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CORRIB OFFSHORE GAS FIELD DEVELOPMENT

CORRIB FIELD TO LANDFALL PIPELINE ROUTE ENVIRONMENTAL SURVEY 2007

January 2008

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1 Corrib Offshore Pipeline Route Survey

1.1 Introduction

The Corrib Gas Field lies in around 350m of water approximately 65km off the coast of County Mayo. The gas in the Field is to be brought ashore using a 20inch pipeline which will landfall at Dooncarton in Broadhaven Bay. From there the pipeline will be routed to the Terminal at Bellanaboy Bridge. The Plan of Development for the Field was approved in 2002, subject to various conditions. While the drilling of wells has continued since then, there have been a number of issues on the coastal and onshore sections of the project, and installation of the pipeline between the Field and Terminal has been delayed as a result.

In 2000, as part of the baseline survey work for the Offshore EIS for the Corrib Development, which was submitted in 2001, a survey of the sediments along the proposed offshore pipeline route and a number of locations within the Corrib Field itself was undertaken. Twelve locations along the selected pipeline route were surveyed at that time, with a number of other stations being located on an alternative route which was being considered (a more northerly approach into Broadhaven Bay).

Shell Exploration and Production Ireland Ltd (SEPIL), who are now the operators of the Corrib Gas Field, commissioned a second baseline survey of the offshore pipeline route, with the aim of updating the information collected during the 2000 survey. Permission to construct the gas pipeline from the Corrib Field to the Terminal was granted under S40 of the Gas Act. However, due to local onshore objections to the route, SEPIL are in the process of submitting another Gas Act application for a revised onshore route. The Gas Act submission will include the whole of the pipeline route, and while the offshore section of the route has not changed since the application was made in 2001, the new application for the whole route will need to include the offshore section. SEPIL have committed to providing updated information to DCENR for the pipeline route, and the 2007 survey was part of the commitment to collect additional data.

1.2 2007 Survey Objectives

This report presents the findings of the 2007 survey of the sediments along the offshore section of the Corrib Pipeline Route. Given the depth of water along the offshore sections of the pipeline route, it was anticipated that the results of the 2007 survey would be similar to those collected in 2000.

The survey plan for 2007 was to revisit the 12 locations along the route which were sampled in 2000, using basically the same sampling techniques as those used previously such that the data generated would be comparable. In addition to repeating the physical sediment sampling, in 2007 seabed photography was also undertaken as the pipeline route stations.

2 Survey Organisation and Methods

2.1 Survey Team

SEPIL contracted Osiris Projects to provide a vessel and crew to undertake the offshore survey work, providing accurate navigational services. RSK provided the scientific crew for the survey, together with the majority of the survey equipment.

2.2 Survey Vessel

Sampling operations were carried out from the jointly operated University of Wales, Bangor/Vosper Thorneycroft–Ocean Sciences, research vessel; *R/V Prince Madog*. The *Prince Madog* (Figure 1) is a 34 metre dedicated research vessel, licensed for survey operations in waters of the continental shelf, as far as the shelf break. The Prince Madog's home port is Menai Bridge, northWales.

Figure 1: R/V Prince Madog

2.3 Survey Dates

Mobilisation of the Prince Madog commenced on 28th July, continuing on 29th, with the vessel leaving her berth in Menai Bridge later that day. Transit time from Menai Bridge to Killybegs was 1.5 days. The Prince Madog was then effectively based out of Killybegs for the duration of the survey period.

The survey was forced on several occasions to break due to poor weather conditions. The first survey operations carried out were 31st July, and the remainder of the programme was determined by weather and sea conditions, with the objective being to collect as many samples as possible from the pipeline route, the vicinity of the outfall pipeline and the Corrib Field itself. Results from the Corrib Field and the outfall

location are not further discussed in this report. Final sampling along the pipeline route was completed on 8th August.

2.4 Survey Operations

During the survey operations along the pipeline route the scientific crew aboard worked according to two 12-hour watches, to enable sampling operations to continue over 24 hours. Each watch comprised three scientists with a dedicated shift leader.

2.5 Survey Navigation

Osiris Projects provided survey navigation sevices. The following equipment was mobilised aboard the vessel for the survey:

- CSi dGPS max receiver
- High specification navigation PC supporting Quincy V8 (spare PC)
- TSS Meridian Gyro
- Simrad HPR 400 subsea positioning system over-the-side mount
- Simrad 60 series single beam echo sounder.

The vessel's existing Trimble dGPS was used as a secondary navigation system. The survey was undertaken in WGS84 and recorded with both UTM Grid and geographical positions. The target accuracy for the survey was 30m (benthic samples), although the sea conditions often made achieving this target extremely difficult.

2.6 Sampling Methods

Survey operations along the pipeline route consisted of the sampling of the seabed sediments and seabed photography, using a combined Sediment Profile Imagery (SPI) camera and vertical drop down camera. A total of 12 locations along the pipeline route were targeted for sediment grab sampling, and the same locations were also targeted for seabed photography. The locations selected had previously been visited in 2000 as part of the Corrib baseline surveys which were reported in the 2001 Corrib Offshore EIS. Figure 2 shows the locations along the pipeline route at which seabed sampling operations were carried out.

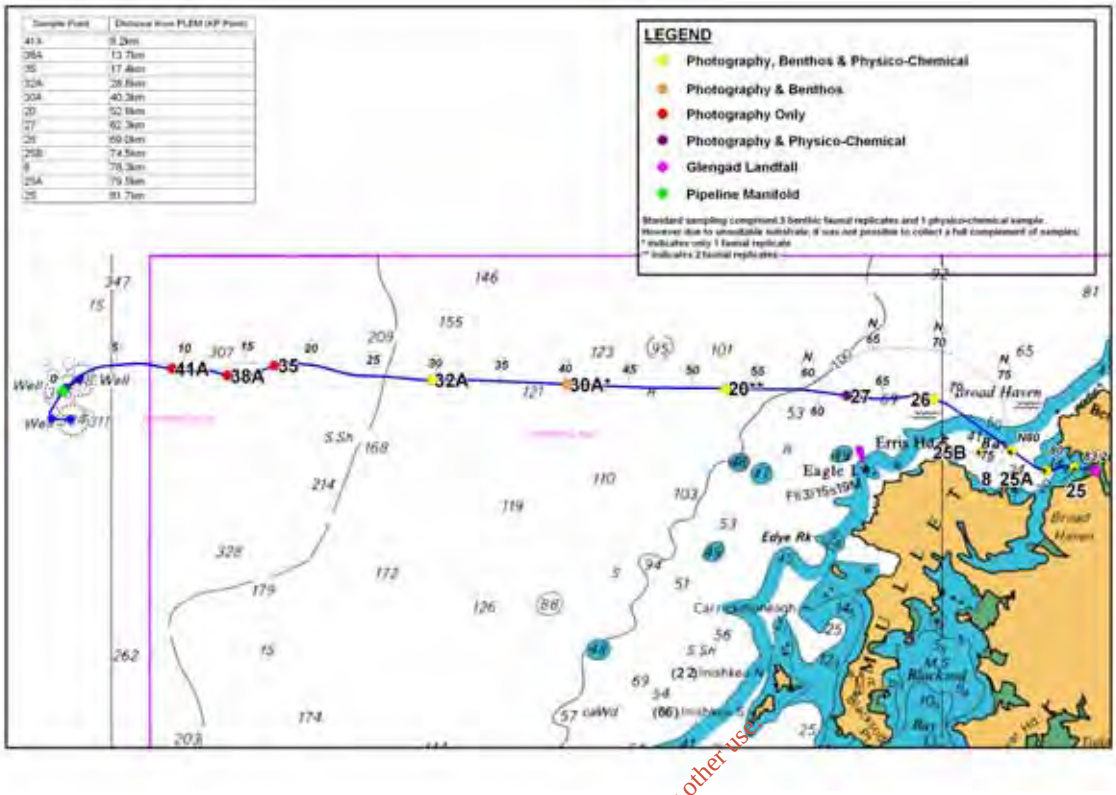

Figure 2: Locations for seabed sediment, benthos sampling and seabed photography

2.6.1 Sampling of Seabed Sediment

At each station 4 replicate samples were to be taken, 3 were retained directly for macrofaunal analysis the fourth was sub sampled for physico-chemical analysis. A double Van-Veen grab (Figure 3) was provided for sediment collection, each bucket sampling an area of 0.1m^2. A Day grab was also provided as back up, this device sampled 0.1m^2 in a single bucket. The intention was to use the Van-Veen where possible, to reduce the number of grab deployments necessary per station.

At some of the stations furthest offshore neither the Van-Veen nor the Day grab were able to collect a satisfactory sample (due to a combination of factors; water depth, nature of the seabed sediments and weight of the grab). A decision was taken to provide a Hamon grab as a further sediment sampling device, and this was transported from Galway to Killybegs where it was loaded onto the Prince Madog. Due to the size of the Hamon grab, good survey conditions would be required for deployment.

In addition to the above, the following additional information was recorded following the recovery of each grab:

- Position in UTM co-ordinates
- Date
- Time
- Water depth
- A visual inspection noting sediment type, colour, smell, vertical layering, clearly defined RDL (Redox Discontinuity Layer) with depth and biological comments.

- A digital surface photograph of the sample in the grab was taken (minimum of 1 photo per site).
- A measurement of REDOX was taken at 1, 5 and 10cm (minimum one grab per site) where sufficient sediment sample was obtained. Depths were adjusted depending on sample size.
- The volume of sediment was recorded (this was carried out in-situ by measuring the depth of sediment in the centre of the grab).

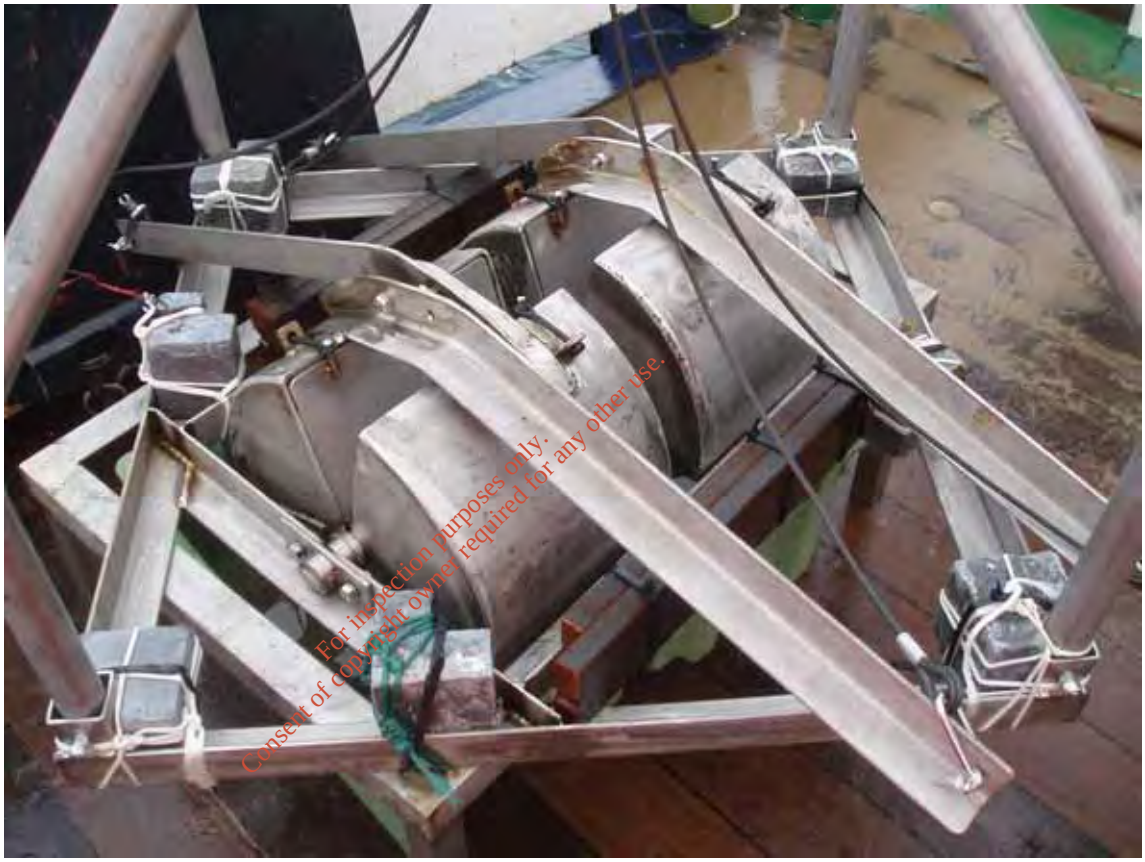

Figure 3: Photograph of double Van-Veen grab in "set" position

2.6.2 Seabed Photography

Seabed photographs were to be taken at the 12 benthic sampling locations. The camera equipment used was basically a Sediment Profile Imagery (SPI) still camera, which also had an attached drop-down still camera. As the camera approached the seabed, a weight would first contact the seabed, triggering the drop-down camera to take a photograph of the seabed just before the main body of the camera equipment came into contact with it. When the full weight of the camera equipment came into contact with the seabed and its weight came off the cable the SPI camera was triggered. The SPI component slid under its own weight until it had penetrated into the sediment, whereupon it would take a photo of the top few centimetres of the seabed sediments in profile. The camera equipment was then raised from the seabed before further replicate photographs at the location were taken. A total of 4 replicates were taken at each sampling location. Between each sampling location the equipment was returned

to the deck of the vessel and the digital photographs downloaded to a computer. Figure 4 shows the SPI camera used during the survey being deployed over the stern of the vessel.

Figure 4: Deployment of the SPI camera equipment

At each photographic location a log sheet was filled in with information regarding:

- Location (in +UTM coordinates)
- Time
- Water depth
- Number of replicates

2.7 Sample Processing

Macrofaunal Samples

The 3 samples retained for macrofaunal analysis were sieved aboard the vessel using a Wilson Autosiever. This equipment sieves macrofaunal samples gently using a regulated curtain of seawater. The samples were sieved through a mesh of 500 µm. The retained material was transferred into appropriate containers for preservation and storage on board the vessel. Samples were preserved using a solution of 10-20% buffered formaldehyde in seawater. The samples were then stored securely aboard the

vessel at ambient temperature. A range of sizes of containers was used for the storage of macrofaunal samples, the size being dependent on the degree of reduction of the samples when sieved. An internal identification tag was placed inside the sample container, and an additional I.D label fixed to the outside. At the end of the survey the samples were transferred according to Chain-of-Custody procedures to the analytical laboratory (Hebog Environmental Ltd) for identification and enumeration analysis.

Physico-chemical Samples

The fourth replicate collected for physico-chemical analysis was sub sampled as follows:

- Two replicates were taken for analysis of organic chemistry, sub sampled into two acid washed 300ml aluminium tins. These samples were taken directly into the tins from the top surface of the sediment in the grab, without using other sampling implements. The containers had an identifying label fixed to the outside.

- Two replicates were taken for particle size analysis. These sub samples were taken from the top 5cm of the sediment in the grab sampler using a disposable plastic spoon and stored in a small polythene Ziploc bag. The samples were then double bagged and an internal identification tag put between the two bags.

- A single replicate was taken for analysis of inorganic chemistry (trace metals and TOC). The sample was taken from the surface of the sediment in the grab using a disposable plastic spoon and stored in a 500 ml plastic tub. An identification label was fixed to the outside of the container.

- A single additional replicate was taken as separate sample for the analysis of mercury. This sample followed the same procedure as that of the inorganic chemistry sample.

All physico-chemical samples were taken by the same surveyor on each watch, who wore a pair of nitrile gloves (disposed of after each station, to avoid cross contamination). A new disposable plastic spoon was used for each sub sample, with the exception of the organic chemistry.

All samples were taken from sediment that had not been in contact with the metal of the grab sampler. Between each deployment the grab sampler was thoroughly rinsed and scrubbed clean to limit cross contamination between sampling locations.

All samples taken from the fourth grab replicate were frozen immediately following their processing. At the end of the survey the samples were transferred to cold boxes containing ice packs. These samples were then transferred under Chain-of-Custody procedures to the various analytical laboratories.

The grain size, total organic carbon and metal analyses were were undertaken by the UK Environment Agency Laboratory in Llanelli using UKAS or MCerts accredited methods. Sample analysis for organic compounds was undertaken by M-Scan Ltd, via a subcontract through Benthic Solutions Ltd.

3 Operations

In some areas the sediments were of a nature that prevented the Van-Veen grab penetrating sufficiently, and in these instances it was necessary to use an alternative grab sampler. Therefore at some locations along the proposed pipeline route the seabed sediments were sampled using a 0.1m^2 Day grab.

There were also some locations along the route where repeated attempts using both the Van Veen and the Day grab failed to collect sufficient samples. The decision to provide a Hamon grab as an alternative it described above. Unfortunately, following the loading of the Hamon grab onto the survey vessel, weather and sea conditions were such that it was not possible to safely deploy it.

There were no issues with the operation or success of collection of photographic images of either the surface or profiles of the seabed.

4 RESULTS

4.1 Physical Data

Results from the grain size analysis of samples taken along the pipeline route are provided in Table 1. It can be seen that sand is the predominant fraction present, with some gravel present at three sites (26, 27 and 32A). Percentages present in all fractions sampled are presented in Appendix A.

Site 30a was sampled, however only one sample was retrieved, and this was used for faunal taxonomy, therefore no physical or chemical data are available for that site. However, observations from the faunal taxonomists stated that the macrofaunal sample from site 30a contained large pebbles.

Table 1: Grain size data summary

Sample	%			Median Grain Size (mm)	Mean Grain Size (mm)	Sediment Description (Udden Wentworth)	Total Organic Carbon (%)
	Gravel	Sand	Mud				
26	23.1	76.9	0	1.416	1.542	Very Coarse Sand	5.9
27	5	95	0	0.301	0.399	Medium Sand	0.22
20	0	100	0	0.209	0.247	Fine Sand	0.3
32A	20.9	79.1	0	1.419	1.686	Very Coarse Sand	0.36
25A	0	100	0	0.207	0.251	Medium Sand	0.44
25	0	100	0	0.235	0.282	Medium Sand	0.33
08	0	100	0	0.182	0.193	Fine Sand	0.23
25B	0	100	0	0.195	0.224	Fine Sand	0.36

The results presented above are broadly as expected based on the previous results from the 2000 survey, and accord with the seabed photography taken along the route (see Section 4.4).

Total organic carbon levels are generally low, as would be expected in sediments where there are very low levels of fine material (mud). It would appear from Table 1 that site 26 has mixed characteristics, with very coarse sand, and the highest levels of organic material present. The seabed photography undertaken at site 26 shows that the site has very coarse grained material, with some small patches of what appears to be mud – although that finer material was not recorded from the grain size analysis.

4.2 Chemical Data

4.2.1 Metals

Concentrations of a range of metals were measured in the sediments collected from the pipeline route. The results of these analyses are presented in Table 2.

Table 2: Results for metals in sediments along the pipeline route (**All results expressed as mg/kg dry weight)**

Station	Hg	Cd	Cr	Pb	As	Zn	Ba	Ni	Cu
26	<0.10	0.32	10.5	7.9	12.7	10.2	11.0	3.76	1.36
27	<0.10	0.094	15.3	9.2	8.5	11.9	0.67	1.51	0.54
20	<0.10	0.111	26.0	11.1	7.0	21.9	2.20	4.43	1.53
32A	<0.10	0.116	23.4	11.9	9.4	13.1	2.17	2.49	0.73
25A	<0.10	0.127	11.2	8.9	2.9	25.2	11.0	2.75	1.87
25	<0.10	0.160	12.0	8.5	2.4	21.0	7.83	2.19	0.85
08	<0.10	0.338	39.2	10.9	2.5	38.6	5.73	3.29	0.60
25B	<0.10	0.114	13.3	8.9	3.0	15.5	6.60	2.23	0.77

To put these results into context, Table 3 presents a comparison of the range of concentrations found along the Corrib pipeline with OSPAR and Environment Canada guidelines. The 2007 results are then further compared with data from other locations around Ireland and Britain (Table 4)**.**
Not surprisingly the data reflect conditions as would be expected for a site with little or no anthropogenic impact, and low levels of fine material, with which many metals are generally associated.

Specific determinands

Mercury

All reported values are below the Minimum Reporting Value (MRV) – 0.10 mg/kg.

Cadmium

Although the concentrations do not appear to be anthropogenically impacted, the range 0.094 - 0.32 mg/kg is somewhat higher than for sediments from the central North Sea that has reported values as low as 0.01 mg/kg and a mean of 0.050 mg/kg (OSPAR, 2003). The observed range brackets the OAPAR Background Concentration (BC) (0.2 mg/kg) and is well below levels anticipated to give rise to any biological effect.

Chromium

The results (11.2 – 39.2 mg/kg) are consistent with the low end of the ranges reported by Taylor (1986) and Nixon (1995) for the Dee estuary, Liverpool Bay and the Cumbria coast and lower than sediments collected off the west coast of Scotland. All results are below the accepted BC by a factor of at least two.

Lead

Most values were <10 mg/kg, and are generally lower than published values for other sea areas and apparently lower than the BC by a factor of two.

Arsenic

Concentrations were typically <5 mg/kg with a few stations exceeding 10 mg/kg, reflecting a situation similar to the central North Sea (OSPAR, 2003), with both data sets consistent with the BC of 15 mg/kg. Arsenic levels are known to be naturally elevated in Donegal Bay, and the levels recorded during the present survey are not unexpected.

Zinc

With the exception of Station 08 (38.6 mg/kg) most values were <20 mg/kg similar to the lowest reported findings for Liverpool Bay (that receives contaminated run-off from the Mersey and was formerly a site for sea disposal of sewage sludge and dredging spoil) and the North Sea. The data are well below the accepted BC (90 mg/kg).

Barium

Data for other sea areas are sparse making comparisons difficult. The observed range (0.67 – 11.0 mg/kg) was much lower than that recorded off the UK Fylde coast (Gateway Gas Storage Project EIA) which are in the range 220-310 mg/kg, possibly as a consequence of drilling operations.

Nickel

The results (1.51 – 4.43 mg/kg) are consistent with the low end of the ranges reported for apparently non-impacted locations. All values are significantly lower than the BC (30 mg/kg).

Copper

The results fell into the range <1 to ca. 2 mg/kg. Again these findings are in accord with the lowest values reported by other workers and are below the BC (20 mg/kg).

Table 3: Observed range along the proposed Corrib Pipeline route and guideline concentrations

Metal mg/kg	Corrib Pipeline range	OSPAR BC*	OSPAR EAC lower limit	OSPAR EAC upper limit	Environment Canada TEL	Environment Canada PEL
Hg	<0.10	0.05	0.05	0.50	0.13	0.70
Cd	0.094-0.32	0.2	0.10	1.00	0.676	4.21
Cr	11.2-39.2	60	5.00	50.00	52.3	160
Pb	7.9-11.9	25	5.00	50.00	30.3	112
As	<1.0-12.7	15	1.00	10.00	7.24	41.6
Zn	10.2-38.6	90	10.00	100.00	124	271
Ba	0.67-11.0		-	-	-	-
Ni	1.51-4.43	30	5.00	50.00	15.9	42.8
Cu	0.54-1.87	20	5.00	50.00	18.7	108

Note: *BC Background Concentration. OSPAR Agreement 2005-6. – formerly termed Background Reference Concentration (BRC)
TEL – Threshold Effects Limit
PEL – Probably Effects Limit

Table 4: Comparison with published data for UK and Irish coastal waters

Author(s)	Locality	Hg	Cd	Cr	Pb	As	Zn	Ba	Ni	Cu
Corrib 2007	**Pipeline route**	<0.10	0.094-0.32	11.2-39.2	7.9-11.9	<1.0-12.7	10.2-38.6	0.67-11.0	1.51-4.43	0.54-1.87
Taylor, 1986	**Urr Water**	0.03-0.17	0.8-1.3	3.8-7.5	11.5-34.1	No data	24.8-65.0	No data	6.1-14.3	1.9-12.1
	Dee	0.02-1.0	0.1-1.2	2.9-66.2	6.0-15.2	No data	27.6-3480	No data	3.0-34.9	0.9-56.8
	Liverpool Bay	0.01-1.44	0.3-2.1	0.5-35.9	6.9-101	No data	9.4-327	No data	1.2-16.5	1.8-33.7
Nixon, 1995	**Cumbria Coast**	0.005-0.17	0.007-0.46	10.7-85.8	10.3-69.7	No data	22.4-129.4	No data	No data	1.8-49.4
FRS & SEPA 1998	**Scottish waters Minches**	0.05	0.018	57	24	4.3	45	No data	6.4	7.3
NSTF, 1993	**North Sea**	75% of samples <0.025	0,010-0.38 mean 0.050	No data	1.7-288 mean 21	1.2-33 mean 11	3-510 mean 39	No data	1.5-113 mean 23	0.1-87 mean 14

Quality Control

A Certified Reference Material (CRM) was provided to the Environment Agency laboratory with the offshore pipeline route samples. The CRM contained document levels of various trace metals, and was analysed at the same time as the field samples. The results from the analysis of the CRM, together with the documented levels from the material are presented in was analysed concurrently with the material collected on site. The data are presented in Table 5, the similarity between the results obtained and the certified levels show that we can be confident in the results reported from the pipeline route samples.

Table 5: Analyses of Certified Reference Materials (supplied by National Research Council Canada)

Sediment (MESS-3) mg/kg		
Metal	**EA data**	**Reference value**
As	19.3	21.2
Cd	0.325	0.24
Cr	86.3	105
Cu		33.9
Pb	21.5	21.1
Ni	36.6	46.9
Zn	134	159
Ba	8.53	-
Al	43400	-
Ag	<10	0.18

Hg	0.0079	0.091

4.2.2 Hydrocarbons

Total Organic Extracts (TOE)

As in previous surveys carried out in the Corrib Field since 1997, the total organic extracts were analysed to detect any saturate hydrocarbons (including anthropogenic hydrocarbons such as drilling related base-oils) that may be present in the sediment. The concentrations of TOE have been calculated from the GC analyses and are shown in Table 6**.** TOE concentrations ranged from 4.7 to 10 µg/g. Concentrations of TOE in these samples are considered consistent with 'background' levels as previously seen in the offshore Corrib Field (Benthic Solutions Limited, 2006). Benthic Solutions Limited were responsible for analysis and reporting of the organics data for the current project, and their complete report is attached as Appendix B to this report. References to appendices in the following paragraphs relate to the appendices to the Benthic Solutions Report.

Comparison with similar data, from surveys in the North Sea Oil and Gas fields (including both baseline studies and reference background stations from around fields where drilling operations have taken place) suggests that the background concentration of total hydrocarbons typically ranges between 1-10ppm. This agrees with data from the North Sea Task Force (NSTF 1993), and Law (Law *et al*., 1982), although other studies have shown higher concentrations (e.g. McIntosh *et al*., 1983; 10-60ppm in sediments between the Firth of Forth and the Forties field).

Apart from the internal standards, the GC traces show clear evidence of the presence of a number of resolved peaks. The TOE of sample S2 (one of the sites around the proposed outfall) was further analysed by GC-MS to characterise these components. They include a range of fatty acids (dominated by C_{14} (myristic), C_{16} (palmitic) and C_{18} (stearic) acids), sterols, long chain alcohols and long-chain (C_{39-42}) ketones, which have been previously identified in the North Sea sediments and in the marine coccolithophore *Emiliana huxleyi.* These are all considered to be of biogenic rather than petrogenic origin, and confirm a very low level of petrogenic contamination within the sediments.

The GC traces preclude the presence of the three synthetic base oils previously identified in the Corrib field development ("Ecosol", "Ecomul" and "Esterkleen"). The base oil "Ecomul" comprises almost entirely of paraffins, while "Esterkleen" is based upon 45-70% 2-ethyl-hexyloleate. The base oil "Ecosol" is 60% paraffins, 20% poly-alpha olefins and 20% linear alpha olefins. For comparison a GC trace of the "Ecosol" base oil from previous analyses is included as *Appendix 1*. This base oil was spiked into a portion of the sample from Station 25 at 52.7ppm; this was extracted and analysed in parallel with the other samples, and the trace is shown as *Figure 22 (Appendix II)*. The measured concentration of the base oil in the extracted sediment was 49.9ppm.

There was also no evidence in the sediments for the presence of base oils of mineral origin (e.g. "low-tox" or diesel).
A portion of pre-extracted sediment was utilised as a "trip" blank. This sediment was extracted and the data included for comparison with a portion of pre-extracted sediment retained within the laboratory. The chromatograph for trip blank sample showed evidence for a series of resolved peaks between 22-30 minutes, and a narrow-range UCM (unresolved complex mixture) between 30-34 minutes. Inspection of the GC-MS data of the aromatic fraction for this sample indicates that the UCM comprises mixed long-chain phthalates, which are widely used as plasticisers. The

source of this contamination is unclear. However, these components were not detected in the sediments analysed, and so they are not considered significant in this context.

Table 6: Concentrations of Total Organic Extractables (TOE)

Station	TOE (µg/g; ppm)
08	7.0
20	4.7
25	5.8
25A	6.7
25B	8.6(13)
26	10
27	6.5
32A	10

Polycyclic Aromatic Hydrocarbons (PAHs)

Concentrations of PAHs in the sediments are given in Table 7**,** and includes naphthalenes, phenanthrenes and dibenzothiophenes (NPD) and the sixteen priority PAHs defined by the US EPA.

Polyaromatic hydrocarbons and their alkyl derivatives have been recorded in a wide range of marine sediments (Laflamme & Hites, 1978) with the majority of compounds produced from what is thought to be pyrolytic sources. These are the combustion of organic material such as forest fires (Youngblood & Blumer, 1975), the burning of fossil fuels and, in the case of offshore oilfields, flare stacks, etc. The resulting PAHs, rich in the heavier weight 4-6 ring aromatics, are normally transported to the sediments via atmospheric fallout or river runoff. Another PAH source is petroleum hydrocarbons, often associated with localised drilling activities. These are rich in the lighter, more volatile 2 and 3 ring PAHs (NPD; naphthalene (128), phenanthrene, anthracene (178) and dibenzothiophene (DBT) with their alkyl derivatives).

The concentrations of NPD (Table 7) range from 0.03ng/g (ppb; Station 26) to 1.4ng/g (Station 32A). The concentrations of NPD in these samples are considered consistent with 'background' levels previously seen in the sediments around the Corrib field development (Benthic Solutions Limited, 2006), which are generally similar to the background levels observed in the North Sea (Davies *et al*., 1984).

The concentrations of the EPA 16 PAHs **(**Table 7**)** range from 0.40ng/g (Station 25) to 2.8ng/g (Station 32A). These values, again, are generally similar to those observed in the 'background' levels previously seen around the Corrib field development (Benthic Solutions Limited 2006), and are also generally similar to the background levels observed in North Atlantic sediments. Data from surveys around North Sea fields and the North Atlantic suggest that the background concentrations of the EPA16 PAH concentrations typically range up to 50ng/g, whilst NPDs are typically in the region of 10ng/g.

Table 7: Concentrations of 2-6 ring Polycyclic Aromatic Hydrocarbon (ng/g (ppb); dry weight basis)

Station No.	**8**	**20**	**25**	**26**	**25A**	**25B**	**27**	**32A**
Naphthalene	nd	0.02	0.06	Nd	0.08	Nd	0.52	0.43
C1-Naphthalenes	nd	Nd	0.04	Nd	nd	Nd	0.31	nd
C2- Naphthalenes	nd	Nd	nd	Nd	0.95	Nd	Nd	0.95
C3- Naphthalenes	nd	1.2	nd	Nd	nd	Nd	Nd	nd
C4- Naphthalenes	nd	Nd	nd	Nd	nd	Nd	Nd	nd
Total Naphthalenes	nd	1.2	0.10	Nd	1.0	Nd	0.83	1.4
Phenanthrene	nd	0.06	0.09	0.03	0.01	Nd	0.07	0.03
C1-Phenanthrenes	nd	Nd	nd	Nd	nd	Nd	Nd	nd
C2- Phenanthrenes	nd	Nd	nd	Nd	nd	Nd	Nd	nd
C3- Phenanthrenes	nd	Nd	nd	Nd	nd	Nd	Nd	nd
Total Phenanthrenes	nd	0.06	0.09	0.03	0.01	Nd	0.07	0.03
Dibenzothiophene	nd	Nd	nd	Nd	nd	nd	Nd	nd
C1-Dibenzothiophenes	nd	Nd	nd	Nd	nd	nd	Nd	nd
C2-Dibenzothiophenes	nd	Nd	nd	Nd	nd	nd	Nd	nd
C3-Dibenzothiophenes	nd	Nd	nd	Nd	nd	nd	Nd	nd
Total DBT	nd	Nd	nd	Nd	nd	nd	Nd	nd
Total NPD	nd	1.3	0.19	0.03	1.0	nd	0.90	1.4
Acenaphthylene	nd	Nd	nd	nd	nd	nd	Nd	nd
Acenaphthene	nd	Nd	nd	Nd	nd	nd	Nd	nd
Fluorene	nd	Nd	nd	Nd	nd	nd	Nd	nd
Anthracene	nd	Nd	nd	Nd	nd	nd	Nd	nd
Fluoranthene	0.08	0.16	0.08	0.17	0.07	0.10	0.12	0.17
Pyrene	nd	Nd	nd	0.13	0.05	0.05	0.09	0.10
C_1-Fluoranthenes/Pyrenes	nd	Nd	nd	Nd	nd	nd	Nd	nd
C_2-Fluoranthenes/Pyrenes	nd	Nd	nd	Nd	nd	nd	Nd	nd
C_3-Fluoranthenes/Pyrenes	nd	Nd	nd	Nd	nd	nd	Nd	nd
Benzo(a)anthracene	nd	0.05	0.04	0.11	0.03	nd	0.08	0.05
Chrysene	nd	0.09	0.07	0.11	0.05	nd	0.06	0.08
C_1-Benanthracenes/Chrysenes	nd	Nd	nd	Nd	nd	nd	Nd	nd
C_2- Benanthracenes/Chrysenes	nd	Nd	nd	Nd	nd	nd	Nd	nd
Benzo(b)fluoranthene	0.01	0.11	nd	0.37	0.13	0.17	0.22	0.64
Benzo(k)fluoranthene	0.14	0.24	nd	0.12	0.04	0.08	0.08	0.15
Benzo(a)pyrene	nd	0.07	nd	0.12	0.06	0.06	0.09	0.10
C_1-Benzofluoranthenes/Benzpyrenes	nd	Nd	nd	Nd	nd	nd	Nd	nd
C_2- Benzofluoranthenes/Benzpyrenes	nd	Nd	nd	Nd	nd	nd	Nd	nd
Indeno(1,2,3-cd)pyrene	0.12	0.33	nd	0.30	0.21	0.17	0.24	0.58
Dibenzo(a,h)anthracene	nd	0.10	nd	0.03	0.03	nd	Nd	0.07
Benzo(ghi)perylene	0.11	0.25	nd	0.24	0.15	0.18	0.18	0.38
Total EPA 16	0.46	1.5	0.40	1.7	0.91	0.80	1.8	2.8
4-6 Ring PAH/NPD	-	1.15	2.11	56.67	0.91	-	2.00	2.00

The above findings are generally lower than the levels quoted by OSPAR as background concentrations (OSPAR 2005-6) (Table 8).

Table 8: OSPAR BCs and provisional BACs for PAHs in sediments – OSPAR 2005 –6

PAH	Sediment (µg kg^{-1} dry weight normalised to 2,5% organic carbon)		Corrib Pipeline route ranges
	BC	*BAC*	
Naphthalene	5	8	Nd – 0.52
Phenanthrene	17	32	Nd – 0.09
Anthracene	3	5	Nd
Fluoranthene	20	39	0.07 – 0.17
Pyrene	13	24	Nd – 0.13
Benzo[*a*]anthracene	9	16	Nd – 0.11
Chrysene	11	20	Nd – 0.11
Benoz[*a*]pyrene	15	30	Nd – 0.12
Benzo[*ghi*]perylene	45	80	Nd – 0.38
Indeno[123-*cd*]pyrene	50	103	Nd – 0.58

4.3 Biological Data

4.3.1 Univariate analysis

A number of common ecological indices were calculated for the per replicate and pooled replicate (per site) data. These summarise, by means of a single number, information about some aspect of community structure.

Species numbers and abundances for macrofauna are shown on a per replicate (Table 9) and per site (Table 10) basis. Percentage of each phylum that makes up the community at each site is also shown in Table 10. Species that are encrusting and/or colonial are included in the number of species per replicate and site but were excluded from abundance counts.

Table 9: Univariate Indices by replicate for sample sites on the Corrib pipeline route

Station	No. species (including encrusting species)	No. individuals	Pielou's Evenness	Shannon-Weiner Diversity (log_e)	Simpson's Dominance index
8-A	60	470	0.79	3.23	0.06
8-B	51	339	0.83	3.25	0.06
8-C	55	378	0.79	3.17	0.07
20-A	57	197	0.87	3.52	0.05
20-B	58	211	0.90	3.62	0.03
25-A	26	230	0.65	2.13	0.17
25-B	28	283	0.62	2.05	0.20
25-C	24	257	0.64	2.04	0.19
25a-A	35	437	0.52	1.85	0.35
25a-B	42	592	0.49	1.81	0.40

Station	No. species (including encrusting species)	No. individuals	Pielou's Evenness	Shannon-Weiner Diversity (log_e)	Simpson's Dominance index
25a-C	46	607	0.57	2.18	0.28
25b-A	62	389	0.84	3.48	0.05
25b-B	50	304	0.82	3.19	0.06
25b-C	49	250	0.85	3.30	0.06
26-A	58	739	0.61	2.46	0.22
26-B	55	648	0.62	2.46	0.20
26-C	74	722	0.72	3.11	0.09
30a-A	31	28	0.92	2.56	0.06
32a-A	85	1451	0.33	1.45	0.58
32a-B	86	1503	0.39	1.75	0.49
32a-C	121	2243	0.28	1.35	0.64

Species numbers and abundances were high at the majority of sites. Per site, the number of species ranged from 24 to 121 per $0.1m^2$, whilst abundances ranged from 23 to 2243 individuals per $0.1m^2$.

Table 10: Univariate Indices (abundances were used to calculate the percentage of each phyla at each site except for site 30a where species numbers were used)

						% of each phyla				
Station	S	N	J'	H'	λ	Annelida	Crust	Mollusca	Echino	Other
8	84	396	0.75	3.32	0.06	32.18	29.65	14.91	4.97	18.28
20	83	204	0.86	3.78	0.04	64.95	21.32	4.66	3.92	5.15
25	44	257	0.57	2.16	0.18	34.29	62.99	0.65	1.30	0.78
25a	61	545	0.50	2.05	0.33	10.27	84.60	1.83	1.90	1.41
25b	84	314	0.80	3.53	0.05	33.62	33.83	13.68	8.06	10.82
26	103	703	0.61	2.82	0.16	53.11	4.74	2.70	2.70	36.75
30a	31	28	0.92	2.56	0.06	19.35	9.68	16.13	3.23	51.61
32	148	1732	0.31	1.55	0.58	91.09	3.21	1.31	2.46	1.92

S = Number of species (including encrusting species)
N = Number of individuals
J' = Pielou's Evenness
H'= Shannon-Weiner Diversity (log_e)
λ = Simpson's Dominance index

Diversity was moderate to high at all sites, ranging from 1.34 at site 32a-C to 3.62 at site 20-B. Diversity at site 32a was the lowest due to the high numerical dominance of the polychaete *Galathowenia oculata* as reflected in the low evenness and relatively high dominance values for this site.

Dominance by a single or small group of species was low throughout the rest of the dataset with values for Pielou's evenness being approximately 0.5 or more and all dominance scores being less that 0.5.

Ranked taxa showing the 10 most abundant species at each site are shown in Table 11. This indicates that Annelida or Crustacea generally dominate the communities at the sites in the sampling area. Site 30a was an exception, in that Bryozoa were a dominant component of the community.

Numerically, the most dominant animal was the tube-dwelling polychaete *Galathowenia oculata*, but this was due to its extremely high numbers at site 32 and it was found to be rare or absent at other sites. With the exception of site 30a, which was generally composed of encrusting organisms, and site 26 which was dominated by nematodes, the interstitial polychaete *Polygordius* and the polychaete *Pisione remota*, most organisms recorded were characteristic of sandy environments. Common to these environments and recorded throughout the dataset were the polychaetes *Chaetozone christiei* and taxa from the family Spionidae, particularly the genus *Spiophanes*, crustaceans from the order cumacea, particularly *Pseudocuma longicornis* and *Bodotria* and the amphipods *Bathyporeia* and *Siphonocetes*. Echinoidea (sea urchins) were also present at all sites except 30a.

Table 11: Top 10 ranked taxa list for sites along proposed Corrib pipeline. Taxa comprising the top 50% (approx) of the population are in bold.

8		20		25		25a		25b		26		30a		32a	
Spiophanes bombyx	**57**	**Scoloplos armiger**	**28**	**Bathyporeia**	**72**	**Bathyporeia elegans**	**308**	**Spiophanes bombyx**	**39**	**Nematoda**	**254**	**Neocrania anomala**	**5**	**Galathowenia oculata**	**1317**
Edwardsiidae	**46**	**Spiophanes kroyeri**	**13**	**Bathyporeia elegans**	**65**			**Magelona filiformis**	**27**	**Polygordius**	**81**	**Hydroides norvegica**	**4**		
Pseudocuma longicornis	**30**	**Lumbrineris gracilis**	**12**			Bathyporeia	43	**Edwardsiidae**	**22**	**Pisione remota**	**43**	**Modiolula phaseolina**	**3**	Spiophanes kroyeri	28
Bathyporeia	**26**	**Urothoe elegans**	**9**	Spiophanes bombyx	37	Pseudocuma longicornis	23	**Bathyporeia**	**22**			**Hiatella arctica**	**3**	Prionospio fallax	23
Phoronis	**25**	**Spiophanes bombyx**	**8**	Spio decorata	33	Spio decorata	20	**Echinocyamus pusillus**	**22**	Spio filicornis	39			Tharyx killariensis	23
Chaetozone christei	**23**	**Harpinia antennaria**	**8**	Nephtys	8	Iphinoe trispinosa	19	**Bodotria pulchella**	**15**	Protodorvillea kefersteini	21	Autolytus	2	Minuspio cirrifera	22
		Minuspio cirrifera	**7**	Pontocrates altamarinus	6	Diastylis bradyi	15	**Perioculodes longimanus**	**11**	Syllis 'H'	20	Syllis	1	Edwardsiidae	19
Magelona filiformis	21	**Tharyx killariensis**	**7**	Nephtys cirrosa	5	Atylus falcatus	13			Glycera lapidum	19	Eunice ?norvegica	1	Aonides paucibranchiata	17
Pariambus typicus	14	**Mediomastus fragilis**	**6**	Diastylis bradyi	3	Spiophanes bombyx	12	Phoronis	10	Polygordius appendiculatus	19	Galathowenia oculata	1	Echinoidea	16
Chamelea striatula	13	**Copepoda**	**6**	Cumopsis fagei	3	Chaetozone christei	9	Chaetozone christei	9	Aonides paucibranchiata	17	Lanice conchilega	1	Spiophanes bombyx	12
Echinocyamus pusillus	9			Echinoidea	3	Megaluropus agilis	7	Pseudocuma longicornis	8	Goniadella bobretzkii	13	Bathyporeia	1	Copepoda	12
No. of individuals	396	No. of individuals	205	No. of individuals	257	No. of individuals	546	No. of individuals	314	No. of individuals	703	No. of individuals	28	No. of individuals	1736
50% of individuals	198	50% of individuals	103	50% of individuals	128	50% of individuals	273	50% of individuals	157	50% of individuals	352	50% of individuals	14	50% of individuals	868

The results of per replicate group average clustering analysis using Bray Curtis similarity are shown per replicate (Figure 5) and per site (Figure 6).

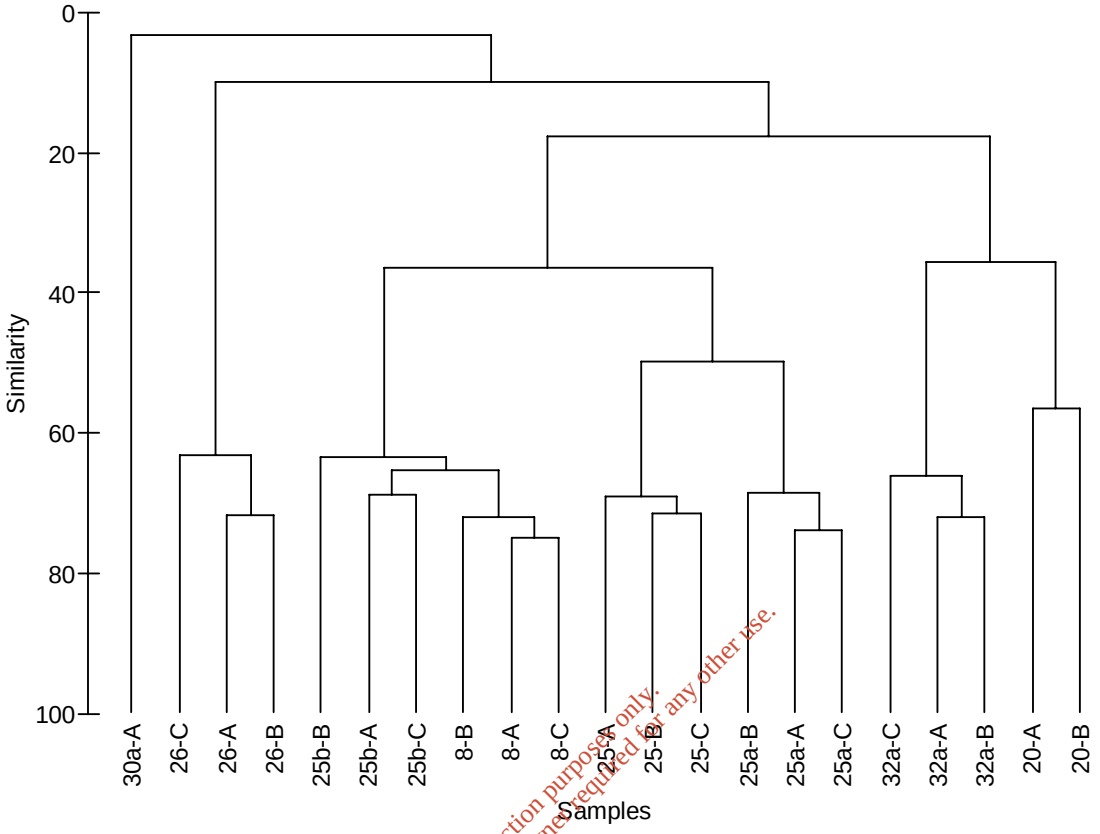

Figure 5: Dendrogram showing clustering of communities using per replicate sample data from sites on the proposed Corrib pipeline route. Data was square root transformed.

Within site variability was found to be low, replicates of each site had a 50% or more similarity with each other. As species numbers and abundances at most sites are moderate to high, an addition of a rare species would make little difference to the community composition.

The dendrograms show that there is clear clustering of sites. Conversely, there is also clear separation between certain sites. The first difference observed was between site 30a and all other sites. The community at this site had a similarity of less than 5% with all other sites, this can be attributed its sediment structure of large pebbles and associated community of tube-dwelling and encrusting organisms. Sites then separated depending upon their position in the sampling area. At approximately 20% similarity two clusters formed, sites 8, 25, 25a and 25b situated in Broadhaven Bay and sites 20, 26 and 32a which were outside the Bay. Site 26 subsequently showed differences to sites 20 and 32a, with a similarity between these sites of approximately 22%.

The results of multi-dimensional scaling using the similarity matrices derived from cluster analysis are plotted two dimensionally for each replicate in Figure 7 and for each site in Figure 8. Stress values were very low (0.05 and 0.01 respectively), indicating the two-dimensional MDS diagram is an excellent representation of how sites are related to each other. Together with the dendrograms, it was seen that there were four distinct

clusters using both replicate data and site data. Cluster 1 comprised site 30a, cluster 2 site 26, cluster 3 sites 8, 25, 25a and 25b and cluster 4 sites 20 and 32a.

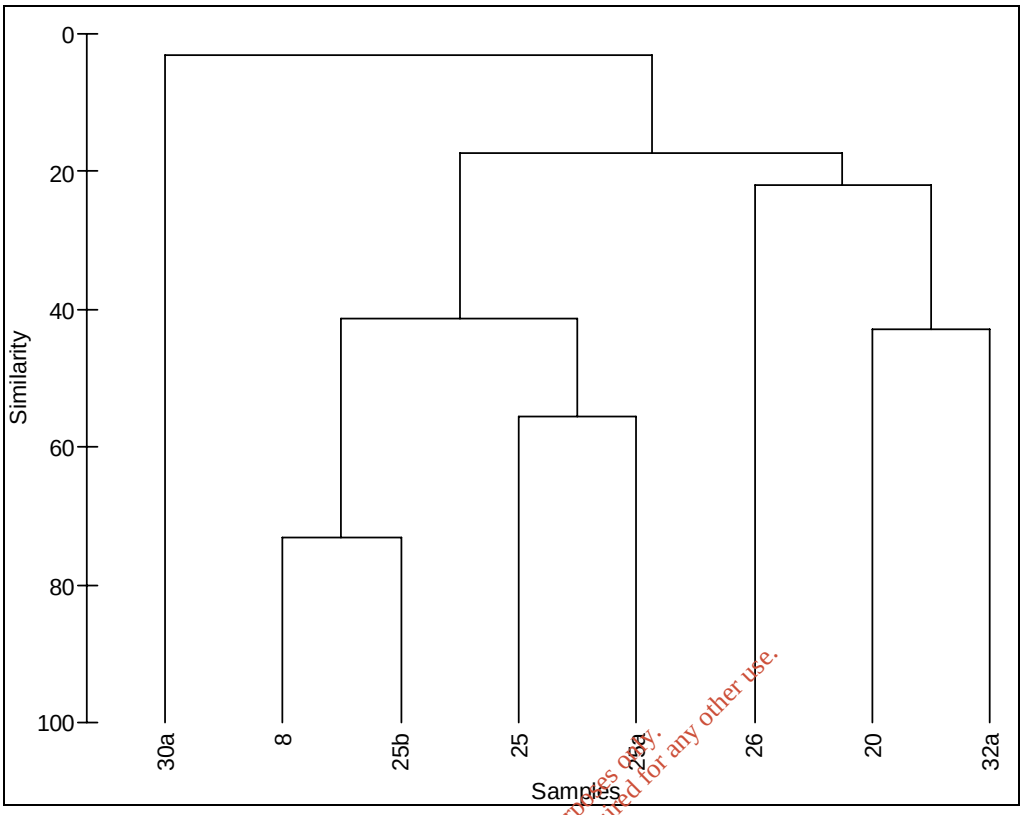

Figure 6: Dendrogram showing clustering of communities using per replicate sample data from sites on the proposed Corrib pipeline route. Data was square root transformed.

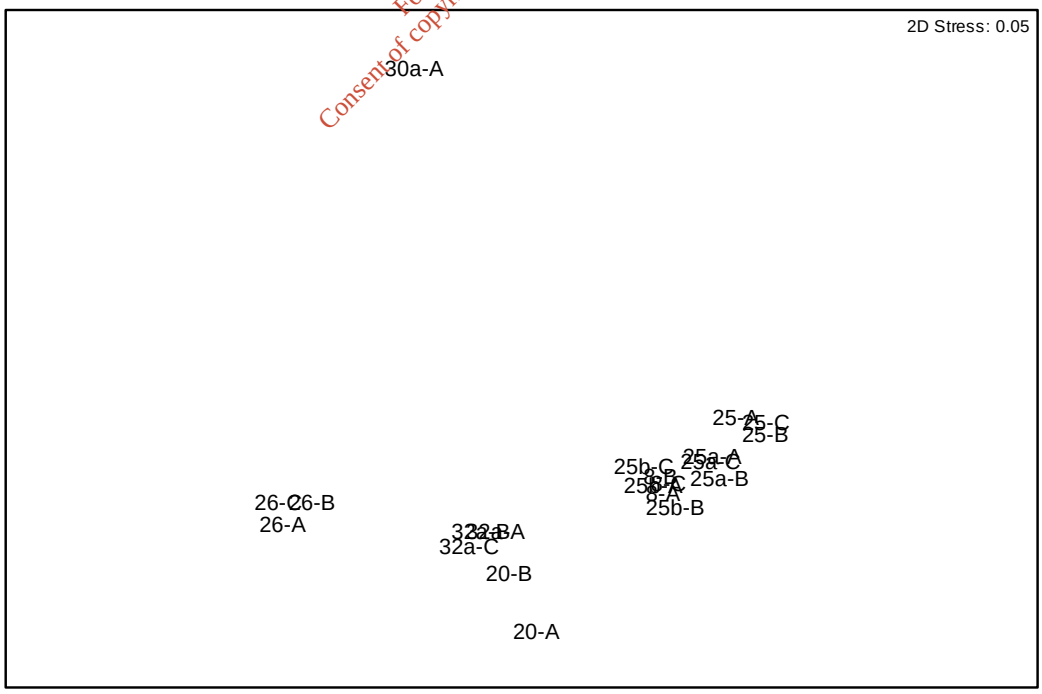

Figure 7: MDS plot of sample sites (per replicate data) along the proposed Corrib pipeline route.

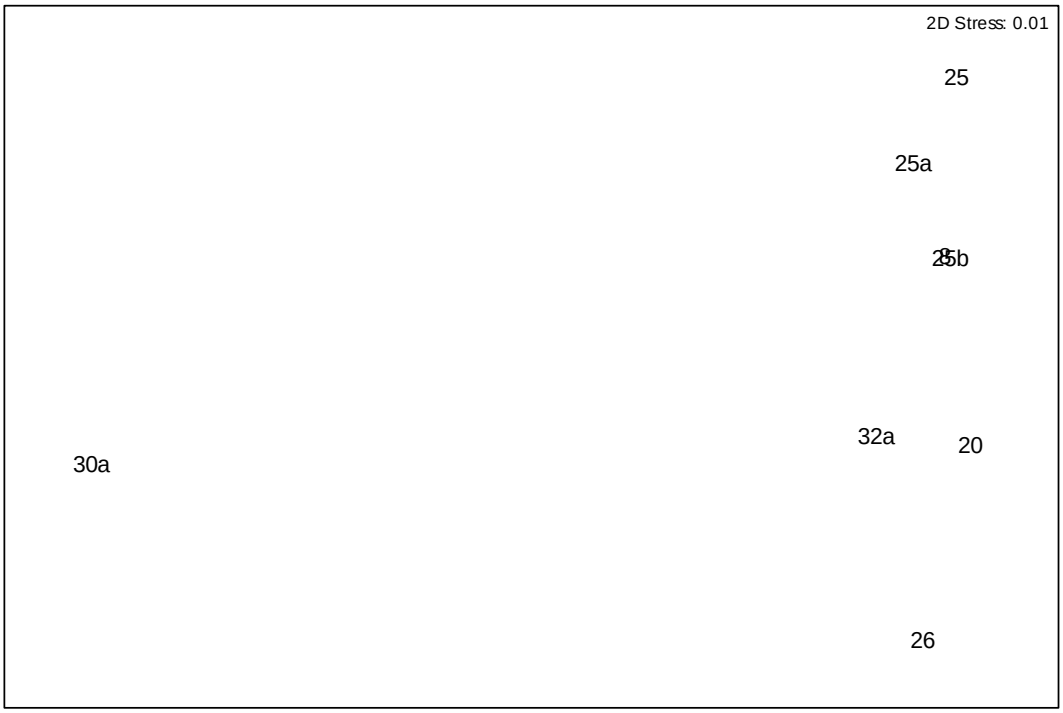

Figure 8: MDS plot of sample sites (pooled replicate data) along the proposed Corrib pipeline route.

A SIMPER analysis was performed to discover which species contributed most to each cluster, or similar community, and which species contributed most to the differences seen between clustered sites. The results for this are shown in Table 12.

Cluster one comprised of only one replicate from 30a. This community had mainly encrusting fauna, half of the species being bryozoans and hydroids. Of those that were enumerated only five species occurred more than once, these were the encrusting brachiopod, *Neomania anomala*, the calcerous-tubed polychaete *Hydroides norvegica*, the molluscs *Modiolula phaseolina* and *Hiatella arctica* and the polychaete *Autolytus*. The erect bryozoan, *Hornea lichenoides*, found in abundance at this site has only previously been found at more northern locations such as the Shetland Islands. The hard coral, *Scleractina* was also found to be abundant at this site.

Cluster 2, site 26, had an average similarity of 82.46%. Those species that contributed up to 50% of this similarity were nematodes, and the interstitial polychaetes *Polygordius* and *Pisione remota*.

Cluster 3, sites 8, 25, 25a and 25b, had an average similarity of 58.49%. Those species that contributed to this similarity were all typical of a sandy environment. The polychaetes *Spiophanes bombyx* and *Spio decorata* and the amphipod *Bathyporeia* all contributed up to 50% of the similarity between sites.

The high abundance of the sand-encased polychaete *Galathowenia oculata* significantly contributed to the similarity between sites within cluster 4 (site 20 and 32a). The presence of this species in high numbers at site 32a may have altered results from this SIMPER analysis as they were only found to be rare at site 20. However, similarity in

this cluster was 55.97% with the polychaetes *Spiophanes kroyeri* and *Spiophanes bombyx* also to made significant contributions.

Table 12: SIMPER output of those species that contribute (top 50%) to the similarity between sites along the proposed Corrib pipeline using Bray-Curtis similarity on standardised square root transformed data. The columns shown give the average abundance, the average contribution to the similarity, the percentage contribution to overall similarity and the cumulative contribution to similarity.

Cluster 1 (Sites 8,25,25a,25b)				
Average similarity:	58.49			
Species	Av. Abund	Av. Sim	Contrib%	Cum%
Spiophanes bombyx	5.81	9.39	16.05	16.05
Bathyporeia (sp.indet)	5.86	8.58	14.67	30.71
Bathyporeia elegans	7.32	6.78	11.59	42.30
Spio decorata	3.63	5.12	8.75	51.06
Cluster 2 (Sites 20 & 32a)				
Average similarity:	55.97			
Species	Av. Abund	Av. Sim	Contrib%	Cum%
Galathowenia oculata	22.17	15.07	26.92	26.92
Spiophanes kroyeri	4.59	6.89	12.30	39.22
Spiophanes bombyx	3.23	5.26	9.40	48.62
Lumbrineris gracilis	2.80	4.27	7.62	56.25
Cluster 3 (Site 26)				
Average similarity:	82.46			
Species	Av. Abund	Av. Sim	Contrib%	Cum%
Nematoda	15.78	24.34	29.52	29.52
Polygordius	8.98	14.38	17.45	46.96
Pisinoe remota	6.57	10.92	13.24	60.20
Cluster 4 (Site 30a, one rep)				
Average similarity:	100.00			
Species	Av. Abund	Av. Sim	Contrib%	Cum%
Hydroides norvegica	4.00	-	10.53	10.53
Modiolula phaseolina	3.00	-	7.895	18.42
Hiatella arctica	3.00	-	7.895	26.32
Autolytus	2.00	-	5.263	31.58

Differences between clusters was found to be high, with dissimilarities of more than 75% occurring between all clusters. Cluster 1, site 30a, was the most dissimilar to all other sites. Dissimilarities between clusters were high throughout the dataset, as those species that characterised communities in each defined cluster were found to be absent or rare in the others. For example, cluster 4 (site 32a and 20) and 3 (sites 8, 25, 25a and 25b) had a dissimilarity of 78.48%. The amphipod, *Bathyporeia elegans* contributed highly to this dissimilarity as there was a high average abundance in cluster 3 but few in cluster 4.

4.3.2 Multivariate analysis

A BIO-ENV analysis was performed for all sites. This looks at the best correlation between the biological and environmental data and endeavours to show which set of chemical and/or physical variables best explains the variation observed in the biological communities. Site 30a was removed from analysis as there was no environmental data

for this location. For all other sites, particle size, total organic carbon and heavy metals were included in the analysis.

Prior to this analysis, the data was examined for patterns relating to factors that were not measured. It was seen that clustering related to a certain extent upon geographical position. Sites 8, 25, 25a and 25b had very similar communities and all geographically close together within Broadhaven Bay (Figure 2). Site 26 which had high organic carbon content and an obviously different community to other sites was situated close to the outfall. Site 30a, excluded from sediment and chemical analysis had fauna typical of a pebbly/boulder environment. Sites 20 and 32a lay further offshore than the others.

The BIO-ENV analysis resulted in strong correlations with five variables (r = 0.949). These were sediment grain size of medium size sand (261-564µm), arsenic, aluminium, barium and nickel. The values for each these environmental variables at each site are shown in Section 4.2 and MDS overlays of these environmental variables are plotted for 261-564µm in Figure 9, arsenic in Figure 10, aluminium in Figure 11, barium in Figure 12 and nickel in Figure 13.

When transposing these values onto MDS plots, patterns between position of station and variables were observed. However, these patterns were not consistent for all the variables to be able to explain the clustering of sites. Arsenic concentration was the only variable that showed patterns relating to prior clustering, sites 20, 26 and 32a exhibited higher concentrations of arsenic than the sites which lie within the Bay.

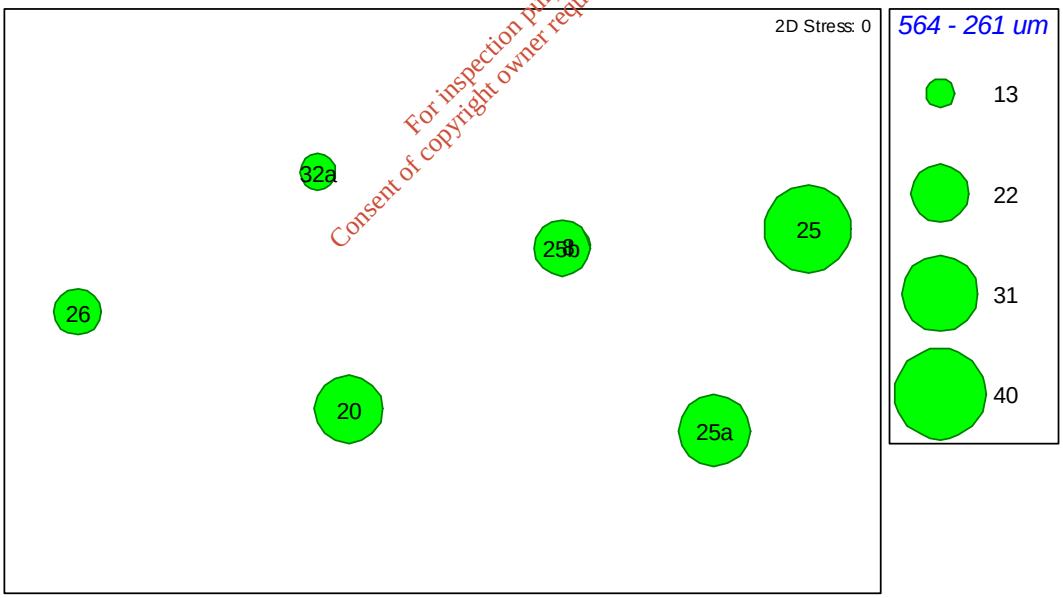

Figure 9: MDS plot of sites along the proposed Corrib pipeline route with superimposed bubbles representing the percent of sediment fraction 564-261µm (medium sand) at each site.

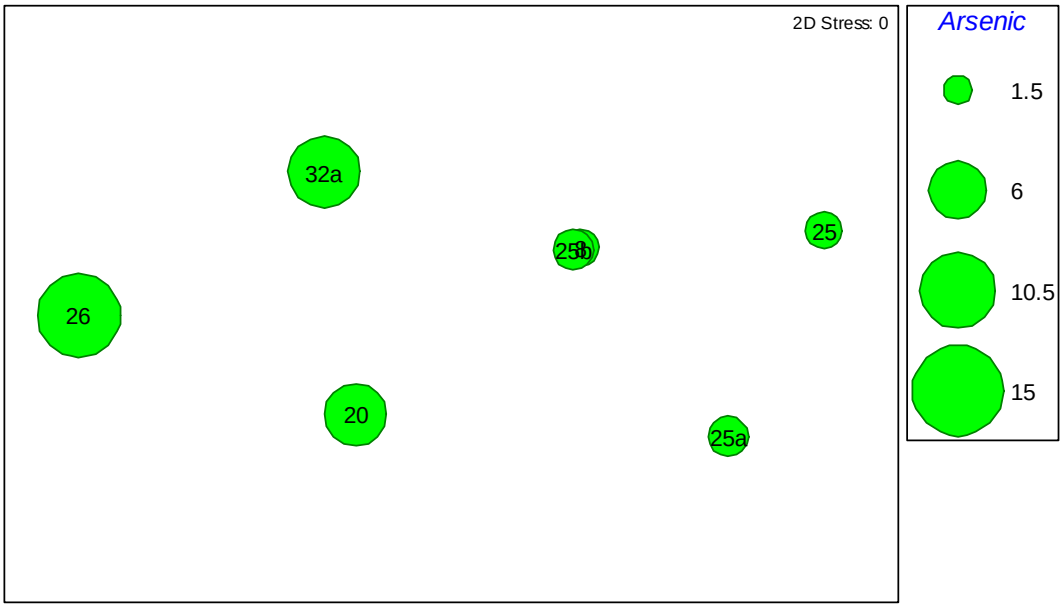

Figure 10: MDS plot of sites along the proposed Corrib pipeline route with superimposed bubbles representing arsenic concentration (mgkg^{-1}) at each site.

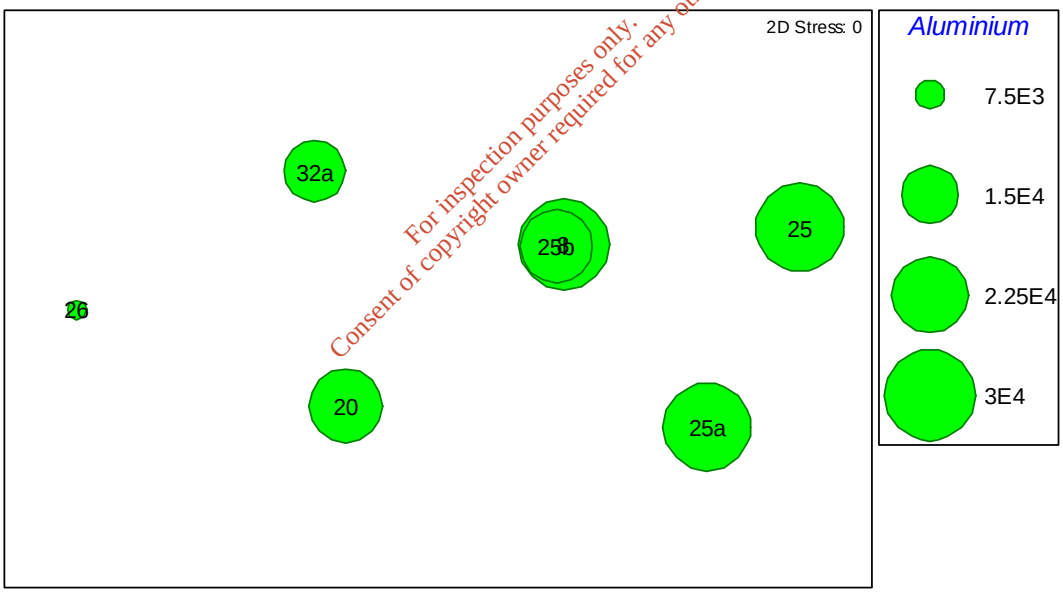

Figure 11: MDS plot of sites along the proposed Corrib pipeline route with superimposed bubbles representing aluminium concentration (mgkg^{-1}) at each site.

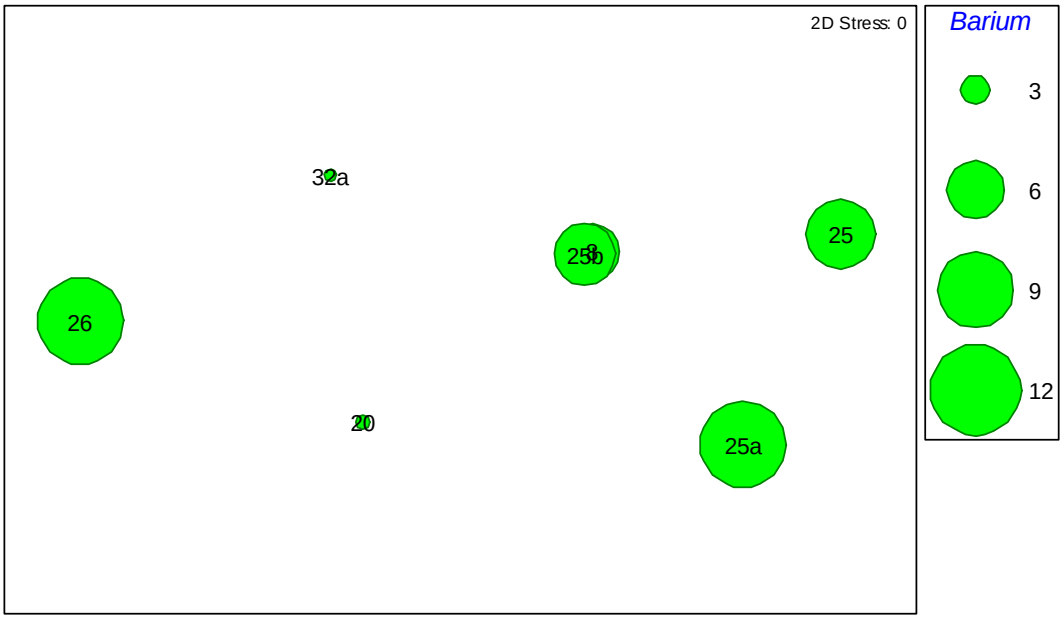

Figure 12: MDS plot of sites along the proposed Corrib pipeline rout with superimposed bubbles representing barium concentration (mgkg^{-1}) at each site.

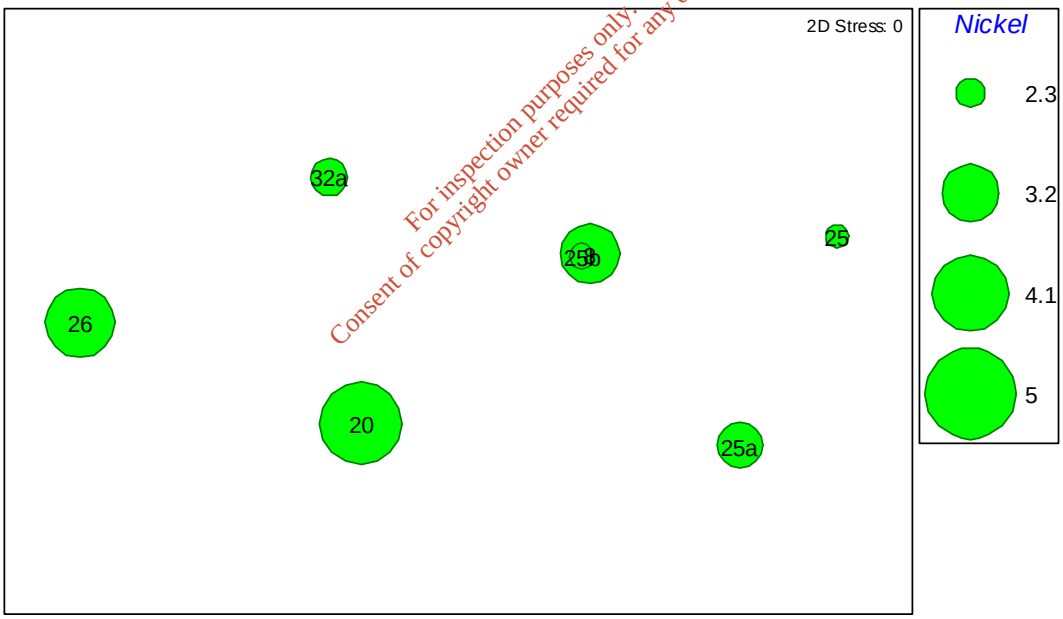

Figure 13: MDS plot of sites along the proposed Corrib pipeline route with superimposed bubbles representing nickel concentration (mgkg^{-1}) at each site.

4.4 Seabed Photography

Seabed surface photography was completed at all proposed stations along the offshore pipeline route, SPI images were also collected from each of the 12 stations along the route. The seabed surface and SPI image collection was carried out by Aqua-Fact. A selection of the surface images are presented in Figure 14 to Figure 21. Appendix C (Aqua-Fact report) presents

surface and SPI images from all stations sampled during the survey (including several in the Corrib Field itself).

Aqua-Fact report that the penetration depths for the SPI camera were moderate to low at many of the stations surveyed. The camera system was used with a fully loaded weight carriage for maximum penetration throughout the survey – therefore any variation seen in penetration is due to variation in the physical characteristics of the sediment itself. Highest penetration values were achieved where sediments had been fluidised through the activities of burrowing fauna (bioturbation – generally prevalent at deeper stations) or in shallower waters due to the effects of surface waves and swell.

The penetration depths of the SPI camera rig illustrate the compactness of the seabed and show why the Van Veen and Day-grab samplers were unable to penetrate in some areas.

Figure 14: Seabed surface photograph, Station 3

Figure 15: Seabed surface photograph, Station 20

Figure 16: Seabed surface photograph, Station 25a

Figure 17: Seabed surface photograph, Station 26

Figure 18: Seabed surface photograph, Station 27

Figure 19: Seabed surface photograph, Station 32a

Figure 20: Seabed surface photograph, Station 38

Figure 21: Seabed surface photograph, Station 41

The information gathered from the surface and SPI images is used by Aqua-Fact to assess the status of the habitat and communities. All of the pipeline route stations were allocated a stage III successional stage. This was largely due to the presence of characteristically deep "apparent redox potential discontinuity" (ARPD)s, presence of fauna and prominent biogenic features such as burrows, tubes and feeding. This stage was also allocated due to the absence of any definite evidence of impact or habitat quality degradation. Stage III indicates that the community is stable, and present in mature, healthy conditions.

In addition to the status of the sediments assessed above, Aqua-Fact also state that no sensitive environments were found during the survey.

5 Summary

5.1 Physico-chemical

Sediment grain size results are broadly as expected given the previous sampling in the area. Sediment tends to be coarse in the nearshore areas, and slightly finer offshore, though no fine material was collected at any station. Total organic carbon levels are low, in line with the coarse sediment material.
The data sets for both metals and hydrocarbons reflect a pristine environment. The data are in accord with other published work. No determinand was found at concentrations that would give rise to concern regarding potential biological impacts.

5.2 Fauna

In summary, it can be seen that the faunal communities observed in the current survey were of moderate to high diversity and exhibited high evenness and low dominance. Communities were variable throughout the dataset but generally comprised of animals that inhabit sandy and coarser grain sediments.

When analysed, the data showed low intra-site variance with all sites containing replicates with a similarity of 50% or more. Sites clustered well into four distinct clusters, each exhibiting a high similarity and therefore very similar community structure within each cluster. Between-cluster differences were also high, with species typical of one community being absent or rare in the others. This resulted in high correlations with regard to species distribution and physical and chemical parameters. The combination of the five variables percentage medium sand fraction (261-564µm) and concentrations ($mgkg^{-1}$) of arsenic, aluminium, barium and nickel were found to correlate best. However, this was not a clear relationship as concentrations of all these except arsenic varied within clusters.

Community composition seemed to also be dependent upon geographical position, although to what degree is unknown. Sites 8, 25, 25a and 25b all had similar communities and all lay within Broadhaven Bay. Site 26 was situated close to the outfall, had a higher organic carbon and nickel concentration than any other site and was comprised of some animals typical of more impacted environments (i.e. Nematoda). Site 30a also had a highly different community to the others, being dominated by encrusting/colonial species as sediment at this site comprised mainly of large pebbles (pers obs.). Site 20 and 32a had communities typical of coarser grained sediments, although these were again different from those found with the bay.

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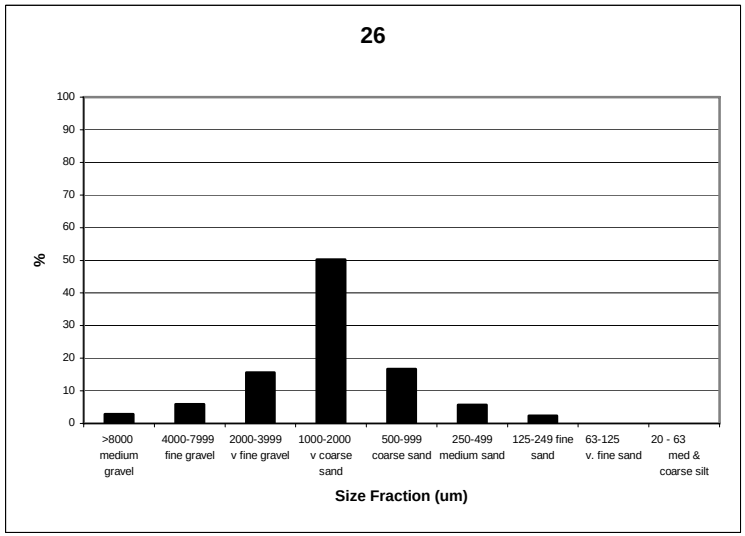
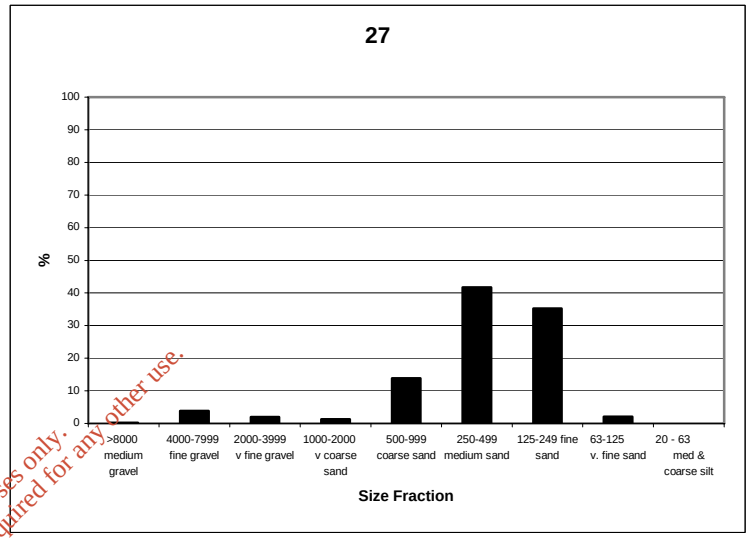
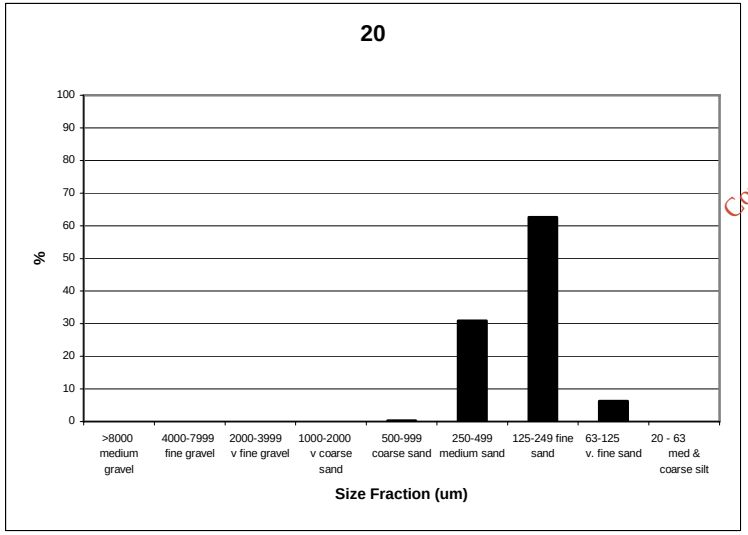
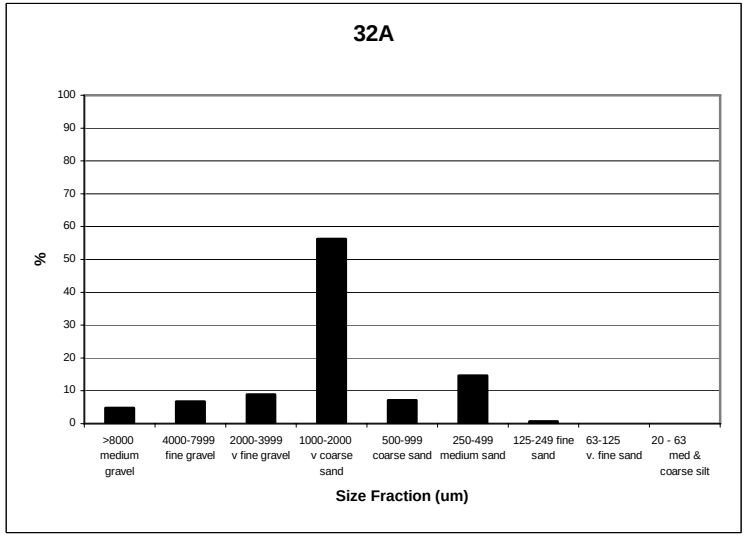
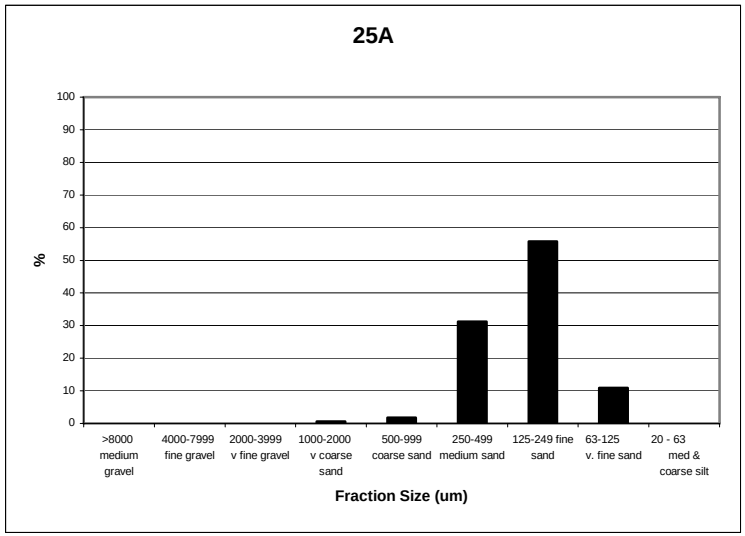
Appendix A: Particle Size Graphs

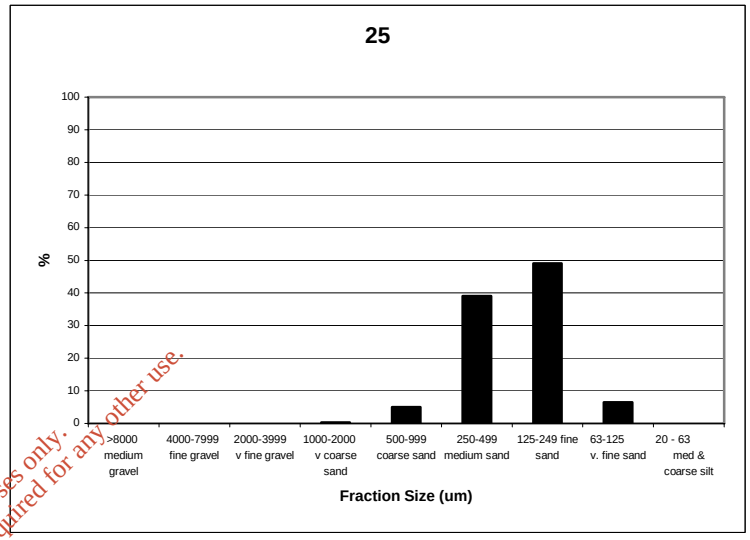


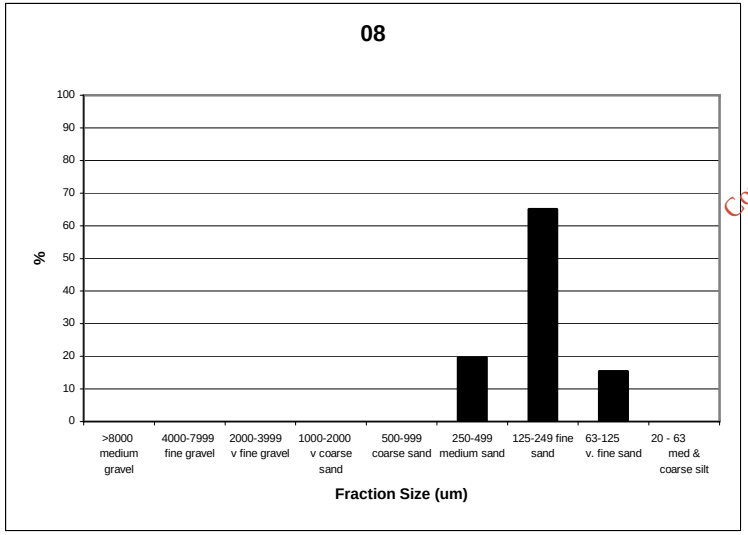


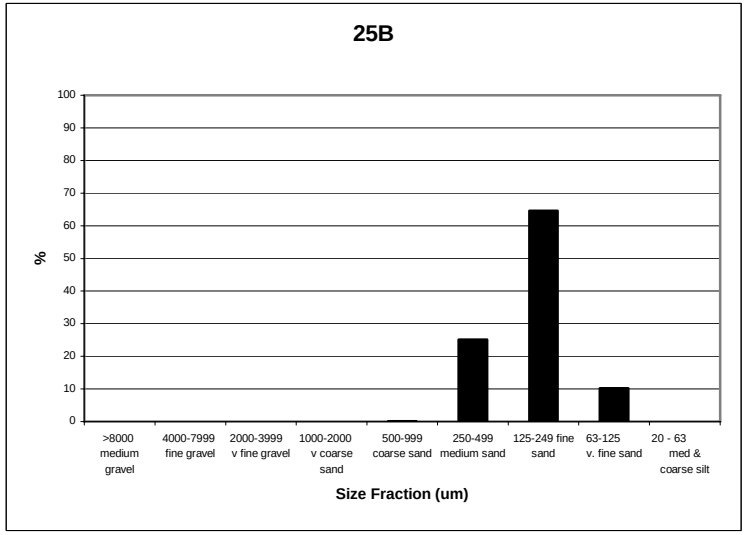












Appendix B: BenthicSolutions Report on hydrocarbon concentrations in sediments from the offshore pipeline route

An Examination of Hydrocarbons in Seabed Sediments Collected from the Proposed Corrib Outfall & Pipeline Route Corridor, County Mayo Ireland.

