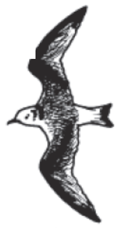
Macrobenthic monitoring in Sullom Voe Sediments

2018



A report to the Shetland Oil Terminal

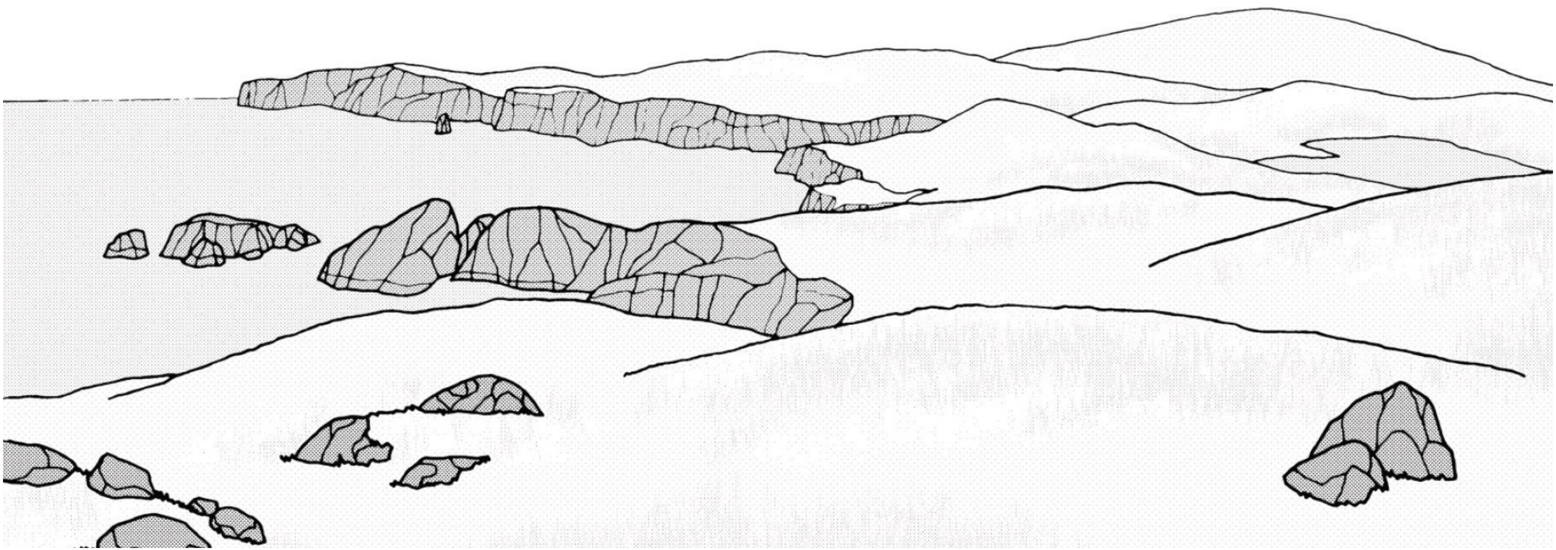
Environmental Advisory Group

by

SGS United Kingdom Limited

And

Eco Marine Consultants Limited



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Non-technical Summary

As part of an ongoing monitoring programme, Eco Marine Consultants Limited (Eco Marine) was commissioned by the SGS to undertake a benthic survey in Sullom Voe and the surrounding areas to determine the status of infaunal communities and seafloor sediments in June 2018. The 2018 survey followed on from monitoring surveys undertaken in 2016 and 2014 by Marine Ecological Surveys Limited (MESL) and prior to this since 2002 under the current programme.

This report presents the findings of the study and includes infaunal and sediment data collected from the Sullom Voe benthic survey conducted 6th-10th June 2018 aboard the '*Sullom Shearwater*' using a Day Grab.

The main findings of this report are:

- Overall the total abundance of macrobenthic organisms sampled during 2018 has increased compared to that recorded in 2016 and remains in line with background levels of abundance recorded in previous survey years.
- Faunal diversity across the stations at Sullom Voe decreased slightly in 2018 compared to recent survey years though remained within the window of natural variability exhibited by fauna since monitoring began in 2002 under the current programme.
- In line with the findings of the previous monitoring surveys, some of the most commonly encountered and abundant fauna recorded during 2018 (other than Nematoda) were the bivalves *Thyasira flexuosa* and *Kurtiella bidentata* and the annelid *Prionospio fallax.*
- In 2018 the dominant biotope identified across the stations was '*Mysella* (*Kurtiella*) *bidentata* and *Thyasira* spp. in circalittoral muddy mixed sediment (SS.SMx.CMx.MysThyMx)' due to the presence of mixed sediments and substantial number of *Kurtiella bidentata* and *Thyasira* spp. This is consistent with the findings of previous monitoring surveys and biotope information available for the Sullom Voe area.
- Slight variations in the proportion of sediment fractions have been observed over recent monitoring surveys with an increase in the proportion of mud apparent in both 2016 and 2018.
- Overall, the macrobenthic communities sampled throughout Sullom Voe in 2018 remained rich, characteristic of the assemblages recorded during historical monitoring of the area.
- A number of rare, alien and protected species were recorded in the 2018 faunal samples. These included the OSPAR-listed ocean quahog *Arctica islandica,* the nationally rare sea slug *Calliopaea bellula,* the nationally scarce orange-footed sea cucumber *Cucumaria frondosa,* the IUCN Red-listed edible sea urchin *Echinus esculentus,* the nationally scarce purple sea urchin *Paracentrotus lividus*, and the alien soft-shell clam *Mya arenaria*.
- The six variables found to be driving faunal community structure and distribution at Sullom Voe were % gravel, % sand, % mud, depth (m), total naphthalene and total dibenzothiophene.

CONTENTS

1. INTRODUCTION

Eco Marine Consultants Limited (Eco Marine) was commissioned by the SGS on behalf of Shetland Oil Terminal Environmental Advisory Group (SOTEAG) to undertake a benthic survey in Sullom Voe and surrounding areas to determine the status of infaunal communities and seafloor sediments in June 2018.

The Sullom Voe and neighbouring Orka Voe area is subject to numerous anthropogenic activities, most notably shipping and subsurface oil export through the Sullom Voe oil complex, operated by Enquest. The Sullom Voe complex receives oil by pipeline from the East Shetland Basin oilfields and by shuttle tanker, and as such is closely monitored so that any resulting impacts on local benthic communities and sediments are fully captured.

Benthic monitoring has been carried-out biennially in the coastal region of Sullom Voe and neighbouring Orka Voe since 2002, though the area has been subject to investigation for many years preceding this due to the unique marine life found there. This report outlines the findings of the 2018 survey and pays special attention to temporal changes observed in macrofaunal communities since monitoring commenced under the current programme design in 2002.

1.1. SITE DESCRIPTION

Sullom Voe is a highly diverse marine environment that was designated as a Special Area of Conservation (SAC) under the EC Habitats Directive (92/43/EEC) in 2005 for the following Annex I habitats:

- Large shallow inlets and bays (primary feature);
- Coastal lagoons; and
- Reefs

The Sullom Voe SAC is the most northerly site in the UK to be selected as a representative of large shallow inlets and bays, and the only Scottish example of a ria (known locally as a 'voe'); a large coastal inlet formed by the submergence of a river valley. The boreal-arctic species-rich communities of Sullom Voe are restricted only to Shetland voes and are not represented elsewhere in the SAC network, making them a unique feature. At 6.5 miles in length and up to 0.25 miles in width, Sullom Voe is the largest voe in Shetland. Water depth varies between 20 and 35 metres for much of its length except at the head and inner basin where at points it reaches depths of over 50m.

Previous monitoring of Sullom Voe and Orka Voe (an inlet to the north east of Sullom Voe) has revealed that the intertidal sediments of the site are confined to lagoons near the mouth of the Voes and are predominately colonised by a diverse faunal community including bivalves, annelids and sea cucumber species. Additionally, a range of bivalves, annelids and amphipods can also be found in the organically enriched shell-sand, gravel and muddy sediments.

The sublittoral sediments of Sullom Voe are typically known to be characterised by poorly-mixed, muddy sediments and are colonised by the horse mussel *Modiolus modiolus,* the sea-pen *Virgularia mirabilis* and diverse burrowing communities (MESL, 2016). A range of bivalves, polychaetes and amphipods can also be found in the organically enriched shell-sand, gravel and muddy-sand sediments. The rich faunal communities present at Sullom Voe have been attributed to the variety of sediment types present which provide an array of habitats as well as a plentiful nutrient supply, possibly derived from eroding peat. Hoppe (1965) notes the widespread occurrence of submerged peat (now a UK Post-2010 Biodiversity Framework priority habitat) in many areas of Shetland, including Sullom Voe.

Areas of interest within the Sullom Voe area are Garths Voe, Houb of Scatsta and Orka Voe; contaminant samples were collected from all three of these sites and faunal samples were also collected at Orka Voe during the 2018 survey.

Situated locally to the Shetland Oil Terminal is Garth's Voe, an intertidal area with particularly elevated potential to be exposed to anthropogenic pressures. In 1974, Garth's Voe was reported as having occasionally exposed sandy sediments overlying a dense layer of submerged peat, with fauna dominated by *Thyasira, Abra*, *Ophiura* and *Leptosynapta*, all of which are considered to be characteristic of fairly fine sandy mud (Pearson, 1974). The Houb of Scatsta is a shallow intertidal area located next to the Scatsta airport to the south of Sullom Voe oil terminal and where mussel beds have been previously observed. Orka Voe is a subtidal area located in the outer reaches of Sullom Voe and is a more exposed voe subjected to pressures resulting from the landfall of major oil and gas pipelines from the north.

1.2. AIMS AND OBJECTIVES

The overarching aim of the 2018 benthic survey was to determine the current condition of the infaunal communities and sediments present at Sullom Voe and in the surrounding areas. Additionally, this report has assessed the status of benthic fauna and sediments by examining data collected in 2018 alongside historical data to determine ecological and environmental changes over time.

The project objectives were therefore as follows:

- To undertake a subtidal survey of Sullom Voe and Orka Voe in line with the historic methodology;
- To undertake an intertidal survey of the Garth's Voe and Houb of Scatsta in line with the historic methodology;
- To undertake analysis of the 2018 data against the historical data to contextualise any trends in infauna, sediment and contaminants over time; and
- To provide a technical report complete with maps of the infaunal communities, sediments and biotopes present at the study site.

To achieve these aims and objectives Eco Marine conducted a survey alongside SGS in the vicinity of Sullom Voe in June 2018. The results from the survey are presented in this document.

2. METHODS

2.1. SAMPLING PROTOCOL

All field work for the 2018 sampling was carried out between the 6th June and the 10th June 2018 on-board the vessel Sullom Shearwater. A total of 26 sample stations were targeted in triplicate for sampling, corresponding to the locations of the historic sampling points.

Quantitative samples for faunal analysis were obtained using a Day grab, which removed 0.1m2 of sediment to a depth of approximately 10cm. Five replicate biological samples were taken at each of the 26 macrofaunal target stations, of which three samples were kept for infaunal, sediment and contaminant analysis where possible. The location and distribution of stations can be seen in Figure 1.

Following deployment, the grab was brought aboard, checked for capacity and the sample was discharged into a collection box. A photograph of each untouched sample in the grab was taken as evidence of collection (Appendix Plate 1). A photograph of each faunal sample following sieving was also taken for future reference. Detailed field notes were recorded including, as a minimum, the grab coordinates, time of sampling, depth, sample volume and weather. Where a 5L minimum size sample could not be recovered on the first attempt (due to seabed conditions in areas of high scour and bedrock), a further two attempts were made. If a sample greater than 5L could not be obtained following three attempts, the largest of the collected samples was kept for qualitative faunal analysis.

Sub samples of approximately 0.5L were taken for sediment particle size analysis (PSA) from each sample and carefully labelled. The remainder of the sample was placed on a 1mm-mesh net supported on a stainless-steel sieve and gently eluted with seawater to remove excess fine sediments. The sample was then transferred into a secure and labelled container and preserved in buffered formalin. The samples were then retained for subsequent analysis of the benthic infauna in the laboratory.

At each station, sub-samples for contaminant analysis (hydrocarbon and organic content) were collected from the top 2cm of the three samples retained for faunal analysis. PSA and contaminant samples were also taken at six soft shore sites in Gluss Voe and the Houb of Scatsca, which were accessed by foot. No macrofaunal samples were collected at Gluss Voe or the Houb of Scatsca.

Historically, when samples of less than 5L of sediment was collected, PSA and the full range of contaminants samples were not retained to maximise the amount of sediment available for faunal analysis. Samples for PSA and organic content were collected at all stations. Total aliphatic hydrocarbon and total organic carbon samples were retained from all stations, while aromatic hydrocarbon (PAH/NPD) samples were only taken from Stations SV1, SV4, SV6, SV6F, SV7, SV17, SV34, OV1B and OV5B due to the limited volume of sediment which could be retained for chemical analysis.

