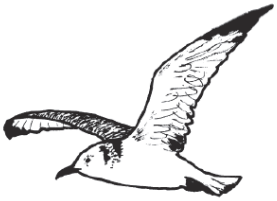
SOTEAG



Chemical and macrobenthic monitoring in Sullom Voe Sediments

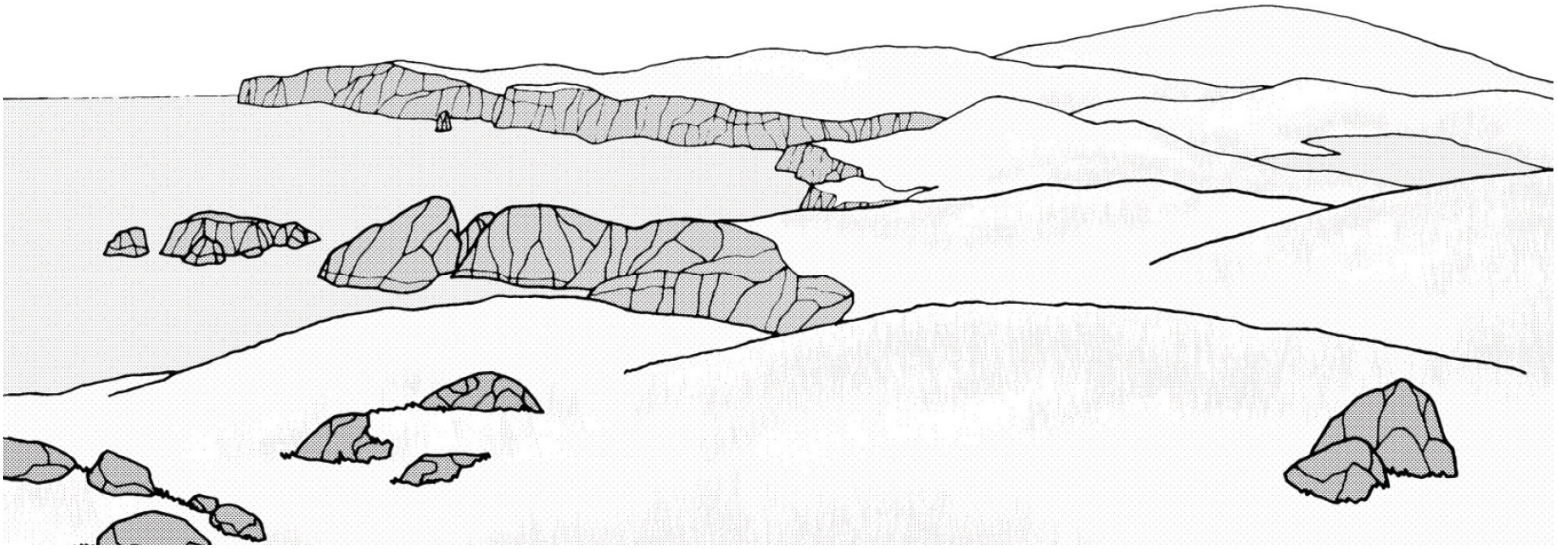
2016

A report to the Shetland Oil Terminal

Environmental Advisory Group

by

SGS United Kingdom Limited



TITLE:	**Chemical and Macrobenthic Monitoring in Sullom Voe Sediments - 2016**
SUB-TITLE:	**Macrobenthic and Chemical Report**
CLIENT:	**The Sullom Voe Association Limited**
REPORT REF:	**BV16-00552**
STATUS:	**Final**

Prepared on behalf of SGS United Kingdom Limited

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EXECUTIVE SUMMARY

This reports details the findings of the 28th chemical and macrobenthic monitoring survey carried out in June 2016 on the marine sediments around the oil terminal at Sullom Voe which was conducted by SGS United Kingdom Ltd for the Shetland Oil Terminal Environmental Advisory Group (SOTEAG). This report is a monitoring survey and the scope of the survey is not dictated by regulatory bodies. This report covers the macrobenthic analysis and the chemical analysis, including the particle size analysis, the aliphatic hydrocarbon content and the poly aromatic hydrocarbon content (PAH).

The survey comprised of 32 stations in Sullom Voe. As in previous years, the survey consisted of six soft shore samples from the Houb of Scatsta and Gluss Voe and twenty six benthic sediment samples obtained by Day grab, (five from Orka Voe, and twenty-one from Sullom Voe, Garths Voe and southern Yell Sound). Seven of the stations (SV36, SV37 and OV1-OV5) were identified as being within a 200m proximity zone of underwater pipeline assets and hence the location of these stations was re-established at the nearest point to the original station which was outside the proximity zone. Seabed samples were taken for hydrocarbon, sediment grain size, organic matter content and macrofaunal analyses. The survey was conducted from the BP work vessel *Stanes Moor*. The hydrocarbon analysis was performed by SGS United Kingdom Limited and the macrobenthic analysis was performed by Marine Ecological Surveys Limited.

Macrofauna

Sullom Voe is a highly diverse environment identified as a Special Area of Conservation (SAC). It is well known for its rich benthic fauna characteristic of the mixed sediment types and organically-enriched conditions that are commonly encountered here.

Overall the total abundance of macrobenthic organisms sampled during 2016 has decreased compared to that recorded in 2014, although it remains in line with background levels of abundance recorded in previous survey years and it has not significantly changed.

In line with the findings of the 2012 and 2014 monitoring, some of the most commonly encountered and abundant fauna recorded during 2016 included *Thyasira flexuosa*, *Phoronis muelleri* and *Prionospio fallax.* The large numbers of *Balanus crenatus* previously observed in 2014 were no longer present in 2016 and had returned to background levels in line with 2012 data.

In 2016 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 amount of *Kurtiella bidentata* and *Thyasira* spp. present at numerous stations. Sublittoral cohesive mud and sandy mud (SS.SMu) communities were also present in significant numbers. This is consistent with the findings of previous monitoring and biotope information available for the Sullom Voe area.

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

Sediments

Overall sediment character was broadly comparable with that found during recent surveys, with the majority of sediments being classified as slightly gravelly muddy sands. However, most of the stations show some variations in the relative proportions of sand, mud or gravel compared with the characteristics noted in 2014. The mud contents of the benthic sediments

are noticeably higher at all stations when compared to the 2014 survey and the historic mean result for the period 2000-2014. Many of the 2016 mud content results correlate with the levels observed in the 2004 survey, for some stations there are spikes in the particle size analysis historic data. The methodology for the particle size analysis and mud content have changed in 2016 to the NMBAQC protocols at the request of SOTEAG (2014 recommendations) and higher levels of mud are likely to be observed due to differences between the gravimetric and volumetric measurements.

The organic matter content of the sediments is generally similar to the 2014 survey, with a mean organic content of 5.0% (5.4% in 2014). As is normally observed, the highest content of organic matter was observed at Station SV1.

Hydrocarbons

The hydrocarbon analysis was performed at a different SGS laboratory to earlier surveys. Method validation and quality controls were performed and found to be acceptable against the anticipated method performance. The aliphatic hydrocarbon levels in the Sullom Voe sediments range from 1.9 $\mu g.g^{-1}$ to 190 $\mu g.g^{-1}$, which is a comparable range to that seen in 2014. As in the previous surveys (except 2010), the highest level was recorded at Station SV1 in the Inner Basin. The overall observed levels of total aliphatic hydrocarbons in 2016 had changed slightly against the mean result of the historic data from the period 2004-2014, with the exception of Station SV9. The average total aliphatic hydrocarbon result for all stations in 2016 was 33.2 $\mu g.g^{-1}$, the 2014 average result was 31.7 $\mu g.g^{-1}$, and the average historic mean for period 2004-2014 was 34.6 $\mu g.g^{-1}$. Concentrations generally decrease northwards along the main Sullom Voe axis to concentrations similar to open-water North Sea sediments. There is no clear evidence for any fundamental alteration in the distribution of hydrocarbons in the sediments in 2016 compared with the 2014 survey.

The percentage of unresolved complex mixture (UCM) in the total aliphatic hydrocarbon was higher than in previous surveys during 2004-2014 at all stations (except SV9). This increase was on average for all stations equivalent to +2.2 standard deviations from the historic mean for period 2004-2014.The average result for all stations in 2016 was 63.8%, the 2014 average result was 48.0%, and the average historic mean for period 2004-2014 was 51.8%. While the 2016 results show a noticeable difference from the trend for period 2010-2014, the unresolved complex mixture results from 2008 demonstrated a similar positive bias.

The hydrocarbon analysis for the seven stations (SV36B, SV37B and the OV1B-OV5B) which were re-located in 2016, are tabulated in this report but due to significant changes in their position on the sediment bed and to the hydrocarbon content little focus has been given to them.

GC-MS analyses of aromatic hydrocarbons reveal the presence of PAH derived from petrogenic and pyrolytic (combustion) sources in the sediments, although as on previous surveys those from pyrolytic sources predominate (i.e. 4-6 ring PAHs, with parent compounds dominant over the alkylated derivatives). In the seven sediments analysed from unchanged stations, the proportion of 4-6 ring PAHs range from 79-92% of the total PAH, which is similar to level in 2014 which was 80-89%, with the highest value recorded at Station 1. The revised Orka Voe stations demonstrated a lower percentage of 4-6 rings to the total PAH (2016 OV1B 68%, OV5B 70%; 2014 OV1 82% and OV5 87%) The mean concentration of 2-6 ring PAHs has decreased for the unchanged stations from 1530 $ng.g^{-1}$ in 2014 to 1310 $ng.g^{-1}$, however the result is similar to the average for the historic mean for period 2004-2014 which was 1380 $ng.g^{-1}$ Six of the seven unchanged stations have shown

increases in the percentage 4-6 ring PAHs of the total PAHs since the last survey; on average this was +1.6 standard deviations from the historic mean for period 2004-2014. These increases are attributable predominantly to increases in 4-6 ring PAH concentrations (i.e. from pyrolytic rather than petrogenic sources). As in previous surveys, due to the high energy environment and relatively coarse sediments, Stations 34 (140 $ng.g^{-1}$), OV1B (56 $ng.g^{-1}$) and OV5B (280 $ng.g^{-1}$) have much lower concentrations of 2-6 ring PAHs compared to the rest of the stations.

Major and Trace Element Analysis

No analysis was performed during the 2016 survey and this analysis was last performed during the 2014 survey.

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1 INTRODUCTION

This reports details the findings of the 28th chemical and macrobenthic monitoring survey carried out in June 2016 of the marine sediments around the oil terminal at Sullom Voe which was conducted by SGS United Kingdom Ltd for the Shetland Oil Terminal Environmental Advisory Group. This report is a monitoring survey and the scope of the survey is not dictated by regulatory bodies. This report covers the chemical analysis, including the particle size analysis, the aliphatic hydrocarbon content and the poly aromatic hydrocarbon content.

The survey comprised of 32 stations in Sullom Voe. As in previous years, the survey consisted of six soft shore samples from the Houb of Scatsta and Gluss Voe and twenty six benthic sediment samples obtained by Day grab, (five from Orka Voe, and twenty-one from Sullom Voe, Garths Voe and southern Yell Sound). Seven of the stations (SV36, SV37 and OV1-OV5) were identified as being within a 200m proximity zone of underwater pipeline assets and hence the location of these stations was re-established at the nearest point to the original station which was outside the proximity zone. Seabed samples were taken for hydrocarbon, sediment grain size, organic matter content and macrofaunal analyses. The survey was conducted from the BP work vessel *Stanes Moor*. The hydrocarbon analysis was performed by SGS United Kingdom Limited and the macrobenthic analysis was performed by Marine Ecological Surveys Limited.

Marine Ecological Surveys Limited (MESL) has been commissioned by SGS on behalf of Shetland Oil Terminal Environmental Advisory Group (SOTEAG) to conduct a benthic survey, conduct all associated analyses and prepare a technical report for the benthic macrofaunal and sediment characteristic portions of the 2016 Sullom Voe monitoring investigation.

The Sullom Voe area is subject to numerous anthropogenic activities, most notably shipping and subsurface oil export through the Sullom Voe oil complex, operated by BP Exploration Operating Company Ltd. The Sullom Voe complex receives oil by pipeline from the oilfields in the East Shetland Basin and by shuttle tanker, and as such is closely monitored so that any possible impacts resulting from the oil industry are captured.

Benthic monitoring has been carried-out every two years in the diverse coastal area of Sullom Voe since 2002, though the area has been subject to investigation for many years preceding this due to the unique marine life found there. Marine Ecological Surveys Limited (MESL) has been involved with conducting benthic surveys and has performed the macrofaunal analysis of samples since 2012 with the most recent survey being completed in June 2016. This report outlines the findings of the June 2016 survey and pays special attention to temporal changes observed in macrofaunal communities since monitoring commenced.

2 SITE DESCRIPTION

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

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

The 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 (northern) species-rich communities of Sullom Voe are restricted to Shetland voes and are not represented elsewhere in the SAC series, 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 in the Voe varies between 20 and 35 metres for much of its length except at the head, or inner basin where it reaches over 50m.

Previous monitoring of the Sullom Voe area has revealed that the intertidal sediments of the site are confined to lagoons near the mouth of the voe 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 characterised by poorly-mixed, muddy sediments and are colonised by the horse mussel *Modiolus modiolus,* the sea-pen *Virgularia mirabilis* and diverse burrowing communities. A range of bivalves, polychaetes and amphipods can also be found in the organically enriched shell-sand, gravel and muddy-sand sediments. This rich benthic fauna has been attributed to the considerable variation in available sediment types, providing a large range of habitats and coupled with an enhanced food 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.

Within the eastern reaches of Sullom Voe, Garth's Voe is subjected to a variety of pressures, being situated close to the Shetland Oil Terminal, loading area and tug vessel jetty area. In 1974 Garth's Voe was reported as having sandy sediments overlying a dense layer of submerged peat, which is exposed at the sediment surface in places, with the fauna dominated by *Thyasira, Abra*, *Ophiura* and *Leptosynapta*, all of which are considered to be characteristic of fairly fine sandy mud (Pearson, 1974). Orka Voe is located in the outer reaches of Sullom Voe, is a more exposed Voe, and is subjected to pressures resulting from the landfall of a major oil and gas pipeline from the north.

3 METHODOLOGY

3.1 SAMPLE STATION LOCATIONS

The positions of the sampling stations are described in Table 1, and illustrated in Figure 1 & 2. During the permit application process it was identified that seven of the 2014 coordinates were within 200m of pipe line assets in the Sullom Voe. Revised coordinates were identified for stations SV36, SV37 and OV1-OV5, these stations have been labelled with post-fix B. The revised coordinates were prepared by overlaying maps containing the assets, the sediment bed and the 2014 coordinates. While the revised coordinates were positioned in the sediment bed during planning during the field work it was not possible to obtain satisfactory grabs at any of the seven stations as they were outside the sediment bed or at the edge of the sediment bed. This may indicates that the sediment maps used are not accurate. At station SV36B no sediment was retrieved in any of the five attempted grabs. At

station SV37 a small amount of sediment (<5L) was retrieved from one of the five attempted grabs, qualitative analysis only has been performed on this sample. At stations OV1B-OV5B a small amount of sediment (<5L) was retrieved from most of the five grabs at each of the stations, qualitative analysis only has been performed on these samples.
Attempts were made to move the stations again but to maintain the stations outside the 200m proximity zone. The sonar equipment on the Stanes Moor gave a visual image of the ground beneath the vessel and it was clear that for the area of Calbeck Ness around the revised coordinates for SV36B and SV37B were not within the sediment bed.

The station locations were determined using the *Stanes Moor's* dGPS and the soft shore locations were determined using handheld GPS.

Table 1 - Positions of sampling stations, June 2016

Station	Location	Station Position				Depth (m)
Yell Sound and north of Calback Ness						
SV1	Inner Basin	60°	24.097'N	001°	22.157'W	45m
SV3	Southern Sullom Voe	60°	25.524'N	001°	20.949'W	22m
SV4	Southern Sullom Voe	60°	26.150'N	001°	20.620'W	22m
SV5	Fugla Ness	60°	26.688'N	001°	19.230'W	21m
SV7	Jetty Grid	60°	27.203'N	001°	16.815'W	19m
SV8	Jetty Grid	60°	27.180'N	001°	17.830'W	23m
SV8A	Jetty Grid	60°	27.794'N	001°	18.980'W	30m
SV9	Outer Voe	60°	27.895'N	001°	15.505'W	14m
SV10	Outer Voe	60°	28.548'N	001°	18.881'W	38m
SV11	Outer Voe	60°	28.799'N	001°	17.699'W	39m
SV17	Jetty Grid	60°	27.492'N	001°	18.193'W	28m
SV12	Little Roe	60°	30.260'N	001°	17.214'W	51m
SV33	Calbeck Ness	60°	29.530'N	001°	17.605'W	52m
SV34	Calbeck Ness	60°	29.597'N	001°	17.276'W	52m
SV35	Calbeck Ness	60°	27.452'N	001°	15.791'W	18m
SV36B	Calbeck Ness	60°	29.623'N	001°	14.776'W	NS
SV37B	Calbeck Ness	60°	28.831'N	001°	14.772'W	NS
SV6	Garths Voe	60°	26.775'N	001°	16.219'W	10m
SV6A	Garths Voe	60°	26.759'N	001°	16.210'W	6m
SV6F	Garths Voe	60°	26.691'N	001°	16.123'W	5m
SV32	Garths Voe	60°	26.969'N	001°	16.287'W	11m
Orka Voe						
OV1B	Orka Voe	60°	28.689'N	001°	16.159'W	NR/NS
OV2B	Orka Voe	60°	27.787'N	001°	16.051'W	NR/NS
OV3B	Orka Voe	60°	28.836'N	001°	16.005'W	NR/NS
OV4B	Orka Voe	60°	28.892'N	001°	15.964'W	18m/NS
OV5B	Orka Voe	60°	28.942'N	001°	15.983'W	17m/NS
Gluss Voe						
GV1	Gluss Voe	60°	28.820'N	001°	21.002'W	Intertidal
GV2	Gluss Voe	60°	28.805'N	001°	21.069'W	Intertidal
GV3	Gluss Voe	60°	28.760'N	001°	21.190'W	Intertidal
Houb of Scatsta						
HS1	Houb of Scatsta	60°	26.431'N	001°	16.959'W	Intertidal
HS2	Houb of Scatsta	60°	26.369'N	001°	16.852'W	Intertidal
HS3	Houb of Scatsta	60°	26.355'N	001°	16.753'W	Intertidal

NR – Not recorded by vessel
NS - No valid sample was obtained

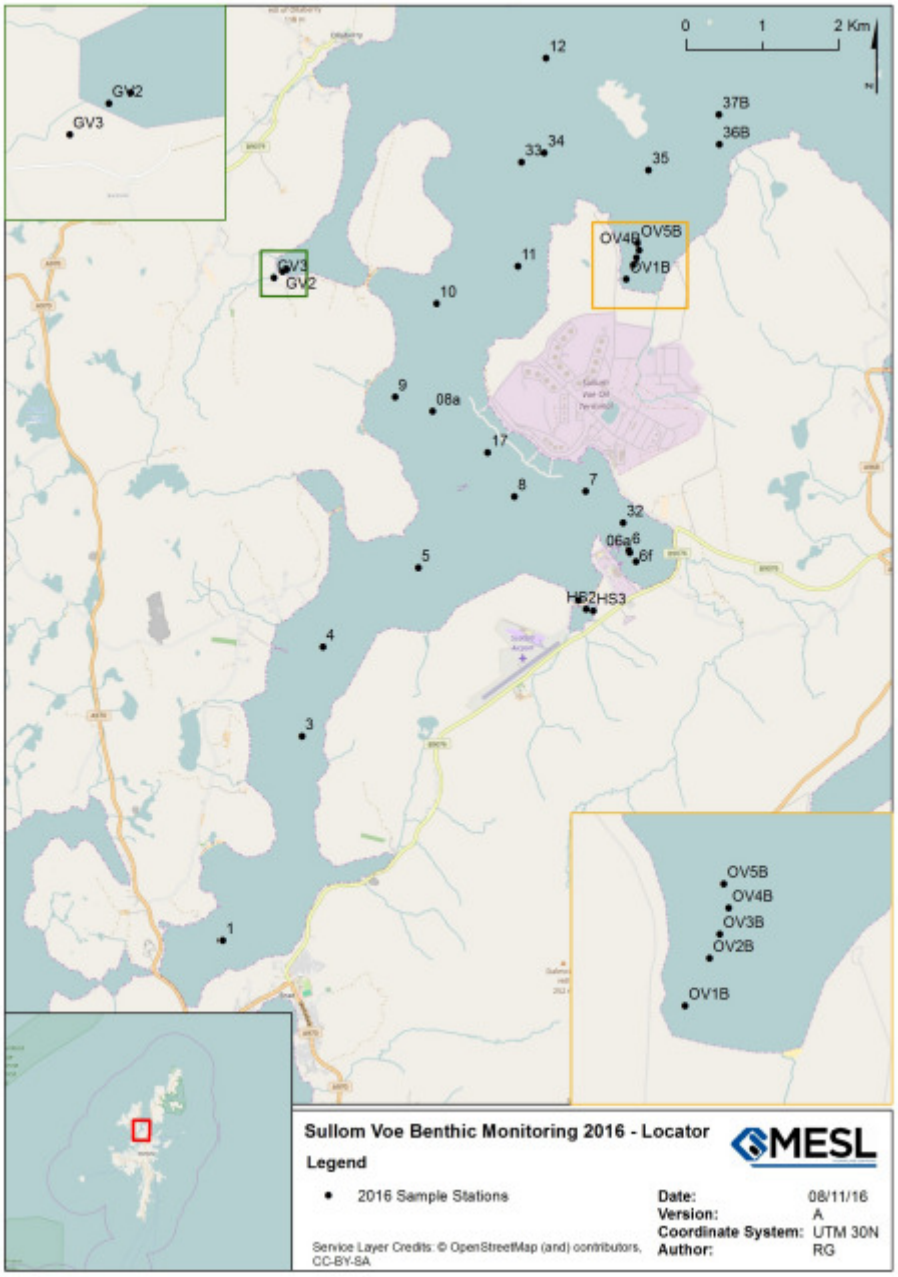

Figure 1 - The location and distribution of target stations at Sullom Voe in 2016.

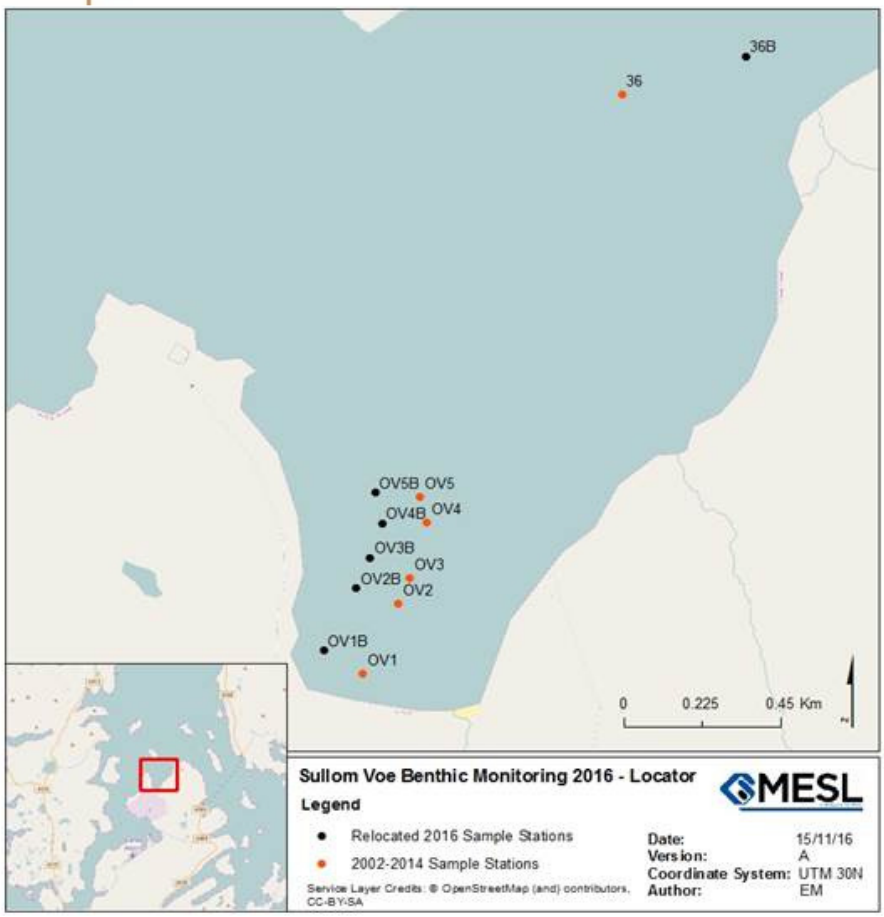

Figure 2 - The location of historic and alternative stations in Orka Voe and North Calbeck Ness, June 2016.

3.2 FIELD SAMPLING METHODS

The sampling methods were similar to those used in previous years. Method details are provided in more depth within the "terms of reference" document. The 2016 Survey Events Log is provided in Appendix 1.

In summary, seabed sediment samples were collected using a Day grab which had a surface area of 0.1m^2. Grabs were taken and sub-sampled for the analysis of the following parameters: sediment grain size; organic matter and total, aliphatic and aromatic hydrocarbons.

As in previous years the subsamples for sediment grain size and organic matter were taken from each of the five grab sample to make a composite. In deviation from previous years, the sub-samples for hydrocarbon analysis were taken from each the sediment of the three Day grab samples identified for macrobenthic analysis. The hydrocarbon subsample was taken from the top 2 cm of sediment as per previous surveys. This was agreed before the trial as a way to improve the measurement of the hydrocarbon analysis. Also, so that if there was a high variation in the macrobenthic analysis at a station, this could be investigated to assess if the hydrocarbon content for each grab correlated with the observed pattern.

Samples of sediment for hydrocarbon analysis and grain size distribution were taken at each of the soft shore stations in Gluss Voe and the Houb of Scatsta.

Hydrocarbon samples were frozen after collection, and were kept frozen during transportation to the analytical laboratory.

Complete grab samples were used for the analysis of benthic macrofauna. Samples were carefully washed through a 1mm mesh sieve and preserved in approximately 5-10% solution of buffered formalin in seawater.

3.3 LABORATORY METHODS

The laboratory method details are provided in more depth within the "terms of reference" document.
A brief summary of each method and a discussion of the principles involved in the interpretation of the data are given below. Several of the recommendations following the 2014 survey focused on improving the quality of measurement and making changes to ensure that the impact of changing laboratory for the sediment analysis is minimised through the use of standard test methods and methodologies where possible.

3.3.1 INFAUNAL ANALYSIS

All faunal analysis was undertaken by MESL. MESL participates in the National Marine Biological Analytical Quality Control scheme (NMBAQC) and consistently achieves between 97% and 100% accuracy ratings, and ranks within the top laboratories in the UK.

The processing of benthic faunal samples is a relatively standard procedure and the process has not altered from previous methodologies. On arrival at the MESL analytical laboratory the samples were checked against the field notes in accordance with standard operating procedures and signed against the list of samples collected. The excess formalin 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. Nematodes were enumerated but, being generally regarded as meiofauna, were excluded during data analysis. 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 by senior analysts and against a reference collection held for ease of use in the analytical laboratory. Species identification was recorded in a standard format using species codes from Howson & Picton (1997). Following this, the data were entered into our UNICORN database. Subsequently all taxon names were then checked against the WORMS database to ensure that the most up-to-date names were used and compliant with WORMS. Species identification was recorded in a standard format using WoRMS Aphia identification codes assigned to each name. All species names from the 2012 and 2014 faunal data were run through the WoRMS database prior to temportal faunal analysis to ensure that no false diversity records would occur. The full species abundance matrix for the 2016 survey is in Appendix 3.

All faunal data was pooled prior to any analyses being conducted so that each station was epresented by the contents of the three processed grab samples. This removed the need of averaging station data from the last three survey years where station by station abundance and diversity values were available to MESL. Data since 2002 has been examined for univariate analysis while data from the last three survey years (2012, 2014 and 2016) was interrogated for 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 and 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 was conducted in R to determine any significant differences in the abundance and diversity data between the three most recent survey years and between individual stations in 2016.

A BEST BIOENV routine in PRIMER, was also used to relate physicochemical variables to the biological data. This analysis is based on the premise that, if a suite of physicochemical variables are 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 2016 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 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).

3.3.2 SEDIMENT GRAIN SIZE ANALYSIS AND ORGANIC MATTER

The particle size analysis was subcontracted to Kenneth Pye Associates Limited, which is a different laboratory to previous surveys. One of the SOTEAG recommendations following the 2014 survey was that the particle size analysis was performed using NMBAQC methodology and that the laboratory should participate in the NMBAQC proficiency testing scheme.
The NMBAQC methodology has noticeable differences from the methodology which has been used in previous surveys. The NMBAQC protocol includes wet separation at 1 mm, laser diffraction analysis of the < 1 mm fraction, sieving of any > 1mm material, mathematical combination of the laser and sieve data, reporting of size frequency at ' half phi intervals. The protocol from previous years includes wet separation at 2mm, sieving of any >2mm material, display of laser and sieve data on same graph but not merged, reporting of size frequency at 'single phi intervals'. The mud content was determined by wet sieving at 63µm.

The outcome of the change in methodology is that the mud content in 2016 is likely to be observed at higher level than in previous years as the mud content will be determined volumetrically using laser diffraction rather than gravimetrically using wet sieving. This will lead to uncertainty when trying to interpret the data in the context of the historic data trend.
From Kenneth Pye Associates Limited: "The quantification of mud by laser diffraction usually results in higher apparent mud content than that produced by wet separation through a 63 µm sieve for a number of reasons. These include the fact that laser diffraction results are expressed as volume percentage frequency based on interpolated particle spherical particle diameter, whereas the method based on sieve separation and drying is based on weight. Many 'mud fractions' have a high content of organic matter and other low density materials which have a lower weight to volume ratio than sand (which is often composed predominantly of quartz). Hence the < 63 µm fraction analysed by laser may have a volume which is relatively large relative to the weight. Moreover, sieve separation is related to the probability of a particle passing through the sieve mesh aperture. In the case of platy particles such as micas, clays or shell fragments, which have large 'L' (length) relative to short (S) and sometimes the intermediate (I) dimensions, not all the particles will pass

through the sieve mesh unless the I x S projection is presented exactly parallel to the corner to corner dimension of the sieve mesh aperture; this rarely happens during wet and dry sieving, and hence such platy particles are retained on the 63 um sieve and described as 'fine sand'. If a suspension of sediment containing such particles is analysed by laser diffraction, on the other hand, the instrument algorithms interpret the composite diffraction pattern to include particles in the full size range being measured (in the case of the Coulter LS13320 that is 0.004 um to 2mm), and platy particles with an apparent sieve size of > 63 µm are recorded as particles with an equivalent spherical diameter considerably smaller than 63 µm. Hence it is to be expected that laser analysis will indicate more mud than wet sieving at 63 µm."

Kenneth Pye associates achieved a "good" status in each aspect of their analysis of the Q1-2 2016 NMBAQC proficiency testing scheme.

Further work is planned to be done during the 2018 survey to investigate and attempt to quantify the differences between the two methodologies used for mud content measurement. The mud content results from 2016 may require some adjustment so that they can be compared to the historic data more robustly.

Table 2 - Main differences between NMBAQC and Historic Methodology.

	NMBAQC Methodology	**Historic Methodology**
Wet Sieving to separate	1mm	2mm
Reporting size frequency	1/2 phi	1 phi
Data presentation	Mathematically merged laser and sieve results	Separate graphs for sieve and laser results
Mud content by	Laser Diffraction (volumetric)	Gravimetric Sieving <63µm (weight)

Particle size has been expressed using the phi (Ø) scale where Ø = $-\log_2$ diameter of the particle in mm. Particle size distribution of the sediments was analysed by dry sieving for particles larger than 1 Ø in diameter and by laser sizing for material smaller than 1 Ø.
The mud content of each sample was also calculated and is defined as that fraction of the sediment below 4.0 Ø (63µm) and includes both silt and clay.

Total organic carbon was determined by a different analytical technique. In previous years the total organic carbon has been determined gravimetrically by loss on heating at 450°C and presented as percent weight of sample. This year the total organic content has been determined using British Standard method BS 13137, which involves acid treatment of the sediment to remove any inorganic carbon (such as carbonate), then combustion of the sample at 1300°C and subsequent detection of the carbon dioxide generated by non dispersive infrared detection.

For method BS 13137 there are a number of quality control measures; each sample is analysed in duplicate and both results must be with 10% of the mean of the two results, blanks and control samples are ran with the samples and have to be within 10% of the method specified values.

3.3.3 SEDIMENT HYDROCARBON ANALYSIS

The analytical procedures used in the present study are the same as those used since 1992 when gravimetric analyses were replaced by improved methods, which are detailed in the "terms of reference" document reference.

In previous years the hydrocarbon analysis had been performed by SGS M-Scan limited, in 2016 the hydrocarbon analysis was performed by SGS United Kingdom limited at a different laboratory location.

In order to ensure that the effects of changing laboratory were minimised, a copy of the extraction method was given to SGS United Kingdom and validated by analysing certified reference materials and also by performing spike and recovery experiments. The quality control requirements were taken from Marine Management Organisation guidance for chemical determinands January 2015 (reference). The validation demonstrated that the method recovery for 100µg.g^{-1} based on 50g dry weight sample was 107%, which meets the expected 70-120% (range 0.01 to 0.1mg/kg) specified by SEPA and the standard deviation of the data set was 7% which meets the expected 20% precision (within laboratory reproducibility) – relative standard deviation, excluding any contribution due to sample heterogeneity.

To improve the quality of the hydrocarbon measurement, blanks and certified reference materials were extracted alongside the samples, at a frequency of 1 per 10 sediment samples.

SGS United Kingdom participates in the LGC CONTEST proficiency testing scheme for total petroleum hydrocarbon testing in soil samples, and achieved a "good" status in the 2016 round using their in-house method. The extraction methodology for the Sullom Voe sea sediments is different from the standard in-house method but when the same proficiency testing sample was analysed using this method a status of "good" was achieved.

The hydrocarbon analysis was performed at a ISO 17025 accredited laboratory, and while the test method itself was not within the scope of the ISO 17025 accreditation the analysis was performed under the same quality management system.

The concentrations of total aliphatic hydrocarbons, unresolved complex mixture (UCM), and other selected parameters have been calculated by integration of GC (gas chromatography) data.

The concentrations of 2-6 ring polycyclic aromatic hydrocarbons (PAH; parent PAH and alkylated homologues) in nine selected sediments were determined using GC-MS. This was carried out because in petroleum products there are substantial amounts of both parent and alkylated PAHs.

3.3.4 SEDIMENT MAJOR AND TRACE ELEMENT ANALYSIS

Major and trace element analysis was not scheduled for the 2016 survey. This analysis was last performed on the 2014 survey.

4 RESULTS AND DISCUSSION

4.1 RECOMMENDATIONS AND CHANGES

The monitoring program is planning to change how the data is analysed and interpreted to include a more thorough assessment of the data every 6 years, this will include a more detailed interrogation of time series and temporal trends.

In contrast to the report from previous studies and with the agreement of SOTEAG, in 2016 this section will focus on the presentation of the raw data for each test parameter and then for each site the presentation of current data against the historical data utilising charts. It is hoped that the charts will enable a visual assessment of the current data points against the historic data so that changes can be more easily identified.

For each test parameter, basic statistical tools have been used to aid interpretation of the data; mean results and standard deviations. The charts comprise of the historic and current data points, a trend line (using all the data points), and standard deviation lines which are equivalent to -3,-2,-1,+1,+2 and +3 standard deviations. The standard deviations for the hydrocarbon analysis (total aliphatic hydrocarbon content, the percentage unresolved complex mixture to total aliphatic hydrocarbon content, and the poly-aromatic hydrocarbon content) have been calculated using the historic data set from 2004 to 2014.

The standard deviations have been used to help assess if there has been a significant change in the 2016 result against the 2004-2014 results. Where historic mean results and standard deviations are referenced in the report they have been calculated from the data set 2004-2014, unless stated otherwise. Stations that have changed position have not been included in this assessment and where an observed mean result from all stations is referenced to, only the results from the same stations are compared.
The below outlines how the standard deviations are presented and should be interpreted;

-1 and +1 standard deviation lines are coloured yellow.
-2 and +2 standard deviation lines are coloured orange.
-3 and +3 standard deviation lines are coloured red.

-1 to +1 SD indicates little change against the historic data.
-2 to -1 and +1 to +2 SD indicates some change against the historic data.
-2 to -3 and +2 to +3 SD indicates significant change against the historic data.
<-3 and >+3 SD indicates very significant change against the historic data

Standard deviations lines are not included where the line is outside the scope of the measurement eg <0 concentration or outside 0-100%.

4.2 MACROBENTHIC RESULTS

Basic faunal abundance and diversity data was available for each survey conducted from 2002-2016, though species matrices were not available to MESL 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 were only possible for the survey years 2012, 2014 and 2016.

4.2.1 UNIVARIATE DATA ANALYSIS

Total faunal abundance has been variable since monitoring commenced in 2002, ranging from 36,132 individual specimens in 2002 to a peak of 77,070 individuals in 2006 (Figure 3).

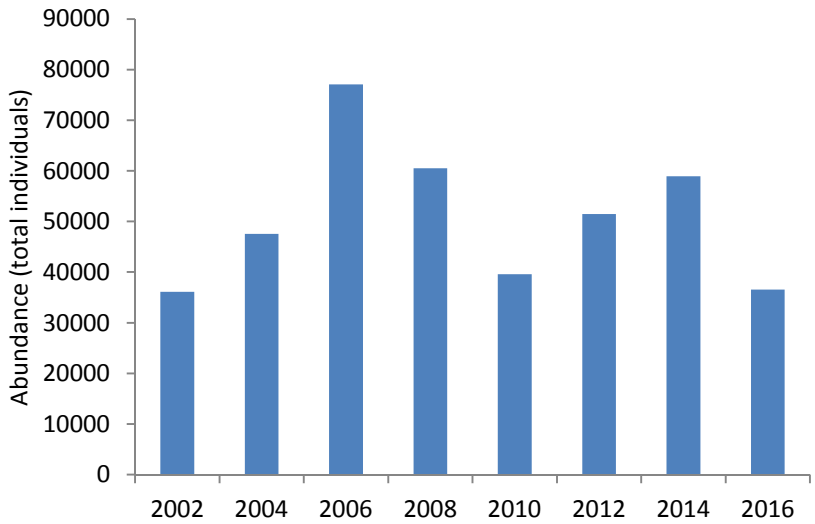

Figure 3. Total faunal abundance across all stations at Sullom Voe per survey year 2002-2016.

The total number of individuals recorded in 2016 was the second lowest observed since 2002 although it should be noted that 7 samples were undersized (<5L) and therefore the data for those samples is considered as qualitative rather than quantitative, possibly influencing the 2016 results. Though the abundance figure for 2016 is lower than some previous years, it is not the lowest so remains within the range of variability exhibited by the wider dataset and is similar to the totals observed in 2002 and 2010.

Species abundance per station for 2012-2016 is illustrated in Figure 4.

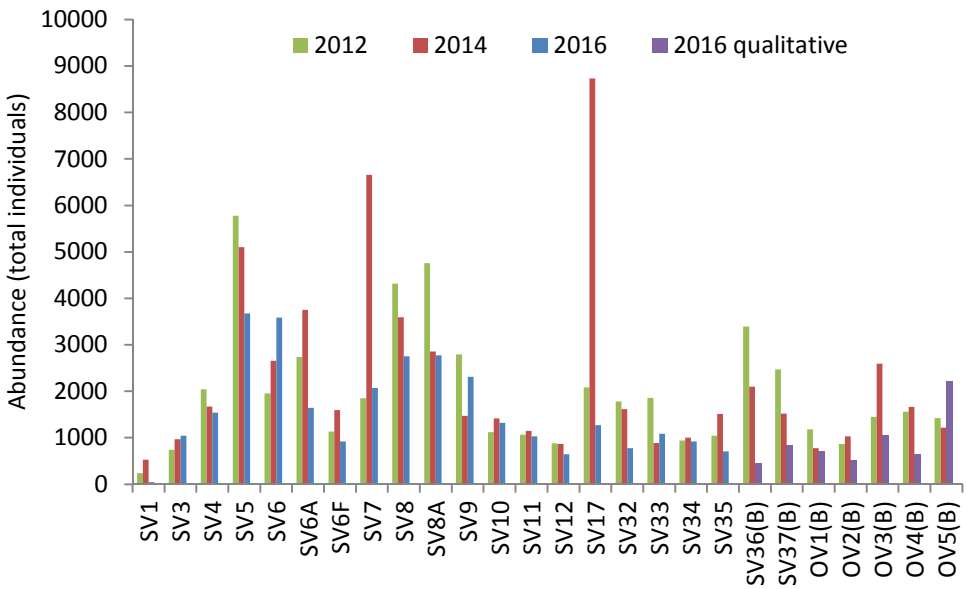

Figure 4. Species abundance per station at Sullom Voe, 2012-2016. Note relocated 'B' stations where qualitative data was collected are shown in purple.