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Survey Dates: 29.07.2007 to 10.08.2007
Date of Report: 03.10.2007

1. Organic Analysis Aims

1.1 To extract twenty-one seabed sediments to determine the concentrations of total organic extractables (TOE) therein using gas chromatography (GC), with particular reference to identify any type of base oils present.

1.2 To determine the concentrations of a range of polyaromatic hydrocarbons (PAH), including naphthalenes, phenanthrenes and dibenzothiophenes (NPD) and the EPA 16 polyaromatic hydrocarbons in the twenty-one sediment samples.

2. Sample Details

Twenty-one sediment samples from the proposed outfall location and Corrib Pipeline Route Corridor, off the Irish West coast, were received delivered to the analytical laboratory (M-Scan) on the 14th August 2007. All samples were stored at -18°C immediately after sampling in the field, remaining frozen at all times prior to analysis. On receipt, each sample was given a unique processing reference number, as follows:

Sample (Date)	Reference No
08 (02/08/07)	80136
20 (01/08/07)	80137
25 (02/08/07)	80138
26 (01/08/07)	80139
27 (01/08/07)	80140
25A (02/08/07)	80141
25B (02/08/07)	80142
32A (01/08/07)	80143
S1 (06/08/07)	80144
S10 (02/08/07)	80145
S10 Duplicate (08/08/07)	80146

Sample (Date)	Reference No
S11 (08/08/07)	80147
S15 (07/08/07)	80148
S17 (02/08/07)	80149
S2 (08/08/07)	80150
S4 (08/08/07)	80151
S5R (08/08/07)	80152
S5 (08/08/07)	80153
S6 (08/08/07)	80154
S6R (07/08/07)	80155
S9 (02/08/07)	80156

Parenthesis: Date sample recovered from the seabed.

3. Analytical Methodology

3.1 Extraction of Hydrocarbons

Samples were stored in metal cans at -18°C prior to extraction and analysis. In the laboratory, the samples were defrosted, homogenised and sub-samples weighed out for analysis. Known amounts of heptamethylnonane (HMN), chlorooctadecane (COD), squalane (Sq), d_8-naphthalene (d_8-N), d_{10}-phenanthrene (d_{10}-P) and d_{10}-pyrene (d_{10}-Py) were added to each sediment prior to extraction as internal standards, and the sample re-homogenised. After the addition of 100ml of isopropanol/hexane (4:1), the sediments were extracted using ultra-sonication (2 x 5 min, stirring in between) and then centrifuged at 2000rpm for 10 minutes. The supernatant extract was then decanted and partitioned between water and pentane. The resulting organic fractions were collected in pre-cleaned 500ml round bottom flasks. The extraction procedure was then repeated with a further 100ml of isopropanol/hexane (4:1), omitting the addition of internal standards. Organic fractions were combined and re-washed to give a total organic extract (TOE). This TOE was reduced under vacuum to *ca*. 2ml, and was analysed by gas chromatography (GC) to obtain quantification of any saturate organics present (including drilling related base-oils, if found). Following the GC analysis, the TOE was further processed though a silica chromatography column (silica, 60-230 mesh). 40ml of pentane were used to elute the aliphatic fraction, followed by 50ml of DCM to elute the aromatic fraction. The fractions were collected in pre-cleaned 100ml round bottom flasks. Each fraction was reduced under vacuum (<30°C) to *ca*.1ml, transferred to a glass vial and further concentrated using dry nitrogen blow-down. The aromatic hydrocarbon fractions were then analysed by GC-mass spectrometry (GC-MS).

The analysis of a procedural blank, along with a duplicate sample and a pre-extracted trip blank were carried out in parallel with the field samples.

3.2 Gas Chromatography (GC)

An aliquot (1µl) of the TOE fraction was analysed by GC under the following conditions:

GC	
Instrument	Hewlett Packard 6890
Columns	30m x 0.32mm i.d. x 0.25µm d.f DB5-MS (J&W)
Injection	Splitless at 325°C
Temperature Prog.	40°-325°C at 8°C/min, 325°C (10 min)
Carrier Gas	Helium at 2ml/min; constant flow
Data handling	Hewlett Packard Chemstation Series 7.1

Quantification of total organic extractables (TOE) was carried out against the internal standard squalane.

3.3 Gas Chromatography- Mass Spectrometry (GC-MS)

Aliquots (1.0µl) of the sediment aromatic fractions, dissolved in dichloromethane, were analysed by GC-MS using a Perkin Elmer Turbomass Gold mass spectrometer with Turbomass version 4.4 data system, under the following conditions:

GC	
Column	30m x 0.32mm i.d x 0.25µm d.f. DB5-MS (J&W)
Injection	Splitless at 325°C
Temperature Prog.	40°-100°C at 45°C/min, 100°-325°C at 8°C/min, 325°C (10 min)
Carrier Gas	Helium at 1.5ml/min; constant flow
MS	
Ionisation Voltage	70eV
Mass Range	90-350 amu
Scan Rate	ca. 0.5 second cycle
MS Resolution	Unit

4. Results And Discussion

4.1 GC Analysis of Total Organic Extracts (TOE)

The total organic extracts (TOE) of the sediments were analysed by gas chromatography (GC) to detect any saturate hydrocarbons (including anthropogenic hydrocarbons such as drilling related base-oils) that may be present in the sediment. This is the same procedure as previously used in earlier survey undertaken in and around the Corrib field development since 1997.

The TOE GC traces of the sediments are given in *Figures 1-24*, while that of the procedural blank is shown in *Figure 25*. The concentrations of TOE have been calculated from the GC analyses and are shown in *Table 1*. TOE concentrations range from 0.69µg/g at Station 17 to 13µg/g at Stations 25B and the S10 Duplicate. Concentrations of TOE in these samples are considered consistent with 'background' levels as previously seen in the offshore Corrib field (Benthic Solutions Limited 2006).

Table 1 Concentrations of Total Organic Extractables (TOE)

Station	TOE (µg/g; ppm)
08	7.0
20	4.7
25	5.8
25A	6.7
25B	8.6(13)
26	10
27	6.5
32A	10
S1	2.2
S2	8.2
S4	10
S5	5.9

Station	TOE (µg/g; ppm)
S5R	9.5
S6	2.7
S6R	4.5
S9	1.1(0.89)
S10	8.1
S10 D	13
S11	6.6
S15	0.96
S17	0.69

Pre-extract	1.2
Trip Blank	30

Parenthesis: Duplicate analysis

Comparison with similar data, previously analysed from surveys in the North Sea Oil and Gas fields (including both baseline studies and reference background stations from around fields where drilling operations have taken place) suggests that the background

concentration of total hydrocarbons typically ranges between 1-10ppm. This agrees with data from the North Sea Task Force (NSTF 1993), and Law (Law et al, 1982), although other studies have shown higher concentrations (e.g. McIntosh et al, 1983; 10-60ppm in sediments between the Firth of Forth and the Forties field).

Apart from the internal standards, the GC traces show clear evidence for the presence of a number of resolved peaks. The TOE of sample S2 was further analysed by GC-MS to characterise these components. They include a range of fatty acids (dominated by C_{14} (myristic), C_{16} (palmitic) and C_{18} (stearic) acids), sterols, long chain alcohols and long-chain (C_{39-42}) ketones, which have been previously identified in the North Sea sediments and in the marine coccolithophore *Emiliana huxleyi.* These are all considered to be of biogenic rather than petrogenic origin, and confirm a very low level of petrogenic contamination within the sediments.

The GC traces preclude the presence of the three synthetic base oils previously identified in the Corrib field development ("Ecosol", "Ecomul" and "Esterkleen"). The base oil "Ecomul" comprises almost entirely of paraffins, while "Esterkleen" is based upon 45-70% 2-ethyl-hexyloleate. The base oil "Ecosol" is 60% paraffins, 20% poly-alpha olefins and 20% linear alpha olefins. For comparison a GC trace of the "Ecosol" base oil from previous analyses is included as *Appendix 1.* This base oil was spiked into a portion of the sample from Station 25 at 52.7ppm; this was extracted and analysed in parallel with the other samples, and the trace is shown as *Figure 22 (Appendix II)*. The measured concentration of the base oil in the extracted sediment was 49.9ppm.

There was also no evidence in the sediments for the presence of base oils of mineral origin (e.g. "low-tox" or diesel).

A portion of pre-extracted sediment was utilised as a "trip" blank. This sediment was extracted and the data included for comparison with a portion of pre-extracted sediment retained within the laboratory. The data are included as *Figures 23* and *24 (Appendix II)*. The trip blank sample shows evidence for a series of resolved peaks between 22-30 minutes, and a narrow-range UCM between 30-34 minutes. Inspection of the GC-MS data of the aromatic fraction for this sample indicates that the UCM comprises mixed long-chain phthalates, which are widely used as plasticisers. The source of this contamination is unclear. However, these components were not detected in the sediments analysed, and so they are not considered significant in this context.

4.2 GC-MS Analysis of Polycyclic Aromatic Hydrocarbons (PAHs)

Total ion current traces for the sediment aromatic fractions are given in *Figures 26-46*, whilst that of the procedural blank is given in *Figure 47 (Appendix III)*. Concentrations of PAHs in the sediments are given in *Table 2* and include naphthalenes, phenanthrenes and dibenzothiophenes (NPD) and the sixteen PAHs defined by the US EPA.

Polyaromatic hydrocarbons and their alkyl derivatives have been recorded in a wide range of marine sediments (Laflamme & Hites, 1978) with the majority of compounds produced from what is thought to be pyrolytic sources. These are the combustion of organic material such as forest fires (Youngblood & Blumer, 1975), the burning of fossil fuels and, in the case of offshore oilfields, flare stacks, etc. The resulting PAHs, rich in the heavier weight 4-6 ring aromatics, are normally transported to the sediments via atmospheric fallout or river runoff. Another PAH source is petroleum hydrocarbon, often associated with localised drilling activities. These are rich in the lighter, more volatile 2 and 3 ring PAHs (NPD; naphthalene (128), phenanthrene, anthracene (178) and dibenzothiophene (DBT) with their alkyl derivatives).

The concentrations of NPD (*Table 2*), range from 0.03ng/g (ppb; Station 26) to 11ng/g (Station S6). The concentrations of NPD in these samples are considered consistent with 'background' levels previously seen in the sediments around the Corrib field development (Benthic Solutions Limited 2006), which are generally similar to the background levels observed in the North Sea (Davies *et al*., 1984).

The concentrations of the EPA 16 PAHs range from 0.11ng/g (Station 15) to 2.8ng/g (Station 32A). These values, again, are generally similar to those observed in the 'background' levels previously seen around the Corrib field development (Benthic Solutions Limited 2006), and are also generally similar to the background levels observed in North Atlantic sediments. Previous data from surveys around North Sea fields and the North Atlantic suggest that the background concentrations of the EPA16 PAH concentrations typically range up to 50ng/g, whilst NPDs are typically in the region of 10ng/g.

Table 2a. *Concentrations of 2-6 ring **Polycyclic** Aromatic **Hydrocarbons** (ng/g (ppb); dry weight basis)*

Station No.	8	20	25	26	25A	25B	27
Naphthalene	nd	0.02	0.06	nd	0.08	nd	0.52
C1-Naphthalenes	nd	nd	0.04	nd	nd	nd	0.31
C2- Naphthalenes	nd	nd	nd	nd	0.95	nd	nd
C3- Naphthalenes	nd	1.2	nd	nd	nd	nd	nd
C4- Naphthalenes	nd	nd	nd	nd	nd	nd	nd
Total Naphthalenes	nd	1.2	0.10	nd	1.0	nd	0.83
Phenanthrene	nd	0.06	0.09	0.03	0.01	nd	0.07
C1-Phenanthrenes	nd	nd	nd	nd	nd	nd	nd
C2- Phenanthrenes	nd	nd	nd	nd	nd	nd	nd
C3- Phenanthrenes	nd	nd	nd	nd	nd	nd	nd
Total Phenanthrenes	nd	0.06	0.09	0.03	0.01	nd	0.07
Dibenzothiophene	nd	nd	nd	nd	nd	nd	nd
C1-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd
C2-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd
C3-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd
Total DBT	nd	nd	nd	nd	nd	nd	nd
Total NPD	nd	1.3	0.19	0.03	1.0	nd	0.90
Acenaphthylene	nd	nd	nd	nd	nd	nd	nd
Acenaphthene	nd	nd	nd	nd	nd	nd	nd
Fluorene	nd	nd	nd	nd	nd	nd	nd
Anthracene	nd	nd	nd	nd	nd	nd	nd
Fluoranthene	0.08	0.16	0.08	0.17	0.07	0.10	0.12
Pyrene	nd	nd	nd	0.13	0.05	0.05	0.09
C_1-Fluoranthenes/Pyrenes	nd	nd	nd	nd	nd	nd	nd
C_2-Fluoranthenes/Pyrenes	nd	nd	nd	nd	nd	nd	nd
C_3-Fluoranthenes/Pyrenes	nd	nd	nd	nd	nd	nd	nd
Benzo(a)anthracene	nd	0.05	0.04	0.11	0.03	nd	0.08
Chrysene	nd	0.09	0.07	0.11	0.05	nd	0.06
C_1-Benanthracenes/Chrysenes	nd	nd	nd	nd	nd	nd	nd
C_2- Benanthracenes/Chrysenes	nd	nd	nd	nd	nd	nd	nd
Benzo(b)fluoranthene	0.01	0.11	nd	0.37	0.13	0.17	0.22
Benzo(k)fluoranthene	0.14	0.24	nd	0.12	0.04	0.08	0.08
Benzo(a)pyrene	nd	0.07	nd	0.12	0.06	0.06	0.09
C_1-Benzofluoranthenes/Benzpyrenes	nd	nd	nd	nd	nd	nd	nd
C_2- Benzofluoranthenes/Benzpyrenes	nd	nd	nd	nd	nd	nd	nd
Indeno(1,2,3-cd)pyrene	0.12	0.33	nd	0.30	0.21	0.17	0.24
Dibenzo(a,h)anthracene	nd	0.10	nd	0.03	0.03	nd	nd
Benzo(ghi)perylene	0.11	0.25	nd	0.24	0.15	0.18	0.18
Total EPA 16	0.46	1.5	0.40	1.7	0.91	0.80	1.8
4-6 Ring PAH/NPD	-	1.15	2.11	56.67	0.91	-	2.00

nd = not detected

Table 2b. *Concentrations of 2-6 ring **Polycyclic** Aromatic **Hydrocarbons** (ng/g (ppb); dry weight basis)*

Station No.	32A	S1	S2	S4	S5	S5R	S6
Naphthalene	0.43	0.23	0.04	0.21	nd	nd	2.3
C1-Naphthalenes	nd	nd	0.17	0.28	0.09	0.12	4.7
C2- Naphthalenes	0.95	nd	nd	1.2	nd	1.0	4.3
C3- Naphthalenes	nd	nd	nd	nd	nd	nd	nd
C4- Naphthalenes	nd	nd	nd	nd	nd	nd	nd
Total Naphthalenes	1.4	0.23	0.21	1.7	0.09	1.1	11
Phenanthrene	0.03	0.02	0.04	0.08	0.03	0.02	0.27
C1-Phenanthrenes	nd	nd	nd	nd	nd	nd	nd
C2- Phenanthrenes	nd	nd	nd	nd	nd	nd	nd
C3- Phenanthrenes	nd	nd	nd	nd	nd	nd	nd
Total Phenanthrenes	0.03	0.02	0.04	0.08	0.03	0.02	0.27
Dibenzothiophene	nd	nd	nd	nd	nd	nd	nd
C1-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd
C2-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd
C3-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd
Total DBT	nd	nd	nd	nd	nd	nd	nd
Total NPD	1.4	0.25	0.25	1.8	0.12	1.1	11
Acenaphthylene	nd	nd	nd	nd	nd	nd	nd
Acenaphthene	nd	nd	nd	nd	nd	nd	nd
Fluorene	nd	nd	nd	nd	nd	nd	nd
Anthracene	nd	nd	nd	nd	nd	nd	nd
Fluoranthene	0.17	0.10	0.04	0.17	0.10	0.09	nd
Pyrene	0.10	0.04	0.03	0.11	0.05	0.06	nd
C_1-Fluoranthenes/Pyrenes	nd	nd	nd	nd	nd	nd	nd
C_2-Fluoranthenes/Pyrenes	nd	nd	nd	nd	nd	nd	nd
C_3-Fluoranthenes/Pyrenes	nd	nd	nd	nd	nd	nd	nd
Benzo(a)anthracene	0.05	nd	nd	0.05	0.05	0.06	nd
Chrysene	0.08	nd	nd	0.09	0.10	0.08	nd
C_1-Benanthracenes/Chrysenes	nd	nd	nd	nd	nd	nd	nd
C_2- Benanthracenes/Chrysenes	nd	nd	nd	nd	nd	nd	nd
Benzo(b)fluoranthene	0.64	0.07	0.04	0.12	0.15	0.10	nd
Benzo(k)fluoranthene	0.15	0.06	0.01	0.19	0.08	0.04	nd
Benzo(a)pyrene	0.10	0.01	nd	0.08	0.09	0.04	nd
C_1-Benzofluoranthenes/Benzpyrenes	nd	nd	nd	nd	nd	nd	nd
C_2- Benzofluoranthenes/Benzpyrenes	nd	nd	nd	nd	nd	nd	nd
Indeno(1,2,3-cd)pyrene	0.58	0.07	nd	0.24	0.16	0.16	nd
Dibenzo(a,h)anthracene	0.07	0.02	nd	nd	nd	nd	nd
Benzo(ghi)perylene	0.38	0.11	nd	0.22	0.16	0.29	nd
Total EPA 16	2.8	0.73	0.21	1.6	0.97	0.93	2.6
4-6 Ring PAH/NPD	2.00	2.92	0.84	0.89	8.08	0.85	0.24

nd = not detected

Table 2c. *Concentrations of 2-6 ring* ***Polycyclic*** *Aromatic* ***Hydrocarbons*** *(ng/g (ppb); dry weight basis)*

Station No.	S6R	S9	S10	S10 D	S11	S15	S17
Naphthalene	0.62	1.6	nd	0.01	nd	0.11	0.04
C1-Naphthalenes	2.0	3.9	nd	0.37	nd	0.16	nd
C2- Naphthalenes	2.3	3.4	nd	1.5	nd	nd	nd
C3- Naphthalenes	nd	nd	nd	nd	nd	nd	nd
C4- Naphthalenes	nd	nd	nd	nd	nd	nd	nd
Total Naphthalenes	4.9	8.9	nd	1.9	nd	0.27	0.04
Phenanthrene	0.13	0.08	nd	0.11	0.10	nd	0.06
C1-Phenanthrenes	nd	nd	nd	nd	nd	nd	nd
C2- Phenanthrenes	nd	nd	nd	nd	nd	nd	nd
C3- Phenanthrenes	nd	nd	nd	nd	nd	nd	nd
Total Phenanthrenes	0.13	0.08		0.11	0.10	nd	0.06
Dibenzothiophene	nd	nd	nd	nd	nd	nd	nd
C1-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd
C2-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd
C3-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd
Total DBT	nd	nd	nd	nd	nd	nd	nd
Total NPD	5.0	9.0	nd	2.0	0.10	0.27	0.10
Acenaphthylene	nd	nd	nd	nd	nd	nd	nd
Acenaphthene	nd	nd	nd	nd	nd	nd	nd
Fluorene	nd	nd	nd	nd	nd	nd	nd
Anthracene	nd	nd	nd	nd	nd	nd	nd
Fluoranthene	0.12	nd	0.10	0.16	0.13	nd	0.08
Pyrene	0.04	nd	0.07	0.08	0.18	nd	0.15
C_1-Fluoranthenes/Pyrenes	nd	nd	nd	nd	nd	nd	nd
C_2-Fluoranthenes/Pyrenes	nd	nd	nd	nd	nd	nd	nd
C_3-Fluoranthenes/Pyrenes	nd	nd	nd	nd	nd	nd	nd
Benzo(a)anthracene	nd	nd	nd	0.10	0.04	nd	nd
Chrysene	nd	nd	nd	0.07	0.11	nd	nd
C_1-Benanthracenes/Chrysenes	nd	nd	nd	nd	nd	nd	nd
C_2- Benanthracenes/Chrysenes	nd	nd	nd	nd	nd	nd	nd
Benzo(b)fluoranthene	0.10	nd	0.15	0.38	0.31	nd	nd
Benzo(k)fluoranthene	0.04	nd	0.10	0.09	0.05	nd	nd
Benzo(a)pyrene	0.03	nd	0.07	0.11	0.07	nd	nd
C_1-Benzofluoranthenes/Benzpyrenes	nd	nd	nd	nd	nd	nd	nd
C_2- Benzofluoranthenes/Benzpyrenes	nd	nd	nd	nd	nd	nd	nd
Indeno(1,2,3-cd)pyrene	0.14	nd	0.29	0.30	0.17	nd	nd
Dibenzo(a,h)anthracene	nd	nd	nd	0.05	nd	nd	nd
Benzo(ghi)perylene	0.14	nd	0.25	0.27	0.13	nd	nd
Total EPA 16	1.4	1.7	1.03	1.7	1.3	0.11	0.33
4-6 Ring PAH/NPD	0.28	0.19	-	0.85	13.00	0.41	3.30

nd = not detected

5. Conclusions

- TOE concentrations in the sediments range from 0.69µg/g at Station 17 to 13µg/g at Stations 25B and the S10 Duplicate. Concentrations of TOE in these samples are considered consistent with 'background' levels previously seen further offshore around the Corrib field development.

- The GC traces preclude the presence of the synthetic base oils previously identified in the Corrib field ("Ecosol", "Ecomul" and "Esterkleen). There was also no evidence for the presence of base oils of mineral origin (such as "low toxicity Oil Based Muds" or diesel related hydrocarbons from shipping related activities).

- The concentrations of naphthalenes, phenanthrenes and dibenzothiophenes (NPDs) in the sediments, which are generally thought to be of petrogenic origin, range from 0.03ng/g (ppb; Station 26) to 11ng/g (Station S6). The concentrations of the EPA 16 PAHs range from 0.11ng/g (Station 15) to 2.8ng/g (Station 32A). These concentrations are generally similar to those previously observed in the 'background' sample taken around the Corrib field development, and are also generally similar to the background levels found in North Atlantic sediments.

6. References

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(Block 18/20-P4), December 2006. Survey report for Shell E&P and RSK.

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APPENDIX I

Total Organic Extractables (TOE)

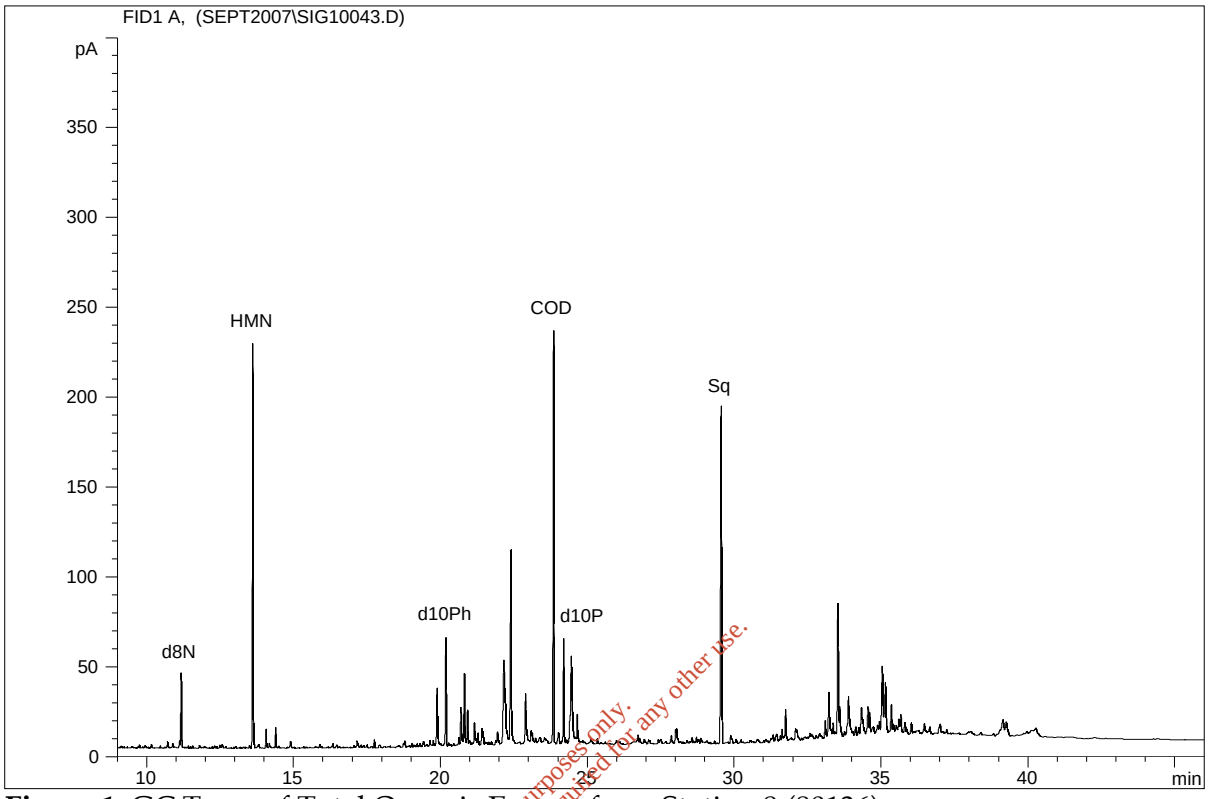


Figure 1: GC Trace of Total Organic Extract from Station 8 (80136)

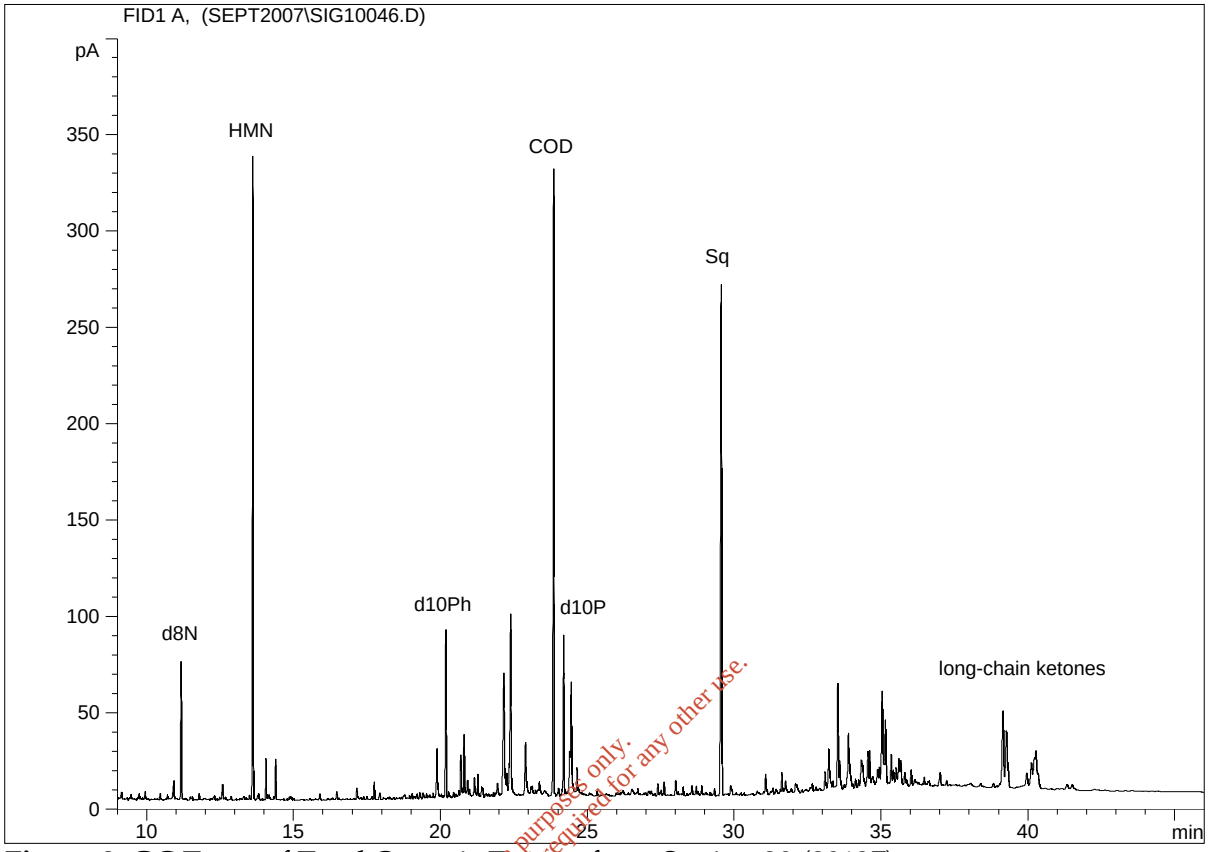


Figure 2: GC Trace of Total Organic Extract from Station 20 (80137)

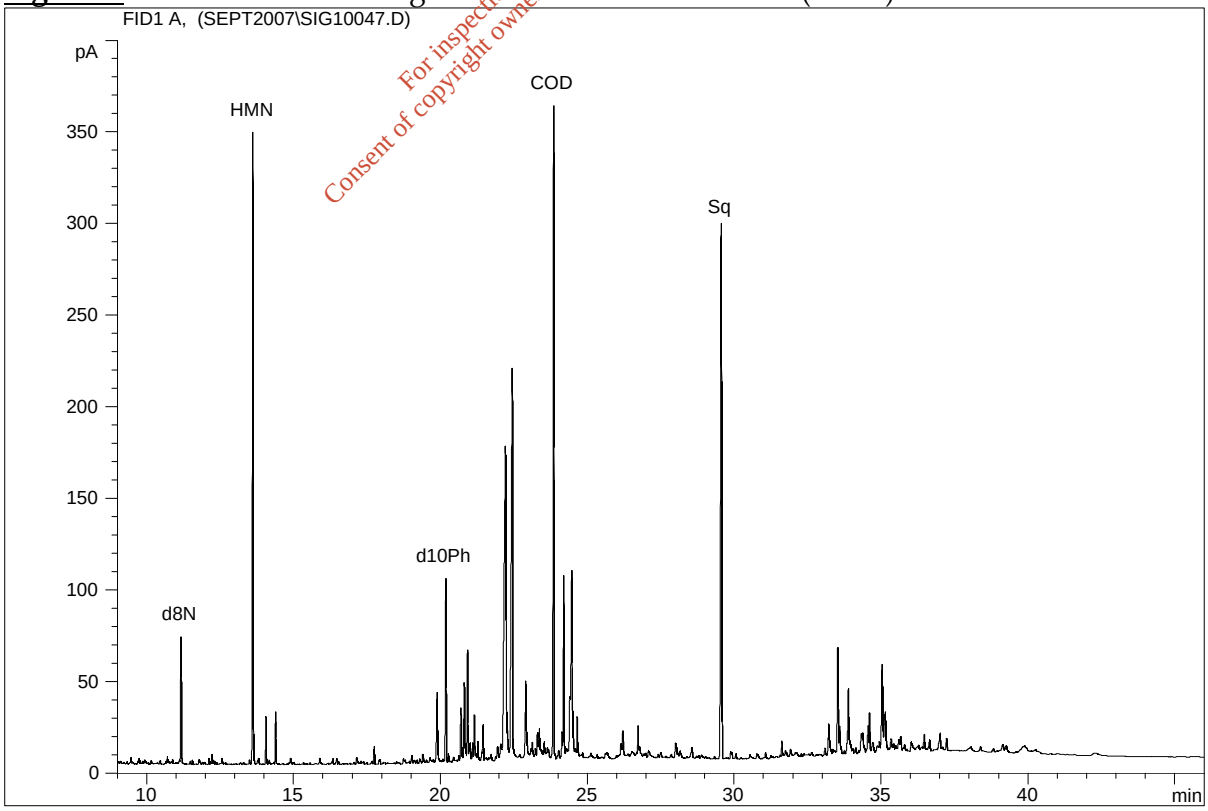


Figure 3: GC Trace of Total Organic Extract from Station 25 (80138)

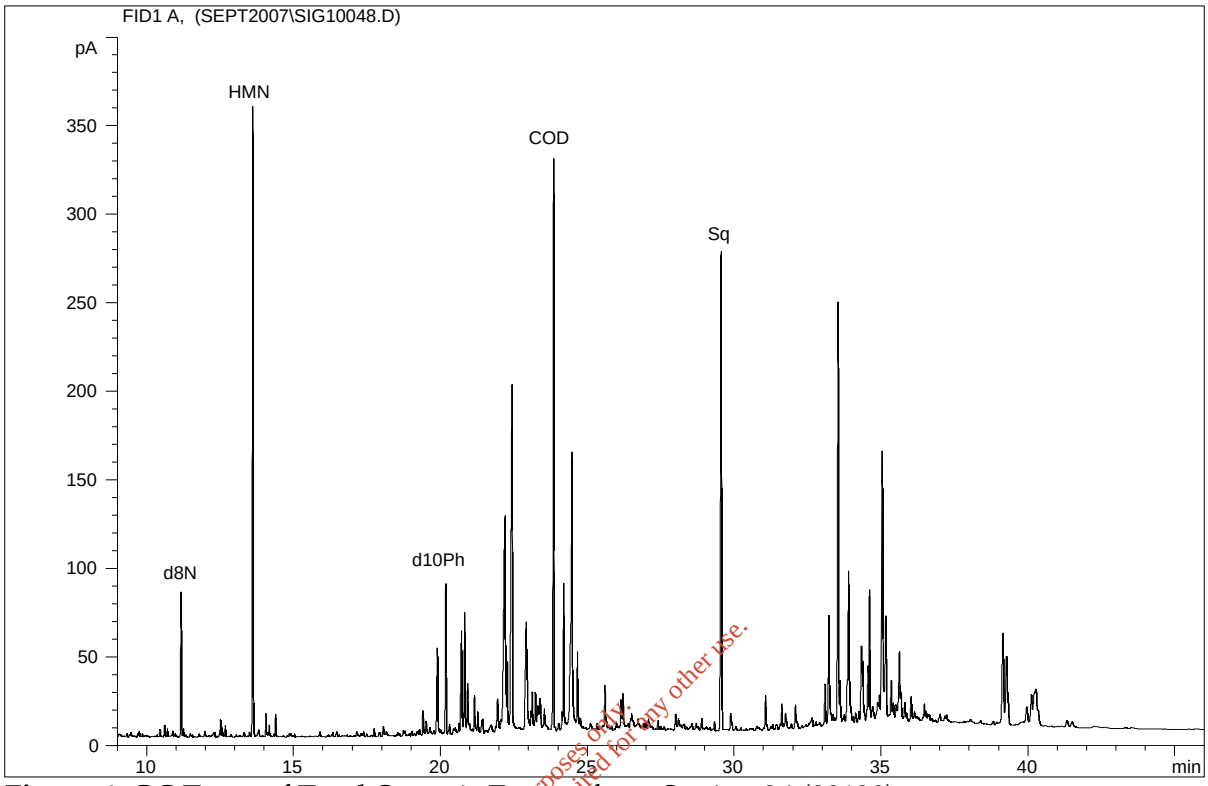


Figure 4: GC Trace of Total Organic Extract from Station 26 (80139)

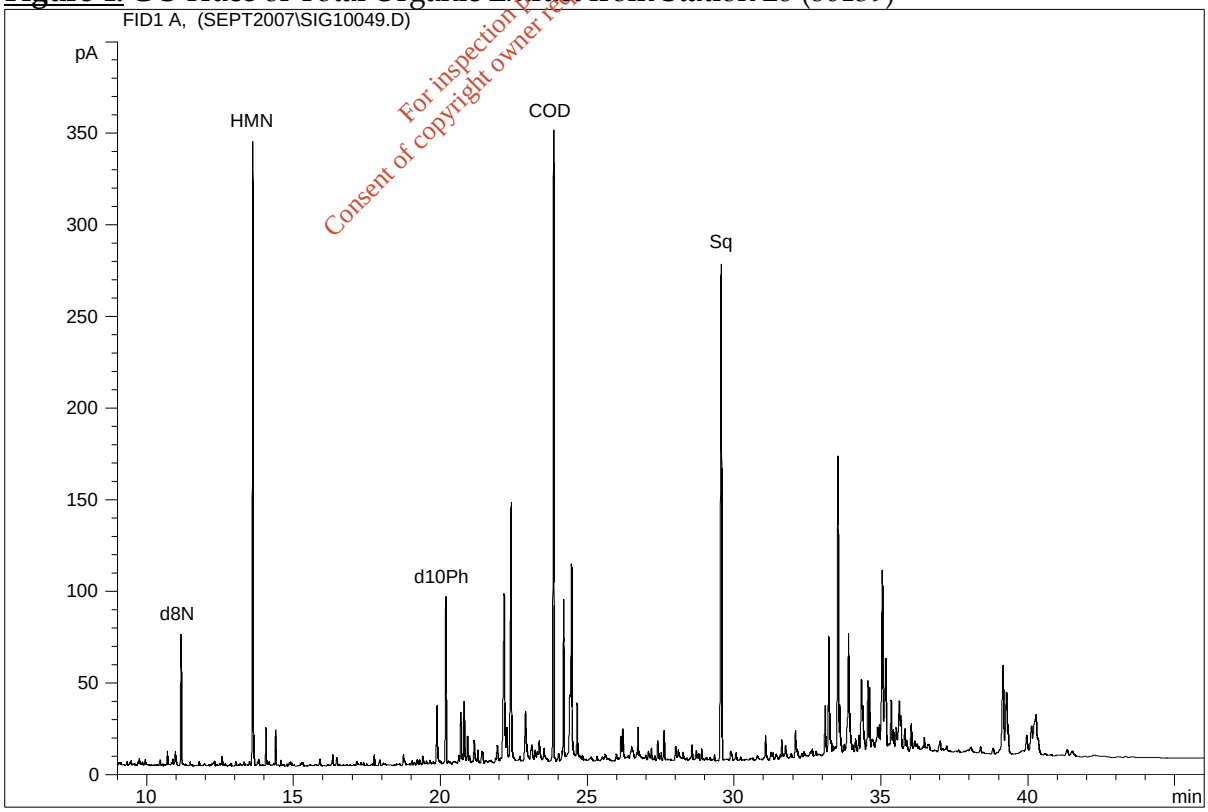


Figure 5: GC Trace of Total Organic Extract from Station 27 (80140)

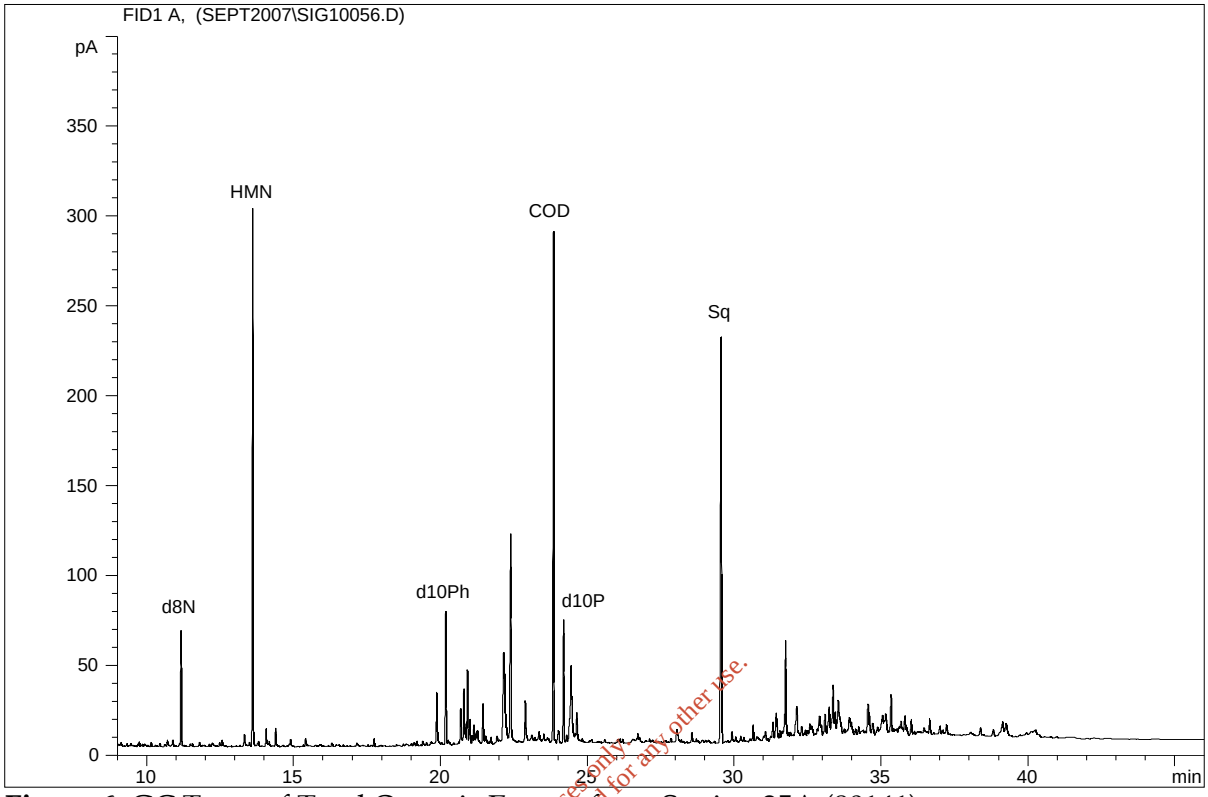


Figure 6: GC Trace of Total Organic Extract from Station 25A (80141)

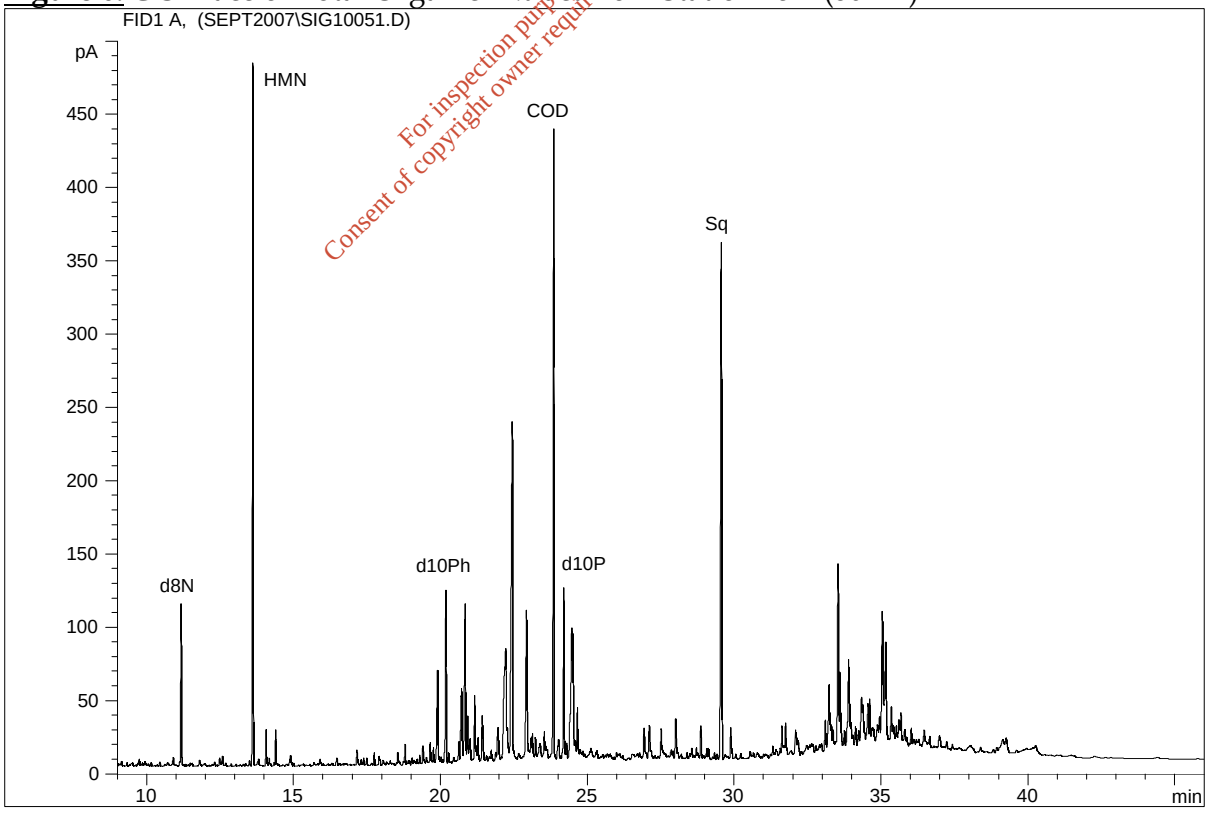


Figure 7: GC Trace of Total Organic Extract from Station 25B (80142)

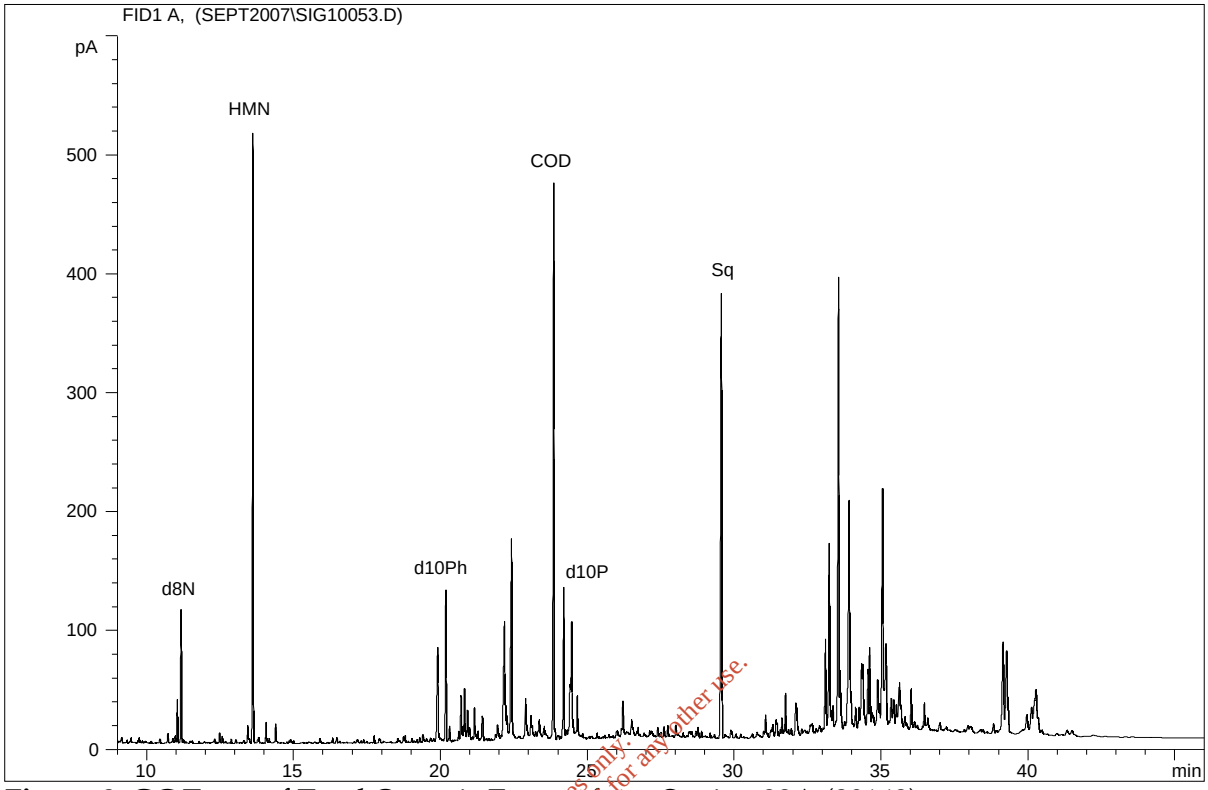


Figure 8: GC Trace of Total Organic Extract from Station 32A (80143)

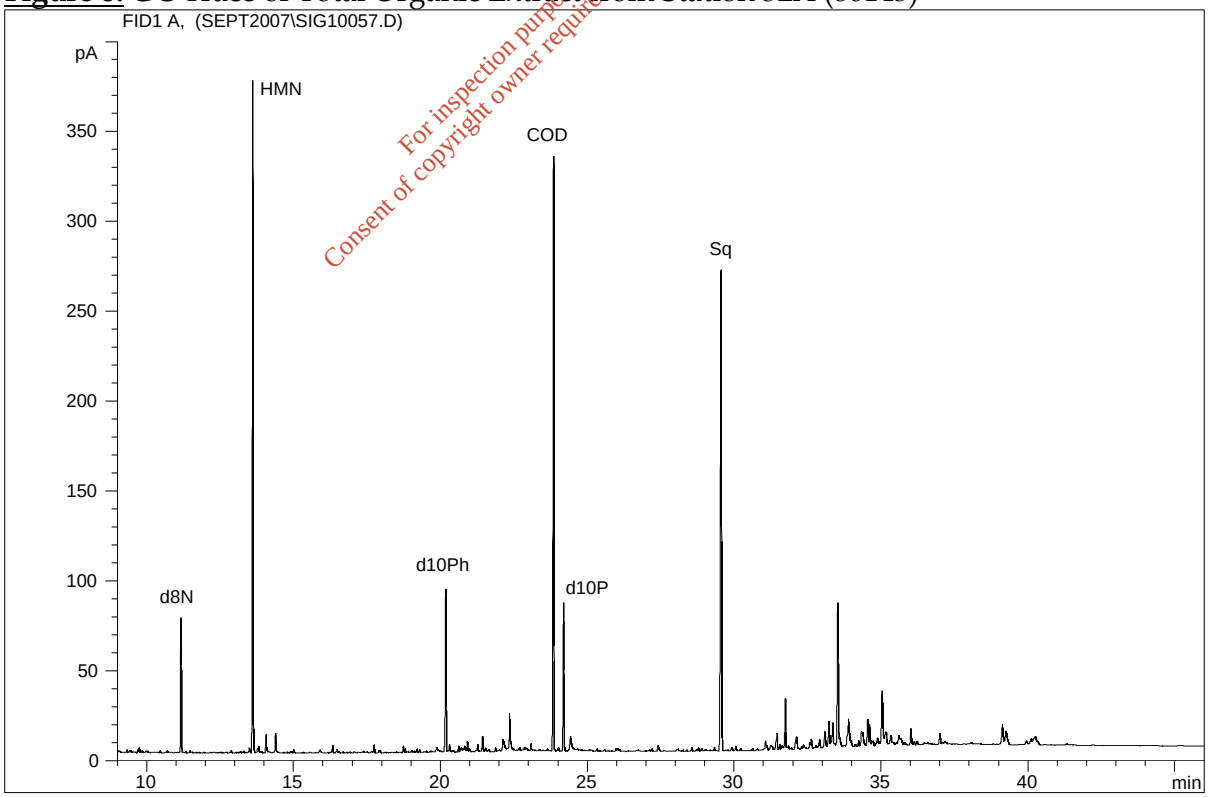


Figure 9: GC Trace of Total Organic Extract from Station 1 (80144)

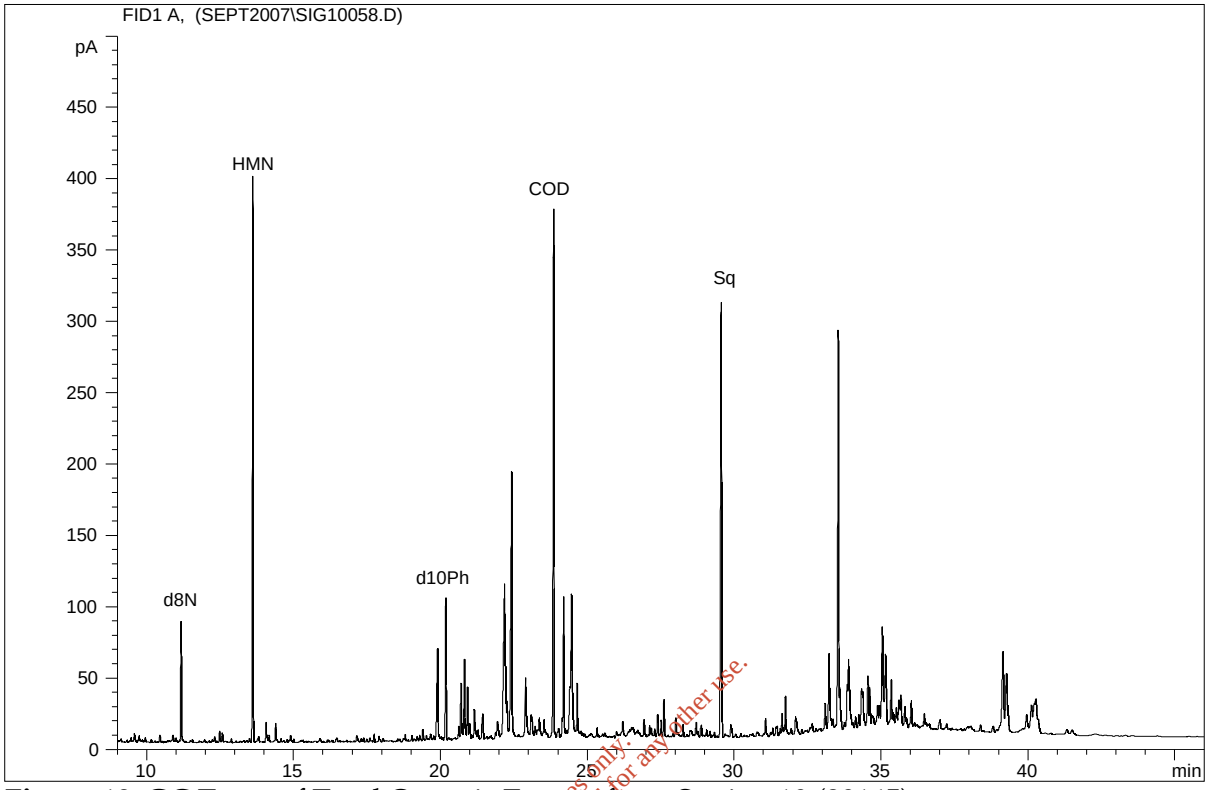


Figure 10: GC Trace of Total Organic Extract from Station 10 (80145)

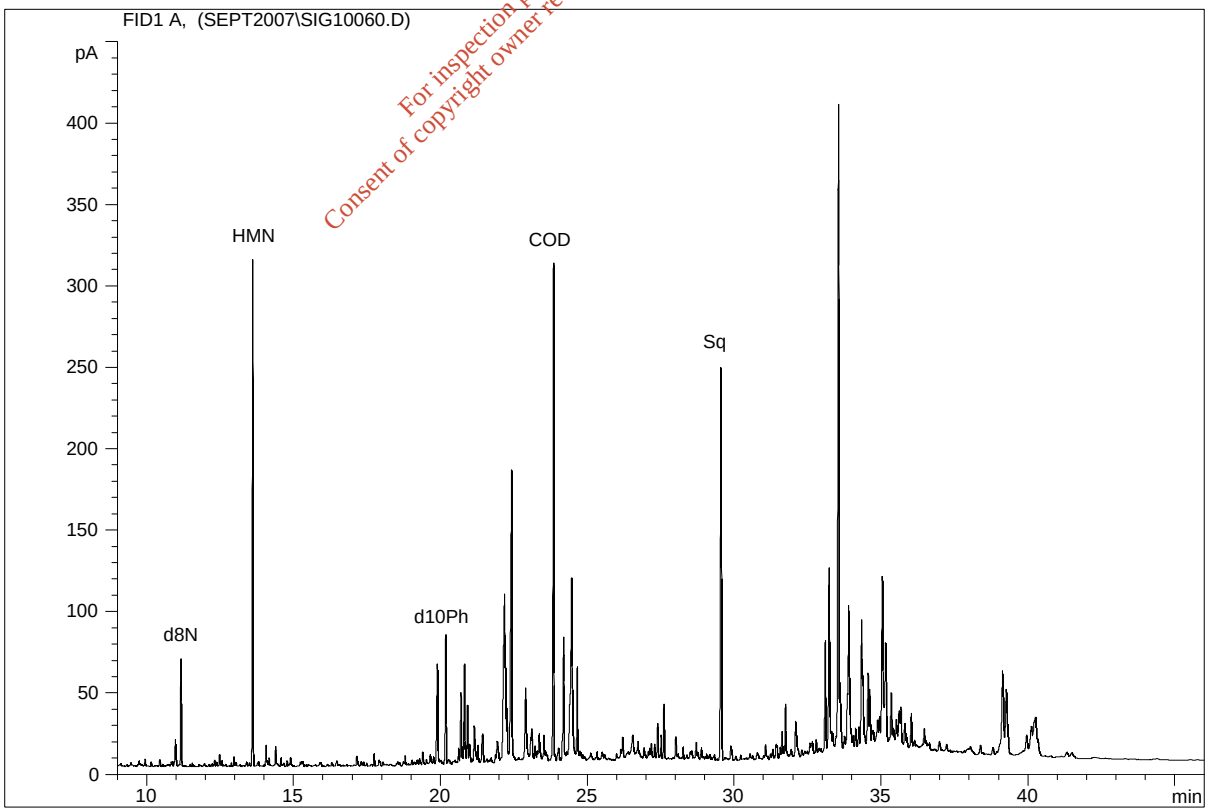


Figure 11: GC Trace of Total Organic Extract from Station 10 Duplicate (80146)

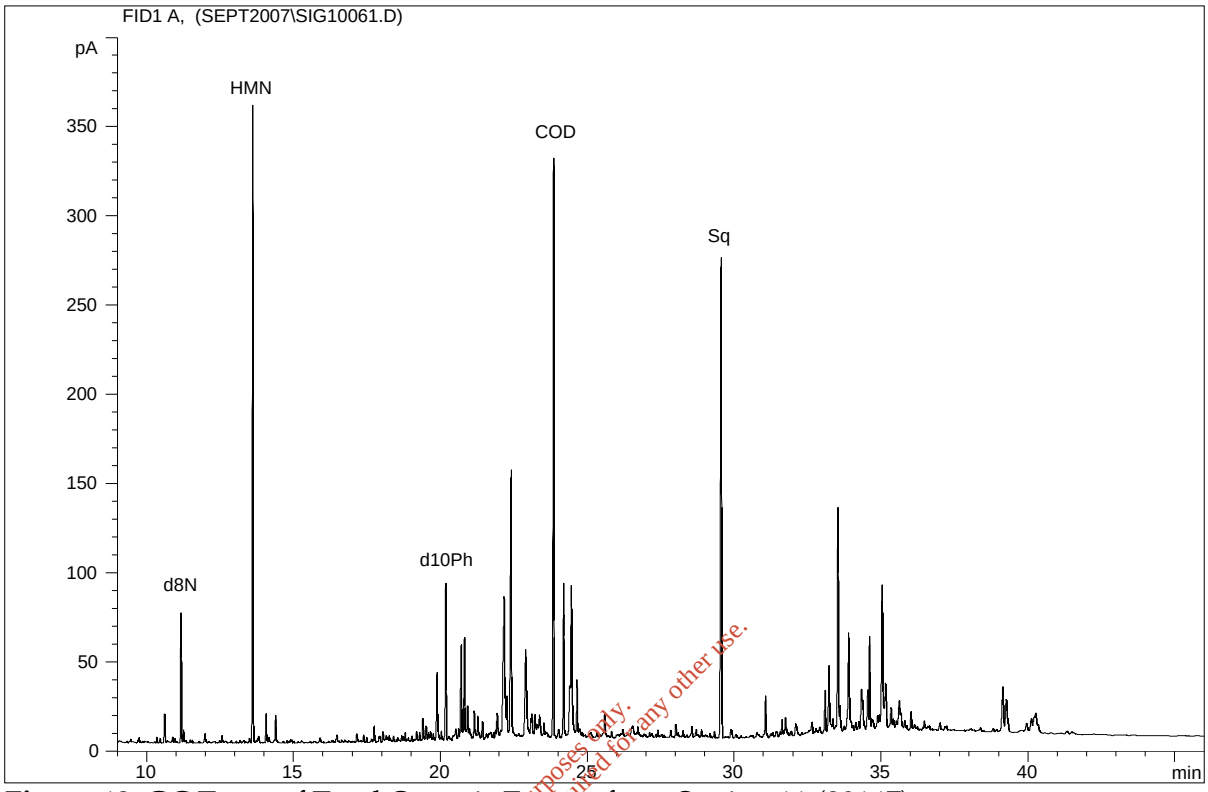


Figure 12: GC Trace of Total Organic Extract from Station 11 (80147)

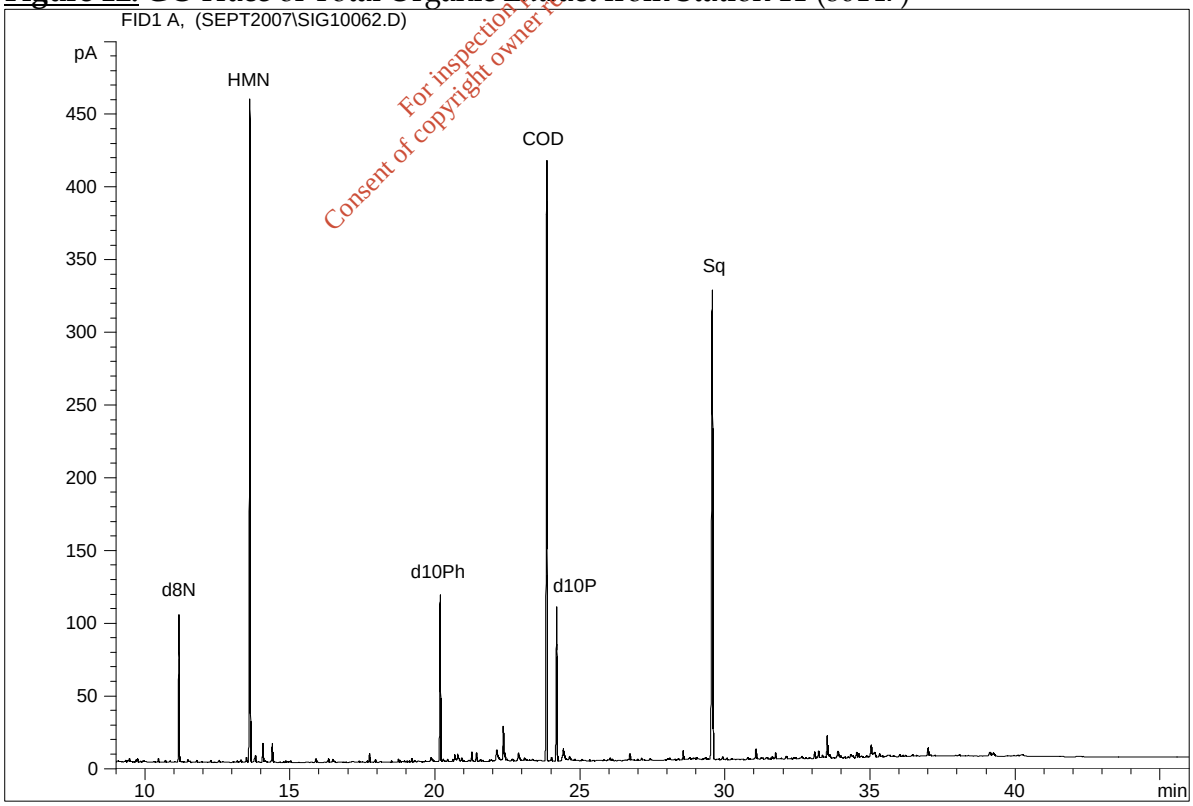


Figure 13: GC Trace of Total Organic Extract from Station 15 (80148)

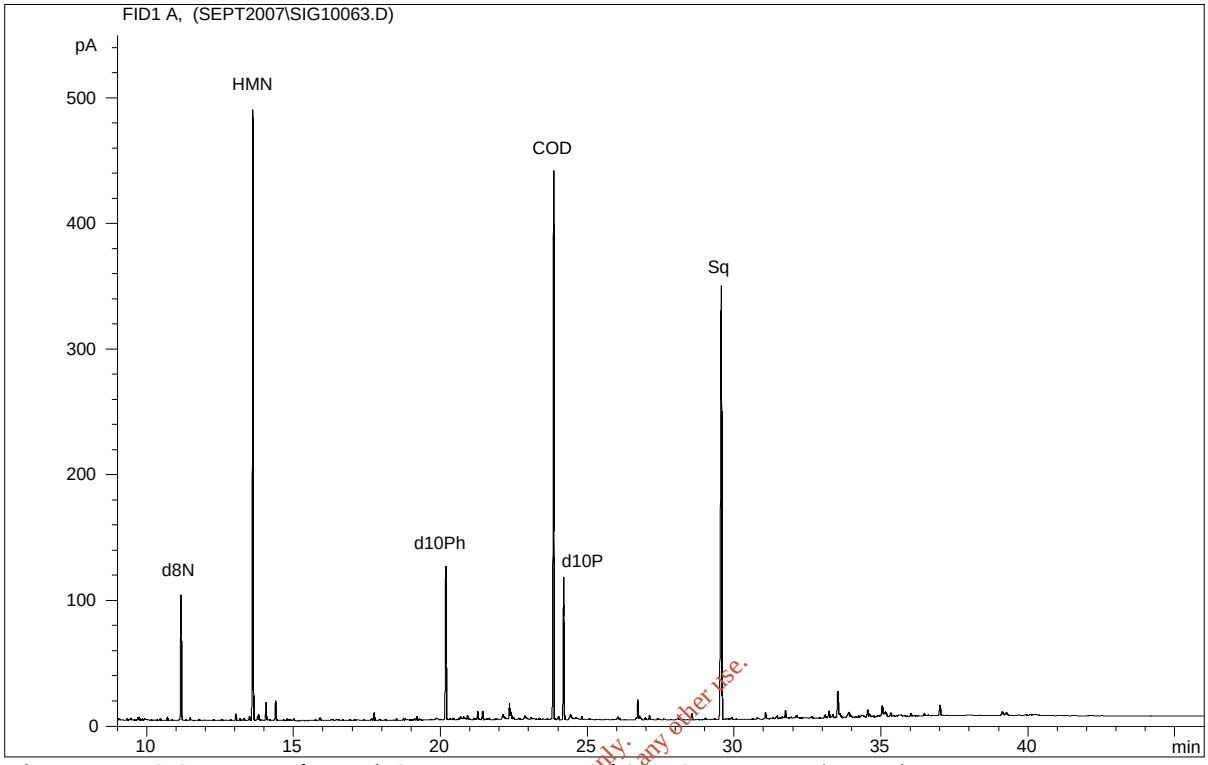


Figure 14: GC Trace of Total Organic Extract from Station 17 (80149)

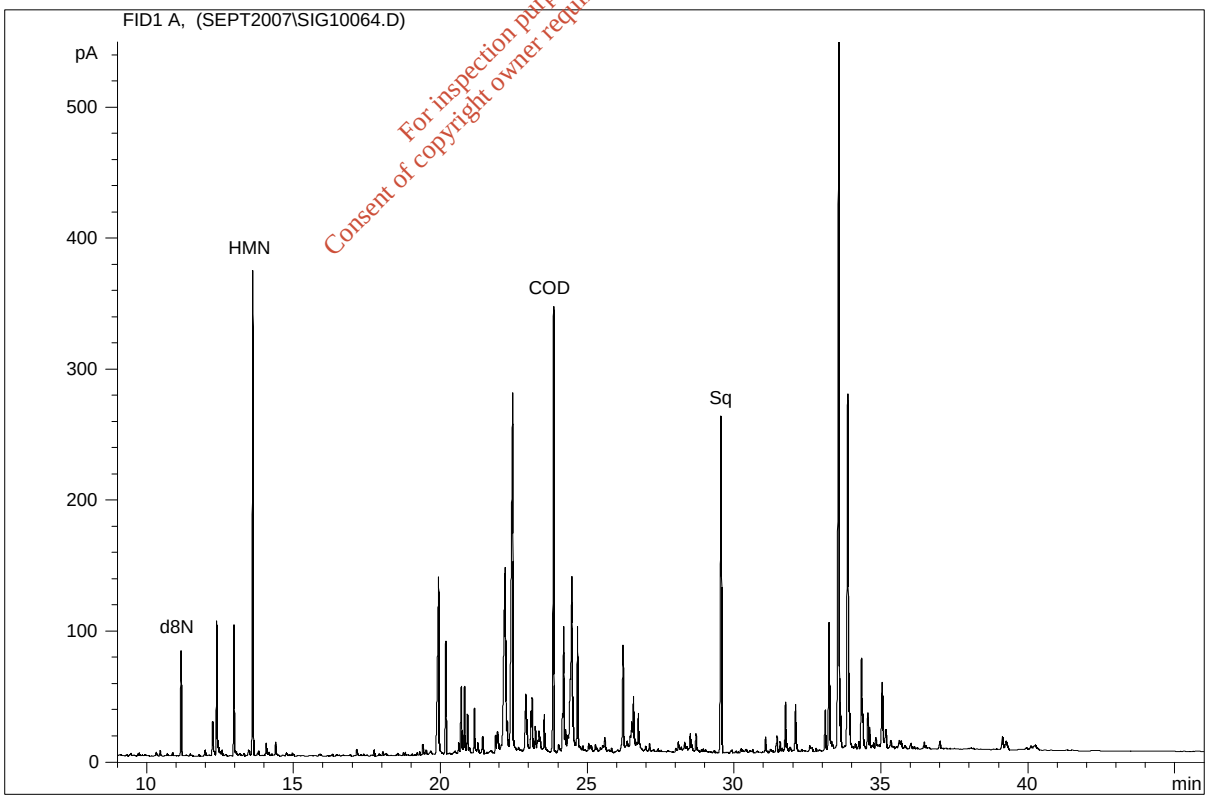


Figure 15: GC Trace of Total Organic Extract from Station 2 (80150)

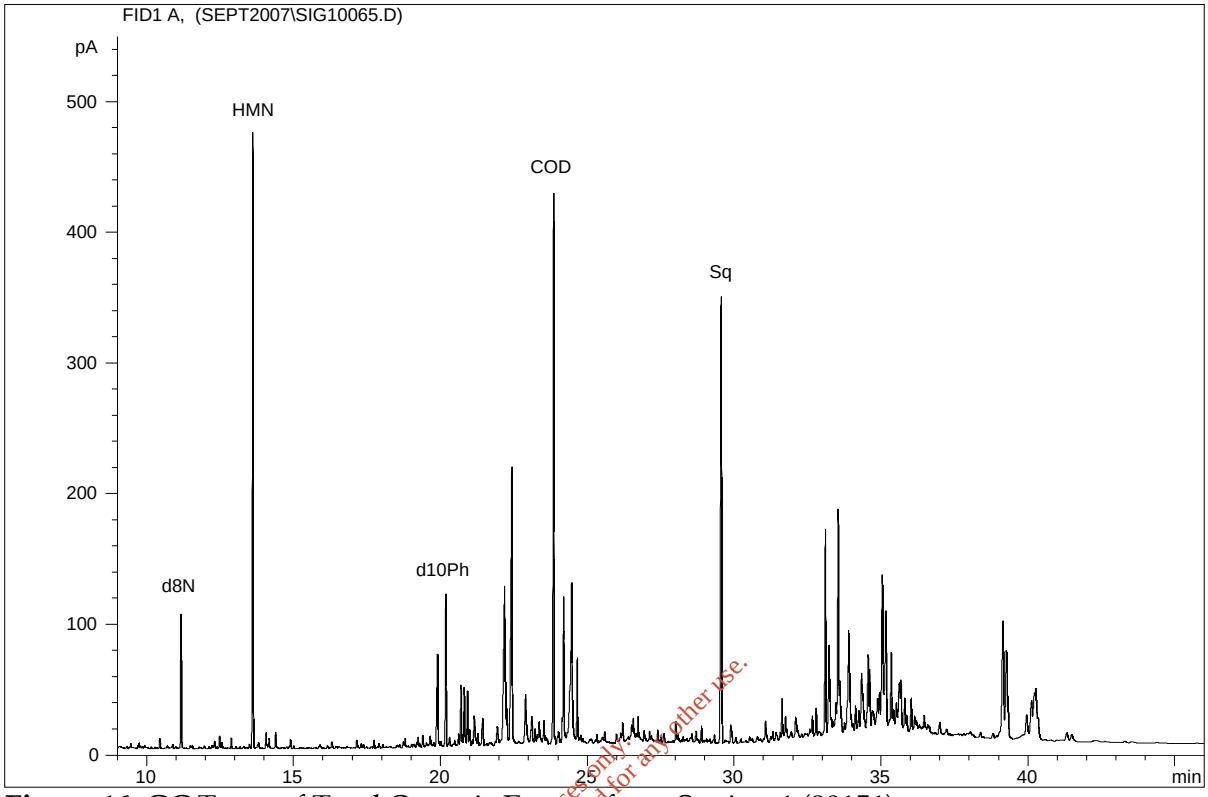


Figure 16: GC Trace of Total Organic Extract from Station 4 (80151)

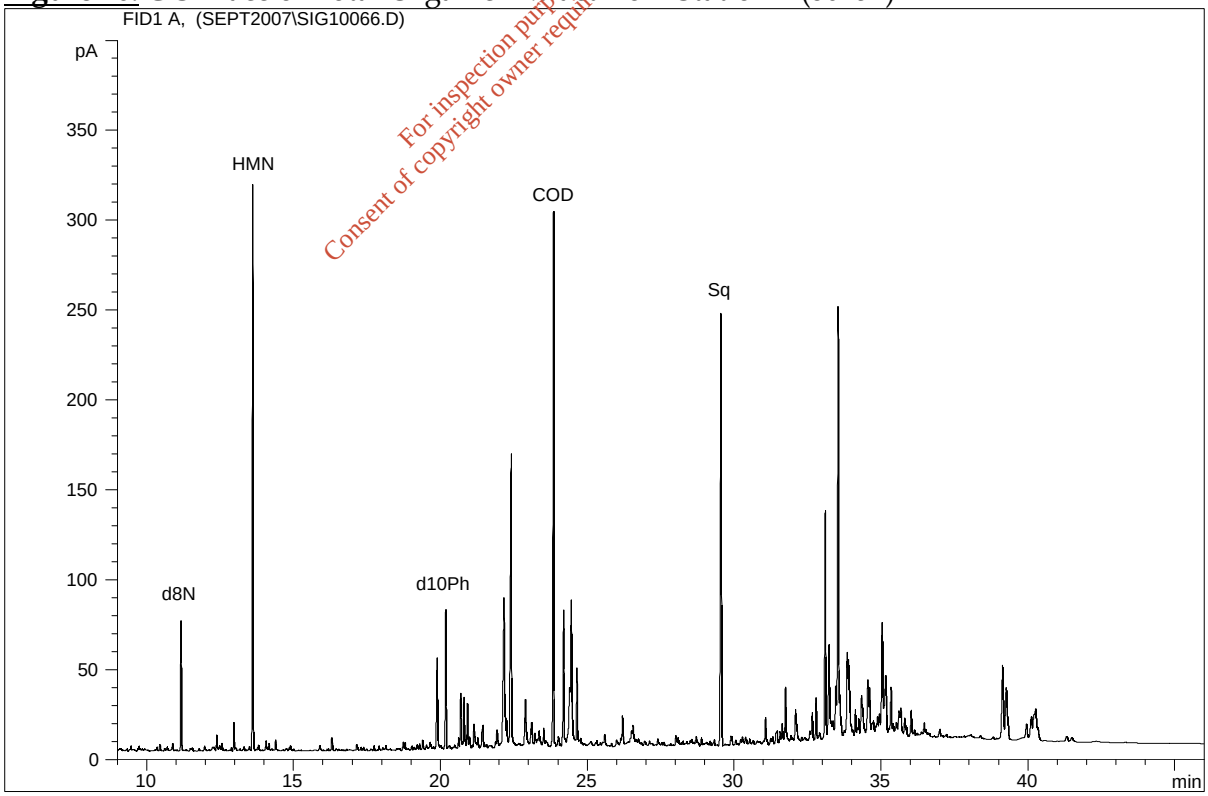


Figure 17: GC Trace of Total Organic Extract from Station 5R (80152)

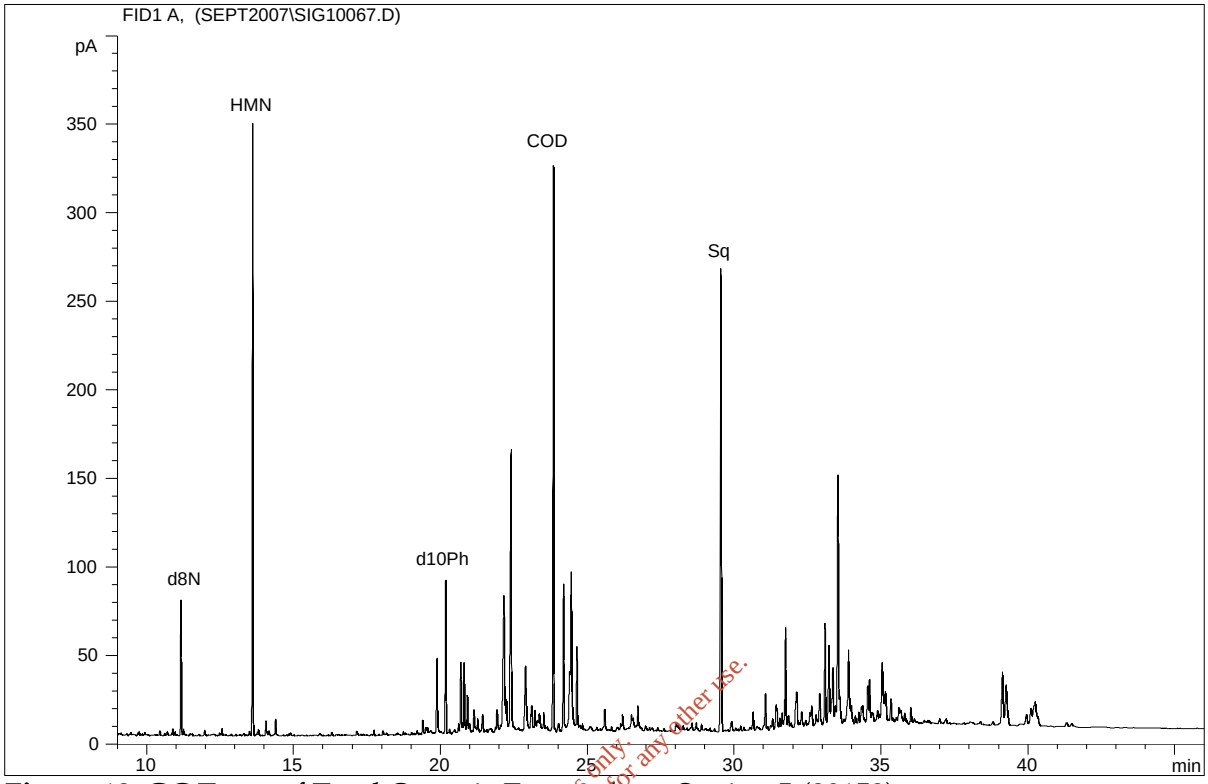


Figure 18: GC Trace of Total Organic Extract from Station 5 (80153)

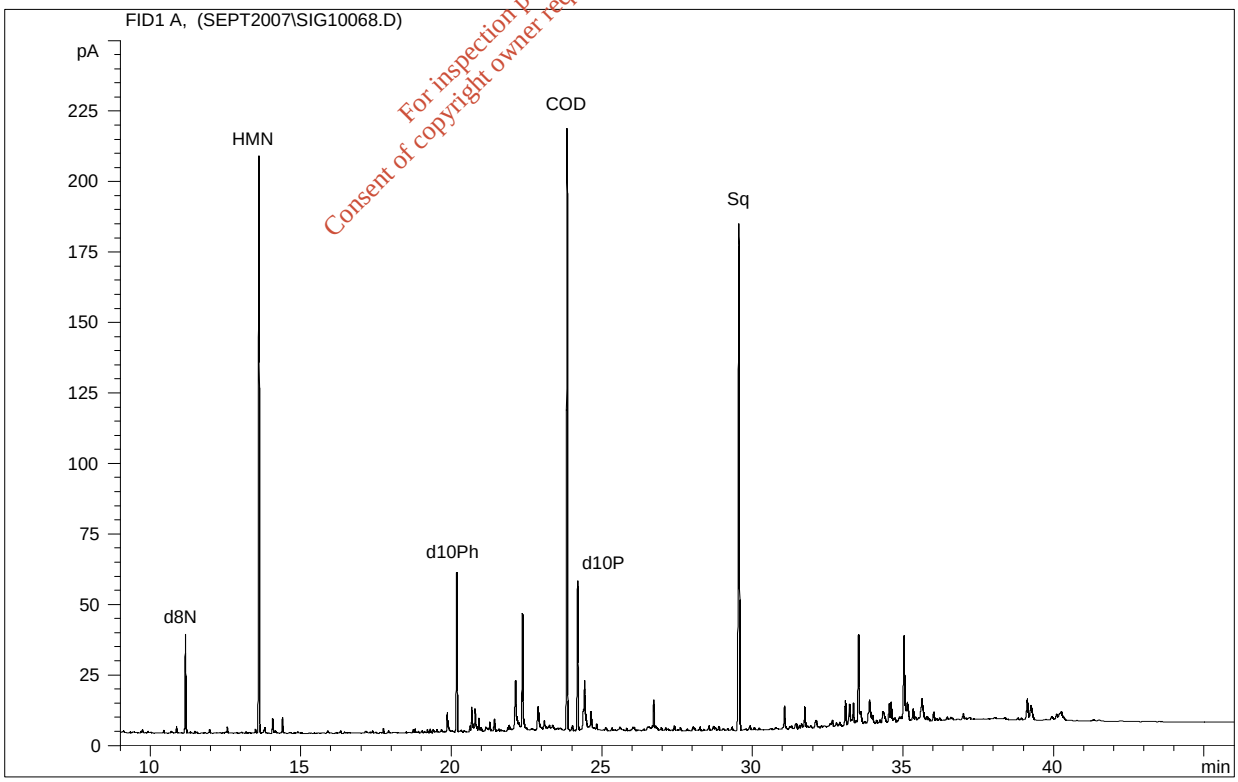


Figure 19: GC Trace of Total Organic Extract from Station 6 (80154)

