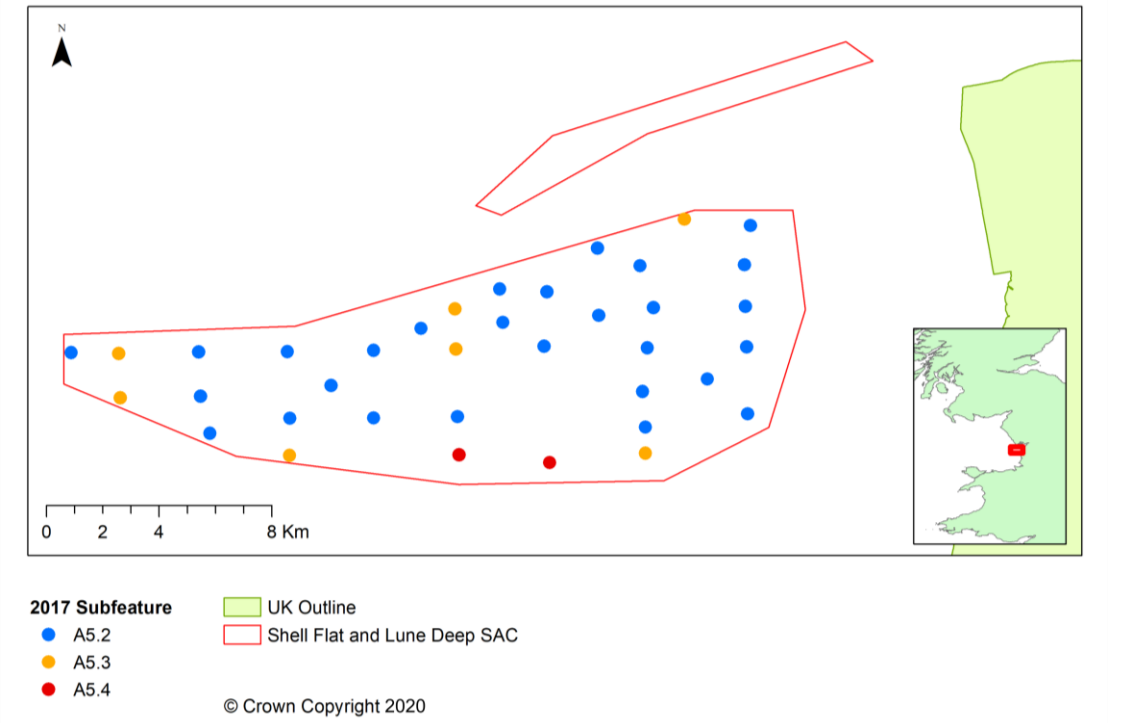

Figure 4. Spatial distribution of subfeatures within Shell Flat based on the PSD of the 37 stations sampled in Shell Flat in 2017 for which infaunal samples were obtained.

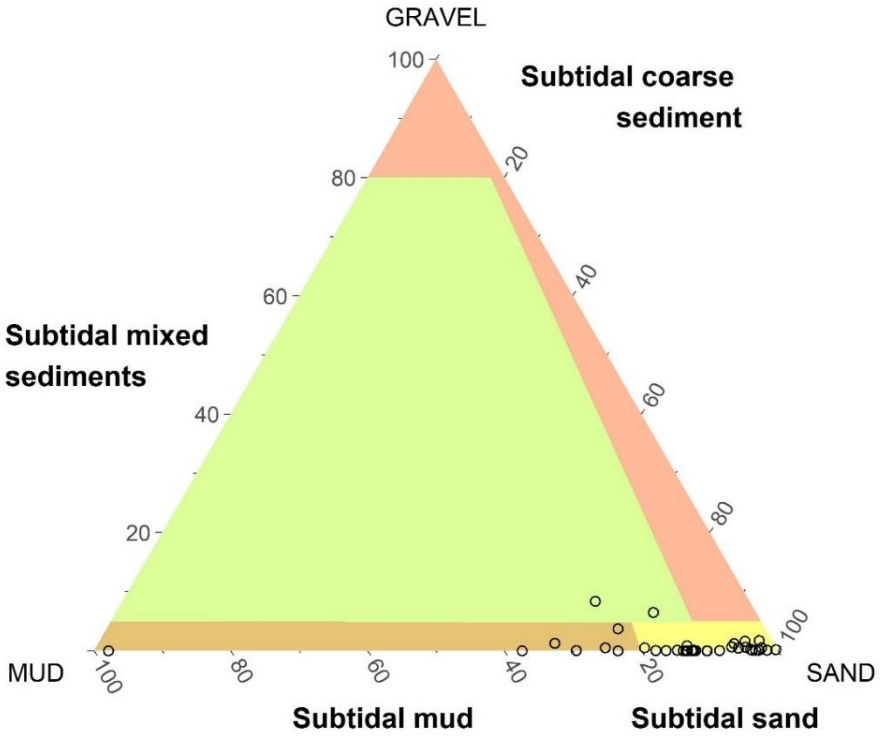

Figure 5. Folk triangle (Folk, 1954) based on the PSD percentages of the 37 stations sampled in Shell Flat in 2017 for which infaunal samples were obtained (© Natural England and Cefas 2022).

Entropy analysis of the full PSD data using EntropyMax resulted in four main sediment groups, with groups 2 and 3 being further divided into smaller sub-groups (Table 3). In 2017, two stations represented the coarser, slightly gravelly sand group 1a; these are located at the south-eastern edge of Shell Flat (Figure 6). Eleven stations characterise the slightly gravelly sand group 2b; these are found sporadically across the whole of Shell Flat except for the northern region where sediments of slightly gravelly, muddy sand (group 3a) dominate. Group 3b is found along the southern and western edge of Shell Flat and 3c is found spradically across the area. The contrasting muddy station observed towards the western limit of Shell Flat is categorised as group 4a, or slightly gravelly sandy mud.

Table 3. Sediment Entropy groups using EntropyMax based on the PSD from samples taken at the Shell Flat and Lune Deep SAC in 2017 (© Natural England and Cefas 2022). Average proportion of gravel, sand and silt/clay is given for each group.

Sediment group	Sample no.	Sample type	Sediment description	Gravel (%)	Sand (%)	Silt/clay (%)
1a	2	Unimodal, Moderately Well Sorted	Slightly Gravelly Sand	4.36	94.83	0.81
2a	0	Polymodal, Very Poorly Sorted	Sandy Gravel	48.28	50.43	1.29
2b	11	Unimodal, Moderately Well Sorted	Slightly Gravelly Sand	0.47	96.63	2.90
3a	15	Unimodal, Moderately Sorted	Slightly Gravelly Muddy Sand	0.08	86.11	13.81
3b	5	Unimodal, Poorly Sorted	Slightly Gravelly Muddy Sand	2.96	74.08	22.96
3c	3	Bimodal, Poorly Sorted	Slightly Gravelly Muddy Sand	0.13	60.75	39.13
4a	1	Bimodal, Very Poorly Sorted	Slightly Gravelly Sandy Mud	2.36	16.91	80.73

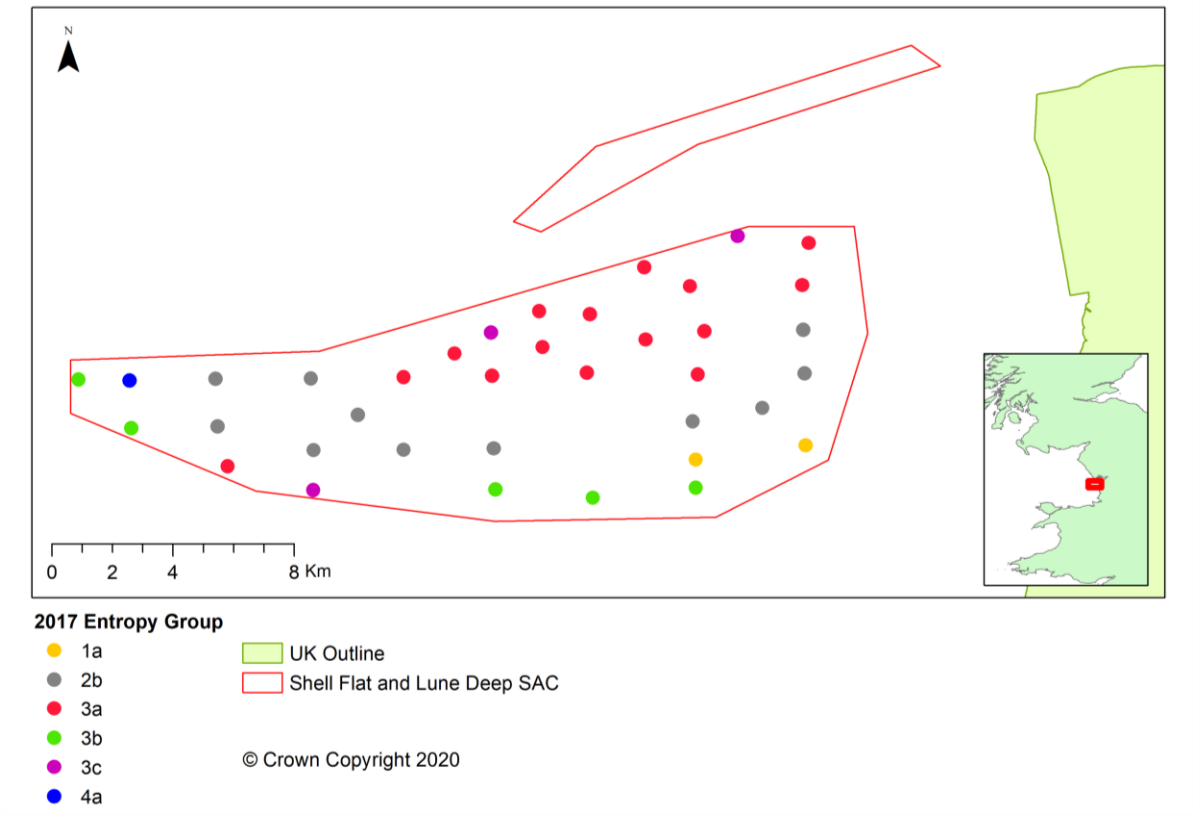

Figure 6. Spatial distribution of 37 stations sampled in 2017 across Shell Flat showing the Entropy groups classified based on their sediment PSD. Entropy groups were derived by EntropyMax based on all sediment PSD from samples acquired during 2012 and 2017.

3.1.2 Infaunal assemblages of Shell Flat

3.1.2.1 Assemblage cluster groups across Shell Flat

The SIMPROF routine during the clustering process of the infaunal data revealed the existence of seven statistically distinct assemblages; the relationship between infaunal cluster groups and subfeature membership is displayed in Figure 7. With a stress value of 0.16, Figure 7 should only be used for general trends, not for detailed analysis of the plot. The two samples from ‘A5.4 Subtidal mixed sediments’ and one sample from ‘A5.3 Subtidal mud’ form cluster ‘a’ and cluster ‘b’ is represented by two samples from ‘A5.3 Subtidal mud’ and one from ‘A5.2 Subtidal sand’. These two infaunal cluster groups are more dissimilar from the remaining cluster groups ‘c’, ‘d’, ‘e’ and ‘f’ (Figure 8). These latter four groups show relatively large similarity (Figure 8), with the results of the SIMPER analysis (

Table 4) revealing that they share co-dominance by the bivalves *Nucula nitidosa* and *Fabulina fabula* and the cumacean *Pseudocuma longicornis*, amongst others. Given the commonality of the discriminating taxa for cluster groups 'c', 'd', 'e' and 'f', it may be postulated that although significantly different, these groups may be regarded as a single assemblage with subtle numerical differences in the dominant taxa. The dissimilarity of infaunal clusters 'a' and 'b' mainly results from the increased abundance of the bivalve *Kurtiella bidentata*, particularly in cluster 'a' where the average number of individuals of this bivalve species is 279 per grab.

The assemblages of 'A5.2 Subtidal sand' and 'A5.3 Subtidal mud' also show a large structural overlap, although the test indicated significance (ANOSIM R = 0.24, p = 0.034), supporting the notion that they may be regarded as largely comparable (Figure 7). Two samples are not sufficient to acurately characterise the infaunal assemblages of 'A5.4 Subtidal mixed sediments' which precludes this habitat from statistical testing. However, Figure 7 indicates that the presence of 'A5.4 Subtidal mixed sediments' would be associated with an altered assemblage structure.

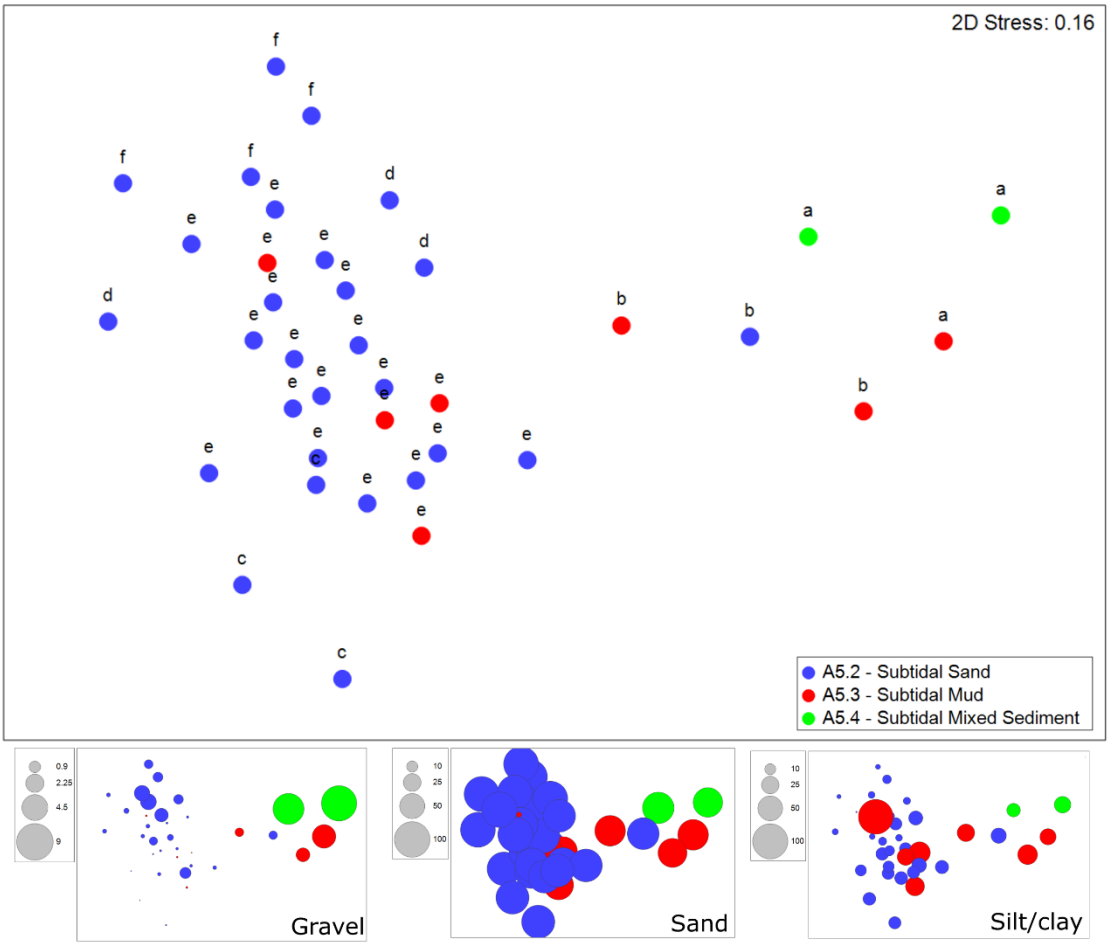

Figure 7. Non-metric 2D Multidimensional scaling (nMDS) plot of 2017 Shell Flat data with subfeatures and SIMPROF clusters (letters 'a' to 'f') based on Bray-Curtis similarity matrix of log(n+1) transformed abundance data (© Natural England and Cefas 2022). Bubble plots of

sediment category percentages of each station in the nMDS are placed at the bottom of the figure.

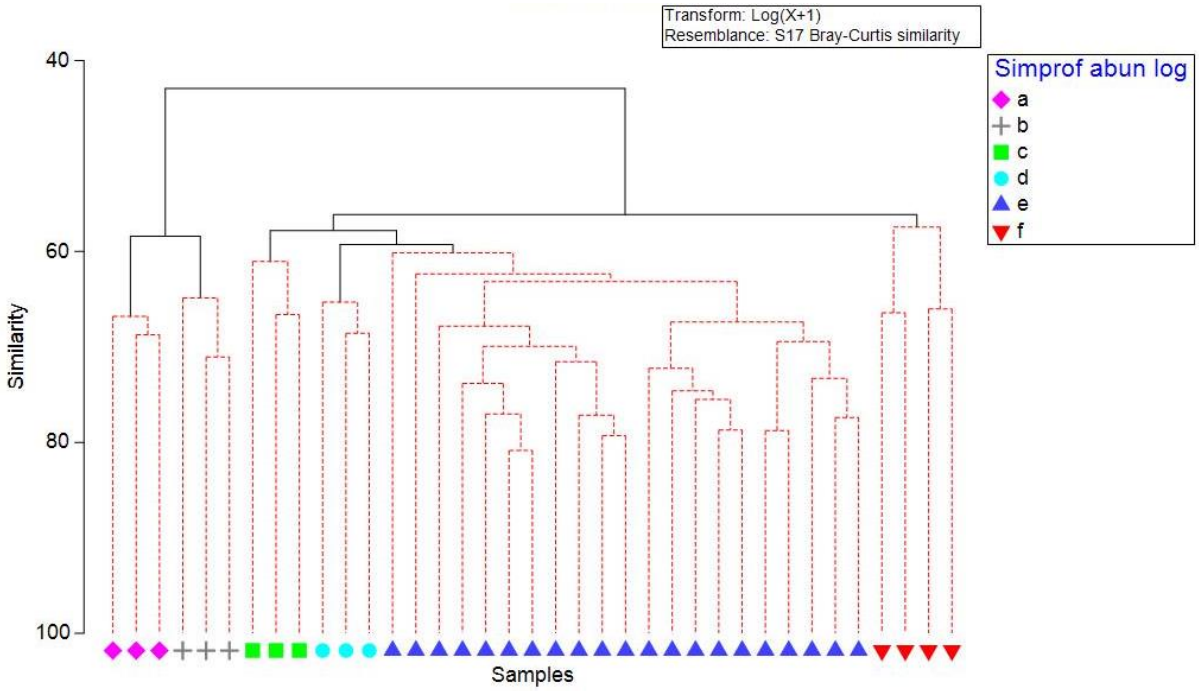

Figure 8. Dendrogram of infaunal assemblages of the 37 samples from Shell Flat from the 2017 survey. Samples are grouped according to infaunal clusters defined by SIMPROF routine (10%) on PRIMER v7 (© Natural England and Cefas 2022). Dendrogram produced based on hierarchical agglomerative clustering using group average linking.