Please note that data from the relocated ‘B’ stations (purple in Figures 4 and 7) cannot be directly compared to data collected in previous years due to the new station locations.

Disparity between years for species abundance is variable depending on the individual station being considered. Many stations, such as SV3, SV11 and SV12, have demonstrated similar abundance values between years, while others have shown more 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 is lower in 2016 than in both 2012 and 2014 with few exceptions.

Abundance at the southern-most station, SV1, was especially low in 2016 compared to all other stations and when compared to previous years (48 individuals recorded in 2016 compared to 525 in 2014), although it should be noted that the values at this site have been recorded as low compared to other stations in all recent survey years. Conversely, abundance at SV6 was higher in 2016 than in the previous two survey years, which was largely attributable to a high presence of several Annelida and small bivalve species at the station.

Remarkably, despite undersized samples being collected at the relocated ‘B’ stations, abundance in at OV1B-5B and SV36B-SV37B was not hugely dissimilar to background values recorded at other stations in 2016. For contextual rather than comparative purposes, it has been observed that abundance at OV5B was higher in than abundance at OV5 was in 2012 or 2014. This suggests that populations in the relocated stations are healthy in terms of abundance, though the ‘B’ stations cannot be directly compared to the originals due to spatial differences.

Figure 4 illustrates the geographical change in abundance values at each station between the three most recent survey years. Faunal abundance is consistently highest in the mid-channel near to the Sullom Voe Oil Terminal, though it is clear that values are reduced in 2016 compared to 2012 and 2014. Abundance values in 2016 remain similar to 2014 and 2012 in the southern portion of the channel, although values at the stations to the north of Orca Voe (Station 36B in particular) are slightly reduced when compared to 2012. It should be noted that Stations 36B, 37B and all of the Orca Voe stations were relocated and each of the samples was undersized and as such should only be considered qualitatively.

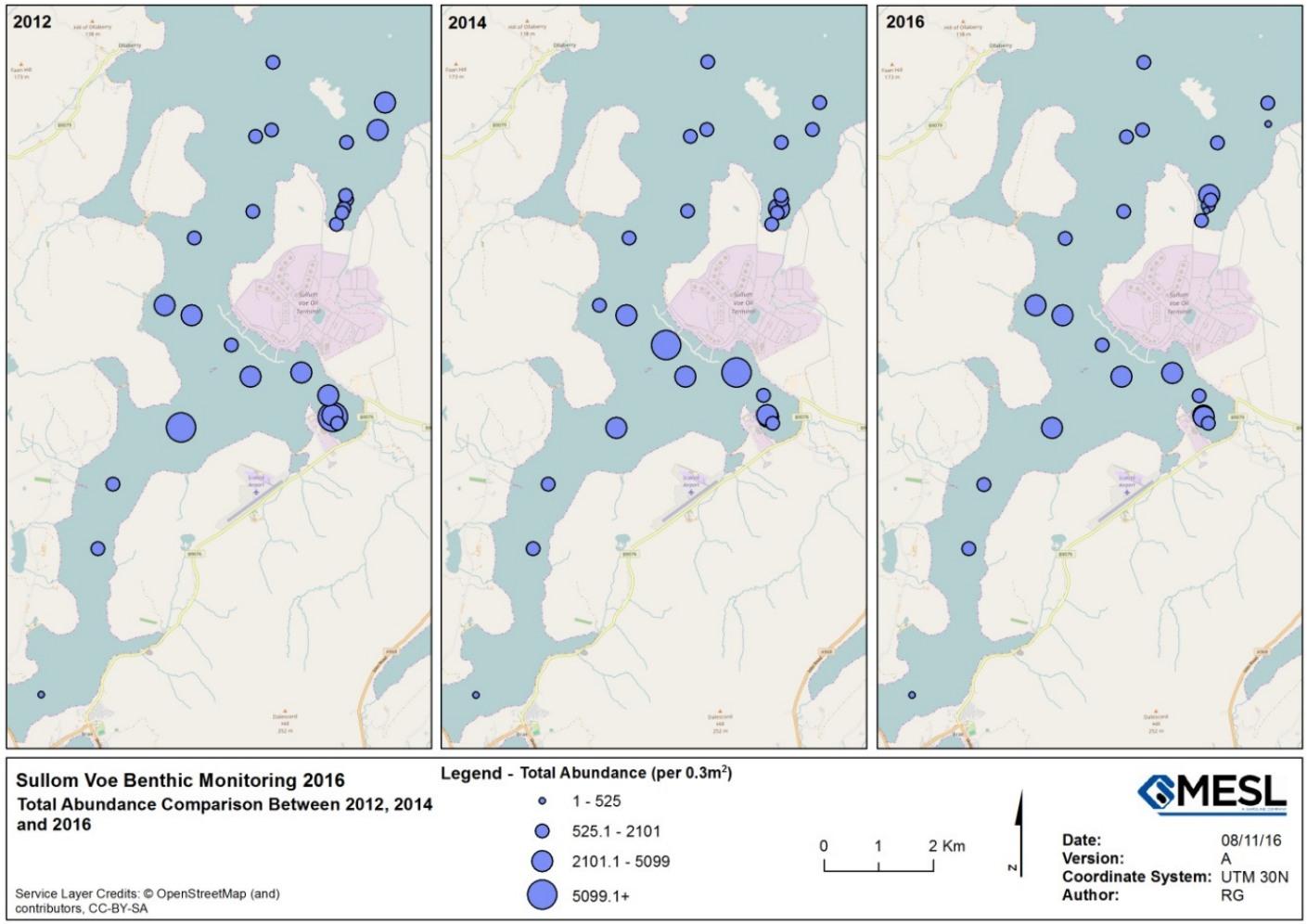

Figure 5. Total abundance of individual specimens across the Sullom Voe survey area in 2012, 2014 and 2016.

A total of 609 taxa (including juveniles and egg records) were recorded in 2016 across the Sullom Voe survey area compared to 660 taxa in 2014 and 622 in 2012. Evidence suggests that diversity has decreased slightly but remains comparable to previous observed levels, despite the relocation of several of the stations. On average, 118 species were observed at each station in 2016 (Figure 5), the fifth highest record since 2002. When considering data since 2002 only, 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 2016 was securely within the boundaries of variability which has been observed in previous years.

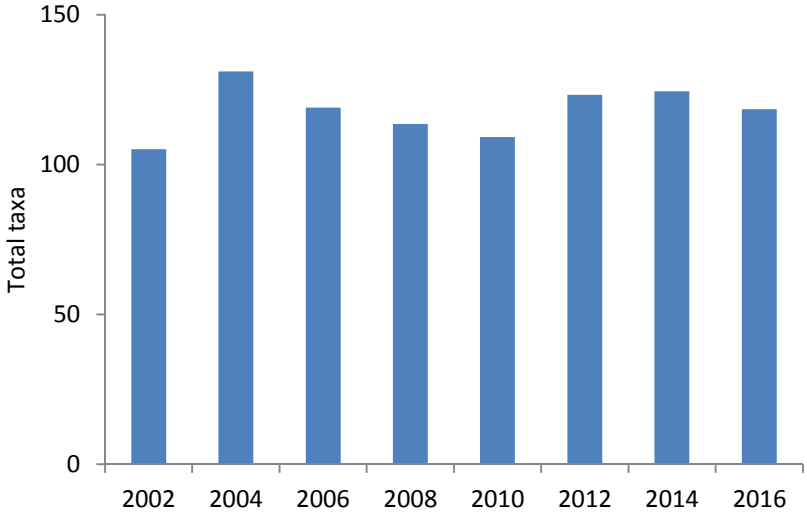

Figure 6. Average species diversity at Sullom Voe per station for survey years 2002-2016.

Total species diversity per station for recent survey years is illustrated in Figure 6.

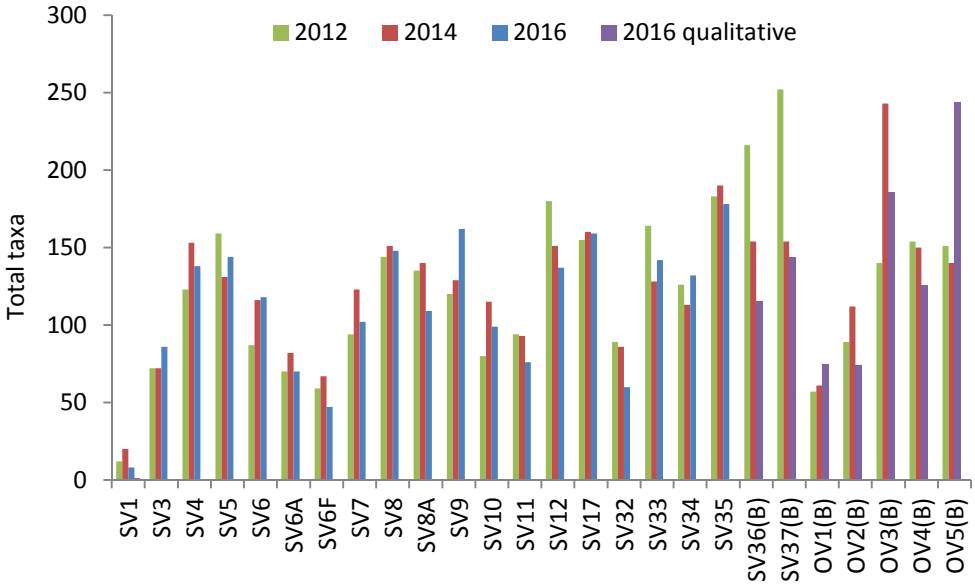

Figure 7. Total species diversity per station during the Sullom Voe 2016 benthic survey. Note relocated 'B' stations where qualitative data was collected is in purple.

It is evident that there is less disparity between survey years in terms of diversity than when considering faunal abundance. Diversity is decreased when compared to 2012 and 2014 though not substantially and though diversity is lower at some stations than in recent years, values at some stations such as SV17 have remained consistently similar despite abundance fluctuating significantly.

Diversity in 2016 is regularly higher per station than in either 2012 or 2014 and occasionally, both years. Diversity is especially high in 2016 at several of the relocated Orca Voe stations compared to 2012 and 2014, though this may be attributable to the altered site locations. Conversely, diversity was has decreased at SV36 and SV37 when compared to previous years though this change in 2016 cannot be may again be attributable to the relocation of these stations.

Figure 8 illustrates geographical changes in total species diversity over time from 2012-2016. It is evident that diversity in 2016 has varied geographically compared to 2012 and 2014. Species diversity in the northern section of the survey region increased in 2016 compared to 2014, though reduced when compared to 2012. The stations in the mid-section near to the Sullom Voe Oil Terminal have either maintained or increased in diversity when compared to previous years.

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.

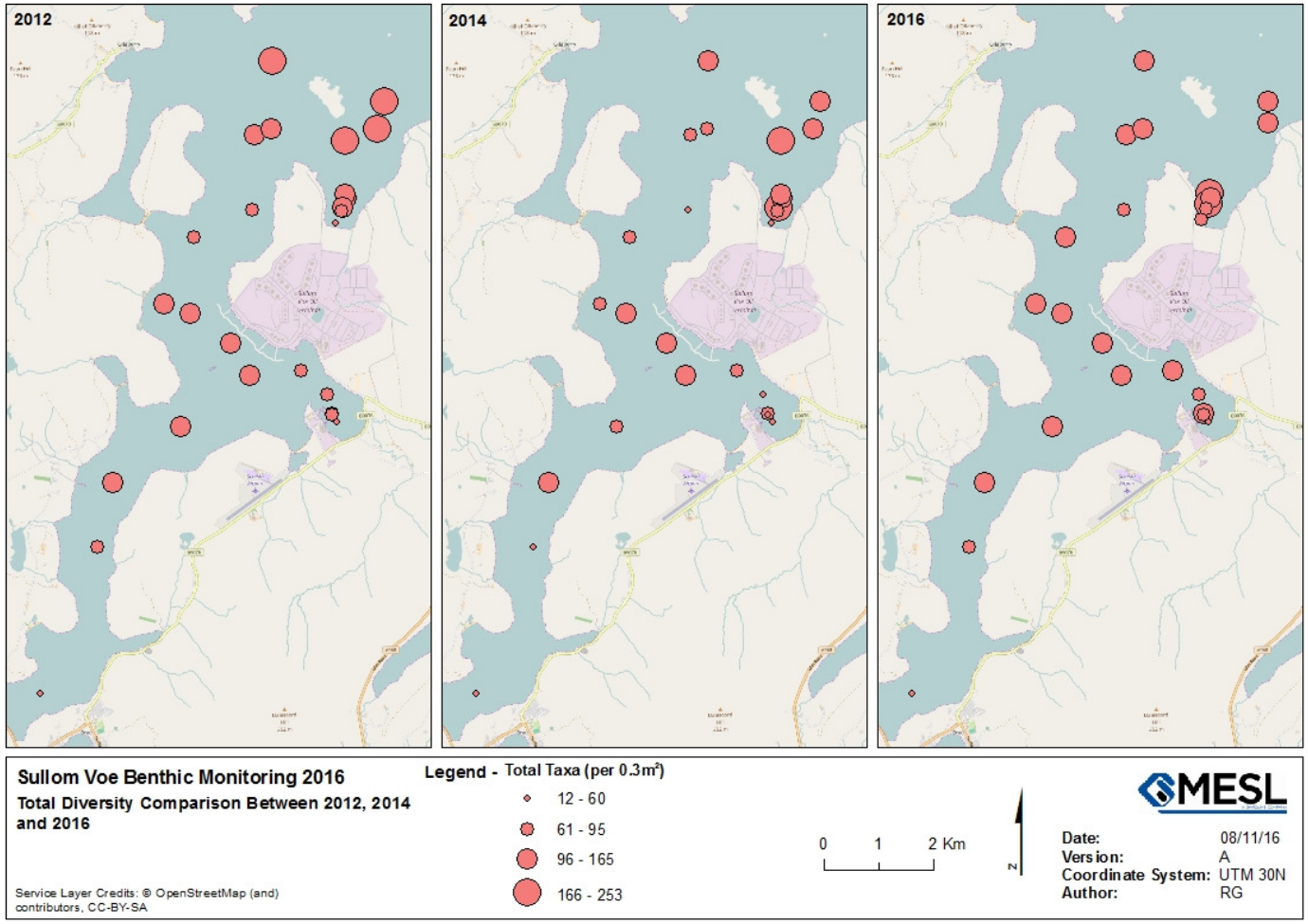

Figure 8. Total diversity of individual taxa at Sullom Voe in 2012, 2014 and 2016

Individual species contributions at Sullom Voe in the last three survey years have remained relatively similar, with the same common taxa being recorded year on year (Table 1).

Table 3. The ten most commonly observed species (excluding Nematoda) in the 2012, 2014 and 2016 benthic surveys at Sullom Voe. (An) = Annelida; (Cr) = Crustacea; (Mi) = Miscellanea; (Mo) = Mollusca

2012		2014		2016	
Species	**Total**	**Species**	**Total**	**Species**	**Total**
Phoronis muelleri (Mi)	10795	*Balanus crenatus* (Cr)	15299	*Thyasira flexuosa* (Mo)	4720
Thyasira flexuosa (Mo)	4629	*Thyasira flexuosa* (Mo)	5857	*Phoronis muelleri* (Mi)	3891
Prionospio fallax (An)	2352	*Phoronis muelleri* (Mi)	3719	*Prionospio fallax* (An)	2606
Tubificoides benedii (An)	2174	*Kurtiella bidentata* (Mo)	1583	*Kurtiella bidentata* (Mo)	1845
Exogone naidina (An)	1416	*Tubificoides benedii* (An)	1383	*Tubificoides benedii* (An)	1595
Ampelisca tenuicornis (Cr)	1282	*Prionospio fallax* (An)	1377	*Turritella communis* (Mo)	1481
Dipolydora coeca (An)	1082	*Turritella communis* (Mo)	1233	Spirobinae (An)	1341
Spirobranchus triqueter (An)	1004	*Galathowenia oculata* (An)	826	*Lumbrineris cingulata* (An)	748
Kurtiella bidentata (Mo)	990	*Spirobranchus triqueter* (An)	824	*Mediomastus fragilis* (An)	714
Galathowenia oculata (An)	951	Nemertea (Mi)	709	*Balanus crenatus* (Cr)	609

Thyasira flexuosa has been one of the top two, and *Phoronis muelleri* one of the top three, most contributing species every year since 2012, with the Annelida species *Prionospio fallax* also contributing highly throughout.

T. flexuosa was the most abundant taxon in 2016 and likewise would have been in 2014 if not for the very high abundance of *Balanus crenatus* recorded. The oligochaete *Tubificoides benedii* has also consistently contributed substantially to the faunal populations across the Sullom Voe site.

B. crenatus was present in especially elevated numbers in 2014 but has since decreased to more typical abundance levels in 2016. The gastropod *Turritella communis* has increased in abundance in recent surveys, contributing more substantially in 2016 than in 2012 or 2014.

4.2.2 SPECIES OF INTEREST

Throughout the faunal analysis of the 2016 data a number of rare, alien and protected *Strongylocentrotus droebachienis, the* nationally-rare bryozoan *Cylindroporella tubulosa*, the OSPAR-listed Icelandic ocean quahog *Arctica islandica,* the alien soft-shell clam *Mya arenaria* and *Echinus esculentus,* the IUCN Red-listed sea urchin. Though recorded in 2014, the nationally-scarce amphipod species *Harpinia laevis* was not observed in 2016.

The green sea urchin known as *Strongylocentrotus droebachienis* was recorded at a single station (SV6A – Figure 9) during the 2016 survey; it was also recorded once in 2014. It is listed as nationally scarce in British waters and is recorded as occurring on North Sea coasts from Shetland to the southern coast of the UK, although recent records are from shallow inshore areas of Shetland only.

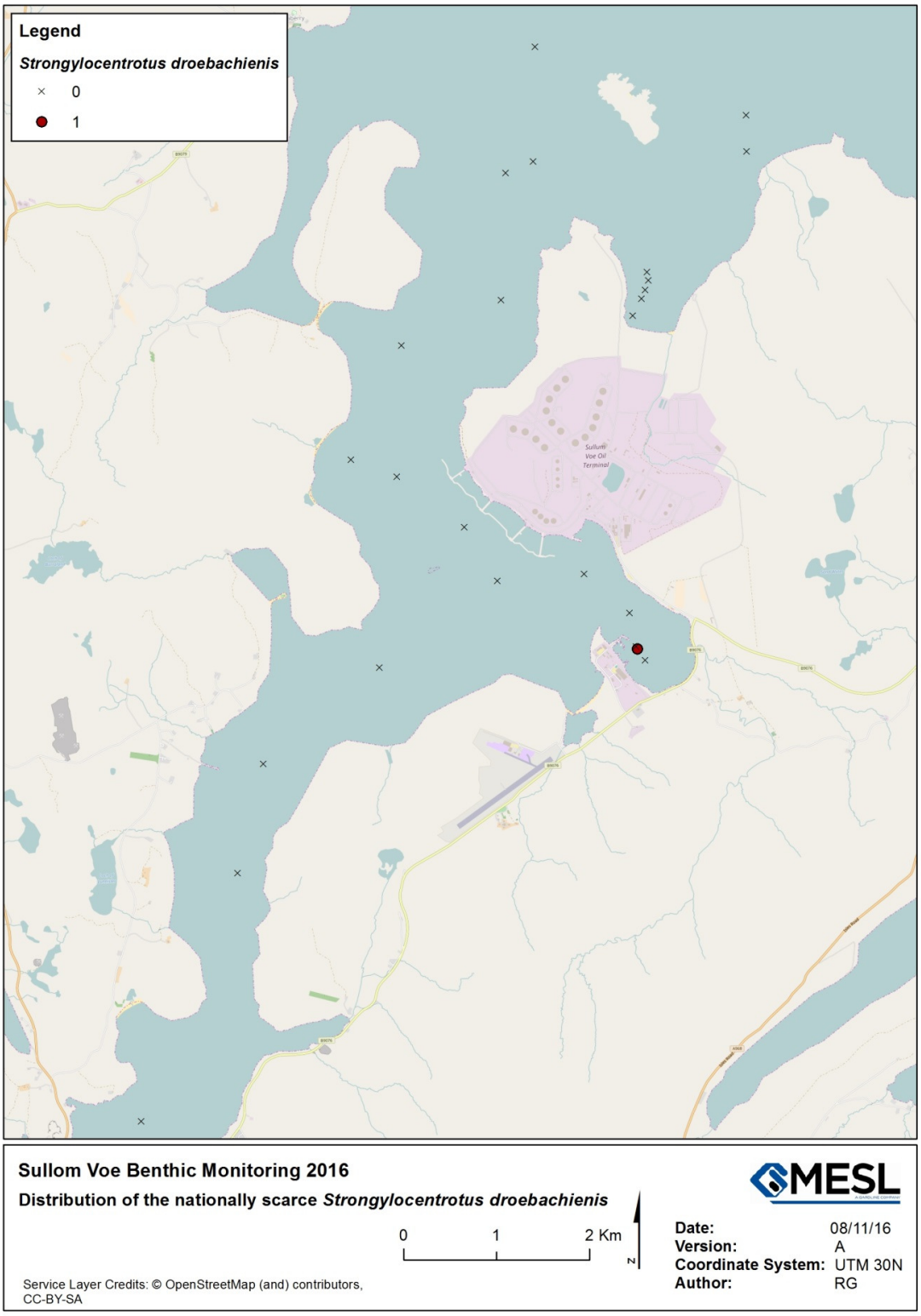

Figure 9. The abundance distribution of *Strongylocentrotus droebachienis* (per 0.3m^2) as determined during the June 2016 survey of Sullom Voe.

As in 2014, the bryozoan *Cylindroporella tubulosa* was recorded at three stations in low numbers (Figure 10), though the stations at which the bryozoan was present has changed slightly. This colonial species is regarded as nationally rare, and the isolated records in the literature (JNCC, 1999) on the Shetlands and in northern Scotland are thought to represent the southerly limit of this species, which has been recorded during previous monitoring.

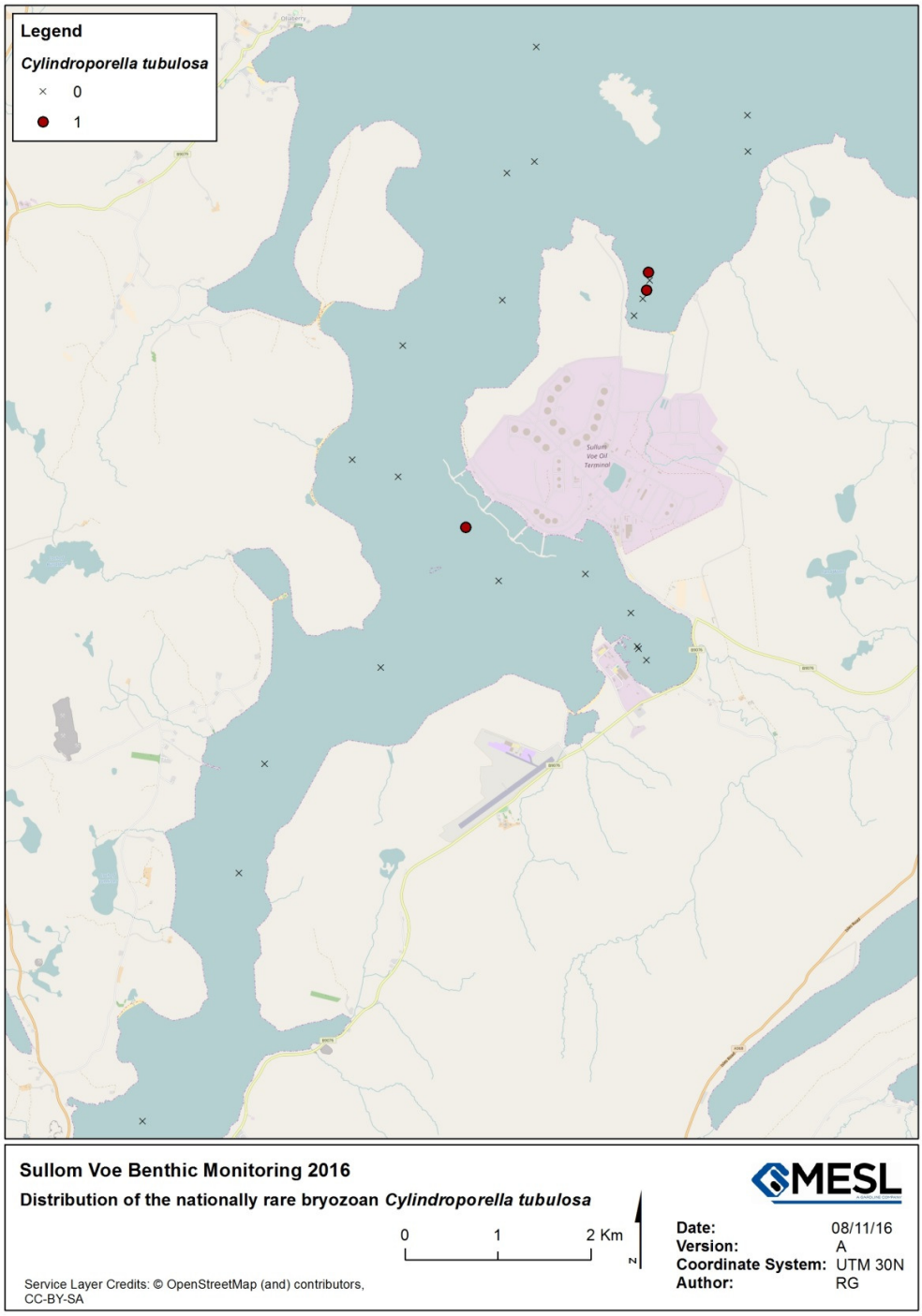

Figure 10. The abundance distribution of *Cylindroporella tubulosa* (per 0.3m^2) as determined during the June 2016 survey of Sullom Voe.

The long-lived Icelandic or ocean quahog *Arctica islandica* was sampled in low to medium abundances at 11 stations during 2016 (Figure 11) with juveniles being more abundant than mature individuals. A total of 27 individuals were recorded across the survey are in 2016 compared to 33 in 2014 and 15 in 2012. It is an OSPAR-listed species known for its slow growth rate and long lifespan. This bivalve is known to occur throughout the UK including the Shetlands, and has been recorded at similar stations during previous monitoring.

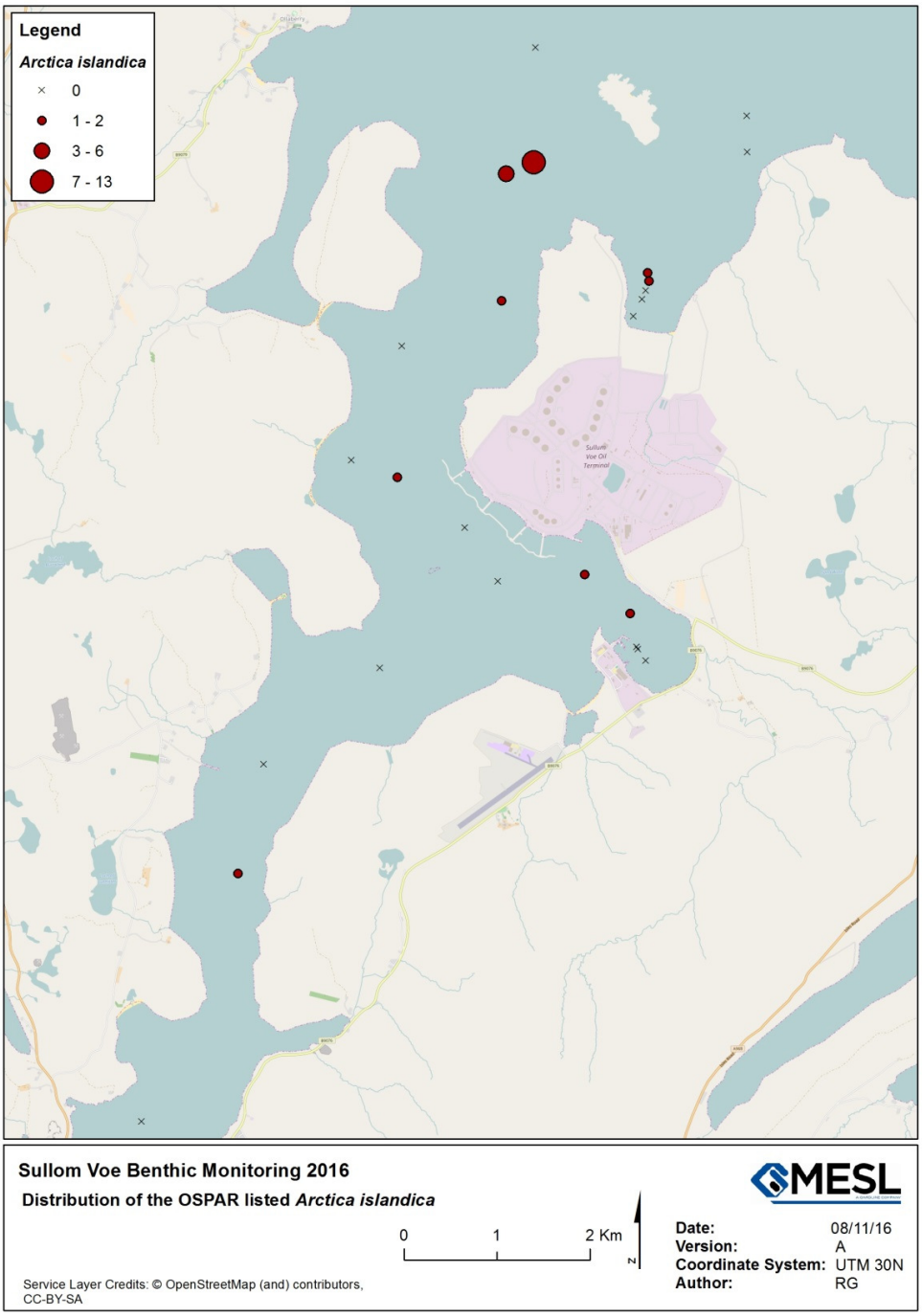

Figure 11. The abundance distribution of *Arctica islandica* (per 0.3m^2) as determined during the June 2016 survey of Sullom Voe.

The sand gaper *Mya arenaria* was found at two stations (SV3 and SV9 – Figure 12) in 2016 compared to seven locations in 2014. This distribution remains similar to that of 2012 when the species was also only recorded at two stations. This bivalve is an introduced alien species that is found on all British coasts, including the Shetlands (Oliver *et al.,* 2010).

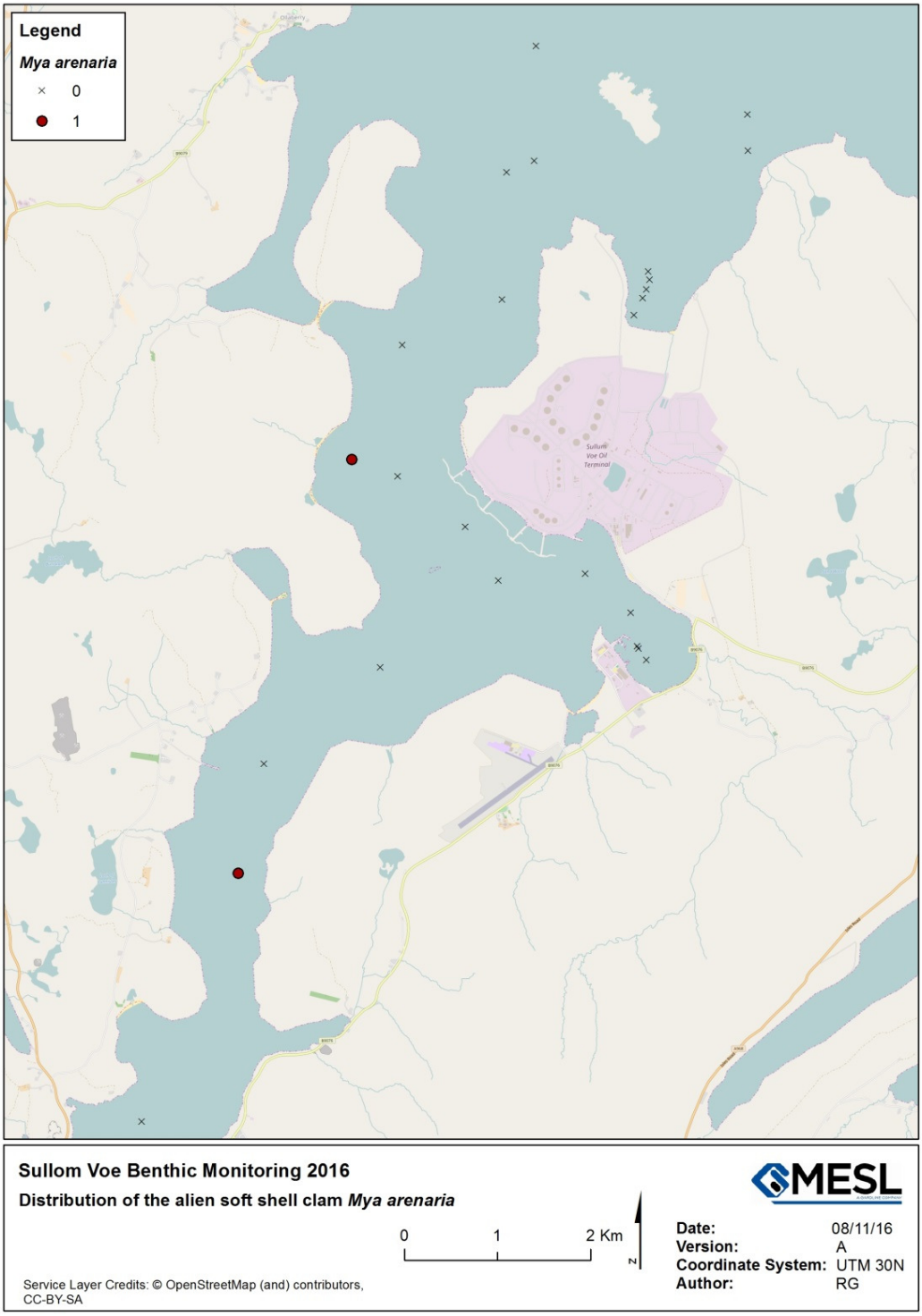

Figure 12. The abundance distribution of *Mya arenaria* (per 0.3m^2) as determined during the June 2016 survey of Sullom Voe.

The edible sea urchin *Echinus esculentus* was found at a single station (SV36B – Figure 13) in 2016 and was not recorded at all in 2012-2014. This sea urchin is listed on the global IUCN Red List as 'Near Threatened', though in the UK it is relatively common and is listed as not rare/scarce.

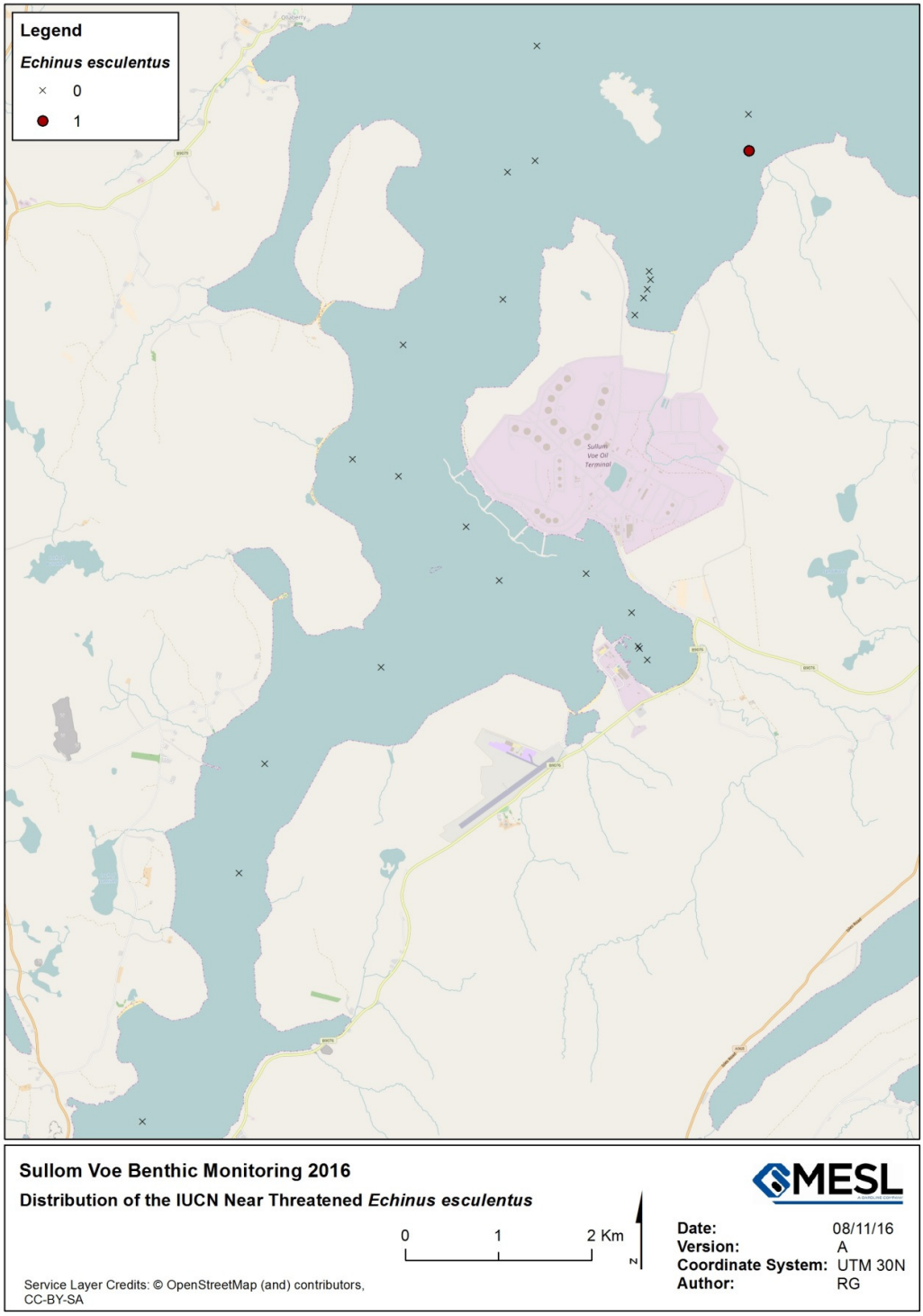

Figure 13. The abundance distribution of *Echinus esculentus* (per 0.3m^2) as determined during the June 2016 survey of Sullom Voe.

4.2.3 MULTIVARIATE DATA ANALYSIS

Multivariate analysis has been used to scrutinise abundance data using groupings of samples. An analysis of similarity (ANOSIM) test has been carried out on the 2012, 2014 and 2016 abundance data to assess the differences in the infaunal communities between years (Table 2). The test revealed a high degree of overlap between the community composition of Sullom Voe as a whole between 2012, 2014 and 2016, suggesting that that although some change has occurred, the faunal communities present remain very similar (R = 0.186, significance level = 0.1%).

Table 4. Outputs of the ANOSIM test conducted using faunal data from the surveys undertaken at Sullom Voe in 2012, 2014 and 2016.

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

In support of the ANOSIM test, a Kruskal-Wallis rank sum test was conducted in R which revealed that there was not a significant difference in abundance between years (Kruskal-Wallis chi-squared = 5.4769, df = 2, p-value = 0.06467 where p=0.05) though there was a significant difference in abundance between stations (Kruskal-Wallis chi-squared = 55.446, df = 25, p-value = 0.0004299).

Additionally, an examination of the diversity data for 2012, 2014 and 2016 revealed that there has been no significant change in diversity between years (Kruskal-Wallis chi-squared = 0.24796, df = 2, p-value = 0.8834) though there is a very significant difference between stations (Kruskal-Wallis chi-squared = 66.664, df = 25, p-value = 1.189e-05).

SIMPROF analysis using PRIMER v6 found 18 statistically-distinct faunal assemblages within the 2016 abundance dataset (compared to 16 in 2014) and the pattern seen in the corresponding MDS ordination was similar to that seen in the previous two surveys. SIMPROF groups were numerous and often represented communities at a single station. As such a manual cut-off of 40% on the cluster dendrogram was used to create fewer groups and the species composition of each group was identified through a SIMPER analysis. The five faunal groups derived from the 40% cut-off were often similar to those identified during the 2014 monitoring and provided a clearer indication of the geographical distribution of the faunal assemblages (Figures 14 -16).