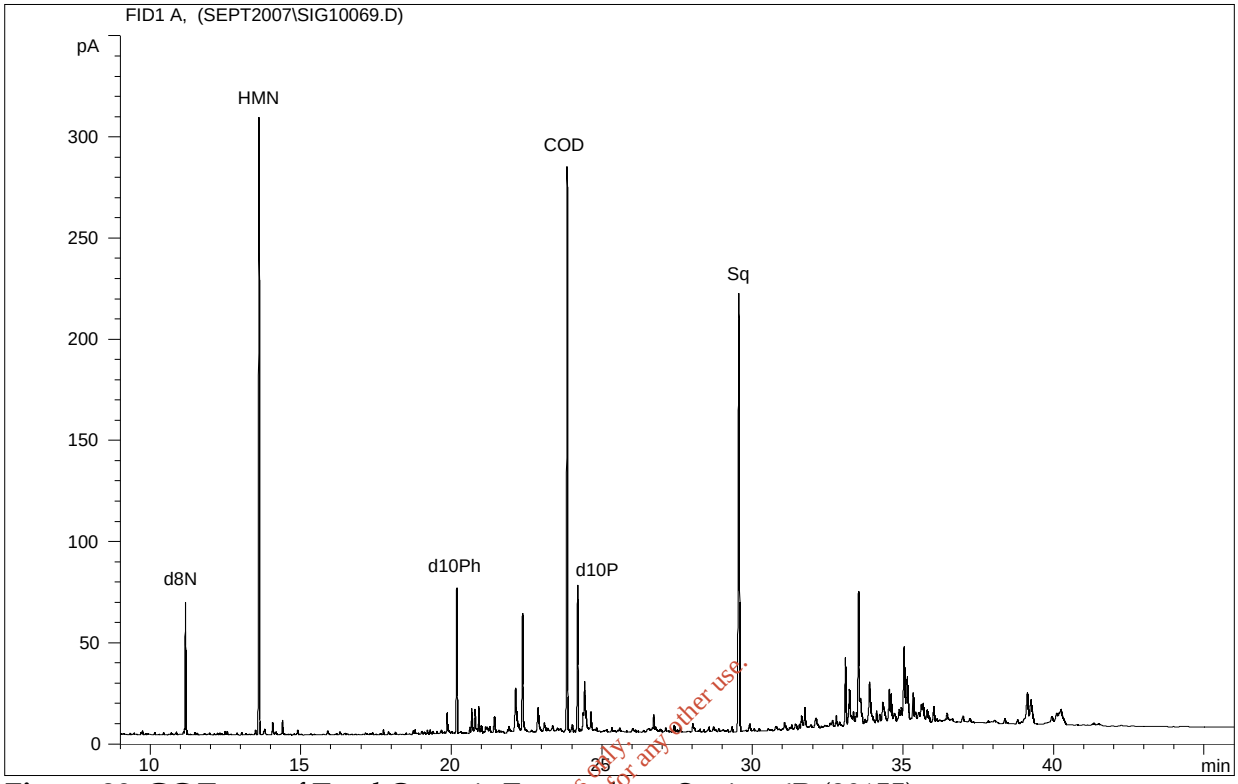


Figure 20: GC Trace of Total Organic Extract from Station 6R (80155)

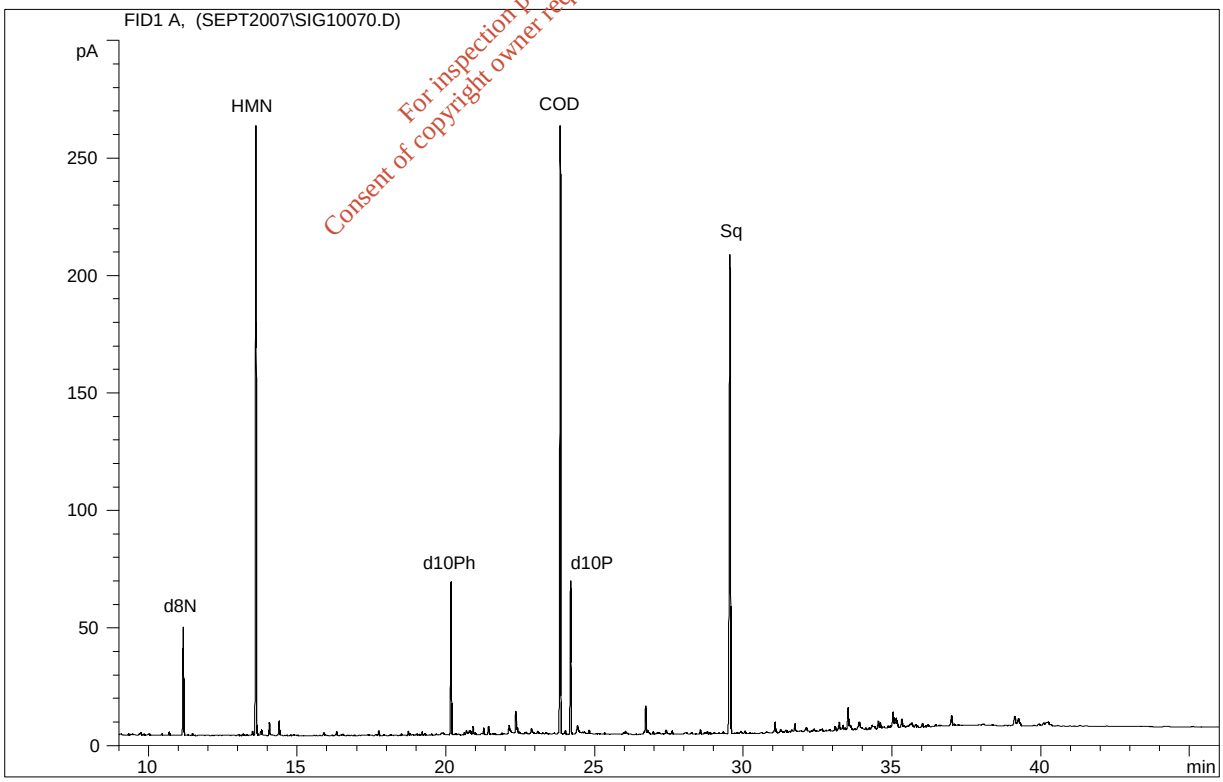


Figure 21: GC Trace of Total Organic Extract from Station 9 (80156)

APPENDIX II

Quality Assurance Analysis for

Total Organic Extractables (TOE)

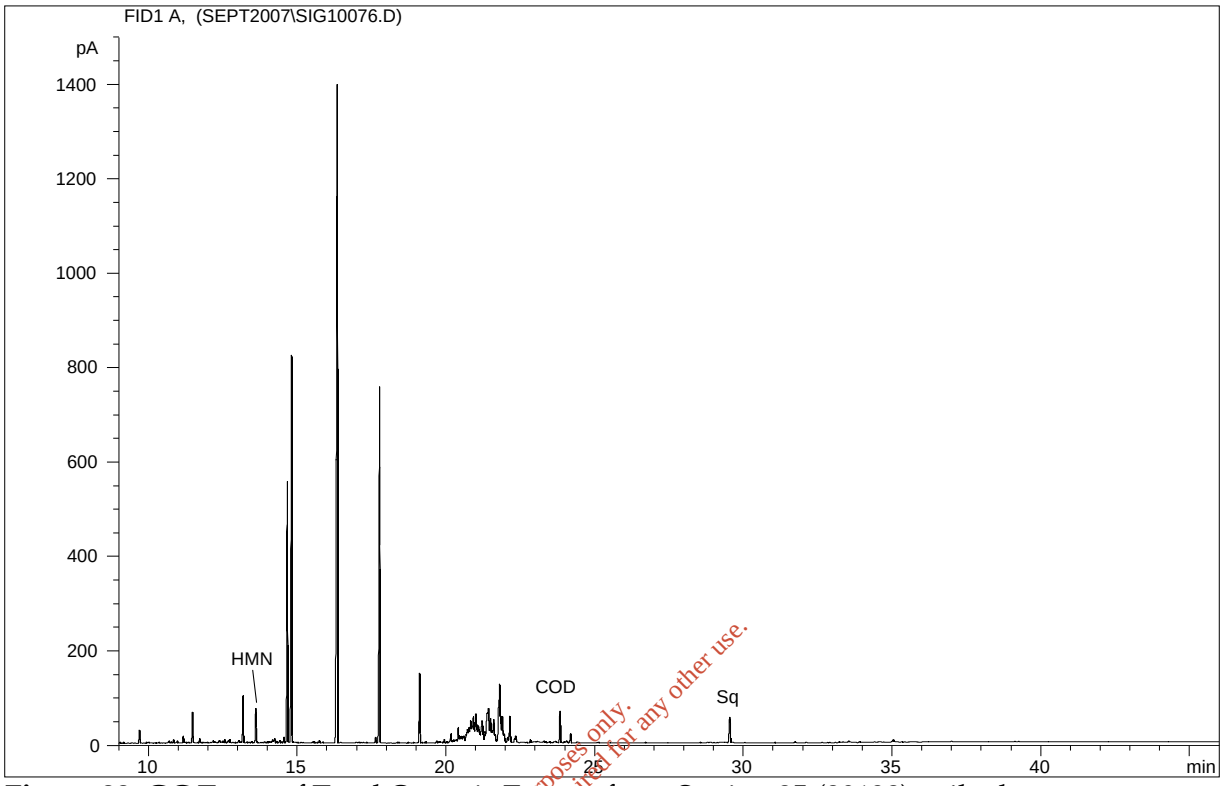


Figure 22: GC Trace of Total Organic Extract from Station 25 (80138) spiked with Ecosol Base Oil

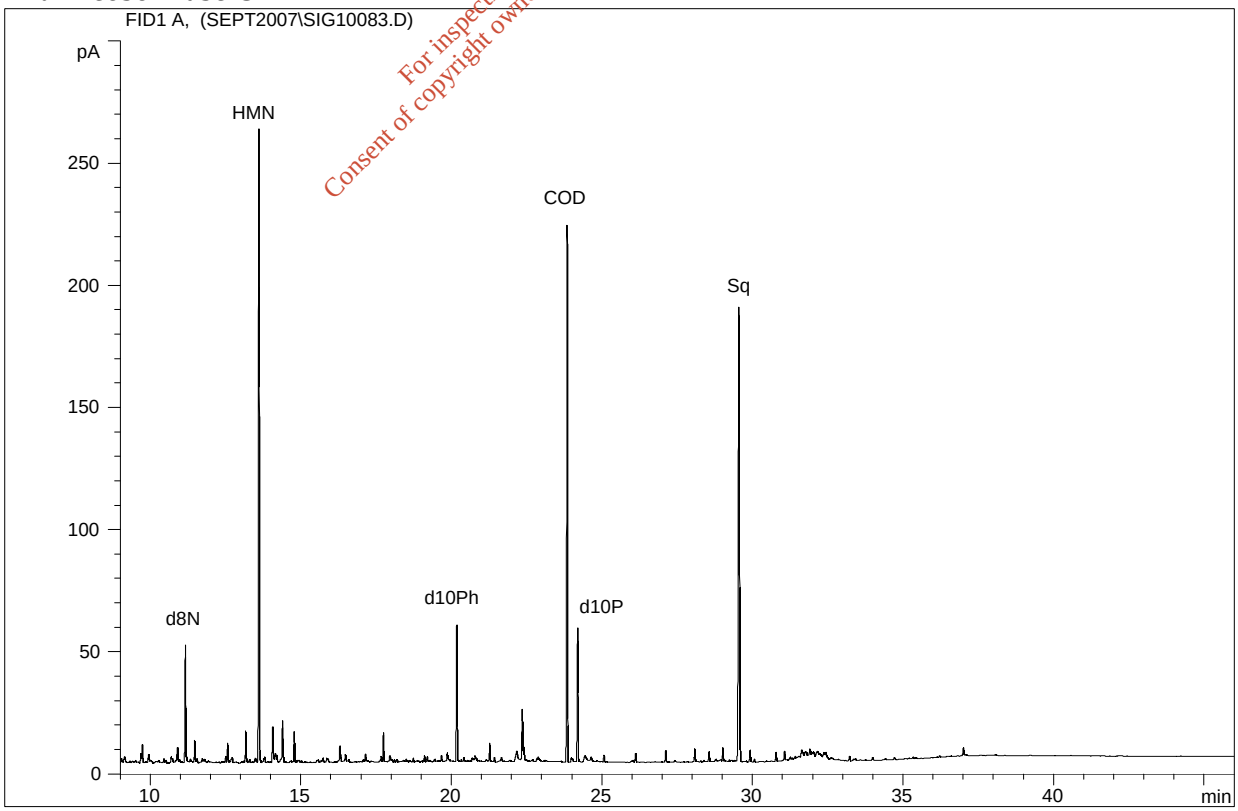


Figure 23: GC Trace of Total Organic Extract from Pre-Extracted Sediment 1

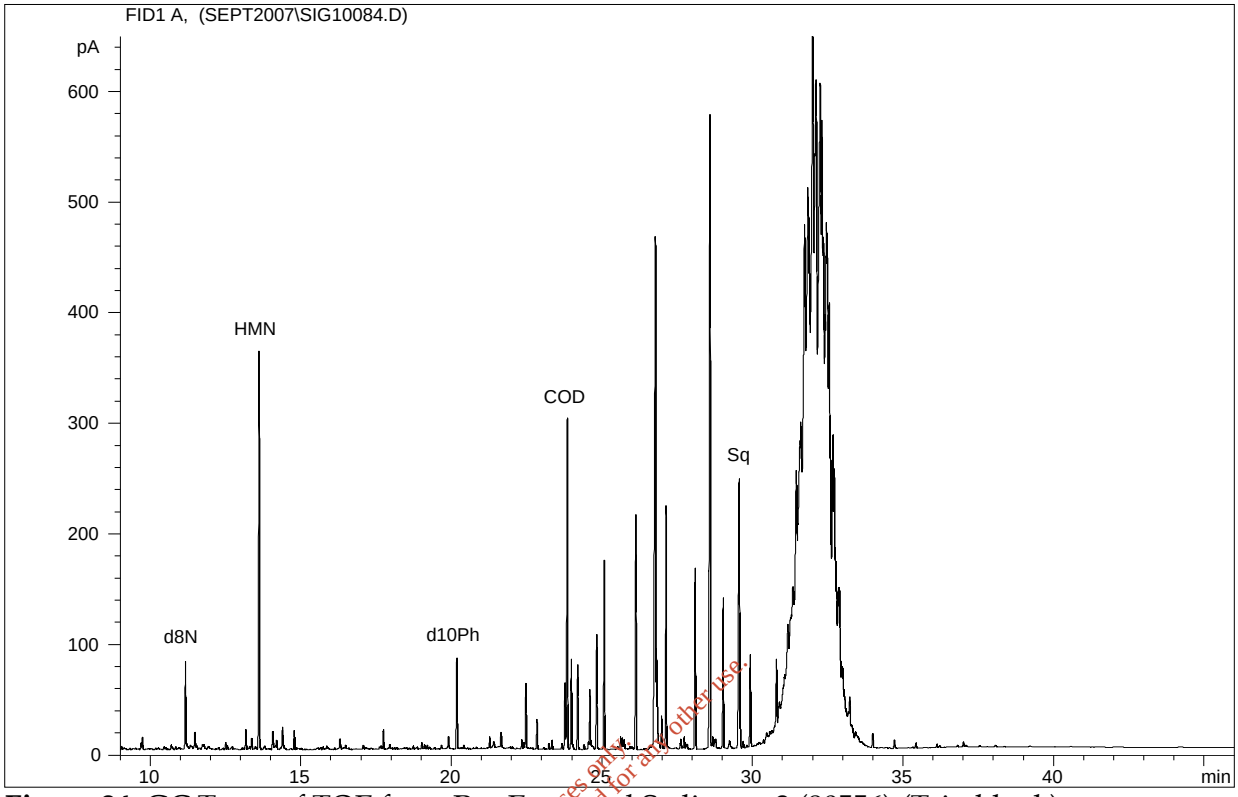


Figure 24: GC Trace of TOE from Pre-Extracted Sediment 2 (80556) (Trip blank)

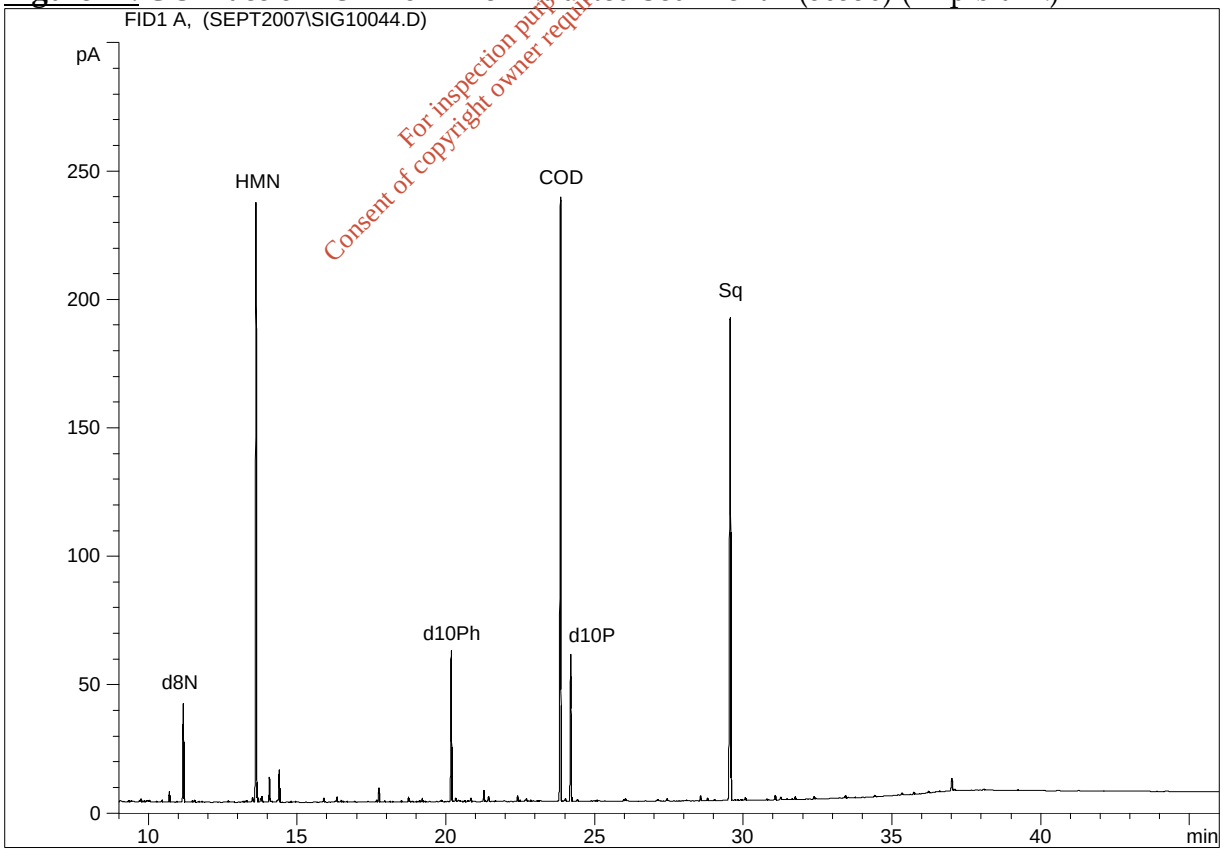


Figure 25: GC Trace of Total Organic Extract from Procedural Blank

APPENDIX III

Polycyclic Aromatic Hydrocarbons Total Ion Current (TIC)

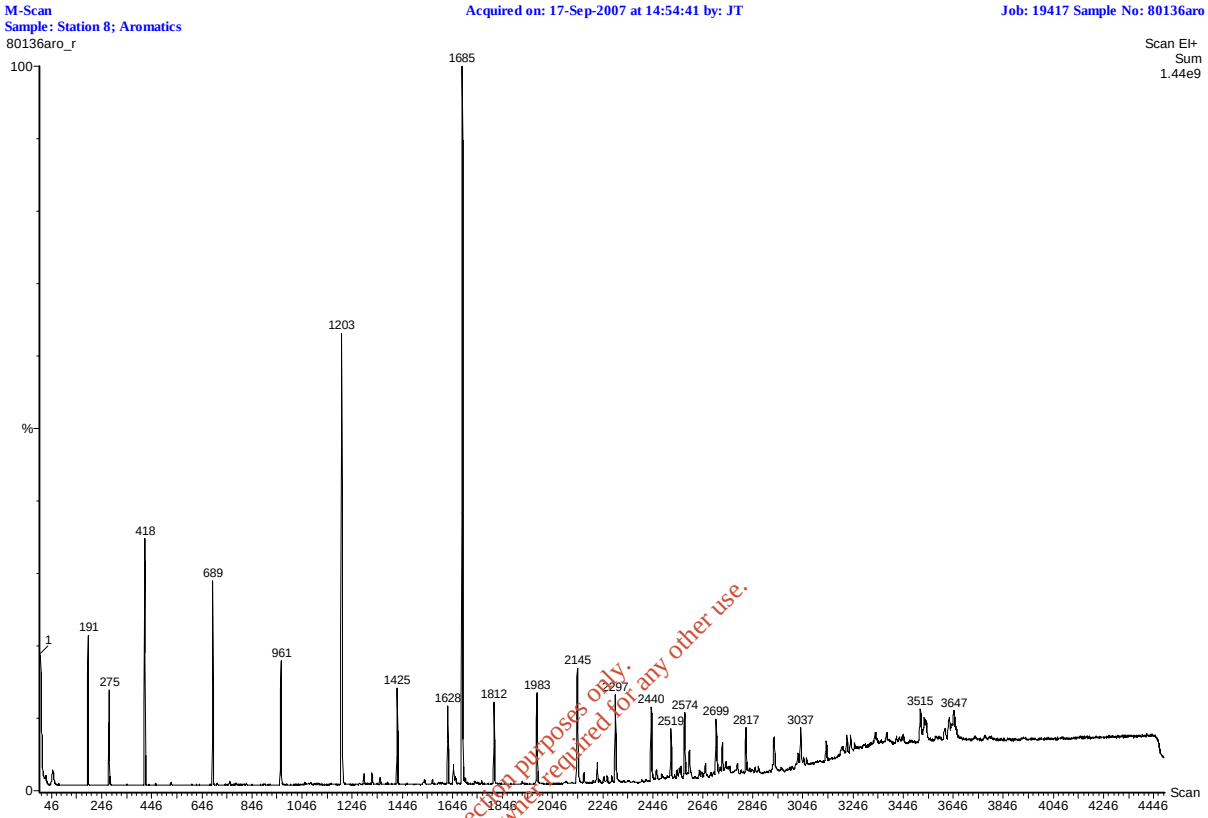


Figure 26: GC-MS TIC trace for aromatic hydrocarbon fraction, Station 8 (80136)

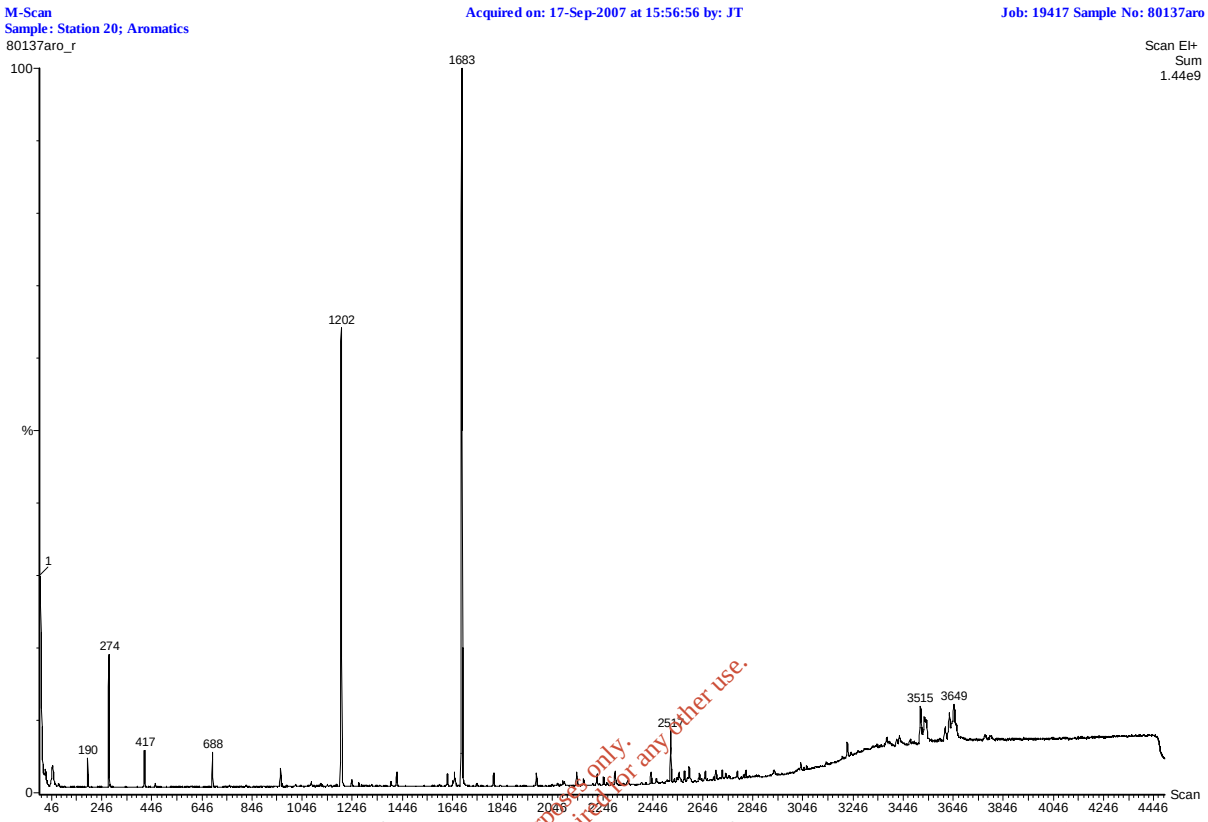


Figure 27: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 20 (80137)

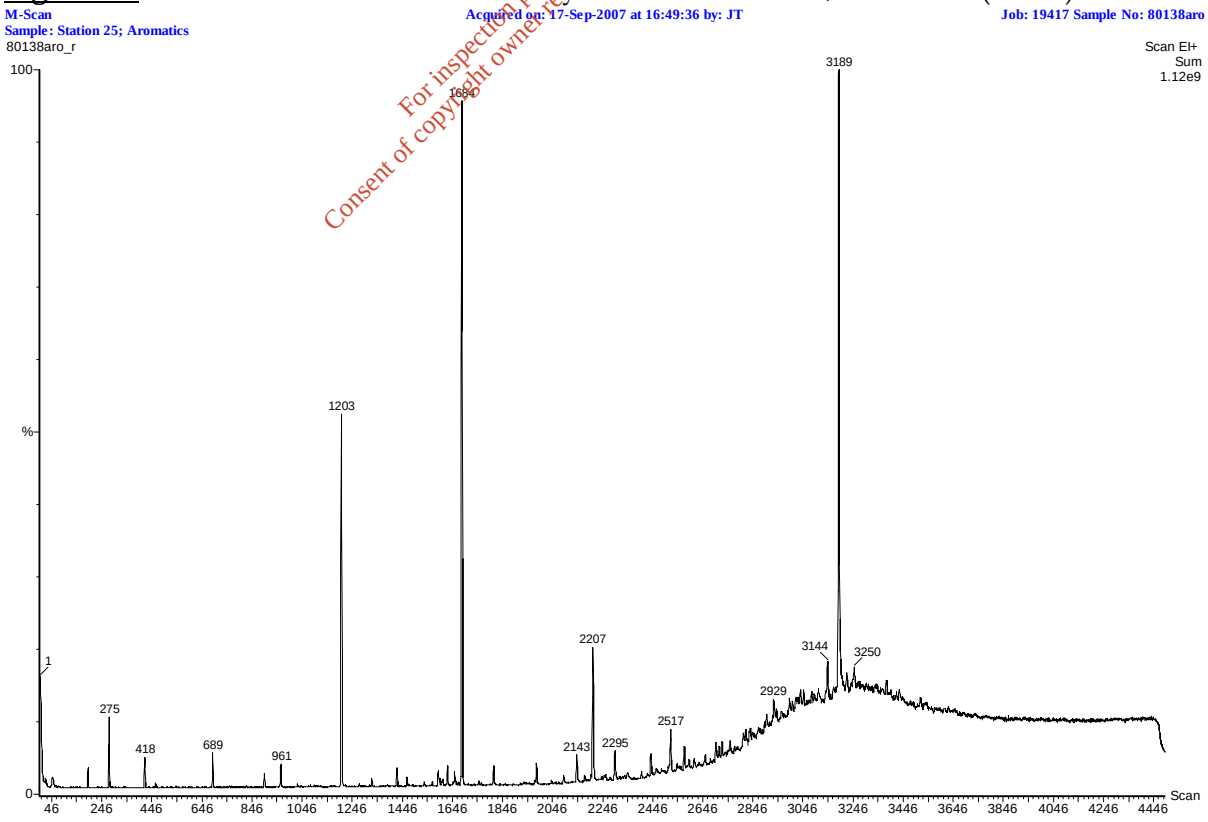


Figure 28: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 25 (80138)

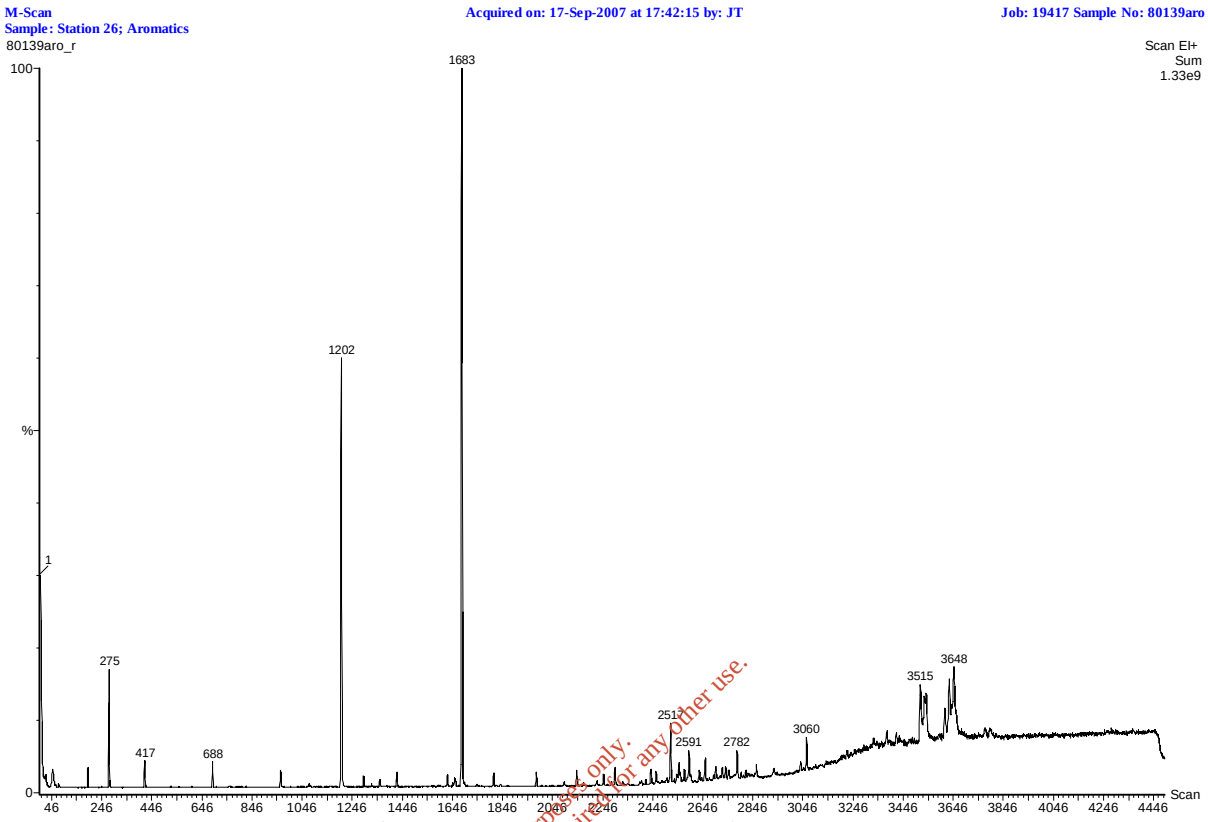


Figure 29: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 26 (80139)

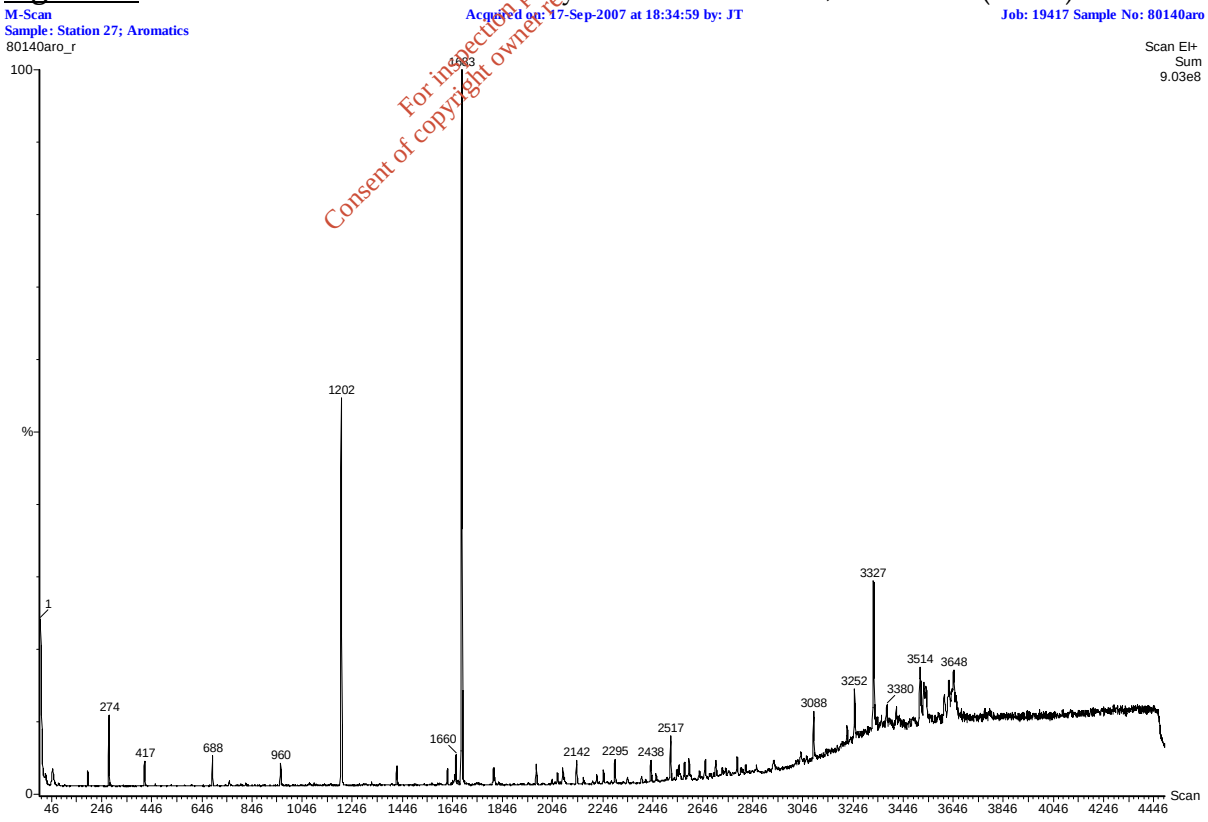


Figure 30: GC-MS TIC trace for aromatic hydrocarbon fraction, Station 27 (80140)

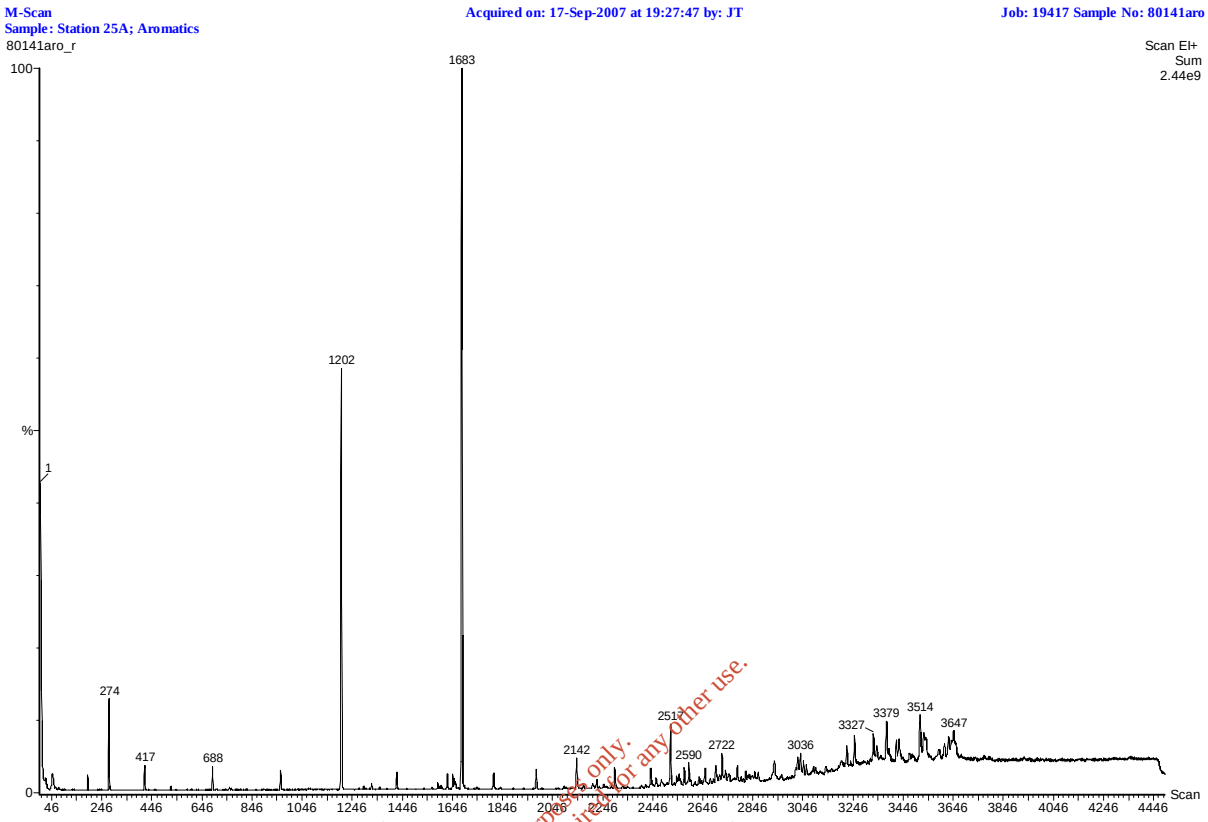


Figure 31: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 25A (80141)

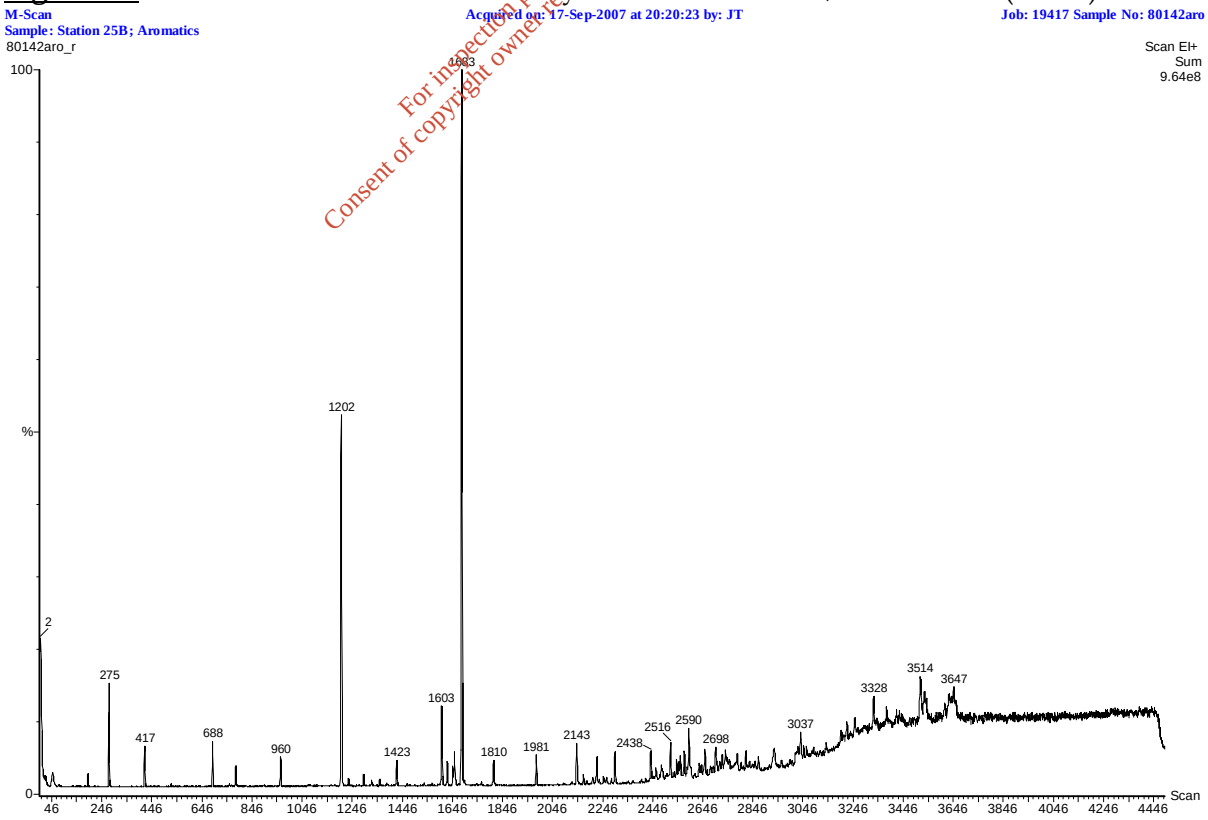


Figure 32: GC-MS TIC trace for aromatic hydrocarbon fraction, Station 25B (80142)

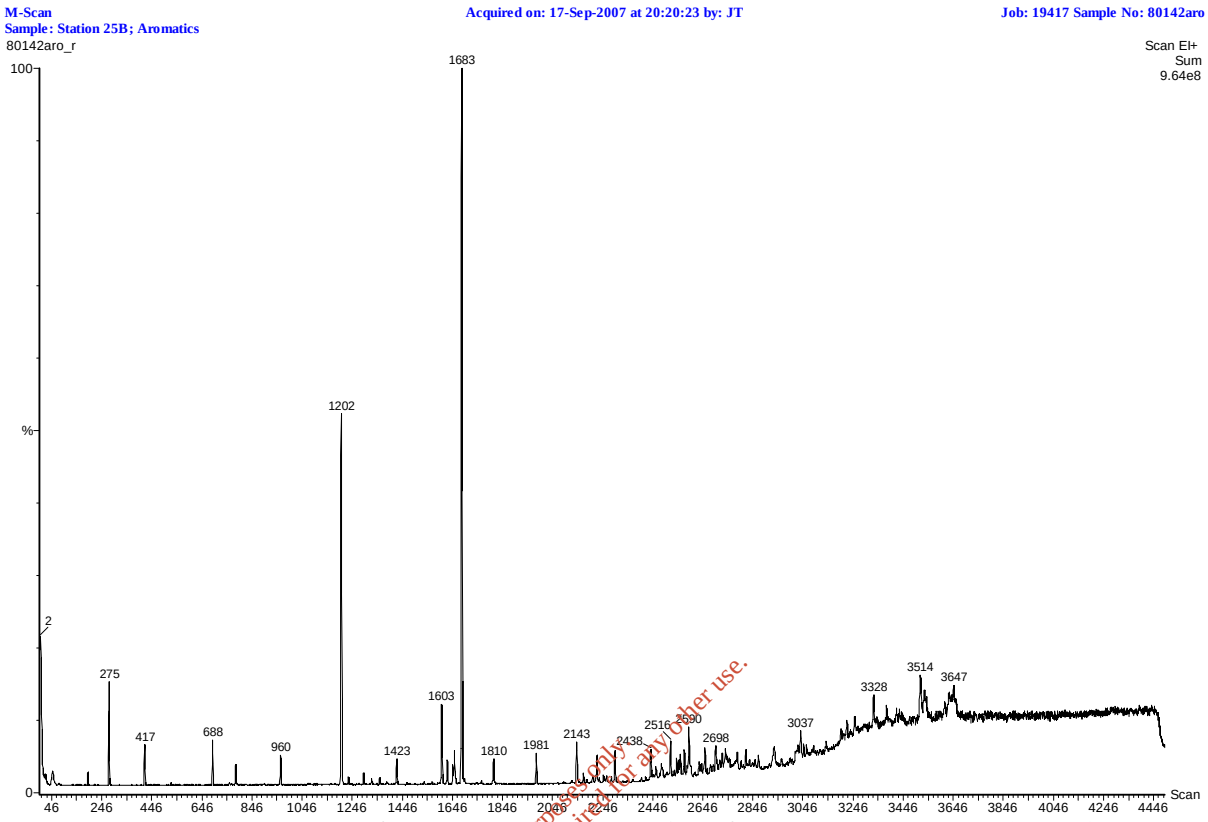


Figure 33: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 32A (80143)

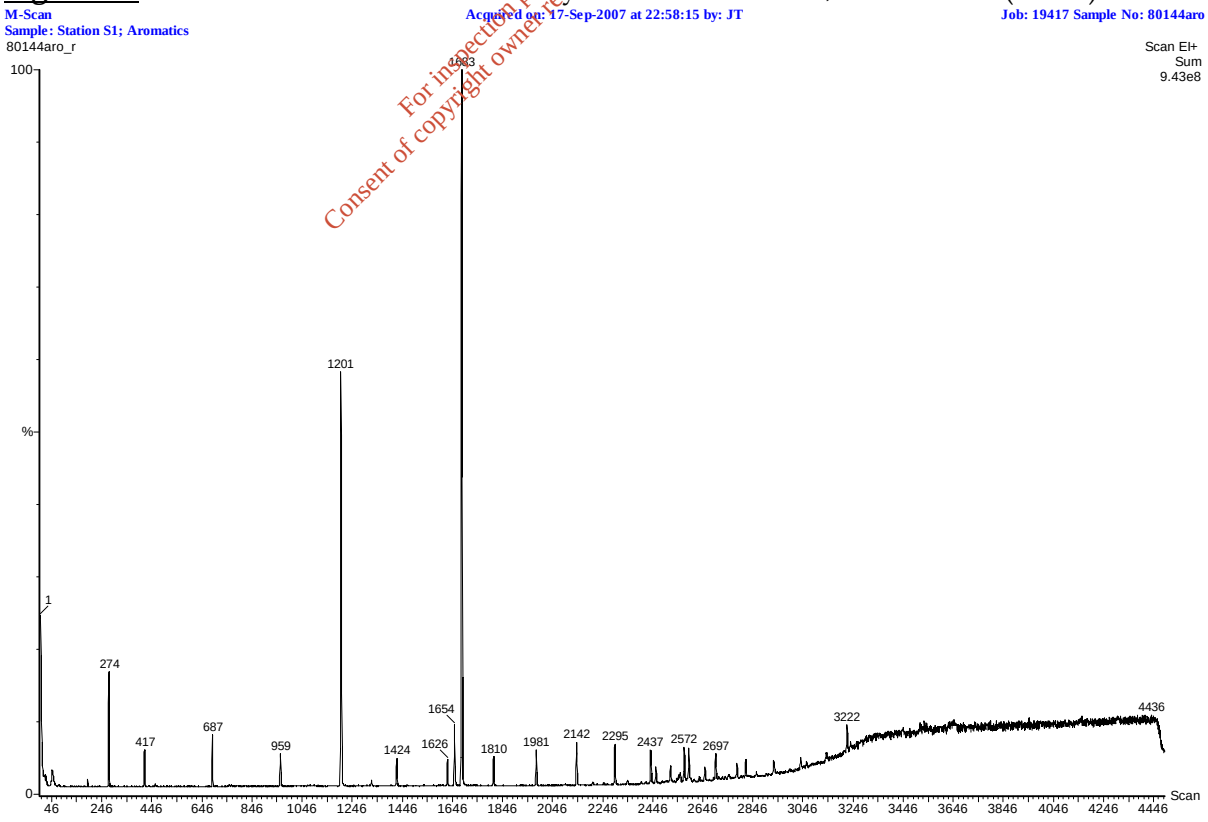


Figure 34: GC-MS TIC trace for aromatic hydrocarbon fraction, Station 1 (80144)

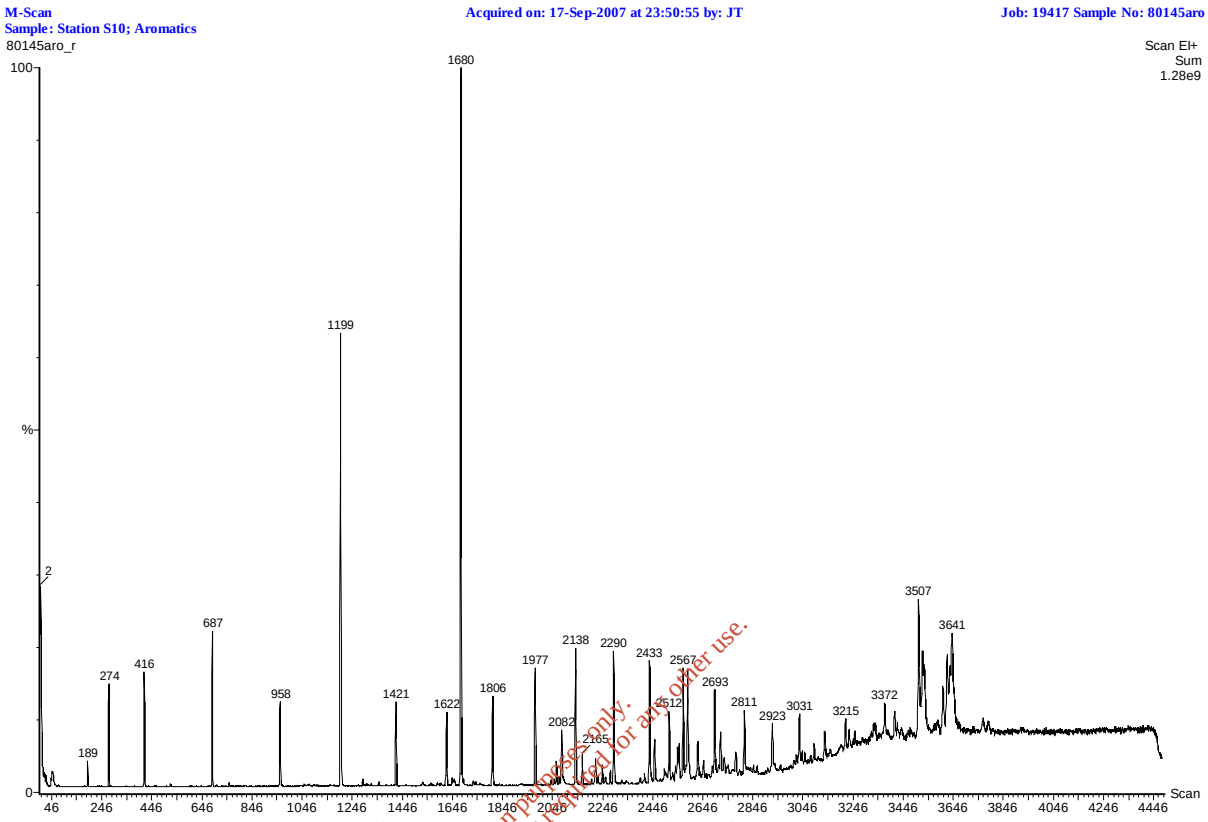


Figure 35: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 10 (80145)

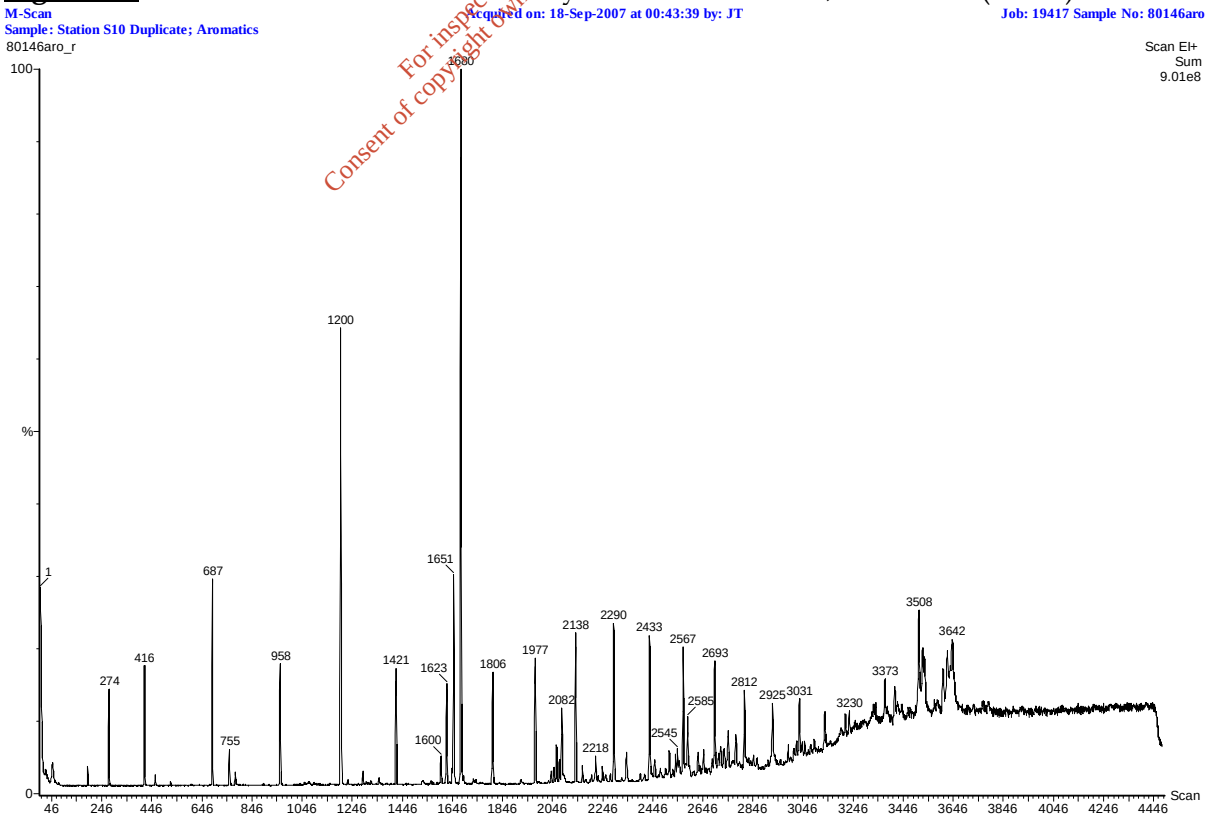


Figure 36: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 10 (80146)

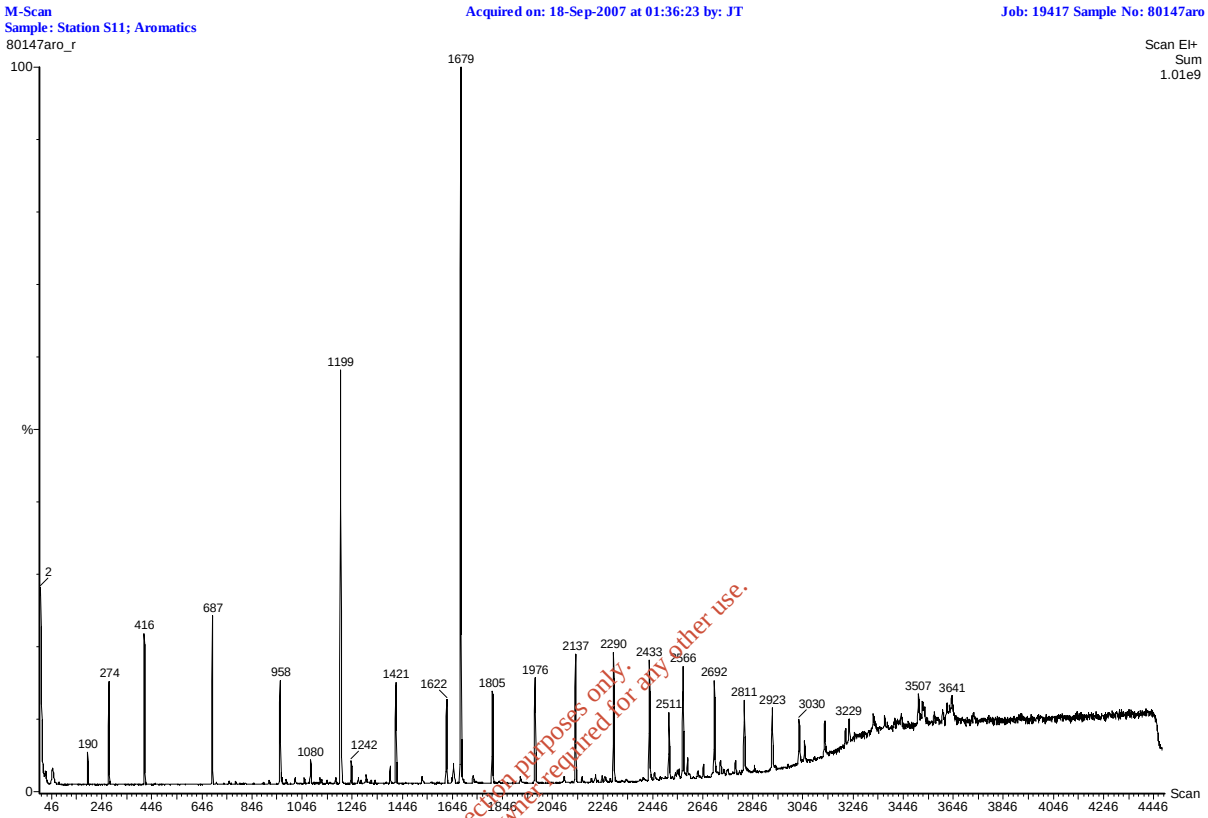


Figure 37: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 11 (80147)

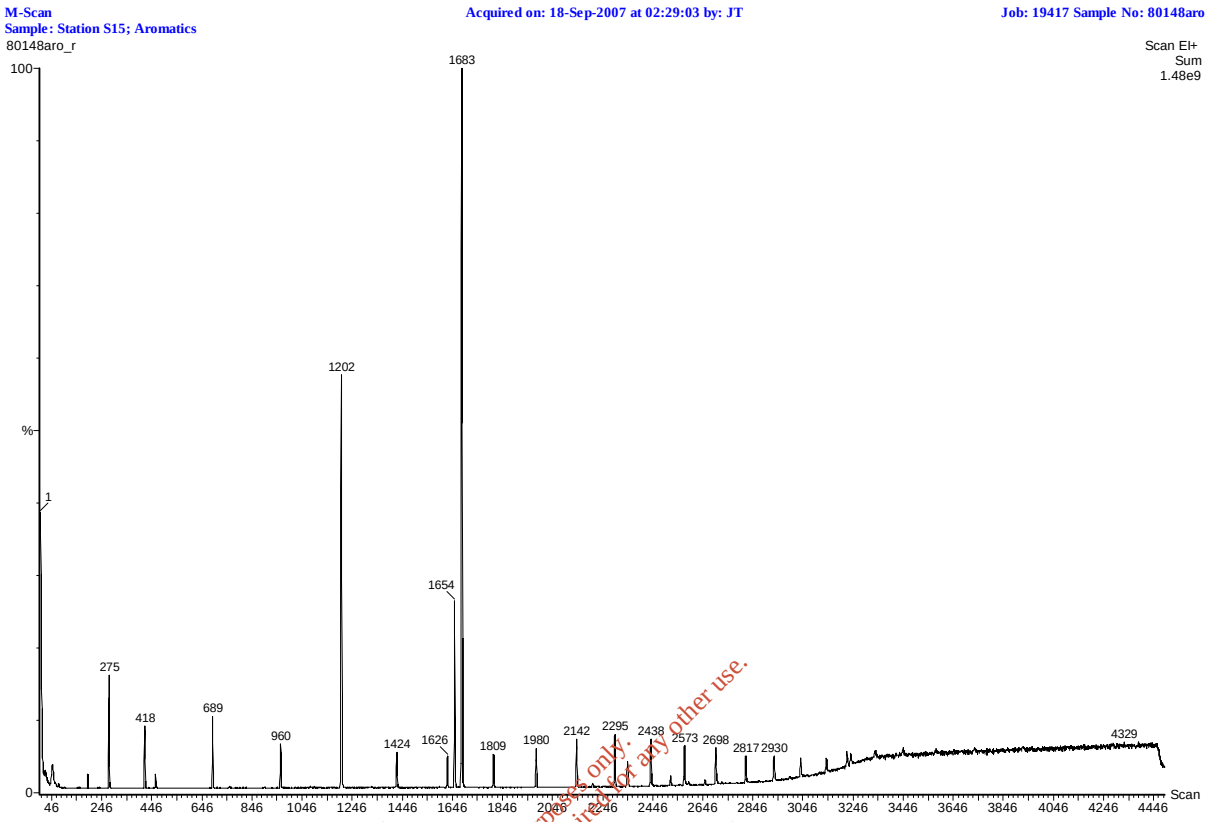


Figure 38: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 15 (80148)

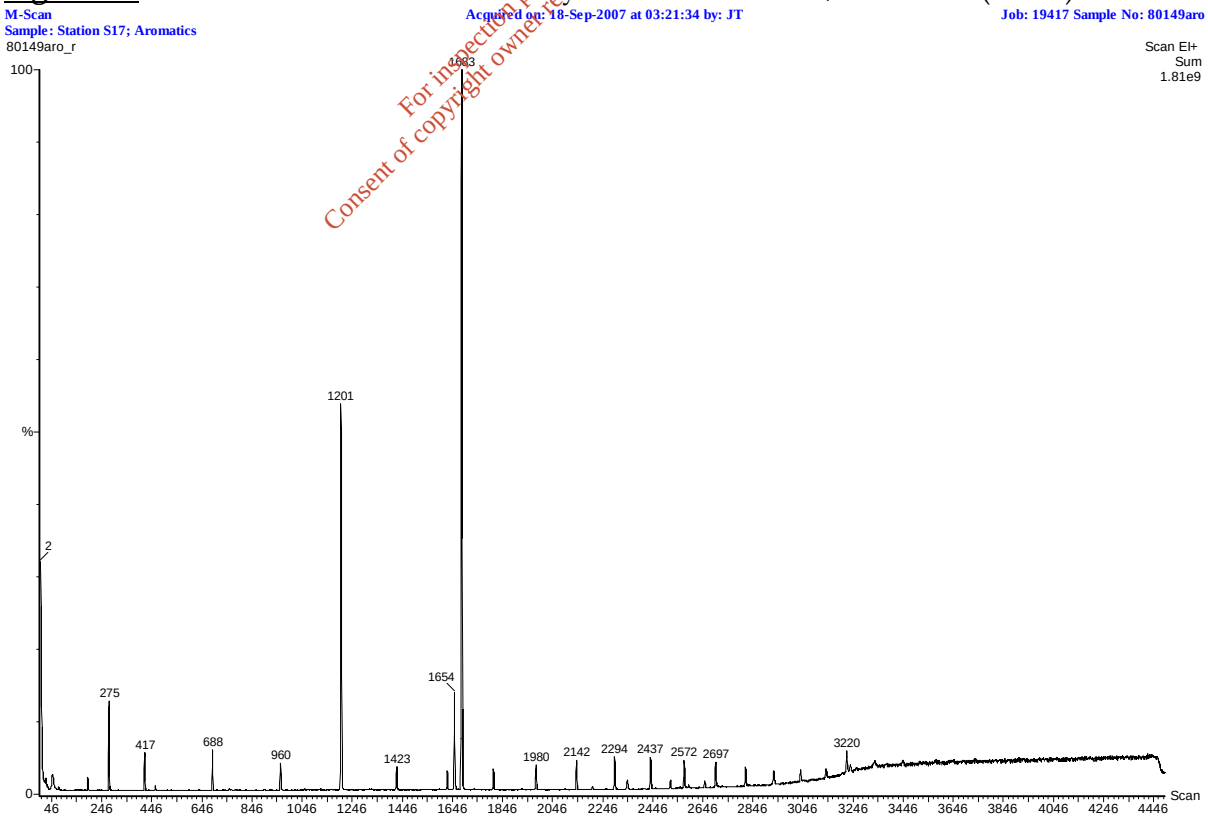


Figure 39: GC-MS TIC trace for aromatic hydrocarbon fraction, Station 17 (80149)

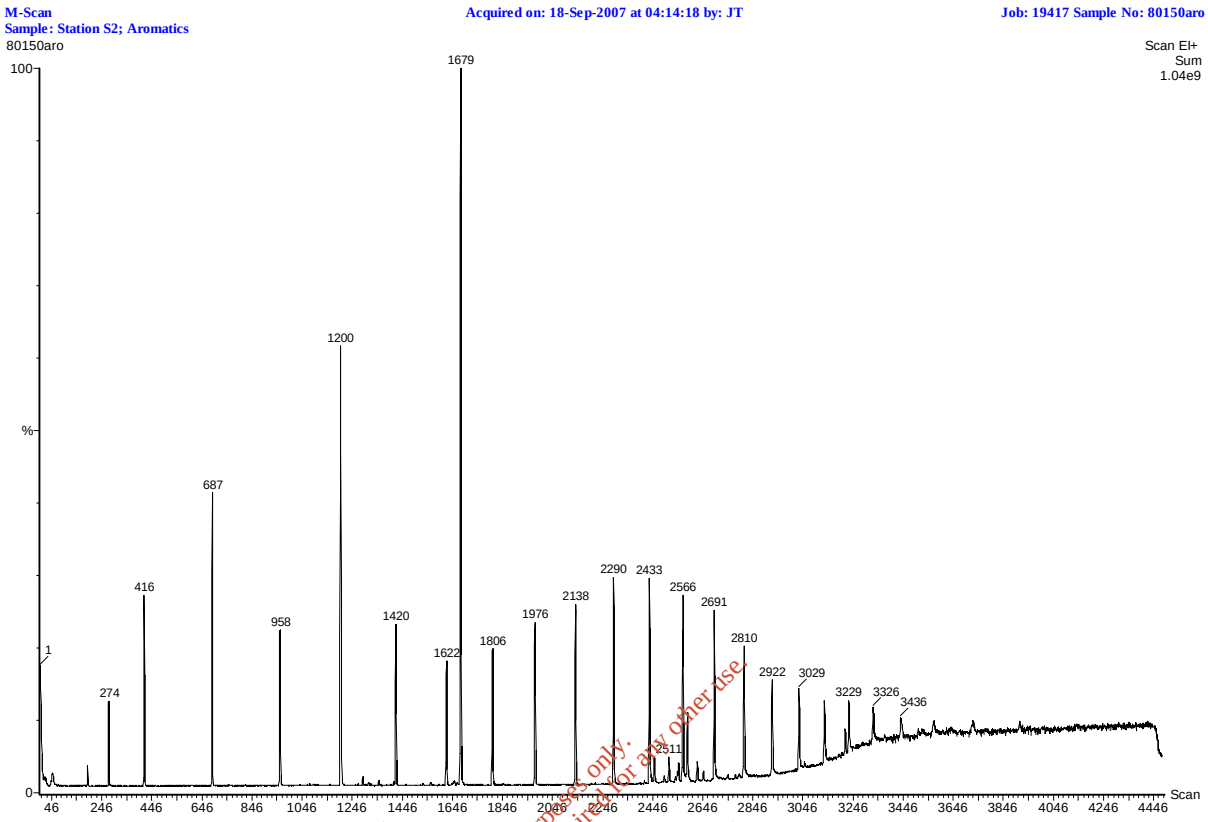


Figure 40: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 2 (80150)

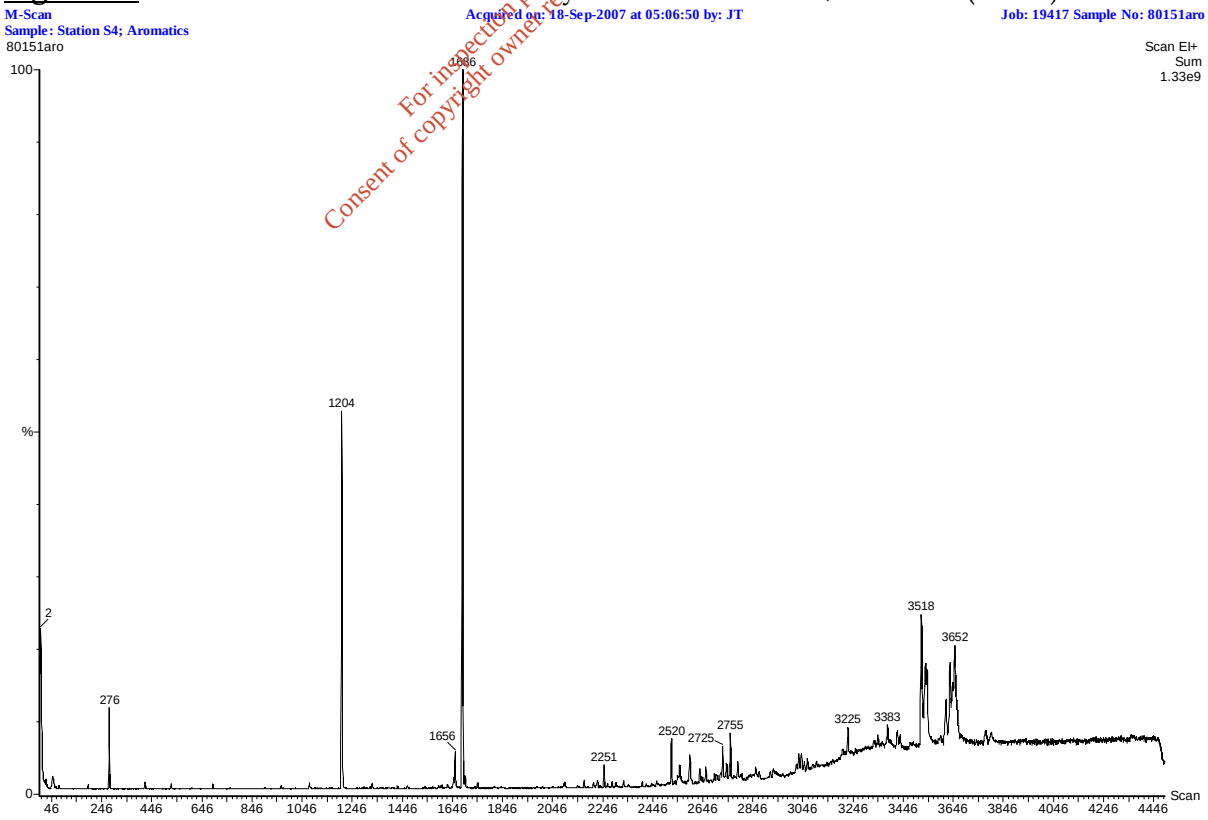


Figure 41: GC-MS TIC trace for aromatic hydrocarbon fraction, Station 4 (80151)

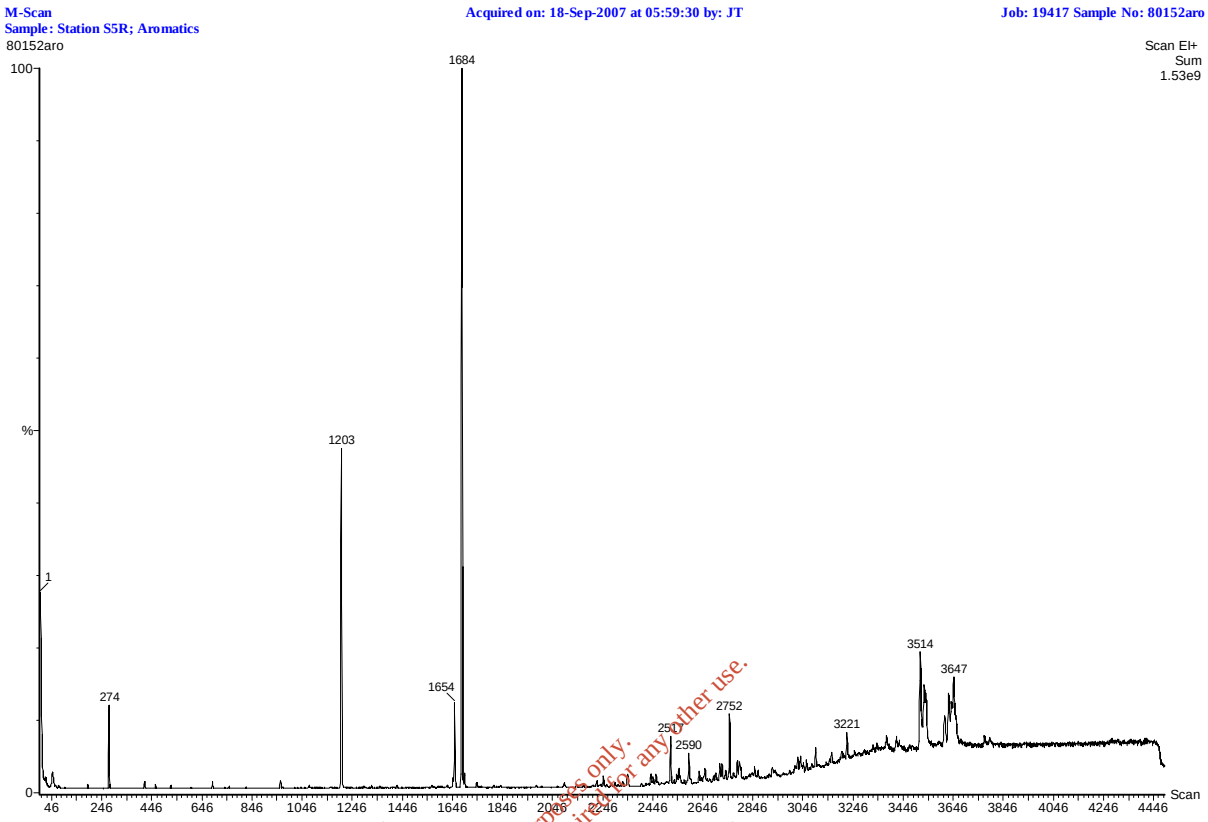


Figure 42: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 5R (80152)

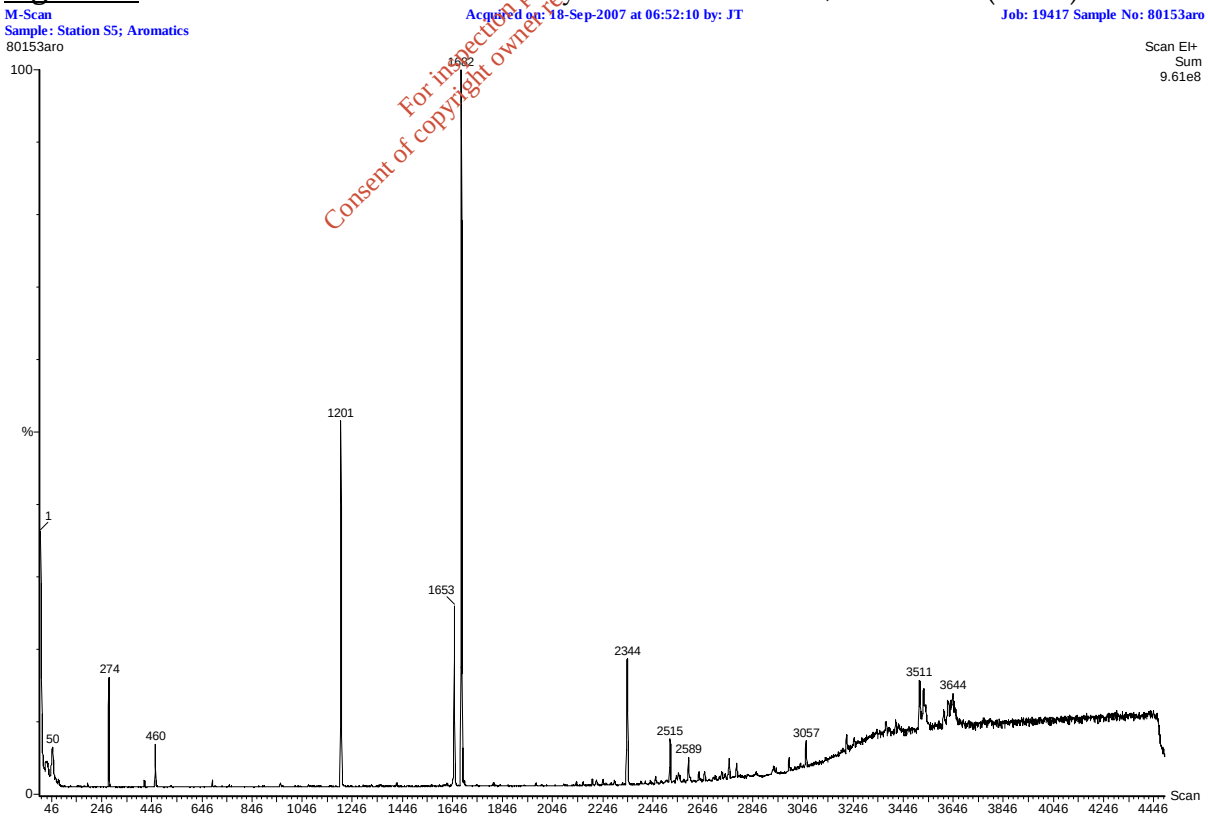


Figure 43: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 5 (80153)

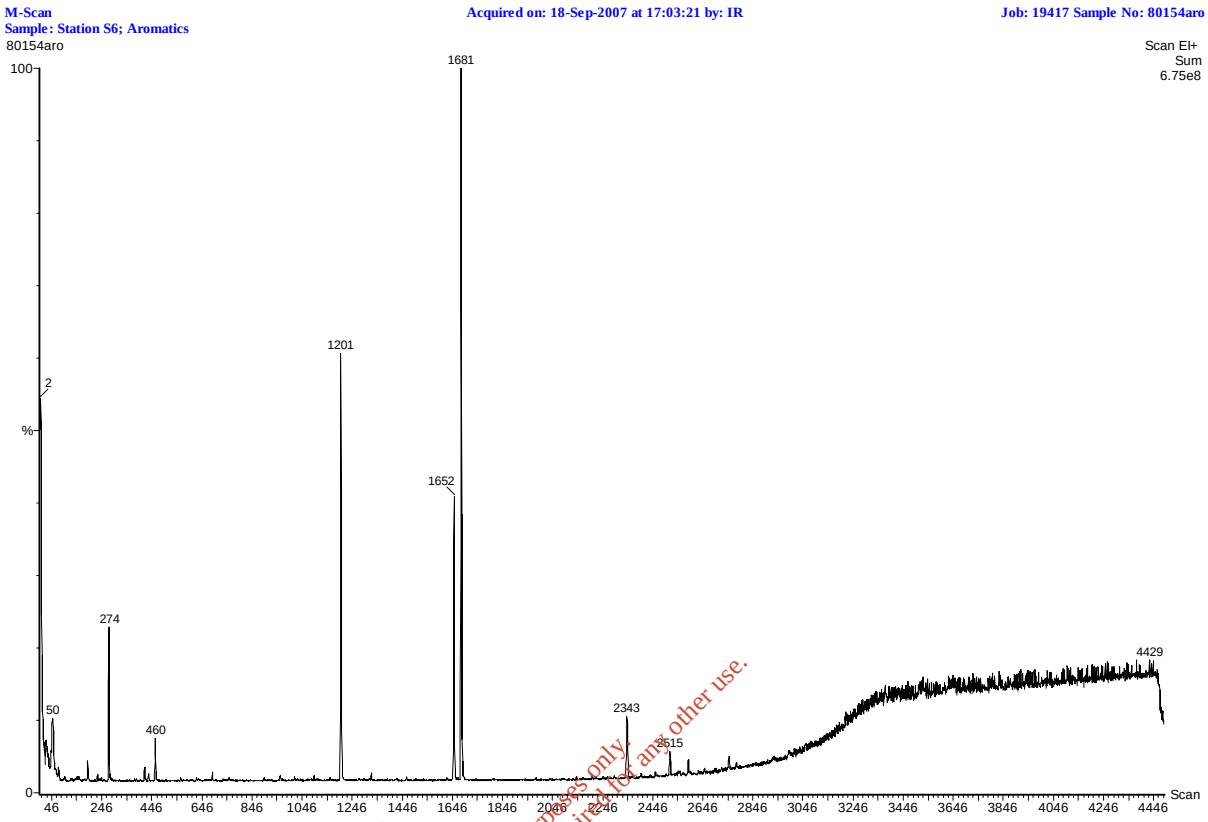


Figure 44: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 6 (80154)

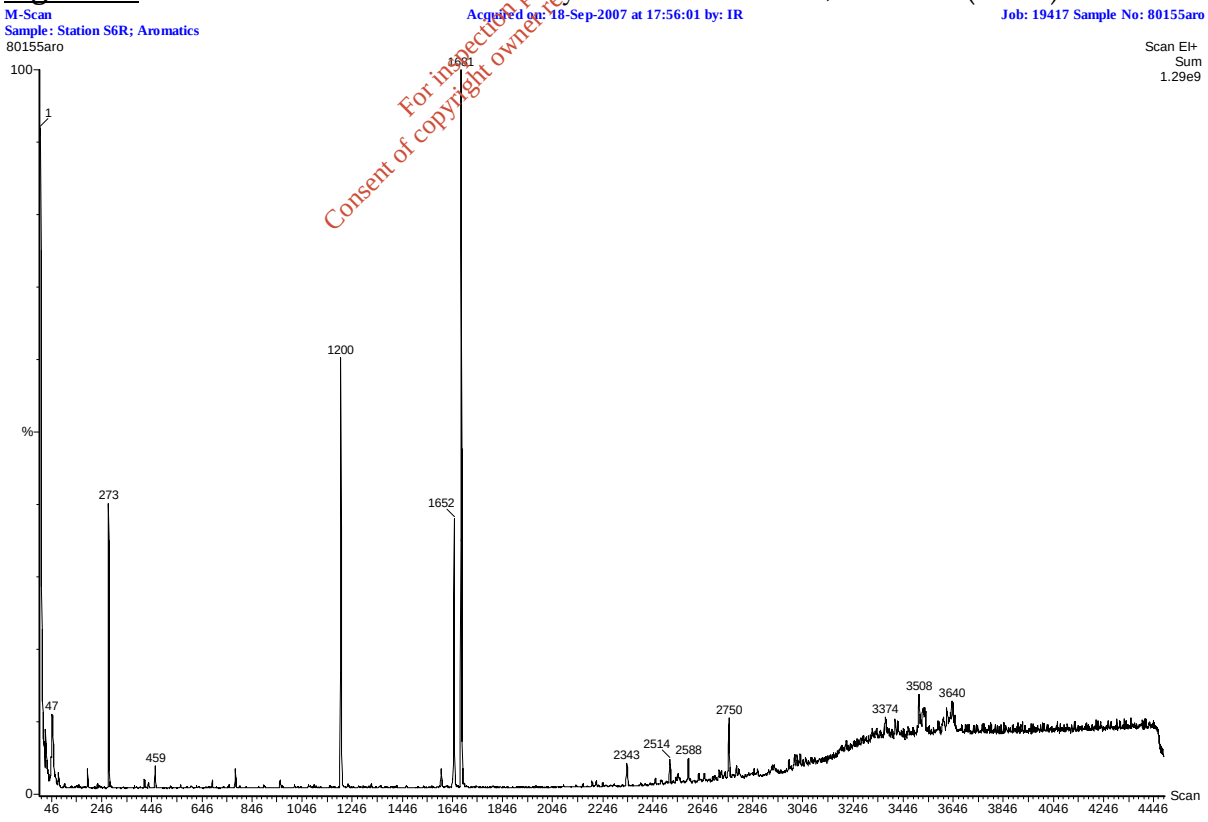


Figure 45: GC-MS TIC trace for aromatic hydrocarbon fraction, Station 6R (80155)

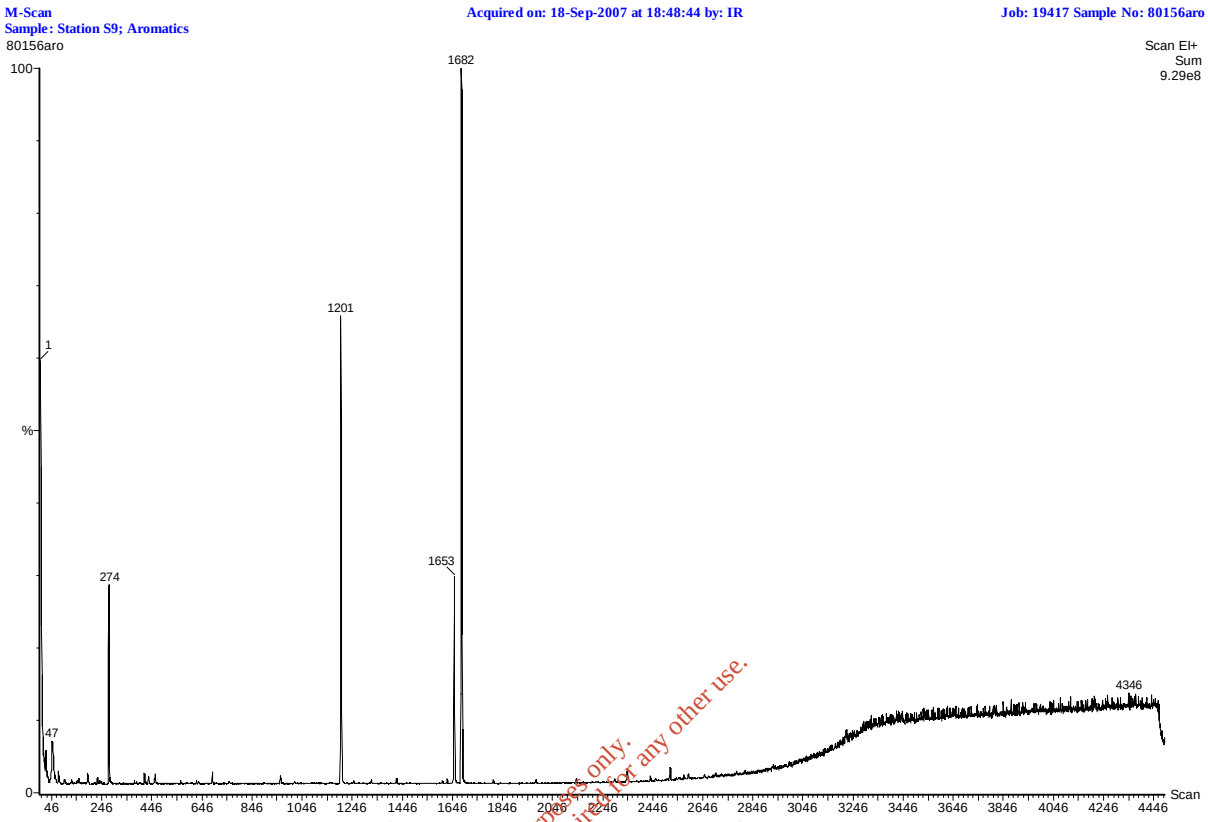


Figure 46: GC-MS TIC trace for aromatic hydrocarbon fraction, Station 9 (80156)

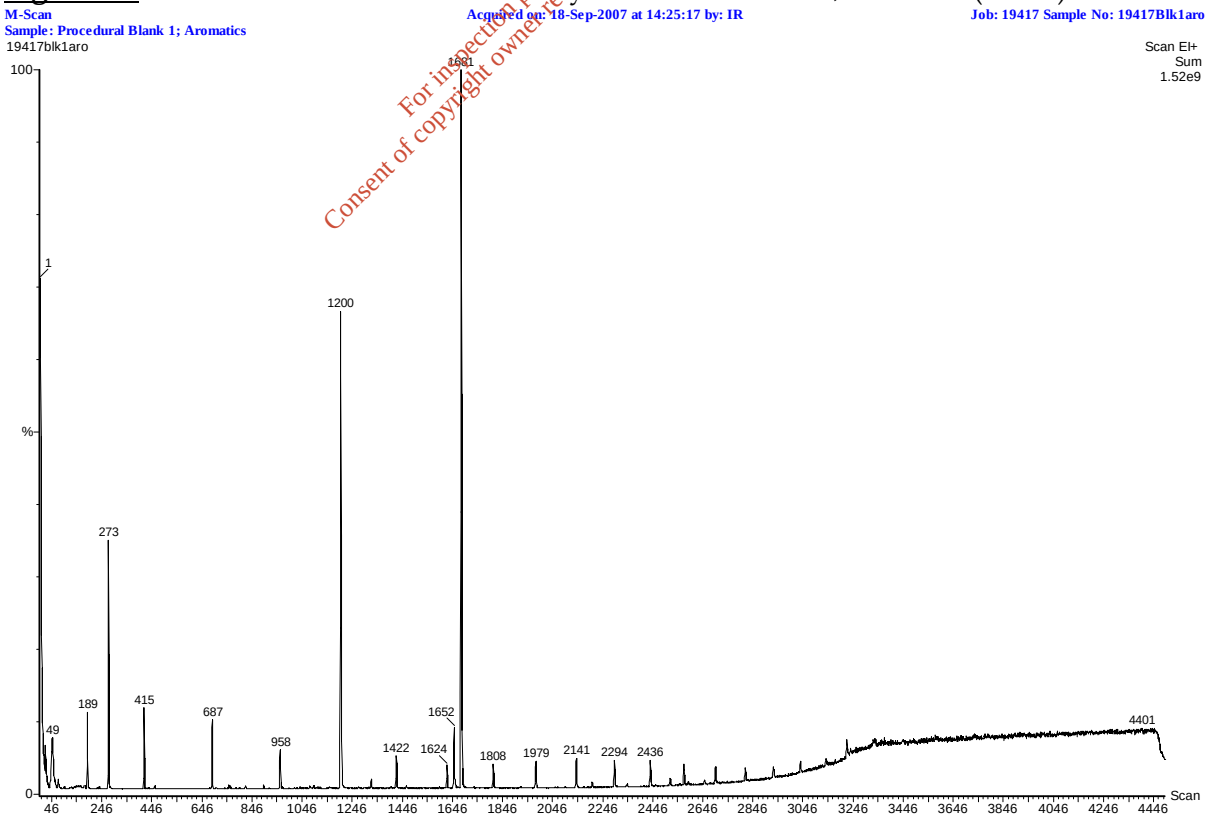
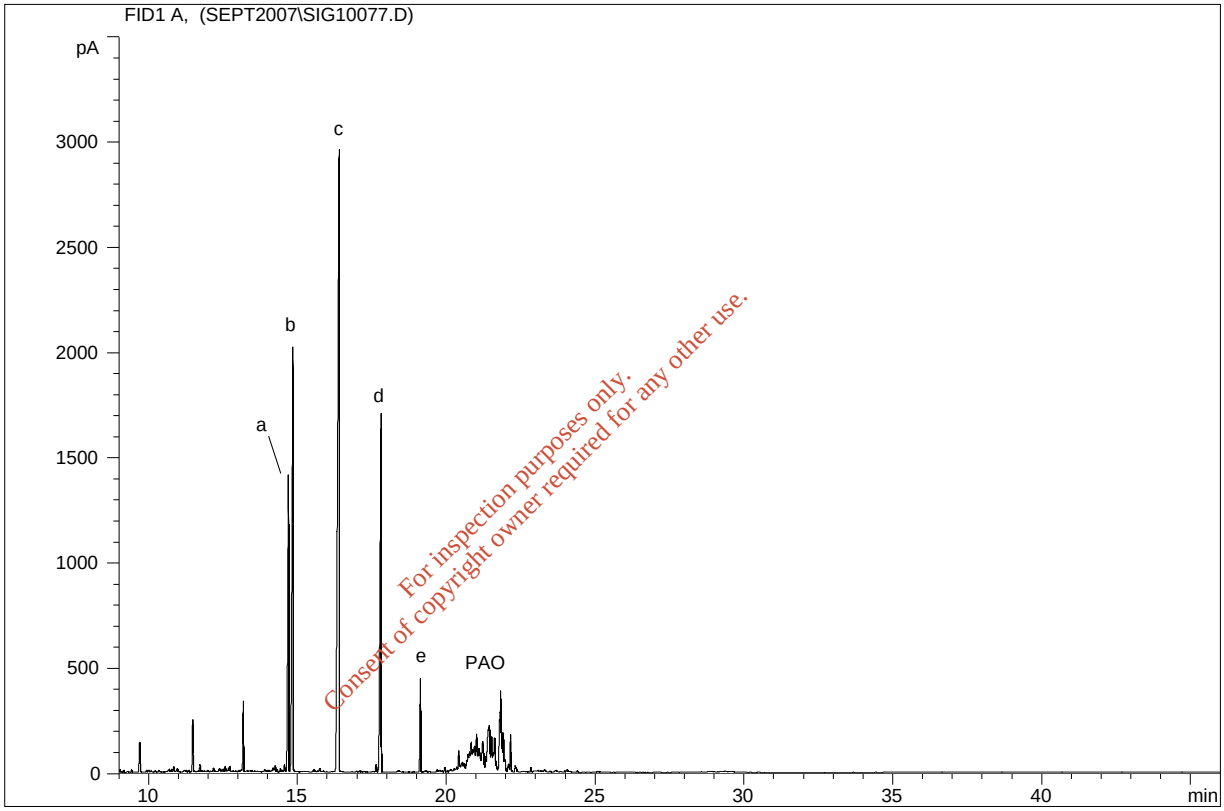


Figure 47: GC-MS TIC trace for aromatic hydrocarbon fraction, Procedural Blank

APPENDIX IV

GC Trace of the "Ecosol" Base Oil



b-e n-alkanes
POA poly-alpha olefins

APPENDIX V: Service Warranty

This report, with its associated works and services, has been designed solely to meet the requirements of the contract agreed with you, our client. If used in other circumstances, some or all of the results may not be valid and we can accept no liability for such use. Such circumstances include different or changed objectives, use by third parties, or changes to, for example, site conditions or legislation occurring after completion of the work. In case of doubt, please consult Benthic Solutions Limited.