Prior to the commencement of the last benthic survey in 2016, seven of the macrofaunal station locations that had been historically sampled were relocated due to their close proximity to potential features of conflict, including an oil pipeline. Each of these stations was relocated so that they were a minimum of 200m from any potentially sensitive infrastructure. Samples were collected from these relocated stations in 2018 and can be identified by the suffix of 'B' after the original location codes used in previous surveys, for example, OV1 is now referred to as OV1-B. Each of the stations sampled during the 2018 survey are shown in Figure 1 below.

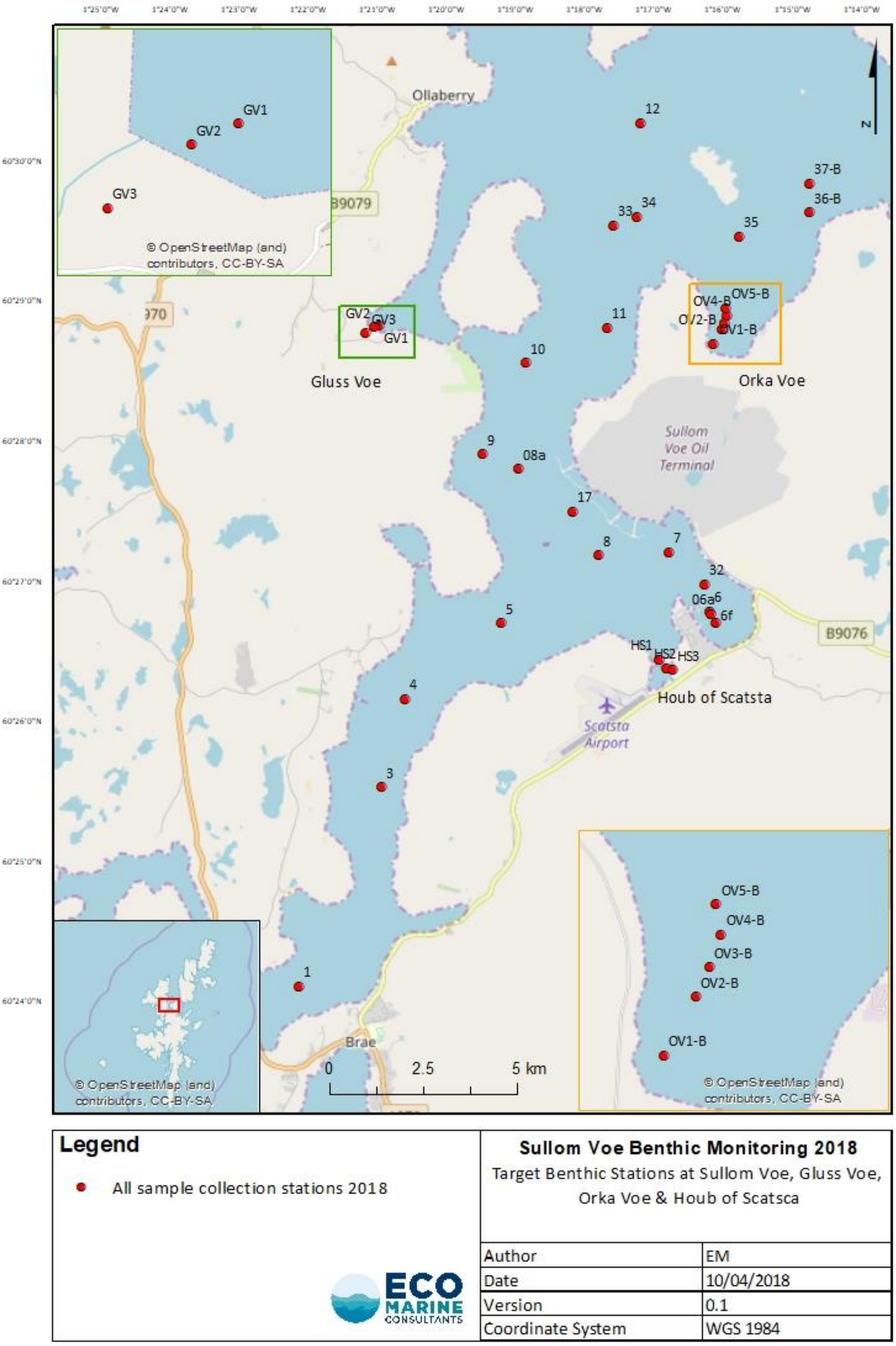

Figure 1. The location and distribution of target macrofaunal and sediment particle size analysis stations at Sullom Voe and Orka Voe in 2018.

2.2. INFAUNAL ANALYSES

To ensure continuity of the data, the methodology for the processing of benthic faunal samples was not altered from previous years. Additionally, highly trained Senior Taxonomists with experience in processing Sullom Voe samples and had full access to the Sullom Voe reference collection undertook the faunal analysis. On arrival at the Eco Marine analytical laboratory facilities the samples were checked against the field notes (Appendix 1) in accordance with standard operating procedures and signed against the list of samples collected. The excess formalin from each sample was poured through a 1mm-mesh sieve and collected for licensed disposal. Each sample was gently eluted with tap water through a 1mm-mesh sieve to extract the low-density components (crustaceans and polychaetes) and combined with the floating material initially separated from the formalin in the sample. The larger macrofauna were removed from the eluted material and preserved for analysis. This stage in the initial sorting process was carried out in the open air to reduce the effects of residual formalin used to fix the sample in the field.

The sediments were sorted under a stereomicroscope with the aim of extracting the fauna. The entire sample of separated fauna was then preserved in industrial methylated spirit (IMS) for subsequent analysis. Each of the extracted samples was sorted into major faunal groups before being analysed by experienced taxonomists, who sign a log sheet on completion of the analysis of each individual sample.

Organisms were identified to the highest possible taxonomic resolution (species level where possible). Colonial organisms (e.g. hydroids and bryozoans) and attached epifaunal taxa were recorded qualitatively. Examples of taxa not previously identified in samples collected as part of this monitoring programme survey were preserved separately and added to the ongoing reference collection.

Taxonomic identification was checked against strict QA measures throughout the process. Species identification was recorded in a standard format using species codes from Howson & Picton (1997). Following this, the data were entered into the Eco Marine database in a standardised format. Subsequently all taxon names were then checked against the World Register of Marine Species (WoRMS) database to ensure that the most up-to-date names were used. Species identification was recorded in a standard format using WoRMS Aphia identification codes assigned to each name. All species names from the faunal data were run through the WoRMS database prior to temporal faunal analysis to ensure that no false diversity records would occur. The full species abundance matrix for the 2018 survey is in Appendix 2.

The sediment samples were subjected to PSA carried out by SGS. PSA samples were obtained from all sample stations with the exception of SV36B and SV36C where full faunal samples could not be collected as they were considered undersized.

The sediments were sieved at ½ phi[1] intervals over a particle size range of 64mm-0.063mm on the Wentworth Scale. The PSA values are summarised in Appendix 3 into higher groupings of % silt (<0.063mm), % sand (0.063-2mm) and % gravel (>2mm), for ease of broad-scale substrate assessment. These data were used for the description and classification of sediments.

[1] Phi = $-\log_2 D/D_0$ (D is the diameter of the particle, D_0 is a reference diameter, equal to 1mm).

Sub-samples were also collected from each sample for chemical analyses which were also completed by SGS. All benthic samples were tested for percentage organic content, UCM, UCM % total aliphatics. Samples from SV1, SV6, SV6f, SV7, SV17, SV34, OV1B and OV5B were also tested for total naphtalenes, total phenathrenes, total dibenzothiophene, ΣNPD, total fluoranthenes/pyrenes, total benzanthracenes/chrysenes, total benzofluorathenes/benzpyrenes, total m/z276 and total 206 ring PAH.

2.3. Statistical Analyses

Basic faunal abundance and diversity data were available for each survey conducted from 2002-2018, though species matrices were not available to Eco Marine for the years 2002-2010. As such, overall abundance and diversity trends since 2002 have been examined, though a station by station breakdown and multivariate analyses was only possible for the survey years 2012, 2014, 2016 and 2018. Following the methods adopted in previous years, all faunal data were pooled prior to any analyses being conducted so that each station was represented by the contents of the three processed grab samples. This removed the need of averaging station data from the last four survey years where station by station abundance and diversity values were available to Eco Marine. Data since 2002 has been examined using univariate analysis while data from the last four survey years (2012, 2014, 2016 and 2018) was interrogated using multivariate analysis.

The principle tool used to undertake the suite of multivariate analysis on both the biotic and abiotic datasets was PRIMER v6.

The multivariate classification of the biological data used an agglomerative hierarchical clustering method in PRIMER-6. This technique was applied to a between-sample similarity matrix constructed using Bray-Curtis similarities (Bray & Curtis, 1957) that were derived from suitably transformed abundance values and with group-average sorting. Multi-dimensional scaling (MDS) ordination was used to represent, in two dimensions, the similarities between sample sites on the basis of their faunal composition. Following this, an analysis of similarity (ANOSIM) test was been carried out using abundance data to assess the differences in the infaunal communities between years.

In addition to the ANOSIM test, a Kruskal-Wallis rank sum test (as data were nonparametric) was conducted to determine any significant differences in the abundance and diversity data between the four most recent survey years.

A BEST BIOENV routine in PRIMER was also used to relate physicochemical and environmental variables to the biological data. This analysis is based on the premise that if a suite of environmental variables is structuring the biological community, then samples with similar values for these variables would be expected to have similar species compositions. Therefore, an ordination based on these abiotic variables should closely resemble the ordination of samples based on the biota. Selecting different combinations of the full set of environmental variables should allow the determination of an 'optimal' match of the separate biotic and abiotic ordinations. The exclusion of a key determinant will degrade the match, as will the inclusion of environmental variables that differ markedly between the samples but have no effect on community composition (Clarke & Ainsworth, 1993).

All data on the available environmental variables collected during 2018 were loaded into the PRIMER-6 workspace containing the biological multivariate analysis already presented. From this, draftsman’s plots (pairwise scatter plots) were generated to check if the samples were evenly distributed across the range of each variable. Skewed distributions were identified, and appropriate transformations applied to those variables, as skewed distributions must be transformed to justifiably use Euclidean distance as a similarity measure on normalised environmental variables. Draftsman's plots were also used to look for linear or curvilinear relationships, as such variables are effectively the same rather than independent. No variables were highly correlated enough to justify exclusion from the data set.

The dominant biotopes for each station were identified using sediment and faunal abundance data. Where possible, biotopes were identified to Level 6 but where a biotope did not fit or there was not enough information available, biotopes were only taken as far as confidently possible, which on occasion was Level 3. As in previous reports, biotopes were recorded in the MNCR format (Connor *et al*., 2004).

3. RESULTS

3.1. UNIVARIATE ANALYSIS

3.1.1. FAUNAL ABUNDANCE AT SULLOM VOE & ORKA VOE

Total faunal abundance at Sullom Voe has been variable since monitoring under the current format commenced in 2002, ranging from 36,132 individual specimens in 2002 to a peak of 77,070 individuals in 2006 (Figure 2).

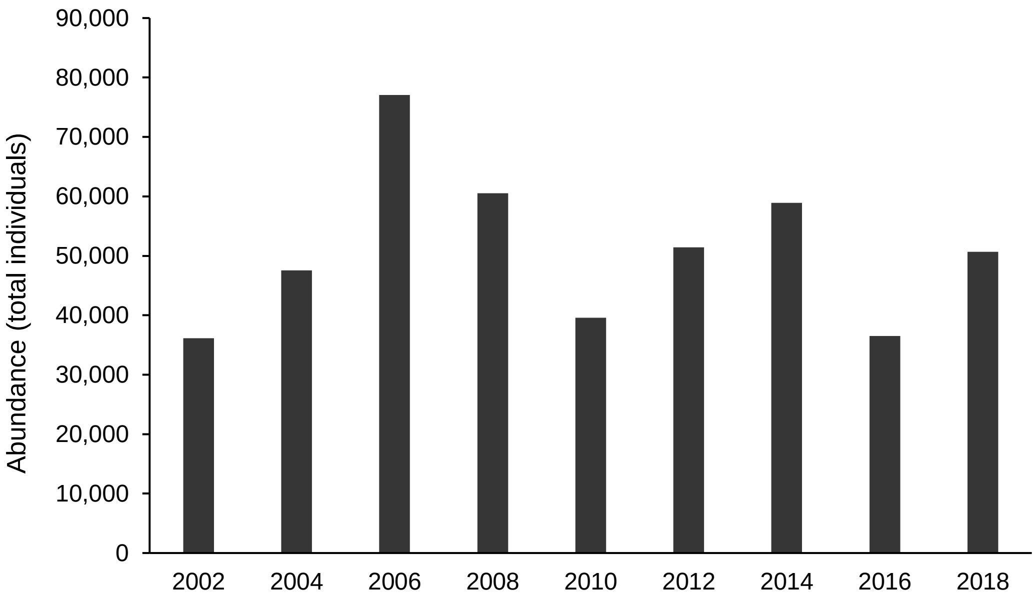

Figure 2. Total faunal abundance across all stations at Sullom Voe per survey year 2002-2018.