Table 4. The main characterising taxa of the six macrofaunal cluster groups derived by the SIMPROF routine in PRIMER v7 (© Natural England and Cefas 2022). The number of stations of each EUNIS BSH within each cluster group is also given.

Cluster	EUNIS code	Within-group similarity	Main taxa	Average abundance	Percent contribution to similarity	Cumulative percent contribution
a	A5.3 (n=1)	67.44%	*Kurtiella bidentata*	279.00	14.52	14.52
			Nucula nitidosa	37.00	9.14	23.66
	A5.4 (n=2)		*Lagis koreni*	31.33	7.97	31.63
			Pholoe baltica	29.67	7.74	39.37
			Nemertea	10.00	5.88	45.25
b	A5.2 (n=1)	66.94%	*Kurtiella bidentata*	67.67	11.72	11.72
			Nucula nitidosa	57.67	10.98	22.70
	A5.3 (n=2)		*Pseudocuma longicornis*	11.33	7.08	29.78
			Abra alba	14.33	6.95	36.74
			Corbula gibba	14.67	6.03	42.77
c	A5.2 (n=3)	62.91%	*Nucula nitidosa*	18.67	16.50	16.50
			Pseudocuma longicornis	10.00	15.11	31.61
			Glycera tridactyla	7.33	12.97	44.58
			Magelona johnstoni	6.33	11.32	55.90
			Magelona filiformis	6.00	8.97	64.87
d	A5.2 (n=3)	66.39%	*Nucula nitidosa*	88.00	19.92	19.92
			Fabulina fabula	52.33	16.71	36.63
			Pseudocuma longicornis	49.67	16.15	52.78
			Perioculodes longimanus	5.67	7.84	60.62
			Magelona filiformis	3.67	4.99	65.61
e	A5.2 (n=17)	65.63%	*Nucula nitidosa*	31.76	14.58	14.58
			Fabulina fabula	32.95	13.41	27.99
	A5.3 (n=4)		*Magelona filiformis*	13.62	11.10	39.09
			Pseudocuma longicornis	12.62	10.06	49.15
			Magelona johnstoni	9.10	9.90	59.05
f	A5.2 (n=4)	60.37%	*Fabulina fabula*	54.50	21.64	21.64
			Nucula nitidosa	64.25	18.96	40.60
			Magelona johnstoni	12.25	12.17	52.78
			Nemertea	10.25	11.84	64.62
			Mytilus edulis	10.75	5.28	69.90

The geographical locations of the stations of the seven cluster groups reveal that the southern flank of Shell Flat is characterised by the two more faunistically-distinct groups ‘a’ and ‘b’. The locations of the remaining five infaunal cluster groups do not share any particular characteristics, and stations belonging to each are generally interspersed across the remainder of the site (Figure 9).

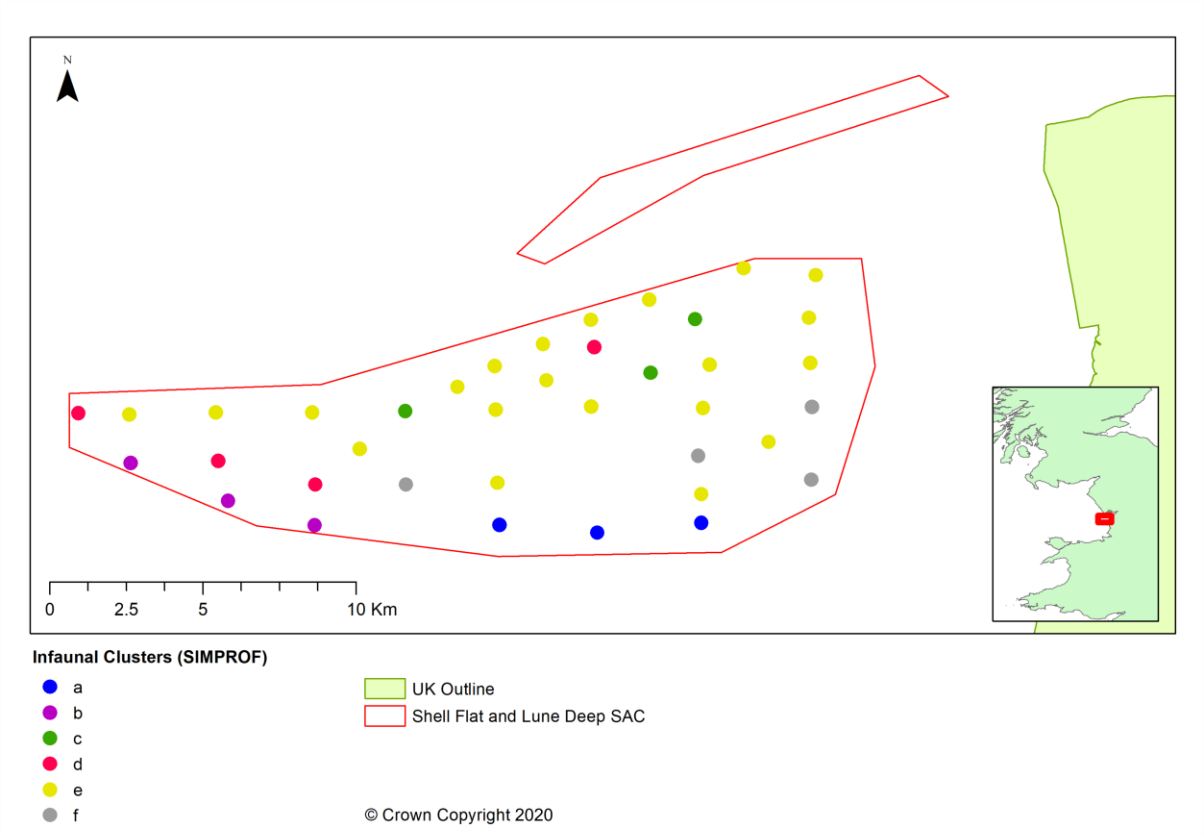

Figure 9. Map of the 37 stations sampled inside Shell Flat in 2017 categorised according to their infaunal assemblage cluster group (see text).

Infaunal assemblage structure is related to sediment Entropy group (**Error! Reference source not found.**), particularly the main groups 1-4, as opposed to the sediment subgroups. While all samples belonging to infaunal clusters ‘a’, ‘b’ and ‘c’ belong to Entropy group 3 (i.e. 3a, 3b and 3c, classified as slightly gravelly muddy sand), those of infaunal cluster group ‘f’ belong to Entropy group 1a (slightly gravelly sand) or 2b (sandy gravel). With a stress value of 0.16, Figure 10 should only be used for general trends, not for detailed analysis of the plot. The widely occurring assemblages of clusters ‘d’ and ‘e’ however are found to be associated with a range of Entropy groups.

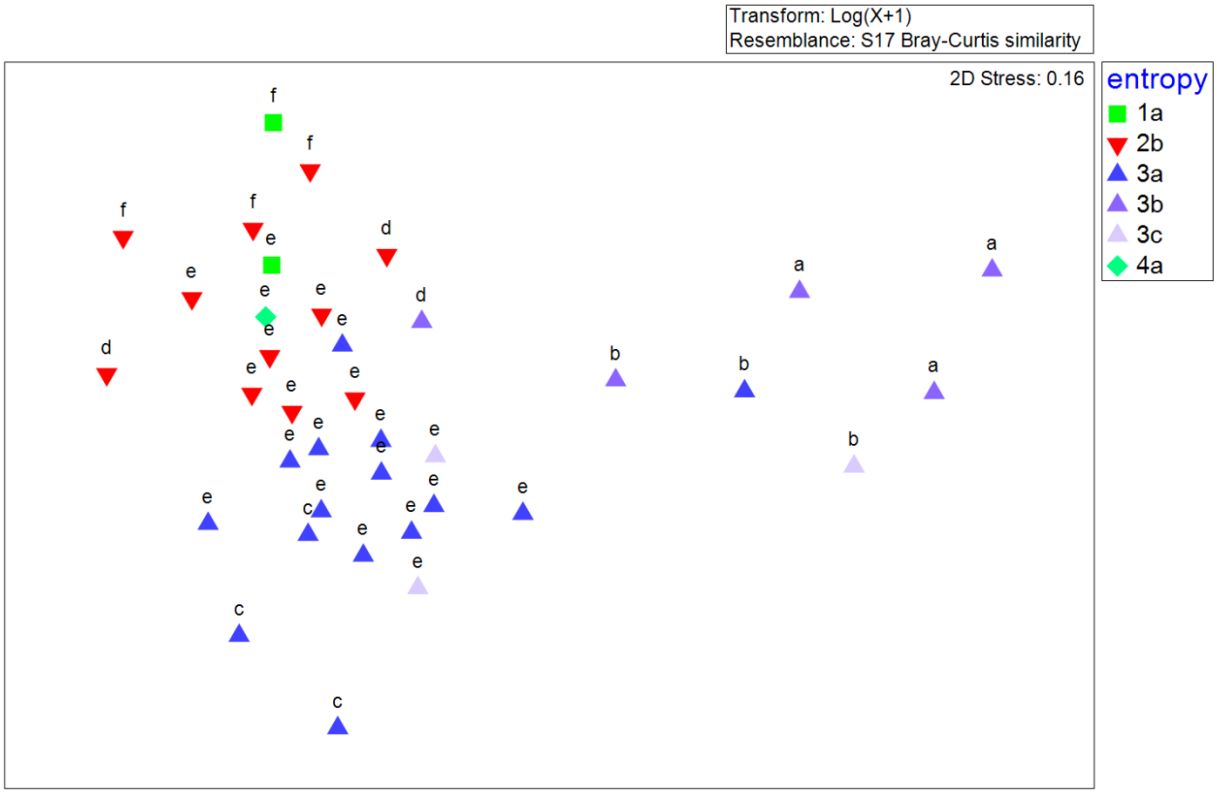

Figure 10. Non-metric 2D Multidimensional scaling (nMDS) plot of 2017 Shell Flat infaunal data with Entropy groups (symbols) and SIMPROF clusters (letters, p < 0.05) based on Bray-Curtis similarity matrix of log($_{x+1}$) transformed abundance data (© Natural England and Cefas 2022).

The BEST analysis in PRIMER revealed that 53% of the variability in infaunal assemblage structure across the full dataset could be explained by variability in gravel and sand content, in addition to water depth (Table 5). The single variable explaining most variability of infaunal assemblage structure was gravel content (42%).

Table 5. Results of BIO-ENV analysis (PRIMER v7) relating the sediment particle size distribution data, water depth and grab sample volume with infaunal assemblage structure (© Natural England and Cefas 2022).

No. of Variables	Rho	Variables				
1	0.42	Gravel				
2	0.50	Gravel	Water depth			
3	0.53	Gravel	Water depth	Sand		
4	0.52	Gravel	Water depth	Sand	Grab volume	
5	0.50	Gravel	Water depth	Sand	Grab volume	Silt/Clay

To summarise, the infaunal assemblages of Shell Flat sampled in 2017 show a large amount of commonality, with subtle differences being observed in the relative dominance of a small number of taxa. Of this, greater numerical dominance is shown by *K. bidentata* across the southern flank of the sandbank, corresponding to the two stations categorised as 'A5.4 Subtidal mixed sediments' and three of the seven

'A5.3 Subtidal mud' stations. Variability of infaunal structure is partially driven by sediment composition, a relationship which is evident when sediments are categorised by both subfeature type and Entropy group.

3.1.2.2 Secondary production

With respect to functional variability, total secondary production estimates varied between 12.2 kJ m^{-2} y^{-1} towards the north-western boundary of Shell Flat and 203 kJ m^{-2} y^{-1} along the southern boundary (Figure 11). The stations along the southern edge of the site, i.e. those belonging to infaunal clusters 'a' and 'b' with high numbers of *K. bidentata*, generally displayed higher secondary production estimates than those elsewhere within the site. Total production was predominantly comprised of annelids and molluscs, although it is notable that echinoderms (comprising Asteroidae, Ophiuroidae and Echinoidae) contributed disproportionate amounts to total production at a number of stations, particularly along the southern boundary and at the central stations (Figure 12).

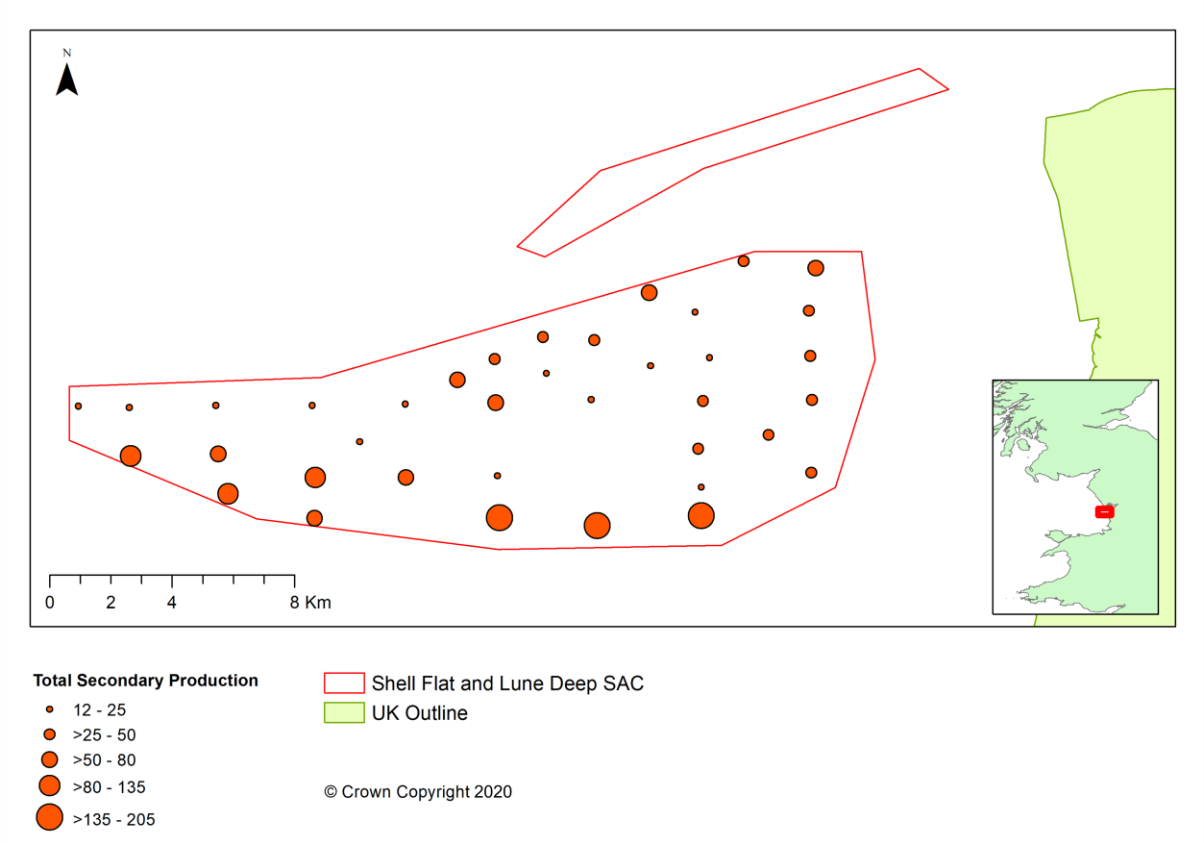

Figure 11. Total secondary production estimates (kJ m^{-2} y^{-1}) of the infaunal assemblages sampled at the 37 stations inside Shell Flat during 2017.

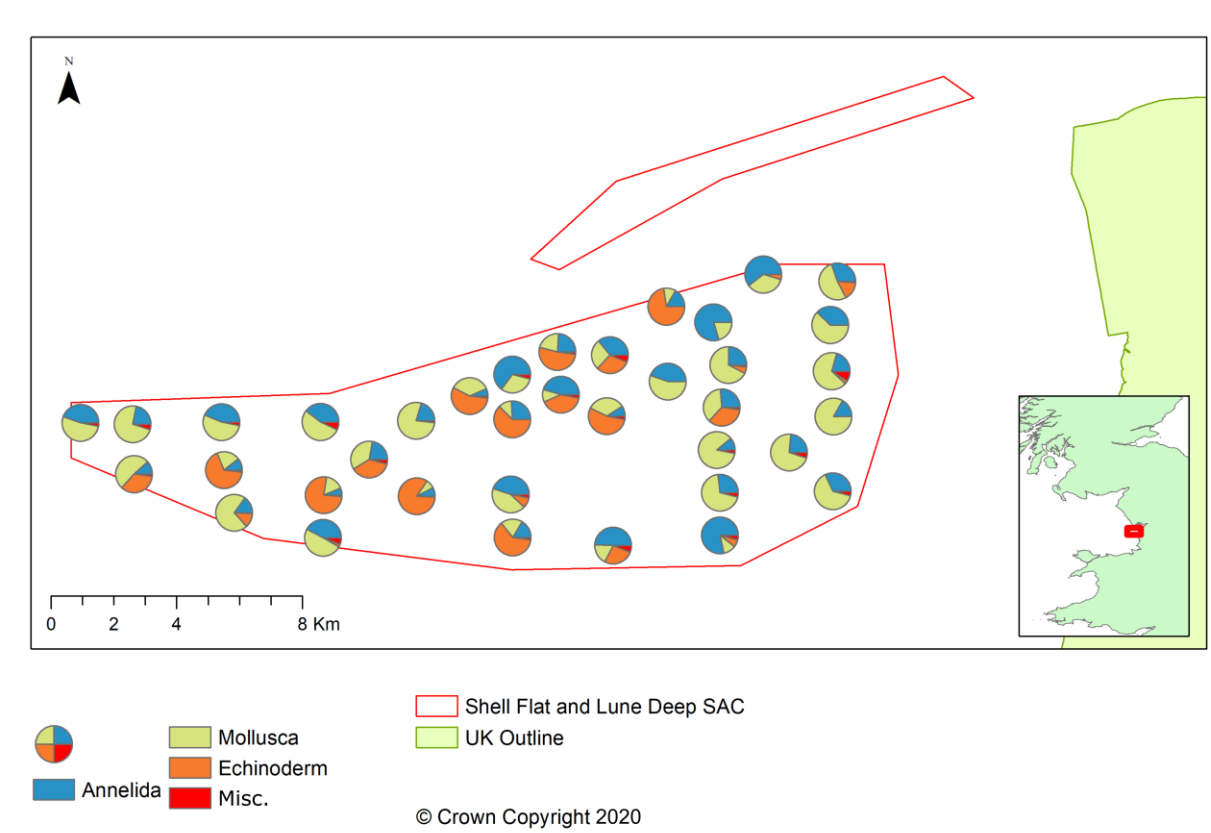

Figure 12. Proportional contribution to estimated total production of the main taxonomic phyla for the infaunal assemblages sampled within Shell Flat during 2017. Misc = pooled Arthropoda, Cnidaria, Platyhelminthes, Nematoda and Phoronida.