Appendix C: Aqua-Fact Sediment Profile Imagery Survey

Sediment Profile Imagery Survey
Corrib Field Development
Proposed Pipeline Route
& Field

August 2007

Produced by

Aqua-Fact International Services Ltd

On behalf of

RSK Environment Ltd.

August 2007

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Appendix I – Survey Stations – Representative SPI and Surface Photographs, Corrib Field Development Area, Co. Mayo – August 2007

Appendix II – SPI – Sediment Profile Imagery Apparatus and Data Analysis – August 2007

1. Introduction

Aqua-Fact International Services Ltd. was contracted by RSK Environment Ltd. to conduct a Sediment Profile Imagery (SPI) survey of the seafloor along a proposed pipeline route corridor of the Mayo coast. In all, 18 stations were sampled using SPI between 06th and 08th August 2007 - 12 of these were located on the proposed pipeline route corridor while the 6 remaining stations were located on the Corrib Field itself (see Figures 1, 2 and 3). Water depths for the stations sampled are shown in Figure 4. This report documents the environmental conditions of the seabed at each of the stations surveyed as recorded by the SPI cameras during the course of the survey.

Figure 1. Location map for the Corrib Field study area, August 2007.

The main objectives of this survey were:

- To analyse sediments for grain size, degree of compaction and depth of bioturbatory activity (re-working or irrigation of the sediment by animals).

- To document infauna (animals living in the sediment) and epifauna (animals living on the bottom) and to infer from their presence the health of the benthos.

- To assess the overall state of the seafloor at 18 stations surveyed

Sediment Profile Imagery incorporates the use of an underwater camera that takes *in situ* photographs of vertical sections of the sediment, from which important ecological parameters can be ascertained. It reveals many aspects of the processes within sediments on the seafloor that other conventional tools fail to reveal or destroy in the process of sampling. Its use in marine benthic studies has revolutionised our knowledge of infaunal activities and infaunal relationships. Its application on fish farms can tell a great deal about the bottom sediments and their state of enrichment. It is non-destructive and therefore, comparisons can be directly made with baseline and previous SPI studies. An additional downward-looking surface camera mounted on the SPI frame is used to obtain a pre-penetration photograph of the seafloor where the profile shot is to be taken. Additional information can be gleaned from these surface photographs – when combined with information already recorded in the profile shots this helps to build a complete picture of the seafloor being studied. As the data return is relatively rapid, this allows the implementation of management decisions which are based on current information rather than the 'after the fact' remedial actions imposed by the more traditional surveying/monitoring methods. The SPI parameters analysed and their results and implications for the seafloor are discussed in detail in Appendix II (details on apparatus and deployment are also available here).

1.1. Site History

The Corrib Field was discovered in 1996 and was the first significant find offshore Ireland since Kinsale Head in 1973 (Wilson, 2007). The Corrib field development was sanctioned in February 2001, and the production license was granted in late 2001 with a 30-year duration. The development will incorporate seven subsea wells with export directly through a pipeline to an onshore terminal. This receiving facility will be constructed on the coast of County Mayo. The Corrib project was sanctioned for a scheduled production start-up in October 2003. Due to the objections received relating to the planning permission for the gas terminal, the start up was delayed. Corrib is a Triassic gas field located some 65 km west of County Mayo (Figure 1) in approximately 350 m water depth. The proposed pipeline route currently runs east from the Field into Broadhaven bay and a proposed landfall immediately west to the mouth of the Sruwaddacon bay, although a number of alternative landfalls and route corridors from Broadhaven bay are currently being considered.

Extensive survey operations have previously been undertaken as part of the Corrib Field development. The pipeline route was surveyed by Gardline Surveys and Aqua-Fact in 2000, whilst the proposed outfall was surveyed by Ecoserve Ltd. in 2001. The field itself has been surveyed extensively since 1996 using a combination of opportunistic ROV sampling and dedicated benthic sampling using surface deployed seabed samplers. In all cases, either the field sampling and or the processing of the benthic material was previously carried out by Gardline Surveys Ltd. (and or Ian Wilson) with a high level of continuity maintained.

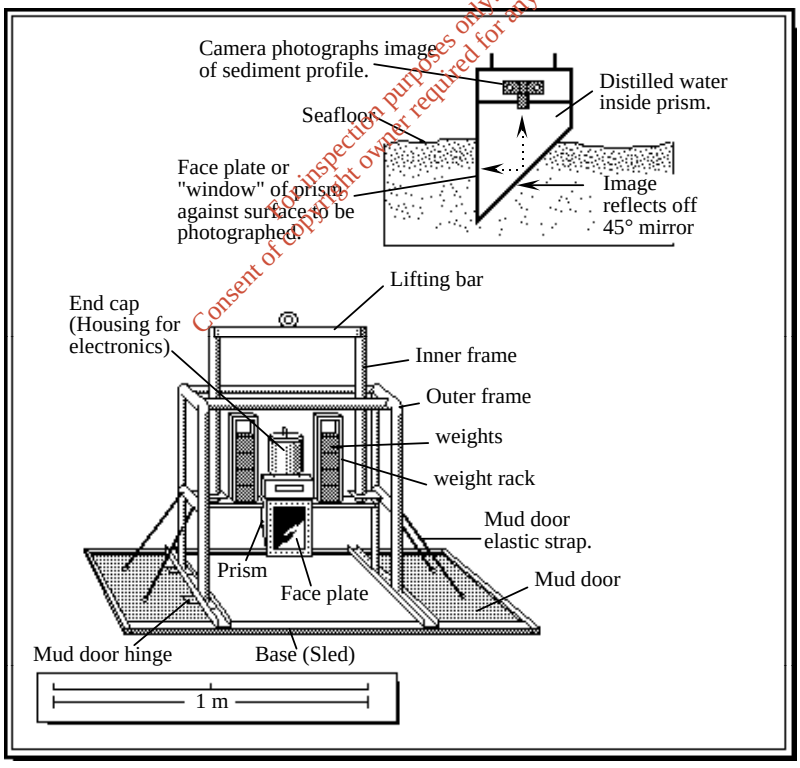
Whilst the majority of previous survey activities related to the drilling of one or two wells at any one time, a more regional assessment was undertaken by Gardline Surveys in 2000. This was a combination of physico-chemical /macrofaunal sampling operations, and seabed video and photograph survey in the vicinity of the Corrib Field and along the proposed pipeline route. Macrofaunal grab samples were taken from 27 sites within the Field with a further 12 stations sampled along the pipeline route between the Field and the landfall. For the most part, many of the stations will be re-surveyed as part of the current study. In addition to sampling, seabed photography was also undertaken. The sediment surface was photographed at many sites by Gardline Surveys, and for the

field, sediment profile imagery (SPI) recorded vertical profiles and surface photographs of the sediments by Aqua-Fact. The aim of the surface photography was to provide a record of the fauna and flora present on the seabed and to avoid potential environmental hazards, such as Annex 1 habitats. In the event, no sensitive environments were found.

2. Methods

2.1. Sediment Profile Imagery

In order to examine the nature of the seafloor, Sediment Profile Imagery (SPI) was employed. Using SPI, one can deduce the dynamics of biological and physical seafloor processes from imaged structures. The SPI camera differs from other underwater cameras in that it effects a vertical profile of the sediment water interface and obtains a photographic image of that profile (see Figure below; see also Appendix II). Since the SPI camera obtains images of the undisturbed sediment *in situ*, it delivers information on benthic processes that is not readily available using many conventional sampling tools (Rosenberg and Diaz, 1993). Furthermore, as the object being photographed is directly against the faceplate of the camera assembly, water turbidity is never a limiting factor.



Representation of the remotely operated **S**ediment **P**rofile **I**magery camera.

Sediment Profile Imaging (SPI) can remotely identify the successional status of the seafloor and also has the potential to document its maintenance, development and/or destruction over time. With experience, both the physical and biological forces responsible for maintaining or driving a succession (*e.g.* bottom erosion or deposition, changes in substratum type, relative changes in levels of dissolved oxygen, organic decomposition processes, *etc*.) can also be detected with confidence. This also applies to chemical driving forces where sensing probes are used in conjunction with the SPI instrument. A great deal of information about benthic processes is available from sediment profile images and while certain features (*e.g*. deep-living infaunal forms) may escape direct observation on the SPI images, their presence can typically be inferred from their impacts on the sediment structure (Appendix II). The combining of information from both sediment profile and sediment surface images allows an appreciation of the nature of the seabed on two planes - a quasi-3-dimensional model of the seafloor.

The survey was carried out on in August 2007 from the RV *Prince Madog*. Station position fixes were taken by on-board GPS.

SPI and digital seafloor images were obtained from numerous separate deployments of the SPI machine at each of the 18 sampling locations. All sediment profile images taken were analysed for each station using a dedicated image analysis system. Appendix II outlines the rationale and methods of analyses of Sediment Profile Imagery (SPI).

The SPI parameters measured from each image include:

1) – sediment **type** measured from the upper 5 cm sediment layer

2) – prism **penetration depth** which gives an indication of relative sediment compaction and coarseness

3) – **sediment boundary roughness** which indicates the degree of physical disturbance or biotic activity at the sediment water boundary

4) – sediment **apparent redox potential discontinuity depth (ARPD),**

assesses the depth of oxygenated sediment on the bottom (not visible)

5) – **infaunal successional status** which qualifies the type of animals living in the bottom

6) – **additional parameters** such as the presence of mud clasts, epifauna (surface living animals), infaunal burrows and tubes, outgassing of sediments (due to production of hydrogen sulphide and ammonia as by-products of anaerobic metabolism) *etc.* were also assessed

7) – calculation of a **mean organism sediment index** (OSI value) which integrates the information gained from the other parameters measured into a single index which is indicative of the health status of the location under investigation (see Appendix II).

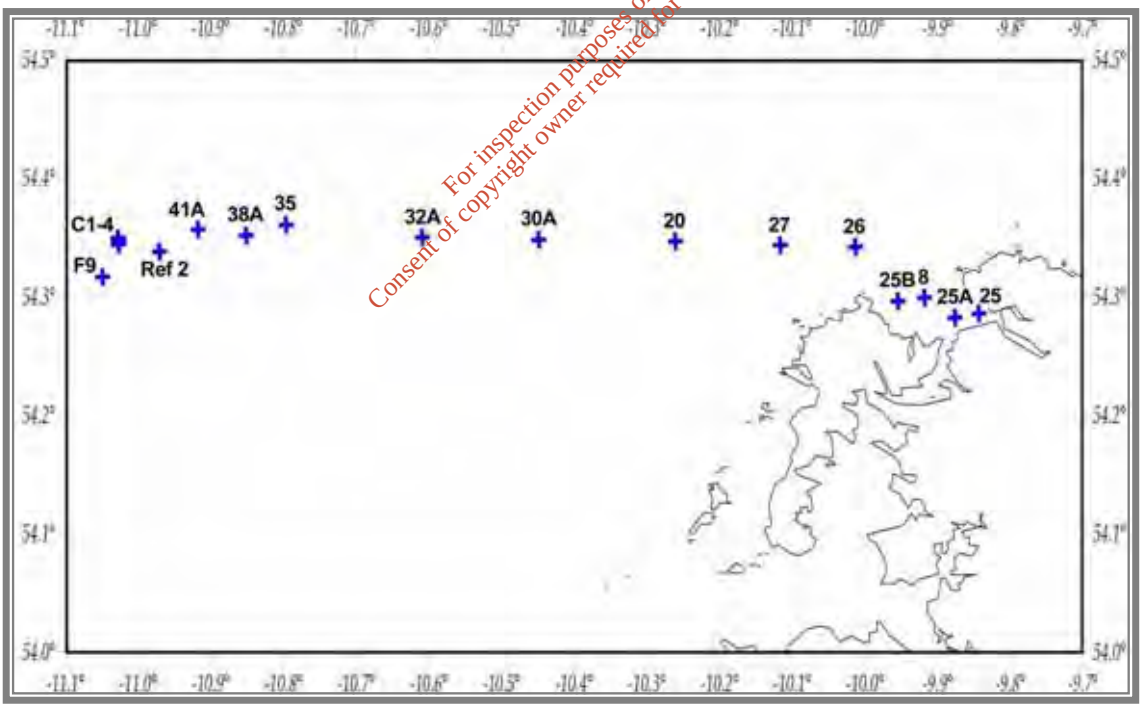


Figure 2. Overall view of survey area & stations sampled on the pipeline route & field.

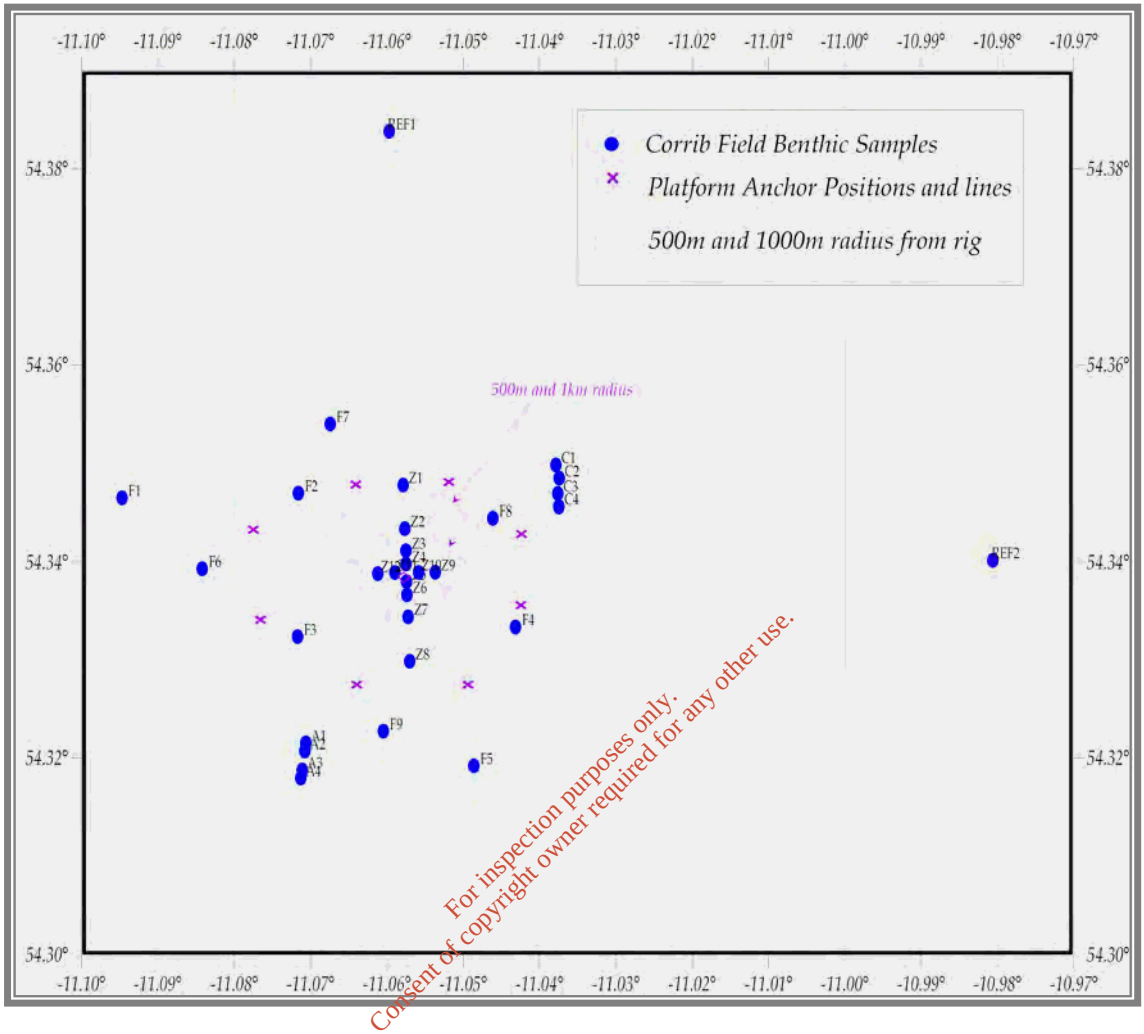


Figure 3. Detailed view of the Corrib Field benthic sampling locations. Images were only obtained from Stations C1 – C4, F9 and REF 2 during the current survey (from Wilson, 2007).

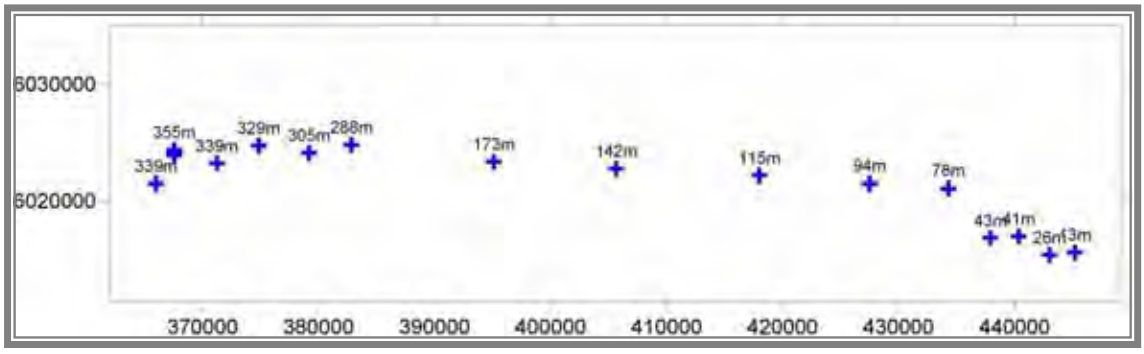


Figure 4. Water depths (metres) on the Corrib route & field benthic sampling locations.

3. Results

Sediment Profile Imagery

Figures showing sediment profile and sediment surface shots for each station surveyed are given in Appendix I, along with measured parameters superimposed on the representative shot for each station.

3.1. Sediment type

The sediment major mode is assessed from the top 5cm of the sediment (see station tables superimposed on the SPI shots in Appendix I). Based on this, the majority of stations at the landward end of the pipeline route have a predominance of fine sands (3-2 Ø) in the topmost layers of the sediment (see Figure 5 below). A very coarse sand substrate (*0-(-1.0) Φ*) with some shelly gravel was recorded at station 27 (see also images presented in Appendix I).

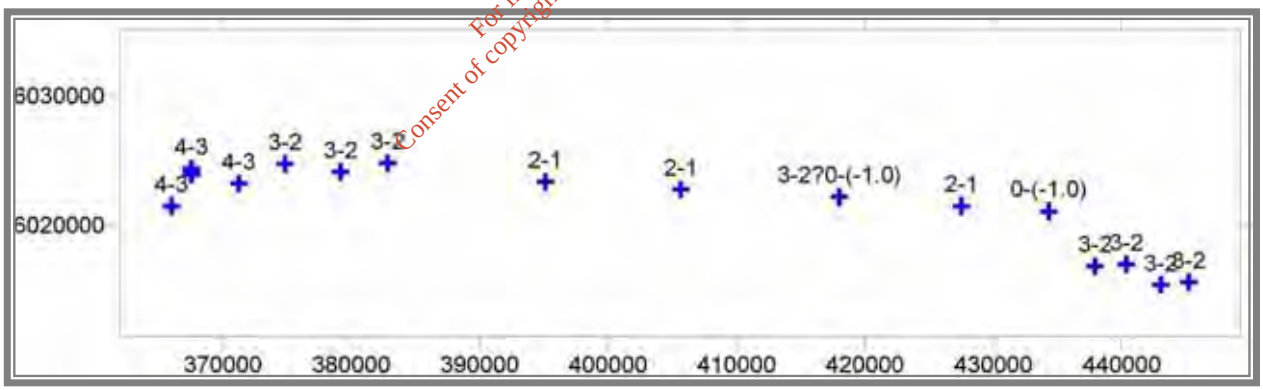


Figure 5. Map of sediment major mode distribution (Φ units), Aug 2007 (scale in metres).

Beyond Stations 27, medium sands were recorded at Station 20. There is some degree of heterogeneity of bottom type at Station 20 – where both very coarse sand and fine sand were recorded. Medium sand was also recoded at Stations 30A and 32A. Fine sand (3-2 Ø) was recorded at Stations 35, 38A and 41A - the final three stations on the

pipeline route. Sediment recorded in deeper water on the field itself (Stations C1 - C4, F9 and Ref 2) were all characterised by the presence of very fine sands.

3.2. Mean prism penetration depth

The maximum prism penetration depths (in centimetres) achieved in a single deployment at each of the 18 sampling locations are presented in Figure 6 below (see also tables superimposed on the photosets presented in Appendix I). These figures reflect both the grain size composition and compactness of the bottom deposits.

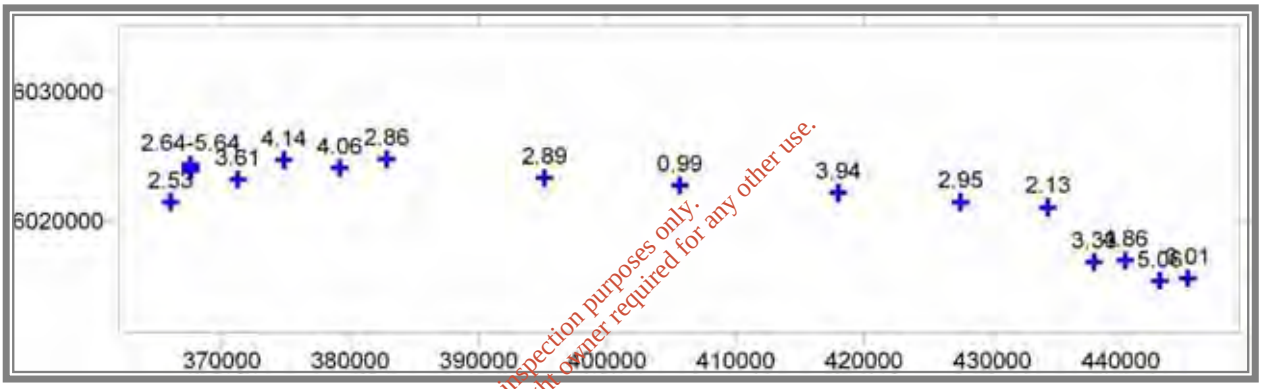


Figure 6. Mean SPI prism penetration (centimetres), August 2007 (plot scale in metres).

Penetration depths were moderate to low at many of the stations surveyed, though image quality was always excellent. The camera system was used with a fully loaded weight carriage for maximum penetration throughout the survey – therefore any variation seen in penetration is due to variation in the physical characteristics of the sediment itself. Highest penetration values were achieved where sediments had been fluidised through the activities of burrowing fauna (bioturbation – generally prevalent at deeper stations) or in shallower waters due to the effects of surface waves and swell.

3.3. Sediment surface boundary roughness

Surface boundary roughness is an indication of the unevenness of the sediment surface resulting from either bioturbation (animals in the sediment) or from physical disturbance (see Figure 7). In the case of the current survey, SBR is attributable to the presence of physical bedforms in the shallowest stations surveyed – Stations, 25, 25A, 8, 25B, 26 and to a certain extent at Station 27. Physical disturbance in the present survey is characterised by the presence of sand ripples on the sediment surface. These features are visible in profile and surface shots (for example, ripples with an 8cm wavelength are present at Station 8). At all remaining stations in the deeper waters beyond Station 20, small scale sediment relief is due almost exclusively to bioturbation. Here numerous burrows and feeding mounds were recorded. Mobile fauna such as the numerous ophiuroids recorded also contribute substantially to bioturbation here.

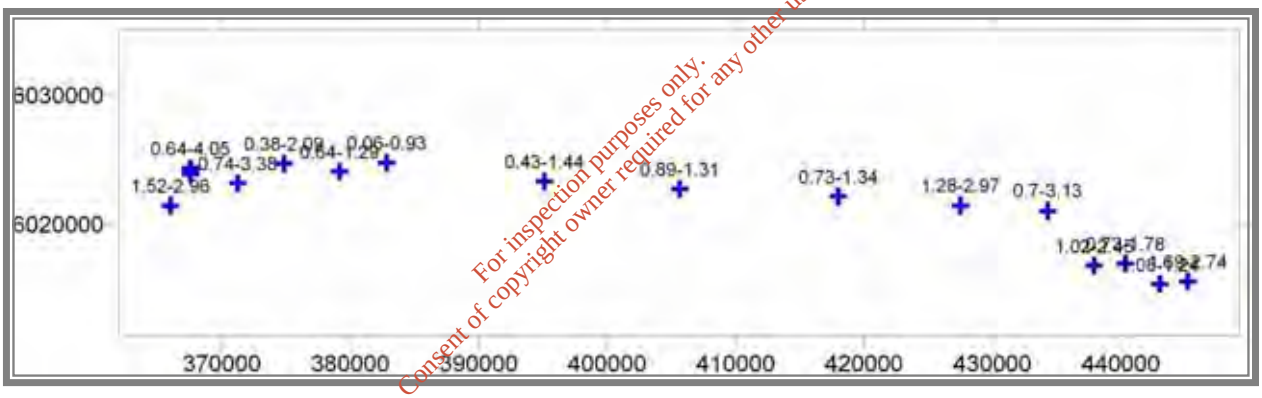


Figure 7. Map of SBR range on the Corrib pipeline route & field, Aug 2007 (plot scale in m).

3.4. Apparent redox potential discontinuity (ARPD)

The apparent redox potential discontinuity (ARPD) depth is the visible line between oxygenated and reduced sediment in a profile image. Small areas of reduced sediments were noted at Station C2 on the field itself. The presence of these is indicative of some degree of elevated organics – possibly due to contamination with drill muds (these stations are in close proximity to drilled wells). It is interesting to note that

(along with Station F5 – not surveyed in the current survey) Station C2 was highlighted as having a low ARPD depth in a similar sediment profile imagery survey carried out by Aqua-Fact in July 2000 (Aqua-Fact, 2000) – indicating incorporation of drilling material into the seafloor there.

3.5. Infaunal successional stage & bioturbation depth

Infaunal successional stages calculated for the stations surveyed are presented on the SPI shots in Appendix I. Stage III environments (mature, healthy conditions) are typically characterised by deep redox boundary depths. All stations were assigned a Benthic Habitat Quality Index following the methodology proposed by Nilsson and Rosenberg (1997). This is described in detail in Table 3.1 below. Successional stages were then assigned to each sediment profile image based on this calculated value.

All but one of the stations surveyed were allocated a stage III successional stage. This was largely due to the presence of characteristically deep ARPDs, fauna and prominent biogenic features such as burrows, tubes and feeding casts (refer to Figure 3.1 below). It was also due to the absence of any definite evidence of impact or habitat quality degradation. Sediments at Station C2 were allocated a Stage II successional status due to the presence of reduced sediments in the profile images recorded there. Along with Station F5, Station C2 was classified as supporting a stage I type community in a previous SPI survey carried out on the Corrib Field in 2000 (Aqua-Fact, 2000a & b). The allocation of a stage II type environment in the current survey indicates that some improvement of habitat quality has taken place during the intervening time (mainly due to a deepening of the ARPD depth and the presence of biogenic features in the sediment). Since little variation was detected in the area surveyed this derived habitat quality indicator is not mapped.

A	Surface Structures	Faecal pellets	1
		Tubes ≤ 2 mm in diameter	1
		or Tubes > 2mm in diameter	2
		Feeding pit or mound	2
B	Subsurface Structures	Infauna	1
		Burrows 1-3	1
		or Burrows # > 3	2
		Oxic Void at ≤ 5 cm depth	1
		or *Oxic Void at > 5 cm depth*	2
C	Mean Depth of ARPD	0 cm	0
		0.1 cm – 1.0 cm	1
		1.1 cm – 2.0 cm	2
		2.1 cm – 3.5 cm	3
		3.6 cm – 5.0 cm	4
		5 cm	5

Table 3.1 Calculation of the Benthic Habitat Quality (BHQ) index from sediment profile images. BHQ = Σ*A* + Σ*B* + *C*, where *A* is surface structures, *B* subsurface structures and C means sediment depth of the apparent redox potential discontinuity (RPD). The BHQ value varies between 10 and 15. The BHQ index corresponds to the different successional stages depicted in Figure 3.6.1 below.

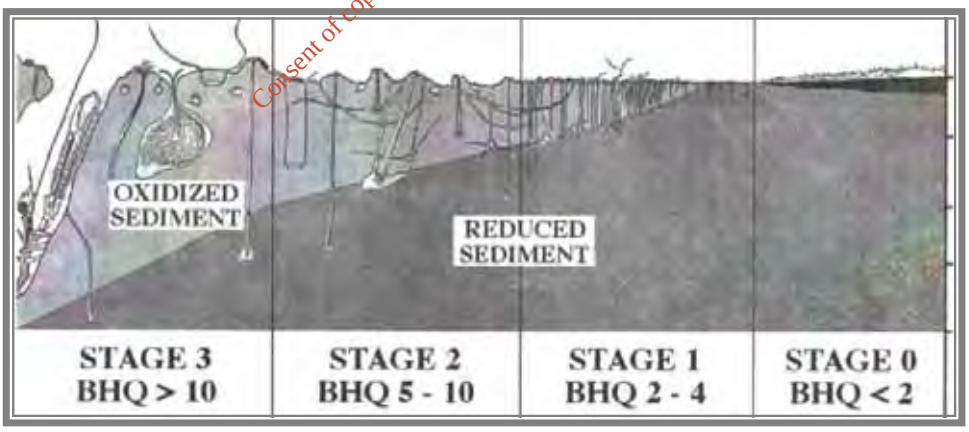


Figure 3.5.1 The distribution of benthic infaunal successional stages along a gradient of increased environmental disturbance from left to right (from Nilsson and Rosenberg, 1997 – after Pearson and Rosenberg, 1978) and the associated Benthic Habitat Quality index (described in table 3.6.1 above. The successional stages are similar but not identical to those described by Rhoads and Germano (1986).

3.6. Additional biological information

Many of the stations surveyed showed signs of faunal activity. In some cases numerous faunal species were imaged. Little evidence of faunal activity was recorded on the seafloor at the shallower stations surveyed. Some *Lanice conchilega* tubes were noted among the sand ripples at Station 8. Some worm tubes and feeding casts were recorded at Station 25, and a single sand tube at Station 27. Numerous scaphopod tubes were noted at the sediment surface at Station 32A (see images for this station presented in Appendix I). Encrusted stones were also images in one of the surface images captures at this station. Faunal activity at the remaining stations on the pipeline route was characterised as follows:

- 35 – A rather flat seafloor with occasional ophiuroids, eupagurids and burrows
- 38 – Small feeding mounds and burrows with evidence of substantial sediment surface reworking by ophiuroids
- 41 – end of the pipeline route. Frequent ophiuroids, feeding mounds and (decapod?) burrows. A small anemone was also imaged on the sediment at this station.

The most substantial faunal activity was noted in images taken at the deeper stations present on the field itself and in images taken at Station REF2. Faunal activity at these stations was characterised as follows:

- C1 – intensively re-worked sediments with frequent ophiuroids, mounds burrows. A single urchin was imaged on the sediment surface in profile
- C2 – intensively bioturbated sediments with frequent ophiuroids, mounds, burrows. An urchin was imaged in surface view.
- C3 – intensively re-worked sediments with frequent ophiuroids, mounds and burrows. An anemone (*Actinuage richardi*) was images in one of the surface images taken here.

- C4 – intensively re-worked sediments with frequent ophiuroids, mounds and burrows. A single starfish (the sand star, *Astropecten irregularis*) was imaged at the sediment surface at this station.
- F9 – intensively reworked very fine sands with occasional ophiuroids, and frequent mounding and burrows. A single polychaete was imaged at the sediment surface at this station (*Terebellidae* idet.).
- REF2 – reworked very fine sands – ophiuroids, burrows, pits and mounds common. A juvenile asteroid was imaged in one of the sediment surface images taken at this station.

Organism Sediment Index (OSI)

Organism Sediment index (OSI) is the sum of a series of weighted values (see Appendix II) allocated to the various physical/chemical and biological SPI parameters measured and with the inclusion of measurements of dissolved oxygen concentrations in the water column, has a potential value range of -10 to +11. As with the present survey where dissolved oxygen concentrations are not included, the OSI values have a potential range of -6 to +11.

Habitat quality is defined relative to the two end-member standards of OSI values. The lowest value is given to bottom types that have (low or no dissolved oxygen in the overlying bottom water), no apparent macrofaunal life and methane gas present in the sediment. The SPI OSI value for such a condition is -10 or -6 depending on whether dissolved oxygen measurements in the water column are included or not. At the other end of the scale, an aerobic bottom with a deeply depressed ARPD, evidence of a mature macrofaunal assemblage and no apparent methane gas bubbles at depth will have a SPI OSI value of +11. From experience of mapping with this parameter values of +7 to +11 are indicative of high quality habitats. In dealing with areas that are subject to organic enrichment, OSI values in the range +6 to +1 generally indicate an increased input of organic material. Index values which fall in the range +1 to - 6 identify varying degrees of habitat degradation. This parameter was not mapped due to the fact that ARPD depths were not measurable in any of the images analysed during the current survey.

4. Conclusion

- The sea floor was investigated using sediment profile imagery (SPI) at 12 stations of varying depth along a proposed pipeline route, at 5 stations on the Corrib Field and at a single reference station.
- The predominant sediment type along the survey route varied from fine sand at the landward end, to very coarse sand, to medium sand and back to fine sand with increasing depth at the seaward end of the pipeline route. Intensively faunally reworked very fine sands were recorded on Stations C1-C4, F9 and REF2 on the Corrib Field.
- Physical bedforms were the dominating sediment surface relief modifier at the shallower stations surveyed (to station 27 on the pipeline route). Bioturbation is the main sediment surface relief modifier at all stations beyond this depth.
- Camera prism penetration was moderate to low throughout the survey. This is due to the compactness of the sands in this area.
- ARPD depth was visible at only a single station during the current survey (Station C2 near wellhead 18/20-3 – indicative of contamination of sediment shere with drill muds. Habitat quality recorded in SPI images taken at this station shows improvement when compared with conditions recorded in profile images taken in July 2000 (Aqua-Fact, 2000).
- Faunal activity was most evident at stations imaged in deep water - Stations C1-C4, F9 and REF2 and was relatively low along most of the pipeline route itself. The most common fauna imaged were the numerous ophiuroids (brittlestars) imaged in the field and reference stations. Numerous feeding mounds, pits and burrows were also imaged indicative of healthy bottom conditions in this area. A single urchin was imaged in profile at station C1, an anemone (*Actinuage richardi*) at Station C3, a sand star (*Astropecten irregularis*) at Station C4, a feeding terebellid polychaete at Station F9 and a juvenile asteroid at REF2.
- The results of this photographic survey constitute valuable baseline information for any further investigations carried out on the proposed Corrib Field pipeline route.

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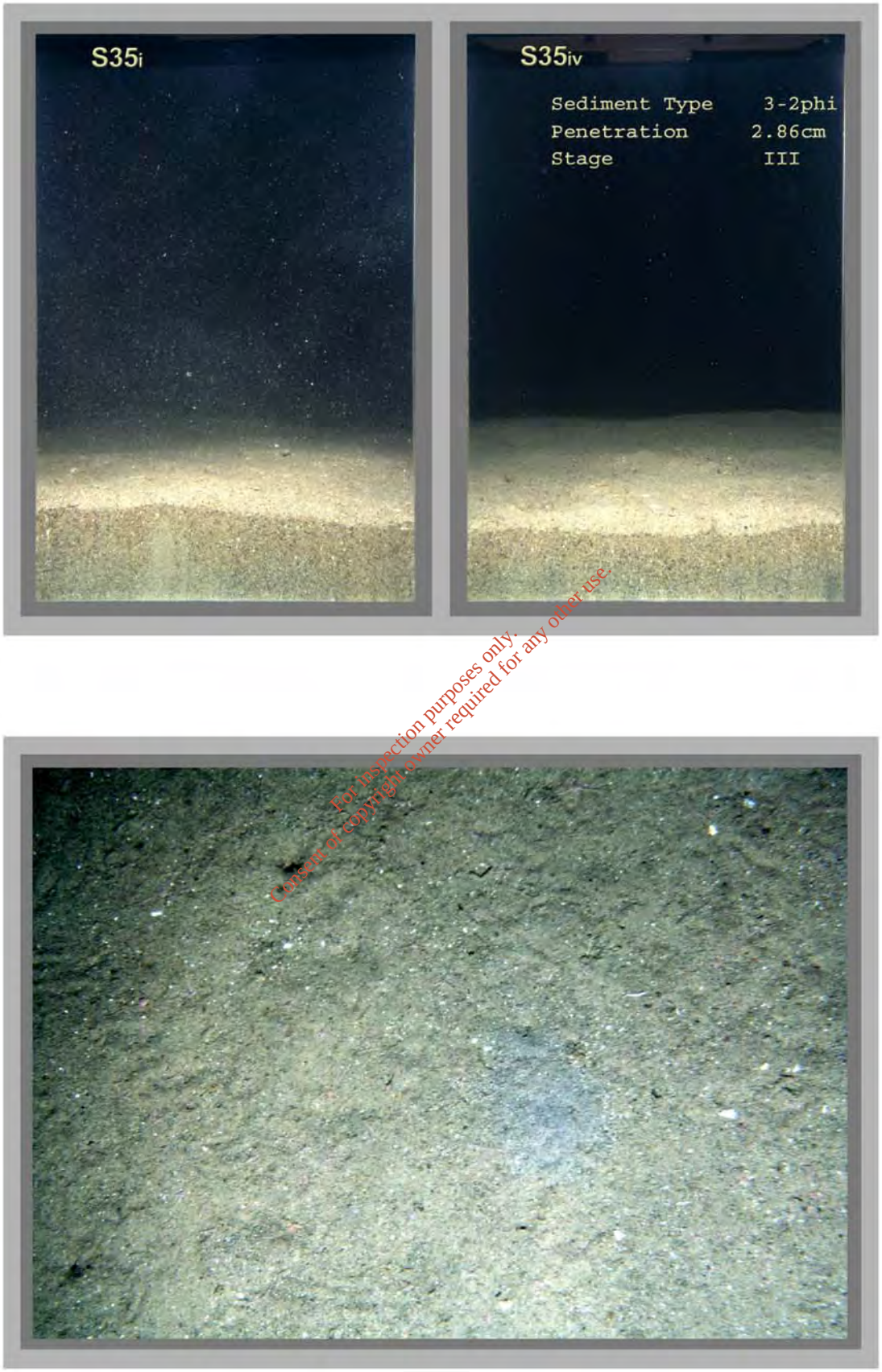
APPENDIX I

SURVEY STATIONS REPRESENTATIVE SPI & SURFACE PHOTOGRAPHS CORRIB FIELD CO. MAYO

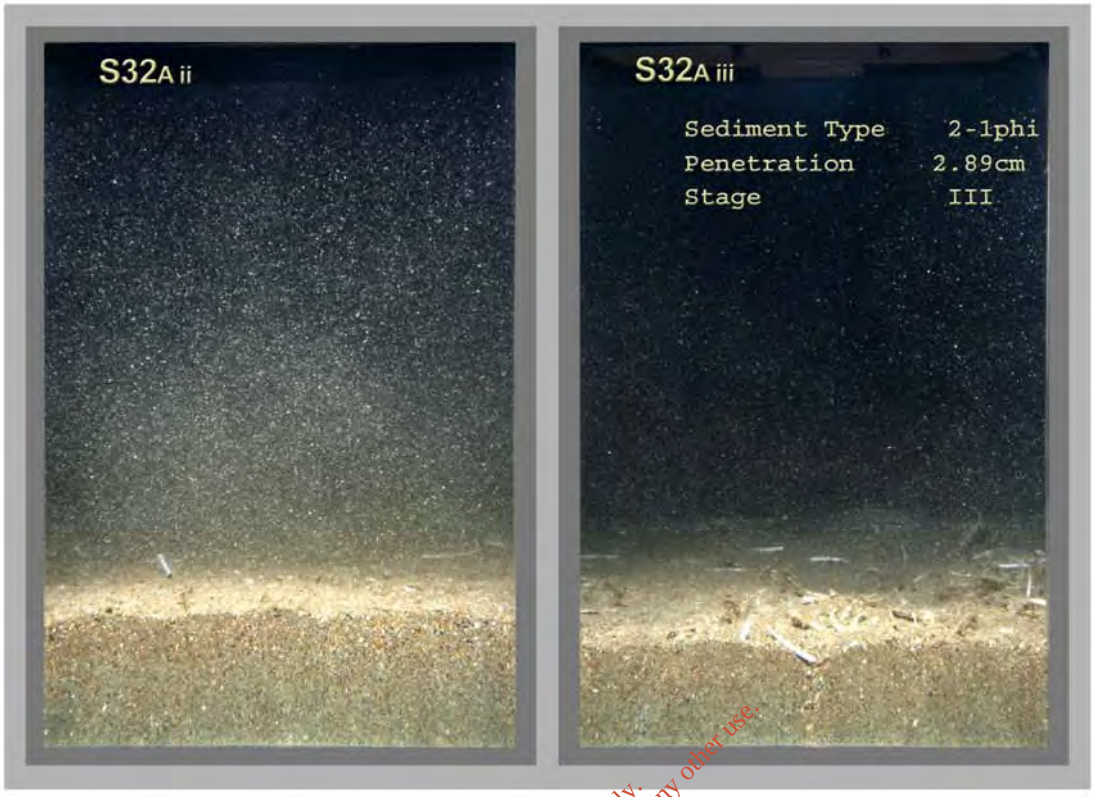
AUGUST 2007

Station 41a: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

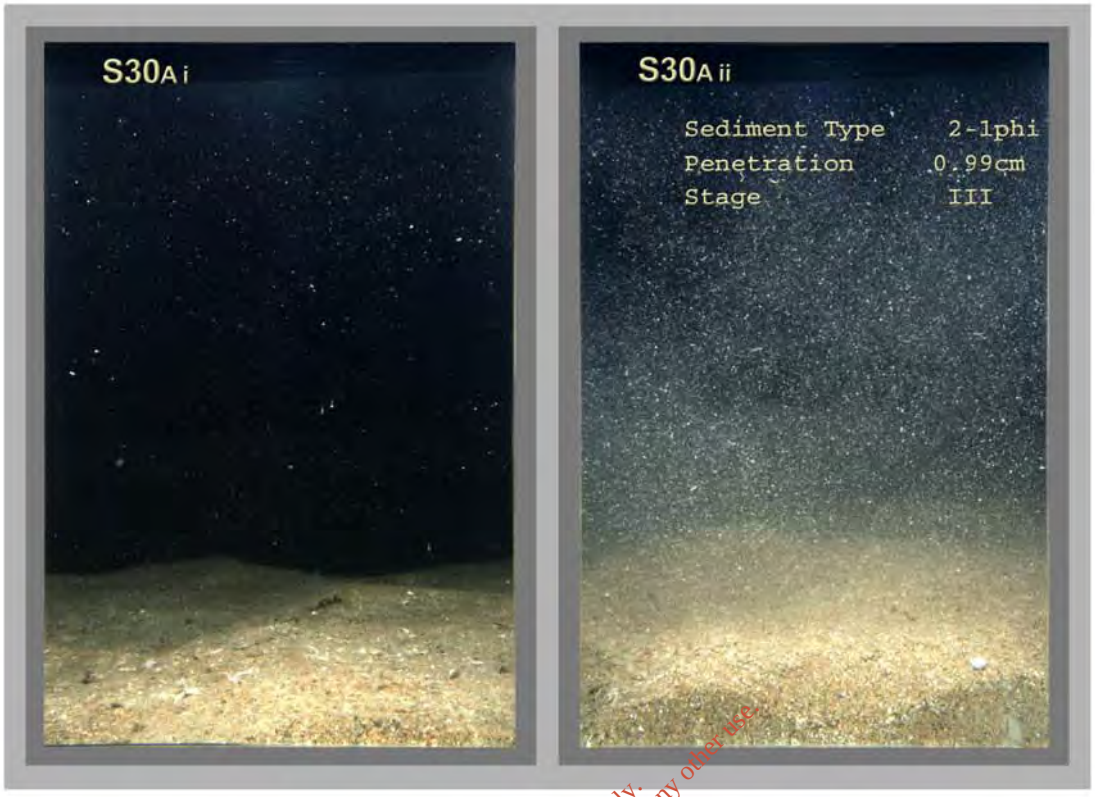
Station 38a: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.



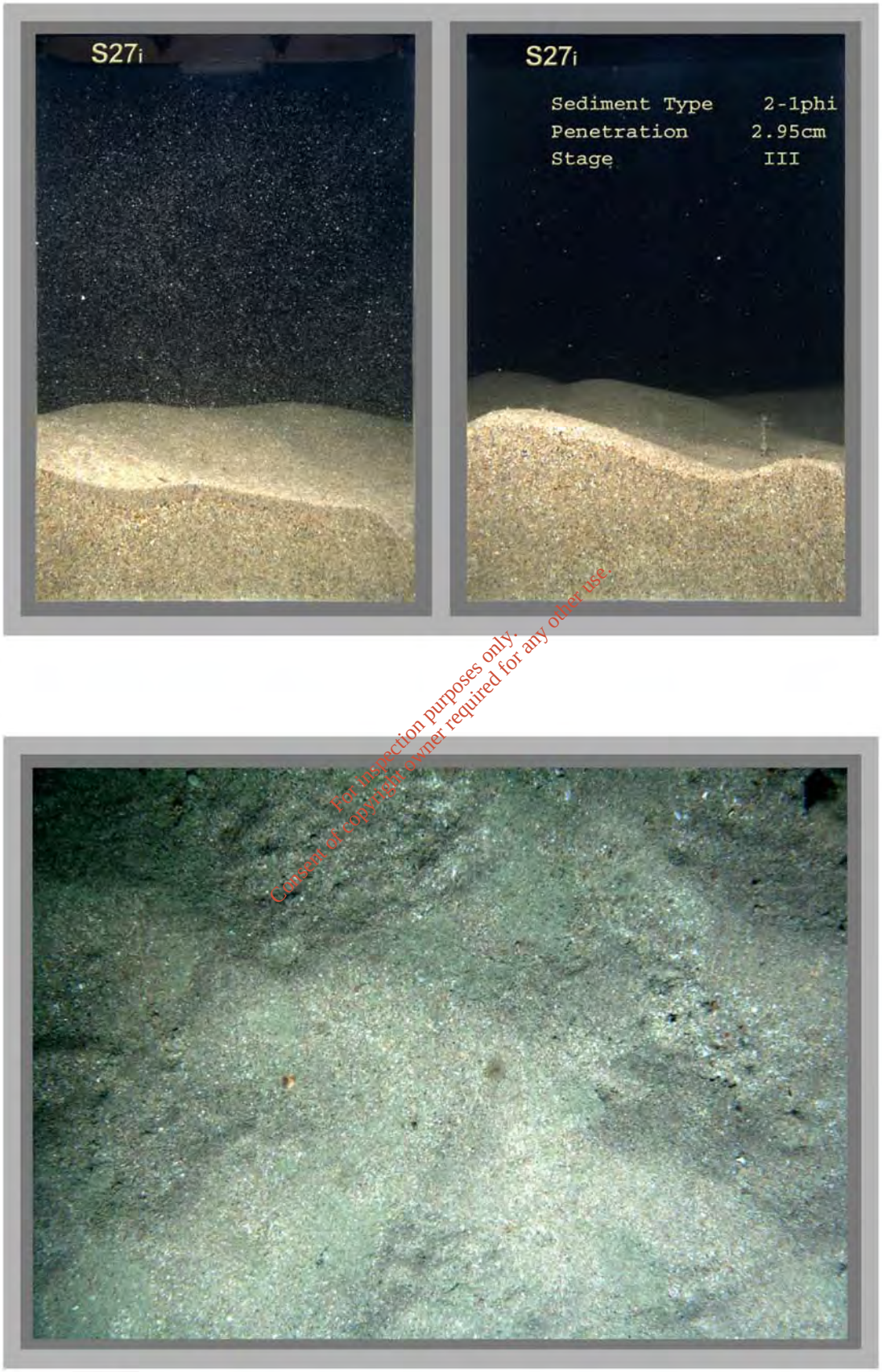
Station 35: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.



Station 32a: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

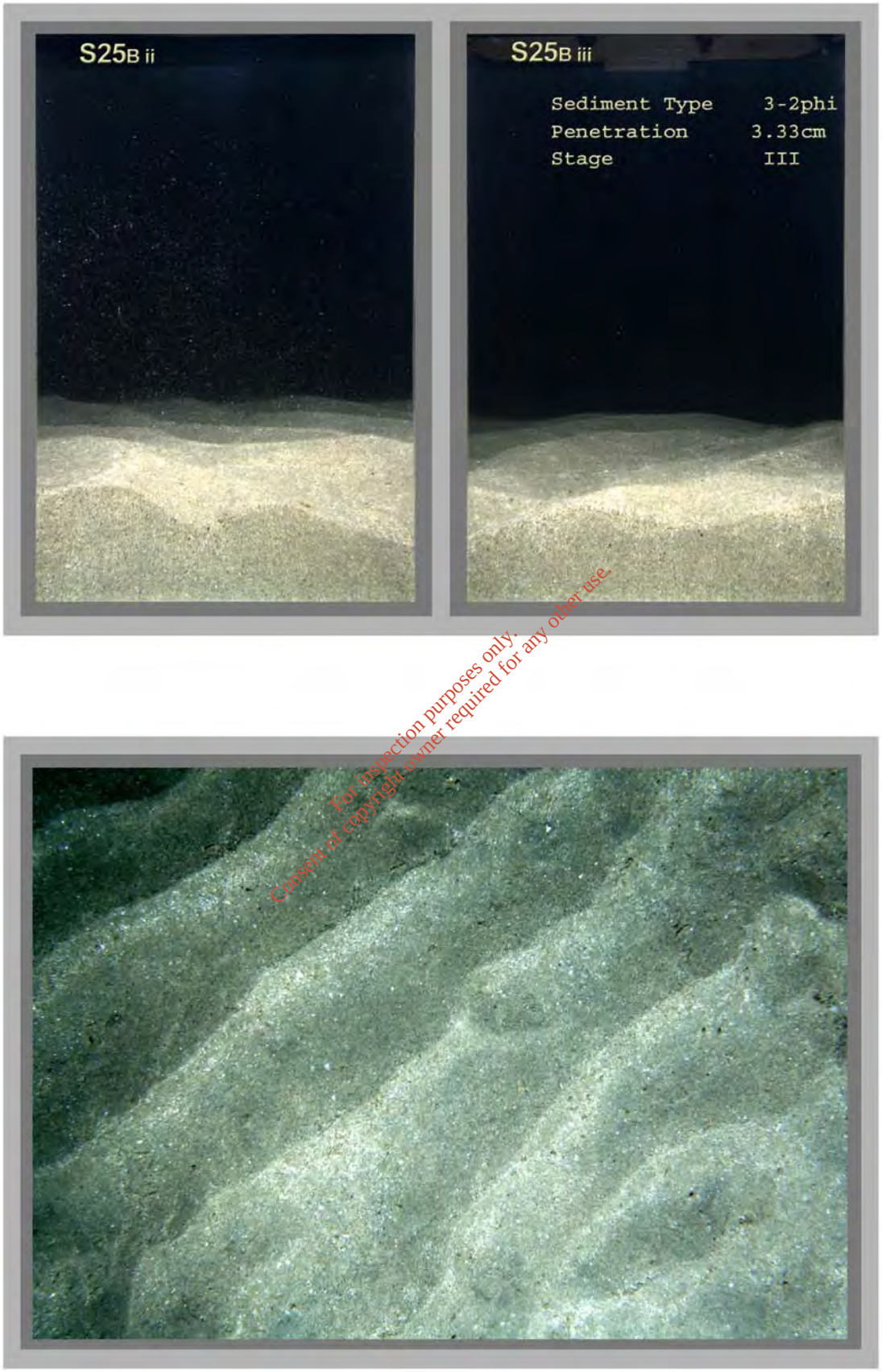


Station 30a: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

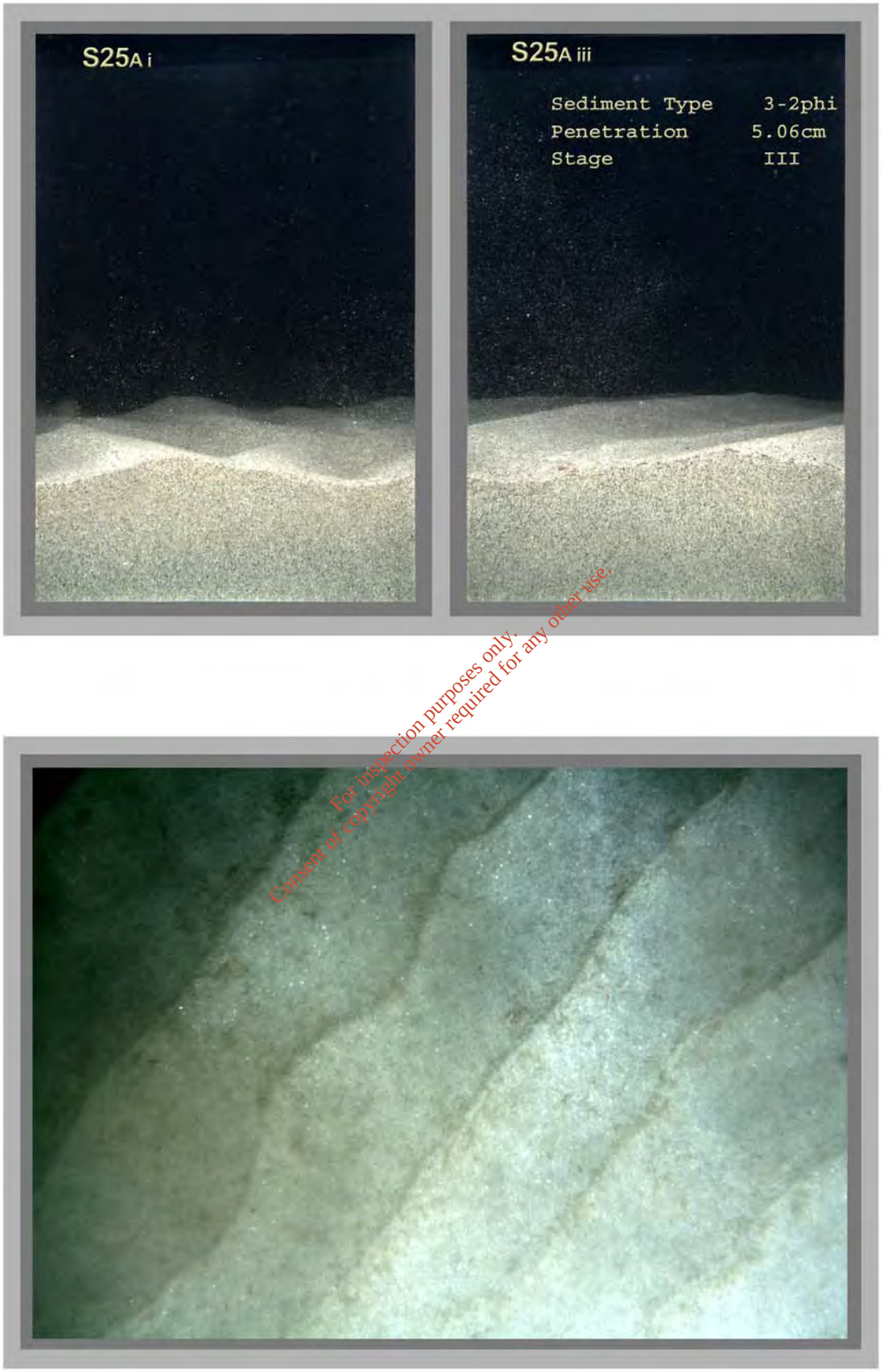


Station 27: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

Station 26: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

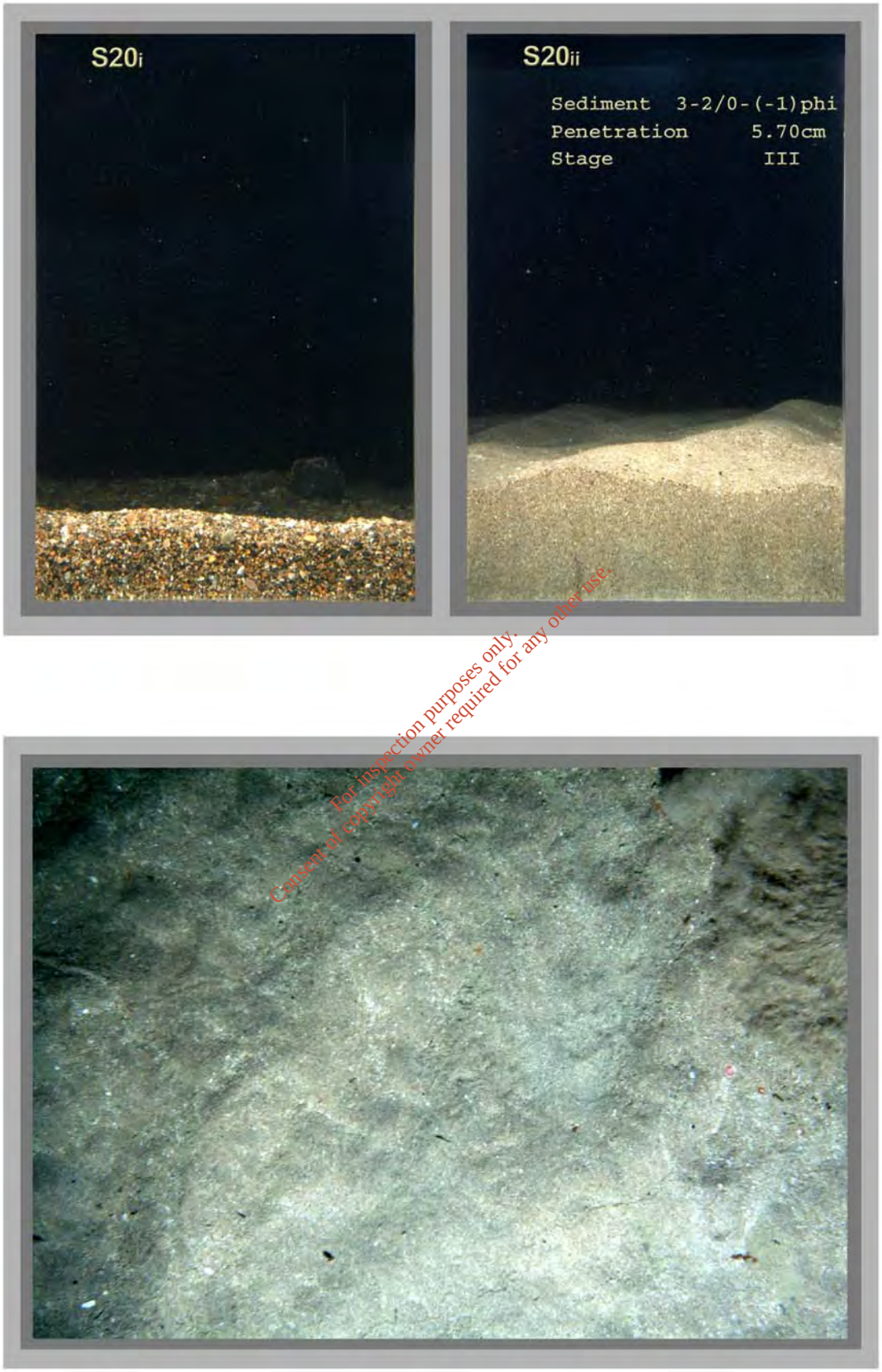


Station 25b: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

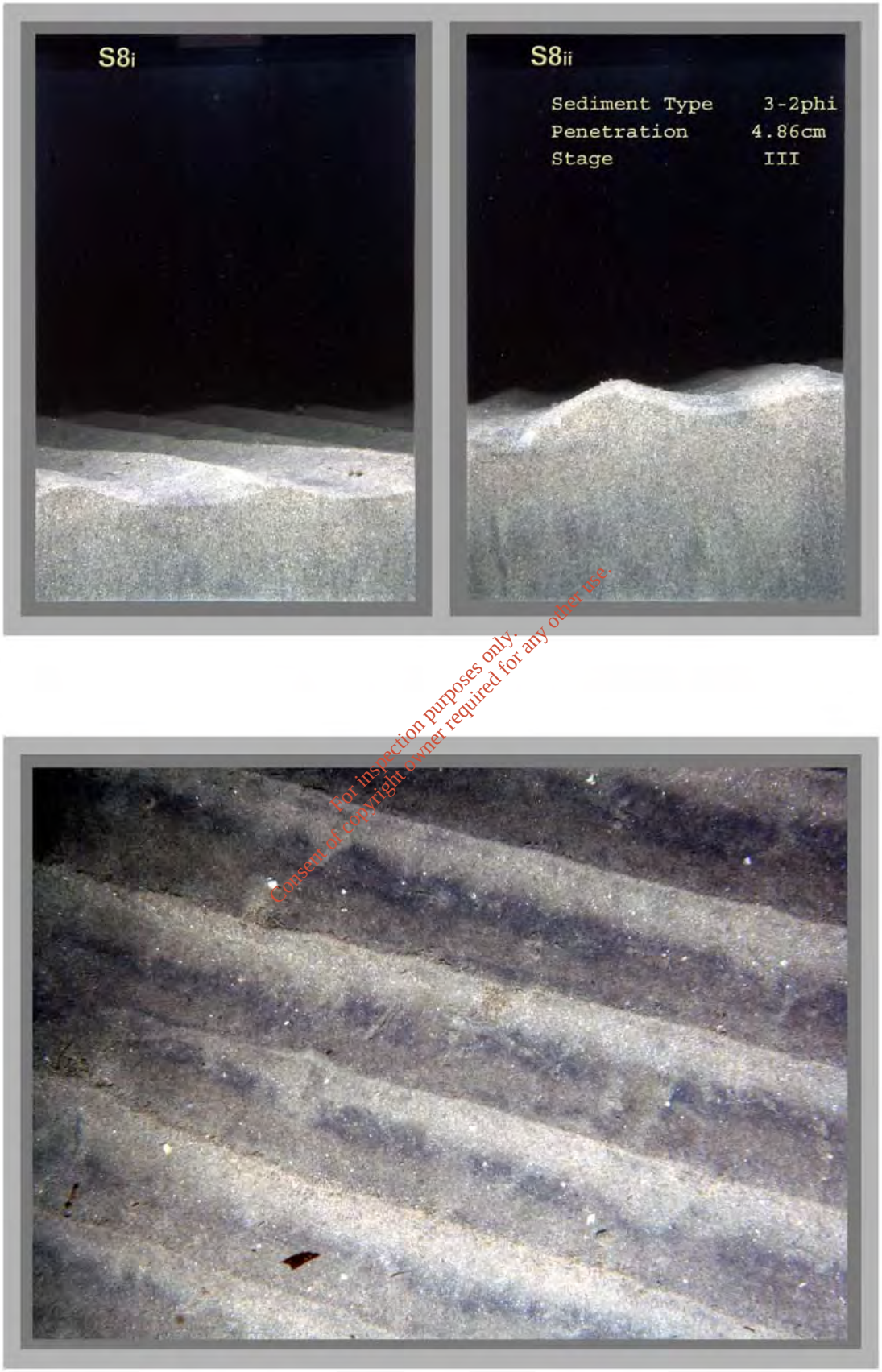


Station 25a: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

Station 25: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.



Station 20: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.



Station 8: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

APPENDIX II

SPI - SEDIMENT PROFILE IMAGERY APPARATUS & DATA ANALYSIS

AUGUST 2007

SEDIMENT PROFILE IMAGERY:

APPARATUS AND DATA ANALYSES

APPARATUS AND DEPLOYMENT.

A remotely operated sediment profile camera is used to obtain *in situ* digital profile images of up to 20 cm of the top layers of sediment on the seafloor. It differs from other underwater cameras in that it vertically slices through the sediment-water interface and images the sediment section in profile. Functioning like an inverted periscope, it consists of a wedge-shaped prism with a plexiglass face plate. Light is provided internally by a flash strobe and the back of the prism has a mirror mounted at a 45° angle. This reflects the image of the sediment-water interface at the face plate up to the camera, which is housed on top of the prism. The camera - prism assembly is supported by an inner frame or cradle which can move relative to an outer supporting frame under control of a 'passive' hydraulic piston (see Figure 1).

The camera prism assembly cradle can be moved up and down by producing tension or slack on the winch wire. As the camera is lowered to the seafloor, tension on the winch wire keeps the prism in the up position. The supporting frame lands on the bottom first, leaving the area directly under the prism undisturbed. As the winch wire is slackened, the prism cradle descends toward the bottom at a controlled rate of fall (Figure 2). The wedge-shaped prism enters the bottom and is driven into the sediment by its weight. The piston ensures that the prism enters the bottom slowly and does not disturb the sediment - water interface. Additional lead weights can be attached to the prism cradle to assist prism penetration if required.

On impact with the bottom, a trigger activates a time delay on the camera shutter release and a digital photograph is taken when the prism comes to rest. Because the sediment is photographed directly against the face plate, turbidity of the ambient seawater does not affect image quality. After the photograph or image is taken, tension on the winch wire raises the prism cradle to the up position, a wiper blade cleans off the face plate, the strobe is recharged and the camera can be lowered for another image. In this manner the SPI assembly can be rapidly 'hopped' over the seabed and a series of images obtained at any one sampling location. After the camera is taken back on board a rubber ring records the depth the camera had penetrated and a counter records the number of successful image

shots taken. Specific measurement techniques and interpretive considerations for the analysis of a range of parameters from the SPI images are presented below.

A compact, equally effective diver operated sediment profile camera apparatus (Figure 3) has been developed for operation in shallow waters and shallow areas generally inaccessible by the larger remotely operated machine. As with the remotely operated SPI camera, the camera prism is mounted on a supporting stabiliser frame which can be moved up and down in an action controlled by a hydraulic system. Once the camera's frame touches the bottom, the scientific diver exerts pressure on the prism housing causing it to penetrate the sediment fabric under control of the hydraulic piston. This allows the optical prism to enter the bottom at approximately 6 cm sec^{-1}. The slow fall rate ensures that the descending prism does not impact the bottom at a high rate and therefore minimizes disturbance of the sediment-water interface. The prism is driven several centimeters into the seafloor and the camera trigger is tripped so that a photograph is taken. The diver ensures that the SPI frame is not moved or disturbed in any way while the camera is taking a picture so that any physical disturbance of the sediment detected in a SPI image is not an artifact caused by the instrument itself.

DATA ANALYSIS.

Images are captured using Canon EOS 350D digital SLR cameras and Nikkor optics and are stored on compact flash memory cards. They are downloaded to a laptop computer before being analysed in detail. The image analysis system used can discriminate a wide range of different grey scales, so subtle features can accurately be digitised and measured.

Customised software in conjunction with an image analysis system is used for the analysis of a series of 21 physical, chemical and biological parameters on each image. Before all measurements from each SPI image are stored on disk, a summary display is made on the screen so the operator can verify if the values stored in memory for each variable are within expected range; if anomalous values are detected, software options allow re-measurement before storage on disk. All data stored on disks are printed out on data sheets for editing by the principal investigator and as a hard-copy backup of the data stored on disk; a separate data sheet is generated for each SPI image. Disk storage of all SPI parameters allows any variable of interest to be compiled, sorted, graphed, or compared statistically.

A great deal of information about benthic processes is available from sediment

profile images. Measurable parameters, many of which are calculated directly by image analysis, include physical / chemical parameters (i.e. sediment type measured as grain size major mode, prism penetration depth providing a relative indication of sediment shear strength, sediment surface relief, condition of mud clasts, redox potential discontinuity depth and degree of contrast, sediment gas voids) and biological parameters (i.e. infaunal successional stage of a well documented successional paradigm for soft marine sediments (see Pearson and Rosenberg, 1978), degree of sediment reworking, dominant faunal type, epifauna and infauna, apparent species richness, depth of faunal activity, presence of microbial aggregations).

A multi- parameter organism-sediment index (OSI) is calculated on the basis of the measured physical and biological parameters. This index characterises habitat quality and has been found to be an excellent parameter for mapping disturbance gradients and the health status of the seabed. Specific analytical and interpretative aspects of the parameters measured from the SPI images are outlined below.

SEDIMENT TYPE DETERMINATION

The sediment grain-size major mode and range are visually estimated from the photographs by overlaying a grain-size comparator, which is at the same scale. This comparator was prepared by using the SPI camera to photograph a series of pre-prepared sediments which were graded according to the Udden-Wentworth size classification scheme. The classes of sediment used ranged from mud to granule. There are seven grain-size classes are on the comparator, i.e. < 0.063mm (≥ 4Ø) (i.e. silt clay), 0.063 - 0.125mm (4-3Ø) (i.e. very fine sand), 0.0125 - 0.25mm (3-2Ø) (i.e. fine sand), 0.025-0.5mm) (2-1 Ø) (i.e. medium sand), 0.5 - 1.0mm (1-0Ø) (i.e. coarse sand), 1.0 -2.0mm (0 to –(-)1Ø) (i.e. very coarse sand), > 2.0mm (< -1Ø) (i.e. gravel). Seven grain-size classes are on this comparator: ≥ 4Ø, 4-3Ø, 3-2Ø, 2-1Ø, 1-0Ø, 0-(-)1Ø, < -1Ø. The lower limit of optical resolution of the photographic system is about 0.062mm, allowing recognition of grain sizes equal to or greater than coarse silt. The accuracy of the method has been documented by comparing the SPI estimates with grain-size statistics determined from laboratory sieve analyses.

PRISM PENETRATION DEPTH

The SPI prism penetration depth is determined by measuring both the largest and smallest linear distance between the sediment-water interface and the bottom of

the digital image frame. The SPI analysis software automatically averages these maximum and minimum values to determine the average penetration depth. All three values, (maximum, minimum, and average penetration depth) are included on the data sheets. Prism penetration is potentially a noteworthy parameter; if the number of weights used in the camera is held constant throughout a survey, the camera functions as a static-load penetrometer. Comparative penetration values from sites of similar grain-size give an indication of the relative sediment bearing capacity or shear strength.

SEDIMENT BOUNDARY ROUGHNESS

Sediment boundary roughness is determined by measuring the vertical distance (parallel to the digital image border) between the highest and lowest points of the sediment-water interface. In addition, the likely origin (e.g. physical or biogenic) of this small-scale topographic relief is indicated when it is evident. In sandy sediments, boundary roughness can be a measure of sand wave height. On silt-clay bottoms, boundary roughness values often reflect biogenic features such as faecal mounds or surface burrows.

MUD CLASTS

When fine-grained, cohesive sediments are disturbed, either by physical bottom scour or faunal activity (e.g. decapod foraging), intact clumps of sediment are often scattered about the seafloor. These mud clasts can be seen at the sediment-water interface in SPI images. During analysis, the number of clasts is counted, the diameter of a typical clast is measured, and their oxidation state is assessed. Depending on their place of origin and the depth of disturbance of the sediment column, mud clasts can be reduced or oxidised (in SPI images, the oxidation state is apparent from their reflectance value; see 'Apparent redox potential discontinuity depth' section below). Also, once at the sediment-water interface, these sediment clumps are subject to bottom-water oxygen levels and bottom currents. Based on laboratory microcosm observations of reduced sediments placed within an aerobic environment, oxidation of reduced surface layers by diffusion alone is quite rapid, occurring within 6-12 hours. Consequently, the detection of reduced mud clasts in an obviously aerobic setting suggests a recent origin. The size and shape of mud clasts, e.g. angular versus rounded, is also considered. Mud clasts may be moved about and broken up by bottom currents and/or animals (macro- or meiofauna) (Germano, 1983). Over time, large angular clasts become small and rounded. Overall, the abundance, distribution, oxidation state, and appearance of mud clasts are used to make inferences about the recent pattern of seafloor disturbance in an area.

APPARENT REDOX POTENTIAL DISCONTINUITY (ARDP) DEPTH

In fine-grained coastal areas, when there is oxygen in the overlying water column, the near surface sediment will have a higher reflectance value relative to hypoxic or
anoxic sediment underlying it. This is because the oxidised surface sediment contains particles coated with ferric hydroxide (an olive colour when associated with particles), while the suphidic sediments below this oxygenated layer are grey to black. The boundary between the coloured ferric hydroxide surface sediment and underlying grey to black sediment is defined here as the apparent redox potential discontinuity (abbreviated as the RPD). This 'apparent' depth may, or may not, be equivalent to the actual RPD depth, which is defined as the depth at which the Eh = 0 as measured by microelectrodes. As explained below, in most cases, the depth of Eh = 0 potential in the sediment differs from the 'apparent' RPD as imaged by SPI.

The difference between the depth of the true RPD (Eh = 0) and the imaged apparent RPD can be explained as follows. As dissolved oxygen diffuses into sediment pore water, it is consumed by a variety of biological and geo-chemical reactions. One of these reactions involves the oxidation of iron, which is precipitated onto mineral grains located at, or near, the sediment surface. Once oxidised, these ferric hydroxide-coated particles are bioturbated downward into pore-waters, which lack free molecular oxygen (negative Eh). However, the ferric hydroxide coatings are meta-stable, and reduction of the iron is a slow process relative to the rate of bioturbation. This explains the presence of oxidised grain coatings (high optical reflectance sediment) in reducing pore waters. In the presence of bioturbating infauna, the thickness of the RPD directly reflects the particle bioturbation depth.

The areal extent of the RPD is determined by digitising its unique reflectance value. This oxidised, high-reflectance area is digitised, measured to scale, and divided by the prism window width to obtain a mean depth for the RPD (or particle bioturbation depth). The RPD depth is given special attention in these analyses, because it is a sensitive indicator of the biological mixing depth, infaunal successional status, and within-station sediment patchiness. In the absence of bioturbating infauna, the RPD will achieve a maximum depth of up to 5 mm solely by diffusion depending on the concentration gradient of dissolved oxygen, reducing substrates within the sediment, water temperature (reaction rates), and sediment permeability.