The total number of individuals recorded in 2018 was 50,670 (including Nematoda) which was the fifth highest observed since monitoring began in 2002. It should be noted that only a single sample could be obtained at Station 36 due to underlying bedrock on the seafloor, therefore faunal abundance at this station and by extension the overall dataset may be slightly underrepresented. Faunal abundance was elevated in 2018 when compared to 2016 and generally represented a median figure when compared to previous years. The total number of individuals in 2018 remained comfortably within the range of variability exhibited by the wider dataset since monitoring efforts commenced.

Species abundance per station for 2012-2018 is illustrated in Figure 3. It should be noted that samples from the 'B' stations in 2016 and 2018 were collected from slightly different locations from those collected at SV1-5 in 2002-2014 and should as such be observed with a degree of caution.

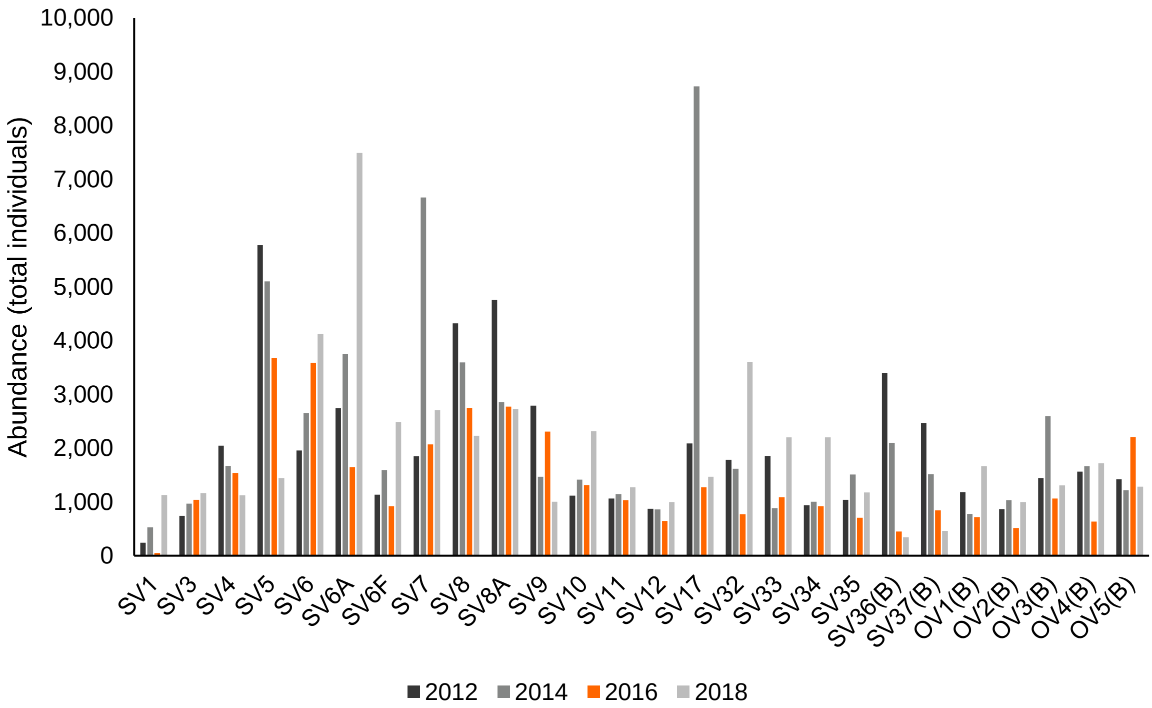

Figure 3. Faunal abundance per station at Sullom Voe, 2012-2018.

Disparity between years for species abundance is variable depending on the individual station being considered. Many stations, such as SV3, SV11 and SV12, demonstrate similar abundance values between years, while others show a greater level of variability. It is apparent that abundance at Stations SV7 and SV17 were especially elevated in 2014, which is largely attributable to very high records of the barnacle *Balanus crenatus* at these locations during the survey period. Abundance per station in 2018 was elevated when compared to previous years at several locations including Stations SV6A, SV10, SV32, SV33 and SV 34.

Though historically low, abundance at the southern-most station, SV1, was considerably higher in 2018 than in previous years with 1,130 individuals recorded compared to 48 individuals in 2016 and 525 in 2014. Conversely, abundance at SV6, SV8A and SV9 was lower in 2018 than in the previous three survey years, though by a relatively small amount.

Figure 4 illustrates the geographical change in abundance values at each station between the three most recent survey years. Faunal abundance was consistently highest in the mid-channel near to the Sullom Voe Oil Terminal, with abundance in 2018 being much more comparable to that of 2014 following an increase in specimens per station after the reduced numbers recorded in 2016. Abundance values in 2018 at the outermost stations (SV36B, SV37B and SV12) and the mid stations (SV10 and SV11) were elevated when compared to the two previous years though abundance at the station nearest to Sullom Voe was slightly reduced when compared to 2014 and 2016.

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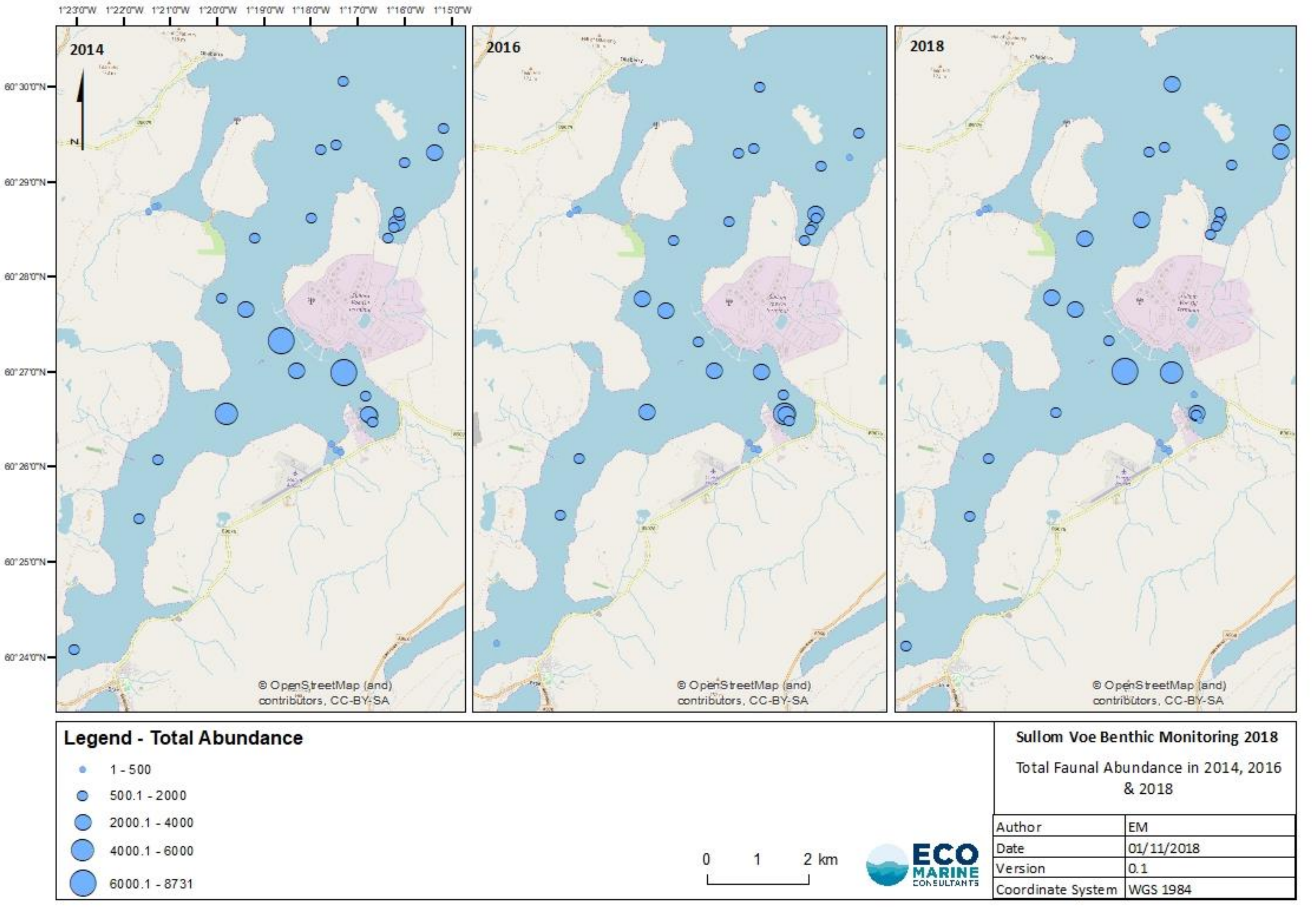

Figure 4. Total abundance of individual specimens identified in samples collected from the Sullom Voe survey area in 2014, 2016 and 2018.

3.1.2. Faunal Diversity at Sullom Voe & Orka Voe

A total of 575 taxa (including juveniles and egg records) were recorded in 2018 across the Sullom Voe survey area compared to 609 in 2016, 660 in 2014 and 622 in 2012. Faunal diversity has decreased slightly over the past two survey years but remained comparable to previously recorded levels. On average, 114 species were observed at each station in 2018 compared to 118 in 2016 and 124 in 2014 (Figure 5). When considering data since 2002, the highest average diversity per station was recorded in 2004 when 131 species per station was observed, while the lowest was recorded in 2002 when 105 species were recorded on average per station. The species diversity in 2018 was securely within the boundaries of variability which has been observed in previous years. It should be noted that while diversity in 2018 was decreased in comparison to 2016, a number of new species were recorded in 2018 which have not been observed in at least the last four survey years. This suggests that there is a degree of natural variation occurring within the faunal communities at Sullom Voe and that the observed decrease in diversity is not necessarily indicative of a decrease in localised community complexity.

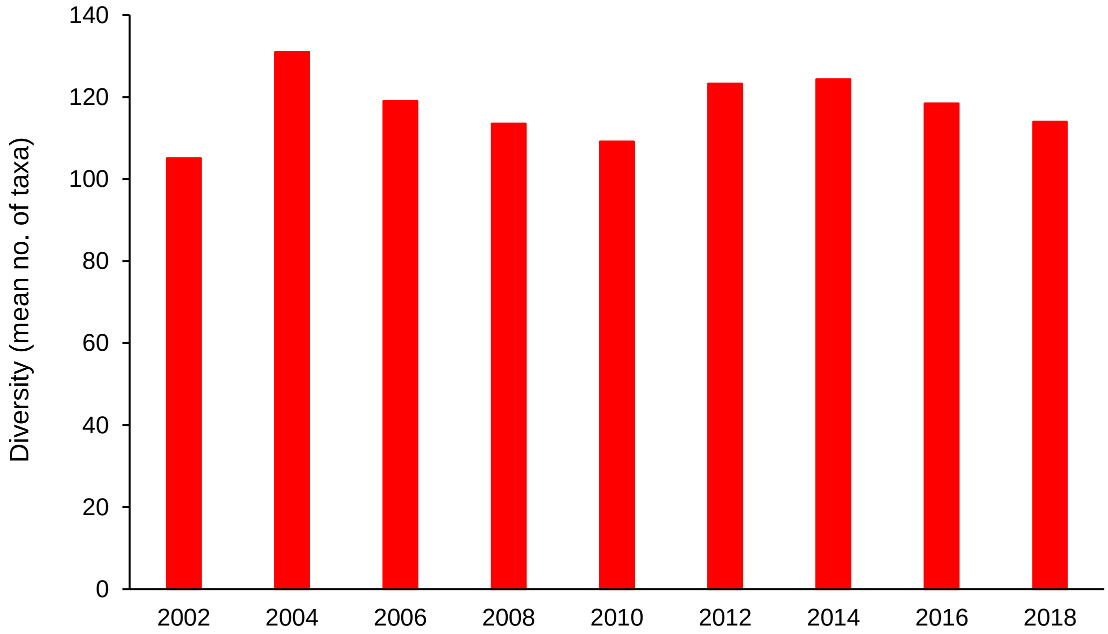

Figure 5. Average species diversity at Sullom Voe per station for survey years 2002-2018.

Total species diversity per station for recent survey years is illustrated in Figure 6. As with faunal abundance, it should be noted that samples from the 'B' stations in 2016 and 2018 were collected from slightly different locations from those collected at SV1-5 in 2002-2014 and should as such be observed with a degree of caution.