3.1.2.2 Infaunal assemblages categorised by subfeature

An overview of the infaunal assemblages of the three subfeatures ‘A5.2 Subtidal sand’, ‘A5.3 Subtidal mud’ and ‘A5.4 Subtidal mixed sediments’ is given in Table 6. As only two samples represented the latter subfeature, some caution must be practiced when using the acquired data as the basis for assessing subsequent changes in its health and status.

Table 6.Summary table of multivariate and univariate parameters per subfeature in 2017 (© Natural England and Cefas 2022). Within-group similarity and characterising taxa from SIMPER routine in PRIMER v7: Abun. = average abundance, Cum% = cumulative contribution. Secondary productivity in kJ m^{-2} y^{-1}. Univariate metrics S = total species 0.1 m^{-2}, N = total individuals 0.1 m^{-2}, d = Margalef index, H' = Shannon Index.

A5.2 Subtidal sand					**A5.3 Subtidal mud**					**A5.4 Subtidal mixed sediments**				
n = 28					**n =** 7					**n =** 2				
Entropy groups: 1a, 2b, 3a, 3b					**Entropy groups:** 3a, 3b, 3c, 4a					**Entropy groups:** 3b				
Within-group similarity: 59.8%					**Within-group similarity:** 55.1%					**Within-group similarity:** 67.2%				
Taxon		**Abund.**	**Cum%**		**Taxon**		**Abund.**	**Cum%**		**Taxon**		**Abund.**	**Cum%**	
Nucula nitidosa		44.1	17.6		*Nucula nitidosa*		29.4	11.7		*Kurtiella bidentata*		257.0	13.5	
Fabulina fabula		34.6	30.7		*Pseudocuma longicornis*		16.1	22.3		*Nucula nitidosa*		43.5	23.0	
Pseudocuma longicornis		14.7	41.0		*Kurtiella bidentata*		71.3	32.3		*Pholoe baltica*		37.0	30.7	
Magelona johnstoni		8.4	50.9		*Mytilus edulis*		16.1	41.2		*Lagis koreni*		19.0	38.1	
Magelona filiformis		9.2	60.5		*Magelona filiformis*		13.6	50.0		Nemertea		12.0	44.8	
SIMPROF clusters: b, c, d, e, f					**SIMPROF clusters:** a, b, e					**SIMPROF clusters:** a				
		mean	**min**	**max**			**mean**	**min**	**max**			**mean**	**min**	**max**
Secondary productivity		37.1	12.2	105.6	**Secondary productivity**		71.3	18.6	187.5	**Secondary productivity**		169.6	135.2	203.9
	S	**N**	**d**	**H'**		**S**	**N**	**d**	**H'**		**S**	**N**	**d**	**H'**
mean	19.0	157.1	3.6	2.1	**mean**	25.4	230.0	4.5	2.2	**mean**	36.0	456.5	5.8	1.9
min	12.0	49.0	2.2	1.6	**min**	15.0	102.0	3.0	1.6	**min**	35.0	340.0	5.7	1.6
max	33.0	259.0	5.8	2.6	**max**	36.0	508.0	6.3	2.4	**max**	37.0	573.0	5.8	2.3

3.2 Biotopes

Objective 2: Assign biotopes (where possible) to the infaunal communities inside and outside the site, based on 2017 data.

The infaunal assemblages of all 37 stations sampled inside the Shell Flat boundary were numerically dominated by bivalve molluscs, with SIMPROF cluster groups generally being characterised, and distinguished from others, by different bivalve taxa (i.e. *K. bidentata*, *N. nitidosa*, *F. fabula*;

Table 4). As such, and as the sediments of these stations are predominantly sandy with small but varying proportions of mud and/or gravel (Figure 5), all 37 stations were found to be comparable to the biotope '*Abra alba* and *Nucula nitidosa* in circalittoral muddy sand or slightly mixed sediment' (SS.SSa.CMuSa.AalbNuc), with *F. fabula* substituting *A. alba* as the numerical dominant. The biotope '*Fabulina fabula* and *Magelona mirabilis* with venerid bivalves and amphipods in infralittoral compacted fine muddy sand' (SS.SSa.IMuSa.FfabMag) can also be considered a comparable biotope for these stations, as *M. filiformis* (as opposed to *M. mirabilis*) was also an abundant taxon across the site. The six stations assigned to SIMPROF infaunal clusters 'a' and 'b' could also be compared to the '*Mysella* [*Kurtiella*] *bidentata* and *Abra* spp. in infralittoral sandy mud' (SS.SMu.ISaMu.MysAbr) biotope.

3.3 Temporal comparison of infaunal assemblages

Objective 3*: Conduct a temporal comparison of sediment composition and infaunal assemblages, and specified univariate metrics, inside the SAC between 2012 and 2017*.

The August surveys conducted in 2012 and 2017 both sampled stations across Shell Flat for sediment and infaunal characterisation. Seventeen stations were sampled in both years; the data pertaining to these spatially coincident samples were analysed and the results presented in sub-section 3.3.1. Both the 2012 and the 2017 surveys contained additional spatially distinct stations within Shell Flat, three in 2012 and 20 in 2017. While these stations do not have spatial counterparts in the other year, these additional data were included for analysis in sub-section 3.3.2. The aim of the latter sub-section is to present a temporal comparison of infaunal assemblages between 2012 and 2017 based on a more spatially extensive dataset.

3.3.1 Temporal comparison for stations sampled in both years

Based on the observed PSD of the 17 stations sampled in both 2012 and 2017, five displayed a contrasting subfeature classification in 2017 compared to 2012. An nMDS based on assemblage composition shows that there has been a common shift in multivariate structure over this period (Figure 13), with stations progressing from the bottom to the top of the plot. With a stress value of 0.16, the MDS plot should only be used for general trends, not for detailed analysis of the plot. Of the five stations which displayed a temporal shift in subfeature (stations 05, 12, 13, 19, 29), three changes involved 'A5.2 Subtidal sand' and 'A5.3 Subtidal mud', while 'A5.1 Subtidal coarse sediment' was only observed in 2012 and 'A5.4 Subtidal mixed sediments' was only sampled in 2017. The magnitude of these changes needs to be borne in mind, as the PSD of these stations were generally located close to the Folk delineation between subfeatures (Figure 14). The single station classed as 'A5.1 Subtidal coarse sediment' (i.e. station code 5), for example, still comprises mostly (>85%) sand, while the sample representing 'A5.4 Subtidal mixed sediments' (i.e. station 19) is located very close to

the delineation for ‘A5.2 Subtidal sand’ (it’s designation in 2012) in the Folk triangle. Three of these five stations (i.e. stations 12, 19 and 29), however, exhibited a change in their Entropy group identity to a higher group number in 2017 signifying a shift towards coarser sediments (Table 3). As is the case for infaunal temporal comparisons (see Section 3.3.2), one must be cautious assessing temporal changes in PSD due to the large differences in grab volume between the two sampling years.

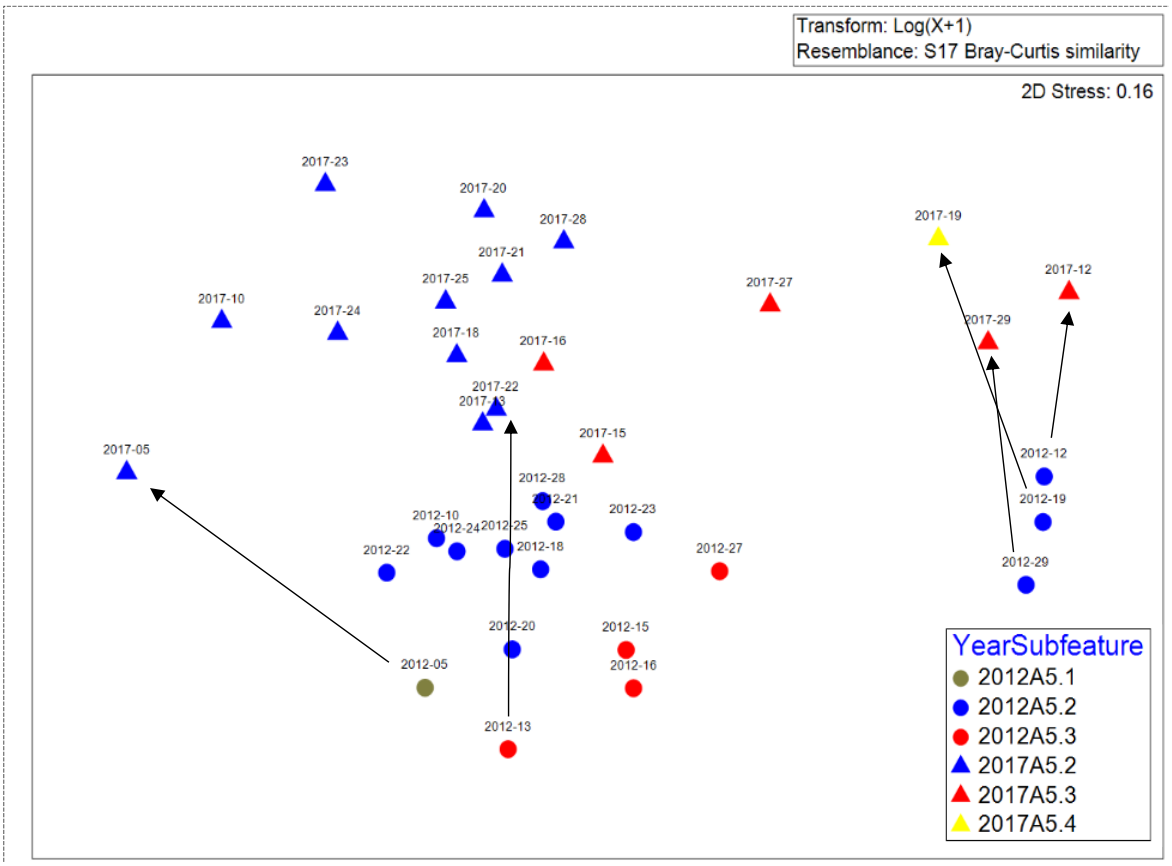

Figure 13. Non-metric 2D Multidimensional scaling (nMDS) plot of the infaunal assemblages sampled at the 17 stations which were sampled in both 2012 and 2017 (© Natural England and Cefas 2022). Stations are categorised according to their subfeature class based on their PSD. Station labels refer to year sampled and station code. Stations showing a change in subfeature class are identified by arrows.

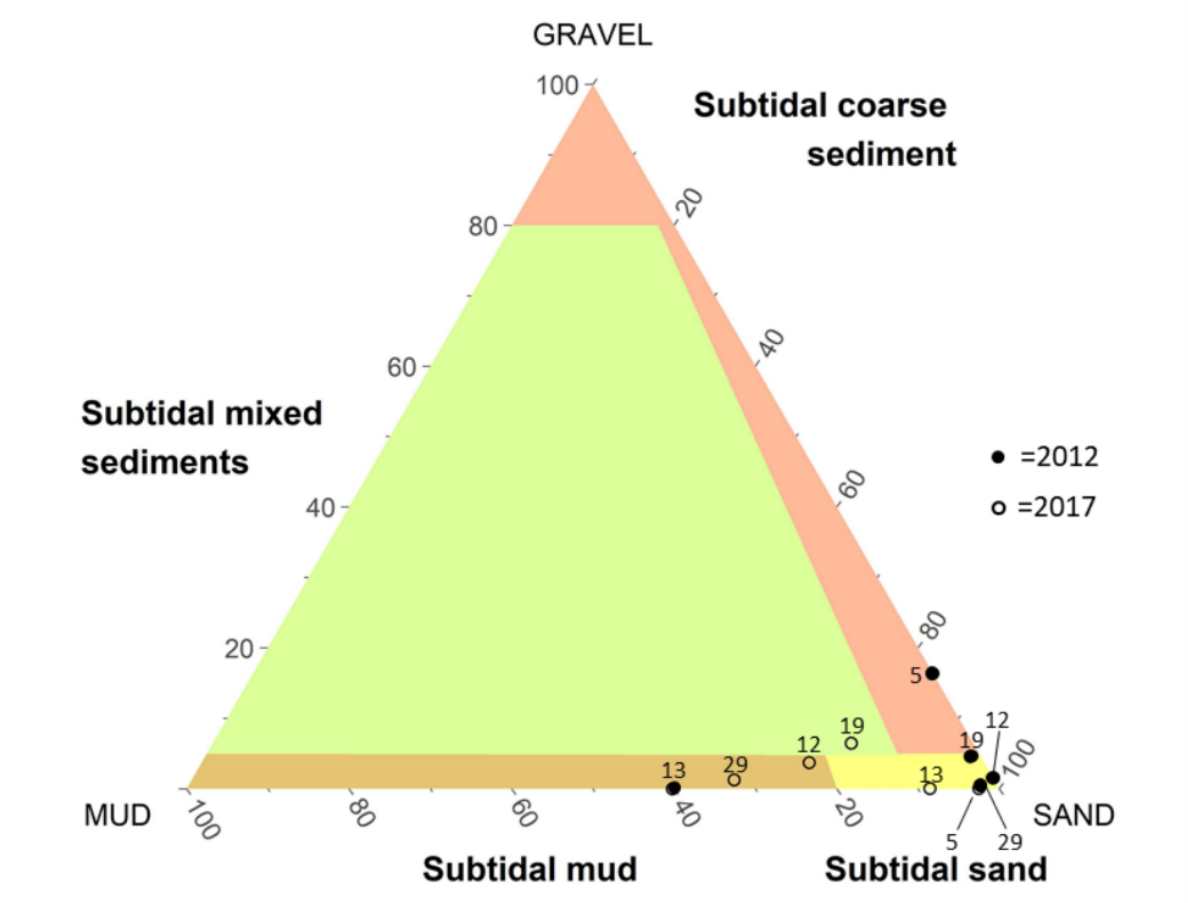

Figure 14. Folk triangle (Folk, 1954) of proportional composition of sediments of the five stations sampled in Shell Flat in 2012 (filled circles) and 2017 (open circles) which displayed a change in subfeature type between years. Numbers next to each symbol depicts station number (© Natural England and Cefas 2022).

There has been a marked decrease in the total number of individuals from 2012 to 2017 for both 'A5.2 Subtidal sand' and 'A5.3 Subtidal mud' (Figure 15). For 'A5.2 Subtidal sand', despite an increase in the density of tellinid bivalves, this overall decrease is primarily due to declines in the numbers of *M. edulis*, *M. filiformis* and ophiuroids (Table 7). While *K. bidentata* displayed increased abundances in 2017 in 'A5.3 Subtidal mud', the significant decline in total abundance reflects the combined outcome of the decreases in mactrid bivalves, in the cumacean *P. longicornis*, and, as was witnessed for 'A5.2 Subtidal sand', *M. edulis* and ophiuroids (amongst others). This density change in a number of taxa common to both subfeatures explains the harmonised temporal shift witnessed in Figure 13. Total number of species per grab declined for both subfeatures, and the Margalef index of diversity decreased for 'A5.3 Subtidal mud'. Shannon diversity remained consistent over the five-year period (Figure 15).

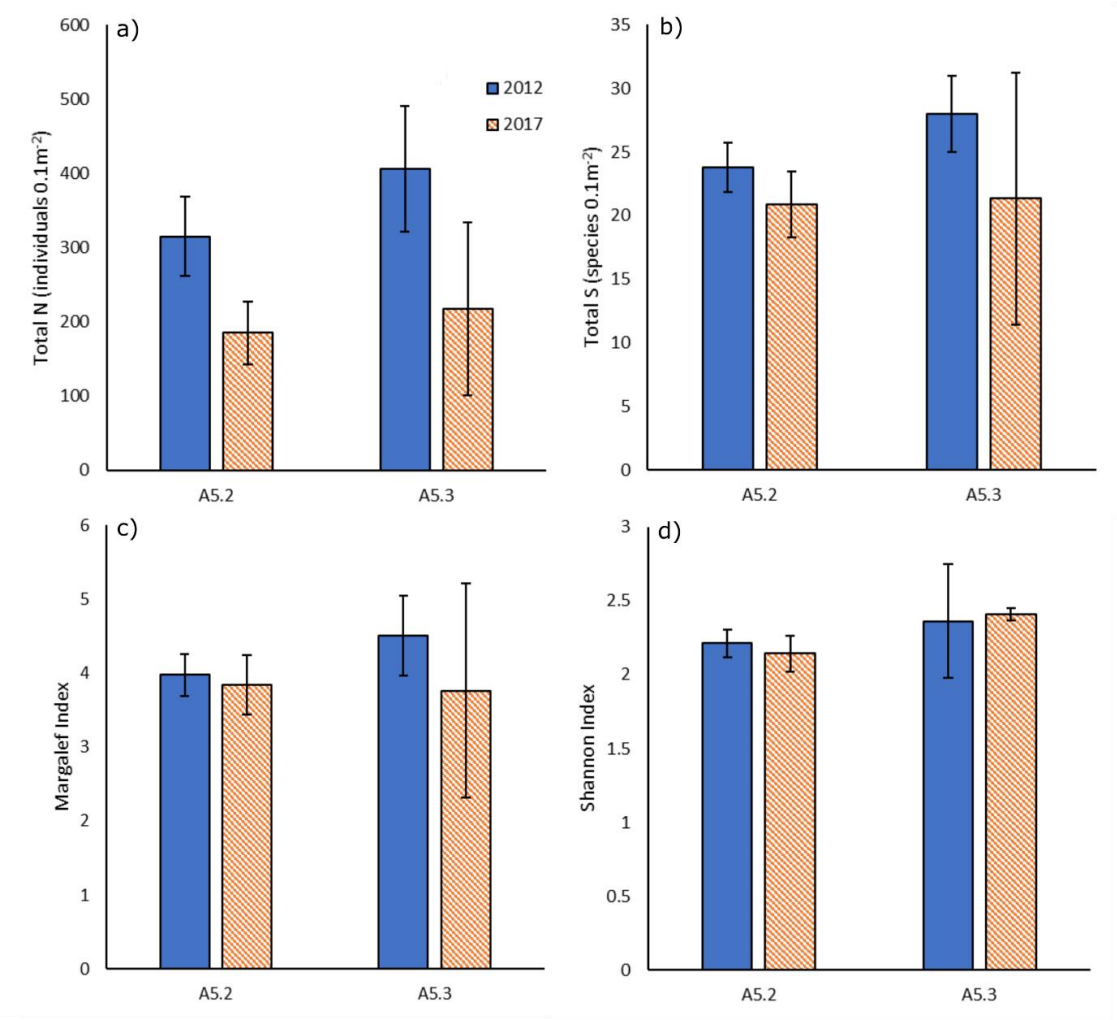

Figure 15. Univariate indices for infauna community abundance (means ± 95% CI) (© Natural England and Cefas 2022). Comparison of years for each subfeature based on stations sampled in both 2012 and 2017. Sample sizes for both 2012 and 2017: A5.2 n=9, A5.3 n=3.

Table 7. The main characterising taxa of the assemblages of the two EUNIS classes at Shell Flat (SIMPER routine on PRIMER v7) based on stations sampled in 2012 and 2017 (© Natural England and Cefas 2022). Data based on 12 stations where subfeature designation remained consistent between survey years. Average abundances colour coded green-yellow-red from low to high.