The configuration of the RPD boundary is also of significance. In sandy sediments, physical forces dominate surface relief and RPD depth, which tends to be constant or uniform and does not necessarily follow the surface contours provided by bed-forms. In muddy sediments, the RPD is more complex and convoluted. Here, the RPD layers tend to be broadly uniform and more or less follow the contours of surface sediments. However, smaller scale convolutions are superimposed on this pattern in response to biogenic reworking by a resident infauna. Biogenic structures are regions of enhanced biological and geo-chemical activity where the activities of infaunal organisms can increase flux across the oxic-anoxic sediment interface (Diaz and Schaffner, 1988). Consequently, the RPD boundary is a complicated surface much greater in actual area than a simple aerial measurement would estimate and with a greater effect on sediment-water interface flux rates than is initially apparent (Diaz and Schaffner, 1988).

Another important characteristic of the RPD is the degree of contrast in reflectance values at this boundary. This contrast is related to the interactions among the amount of organic-loading and bioturbational activity in the sediment, and the levels of bottom water dissolved oxygen in an area. High inputs of labile organic material increase sediment oxygen demand, and subsequently sulphate reduction rates (and the abundance of sulphide end-products). This results in more highly reduced (lower-reflectance) sediments at depth and higher RPD contrasts. Although the SPI image analysis system quantifies the degree of contrast, this value can vary as a function of light intensity controls on the image analysis system, which are adjusted by the operator when a wide range of sediment types (e.g. silt-clay to coarse sand) is encountered. As a result, the quantified RPD contrast level may not be a meaningful parameter. However, a qualitative (visual) assessment of the RPD contrast (i.e. high versus low) is often considered in the interpretive process.

SEDIMENTARY METHANE

At extreme levels of organic-loading, pore-water sulphate is depleted, and methanogenesis occurs. The process of methanogenesis is detected by the appearance of methane bubbles in the sediment column. These gas-filled voids are readily discernible because of their irregular, generally circular aspect and glassy texture (due to the reflection of the strobe off the gas). If present, the number and total aerial coverage of all methane pockets is measured.

INFAUNAL SUCCESSIONAL STAGE

The mapping of successional stages is based on the theory that organism-sediment interactions follow a predictable sequence after a major seafloor

perturbation. This theory states that primary succession results in the predictable appearance of macrobenthic invertebrates belonging to specific functional types following a benthic disturbance. These invertebrates interact with sediment in specific ways. Because functional types are the biological units of interest, this definition does not demand a sequential appearance of particular invertebrate species or genera. This theory is now well established in the scientific literature (see Pearson and Rosenberg, 1978; Rhoads and Boyer, 1982; Rhoads and Germano, 1986).

The term disturbance is used here to define natural processes, such as seafloor erosion, changes in seafloor chemistry, foraging disturbances which cause major reorganisation of the resident benthos, or anthropogenic impacts, such as dredged material or sewage sludge dumping, thermal effluents from power plants, pollution impacts from industrial discharge, etc. An important aspect of using this successional approach to interpret benthic monitoring results is relating organism-sediment relationships to the dynamical aspects of end-member seres. This involves deducing dynamics from structure, a technique pioneered by Johnson (1972) for marine soft-bottom habitats. The application of an inverse methods approach to benthic monitoring requires the *in situ* measurements of salient structural features of the organism-sediment relationships measured through SPI technology.

Pioneering (Stage 1) species are the first to colonise a new or newly disturbed bottom and reach high densities in a short time. Pioneering (Stage I) assemblages usually consist of dense aggregations of tubicolous or otherwise sedentary organisms that live near the sediment surface and feed at the surface or from the water column (Pearson and Rosenberg, 1978; Rhoads and Germano, 1986). *Capitella capitata*, *Malacoceros fuliginosus* and Spionidae species are typical forms. These functional types are usually restricted to the near surface of the bottom and their sedimentary effects include (i) the construction of dense tube aggregations which can influence sedimentation/erosion, (ii) deepening of the redox boundary by fluid bioturbation, and (iii) the occlusion of the sediment surface with faecal pellets. These associations are typically characterised by a shallow redox boundary and shallow bioturbation depths, particularly in the earliest stages of colonisation.

In the absence of further physical, chemical or biological disturbance, the pioneering assemblages are replaced by deposit feeders. This is progressive and can be arbitrarily divided into an intermediate and an equilibrium phase (Stages II and III, respectively). Typical Stage II species are shallow dwelling bivalves, tubicolous amphipods and some polychaete species.

Stage III taxa, in turn, represent high-order successional stages typically found in low disturbance regimes. A Stage III or equilibrium assemblage is persistent and is dominated by a bioturbating infauna, which feed at depth within the sediment. Sedimentary effects are distinctive and include (i) the transfer of water and particles over vertical distances of 10 - 20 cm, (ii) the production of homogeneously mixed fabrics by intensive reworking, with faecal pellets at and below the sediment surface, (iii) the creation of void feeding spaces at depth within the bottom, (iv) the extension of the redox boundary to c. 20 cm, and (v) the production of a distinctive surface microtopography unless smoothed over by tidal resuspension. Such deep-dwelling species as the polychaetes, *Pectinaria* sp., Maldanidae sp., the echinoderm, *Trachythyone elongata, Amphiura sp*. and *Echinocardium sp*. and the crustaceans *Lysiosquilla* sp., *Nephrops* sp. and *Upogebia* sp. These invertebrates are infaunal, and many feed at depth in a head-down orientation. The localised feeding activity results in distinctive excavations called feeding voids. Diagnostic features of these feeding structures include: a generally semicircular shape with a flat bottom and arched roof, and a distinct granulometric change in the sediment particles overlying the floor of the structure. This relatively coarse-grained material represents particles rejected by the head-down deposit-feeder. These deep-dwelling infaunal taxa preferentially ingest the finer sediment particles. In the retrograde transition of Stage III to Stage I, it is sometimes possible to recognise the presence of relict (i.e. collapsed and inactive) feeding voids. (It should be added to the above generalisations that pioneering and higher successional species may coexist, if disturbance involves only the superficial sediment layers).

These end-member stages (Stages I and III) are easily recognised in SPI images by the presence of dense assemblages of near-surface polychaetes and/or the presence of subsurface feeding voids. Both types of assemblages may be present in the same image.

ADDITIONAL BIOLOGICAL PARAMETERS

Several additional biological parameters are measured from the digital images using the computer image analysis system. These include: the density per linear cm

of polychaete and/or amphipod tubes at the sediment water interface; the minimum and maximum depth of faecal pellet layers and the minimum and maximum depth of feeding voids. Dominant faunal type (i.e. epifauna or infauna) and apparent species richness are also estimated.

SPI ORGANISM-SEDIMENT INDEX (OSI)

A multi-parameter SPI Organism-Sediment Index (OSI) has been constructed to characterise habitat quality and the method of its calculation is shown in Table 1.

The OSI is the sum of values allocated to the various physical/chemical and biological SPI parameters measured and it has a potential value range of -10 to +11. The Organism-Sediment Index is calculated automatically from the software after completion of all measurements from each digital image. This index has been found to be an excellent parameter for mapping disturbance gradients in an area and documenting eco-system recovery after disturbance.

Habitat quality is defined relative to two end-member standards. The lowest value is given to those bottoms which have low or dissolved oxygen in the overlying bottom water, no apparent macrofaunal life, and methane gas present in the sediment. The SPI OSI value for such a condition is minus 10. At the other end of the scale, an aerobic bottom with a deeply depressed RPD, evidence of a mature macrofaunal assemblage, and no apparent methane gas bubbles at depth will have a SPI OSI value of plus 11.

Chemical parameters	Index value	Biological parameters	Index value
Mean apparent RPD depth (cm)		**Successional stage (Primary succession)**	
0	**0**		
>0 - 0.75	**1**	Azoic	**-4**
0.76 - 1.50	**2**	Stage 1	**1**
1.51 - 2.25	**3**	Stage 1-2	**2**
2.26 - 3.00	**4**	Stage 2	**3**
3.01 - 3.75	**5**	Stage 2-3	**4**
>3.75	**6**	Stage 3	**5**
Methane Present	**-2**	**(Secondary succession)**	
No / low oxygen	**-4**	Stage 1 on Stage 2	**5**
		Stage 2 on Stage 3	**5**

Table 1. Method of calculating the Organism - Sediment Index (OSI) value.

From experience with mapping this parameter, values of +7 to +11 are typical of undisturbed sediments while values ≤ 6 tend to be found at sites which have experienced recent physical disturbance (e.g. bottom erosion by currents or disturbance of the bottom by scavenging fish or crustaceans) or are chemically stressed, organically loaded, sulphidic or contaminated in some way. In dealing with areas which are subject to organic enrichment (which may have a variety of origins ranging from natural runoff to anthropogenic inputs), OSI values in the range +6 to +1 generally indicate an overload situation where inputs exceed the capacity of the system and organic matter accumulates on the bottom. Index values which fall in the range +1 to -10 identify varying degrees of habitat degradation associated with a continual accumulation of organic matter and an oxygen depletion on the bottom. At the upper end of the scale, it has been found that OSI values of the order of +11 may reflect a productivity enhancement stage of organic enrichment where natural plant and animal production is increase in response to the ready availability of particulate organic material.

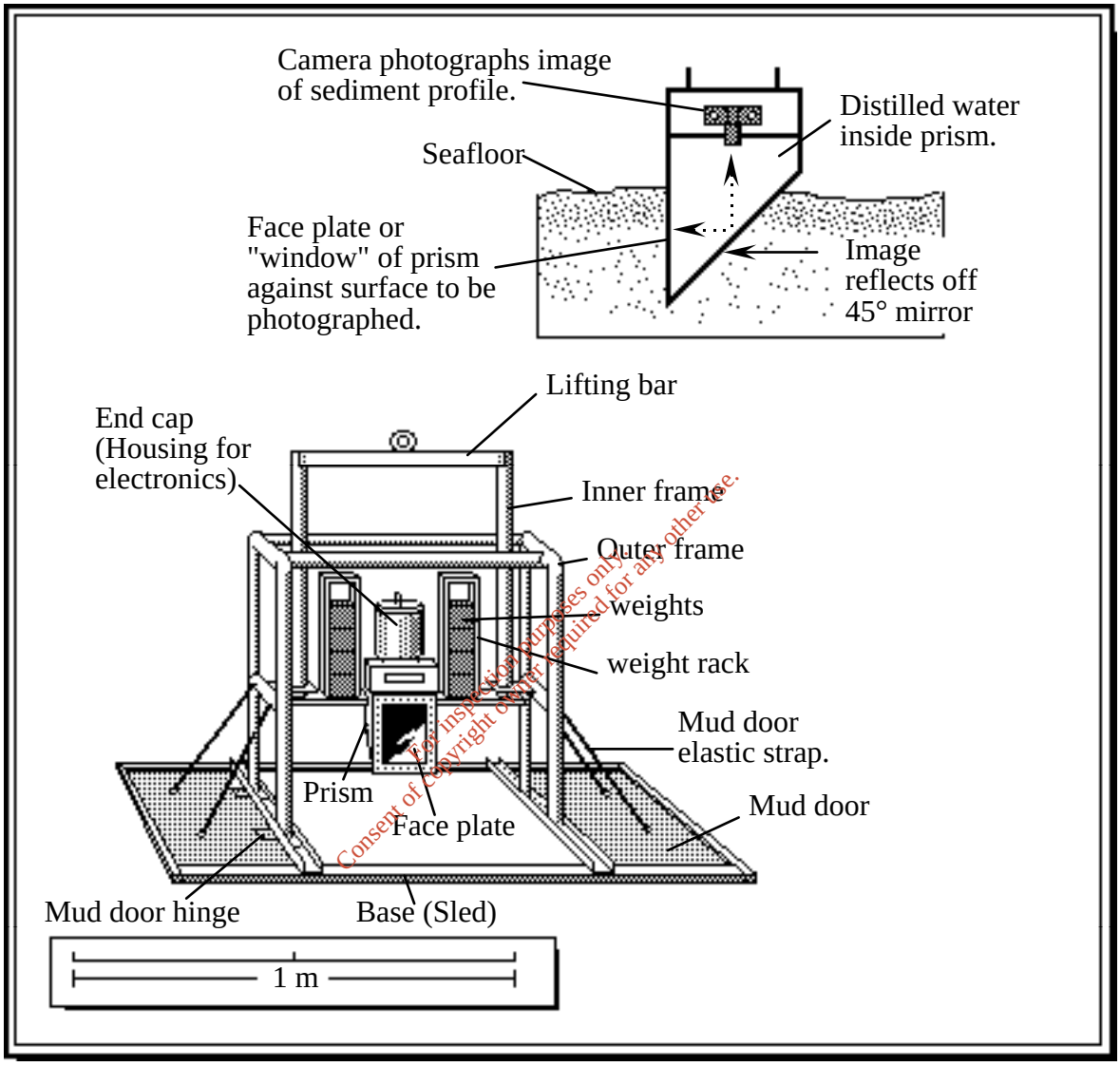


Figure 1. Representation of the remotely operated **S**ediment **P**rofile **I**magery camera.

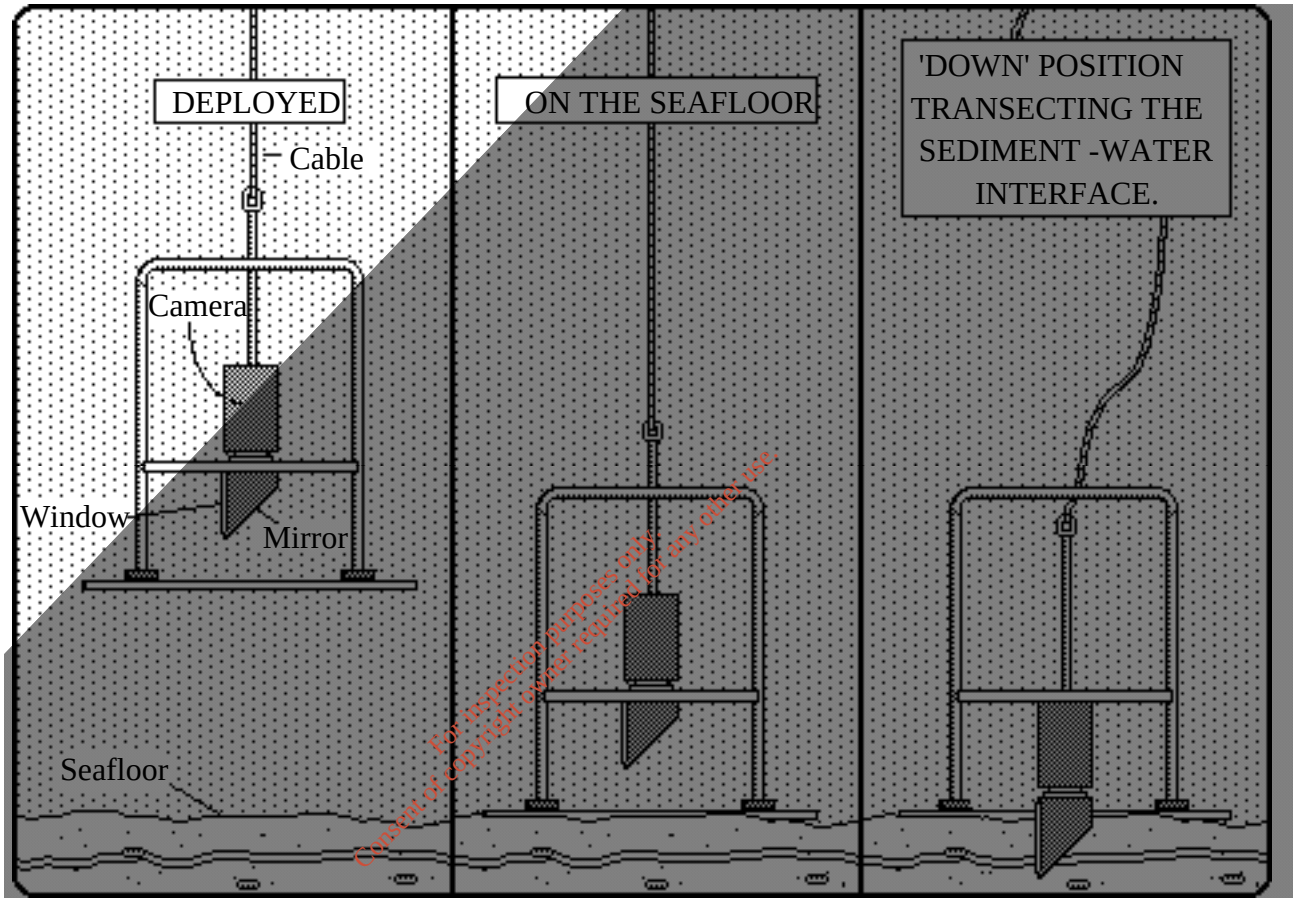


Figure 2. **S**ediment **P**rofile **I**magery (SPI): camera deployment on the seafloor.

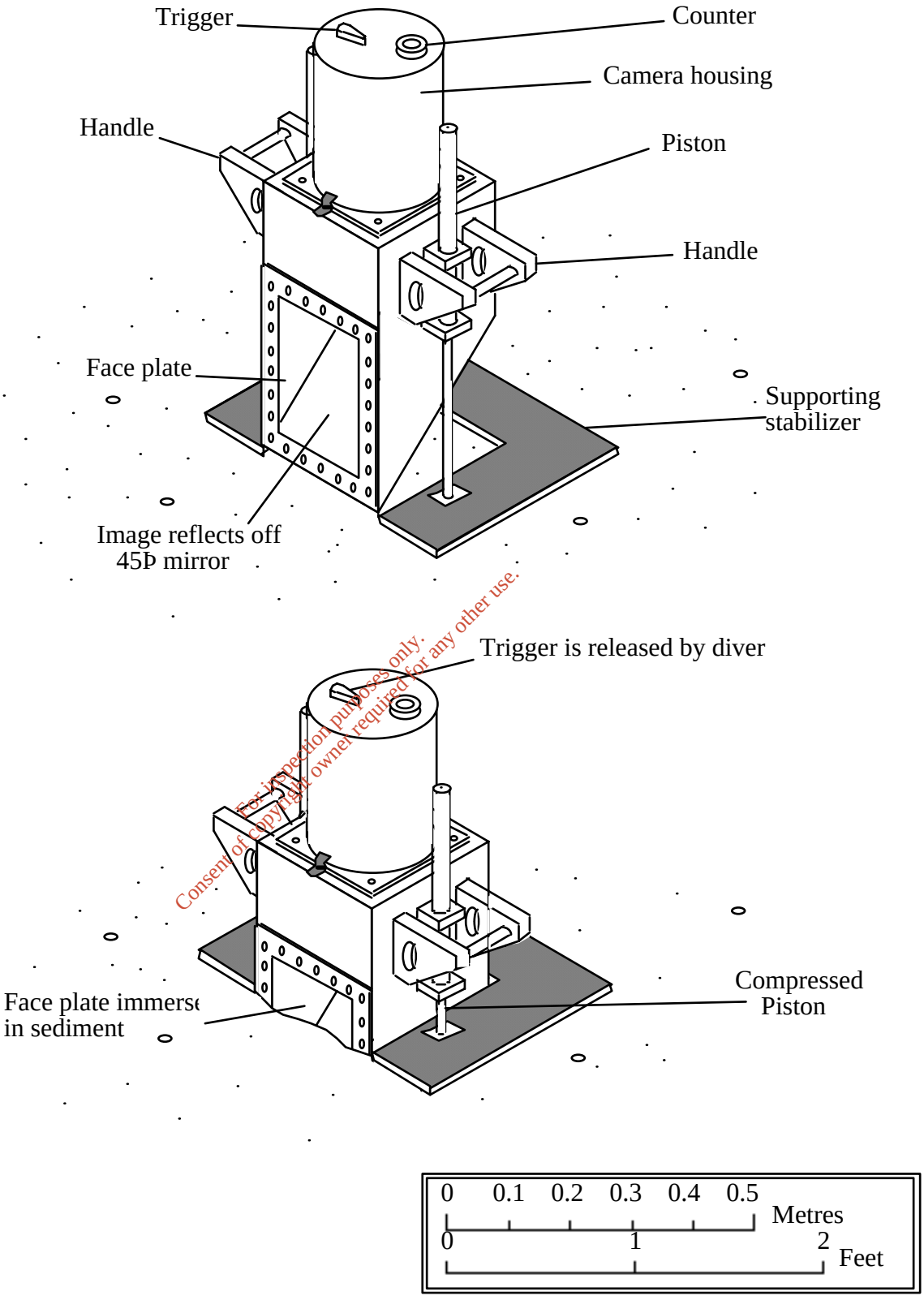


Figure 3. Details of the diver operated **S**ediment **P**rofile **I**magery (SPI) camera.

CORRIB OFFSHORE GAS FIELD DEVELOPMENT

CORRIB OFFSHORE FIELD ENVIRONMENTAL SURVEY 2008

September 2009

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1 Introduction

The Corrib gas field lies in around 350m of water approximately 65km off the coast of County Mayo. The gas in the field is to be brought ashore using a 20-inch-diameter pipeline, which will landfall at Dooncarton in Broadhaven Bay. From there, a pipeline will be routed to the terminal at Bellanaboy Bridge. The plan of development for the field was approved in 2002. While the drilling of wells has continued since then, there have been several issues on the coastal and onshore sections of the project, and installation of the pipeline between the field and terminal has been delayed as a result.

The key events in the progression of the development are summarised below:

- At the time of submission of the 2001 environmental impact statement (EIS) (2000 field survey data), five wells had been drilled in the field (P1–P5); these wells were suspended temporarily.
- In 2006, the SEDCO 711 drilling rig completed wells P3 and P4, and installed wellhead protection structures over the other three wells.
- In 2007, the SEDCO 711 returned to the field to drill well P6 (which is located close to the manifold) and well P101 (which is effectively a sidetrack of well P1). Christmas trees were installed at both of these wells, and at well P5 to the south-west of the main well cluster. All three wells are covered by wellhead protection structures.
- In 2008, the SEDCO 711 returned to the field and completed wells P5, P6 and P101. The P4 wellheads were opened before operation was suspended.
- In terms of seabed infrastructure, the foundations for the collection manifold have been installed and the pipeline end manifold (PLEM) has been laid on the seabed. Installation of the infield flow lines and umbilical are currently ongoing and should be completed in 2009.

Shell Exploration and Production Ireland Ltd (SEPIL), which is now the operator of the Corrib gas field, commissioned a second baseline survey of the Corrib field, with the aim of updating the information collected during the 2000 survey.

The objective of the 2008 survey was to obtain data on the biological communities and physico-chemical aspects of sediments in the Corrib field to assess any potential impacts of drilling activities and compare the data recorded during the 2000 (Corrib 2001 EIS).

A summary of the well locations and drilling activities in the Corrib field is shown in **Table 1.1**. A more specific breakdown of 2008 operations within the Corrib field survey area is listed in **Table 1.2**.

As shown in **Table 1.2**, several well operations were undertaken in the months immediately pre-dating the 2008 field survey, and hence any sediment disturbance or potential chemical contamination that has occurred during this time could be reflected in the chemical results obtained in 2008. Operations also occurred at well P5 during July 2008, precluding the collection of the samples at proposed locations A1–A4 owing to the presence of the SEDCO 711 drilling rig.

Table 1.1: Summary of annual drilling activities in the Corrib field area since 1996

NA Block (Well number)	Well location		Summary of drilling and installation activity
	Latitude (N)	Longitude (W)	
18/20-1 (Discovery Well)	54°20'47.554"	11°05'41.114"	1996 = Discovery well drilled, later plugged & abandoned
18/20-2z (P1)	54°20'20.169"	11°03'26.819"	1998 = Appraisal well drilled 2006 = Wellhead protection fitted
18/25-1 (P2)	54°19'09.119"	11°02'54.963"	1999 = Appraisal well drilled 2006 = Wellhead protection fitted
18/20-3 (P3)	54°20'51.419"	11°02'15.468"	2000 = Appraisal well drilled 2006 = Well completion
18/20-4 (P4)	54°20'19.348"	11°03'26.173"	2000 = Appraisal well drilled 2006 = Well completion
18/25-3 (P5)	54°19'14.467"	11°04'09.378"	2001 = Appraisal well drilled 2006 = Wellhead protection fitted 2007 = Christmas tree installed 2008 = Well completion
18/20-5 (P6)	54°20’18.222”	11°03’26.705”	2007 = Well drilled = Wellhead protection fitted = Christmas tree installed 2008 = Well completion
18/20-6 (P101)	54°20’20.698”	11°03’26.651”	2007 = Well drilled = Wellhead protection fitted = Christmas tree installed 2008 = Well completion
Manifold	54°20’20.386”	11°03’30.751”	2008 = Manifold foundations installed

Table 1.2: Summary of 2008 drilling activities in the Corrib field

Date	Time	Well	Activity
28 Apr	19:45		Transocean S711 under contract to SEPIL
6 May	22:15	Corrib UTIL	End of mobilisation, load outs, anchor handling
6 May	22:15	18/20-6(**P101**)	Commenced operations
			Open wellhead protection structure
7 May	7:00	18/20-6(**P101**)	Operations suspended
7 May	7:00	18/20-4(**P4**)	Commenced operations
			Open wellhead protection structure
8 May	0:00	18/20-4(**P4**)	Suspended operations
8 May	0:00	18/20-5(**P6**)	Commenced operations
			18/20-5 (**P6**) completion operations
9 Jun	2:30		Suspended operations
		18/20-5(**P6**)	Pressure leak in tubing between packer and hanger
9 Jun	2:30	18/20-6(**P101**)	Commenced operations
12 Jul	1:45	18/20-6(**P101**)	Suspended operations
12 Jul	1:45	18/25-3(**P5**)	Commenced operations
12 Jul			***Commenced Corrib field survey***
30 Jul			***Completed and demobilised from field survey***
17 Sep	16:15	18/25-3(**P5**)	Suspended operations
17 Sep	16:15	18/20-5(**P6**)	Commenced operations
28 Dec	7:24	18/20-5(**P6**)	End of operations on **P6**

2 Survey

SEPIL commissioned RSK Environment Ltd (RSK) to manage the environmental survey within the Corrib field. RSK contracted Osiris Projects to act as vessel operators and provide navigational surveyors. Survey staff were also subcontracted from Benthic Solutions Ltd (BSL) while environmental consultancy Aqua-Fact provided the SPI and drop-down camera equipment, and personnel to operate it.

Sampling operations were carried out from the M/V *Deepworker*, operated by Retech Marine Services Ltd contracted to Osiris. Mobilisation of the *Deepworker* commenced in Foynes on 11 July, with the vessel leaving her berth on 12 July. Transit time from Foynes to the Corrib offshore field was approximately 30 hours; while underway, an accuracy and calibration check on the vessel's survey navigation and dynamic positioning systems was completed successfully.

Survey operations were postponed on several occasions owing to poor weather conditions; during these periods, the vessel either stood off in proximity to the areas of survey or sought shelter in Killala or Broadhaven Bay. The progression of the survey is summarised in **Table 2.1**. Please note that demobilisation occurred following additional survey operations at the treated surface-water discharge location (not covered in this report).

Osiris provided an onboard positioning package and helmsman display from which to position the vessel during survey operations. Vessel navigational equipment mobilised aboard the vessel for the survey is listed in **Appendix 1.**

Table 2.1: Summary of survey progress in 2008

Date (2008)	Operation
11 July	Mobilisation of the *Deepworker*
12 July	*Deepworker* vessel departs berth in Foynes
12–13 July	Accuracy and calibration check on vessel's navigation and dynamic positioning systems
13 July	First survey operations undertaken at the Corrib offshore field
23 July	Corrib field survey operations completed
23–30 July	Vessel on station at outfall location for survey work here (*not covered in this report*)
30 July	Demobilisation of the survey vessel and personnel in Foynes

2.1 Planned Sampling

Survey operations at the Corrib field consisted of sampling seabed sediments (both physico-chemical and biological) and seabed photography; the latter of which consisted of a combined sediment profile imagery (SPI) camera and a vertical drop-down camera. Thirty-three stations were proposed in and around the Corrib field. All of these were targeted for sediment grab sampling (four of which were reference stations at locations outside, but in the vicinity, of the field) and seabed photography (SPI and drop-down imaging). **Figure 2.1**

shows the location of the planned sample locations, and **Figure 2.2** presents a larger scale map of the stations in the Corrib field.

2.1.1 Grab Sampling

A double Van Veen grab (**Figure 2.3**) was used to collect seabed sediment, with each bucket sampling an area of 0.1m^2. At each station, four replicate samples were taken; three were retained directly for macrofaunal analysis, while the fourth was sub-sampled for physico-chemical analysis. The Van Veen was used to reduce the number of grab deployments necessary per station and to ensure accurate and comparative sampling continuity.

The following information was recorded for each grab:

- Position in UTM co-ordinates;
- Date;
- Time;
- Water depth;
- Notes from a visual inspection of sediment type, colour, smell, any vertical layering present, clearly defined redox discontinuity layer (RDL) with depth and biological comments (megafauna, burrows, tube worms etc.);
- A digital surface photograph of the sample in the grab (minimum of one photo per grab); and
- The penetration depth into the sediment (this was carried out *in situ* by measuring the depth of sediment in the centre of the grab).

2.1.1.1 Macrofaunal Samples

The 3 samples retained for macrofaunal analysis from the grab were sieved aboard the vessel through a 500µm mesh using a Wilson Autosiever. The retained material was transferred into appropriate containers for preservation and storage on board the vessel. Samples were preserved using a solution of 4–10% buffered formaldehyde in seawater in accordance with recognised scientific methodologies (Eleftheriou and Holme, 1984). The samples were then stored securely aboard the vessel at ambient temperature. A waterproof internal identification tag was placed inside the sample container, and an additional label fixed to the outside. At the end of the survey, the samples were transferred to the taxonomic laboratory (Hebog Environmental Ltd) for identification and enumeration analysis according to chain-of-custody procedures.

2.1.1.2 Physico-chemical Samples

The fourth replicate collected for physico-chemical analysis was sub-sampled as presented in **Table 2.2**.

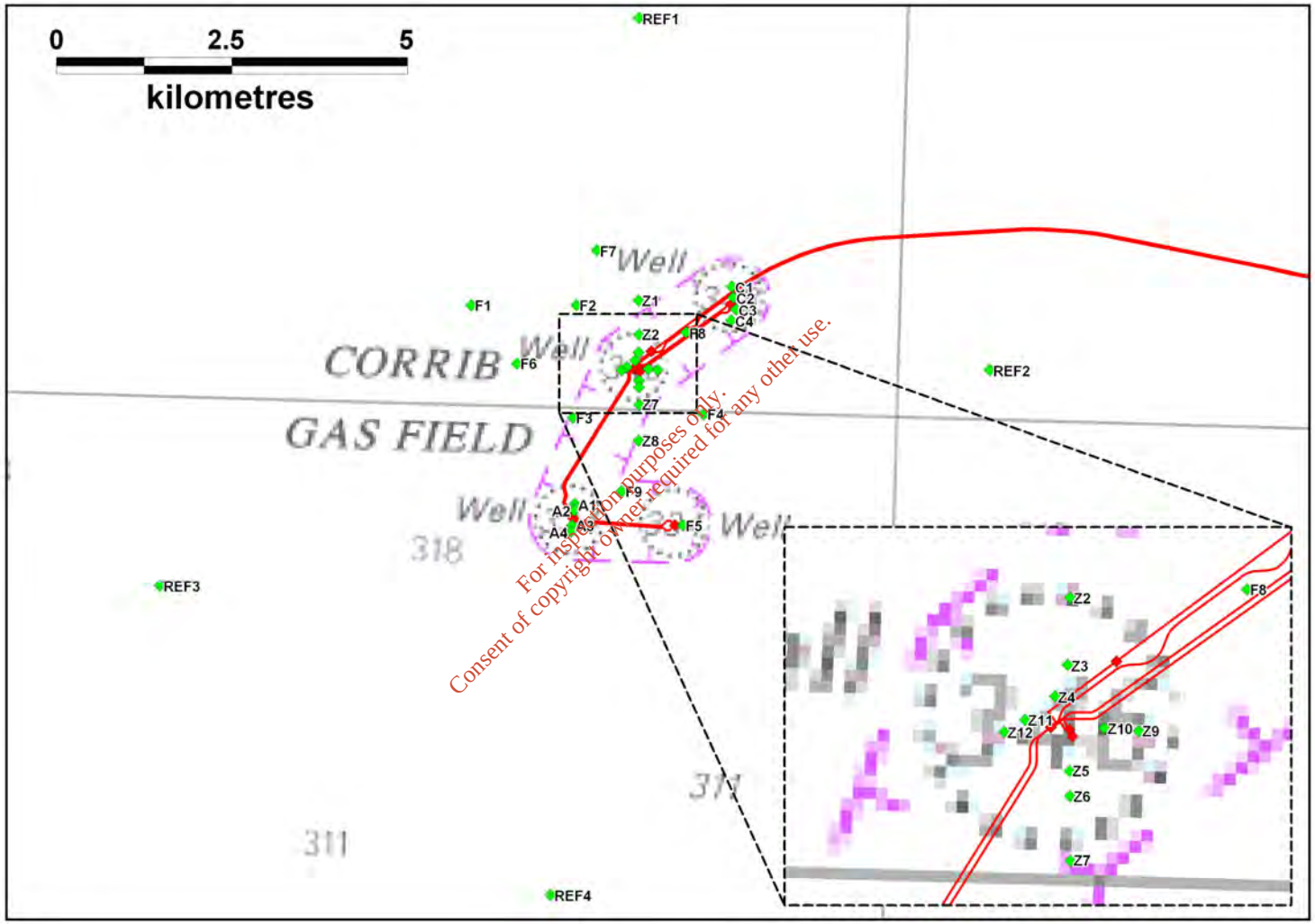

Figure 2.1: Overview map of planned locations in the Corrib field for summer 2008

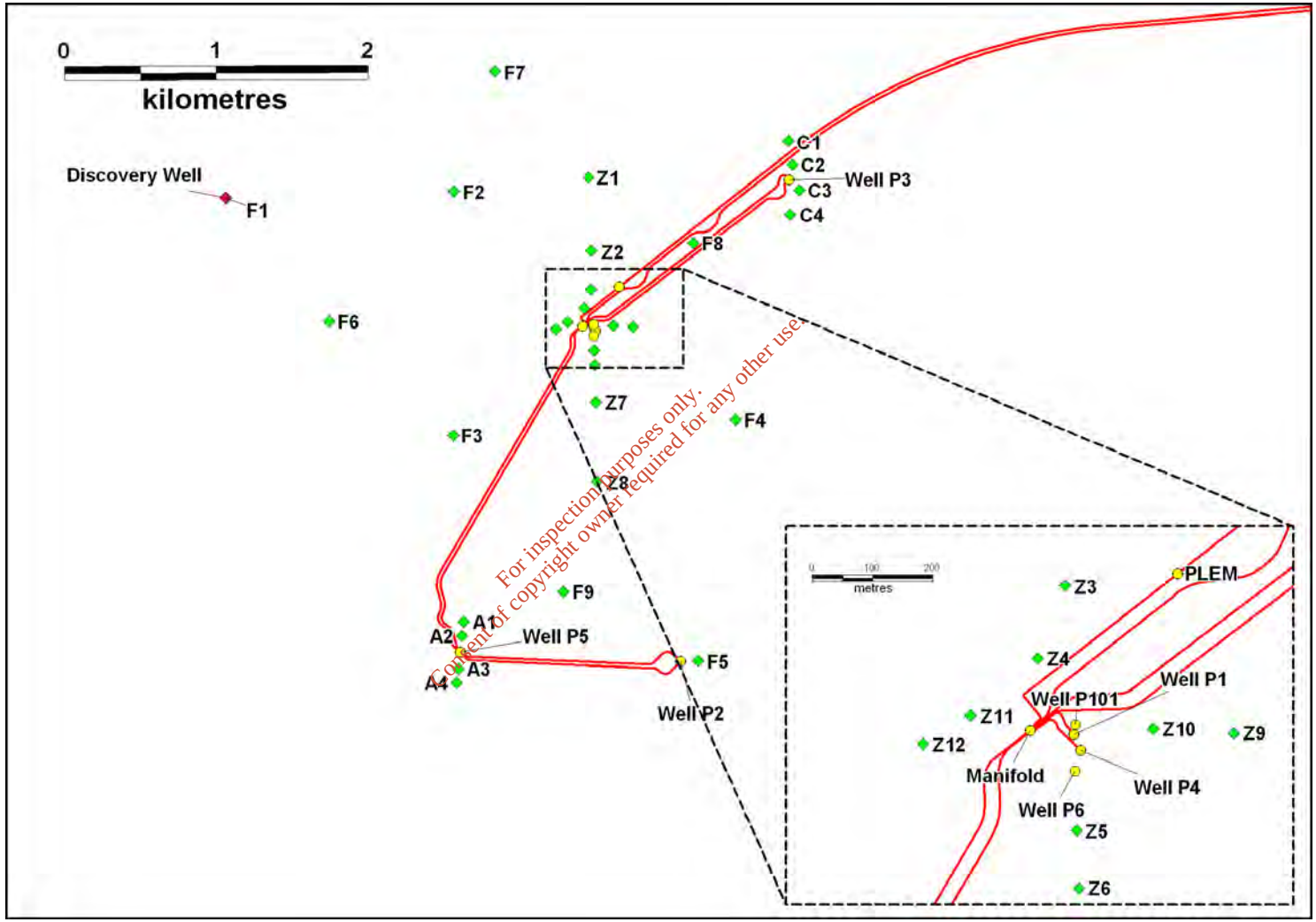

Figure 2.2: Detailed map of planned stations in the Corrib field.

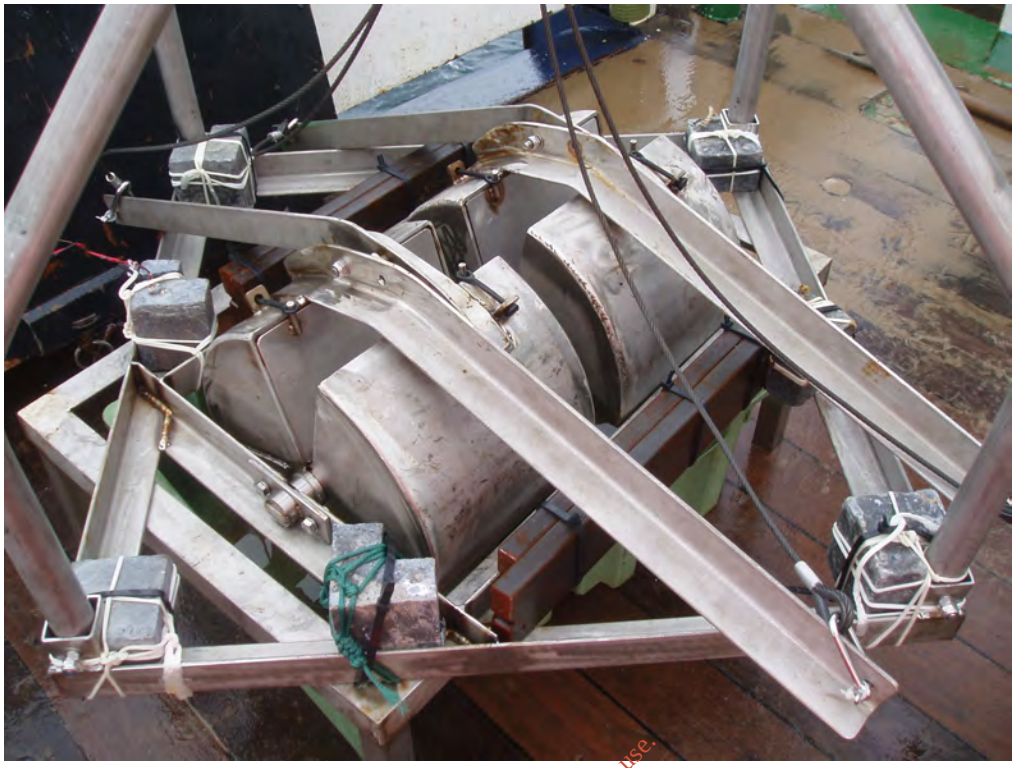

Figure 2.3: Double Van Veen grab used for sediment sampling

Table 2.2: Sediment quality sub-samples collected

Parameter	Weight/ Volume	Container	Preservation	Analysis
Particle size analysis	*c*.1kg	Double-labelled plastic tub or Ziploc bag	Frozen	Full particle size distribution (phi scale, includes the <63µm fraction)
Total organic carbon				Complete levels of organic carbon present
Inorganic chemistry (hydrocarbons and saturates)				Solvent extraction to produce a total organic extract (TOE), qualitative and quantitative analysis of the total hydrocarbon fraction by GC-FID. Polycyclic aromatic hydrocarbons (2-6 ring EPA16 PAH and NPD (naphthalenes, phenanthrenes, dibenzothiophenes + alkylated homologues));
Metals	*c*.300ml (*duplicate taken*)	Double-labelled aluminium tins or glass jars	Frozen	Heavy and trace metals (totals following aqua regia digest) Insoluble Ba (following sodium fusion)

To avoid contamination, a scientist wearing nitrile gloves recovered samples from the surface of the sediment. With the exception of organic chemistry

(collected by directly placing tins onto the sediment surface), all samples were taken using a new, clean disposable plastic spoon, ensuring there was no contact with the grab. The grab was scrubbed and rinsed down thoroughly between stations.

All of the physico-chemical samples were frozen immediately. On completion of the survey, these were dispatched in chilled cool boxes to the various analytical laboratories according to chain-of-custody procedures. Grain size, total organic carbon and metal analyses were undertaken by an Environment Agency laboratory using appropriate UKAS or MCERTS-accredited methods. M-Scan Ltd (contracted through BSL) undertook sample analysis for organic compounds.

2.1.2 Seabed Photography

Still photographs of the seabed were scheduled to be taken at 33 locations in the Corrib field using an SPI camera with an attached drop-down camera. Four replicates were to be taken at each sampling location.

Between each sampling location, the equipment was returned to the deck of the vessel and the digital photographs downloaded.

At each photographic location, a log sheet was filled in with information relating to the:

- Location (in UTM coordinates);
- Time;
- Water depth; and
- Number of replicates.

The SPI parameters measured from each image provided information that allowed the interpretation of:

1) Sediment type (measured from the upper 5cm sediment layer);
2) Prism penetration depth (indicator of relative sediment compaction and coarseness);
3) Sediment boundary roughness (indicators of the degree of physical disturbance or biotic activity at the sediment water boundary);
4) Sediment apparent redox potential discontinuity depth (ARPD) (assesses the depth of oxygenated sediment on the seabed);
5) Infaunal successional status (the type of fauna living within the sediment);
6) Additional parameters (such as the presence of mud casts, epifauna (animals living on the seabed surface), infaunal burrows and tubes, outgassing of sediments (due to production of hydrogen sulphide and ammonia as by-products of anaerobic metabolism) etc. were also assessed);
7) Sediments for bioturbatory activity (re-working or irrigation of the sediment by animals);
8) Infauna (animals living in the sediment) and epifauna (animals living on the bottom), and to infer from their presence the health of the benthos; and

9) The overall state of the seafloor at the stations surveyed.

All sediment profile images taken were analysed for each station using a dedicated image analysis system. The seabed surface and SPI analysis was carried out by Aqua-Fact.

2.2 Operations

Of the 33 stations where surveying was planned, grab sample collection was only possible at 29 of the stations. **Figure 2.1** shows the locations at the field where seabed-sampling operations were undertaken during the 2008 survey (stations A1–A4 are shown for reference but were not sampled in 2008; however, owing to the presence of the SEDCO-711 drilling rig at well P5, the four 'A' stations were within the rig's anchor-pattern exclusion zone). The majority of the stations are as sampled in the 2000 survey, with the exception of the reference stations, two of which (references 3 and 4) were added to the 2008 programme.

Some issues were encountered during the survey, for example, repeated grab sampling was often required to collect samples as the nature of the sediments did not allow for full penetration of the grab. More significantly, the seabed camera was lost following deployment at Station E8 on 20 July 2008, when the winch cable parted. The camera was not recovered from the seabed until Friday 22 August 2008. As a result, it was not possible to complete photography at all of the 33 planned stations at the Corrib field during the sampling schedule. **Table 2.3** summarises planned and actual benthic grab and photography samples.

Table 2.3: Planned and actual grab and photography samples

Site	Location		Grab successful	Photography successful
	Latitude	Longitude		
REF 1	N 54° 23' 01.7232"	W 11° 03' 34.9128"	Yes	Yes
REF 2	N 54° 20' 24.6876"	W 10° 58' 50.1924"	Yes	Yes
REF 3	N 54° 18' 34.0092"	W 11° 09' 39.4776"	Yes	Yes
REF 4	N 54° 16' 17.7600"	W 11° 04' 24.9600"	Yes	Yes
A1	N 54° 19' 17.5404"	W 11° 04' 14.2068"	**No** - drilling rig near station	
A2	N 54° 19' 14.5308"	W 11° 04' 14.7000"	**No** - drilling rig near station	
A3	N 54° 19' 07.5972"	W 11° 04' 15.9096"	**No** - drilling rig near station	
A4	N 54° 19' 04.6380"	W 11° 04' 16.5864"	**No** - drilling rig near station	
C1	N 54° 20' 59.3772"	W 11° 02' 16.2744"	Yes	**No** – camera lost
C2	N 54° 20' 54.5172"	W 11° 02' 14.7048"	Yes	**No** – camera lost
C3	N 54° 20' 48.8688"	W 11° 02' 12.2820"	Yes	**No** – camera lost
C4	N 54° 20' 44.1888"	W 11° 02' 14.9136"	Yes	Yes
F1	N 54° 20' 47.3280"	W 11° 05' 40.9092"	Yes	Yes
F2	N 54° 20' 49.0236"	W 11° 04' 17.7384"	Yes	Yes
F3	N 54° 19' 57.1656"	W 11° 04' 17.8608"	Yes	**No** – camera lost
F4	N 54° 20' 00.2868"	W 11° 02' 35.3364"	Yes	**No** – camera lost

F5	N 54° 19' 09.1020"	W 11° 02' 49.2072"	Yes	**No** – camera lost
F6	N 54° 20' 21.6060"	W 11° 05' 03.1020"	Yes	Yes
F7	N 54° 21' 14.3604"	W 11° 04' 02.7228"	Yes	Yes
F8	N 54° 20' 37.9788"	W 11° 02' 50.8308"	Yes	Yes
F9	N 54° 19' 23.4660"	W 11° 03' 037.728"	Yes	**No** – camera lost
Z1	N 54° 20' 52.0044"	W 11° 03' 28.3104"	Yes	Yes
Z2	N 54° 20' 36.2904"	W 11° 03' 27.5256"	Yes	Yes
Z3	N 54° 20' 28.2408"	W 11° 03' 27.0108"	Yes	Yes
Z4	N 54° 20' 24.0288"	W 11° 03' 30.1176"	Yes	Yes
Z5	N 54° 20' 15.1224"	W 11° 03' 26.6364"	Yes	Yes
Z6	N 54° 20' 12.0696"	W 11° 03' 26.5356"	Yes	Yes
Z7	N 54° 20' 04.0200"	W 11° 03' 25.9668"	Yes	Yes
Z8	N 54° 19' 47.7552"	W 11° 03' 25.2108"	Yes	**No** – camera lost
Z9	N 54° 20' 20.3532"	W 11° 03' 13.1580"	Yes	Yes
Z10	N 54° 20' 20.3064"	W 11° 03' 20.1420"	Yes	**No** – camera lost
Z11	N 54° 20' 20.7600"	W 11° 03' 36.6912"	Yes	**No** – camera lost
Z12	N 54° 20' 19.8276"	W 11° 03' 40.2696"	Yes	**No** – camera lost

2.3 Quality Control of Sediment Samples

As part of RSK's quality assurance procedure, the laboratory tasked with analysing saturates and polycyclic aromatic hydrocarbons (PAHs) was asked to undertake a blind duplicate analysis of randomly selected marine sediment samples; this is discussed further in the results section.

In addition, in accordance with recognised best practices, a certified reference material (CRM) of marine sediment was provided to the Environment Agency laboratory with the offshore field samples. The CRM contained pre-determined levels of various trace metals and RSK used this as a method of assessing the accuracy of the results provided by the analytical laboratory.

3 Results and Discussion

3.1 Physical

Table 3.1 presents a summary of physical data from analysis of the Corrib field samples taken in 2008. Raw particle size data is provided in **Appendix 2**.

Table 3.1: Grain size and total organic carbon data summary from the Corrib field sites

Station	%			Median Grain Size (mm)	Mean Grain Size (mm)	Sediment Description (Udden Wentworth)	Total Organic Carbon (%)
	Gravel (>2000µm)	Sand (<63-2000µm)	Mud (<63µm)				
REF 1	0.0	76.2	23.8	0.133	0.109	Fine Sand	0.29
REF 2	0.0	73.6	26.4	0.155	0.109	Fine Sand	0.85
REF 3	0.0	76.4	23.6	0.127	0.106	Fine Sand	0.82
REF 4	0.0	71.2	28.8	0.120	0.094	Very Fine Sand	2.94
C1	0.0	65.6	34.4	0.107	0.077	Very Fine Sand	0.92
C2	0.0	64.8	35.2	0.106	0.071	Very Fine Sand	1.98
C3	0.0	66.7	33.3	0.109	0.080	Very Fine Sand	0.09
C4	0.0	73.1	26.9	0.120	0.093	Very Fine Sand	0.53
F1	0.3	64.8	34.9	0.115	0.077	Very Fine Sand	1.55
F2	0.0	73.2	26.8	0.115	0.093	Very Fine Sand	0.08
F3	0.0	67.6	32.4	0.107	0.083	Very Fine Sand	0.09
F4	0.0	72.5	27.5	0.111	0.091	Very Fine Sand	1.45
F5	0.0	70.7	29.3	0.117	0.093	Very Fine Sand	1.32
F6	0.0	74.0	26.0	0.124	0.101	Very Fine Sand	0.31
F7	0.0	70.3	29.7	0.118	0.091	Very Fine Sand	0.67
F8	0.0	70.3	29.7	0.124	0.093	Very Fine Sand	1.95
F9	0.0	73.5	26.5	0.120	0.098	Very Fine Sand	2.95
Z1	0.0	68.9	31.2	0.116	0.087	Very Fine Sand	0.26
Z2	0.0	70.7	29.3	0.119	0.093	Very Fine Sand	0.77
Z3	0.0	72.8	27.2	0.120	0.097	Very Fine Sand	1.13
Z4	0.0	68.4	31.6	0.110	0.084	Very Fine Sand	0.58
Z5	0.0	74.2	25.8	0.121	0.099	Very Fine Sand	1.11
Z6	0.0	73.6	26.4	0.120	0.098	Very Fine Sand	1.6
Z7	0.0	66.9	33.1	0.107	0.081	Very Fine Sand	2.61
Z8	0.0	67.4	32.6	0.107	0.081	Very Fine Sand	0.44
Z9	0.0	70.4	29.6	0.116	0.091	Very Fine Sand	2.63
Z10	0.0	63.5	36.5	0.146	0.068	Fine Sand	1.73
Z11	0.0	65.4	34.6	0.106	0.079	Very Fine Sand	0.81
Z12	0.0	70.5	29.5	0.117	0.091	Very Fine Sand	0.44

Sediment types recorded are relatively consistent across the Corrib field in that the largest proportion of the material is sand (approximately two thirds in most cases), with the remaining third being mud. Gravel was recorded only at station F1 and in a very small quantity. The majority of sites sampled (86%) had sediments defined under the Udden Wentworth scale as Very Fine Sand, with the remainder being recorded as Fine Sand (these sites being reference stations 1, 2 and 3, and station Z10).

While the range of percentages of sand and mud in the samples varies little (**Table 3.1**), total organic carbon (TOC) levels are quite variable and range from very low (0.08% at station F2) to quite high (2.95% at F9), as would be expected in sediments where there are high levels of mud present. An average of 1.13% TOC is observed over the 29 stations sampled. There is no apparent correlation between grain size and TOC (it is more often the case that where median grain size is lower, TOC levels are higher).

The 2008 physical results are broadly as expected based on the previous results from the 2000 Corrib field survey, and are in accordance with the seabed photography taken in the field.

For both PSA and TOC there are no noticeable trends in relation to geographical location or water depth. When using the SPI camera, prism penetration was moderate to low throughout the survey; this being due to the compactness of the sands in this area.

The distribution of the two described sediment types (fine sand and very fine sand) is difficult to attribute to the field development activities. There is, however, a noticeable increased percentage of sand compared to mud in three of the four reference sites, which has led to an increased average grain size and a classification of fine sand for these three sites.

Generally, it is evident that for two thirds of the sites the mean grain size has increased between 2000 and 2008. In the 2000 survey, the sediment was described as consisting largely of coarse silt and very fine sand, whereas average grain size appears to have increased marginally in 2008 to be dominated by largely very fine sands with some fine sand areas. It is important to note that the largest increase in mean sediment grain size at a single site has been recorded at F1 where previously medium silt sediment with a mean grain size of 22.03µm was recorded. In 2008, site F1 was recorded as being very fine sand sediment with a mean grain size of 77µm.

Within the immediate area of the manifold in the Corrib field, the survey station that recorded the highest percentage of fine particles (i.e. percentage of mud) was Z10, where 36.5% of the sediment sample was composed of mud and 63.5% sand; the mean grain size here was 0.068mm (68µm). Station Z10 is located to the east of well P101 and east–north-east of wells P4 and P6. As **Table 1.2** shows, wells P4, P6 and P101 have experienced more recent operations before and, in the case of P101, during the Corrib field 2008 survey. These ‘recent’ operations near the field may have led to some degree of sediment disturbance and redistribution of fine materials.

Current measurements from the Corrib field indicate that the residual current direction across the area is to the north or north-east. The higher percentage of mud particles recorded at station Z10 could therefore be a result of the recent well activities that have remobilised fine sediment, which has then travelled in suspension down current to Z10.

3.2 Chemical

3.2.1 Metals

Table 3.2 presents a summary of sediment metal data from the Corrib field stations.

Table 3.2: Metal concentrations in sediments from the Corrib field

Station	Hg	Cd	Cr	Pb	As	Zn	Ba	Ni	Cu	Al	Fe	V	Li	Mn
	(mg/kg dry weight)													
REF 1	0.0044	0.094	22.0	7.84	2.06	24.3	22.8	6.56	5.15	25100	8360	12.5	15.7	147
REF 2	0.0049	0.073	20.0	12.1	2.34	22.3	22.6	6.22	4.49	23400	8380	11.7	15.8	133
REF 3	0.0072	0.081	19.3	8.56	2.13	25.8	18.6	6.03	5.43	25100	8310	11.0	15.8	152
REF 4	0.0088	0.068	22.7	7.41	2.10	20.9	18.3	5.60	4.63	23500	8130	10.0	15.6	137
C1	0.0066	0.088	28.7	7.53	2.32	25.3	120	6.18	5.52	26300	8310	11.2	18.1	153
C2	0.0064	0.084	28.6	8.24	2.54	27.6	1100	7.36	6.02	27500	10000	13.1	19.1	162
C3	0.0046	0.087	23.1	8.84	3.07	29.2	811	7.48	6.30	26800	10600	14.3	17.6	165
C4	0.0042	0.102	24.3	8.32	2.53	24.3	110	6.59	4.84	24100	9290	12.5	15.3	165
F1	0.0325	0.131	49.1	16.3	4.13	66.1	1310	21.9	16.5	26300	14500	26.9	16.4	245
F2	0.0046	0.085	24.6	7.20	2.19	25.6	42.9	6.74	5.38	24000	8980	12.4	17.2	163
F3	0.0047	0.108	30.7	8.61	2.79	24.9	34.5	7.21	6.05	27700	8910	12.4	18.5	165
F4	0.0046	0.088	28.7	8.45	2.94	27.1	52.7	5.96	5.59	24600	9370	12.3	16.0	147
F5	0.0204	0.084	30.9	19.5	2.61	23.4	1740	7.09	5.79	26100	9920	12.4	18.3	160
F6	0.0049	0.078	22.4	8.24	2.41	24.2	33.6	6.33	4.91	24400	8800	12.0	15.5	136
F7	0.0040	0.095	24.9	8.38	2.33	27.3	44.2	6.49	5.53	26100	9580	13.1	16.3	162
F8	0.0049	0.084	22.4	8.14	2.54	27.2	78.9	6.05	5.64	25000	9420	12.2	16.3	147
F9	0.0053	0.085	23.5	9.82	2.64	24.0	49.9	6.68	4.77	23900	9430	12.5	17.1	156
Z1	0.0051	0.088	26.4	7.28	1.94	22.0	72.0	7.13	5.51	22400	9540	12.9	18.7	159
Z2	0.0054	0.084	24.1	7.86	2.38	25.3	154	7.08	5.37	24100	9110	11.9	15.8	153
Z3	0.0086	0.085	25.5	11.3	2.15	26.1	743	7.90	5.82	25800	10100	13.7	17.6	156
Z4	0.0087	0.088	24.1	32.4	2.15	30.2	1880	7.04	6.41	25200	9740	13.7	15.9	174
Z5	0.0077	0.082	20.6	8.69	2.60	27.1	1390	7.16	6.05	25600	9310	12.2	18.3	166
Z6	0.0048	0.088	31.8	8.38	2.25	21.4	597	6.84	5.15	22100	9490	12.5	18.0	156
Z7	0.0060	0.084	30.1	7.93	2.63	34.0	170	7.48	5.61	26100	10900	15.5	19.2	175
Z8	0.0051	0.096	31.4	9.29	2.40	29.3	64.1	6.83	6.59	28100	10100	13.3	18.4	169
Z9	0.0093	0.078	19.4	7.48	2.11	23.5	564	6.66	4.81	23000	8450	11.6	16.3	161
Z10	0.0174	0.083	28.8	10.6	2.92	28.6	1740	7.32	7.49	26900	9280	13.6	18.6	158
Z11	0.0060	0.089	28.8	7.28	2.76	25.8	151	7.16	5.53	25300	9180	13.6	18.1	169
Z12	0.0045	0.079	25.2	7.40	2.09	24.7	62.3	5.95	4.98	24900	8570	10.9	17.9	139

Note, cells shaded in yellow highlight maximum values and cells shaded in green show minimum values recorded for each metal.

It is evident from those cells shaded in yellow that the maximum recorded values across the range (with the exception of aluminium, lead, lithium and barium) tended to be recorded at station F1. This site had highest concentrations of mercury, cadmium, chromium, arsenic, zinc, nickel, copper, iron, vanadium and manganese. Although F1 had high values of aluminium, lead and barium, the maximum lead value of 19.5mg/kg was recorded at station F5, the maximum of 1880mg/kg barium recorded at station Z4, the maximum lithium concentration of 19.2mg/kg lithium at station Z7, and 28,100mg/kg of aluminium at station Z8. Site F1 also had highest concentrations of several metals in the 2000 survey. F1 is not particularly close to any of the production wells compared with other stations. However it is located in almost exactly the same position as the initial discovery well (see **Table 1.1**), which was drilled in 1996 then later plugged and abandoned.

The cells shaded in green (**Table 3.2**) highlight the minimum recorded value across the 29 sample sites. Results shown that the lowest concentrations of cadmium, copper and manganese were recorded at reference site 2, for chromium at reference site 3, and for zinc, barium, nickel, iron and vanadium at reference site 4.

Most of the offshore sites had metal concentrations very similar to those observed closer inshore (near to Erris Head), with no readily discernible distribution pattern and again reflecting a relatively pristine location.

To put the metal concentrations recorded in the Corrib field into context, Table 3.3 presents a comparison of the range of concentrations found in 2008 with OSPAR and Environment Canada guidelines (CCME, 1999). Note that several

of the metals have not been included here, for example iron and aluminium, as they are not included in OSPAR background concentrations (BC) and Environment Canada threshold effects limit (TEL) and probable effects limit (PEL) guidance for marine sediments.

Table 3.3: Observed range of metals recorded in marine sediment at the Corrib field sites in relation to international guideline concentrations

Metal	Corrib Field range 2008 (mg/kg)	Corrib Field range 2000 (mg/kg)	OSPAR BC* (mg/kg)	OSPAR EAC lower limit	OSPAR EAC upper limit	Environment Canada TEL (mg/kg)	Environment Canada PEL (mg/kg)
Hg	<0.004–0.0325	No data	0.05	0.05	0.50	0.13	0.70
Cd	0.073–0.131	<0.01–0.2	0.2	0.10	1.00	0.676	4.21
Cr	19.3–49.1	7.7–17	60	5.00	50.00	52.3	160
Pb	7.28–32.4	3.4–23	25	5.00	50.00	30.3	112
As	1.94–4.13	1.7–4.7	15	1.00	10.00	7.24	41.6
Zn	20.9–66.1	10–78	90	10.00	100.00	124	271
Ni	5.95–21.9	6.1–16	30	5.00	50.00	15.9	42.8
Cu	4.49–16.5	2.6–12	20	5.00	50.00	18.7	108

*BC Background concentration. OSPAR Agreement 2005-6 – formerly termed background reference concentration (BRC); TEL – threshold effects limit; PEL – probable effects limit

3.2.1.1 *Mercury*

The 2000 survey scope did not include sampling for mercury and hence levels recorded in the 2008 survey cannot be compared. However, compared with background levels in the above table, the highest recorded figure for 2008 (0.0325mg/kg) was well below these.

3.2.1.2 *Cadmium*

While the Corrib field cadmium concentrations do not appear to be anthropogenically impacted (relatively low values recorded), the range recorded (0.073–0.131mg/kg) is somewhat higher than for sediments from the central North Sea (where values as low as 0.01mg/kg and a mean of 0.050mg/kg have been reported – OSPAR, 2003). The observed range is below the OSPAR BC of 0.2mg/kg and well below Environment Canada PEL shown in **Table 3.3**.

Cadmium levels were higher at every station in 2008 than they were in 2000 with the exception of site F1. In both 2000 and 2008 surveys, station F1 recorded the highest cadmium concentration of 0.2mg/kg and 0.131mg/kg accordingly.

3.2.1.3 *Chromium*

The results (19.3–49.1mg/kg) are consistent with the low end of the ranges reported by Taylor (1986) and Nixon (1995) for the Dee estuary, Liverpool Bay and the Cumbria coast, and lower than sediments collected off the west coast of Scotland. All results are below the accepted OSPAR BC.

A review of the results for chromium levels recorded in the 2000 survey shows that the 2008 recordings are elevated; 2008 concentrations being on average two to three times higher than those recorded in 2000.

3.2.1.4 *Lead*

Most sediment values for lead recorded at the stations were <10mg/kg, and are generally lower than published values for other areas around the UK and Ireland. The maximum value 32.4mg/kg (recorded at station Z4) is above the OSPAR BC (25mg/kg) and slightly greater than the Environment Canada TEL (30.3mg/kg), although this figure is unlikely to be of significant concern, as the PEL is 112mg/kg.

Again, levels of lead that were recorded in sediment during the 2008 field survey were greater than those stated in the 2000 survey, almost double in the large majority of cases. The only exception to this pattern being at station F1 where 23mg/kg was recorded in 2000 and only 16.3mg/kg was recorded in 2008.

3.2.1.5 *Arsenic*

Concentrations from the 2008 survey ranged between 1.94mg/kg and 4.13mg/kg, with all sites being <5mg/kg, reflecting a situation similar to the central North Sea (OSPAR, 2003). Concentrations at all stations were below the Environment Canada TEL.

Arsenic levels were on average 15% higher in the 2008 survey at approximately 80% of the stations that were sampled in 2000. Those that did not show an increase recorded only a minor drop in arsenic levels i.e. F1, F5, Z1, Z3, Z4 and Z12.

3.2.1.6 *Zinc*

With the exception of Station F1 (66.1mg/kg), most values were <30mg/kg, similar to the lowest reported findings for Liverpool Bay (which receives contaminated run-off from the Mersey and was formerly a site for sea disposal of sewage sludge and dredging spoil) and the North Sea. The 2008 results are well below the accepted OSPAR BC (90mg/kg).

Again, approximately 80% of the stations that were sampled in 2000 for zinc recorded increased levels in the 2008 field survey. The exceptions to this were stations C2, F1, F5, F8, Z1 and Z4. The highest value for zinc recorded in the 2000 survey was 78mg/kg at station F1.

3.2.1.7 *Barium*

High concentrations of barium were found at several sites (**Table 3.2**), which may be a consequence of local drilling activities. Barium is a constituent of water-based drilling muds and in 2008 the highest value for barium was recorded at station Z4, which is located adjacent to the manifold and production well P101, a side track of P1, and relatively close to P1, P4 and P6. Z4 is also immediately north of the wells where most recent operational activities have occurred (being particularly close to the manifold). **Figure 3.1** shows the barium levels recorded in sediments taken from the Corrib field sampling stations in 2008.

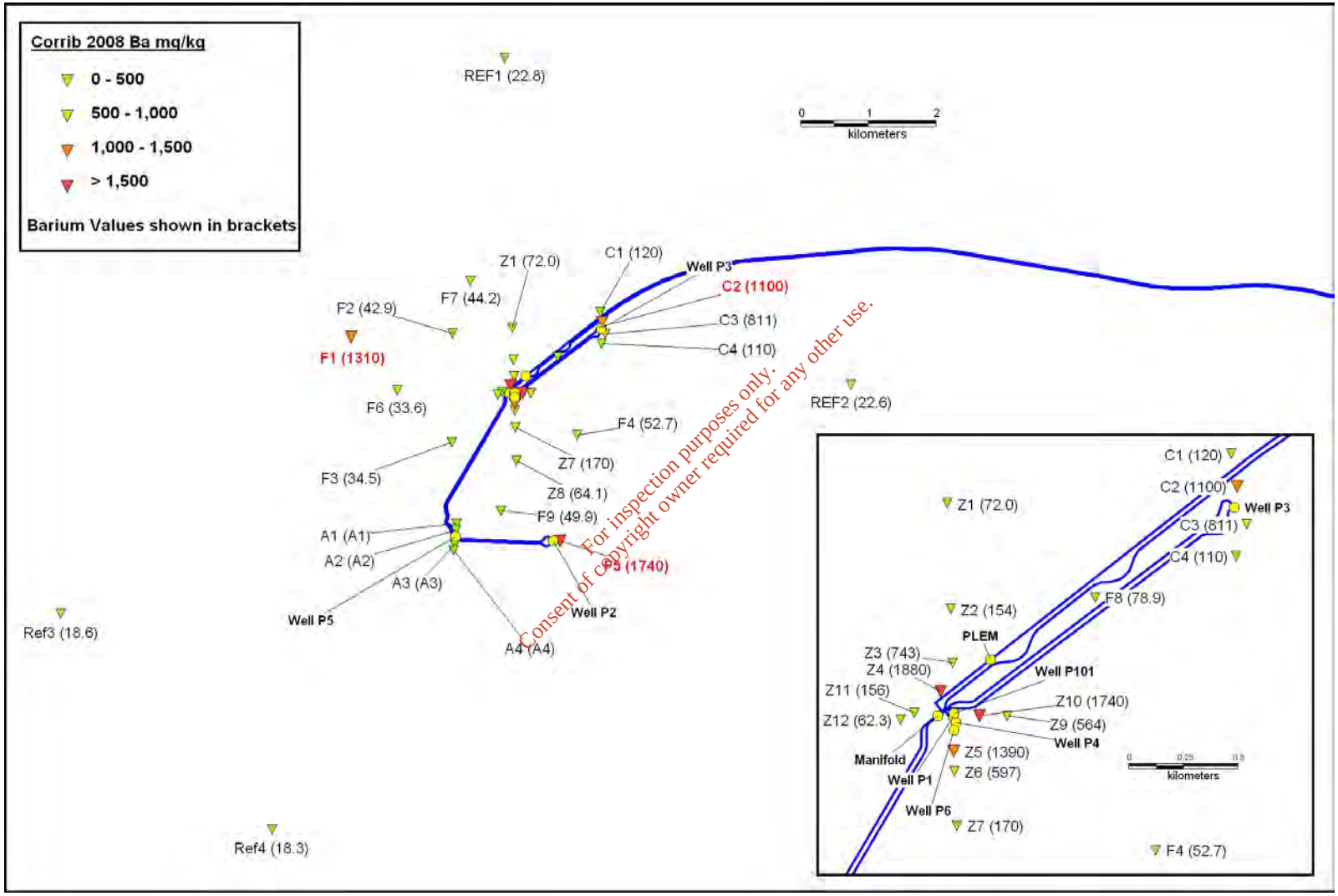

Figure 3.1: Barium concentrations (mg/kg) in sediment from the 2008 Corrib field survey

By far the most abundant metal in the majority of drilling muds is barium, in the form of barite ($BaSO_4$). Owing to its low solubility and the fact that it is not toxic as the sulphate, elevated barium concentrations are rarely of toxicological concern. However, sediment concentrations of barite/barium can provide valuable information concerning the extent to which drill cuttings have been transported from well locations.

Barium levels are greatly reduced at all four reference sites compared with other stations that were sampled. This is to be expected as the reference sites were chosen to be in areas distant from drilling activities.

In comparing barium concentrations between 2000 and 2008 in the Corrib field, it is evident that there had been a decrease at all sites in 2008. The highest value recorded in 2008 was 1880mg/kg compared with 4550mg/kg recorded in 2000. It is also evident that the smallest changes in barium concentrations are found at reference stations 1 and 2.

Data for other sea areas are sparse making comparisons difficult. There are no guideline concentrations for barium in sediments. The component chemicals of the WBM system are generally considered to pose little or no risk to organisms in the receiving water (both barite and bentonite are currently listed by OSPAR as posing little or no risk to the environment). They are typically of low toxicity with low bioaccumulation potential and are not persistent. The most common effect of WBM discharge is an elevation of barium concentrations in the sediments, which may extend up to 1,000m from the drilling location along the predominant tidal axis. The main effects of WBM use on the benthic communities are considered to be related to smothering, which is more closely associated with cuttings than with the discharge of drilling mud. It is unlikely that discharged WBM will cause a noticeable change to the marine ecosystem.

3.2.1.8 Nickel

The results for nickel (5.95–21.9mg/kg) are consistent with the low end of the ranges reported for apparently non-impacted locations (**Table 3.2**). Most results were <10mg/kg and all values were below the OSPAR BC (30mg/kg), the majority (except station F1) being significantly so.

The large percentage of field stations where nickel sediment sampling was duplicated in 2008 showed a decrease from levels recorded in 2000. The highest concentration of nickel was found at station F5 (9.5mg/kg) in 2000, whereas the highest concentration in 2008 was recorded at F1 (21.9mg/kg).

3.2.1.9 Copper

Survey results recorded for 2008 were in the range 4.49–16.5mg/kg (station F1). Again, these findings are in accordance with the lowest values reported from similar marine surveys around the UK and Ireland (**Table 3.4**) and below OSPAR BC (20mg/kg).

Copper levels were generally higher in the sediment samples collected during the 2008 Corrib field survey, when compared with those recorded in 2000. The highest copper value recorded in 2000 (12mg/kg) was also found at station F1.

3.2.1.10 *Aluminium*

A review of aluminium concentrations across the field sites in 2008 shows a range of 22,100–28,100mg/kg; the maximum level being recorded at station Z8. Aluminium is often used as a surrogate for grain size (high aluminium concentrations reflecting low grain sizes), and it is notable that the third lowest median grain size was recorded from Z8. No OSPAR BC or Environment Canada PEL and TEL exist for aluminium in marine sediment and hence these levels cannot be compared.

Aluminium concentrations were not measured in the 2000 survey.

3.2.1.11 *Iron*

The iron concentrations recorded in the 2008 field survey ranged from 8130–14,500mg/kg, the highest of these being recorded at site F1. No OSPAR BC or Environment Canada PEL and TEL exist for iron in marine sediment and hence these levels cannot be compared.

Iron concentrations were not measured in the 2000 survey.

3.2.1.12 *Vanadium*

Survey results recorded in 2008 from the Corrib field ranged from 10.9 to 26.9mg/kg, the maximum being found at station F1. No OSPAR BC or Environment Canada PEL and TEL exist for vanadium in marine sediment and hence these levels cannot be compared.

In comparison with results from the 2000 survey, recorded vanadium levels were much higher in sediment from the 2008 Corrib field survey. The maximum level in 2000 was recorded at F1 also, but was only 19mg/kg.

3.2.1.13 *Lithium*

Corrib field survey results from 2008 showed that concentrations of lithium ranged from 15.3 to 19.2mg/kg across the sites, the maximum being recorded at station Z7. No OSPAR BC or Environment Canada PEL and TEL exist for lithium in marine sediment and hence these levels cannot be compared.

Lithium concentrations were not measured in the 2000 survey.

3.2.1.14 *Manganese*

Manganese concentrations recorded from the 2008 field survey ranged from a minimum of 133mg/kg recorded at reference station 2 to 245mg/kg at F1. No OSPAR BC or Environment Canada PEL and TEL exist for manganese in marine sediment and hence these levels cannot be compared.

Manganese concentrations were not measured in the 2000 survey.

The 2008 Corrib field results have been further compared with data from other locations around Ireland and Britain (**Table 3.4**).

Table 3.4: Comparison of metals in sediment from Corrib Field with data for UK and Irish coastal waters

Survey/ Reference	Locality	Hg	Cd	Cr	Pb	As	Zn	Ba	Ni	Cu
		mg/kg								
Corrib July 2008	Field sites	<0.004 – 0.0325	0.073 – 0.131	19.3 – 76.9	7.28 – 32.4	1.94 – 4.13	20.9 – 66.1	18.8 – 1880	5.95 – 21.9	4.49 – 16.5
Corrib 2000	Field sites	No data	<0.01 –0.2	7.7– 17	3.4– 23	1.7– 4.7	10– 78	25– 4550	6.1– 16	2.6– 12
Corrib 2007	Pipeline route	<0.10	0.094 –0.32	11.2 – 39.2	7.9– 11.9	<1.0 – 12.7	10.2– 38.6	0.67 – 11.0	1.51 – 4.43	0.54 – 1.87
Nixon, 1995	Cumbria Coast	0.005– 0.17	0.007 –0.46	10.7 – 85.8	10.3 – 69.7	No data	22.4– 129.4	No data	No data	1.8– 49.4
FRS & SEPA 1998	Scottish waters Minches	0.05	0.018	57	24	4.3	45	No data	6.4	7.3
NSTF, 1993	North Sea	*75% of samples <0.025*	0.010 –0.38 (avg. 0.050)	No data	1.7– 288 (avg . 21)	1.2– 33 (avg . 11)	3– 510 (avg. 39)	No data	1.5– 113 (avg. 23)	0.1– 87 (avg. 14)

The metal concentration data recorded from the 2008 Corrib field survey reflect a minimal amount of anthropogenic impact. Lead is the only metal that exceeds the set OSPAR BC (25mg/kg), where one station (Z4) produced a concentration of 32.4mg/kg; however, all other stations are comfortably within the BC. Aside from OSPAR BCs, two metals exceed the Environment Canada TEL, these being lead (which is again only recorded at such a level at site Z4) and nickel. Results show that nickel concentrations are fairly consistent throughout the survey area aside from site F1, where this marginally exceeds the TEL; however, this value is well within the PEL.

In relation to other survey data published for the UK and Ireland shown in Table 3.4, the metal concentration results for the 2008 Corrib field survey are seen to be reasonably similar. In a couple of instances, with metals such as chromium and nickel, the concentrations appear a little higher at the Corrib field, although only marginally.

A review of the metal concentration ranges recorded in the 2000 survey and during the 2008 Corrib field survey (as shown in **Table 3.4**) shows that there is generally little variation. However, two metals that stand out when comparing 2000 values with those of 2008 are chromium and barium. The maximum levels of chromium recorded in 2008 were approximately four times the level recorded in 2000. With regard to barium, the opposite is true, and maximum-recorded levels have more than halved in 2008 compared with the 2000 survey.

3.2.1.15 *Certified Reference Material (CRM)*

For quality assurance purposes, a reference material (MESS-3) was sent to the analytical laboratory along with the field samples. **Table 3.5** presents the certified concentration data for the MESS-3 marine sediment CRM from the NRCC, together with the results of the analysis performed on the sample by the EA's National Laboratory Service. The difference between the certified and measured values is presented as a percentage calculated as follows:

$$\left(\frac{EAvalue - REFvalue}{REFvalue}\right) \times 100\%$$

Table 3.5: Analyses of marine sediment CRM by Environment Agency

Metal	Marine Sediment (MESS-3) Reference value	EA data	% Difference from MESS-3
Ag	0.18	<10.0	N/A
As	21.2	22.1	+ 4.2%
Cd	0.24	0.322	+ 34.2%
Cr	105	98.3	- 6.4%
Cu	33.9	37.5	+ 10.6%
Hg	0.091	0.1004	+ 10.3%
Li	73.6	75.3	+ 2.3%
Mn	324	325	+ 0.3%
Ni	46.9	41.2	- 12.2%
Pb	21.1	23.3	+ 10.4%
V	243	103	- 57.6%
Zn	159	157	- 1.3%

The similarity between the certified and measured results shows confidence in the EA analysis of sediment samples at the Corrib alternative outfall sites. The sample analyses that do stand out, however, are the differences recorded for cadmium and vanadium.

The degree of error that is observed between the certified result and the EA laboratory result for cadmium is believed to be due to interference from tin oxide in the reference material. The EA has recently carried out an investigation into this issue and has determined that it appears to affect only the CRM, and can be overcome by analysing for the 114 isotope of cadmium only. Their investigations (using various spikes etc, also show that field samples tend to be unaffected by the tin oxide effects).

The degree of error observed in the results for vanadium are because the EA laboratory prepares its sediment samples for analysis using an aqua regia digestion, rather than a hydrofluoric acid digestion. Aqua regia is a significantly less vigorous digestion technique that achieves lower recoveries than hydrofluoric acid digestion, which is what the reference values for the CRM are based. The EA have stated that the reason they use aqua-regia is that it releases only the vanadium which is biologically available, rather than all of the metal in the sediment. Hence the results from the field samples reflect the biologically available vanadium.

3.2.2 Hydrocarbons

3.2.2.1 Saturates (Total Organic Extractables)

Table 3.6 presents a summary of total organic extractables (TOE) data for the Corrib field stations. The sediment recovered was analysed for Ecomul, Ecosol and Esterkleen, as these are all base oils present in oil-based (synthetic-based) drilling muds (OBMs) historically used in drilling activity in the Corrib field.

Table 3.6: Concentrations of TOE

	Sample	TOE	Ecomul	Ecosol	Esterkleen	Low Toxicity Base Oil
		(µg/g; ppm)				
Corrib Field Stations	REF1	**6**	*nd*	*nd*	*nd*	*nd*
	REF2	**5.1**	*nd*	*nd*	*nd*	*nd*
	REF3	**5.6**	*nd*	*nd*	*nd*	*nd*
	REF4	**4.9**	*nd*	*nd*	*nd*	*nd*
	C1	**12**	*nd*	*nd*	*nd*	*nd*
	C2	**15**	**0.85**	*nd*	*nd*	*nd*
	C3	**11**	**0.48**	*nd*	*nd*	*nd*
	C4	**8.8**	*nd*	*nd*	*nd*	*nd*
	F1 a*	**14**	*nd*	**3.9**	*nd*	*nd*
	F1 b*	**16**	*nd*	**4.3**	*nd*	*nd*
	F2	**8.5**	*nd*	*nd*	*nd*	*nd*
	F3	**7.7**	*nd*	*nd*	*nd*	*nd*
	F4	**7.1**	*nd*	*nd*	*nd*	*nd*
	F5	**7.5**	*nd*	*nd*	*nd*	*nd*
	F6	**5.8**	*nd*	*nd*	*nd*	*nd*
	F7	**10**	*nd*	*nd*	*nd*	*nd*
	F8	**9.2**	*nd*	*nd*	*nd*	**1**
	F9	**7.9**	*nd*	*nd*	*nd*	*nd*
	Z1	**8.7**	*nd*	*nd*	*nd*	**1**
	Z2	**5.4**	*nd*	*nd*	*nd*	*nd*
	Z3	**8.7**	*nd*	*nd*	*nd*	*nd*
	Z4 a*	**26**	**1.5**	*nd*	*nd*	**12**
	Z4 b*	**13**	**0.77**	*nd*	*nd*	**2.8**
	Z5	**9.2**	*nd*	*nd*	*nd*	*nd*
	Z6	**12**	*nd*	*nd*	*nd*	**2.5**
	Z7	**5.5**	*nd*	*nd*	*nd*	*nd*
	Z8	**6.6**	*nd*	*nd*	*nd*	*nd*
	Z9	**45**	*nd*	*nd*	*nd*	**23**
	Z10	**69**	**3.4**	*nd*	*nd*	**27**
	Z11	**9.8**	*nd*	*nd*	*nd*	*nd*
	Z12	**7.7**	*nd*	*nd*	*nd*	**0.8**

Key:		
		Shows maximum value recorded
		Shows minimum value recorded (minimums have not been recorded where non detectable (nd) values exist)

** Duplicate analysis undertaken at the laboratory for quality assurance purposes*

All TOE listed in the table above commonly occur in OBMs, the discharge of which has effectively been banned since 16 January 2001 (when the OSPAR Decision 2000/3 entered into force). Since this date, only water-based drilling muds (WBMs) have been used at the Corrib field site.

In the 2008 Corrib field survey, Ecomul was only detected at four sites (C2, C3, Z4 and Z10) and Ecosol only at site F1: albeit all in low concentrations. Low-

toxicity OBM was detected at several sites, ranging in value from 0.8µg/g at Z12 to 27µg/g at Z10, although it was not detectable at the majority of stations sampled. Esterkleen was 'not detectable' at any of the sample stations in 2008. Aside from Ecosol, all other maximum values for the analysed saturates were recorded at station Z10.

When looking at recorded levels of saturates across the sampled stations, two sites are notably different. Both Z9 and Z10 within the Corrib field show high levels of TOE and low-toxicity base oil compared with the other 27 stations sampled, the highest concentrations being recorded at Z10. The average TOE recorded from the four reference stations was only 5.4µg/g, compared with 45µg/g and 69µg/g at stations Z9 and Z10 respectively. All Corrib field sites had TOE values in excess of 5µg/g (typically ca. 10µg/g); in contrast, the majority of the inshore sites sampled in 2007 around the proposed outfall location off Erris Head (Corrib Outfall Report, RSK, 2007) had values <5µg/g, with only one station (S10) exceeding this (14µg/g).

Compared with results from 2000 and previous surveys (when a certain degree of exploratory drilling had taken place using OBMs), the levels of saturates have generally reduced. Of the 27 stations where sampling was duplicated in 2000 and 2008, only 2 of these (Station Z9 and Z10) showed an increase in levels of TOE (approximately four-fold at each station) in 2008. However, TOE was still present at all other stations. Of the 27 re-sampled stations, 25 stations had detectable levels of Ecomul in 2000 and approximately 20 of these had non-detectable levels when revisited in 2008. Two stations to note with regard to Ecomul levels are Z4 and Z10 where recorded levels of Ecomul have actually increased, the increase was less than 10% at Z4; however, Z10 showed an increase of approximately 50%. Similarly in 2000, 8 stations produced a detectable value for Esterkleen. However, when sampling was undertaken again in 2008, no detectable levels were recorded at any of the stations. Finally, of the 27 stations, 4 sediment samples recorded detectable levels of Ecosol in 2000. When these were revisited in 2008, only one site (station F1) produced a detectable level.

As the discharge of OBM on cuttings was effectively banned, OBM concentrations in marine sediment are expected to decrease with time and biota will recover, as this has been borne out at the majority of stations sampled initially in 2000 and again in 2008. However, the time scales vary depending upon:

- The type of mud;
- Depth of the cuttings pile; and
- Characteristics of the receiving environment, e.g. water depth, temperature, waves and currents.

Recovery for deeper accumulations is thought to be much slower than for thin accumulations. Initial cuttings pile depth will depend on the current profile and water depth. Stronger currents lead to wider dispersion before deposition, and greater water depth will generally lead to thinner initial deposits. The duration of impact upon the benthic community is related to the persistence of OBM cuttings accumulations and associated hydrocarbons in the sediment (International Association of Oil & Gas Producers, May 2003).

3.2.2.2 *Polycyclic Aromatic Hydrocarbons*

Raw data on sediment concentrations of polycyclic aromatic hydrocarbons (PAHs) are listed in **Appendix 3**. These include naphthalenes, phenanthrenes, dibenzothiophenes (NPD) and the 16 priority PAHs defined by the US EPA (Environment Protection Agency).