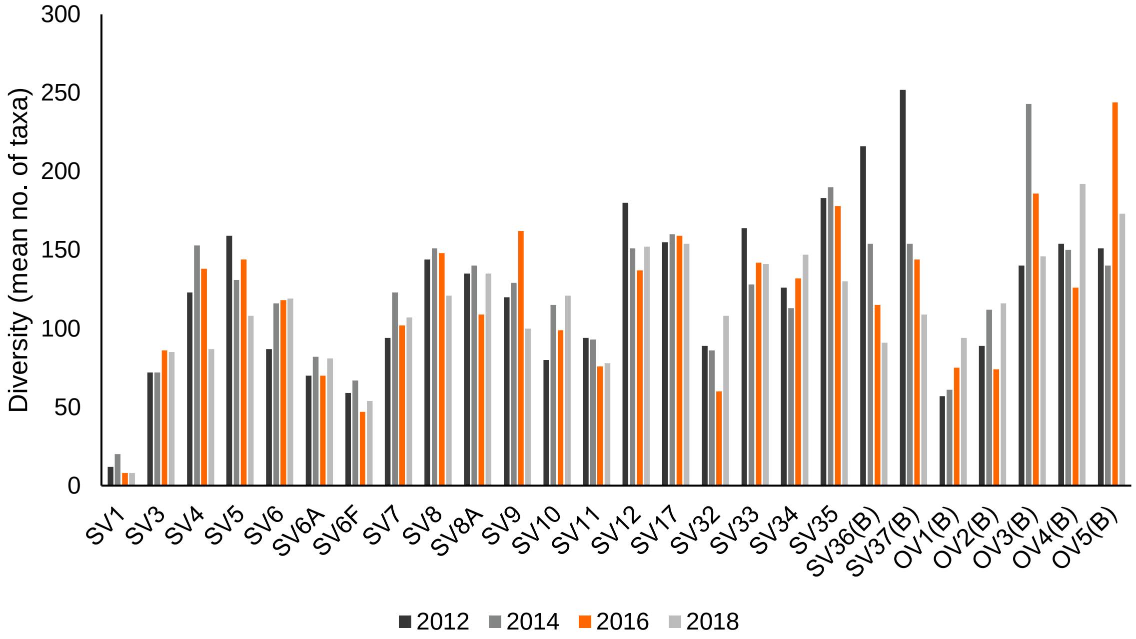

Figure 6. Mean species diversity per station during the Sullom Voe 2018 benthic survey.

It is evident from Figure 6 that there is less disparity between survey years in terms of diversity than when considering faunal abundance. Diversity has decreased slightly with each survey since 2014 though not substantially. While diversity is lower at some stations in 2018 than in previous years, values at several stations demonstrated higher diversity despite fluctuations in abundance.

Diversity was especially high in 2018 at several of the Orka Voe stations when compared to previous years which may be due to natural variability within faunal communities, although may also be attributable to the relocation of these sites from 2016 onwards. Conversely, diversity decreased at the two other relocated stations (SV36 and SV37) in both 2016 and 2018 when compared to previous years.

Figure 7 illustrates geographical changes in species diversity over the past three survey years. It is evident that diversity in 2018 has varied geographically compared to 2014 and 2016. In particular, diversity in the central channel stations adjacent to Sullom Voe (SV8 and SV 17) has decreased though the number of taxa recorded at other stations remained similar to that recorded previously. The increase in abundance and decrease in diversity at these central channel stations suggests that a few taxa have become more successful here and were more dominant in the benthic community in 2018. The taxa recorded in the samples collected from SV8 and SV 17 were typically dominated by numerous Annelida such as *Prionospio fallax* and *Lumbrineris cingulata* as well as small bivalves such as *Thyasira flexuosa* and barnacles.

Proportionally, species abundance at Sullom Voe has decreased to a greater extent than diversity in 2016 compared to previous years, suggesting that while the number of individuals may have declined marginally, general populations have remained healthy and are represented by the same species seen throughout the monitoring programme from 2012 onwards.

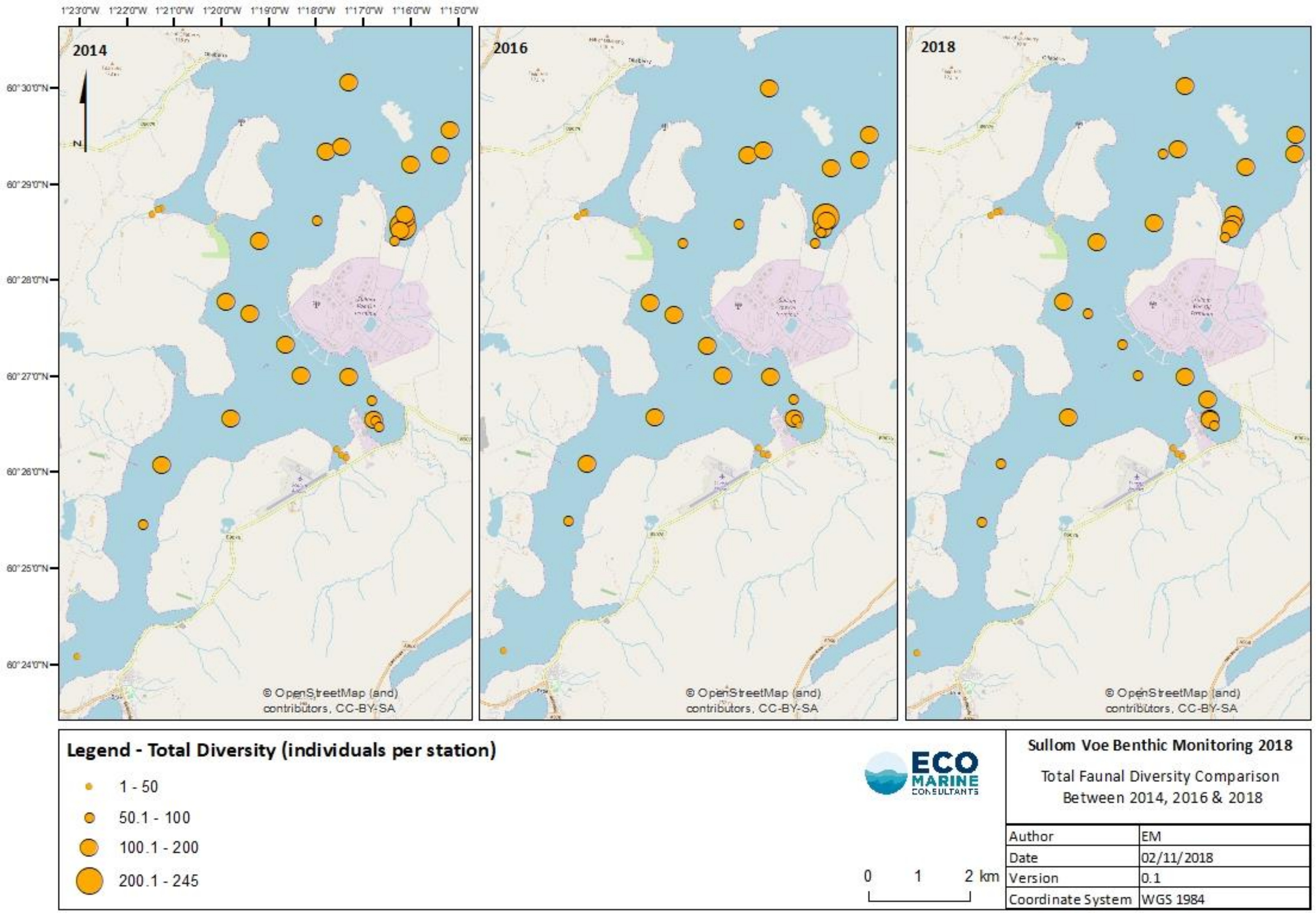

Figure 7. Total diversity of individual taxa per station at Sullom Voe in 2014, 2016 and 2018.

Individual species contributions at Sullom Voe in the last three benthic surveys have remained relatively similar, with the same common taxa being recorded year-on-year as shown in Table 1. Similarities in the faunal communities observed at Sullom Voe in recent years suggests a degree of stability within the benthic environment which has allowed some taxa to thrive in high numbers. It should be noted that the abundance for Nematoda has been excluded from Table 1 due to the extremely high number recorded within samples during each survey year.

Table 1. The ten most abundant species (excluding Nematoda) in the past three survey years (2014 2016 and 2018) at Sullom Voe. (An) = Annelida; (Cr) = Crustacea; (Mi) = Miscellanea; (Mo) = Mollusca.

2014		2016		2018	
Taxon Name	Total	Taxon Name	Total	Taxon Name	Total
Balanus crenatus (Cr)	15,299	*Thyasira flexuosa* (Mo)	4,720	*Thyasira flexuosa* (Mo)	4,644
Thyasira flexuosa (Mo)	5,857	*Phoronis muelleri* (Mi)	3,891	*Prionospio fallax* (An)	4,349
Phoronis muelleri(Mi)	3,719	*Prionospio fallax* (An)	2,606	*Kurtiella bidentata* (Mo)	2,907
Kurtiella bidentata (Mo)	1,583	*Kurtiella bidentata* (Mo)	1,845	*Tubificoides benedii* (An)	2,829
Tubificoides benedii (An)	1,383	*Tubificoides benedii*(An)	1,595	*Phoronis muelleri* (Mi)	1,915
Prionospio fallax (An)	1,377	*Turritella communis* (Mo)	1,481	*Mediomastus fragilis* (An)	1,837
Turritella communis (Mo)	1,233	Spirobinae (An)	1,341	Copepoda (Cr)	1,686
Galathowenia oculate (An)	826	*Lumbrineris cingulata* (An)	748	*Capitella* (An)	1,334
Spirobranchus triqueter (An)	824	*Mediomastus fragilis* (An)	714	*Lumbrineris cingulata* (An)	1,226
Nemertea (Mi)	709	*Balanus crenatus*(Cr)	609	*Paradoneis lyra*	1,111

Table 1 illustrates an overall greater abundance in the most recorded species in 2018 when compared to 2016. Additionally, a larger number of taxa were more abundant than in previous years, with the ten most abundant taxa recorded more than 1,000 times each across the 76 faunal samples.

As has been observed in previous years, the small bivalve *T. flexuosa* was highly abundant across Sullom Voe and Orka Voe in 2018. Individual numbers have reduced marginally over the past three surveys though *T. flexuosa* remained the most frequently recorded specimen in 2018. *Prionospio fallax* increased in abundance in 2018 when compared to previous years, though as a species it has always been abundant and was recorded as the sixth and third most abundant species in 2014 and 2016 respectively. *K. bidentata* was the third most recorded species in 2018 and has been observed in abundance in previous years though individual records increased in 2018.

There was generally a lower occurrence of Cirripedia (barnacles) in 2018, with fewer records of *Balanus crenatus* in particular when compared to the previous two survey years. High records of *B. crenatus* are typically associated with the recovery of boulders and cobbles within grab samples as Cirripedia rely on these for anchor points. As such, overall Cirripedia abundance can be highly influenced by the presence of one or two heavily colonised rocks within samples, which may have been absent in 2018.

Both annelids *Capitella* and *Lumbrineris cingulata* were more abundant in 2018 than the previous two survey years as was the crustacean Copepoda. Historically, *L. cingulata* has been recorded in relatively high abundance at Sullom Voe, though *Capitella* less so (53 and 244 times in 2014 and 2016 respectively). The elevation of the *Capitella* population in recent years may be pertinent as *Capitella capitata* may be used as a positive indicator of a stressed community due to pollution (Dean, 2008). However, *C. capitata* is considered to be a widespread and cosmopolitan species and as such, any relationship to a degradation in the benthic environment at Sullom Voe remains ambiguous.

3.1.3. Rare and Non-Native Species of Interest at Sullom Voe

A number of rare, alien and protected species were recorded in the 2018 faunal samples. These included the OSPAR-listed ocean quahog Arctica islandica, the nationally rare sea slug Calliopaea bellula, the nationally scarce orange-footed sea cucumber Cucumaria frondosa, the IUCN Red-listed edible sea urchin Echinus esculentus, the nationally scarce purple sea urchin Paracentrotus lividus, and the alien soft-shell clam Mya arenaria. The distribution of these species in 2018 is shown in Figures 8-10).

Though recorded in 2016, the green sea urchin, Strongylocentrotus droebachienis was not recorded in 2018. It is listed as nationally scarce in British waters and recent records are from shallow inshore areas of Shetland only. Similarly, the nationally-scarce amphipod species Harpinia laevis which was last recorded in 2014 was unobserved in both 2016 and 2018. The nationally rare bryozoan Cylindroporella tubulosa was recorded in 2014 and 2016 but was absent from the faunal samples in 2018. It is understood from isolated records (JNCC, 1999) that the Shetlands and northern Scotland represent the southerly limit of this species and as such records within the historical dataset are expected to be variable.

As illustrated in Figure 8, the long-lived Icelandic or ocean quahog Arctica islandica was sampled in low to medium abundances at 10 stations during 2018. A total of 23 individuals were recorded during the most recent survey compared to 27 in 2016 and 33 in 2014. A. islandica is an OSPAR-listed species known for its slow growth rate and long lifespan and is known to occur throughout the UK including the Shetlands. The distribution of the species in 2018 is similar to that recorded during previous monitoring surveys of Sullom Voe.

A total of 20 individuals of the sand gaper Mya arenaria was recorded across eight stations in 2018 compared to two and seven stations in 2016 and 2014 respectively (Figure 9). This bivalve is an introduced alien species that is found on all British coasts, including the Shetlands (Oliver et al., 2010), although is not a recent introduction.

As can be seen in Figure 10, a single Calliopaea bellula specimen was recorded in 2018 at one of the northernmost stations, SV36B. The record of this nationally rare sea slug is the first at Sullom Voe within recent data available to Eco Marine. Records of C. bellula in Britain are exceedingly rare though it has been recorded elsewhere across Norway and the Mediterranean (NBN, 2017).