4.2.3.1 Faunal Group A – Stations SV36B and SV37B

The average similarity between faunal assemblages at the two stations encompassed by faunal Group A was 44%, which was accounted for by the contributions of 13 taxa. Both stations were located to the north of the site and were relatively isolated from other stations. The samples collected at the sites were dominated by *Spirobranchus triqueter*, *Dipolydora coeca* and *Dipolydora socialis* (% contributions to group: 6.2, 5.1 and 4.8 respectively). Folk classification and biotopes at these sites could not be determined due to a lack of PSA data.

4.2.3.2 Faunal Group B – Stations OV1B and OV2B

The average similarity between faunal assemblages at the two stations grouped in faunal Group B was 47%, which was accounted for by the contributions of five taxa at a 90% cut-off. The two neighbouring Orca Voe stations within this group are the most inshore of the 'OV' stations. The faunal assemblages at the stations in Group B were dominated by Spirobinae, *Kurtiella bidentata* and *Crenella decussata,* (% contributions to group: 20, 6.6 and 5.6 respectively). Folk classification and biotopes at these sites could not be determined due to a lack of PSA data.

4.2.3.3 Faunal Group C – Stations SV6, SV6A, SV6F and SV32

The average similarity between faunal assemblages at the four stations encompassed by faunal Group C was 47%, which was accounted for by the contributions of four taxa at a 90% cut-off. All four of the stations in Group C are geographically clustered in the bay to the south-east of the Sullom Voe Oil Terminal and located in some of the shallowest areas within the voe, ranging from just 5 to 11m. The sediment classifications at the stations within this group were 'slightly gravelly muddy Sand' ((g)mS) 'muddy Sand' (mS) and 'gravelly muddy sand' (gmS). Station SV6 does not fit into an existing biotope though historically high numbers of one of *Aphelochaeta* and *Tubificoides* spp. have been recorded here. Given the potential for variable salinity in the area it is possible that the sandy mud biotope such as '*Aphelochaeta marioni* and *Tubificoides* spp. in variable salinity infralittoral mud (SS.SMU.SMuVS.AphTubi)' is most appropriate for SV6. The other stations in this group are most likely to belong to the biotope '*Mysella bidentata* and *Thyasira* spp. in circalittoral muddy mixed sediment (SS.SMx.CMx.MysThyMx)'. The samples collected at the stations in this group were dominated by *K. bidentata*, *T. flexuosa* and *T. benedii* (% contributions to group: 11, 11 and 10 respectively).

4.2.3.4 Faunal Group D – SV3, SV4, SV5, SV7, SV8, SV8A, SV10, SV11, SV33 and SV34

The average similarity between faunal assemblages at the 10 stations encompassed by faunal Group D was 47%, which was accounted for by the contributions of nine taxa at a cut off of 90%. All of the stations in Group D are in the mid-channel and immediately to the south of Sullom Voe Oil Terminal. Each station within this group is located in a range of water depths from 19 to 52m. The stations within this faunal group had a range of sediment types which were 'slightly gravelly sandy Mud' ((g)sM), 'gravelly Mud' (gM), 'gravelly muddy Sand' (gmS), 'slightly gravelly muddy Sand' ((g)mS) and 'muddy Sand' (mS). The species 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)'. There was also some evidence of the biotope 'Sublittoral sands and muddy sands (SS.SSa)' which could only be identified at Level 3 due to species not fitting biotope descriptions. These stations were characterised by mixed sediments of 'Mixed' (gM and gmS) and 'Mud' ((g)sM, (g)mS and mS) sands. The samples collected at the stations in this group were dominated by *T. flexuosa, P. fallax* and *T. communis* (% contributions to group: 10, 8.4 and 5.6 respectively).

4.2.3.5 Faunal Group E – SV9, SV17, SV35, OV3B, OV4B and OV5B

The average similarity between faunal assemblages at the six stations encompassed by faunal Group E was 47%, which was accounted for by the contributions of 24 taxa at a 90% cut-off. All of the stations encompassed by Group E were spread either in the northern sector of Orca Voe or to the south in the central channel near to the oil terminal. Each station within

this group is located in a range of water depths from 14 to 28m. These stations were characterised by mixed sediments of 'Mixed' (gmS) and 'Sand' (gS). The biotopes '*Mysella bidentata* and *Thyasira* spp. in circalittoral muddy mixed sediment (SS.SMx.CMx.MysThyMx)' and 'Sublittoral sands and muddy sands (SS.SSa)' were common amongst the stations in this faunal group. It can be seen in Figures 14 and 16 that there is a slight divide in similarity between the more southern and northern counterparts of this group. The samples collected at the stations in this group were dominated by *T. flexuosa, K. bidentata* and *Lumbrineris cingulata* (% contributions to group: 4.5, 3.1 and 3.1 respectively).

4.2.3.6 Outliers – SV1 and SV12

Two stations were identified as outliers: SV1 and SV12. These sites were the southern- and northern-most stations in the survey region and were isolated in comparison to other stations and had a relatively low faunal presence. These were the two of the deepest stations recorded during the 2016 survey with a depth of 45m measured at SV1 and 51m at SV12. The Folk description at SV1 was sandy mud (sM), which differs from the sediment type recorded in 2014 ('muddy Sand', mS) but is the same as the sediment type recorded in 2012. Given the characterising species (*Capitella* spp. and *Lagis koreni*) and sediment type at this site, an appropriate biotope could not be identified, though '*Lagis koreni* and *Phaxas pellucidus* in circalittoral sandy mud (SS.SMu.CSaMu.LkorPpel)' has been suggested in previous reports. The sediment at SV12 was 'mixed sandy Gravel' (msG) which differs from 'sandy Gravel' which was recorded in 2014, and the dominant biotope in 2016 was '*Mediomastus fragilis, Lumbrineris* spp. and venerid bivalves in circalittoral coarse sand or gravel (SS.SCS.CCS.MedLumVen)'.

4.2.4 SEDIMENT DISTRIBUTION

As is evident in Figure 17, there has been a marginal change in dominant sediment fractions across Sullom Voe from 2012-2016. The proportion of silt has increased in 2016 especially when compared to 2012. Station SV1 and other lower mid-channel stations in particular have been subject to an increasing silt fraction. Since 2012, the stations to the south of the oil terminal in the Houb of Scatsca have become increasingly sandy and are now sand dominated while nearby stations adjacent to the oil terminal have remained fairly similar, though there has been some slight adjustment in silt and gravel proportions.

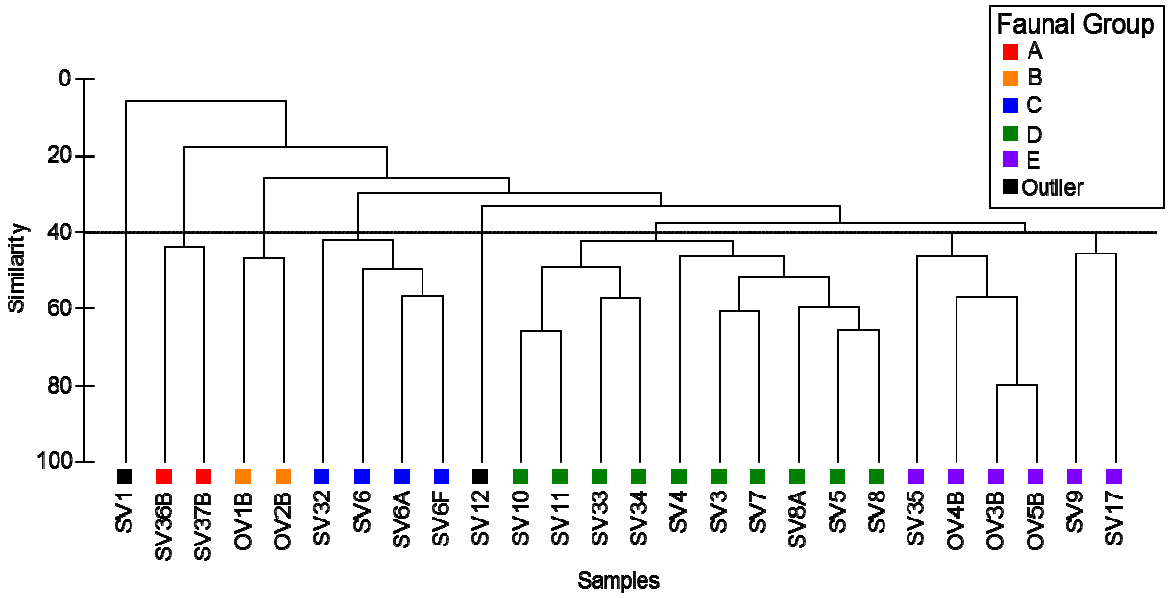

Figure 14. Cluster dendrogram representation of 2016 pooled abundance data from the Sullom Voe survey grouped according to similarities in faunal communities at a 40% cut-off(based on Bray-Curtis similarity and square root transformation).

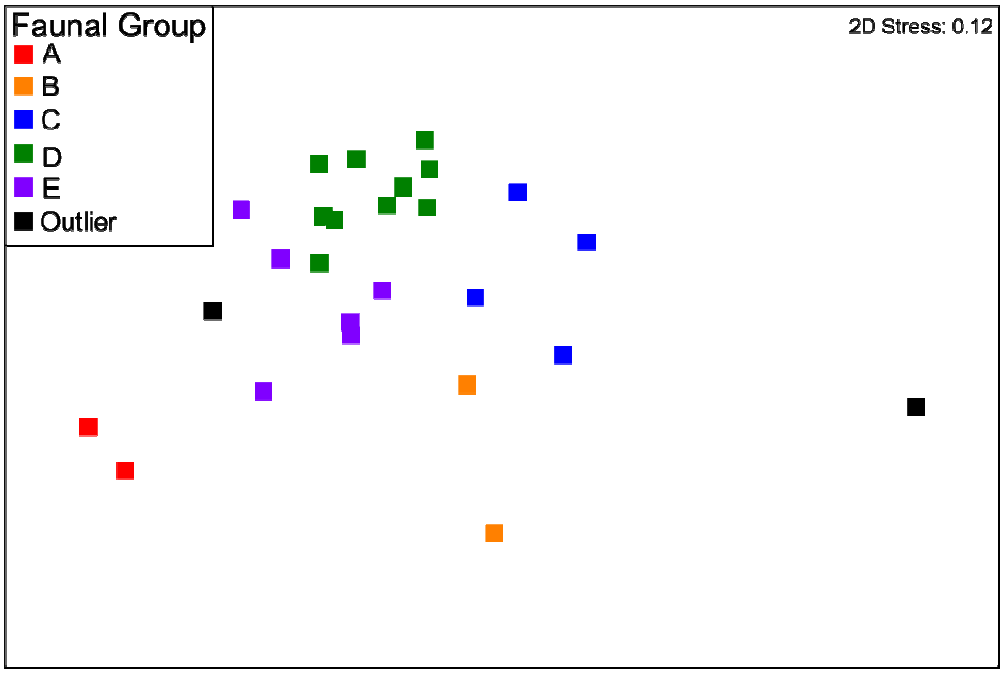

Figure 15. Two-dimensional representation of MDS ordination using 2016 pooled abundance data from the Sullom Voe survey grouped according to faunal group (based on Bray-Curtis similarity, square root transformation).

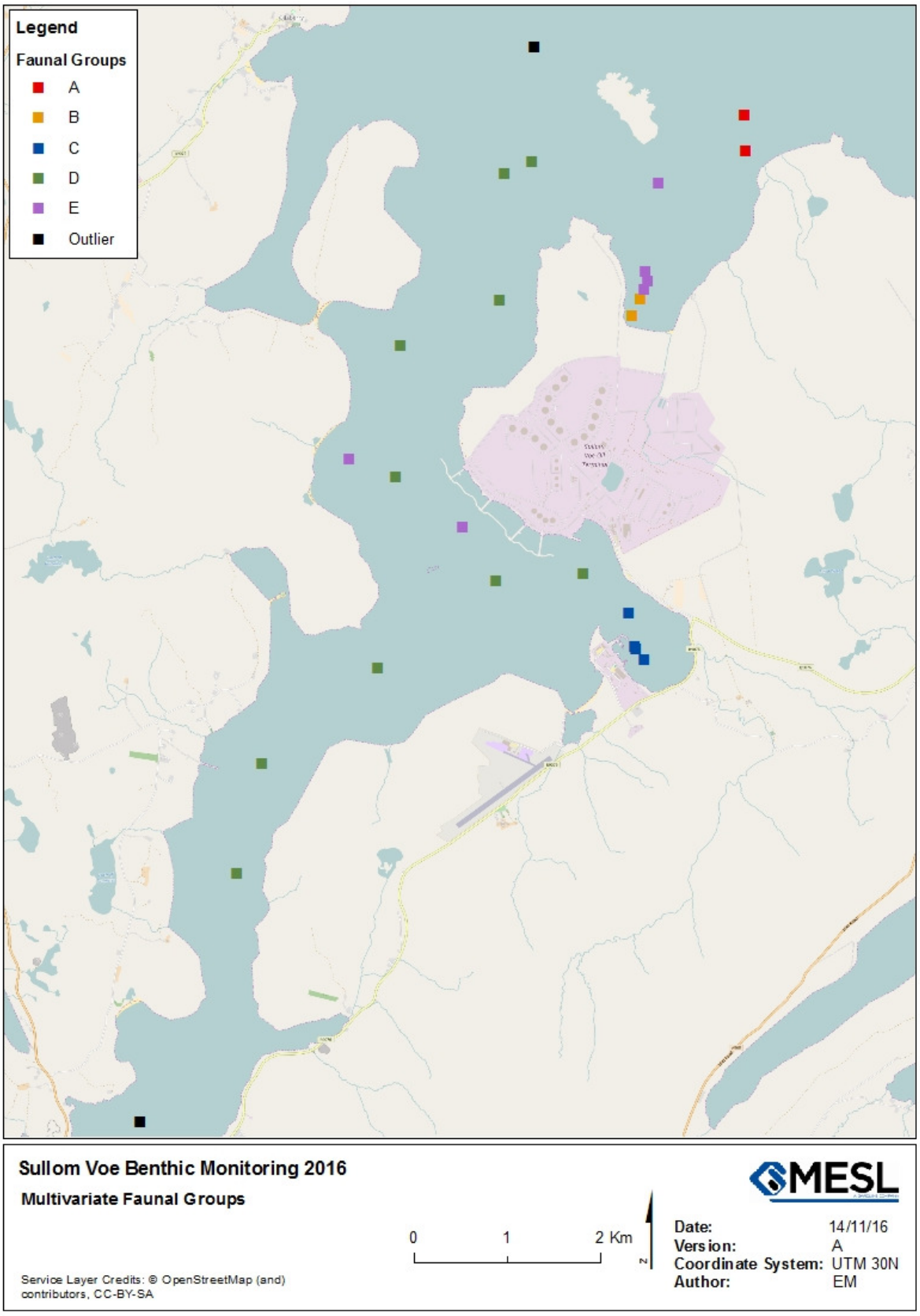

Figure 16. The distribution of faunal groups at Sullom Voe in 2016.

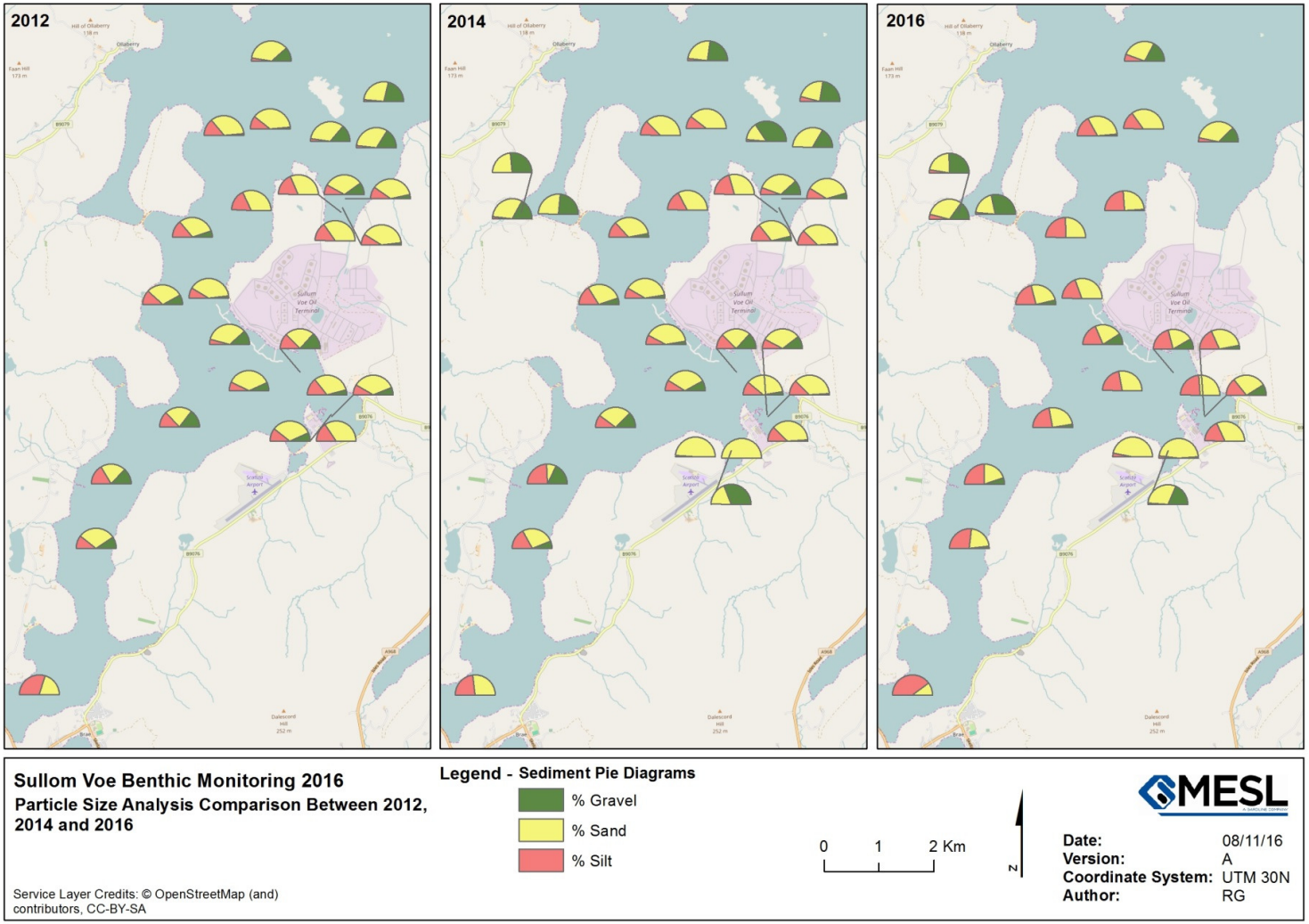

Figure 17. Sediment particle size analysis comparison between the three most recent survey years at Sullom Voe

4.2.5 Relating Environmental Parameters to Biological Data

Draftsman's plot examinations in Primer revealed that UCM percent of total aliphatics and total naphthalene data was skewed and in an attempt to distribute the data more evenly, both were subject to square-root transformations. This acted to improve the distribution of the total naphthalene data in the Draftsman's plots, though not UCM percent of total aliphatics as the outputs became increasingly skewed. As such, a fourth-root transformation was undertaken for this variable which did not improve the data and so the UCM percent of total aliphatic data remained un-transformed for the BEST procedure. Few correlations were seen in the Draftsman's plots and where they occurred, affected variables were considered too important to exclude, meaning that all tested abiotic data were included in the BEST analysis.

The BEST procedure was then run using BIOENV on the transformed abiotic data selecting Spearman correlation (rho value) and the Bray-Curtis resemblance matrix of biotic abundance data. The results of the best variable combinations are presented below. 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.

Table 5. Results of the BEST tests conducted using Primer for the 2016 Sullom Voe faunal abundance and biotic data

Best variable combinations		Rho
1	Total aliphatics	0.467
2	Total aliphatics, depth	0.524
3	Depth, % silt, UCM	0.556
4	Depth, % silt, UCM, % gravel	0.561
5	Depth, % silt, UCM , % gravel, total dibenzothiophenes	0.561
6	Depth, % silt, UCM, % gravel, total dibenzothiophenes, Phi mean	0.562

The BEST results suggest that total aliphatic hydrocarbon is the abiotic variable which best groups the stations in a manner consistent with the biotic patterns with a rho value of 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 0.562. When the number of variables above this was increased, the value of rho reduced.

Historically, the percentage of gravel and organic matter were shown to be some of the key structuring drivers behind the biological community patterns, though analyses have not shown organic matter to be a highly influential variable in 2016 and gravel is a less causative variable than silt. In previous years it has been hypothesised that high organic matter content, such as that recorded at Station SV1 (in 2016 as well as other recent years) combined with high mud content created a habitat suitable for a relatively high abundance of specifically tolerant species such as *Capitella* spp.. Though organic content and sediment composition at this station are relatively unchanged since 2014, total aliphatic hydrocarbon presence was seen as a more influential driver behind community structure across the site in 2016. This variable was followed by others, such as depth and percentage mud, which have

also been observed to be crucial variables in preceding years (though it should be noted that PSA data was not available for any of the Orca Voe stations or Stations 36B and 37B).

The two most unique faunal communities were observed at stations classified as outliers during the SIMPROF routine. Stations SV1 and SV12 are geographically-isolated compared to many of the other stations and are also substantially deeper than most (45m and 51m respectively). The BEST analysis suggests that depth is the most likely driver for the difference in community structure at SV1 and SV12 as they were the two deepest stations within the Sullom Voe array.

As in previous years, sediment type played a perceptible role in determining biological community structure, with silt and gravel (rather than sand) having the most marked effects on the infauna at each station. Particle size fractions across the Sullom Voe survey region have been slightly variable in the three most recent survey years (Figure 17), which accounts for changes in the most influential environmental parameters between years. It is evident that silt is a more dominating component of sediment in 2016, particularly in the mid- and upper-channel stations and to the south of the Oil Terminal. A full PSA breakdown for the 2016 survey samples can be found in Appendix 4.

This 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 (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.

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 2016 data, the real value of rho is 0.561, comfortably to the right of the null distribution; the null hypothesis can therefore be rejected at a significance level of 1%, implying there is a significant relationship between biotic and abiotic data.

4.3 SEDIMENT CHARACTERISATION

The results of the analyses of sediment particle distribution for 2016, organic matter and sediment type classification according to Folk (1954) are given in Table 2. Combined Particle size distribution (PSD) graphs are included as Appendix 2.

The particle size distribution was performed by the NMBAQC methodology in 2016 which is different from previous years. The key differences between the methodologies are outlined in section 2.4 . The outcome of the change in methodology is that the mud content of the sediments will be greater using the NMBAQC methodology. It is therefore more difficult to interpret the 2016 data set in context of the historical data.

The mud content results for 2016 are noticeably higher than in recent studies, the average 2016 results for all stations are +2.1 standard deviations higher than the historic data set (2004-2014) and +1.4 standard deviations higher than the mean for the historic data set (1981-2014).

For the review of particle size distribution results in context of the historical data no standard deviation lines have been included on the charts.

The total organic content was determined using method British Standard (BS) 13137. The quality control measures were acceptable for all the reported results at each station. Each sample was analysed in duplicate and both results were within 10% of the mean of the two results, blanks and control samples were ran with the sediment samples and were within 10% of the method specified values.

Table 6 - Physical parameters of sediments from all stations, June 2016.

STATION	Phi Mean	Phi Skewness	Phi Kurtosis	% Mud	% Sand	% Gravel	% Organic Content (BS 13137)	Textural Group
1	5.305	0.104	1.075	79.7	20.2	0.1	18.8	Slightly Gravelly Sandy Mud
3	3.970	-0.100	1.143	53.3	43.0	3.7	5.0	Slightly Gravelly Sandy Mud
4	3.366	-0.197	0.847	49.5	40.1	10.4	5.7	Gravelly Mud
5	3.367	-0.053	0.866	43.8	50.8	5.4	4.6	Gravelly Muddy Sand
7	2.851	-0.226	1.055	41.7	41.5	16.8	7.8	Gravelly Mud
8	3.517	0.086	0.838	42.7	55.8	1.5	7.5	Slightly Gravelly Muddy Sand
8A	3.551	0.153	1.049	37.9	61.2	1.0	3.8	Slightly Gravelly Muddy Sand
9	3.498	-0.05	1.064	42.3	50.0	7.7	8.3	Gravelly Muddy Sand
10	4.302	0.229	1.142	48.5	50.2	1.3	5.2	Slightly Gravelly Muddy Sand
11	4.347	0.211	1.375	48.2	49.3	2.5	3.6	Slightly Gravelly Muddy Sand
17	2.511	-0.103	0.960	37.2	44.9	17.9	2.0	Gravelly Muddy Sand
12	-0.08	-0.199	0.842	11.4	53.7	34.9	1.1	Muddy Sandy Gravel
33	3.721	0.290	1.321	34.5	62.4	3.1	2.0	Slightly Gravelly Muddy Sand
34	3.541	0.352	1.561	28.9	69.3	1.8	1.7	Slightly Gravelly Muddy Sand
35	0.432	0.174	1.013	6.0	70.1	23.9	2.5	Gravelly Sand
6	3.046	-0.027	0.933	36.4	57.8	5.8	4.4	Gravelly Muddy Sand
6A	2.163	-0.252	1.19	28.4	54.0	17.6	6.9	Gravelly Muddy Sand
6F	3.352	0.152	0.955	35.6	63.1	1.2	12.3	Slightly Gravelly Muddy Sand
32	3.984	0.097	1.006	47.5	51.8	0.8	11.1	Slightly Gravelly Muddy Sand
GV1	-0.599	0.385	0.872	5.5	44.0	50.5	1.5	Muddy Sandy Gravel
GV2	-1.543	0.332	0.620	3.3	40.1	56.6	<0.1	Sandy Gravel
GV3	0.135	-0.079	1.013	7.6	62.5	29.9	2.0	Gravelly Muddy Sand
HS1	-0.544	-0.419	0.809	2.1	61.0	36.9	0.7	Sandy Gravel
HS2	2.069	0.141	1.138	6.6	93.4	0.0	0.8	Slightly Gravelly Sand
HS3	1.694	0.924	1.258	4.0	93.8	2.2	1.7	Slightly Gravelly Sand

4.4 HYDROCARBONS

4.4.1 GAS CHROMATOGRAPHY OF ALIPHATIC HYDROCARBONS

The total aliphatic hydrocarbon (TAH) and unresolved complex mixture (UCM) results are detailed in table 5 below. Comparison charts with previous year's data are provided for each station in section 3.4

4.4.1.1 Quality Control

4.4.1.1.1 Extraction Blanks

Blanks were analysed with each batch of 10 samples and the levels were found to between 1.0 to 1.3 µg.g^{-1} based on 50g dry weight basis. There was a small cluster of peaks which were impurities in the solvent which would be present in the sample chromatograms. The amount of total aliphatic hydrocarbon determined in the extraction blank was subtracted when quantifying the results for the sample analysis.

4.4.1.1.2 Quality Control Sample

5g certified reference material, which consisted of dried sea sediment spiked with diesel range organics at 465 mg/Kg was analysed with each batch of 10 samples using the test method. The actual concentration for this certified reference material was equivalent to 50% of the calibration range for the method. The recoveries for the certified reference material had a mean of 99% and standard deviation of 12%. The results were within the expected method performance of 70-120% (red line) and seven of the eight results were within the confidence interval (orange line) for the certified reference material.

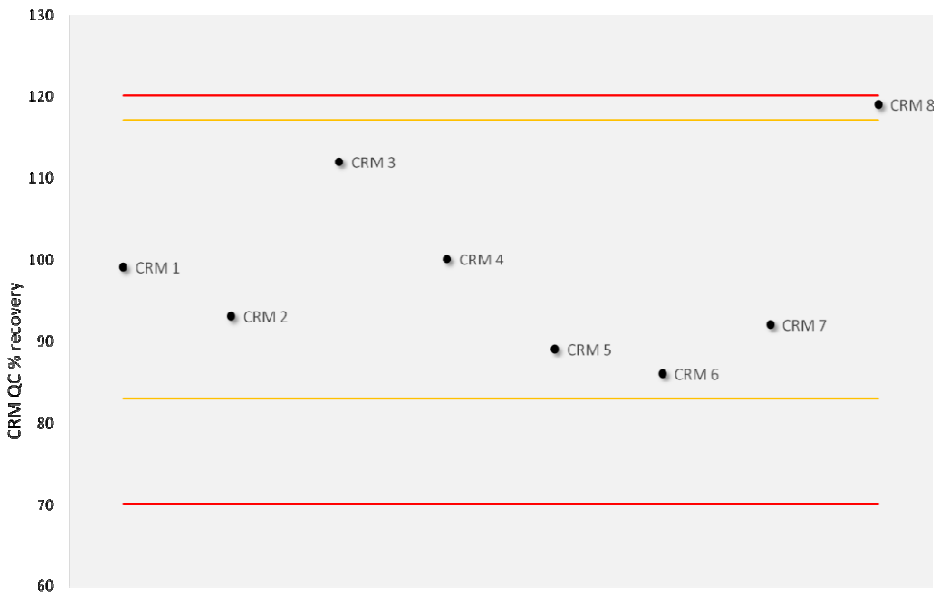

Figure 18 - Certified Reference Material percentage recovery chart

4.4.1.2 Analysis of Three Grab Samples

In contrast to previous years, each grab sample which was to be tested for macro benthic analysis was sub-sampled for hydrocarbon analysis. In previous years a composite was prepared from the three grab samples used for macrobenthic analysis and this was homogenised and used for the hydrocarbon analysis.

A number of stations demonstrated high levels of variation between the results obtained from the three grab samples. For stations, 1,7,10,17 the relative standard deviation for the three replicates was 49,47,41,50 percent respectfully. This deviation does not correlate with the distribution of the stations or particle size distribution of the sediments. However the mean of the three grab sample results showed very good correlation to the mean from the historic data period 2004-2014. The number of standard deviations from the mean for the data set 2004-2014 was 0,-0.3,0.2,-0.3 respectfully to the stations detailed above. So while high deviation was observed at some stations this had little effect on the mean result from the three grab samples from the site.
Other stations also demonstrated high levels of variation between the three grab samples but at lower hydrocarbon concentrations (<10µg.g^{-1}) where the uncertainty of measurement is higher as it reaches the detection limit of the method. The relative standard deviation of the stations with <10µg.g^{-1} hydrocarbons were within the acceptable 30 percent relative standard deviation expected by the SEPA quality control requirement, this value does not include contribution due to sample homogeneity.

4.4.1.3 Total Aliphatic Hydrocarbon Results

The total aliphatic hydrocarbon (TAH) results are details in table 5 below.

The GC traces for the current survey are similar to those for the same stations in the 2014 survey. There is no clear evidence for any fundamental alteration in the distribution of hydrocarbons in most of the sediments in 2016 compared with the 2014 survey. Examination of the GC traces shows selected normal (n-) alkanes in the range of n-C_{12} to n-C_{35} superimposed on an extended molecular weight unresolved complex mixture (UCM). The GC traces of most of the stations are similar with only the relative intensities of various components altering.

The total aliphatic hydrocarbon (TAH) results demonstrated little evidence of change across all the stations. The average TAH result was 33.2 µg.g^{-1} for all valid stations in 2016, in 2014 this was 31.7 µg.g^{-1} for the same stations, the historic mean TAH result for the period 2004-2014 was 34.6 µg.g^{-1} for the same stations. The average number of standard deviations from the historic mean (for period 2004-2014) across all valid stations was -0.08, this demonstrates that there has been little change in the overall TAH concentration in the Sullom Voe area.
There are some stations and areas which demonstrate some change, for example the Garths Voe stations SV6 and SV6F have lower TAH concentrations, and they are -1.6 and -1.5 standard deviations from the historic mean for data period 2004-2014. The relative standard deviation between the three grab samples at these stations was 6% and 14% respectfully. Repeat analysis of the sediment correlated with the original results within the method precision. Also, Outer Voe Station SV9 has the largest increase in TAH concentration and was +1.7 standard deviations from the historic mean for data period 2004-2014.

4.4.1.4 Unresolved Complex Mixture Results

The unresolved complex mixture (UCM) results are details in table 5 below.

The UCM is expressed in the analytical units ($\mu g.g^{-1}$) and also as a percentage of the TAH concentration. The UCM ($\mu g.g^{-1}$) demonstrated evidence of increasing on average across all the stations.

The average UCM ($\mu g.g^{-1}$) result was 22.4 $\mu g.g^{-1}$ for all valid stations in 2016, in 2014 this was 14.8 $\mu g.g^{-1}$ for the same stations, the historic mean UCM result for the period 2004-2014 was 17.7 $\mu g.g^{-1}$ for the same stations. The average number of standard deviations from the historic mean (for period 2004-2014) across all valid stations was +0.75, this demonstrates that there has been a slight increase in the overall UCM concentration in the Sullom Voe area.

For all stations, the relative standard deviation of the historic data set 2004-2014 was <20% for each station The average UCM (UCM as a % of TAH) result was 63.8% for all valid stations in 2016, in 2014 this was 48.0% for the same stations, and the historic mean UCM result for the period 2004-2014 was 52.8% for the same stations. The average number of standard deviations from the historic mean (for period 2004-2014) across all valid stations was +2.2, this demonstrates that there has been a change in the overall UCM concentration in the Sullom Voe area. The most significant change in the UCM (as a % of the TAH) was at stations SV1,SV7,SV32 and GV2, where the 2016 result was 3.4, 9.6, 3.9 and 8.3 standard deviations from the historical mean for period 2004-2014, respectfully. The average (excluding the four significantly high stations listed above) number of standard deviations from the historic mean for period 2004-2014 was +1.6, which still demonstrates some change.

While the 2016 show a noticeable difference from the trend for period 2010-2014, the unresolved complex mixture results from 2008 demonstrate a similar positive biased outlier.

Table 7 - Summary of parameters calculated from GC analysis of aliphatic hydrocarbons in all stations, June 2016

STATION	Mean Total Aliphatics (µg/g)	Relative Standard Deviation of Total Aliphatics (%)	Mean UCM (µg/g)	UCM of Total Aliphatics (%)	Relative Standard Deviation of % UCM (%)
1	190	49	140	68	7
3	32	25	20	63	11
4	33	20	21	63	9
5	31	25	20	66	12
7	57	47	39	68	1
8	26	21	18	70	2
8A	14	27	11	75	6
9	40	12	25	63	16
10	21	41	14	67	19
11	19	26	14	75	7
17	13	50	8.7	69	6
12	4.0	9	2.9	81	22
33	11	46	7.7	70	9
34	8.2	25	5.6	69	2
35	1.9	46	1.5	81	19
36	NR	NR	NR	NR	NR
37B *	2.1	-	1.1	55	-
6	38	5	23	62	13
6A	92	24	63	68	3
6F	97	14	66	68	6
32	110	5	70	64	7
OV1B	2.9	23	1.6	57	5
OV2B	3.4	16	1.9	59	16
OV3B	5.6	16	3.1	55	13
OV4B	8.0	18	5.4	67	3
OV5B	14	18	9.2	68	6
GV1	3.3	7	0.7	21	1
GV2	2.1	45	1.4	66	6
GV3	3.0	48	1.2	38	10
HS1	3.4	25	2.4	72	12
HS2	6.8	24	3.1	47	14
HS3	4.8	32	2.3	49	11

NR – No result – no sediment was obtained from grabs at revised station coordinates.
* - Only one grab contained sediment from revised station coordinates.
All results are expressed on a dry weight basis.
UCM – Unresolved Complex Mixture

4.4.2 GC/MS - Polycyclic Aromatic Hydrocarbons (PAHs)

4.4.2.1 Polycyclic Aromatic Hydrocarbons (PAHs)

The polycyclic aromatic hydrocarbon results (PAH) are detailed in table 6 below. Comparison charts with previous year's data are provided for each station in section 3.4

Extracts from 9 stations were analysed for concentration of 2-6 ring PAHs and also the percentage of 4-6 ring PAHs to the total PAHs. The stations OV1B and OV5B were analysed but not assessed against historic data as their coordinates had been revised in 2016.

As with the GC traces for the aliphatic fractions, the distribution of aromatic hydrocarbons in the total ion chromatogram (TIC) traces for the sediments are very similar to the 2014 survey. Complex mixtures of PAH were detected by gas chromatography with mass chromatography (GC-MS) including alkyl substituted compounds as well as their un-substituted (parent) homologues.

In petroleum products there are substantial amounts of alkylated PAH. Hence a relatively high proportion of these derivatives with respect to the non-alkylated parent PAH indicates a petrogenic input. Petrogenic aromatic hydrocarbon distributions in sediments differ from those of fresh crude oils, as the latter are dominated by alkylnaphthalenes and alkylphenanthrenes. These components are preferentially removed by the processes of weathering. Not only do the volatile naphthalenes evaporate during exposure to the elements but alkylnaphthalenes and alkylphenanthrenes are gradually removed by bacterially mediated aerobic degradation (Jones et al., 1983).

The 2-6 ring PAH results demonstrated little evidence of change across all the seven stations analysed. The average 2-6 ring PAH result was 1310 $ng.g^{-1}$ for all valid stations in 2016, in 2014 this was 1528 $ng.g^{-1}$ for the same stations, the historic mean 2-6 ring PAH result for the period 2004-2014 was 1382 $\mu g.g^{-1}$ for the same stations. The average number of standard deviations from the historic mean (for period 2004-2014) across all valid stations was -0.2, this demonstrates that there has been little change in the overall PAH concentration in the Sullom Voe area.

There was one station SV6F which demonstrated change. The 2-6 ring PAH concentrations at SV6F, was -2.8 standard deviations from the historic mean for data period 2004-2014. The analysis of the other 2 grab samples for station SV6F give similar results. The TAH result at this station was at 64% of the mean level for historic period 2004-2014.

The percentage of 4-6 ring PAH results demonstrated evidence of an average change across all the seven unchanged stations analysed. The average 4-6 ring PAH of total PAH result was 88 % for all unchanged stations in 2016, in 2014 this was 85 % for the same stations, the historic mean TAH result for the period 2004-2014 was 77% for the same stations. The average number of standard deviations from the historic mean (for period 2004-2014) across all unchanged stations was +1.6, this demonstrates that there has been some change in the overall percentage of 4-6 ring PAH of total PAH concentration in the Sullom Voe area. This correlates with the increase in the percentage UCM of total aliphatic hydrocarbon.

Table 8 Concentrations of 2-6 ring aromatic hydrocarbons in selected sediments, 2016 (ng.g^{-1} dry weight sediment; ppb).

Station	**1**	**4**	**7**	**17**	**34**
Naphthalene(N)	<0.1	<0.1	0.3	1.6	<0.1
C1-Naphthalenes	1.4	0.3	1.3	2.5	0.1
C2-Naphthalenes	73	13	19	14	11
C3-Naphthalenes	4.1	1.0	3.1	3.5	<0.1
C4-Naphthalenes	<0.1	0.5	<0.1	1.3	<0.1
Total Naphthalenes(N)	**79**	**15**	**24**	**22**	**11**
Phenanthrene/Anthracene(P)	11	5.2	33	35	1.3
C1-Phenanthrenes/Anthracenes	12	1.7	13	11	1.5
C2-Phenanthrenes/Anthracenes	19	4.0	13	6.5	1.3
C3-Phenanthrenes/Anthracenes	19	3.4	11	4	1.5
Total Phenathrenes(P)	**60**	**14**	**71**	**56**	**4.1**
Dibenzothiophene(D)	0.8	0.3	2.0	2.2	0.1
C1-Dibenzothiophenes	2.8	0.8	1.9	1.7	0.3
C2-Dibenzothiophenes	3.6	1.4	1.6	1.8	0.3
C3-Dibenzothiophenes	2.2	1.6	1.9	1.8	0.4
Total Dibenzothiophenes(D)	**9.4**	**4.2**	**7.4**	**7.5**	**1.0**
ΣNPD	**150**	**33**	**100**	**86**	**16**
Fluoranthene/Pyrene	174	93	470	450	21
C1-Fluoranthenes/Pyrenes	50	12	50	40	3.0
C2-Fluoranthenes/Pyrenes	54	120	39	24	3.0
C3-Fluoranthenes/Pyrenes	41	8.0	21	10	3.0
Total Fluoranthenes/Pyrenes	**320**	**230**	**580**	**520**	**30**
Benzanthracene/Chrysene	210	52	230	210	12
C1-Benzanthracenes/Chrysenes	40	10	33	31	2.3
C2-Benzanthracenes/Chrysenes	12	4.4	7.2	6.2	<0.1
Total Benzanthracenes/Chrysenes	**260**	**66**	**270**	**250**	**14**
Benzofluorathenes/Benzpyrene	550	110	410	260	31
C1-Benzofluorathenes/Benzpyrenes	98	16	49	31	5.1
C2-Benzofluorathenes/Benzpyrenes	91	13	30	15	3.0
Total Benzofluorathenes/Benzpyrenes	**740**	**140**	**490**	**300**	**39**
m/z 276	526	91	240	170	35
C1-m/z276*	61	8.9	17	13	3.2
c2-m/z276*	75	9.4	19	11	3.3
Total m/z276*	**660**	**110**	**270**	**196**	**42**
Total 2-6 ring PAH	**2200**	**600**	**2100**	**1400**	**144**
% 4-6 ring PAHs as a % of the total PAHs	**91**	**92**	**79**	**89**	**86**

Table 8 (continued) - Concentrations of 2-6 ring aromatic hydrocarbons in selected sediments, 2016 (ng.g-1 dry weight sediment; ppb).