EUNIS code	Within-group dissimilarity	Main taxa	Average abundance 2012	Average abundance 2017	Contribution to dissimilarity (%)	Cumulative contribution (%)
A5.2 (n=9)	38.12%	*Mytilus edulis*	42.00	5.22	8.61	8.61
		Magelona filiformis	26.22	4.44	5.58	14.20
		Chaetozone christiei	4.44	0.00	4.97	19.17
		Kurtiella bidentata	0.22	4.56	4.56	23.72
		Ophiuroidea	12.44	4.22	4.36	28.08
		Donax vittatus	6.56	0.11	4.33	32.41
		Pharidae	5.33	0.78	4.16	36.58
		Thracioidea	0.33	3.00	3.37	39.94
		Tellinidae	23.56	43.89	3.21	43.16
		Magelona johnstoni	12.44	5.11	2.99	46.14
A5.3 (n=3)	38.10%	Mactridae	15.00	0.33	6.36	6.36
		Kurtiella bidentata	1.33	21.00	6.28	12.64
		Echinoidea	5.00	0.00	5.01	17.65
		Pharidae	20.00	3.67	4.20	21.85
		Pseudocuma longicornis	103.67	19.00	4.16	26.00
		Lagis koreni	6.67	1.00	4.05	30.05
		Donax vittatus	8.67	0.00	4.02	34.06
		Mytilus edulis	62.33	25.00	3.96	38.03
		Nucula nitidosa	51.33	35.33	3.30	41.33
		Ophiuroidea	26.67	8.33	3.25	44.58

3.3.2 Temporal comparison of infaunal assemblages using all stations in 2017

The nMDS plot of infaunal structure of all stations sampled in August in Shell Flat across both years (i.e. including the additional 20 stations in 2017) reveals a comparable result to that based only on the 17 spatially coincident stations (Figure 16). With a stress value of 0.19, the plot should only be used for general trends, not for detailed analysis of the plot. Based on the PSD, none of the additional stations were classed as ‘A5.1 Subtidal coarse sediment’, which indicates that this is subfeature is very restricted spatially. The additional stations provide further data regarding the infaunal assemblages of both ‘A5.2 Subtidal sand’ and ‘A5.3 Subtidal mud’. The

similarities between the taxa in Table 7 and Table 8, notably *M. edulis* and *M. filiformis* for 'A5.2 Subtidal sand' and Macritridae and *K. bidentata* for 'A5.3 Subtidal mud', provide further confirmation that these taxa are responsible for the temporal changes of the two subfeatures evidenced in Figure 16. The differences in univariate metrics of assemblage structure over time as seen in the stations sampled in both years (Figure 15) are further supported in the wider dataset (Figure 17).

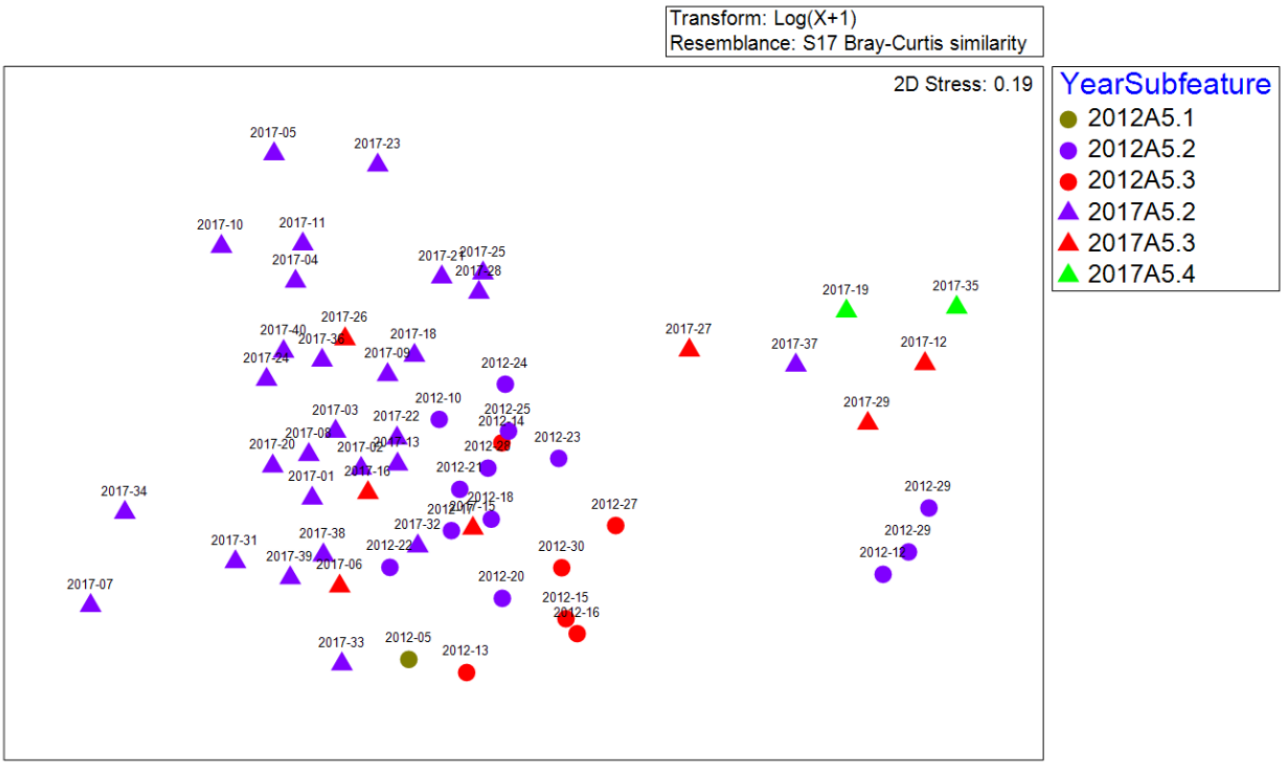

Figure 16. Non-metric 2D Multidimensional scaling (nMDS) plot of the macrofaunal assemblages sampled in 2012 and 2017 (© Natural England and Cefas 2022). Stations are categorised according to their EUNIS Broadscale Habitats.

Table 8. The main characterising taxa of the two subfeatures sampled at Shell Flat (SIMPER routine on PRIMER v7) (© Natural England and Cefas 2022). Average abundances per grab are presented for the data acquired during 2012 (n = 17) and 2017 (n = 37). Average abundances colour coded green-yellow-red from low to high.

EUNIS code	Within-group dissimilarity	Main taxa	Average abundance 2012	Average abundance 2017	Contribution to dissimilarity (%)	Cumulative contribution (%)
A5.2	42.6%	*Mytilus edulis*	34	7.4	5.3	5.3
		Kurtiella bidentata	9.6	8.4	4.9	10.2
		Ophiuroidea	12.2	2.8	4.7	14.8
		Pharidae	9.5	1.2	4.6	19.4
		Pseudocuma longicornis	27.4	14.7	4.2	23.6
		Tellinidae	18.7	34.6	4.1	27.7
		Lagis koreni	27.7	0.6	3.7	31.4
		Chaetozone christiei	3.4	0	3.6	35.1
		Abra spp.	19.8	7	3.5	38.6
		Magelona filiformis	19.5	9.2	3.9	42.0
A5.3	42.1%	*Kurtiella bidentata*	1.8	71.3	6.0	6.0
		Mytilus edulis	156.7	16.1	5.9	11.9
		Mactridae	10.5	0.7	4.6	16.5
		Pseudocuma longicornis	59.8	16.1	3.7	20.3
		Ophiuroidea	17.5	6.1	3.5	23.8
		Lagis koreni	4.7	10.1	3.5	27.3
		Pharidae	12.7	4.4	3.2	30.5
		Donax vittatus	5.5	0	3.1	33.5
		Nucula nitidosa	58.2	29.4	3.1	36.6
		Magelona johnstoni	11.8	5.3	2.8	39.4

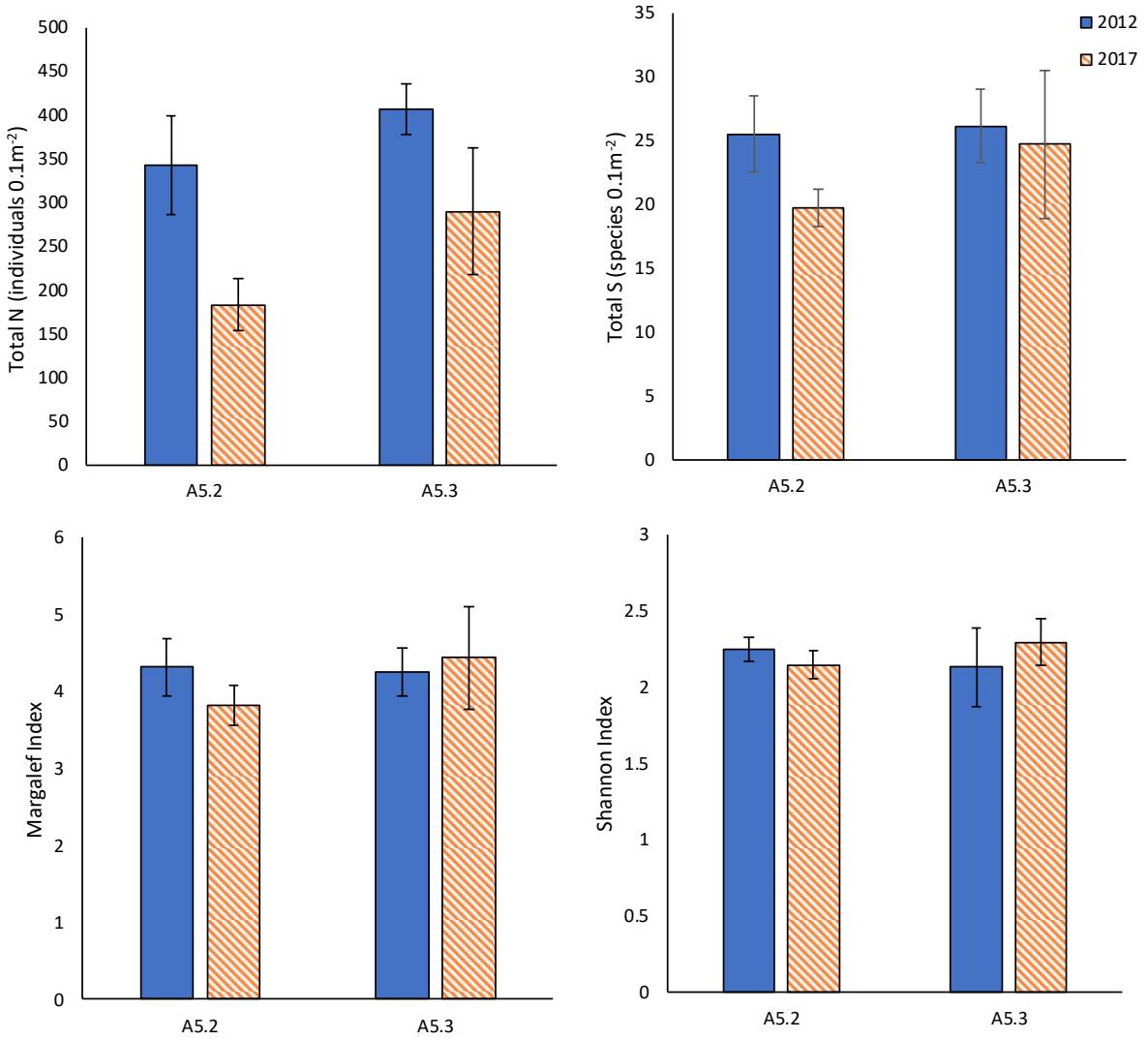

Figure 17. Univariate indices for infauna community abundance (means ± 95% CI) (© Natural England and Cefas 2022). Comparison of years for each subfeature (n = 17, n = 37 for 2012 and 2017 respectively).

3.4 Effects of Douglas Oil Spill

Objective 4: *Conduct a temporal comparison of contaminant levels inside the site between 2012 and 2017 and describe their relationships with those outside the site for 2017 data to explore signs of any impact of the 2017 Douglas Field oil spill*.

The sediment PAH concentrations for the six stations (all inside Shell Flat) sampled in 2012 and nine stations during 2017 (four inside Shell Flat, five outside) were assessed to explicitly address this objective. A spatial assessment of the 2017 PAH concentrations, specifically focusing on whether any differences in sediment PAHs exist within Shell Flat relative to outside, reveals that concentrations outside the site are slightly higher than those inside (Table 9). The mean concentrations of the five stations outside are higher than the means of the four inside for all low molecular weight (LMW) and high molecular weight (HMW) PAHs (Table 9). Maps of LMW,

HMW and total PAH concentrations support this observation (Figure 18 to Figure 20). However, it is important to highlight that all concentrations are low, and although the effects range low (ERL) background assessment concentration (BAC) for benzo(ghi)perylene is slightly exceeded at one station outside Shell Flat (SFLD54 with a concentration of 92.1 µg kg^{-1} dry weight (dw); ERL for benzo(ghi)perylene is 85 µg kg^{-1} dw), all other concentrations were well below their respective ERLs (Table 9).

The temporal comparison of sediment PAH concentrations between 2012 and 2017 is limited to data from within Shell Flat (data outside Shell Flat do not exist for 2012). The results (Table 10) reveal that, consistent with that for 2017, observed concentrations for 2012 were low relative to ERL and effects range median (ERM) values with all values markedly below their respective thresholds (Table 10). The mean of the concentrations sampled from the six stations in 2012 are, however, approximately twice those of the four stations sampled in Shell Flat during 2017. Concentrations of LMW PAHs, HMW PAHs and total PAH concentrations also appear elevated in 2012 relative to those in 2017 (Figure 21 to Figure 23).

Based on the somewhat spatially limited sediment PAH data for Shell Flat, therefore, it may be concluded that concentrations of all PAHs are low for this site, both inside and outside the Shell Flat boundary, and that no significant change is discernible between the 2012 and 2017 surveys. It follows that no evidence that contamination from the Douglas Field oil spill, which occurred shortly before the acquisition of the 2017 sediment samples, can be detected using the available data.

Table 9. Concentrations of PAHs (μg kg^{-1} dw) sampled at Shell Flat SAC during 2017 (© Natural England and Cefas 2022). Means and 95% CI values are presented for the stations inside the SAC (left; n = 4) and outside the site (right; n = 5). Summed low molecular weight (LMW) and high molecular weight (HMW) PAH concentrations are presented for each station. * denotes concentration exceeds the ERL. BAC refers to the background assessment concentration developed by OSPAR.

		Stations inside Shell Flat						Stations outside Shell Flat						BAC	
PAH	**MW**	**SFLD 09**	**SFLD 27**	**SFLD 35**	**SFLD 38**	**Mean**		**SFLD 41**	**SFLD 44**	**SFLD 52**	**SFLD 59**	**SFLD 54**	**Mean**	**ERL**	**ERM**
Anthracene	Low	<1.0	3.9	6.7	1.0	**3.2 ± 2.4**		18.2	5.1	15.7	3.5	19.7	**12.5 ± 6.6**	85.0	1100.0
Naphthalene	Low	<5.0	7.3	8.4	<5.0	**6.4 ± 1.5**		20.6	9.2	20.6	5.7	32.2	**17.7 ± 9.2**	160.0	2100.0
Phenanthrene	Low	<5.0	20.1	37.6	5.6	**17.1 ± 13.5**		71.1	25.6	76.0	13.2	80.8	**53.3 ± 27.6**	240.0	1500.0
	ΣLMW PAHs	**11.0**	**31.30**	**52.7**	**11.6**	**26.7 ± 17.3**		**109.9**	**39.9**	**112.3**	**22.4**	**132.7**	**83.5 ± 42.9**		
Benzo(a)anthracene	High	3.6	16.0	25.5	3.9	**12.2 ± 9.3**		72.9	23.0	55.6	12.4	69.5	**46.7 ± 24.1**	261.0	1600.0
Benzo(a)pyrene	High	5.4	21.1	29.2	5.5	**15.3 ± 10.4**		86.9	29.9	68.8	15.8	96.0	**59.5 ± 30.9**	430.0	1600.0
Benzo(ghi)perylene	High	5.6	19.4	24.3	5.9	**13.8 ± 8.3**		62.6	26.8	59.9	14.1	*92.1	**51.1 ± 27.2**	85.0	N/A
Chrysene + Triphenylene	High	4.7	21.4	30.0	5.4	**15.4 ± 10.9**		84.7	27.3	66.6	15.1	88.0	**56.3 ± 29.3**	384.0	2800.0
Fluoranthene	High	6.8	28.5	49.3	6.9	**22.9 ± 17.8**		120.0	36.7	112.0	21.7	128.0	**83.7 ± 44.1**	600.0	5100.0
Indeno(1,2,3-c,d)pyrene	High	5.8	20.2	25.9	6.2	**14.5 ± 8.9**		64.6	28.3	63.4	14.9	99.1	**54.1 ± 29.2**	240.0	N/A
Pyrene	High	6.6	27.9	44.4	6.7	**21.4 ± 16.1**		120.0	37.2	98.5	21.4	120.0	**79.4 ± 41.1**	665.0	2600.0
	ΣHMW PAHs	**38.5**	**154.5**	**228.6**	**40.5**	**115.5 ± 81.4**		**611.7**	**209.2**	**524.8**	**115.4**	**692.7**	**430.8 ± 222.9**		

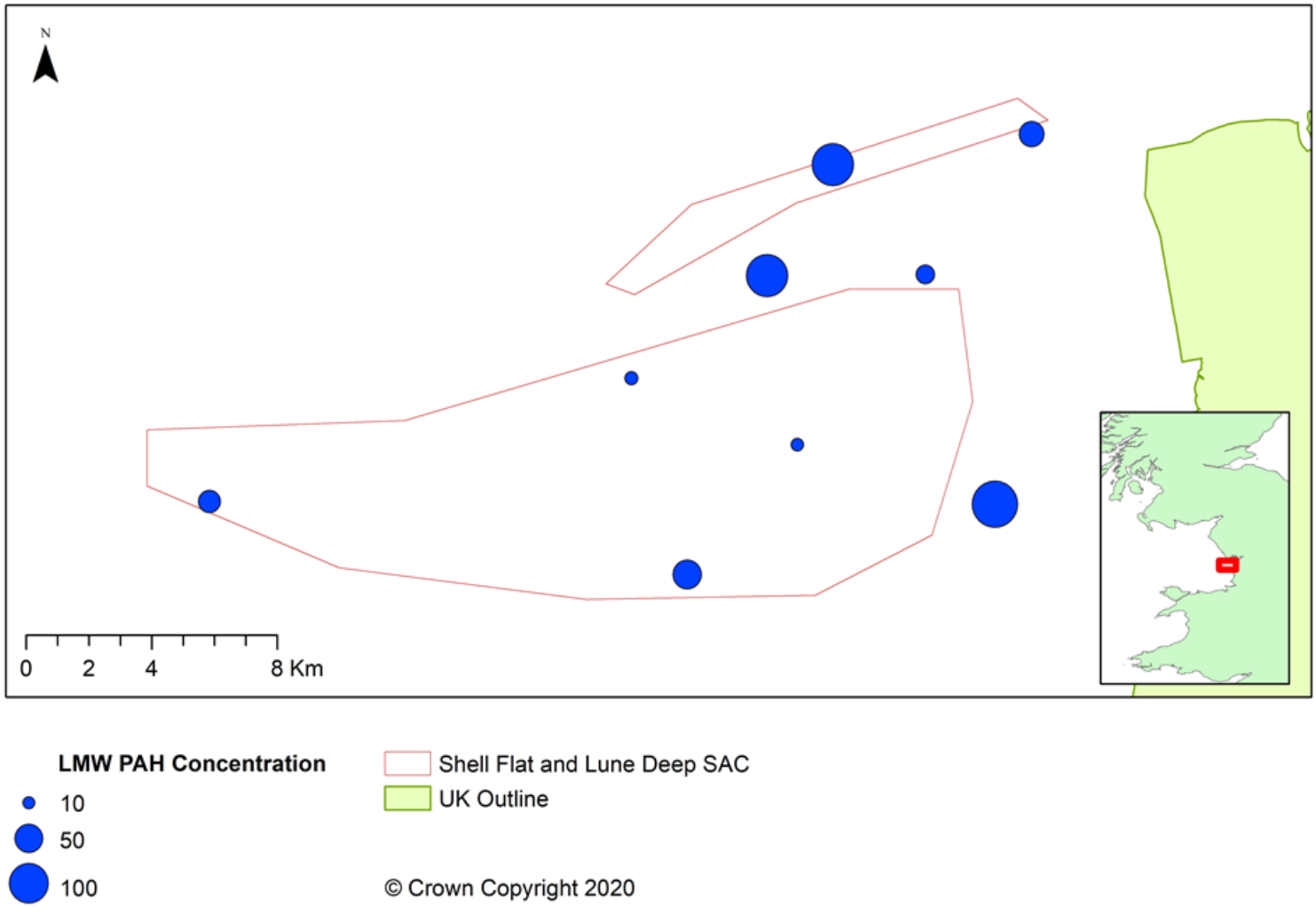

Figure 18. Summed low molecular weight PAHs in μg kg^{-1} dw of the sediments sampled in 2017.