A single record of the orange-footed sea cucumber C. frondosa was made in 2018 at Station SV5 in the central channel of the Voe (Figure 10). The distribution of C. frondosa is known to be limited to the Shetland and Orkey Islands in the UK though this is the first record at Sullom Voe within recent data available to Eco Marine. C. frondosa is most commonly found on the lower shore on coarse grounds and among kelp holdfasts (Bleach, 2008) which are numerous in the wider Sullom Voe area.

A single edible sea urchin, Echinus esculentus was recorded at SV8A in the central channel in 2018 (Figure 10; Plate 1). E. esculentus is listed as 'near threatened' on the global IUCN red-list but is relatively abundant in the north east Atlantic (Tyler-Walters, 2008). A single E. esculentus was also recorded at Sullom Voe in 2016 though was not observed in 2012 or 2014.

Plate 1. A *Echinus esculentus* (edible sea urchin) recovered at Station SV8A during the benthic survey of Sullom Voe in 2018.

The nationally rare purple sea urchin Paracentrotus lividus was recorded once at Station SV9 located to the west of the central channel in 2018 (Figure 10). Though nationally rare, P. lividus is known to be distributed across the UK, although records so far north as the Shetland Islands are unusual (Pizzolla, 2008) and it has not been recorded at Sullom Voe within recent datasets (since 2012).

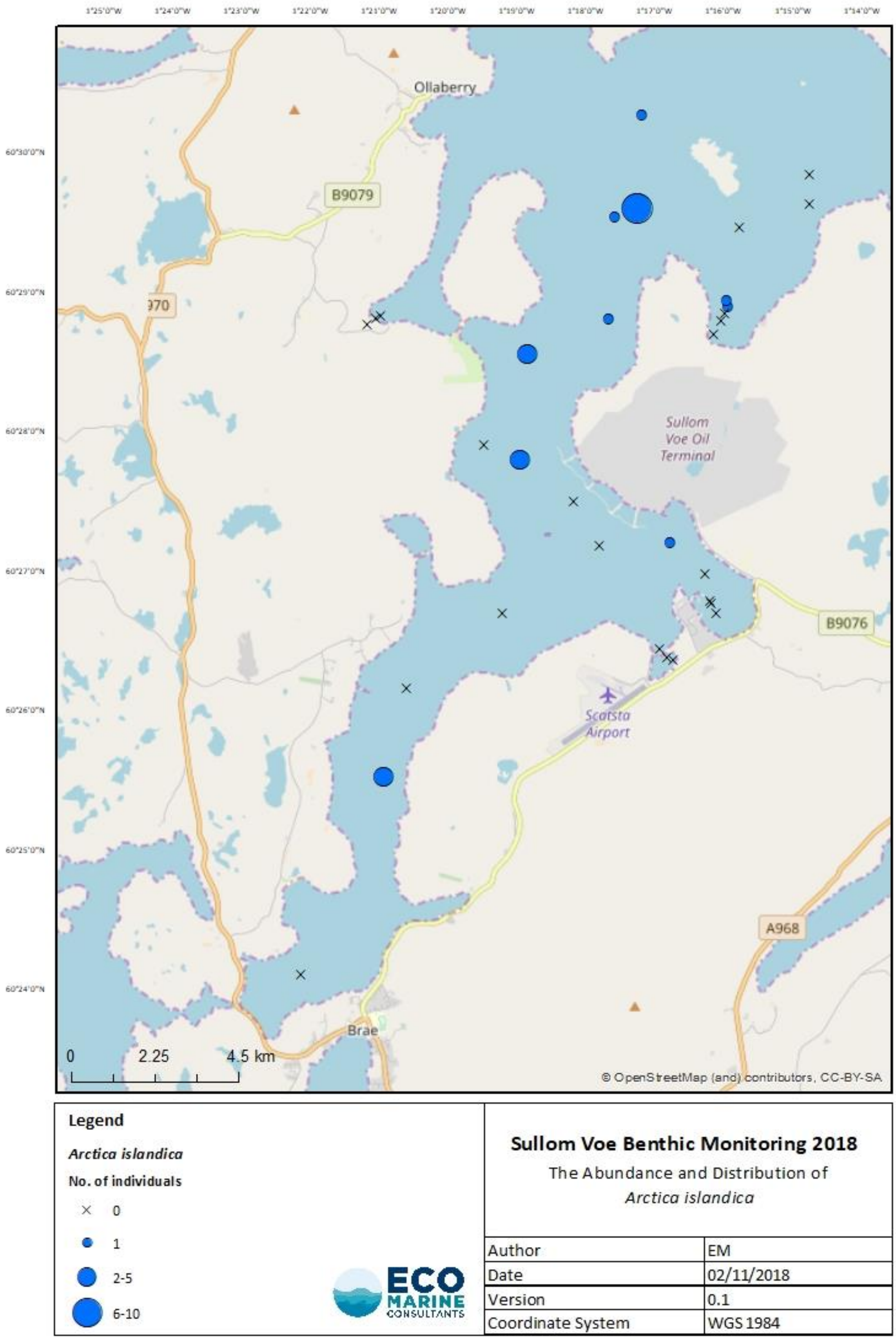

Figure 8. The abundance distribution of *Arctica islandica* as determined during the 2018 survey of Sullom Voe.

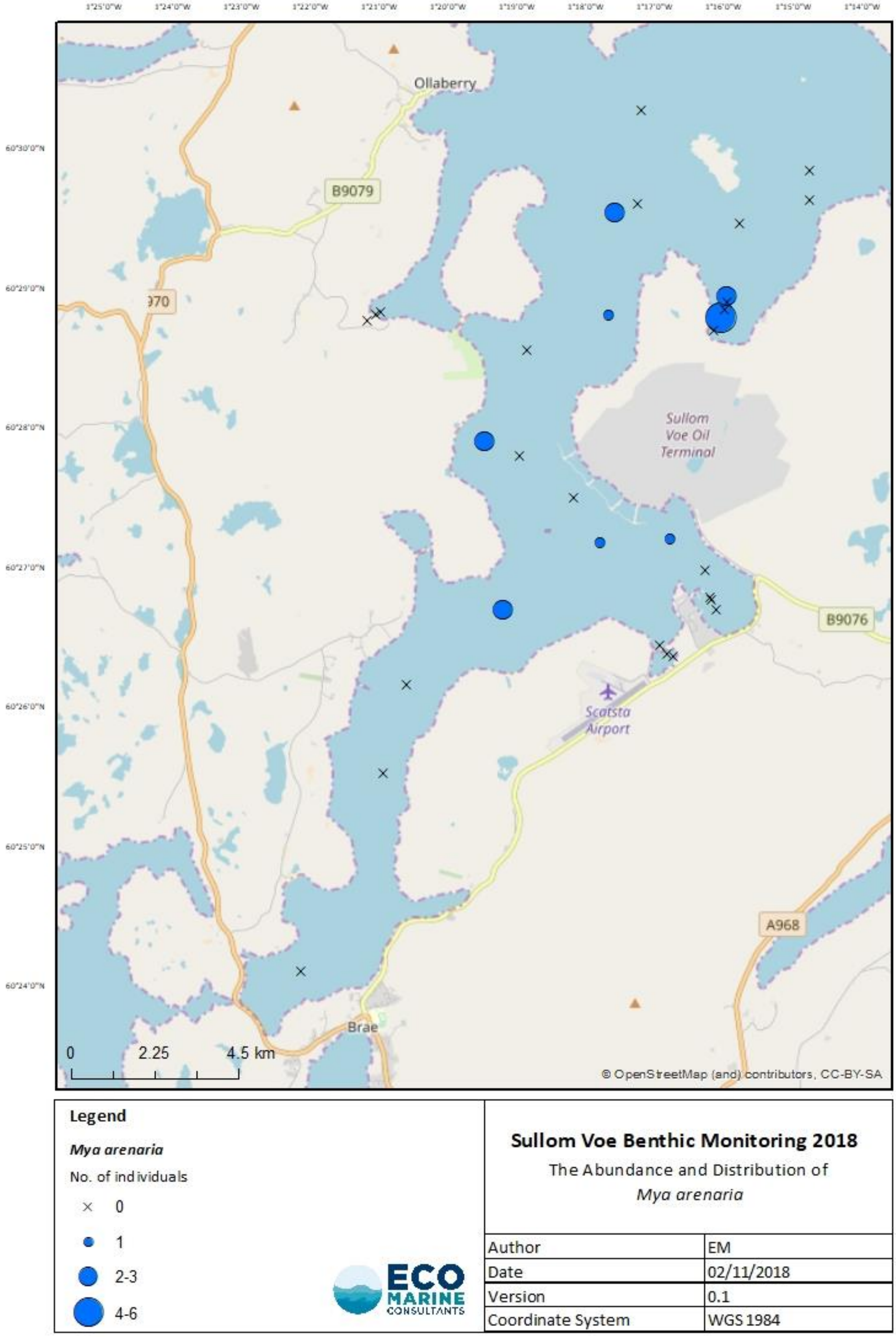

Figure 9. The abundance distribution of *Mya arenaria* as determined during the 2018 survey of Sullom Voe.

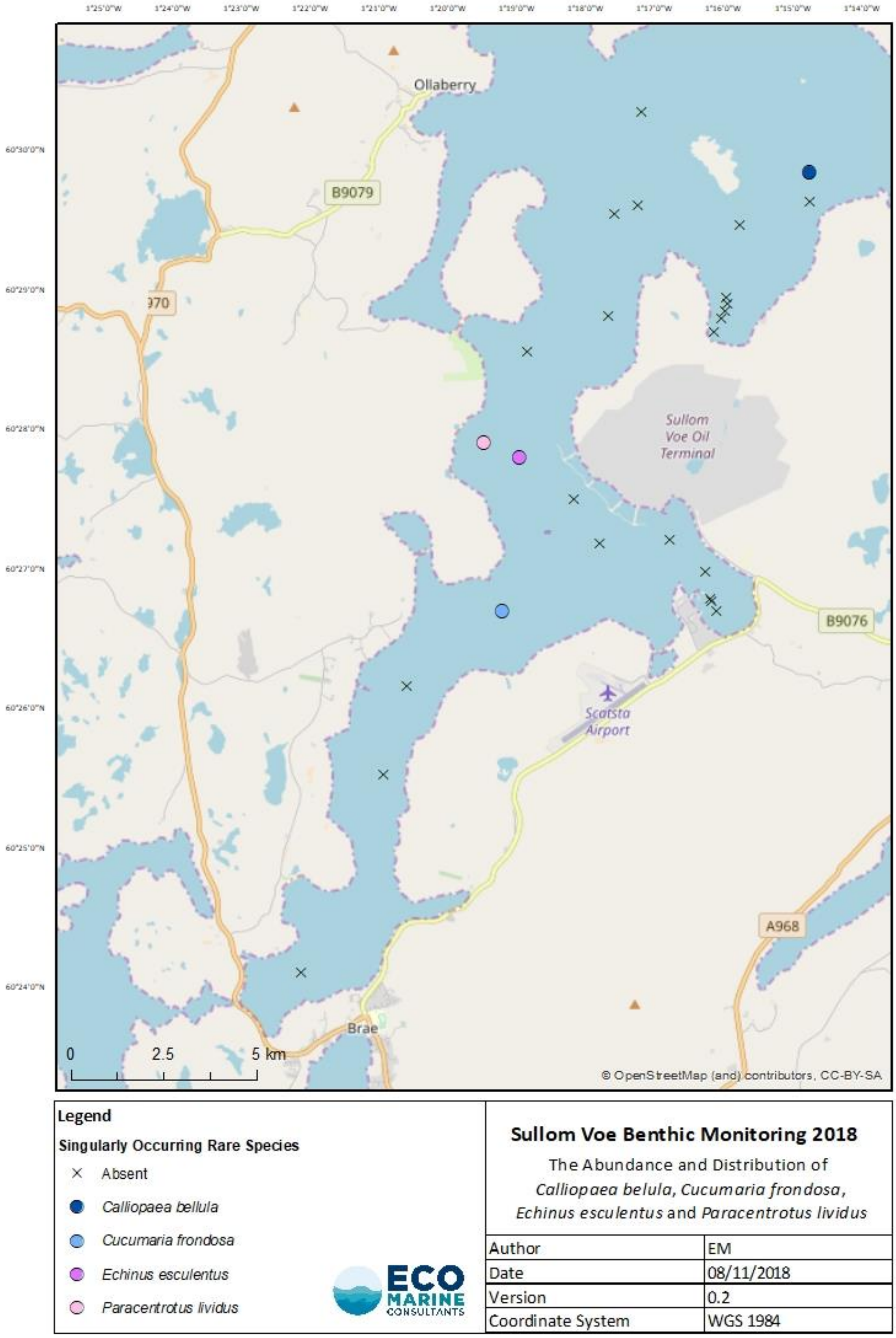

Figure 10. The abundance distribution of *Calliopaea bellula, Cucumaria frondosa, Echinus esculentus and Paraciticus lividus* as determined during the 2018 survey of Sullom Voe.