Station	6	6F	OV1B	OV5B
Naphthalene(N)	<0.1	<0.1	<0.1	<0.1
C1-Naphthalenes	0.7	<0.1	<0.1	0.7
C2-Naphthalenes	21	12	0.3	33
C3-Naphthalenes	2.1	3.8	<0.1	1.1
C4-Naphthalenes	7.0	2.7	<0.1	<0.1
Total Naphtalenes(N)	**30**	**19**	**0.3**	**34**
Phenanthrene/Anthracene(P)	13	17	0.4	20
C1-Phenanthrenes/Anthracenes	12	11	9.2	2.2
C2-Phenanthrenes/Anthracenes	26	19	1.2	13
C3-Phenanthrenes/Anthracenes	25	23	5.0	5.8
Total Phenathrenes(P)	**76**	**71**	**16**	**41**
Dibenzothiophene(D)	1.0	1.1	<0.1	5.2
C1-Dibenzothiophenes	2.6	1.7	0.2	1.3
C2-Dibenzothiophenes	5.7	3.3	<0.1	1.9
C3-Dibenzothiophenes	11	9.4	<0.1	1.6
Total Dibenzothiophenes(D)	**20**	**16**	**0.2**	**10**
ΣNPD	**130**	**110**	**16**	**85**
Fluoranthene/Pyrene	280	310	7.4	30
C1-Fluoranthenes/Pyrenes	40	46	1.2	6.1
C2-Fluoranthenes/Pyrenes	42	39	0.5	5.1
C3-Fluoranthenes/Pyrenes	16	26	0.2	3.8
Total Fluoranthenes/Pyrenes	**380**	**420**	**9.3**	**45**
Benzanthracene/Chrysene	150	160	4.4	24
C1-Benzanthracenes/Chrysenes	32	27	0.7	15
C2-Benzanthracenes/Chrysenes	5.9	8.6	10	<0.1
Total Benzanthracenes/Chrysenes	**180**	**190**	**15**	**40**
Benzofluorathenes/Benzpyrene	300	300	6.6	42
C1-Benzofluorathenes/Benzpyrenes	41	44	0.7	8.8
C2-Benzofluorathenes/Benzpyrenes	36	29	0.5	5.7
Total Benzofluorathenes/Benzpyrenes	**380**	**370**	**7.9**	**56**
m/z 276	190	190	4.4	43
C1-m/z276*	20	44	1.4	4
c2-m/z276*	23	27	0.8	3.9
Total m/z276*	**240**	**260**	**7.0**	**51**
Total 2-6 ring PAH	**1300**	**1400**	**56**	**280**
% 4-6 ring PAHs as a % of the total PAHs	**88**	**89**	**70**	**68**

4.5 Sullom Voe Stations - 2016 Chemistry Data viewed against Historic Data

4.5.1 Inner Basin and Southern Sullom Voe (Stations 1, 3, 4 and 5)

4.5.1.1 Inner Basin Station SV1

For station SV1, the mud content in 2016 is significantly higher than in the previous 5 surveys from 2006 to 2014, but is similar to mud concentrations determined during the 2004, 2000 and 1996 surveys. The 2016 result was +1.5 standard deviations from the historic mean for period 2004-2014, which is higher than the +2.1 average standard deviations from the historic mean for all stations in 2016. It is not possible to determine the significance of the 2016 result against the historic data due to changes in the particle size distribution methodology.

The organic content in 2016 was 18.8% which is similar to the 2014 result of 21.96%.The methodology for the organic content has also changed in 2016.

The concentration of total aliphatic hydrocarbons (TAH) at Station SV1, is similar to the 2014 result and the historic mean for the results from 2004-2014. This suggests very little change in the overall TAH concentration at station SV1. The percentage of UCM in the TAH is significantly higher than in 2014 and the highest recorded at this site. The percentage of UCM in the TAH is higher than the historic mean and is +3.4 standard deviations from the historic mean. The 2016 result is higher than the general trend as the percentage of UCM in the TAH is on average +2.2 standard deviations from the historic mean for all stations in 2016.

The concentration of 2-6 ring PAH concentration at Station SV1, is similar to the 2014 result and the historic mean for the results from 2004-2014. This suggests very little change in the overall PAH concentration at station SV1. The percentage of 4-6 ring PAHs to the total PAHs has increased slightly. The 2016 result was +0.9 standard deviations from the historic mean, which is lower than the +1.6 average standard deviations from the historic mean at all stations in 2016.

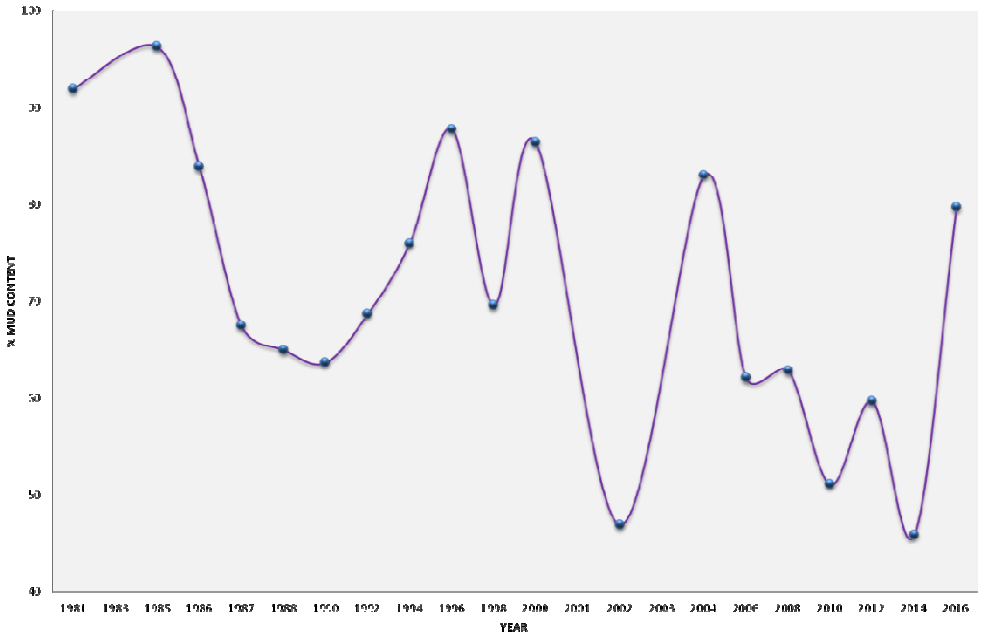

Figure 19 - SV1 Percentage Mud content

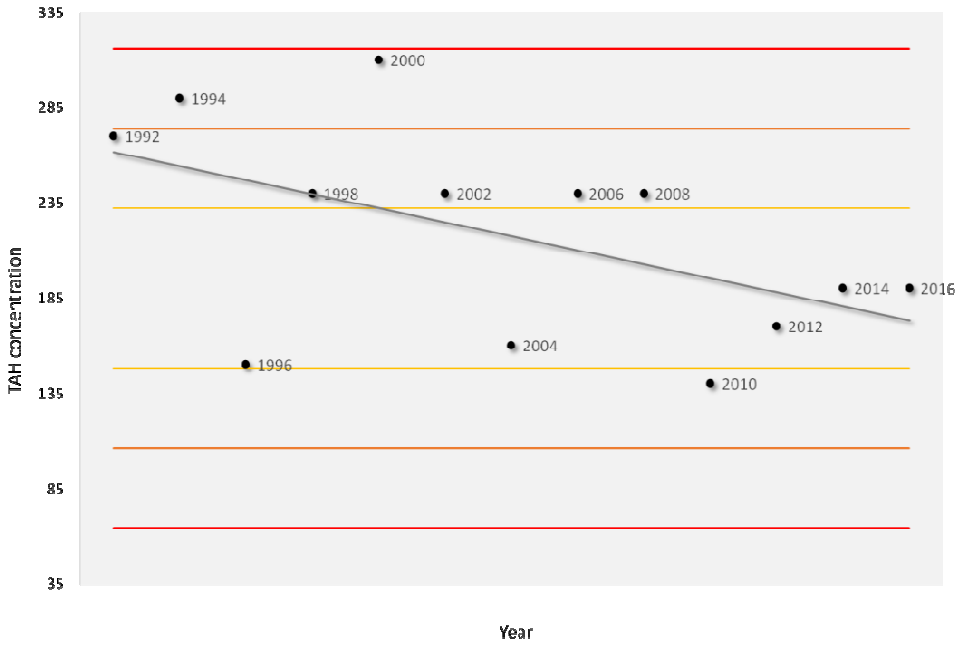

Figure 20 - SV1 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

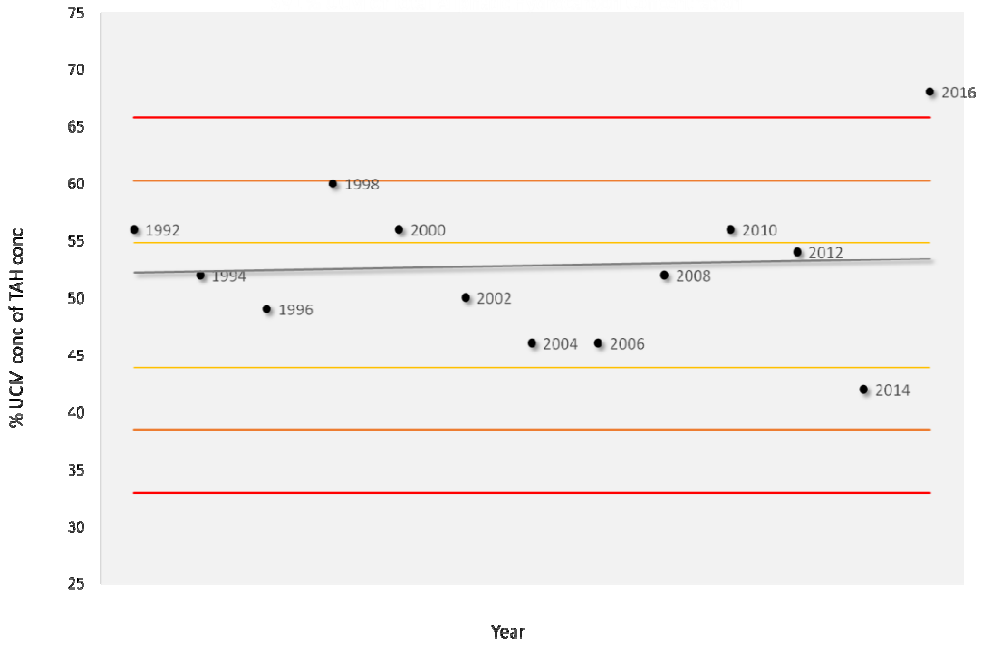

Figure 21 – SV1 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

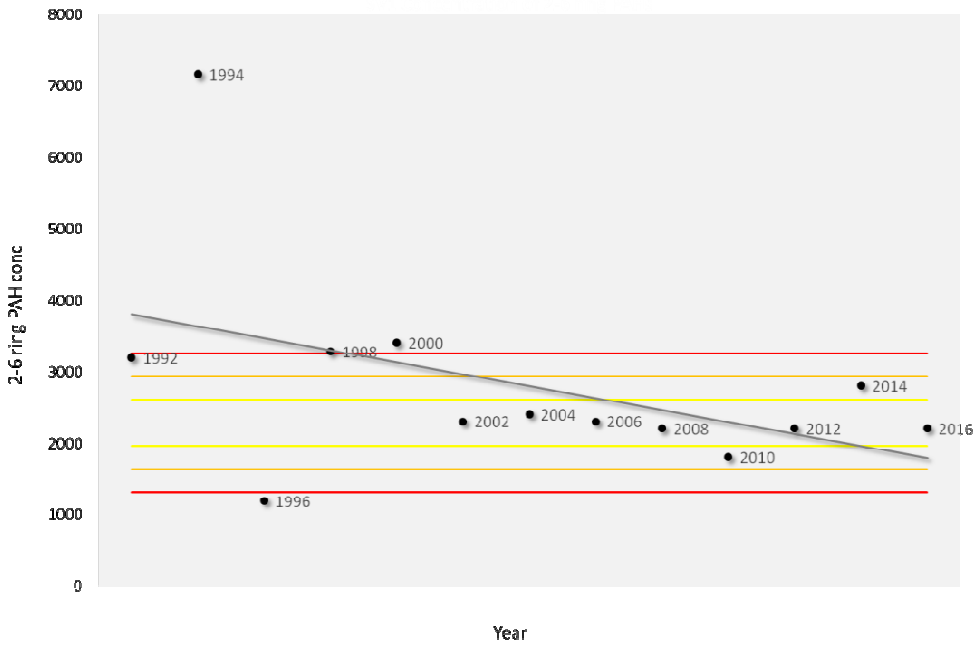

Figure 22 - SV1 2-6 ring PAH concentration (ng.g-1 dry sed.)

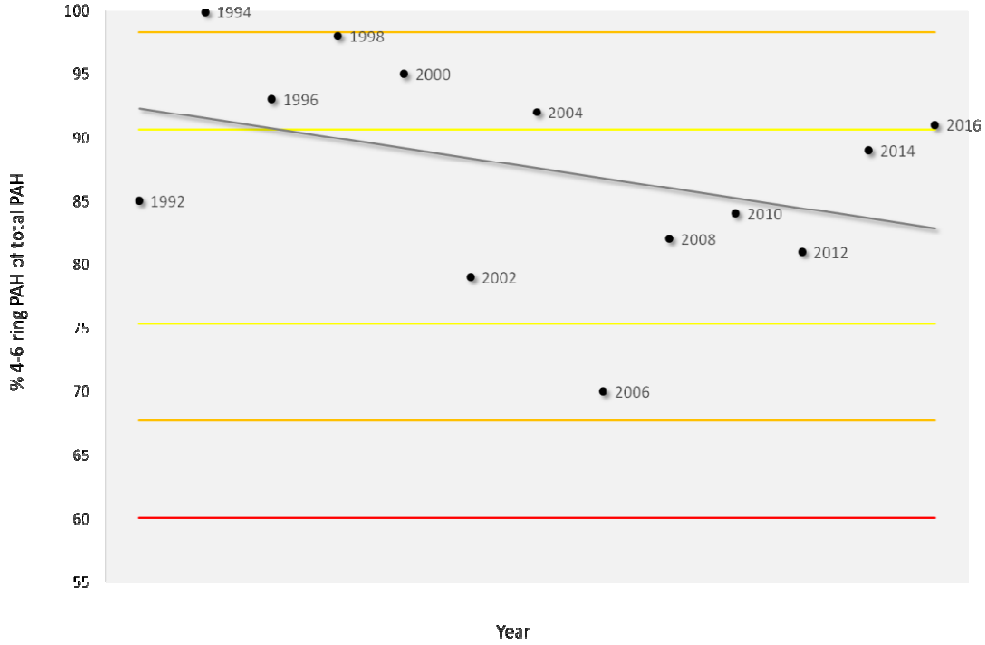

Figure 23 - SV1 4-6 ring PAHs as a percentage of the total PAHs (%)

4.5.1.2 Southern Sullom Voe SV3

For station SV3, the mud content in 2016 is significantly higher than in the previous 5 surveys from 2006 to 2014, and was higher than the mean. The 2016 result was +2.7 standard deviations from the mean, which is higher than the +2.1 average for all stations in 2016. The 2016 result is similar to the 1998 result and is not the highest result observed at the site. It is not possible to determine the significance of the 2016 result against the historic data due to changes in the particle size distribution methodology.

The organic content in 2016 was 5.0% which is similar to the 2014 result of 5.41%.The methodology for the organic content has also changed in 2016.

The concentration of total aliphatic hydrocarbons (TAH) at Station 3 in 2016 is within one standard deviation of the mean for the results from 2004-2014. This suggests little change in the overall TAH concentration at station SV3. The percentage of UCM in the TAH is higher than in 2014, +1.7 standard deviations of the historic mean and the highest recorded at this site. This is a general trend and the percentage of UCM in the TAH is on average +2.2 standard deviations from the mean for all stations in 2016.

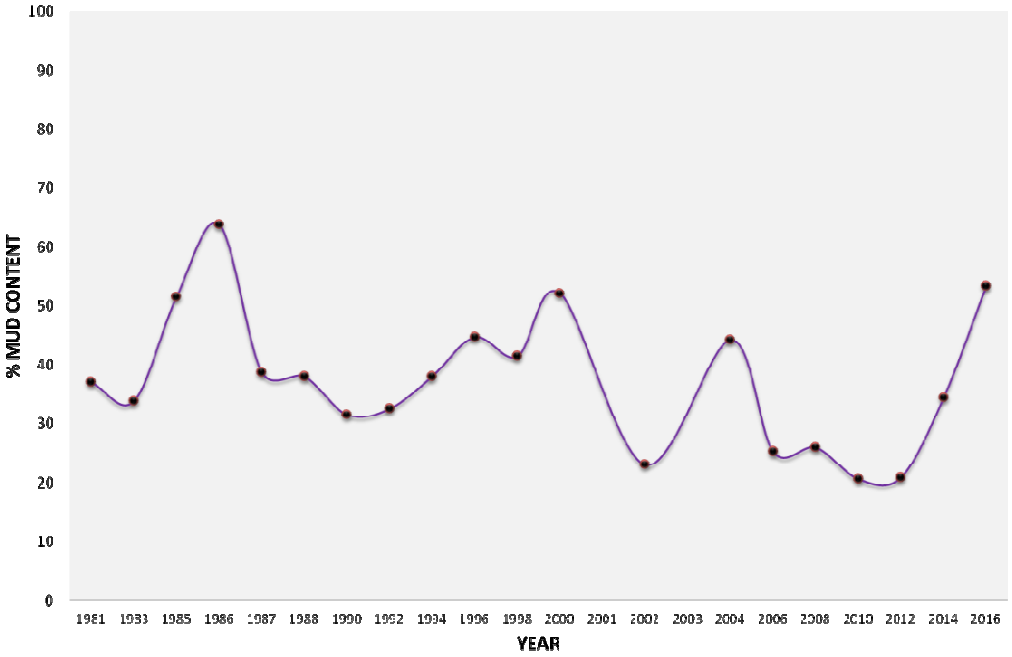

Figure 24 – SV3 Percentage Mud content

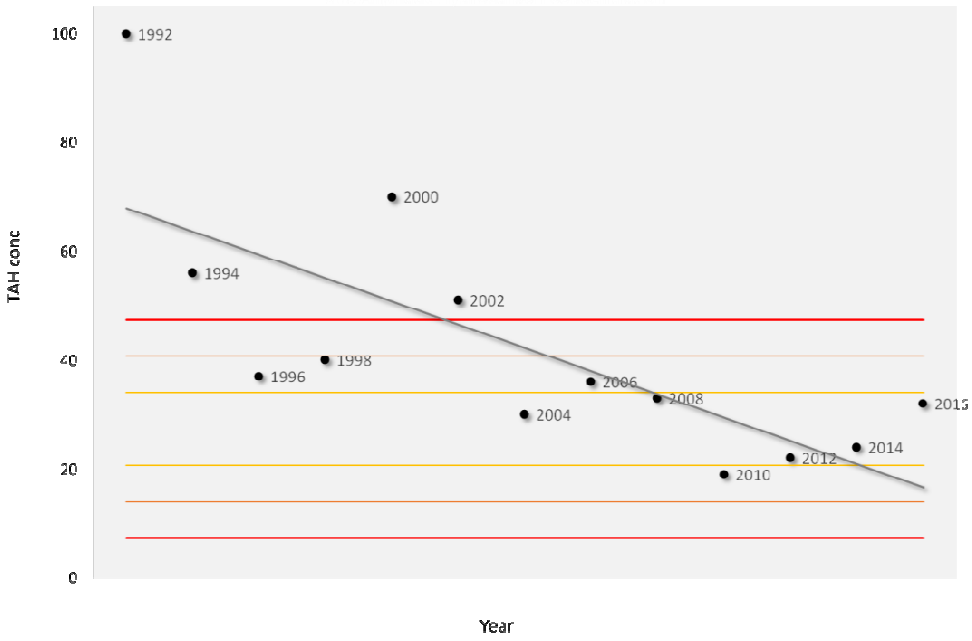

Figure 25 – SV3 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

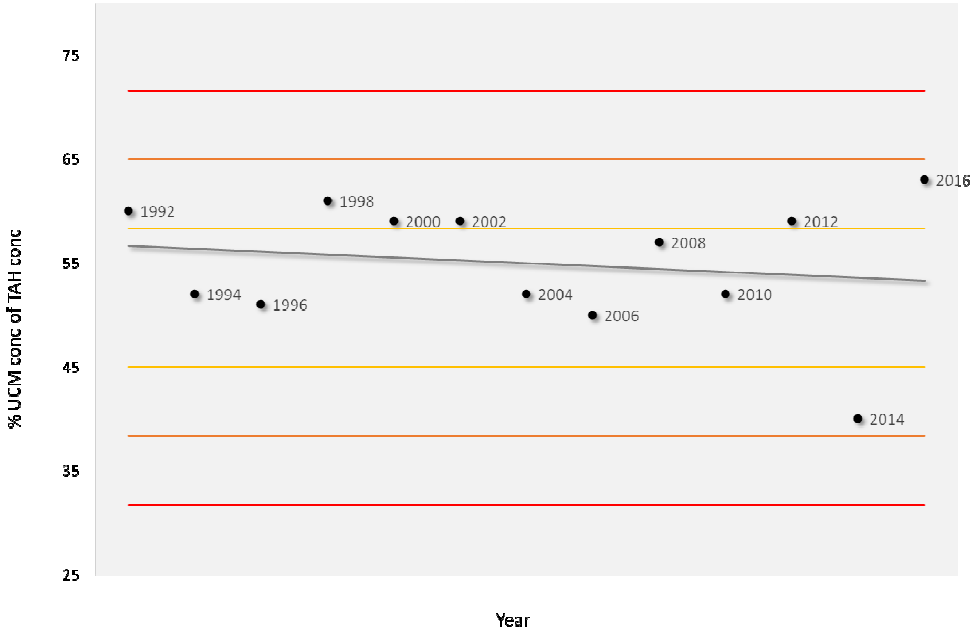

Figure 26 – SV3 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

4.5.1.3 Southern Sullom Voe SV4

For station SV4, the mud content in 2016 had not changed against the level determined in 2014 but was higher than the historic mean. The 2016 result was +1.5 standard deviations from the historic mean, which is lower than to the +2.1 average for all stations in 2016. It is not possible to determine the significance of the 2016 result against the historic data due to changes in the particle size distribution methodology.

The organic content in 2016 was 5.7% which is similar to the 2014 result of 4.96%. The methodology for the organic content has changed in 2016.

The concentration of total aliphatic hydrocarbons (TAH) at Station SV4 in 2016 is comparable to the historic mean and very little change has been observed. The 2016 result was +0.2 standard deviations from the historic mean. The percentage of UCM in the TAH is higher than in 2014 but conforms to a cyclical pattern observed at the site since 1992. The 2016 result is +1.4 standard deviations from the historic mean. This is a general trend and the percentage of UCM in the TAH is on average +2.2 standard deviations from the historic mean for all stations in 2016.

The concentration of 2-6 ring PAH concentration at Station SV4 in 2016 has demonstrated little change. The 2016 result was +0.5 standard deviations from the historic mean. The percentage of 4-6 ring PAHs of the total PAHs has increased, the 2016 result was +1.7 standard deviations from the historic mean, which is similar to the +1.6 average standard deviation at all stations in 2016.

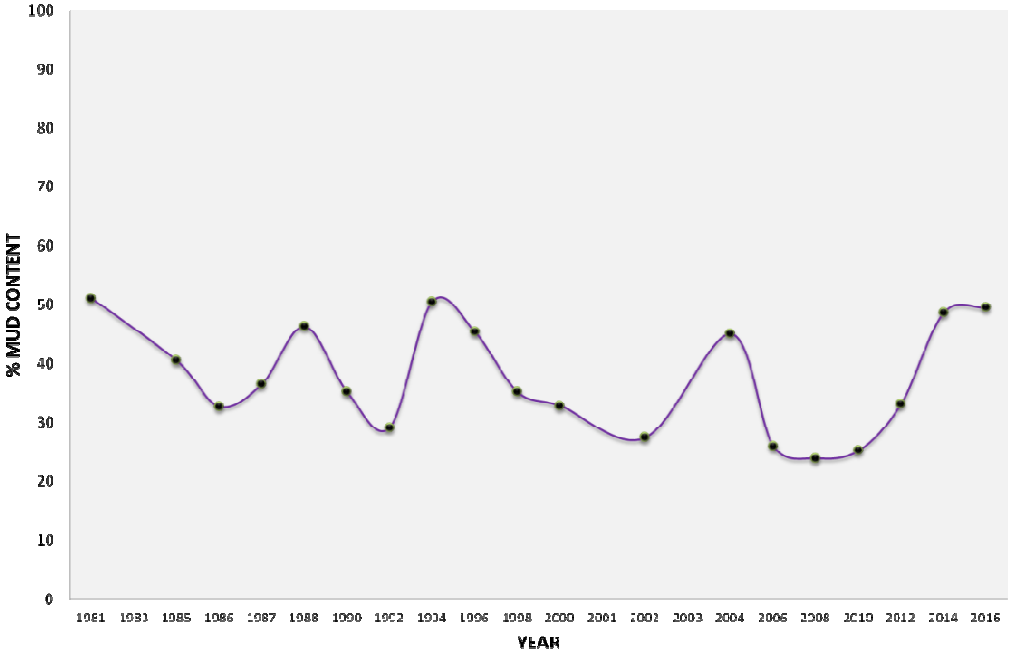

Figure 27 – SV4 Percentage Mud content

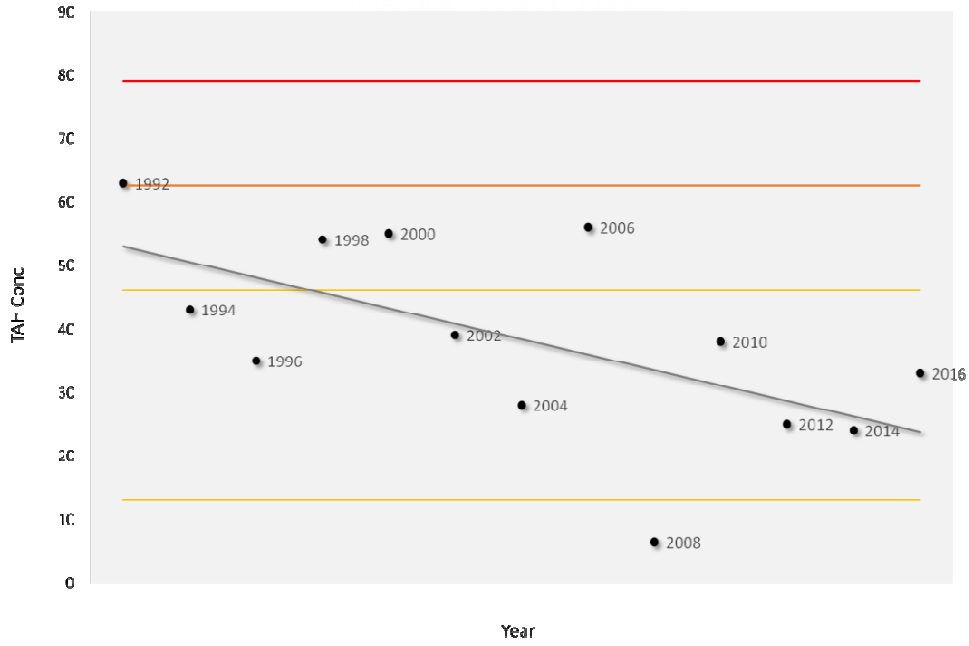

Figure 28 – SV4 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

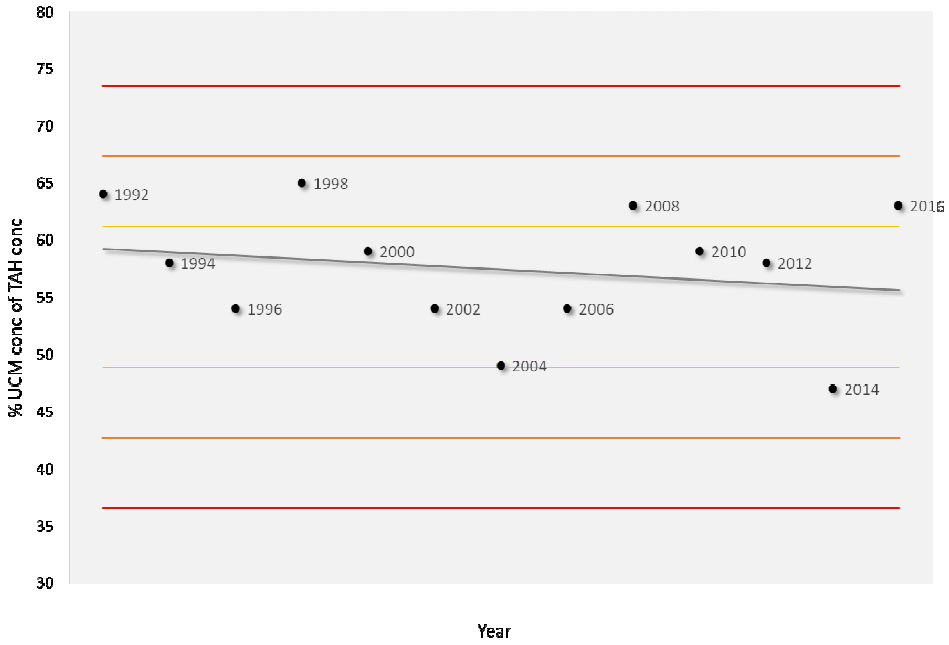

Figure 29 – SV4 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

Figure 30 – SV4 2-6 ring PAH concentration (ng.g-1 dry sed.)

Figure 31 – SV4 4-6 ring PAHs as a percentage of the total PAHs (%)

4.5.1.4 Fluga Ness SV5

For station SV5, the mud content in 2016 has changed against the historic mean, the variation in mud concentration has increased during the period 2004-2016 in contrast to the period 1981-2002. The 2016 result was +0.7 standard deviations from the historic mean, which is lower than the +2.1 average for all stations in 2016, but this is lower due to the higher variation in results during 2004-2014. It is not possible to determine the significance of the 2016 result against the historic data due to changes in the particle size distribution methodology.

The organic content in 2016 was 4.6% which is similar to the 2014 result of 4.37%.The methodology for the organic content has changed in 2016.

The concentration of total aliphatic hydrocarbons (TAH) at Station SV5 in 2016 is close to the historic mean and demonstrates very little change. The 2016 result was -0.3 standard deviations from the historic mean. The percentage of UCM in the TAH is higher than the historic mean and is +2.2 standard deviations from the historic mean. This is a general trend and the percentage of UCM in the TAH is on average +2.2 standard deviations from the historic mean for all stations in 2016.

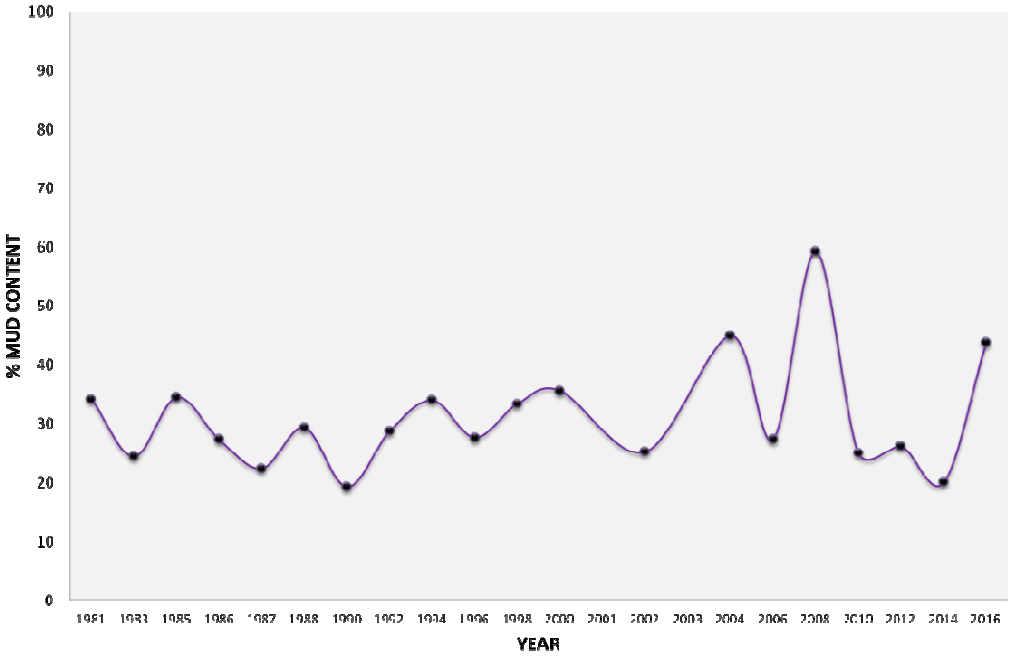

Figure 32 – SV5 Percentage Mud content

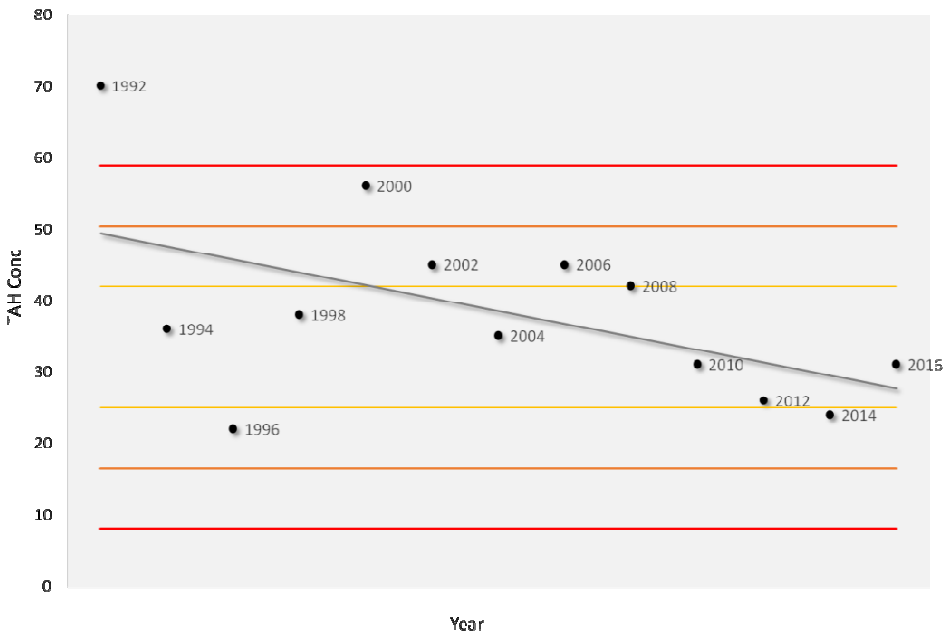

Figure 33 – SV5 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

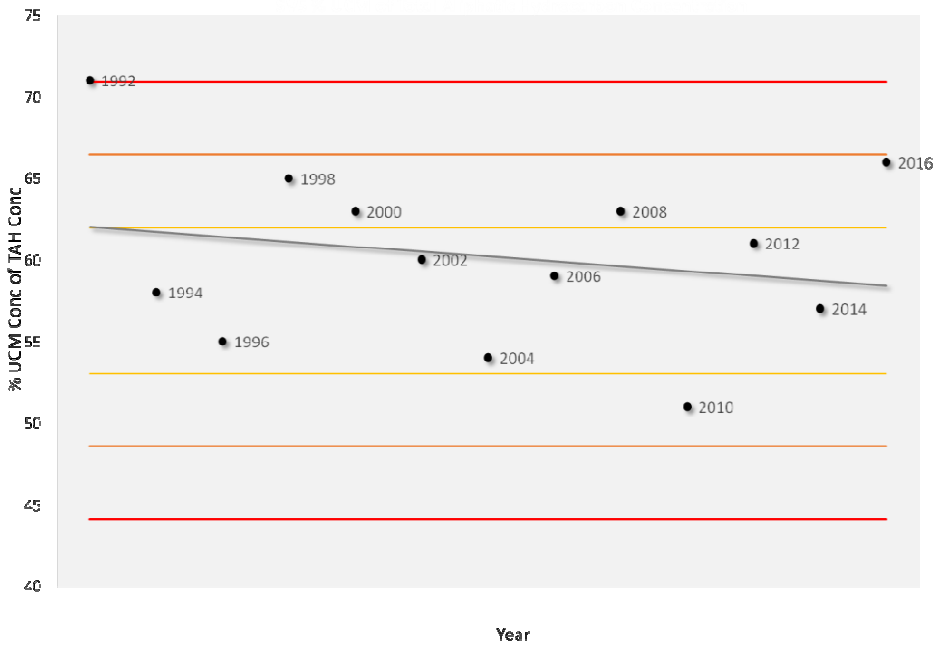

Figure 34 – SV5 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

4.5.2 JETTY AREA AND WEST OF CALBECK NESS (STATIONS 7-11 AND 17)

4.5.2.1 Jetty Grid SV7

For station SV7, the mud content in 2016 has changed against the historic mean, the variation in mud concentration at this site is historically high. The 2016 result was +1.7 standard deviations from the historic mean, which is lower than the +2.1 average for all stations in 2016. The 2016 mud content is similar to the level in 2004 and the period 1981-1990. It is not possible to determine the significance of the 2016 result against the historic data due to changes in the particle size distribution methodology.

The organic content in 2016 was 7.8% which is similar to the 2014 result of 7.72%.The methodology for the organic content has changed in 2016.

The concentration of total aliphatic hydrocarbons (TAH) at Station SV7 in 2016 is simliar to the historic mean and demonstrates very little change. The 2016 result was -0.3 standard deviations from the historic mean. The percentage of UCM in the TAH is significantly higher than the historic mean and is +9.6 standard deviations from the historic mean. This is a much more significant change than the general trend and the percentage of UCM in the TAH is on average +2.2 standard deviations from the historic mean for all stations in 2016. While the relative standard deviation between the three grab samples at SV7 for TAH was high 47%, the relative standard deviation between the three grabs for the percent UCM to TAH was 1%. There are other positive outliers in the historic data set 1992-2014, including 1992 (68%) and 2000 (59%).

The concentration of 2-6 ring PAH concentration at Station SV7 in 2016 has demonstrated little change. The 2016 result was -0.2 standard deviations from the historic mean. The percentage of 4-6 ring PAHs of the total PAHs has demonstrated little change, the 2016 result was -0.2 standard deviations from the historic mean, which is in contrast with the +1.6 average standard deviations from the historic mean at all stations in 2016.