Of the stations sampled, eight sites had concentrations of 'total NPD' <1µg/kg: 21 sites exceeded this value with the maximum (15µg/kg) found at Z10. Concentrations of 'total NPD' at all references sites were <1µg/kg, and concentrations at the majority of other locations were between 0.4 and 3µg/kg, with sites Z4 and Z10 having elevated values of 6.9 and 15.0µg/kg respectively. 'Total EPA 16' PAH results were in the range 0.89–11.0µg/kg. It should be noted that this category excludes dibenzothiophene, and unlike the 'total NPD data' these do not include the C1 to C4 alkyl derivatives.

In the majority of cases, the concentrations of PAH recorded in the 2008 field survey are far lower than the levels quoted by OSPAR as background concentrations (OSPAR 2005-6). **Table 3.7** provides the Environment Canada TEL and PEL for individual PAHs as well as the OSPAR BC, compared to results from the Corrib 2008 field survey.

Table 3.7: OSPAR BCs and provisional BACs for PAHs in sediments (OSPAR 2005–6) and standards for polycyclic aromatic hydrocarbons (PAHs) in sediments as µg/kg (ppb)

PAH	Environment Canada TEL (µg/kg, ppb)	Environment Canada PEL (µg/kg, ppb)	Sediment (µg/kg, ppb)*		Corrib Field Maximum (µg/kg, ppb)
			BC	*BAC*	
Acenaphthene	6.7	88.9	-	-	0.11
Acenaphthylene	5.9	128	-	-	0.06
Anthracene	46.9	245	3	5	0.18
Benz(a)anthracene	74.8	693	9	16	0.53
Benzo(a)pyrene	88.8	763	15	30	0.88
Benzo(b)fluoranthene	No data	No data	-	-	1.8
Benzo(g,h,i)perylene	No data	No data	45	80	0.84
Benzo(k)fluoranthene	No data	No data	-	-	0.52
Chrysene	108	846	11	20	1.1
Dibenz(a,h)anthracene	6.2	135	-	-	0.08
Fluoranthene	113	1,494	20	39	1.9
Fluorene	21.2	144	-	-	0.10
Indeno(1,2,3,cd)pyrene	No data	No data	50	103	1
Naphthalene	34.6	391	5	8	1.2
Phenanthrene	86.7	544	17	32	0.99
Pyrene	153	1,398	13	24	1.4

*Note, the BC and BAC sediment figures are listed as a dry weight normalised to 2.5% organic carbon, whereas the Corrib field samples were not normalised. However, the majority of the data have organic carbon levels of <1%

From **Table 3.7** it can be seen that maximum PAH levels recorded from the 2008 Corrib field survey were generally low compared with BC, TEL and PEL.

In comparing PAH levels from the 2000 survey with those recorded on the 2008 Corrib field survey, there are evident trends in the data. A decrease in the

total NPD (naphthalene, phenanthrene and dibenzothiophene) is present from 2000 to 2008, although F6, F7, Z7, Z8, Z11 and Z12 are exceptions to this trend. Total US EPA PAH levels have also decreased between 2000 and 2008 at all but one of the sites; Z12 showed an increase of approximately 40% over its initial value.

Sites Z11 and Z12 lie immediately west of P4, P6 and P101 – the wells where most recent operational activity has occurred – approximately 200–300 metres away. The main tidal current axis is south or south-west to north or north-east in this area, so while the concentrations at Z11 and Z12 could be a result of drilling activity in the manifold area, it would be expected that other sites such as Z4 and Z10 (to the north and north-east) would also exhibit high concentrations of PAH, and hence their levels should have followed this pattern and increased from 2000 to 2008.

When considering each PAH separately, the maximum values recorded in the 2000 survey are greater than those from the 2008 survey for all but one hydrocarbon, benzo(k)flouranthene, where an increase of ~5% is recorded at reference station 2. The presence of PAHs in marine sediment is commonly associated with anthropogenic influences such as drilling with OBMs, fuel or chemical spills and natural seepages.

3.2.2.3 Quality Assurance - Duplicate Laboratory Analysis

Laboratory duplicates were selected from the marine sediment samples to allow quality assurance of the chemical analysis that was undertaken. This PAH analysis was undertaken by the RSK subcontractor Benthic Solutions.

Duplicating sediment analysis from a single grab sample is somewhat different to duplicating water analysis, for example, as sediment is regarded as having a more heterogeneous consistency in comparison to a more homogenous (well-mixed and uniform) water sample. The analysis of saturates at two stations (F1 and Z4) and PAHs at a single station (Z4) were completed to fulfil RSK's quality assurance procedure, with the aim of revealing the level of precision of sediment sample analysis in the lab. Results for saturates at both F1 and Z4 replicates are shown in **Table 3.6**, whereas results for Z4 PAH is shown in **Appendix 3**.

The results from duplicate analyses shown in **Table 3.6** provide an illustration of the variability that can occur when duplicating sediment analysis. Both duplicates from Site F1 have similar results for TOE, showing good precision. However, when examining duplicate samples for site Z4 there is a much greater degree of variability between the two, with results for TOE and Ecomul being nearly twice the value for 'Z4a' in comparison to 'Z4b'. Again, these results show nearly twice the value of PAHs are recorded in the 'Z4a' replicate in comparison to 'Z4b'.

The variation from replicates, evident at Z4 more so than F1, is not surprising and unlikely to be a result of inaccurate laboratory analysis. These findings provide evidence for the heterogeneous nature of marine sediment, particularly when comparing areas that may or may not have been affected by anthropogenic activities.

3.3 Biological

All raw benthic invertebrate is presented in **Appendix 4**, and the associated analytical report is included in **Appendix 5**. To summarise, 21, 342 individuals of 291 species were recorded from the 2008 Corrib field benthic survey.

3.3.1 Univariate Analysis

Several common ecological indices were calculated, for both the 'per replicate' and 'per site' (i.e. pooled replicate) data. These indices summarise, by means of a single number, information about aspects of community structure.

Table 3.8 presents a summary of biological data for the Corrib field stations on a 'per site' basis; these values exclude encrusting species.

In addition to the univariate data, **Table 3.9** also provides a summary of the percentage of biological material recorded in terms of the phyla that it represented i.e. Annelida, Crustacea, Mollusca, Echinodermata and 'Others'.

Table 3.8: Univariate indices per site from the Corrib field

Station	No. of Species* (S)	No. of individuals (N) per m^2	Pielou's Evenness (J')	Shannon-Weiner Diversity (log_e) (H')	Simpson's Dominance index (λ)
REF1	86	1737	0.63	2.83	0.22
REF2	75	1803	0.56	2.43	0.30
REF3	78	2253	0.58	2.52	0.27
REF4	86	2757	0.53	2.34	0.32
C1	82	2697	0.64	2.83	0.20
C2	104	2843	0.74	3.44	0.10
C3	104	2670	0.57	2.67	0.27
C4	76	1947	0.60	2.60	0.26
F1	95	3080	0.59	2.71	0.24
F2	92	3190	0.52	2.33	0.34
F3	84	2560	0.51	2.26	0.36
F4	82	2547	0.52	2.28	0.33
F5	94	3313	0.54	2.46	0.29
F6	55	1503	0.50	2.01	0.38
F7	69	2590	0.47	1.98	0.41
F8	83	2980	0.48	2.11	0.39
F9	74	2130	0.54	2.33	0.32
Z1	89	2393	0.61	2.73	0.24
Z2	77	1930	0.57	2.46	0.30
Z3	89	2293	0.57	2.54	0.29
Z4	60	1620	0.54	2.22	0.33
Z5	100	2397	0.69	3.17	0.15
Z6	90	2390	0.54	2.42	0.31
Z7	85	3897	0.42	1.86	0.45
Z8	79	2123	0.57	2.48	0.29
Z9	72	2740	0.55	2.34	0.30
Z10	70	1667	0.65	2.76	0.21
Z11	78	3000	0.43	1.89	0.45
Z12	84	2090	0.59	2.62	0.25

Table 3.9: Distribution of dominant phyla per site from the Corrib field

Station	% of each phyla				
	Annelida	Crustacea	Mollusca	Echino	Other
REF1	68.71	8.45	11.71	8.06	3.07
REF2	81.15	6.65	6.10	4.25	1.85
REF3	83.14	6.36	6.66	2.81	1.04
REF4	84.76	3.26	8.95	1.81	1.21
C1	76.89	3.09	13.10	4.08	2.84
C2	70.81	3.87	17.94	2.58	4.81
C3	81.90	4.99	7.24	2.87	3.00
C4	71.75	4.97	15.41	6.16	1.71
F1	82.14	2.71	9.96	1.62	3.57
F2	83.80	3.55	8.36	3.03	1.25
F3	79.56	3.52	9.77	4.95	2.21
F4	71.99	3.66	18.46	4.58	1.31
F5	75.75	3.22	15.79	3.12	2.11
F6	70.95	8.43	14.86	5.10	0.67
F7	81.85	5.92	4.25	6.69	1.29
F8	80.76	2.46	9.17	5.48	2.13
F9	76.84	4.07	12.68	3.60	2.82
Z1	82.73	2.79	8.64	3.20	2.65
Z2	82.56	5.01	6.22	5.01	1.21
Z3	75.58	4.07	14.24	4.07	2.03
Z4	75.51	2.06	16.26	5.56	0.62
Z5	73.57	2.50	14.88	6.95	2.09
Z6	75.31	3.35	16.60	3.77	0.98
Z7	83.49	1.63	10.86	2.91	1.11
Z8	74.73	5.34	12.72	5.34	1.88
Z9	76.64	5.60	13.75	2.55	1.46
Z10	69.20	2.80	18.40	7.00	2.60
Z11	78.22	4.78	11.11	5.22	0.67
Z12	74.16	2.87	15.47	5.58	1.91

Note, cells shaded in yellow highlight maximum values and cells shaded in green show minimum values recorded for each index.

Species numbers and abundances were relatively constant at all sites. In 2008, the average number of species per site (82) was high compared with 2000 survey data (averaging approximately 50 species per site), ranging from 55 at site F6, to 104 at sites C2 and C3. Abundances at each site were moderate throughout, ranging from 1503/m^2 at site F6 to 3897/m^2 at site Z7.

Diversity was moderate to high at all sites, ranging from 1.86 at site Z7 to 3.44 at site C2, and dominance and evenness were found to be moderate with observed averages of 0.30 and 0.56 respectively (this reflected the high numerical abundances of the Polychaeta *Galathowenia oculata)*.

Ranked taxa showing the 10 most abundant species at each site are shown in a tabulated format within **Appendix 5**. From this it is clear that community composition showed little change throughout the sampling area. Annelida comprised the highest percentage of animals at all sites with the maximum recorded at reference site 4 (84.76%) and an overall average of 77%. Mollusca proved to be the next most important phyla throughout the sampling area, and on average made up 12% of the community. Crustacea and Echinodermata contributed an average of 4% of the individuals found.

The numerical dominance of annelids was largely due to the presence of the tube-dwelling Polychaeta *G. oculata*, which was found to be the most abundant

animal throughout the sampling area. At all but seven sites, this species made up a minimum of 50% of the individuals found. At site C2, *G. oculata* had the lowest relative abundance, only contributing a third of the individuals found. Other key species at this site were the Spionidae Polychaeta *Prionospio fallax* and *Levinsenia gracilis*, the Capitellidae Polychaeta *Peresiella clymenoides* and the bivalves *Adontorhina similis*, *Kelliella abyssicola* and *Abra* sp. These animals were also found to be important at all other sites but to lesser degrees.

The Mollusca recorded were mainly small and juvenile bivalves typical of those inhabiting the continental slope, for example species from the family Thyasiridae, and the genera *Cuspidaria*, *Kelliella* and *Yoldiella*. Amphipod and Isopoda Crustacea were recorded throughout the sampling area but only the isopod *Natatolana borealis* was found in abundance. Many of the Crustacea found were those associated with deeper water environments such as the mysids *Pseudomma affine* and *Hypererythrops* and amphipods from the family Pardaliscidae, which is the most abundant Gammaridea family at abyssal depths. Deeper water Pycnogonidae (sea spider) from the genus *Nymphon* were present at more than one station. Juvenile starfish (Asteroidea) and sea urchins (Echinoidea) were also present at the majority of sites.

When ranking taxa, it was clear that community composition was fairly constant throughout the survey area, with annelids (such as *G. oculata*) making up the highest percentage of animals at all sites. At all sites, a large proportion of the community was made up of infrequently occurring species with a very low overall abundance. For example at site Z4, 40 out of the 60 species recorded had an average abundance of 10 per $1m^2$.

As the marine sediment type does not vary a great deal across the sample sites, it is very difficult to highlight any trends with regard to the biota present or absent with the existing sediment type. What can be noted when comparing **Table 3.1** and **Table 3.8** is that the presence of Crustacea among the fauna increases at the fine sand stations in comparison to the very fine sand stations, the only exception being Z10.

Very few organic pollution indicator species (i.e. the polychaete worms *Capitella* (an indicator of organically enriched sediment) and *Cirratulus)* were identified at the survey sites in the vicinity of the Corrib field. The two sites where they were recorded (Z9 and Z11) are close to the location of more recent drilling activity (P4, P6 and P101). However, the fact that these organisms are only recorded in low numbers and they do not dominate the samples taken at these sites suggests that any pollution is minimal.

Annelid worms, particularly Polychaeta, generally dominate the communities across the fine sand and very fine sand habitats. In 2000 *Capitella* (occurring at Z4 and F5) and *Cirratulus* (logged at C2, F6, F7 and F9) were not recorded at reference sites and hence their presence at Z9 and Z11 may be attributed to the discharge of drilling mud on cuttings from exploration and appraisal well drilling. These indicate that the site may be seen as disturbed owing to the dominance of opportunistic species, although contaminant levels were at a minimum. In 2008 *Capitella* and *Cirratulus* were recorded at a limited number of stations (Z9, Z11 etc.) in low abundances, generally juvenile Cirratulidae were recorded at C3, F5, F9, Z4, Z5 and Z12.

3.3.2 Multivariate Analysis

Multivariate analysis is used to assess the variability of communities from replicates within a site. This analysis can then be interpreted to determine how different or similar the replicates are that were collected, with the ultimate aim of giving a more accurate site description (Nicolaidou *et al*., 1993).

Aside from on a per replicate basis, multivariate analysis can also be undertaken to analyse the variability of communities at sites over the survey area. Multivariate analysis deals with observations on more than one variable where there is some inherent interdependence between the variables.

Site-based and replicate-based data has been tabulated to enable multivariate analysis to be undertaken, and then placed into PRIMER statistical software where results have been produced showing statistical similarities in the form of two separate dendrograms. From the dendrogram showing replicate-based data (**Figure 3.2**), it is evident that similarities between replicates are relatively low across the Corrib field survey area. There was a relatively high degree of biological homogeneity throughout the sampling area. Similarities of more than 40% on a per replicate basis and 50% on a per site basis (**Figure 3.3**) were observed.

Within-site variability was found to be low at all of the sites. However, there was such a high degree of similarity throughout the whole sampling area that replicates tended not to cluster together; this only occurred at sites C3 and F1.

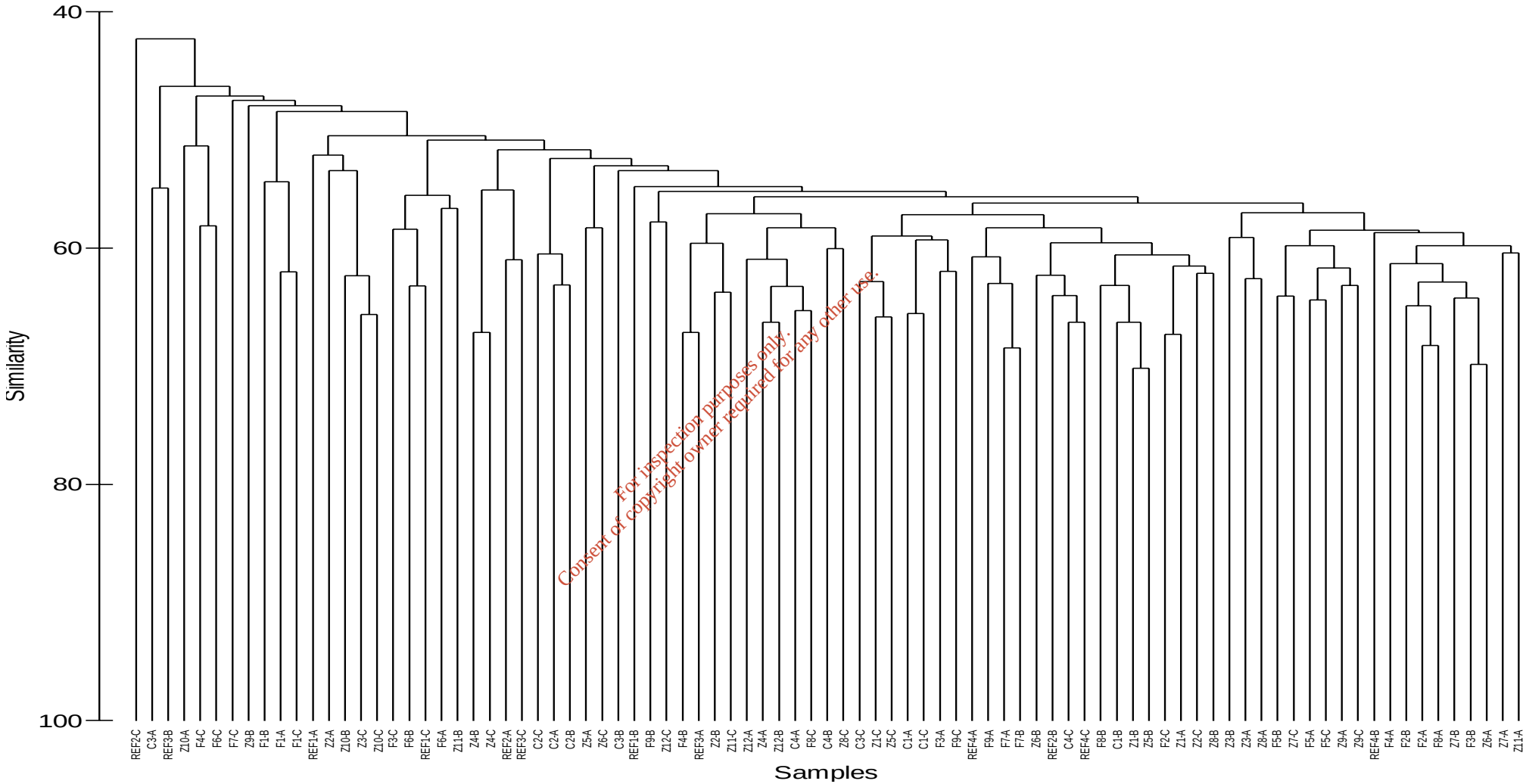

Figure 3.2: Dendrogram showing clustering of communities (per replicate) from sites at the Corrib field (square root transformed data)

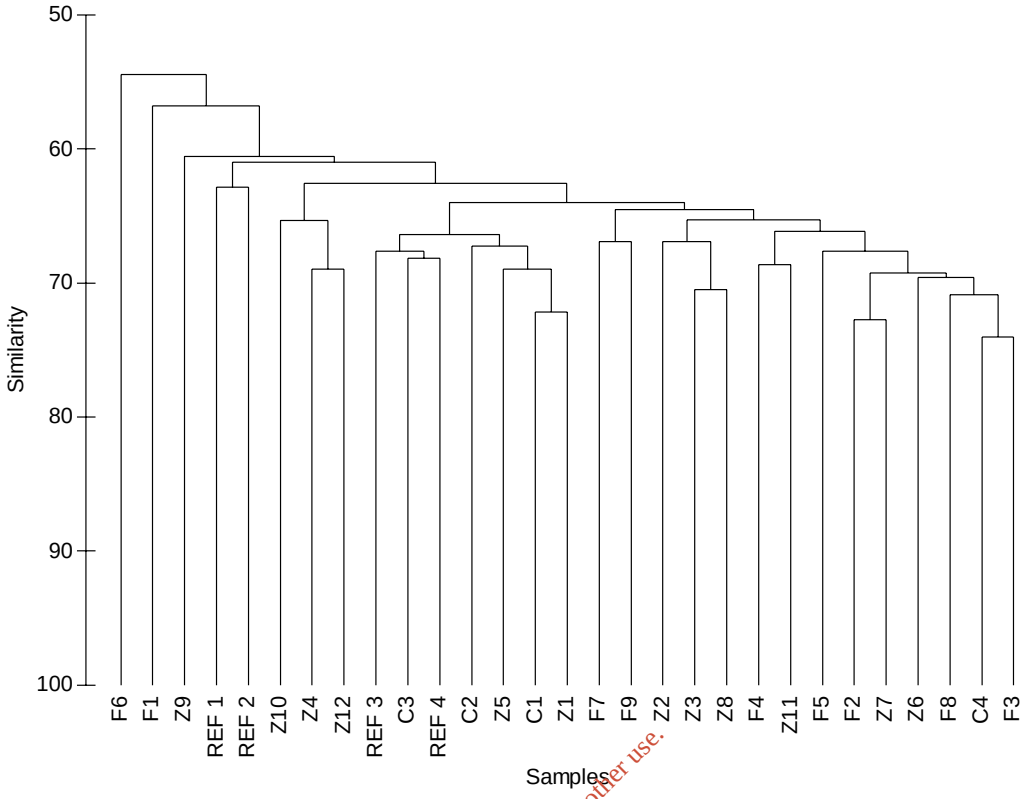

Figure 3.3: Dendrogram showing clustering of communities (per site) at the Corrib field (square root transformed data)

Results from the multivariate statistical analysis, shown in the dendrogram **Figure 3.3**, highlighted that sites F6, F1 and Z9 differed from all other sites at approximately the 55%-60% level.

Due to the size of the environmental dataset, multivariate analysis was performed for all sites to identify differences in community composition. Looking at the best correlation between the biological and environmental data and endeavouring to show which set of chemical and/or physical variables best explains the variation observed in the biological communities.

The analysis showed that no single variable accounted for the observed variance between sites. However, moderate multi-variant correlations were found, the best being with six variables: chromium, lithium, manganese, TOE, total naphthalenes, and total NPD. Multi-dimensional scaling (MDS) overlays of these relevant environmental variables were plotted and are shown in **Appendix 5**. Patterns were weak but generally showed that site F1 had higher concentrations of chromium and manganese than other sites, and sites Z10, Z4 and, to some extent, Z9 and C2 had higher concentrations of organic compounds than other sites. Lithium showed no visible patterns and therefore no MDS figure is included.

From the results collected there does not appear to be any geographic pattern in community types, and the physical environment. For example, the sediment composition does not appear to have a great influence on the variety of macrofauna present, this is undoubtedly linked to the very small fluctuation in sediment types present across the survey stations, which attract similar communities to inhabit them.

No group appears to become more common with depth, sediment type, TOC or anthropogenic influence.

3.3.3 *Comparing 2000 and 2008 Benthic Data*

In contrast to literature from the 2000 survey, anemones were not recorded as widespread in the 2008 Corrib field survey. The susceptibility of anemones to high levels of suspended sediment and potential contaminants ingested while filter feeding has previously been linked to offshore oil and gas drilling activities. Another noticeable feature when comparing the macrofauna present from both surveys is the absence/reduced number of echinoderms present (which are susceptible to contaminants and smothering like anemones), this phylum featured more heavily in the 2000 field survey. However, as a result of drilling activities occurring before the Corrib 2000 offshore field survey, it is unlikely that the reduced presence from 2000 to 2008 of both anemones and echinoderms are a result of this.

Following statistical analysis of 2008 data, and comparing these results with those recorded in the 2000 survey, there is some notable variation in species and individuals (abundance) recorded, in addition to diversity and 'evenness'. Since the 2000 survey, the average number of species recorded per station sampled has only increased by 0.3 from 2000 to 2008 and is therefore not significant.

The data from the 2008 Corrib field survey shows a reduced variation in abundance (i.e. numbers per 0.1m^2) within the same depth range (in comparison with 2000 where a large variation in abundance was recorded as shown in **Table 3.10**). This could possibly indicate an increased stress gradient, with more extreme values representing the effect of disturbance on macrofaunal density. These observed variations in abundance were probably due to a lack of organic enrichment and sediment variation resulting from reduced drilling activities in the area.

Table 3.10: Data summary for the 2000 and 2008 Corrib field survey benthic fauna

Benthic Macrofauna Data Summary	2000 Field Survey	2008 Field Survey
Total benthic macrofaunal species recorded	261	289
Average number of individuals per station (0.1m^2)	355	236
Average number of species per station (0.1m^2)	9.7	10.0
Average Shannon-Weiner Diversity per station	3.91	2.56
Average Evenness (Pielou's) per station	0.71	0.58

Results from the 2008 survey showed a relatively low diversity of benthic fauna. When comparing macrofaunal diversity from both the 2000 and 2008 field surveys, it is noted that the diversity was generally lower in 2008 compared with 2000 data and indeed other deep-sea locations worldwide (particularly the Atlantic Frontier Environmental Network (AFEN) region to the north of the Corrib field). When comparing abundances (number of individuals) per site over the two survey periods, records from 2000 are relatively comparable to AFEN locations. Abundance figures for 2008 recorded in the Corrib field are notably reduced compared with the 2000 field survey; however,

these are still in line with data collected from 1996 and 1998 AFEN locations. One key difference here is that large variations in abundance levels were recorded in 2000, whereas little variation was seen throughout the 2008 survey.

When comparing evenness (Pielou's evenness) from both surveys, in 2000 the average evenness of species distribution was found to be lower in the Corrib field compared with AFEN 96 and 98 studies. Results for 2008 showed evenness as being reduced further compared with the 2000 results.

Impacts to the benthic fauna can result from several factors, including chemical toxicity of the drilling mud base fluid, oxygen depletion due to biodegradation of drilling muds in the sediment, and physical impacts from burial or changes in grain size. Since OBMs are biodegradable organic compounds, their (historic) presence with the cuttings on the sediments increases the oxygen demand in the sediments. This can lead to anoxic/anaerobic conditions as degradation of the organic material occurs. Anoxic conditions can also arise from the burial of organic matter by sediment redistribution. Organic compounds in the sediment, whether OBMs or settled biomass such as algae and other detrital material, will biodegrade by the actions of the naturally occurring micro-organisms. Biodegradation occurs more rapidly under aerobic than anaerobic conditions. As OBMs biodegrade, the cuttings become more hydrophilic and the fine particulate solids are released. Bottom currents can then more easily disperse these.

The potential for significant bioaccumulation of OBMs in aquatic species is believed to be low. Typically, over the longer term, the affected areas are recolonised by biological communities in a successional manner. Initial colonisation is by species that are tolerant of hydrocarbons such as the Polychaete worm *Capitella*, and/or opportunistic species that feed on bacteria that metabolise hydrocarbons. As time passes, and hydrocarbon loads diminish, other species return via in-migration, and the community structure returns to something more closely resembling its former state (International Association of Oil & Gas Producers, May 2003). The slight increase in numbers of species per site between 2000 and 2008 indicates that this process has commenced in the Corrib Field.

3.4 Seabed Photography

The full report on photography of the seabed surface and SPI can be found in the Aqua-Fact report in **Appendix 6**. A summary of the findings is discussed here.

As noted previously, owing to the loss of the camera it was not possible to complete SPI seabed photography at 15 stations (C1–C3, F3–F5, F9, Z8 and Z10–Z12 in addition to the A-stations, which were excluded owing to the presence of the SEDCO 711 drilling rig). However, following recovery of the camera, SPI and seafloor surface images were obtained from the separate deployments at 18 sampling locations. **Table 2.3** summarises planned and actual photography sampling locations.

It was evident from the seabed surface images retrieved during the 2008 Corrib field survey that most of the stations surveyed showed signs of faunal activity. The large majority of mounds, casts and burrows indicated the presence of burrowing organisms, most likely worms, i.e. Annelida.

Figure 3.4 displays the surface at reference site 4, showing intensively re-worked sediments with mounds and burrows. An anemone (*Actinuage richardi*) can be seen on the surface image included here, and a decapod is present at a burrow entrance.

Figure 3.4: Seabed surface, station ref 4

Surface photographs at stations ref 4 and Z1 (**Figure 3.4** and **Figure 3.5** respectively) show evidence of increased bioturbation with the presence of numerous burrows, casts and epifauna.

Station Z1 is a good example of the stations that were sampled (**Figure 3.5**); the flecks of coarse unidentified material are obvious among the sediment.

Appendix 6 presents sediment profile and sediment surface shots for each station surveyed.

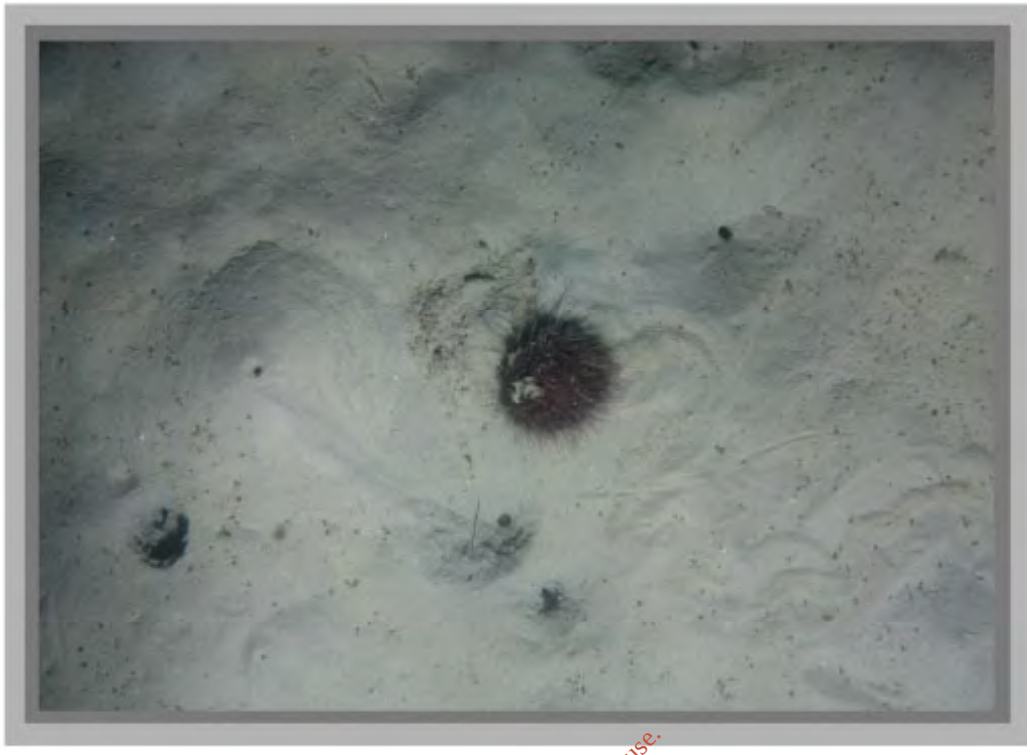

Figure 3.5: Seabed surface, station Z1

Figure 3.6 shows the seabed at station F1, revealing small surface tubes and reduced evidence of bioturbation. Flecks of (coarse) unidentified material are again evident on the sediment, which could be drill cuttings (Aqua-Fact **Appendix 6**) or the 'gravel' recorded during the grain size analysis (see **Table 3.1**). **Figure 3.7** also shows the shaded apparent redox potential discontinuity (ARPD) layer at site F1, being approximately 6–7cm beneath the surface of the seabed. The presence of an ARPD is indicative of some degree of elevated organics, possibly due to contamination with drilling muds. It should also be noted that the maximum penetration depth for SPI was achieved at station F1 where the ARPD level was noted.

Figure 3.6: Seabed surface photograph, station F1

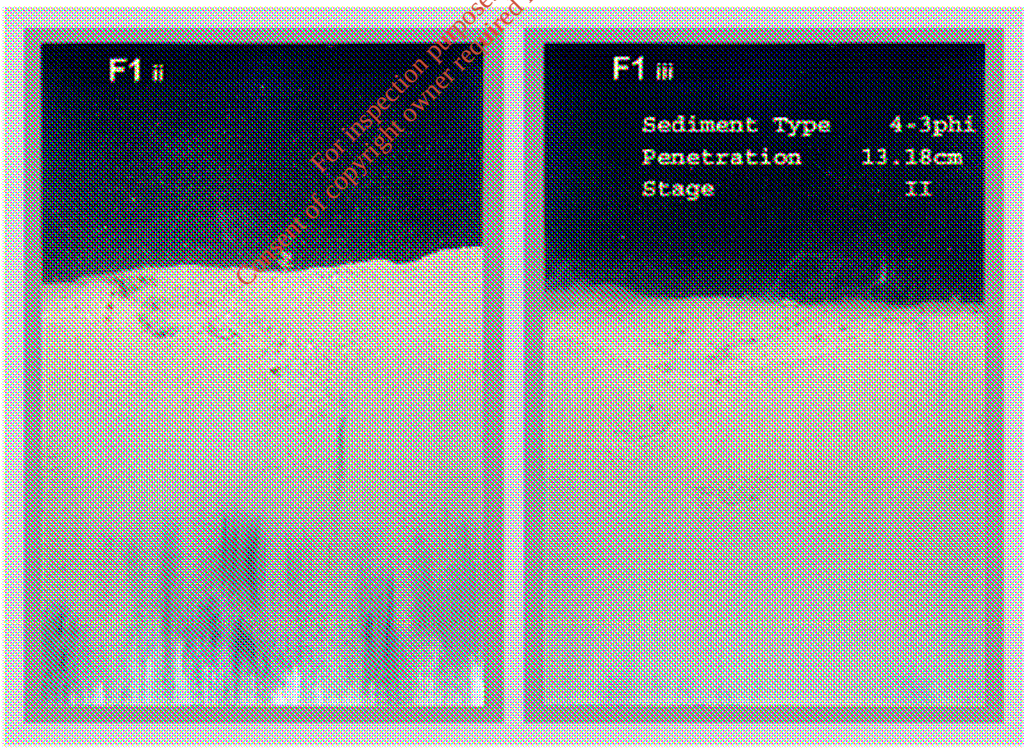

Figure 3.7: Seabed SPI at station F1, ARPD visible

The report in **Appendix 6** allocates the seabed photography locations into different categories based on observations that can be made from the photographs.

Stage III environments (mature, healthy conditions) are typically characterised by deep redox boundary depths. With the exception of F1, all stations surveyed were allocated a stage III successional stage because of the presence of characteristically deep ARPD layers, fauna and prominent biogenic features such as burrows, tubes and feeding casts (**Figure 3.7** and **Figure 3.4**) (largely as a result of the presence of annelids in the survey area) and the absence of any definite evidence of impact or habitat quality degradation. Information gathered from both the surface and SPI images was used to assess the status of the habitat and communities present. Very fine sands that are reworked intensively by fauna were recorded for all stations (with the exception of F1) in the Corrib field. Sediments at station F1 were allocated a stage II successional status owing to the presence of reduced bioturbation in the profile images recorded, presence of an ARPD layer, and a lack of features indicative of a stage III community. The overwhelming dominance of stage III environments at the field survey stations indicates that the community is stable and in a mature, healthy condition.

Faunal activity was evident at all of the stations imaged, as was the case at the 2007 Corrib field SPI survey stations where several SPI and seabed photographs were taken. As described within the Aqua-Fact report (2007), flecks of coarse (unidentified) material were seen on the sediment surface at each of the F series of stations and at station Z1. Aqua-Fact suggest that the photographs (shown within **Appendix 6**) may provide evidence of the presence of drill cuttings, although this cannot be confirmed.

No protected or designated habitats (such as Annex 1 habitats, i.e. biogenic reefs) were found during the 2008 Corrib field survey.

In 2000, seabed photography was also undertaken in the Corrib field, including some SPI work (Aqua-Fact 2000a, 2000b). Images from 2008 are generally similar to those from 2000, which show worm burrows among a slightly finer-looking sediment, i.e. sandy silt (finer sediment was recorded at the majority of stations in 2000). In the 2000 survey, ARPD depth was visible at only a couple of the stations (C2 and F9) and is possibly indicative of reduced faunal activity and bioturbidity of the surface sediment. Aside from a slight increase in grain size/sediment description, there does not appear to be a great deal of difference at the sample stations between 2000 and 2008.

4 Summary

4.1 Physical

Sediment classification ranged from fine sands to very fine sands across the survey area; the majority being sand sized particles (0.063 – 2mm) (approximately two thirds in most cases) with the remainder being predominantly mud (<0.063mm). An increased percentage of sand was found at three of the four reference sites, which in turn has created an increase in average grain size, i.e. fine sand. For both PSA and TOC, there are no noticeable trends in relation to geographical location, the water depth or recorded sediment type. Within the immediate area of the manifold in the Corrib field, station Z10 recorded the highest percent of fine particles (i.e. % mud).

In the 2001 EIS (surveys undertaken in 2000), the sediment was described as consisting largely of coarse silt and very fine sand; since then, the average grain size appears to have increased slightly and sediment in 2008 can be described as very fine sands with some fine sand areas.

4.2 Chemical

Overall, the metal concentrations within the 2008 sediment samples showed no cause for concern in relation to recorded OSPAR background concentrations and Environment Canada TEL and PEL. When comparing metal concentrations from the 2000 survey with the 2008 field survey, it is evident that at the majority of stations levels of arsenic, cadmium, chromium, copper, lead, vanadium and zinc have increased. In contrast, the majority of stations in 2008 show a decrease in the concentration of barium and nickel when compared to the 2000 survey data. Mercury was not analysed in the 2000 survey and hence results cannot be compared, although the data produced in 2008 shows the levels present are of no environmental concern.

Although reduced when compared with 2000, high concentrations of barium were found at several sites (levels being greatly reduced at reference sites), these values are likely to be a consequence of local drilling activities. No guidelines exist for levels of barium in marine sediments and the biological consequences are uncertain, but are currently viewed as unlikely to give rise to harmful disturbance. As a component in water-based drilling muds, the highest value for barium in 2008 was recorded at station Z4.

The metals data for the Corrib field in 2008 reflect conditions that would be expected for a site with little or no anthropogenic impact, and low levels of fine material with which many metals are generally associated.

When analysing saturates within the Corrib field in 2008, stations Z9 and Z10 show high levels of TOE and low-toxicity base oil compared with the other 27 stations sampled, the greater of these being recorded at Z10. In comparison to results from the 2000 survey, the levels of saturates largely appear to be reduced. Of the stations where sampling was duplicated in 2000 and 2008, only two of these (Z9 and Z10) showed a rise in levels of TOE, although TOE was still present at all other stations. Ecomul levels (base oil A) have actually

increased since 2000 at Z4 and Z10. Note that stations Z4, Z9 and Z10 are all either north or west and within a couple of hundred metres of wells that have undergone operational activity in 2008.

The presence of PAHs in marine sediment can be commonly associated with anthropogenic influences such as drilling with oil-based muds, fuel or chemical spills, in addition to natural seepages. In the large majority of cases, the concentrations of PAHs recorded are lower than the levels quoted by OSPAR as background concentrations, and maximum levels recorded were generally low in comparison to Environment Canada TEL and PEL. A decrease in the total NPD is evident from 2000 to 2008. Total EPA 16 levels also dropped between 2000 and 2008 at all but one of the sites (Z12. When looking at separate PAHs the maximum values recorded for 2000 far outweigh those for 2008 with all but one hydrocarbon (benzo(k)fluoranthene), where a minimal increase is noted.

4.3 Biological

Infaunal communities observed in the 2008 survey were of moderate to high diversity, where dominance and evenness were found to be moderate. This reflected the high numerical abundances of a single species of tube-dwelling Polychaeta *Galathowenia oculata*. When ranking taxa it was clear that community composition was fairly constant throughout the survey area, with annelids making up the highest percentage of animals at all sites. The dominance of annelids over the survey area is expected given the relatively fine grain size of the substrate, yet dominance of sand.

Very few organic pollution indicator species were identified at the survey sites in the vicinity of the Corrib field, i.e. the polychaete worms *Capitella* and *Cirratulus*. The two sites where they were recorded (Z9 and Z11) are in the centre of the field development and very close to more recent drilling sites (P4, P6 and P101). However, the fact that these organisms are only recorded in low numbers and they do not dominate the samples taken at these sites suggests that any pollution is minimal. In 2000, *Capitella* and *Cirratulus* were not recorded at reference sites and hence their presence elsewhere may be attributed to the discharge of mud on cuttings from exploration and appraisal well drilling.

In contrast to the 2000 survey, anemones were not recorded as widespread in the 2008 field survey, the susceptibility of anemones to high levels of suspended sediment and potential contaminants ingested while filter feeding could be linked to drilling activities following the EIS submission and evidence that the Corrib field marine fauna has not completely recovered.

In the 8 years between surveys, the maximum number of species recorded at a single station increased from 73 to 104. The stations with the highest number of species are located adjacent to well P3, which has not been subject to any operational activity i.e. drilling/capping since 2006 and hence the increase in species number is a good indicator that the site is recovering. The lowest number of species recorded in any sample is also twice that recorded in 2000. The increase in average species number in 2008 is indicative of a recovering environment.

4.4 Seabed Photography

The most common evidence indicating the presence of marine fauna was the numerous worm burrows (most likely to be those of *G. oculata*). As with the 2007 Corrib field SPI survey, these numerous feeding mounds, pits and burrows were also indicative of healthy seabed conditions in this area. No protected or designated environments (such as Annex 1 habitats, i.e. biogenic reefs) were found during the 2008 Corrib field survey.

Camera prism penetration was moderate to low throughout the survey. This is due to the compactness of the sands in this area. ARPD depth was visible at only a single station (Station F1) where there was reduced evidence of bioturbation. Aside from F1, all of the stations surveyed were allocated a stage III successional stage; stage III indicates that the community is stable and in a mature, healthy condition.

General seabed surface footage across the stations in 2000 is similar to that recorded in 2008. In the 2000 survey, ARPD depth was visible at only a couple of the stations and is possibly indicative of reduced faunal activity and bioturbidity of the surface sediment. Aside from a slight increase in grain size/sediment description, and an absence of the dark 'flecks of coarse unidentifiable material', there does not visually appear to be a great deal of difference at the sample stations between 2000 and 2008.

4.5 Overview

From the analysis of the 2008 results, there does not appear to be any obvious geographic pattern in community types or physical conditions. For example, the sediment types do not appear to have a great influence on the variety of macrofauna present; this is probably linked to the very small diversity of sediment types present across the survey stations. In addition, no group appears to become more common with depth, salinity, sediment type, TOC or anthropogenic influence.

Benthic communities appeared to be typical of those expected for the area and the substrate type, with the exception of those near the wells, which showed some evidence of disturbed conditions. No species or habitats were of particular conservation interest. While elevated concentrations of barium and some PAHs have been recorded at a number of sites from the Corrib field as a consequence of drilling activities, no determinand was found at concentrations that would give rise to concern regarding potential biological impacts.

5 References

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APPENDIX 1: VESSEL NAVIGATIONAL EQUIPMENT

The following equipment was mobilised aboard the vessel for the survey:

- CSi d-GPS (differential-global positioning system) max receiver;
- High-specification navigation PC supporting Quincy V8 (spare PC);
- TSS Meridian Gyro;
- Simrad HPR 400 subsea positioning system over-the-side mount; and
- Simrad 60 series single beam echo sounder.

The vessel's existing navigation system (Trimble dGPS) was used as a secondary resource. WGS-84 datum was used throughout. The target accuracy for benthic samples was within 30m of the position, although sea conditions often made achieving this target difficult.

APPENDIX 2: SEDIMENT PARTICLE SIZE DATA

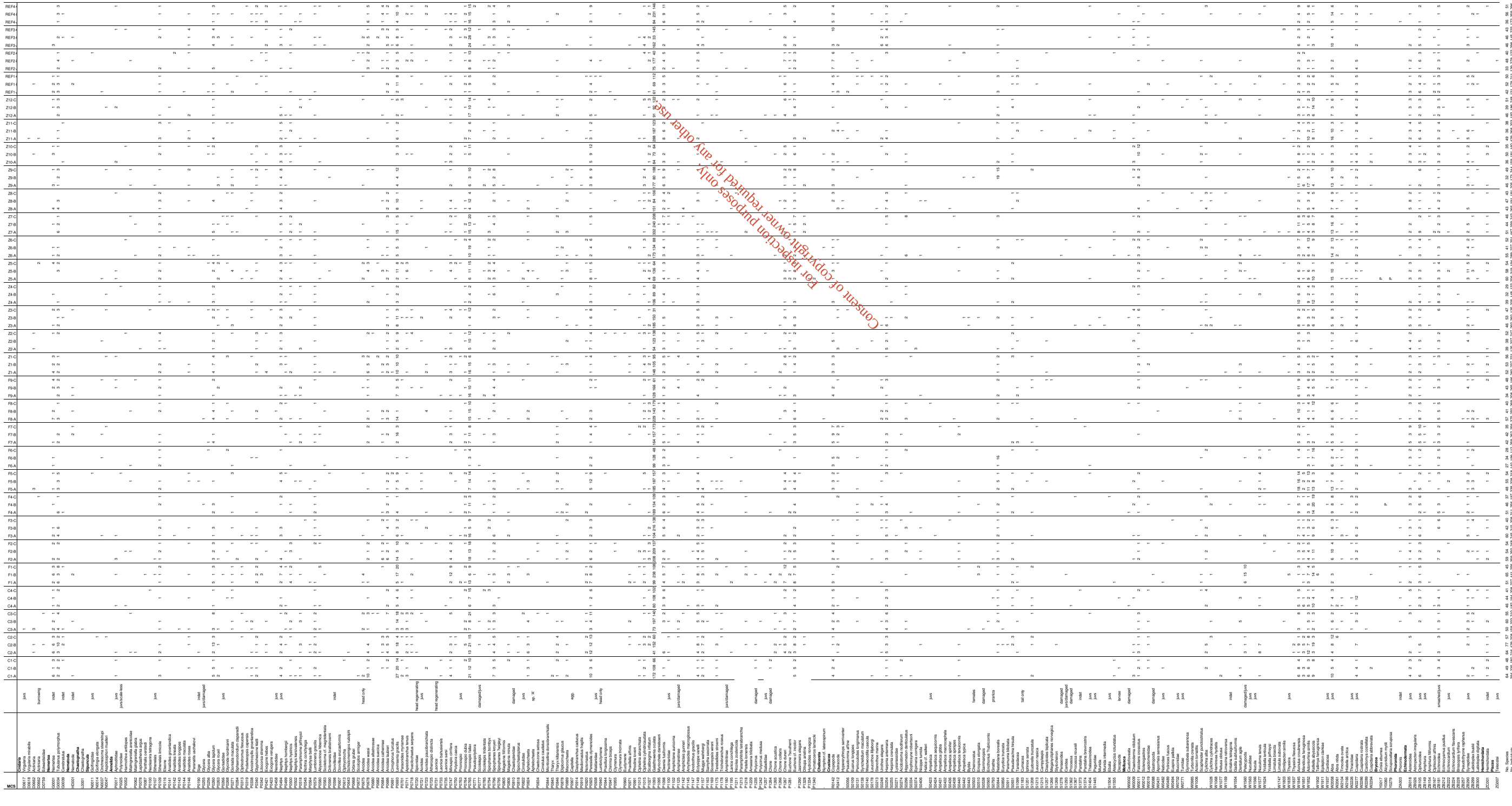
Aperture (mm)	8.000	4.000	2.000	1.000	0.710	0.500	0.355	0.250	0.180	0.125	0.090	0.063	0.044	0.032	0.022	0.016	0.011	0.008	0.006	0.004	0.002	0.001	<0.001
Grade	>8000	fine gravel	v fine gravel	v coarse sand	coarse sand		medium sand		fine sand		v. fine sand		med & coarse silt			clay & fine silt							
Station	**8.000**	**4.000**	**2.000**	**1.000**	**0.710**	**0.500**	**0.355**	**0.250**	**0.180**	**0.125**	**0.090**	**0.063**	**0.044**	**0.032**	**0.022**	**0.016**	**0.011**	**0.008**	**0.006**	**0.004**	**0.002**	**0.001**	**<0.001**
C1	0.00	0.00	0.00	0.00	0.00	0.54	2.37	4.75	8.12	14.79	17.24	17.84	12.15	5.63	2.75	1.97	2.25	2.26	1.99	1.53	1.87	0.99	0.96
C2	0.00	0.00	0.00	0.00	0.00	0.22	2.27	5.18	8.70	15.05	16.69	16.71	11.23	5.29	2.77	2.13	2.46	2.52	2.30	1.83	2.29	1.21	1.14
C3	0.00	0.00	0.00	0.00	0.00	0.19	2.41	5.43	8.92	15.31	17.10	17.35	11.75	5.41	2.57	1.82	2.14	2.23	2.00	1.55	1.90	0.99	0.93
C4	0.00	0.00	0.00	0.00	0.00	0.69	2.87	6.07	10.12	17.06	18.42	17.91	11.39	4.71	1.85	1.22	1.50	1.50	1.25	0.92	1.15	0.68	0.70
F1	0.00	0.00	0.26	1.09	1.28	1.65	2.54	5.30	8.89	14.27	14.90	14.88	10.58	5.53	3.08	2.04	2.07	2.11	2.03	1.75	2.52	1.61	1.61
F2	0.00	0.00	0.00	0.00	0.00	0.44	2.21	4.75	8.75	16.81	19.96	20.32	12.85	4.81	1.34	0.77	1.24	1.34	1.14	0.86	1.13	0.66	0.62
F3	0.00	0.00	0.00	0.00	0.00	0.87	2.03	3.85	7.33	15.01	18.69	19.85	13.38	5.74	2.30	1.53	1.93	1.95	1.60	1.13	1.31	0.74	0.78
F4	0.00	0.00	0.00	0.00	0.00	0.42	1.61	3.80	7.98	16.54	20.50	21.66	14.34	5.66	1.53	0.58	0.97	1.08	0.85	0.57	0.75	0.55	0.62
F5	0.00	0.00	0.00	0.00	0.00	0.71	2.84	5.73	9.34	15.93	17.84	18.28	12.55	5.74	2.39	1.28	1.42	1.44	1.21	0.86	1.03	0.66	0.77
F6	0.00	0.00	0.00	0.00	0.00	0.67	3.60	7.21	10.85	16.96	17.70	16.99	10.73	4.39	1.68	1.10	1.41	1.49	1.32	1.04	1.34	0.76	0.77
F7	0.00	0.00	0.00	0.00	0.04	1.04	3.27	6.10	9.47	15.78	17.34	17.29	11.35	4.91	2.08	1.43	1.80	1.89	1.67	1.28	1.57	0.86	0.85
F8	0.00	0.00	0.00	0.00	0.00	0.95	4.37	8.17	11.16	15.74	15.37	14.55	9.64	4.57	2.37	1.74	1.97	2.03	1.86	1.49	1.93	1.08	1.01
F9	0.00	0.00	0.00	0.00	0.00	0.63	2.94	6.15	10.10	17.01	18.52	18.12	11.48	4.58	1.61	1.04	1.43	1.52	1.32	0.99	1.23	0.67	0.65
Z1	0.00	0.00	0.00	0.00	0.00	0.64	3.29	6.43	9.76	15.61	16.68	16.45	10.87	4.91	2.37	1.81	2.16	2.19	1.92	1.46	1.75	0.89	0.83
Z2	0.00	0.00	0.00	0.00	0.00	0.56	3.28	6.75	10.27	16.16	16.98	16.67	11.09	5.05	2.33	1.55	1.78	1.81	1.59	1.19	1.42	0.77	0.77
Z3	0.00	0.00	0.00	0.00	0.00	0.95	3.25	6.05	9.59	16.42	18.28	18.21	11.74	4.85	1.87	1.23	1.54	1.54	1.27	0.91	1.10	0.62	0.56
Z4	0.00	0.00	0.00	0.00	0.04	0.77	2.26	4.62	8.31	15.52	18.15	18.72	12.58	5.55	2.34	1.48	1.78	1.85	1.63	1.24	1.53	0.83	0.79
Z5	0.00	0.00	0.00	0.00	0.00	0.53	2.74	6.00	10.13	17.31	18.93	18.52	11.71	4.66	1.63	1.04	1.40	1.43	1.16	0.81	0.96	0.54	0.50
Z6	0.00	0.00	0.00	0.00	0.00	0.50	2.69	6.06	10.28	17.28	18.63	18.19	11.70	4.91	1.93	1.21	1.45	1.40	1.11	0.76	0.89	0.52	0.50
Z7	0.00	0.00	0.00	0.00	0.00	0.29	2.14	4.81	8.40	15.26	17.71	18.30	12.36	5.50	2.39	1.64	2.04	2.15	1.92	1.46	1.78	0.95	0.91
Z8	0.00	0.00	0.00	0.00	0.00	0.20	1.80	4.51	8.26	15.55	18.27	18.80	12.52	5.47	2.39	1.72	2.10	2.11	1.79	1.31	1.56	0.84	0.81
Z9	0.00	0.00	0.00	0.00	0.00	0.56	2.78	5.92	9.70	16.20	17.66	17.60	11.66	5.14	2.20	1.46	1.78	1.83	1.58	1.16	1.35	0.71	0.72
Z10	0.00	0.00	0.00	0.00	0.00	0.03	2.30	5.21	8.52	14.57	16.25	16.58	11.46	5.57	2.97	2.26	2.61	2.68	2.43	1.90	2.32	1.21	1.13
Z11	0.00	0.00	0.00	0.00	0.07	1.09	2.44	4.34	7.39	14.15	17.32	18.63	13.04	5.98	2.61	1.66	1.99	2.11	1.89	1.45	1.80	1.02	1.05
Z12	0.00	0.00	0.00	0.00	0.00	0.25	2.94	6.38	9.96	16.19	17.44	17.28	11.38	4.98	2.13	1.45	1.79	1.87	1.65	1.25	1.50	0.79	0.77
REF 1	0.00	0.00	0.00	0.00	0.00	0.97	4.75	9.14	12.51	17.42	16.52	14.91	9.12	3.78	1.63	1.19	1.47	1.53	1.39	1.09	1.34	0.66	0.58
REF 2	0.00	0.00	0.00	0.00	0.05	1.89	6.54	11.67	14.06	16.07	12.68	10.68	7.37	4.34	2.98	2.17	2.07	1.93	1.67	1.24	1.38	0.65	0.60
REF 3	0.00	0.00	0.00	0.00	0.00	1.00	3.52	7.09	11.14	17.86	18.52	17.31	10.50	4.08	1.49	1.00	1.27	1.26	1.07	0.81	1.04	0.57	0.51
REF 4	0.00	0.00	0.00	0.00	0.00	0.61	3.31	6.88	10.65	16.60	16.99	16.19	10.58	4.90	2.47	1.74	1.91	1.86	1.57	1.14	1.28	0.66	0.68

APPENDIX 3: SEDIMENT POLYCYCLIC AROMATIC HYDROCARBON DATA

Corrib Field Station No.	REF1	REF2	REF3	REF4	C1	C2	C3	C4	F1a	F1b	F2	F3	F4	F5	F6	F7	F8	F9	Z1	Z2	Z3	Z4a	Z4b	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12
Naphthalene	0.06	0.14	0.07	0.15	0.45	1.2	0.37	0.44	0.15	N/A	0.17	0.31	0.38	0.45	0.66	0.31	0.35	0.24	0.23	nd	0.13	0.70	0.37	0.12	0.39	0.15	0.21	0.19	0.55	0.26	0.47
C1-Naphthalenes	0.3	0.25	0.17	0.35	0.46	1.1	0.54	0.3	0.22	N/A	0.2	0.29	0.42	0.42	0.39	0.61	0.43	0.27	0.29	0.13	0.2	1.1	0.82	0.12	0.42	0.2	0.17	0.29	2.1	0.23	0.31
C2-Naphthalenes	0.46	0.35	0.26	0.32	0.97	1.4	0.72	0.48	0.62	N/A	0.39	0.5	0.54	0.66	0.55	1.2	0.75	0.96	0.37	0.27	0.37	2.1	1.1	0.8	0.59	0.31	0.31	0.82	5.3	0.93	0.83
C3-Naphthalenes	nd	nd	nd	nd	nd	0.22	0.06	nd	nd	N/A	nd	nd	nd	0.23	nd	nd	nd	nd	nd	nd	nd	0.60	0.16	0.1	0.17	nd	nd	0.24	2.3	nd	nd
C4-Naphthalenes	nd	nd	nd	nd	nd	nd	nd	nd	nd	N/A	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.24	nd	nd	nd	nd	nd	nd	0.93	nd	nd
Total Naphthalenes	0.82	0.74	0.5	0.82	1.9	3.9	1.7	1.2	0.99	N/A	0.76	1.1	1.3	1.8	1.6	2.1	1.5	1.5	0.89	0.4	0.7	4.7	2.4	1.1	1.6	0.66	0.69	1.5	11	1.4	1.6
Phenanthrene	0.03	0.05	0.02	0.01	0.07	0.33	0.18	0.06	0.15	N/A	0.02	0.02	0.05	0.12	0.02	0.08	0.07	0.1	0.02	nd	0.39	0.99	0.22	0.05	0.04	0.03	0.14	0.14	0.83	0.09	nd
C1-Phenanthrenes	nd	nd	nd	nd	nd	0.19	0.18	nd	0.19	N/A	nd	nd	nd	0.08	nd	nd	nd	nd	nd	nd	0.08	0.43	0.12	nd	nd	nd	nd	0.22	1.4	0.06	nd
C2- Phenanthrenes	nd	nd	nd	nd	nd	nd	0.32	nd	0.46	N/A	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.08	0.42	0.14	nd	nd	nd	nd	0.4	1.1	0.08	nd
C3- Phenanthrenes	nd	nd	nd	nd	nd	nd	0.32	nd	0.54	N/A	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.25	0.12	nd	nd	nd	nd	0.35	0.63	nd	nd
Total Phenanthrenes	0.03	0.05	0.02	0.01	0.07	0.52	1	0.06	1.3	N/A	0.02	0.02	0.05	0.2	0.02	0.08	0.07	0.1	0.02	nd	0.58	2.2	0.61	0.05	0.04	0.03	0.32	1.1	3.9	0.23	nd
Dibenzothiophene	nd	nd	nd	nd	nd	nd	nd	nd	nd	N/A	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.02	nd	nd	nd	nd	nd	nd	0.03	nd	nd
C1-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd	nd	nd	N/A	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.02	nd	nd	nd	nd	nd	nd	0.1	nd	nd
C2-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd	nd	nd	N/A	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
C3-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd	nd	nd	N/A	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Total DBT	nd	nd	nd	nd	nd	nd	nd	nd	nd	N/A	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.04	nd	nd	nd	nd	nd	nd	0.13	nd	nd
Total NPD	0.85	0.79	0.52	0.83	2	4.4	2.7	1.3	2.3	N/A	0.78	1.1	1.4	2	1.6	2.2	1.6	1.6	0.91	0.4	1.3	6.9	3.1	1.2	1.6	0.69	1	2.6	15	1.6	1.6
Acenaphthylene	nd	0.06	nd	nd	nd	nd	nd	nd	0.01	N/A	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.01	0.04	nd	nd	nd	nd	nd	nd	nd	nd	nd
Acenaphthene	nd	nd	nd	nd	nd	0.02	nd	nd	nd	N/A	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.03	0.11	nd	nd	nd	nd	nd	nd	nd	nd	nd
Fluorene	nd	nd	nd	nd	nd	nd	0.02	nd	nd	N/A	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.02	nd	nd	nd	nd	nd	nd	0.1	nd	nd
Anthracene	nd	nd	nd	nd	nd	nd	nd	nd	nd	N/A	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.03	0.05	nd	nd	nd	nd	0.18	nd	nd	nd	nd
Fluoranthene	0.06	0.49	0.05	0.05	0.08	0.24	0.21	0.04	0.15	N/A	0.07	0.06	0.11	0.04	0.03	0.09	0.07	0.12	0.26	0.05	0.7	1.9	0.17	0.1	0.03	0.05	0.88	0.2	0.47	0.15	0.7
Pyrene	0.07	0.92	0.05	0.03	0.15	0.55	0.38	0.13	0.59	N/A	0.11	0.09	0.12	0.06	0.04	0.13	0.07	0.14	0.23	0.07	0.69	1.4	0.22	0.12	0.05	0.04	0.73	0.35	0.83	0.15	0.55
C_1-Fluoranthenes/Pyrenes	nd	0.12	nd	nd	nd	0.09	0.14	nd	0.11	N/A	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.23	0.06	nd	nd	nd	nd	0.09	0.25	nd	nd
C_2-Fluoranthenes/Pyrenes	nd	nd	nd	nd	nd	nd	0.13	nd	nd	N/A	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.13	0.04	nd	nd	nd	nd	0.08	0.21	nd	nd
C_3-Fluoranthenes/Pyrenes	nd	nd	nd	nd	nd	nd	0.1	nd	nd	N/A	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.11	nd	nd	nd	nd	nd	nd	nd	nd	nd
Benzo(a)anthracene	0.02	0.53	0.01	0.01	0.06	0.24	0.24	0.03	0.1	N/A	0.03	0.01	0.04	0.03	nd	0.04	0.02	0.05	0.06	0.02	0.3	0.34	0.14	0.0	0.0	0.0	0.2	0.19	0.48	0.1	0.13

Corrib Field Station No.	REF1	REF2	REF3	REF4	C1	C2	C3	C4	F1a	F1b	F2	F3	F4	F5	F6	F7	F8	F9	Z1	Z2	Z3	Z4a	Z4b	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12
																								6	2	2	4			
Chrysene	0.01	0.33	nd	0.01	nd	nd	0.11	nd	0.03	**N/A**	0.02	0.01	0.02	0.02	nd	0.02	0.01	0.02	0.05	0.02	0.29	1.1	nd	0.04	nd	nd	0.17	0.1	nd	nd	0.17
C_1-Benanthracenes/ Chrysenes	nd	0.09	nd	nd	nd	nd	0.11	nd	0.08	**N/A**	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.15	0.03	nd	nd	nd	nd	0.13	0.1	nd	nd
C_2-Benanthracenes/ Chrysenes	nd	nd	nd	nd	nd	nd	nd	nd	0.22	**N/A**	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.57	0.49	nd	nd	nd	nd	0.11	nd	nd	nd
Benzo(b)fluoranthene	0.3	1.6	0.27	0.28	0.35	0.66	0.69	0.25	0.48	**N/A**	0.55	0.39	0.46	0.24	0.24	0.57	0.25	0.61	0.37	0.4	1.2	1.8	0.68	0.44	0.15	0.37	0.8	0.69	0.85	0.56	0.67
Benzo(k)fluoranthene	0.03	0.35	0.03	0.05	0.05	0.11	0.1	0.05	0.06	**N/A**	0.08	0.05	0.08	0.02	nd	0.09	0.04	0.09	0.05	0.05	0.25	0.52	0.10	0.07	nd	0.04	0.11	0.1	0.12	0.08	0.09
Benzo(a)pyrene	0.01	0.88	nd	nd	0.04	0.11	0.11	nd	nd	**N/A**	0.03	nd	0.03	nd	nd	nd	nd	0.03	0.05	0.03	0.41	0.43	0.05	0.04	nd	nd	0.2	0.1	0.14	0.04	0.16
C_1-Benzofluoranthenes/ Benzpyrenes	nd	0.16	nd	nd	nd	nd	0.22	nd	0.1	**N/A**	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.23	0.11	nd	nd	nd	nd	0.13	nd	nd	nd
C_2-Benzofluoranthenes/ Benzpyrenes	nd	nd	nd	nd	nd	nd	nd	nd	nd	**N/A**	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.08	0.02	nd	nd	nd	nd	nd	nd	nd	nd
Indeno(1,2,3-cd)pyrene	0.26	0.96	0.22	0.21	0.28	0.5	0.43	0.15	0.33	**N/A**	0.5	0.31	0.35	0.14	0.19	0.47	0.17	0.54	0.22	0.29	0.79	1.0	0.52	0.29	0.12	0.3	0.51	0.51	0.54	0.44	0.4
Dibenzo(a,h)anthracene	nd	0.05	nd	0.01	nd	nd	0.02	nd	0.01	**N/A**	0.01	0.01	0.01	nd	nd	0.02	nd	0.01	nd	nd	0.03	0.08	0.02	nd	nd	nd	nd	nd	nd	0.02	nd
Benzo(ghi)perylene	0.18	0.81	0.17	0.17	0.29	0.58	0.47	0.12	0.29	**N/A**	0.33	0.24	0.26	0.13	0.12	0.4	0.15	0.36	0.18	0.21	0.66	0.84	0.44	0.31	0.11	0.29	0.39	0.44	0.62	0.4	0.26
Total EPA 16	1	7.2	0.89	0.98	1.8	4.5	3.3	1.3	2.4	**N/A**	1.9	1.5	1.9	1.3	1.3	2.2	1.2	2.3	1.7	1.1	5.9	11	2.9	1.6	0.91	1.3	4.6	3	5.5	2.3	3.6

APPENDIX 4: RAW BENTHIC INVERTEBRATE DATA


MCS
Oligochaeta
Hirudinea
Mollusca
Gastropoda
Bivalvia
Crustacea
Malacostraca
Amphipoda
Isopoda
Decapoda
Insecta
Ephemeroptera
Odonata
Plecoptera
Hemiptera
Coleoptera
Trichoptera
Diptera
Chironomidae
Simuliidae
Tipulidae
Empididae
Ceratopogonidae
Tabanidae
Stratiomyidae
Dolichopodidae
Athericidae
Rhagionidae
Limoniidae
Psychodidae
Culicidae
Muscidae
Anthomyiidae
Sciomyzidae
Ephydridae
Chaoboridae
Thaumaleidae
Dixidae
Scatopsidae
Hydrozoa
Turbellaria
Nematoda
Nematomorpha
Annelida
Oligochaeta
Hirudinea
Mollusca
Gastropoda
Bivalvia
Crustacea
Malacostraca
Amphipoda
Isopoda
Decapoda
Insecta
Ephemeroptera
Odonata
Plecoptera
Hemiptera
Coleoptera
Trichoptera
Diptera
Chironomidae
Simuliidae
Tipulidae
Empididae
Ceratopogonidae
Tabanidae
Stratiomyidae
Dolichopodidae
Athericidae
Rhagionidae
Limoniidae
Psychodidae
Culicidae
Muscidae
Anthomyiidae
Sciomyzidae
Ephydridae
Chaoboridae
Thaumaleidae
Dixidae
Scatopsidae
Hydrozoa
Turbellaria
Nematoda
Nematomorpha
Annelida
Oligochaeta
Hirudinea
Mollusca
Gastropoda
Bivalvia
Crustacea
Malacostraca
Amphipoda
Isopoda
Decapoda
Insecta
Ephemeroptera
Odonata
Plecoptera
Hemiptera
Coleoptera
Trichoptera
Diptera
Chironomidae
Simuliidae
Tipulidae
Empididae
Ceratopogonidae
Tabanidae
Stratiomyidae
Dolichopodidae
Athericidae
Rhagionidae
Limoniidae
Psychodidae
Culicidae
Muscidae
Anthomyiidae
Sciomyzidae
Ephydridae
Chaoboridae
Thaumaleidae
Dixidae
Scatopsidae
No. Species
No. Individuals
REF4-C
REF4-B
REF4-A
REF3-C
REF3-B
REF3-A
REF2-C
REF2-B
REF2-A
REF1-C
REF1-B
REF1-A
Z12-C
Z12-B
Z12-A
Z11-C
Z11-B
Z11-A
Z10-C
Z10-B
Z10-A
Z9-C
Z9-B
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Z8-B
Z8-A
Z7-C
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Z6-B
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Z5-C
Z5-B
Z5-A
Z4-C
Z4-B
Z4-A
Z3-C
Z3-B
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Z2-C
Z2-B
Z2-A
Z1-C
Z1-B
Z1-A
F9-C
F9-B
F9-A
F8-C
F8-B
F8-A
F7-C
F7-B
F7-A
F6-C
F6-B
F6-A
F5-C
F5-B
F5-A
F4-C
F4-B
F4-A
F3-C
F3-B
F3-A
F2-C
F2-B
F2-A
F1-C
F1-B
F1-A
C4-C
C4-B
C4-A
C3-C
C3-B
C3-A
C2-C
C2-B
C2-A
C1-C
C1-B
C1-A
jars
burrowing
indet
indet
jars
jars/cubis-loss
jars
indet
jars/damaged
jars
jars
jars
indet
head only
jars
head regenerating
jars
head regenerating
jars
jars
dismigrallyus
damaged
jars
spp. 'A'
eggs
jars
head only
jars
jars/damaged
jars/damaged
damaged
jars
damaged
females
damaged
pranica
tail only
damaged
jars/damaged
damaged
indet
jars
jars
larvae
damaged
damaged
jars
jars
indet
jars
dismigrallyus
jars
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smaphallyus
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APPENDIX 5: BENTHIC INVERTEBRATE ANALYTICAL REPORT

1. Methodology

1.1. Univariate analysis

A number of common ecological indices were calculated for the per replicate and pooled replicate (per site) data. These seek, by means of a single number, to summarise information about some aspect of community structure. The indices used in the present study were calculated using PRIMER v.6, and are as follows:

Shannon-Wiener Diversity Index (H') - a widely used measure of diversity, providing an integrated index of species richness and relative abundance (Shannon & Weaver, 1963).

$$H' = -\sum_{i=1}^{s}\left[\frac{n_i}{n}\right]\ln\left[\frac{n_i}{n}\right] = -\sum_{i=1}^{s} p_i \ln\left(p_i\right)$$

Where n = the number of individuals in a sample of a population
n_i = the number of individuals of the *i*th species in a sample of a population
p_i = the proportion of the total count arising from the *i*th species

Pielou's Evenness Index (J') - incorporating the Shannon-Weiner Index and providing a measure of the evenness of the distribution of individuals amongst the different species in each sample (Pielou, 1966).

$$J' = \frac{H'(observed)}{H'_{max}}$$

where H'_{max} = the maximum possible diversity which could be achieved if all species were equally abundant (=logS)

Simpson's Dominance Index (C) – a measure of dominance, essentially the reverse of evenness (Simpson, 1949).

$$C = \sum_{i=1}^{s}\left(\frac{n_i}{N}\right)^2$$

Where: n_i = number of individuals in the *i*th species
N = total number of individuals
S = total number of species

1.2. Multivariate Analysis

Multivariate analyses of benthic data either involve classification or ordination. A commonly used classification method is cluster analysis, a procedure that attempts to

determine the inherent groupings in species and station data. Ordination methods include Multi-dimensional Scaling (MDS), which attempts to reconstruct the relative positions of stations based on a similarity matrix generated from species presence and abundance data.

Cluster Analysis: The technique used in the present study was group average clustering (Lance & Williams 1967) - a hierarchical, agglomerative procedure based on a similarity matrix generated from square root transformed species/station data using the Bray-Curtis similarity coefficient. The results of the analysis are plotted as dendrograms. Analysis was undertaken using the CLUSTER program from the PRIMER statistical package.

Multi-Dimensional Scaling: The technique used in the present study was ordination by non-metric Multi-dimensional Scaling (Kruskal & Wish, 1978). This is based on the similarity matrix generated during cluster analysis (i.e. using the Bray-Curtis coefficient). The similarities between each pair of entities are used to produce a two dimensional map which ideally shows the inter-relationships present. Physical data can be superimposed on the resulting plot in the form of 'bubble' plots.

SIMPROF: This is a test for evidence of structure in an *a priori* unstructured set of samples. A mean profile is calculated from the resemblance matrix and then the π statistic is calculated as the deviation of the actual data profile from the mean profile. This is compared with randomly generated deviations to test for significance.

SIMPER: This technique identifies the species most responsible for similarities within each site or group and also those that contribute most to dissimilarities between groups. The output is given as percent of similarity or dissimilarity and ranks those species that contribute most to this value.

BVStep: This technique selects environmental variables which 'best explain' community pattern by maximising correlation between their respective resemblance matrices. In the BVStep algorithm a stepwise search over the trial variables is used, this is instead of a search through all possible combinations as in the BIO-ENV procedure. BVStep operates sequentially, picking the best single variable then adding a second variable which gives the best combination with the first. It now picks a third and will also start backward elimination where the first variable may be dropped so the combination of the second and third can be considered and so on until no further improvement is possible.

Environmental data (chemical and physical sediment properties) were normalised prior to BVStep analysis.

2. Results

2.1 Transformations

Data transformation acts to weight the contributions of common and rare species for non-parametric, multivariate tests. The appropriate transformation is decided upon by reference to the type of data and the purpose of the study.

In the present study, encrusting species were rare and did not make up a significant proportion of the community composition at the sites where they were found. Therefore the qualitative species were removed from the analysis. Additionally, communities were generally composed of 'rare' species e.g. those that only occurred once or twice at each site. Therefore the data was transformed using square root, a moderate transformation that reduced the weighting of highly abundant species but did not place too much emphasis on the rarer ones.

2.2 Fauna

Species numbers and abundances for macrofauna are shown on a per replicate (Table 1) and per site (Table 2) basis. The percentage of each phylum that contributed to community composition at each site is also shown in Table 2. Species that are encrusting and/or colonial are included in the number of species per replicate and site but were excluded from abundance counts.

Species numbers and abundances were relatively constant at all sites. Per site, the number of species per $0.1m^2$ was high with an average of 82 species per site and a range of 55 at site F6 to 104 at sites C2 and C3. Abundance at each site (individuals per $0.1m^2$) was moderate throughout and ranged from 150 at site F6 to 390 at site Z7.

Ranked taxa illustrating the 10 most abundant species at each site are shown in Table 3. Community composition showed little change throughout the sampling area. Annelids comprised the highest percentage of animals at all sites with the maximum recorded at reference site 4 (85%) and an overall average of 77%. Molluscs proved to be the next most important phyla throughout the sampling area, and on average made up 12% of the community. Crustacea and echinoderms made up on average 4% of the individuals found.

The numerical dominance of annelids was due to the presence of the tube-dwelling polychaete *Galathowenia oculata,* which was found to be the most abundant animal throughout the sampling area. At all but seven sites this species made up 50% of the individuals found. At site C2 *G. oculata* had the lowest relative abundance and only made up a third of the individuals found; other key species were the spionid polychaetes *Prionospio fallax* and *Levinsenia gracilis*, the capitellid polychaete *Peresiella clymenoides* and the bivalves *Adontorhina similis*, *Kelliella abyssicola* and *Abra*. These animals were also found to be important at all other sites but to lesser degrees.

The molluscs found were mainly small and juvenile bivalves typical of those inhabiting the continental slope, for example species from the family Thyasiridae, and the genera *Cuspidaria*, *Kelliella* and *Yoldiella*. Amphipod and isopod crustacea were

recorded throughout the sampling area but only the isopod *Natatolana borealis* was found in abundance. Many of the species found were those associated with deeper water environments such as the mysids *Pseudomma affine* and *Hypererythrops* and amphipods from the family Pardaliscidae which are the most abundant gammaridean family at abyssal depths. A deeper water sea spider from the genus *Nymphon* was present at more than one station. Juvenile starfish (Asteroidea) and sea urchins (Echinoidea) were also present at the majority of sites.

At all sites, a large proportion of the community was made up of 'rare' species- those with a very low abundance. For example at site Z4, 40 out of the 60 species found had an average abundance of 1 or less per $0.1m^2$. In sample Z8 replicate A, a previously undescribed species of cheliostomatid bryozoan was found.

2.3. Particle Size Analysis

Results for particle size analysis are shown in (RSK Table ??). Sites showed little variation in sediment type and can be characterised as having muddy sand. Sites on average comprised 70% of sand (63-1000µm) and 30% fines (<63µm) with a standard deviation of 3.6%. Of this, the highest proportions of sediments were found to be very fine to fine sands (63-250µm).

With the exception of site F1, no gravel content was found at any of the sites. However, at site F1 only insignificant proportions of gravel was found (0.3% of 2000-8000µm).

2.4. Organic Carbon Content

Organic carbon content was low at all sites with concentrations not exceeding 3% (Table?? RSK).

2.5. Univariate analysis

Values of the Shannon-Weiner diversity index, Pielou's evenness index, and Simpson's dominance index are shown on a per replicate (Table 1) and per site (Table 2) basis. These values do not include encrusting species as they are calculated using abundance and species numbers.

Diversity was moderate to high at all sites, ranging from 1.86 at site Z7 to 3.44 at site C2. Dominance and evenness were found to be moderate, with observed averages of 0.30 and 0.56 respectively. This reflected the high numerical abundances of the polychaete *G. oculata*.

2.7. Multivariate analysis

The results of per replicate group average clustering analysis using Bray Curtis similarity are shown per replicate (Figure 1) and per site (Figure 2).

There was a very high degree of biological homogeneity throughout the sampling area. Similarities of more than 40% on a per replicate basis and 50% on a per site basis were observed.

Within site variability was found to be low at all of the sites, replicates of each site having 40% or more similarity with each other. However, there was such a high degree of similarity throughout the whole sampling area replicates tended not to cluster together and this only occurred at sites C3 and F1.

The results of multi-dimensional scaling using the similarity matrices derived from cluster analysis are plotted two dimensionally for each replicate in Figure 3 and for each site in Figure 4. Stress values were high (0.26 and 0.19 respectively). This indicated that a 2-dimensional plot of the sites did not give an accurate representation of the relationships between sites and that multiple variables were involved in determining community composition. This problem was highlighted when the three dimensional plots of the replicates and sites were examined and found to produce lower stress values in the both cases.

A SIMPROF test was performed to determine if and where significant differences lay within the dataset. The outcome of this test showed that there was a significant difference between sites (sample statistic=1.46, p=<0.01). Figure 5 indicated that sites F6, F1 and Z9 were significantly different from all sites and that four other clusters existed, all significantly different from each other. A SIMPER test was performed to discover which species contributed to these observed differences. It was seen that the importance of 'rare' species was very high as they gave higher contributions to dissimilarity when a 'rare' species was found in one cluster but was absent from the other.

This effect of the 'rare' species can further be illustrated by transforming the data with a more severe transformation and therefore placing more weight on these species. A SIMPROF showed that a higher number of significantly different clusters were produced when using this transformation.

Due to the size of the environmental dataset a BVStep test was performed. This looks at the best correlation between the biological and environmental data and endeavours to show which set of physical variables best explains the variation observed in the biological communities.

The BVStep analysis showed that no one single variable was responsible for the observed variance between sites. However, moderate multi-variant correlations were found, the best being with six variables (r = 0.501, p=0.01). These were chromium, lithium, manganese, total organic esters (TOE), total naphthalenes and total napthalenes, phenanthrenes and dibenzothiophenes (Total NPD). MDS overlays of these environmental variables were plotted for chromium in figures 6, manganese in figure 7, TOE in figure 8, Total napthalenes in figure 9 and Total NPD in figure 10. Patterns were weak but generally showed that site F1 had higher concentrations of chromium and manganese than other sites and sites Z10, Z4 and to some extent Z9 and C2 had higher concentrations of organic compounds than other sites. Lithium showed no visible patterns.

3. Conclusions

In summary, the faunal communities observed in the current survey showed a high degree of homogeneity and were typical of those found in muddy sand sediment sampled from the continental slope. They had moderate to high diversity and were dominated by the tube-dwelling polychaete *Galathowenia oculata*, which at all but seven of the sites made up at least 50% of the animals found there.

Also common to communities in the survey area were spinoid, terebellid and sabellid polychaetes, amphipod and isopod crustacea, opistobranch molluscs, bivalves and juvenile echinoderms.

Multivariate analysis showed that communities throughout the sampling area had 50% similarity or more. Even though this high similarity between communities was shown, a SIMPROF test indicated that significant differences lay in the dataset, particularly between sites F1, F6 and Z9 and with all other sites. A SIMPER test showed that these significant differences may have been largely due to the importance of 'rare' (low abundance) species in the communities.

Additionally, these observed differences were unlikely to be explained by a single variable, as 2-dimensional MDS plots had high stress values and therefore did not give an accurate representation of the relationships between sites. This indicated that multiple variables were involved in determining community composition. The BVStep analysis further confirmed this as it showed that no one variable could explain the observed pattern in the dataset and it produced only moderate correlations with six variables. These were chromium, lithium, manganese, total organic esters (TOE), total naphthalenes and total napthalenes, phenanthrenes and dibenzothiophenes (Total NPD). Patterns were weak but generally showed that site F1 had higher concentrations of chromium and manganese than other sites and sites Z10, Z4 and to some extent Z9 and C2 had higher concentrations of organic compounds than other sites.

4. References

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	S	N	N/m^2	J'	H'	λ
C1-A	64	394	2697	0.66	2.74	0.20
C1-B	49	235		0.65	2.54	0.22
C1-C	48	180		0.74	2.86	0.15
C2-A	64	216	2843	0.85	3.56	0.05
C2-B	77	429		0.72	3.13	0.14
C2-C	57	208		0.79	3.18	0.10
C3-A	50	158	2670	0.69	2.68	0.22
C3-B	60	333		0.54	2.21	0.35
C3-C	55	310		0.65	2.62	0.22
C4-A	46	182	1947	0.69	2.65	0.20
C4-B	43	194		0.58	2.17	0.32
C4-C	41	208		0.64	2.39	0.25
F1-A	51	227	3080	0.69	2.72	0.20
F1-B	65	441		0.57	2.40	0.30
F1-C	45	256		0.68	2.61	0.19
F2-A	59	359	3190	0.54	2.22	0.34
F2-B	54	350		0.54	2.14	0.36
F2-C	54	248		0.57	2.28	0.31
F3-A	60	245	2560	0.68	2.80	0.19
F3-B	42	315		0.46	1.72	0.47
F3-C	40	208		0.48	1.78	0.44
F4-A	51	311	2547	0.52	2.05	0.37
F4-B	46	256		0.60	2.29	0.28
F4-C	37	197		0.57	2.07	0.32
F5-A	48	338	3313	0.58	2.23	0.31
F5-B	55	338		0.57	2.27	0.31
F5-C	54	318		0.63	2.50	0.25
F6-A	27	140	1503	0.46	1.51	0.50
F6-B	34	199		0.49	1.74	0.42
F6-C	28	112		0.70	2.33	0.21
F7-A	42	259	2590	0.52	1.94	0.40
F7-B	42	262		0.53	1.99	0.37
F7-C	35	256		0.47	1.66	0.46
F8-A	57	375	2980	0.51	2.07	0.38
F8-B	41	250		0.57	2.11	0.33
F8-C	40	269		0.47	1.73	0.45
F9-A	34	208	2130	0.52	1.85	0.39
F9-B	43	265		0.52	1.94	0.40
F9-C	48	166		0.74	2.88	0.15
Z1-A	52	260	2393	0.56	2.21	0.33
Z1-B	53	237		0.68	2.71	0.20
Z1-C	56	221		0.70	2.83	0.19
Z2-A	39	125	1930	0.72	2.62	0.19
Z2-B	38	207		0.56	2.02	0.36
Z2-C	52	247		0.58	2.29	0.32
Z3-A	46	293	2293	0.51	1.94	0.40
Z3-B	53	260		0.56	2.22	0.34
Z3-C	47	135		0.84	3.23	0.07

	S	N	N/m^2	J'	H'	λ
Z4-A	39	205	1620	0.62	2.26	0.28
Z4-B	32	148		0.56	1.95	0.37
Z4-C	29	133		0.55	1.86	0.38
Z5-A	60	206	2397	0.76	3.08	0.12
Z5-B	58	319		0.69	2.82	0.19
Z5-C	54	194		0.78	3.10	0.12
Z6-A	55	289	2390	0.53	2.13	0.36
Z6-B	41	227		0.54	2.02	0.36
Z6-C	52	201		0.67	2.64	0.20
Z7-A	51	467	3897	0.40	1.58	0.51
Z7-B	44	359		0.45	1.72	0.45
Z7-C	46	343		0.52	1.99	0.37
Z8-A	44	265	2123	0.58	2.18	0.33
Z8-B	47	191		0.69	2.65	0.20
Z8-C	43	181		0.56	2.12	0.35
Z9-A	46	305	2740	0.55	2.09	0.34
Z9-B	32	173		0.66	2.30	0.23
Z9-C	49	344		0.57	2.24	0.31
Z10-A	36	159	1667	0.63	2.25	0.29
Z10-B	50	181		0.72	2.81	0.17
Z10-C	35	160		0.72	2.56	0.18
Z11-A	49	429	3000	0.46	1.78	0.45
Z11-B	36	268		0.44	1.58	0.49
Z11-C	38	203		0.55	1.99	0.37
Z12-A	46	193	2090	0.65	2.49	0.23
Z12-B	39	186		0.64	2.33	0.26
Z12-C	51	248		0.63	2.50	0.25
REF1-A	42	131	1737	0.69	2.59	0.22
REF1-B	52	179		0.74	2.91	0.16
REF1-C	50	211		0.61	2.39	0.29
REF2-A	33	139	1803	0.62	2.16	0.30
REF2-B	48	279		0.51	1.97	0.41
REF2-C	40	123		0.78	2.86	0.12
REF3-A	46	298	2253	0.58	2.23	0.30
REF3-B	46	145		0.80	3.05	0.09
REF3-C	43	233		0.52	1.94	0.39
REF4-A	36	172	2757	0.65	2.31	0.25
REF4-B	56	359		0.47	1.91	0.42
REF4-C	51	296		0.63	2.49	0.25

S = Number of species (including encrusting species)
N = Number of individuals
J' = Pielou's Evenness
H'= Shannon-Weiner Diversity ($\log_e$)
λ = Simpson's Dominance index

Table 1. Univariate Indices by replicate for sample sites around the gas field.