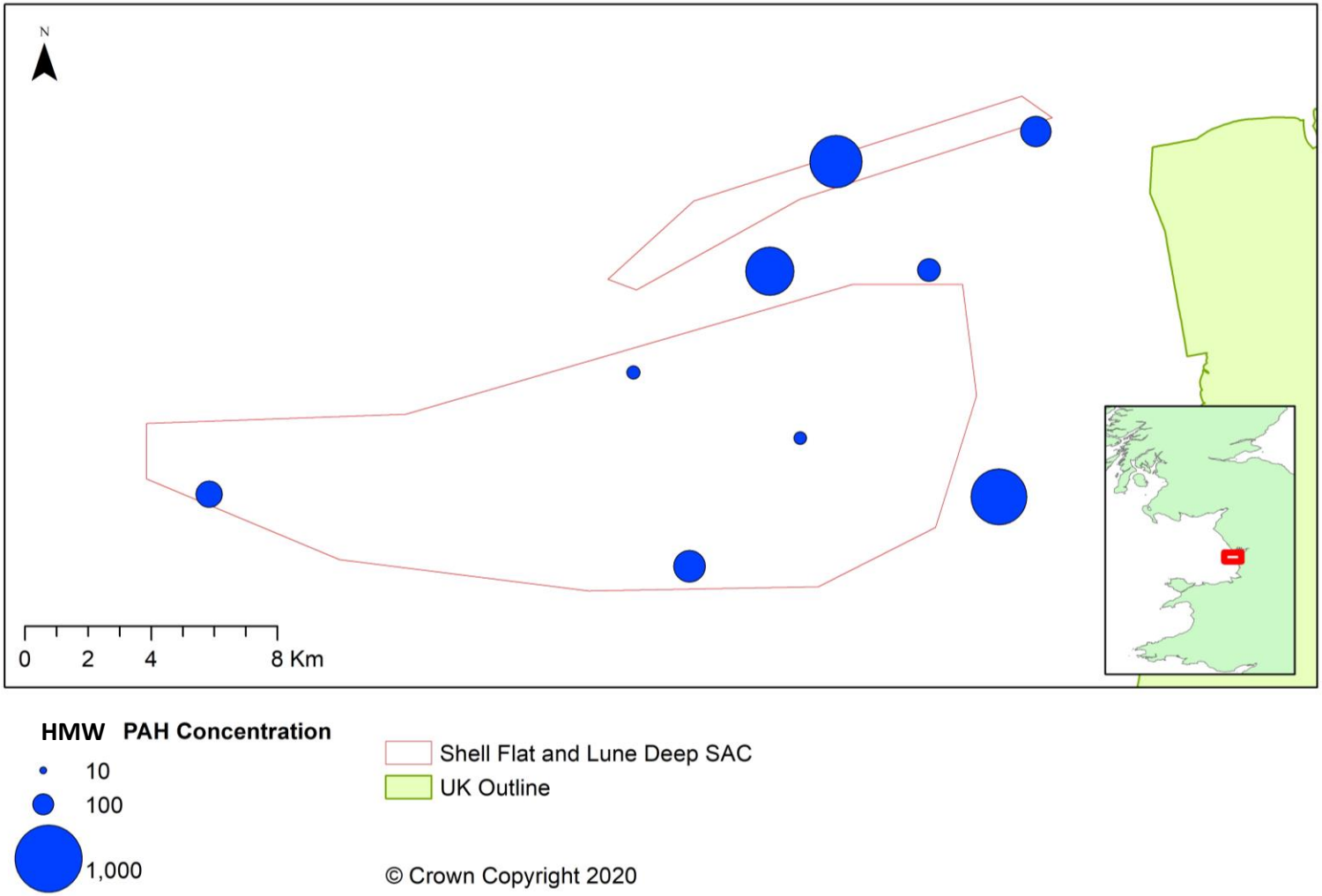

Figure 19. Summed high molecular weight PAHs in μg kg^{-1} dw of the sediments sampled in 2017.

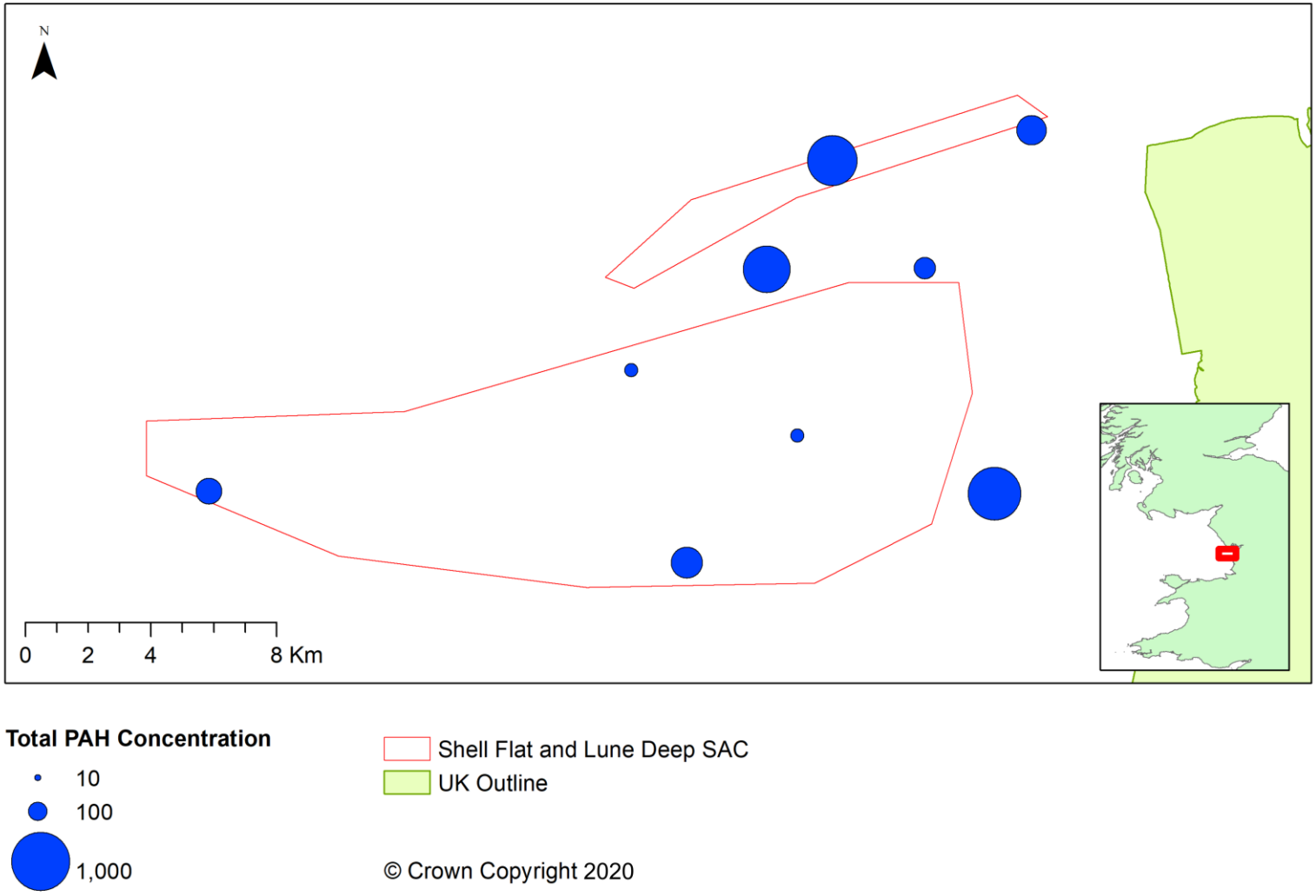

Figure 20. Total PAH concentrations in μg kg^{-1} dw of the sediments sampled in 2017.

Table 10. Concentrations of PAHs sampled at Shell Flat SAC (μg kg^{-1} dw) during 2012 (left; n = 6) and 2017 (right; n = 4) (© Natural England and Cefas 2022). Means and 95% CI values are presented, together with summed low molecular weight (LMW) and high molecular weight (HMW) PAH concentrations. BAC refers to the background assessment concentration developed by OSPAR.

		2012							2017						
PAH	**MW**	**SFNE 1**	**SFNE 5**	**SFNE 9**	**SFNE 15**	**SFNE 19**	**SFNE 27**	**Mean**	**SFLD 09**	**SFLD 27**	**SFLD 35**	**SFLD 38**	**Mean**	**ERL**	**ERM**
Anthracene	Low	5.9	2.6	3.9	10.9	21.6	9.1	**9.0 ± 5.5**	<1.0	3.9	6.7	1.0	**3.2 ± 2.7**	85.0	1100.0
Naphthalene	Low	<30.0	<30.0	<30.0	34.2	<30.0	<30.0	**30.7 ± 1.4**	<5.0	7.3	8.4	<5.0	**6.4 ± 1.7**	160.0	2100.0
Phenanthrene	Low	20.6	14.7	21.7	49.1	76.2	40.0	**37.1 ± 18.6**	<5.0	20.1	37.6	5.6	**17.1 ± 15.1**	240.0	1500.0
	ΣLMW PAHs	**56.5**	**47.3**	**55.6**	**94.2**	**127.8**	**79.1**	**76.8 ± 24.4**	**11.0**	**31.3**	**52.7**	**11.6**	**26.7 ± 19.4**		
Benzo(a)anthracene	High	17.0	9.17	15.4	37.8	52.4	30.5	**27.0 ± 13.0**	3.6	16.0	25.5	3.9	**12.2 ± 10.3**	261.0	1600.0
Benzo(a)pyrene	High	21.1	9.97	17.2	47.6	51.1	39.5	**31.1 ± 13.8**	5.4	21.1	29.2	5.5	**15.3 ± 11.6**	430.0	1600.0
Benzo(ghi)perylene	High	20.0	10.3	14.5	44.4	35.6	36.7	**26.9 ± 11.1**	5.6	19.4	24.3	5.9	**13.8 ± 9.3**	85.0	N/A
Chrysene + Triphenylene	High	18.7	10.4	15.9	42.4	49.0	33.9	**28.4 ± 12.5**	4.7	21.4	30	5.39	**15.4 ± 12.2**	384.0	2800.0
Fluoranthene	High	25.9	13.2	26.5	56.3	88.5	46.5	**42.8 ± 21.8**	6.8	28.5	49.3	6.9	**22.9 ± 19.9**	600.0	5100.0
Indeno(1,2,3-c,d)pyrene	High	19.7	<10.0	14.1	40.5	32.8	33.9	**25.2 ± 9.8**	5.8	20.2	25.9	6.2	**14.5 ± 9.9**	240.0	N/A
Pyrene	High	25.7	15.0	25.0	55.3	78.1	45.3	**40.7 ± 18.8**	6.6	27.9	44.4	6.7	**21.4 ± 17.9**	665.0	2600.0
	ΣHMW PAHs	**148.1**	**69**	**128.6**	**324.3**	**387.5**	**266.3**	**220.6 ± 99.6**		**38.47**	**154.5**	**228.6**	**40.54**	**115.5 ± 91.0**		

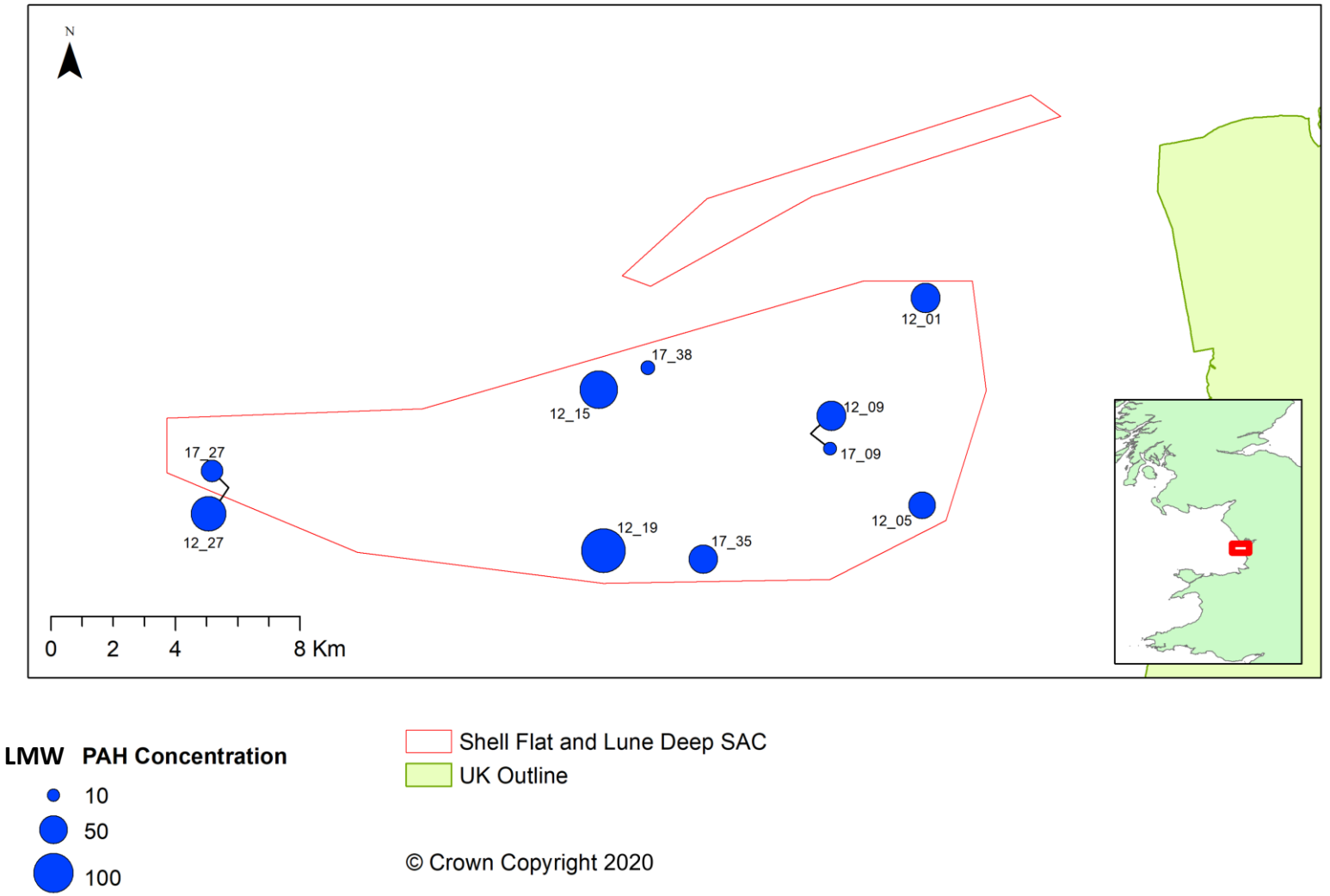

Figure 21. Summed low molecular weight PAHs in µg kg^{-1} dw of the sediments sampled at Shell Flat in 2012 and 2017.