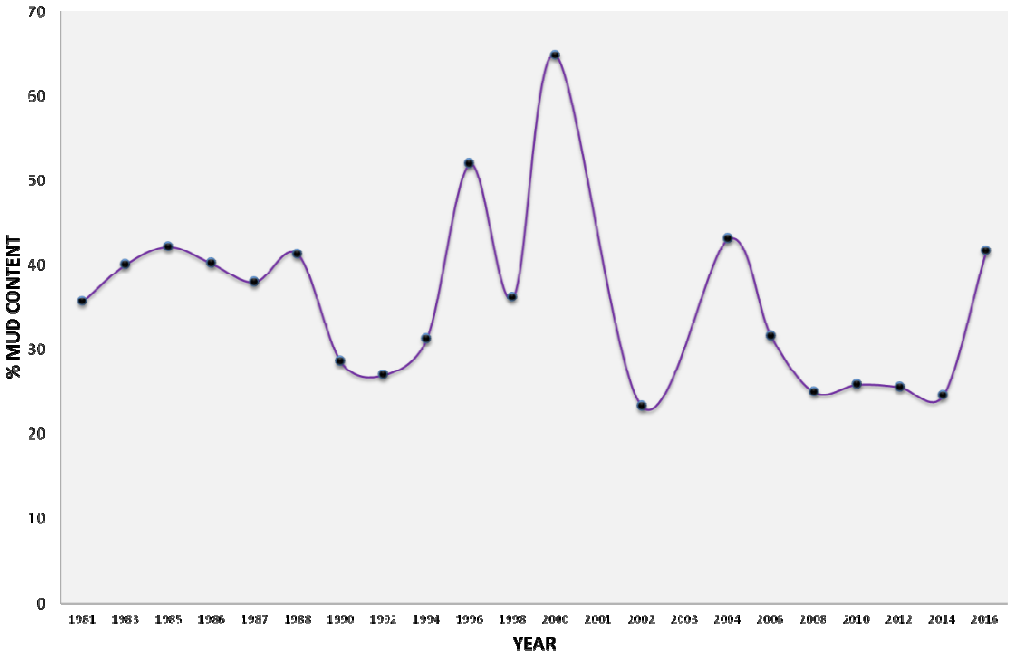

Figure 35 – SV7 Percentage Mud content

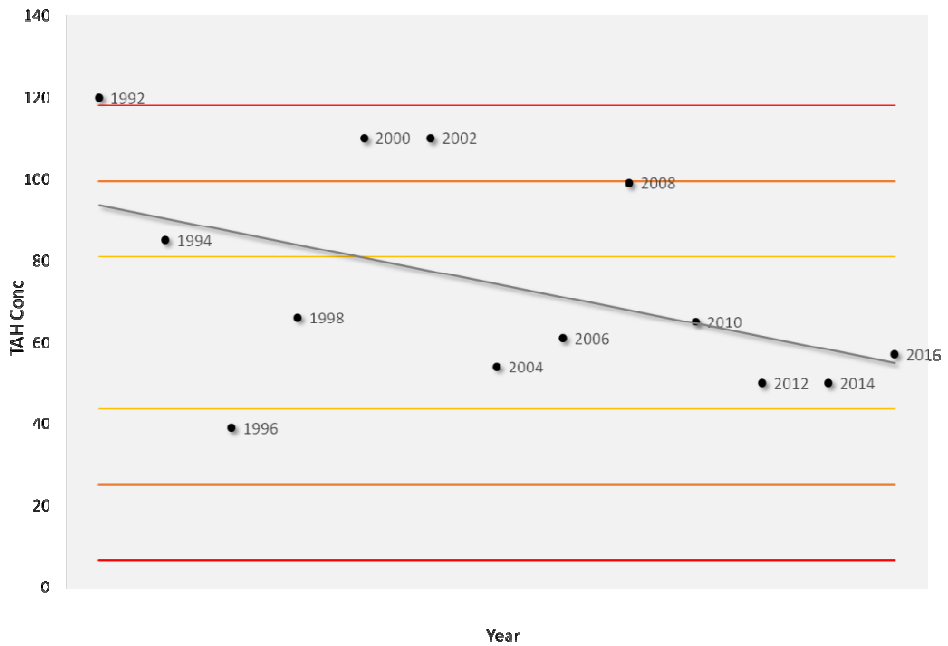

Figure 36 – SV7 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

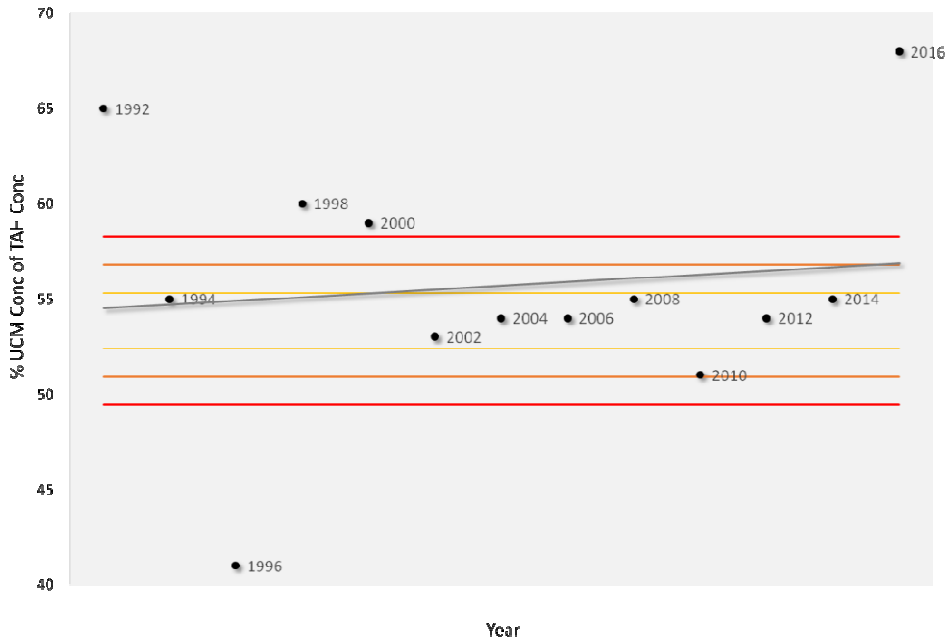

Figure 37 – SV7 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

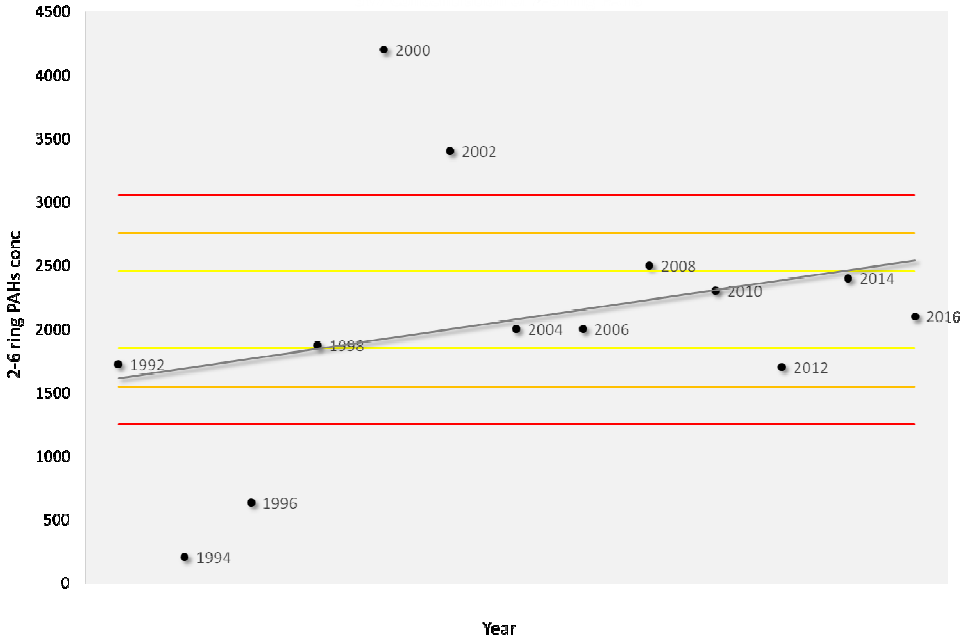

Figure 38 – SV7 2-6 ring PAH concentration (ng.g-1 dry sed.)

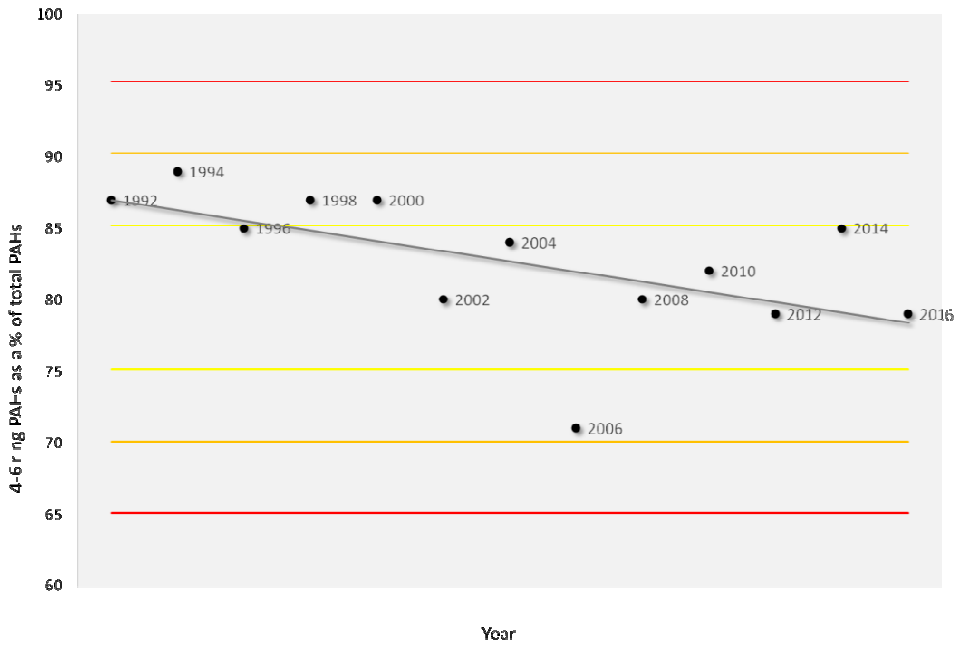

Figure 39 – SV7 4-6 ring PAHs as a percentage of the total PAHs (%)

4.5.2.2 Jetty Grid SV8

For station SV8, the mud content in 2016 has changed against the historic mean and is the highest result recorded at this site. The 2016 result was +3.3 standard deviations from the historic mean, which is higher than the +2.1 average for all stations in 2016. It is not possible to determine the significance of the 2016 result against the historic data due to changes in the particle size distribution methodology.

The organic content in 2016 was 7.48% which is higher than the 2014 result of 4.63%. The methodology for the organic content has changed in 2016.

The concentration of total aliphatic hydrocarbons (TAH) at Station SV8 in 2016 has changed very little. The 2016 result was +0.8 standard deviations from the historic mean. The percentage of UCM in the TAH is higher than the mean and is +2.0 standard deviations from the historic mean. This is a general trend and the percentage of UCM in the TAH is on average +2.2 standard deviations from the historic mean for all stations in 2016.

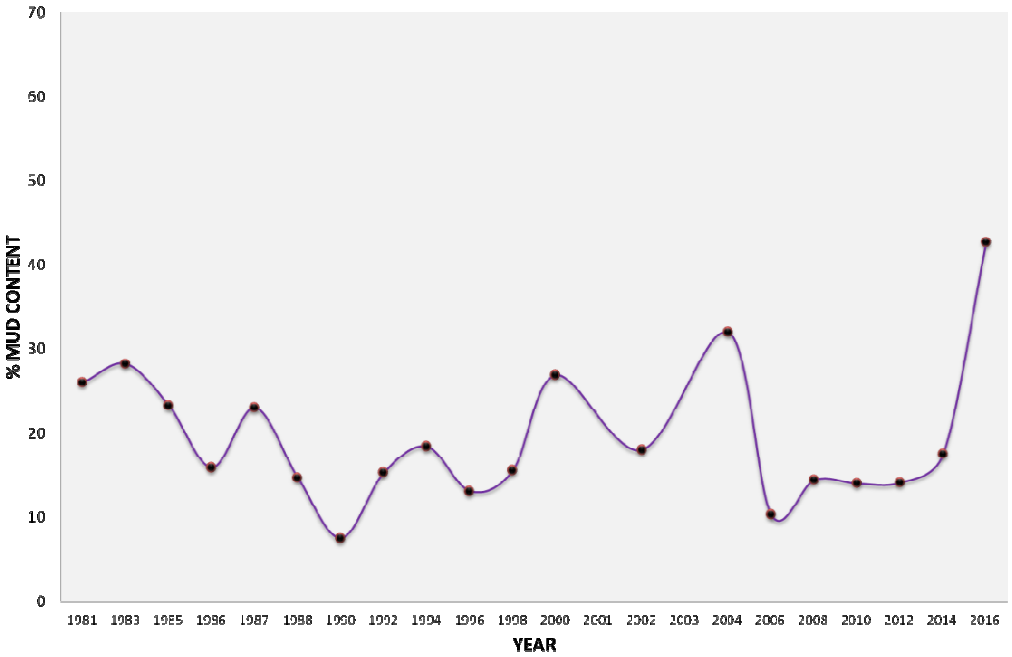

Figure 40 – SV8 Percentage Mud content

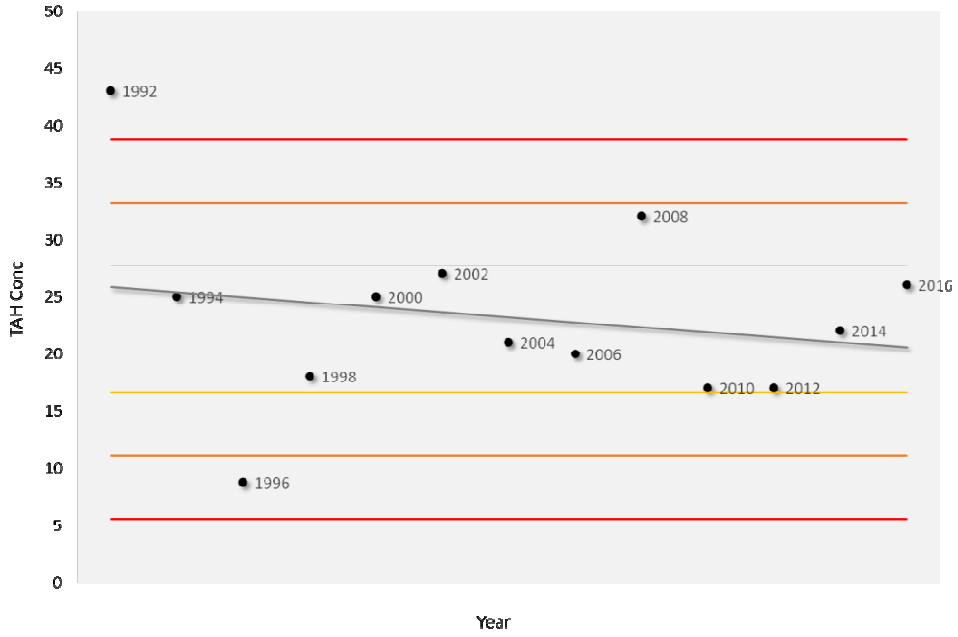

Figure 41 – SV8 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

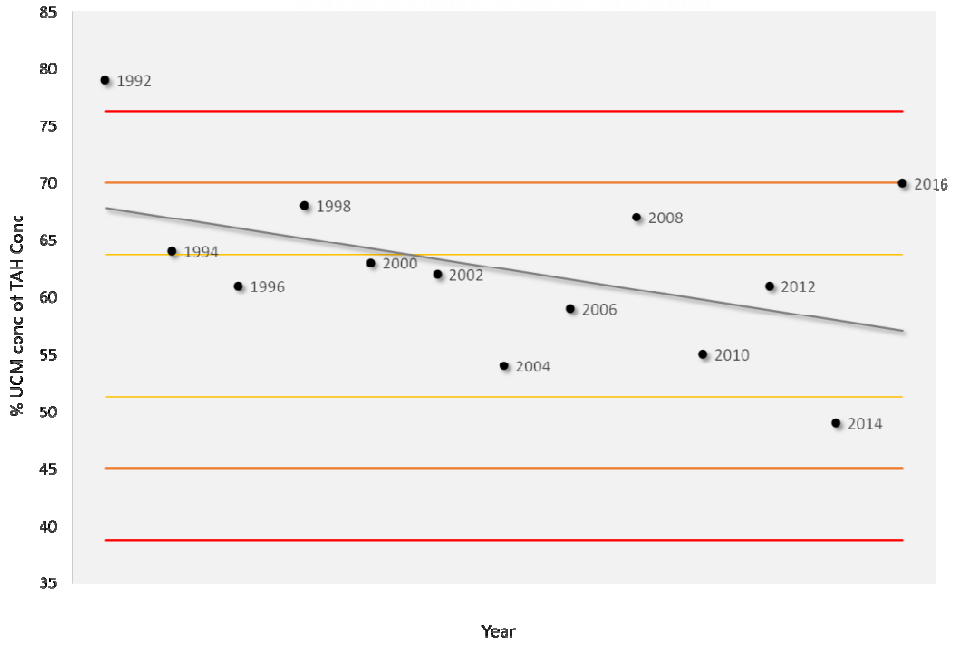

Figure 42 – SV8 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

4.5.2.3 Jetty Grid SV8A

For station SV8A, the mud content in 2016 has changed against the historic mean. The 2016 result was +2.7 standard deviations from the historic mean, which is higher than the +2.1 average for all stations in 2016. The 2016 mud content is similar to the levels observed in 2000 and 2004. It is not possible to determine the significance of the 2016 result against the historic data due to changes in the particle size distribution methodology.

The organic content in 2016 was 3.77% which is higher than the 2014 result of 2.88%. The methodology for the organic content has changed in 2016.

The concentration of total aliphatic hydrocarbons (TAH) at Station SV8A in 2016 has changed very little. The 2016 result was -0.4 standard deviations from the historic mean. The percentage of UCM in the TAH is higher than the mean and is +2.7 standard deviations from the mean. This is higher than the general trend and the percentage of UCM in the TAH is on average +2.2 standard deviations from the historic mean for all stations in 2016.

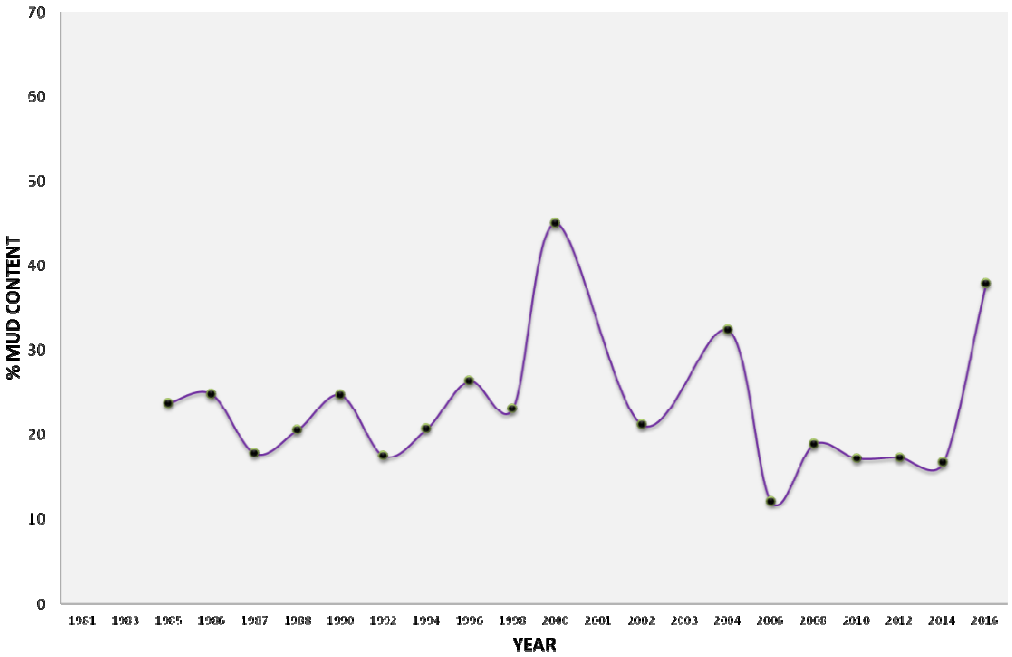

Figure 43 – SV8A Percentage Mud content

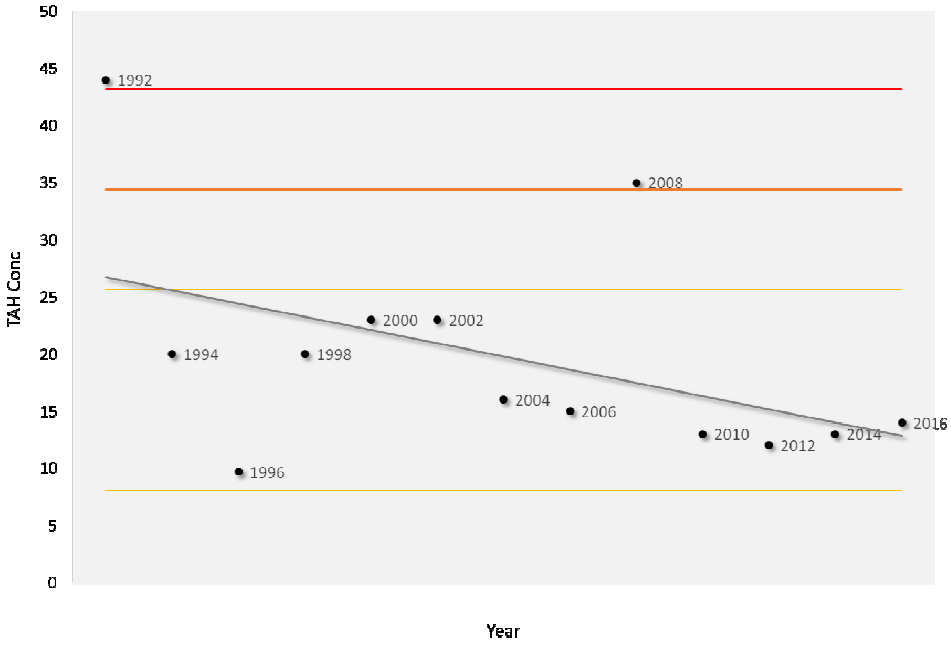

Figure 44 – SV8A Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

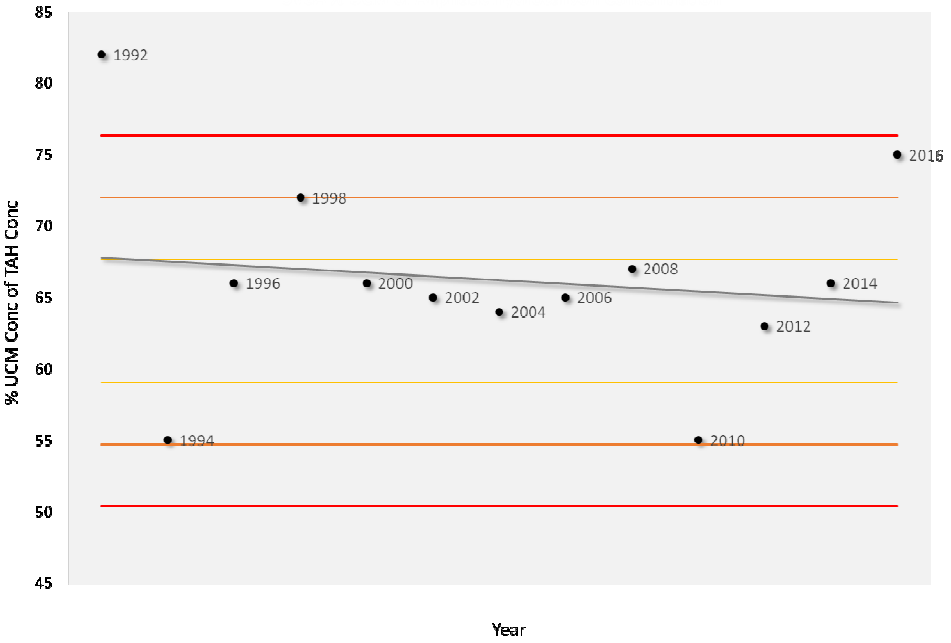

Figure 45 – SV8A Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

4.5.2.4 Outer Voe SV9

For station SV9, the mud content in 2016 has changed slightly against the historic mean. The 2016 result was +1.8 standard deviations from the historic mean, which is similar to the +2.2 average for all stations in 2016. The 2016 mud content is similar to the levels observed in 2000 and 2004. It is not possible to determine the significance of the 2016 result against the historic data due to changes in the particle size distribution methodology.

The organic content in 2016 was 8.29% which is higher than the 2014 result of 5.39%, this correlates with an increase in TAH concentration. The methodology for the organic content has changed in 2016.

The concentration of total aliphatic hydrocarbons (TAH) at Station SV9 in 2016 has increased against the historic mean. The 2016 result was +2.0 standard deviations from the historic mean. A relative standard deviation of 12% was observed between the 3 grab samples analysed. The percentage of UCM in the TAH has not changed and is +0.4 standard deviations from the historic mean. This is lower than the general trend and the percentage of UCM in the TAH is on average +2.2 standard deviations from the historic mean for all stations in 2016.

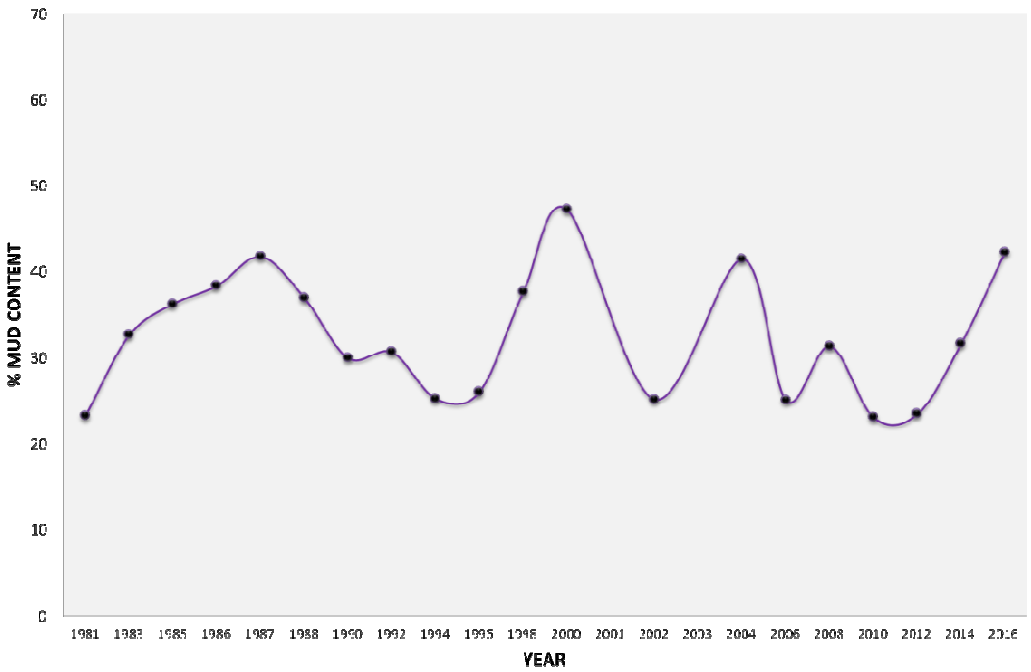

Figure 46 – SV9 Percentage Mud content

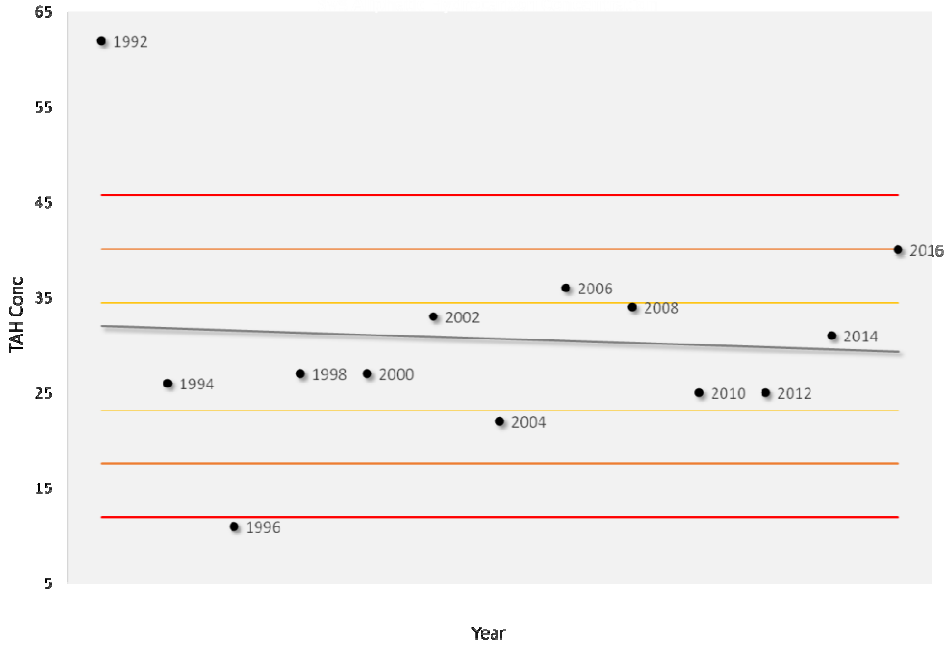

Figure 47 – SV9 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

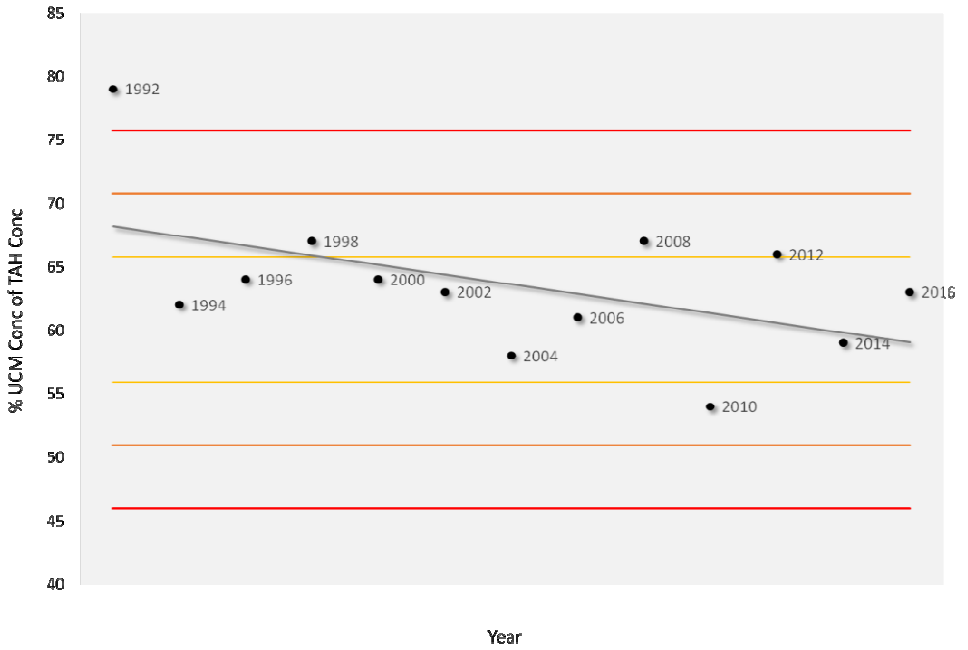

Figure 48 – SV9 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

4.5.2.5 Outer Voe SV10

For station SV10, the mud content in 2016 has changed against the historic mean. The 2016 result was +2.4 standard deviations from the historic mean, which is similar to the +2.2 average for all stations in 2016. The 2016 mud content is similar to the levels observed in 2000 and 2004. It is not possible to determine the significance of the 2016 result against the historic data due to changes in the particle size distribution methodology.

The organic content in 2016 was 5.23% which is similar to the 2014 result of 4.38%. The methodology for the organic content has changed in 2016.

The concentration of total aliphatic hydrocarbons (TAH) at Station SV10 in 2016 has not changed. The 2016 result was +0.2 standard deviations from the historic mean. The percentage of UCM in the TAH is higher than the historic mean and is +1.1 standard deviations from the historic mean. This is lower than the general trend and the percentage of UCM in the TAH is on average +2.2 standard deviations from the historic mean for all stations in 2016.

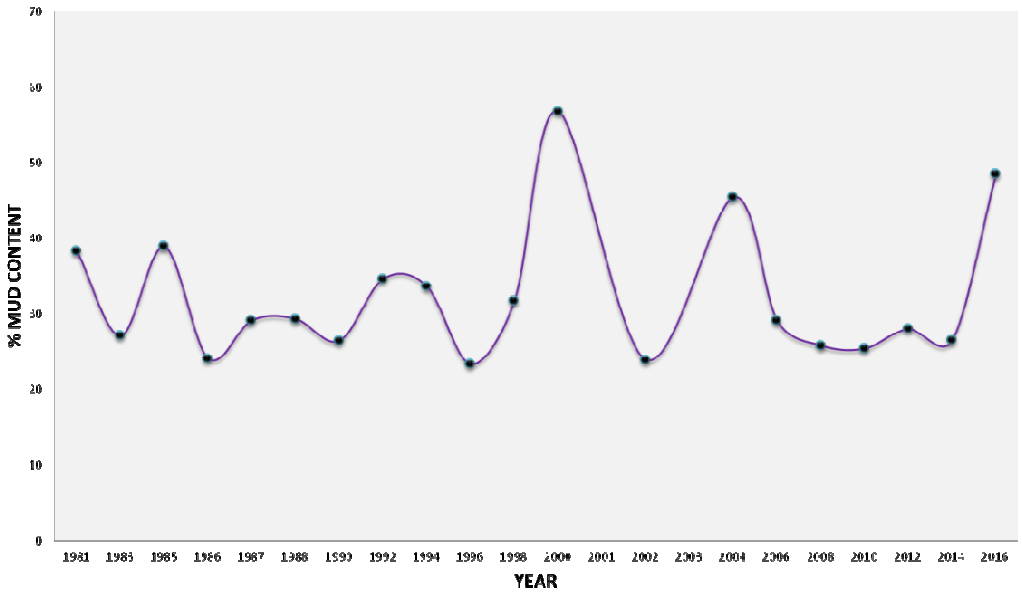

Figure 49 – SV10 Percentage Mud content

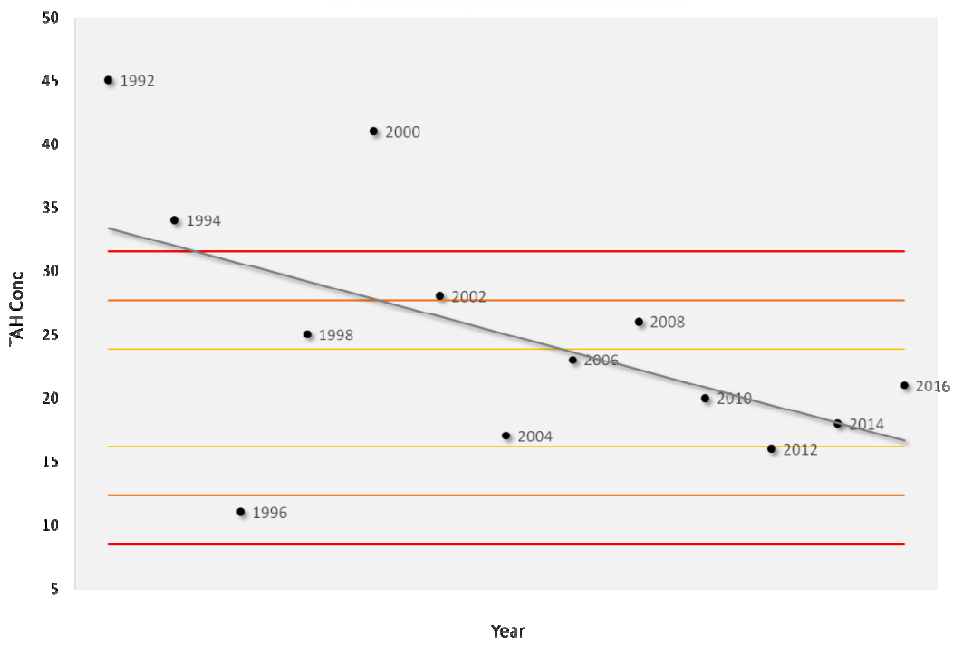

Figure 50 – SV10 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

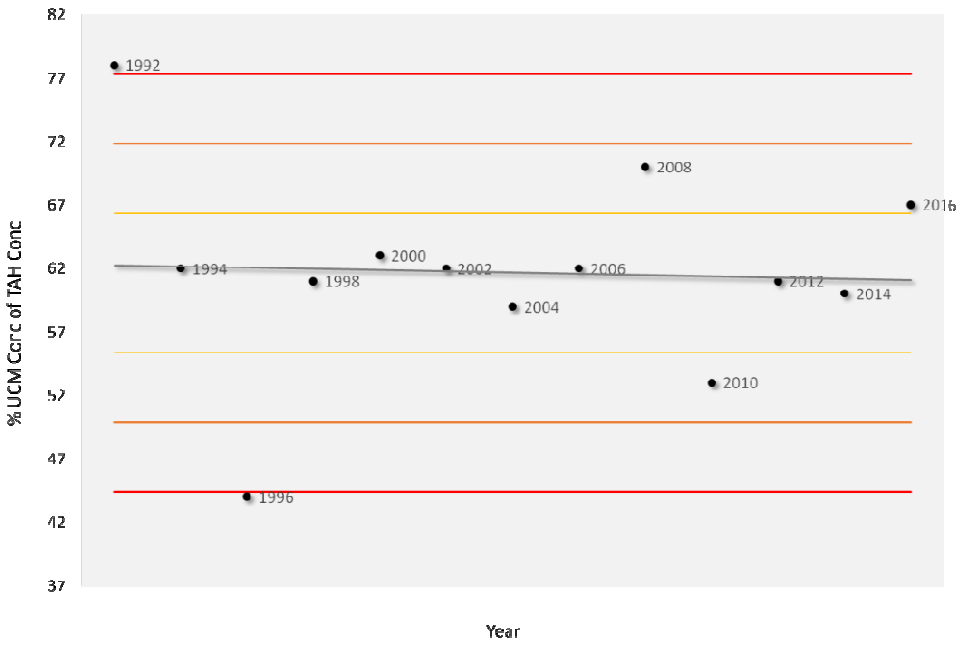

Figure 51 – SV10 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

4.5.2.6 Outer Voe SV11

For station SV11, the mud content in 2016 has changed against the historic mean and is the highest result recorded for this site. The 2016 result was +2.8 standard deviations from the historic mean, which is higher than the +2.2 average for all stations in 2016. It is not possible to determine the significance of the 2016 result against the historic data due to changes in the particle size distribution methodology.

The organic content in 2016 was 3.59% which is similar to the 2014 result of 4.36%. The methodology for the organic content has changed in 2016.

The concentration of total aliphatic hydrocarbons (TAH) at Station SV11 in 2016 has not changed. The 2016 result was -0.3 standard deviations from the historic mean. The percentage of UCM in the TAH is higher than the mean and is +2.0 standard deviations from the historic mean. This is similar to the general trend and the percentage of UCM in the TAH is on average +2.2 standard deviations from the historic mean for all stations in 2016.