							% of each phyla				
	S	N	N/m^2	J'	H	λ	Annelida	Crustacea	Mollusca	Echinoderms	Others
C1	82	270	2697	0.64	2.83	0.20	76.89	3.09	13.10	4.08	2.84
C2	104	284	2843	0.74	3.44	0.10	70.81	3.87	17.94	2.58	4.81
C3	104	267	2670	0.57	2.67	0.27	81.90	4.99	7.24	2.87	3.00
C4	76	195	1947	0.60	2.60	0.26	71.75	4.97	15.41	6.16	1.71
F1	95	308	3080	0.59	2.71	0.24	82.14	2.71	9.96	1.62	3.57
F2	92	319	3190	0.52	2.33	0.34	83.80	3.55	8.36	3.03	1.25
F3	84	256	2560	0.51	2.26	0.36	79.56	3.52	9.77	4.95	2.21
F4	82	255	2547	0.52	2.28	0.33	71.99	3.66	18.46	4.58	1.31
F5	94	331	3313	0.54	2.46	0.29	75.75	3.22	15.79	3.12	2.11
F6	55	150	1503	0.50	2.01	0.38	70.95	8.43	14.86	5.10	0.67
F7	69	259	2590	0.47	1.98	0.41	81.85	5.92	4.25	6.69	1.29
F8	83	298	2980	0.48	2.11	0.39	80.76	2.46	9.17	5.48	2.13
F9	74	213	2130	0.54	2.33	0.32	76.84	4.07	12.68	3.60	2.82
Z1	89	239	2393	0.61	2.73	0.24	82.73	2.79	8.64	3.20	2.65
Z2	77	193	1930	0.57	2.46	0.30	82.56	5.01	6.22	5.01	1.21
Z3	89	229	2293	0.57	2.54	0.29	73.58	4.07	14.24	4.07	2.03
Z4	60	162	1620	0.54	2.22	0.33	75.51	2.06	16.26	5.56	0.62
Z5	100	240	2397	0.69	3.17	0.15	73.57	2.50	14.88	6.95	2.09
Z6	90	239	2390	0.54	2.42	0.31	75.31	3.35	16.60	3.77	0.98
Z7	85	390	3897	0.42	1.86	0.45	83.49	1.63	10.86	2.91	1.11
Z8	79	212	2123	0.57	2.48	0.29	74.73	5.34	12.72	5.34	1.88
Z9	72	274	2740	0.55	2.34	0.30	76.64	5.60	13.75	2.55	1.46
Z10	70	167	1667	0.65	2.76	0.21	69.20	2.80	18.40	7.00	2.60
Z11	78	300	3000	0.43	1.89	0.45	78.22	4.78	11.11	5.22	0.67
Z12	84	209	2090	0.59	2.62	0.25	74.16	2.87	15.47	5.58	1.91
REF1	86	174	1737	0.63	2.83	0.22	68.71	8.45	11.71	8.06	3.07
REF2	75	180	1803	0.56	2.43	0.30	81.15	6.65	6.10	4.25	1.85
REF3	78	225	2253	0.58	2.52	0.27	83.14	6.36	6.66	2.81	1.04
REF4	86	276	2757	0.53	2.34	0.32	84.76	3.26	8.95	1.81	1.21

S = Number of species (including encrusting species)
N = Number of individuals (average per 0.1m^2)
J' = Pielou's Evenness
H'= Shannon-Weiner Diversity ($\log_e$)
λ = Simpson's Dominance index

Table 2. Univariate Indices for sample sites around the gas field.

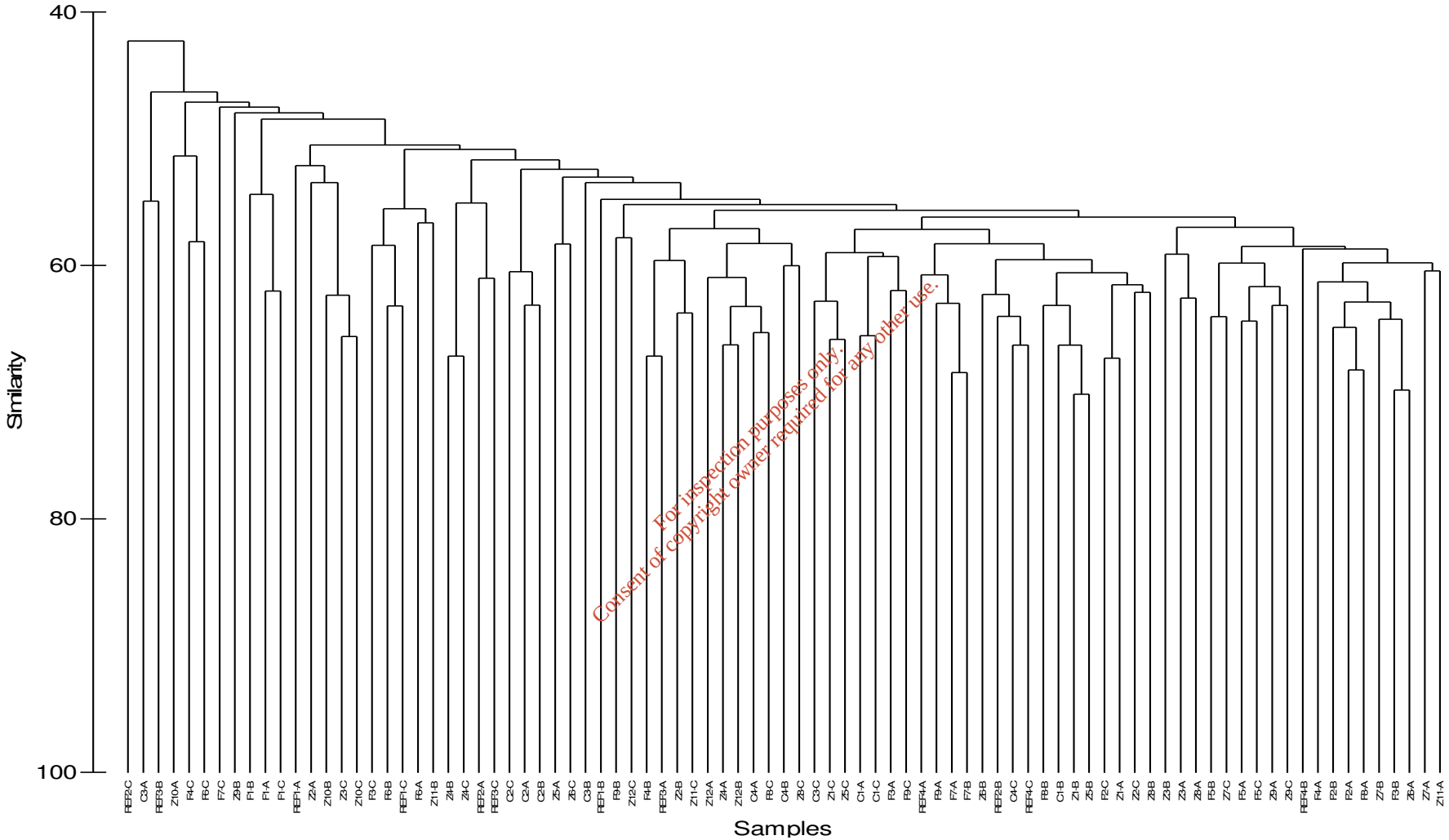

Figure 1. Dendrogram showing clustering of communities using per replicate sample data from sites around the gas field.

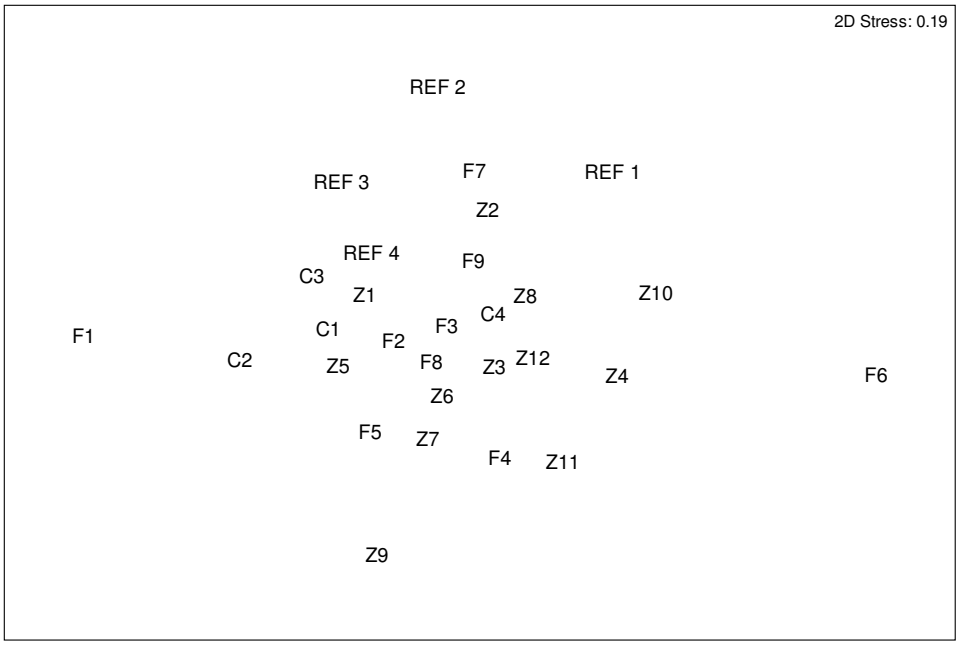

Figure 4. MDS plot of sample sites (per site data) around the gas field.

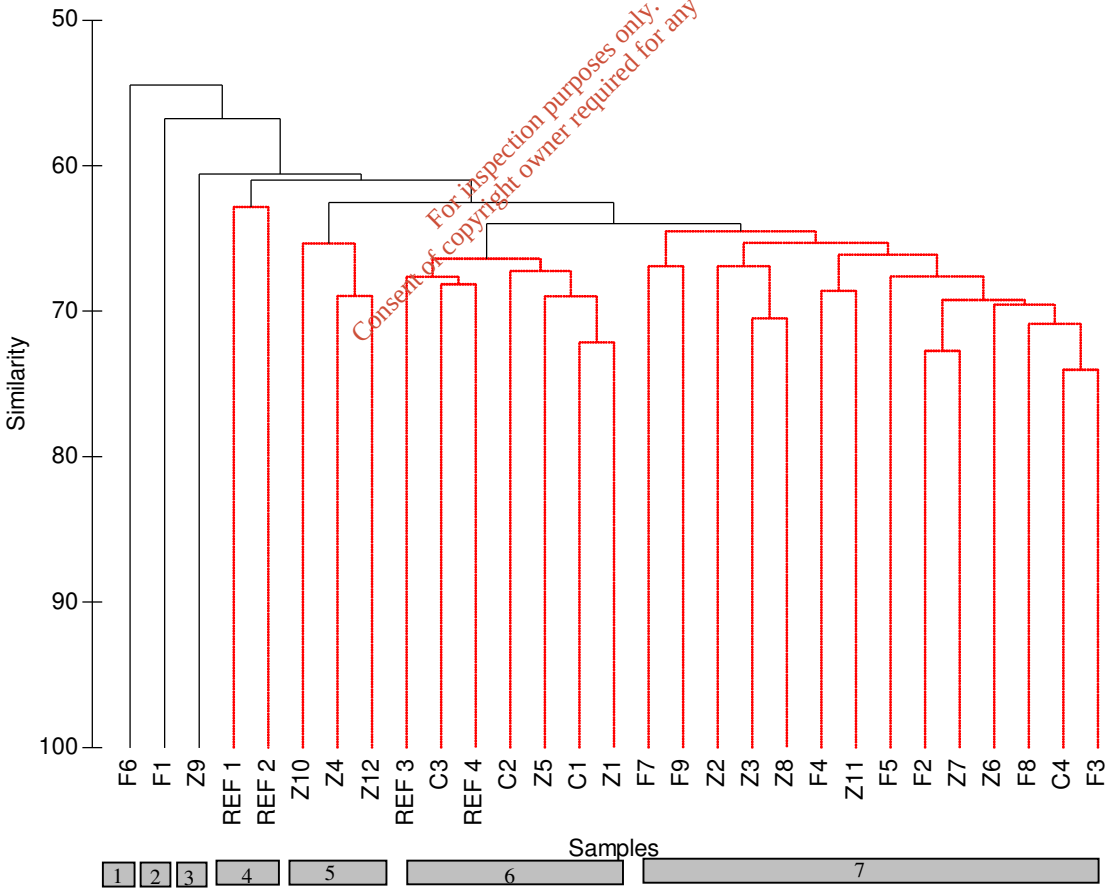

Figure 5. Dendrogram showing clustering of communities using pooled replicate (per site) data taken from sites around the gas field. Black lines indicate where significant differences lie and red dashed lines show sites that are not significantly different.

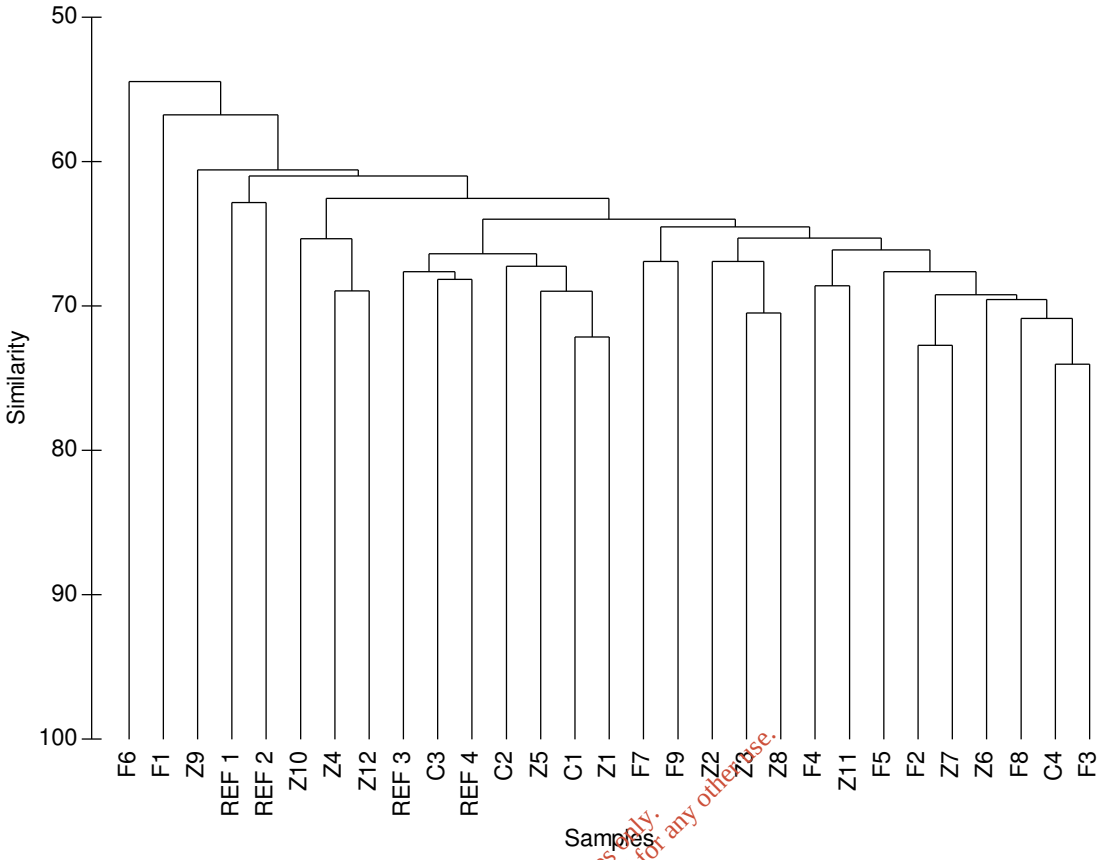

Figure 2. Dendrogram showing clustering of communities using pooled replicate (per site) data taken from sites around the gas field.

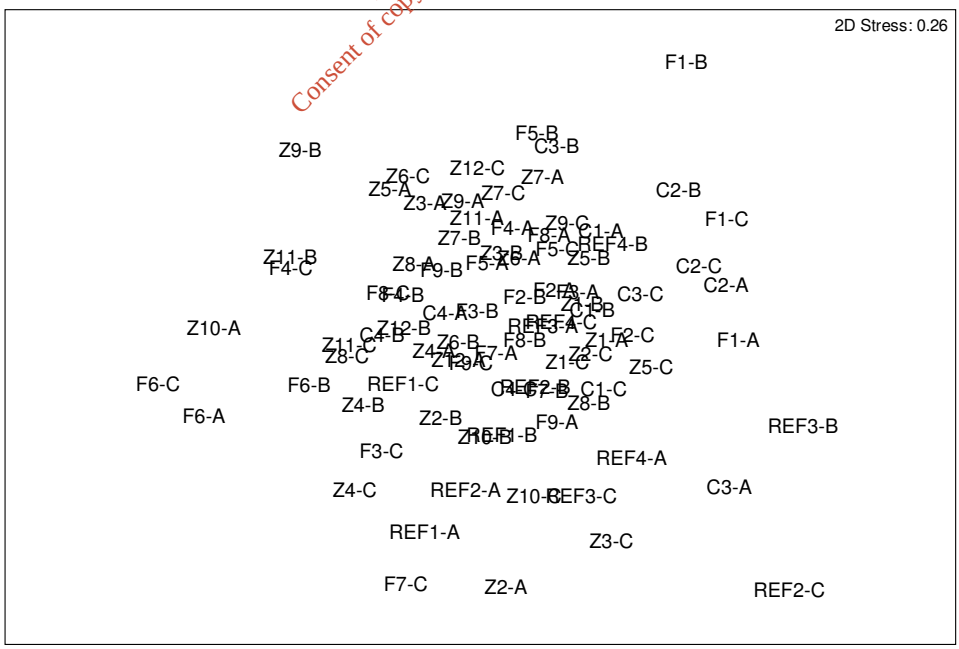

Figure 3. MDS plot of sample sites (per replicate data) around the gas field.

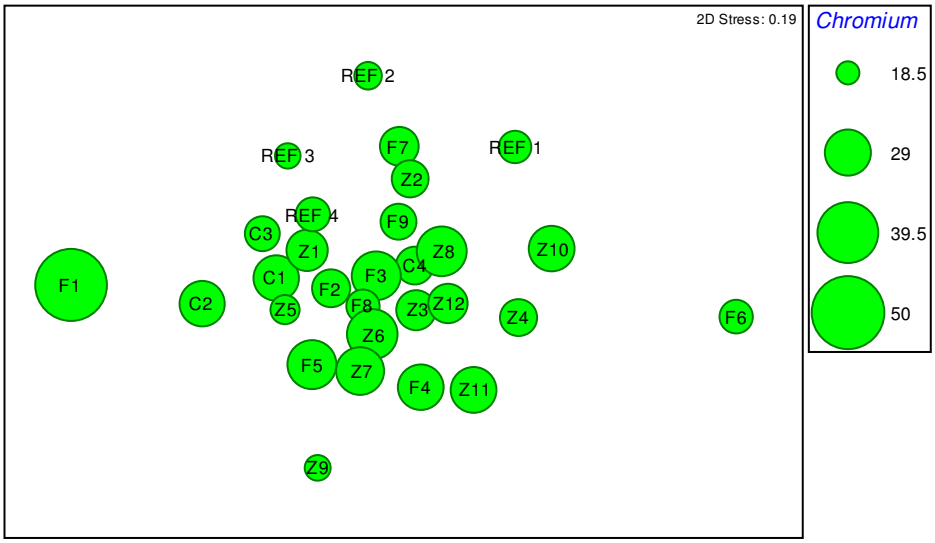

Figure 6. MDS plot of sites around the gas field with superimposed bubbles representing the concentration of chromium ($mgkg^{-1}$) at each site.

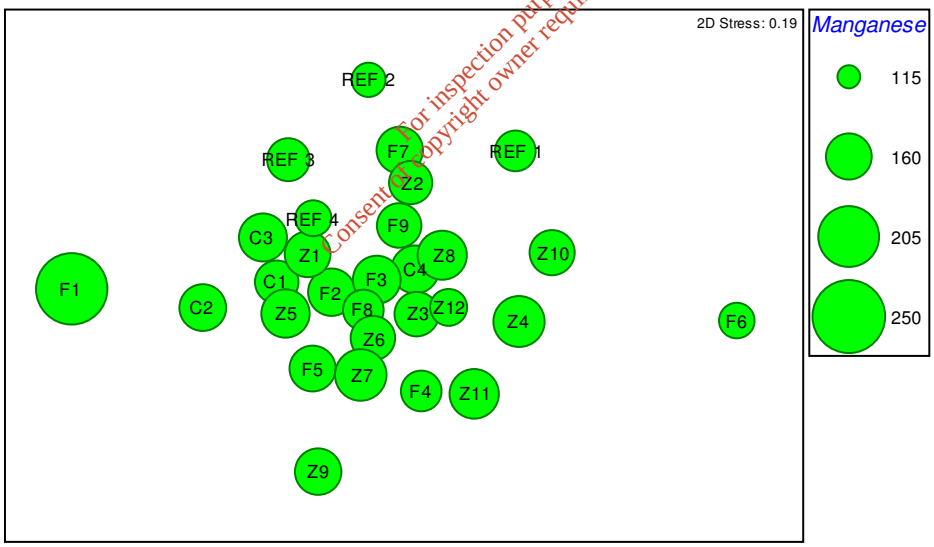

Figure 7. MDS plot of sites around the gas field with superimposed bubbles representing the concentration of manganese ($mgkg^{-1}$) at each site.

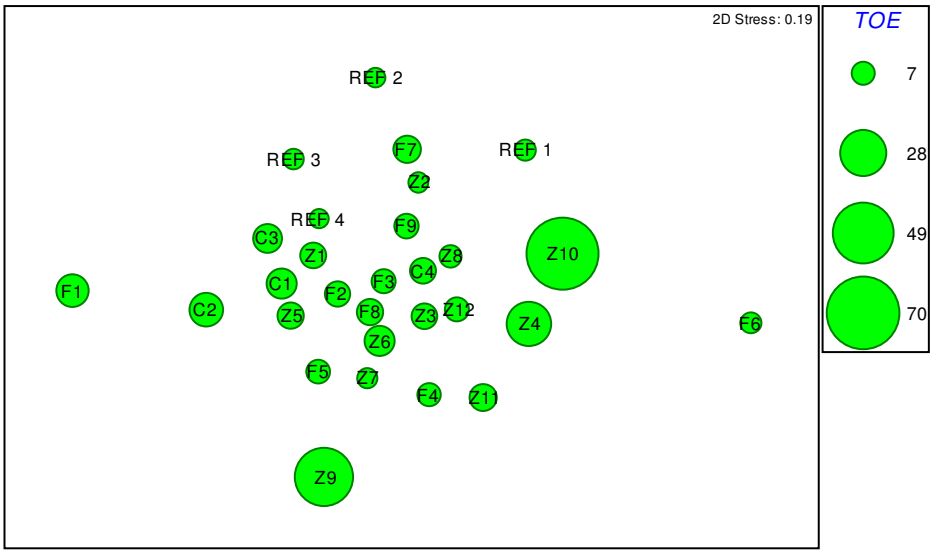

Figure 8. MDS plot of sites around the gas field with superimposed bubbles representing the concentration of total organic esters (ppm) at each site.

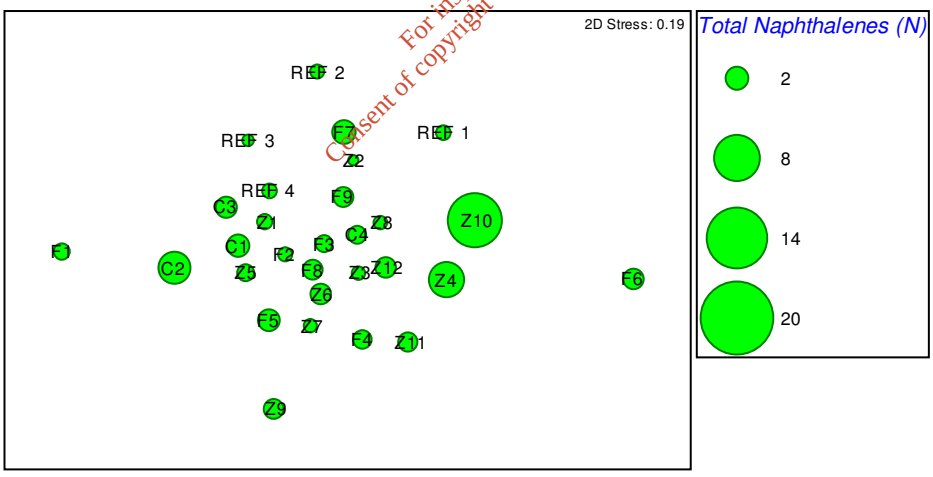

Figure 9. MDS plot of sites around the gas field with superimposed bubbles representing the concentration of total naphthalenes (ppm) at each site.

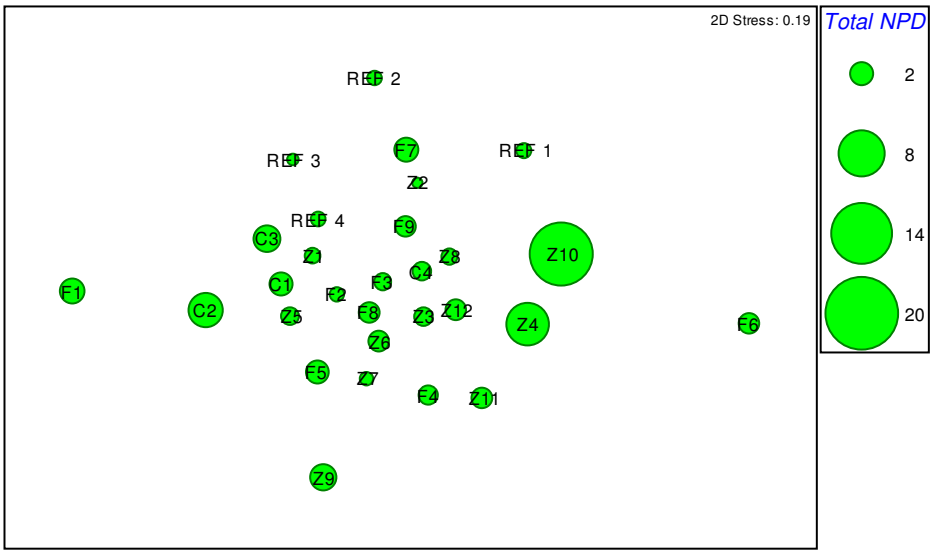

Figure 10. MDS plot of sites around the gas field with superimposed bubbles representing the concentration of total naphthalenes, phenanthrenes and dibenzothiophenes (ppm) at each site.

C1		C2		C3		C4		F1		F2	
Galathowenia oculata	**115**	**Galathowenia oculata**	**84**	**Galathowenia oculata**	**137**	**Galathowenia oculata**	**97**	**Galathowenia oculata**	**148**	**Galathowenia oculata**	**185**
Levinsenia gracilis	**20**	**Prionospio fallax**	**16**					**Levinsenia gracilis**	**14**		
		Peresiella clymenoides	**12**	Prionospio fallax	12	Prionospio fallax	9			Prionospio fallax	16
Prionospio fallax	14	**Levinsenia gracilis**	**10**	Levinsenia gracilis	12	Owenia fusiformis	6	Pelecypoda	10	Levinsenia gracilis	10
Peresiella clymenoides	6	**Adontorhina similis**	**9**	Peresiella clymenoides	6	Levinsenia gracilis	5	Prionospio fallax	9	Abra	7
Abra	6	**Kelliella abyssicola**	**8**	Harpinia antennaria	4	Kelliella abyssicola	5	Minuspio cirrifera	8	Eclysippe vanelli	4
Axinulus croulinensis	6	**Abra**	**8**	Glycera lapidum	4	Abra	5	Euchone cf. incolor	7	Adontorhina similis	4
Kelliella abyssicola	6			Axinulus croulinensis	4	Cuspidaria	4	Chone duneri	6	Kelliella abyssicola	4
Spiophanes kroyeri	5	Glycera lapidum	6	Eclysippe vanelli	3	Ophiuroidea	4	Kelliella abyssicola	6	Minuspio cirrifera	3
Adontorhina similis	5	Nemertea	5	Euchone cf. incolor	3	Axinulus croulinensis	4	Tubulanus polymorphus	6	Aricidea catherinae	3
Aricidea wassi	4	Tubulanus polymorphus	5	Copepoda	3	Peresiella clymenoides	3	Peresiella clymenoides	6	Aricidea laubieri	3
		Nuculoma tenuis	5	Synaptidae	3					Peresiella clymenoides	3
										Euchone cf. incolor	3
										Echinoidea	3
No. of individuals	270	No. of individuals	284	No. of individuals	267	No. of individuals	195	No. of individuals	308	No. of individuals	319
50% of individuals	**135**	**50% of individuals**	**142**	**50% of individuals**	**133**	**50% of individuals**	**97**	**50% of individuals**	**154**	**50% of individuals**	**159**

Table 3. Top 10 ranked taxa list for sites within the Corrib Field. Taxa comprising the top 50% (approx) of the population are in bold. Abundances are per $0.1m^2$

F3		F4		F5		F6		F7		F8	
Galathowenia oculata	**153**	**Galathowenia oculata**	**144**	**Galathowenia oculata**	**176**	**Galathowenia oculata**	**92**	**Galathowenia oculata**	**165**	**Galathowenia oculata**	**184**
Prionospio fallax	10	Kelliella abyssicola	18	Axinulus croulinensis	16	Kelliella abyssicola	8	Prionospio fallax	9	Prionospio fallax	13
Kelliella abyssicola	5	Abra	8	Prionospio fallax	12	Natatolana borealis	6	Levinsenia gracilis	7	Ophiuroidea	7
Owenia fusiformis	5	Prionospio fallax	7	Peresiella clymenoides	9	Abra	4	Copepoda	7	Abra	6
Echinoidea	4	Axinulus croulinensis	7	Adontorhina similis	9	Prionospio fallax	3	Ophiuroidea	7	Axinulus croulinensis	6
Levinsenia gracilis	4	Ophiuroidea	4	Abra	9	Owenia fusiformis	3	Asteroidea	6	Kelliella abyssicola	6
Axinulus croulinensis	4	Owenia fusiformis	4	Kelliella abyssicola	8	Copepoda	3	Abra	4	Levinsenia gracilis	5
Tubulanus polymorphus	3	Eclysippe vanelli	3	Levinsenia gracilis	7	Cuspidaria	3	Euchone cf. incolor	4	Owenia fusiformis	5
Abra	3	Adontorhina similis	3	Owenia fusiformis	5	Echinoidea	3	Peresiella clymenoides	3	Echinoidea	5
Ophiuroidea	3	Cuspidaria	3	Euchone cf. incolor	5	Asteroidea	2	Axinulus croulinensis	3	Euchone cf. incolor	4
No. of individuals	256	No. of individuals	255	No. of individuals	331	No. of individuals	150	No. of individuals	259	No. of individuals	298
50% of individuals	**128**	**50% of individuals**	**127**	**50% of individuals**	**165**	**50% of individuals**	**75**	**50% of individuals**	**129**	**50% of individuals**	**149**

Table 3. Top 10 ranked taxa list for sites within the Corrib Field. Taxa comprising the top 50% (approx) of the population are in bold. Abundances are per $0.1m^2$

F9		Z1		Z2		Z3		Z4		Z5	
Galathowenia oculata	**118**	**Galathowenia oculata**	**116**	**Galathowenia oculata**	**105**	**Galathowenia oculata**	**122**	**Galathowenia oculata**	**92**	**Galathowenia oculata**	**90**
		Prionospio fallax	**12**							**Prionospio fallax**	**11**
Prionospio fallax	12			Prionospio fallax	9	Levinsenia gracilis	7	Axinulus croulinensis	6	Abra	9
Axinulus croulinensis	9	Levinsenia gracilis	10	Levinsenia gracilis	5	Axinulus croulinensis	6	Adontorhina similis	5	Peresiella clymenoides	8
Levinsenia gracilis	5	Glycera lapidum	5	Peresiella clymenoides	4	Prionospio fallax	6	Kelliella abyssicola	5	Levinsenia gracilis	7
Kelliella abyssicola	5	Aricidea wassi	4	Axinulus croulinensis	3	Peresiella clymenoides	5	Echinoidea	5		
Adontorhina similis	4	Axinulus croulinensis	4	Asteroidea	3	Abra	5	Peresiella clymenoides	4	Synaptidae	6
Spiophanes kroyeri	4	Abra	4	Harpinia antennaria	3	Adontorhina similis	4	Abra	4	Adontorhina similis	5
Abra	4	Owenia fusiformis	3	Eclysippe vanelli	2	Kelliella abyssicola	4	Prionospio fallax	3	Kelliella abyssicola	5
Tubulanus polymorphus	2	Nemertea	3	Cuspidaria	2	Eclysippe vanelli	3	Levinsenia gracilis	2	Cuspidaria	4
Asteroidea	2	Eclysippe vanelli	3	Synaptidae	2	Asteroidea	3	Spiophanes kroyeri	2	Axinulus croulinensis	4
		Copepoda	3					Cuspidaria	2		
		Kelliella abyssicola	3								
No. of individuals	213	No. of individuals	239	No. of individuals	193	No. of individuals	229	No. of individuals	162	No. of individuals	240
50% of individuals	**106**	**50% of individuals**	**119**	**50% of individuals**	**96**	**50% of individuals**	**114**	**50% of individuals**	**81**	**50% of individuals**	**120**

Table 3. Top 10 ranked taxa list for sites within the Corrib Field. Taxa comprising the top 50% (approx) of the population are in bold. Abundances are per $0.1m^2$

Z6		Z7		Z8		Z9		Z10		Z11	
Galathowenia oculata	**132**	**Galathowenia oculata**	**260**	**Galathowenia oculata**	**114**	**Galathowenia oculata**	**148**	**Galathowenia oculata**	**74**	**Galathowenia oculata**	**199**
								Peresiella clymenoides	**9**		
Prionospio fallax	11	Prionospio fallax	16	Prionospio fallax	7	Natatolana borealis	11			Abra	10
Abra	10	Abra	12	Abra	7	Adontorhina similis	10	Falcidens crossotus	7	Kelliella abyssicola	7
Adontorhina similis	8	Axinulus croulinensis	9	Levinsenia gracilis	6	Abra	9	Prionospio fallax	5	Owenia fusiformis	5
Axinulus croulinensis	5	Levinsenia gracilis	7	Asteroidea	5	Levinsenia gracilis	7	Axinulus croulinensis	5	Prionospio fallax	5
Levinsenia gracilis	4	Kelliella abyssicola	6	Harpinia antennaria	5	Peresiella clymenoides	7	Abra	5	Adontorhina similis	5
Peresiella clymenoides	4	Adontorhina similis	5	Adontorhina similis	4	Owenia fusiformis	7	Cuspidaria	4	Ophiuroidea	5
Kelliella abyssicola	4	Euchone cf. incolor	4	Axinulus croulinensis	3	Prionospio fallax	6	Echinoidea	3	Natatolana borealis	5
Owenia fusiformis	3	Owenia fusiformis	4	Nephtys	3	Axinulus croulinensis	6	Nephtys	3	Axinulus croulinensis	4
Ophiuroidea	3	Ophiuroidea	4	Kelliella abyssicola	3	Spiophanes kroyeri	5	Asteroidea	3	Synaptidae	4
Synaptidae	3										
No. of individuals	239	No. of individuals	390	No. of individuals	212	No. of individuals	274	No. of individuals	167	No. of individuals	300
50% of individuals	**119**	**50% of individuals**	**195**	**50% of individuals**	**106**	**50% of individuals**	**137**	**50% of individuals**	**83**	**50% of individuals**	**150**

Table 3. Top 10 ranked taxa list for sites within the Corrib Field. Taxa comprising the top 50% (approx) of the population are in bold. Abundances are per $0.1m^2$

Z12		REF 1		REF 2		REF 3		REF 4	
Galathowenia oculata	**102**	**Galathowenia oculata**	**81**	**Galathowenia oculata**	**97**	**Galathowenia oculata**	**113**	**Galathowenia oculata**	**154**
Prionospio fallax	**14**	**Levinsenia gracilis**	**7**						
				Prionospio fallax	10	Prionospio fallax	21	Prionospio fallax	15
Kelliella abyssicola	10	Prionospio fallax	5	Copepoda	7	Levinsenia gracilis	6	Owenia fusiformis	9
Euchone cf. incolor	5	Cuspidaria	4	Owenia fusiformis	4	Abra	5	Abra	8
Abra	5	Ophiuroidea	4	Levinsenia gracilis	3	Copepoda	4	Levinsenia gracilis	8
Adontorhina similis	4	Owenia fusiformis	4	Ophiuroidea	3	Harpinia antennaria	4	Axinulus croulinensis	5
Chone duneri	3	Copepoda	3	Cuspidaria	3	Glycera lapidum	4	Peresiella clymenoides	4
Axinulus croulinensis	3	Axinulus croulinensis	3	Eclysippe vanelli	3	Axinulus croulinensis	4	Adontorhina similis	4
Cuspidaria	3	Chone duneri	3	Chone duneri	3	Aricidea laubieri	3	Aricidea wassi	4
Echinoidea	3	Kelliella abyssicola	3	Tubulanus polymorphus	2	Urothoe elegans	3	Copepoda	4
		Abra	3	Aricidea wassi	2				
		Echinoidea	3	Euchone cf. incolor	2				
				Axinulus croulinensis	2				
No. of individuals	209	No. of individuals	174	No. of individuals	180	No. of individuals	225	No. of individuals	276
50% of individuals	**104**	**50% of individuals**	**87**	**50% of individuals**	**90**	**50% of individuals**	**112**	**50% of individuals**	**138**

Table 3. Top 10 ranked taxa list for sites within the Corrib Field. Taxa comprising the top 50% (approx) of the population are in bold. Abundances are per $0.1m^2$

APPENDIX 6: AQUA-FACT SEABED PHOTOGRAPHY REPORT

Sediment Profile Imagery Survey
Corrib Gas Field Development
Field & Reference
Stations

July 2008

Produced by

AQUAFACT International Services Ltd

On behalf of

RSK Environment Ltd.

September 2008

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Appendix I Survey stations representative SPI and surface photographs, Corrib Field, Co. Mayo, July 2008

Appendix II Sediment Profile Imagery (SPI), apparatus and data analysis

1. Introduction

AQUAFACT International Services Ltd. was contracted by RSK Environment Ltd. to conduct a Sediment Profile Imagery (SPI) survey of the seafloor on the Corrib Gas Field of the Mayo coast, Ireland. In all, 21 stations were sampled using SPI between 11th and 20th July 2008 - 4 of these were outlying reference stations at some distance from the infield subsea structures while the 17 remaining stations were located on the Corrib Field itself (see Figures 1, 2 and 3).

Figure 1 Location map for the Corrib Field study area, July 2008.

This report documents the environmental conditions of the seabed at each of the stations surveyed as recorded by the SPI cameras during the course of the survey.

The main objectives of this survey were:

- To analyse sediments for grain size, degree of compaction and depth of bioturbatory activity (re-working or irrigation of the sediment by animals).

- To document infauna (animals living in the sediment) and epifauna (animals living on the bottom) and to infer from their presence the health of the benthos.

- To assess the overall state of the seafloor at 21 stations surveyed

Sediment Profile Imagery incorporates the use of an underwater camera that takes *in situ* photographs of vertical sections of the sediment, from which important ecological parameters can be ascertained. It reveals many aspects of the processes within sediments on the seafloor that other conventional tools fail to reveal or destroy in the process of sampling. Its use in marine benthic studies has revolutionised our knowledge of infaunal activities and infaunal relationships. Its application on fish farms can tell a great deal about the bottom sediments and their state of enrichment. It is non-destructive and therefore, comparisons can be directly made with baseline and previous SPI studies. An additional downward-looking surface camera mounted on the SPI frame is used to obtain a pre-penetration photograph of the seafloor where the profile shot is to be taken. Additional information can be gleaned from these surface photographs – when combined with information already recorded in the profile shots this helps to build a complete picture of the seafloor being studied. As the data return is relatively rapid, this allows the implementation of management decisions which are based on current information rather than the 'after the fact' remedial actions imposed by the more traditional surveying/monitoring methods. The SPI parameters analysed and their results and implications for the seafloor are discussed in detail in Appendix II (details on apparatus and deployment are also available here).

1.1. Site history

The Corrib Field was discovered in 1996 and was the first significant find offshore Ireland since Kinsale Head in 1973 (Wilson, 2007). The Corrib field development was sanctioned in February 2001, and the production license was granted in late 2001 with a 30-year duration. The development will incorporate seven subsea wells with export

directly through a pipeline to an onshore terminal. This receiving facility will be constructed on the coast of County Mayo. The Corrib project was sanctioned for a scheduled production start-up in October 2003. Due to the objections received relating to the planning permission for the gas terminal, the start up was delayed. Corrib is a Triassic gas field located some 65 km west of County Mayo (Figure 1) in approximately 350 m water depth. The proposed pipeline route currently runs east from the Field into Broadhaven bay and a proposed landfall immediately west to the mouth of the Sruwaddacon bay, although a number of alternative landfalls and route corridors from Broadhaven bay are currently being considered.

Extensive survey operations have previously been undertaken as part of the Corrib Field development. The pipeline route was surveyed by Gardline Surveys and AQUAFACT in 2000, whilst the proposed outfall was surveyed by Ecoserve Ltd. in 2001. The field itself has been surveyed extensively since 1996 using a combination of opportunistic ROV sampling and dedicated benthic sampling using surface deployed seabed samplers. In all cases, either the field sampling and or the processing of the benthic material was previously carried out by Gardline Surveys Ltd. (and or Ian Wilson) with a high level of continuity maintained.

Whilst the majority of previous survey activities related to the drilling of one or two wells at any one time, a more regional assessment was undertaken by Gardline Surveys in 2000. This was a combination of physico-chemical /macrofaunal sampling operations, and seabed video and photograph survey in the vicinity of the Corrib Field and along the proposed pipeline route. Macrofaunal grab samples were taken from 27 sites within the Field with a further 12 stations sampled along the pipeline route between the Field and the landfall. For the most part, many of the stations will be re-surveyed as part of the current study. In addition to sampling, seabed photography was also undertaken. The sediment surface was photographed at many sites by Gardline Surveys, and for the field, sediment profile imagery (SPI) recorded vertical profiles and surface photographs of the sediments by AQUAFACT. The aim of the surface photography was to provide a record of the fauna and flora present on the seabed and to avoid potential environmental hazards, such as Annex 1 habitats. In the event, no sensitive environments were found.

Several stations on the field were again surveyed by AQUAFACT using SPI in 2007 (see AQUAFACT, 2007).

2. Methods

2.1. Sediment Profile Imagery

In order to examine the nature of the seafloor, Sediment Profile Imagery (SPI) was employed. Using SPI, one can deduce the dynamics of biological and physical seafloor processes from imaged structures. The SPI camera differs from other underwater cameras in that it effects a vertical profile of the sediment-water interface and obtains a photographic image of that profile (see Figure below; see also Appendix II). Since the SPI camera obtains images of the undisturbed sediment *in situ*, it delivers information on benthic processes that is not readily available using many conventional sampling tools (Rosenberg and Diaz, 1993). Furthermore, as the object being photographed is directly against the faceplate of the camera assembly, water turbidity is never a limiting factor.

Sediment Profile Imaging (SPI) can remotely identify the successional status of the seafloor and also has the potential to document its maintenance, development and/or destruction over time. With experience, both the physical and biological forces responsible for maintaining or driving a succession (e.g. bottom erosion or deposition, changes in substratum type, relative changes in levels of dissolved oxygen, organic decomposition processes, etc.) can also be detected with confidence. This also applies to chemical driving forces where sensing probes are used in conjunction with the SPI instrument. A great deal of information about benthic processes is available from sediment profile images and while certain features (e.g. deep-living infaunal forms) may escape direct observation on the SPI images, their presence can typically be inferred from their impacts on the sediment structure (Appendix II). The combining of information from both sediment profile and sediment surface images allows an appreciation of the nature of the seabed on two planes - a quasi-3-dimensional model of the seafloor.

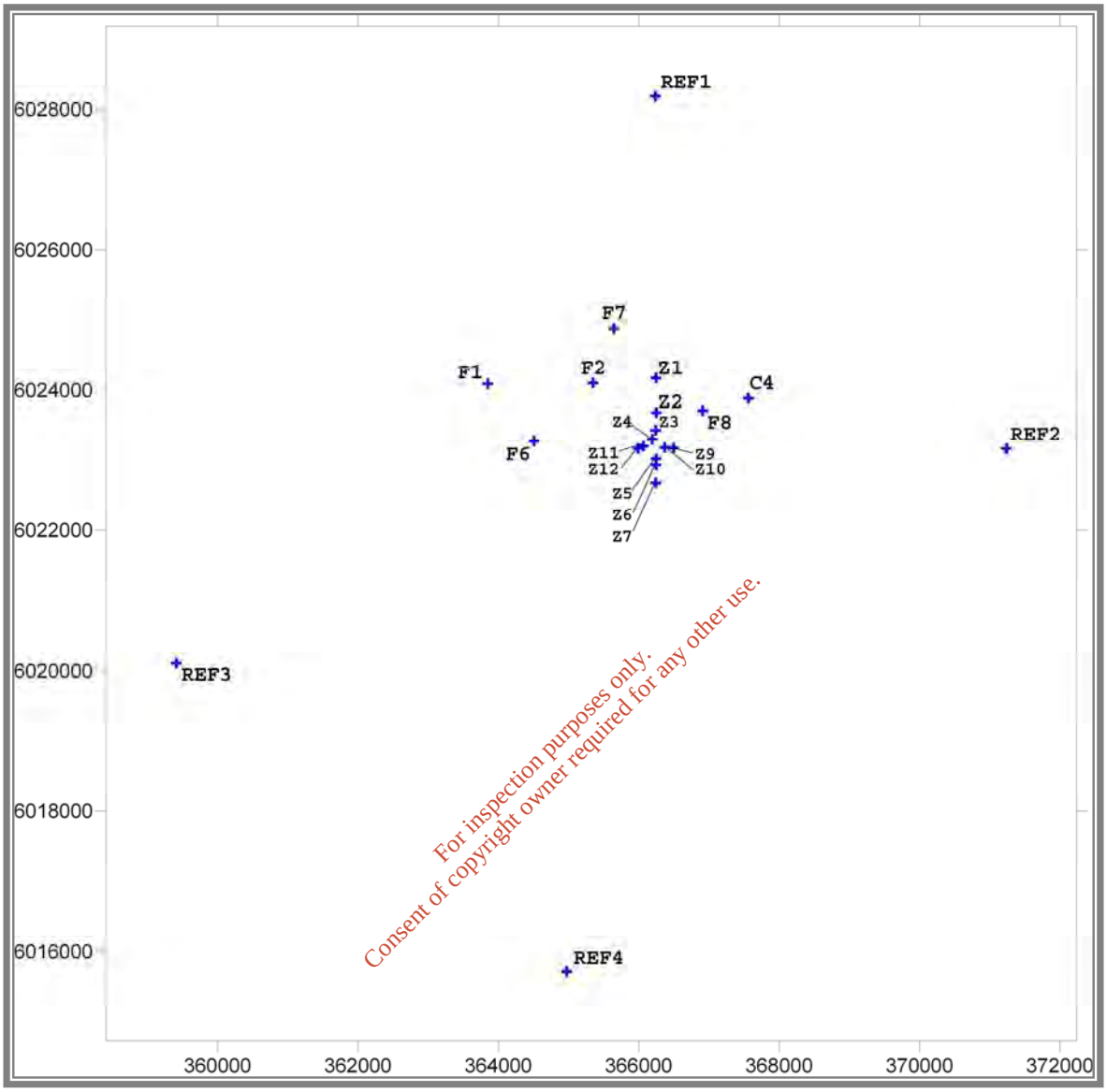

Figure 2 Layout of stations surveyed using SPI on the Corrib Gas Field, July 2008

The survey was carried out on in July 2008 from the salvage vessel *Deepworker*. Station position fixes were taken using a USBL positioning system. The camera was lost when the winch cable parted following deployment at Station F8 on 20th July 2008. It was recovered from the seabed by the Normand Progress on Friday/Saturday 22nd/23rd August, 2008. Due to its loss it was not possible to complete the full planned sampling schedule – the seafloor at 12 remaining stations were not imaged using SPI (C1-C3, F3-F5, F9, Z8 & A1-A4).

SPI and digital seafloor images were obtained from numerous separate deployments of the SPI machine at each of the 21 sampling locations. All sediment profile images taken were analysed for each station using a dedicated image analysis system. Appendix II outlines the rationale and methods of analyses of Sediment Profile Imagery (SPI).

The SPI parameters measured from each image include:

1) – sediment type measured from the upper 5 cm sediment layer

2) – prism penetration depth which gives an indication of relative sediment compaction and coarseness

3) – sediment boundary roughness which indicates the degree of physical disturbance or biotic activity at the sediment water boundary

4) – sediment apparent redox potential discontinuity depth (ARPD), assesses the depth of oxygenated sediment on the bottom (not visible)

5) – infaunal successional status which qualifies the type of animals living in the bottom

6) – additional parameters such as the presence of mud clasts, epifauna (surface living animals), infaunal burrows and tubes, outgassing of sediments (due to production of hydrogen sulphide and ammonia as by-products of anaerobic metabolism) etc. were also assessed

7) – calculation of a mean organism sediment index (OSI value) which integrates the information gained from the other parameters measured into a single index which is indicative of the health status of the location under investigation (see Appendix II).

3. Results

Figures showing sediment profile and sediment surface shots for each station surveyed are given in Appendix I, along with measured parameters superimposed on the representative shot for each station.

3.1. Sediment type

The sediment major mode is assessed from the top 5cm of the sediment (see station tables superimposed on the SPI shots in Appendix I). All stations investigated on the Corrib Gas Field were characterised by the presence of very fine sands. (Due to the fact that sediment major mode at each station was similar this parameter is not presented graphically).

3.2. Mean prism penetration depth

The maximum prism penetration depths (in centimetres) achieved in a single deployment at each of the 21 sampling locations are presented in Figure 3 below (see also tables superimposed on the photosets presented in Appendix I). These figures reflect both the grain size composition and compactness of the bottom deposits.

Penetration depths were moderate to low at many of the stations surveyed, though image quality was always excellent. The camera system was used with a fully loaded weight carriage for maximum penetration throughout the survey – therefore any variation seen in penetration is due to variation in the physical characteristics of the sediment itself. Sediments had been fluidised to a degree through the activities of burrowing fauna (bioturbation). The highest penetration values were achieved at Station F1. Sediments at this station were characterised by a lower amount of bioturbation than seen at surrounding stations. It was also less well developed in terms of faunal succession.

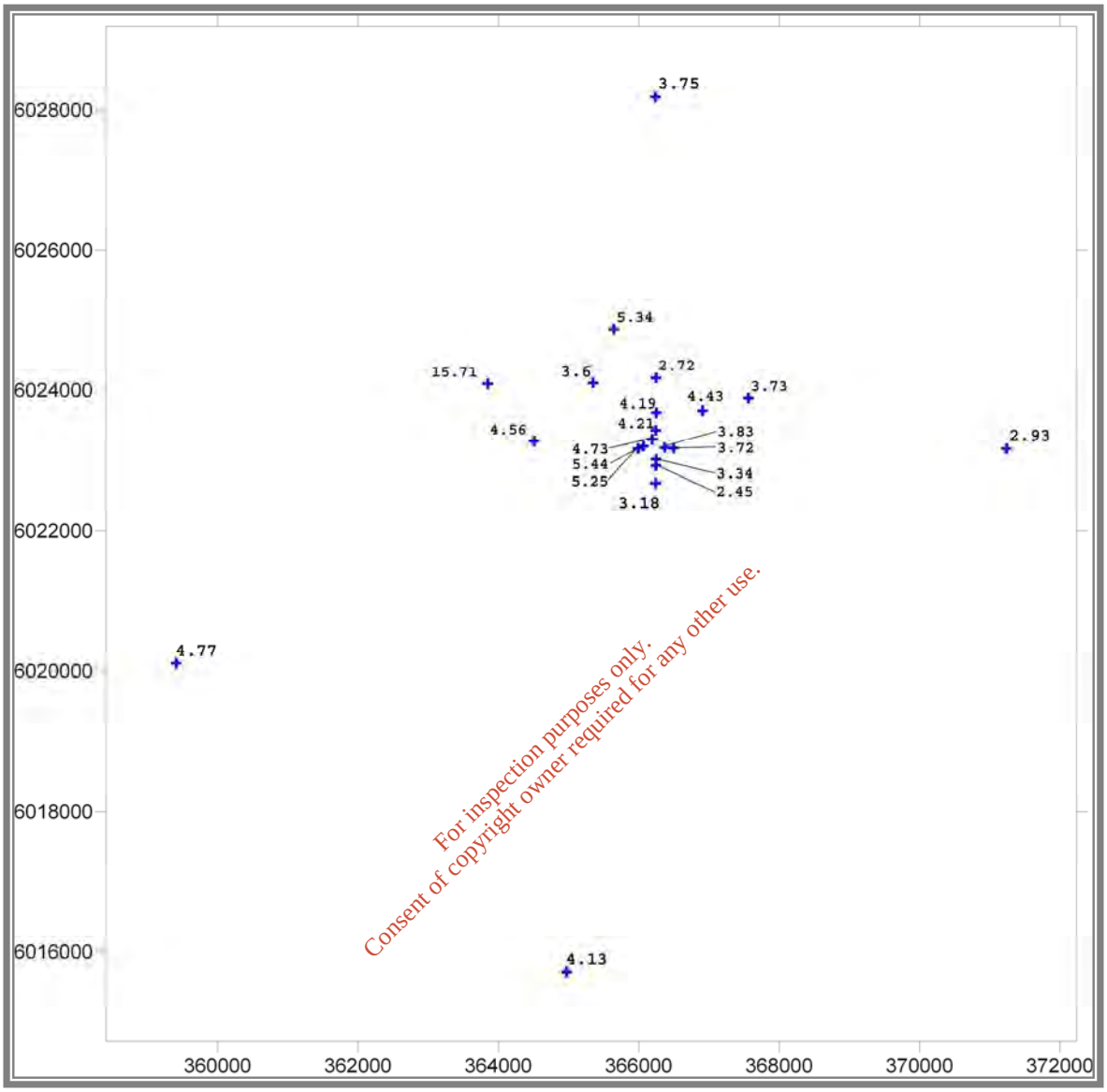

Figure 3 Maximum prism penetration in centimetres achieved in a single deployment at stations surveyed using SPI on the Corrib Gas field, July 2008.

3.3. Sediment surface boundary roughness

Surface boundary roughness is an indication of the unevenness of the sediment surface resulting from either bioturbation (animals in the sediment) or from physical disturbance (see Figure 4). In the case of the current survey sediment relief is due almost exclusively to bioturbation. The images presented in Appendix I show a seafloor that is

intensively worked by benthic fauna – active feeding mounds and burrows were imaged at almost all stations surveyed. The profile and surface images are characteristic of a seafloor with a well-developed faunal community. Mobile fauna such as the numerous ophiuroids recorded also contribute to bioturbation here.

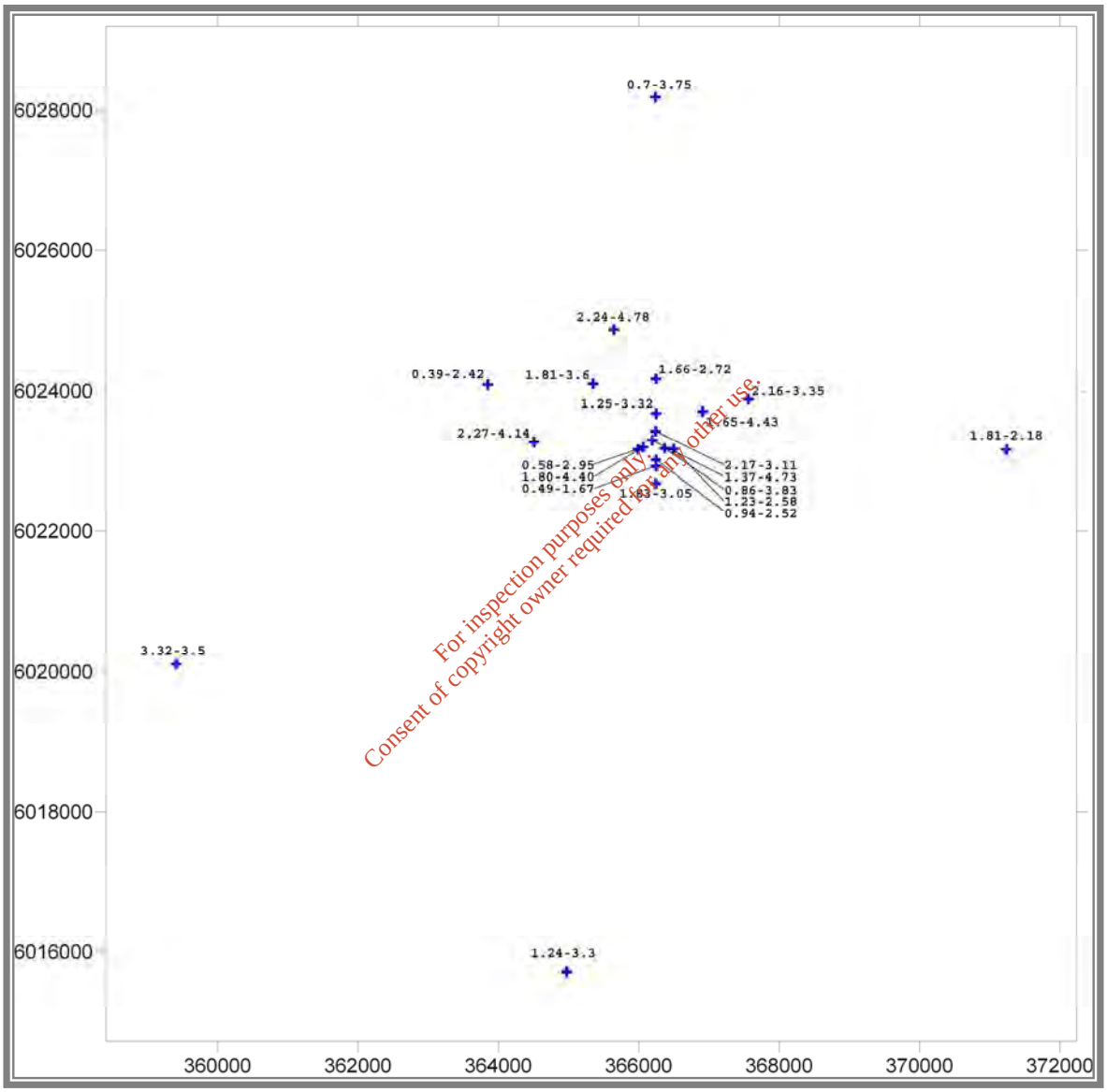

Figure 4 Sediment boundary roughness SBR (ranges in Centimetres) recorded on the Corrib gas field, July 2008.

3.4. *Apparent redox potential discontinuity (aRPD)*

The apparent redox potential discontinuity (aRPD) depth is the visible line between oxygenated and reduced sediment in a profile image. In the 2007 survey of the Corrib field (AQUAFACT, 2008) small areas of reduced sediments were noted at Station C2. The presence of these is indicative of some degree of elevated organics – possibly due to contamination with drill muds (these stations are in close proximity to drilled wells). It is interesting to note that (along with Station F5 – not surveyed in the 2007 survey) Station C2 was highlighted as having a low ARPD depth in a similar sediment profile imagery survey carried out by AQUAFACT in July 2000 (AQUAFACT, 2000) – indicating incorporation of drilling material into the seafloor there. In the current 2008 SPI survey, Station F1 was the only station at which a measurable aRPD was imaged (this parameter is therefore not presented graphically). A white/brown deposit/precipitate also appears at depth in the sediment profile at this station.

3.5. *Infaunal Successional stage & bioturbation depth*

Infaunal successional stages calculated for the stations surveyed are presented on the SPI shots in Appendix I. Stage III environments (mature, healthy conditions) are typically characterised by deep redox boundary depths. All stations were assigned a Benthic Habitat Quality Index following the methodology proposed by Nilsson and Rosenberg (1997). This is described in detail in Table 3-1 below (see also Figure 6). Successional stages were then assigned to each sediment profile image based on this calculated value.

All but one of the stations surveyed were allocated a stage III successional stage. This was largely due to the presence of characteristically deep ARPDs, fauna and prominent biogenic features such as burrows, tubes and feeding casts (refer to Figure 5 below). It was also due to the absence of any definite evidence of impact or habitat quality degradation. Sediments at Station F1 were allocated a Stage II successional status due to the presence of reduced sediments in the profile images recorded there and a lack of features indicative of a Stage III community such as burrows/feeding casts. In the SPI survey carried out on the Corrib Field in 2000

(AQUAFACT, 2000 a & b) Station F1 was classified as supporting a Stage II habitat while Station F5 and Station C2 were classified as supporting a stage I type community.

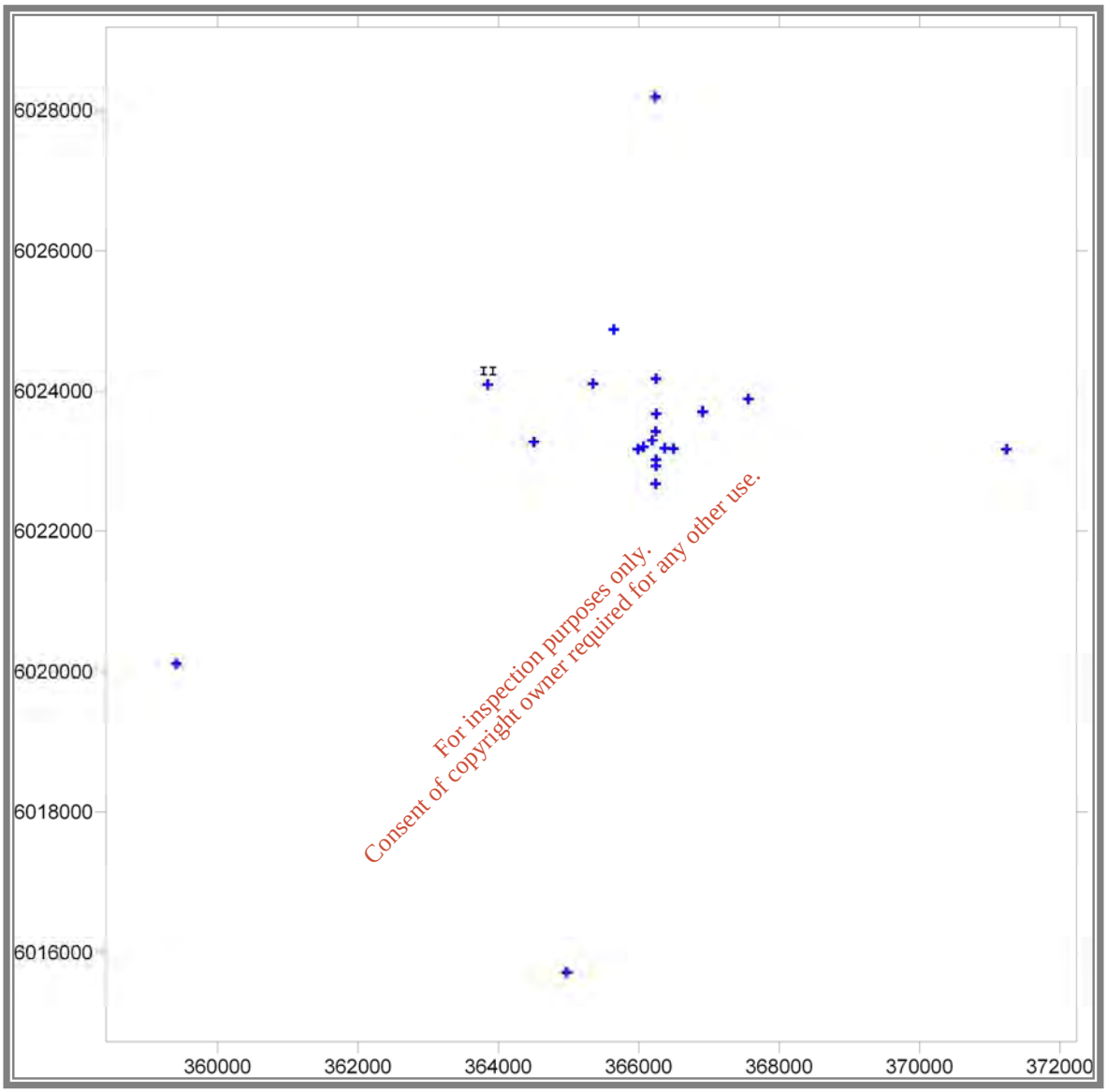

Figure 5 Successional stage recorded by SPI on the Corrib Gas Field. All stations but one (shown) returned a Stage III (healthy/mature) community status.

Table 3-1 Calculation of the Benthic Habitat Quality (BHQ) index from sediment profile images. BHQ = A + B + C, where A is surface structures, B subsurface structures and C means sediment depth of the apparent redox potential discontinuity (RPD). The BHQ value varies between 10 and 15. The BHQ index corresponds to the different successional stages depicted in Figure X below.

A	Surface Structures	Faecal pellets	1
		Tubes ≤ 2 mm in diameter	1
		or Tubes > 2mm in diameter	2
		Feeding pit or mound	2
B	Subsurface Structures	Infauna	1
		Burrows 1-3	1
		or Burrows # > 3	2
		Oxic Void at ≤ 5 cm depth	1
		or *Oxic Void at > 5 cm depth*	2
C	Mean Depth of ARPD	0 cm	0
		0.1 cm – 1.0 cm	1
		1.1 cm – 2.0 cm	2
		2.1 cm – 3.5 cm	3
		3.6 cm – 5.0 cm	4
		5 cm	5

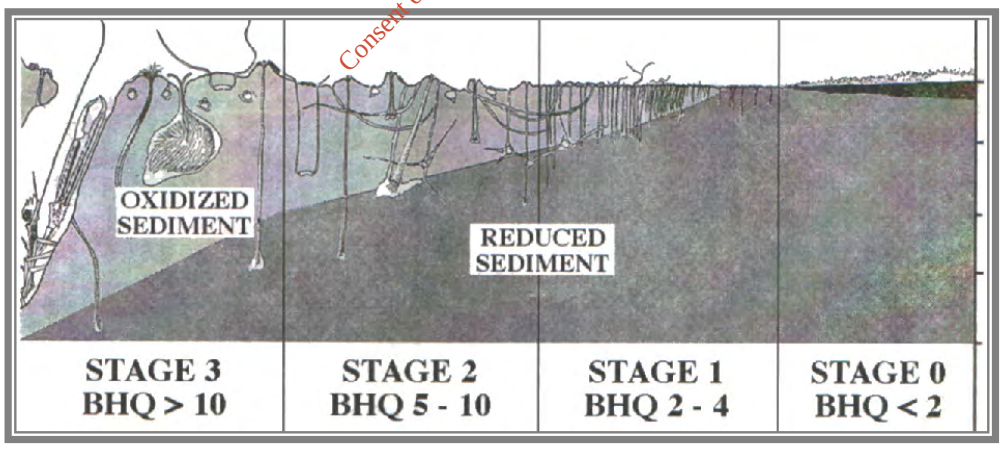

Figure 6 The distribution of benthic infaunal successional stages along a gradient of increased environmental disturbance from left to right (from Nilsson and Rosenberg, 1997 – after Pearson and Rosenberg, 1978) and the associated Benthic Habitat Quality index (described in table 3-1 above. The successional stages are similar but not identical to those described by Rhoads and Germano (1986)

3.6. Additional biological information

Most of the stations surveyed showed signs of faunal activity. In some cases numerous faunal species were imaged. Evidence of substantial faunal activity was noted. Additional biological information recorded on the Corrib Gas Field is detailed below:

- Ref 1 – intensively re-worked sediments with occasional ophiuroids, fresh mounds and burrows.
- Ref 2 – intensively bioturbated sediments with fresh mounds and burrows.
- Ref 3 – intensively re-worked sediments with occasional worm tubes, mounds and burrows.
- Ref 4 – intensively re-worked sediments with anemones, mounds and decapod burrows. Two anemones (*Actinuage richardi*) were imaged in one of the surface images taken here (see Apendix I, Station Ref 4) and a decapod was imaged at a burrow entrance.

The above four stations represented the undisturbed ambient conditions at the Corrib Gas field site. Biological features at many of the in-field stations imaged were broadly similar and are detailed below.

- C4 – intensively reworked very fine sands with occasional ophiuroids, and frequent mounding and burrows. Dark flecks of an unidentified material were imaged at the sediment surface at this station.
- F1 – small surface tubes, very little evidence of bioturbation. Flecks of (coarse) unidentified material at the sediment (drill cuttings?).
- F2 – intensive bioturbation, numerous fresh mounds/burrows. Flecks of unidentified material.
- F6 – intensive bioturbation, numerous fresh mounds/burrows. Gastropod slime trails. Small surface tubes. Planktonic salp at sediment surface. Flecks of unidentified material.
- F7 – intensive bioturbation, numerous fresh mounds/burrows. Occasional ophiuroids. A small decapod (crab) was visible in one of the profile images. A specimen of the anemone *A. richardi* appears in one of the profile images taken at this station (see

appendix I, Station F7. Evidence of feeding at the sediment surface by an animal using a proboscis (numerous linear tracks radiating from a small hole in the sediment surface) is visible in the upper left-hand corner of the surface images presented for this station. Flecks of unidentified material.

- F8 – intensive bioturbation, numerous mounds/burrows. Occasional ophiuroids. An object resembling a pelicans foot shell (*Aporrhais pespelecani – a gastropod mollusc*) is imaged in the top right-hand corner of the surface image taken presented for this station (see Appendix I, Station F8).

Sediment profile images and surface images taken at Stations Z1-Z7 and Z9-Z12 are all broadly similar showing habitats with intensive reworking of sediments by fauna. The following points are worthy of note:

- Z1 – At Station Z1 similar coarse dark flecks of an unidentified material, similar to those seen at the sediment surface in the F series of stations, are visible at the sediment surface. An urchin (Spatangidae?) is also imaged at the sediment surface at this station.
- Z2 – A large worm tube can be seen protruding from the sediment surface in the surface image presented for this station.
- Z3 – Mussel shells and an anemone (*A. richardi*) were both imaged at the sediment surface here.
- Z5 – An impressive specimen of the anemone *A. richardi* is imaged at the sediment surface here – it appears to be reproducing asexually via a lateral bud.

Organism Sediment Index (OSI)

Organism Sediment index (OSI) is the sum of a series of weighted values (see Appendix II) allocated to the various physical/chemical and biological SPI parameters measured and with the inclusion of measurements of dissolved oxygen concentrations in the water column, has a potential value range of -10 to +11. As with the present survey where dissolved oxygen concentrations are not included, the OSI values have a potential range of -6 to +11.

Habitat quality is defined relative to the two end-member standards of OSI values. The lowest value is given to bottom types that have (low or no dissolved oxygen

in the overlying bottom water), no apparent macrofaunal life and methane gas present in the sediment. The SPI OSI value for such a condition is -10 or -6 depending on whether dissolved oxygen measurements in the water column are included or not. At the other end of the scale, an aerobic bottom with a deeply depressed ARPD, evidence of a mature macrofaunal assemblage and no apparent methane gas bubbles at depth will have a SPI OSI value of +11. From experience of mapping with this parameter values of +7 to +11 are indicative of high quality habitats. In dealing with areas that are subject to organic enrichment, OSI values in the range +6 to +1 generally indicate an increased input of organic material. Index values which fall in the range +1 to - 6 identify varying degrees of habitat degradation. This parameter was not mapped due to the fact that ARPD depths were deeper than prism penetration at all but one of the stations surveyed during the current survey.

4. Conclusion

- The sea floor was investigated using sediment profile imagery (SPI) at 21 stations of broadly similar depth (*ca.* 340-350m) on the Corrib Gas Field. This included imaging at four reference stations in the surrounding area.
- Apart from a single station (F1), intensively faunally reworked very fine sands were recorded at all stations on the Corrib Field.
- Bioturbation is the main sediment surface relief modifier at all stations surveyed.
- Flecks of coarse (unidentified) material were imaged on the sediment surface at each of the F series of stations and at Station Z1.
- Camera prism penetration was moderate to low throughout the survey. This is due to the compactness of the sands in this area.
- ARPD depth was visible at only a single station during the current survey (Station F1 – possibly indicative of contamination of sediments here with drill muds). This station was also the least faunally active station imaged during the survey work.
- Faunal activity was clearly evident at all of the stations imaged. The most common fauna imaged were the numerous ophiuroids (brittlestars) imaged in the field and reference stations. As was the case in the 2007 survey numerous feeding mounds, pits and burrows were also imaged indicative of healthy bottom conditions in this area. A single urchin was imaged in surface view at station Z1, anemones (*Actinuage richardi*) at Stations Ref 4, F7, Z3 and Z5 and a large surface tube at Station Z2, with numerous small tubes imaged at various other stations.

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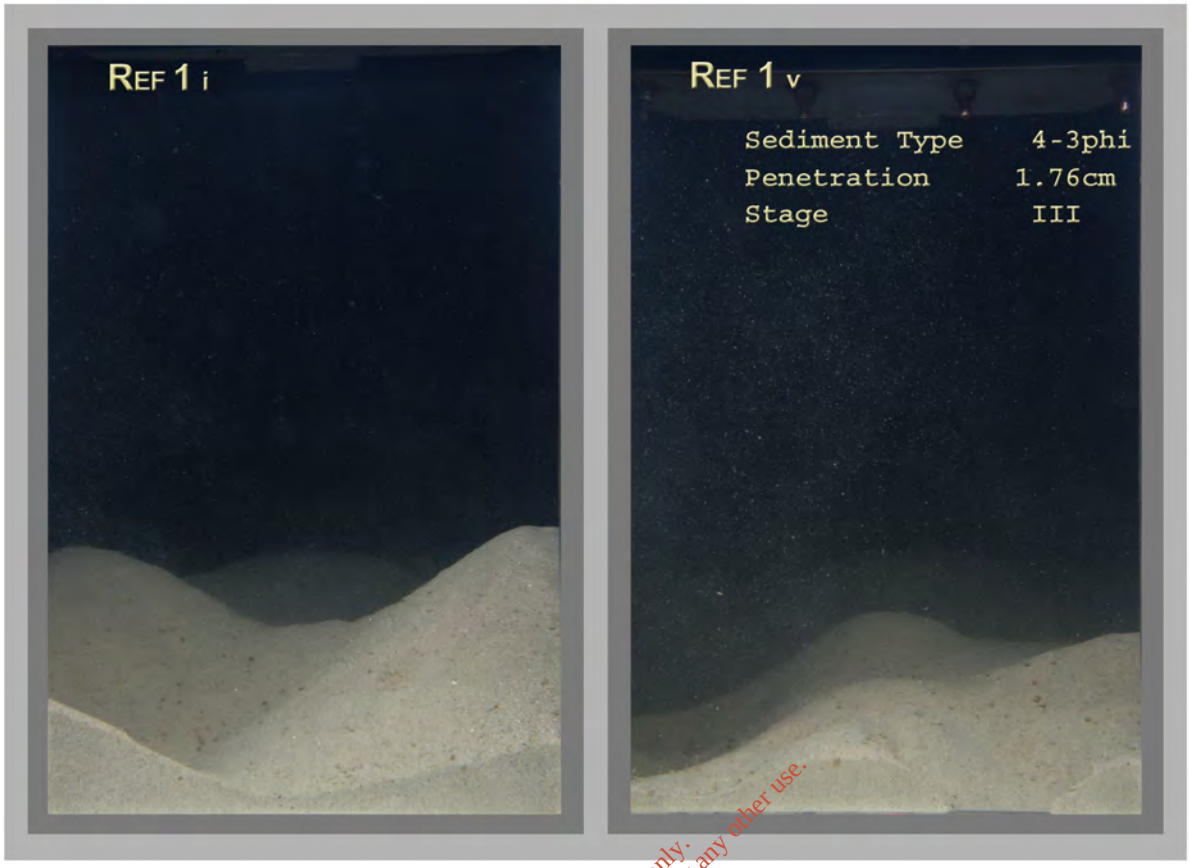
APPENDIX I

SURVEY STATIONS REPRESENTATIVE SPI & SURFACE PHOTOGRAPHS CORRIB FIELD CO. MAYO

JULY 2008

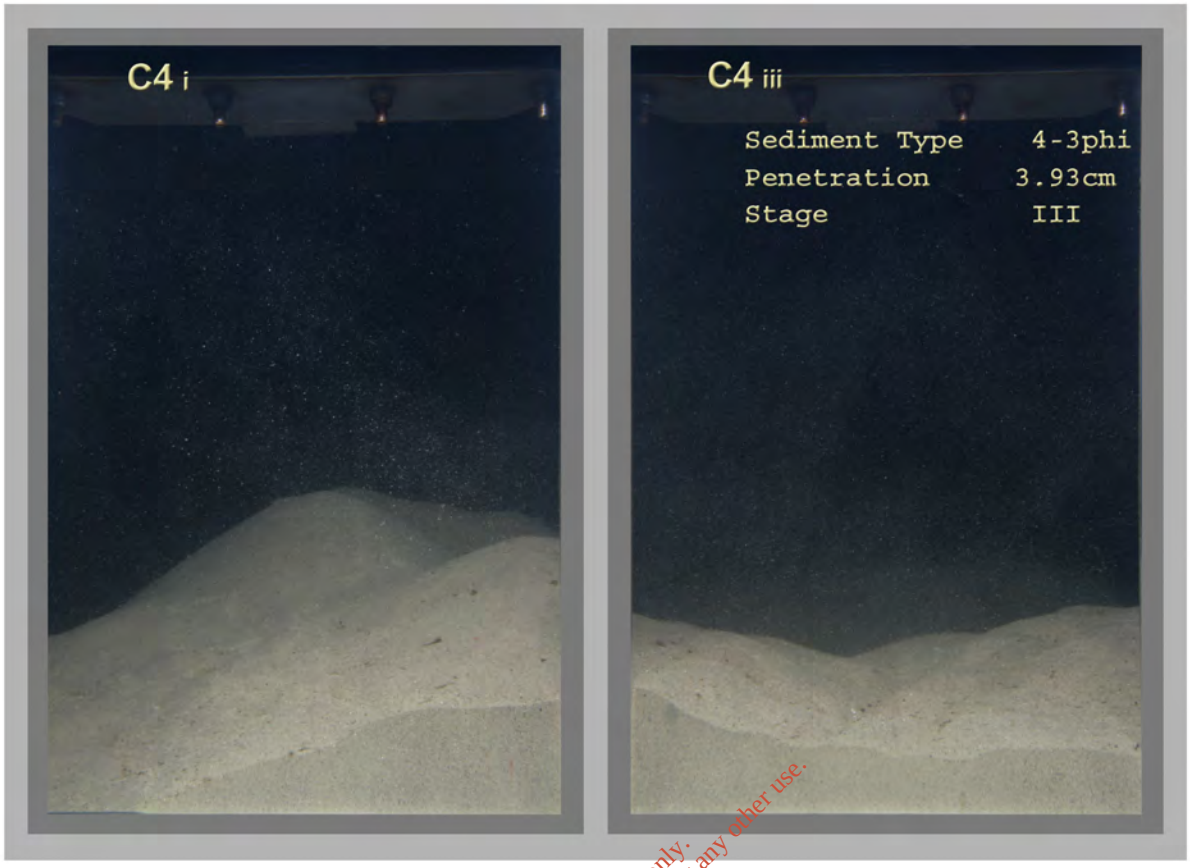


Station Ref 1: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

Station Ref 2: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

Station Ref 3: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

Station Ref 4: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.