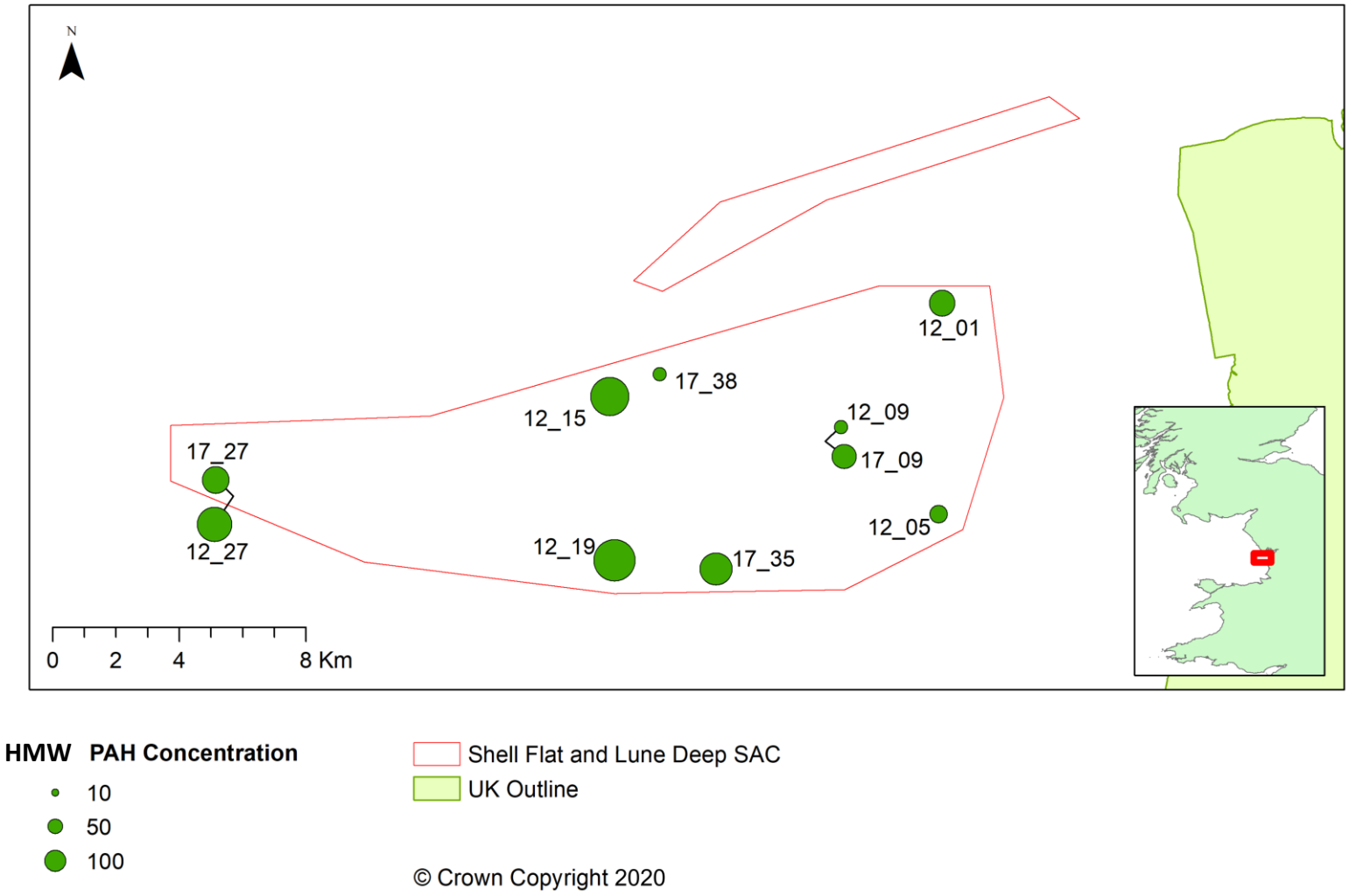

Figure 22. Summed high molecular weight PAHs in μg kg^{-1} dw of the sediments sampled at Shell Flat in 2012 and 2017.

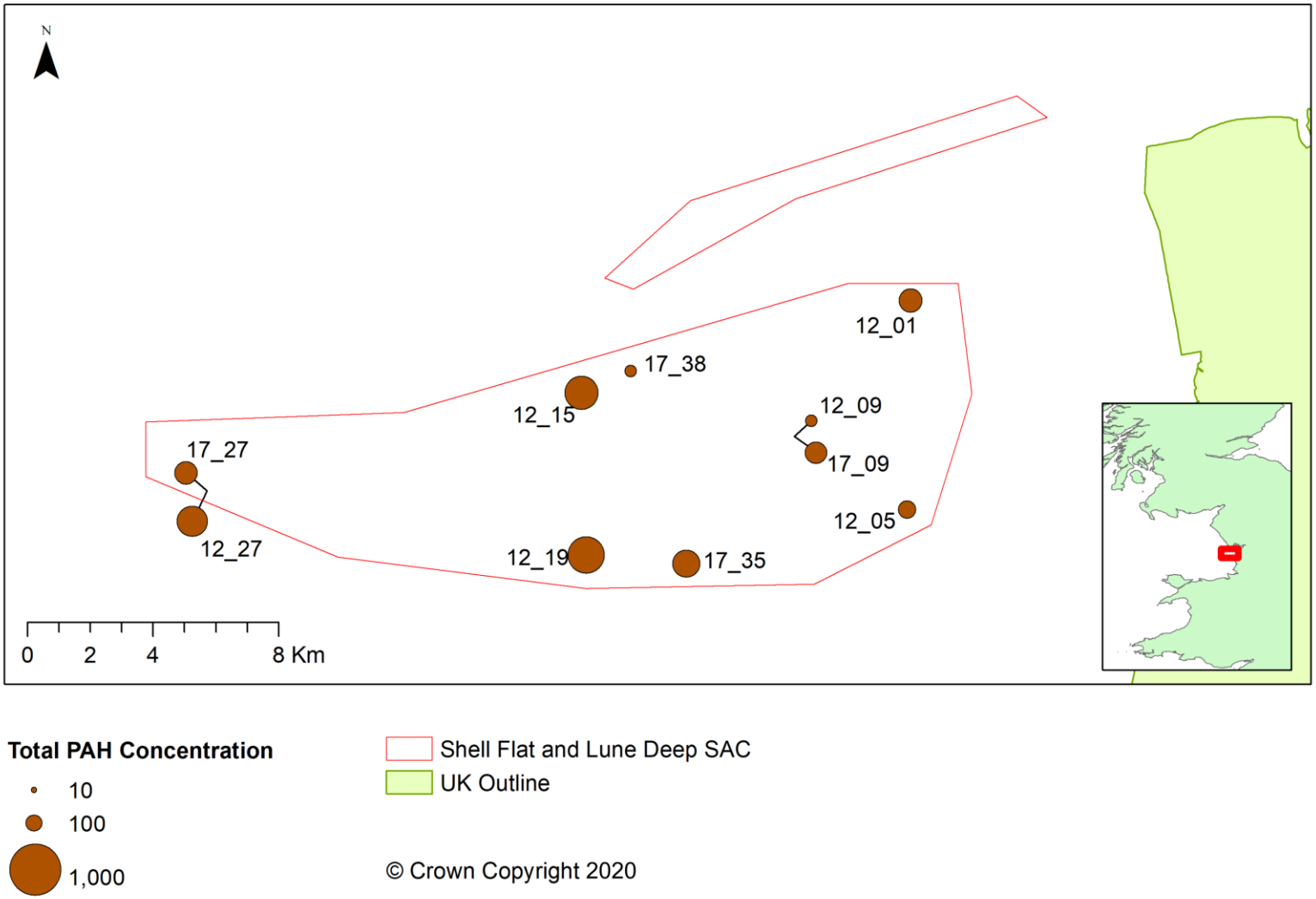

Figure 23. Total PAH concentrations of the sediments in μg kg^{-1} dw sampled at Shell Flat in 2012 and 2017.

3.5 Changes in food resources for Common scoter

Objective 5: *Compare abundance of and size class distributions of Common scoter food resource species between 2012 and 2017 inside and outside the site*.

3.5.1 Temporal comparison

To assess changes in the prey species of the Common scoter, the abundance and biomass of 11 taxa were analysed. Sampling in both 2012 and 2017 took place in August. The greatest sampled densities were generally displayed by the bivalves *N. nitidosa*, *F. fabula* and *A. alba* and the terebellid polychaete *L. koreni* (Figure 24a). *F. fabula* was the only prey taxon to show higher density in 2012. The other three taxa, together with other molluscs such as the venerid bivalve *Mactra stultorum* and razor clams of the Pharidae family, were sampled in greater densities in 2017. Mean total biomass showed marked spatial variability within each year with no observable difference between years for any taxon (Figure 24b). While the biomass of certain taxa such as *A. alba*, *Astropecten irregularis* and *M. stultorum* was higher in 2012, that of others including the bivalve *Chamelea striatula* and the echinoderms *Echinocardium cordatum* and *O. ophiura* was greater in 2017. Finally, evident differences in the mean biomass per individual were observed for some taxa between the two years. While individual biomass of *A. irregularis* was higher in 2012, that of *C. striatula* and *E. cordatum* was greater in 2017 (Figure 24c).

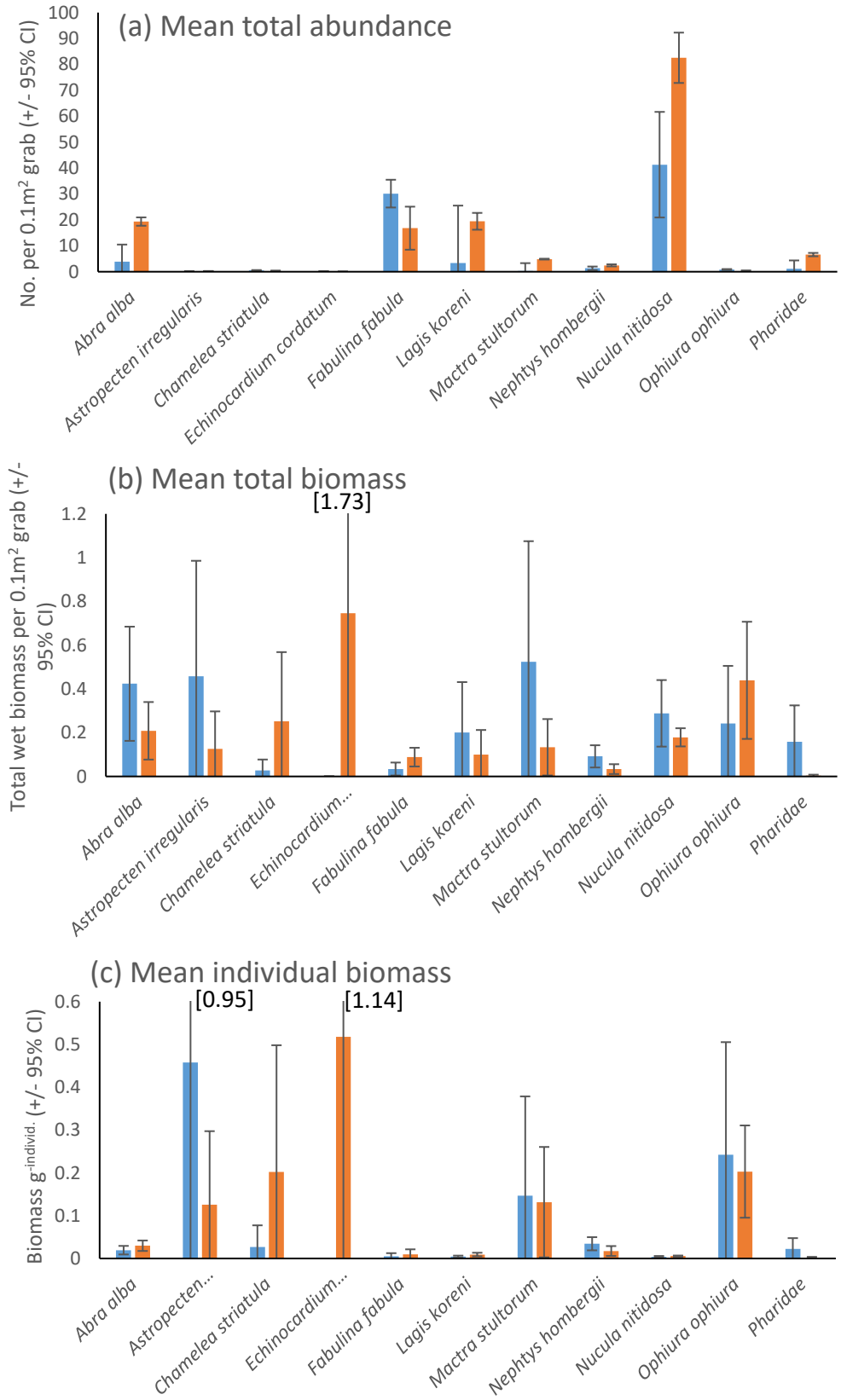

Figure 24. (a) Mean total abundance (per 0.1 m^2 grab), (b) mean total biomass (g wet weight grab^{-1}) and (c) mean individual biomass (in g wet weight) of the main Common scoter prey species for 2012 (blue, n = 20) and 2017 (orange; n = 37) samples from the Shell Flat SAC (© Natural England and Cefas 2022). Error bars signify 95% confidence intervals (values in [ ] signify upper limit).

3.5.2 Spatial comparison (inside vs outside) in 2017

The assessment of differences in abundance, biomass and individual biomass of the prey species was conducted for those taxa which represented the greatest contribution to total biomass across the site and were sampled in at least 25% of the stations. Ten taxa (six of which were bivalves) were, according to this principle, considered the main prey for Common scoter in 2017 (Figure 25a-c). While the density of *F. fabula* was notably greater inside Shell Flat relative to outside, most taxa showed comparable numbers while *Abra alba*, *Kurtiella bidentata* and *Lagis koreni* were more abundant outside Shell Flat (Figure 25a). Mean total biomass generally displayed notable spatial variability both within and outside Shell Flat, and the relative means between inside and outside varied across the ten taxa. While the biomass of *A. alba*, *L. koreni*, *M. stultorum* and *N. nitidosa* was higher inside the site than outside, that of *O. ophiura* and *F. fabula* was higher inside the site (Figure 25b). While the mean individual biomass of *O. ophiura* was greater inside Shell Flat, the individual mass of *A. alba*, *L. koreni*, *N. nitidosa* and *M. stultorum* was higher outside the site.

Five taxa were sampled in sufficient numbers to allow abundance and biomass size frequency assessment (Figure 26). With respect to abundance of individuals across the various size classes, some inside-outside differences are discernible. The population of *F. fabula* was dominated by the smallest size class inside the site but not outside, and similarly, the smaller size classes contribute a greater relative proportion for *G. tridactyla*, *M. stultorum* and *Nepthys hombergii* inside the site. A similar conclusion is reached based on biomass with a greater proportion of biomass observed in the smaller size classes inside the site relative to outside.

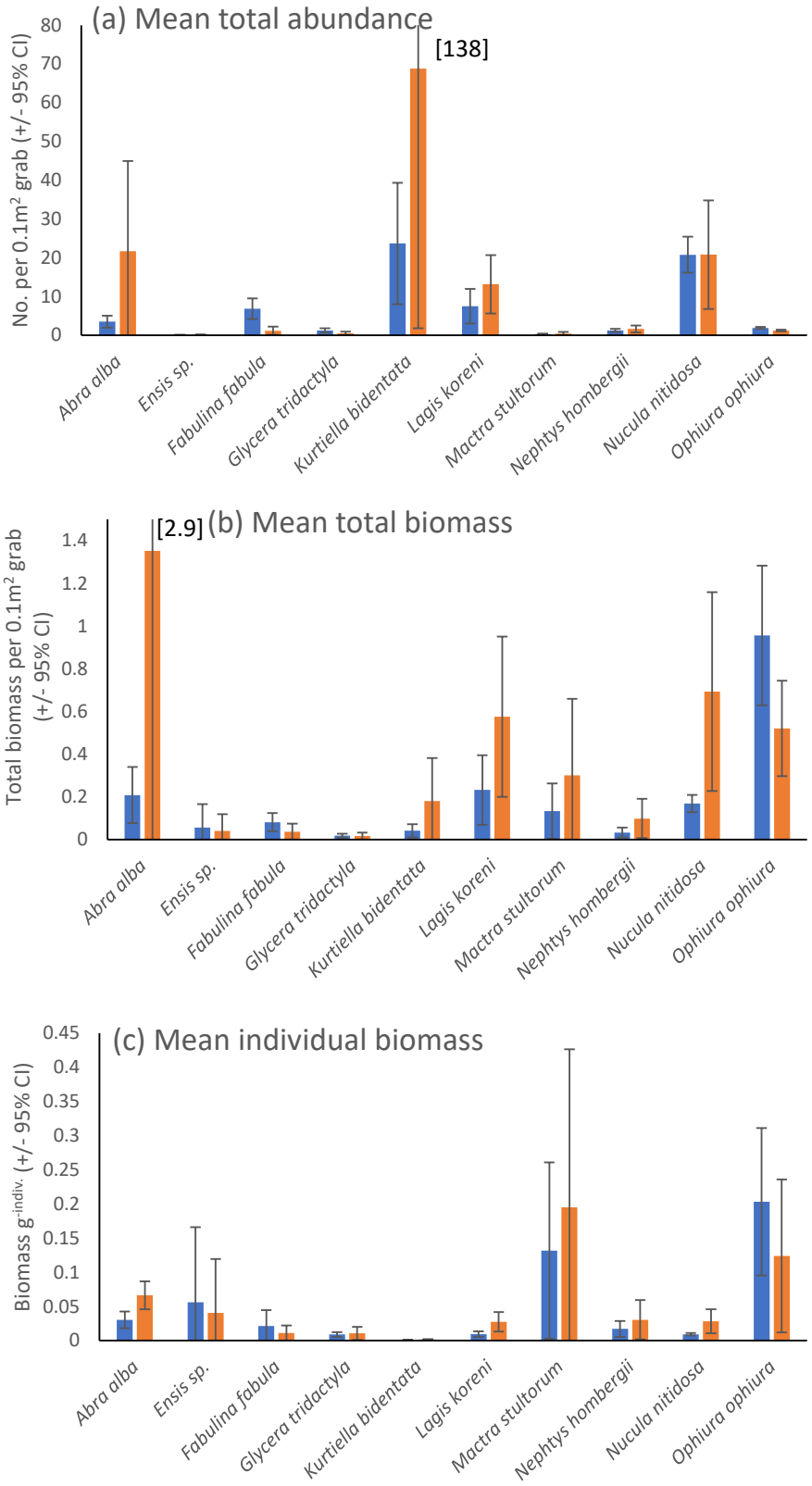

Figure 25. (a) Mean total abundance (per 0.1 m² grab), (b) mean total biomass (g wet weight per grab) and (c) mean individual biomass (in g wet weight) of the main Common scoter prey species for samples inside (blue, n = 37) and outside (orange; n = 16) the Shell Flat SAC in 2017 (© Natural England and Cefas 2022). Error bars signify 95% confidence intervals (values in [ ] signify upper limit).