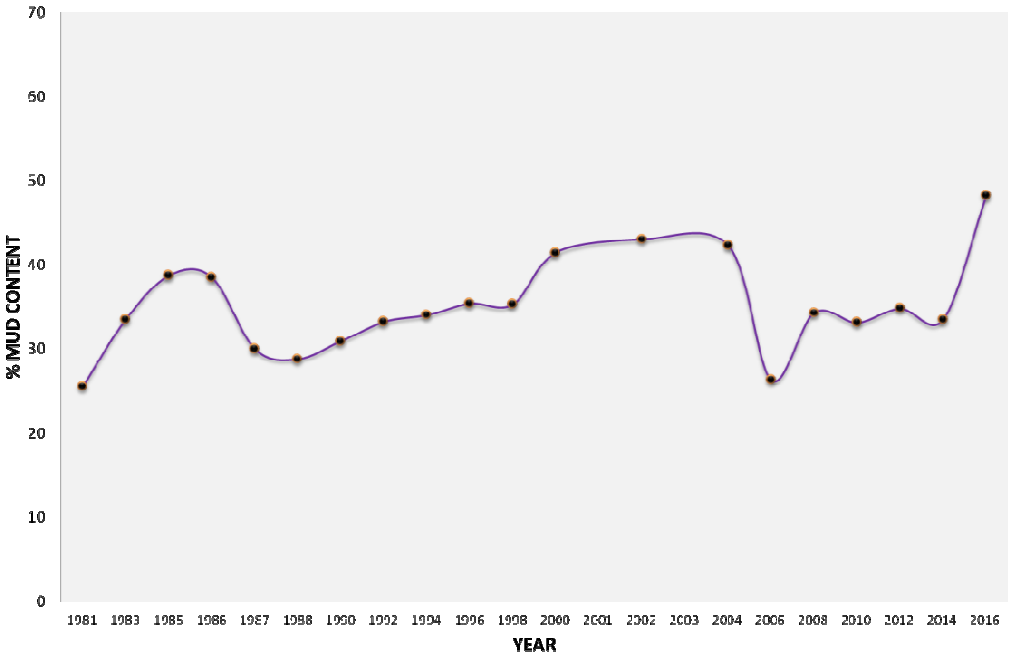

Figure 52 – SV11 Percentage Mud content

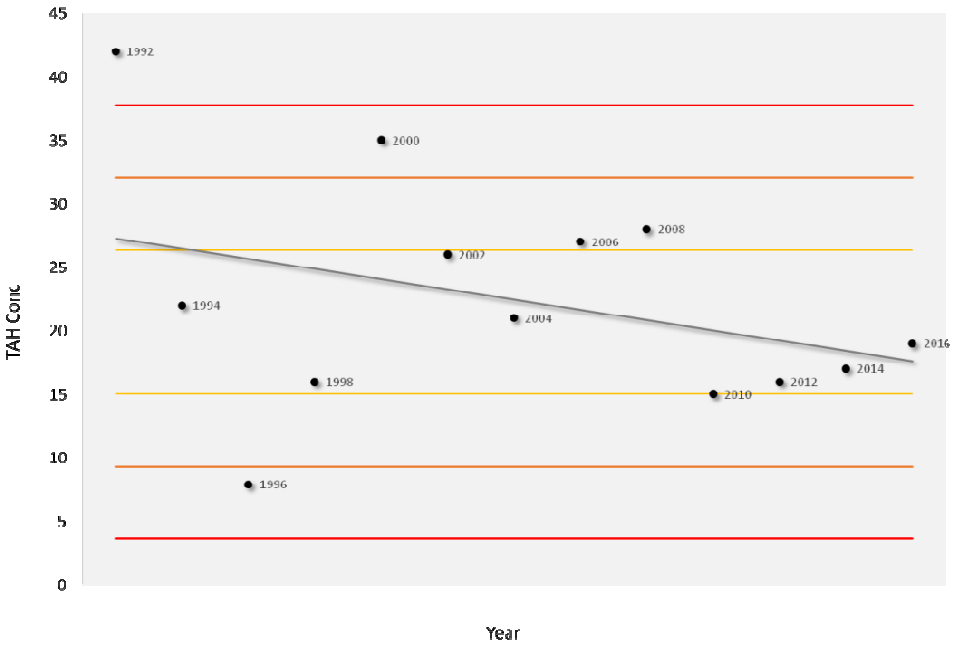

Figure 53 – SV11 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

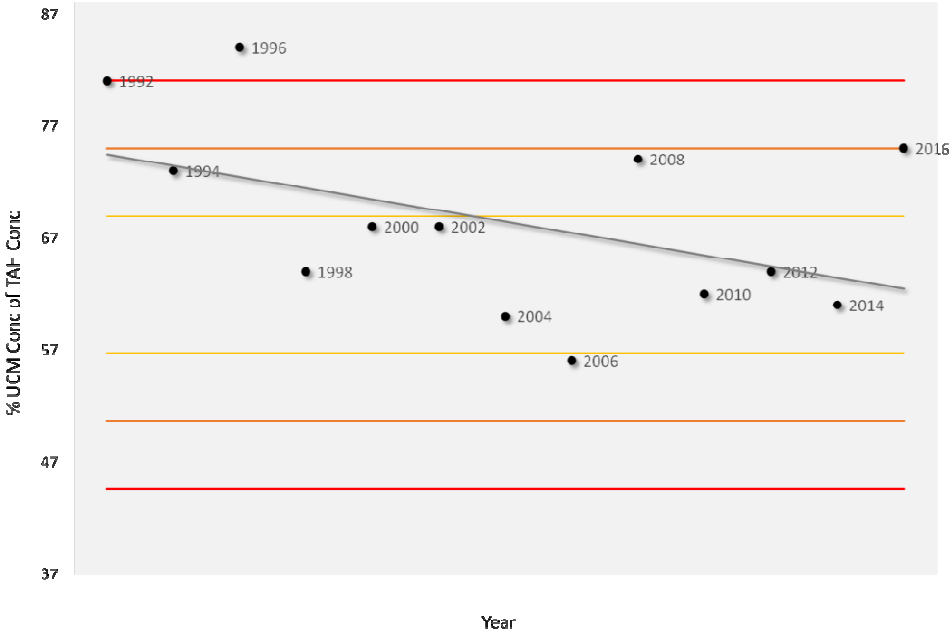

Figure 54 – SV11 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

4.5.2.7 Jetty Grid SV17

For station SV17, the mud content in 2016 has changed against the mean but is similar to results from 1996 and 2004. The mud concentration at this site has a relative standard deviation of 69% for data set the period 2004-2014. The 2016 result was +1.9 standard deviations from the historic mean, which is comparable than the +2.2 average for all stations in 2016. It is not possible to determine the significance of the 2016 result against the historic data due to changes in the particle size distribution methodology.

The organic content in 2016 was 2.01% which is similar to the 2014 result of 3.43%. The methodology for the organic content has changed in 2016.

The concentration of total aliphatic hydrocarbons (TAH) at Station SV17 in 2016 has not changed. The 2016 result was -0.4 standard deviations from the historic mean. The percentage of UCM in the TAH is higher than the historic mean and is +1.4 standard deviations from the historic mean. This is lower than the general trend and the percentage of UCM in the TAH is on average +2.2 standard deviations from the historic mean for all stations in 2016.

The concentration of 2-6 ring PAH concentration at Station SV17 in 2016 has demonstrated little change. The 2016 result was +0.9 standard deviations from the historic mean. The percentage of 4-6 ring PAHs of the total PAHs has changed, the 2016 result was +2.7 standard deviations from the historic mean, which is in higher than the +1.6 average standard deviations from the historic mean at all stations in 2016.

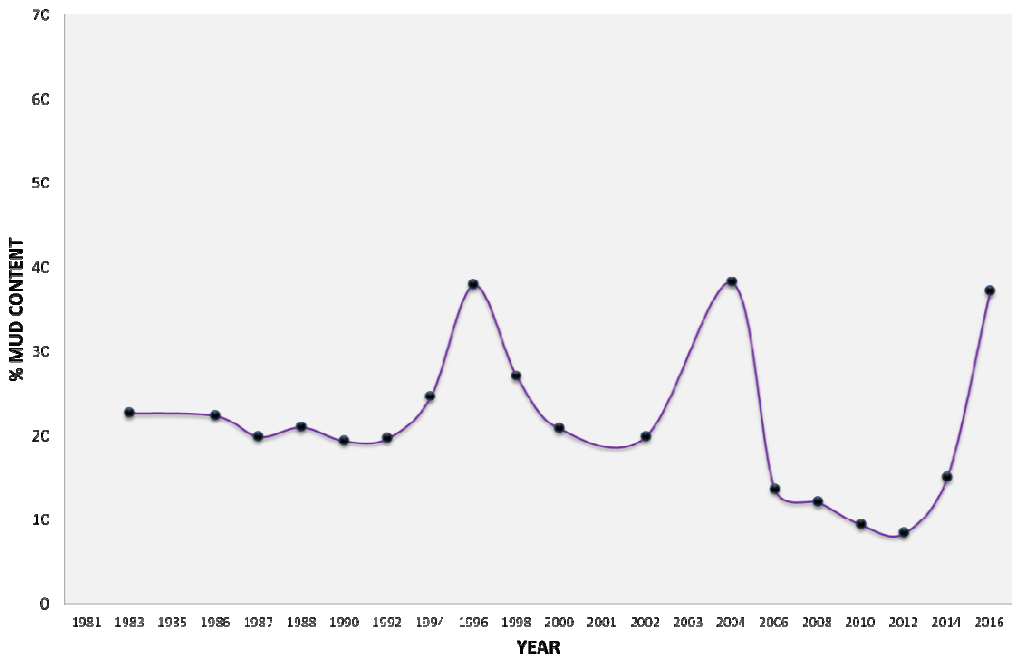

Figure 55 – SV17 Percentage Mud content

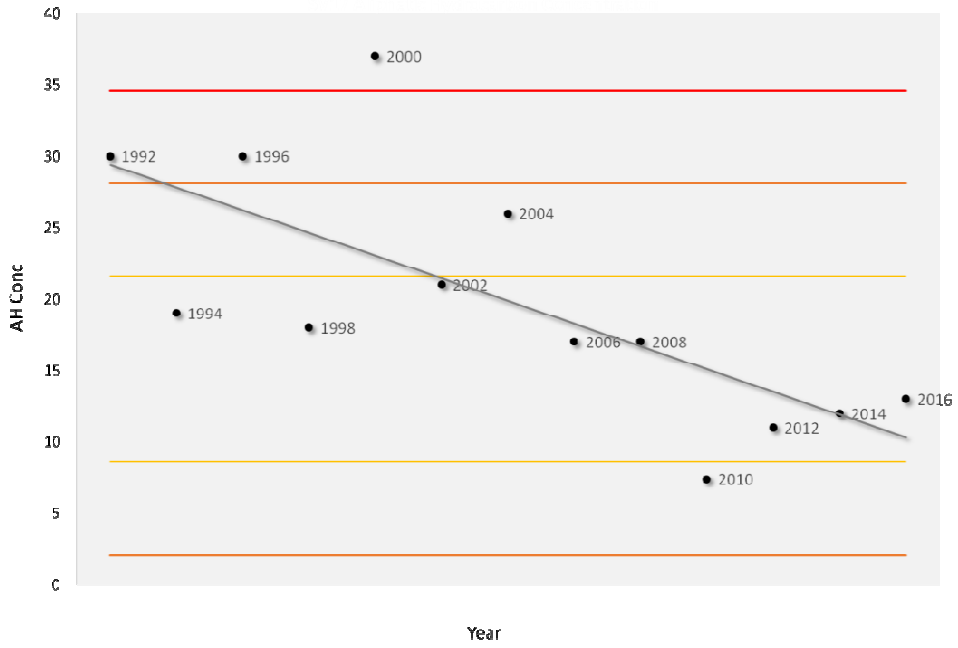

Figure 56 – SV17 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

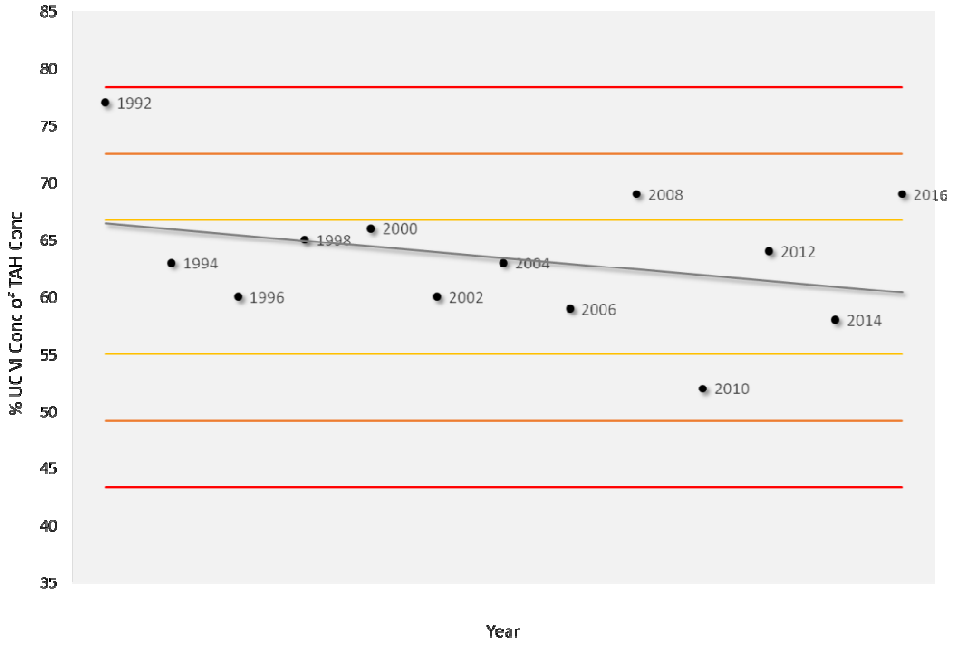

Figure 57 – SV17 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

Figure 58 – SV17 2-6 ring PAH concentration (ng.g-1 dry sed.)

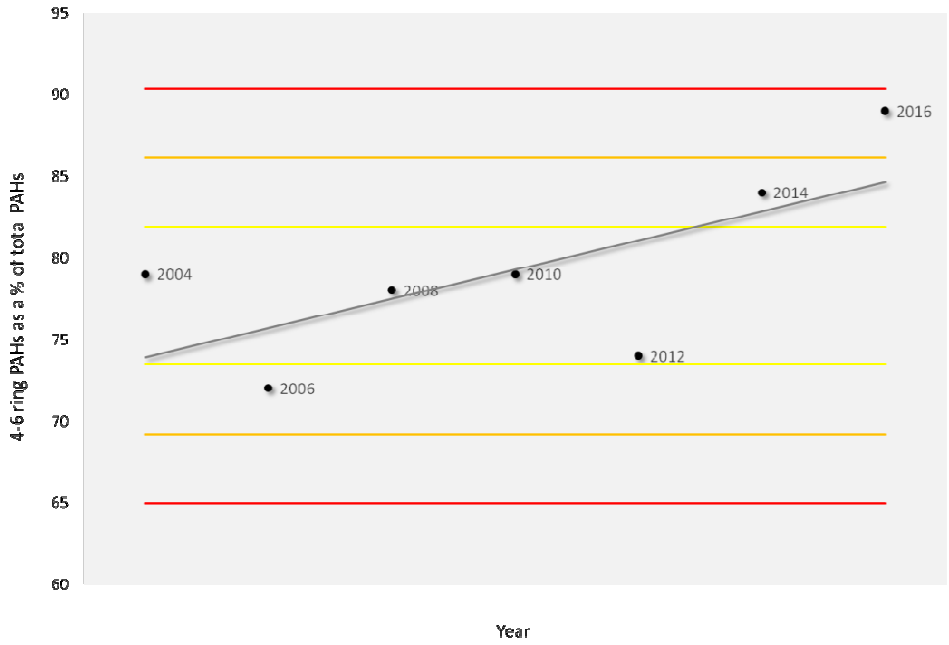

Figure 59 – SV17 4-6 ring PAHs as a percentage of the total PAHs (%)

4.5.3 YELL SOUND AND NORTH OF CALBECK NESS (STATIONS 33 TO 37)

4.5.3.1 Calbeck Ness SV12

For station SV12, the mud content in 2016 has changed against the historic mean but is more similar to results from 2004. The mud concentration at this site has a relative standard deviation of 65% for the period 2004-2014, and 84% for the whole data set 1981-2014. The 2016 result was +0.8 standard deviations from the historic mean for the period , which is lower than the +2.1 average for all stations in 2016. It is not possible to determine the significance of the 2016 result against the historic data due to changes in the particle size distribution methodology.

The organic content in 2016 was 1.08% which is similar to the 2014 result of 3.36%. The methodology for the organic content has changed in 2016.

The concentration of total aliphatic hydrocarbons (TAH) at Station SV12 is generally low (<10µg.g^{-1}) and in 2016 the level has not changed against the historic mean. The 2016 result was 0 standard deviations from the historic mean. The percentage of UCM in the TAH is higher than the historic mean and is +2.8 standard deviations from the historic mean. This is higher than the general trend and the percentage of UCM in the TAH is on average +2.2 standard deviations from the historic mean for all stations in 2016.

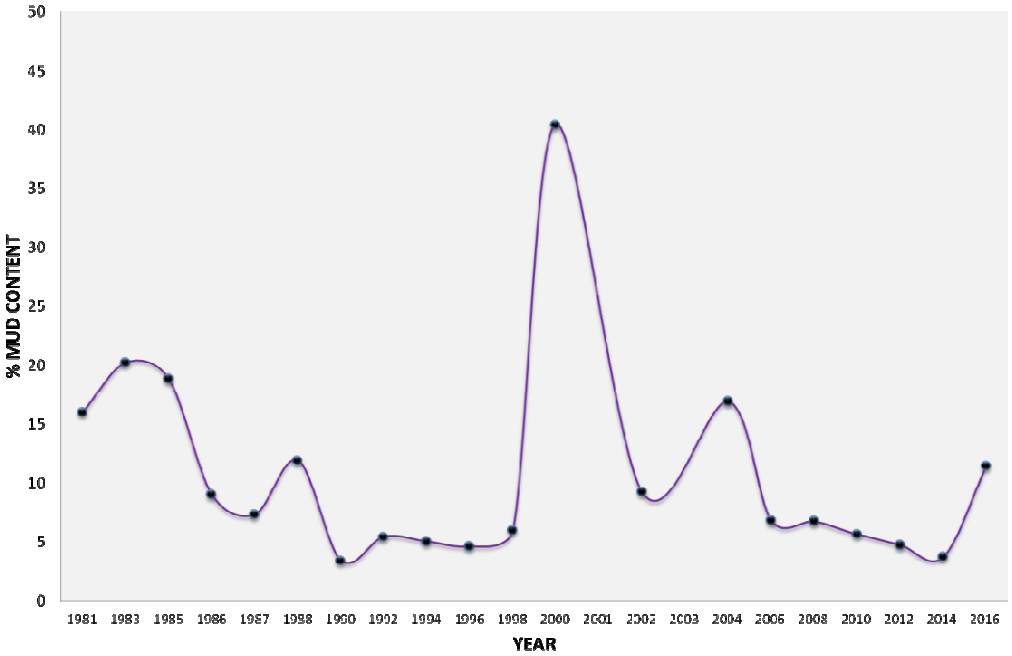

Figure 60 – SV12 Percentage Mud content

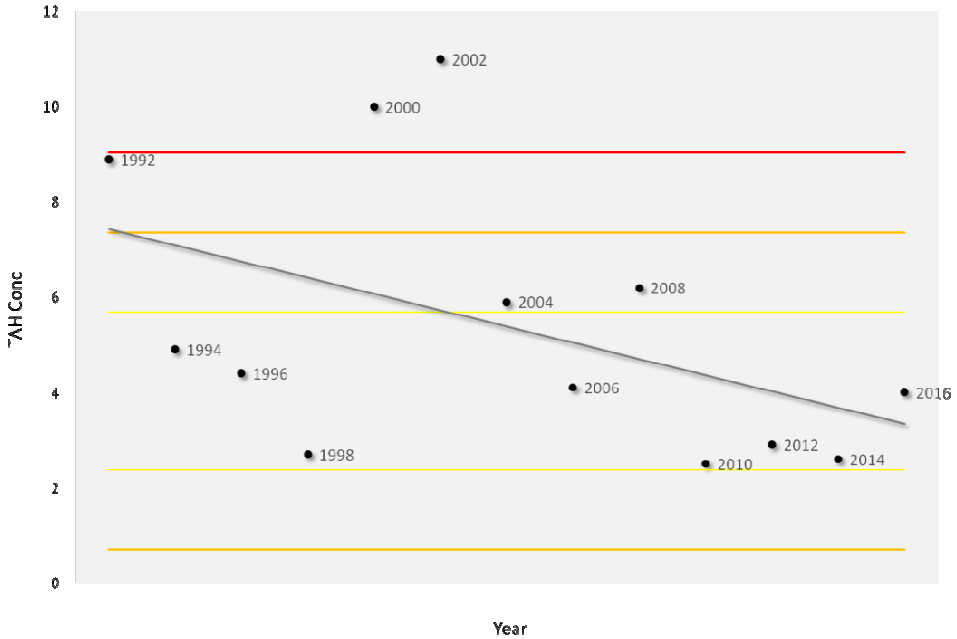

Figure 61 – SV12 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

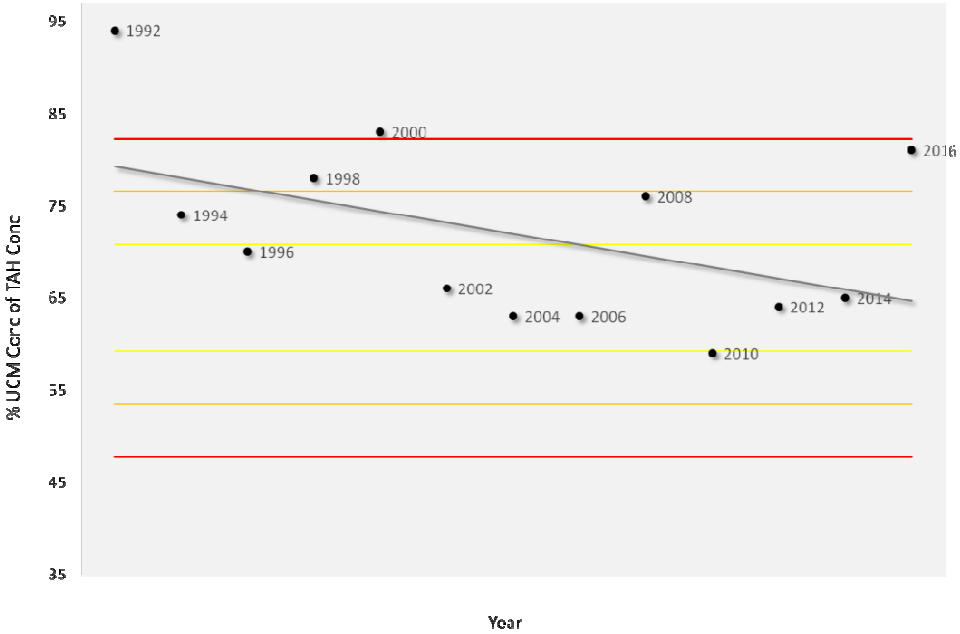

Figure 62 – SV12 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

4.5.3.2 Calbeck Ness SV33

For station SV33, the mud content in 2016 has changed slightly against the historic mean. The 2016 result was +2.0 standard deviations from the historic mean, which is comparable than the +2.1 average for all stations in 2016. It is not possible to determine the significance of the 2016 result against the historic data due to changes in the particle size distribution methodology.

The organic content in 2016 was 2.02% which is similar to the 2014 result of 3.46%. The methodology for the organic content has changed in 2016.

The concentration of total aliphatic hydrocarbons (TAH) at Station SV33 has changed against the level reported in 2010 to 2014 but the 2016 result has not changed significantly against the historic mean. The 2016 result was +0.9 standard deviations from the historic mean. The percentage of UCM in the TAH is higher than the historic mean and is +2.2 standard deviations from the historic mean. This is the same as the general trend and the percentage of UCM in the TAH is on average +2.2 standard deviations from the historic mean for all stations in 2016.

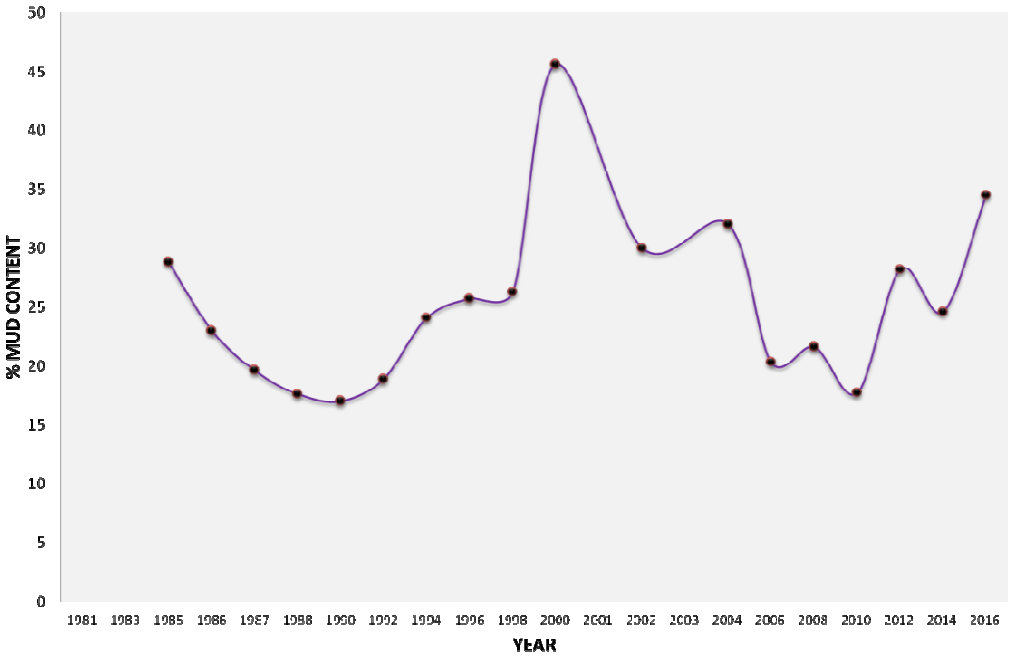

Figure 63 – SV33 Percentage Mud content

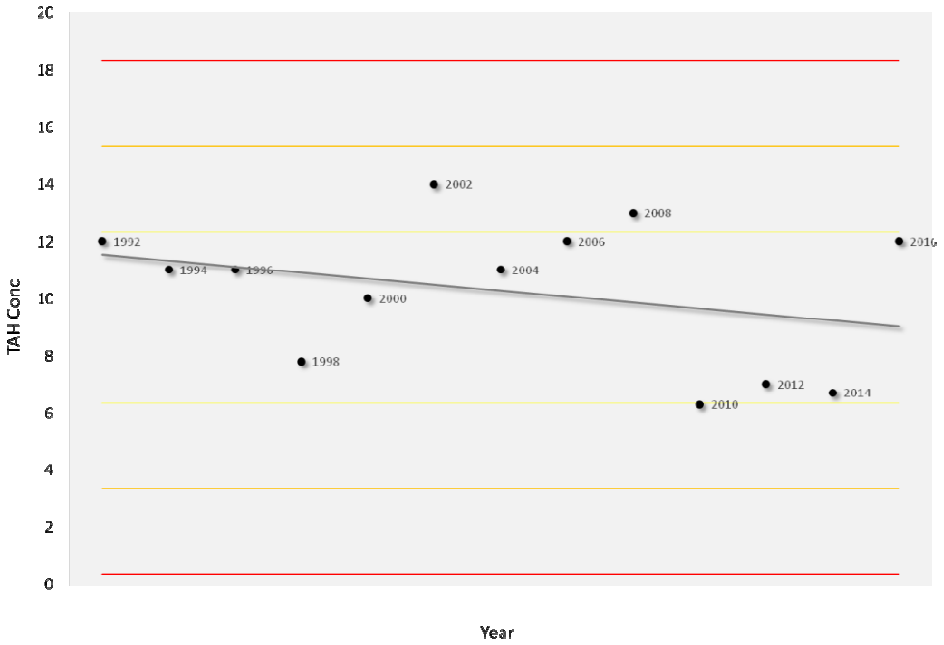

Figure 64 – SV33 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

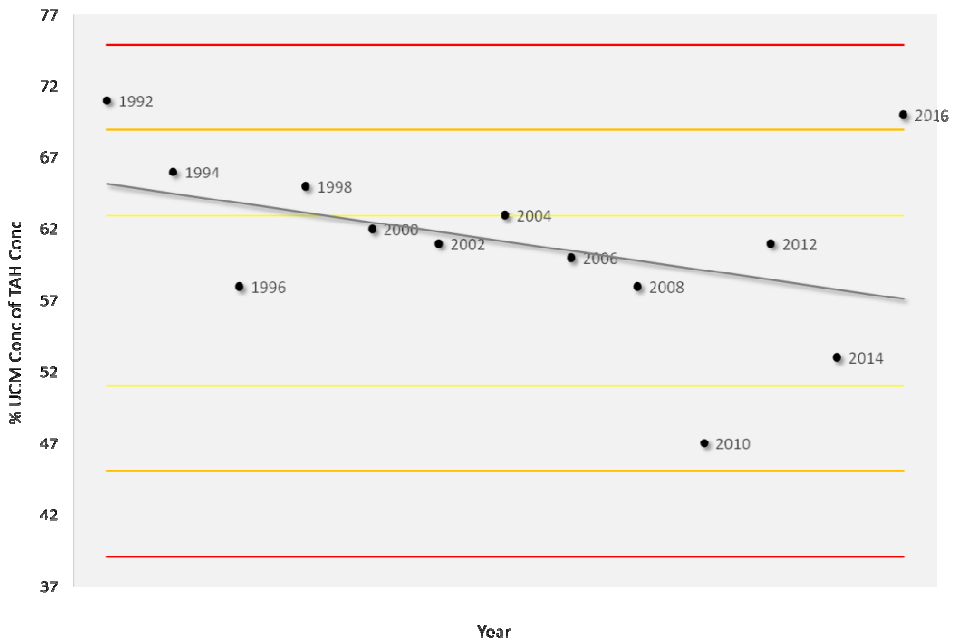

Figure 65 – SV33 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

4.5.3.3 Calbeck Ness SV34

For station SV34, the mud content in 2016 has changed against the mean. The 2016 result was +5.6 standard deviations from the historic mean, which is higher than the +2.1 average for all stations in 2016. The mud content in 2016 is similar to level observed in 2002. It is not possible to determine the significance of the 2016 result against the historic data due to changes in the particle size distribution methodology.

The organic content in 2016 was 1.73% which is similar to the 2014 result of 3.24%. The methodology for the organic content has changed in 2016.

The concentration of total aliphatic hydrocarbons (TAH) at Station SV34 is generally low (<10µg.g^{-1}) and has not changed. The 2016 result was +0.1 standard deviations from the mean. The percentage of UCM in the TAH is higher than the historic mean and is +0.9 standard deviations from the historic mean. This is lower than the general trend and the percentage of UCM in the TAH is on average +2.2 standard deviations from the historic mean for all stations in 2016.

The concentration of 2-6 ring PAH concentration at Station SV34 in 2016 has demonstrated little change. The 2016 result was +0.2 standard deviations from the historic mean. The percentage of 4-6 ring PAHs of the total PAHs has demonstrated little change against the historic mean and also the 2014 result, the 2016 result was +1.1 standard deviations from the historic mean, which is in contrast with the +1.6 average standard deviations from the historic mean at all stations in 2016.

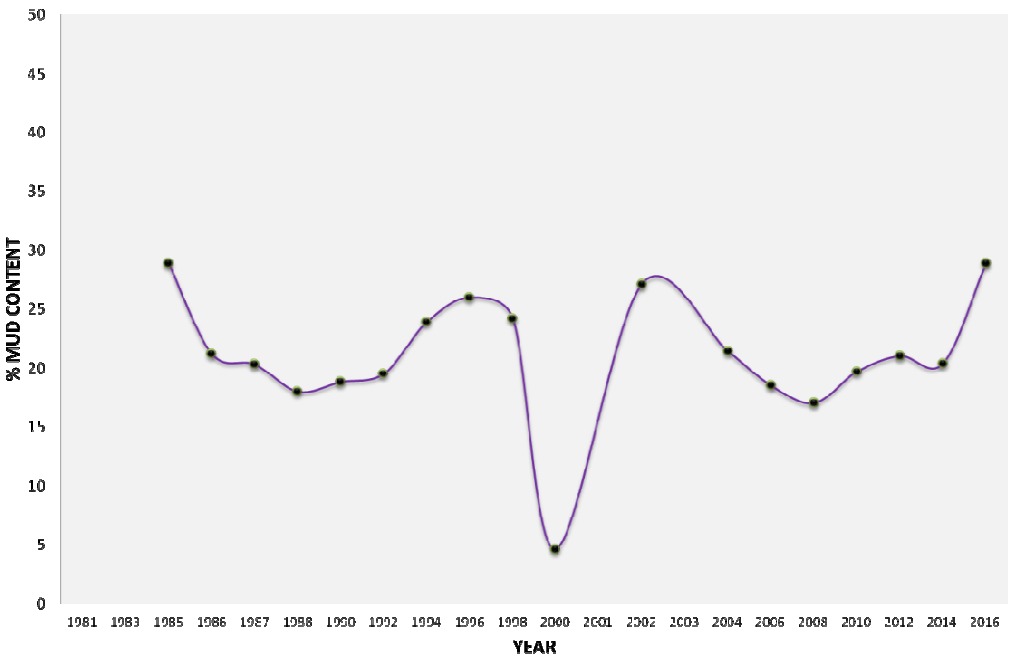

Figure 66 – SV34 Percentage Mud content

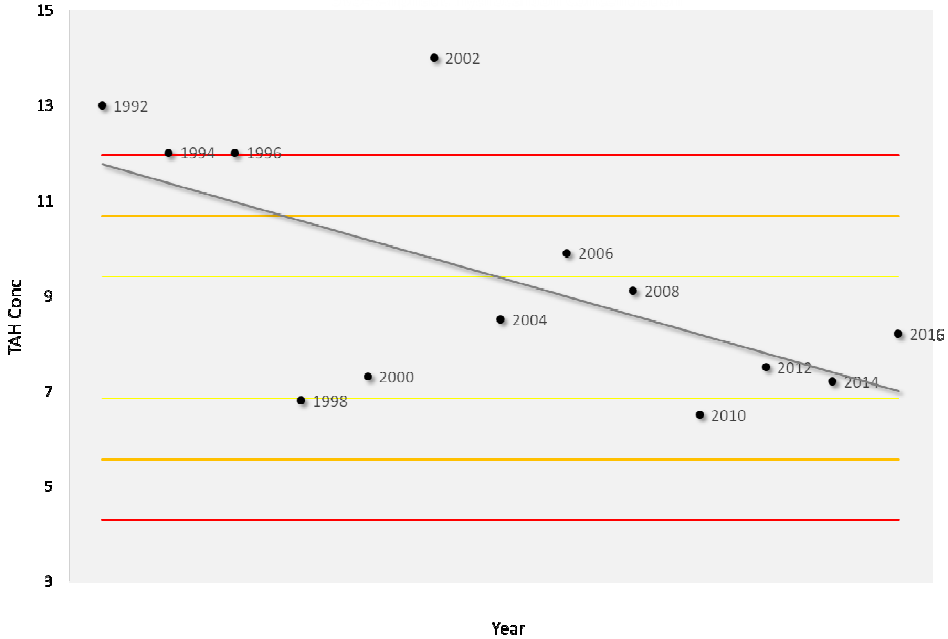

Figure 67 – SV34 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

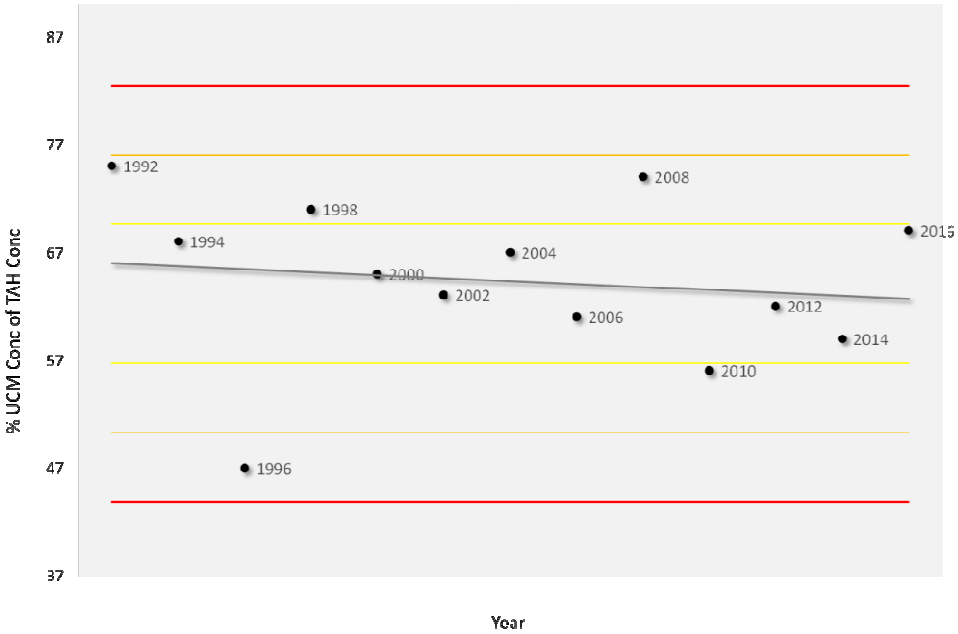

Figure 68 – SV34 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

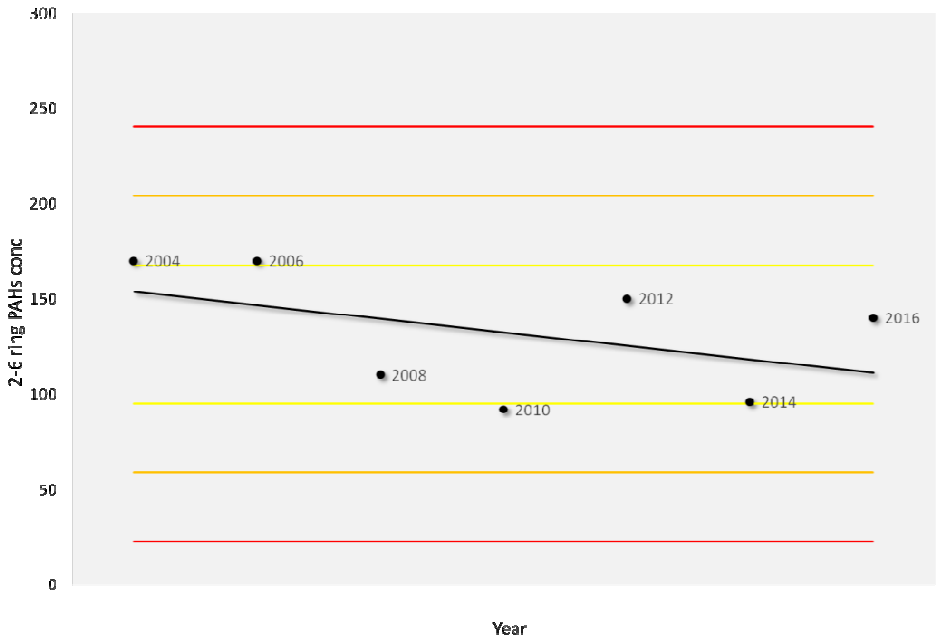

Figure 69 – SV34 2-6 ring PAH concentration (ng.g-1 dry sed.)

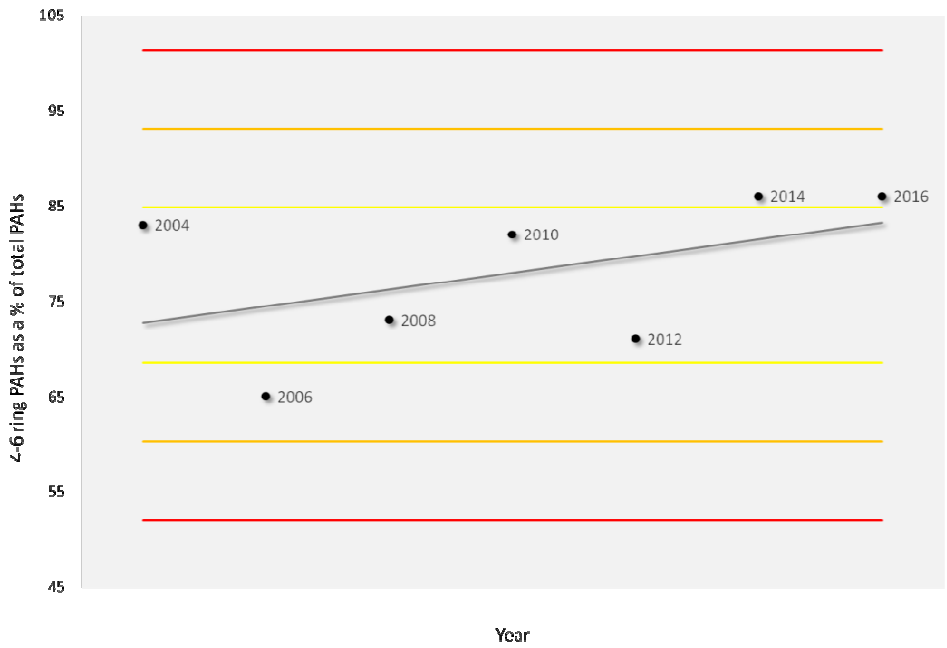

Figure 70 – SV34 4-6 ring PAHs as a percentage of the total PAHs (%)

4.5.3.4 Calbeck Ness SV35

For station SV35, the mud content in 2016 has changed against the mean. The 2016 result was +2.6 standard deviations from the mean, which is higher than the +2.1 average for all stations in 2016. The 2016 mud content is similar to the level in 1998. It is not possible to determine the significance of the 2016 result against the historic data due to changes in the particle size distribution methodology.

The organic content in 2016 was 2.45% which is similar to the 2014 result of 2.26%. The methodology for the organic content has changed in 2016.

The concentration of total aliphatic hydrocarbons (TAH) at Station SV35 is generally low (<10µg.g^{-1}) and has not changed. The 2016 result was -0.1 standard deviations from the historic mean. The percentage of UCM in the TAH is higher than the historic mean and is +2.5 standard deviations from the historic mean. This is higher than the general trend and the percentage of UCM in the TAH is on average +2.2 standard deviations from the historic mean for all stations in 2016.