3.2. MULTIVARIATE DATA ANALYSIS

Multivariate analysis has been used to scrutinise abundance data over time in greater detail. This analysis examines the full faunal community data from each year and uses groupings of samples to identify patterns and differences.

An analysis of similarity (ANOSIM) test has been carried out on the 2012, 2014, 2016 and 2018 abundance data to assess the differences in the infaunal communities between years. The test revealed a high degree of overlap between the community composition of Sullom Voe as a whole between 2012, 2014, 2016 and 2018 suggesting that, although some change has occurred, the faunal communities present remain very similar (R = 0.184, significance level = 0.1%). Further to the results of the overall ANOSIM test, the results of the pairwise tests are shown in Table 2, which illustrates that in each of the years compared, there was a high degree of overlap which was found to be significant in every case.

Table 2. Outputs of the pairwise ANOSIM test conducted using faunal abundance data from the surveys undertaken at Sullom Voe in 2012, 2014, 2016 and 2018. Please note that significance is taken at the 5% mark. Where R is approaching 1, samples are highly different; where R is approaching 0, samples are highly similar.

Groups	R value	Significance level (%)
2016, 2014	0.176	0.1
2016, 2012	0.219	0.1
2016, 2018	0.116	0.1
2014, 2012	0.163	0.1
2014, 2018	0.222	0.1
2012, 2018	0.209	0.1

In support of the ANOSIM test, a Kruskal-Wallis rank sum test was conducted which revealed that there was no significant difference in abundance across stations between survey years since 2012 (H = 5.97, p-value = 1.113, where p = <0.05).

Additionally, an examination of the diversity data for 2012, 2014, 2016 and 2018 revealed that there has been no significant change in diversity across stations between years (H = 0.89, p-value = 0.83).

The SIMPROF routine In Primer V6 was employed to find natural groupings of stations comprising similar faunal communities. The routine determined 17 statistically-distinct faunal assemblages within the 2018 abundance dataset (compared to 18 groups in 2014 and 16 groups in 2014) and the pattern observed in the corresponding MDS ordination was similar to that seen in the previous two surveys. SIMPROF groups were however numerous and often represented communities at a single station which was deemed unhelpful in producing plots to showcase the geographic spread of similar communities. As such a manual cut-off of 42% on a cluster dendrogram run using faunal abundance data was used to create fewer, more meaningful groups. The species composition of each group was identified through a SIMPER analysis. The four faunal groups derived from the 42% cut-off were somewhat similar to those identified during the 2016 monitoring and help provide a clearer indication of the geographical distribution of the faunal assemblages (Figures 11 -13).

Biotope classifications have also been assigned to stations within faunal groups where possible. It should be noted that appropriate biotopes could not be fitted to all stations and for some, more than one biotope appeared to fit though often at differing hierarchical levels. For a full breakdown of biotope assignment by station, please refer to Appendix 6. Some of the biotopes that were assigned to the stations in 2018 have not been recorded at Sullom Voe in recent years, though faunal communities have not demonstrated any large degree of change which is reflected in the similarity in several of the faunal groups produced using the SIMPROF routine in Primer. Biotopes designated in 2018 but not recorded in recent survey years included: ‘Amphiura brachiata with Astropecten irregularis and other echinoderms in circalittoral muddy sand’, ‘Thyasira spp. and Nuculoma tenuis in circalittoral sandy mud’, ‘Circalittoral mixed sediment’, ‘Circalittoral muddy sand’ and ‘Circalittoral sandy mud’.

Descriptions of each faunal group identified in the 2018 Sullom Voe faunal data are described below, along with biotope classifications where appropriate. The cluster dendrogram and MDS plot used to define groups is shown in Figures 11 and 12, and a spatial plot of the groups is shown in Figure 13.

Faunal Group A – Stations SV6, SV6A, SV6F and SV32

The average similarity between faunal assemblages at the four stations encompassed by faunal Group A was 59.2% which was accounted for by the contributions of 41 taxa. All of these stations were located at Garths Voe within the shallow enclosed bay to the south of Sullom Voe oil terminal and were geographically distinct from the other stations. The samples collected at the sites were dominated by Nematoda, K. bidentata, Mediomastus fragilis and Tubificoides benedii, (% contributions to group: 10.04, 8.74, 7.38 and 6.76 respectively). Folk sediment classification and biotopes at these sites were characterised by ‘muddy Sand’ (mS) and ‘slightly gravelly muddy Sand’ ((g)mS).

The species and sediments identified as characteristic of most of the stations in this group are most consistent with those found in the biotopes ‘Circalittoral muddy sand’ (SS.SSa.CMuSa) though the biotope ‘Amphiura brachiata with Astropecten irregularis and other echinoderms in circalittoral muddy sand’ (SS.SSa.CMuSa.AbraAirr) was assigned to SV6A, the only station across Sullom Voe and Orka Voe with this classification. Nonetheless, communities were similar enough at a 42% cut off to be statistically grouped.

Faunal Group B – Stations OV2B, OV3B, OV4B and OV5B

The average similarity between faunal assemblages at the four stations grouped in faunal Group B was 51.68%, which was accounted for by the contributions of 93 taxa. All four stations within Group B were located within the relatively shallow Orka Voe region though notably, Station OV1B was not placed within the group based upon faunal community similarities. The faunal assemblages at the stations in Group B were dominated by Thyasira flexuosa, Copepoda, L. cingulata and Galathowenia oculata (% contributions to group: 6.60, 5.59, 3.67 and 2.71 respectively). Folk classification and biotopes at these stations were ‘slightly gravelly muddy Sand’ (mS), ‘gravelly muddy Sand’ (gmS) and ‘muddy sandy Gravel’ (msG).

The species and sediments identified as characteristic of most of the stations in this group are most consistent with those found in the biotope ‘Mysella bidentata and Thyasira spp. in circalittoral muddy mixed sediment’ (SS.SMx.CMx.MysThyMx)’ though there was also evidence of the Level 3 biotope ‘Circalittoral muddy sand’ (SS.SSa.CMuSa) at OV2 which due to faunal assemblages did not fit with ‘Mysella bidentata and Thyasira spp. in circalittoral muddy mixed sediment’.

Faunal Group C – Stations SV3, SV4, SV5, SV7, SV8, SV8A, SV10 and SV11

The average similarity between faunal assemblages at the four stations encompassed by faunal Group C was 53.41%, which was accounted for by the contributions of 64 taxa. All eight of the stations in Group C were geographically clustered in the deeper waters of the mid bay to the south-west of the Sullom Voe Oil Terminal further to the north. The sediment classifications at the stations within this group were 'slightly gravelly muddy Sand' ((g)mS), 'gravelly Mud' (gM), 'slightly gravelly muddy Sand' ((g)mS). The samples collected at the stations in this group were dominated by T. flexuosa, P. fallax, K. bidentata and Turritella communis (% contributions to group: 10.91, 8.46, 4.63 and 4.28 respectively).

The species and sediments identified as characteristic of most of the stations in this group are most consistent with those found in the biotopes 'Circalittoral sandy mud' (SS.SMu.CSaMu) and 'Circalittoral muddy sand' (SS.SSa.CMuSa) though there was also evidence of 'Mysella bidentata and Thyasira spp. in circalittoral muddy mixed sediment' (SS.SMx.CMx.MysThyMx) at SV3 and 'Thyasira spp. and Nuculoma tenuis in circalittoral sandy mud' (SS.SMu.CSaMu.ThyNten) at SV11 which was the only station for which this biotope was designated.

Faunal Group D – SV12, SV17, SV33 and SV34

The average similarity between faunal assemblages at the four stations encompassed by faunal Group D was 47.58%, which was accounted for by the contributions of 88 taxa %. With the exception of SV17 which was located adjacent to the Sullom Voe Oil Terminal, the stations in Group D were located in the northernmost portion of the survey area. The stations within this group were typically located in deeper waters with a maximum depth of 52.7m recorded at SV33 though SV17 was located in shallower waters (28.2m). The stations within this faunal group had a range of sediment types which were 'gravelly muddy Sand' (gmS), 'muddy sandy Gravel' (msG) and 'slightly gravelly muddy Sand' ((g)mS). The samples collected at the stations in this group were dominated by L. cingulata, Copepoda, Owenia and P. fallax (% contributions to group: 5.67,5.18, 4.00 and 3.87 respectively). Though SV17 is not located closely to the other stations in the group geographically, it demonstrated sediment characteristics more similar to some of the northernmost stations (Figure 14).

The species and sediments identified as characteristic of most of the stations in this group are most consistent with those found in the biotope 'Circalittoral muddy sand' (SS.SSa.CMuSa) though there was evidence of 'Circalittoral mixed sediment' (SS.SMx.CMx) at SV34.

Outliers – SV1, SV9, SV35, SV36B, SV37B and OV1B

Six stations were identified as outliers which did not group with any other stations: SV1, SV9, SV35, SV36B, SV37B and OV1B. These sites were a combination of stations ranging from the southernmost station (SV1) to a single station located in the mid-channel (SV9), the innermost Orka Voe station (OV1B) and the three deeper outer stations (SV35, SV36B and SV37B). Abundance at these stations was mid to high though faunal composition was not similar enough to any of the other stations for them to be grouped at a 42% cut off. Stations classified as outliers were located at a range of depths from 10m at OV1B to 39m at SV1.

As might be expected given the dissimilarity of the faunal communities at each the outlying stations, they were best represented by a variety of biotopes, some of which were observed at only a single station across Sullom Voe. These were 'Lagis koreni and Phaxas pellucidus in circalittoral sandy mud' (SS.SMu.CSaMu.LkorPpel) which was observed only at SV1 (as was also the case in 2016); 'Circalittoral muddy sand' (SS.SSa.CMuSa) which was designated to SV9, 'Mysella bidentata and Thyasira spp. in circalittoral muddy mixed sediment' was designated to SV35 (though many similarities with 'Circalittoral mixed sediment' were also apparent) and 'Circalittoral mixed sediment' (SS.SMx.CMx) which was designated to SV36B, SV37B and OV1B.

Stations SV35, SV36B, SV37B OV1B and SV9 were considered to be outliers despite some being closely located to stations which were grouped due to faunal similarities – most notably OV1B and SV9. When compared to the other stations in Orka Voe, OV1B typically had higher abundance but lower diversity values than other OV stations. Station SV9 had much lower total abundance and diversity when compared to surrounding stations (SV8A and SV10) and notable species such as P. fallax, which were abundant at surrounding stations were absent from samples collected at SV9. Stations SV35, SV36B and SV37B were geographically isolated and located in deeper waters than many other stations; as such a variation in faunal community here was not unexpected.

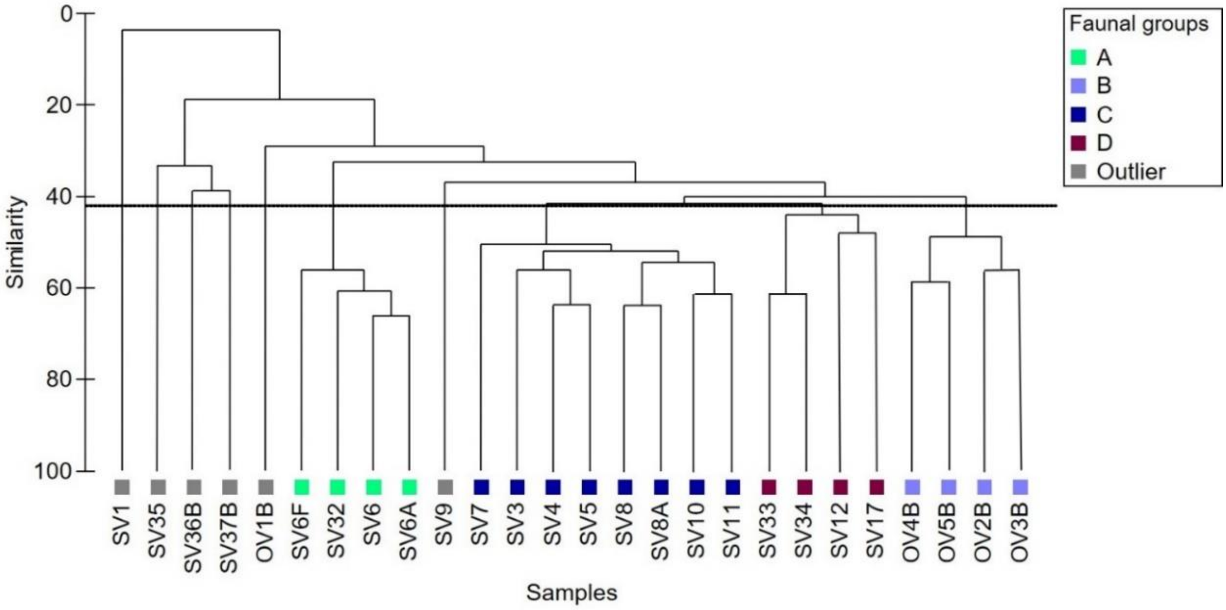

Figure 11. Cluster dendrogram representation of 2018 pooled abundance data from Sullom Voe, grouped according to similarities in faunal communities at a 42% cut-off (based on Bray-Curtis similarity and square root transformation).