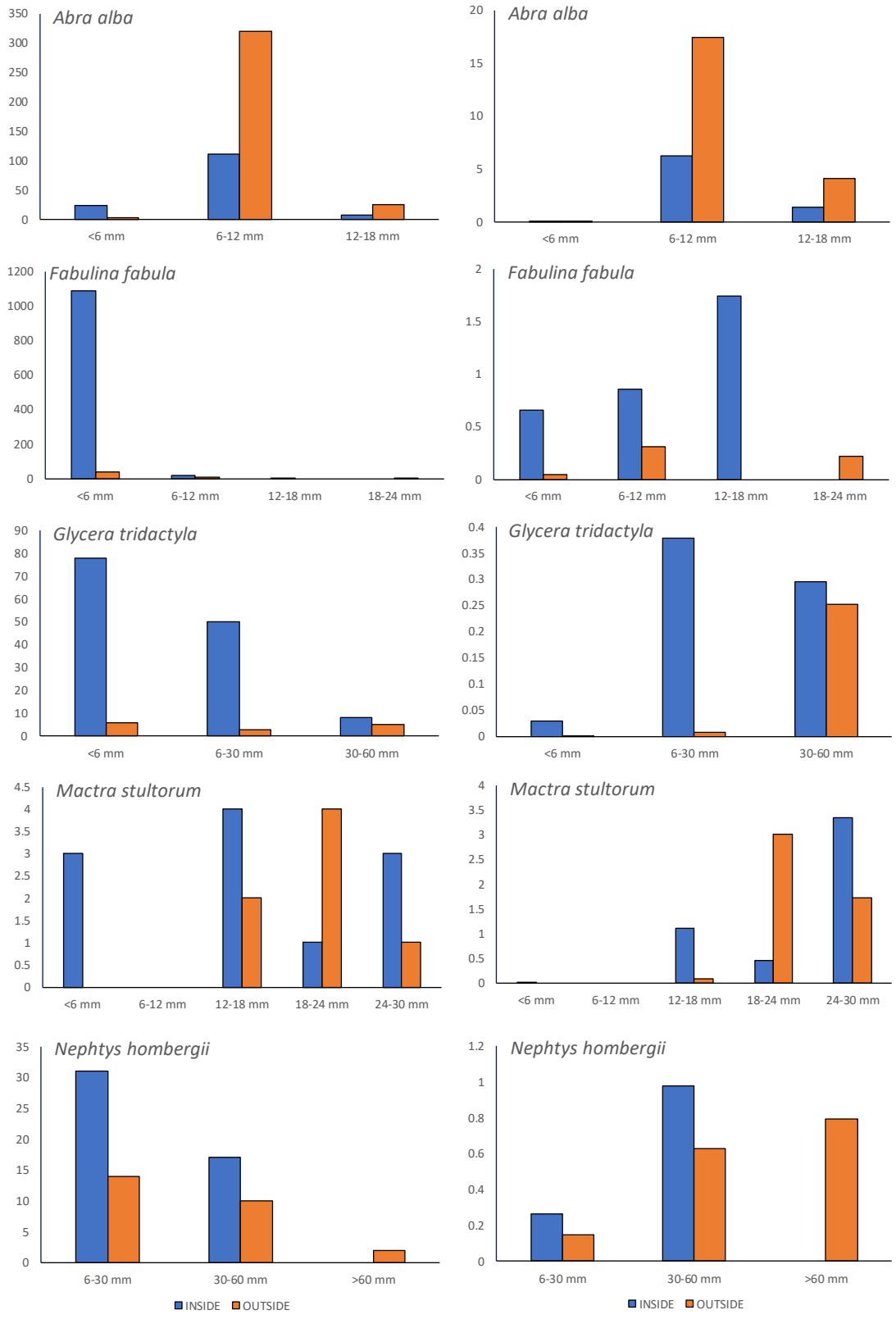

Figure 26. Abundance (total numbers sampled 0.1 m^{-2}; left) and biomass (total wet biomass (g) sampled 0.1 m^{-2}; right) size spectra (mm length) for the main Common scoter prey species sampled inside (blue; n = 37) and outside (orange; n = 16) the Shell Flat SAC during 2017 (© Natural England and Cefas 2022). For taxa where only three size classes are available, only gross differences in size frequencies between the populations inside and outside Shell Flat can be examined.

3.6 Sieve mesh size comparison

Objective 6: *Conduct a comparison of full infaunal community data between 0.5 mm and 1.0 mm sieve mesh sizes, to assess whether a 1.0 mm sieve is appropriate for future use in the field*.

Analyses to address this report objective were conducted solely based on the 2017 samples, which were processed using both sieve mesh sizes. As (reference) sampling stations outside the SAC may vary in future monitoring designs, data from only those stations sampled within the site boundary were included in the analyses to facilitate the outcomes' relevance to future monitoring of Shell Flat.

A comparison of the infaunal assemblages retained on a 1.0 mm mesh sieve with those retained on a 0.5 mm sieve revealed a clear distinction (Figure 27). With a stress value of 0.2, this 2d plot should only be used for general trends, not for detailed analysis. The locations of each station based on their assemblages sampled using either sieve show a common deviation along *circa* a 50^{o} to 90^{o} trajectory on the plot, indicating that the effect of sieve size results from a common suite of taxa. The outcomes of the SIMPER routine in PRIMER (Table 11) reveal that the ten taxa mostly contributing to the dissimilarity between the communities sampled by 0.5 mm and 1.0 mm sieves are, importantly, those which were numerically dominant in the significant infaunal cluster groups (see Objective 1).

Of the 11 taxa which were included in the analysis of Common Scoter food sources, seven (*A. alba*, *F. fabula*, *L. Koreni*, *N. hombergii*, *N. nitidosa*, *O. ophiura*, and Pharidae) were within the top 20 taxa contributing to the dissimilarity between the communities sampled by the different mesh sizes. This indicates that sieve mesh size has a marked influence over the outcomes when assessing energy availability to Common scoter.

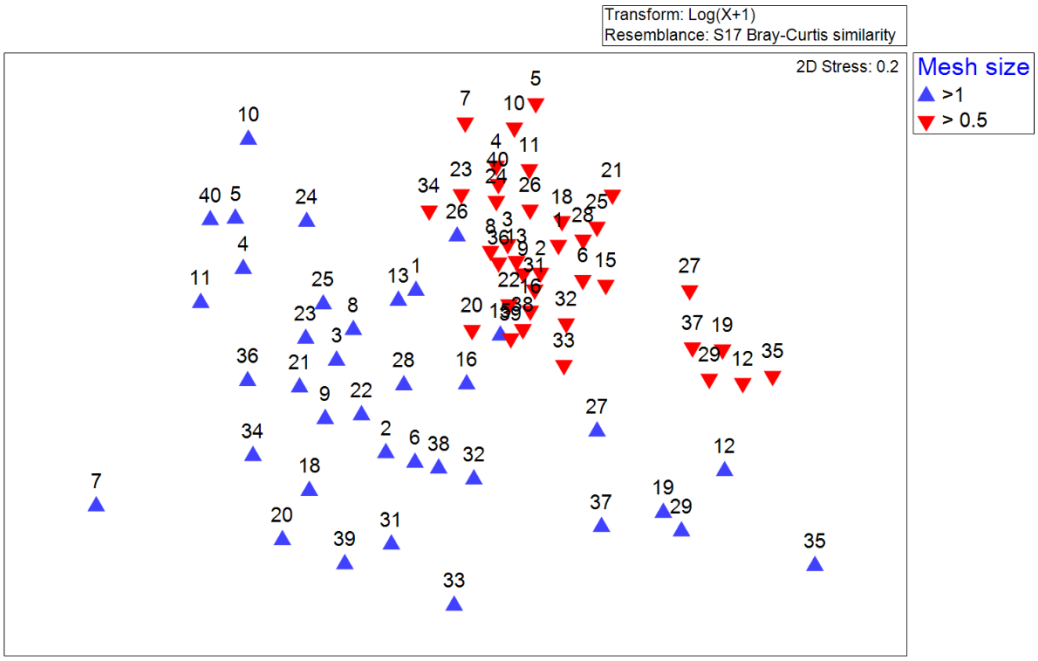

Figure 27. Non-metric 2D Multidimensional scaling (nMDS) plot of the infaunal assemblages of the 37 stations sampled within Shell Flat during 2017 (© Natural England and Cefas 2022). Data based on a 1.0 mm mesh sieve (blue) and a 0.5 mm sieve (red) are presented. Data for the >0.5 mm fraction were derived by pooling the >1.0 mm and 0.5-1.0 mm fractions for each station. Numbers refer to station codes.

Table 11. Outcomes of the SIMPER analysis of the infaunal data of the 17 stations sampled inside Shell Flat during 2017, when processed using a 1.0 mm and a 0.5 mm mesh sieve (© Natural England and Cefas 2022).

Dissimilarity	Main taxa	>1mm average abundance	>0.5mm average abundance	Contribution to dissimilarity (%)	Cumulative contribution (%)
60.07%	*Pseudocuma longicornis*	0.65	14.59	7.10	7.10
	Fabulina fabula	6.84	30.14	5.73	12.83
	Mytilus edulis	0.41	8.78	5.26	18.09
	Magelona filiformis	1.78	9.57	5.24	23.33
	Kurtiella bidentata	16.00	33.70	5.13	28.47
	Magelona johnstoni	2.49	7.41	3.95	32.42
	Abra alba	0.65	5.59	3.61	36.03
	Nemertea	0.89	4.62	3.54	39.57
	Nucula nitidosa	20.78	41.30	3.37	42.93

Twenty-one rarer, less abundant taxa were completely absent from the samples sieved using a 1.0 mm mesh sieve (Table 12). Most of these taxa were not widely distributed across the site (10 taxa were sampled at only one station) and are, perhaps as one might expect, represented by those with small individual size. None of these taxa were those characterising subfeature assemblages nor SIMPROF clusters in 2017 based on the full >0.5 mm dataset (

Table 4, Table 6).

Table 12. Taxa (including colonials) present in 0.5-1.0 mm fraction while not present in the >1.0 mm fraction based on the infaunal data of 37 stations sampled in Shell Flat, 2017 (© Natural England and Cefas 2022).

Taxon	No. of stations present	% of stations present	Total abundance across all stations	Mean abundance per station present
Spio sp.	11	29.7%	18.0	1.6
Eumida sp.	5	13.5%	5.0	1.0
Tubificoides pseudogaster	5	13.5%	5.0	1.0
Parthenina sarsi	4	10.8%	4.0	1.0
Ampelisca sp.	4	10.8%	4.0	1.0
Pseudopolydora pulchra	3	8.1%	3.0	1.0
Pariambus typicus	3	8.1%	3.0	1.0
Euspira nitida	3	8.1%	3.0	1.0
Chaetozone christiei	2	5.4%	2.0	1.0
Capitella sp.	2	5.4%	6.0	3.0
Synchelidium maculatum	2	5.4%	2.0	1.0
Hydrallmania falcata	1	2.7%	1.0	1.0
Mediomastus fragilis	1	2.7%	13.0	13.0
Argissa hamatipes	1	2.7%	1.0	1.0
Nototropis swammerdamei	1	2.7%	1.0	1.0
Megaluropus agilis	1	2.7%	1.0	1.0
Abludomelita obtusata	1	2.7%	1.0	1.0
Pinnotheridae	1	2.7%	1.0	1.0
Retusa umbilicata	1	2.7%	1.0	1.0
Cardiidae	1	2.7%	1.0	1.0
Amathia sp.	1	2.7%	1.0	1.0

With respect to univariate indices of community structure, mean values of all four metrics (total number of individuals, total number of species, Margalef index, Shannon Index) were evidently lower for the assemblages retained on a 1.0 mm mesh sieve relative to those sampled using the 0.5 mm sieve (Figure 28a-d). Species accumulation curves for the two size fractions reveal that a greater number of species is observed using the smaller mesh for any given number of samples (Figure 29). This difference becomes significantly different when the number of samples taken reach approximately 20. The difference in the total number of species estimated to be present within Shell Flat after this number of samples are, purportedly, those identified above in Table 12.

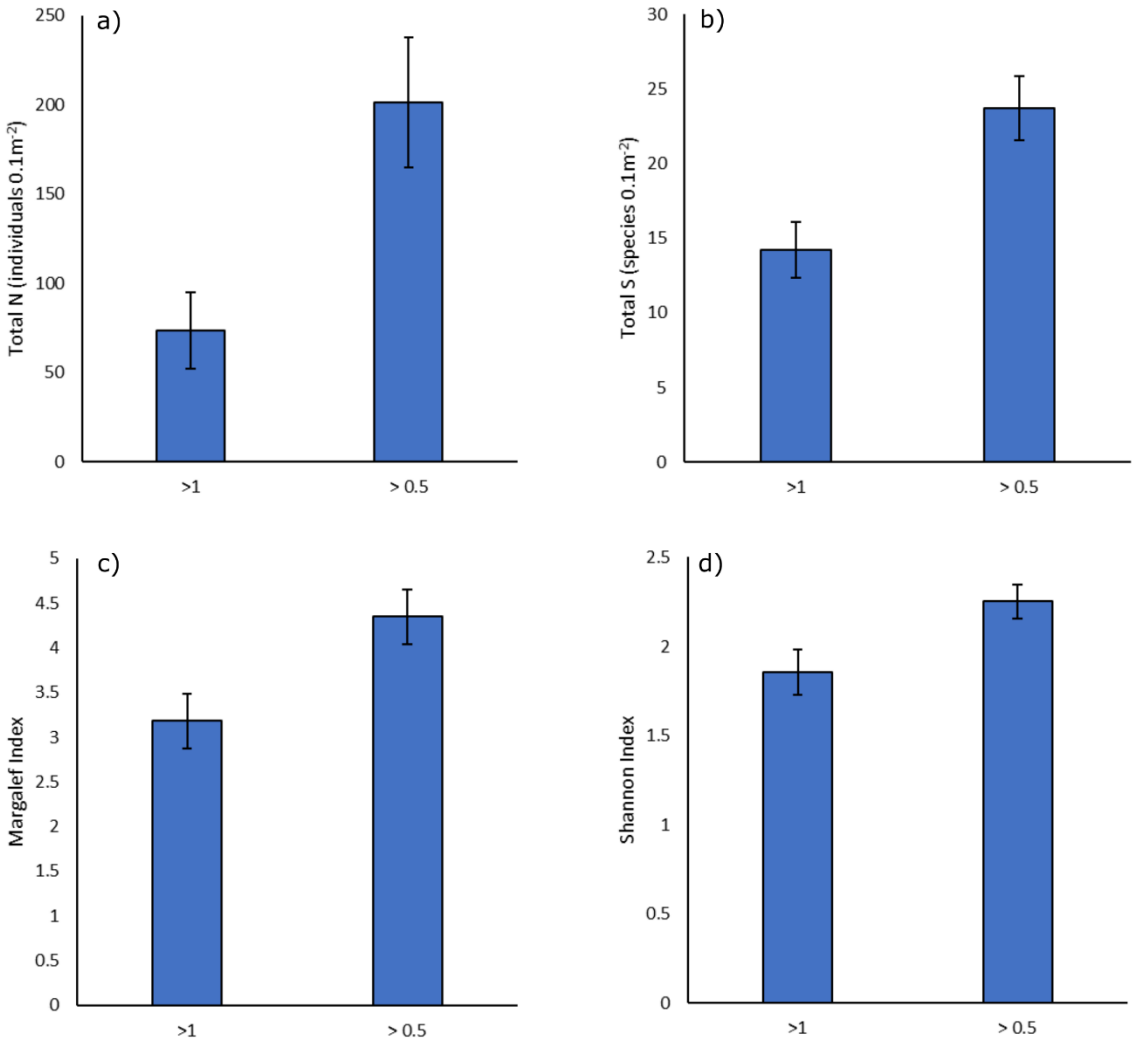

Figure 28(a-d). Univariate (means ± 95% CI) indices of the macrofaunal assemblages sampled using a >1.0 mm mesh sieve (left) and a >0.5 mm mesh sieve (right) (© Natural England and Cefas 2022).

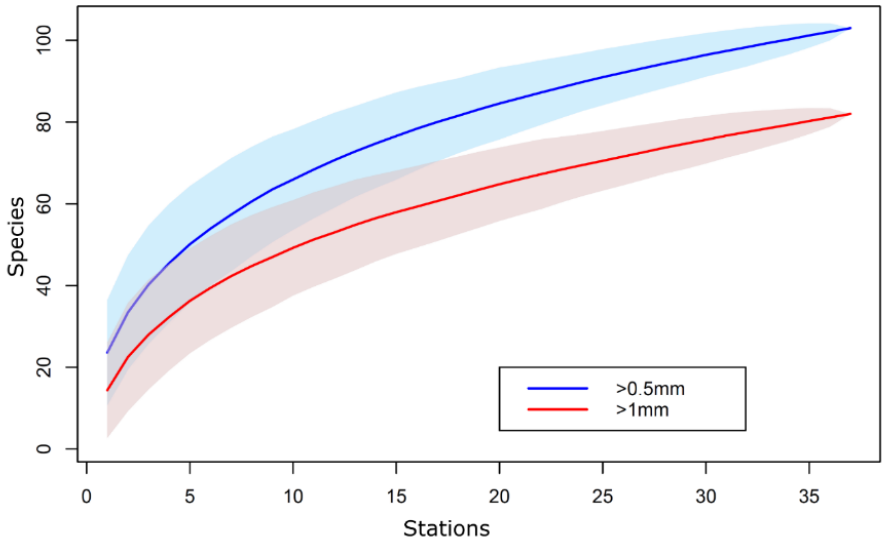

Figure 29. Species cumulation curves for the infauna sampled by the 0.5 mm (blue) and 1.0 mm (red) mesh sizes (means ± 95% CI) (© Natural England and Cefas 2022). Data based on 37 samples from within Shell Flat, 2017.

A comparison of differences in abundance between the mesh sizes across phyla reveals that the subset of taxa sampled by the 1.0 mm mesh was not restricted to certain phyla. Differences between the two sieves were observed for a wide array of phyla (i.e. Annelida, Arthropoda, Mollusca, Nemertea: Figure 30). The difference in Annelida was due to the two polychaete species of the genus *Magelona,* which were key characterising taxa of the 2017 infaunal assemblage (see Objective 1). For Arthropoda, the cumacean *P. longicornis* was the primary contributor and the bivalves *F. fabula* and *M. edulis* contributed greatly to the significant difference observed for Mollusca.

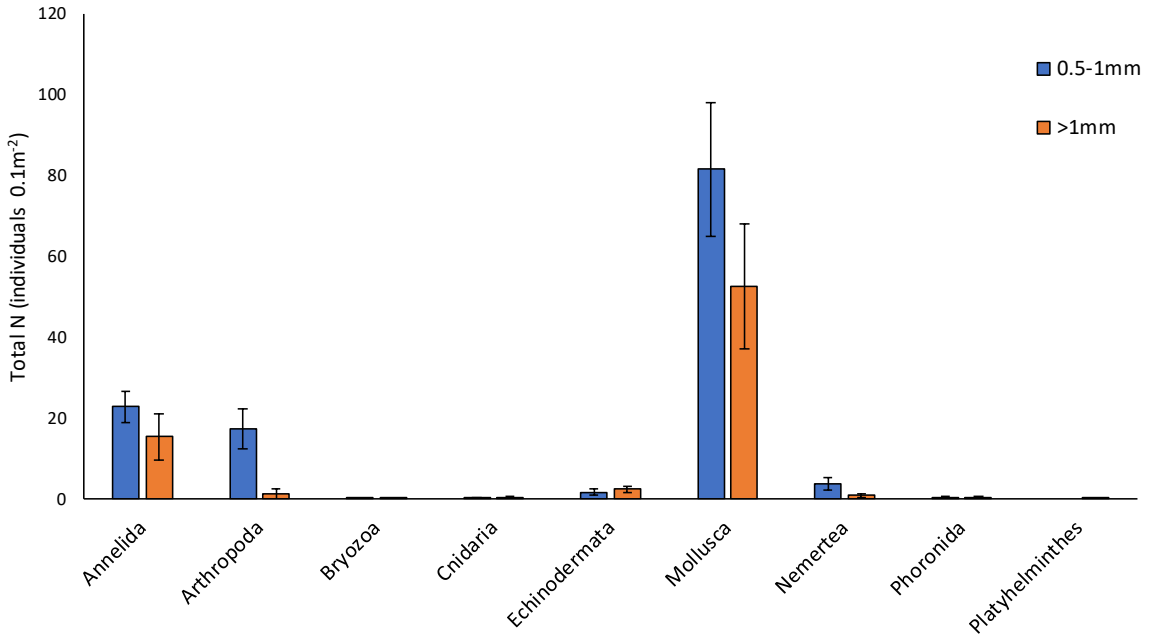

Figure 30. Comparison of phylum abundance (means ± 95% CI) between the 0.5 – 1.0 mm and the larger than 1.0 mm size groups (© Natural England and Cefas 2022). Data based on a 0.1 m^2 grab.