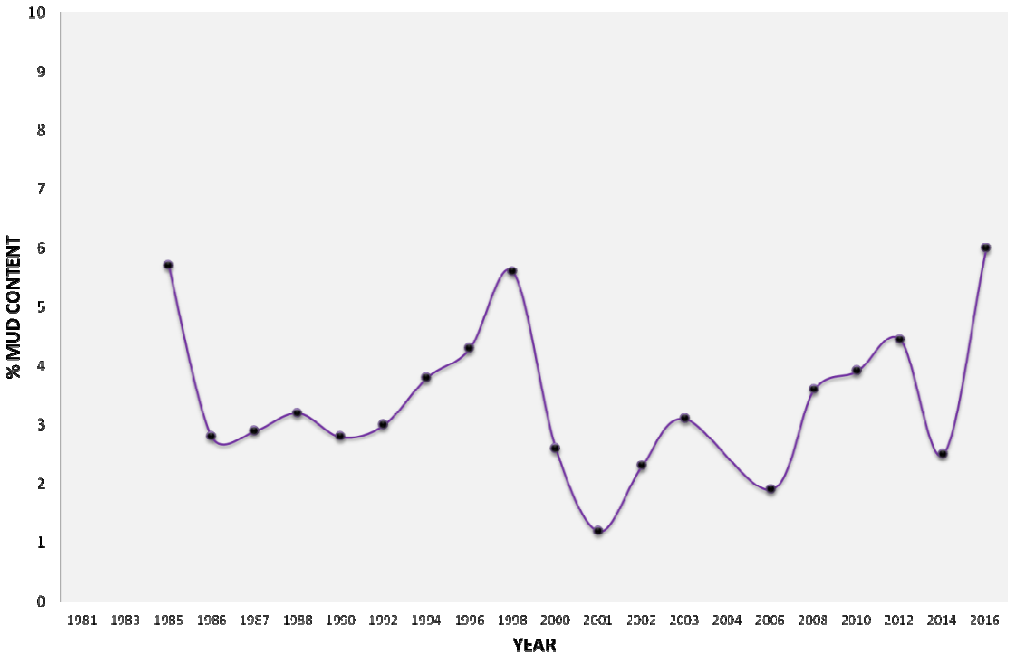

Figure 71 – SV35 Percentage Mud content

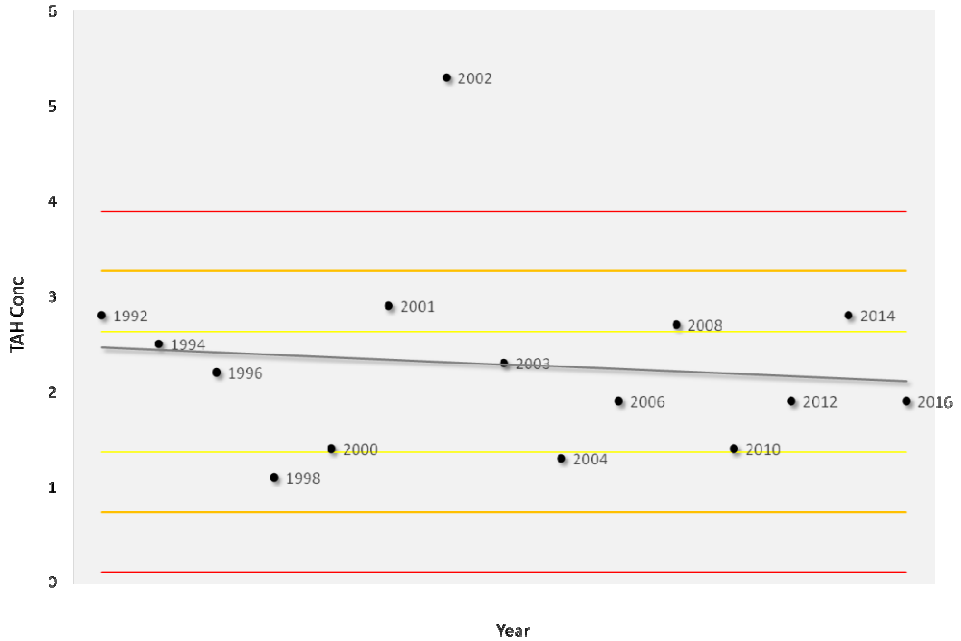

Figure 72 – SV35 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

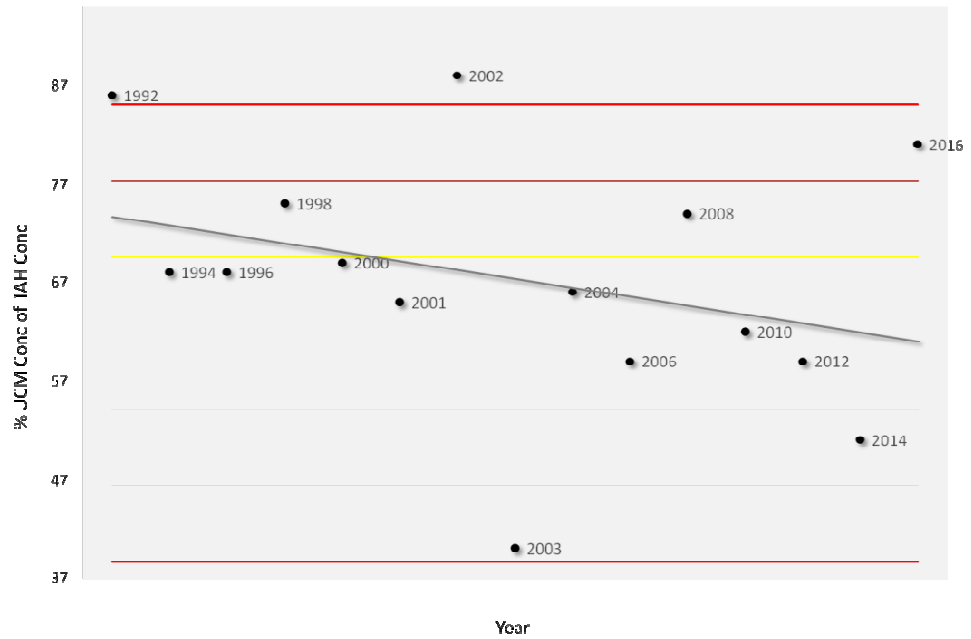

Figure 73 – SV35 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

4.5.3.5 Calbeck Ness SV36B

The coordinates for station SV36 were revised as the original coordinates were within a 200m exclusion zone of pipe line assets. At the new station SV36B, no sediment samples were obtained from the grab sampling operation.

4.5.3.6 Calbeck Ness SV37B

The coordinates for station SV37 were revised as the original coordinates were within a 200m exclusion zone of pipe line assets. At the new station SV37B, only one sediment sample was obtained from the grab sampling operation. Given the relocation of the site and the observed difference in the ground at the station no comparison has been made to the historic data.

4.5.4 GARTHS VOE (STATIONS 6, 6A, 6F TO 32)

4.5.4.1 Garths Voe SV6

For station SV6, the mud content in 2016 has changed against the historic mean. The 2016 result was +1.5 standard deviations from the historic mean, which is similar to the +2.1 average for all stations in 2016. The 2016 mud content is similar to the results obtained in 2004 and 1998. It is not possible to determine the significance of the 2016 result against the historic data due to changes in the particle size distribution methodology.

The organic content in 2016 was 4.40% which is lower than the 2014 result of 8.07%. The methodology for the organic content has changed in 2016.

The concentration of total aliphatic hydrocarbons (TAH) at Station SV34 is similar to the 2014 result but has changed against the historic mean. The 2016 result was -1.8 standard deviations from the historic mean and continues a pattern of decreasing TAH concentration at the site. The percentage of UCM in the TAH is higher than the historic mean and is +2.6 standard deviations from the historic mean. This is higher than the general trend and the percentage of UCM in the TAH is on average +2.2 standard deviations from the historic mean for all stations in 2016.

The concentration of 2-6 ring PAH concentration at Station SV6 in 2016 has demonstrated no change. The 2016 result was 0 standard deviations from the historic mean. The percentage of 4-6 ring PAHs of the total PAHs has change against the historic mean, the 2016 result was +2.4 standard deviations from the mean, which is higher than the +1.6 average standard deviations from the historic mean at all stations in 2016.

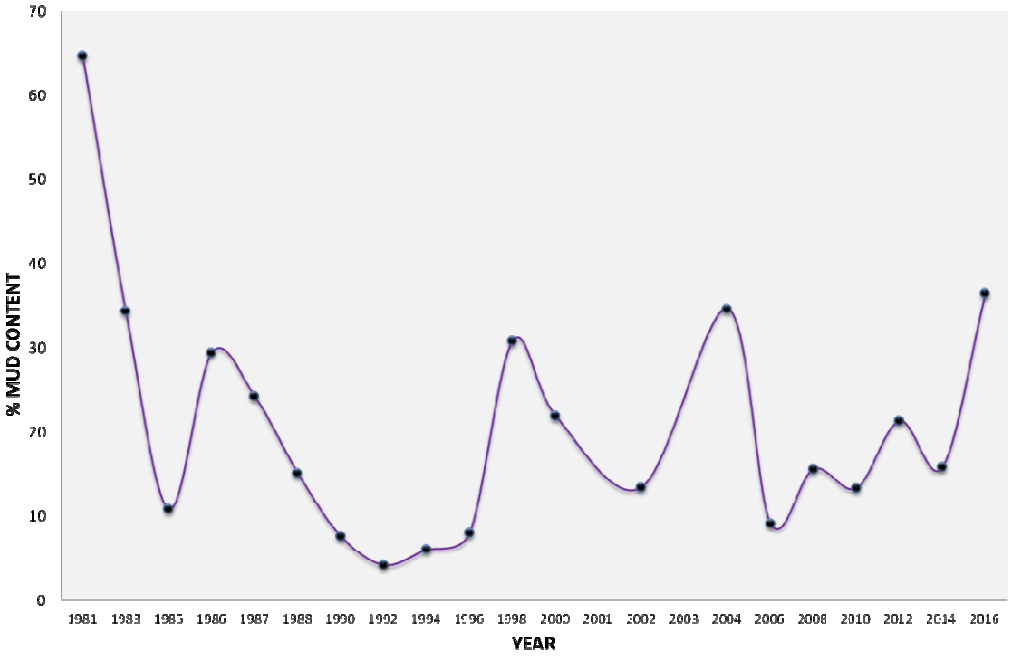

Figure 74 – SV6 Percentage mud content

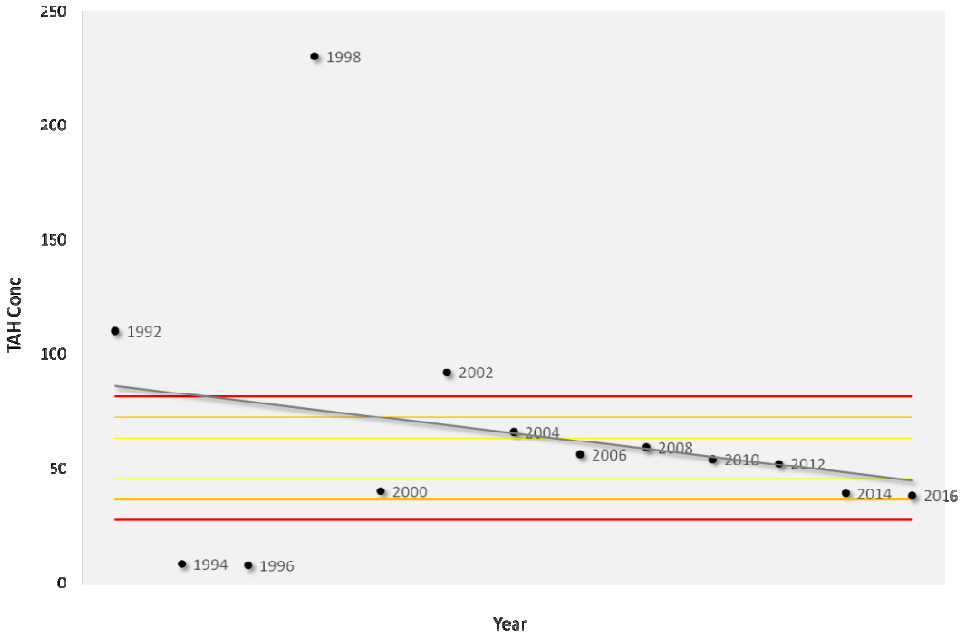

Figure 75 – SV6 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

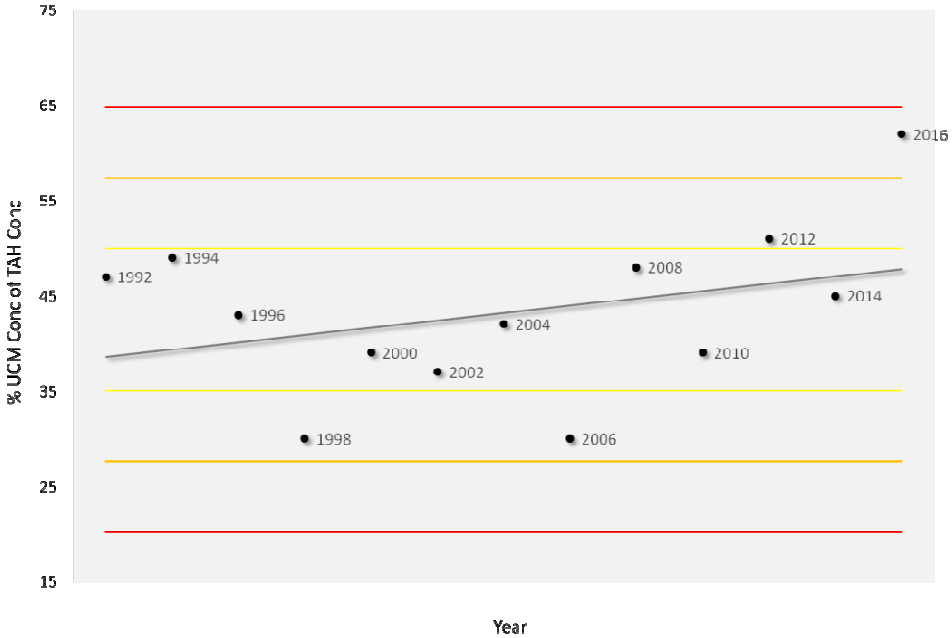

Figure 76 – SV6 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

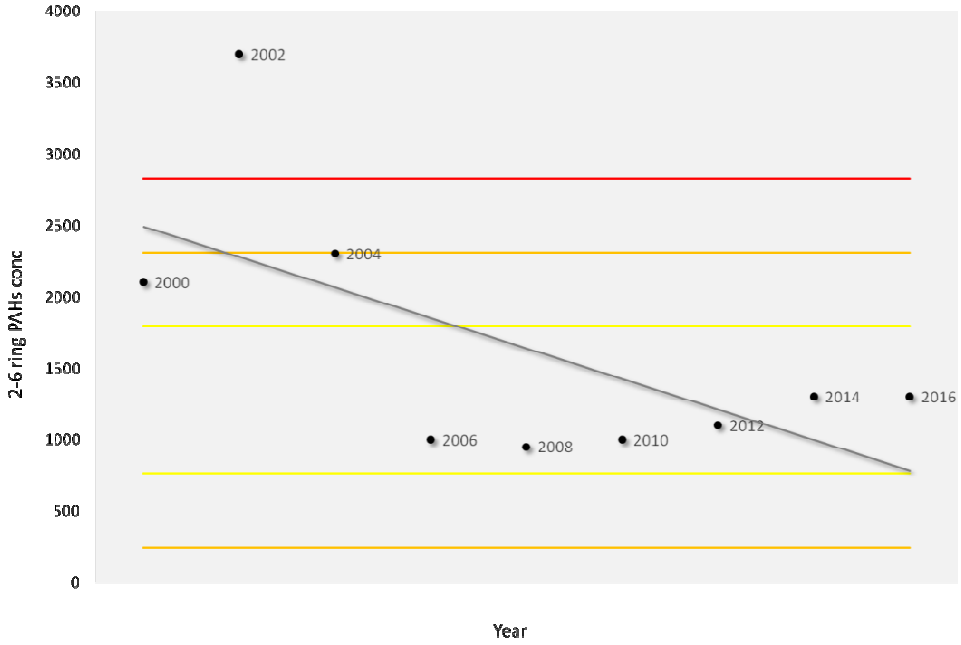

Figure 77 – SV6 2-6 ring PAH concentration (ng.g-1 dry sed.)

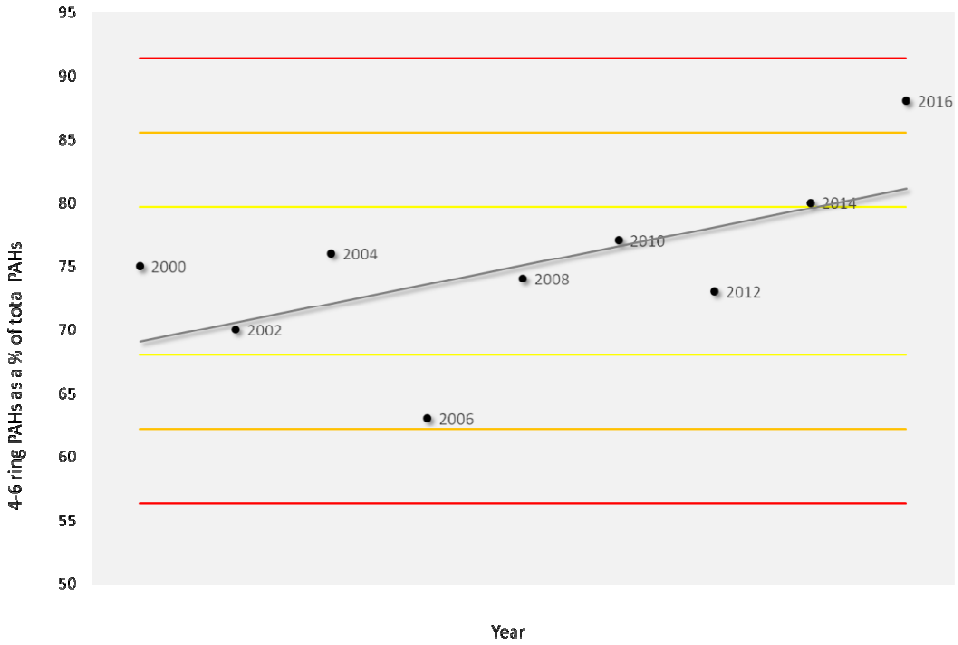

Figure 78 – SV6 4-6 ring PAHs as a percentage of the total PAHs (%)

4.5.4.2 Garths Voe SV6A

For station SV6, the mud content has historically been very high with a relative standard deviation of 70% for the data from period 1985 to 2014. The much content result in 2016 has demonstrated some change against the historic mean. The 2016 result was +1.1 standard deviations from the historic mean, which is lower than the +2.1 average for all stations in 2016. The mud content determined in 2016 is similar to the period 1994-1998 and 2002-2004. It is not possible to determine the significance of the 2016 result against the historic data due to changes in the particle size distribution methodology.

The organic content in 2016 was 6.94% which is lower than the 2014 result of 14.13%. The methodology for the organic content has changed in 2016.

The concentration of total aliphatic hydrocarbons (TAH) at Station SV6A is has not changed against the historic mean. The 2016 result was -0.1 standard deviations from the historic mean. The percentage of UCM in the TAH is higher than the historic mean and is +2.5 standard deviations from the historic mean. This is higher than the general trend and the percentage of UCM in the TAH is on average +2.2 standard deviations from the historic mean for all stations in 2016.

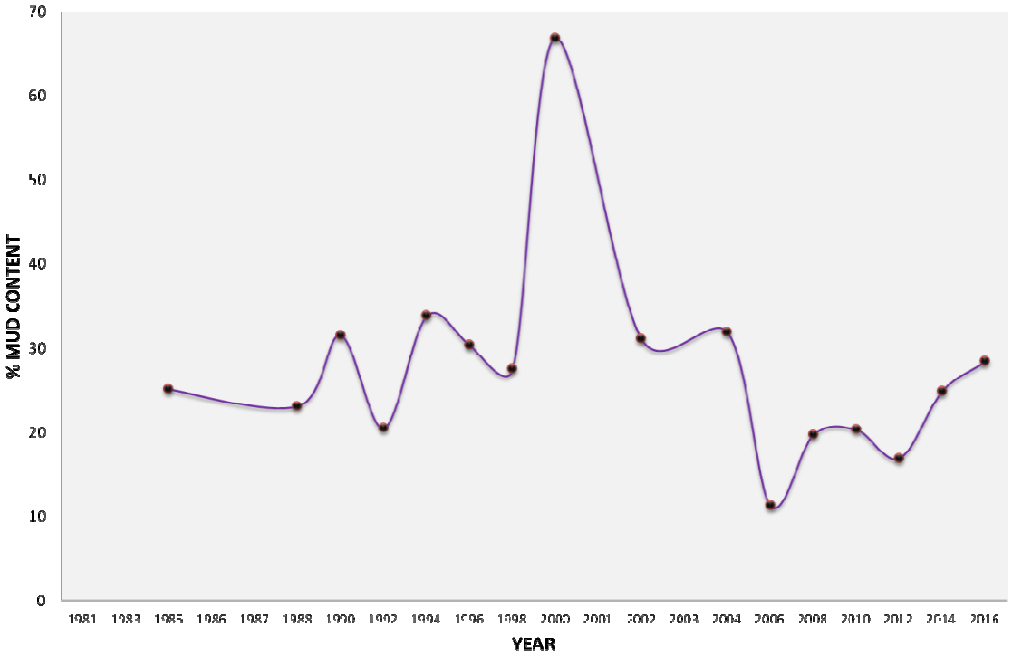

Figure 79 – SV6A Percentage mud content

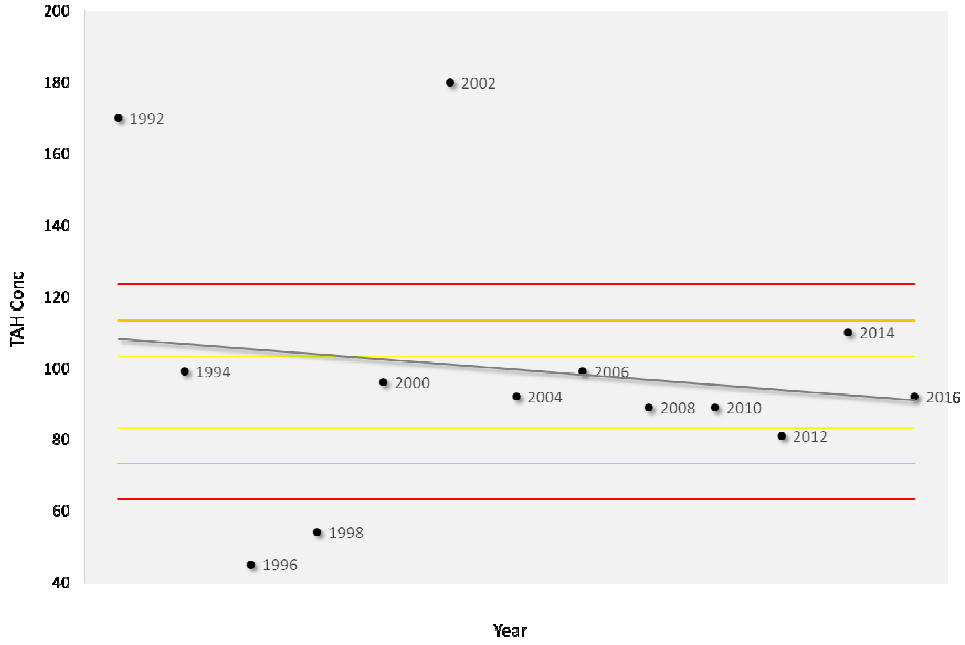

Figure 80 – SV6A Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

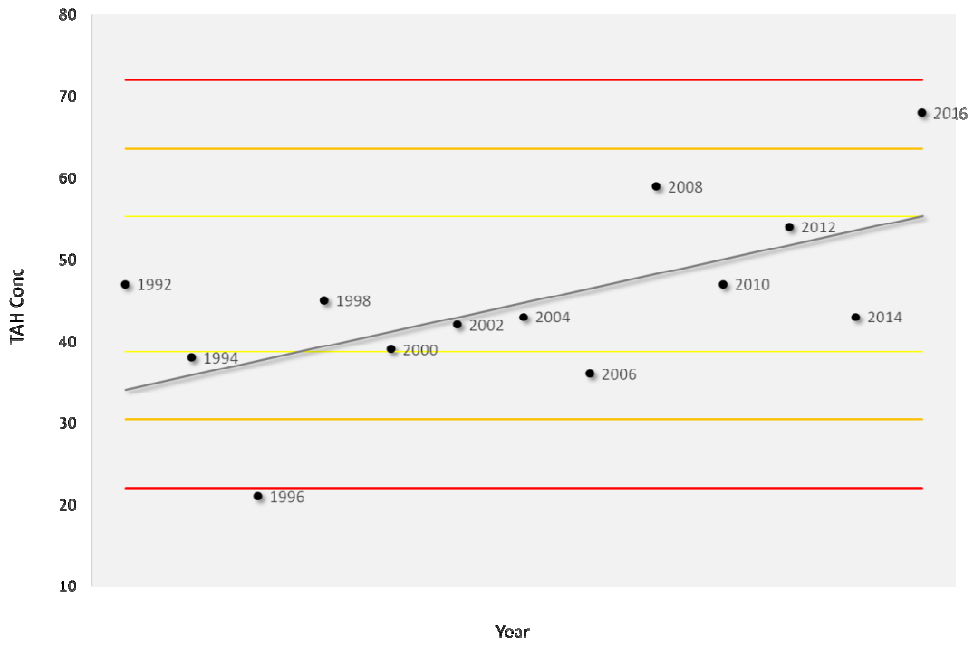

Figure 81 – SV6A Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

4.5.4.3 Garths Voe SV6F

For station SV6F, the mud content in 2016 has some change against the historic mean. There has been a relatively large variation in mud content over the full data set period 1981-2000. The 2016 result was +1.5 standard deviations from the historic mean, which is lower than the +2.1 average for all stations in 2016. It is not possible to determine the significance of the 2016 result against the historic data due to changes in the particle size distribution methodology.

The organic content in 2016 was 12.3% which is comparable to the 2014 result of 13.55%. The methodology for the organic content has changed in 2016.

The concentration of total aliphatic hydrocarbons (TAH) at Station SV6F has changed against the historic mean. The 2016 result was -1.7 standard deviations from the historic mean and continues a pattern of decreasing TAH concentration at the site. The percentage of UCM in the TAH is higher than the historic mean and is +2.3 standard deviations from the historic mean. This is comparable to the general trend and the percentage of UCM in the TAH is on average +2.2 standard deviations from the historic mean for all stations in 2016.

The concentration of 2-6 ring PAH concentration at Station SV34 in 2016 has changed. The 2016 result was -2.8 standard deviations from the historic mean and correlates to the lower TAH result observed. The percentage of 4-6 ring PAHs of the total PAHs has change against the historic mean, the 2016 result was +2.2 standard deviations from the historic mean, which is higher than the +1.6 average standard deviations from the historic mean at all stations in 2016.

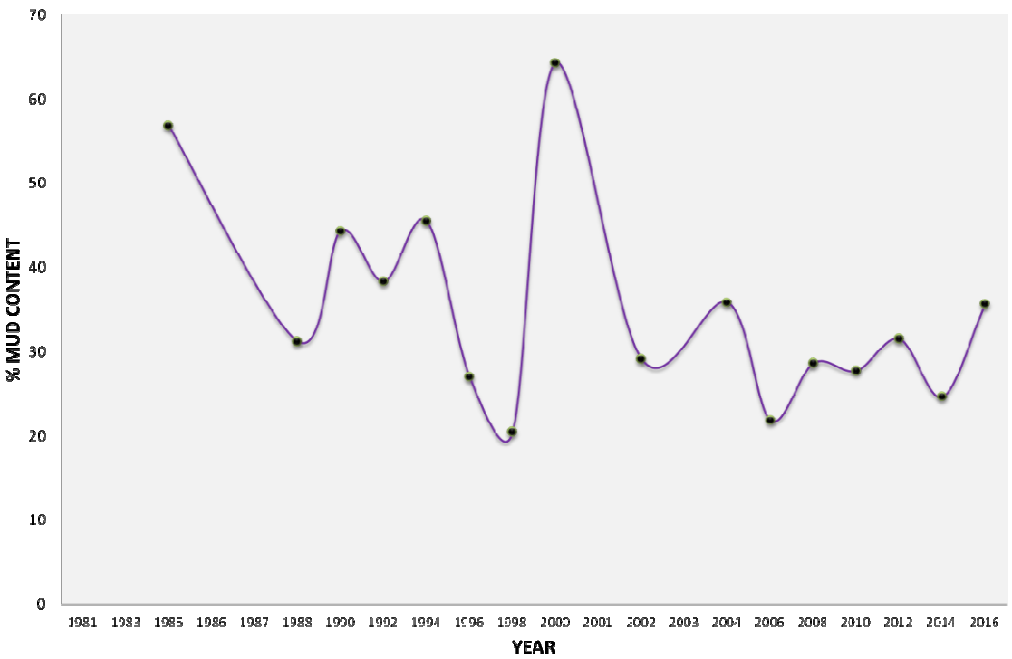

Figure 82 – SV6F Percentage mud content

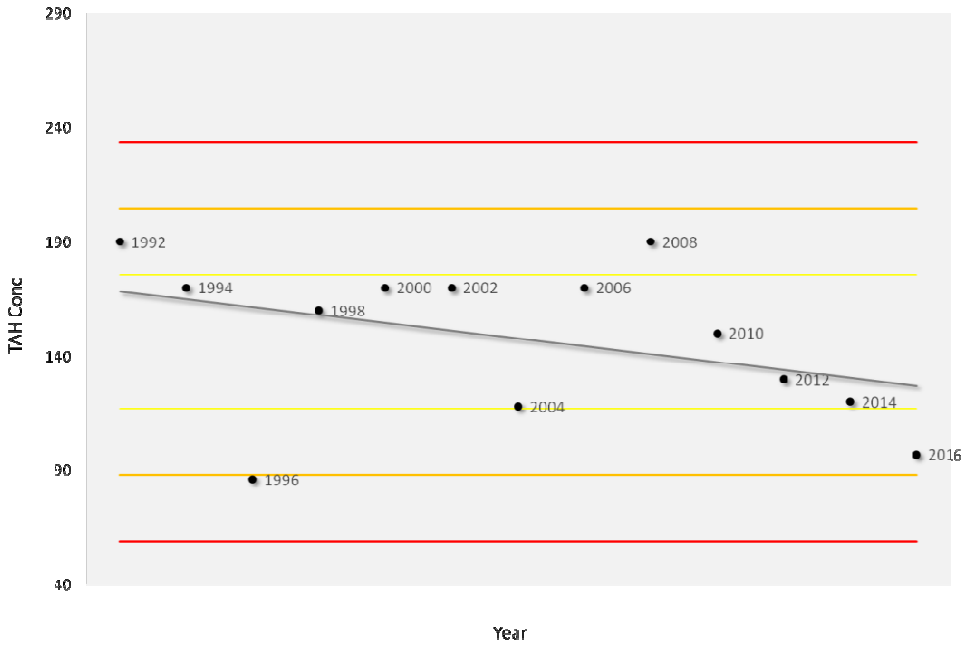

Figure 83 – SV6F Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

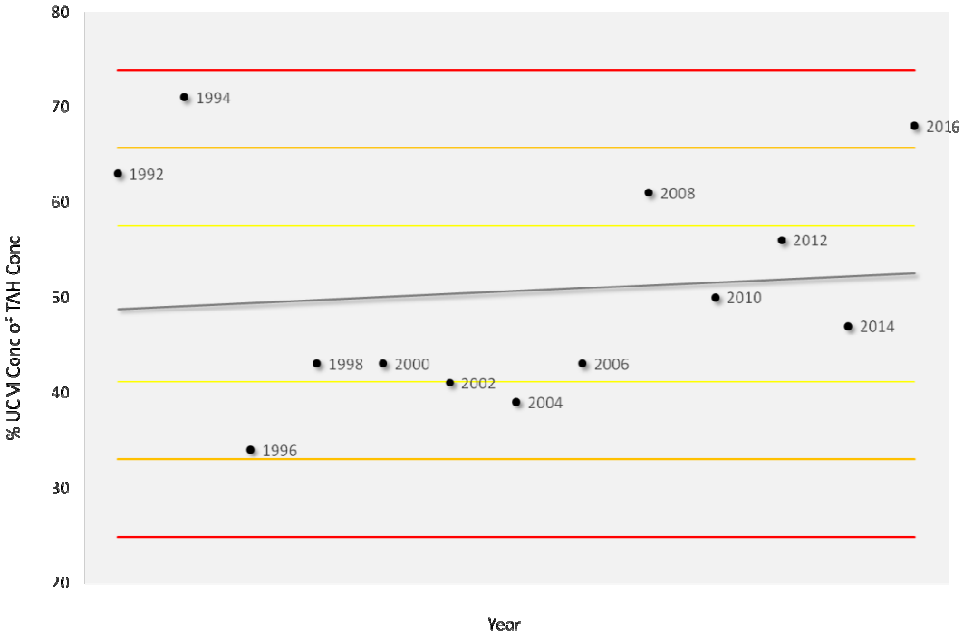

Figure 84 – SV6F Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

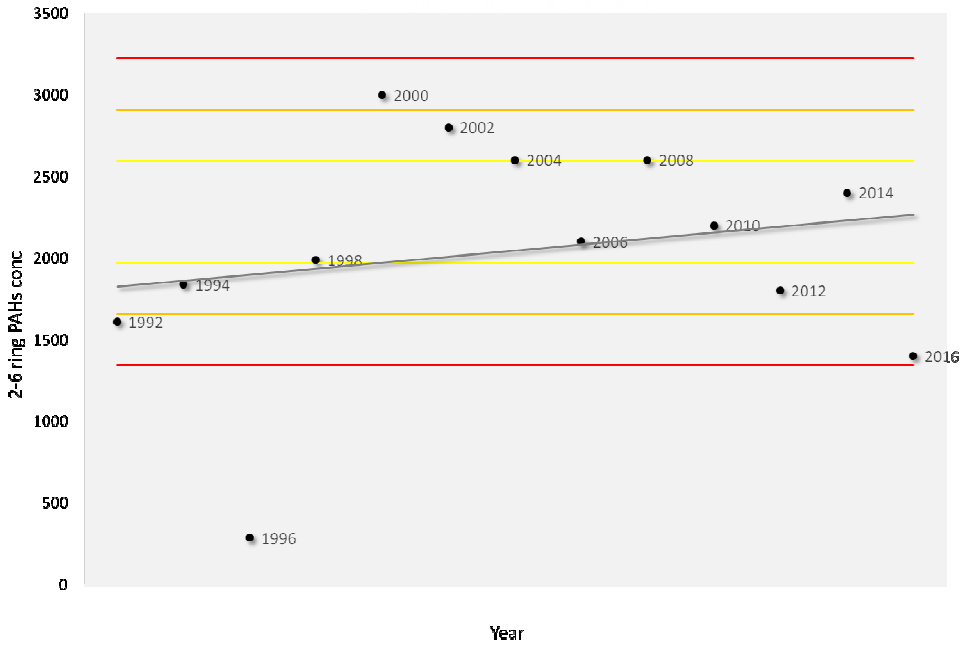

Figure 85 – SV6F 2-6 ring PAH concentration (ng.g-1 dry sed.)

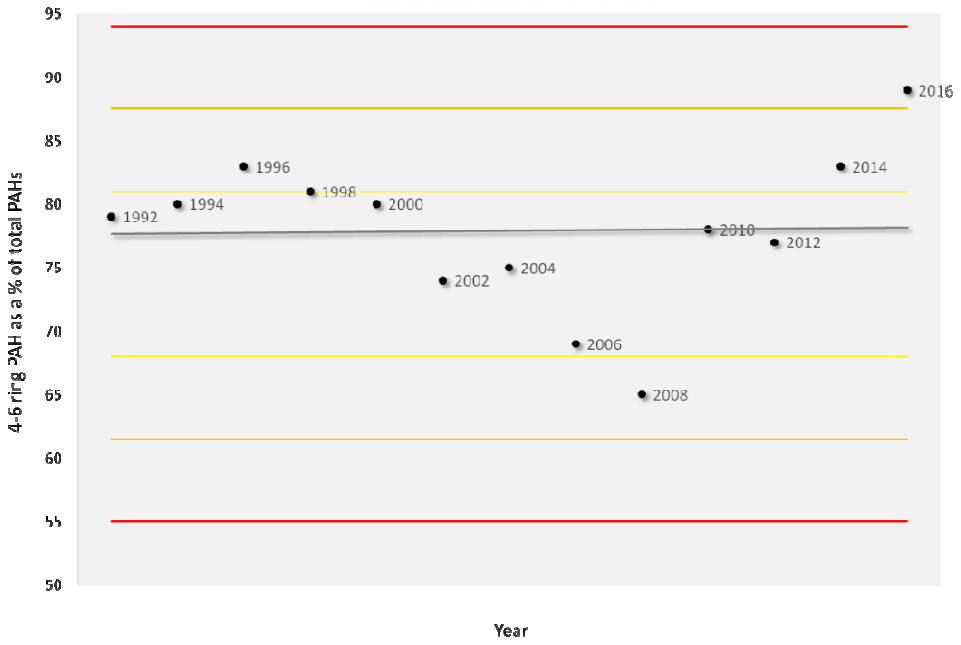

Figure 86 – SV6F 4-6 ring PAHs as a percentage of the total PAHs (%)

4.5.4.4 Garths Voe SV32

For station SV32, the mud content in 2016 has changed against the mean. The 2016 result was +2.1 standard deviations from the mean, which is consistent with the +2.2 average for all stations in 2016. The mud content in 2016 is similar to the results from 1981-1996 and 2000-2004. It is not possible to determine the significance of the 2016 result against the historic data due to changes in the particle size distribution methodology.

The organic content in 2016 was 11.1% which is comparable to the 2014 result of 11.1%. The methodology for the organic content has changed in 2016.

The concentration of total aliphatic hydrocarbons (TAH) at Station SV32 has not changed against the historic mean. The 2016 result was -0.8 standard deviations from the historic mean and continues a pattern of slightly decreasing TAH concentration at the station. The relative standard deviation for the TAH was 5% for the three grab samples analysed. The percentage of UCM in the TAH is significantly higher than the historic mean and is +3.9 standard deviations from the historic mean. This is higher than the general trend and the percentage of UCM in the TAH is on average +2.2 standard deviations from the historic mean for all stations in 2016. The relative standard deviation for the percentage of UCM in the TAH was 7% for the three grab samples analysed.