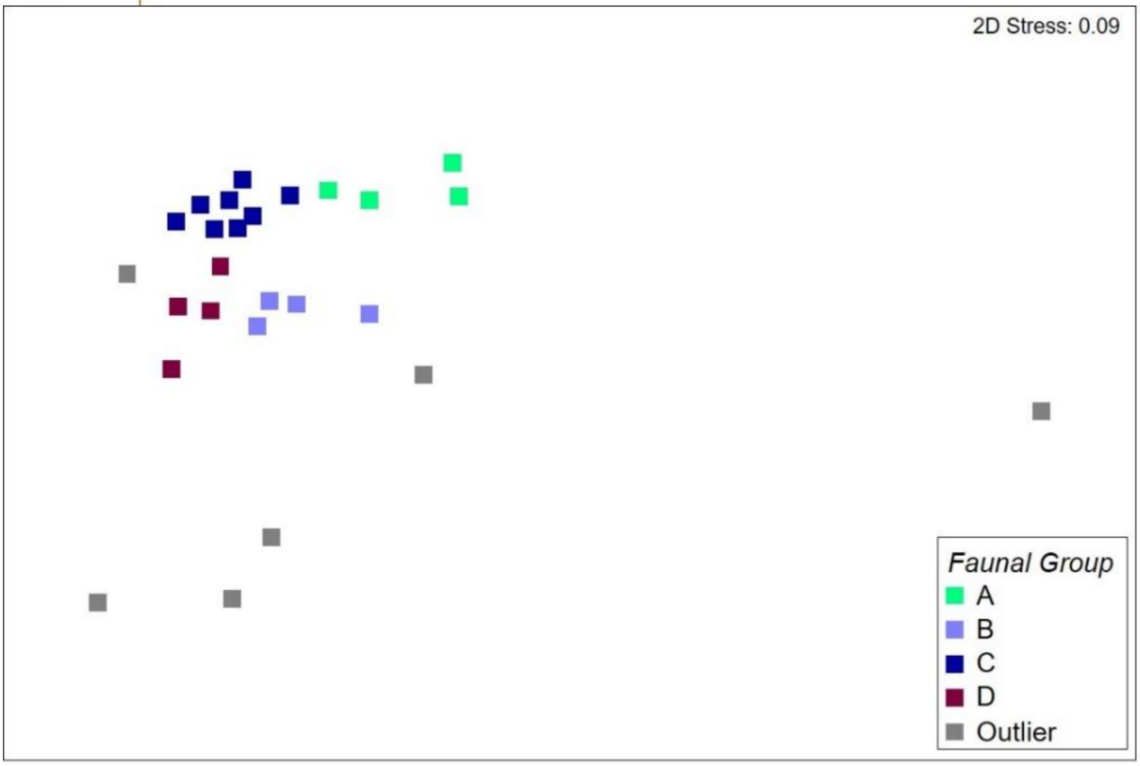

Figure 12. Two-dimensional representation of MDS ordination using 2018 pooled abundance data from Sullom Voe, grouped according to faunal group (based on Bray-Curtis similarity, square root transformation).

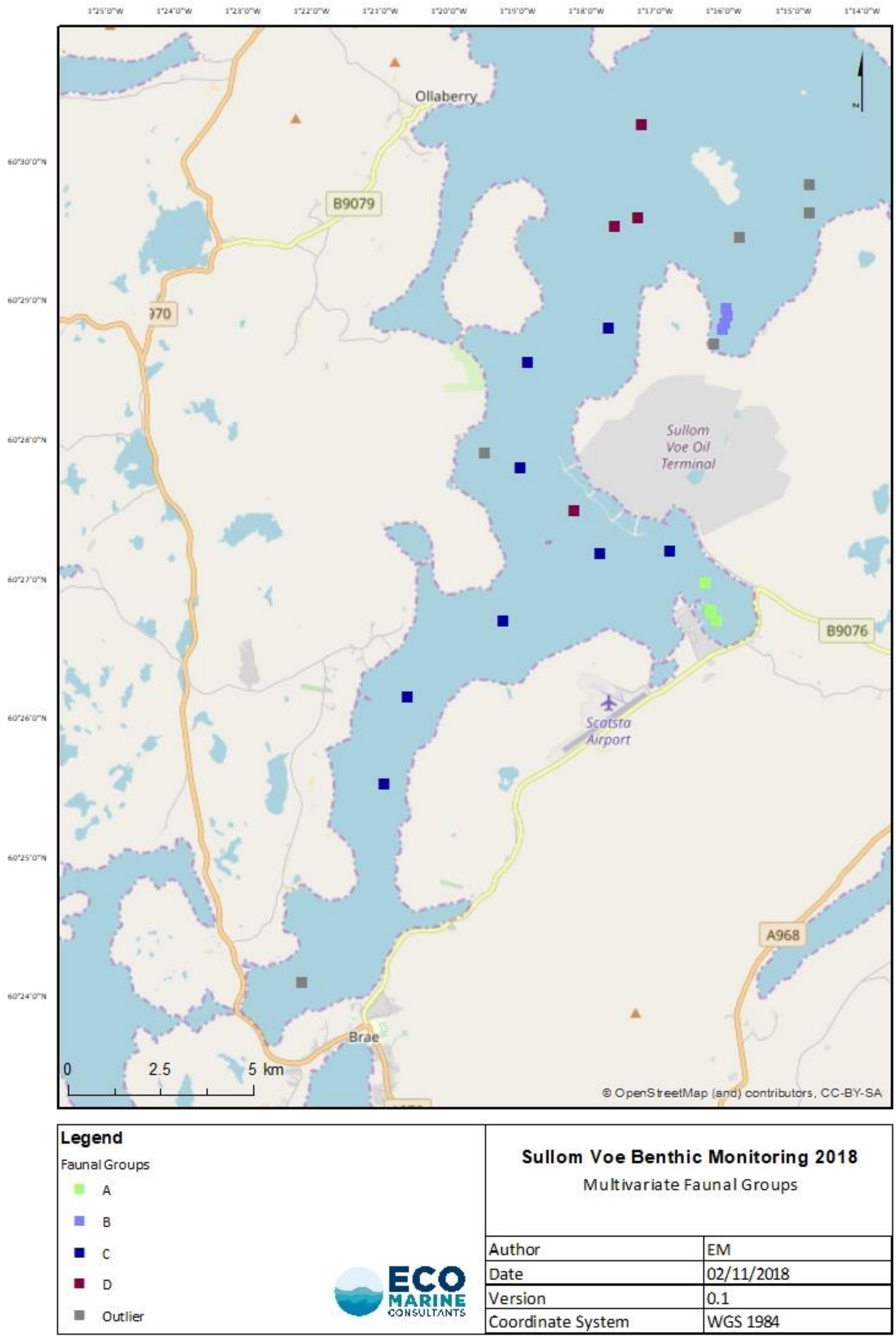

Figure 13. The distribution of faunal groups identified from samples collected at Sullom Voe in 2018.

3.2.1. Sediment Distribution

The pie diagrams in Figure 14 illustrate that the sediment composition of Sullom Voe was generally dominated by sand, although several stations also contained substantial fractions of mud and gravel. A full breakdown of sediment fractions by sieve size can be found in Appendix 2.

In order to further describe the substrate types recorded across the study area, sediment samples have been classified according to the Folk classification system (Folk, 1954). These Folk classifications are shown in Figure 15 (full breakdown in Appendix 3). A total of 11 Folk categories were identified during the 2018 survey: slightly gravelly muddy Sand ((g)mS), slightly gravelly Sand ((g)S), slightly gravelly sandy Mud ((g)sM), gravelly Mud (gM), gravelly muddy Sand (gmS), gravelly Sand (gS), muddy Sand (mS), muddy sandy Gravel (msG), Sand (S), sandy Gravel (sG), and sandy Mud (sM). The predominant Folk category recorded in 2018 was gravelly muddy Sand (gmS) which was recorded at six of the stations and demonstrates the importance of mixed sediments across Sullom Voe.

As is evident in Figure 14, there has been a marginal change in dominant sediment fractions across Sullom Voe from 2012-2018. The proportion of mud has increased in 2018 when compared to 2012 though the proportion of gravel has also become more dominant when compared to 2016. Nonetheless, the percentage of gravel in the samples remains within the envelope of natural variability observed over recent survey years. Station SV1 and other lower mid-channel stations in particular have been subject to an increasing silt fraction since 2012 though the sediment proportions remain similar in 2018 to those recorded in 2016.

Stations to the south of the oil terminal in the Houb of Scatsta which contained higher proportions of sand in 2016 appeared to be slowly returning toward historic sediment proportions more akin to those recorded in both 2012 and 2014 with an increase in gravel presence in 2018. Sediments at Orka Voe remain dominated by coarser fractions with the relocated stations demonstrating similar sediment characteristics to the original stations.

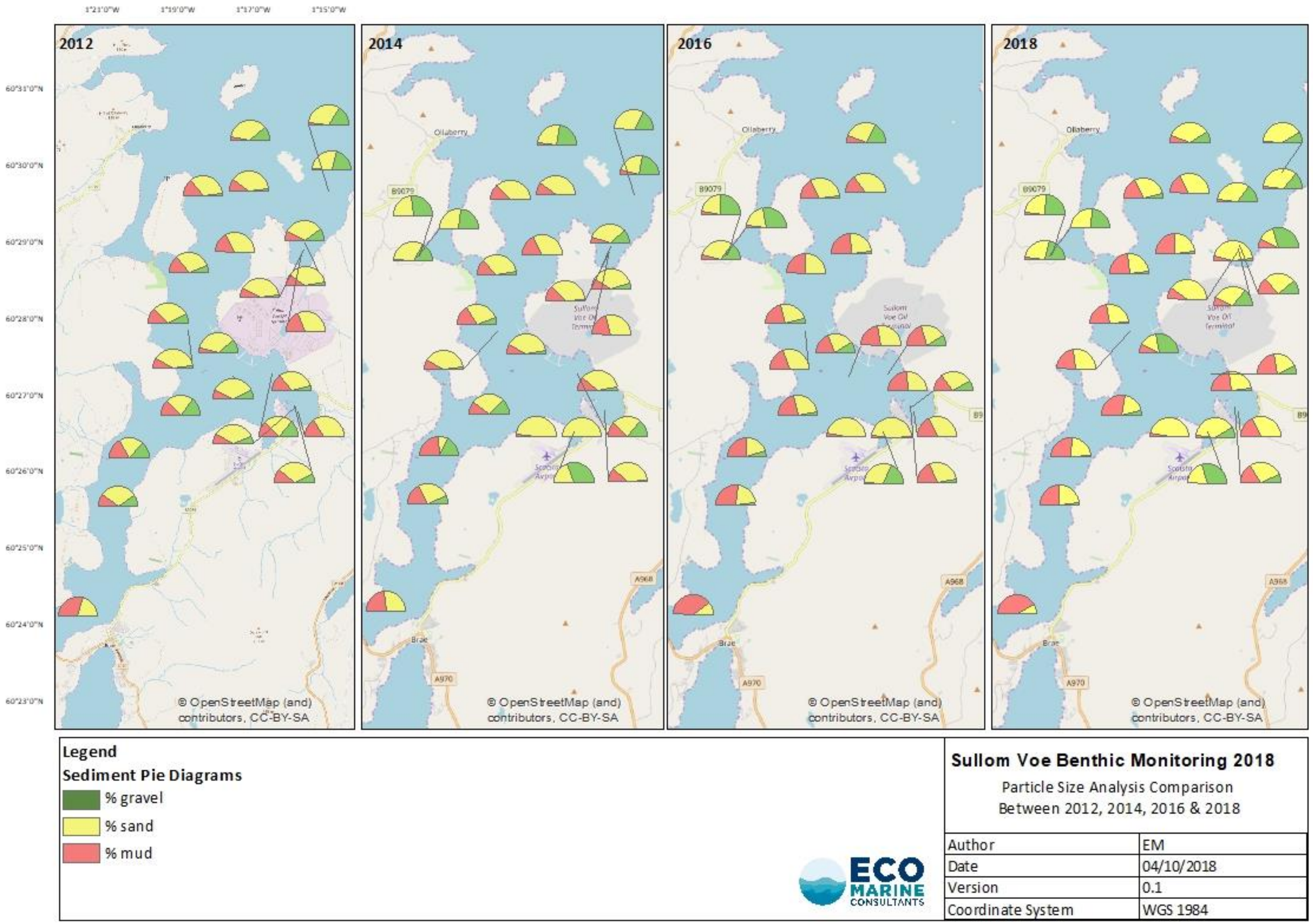

Figure 14. The relative proportions of gravel, sand and mud as a percentage contribution to sediment in PSA samples collected at Sullom Voe in 2012, 2014, 2016 and 2018. It should be noted that pie diagrams represent approximate location of sampling stations only.