3.7 Other OSPAR threatened and/or declining features

Objective 7: *Note observations of OSPAR Threatened and/or Declining Species and Habitats*.

One juvenile ocean quahog (*Arctica islandica*), an OSPAR threatened and/or declining species, was observed in the grab samples acquired during the 2017 survey at Shell Flat and Lune Deep SAC. This specimen was found in the 0.5 mm – 1.0 mm fraction (i.e. it was < 1.0 mm in size) of a sample taken outside Shell Flat. No other OSPAR threatened and/or declining species were observed.

No OSPAR threatened and/or declining habitats were observed to be present within the Shell Flat and Lune Deep SAC based on the 2017 data.

3.8 Litter

Objective 8: *Present evidence relating to marine litter.*

No items of litter were found to be present in the grab sediments from the 40 stations sampled within Shell Flat nor from the 16 stations sampled outside.

The 2017 survey did not acquire any imagery data, therefore it was not possible to record the presence of any larger items of litter on the seabed.

4 Discussion

4.1 Overview

This section coalesces the various outcomes of the 2017 survey focusing on the Shell Flat and Lune Deep SAC, to discuss the area's infaunal assemblages, ecological function, temporal changes between 2012 and 2017 (including potential signs of effects of the Douglas oil spill), and the implications of these findings for future monitoring of feature condition within the site. This report focuses exclusively on the sandbank feature of the SAC; no analyses or interpretation of any data pertaining to the Lune Deep area are presented.

Analyses of the 2017 sediment and infaunal data from within Shell Flat revealed that three subfeatures of the Annex I Sandbank feature were present; 'A5.2 Subtidal sand', 'A5.3 Subtidal mud' and 'A5.4 Subtidal mixed sediments'. While 'A5.2 Subtidal sand' was the most widespread across Shell Flat (28 of 37 stations), 'A5.4 Subtidal mixed sediments' was only observed at two stations along the southern flank. While the sediments of these latter two stations were not compositionally very different from those of the other stations (i.e. they were located close to the boundary on the Folk triangle) they were, however, somewhat faunistically different. While the infaunal assemblage of the two 'A5.4 Subtidal mixed sediments' stations is described in this report, further targeted sampling is ideally required to better define the presence, extent and infaunal assemblages of this subfeature within Shell Flat.

With one exception, stations within Shell Flat may be regarded as possessing sediments classifying them as Annex I Sandbanks (Duncan, 2016). The anomalous station comprised >97 % silt/clay, although this station did not display an infaunal assemblage notably distinct from other stations classified as 'A5.3 Subtidal mud'. The 2017 data revealed that Shell Flat was generally sandy in the central region of the sandbank with slightly elevated muddy areas being present along the north and south banks. This broad overview of the spatial distribution of sediments is in harmony with that observed based on historical data (Envision Mapping, 2014).

The infaunal assemblages were separated into six statistically distinct groups, two of which differed more from the others. The key taxon which was found to cause this difference was the bivalve *K. bidentata,* which was more abundant in these two distinct groups, while the communities of all six groups were characterised by the bivalves *N. nitidosa* and *F. fabula* and the cumacean *P. longicornis*, amongst others. There was no clear difference in PSD, as the six stations representing the two most distinct groups spanned all three subfeature habitat types and were part of the main Entropy cluster. Although only based on data from two stations, the univariate indices indicated that the subfeature 'A5.4 Subtidal mixed sediments' was richer both in number of individuals and number of species than the other subfeatures.

When compared to previous data acquired within the site in 2012, there was a general shift of the community in 2017. The rationale for this was a declining trend in the abundance of key taxa (certain bivalves, polychaetes, ophiuroids and cumaceans) characterising the site. This was also visible in the univariate indices, with significant declines in numbers of individuals and species in 'A5.2 Subtidal sand' and 'A5.3 Subtidal mud'. However, it is plausible that this observation may be an artefact that results from the reduced grab volumes achieved in 2017 (mean *circa* 2.0 L) compared with those in 2012 (mean *circa* 4.5 L). The observation that subfeature designation for five stations changed from 2012 to 2017, in theory, infers a change in subfeature extent during this period. Without replication it is difficult to ascertain whether these changes represent actual temporal shifts or natural spatial variability in sediment granulometry.

The sediment contaminants data were used to indicate whether the sediments within, or of those in the vicinity of, Shell Flat were potentially contaminated by the Douglas Field oil spill which occurred approximately two weeks prior to the survey. This spill represented a diffuse pollution incident and specific, targeted data (e.g. hydrodynamic plume dispersion modelling) regarding the fate of the material around Shell Flat were not available. We therefore cannot categorically state that the sampling stations were within the dispersion plume. The data acquired indicated that the concentrations of PAHs within the sampled sediments were low, with summed LMW PAHs and HMW PAHs all below those observed during 2012. Individual PAH concentrations were all below the ERL and ERMs, although one station outside Shell Flat exhibited a benzo(ghi)perylene concentration slightly higher than the ERL. However, it must be borne in mind that the survey design was not based around an objective to assess the impacts of this incident (e.g. it does not incorporate a suitable reference area) and it may be argued that the data do not allow a robust assessment as such.

The Shell Flat region is an important feeding area of the Common scoter, a bird afforded protection by the Liverpool Bay SPA. Although bivalve molluscs form the main component of their diet, Common scoters appear to also feed on a variety of other phyla (Kaiser *et al*., 2006). As such, analyses of the abundance and biomass of the key biomass dominant infauna were conducted, to provide a proxy for the food availability for this species, and to quantify any temporal and spatial changes. The data revealed no discernible differences in prey availability inside Shell Flat compared with outside. In this respect, Shell Flat is not likely to signify a unique feeding ground for this bird species but forms part of a wider seabed region within Liverpool Bay and the eastern Irish Sea. The shallower depth of Shell Flat compared to surrounding areas which also harbour important prey species, may attract the Common scoter to this area. Further monitoring, particularly regarding observations of bird numbers and behaviour would need to be undertaken to ascertain this. The finding that molluscs contribute to the majority of secondary production at Shell Flat (Figure 12) further supports the importance of the site in supporting a food resource for this bird species.

The 2017 samples were processed using two mesh sieve sizes; a 0.5 mm mesh and a 1.0 mm mesh. The data obtained from both fractions for all 37 stations were compared, evidencing a general shift in multivariate community structure. The taxa responsible for this shift were all less abundant on the 1.0 mm mesh size than on the 0.5 mm mesh size and represented those taxa characterising the community clusters as described in Objective 1. Of the 11 taxa analysed as Common scoter food sources, seven were in the top 20 taxa characterising the dissimilarity between the mesh sizes. Twenty-one taxa were present on the 0.5 mm mesh size but absent on the 1.0 mm mesh size. This manifested as significant differences in univariate indices which were significantly lower for 1.0 mm than 0.5 mm mesh. Finally, the dominant phyla Mollusca, Annelida, Arthropoda and Nemertea were all significantly less abundant on the 1.0 mm mesh size than the 0.5 mm mesh size. Clearly, the choice of sieve results in different estimates of infaunal community structure and subsequent estimates such as Common scoter food resource availability. The decision of which sieve should be adopted for future monitoring can only be made based on the specific details of the aims and objectives of future monitoring events.

4.2 Recommendations for future monitoring

This section fulfils Objective 9 "*Provide practical recommendations for appropriate future monitoring approaches for the sandbank feature and its natural supporting processes (e.g., metric selection, survey design, data collection approaches) with a discussion of their requirements*".

While it is acknowledged that the specific metrics and objectives have not yet been defined for future monitoring at this SAC, there are a number of generic recommendations that can be made based on the evidence presented in this report. Such recommendations are provided for operational and strategic (sub-section 4.2.1) and analytical and data interpretation (sub-section 4.2.2) aspects separately.

4.2.1 Operational and survey strategy

- The 2017 survey acquired a number of grab samples from within and outside Shell Flat, with the aim of addressing a number of report objectives. Each of these objectives, in theory, would require a different sampling design to acquire data that would allow them to be optimally achieved. Limitations of the data to address the various objectives within this report were evidenced. Future surveys should be designed to achieve fewer objectives, to address objectives that share a common sampling design, or to encompass multiple designs (each one specific to a specific Objective) within the single survey.

- The mini-Hamon Grab successfully sampled all but three of the planned stations within Shell Flat and as such may be regarded as being a suitable gear type to acquire infaunal and sediment data from which changes may be assessed. However, grab volumes were small in 2017, the average volume of

the valid infaunal sample being approximately 2.0 L. This is well below the volume commonly cited as being the cut-off of acceptability for mini-Hamon Grabs (i.e. 5.0 L; Ware and Kenny, 2016). Mean grab sample volume (with the same grab type) during the 2012 survey was *circa* 4.5 L. The implications of small sample volumes, and variability in grab volume, must be incorporated into future analyses and interpretation of the resulting data. While grab sample volume was less correlated with infaunal assemblage structure than sediment granulometric properties in 2017, it is possible that it was an influential factor in the observed infaunal shifts (i.e. the significant decrease in number of individuals in 'A5.2 Subtidal sand' and 'A5.3 Subtidal mud' and species richness in 'A5.2 Subtidal sand') observed between years.

- As sea state was not stated as being particularly inclement, one plausible rationale for the small sample volumes in 2017 may be strong tidal currents during survey. Shell Flat, given its relatively shallow nature, may experience relatively strong currents during spring tides. Under such circumstances, increased drift in the survey vessel location during deployment may result in the grab being hauled from the bed at an oblique angle which results in an inadequate sample capture. We recommend that future sampling be conducted during neap tides and/or during periods of reduced tidal flow (e.g. towards low and high-water slack tides).

- Future surveys should be conducted at the same time of year (August) as that in 2017 (and 2012), otherwise it will not be possible to determine whether any observed changes are due to seasonal cycles or reflect actual biological variation.

- The 2017 survey did not include any acoustic data acquisition and thus the capacity of the resulting data to quantify change in extent of subfeatures was limited to point samples.

- The assessment of prey species for the Common scoter in the present study was undertaken with minimal specimens from which to assess size frequency analyses. Should prey availability for this bird species be a primary objective of future monitoring efforts, greater sampling intensity should be undertaken to provide an improved assessment of prey density, biomass and size distribution frequency.

- The present assessment of the potential impacts of the Douglas Field oil spill was conducted using data from a small number of stations which were located largely in the absence of knowledge of the likely trajectory of dispersion of oil from the source incident. Future comparable objectives should be addressed using a more informed design whereby stations within the likely dispersion plume, together with those outside to provide a spatial reference, can be located.

- The temporal assessments of changes in Broadscale Habitats have hitherto been conducted based on direct comparisons of single samples over time. Such comparisons only provide a robust temporal assessment where small-scale spatial variability is negligible. To date, there are no data to support this assumption and any such spatial variability is currently being ascribed to temporal change. Thus, future monitoring efforts should include some replicate sampling at a subset of sampling stations to allow small-scale spatial variability to be quantified.

4.2.2 Analyses and interpretation

- While samples outside Shell Flat were sampled during 2017, the capacity of these stations, or the data they may provide, to act as reference stations from which to monitor change has not been formally addressed here. These stations were not targeted to act as any reference station to monitor changes within Shell Flat. However, based on their sediment PSD (Figure 3) they appear to represent somewhat different habitats (comprising greater silt/clay fractions) relative to those of Shell Flat. This infers that their suitability to act as reference sites is perhaps limited as they may respond differently to any changes in environmental variables or anthropogenic pressures from inside Shell Flat.

- Further studies are required to improve our understanding of the observed variability (spatial and temporal) in biological assemblages found in association with given habitat features. For example, classification of infaunal communities in alignment with the four possible sedimentary BSHs (i.e. sub-section 3.1.2.2 in this report) is not necessarily ecologically relevant. This is because biological communities do not necessarily align with the same physical thresholds used in the classification of sedimentary BSHs according to EUNIS. Indeed, the assemblages sampled at stations classified as ‘A5.2 Subtidal sand’ and ‘A5.3 Subtidal mud’ at Shell Flat showed a large amount of commonality.

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Annex 1. Infauna data truncation

Raw taxon abundance and biomass matrices can often contain entries that include the same taxa recorded differently, erroneously or differentiated according to unorthodox, subjective criteria. Therefore, ahead of analysis, data are checked and truncated to ensure that each row represents a legitimate taxon and they are consistently recorded within the dataset. An artificially inflated taxon list (i.e. one that has not had spurious entries removed) risks distorting patterns in assemblage structure.

Some taxa may require merging 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.

Details of the data preparation and truncation protocols applied to the infaunal datasets ahead of the analyses reported here are provided below:

The first objective was to compare sites within the Shell Flat area from the 2017 survey. The main aim of the data preparation and truncation was to maintain details at lower levels (genus/species) as much as possible through the following steps:

- The colonial organisms in the abundance data were listed with "P" for present. "P" was replaced by "1" throughout the data.
- Some taxa masses were listed as <0.0001 in the biomass data. These were replaced by 0.0001 to make them usable in subsequent quantitative analyses.
- If abundance was reported to family/genus as well as at species level, and within a sample both the genus and at least one other species occurs, the family/genus was treated as a different taxon (i.e. do not truncate to family genus level).
- If abundance was reported to family/genus as well as at species level, but within each sample there was only one occurrence of either, the sample data were combined to the family/genus level.
- Taxa are often assigned as 'juveniles' during the identification stage with little evidence for their actual reproductive natural history (except some well-studied molluscs and commercial species). Many truncation methods involve the removal of all 'juveniles.' However, a decision must be made on whether removal of all juveniles from the dataset is appropriate, or whether they should be combined with the adults of the same species where present. In this instance, where 'juvenile' records were recorded at the same taxonomic level as 'adult' records the two records were combined, whereas if juveniles were recorded at a higher taxonomic level than adults then the 'juvenile' records were

removed to avoid having to reduce the taxonomic resolution of the ‘adult’ records.

- If abundance was reported at class/family and species level, but the class/family level could not be further identified due to damage/missing parts, the class/family record was removed.
- Records of Mysida were removed as these are not part of the infauna.
- Records of meiofauna (i.e. nematodes) were removed.
- Other records not applicable to the further analyses (“Animalia eggs”) were removed.

The third objective was to compare data sets from 2012 and 2017 for Shell Flat infauna. A comparison between years and data sets processed by different companies can be complex since there may have been differences in approaches and guidelines to identification and naming. Therefore, the goal of the truncation was to ensure the comparability of the data sets, although this may result in some loss of resolution in the data.

- When there were values for both genera and species therein, all were merged to genus level, also when genus level entries were juveniles.
- The same merge to higher level was conducted for family, superfamily, class and phylum vs lower levels where needed to maintain comparability between years.
- All colonial taxa (Hydrozoa and Bryozoa) were removed.
- A single juvenile not further identified than Decapoda was removed.
- A single damaged Gastropoda was removed.
- The taxon Pelecypoda, only present in the 2012 data set, was removed.
- Records of Mysida were removed as these are not part of the infauna.
- Records of meiofauna (i.e. nematodes) were removed.
- Other records not applicable to the further analyses (“Animalia eggs”) were removed.

Furthermore, a number of taxa were merged due to nomenclature issues:

- The species *Atylus swammerdamei* and *Nototropis swammerdamei* were merged, together with the genus level to the taxon *Atylus*.
- *Parthenina sarsi* and *Chrysallida indistincta* were merged into *Chrysallida indistincta.*
- *Lumbrineris cingulate* and *Lumbrineris gracilis* were merged into the genus *Lumbrineris.*

- *Anaitides mucosa* and *Anaitides rosea* were merged with the genus *Phyllodoce* into a summed taxon *Phyllodoce.*

For comparing the 0.5 mm and 1 mm mesh sizes in Objective 6, the approach was again different since both size fractions were analysed by the same analysts, using the same guidelines. Because of this, the truncation was not as severe as for the temporal comparison.

- In most cases taxa from different taxonomic levels (e.g. species and corresponding genus) were both present in both mesh sizes and therefore kept in the data.
- When a species was present in both mesh sizes, but a corresponding genus was not, the taxa were merged to the genus level.
- The same was done for family, order or class levels when lower levels were only present in one mesh size.
- A single damaged Gastropoda was removed.
- Records of Mysida were removed as these are not part of the infauna.
- Records of meiofauna (i.e. nematodes) were removed.
- Other records not applicable to the further analyses (“Animalia eggs”) were removed.

Annex 2. Non-indigenous species (NIS).

Table 13. Taxa listed as non-indigenous species (present and horizon) which have been selected for assessment of Good Environmental Status in GB waters under MSFD Descriptor 2 (Stebbing *et al*., 2014).

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		

Table 14. Additional taxa listed as non-indigenous species in the JNCC 'Non-native marine species in British waters: a review and directory' report by Eno *et al*. (1997) which have not been selected for assessment of Good Environmental Status in GB waters under MSFD Descriptor 2.

Species name (1997)	Updated name (2017)
Thalassiosira punctigera	
Thalassiosira tealata	
Coscinodiscus wailesii	
Odontella sinensis	
Pleurosigma simonsenii	
Grateloupia doryphora	
Grateloupia filicina var. luxurians	*Grateloupia subpectinata*
Pikea californica	
Agardhiella subulata	
Solieria chordalis	
Antithamnionella spirographidis	
Antithamnionella ternifolia	
Polysiphonia harveyi	*Neosiphonia harveyi*
Colpomenia peregrine	
Codium fragile subsp. atlanticum	
Codium fragile subsp. tomentosoides	*Codium fragile* subsp. *atlanticum*
Gonionemus vertens	
Clavopsella navis	*Pachycordyle navis*
Anguillicoloides crassus	
Goniadella gracilis	
Marenzelleria viridis	
Clymenella torquata	
Hydroides dianthus	
Hydroides ezoensis	
Janua brasiliensis	
Pileolaria berkeleyana	
Ammothea hilgendorfi	
Elminius modestus	*Austrominius modestus*
Eusarsiella zostericola	
Corophium sextonae	
Rhithropanopeus harrissii	
Potamopyrgus antipodarum	
Tiostrea lutaria	*Tiostrea chilensis*
Mercenaria mercenaria	
Petricola pholadiformis	
Mya arenaria	

Annex 3. Marine litter categories

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.

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*5 cm = 25 cm^2

B: ≤ 10*10 cm = 100 cm^2

C: ≤ 20*20 cm = 400 cm^2

D: ≤ 50*50 cm = 2500 cm^2

E: ≤ 100*100 cm = 10000 cm^2

F: ≥ 100*100 cm = 10000 cm^2

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