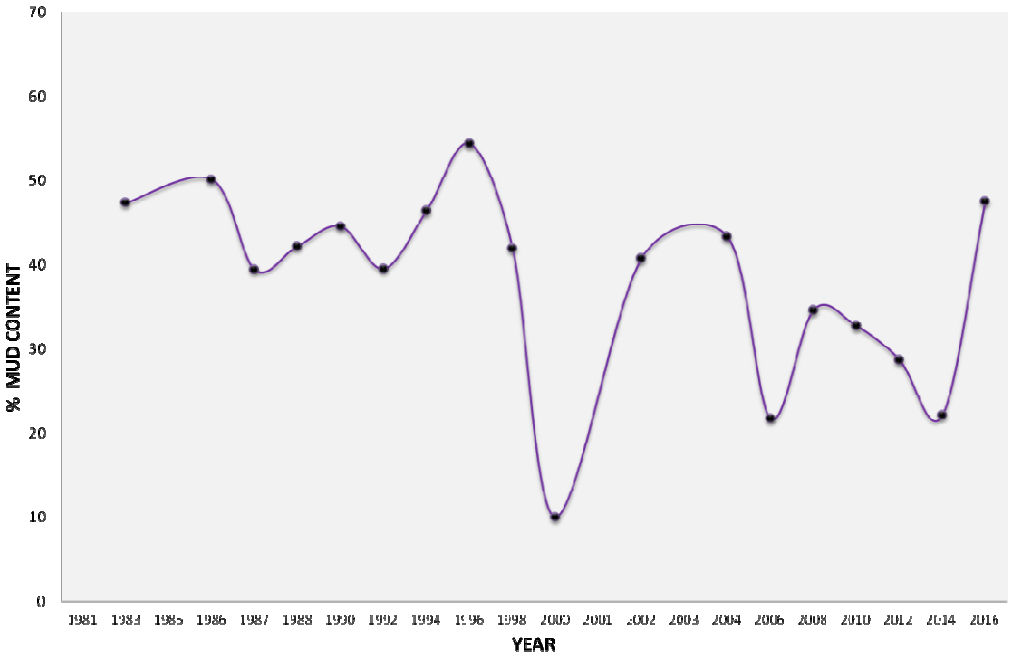

Figure 87 – SV32 Percentage mud content

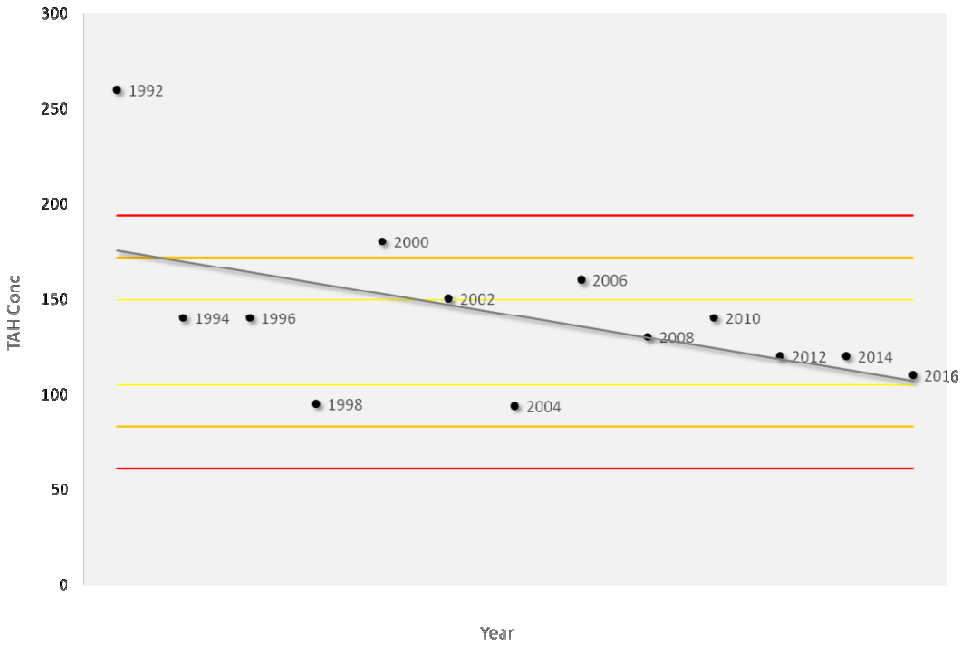

Figure 88 – SV32 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

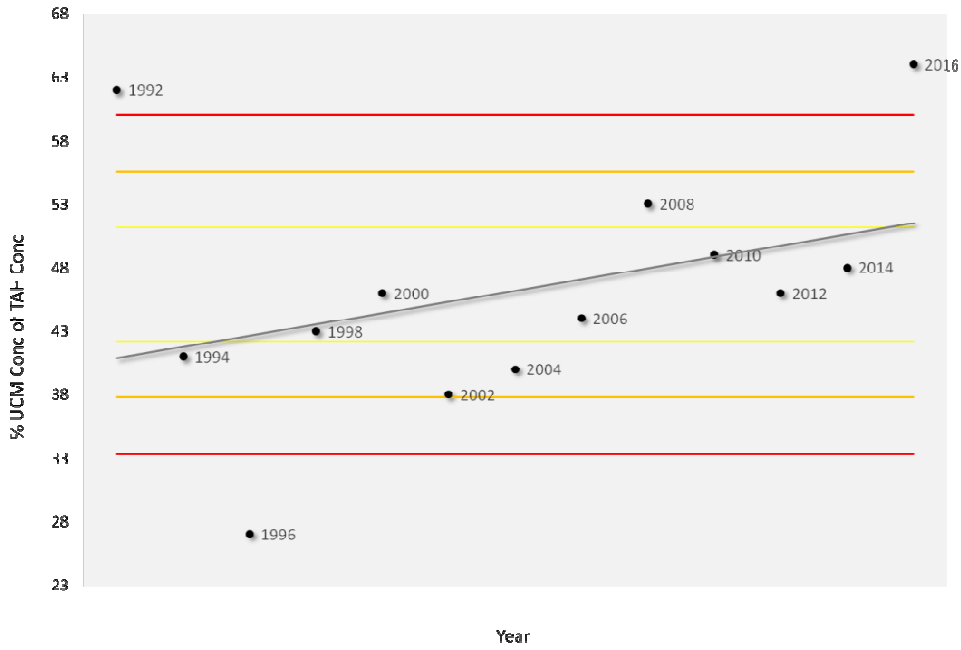

Figure 89 – SV32 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

4.5.5 GLUSS VOE (STATIONS GV1 TO GV3)

The proportions of mud at all three Gluss Voe stations increased in 2016 which was expected following the change to the NMBAQC methodology. At GV1 the 2016 classification was assigned as Muddy Sandy Gravel, rather than Sandy Gravel as the mud content had risen from 0.48% to 5.5%. At GV2 the 2016 classification was assigned as Sandy Gravel, as in previous years although the mud content had risen from 1.3% to 3.3%. At GV3 the 2016 classification was assigned as Muddy Gravelly Sand, the mud content had risen from 3.2% to 7.6%.

In previous reports the current and historic particle size distribution analysis was not included in tabulated format and has not been expressed in chart format in this section.

As in previous surveys, the organic contents remained low in these stations, with values ranging from <0.1% to 2.0% (compared with 1.15% to 1.48% in 2014). The GV2 sample was taken at low tide but there was still tidal activity during the sampling operation which may account for the low TOC result.

4.5.5.1 Gluss Voe GV1

The concentration of total aliphatic hydrocarbons (TAH) at Station GV1 is generally low (<10µg.g^{-1}) the 2016 result has not changed significantly against the historic mean. The 2016 result was +0.8 standard deviations from the historic mean. The percentage of UCM in the TAH is historically very varied at this station, with a relative standard deviation of 67% for the historic mean of data set 2004-2014. The percentage of UCM in the TAH is within +/- 1 standard deviation of the historic mean.

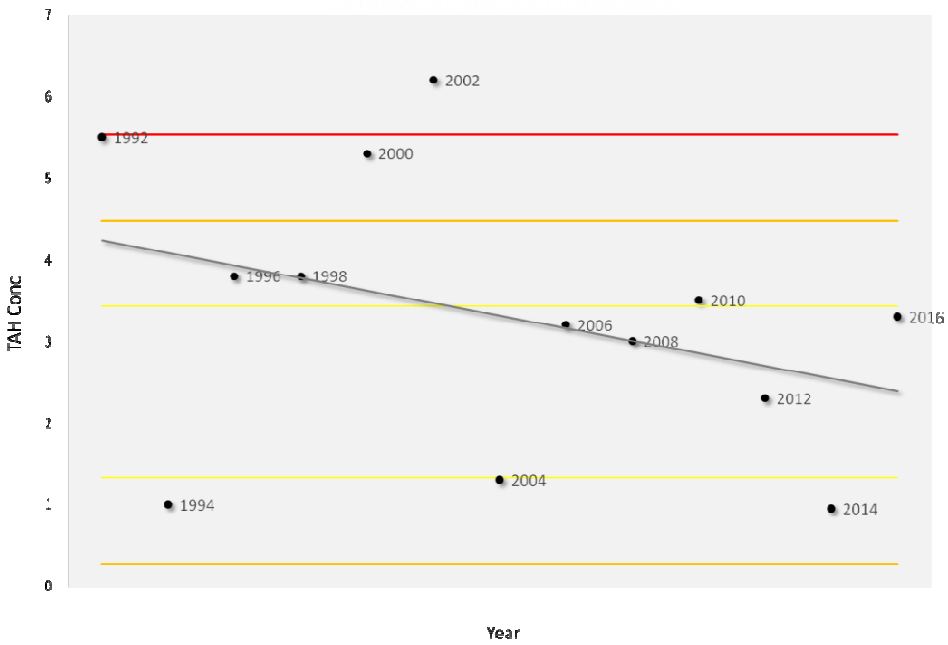

Figure 90 – GV1 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

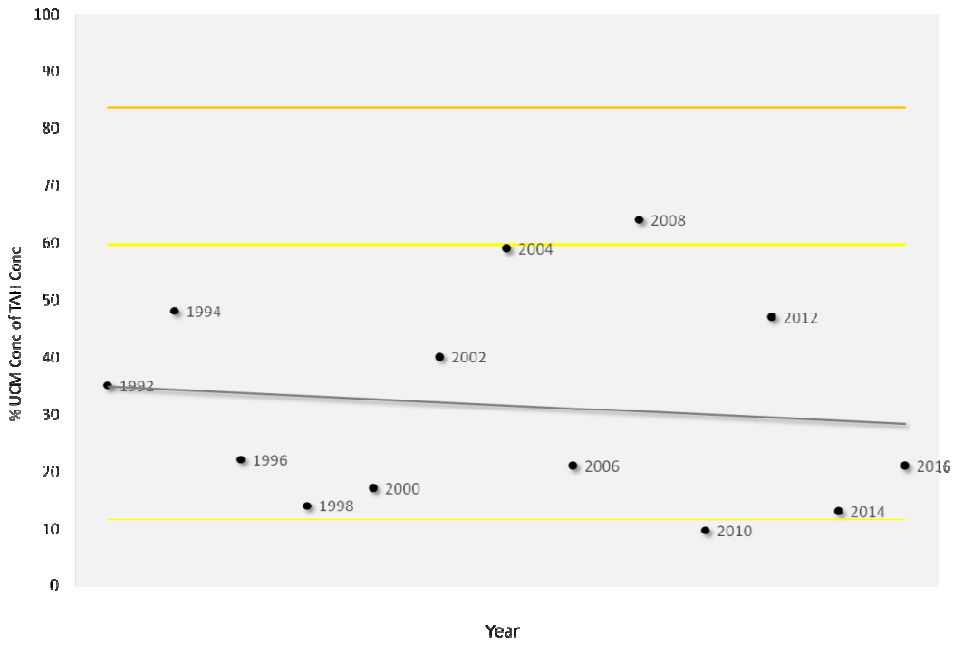

Figure 91 – GV1 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

4.5.5.2 Gluss Voe GV2

The concentration of total aliphatic hydrocarbons (TAH) at Station GV2 is generally low (<10µg.g^{-1}) the 2016 result has not changed significantly against the 2014 result but there is a slight change against the historic mean. The 2016 result was -1.5 standard deviations from the historic mean. The percentage of UCM in the TAH is historically very varied at this station, with a relative standard deviation of 37% against the historic mean for data 2004-2014. The percentage of UCM in the TAH result for 2016 is a significant change to the historic mean. The 2016 result is +5.1 standard deviations from the historic mean. The standard deviation between the three grab samples analysed for this parameter was 6%. Another outlier for this station was observed in the 2002 survey. The difference is thought to be due to the tidal activity during the sampling or due to the higher uncertainties in the analysis at lower concentrations as the approach the reporting limit.

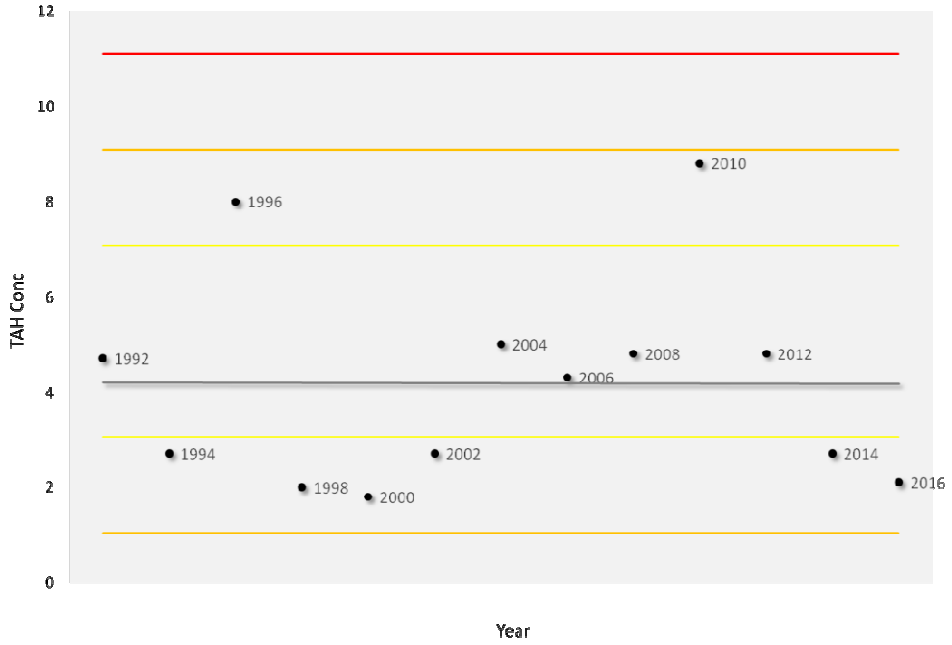

Figure 92 – GV2 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

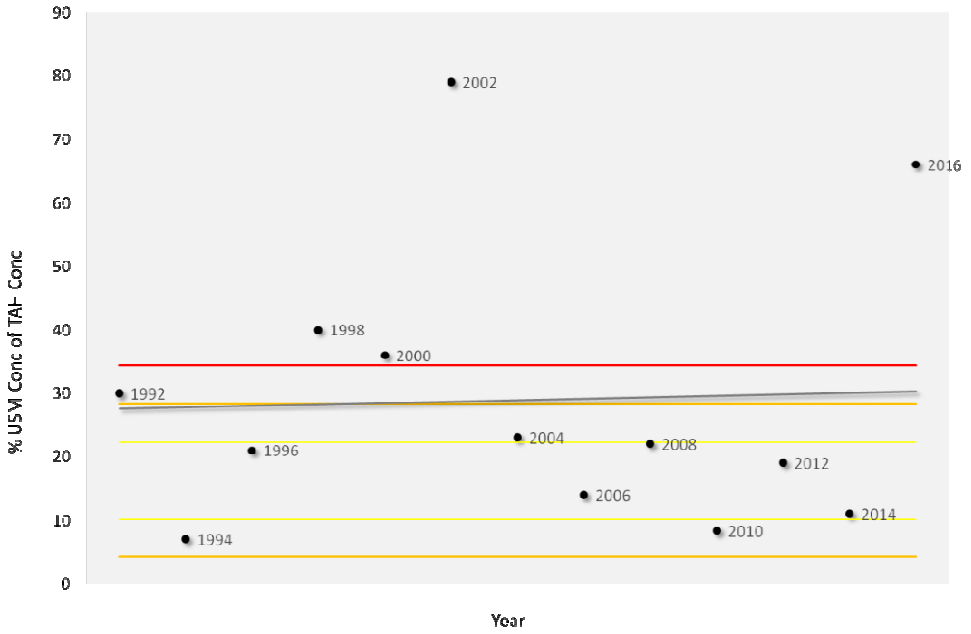

Figure 93 – GV2 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

4.5.5.3 Gluss Voe GV3

The concentration of total aliphatic hydrocarbons (TAH) at Station GV3 is generally low (<10µg.g^{-1}) the 2016 result has not changed significantly against the historic mean. The 2016 result was -0.5 standard deviations from the historic mean. The percentage of UCM in the TAH is historically very varied at this station, with a relative standard deviation of 66% against the historic mean for data 2004-2014. The percentage of UCM in the TAH result for 2016 is a slight change to the historic mean. The 2016 result is +1 standard deviation from the historic mean. This is a general trend and the average standard deviation from the historic mean for all stations in 2016 was +2.2.

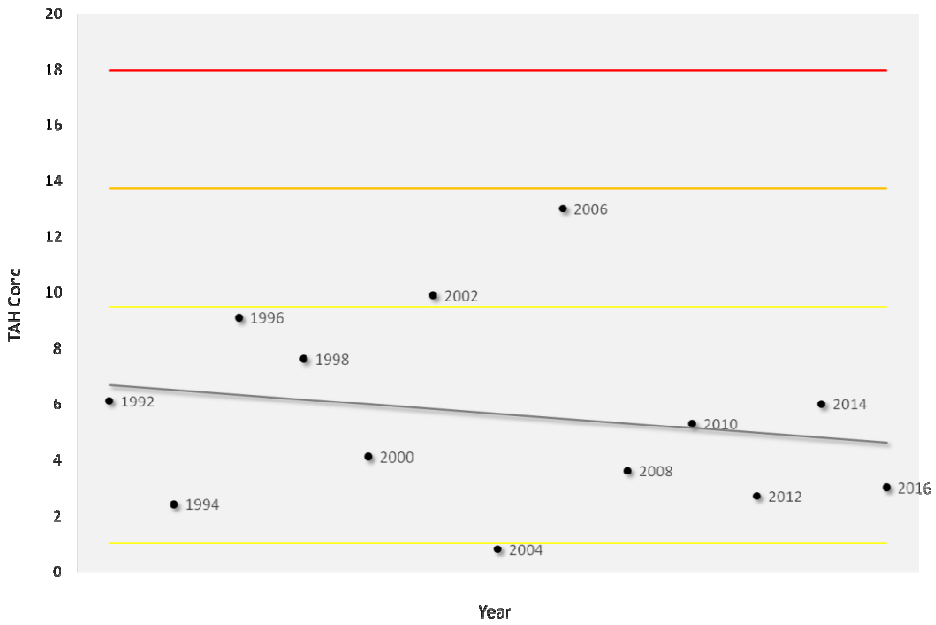

Figure 94 – GV2 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

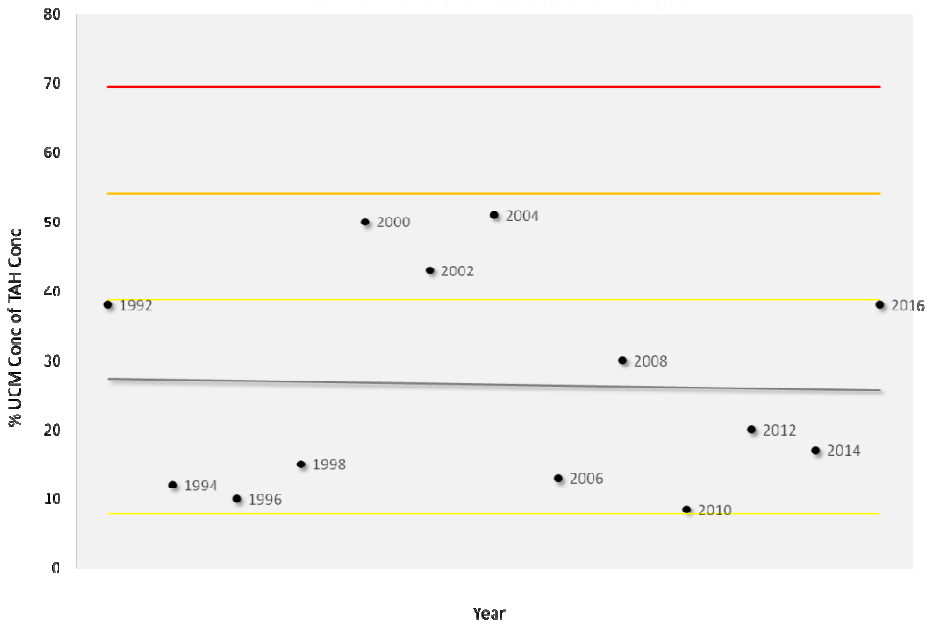

Figure 95 – GV2 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

4.5.6 HOUB OF SCATSTA (STATIONS HS1 TO HS3)

The proportions of mud at all three Houb of Scatsta stations increased in 2016 which was expected following the change to the NMBAQC methodology. As in 2014, the HS1 classification in 2016 was assigned as Sandy Gravel, the mud content had risen from 0.27% to 2.1%. At HS2 the 2016 classification was assigned as Slightly Gravelly Sand, the mud content had risen from 2.0% to 6.6%. At HS3 the 2016 classification was assigned as Slightly Gravelly Sand, the mud content had risen from 0% to 4.0%.

In previous reports the current and historic particle size distribution analysis was not included in tabulated format and has not been expressed in chart format in this section.

As in previous surveys, the organic contents remained low in these stations, with values ranging from 0.67% to 1.72% (compared with 0.87% to 1.22% in 2014).

4.5.6.1 Houb of Scatsta HS1

The concentration of total aliphatic hydrocarbons (TAH) at Station HS1 is generally low (<10µg.g^{-1}). The 2016 result has not changed significantly against the historic mean. The 2016 result was +0.2 standard deviations from the historic mean. The percentage of UCM in the TAH is historically very varied at this station. The percentage of UCM in the TAH is + 1 standard deviation of the historic mean. This is a general trend and the average standard deviation from the historic mean for all stations in 2016 was +2.2.

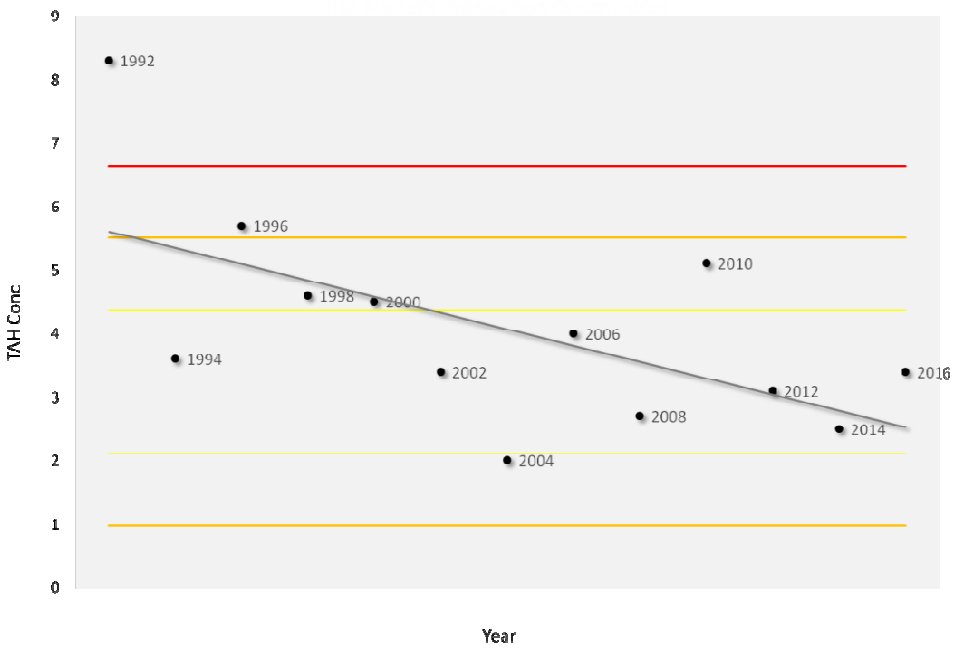

Figure 96 – HS1 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

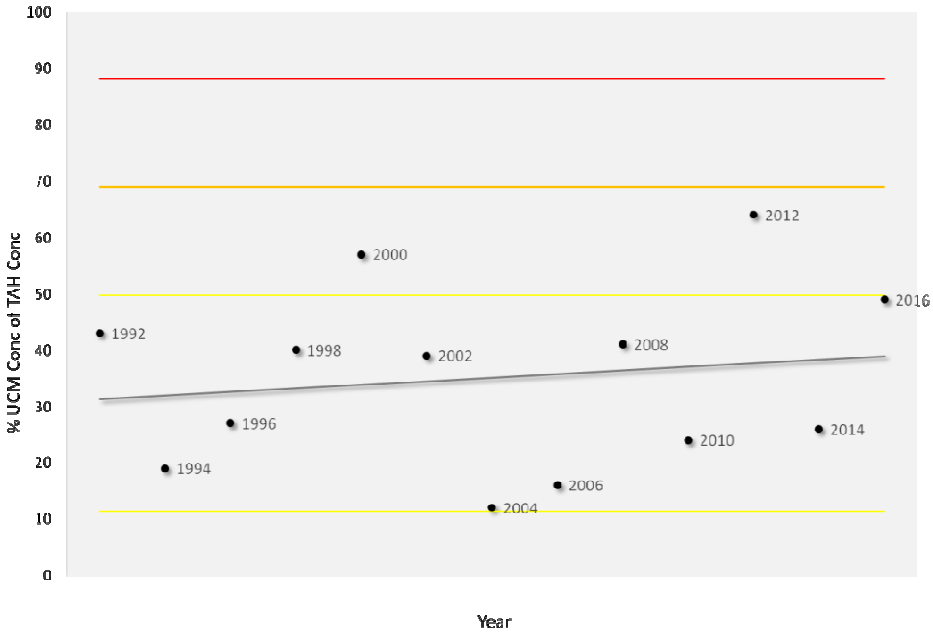

Figure 97 – HS1 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

4.5.6.2 Houb of Scatsta HS2

The concentration of total aliphatic hydrocarbons (TAH) at Station HS2 is generally low (<10µg.g^{-1}) the 2016 result has not changed significantly against the 2014 result but there is a slight change against the historic mean. The 2016 result was 0 standard deviations from the mean. The percentage of UCM in the TAH result for 2016 is a significant change to the historic mean. The 2016 result is +1.7 standard deviations from the mean. This is a general trend and the average standard deviation from the historic mean for all stations in 2016 was +2.2.

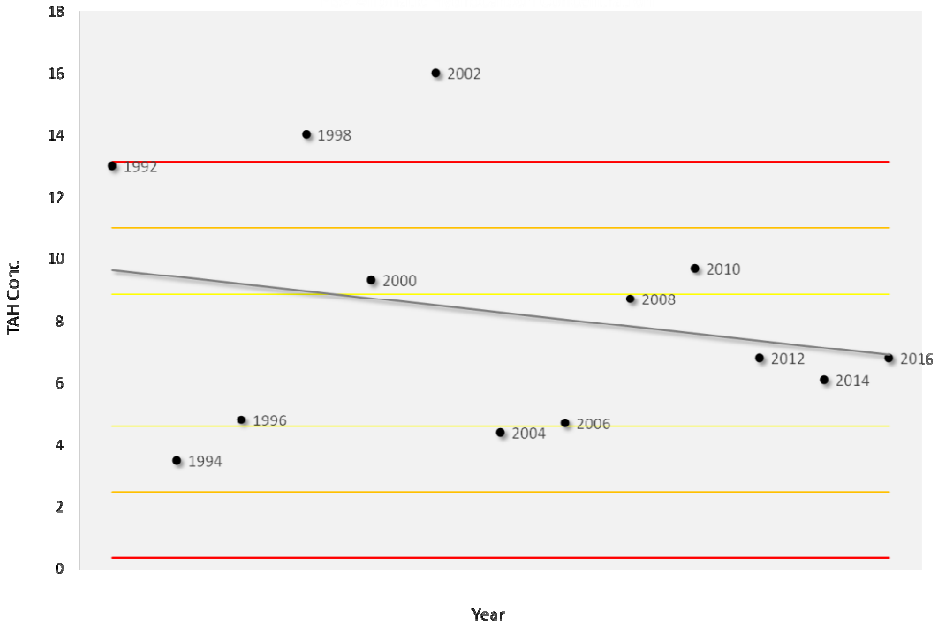

Figure 98 – HS2 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

Figure 99 – HS2 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

4.5.6.3 Houb of Scatsta HS3

The concentration of total aliphatic hydrocarbons (TAH) at Station HS3 is generally low (<20µg.g^{-1}) the 2016 result has not changed significantly against the historic mean. The 2016 result was -0.6 standard deviations from the historic mean. The percentage of UCM in the TAH is historically very varied at this station, with a relative standard deviation of 63% against the historic mean for data 2004-2014. The percentage of UCM in the TAH result for 2016 is a slight change to the historic mean. The 2016 result was +1.0 standard deviations from the historic mean. This is a general trend and the average standard deviation from the historic mean for all stations in 2016 was +2.2.

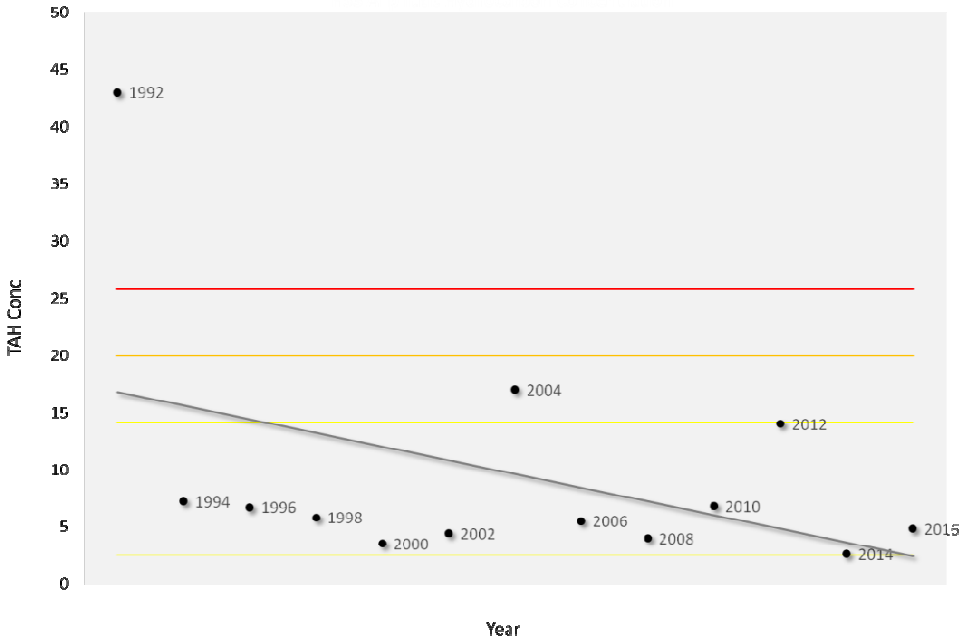

Figure 100 – HS3 Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

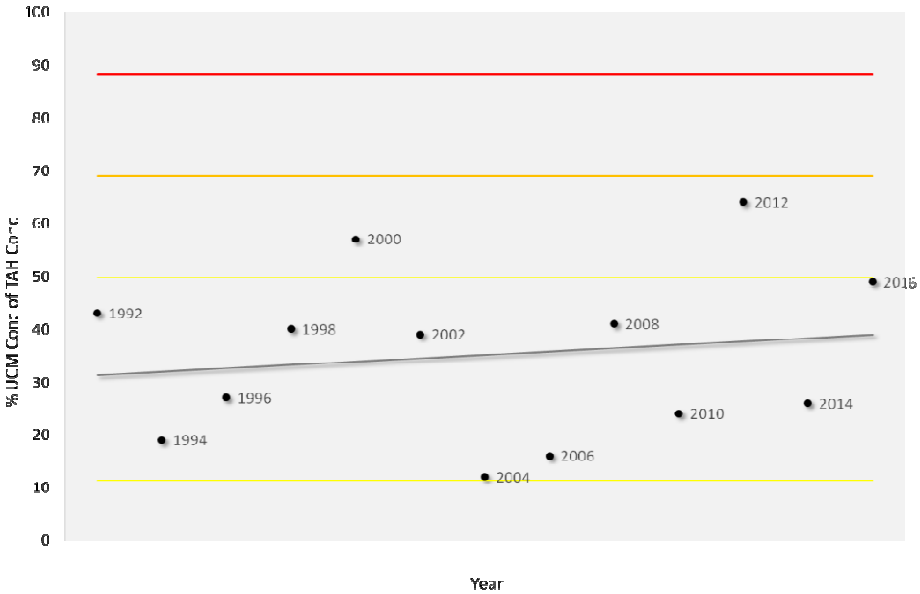

Figure 101 – HS3 Percentage UCM concentration of Total Aliphatic Hydrocarbon concentration (%)

4.5.7 ORKA VOE (STATIONS OV1B TO OV5B)

The coordinates for stations positioned in the Orka Voe area were revised as the original coordinates were within a 200m exclusion zone of pipe line assets. At the new stations OV1B-OV5B, sediment samples were obtained from the grab sampling operations but the amount of sediment retrieved was not sufficient for full quantitative macrobenthic analysis and hence no particle size or TOC analysis was performed. A small amount of sediment was sub-sample for hydrocarbon analysis. The hydrocarbon levels observed were in dynamic contrast to the historic levels as the new coordinates were moved to the edge of the sediment bed, and the hydrocarbon content increased from OV1B towards OV5B, historically the hydrocarbon content has increased from OV5 towards OV1. Given the relocation of the site and the observed difference in the ground at the station no comparison has been made to the historic data. The only site which seemed to correlate with the historic data was OV5B, the 2016 data point have been plotted against the historic data for OV5 below and is for information only.

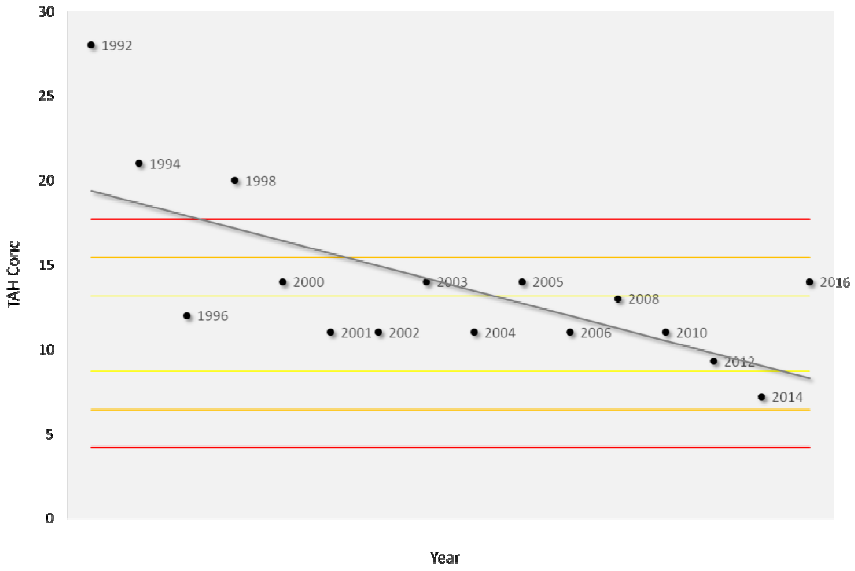

Figure 102 – OV5B Total Aliphatic Hydrocarbon concentration (µg.g-1 dry wt. sed.)

5 CONCLUSIONS

5.1 MACROBENTHIC

Overall the total abundance of macrobenthic organisms sampled during 2016 was less than that recorded in 2014 and 2012 but remained within the range of variability exhibited by the wider dataset. Abundance values were more in line with those recorded in 2002 and 2010 either side of the peak abundance recorded in 2006. Statistical examination revealed that species abundance between the three most recent survey years was not significant though abundance between stations in 2016 was significant.

Quantitative data could not be collected at some stations for infauna and some abiotic variables during the 2016 surveys due to unsuitable seabed substrata at relocated sampling sites. This resulted in a possible under-representation of faunal abundance and diversity as well as a lack of contaminant and sediment data for some stations. Additionally, the data from these seven stations were not directly comparable and this may have influenced the final results.

In line with the findings of the 2012 and 2014 monitoring, some of the most commonly encountered and abundant fauna recorded during 2016 included *Thyasira flexuosa*, *Phoronis muelleri and Prionospio fallax.* The large amounts of *Balanus crenatus* previously observed in 2014 were no longer present in 2016 and had returned to background levels in line with 2012 data.

In comparison with previous years, the values for diversity at most stations were within the range seen since across survey years since 2002. During 2016, diversity was higher than previously recorded in 2012 and 2014 at Stations SV3, SV6, SV9 and SV34. Diversity was also higher than during recent survey years at stations OV1B and OV5B, though values at these stations cannot be directly compared to those recorded in previous years due to

location changes. Diversity was lower than in 2012 and 2014 at several stations but remained generally comparable. 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.

In 2016 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 amount of *Kurtiella bidentata* and *Thyasira* spp. present at numerous stations. Sublittoral cohesive mud and sandy mud (SS.SMu) communities were also present in significant numbers. This is consistent with the findings of previous monitoring and biotope information available for the Sullom Voe area.

SIMPROF analysis using PRIMER v6 found 18 statistically-distinct faunal assemblages and the pattern seen in the MDS ordination was similar to that seen in 2014. The species responsible for the within-group similarity were identified using the SIMPER routine in PRIMER. Five faunal groups were then identified at a broader level using a 40% similarity cut-off on the cluster dendrogram that provided a clearer indication of the geographical distribution of more general faunal assemblages.

PRIMER was also used to relate the abiotic variables to the biotic data to determine the physicochemical variables most responsible for driving the biological patterns. The six variables giving the best correlation were depth, % silt, unresolved complex mixture (UCM), % gravel, total dibenzothiophenes and phi mean. Unlike in previous years where organic content and sediment composition were found to be the most influential drivers, petrogenic elements and depth were shown to be some of the key structuring drivers behind the biological community patterns.

Throughout the faunal analysis a number of rare, alien and protected species were recorded, these included: the sea urchin *Strongylocentrotus droebachienis, the* nationally-rare species *Cylindroporella tubulosa*, the OSPAR-listed species *Arctica islandica, Echinus esculentus,* the IUCN Red-listed sea urchin and the alien species *Mya arenaria*. Though recorded in 2014, the nationally-scarce species *Harpinia laevis* was not observed in 2016.

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

5.2 SEDIMENTS

Overall sediment character was broadly comparable with that found during recent surveys, with the majority of sediments being classified as slightly gravelly muddy sands. However, most of the stations show some variations in the relative proportions of sand, mud or gravel compared with the characteristics noted in 2014.The mud contents of the benthic sediments are noticeably higher at all stations when compared to the 2014 survey and the historic mean result for period 2000-2014. For some stations there are spikes in the historic data and many of the 2016 results correlate with the levels observed in the 2004 survey. The methodology for the particle size analysis and mud content have changed in 2016 to the NMBAQC

protocols and higher levels of mud are likely to be observed due to differences between the gravimetric and volumetric measurements.

The organic matter content of the sediments is generally similar to the 2014 survey, with a mean organic content of 5.0% (5.4% in 2014). As is normally observed, the highest content of organic matter was observed at Station SV1. The methodology for 2016 was the BS 13137 which is a change following the 2014 recommendations.

5.3 HYDROCARBONS

The hydrocarbon analysis was performed at a different SGS laboratory to earlier surveys. Method validation and quality controls were performed and found to be acceptable against the anticipated method performance. The aliphatic hydrocarbon levels in the Sullom Voe sediments range from 1.9 $\mu g.g^{-1}$ to 190 $\mu g.g^{-1}$, which is a comparable range to that seen in 2014. As in the previous surveys (except 2010), the highest level was recorded at Station SV1 in the Inner Basin. The overall observed levels of total aliphatic hydrocarbons in 2016 had changed slightly against the mean result of the historic data from the period 2004-2014, with the exception of Station SV9. The average total aliphatic hydrocarbon result for all stations in 2016 was 33.2 $\mu g.g^{-1}$, the 2014 average result was 31.7 $\mu g.g^{-1}$, and the average historic mean for period 2004-2014 was 34.6 $\mu g.g^{-1}$. Concentrations generally decrease northwards along the main Sullom Voe axis to concentrations similar to open-water North Sea sediments. There is no clear evidence for any fundamental alteration in the distribution of hydrocarbons in the sediments in 2016 compared with the 2014 survey.

The percentage of unresolved complex mixture (UCM) in the total aliphatic hydrocarbon was higher than in previous surveys during 2004-2014 at all stations (except SV9). This increase was on average for all stations equivalent to +2.2 standard deviations from the historic mean for period 2004-2014.The average result for all stations in 2016 was 63.8%, the 2014 average result was 48.0%, and the average historic mean for period 2004-2014 was 51.8%. While the 2016 results show a noticeable difference from the trend for period 2010-2014, the unresolved complex mixture results from 2008 demonstrated a similar positive bias.

The hydrocarbon analysis for the seven stations (SV36B, SV37B and the OV1B-OV5B) which were re-located in 2016, are tabulated in this report but due to significant changes in their position on the sediment bed and to the hydrocarbon content little focus has been given to them.

GC-MS analyses of aromatic hydrocarbons reveal the presence of PAH derived from petrogenic and pyrolytic (combustion) sources in the sediments, although as on previous surveys those from pyrolytic sources predominate (i.e. 4-6 ring PAHs, with parent compounds dominant over the alkylated derivatives). In the seven sediments analysed from unchanged stations, the proportion of 4-6 ring PAHs range from 79-92% of the total PAH, which is similar to level in 2014 which was 80-89%, with the highest value recorded at Station 1. The revised Orka Voe stations demonstrated a lower percentage of 4-6 rings to the total PAH (2016 OV1B 68%, OV5B 70%; 2014 OV1 82% and OV5 87%) The mean concentration of 2-6 ring PAHs has decreased for the unchanged stations from 1530 $ng.g^{-1}$ in 2014 to 1310 $ng.g^{-1}$, however the result is similar to the average for the historic mean for period 2004-2014 which was 1380 $ng.g^{-1}$ Six of the seven unchanged stations have shown increases in the percentage 4-6 ring PAHs of the total PAHs since the last survey; on average this was +1.6 standard deviations from the historic mean for period 2004-2014. These increases are attributable predominantly to increases in 4-6 ring PAH concentrations

(i.e. from pyrolytic rather than petrogenic sources). As in previous surveys, due to the high energy environment and relatively coarse sediments, Stations 34 (140 $ng.g^{-1}$), OV1B (56 $ng.g^{-1}$) and OV5B (280 $ng.g^{-1}$) have much lower concentrations of 2-6 ring PAHs compared to the rest of the stations.

5.4 MAJOR AND TRACE ELEMENT ANALYSIS

No analysis was performed during the 2016 survey and this analysis was last performed during the 2014 survey.

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End of Report