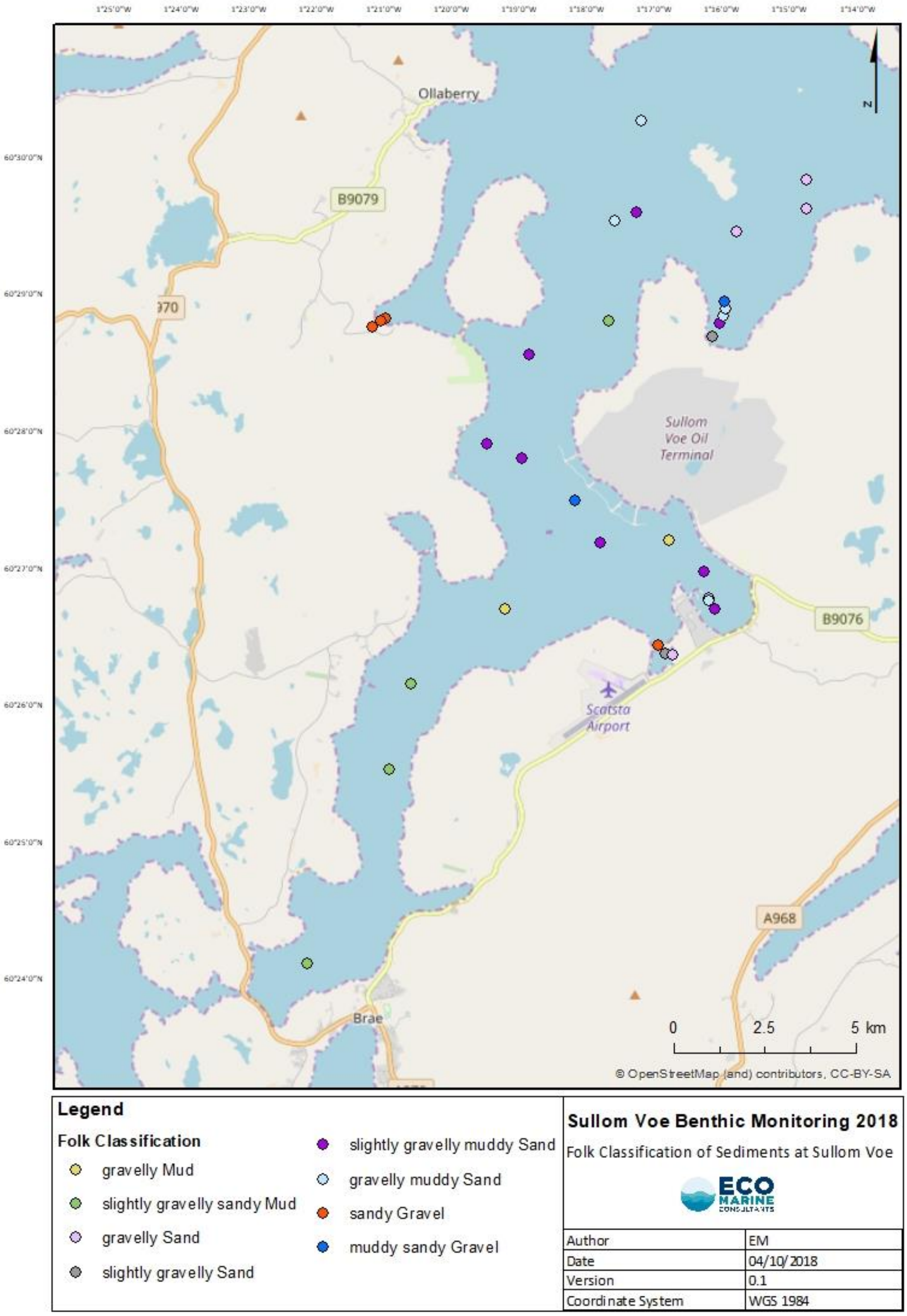

Figure 15. Folk classifications of sediment PSA samples collected at Sullom Voe during the 2018 survey.

3.2.2. Relating Environmental Parameters to Biological Data

To ascertain whether particular environmental variables were influential on biotic community structure at Sullom and Orka Voe, multivariate analyses were conducted using data from stations for which there was a full complement of both biotic and abiotic data (SV1, SV4, SV7, SV17, SV34, SV6, SV6F, OV1B and OV5B).

Draftsman's plot examinations in Primer were initially used to identify any abiotic variables for which data were skewed. The plots indicated that data for the variables '% gravel', 'UCM' and 'UCM % of total aliphatics' were not well distributed, thus these variables were subjected to individual square-root transformations in an attempt to distribute the data more evenly. The remainder of the abiotic variables remained untransformed for the BEST and BIOENV analyses as the data were more evenly distributed.

Following the appropriate abiotic transformations, a BEST procedure was conducted using the BIOENV routine in Primer, selecting Spearman correlation (rho value) and the Bray-Curtis resemblance matrix of square-root transformed biotic abundance data. The results of the BEST variable combinations are presented below in Table 3.

Table 3. Results of the BEST tests conducted using Primer for the 2018 Sullom Voe faunal abundance and biotic data. Note that a rho value of 1 would indicate that the biotic and abiotic patterns were identical, and a rho of 0 that there is no relation between them.

Number of variables	BEST variable combinations	Rho
1	% organic content	0.790
2	% organic content, UCM	0.787
3	% sand, depth (m), total naphthalene	0.799
4	% sand, % mud, depth (m), total naphthalene	0.800
5	% gravel, % sand, % mud, depth (m), total naphthalene	0.803
6	% gravel, % sand, % mud, depth (m), total naphthalene, total dibenzothiophene	0.804

The BEST results suggest that % organic content is the abiotic variable which best groups the stations in a manner consistent with the biotic patterns with a rho value of 0.790. This is considerably greater than the rho-value observed under a single variable when tested in 2016 (total aliphatic rho=0.467). However, this single variable alone does not provide a complete match to the ordination of the biotic data; the optimum match between the biotic and abiotic matrices was derived from a subset of six variables with a rho correlation value of 0.804. When the number of variables above this was increased, the value of rho plateaued.

The results of the examination of biotic and abiotic data in 2018 largely align with those observed in previous years (with a limited exception of 2016), with the percentage of sediment size fraction and organic matter shown to be some of the key structuring drivers behind biological community patterns. In 2016, analyses revealed that total aliphatic hydrocarbon, depth and % silt were most influential variables, some of which remained important in 2018, though rho values were lower in 2016 compared to the present and previous survey years meaning that less of the faunal variability was explained by these abiotic factors.

Analyses have shown organic matter to be a highly influential variable in 2018 with percentage sand being the most causative variable in terms of sediment fractions. UCM content was considered influential on faunal community structure when just two variables were included for analysis but was found to be less so when a greater number of environmental variables were examined. Overall it can be said that a combination of sediment composition, water depth, and concentrations of naphthalene and dibenzothiophene in the sediments when in combination were considered to be the most crucial combination of variables in determining faunal community structure between stations at Sullom Voe and Orka Voe in 2018.

The variation in abiotic factors possibly helps to explain some of the faunal group outliers identified in Section 3.2. Station SV1 was the most dissimilar when compared to all other stations based upon faunal abundance and was geographically isolated and in deeper water than most of the other stations. SV12 which was an outlier in 2016 but was clustered alongside other similar stations in terms of faunal community structure in Group D in 2018, suggesting that the biological community here had become more aligned with those at surrounding stations over the past two years. In previous years it has been hypothesised that high organic matter content, such as that recorded at Station SV1 (in 2018 as well as other recent years) combined with high mud content created a habitat suitable for a high abundance of specifically tolerant species such as *Capitella* spp. (MESL, 2016).

As in previous years, sediment type played a perceptible role in determining biological community structure, with percentage sand and mud (rather than gravel) having the most apparent effects on the infauna at each station though the relationship between all sediment fractions has been influential. Particle size fractions across the Sullom Voe survey region have been slightly variable since 2012 (Figure 17), which may account for changes in the most influential environmental parameters between years. It is evident that silt is a more dominating component of sediment in both 2016 and 2018, particularly in the mid- and upper-channel stations and to the south of the Oil Terminal.

The BIOENV results were then subjected to a significance test by randomly permutating one set of sample labels relative to the other and running through the BIOENV procedure to generate the best match, or rho value. This procedure was conducted repeatedly (999 times) to generate a histogram of rho values which represented the null hypothesis case (i.e. that there was no relationship between the biotic and abiotic data). The real value of rho was then compared to this and if it was larger than any of them the null hypothesis was rejected. In the case of the 2018 data, the real value of rho is 0.803, comfortably to the right of the null distribution; the null hypothesis can therefore be rejected at a significance level of 0.4%, implying there is a significant relationship between biotic and abiotic data.

The link between biodiversity and sediment type is consistent with the large volume of existing literature that documents sediment composition as a key factor in determining the distribution of infaunal communities (e.g. Ellingsen, 2002; Cooper *et al*., 2011). Further to this, Pearson *et al.* (1994) found that variations in community composition for the muddy sand and gravel community common to Shetland's Voes were related to higher proportions of gravel or areas enriched by organic detritus, which the findings of this report support.

4. CONCLUSIONS

The overarching aim of this project was to determine any changes in the benthic faunal communities and habitats present at Sullom Voe since monitoring under the current programme commenced in 2002. The following conclusions can be drawn from the 2018 investigation outlined in this report:

- Overall the total abundance of macrobenthic organisms sampled during 2018 was more than that recorded in 2016 and remained within the range of variability exhibited by the wider dataset. Statistical examination revealed that there was no significant difference in abundance across stations between survey years since 2012.

- In line with the findings of the monitoring surveys, some of the most commonly encountered and abundant fauna recorded during 2018 included *Thyasira flexuosa*, *Prionospio fallax and Kurtiella bidentata.* The large numbers of *Balanus crenatus* previously observed in 2014 were no longer present in 2018 and had returned to background levels in line with previous data.

- Species diversity is less variable between years than abundance. Diversity has decreased slightly with each survey since 2014 though not substantially and while diversity was lower at some stations in 2018, values at several stations demonstrated higher diversity than in previous years. During 2018, diversity was higher than previously recorded in 2002, 2010 and was comparable to 2008. The faunal assemblages sampled were very much in line with the findings of the most recent and historical monitoring of Sullom Voe as well as that described in the literature.

- As was found in previous years, in 2018 the dominant biotope was '*Mysella* (*Kurtiella*) *bidentata* and *Thyasira* spp. in circalittoral muddy mixed sediment (SS.SMx.CMx.MysThyMx)' due to the presence of mixed sediments and substantial abundance of *Kurtiella bidentata* and *Thyasira* spp. at numerous stations. Other biotopes present included '*Lagis koreni* and *Phaxas pellucidus* in circalittoral sandy mud' (SS.SMu.CSaMu.LkorPpel), '*Aphelochaeta marioni* and *Tubificoides* spp. in variable salinity infralittoral mud' (SS.SMU.SMuVS.AphTubi) and 'Sublittoral sands and muddy sands' (SS.SSa). It should however be noted that no biotopes were considered a perfect fit for the Sullom Voe dataset.

- SIMPROF analysis found 17, statistically-distinct, faunal assemblages and the pattern seen in the MDS ordination was similar to that seen in previous years. Four faunal groups were then identified at a broader level using a 42% similarity cut-off on the cluster dendrogram that provided a clearer indication of the geographical distribution of more general faunal assemblages.

- Analyses were undertaken to relate the abiotic variables to the biotic data to determine the physicochemical and environmental factors most responsible for driving the biological patterns. The six variables giving the best correlation were % gravel, % sand, % mud, depth, total naphthalene concentration and total dibenzothiophene concentration. This was in keeping with the findings of previous surveys where sediment fraction composition and depth were found to be influential drivers behind the biological community patterns alongside petrogenic elements and organic content.

- Throughout the faunal analysis a number of rare, alien and protected species were recorded. These included the OSPAR-listed ocean quahog *Arctica islandica,* the nationally rare sea slug *Calliopaea bellula,* the nationally scarce orange-footed sea cucumber *Cucumaria frondosa,* the IUCN Red-listed edible sea urchin *Echinus esculentus,* the nationally scarce purple sea urchin *Paracentrotus lividus*, and the alien soft-shell clam *Mya arenaria* (present in the area since the 1920s).

- Overall the macrobenthic communities sampled throughout Sullom Voe remain rich and characteristic of the assemblages established during historical monitoring of the area.

5. APPENDICES

Appendix 1 – Summary of field notes and positions for the Sullom Voe stations in 2018.

Appendix 2 – Table summarising the sediment particle size analysis (PSA) undertaken for samples collected during the 2018 survey of Sullom Voe.

Appendix 3 – Table summarising the percentage of major sediment fractions of PSA samples collected during the 2018 survey of Sullom Voe.

Appendix 4 – Table summarising the abundance of macrofauna identified in Phase II samples collected during the 201 survey of Sullom Voe.

Appendix 5 – Table summarising the abundance and species diversity of each Phase II sample collected during the 2018 survey of Sullom Voe.

Appendix 6 – Table summarising the biotopes identified at each station during the 2018 survey of Sullom Voe.

Appendix Plate 1 – Contact sheets containing pre-sieved sample photographs taken during the 2018 survey of Sullom Voe.

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