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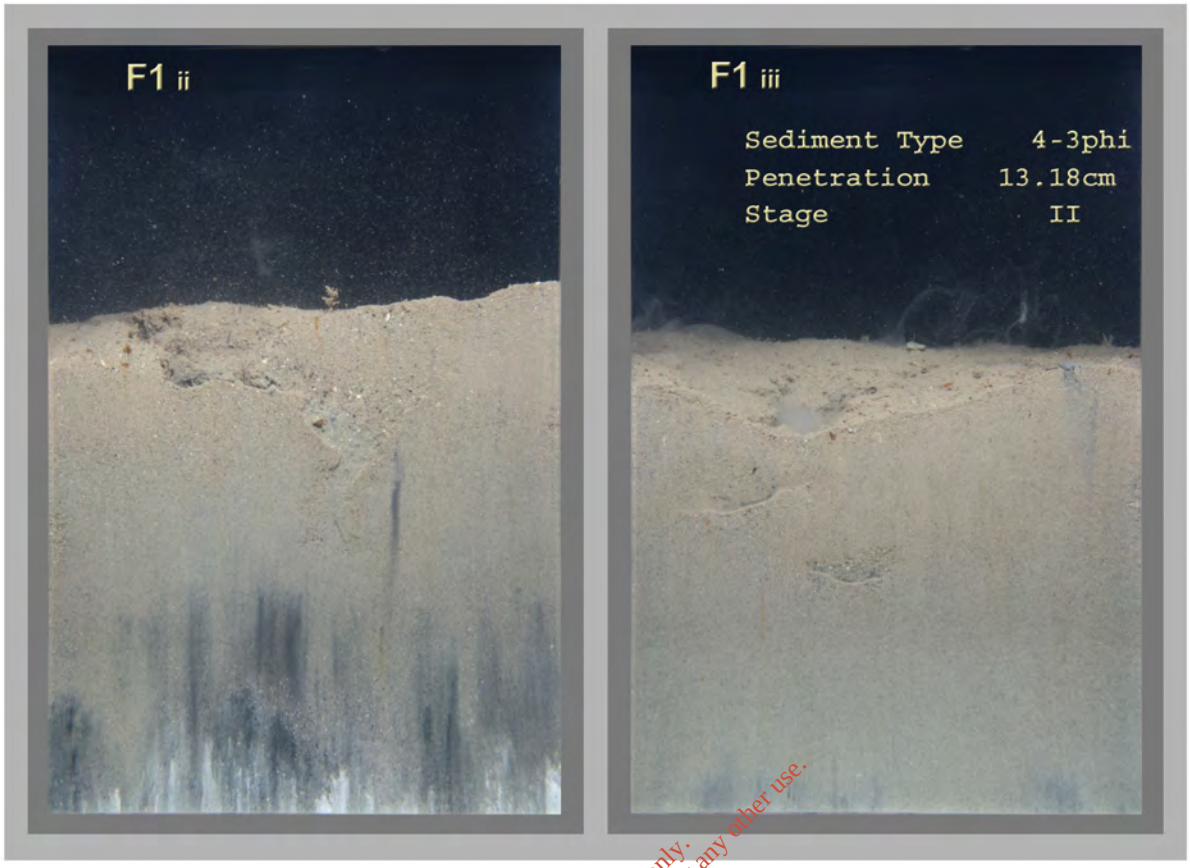
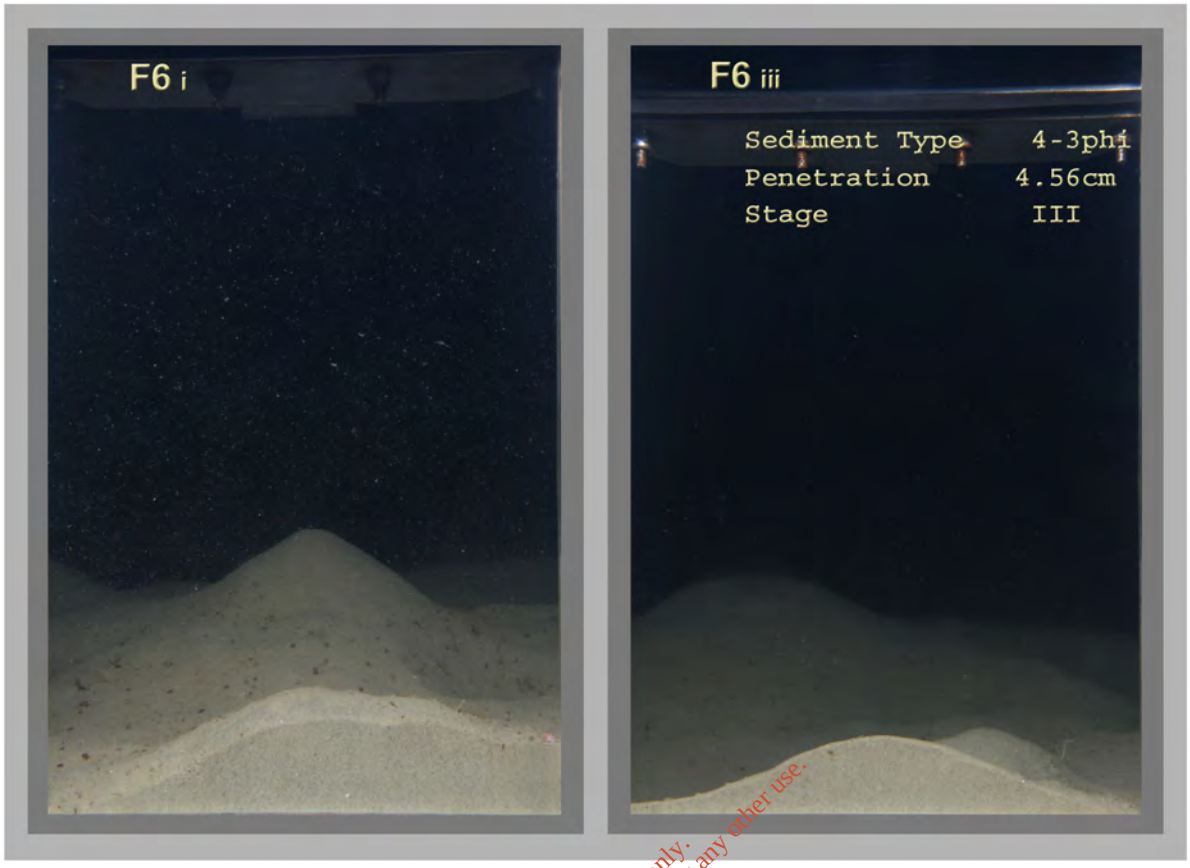
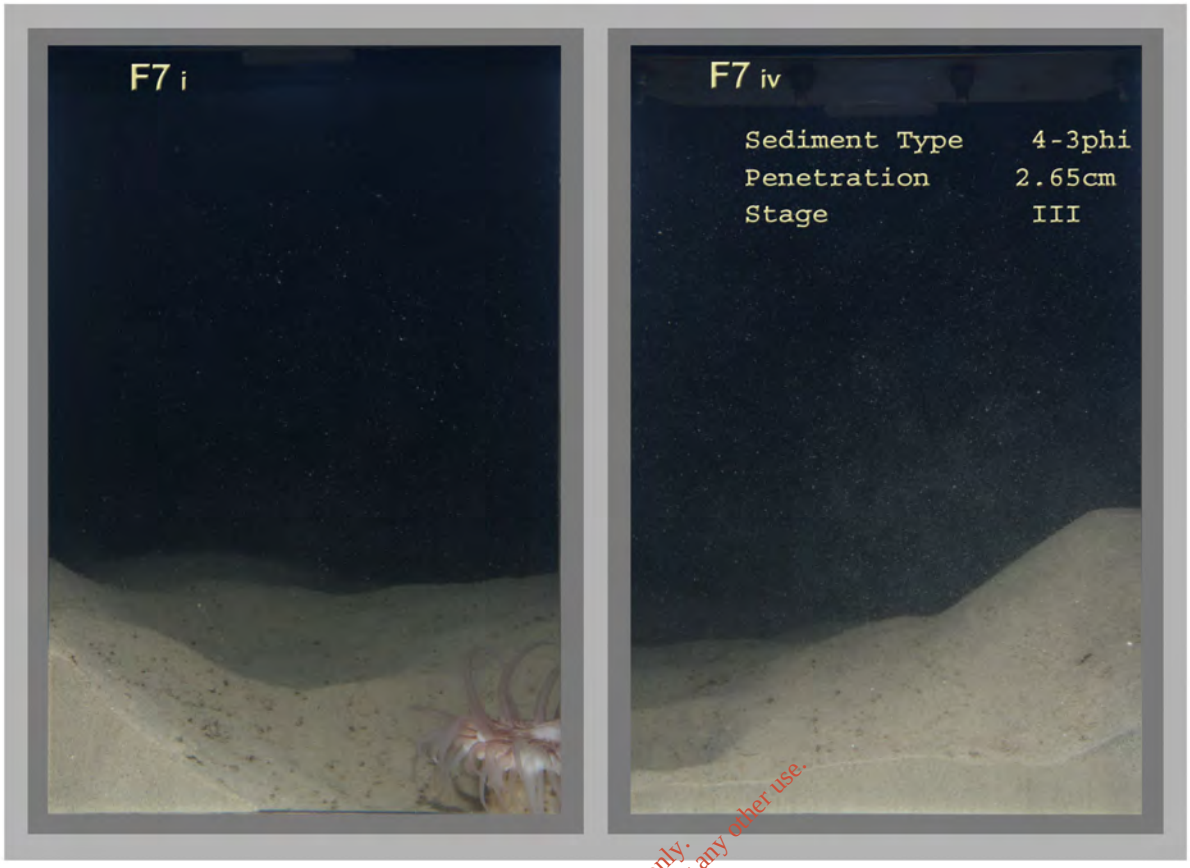


Station F1: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

Station F2: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.



Station F6: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.



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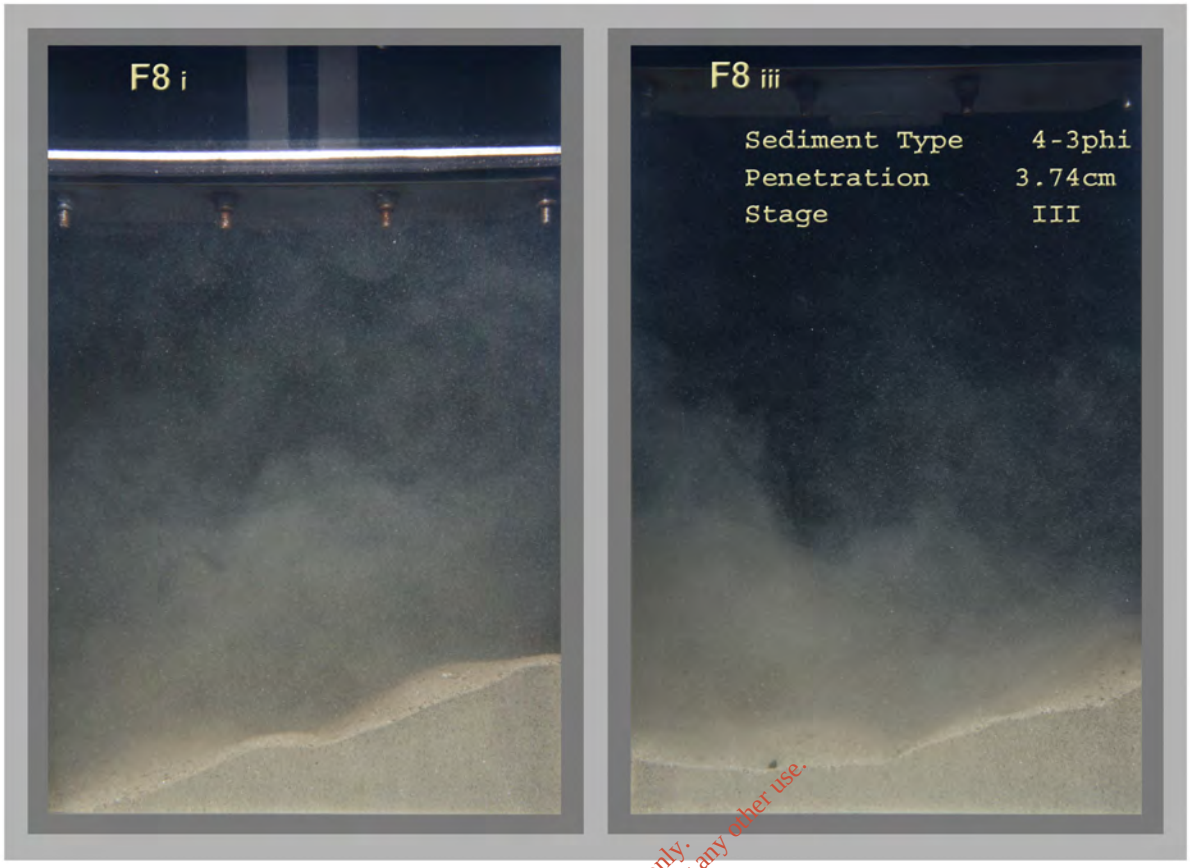
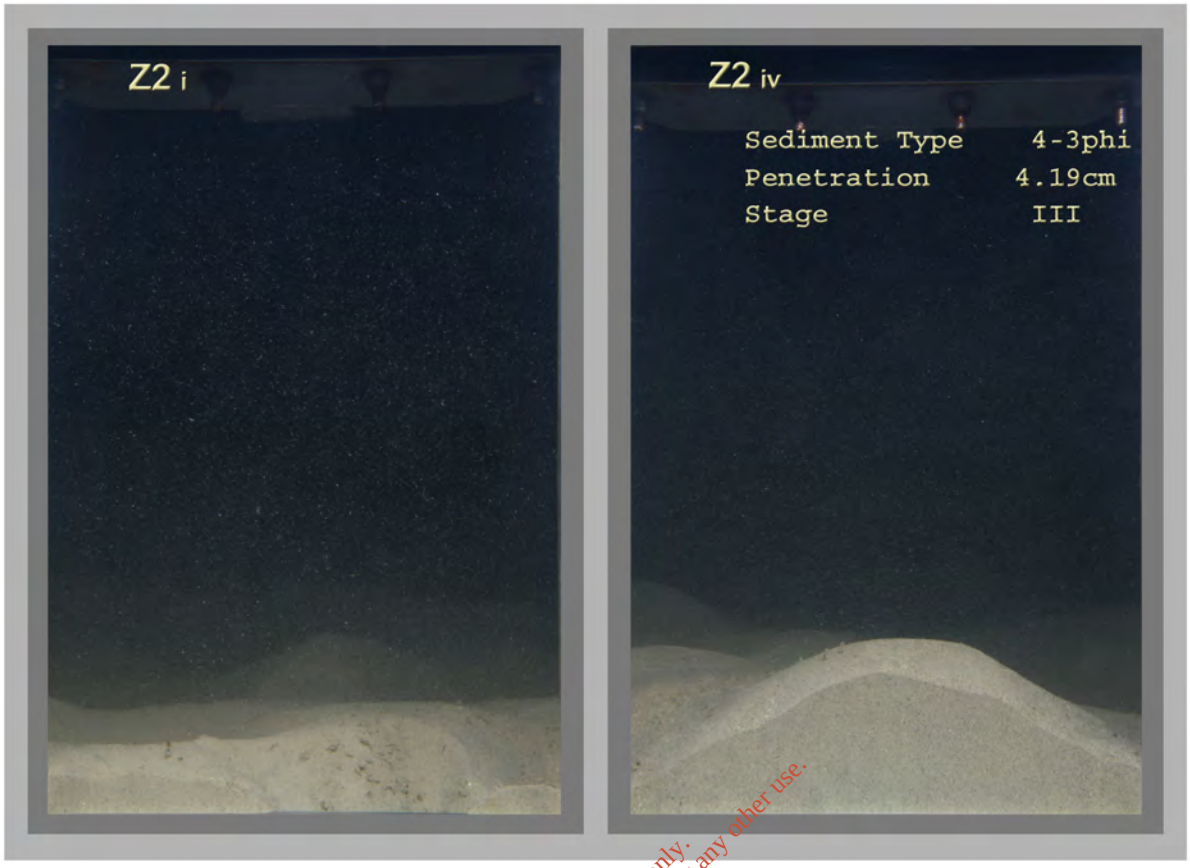


Station F8: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

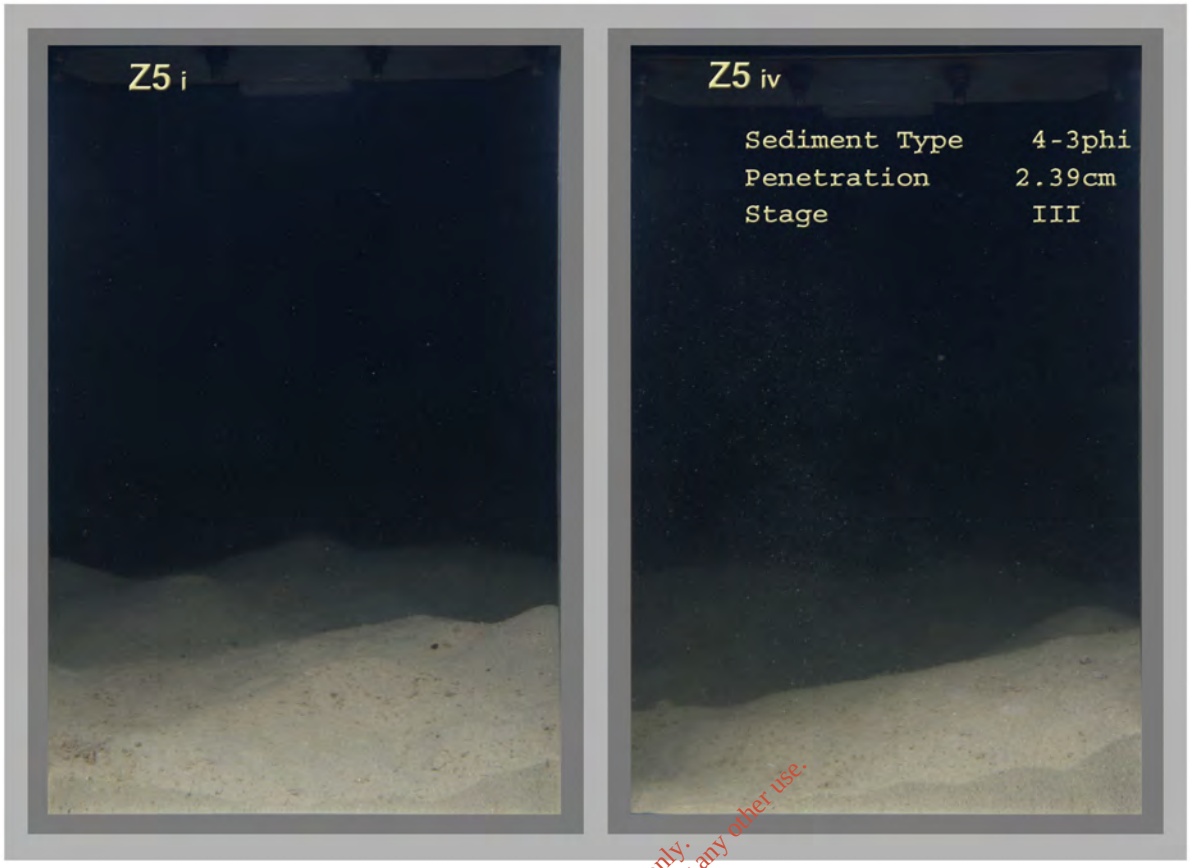
Station Z1: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.



Station Z2: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

Station Z3: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

Station Z4: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.



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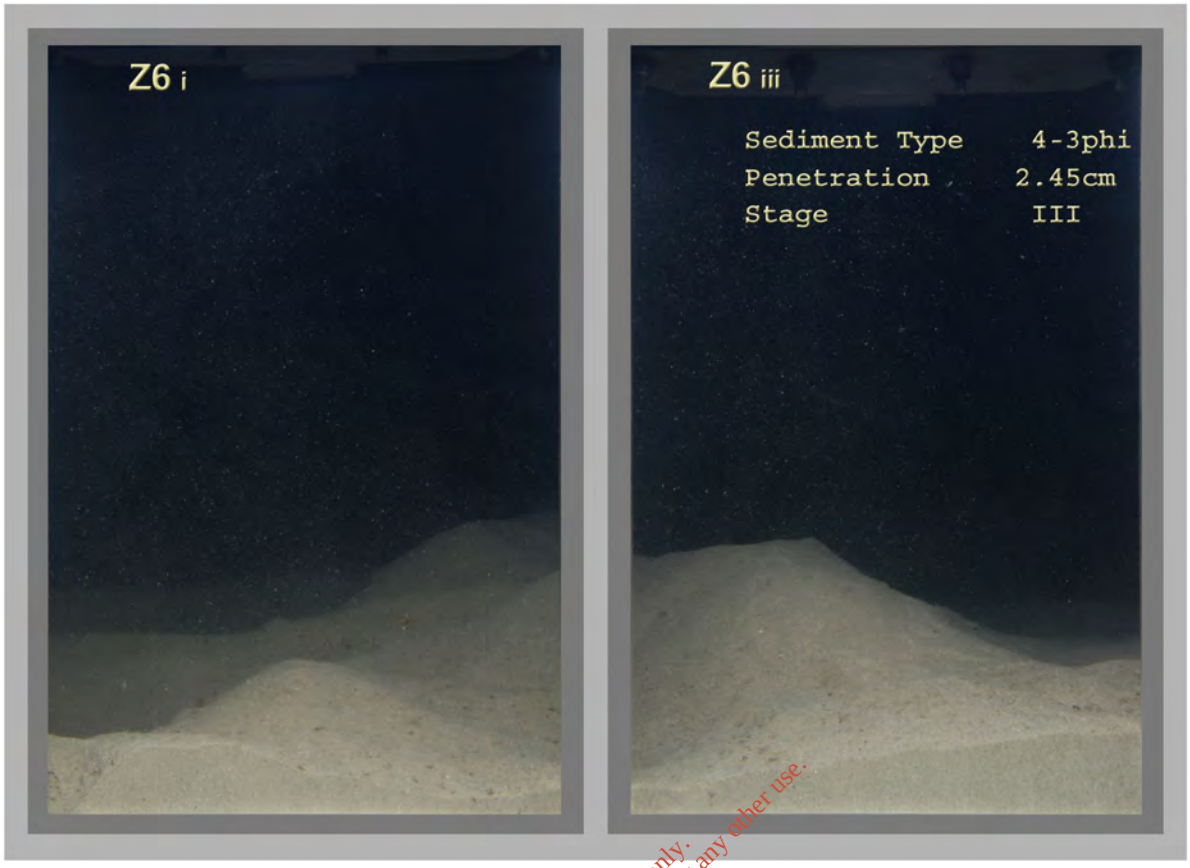
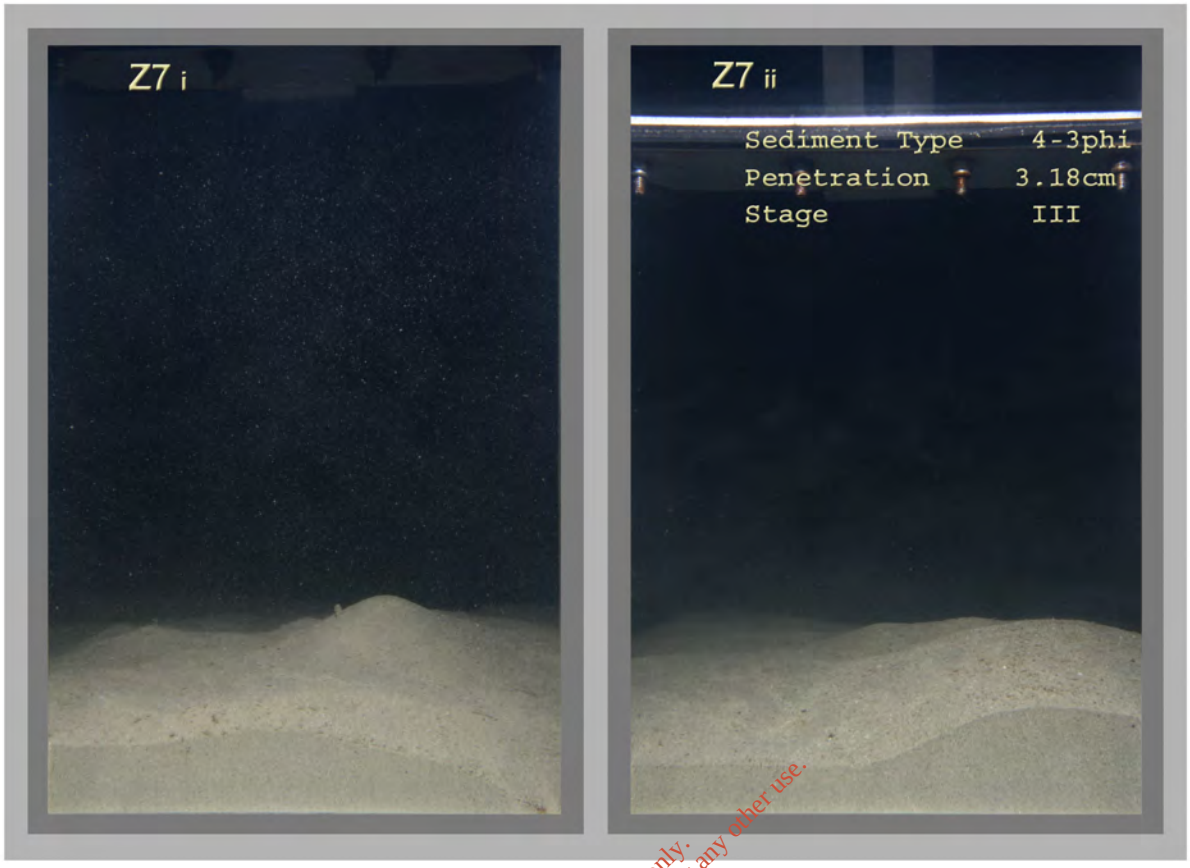
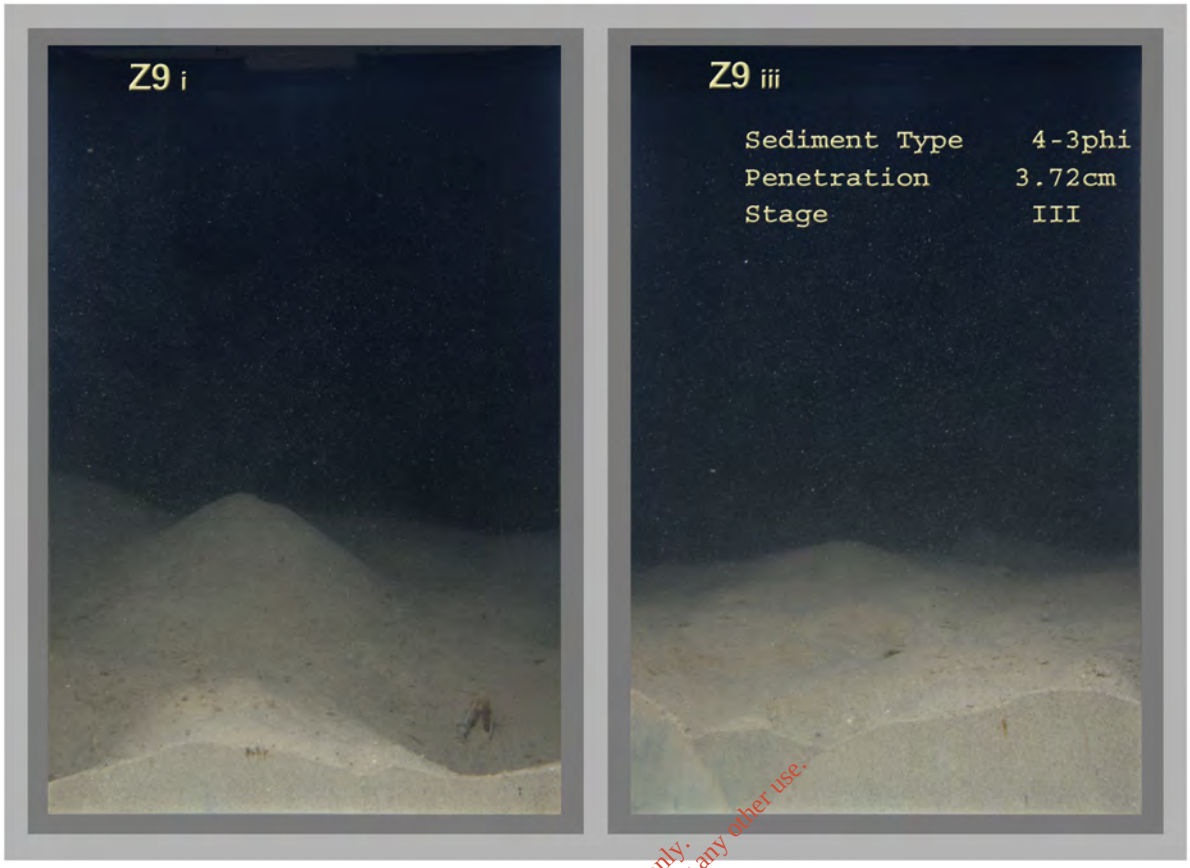


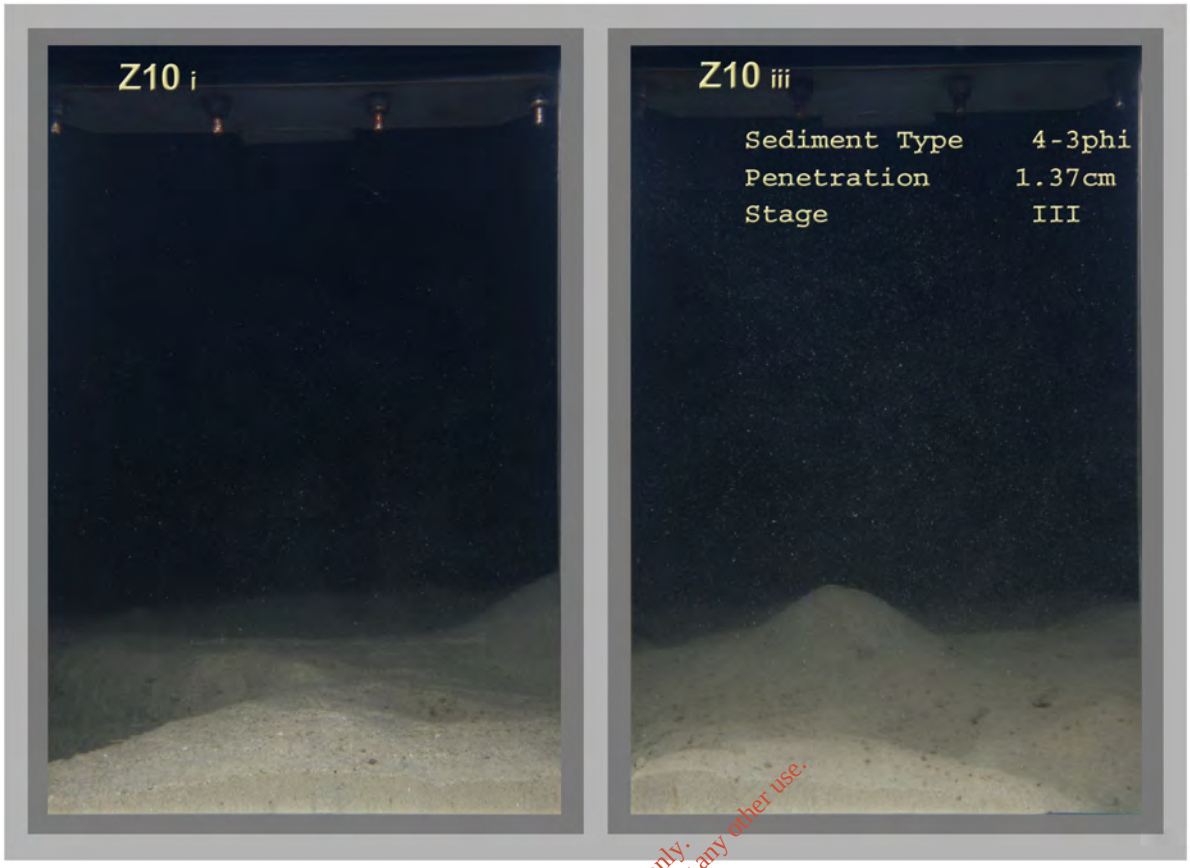
Station Z6: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.



Station Z7: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

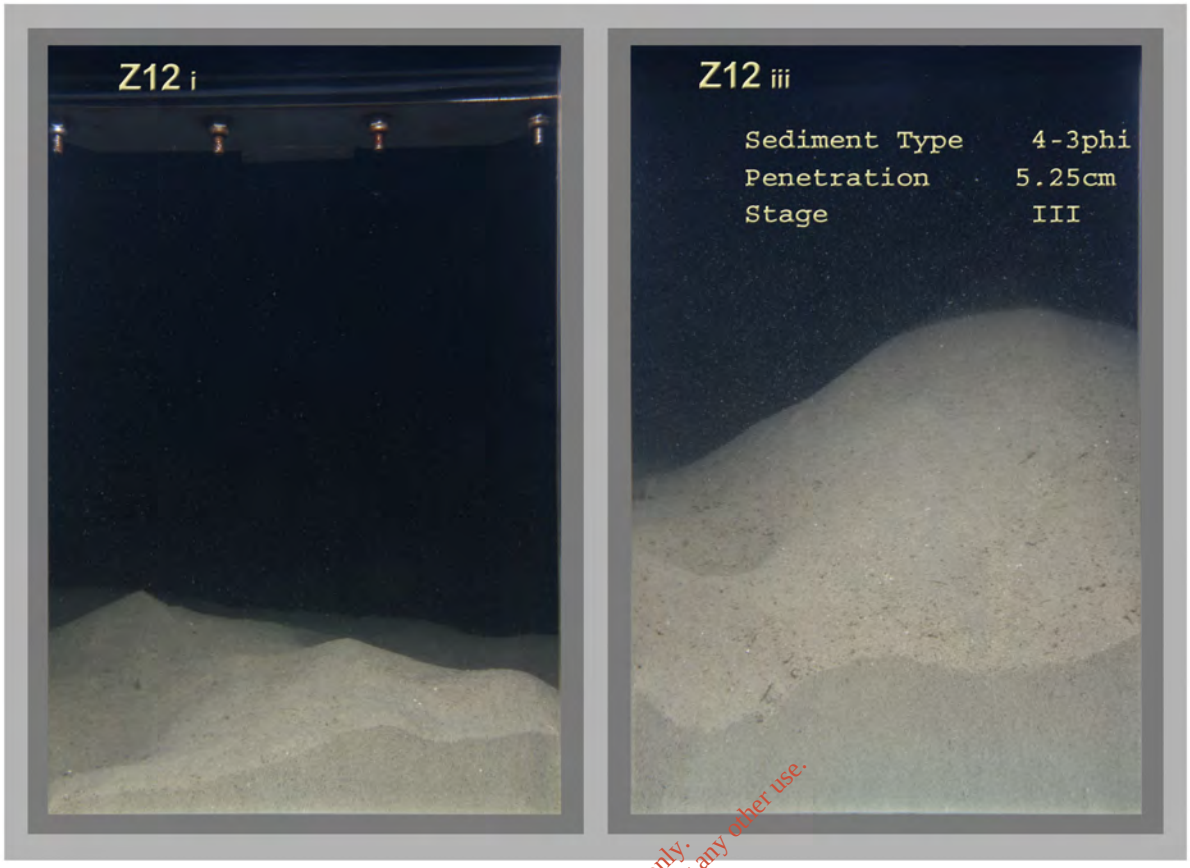


Station Z9: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.



Station Z10: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

Station Z11: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.



Station Z12: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

APPENDIX II

SEDIMENT PROFILE IMAGERY SPI – APPARATUS DATA ANALYSIS

JULY 2008

SEDIMENT PROFILE IMAGERY:

APPARATUS AND DATA ANALYSES

APPARATUS AND DEPLOYMENT

A remotely operated sediment profile camera is used to obtain *in situ* digital profile images of up to 20 cm of the top layers of sediment on the seafloor. It differs from other underwater cameras in that it vertically slices through the sediment-water interface and images the sediment section in profile. Functioning like an inverted periscope, it consists of a wedge-shaped prism with a plexiglass face plate. Light is provided internally by a flash strobe and the back of the prism has a mirror mounted at a 45° angle. This reflects the image of the sediment-water interface at the face plate up to the camera, which is housed on top of the prism. The camera - prism assembly is supported by an inner frame or cradle which can move relative to an outer supporting frame under control of a 'passive' hydraulic piston (see Figure 1).

The camera prism assembly cradle can be moved up and down by producing tension or slack on the winch wire. As the camera is lowered to the seafloor, tension on the winch wire keeps the prism in the up position. The supporting frame lands on the bottom first, leaving the area directly under the prism undisturbed. As the winch wire is slackened, the prism cradle descends toward the bottom at a controlled rate of fall (Figure 2). The wedge-shaped prism enters the bottom and is driven into the sediment by its weight. The piston ensures that the prism enters the bottom slowly and does not disturb the sediment - water interface. Additional lead weights can be attached to the prism cradle to assist prism penetration if required.

On impact with the bottom, a trigger activates a time delay on the camera shutter release and a digital photograph is taken when the prism comes to rest. Because the sediment is photographed directly against the face plate, turbidity of the ambient seawater does not affect image quality. After the photograph or image is taken, tension on the winch wire raises the prism cradle to the up position, a wiper blade cleans off the face plate, the strobe is recharged and the camera can be lowered for another image. In this manner the SPI assembly can be rapidly 'hopped' over the seabed and a series of images obtained at any one sampling location. After the camera is taken back on board a rubber ring records the depth the camera had penetrated and a counter records the

number of successful image shots taken. Specific measurement techniques and interpretive considerations for the analysis of a range of parameters from the SPI images are presented below.

A compact, equally effective diver operated sediment profile camera apparatus (Figure 3) has been developed for operation in shallow waters and shallow areas generally inaccessible by the larger remotely operated machine. As with the remotely operated SPI camera, the camera prism is mounted on a supporting stabiliser frame which can be moved up and down in an action controlled by a hydraulic system. Once the camera's frame touches the bottom, the scientific diver exerts pressure on the prism housing causing it to penetrate the sediment fabric under control of the hydraulic piston. This allows the optical prism to enter the bottom at approximately 6 cm sec^{-1}. The slow fall rate ensures that the descending prism does not impact the bottom at a high rate and therefore minimizes disturbance of the sediment-water interface. The prism is driven several centimeters into the seafloor and the camera trigger is tripped so that a photograph is taken. The diver ensures that the SPI frame is not moved or disturbed in any way while the camera is taking a picture so that any physical disturbance of the sediment detected in a SPI image is not an artifact caused by the instrument itself.

DATA ANALYSIS

Images are captured using Canon EOS 450D digital SLR cameras (12 megapixel) and Nikkor optics and are stored on SD (secure digital) memory cards. They are downloaded to a laptop computer before being analysed in detail. The image analysis system used can discriminate a wide range of different grey scales, so subtle features can accurately be digitised and measured.

Customised software in conjunction with an image analysis system is used for the analysis of a series of 21 physical, chemical and biological parameters on each image. Before all measurements from each SPI image are stored on disk, a summary display is made on the screen so the operator can verify if the values stored in memory for each variable are within expected range; if anomalous values are detected, software options allow re-measurement before storage on disk. All data stored on disks are printed out on data sheets for editing by the principal investigator and as a hard-copy backup of the data stored on disk; a separate data sheet is generated for each SPI image. Disk storage of all SPI parameters allows any variable of interest to be compiled, sorted, graphed, or compared statistically.

A great deal of information about benthic processes is available from sediment profile images. Measurable parameters, many of which are calculated directly by image analysis, include physical / chemical parameters (i.e. sediment type measured as grain size major mode, prism penetration depth providing a relative indication of sediment shear strength, sediment surface relief, condition of mud clasts, redox potential discontinuity depth and degree of contrast, sediment gas voids) and biological parameters (i.e. infaunal successional stage of a well documented successional paradigm for soft marine sediments (see Pearson and Rosenberg, 1978), degree of sediment reworking, dominant faunal type, epifauna and infauna, apparent species richness, depth of faunal activity, presence of microbial aggregations).

A multi- parameter organism-sediment index (OSI) is calculated on the basis of the measured physical and biological parameters. This index characterises habitat quality and has been found to be an excellent parameter for mapping disturbance gradients and the health status of the seabed. Specific analytical and interpretative aspects of the parameters measured from the SPI images are outlined below.

SEDIMENT TYPE DETERMINATION

The sediment grain-size major mode and range are visually estimated from the photographs by overlaying a grain-size comparator, which is at the same scale. This comparator was prepared by using the SPI camera to photograph a series of pre-prepared sediments which were graded according to the Udden-Wentworth size classification scheme. The classes of sediment used ranged from mud to granule. There are seven grain-size classes are on the comparator, i.e. < 0.063mm (≥ 4ø) (i.e. silt clay), 0.063 -0.125mm (4-3ø) (i.e. very fine sand), 0.0125 - 0.25mm (3-2ø) (i.e. fine sand), 0.025- 0.5mm) (2-1 ø) (i.e. medium sand), 0.5 - 1.0mm (1-0ø) (i.e. coarse sand), 1.0 -2.0mm (0 to –(-)1ø) (i.e. very coarse sand), > 2.0mm (< -1ø) (i.e. gravel). Seven grain-size classes are on this comparator: ≥ 4ø, 4-3ø, 3-2ø, 2-1ø, 1-0ø, 0-(-)1ø, < -1ø. The lower limit of optical resolution of the photographic system is about 0.062mm, allowing recognition of grain sizes equal to or greater than coarse silt. The accuracy of the method has been documented by comparing the SPI estimates with grain-size statistics determined from laboratory sieve analyses.

PRISM PENETRATION DEPTH

The SPI prism penetration depth is determined by measuring both the largest and smallest linear distance between the sediment-water interface and the bottom of the digital image frame. The SPI analysis software automatically averages these maximum and minimum values to determine the average penetration depth. All three values,

(maximum, minimum, and average penetration depth) are included on the data sheets. Prism penetration is potentially a noteworthy parameter; if the number of weights used in the camera is held constant throughout a survey, the camera functions as a static-load penetrometer. Comparative penetration values from sites of similar grain-size give an indication of the relative sediment bearing capacity or shear strength.

SEDIMENT BOUNDARY ROUGHNESS

Sediment boundary roughness is determined by measuring the vertical distance (parallel to the digital image border) between the highest and lowest points of the sediment-water interface. In addition, the likely origin (e.g. physical or biogenic) of this small-scale topographic relief is indicated when it is evident. In sandy sediments, boundary roughness can be a measure of sand wave height. On silt-clay bottoms, boundary roughness values often reflect biogenic features such as faecal mounds or surface burrows.

MUD CLASTS

When fine-grained, cohesive sediments are disturbed, either by physical bottom scour or faunal activity (e.g. decapod foraging), intact clumps of sediment are often scattered about the seafloor. These mud clasts can be seen at the sediment-water interface in SPI images. During analysis, the number of clasts is counted, the diameter of a typical clast is measured, and their oxidation state is assessed. Depending on their place of origin and the depth of disturbance of the sediment column, mud clasts can be reduced or oxidised (in SPI images, the oxidation state is apparent from their reflectance value; see 'Apparent redox potential discontinuity depth' section below). Also, once at the sediment-water interface, these sediment clumps are subject to bottom-water oxygen levels and bottom currents. Based on laboratory microcosm observations of reduced sediments placed within an aerobic environment, oxidation of reduced surface layers by diffusion alone is quite rapid, occurring within 6-12 hours. Consequently, the detection of reduced mud clasts in an obviously aerobic setting suggests a recent origin. The size and shape of mud clasts, e.g. angular versus rounded, is also considered. Mud clasts may be moved about and broken up by bottom currents and/or animals (macro- or meiofauna) (Germano, 1983). Over time, large angular clasts become small and rounded. Overall, the abundance, distribution, oxidation state, and appearance of mud clasts are used to make inferences about the recent pattern of seafloor disturbance in an area.

APPARENT REDOX POTENTIAL DISCONTINUITY (ARDP) DEPTH

In fine-grained coastal areas, when there is oxygen in the overlying water column, the near surface sediment will have a higher reflectance value relative to hypoxic or anoxic sediment underlying it. This is because the oxidised surface sediment contains particles coated with ferric hydroxide (an olive colour when associated with particles), while the suphidic sediments below this oxygenated layer are grey to black. The boundary between the coloured ferric hydroxide surface sediment and underlying grey to black sediment is defined here as the apparent redox potential discontinuity (abbreviated as the RPD). This 'apparent' depth may, or may not, be equivalent to the actual RPD depth, which is defined as the depth at which the Eh = 0 as measured by microelectrodes. As explained below, in most cases, the depth of Eh = 0 potential in the sediment differs from the 'apparent' RPD as imaged by SPI.

The difference between the depth of the true RPD (Eh = 0) and the imaged apparent RPD can be explained as follows. As dissolved oxygen diffuses into sediment pore water, it is consumed by a variety of biological and geo-chemical reactions. One of these reactions involves the oxidation of iron, which is precipitated onto mineral grains located at, or near, the sediment surface. Once oxidised, these ferric hydroxide-coated particles are bioturbated downward into pore-waters, which lack free molecular oxygen (negative Eh). However, the ferric hydroxide coatings are meta-stable, and reduction of the iron is a slow process relative to the rate of bioturbation. This explains the presence of oxidised grain coatings (high optical reflectance sediment) in reducing pore waters. In the presence of bioturbating infauna, the thickness of the RPD directly reflects the particle bioturbation depth.

The areal extent of the RPD is determined by digitising its unique reflectance value. This oxidised, high-reflectance area is digitised, measured to scale, and divided by the prism window width to obtain a mean depth for the RPD (or particle bioturbation depth). The RPD depth is given special attention in these analyses, because it is a sensitive indicator of the biological mixing depth, infaunal successional status, and within-station sediment patchiness. In the absence of bioturbating infauna, the RPD will achieve a maximum depth of up to 5 mm solely by diffusion depending on the concentration gradient of dissolved oxygen, reducing substrates within the sediment, water temperature (reaction rates), and sediment permeability.

The configuration of the RPD boundary is also of significance. In sandy sediments, physical forces dominate surface relief and RPD depth, which tends to be constant or uniform and does not necessarily follow the surface contours provided by

bed-forms. In muddy sediments, the RPD is more complex and convoluted. Here, the RPD layers tend to be broadly uniform and more or less follow the contours of surface sediments. However, smaller scale convolutions are superimposed on this pattern in response to biogenic reworking by a resident infauna. Biogenic structures are regions of enhanced biological and geo-chemical activity where the activities of infaunal organisms can increase flux across the oxic-anoxic sediment interface (Diaz and Schaffner, 1988). Consequently, the RPD boundary is a complicated surface much greater in actual area than a simple aerial measurement would estimate and with a greater effect on sediment-water interface flux rates than is initially apparent (Diaz and Schaffner, 1988).

Another important characteristic of the RPD is the degree of contrast in reflectance values at this boundary. This contrast is related to the interactions among the amount of organic-loading and bioturbational activity in the sediment, and the levels of bottom water dissolved oxygen in an area. High inputs of labile organic material increase sediment oxygen demand, and subsequently sulphate reduction rates (and the abundance of sulphide end-products). This results in more highly reduced (lower-reflectance) sediments at depth and higher RPD contrasts. Although the SPI image analysis system quantifies the degree of contrast, this value can vary as a function of light intensity controls on the image analysis system, which are adjusted by the operator when a wide range of sediment types (e.g. silt-clay to coarse sand) is encountered. As a result, the quantified RPD contrast level may not be a meaningful parameter. However, a qualitative (visual) assessment of the RPD contrast (i.e. high versus low) is often considered in the interpretive process.

SEDIMENTARY METHANE

At extreme levels of organic-loading, pore-water sulphate is depleted, and methanogenesis occurs. The process of methanogenesis is detected by the appearance of methane bubbles in the sediment column. These gas-filled voids are readily discernible because of their irregular, generally circular aspect and glassy texture (due to the reflection of the strobe off the gas). If present, the number and total aerial coverage of all methane pockets is measured.

INFAUNAL SUCCESSIONAL STAGE

The mapping of successional stages is based on the theory that organism-sediment interactions follow a predictable sequence after a major seafloor perturbation. This theory states that primary succession results in the predictable appearance of macrobenthic invertebrates belonging to specific functional types following a benthic disturbance. These invertebrates interact with sediment in specific ways. Because

functional types are the biological units of interest, this definition does not demand a sequential appearance of particular invertebrate species or genera. This theory is now well established in the scientific literature (see Pearson and Rosenberg, 1978; Rhoads and Boyer, 1982; Rhoads and Germano, 1986).

The term disturbance is used here to define natural processes, such as seafloor erosion, changes in seafloor chemistry, foraging disturbances which cause major reorganisation of the resident benthos, or anthropogenic impacts, such as dredged material or sewage sludge dumping, thermal effluents from power plants, pollution impacts from industrial discharge, etc. An important aspect of using this successional approach to interpret benthic monitoring results is relating organism-sediment relationships to the dynamical aspects of end-member seres. This involves deducing dynamics from structure, a technique pioneered by Johnson (1972) for marine soft-bottom habitats. The application of an inverse methods approach to benthic monitoring requires the *in situ* measurements of salient structural features of the organism-sediment relationships measured through SPI technology.

Pioneering (Stage 1) species are the first to colonise a new or newly disturbed bottom and reach high densities in a short time. Pioneering (Stage I) assemblages usually consist of dense aggregations of tubicolous or otherwise sedentary organisms that live near the sediment surface and feed at the surface or from the water column (Pearson and Rosenberg, 1978; Rhoads and Germano, 1986). *Capitella capitata, Malacoceros fuliginosus* and Spionidae species are typical forms. These functional types are usually restricted to the near surface of the bottom and their sedimentary effects include (i) the construction of dense tube aggregations which can influence sedimentation/erosion, (ii) deepening of the redox boundary by fluid bioturbation, and (iii) the occlusion of the sediment surface with faecal pellets. These associations are typically characterised by a shallow redox boundary and shallow bioturbation depths, particularly in the earliest stages of colonisation.

In the absence of further physical, chemical or biological disturbance, the pioneering assemblages are replaced by deposit feeders. This is progressive and can be arbitrarily divided into an intermediate and an equilibrium phase (Stages II and III, respectively). Typical Stage II species are shallow dwelling bivalves, tubicolous amphipods and some polychaete species.

Stage III taxa, in turn, represent high-order successional stages typically found in low disturbance regimes. A Stage III or equilibrium assemblage is persistent and is dominated by a bioturbating infauna, which feed at depth within the sediment. Sedimentary effects are distinctive and include (i) the transfer of water and particles over vertical distances of 10 - 20 cm, (ii) the production of homogeneously mixed fabrics by intensive reworking, with faecal pellets at and below the sediment surface, (iii) the creation of void feeding spaces at depth within the bottom, (iv) the extension of the redox boundary to c. 20 cm, and (v) the production of a distinctive surface microtopography unless smoothed over by tidal resuspension. Such deep-dwelling species as the polychaetes, *Pectinaria* sp., Maldanidae sp., the echinoderm, *Trachythyone elongata, Amphiura sp*. and *Echinocardium sp*. and the crustaceans *Lysiosquilla* sp., *Nephrops* sp. and *Upogebia* sp. These invertebrates are infaunal, and many feed at depth in a head-down orientation. The localised feeding activity results in distinctive excavations called feeding voids. Diagnostic features of these feeding structures include: a generally semicircular shape with a flat bottom and arched roof, and a distinct granulometric change in the sediment particles overlying the floor of the structure. This relatively coarse-grained material represents particles rejected by the head-down deposit-feeder. These deep-dwelling infaunal taxa preferentially ingest the finer sediment particles. In the retrograde transition of Stage III to Stage I, it is sometimes possible to recognise the presence of relict (i.e. collapsed and inactive) feeding voids. (It should be added to the above generalisations that pioneering and higher successional species may coexist, if disturbance involves only the superficial sediment layers).

These end-member stages (Stages I and III) are easily recognised in SPI images by the presence of dense assemblages of near-surface polychaetes and/or the presence of subsurface feeding voids. Both types of assemblages may be present in the same image.

ADDITIONAL BIOLOGICAL PARAMETERS

Several additional biological parameters are measured from the digital images using the computer image analysis system. These include: the density per linear cm of polychaete and/or amphipod tubes at the sediment water interface; the minimum and maximum depth of faecal pellet layers and the minimum and maximum depth of feeding voids. Dominant faunal type (i.e. epifauna or infauna) and apparent species richness are also estimated.

SPI ORGANISM-SEDIMENT INDEX (OSI)

A multi-parameter SPI Organism-Sediment Index (OSI) has been constructed to characterise habitat quality and the method of its calculation is shown in Table 1.

The OSI is the sum of values allocated to the various physical/chemical and biological SPI parameters measured and it has a potential value range of -10 to +11. The Organism-Sediment Index is calculated automatically from the software after completion of all measurements from each digital image. This index has been found to be an excellent parameter for mapping disturbance gradients in an area and documenting eco-system recovery after disturbance.

Habitat quality is defined relative to two end-member standards. The lowest value is given to those bottoms which have low or dissolved oxygen in the overlying bottom water, no apparent macrofaunal life, and methane gas present in the sediment. The SPI OSI value for such a condition is minus 10. At the other end of the scale, an aerobic bottom with a deeply depressed RPD, evidence of a mature macrofaunal assemblage, and no apparent methane gas bubbles at depth will have a SPI OSI value of plus 11.

Chemical parameters	Index value	Biological parameters	Index value
Mean apparent RPD depth (cm)		**Successional stage (Primary succession)**	
0	**0**		
>0 - 0.75	**1**	Azoic	**-4**
0.76 - 1.50	**2**	Stage 1	**1**
1.51 - 2.25	**3**	Stage 1-2	**2**
2.26 - 3.00	**4**	Stage 2	**3**
3.01 - 3.75	**5**	Stage 2-3	**4**
>3.75	**6**	Stage 3	**5**
Methane Present	**-2**	**(Secondary succession)**	
No / low oxygen	**-4**	Stage 1 on Stage 2	**5**
		Stage 2 on Stage 3	**5**

Table 1. Method of calculating the Organism - Sediment Index (OSI) value.

From experience with mapping this parameter, values of +7 to +11 are typical of undisturbed sediments while values ≤ 6 tend to be found at sites which have experienced recent physical disturbance (e.g. bottom erosion by currents or disturbance of the bottom by scavenging fish or crustaceans) or are chemically stressed, organically loaded, sulphidic or contaminated in some way. In dealing with areas which are subject to organic enrichment (which may have a variety of origins ranging from natural runoff to anthropogenic inputs), OSI values in the range +6 to +1 generally indicate an overload situation where inputs exceed the capacity of the system and organic matter accumulates on the bottom. Index values which fall in the range +1 to -10 identify varying degrees of habitat degradation associated with a continual accumulation of organic matter and an oxygen depletion on the bottom. At the upper end of the scale, it has been found that OSI values of the order of +11 may reflect a productivity

enhancement stage of organic enrichment where natural plant and animal production is increase in response to the ready availability of particulate organic material.

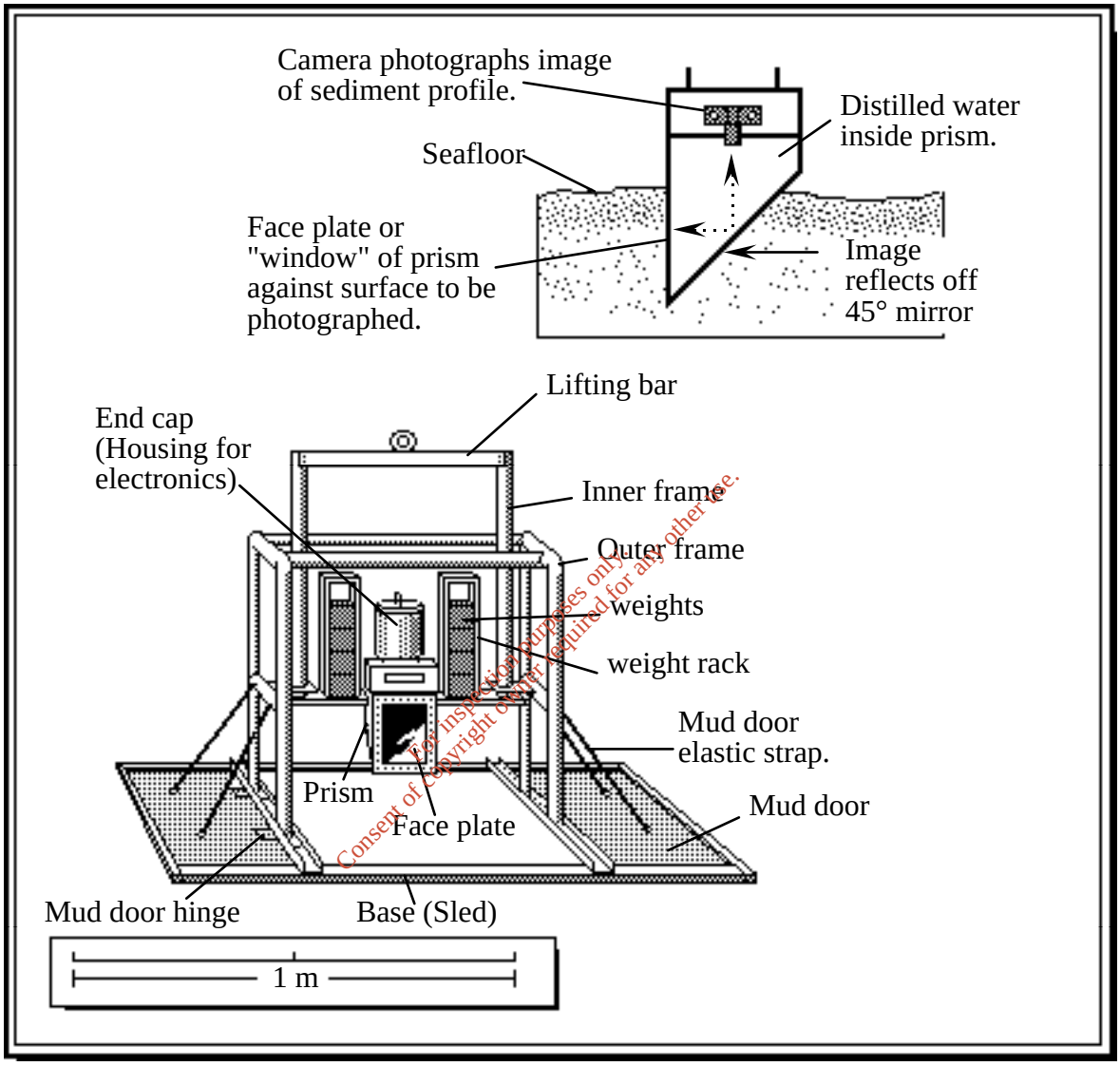


Figure 1. Representation of the remotely operated **S**ediment **P**rofile **I**magery camera.

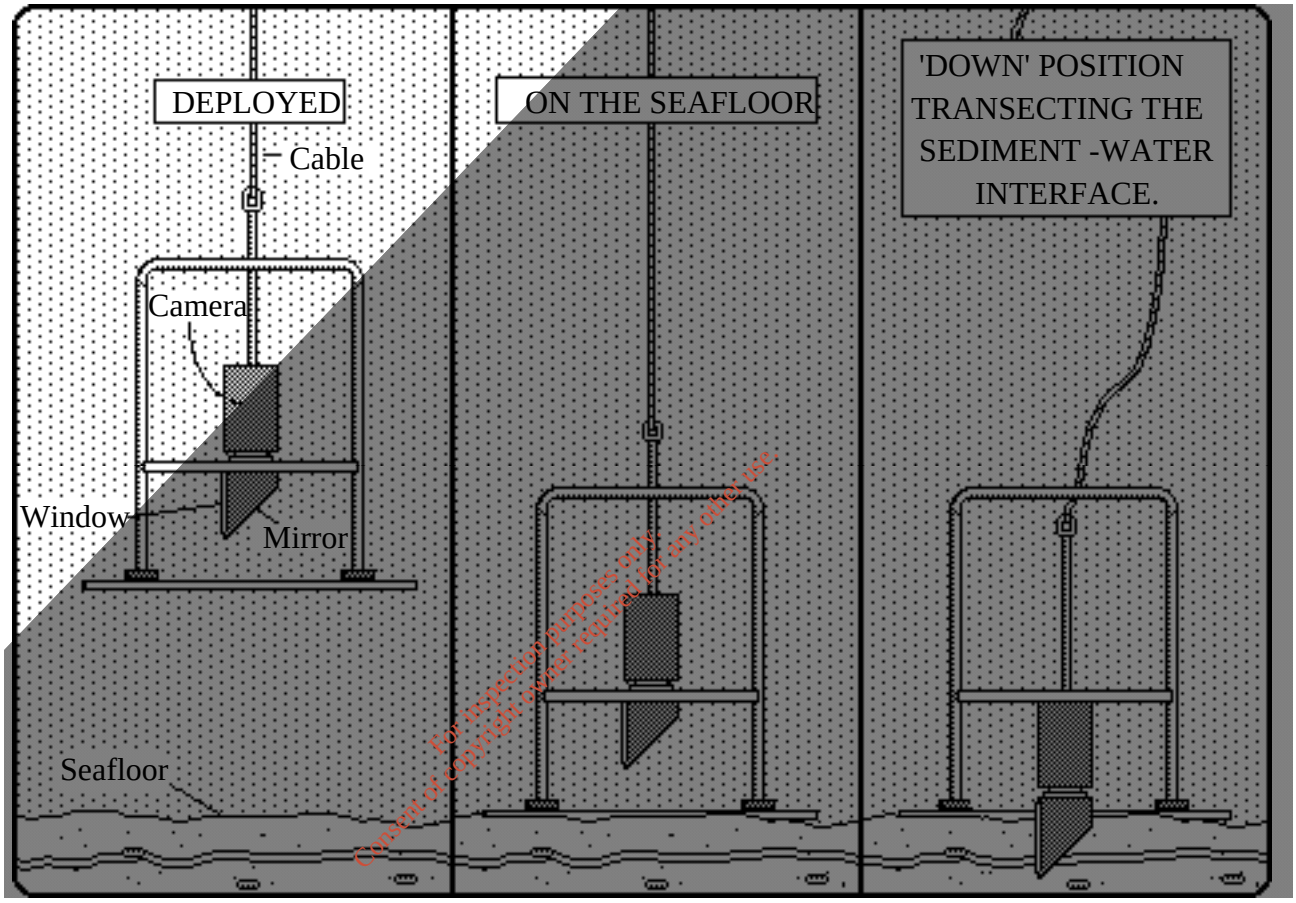


Figure 2. **S**ediment **P**rofile **I**magery (SPI): camera deployment on the seafloor.

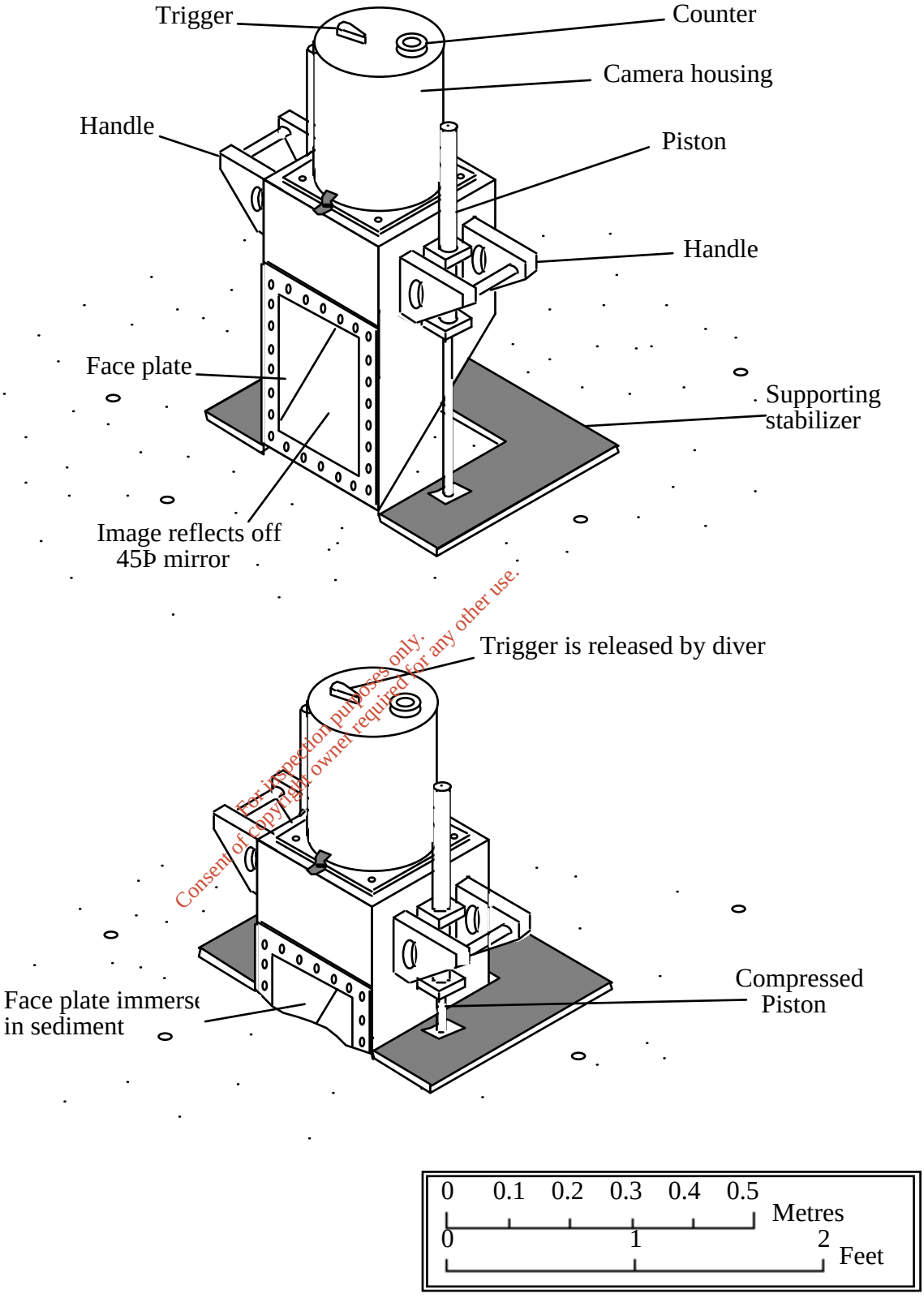


Figure 3. Details of the diver operated **S**ediment **P**rofile **I**magery (SPI) camera.

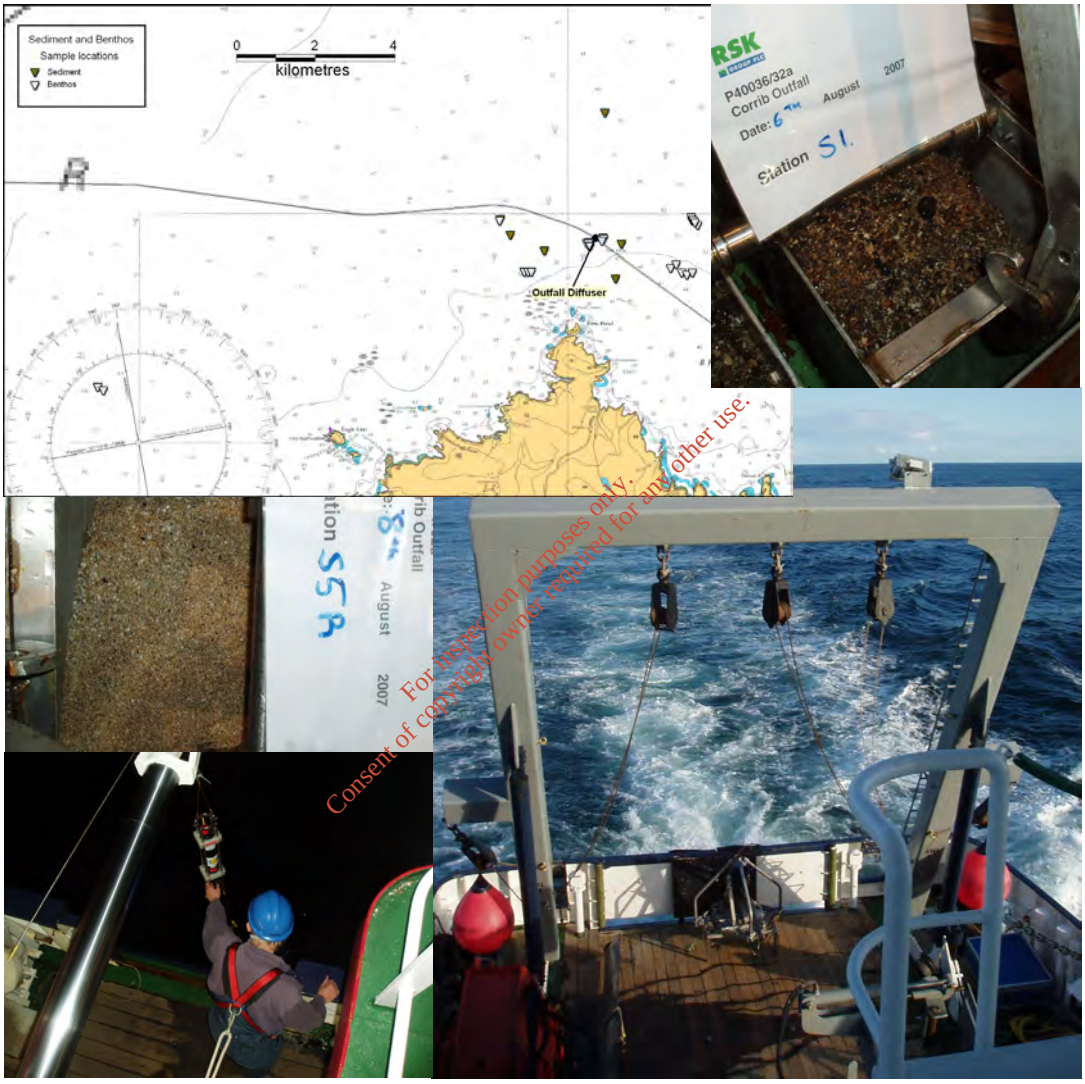
APPENDIX III

CORRIB GAS FIELD
SEDIMENT
PROFILE
IMAGERY
SPI
DATA TABLE

JULY 2008

Station	Pen(a)		Pen (b)		Pen(c)		Sed phi	Sed (Went)	SBRa	SBRb	SBRc	Stage
REF1	3.75	3.12	0.49	1.11	0.41	3.75	4-3	VFS	2.63	0.7	3.75	III
REF3	4.77	4.77	1.27	3.49	0	3.32	4-3	VFS	3.5	3.49	3.32	III
REF4	4.13	3.48	1.17	2.3	1.06	4.13	4-3	VFS	2.31	1.24	3.3	III
REF2	2.93	1.81	0	1.94	0	2.93	4-3	VFS	1.81	1.94	2.18	III
C4	3.73	3.35	0	2.97	0.4	3.73	4-3	VFS	3.35	2.57	2.16	III
F1	15.71	1.24	0.85	15.71	13.29	13.18	4-3	VFS	0.39	2.42	2.06	II
F2	3.6	2.31	0.33	3.46	1.65	3.6	4-3	VFS	1.98	1.81	3.6	III
F6	4.56	2.84	0	2.27	0	4.56	4-3	VFS	2.84	2.27	4.14	III
F7	5.34	4.78	0	3.74	1.5	5.34	4-3	VFS	4.78	2.24	2.72	III
F8	4.43	4.43	0	1.65	0	3.74	4-3	VFS	4.43	1.65	2.41	III
Z1	2.72	2.65	0	1.66	0	2.72	4-3	VFS	2.65	1.66	2.72	III
Z2	4.19	1.25	0	4.19	0.87	1.95	4-3	VFS	1.25	3.32	1.56	III
Z3	4.21	4.21	1.47	3.64	0.53	2.86	4-3	VFS	2.74	3.11	2.17	III
Z4	4.73	4.73	0	4.4	0.59	1.37	4-3	VFS	4.73	3.81	1.37	III
Z5	3.34	1.18	0.24	2.39	0	3.34	4-3	VFS	0.94	2.39	2.52	III
Z6	2.45	2	0.45	2.38	1.89	2.45	4-3	VFS	1.55	0.49	1.67	III
Z7	3.18	2.52	0	3.18	1.35	3.05	4-3	VFS	2.52	1.83	3.05	III
Z9	3.72	2.18	0.95	3.01	0.43	3.72	4-3	VFS	1.23	2.58	1.8	III

CORRIB OFFSHORE GAS FIELD DEVELOPMENT



CORRIB OUTFALL ENVIRONMENTAL SURVEY 2007

MARCH 2008

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1. Introduction

The Corrib Gas Field lies in approximately 350m of water, approximately 65km off the coast of County Mayo. The gas in the field is to be brought ashore using a 20-inch pipeline, which will landfall at Dooncarton in Broadhaven Bay. From there, the pipeline will be routed to the terminal at Bellanaboy Bridge. The plan of development for the field was approved in 2002, subject to various conditions.

Processing of the gas at the terminal will result in the production of waste water, which will be discharged back to sea through a pipeline (consented under an IPPC licence).

The proposed discharge location lies approximately 2km north of Erris Head in water depths of approximately 70m below chart datum. A baseline monitoring exercise was undertaken around the proposed Corrib outfall in June–August 2005 (EcoServe, 2006). This report documents the findings of a second survey around the outfall in 2007.

1.1 2007 Survey Objectives

The aim of the survey was to determine the ambient concentrations of a range of substances of concern (metals and persistent organics) in the water column, in sediments and in mussels.

This report describes the 2007 survey operations and sampling methodologies at the proposed outfall location, and presents the findings of the chemical analyses conducted on water, sediment and biological samples collected during the field assessment.

The survey plan for 2007 was to revisit the 17 locations around the outfall that were sampled in 2005 using the same sampling techniques as previous, so that the data generated would be comparable.

2. Survey Organisation and Methods

2.1 Survey Team

SEPIL contracted Osiris Projects to provide a vessel and crew to undertake the offshore survey work, providing accurate navigational services. RSK provided the scientific personnel for the survey, together with the majority of the survey equipment.

The mussel sampling was undertaken from the shoreline and was completed as a separate exercise by a two-man team of RSK surveyors.

2.2 Survey Vessel

Sampling operations were carried out from the research vessel *R/V Prince Madog*, jointly operated by University of Wales Bangor and Vosper Thorneycroft–Ocean Sciences. The *Prince Madog* (Figure 2-1) is a 34-metre dedicated research vessel, licensed for survey operations in continental shelf waters, as far as the shelf break.

Figure 2-1: ***R/V Prince Madog***

2.3 Survey Dates

Mobilisation of the Prince Madog commenced on 28th July and continued through 29th July, with the vessel leaving her berth in Menai Bridge later that day. Transit time from Menai Bridge to Killybegs was 1.5 days. The Prince Madog was effectively based out of Killybegs for the duration of the survey period.

The survey was forced to halt on several occasions due to poor weather conditions. The first survey operations were carried out on 31st July, with the remainder of the programme determined by weather and sea conditions. The objective was to collect as many samples as possible from the vicinity of the outfall pipeline, the pipeline route

and the Corrib field itself. Results from the Corrib field and along the pipeline route are not discussed further in this report. Final sampling around the outfall was completed on 8th August.

The mussel sampling was undertaken on 13th and 14th November 2007.

2.4 Survey Operations

During the survey operations along the pipeline route, the scientific personnel aboard worked according to two 12-hour watches, to enable sampling operations to continue over 24 hours. Each watch comprised three scientists with a dedicated shift leader.

The mussel collection part of the survey was undertaken during the hours of daylight in November, when tidal and weather conditions allowed the safe collection of samples.

2.5 Survey Navigation

Osiris Projects provided survey navigation. The following equipment was mobilised aboard the vessel for the survey:

- CSi dGPS max receiver;
- High-specification navigation PC supporting Quincy V8 (spare PC);
- TSS Meridian Gyro;
- Simrad HPR 400 subsea positioning system over-the-side mount; and
- Simrad 60 series single beam echo sounder.

The vessel's existing Trimble dGPS was used as a secondary navigation system. The survey was undertaken in WGS84 and recorded with both UTM Grid and geographical positions. The target accuracy for the survey was 30m for benthic samples, and 100m for water samples, although the sea conditions made achieving the target accuracy of 30m while undertaking benthic sampling extremely difficult.

Mussel sampling locations were determined from previous experience of the area and were based partly on the previous survey that took place in 2005. Sample sites were recorded using differential GPS.

2.6 Sampling Methods

Samples of the seabed sediment and of surface and bottom seawater were taken at the outfall diffuser location. In addition, at each water sampling location, a CTD depth profile was cast. A total of 10 locations were sampled for seabed sediment, and 17 locations for water sampling and CTD casts. The positions of these sites are shown in Figure 2-2 and Figure 2-3 respectively.

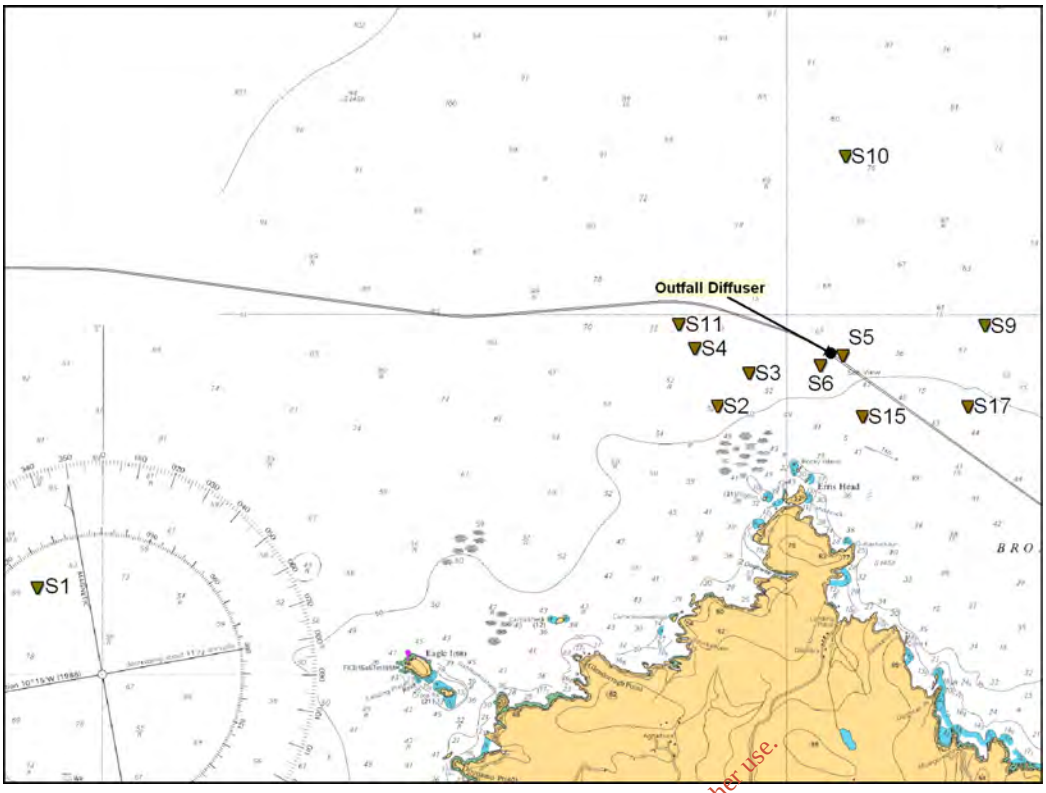

Figure 2-2: Locations of seabed sediment and benthos sampling

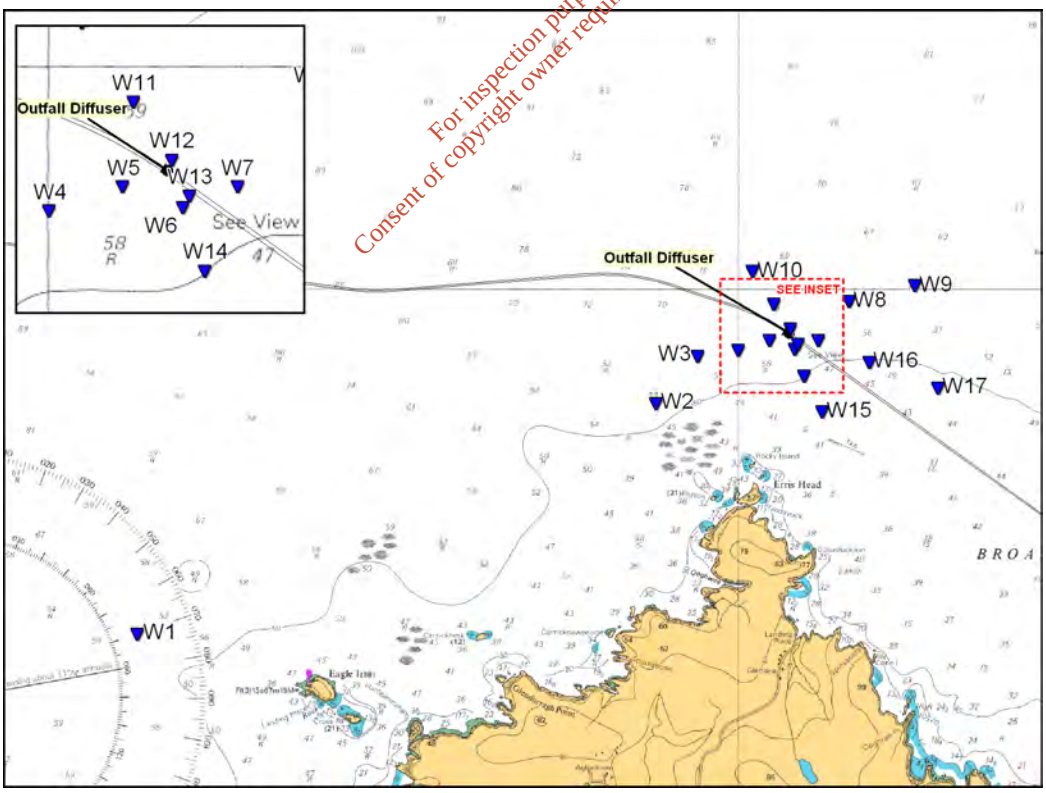

Figure 2-3: Locations of water sampling and CTD profiles

2.6.1 Sampling of Seabed Sediment

At each station, four replicate samples were taken, three were retained directly for macrofaunal analysis and the fourth was sub sampled for physico-chemical analysis.

A double Van-Veen grab (Figure 2-4) was provided for sediment collection, each bucket sampling an area of 0.1m^2. A day grab was provided as back up and sampled 0.1m^2 in a single bucket. The intention was to use the Van-Veen to reduce, where possible, the number of grab deployments necessary per station.

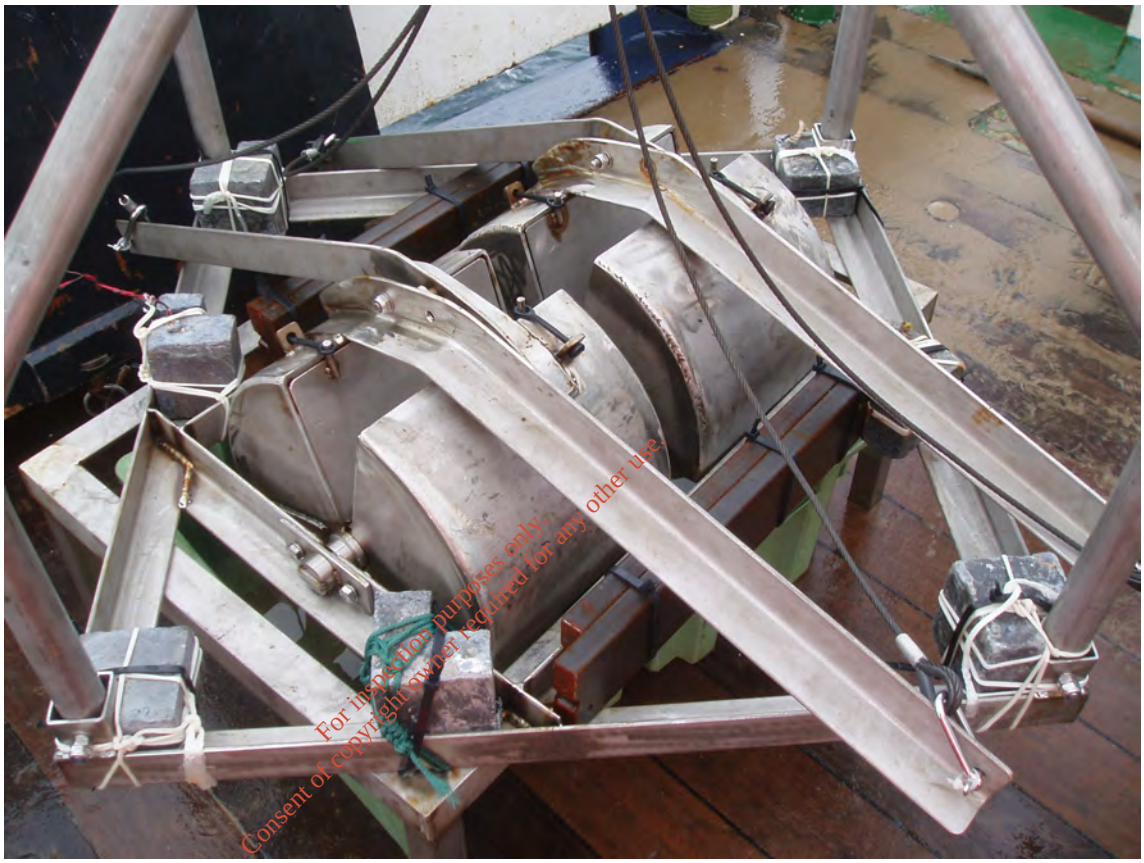

Figure 2-4: Photograph of double Van-Veen grab in "set" position

Figure 2-5 shows a photograph of a sample collected from outfall station S2 locations using the Van-Veen grab.

Figure 2-5: Sample replicate from the Van-Veen grab

In addition, the following information was recorded following the recovery of each grab:

- Position in UTM co-ordinates;
- Date;
- Time;
- Water depth;
- A visual inspection noting sediment type, colour, smell, vertical layering, clearly defined RDL (Redox Discontinuity Layer) with depth and biological comments;
- A digital surface photograph of the sample in the grab (minimum of one photo per site);
- A measurement of REDOX at 1cm, 5cm and 10cm (minimum one grab per site) where sufficient sediment sample was obtained. Depths were adjusted depending on sample size; and
- Volume of sediment (this was carried out *in situ* by measuring the depth of sediment in the centre of the grab).

2.6.2 Water Column Profiling

At each of the 17 water sampling stations, a conductivity, temperature and depth (CTD) probe was deployed. This device was lowered slowly to the seabed to record the above parameters as it moved through the water column. The CTD was lowered and raised at approximately 20m/min to ensure a good profile. The CTD was calibrated and data downloaded to the onboard computer between each deployment.

2.6.3 Discrete Water Sampling

Water samples were collected at all 17 locations near the proposed outfall diffuser. At each station, a sample of the surface water (approximately 1–2m below the sea surface) was collected. A sample was also taken of deep water at 5 of the 17 stations (approximately 5m above the seabed).

Seawater samples were taken using two primary pieces of equipment. The first, to sample sub-surface water, comprised a stainless steel extension pole fitted to a clamp holding a 2.5-litre opaque glass Winchester bottle was used. The bung was attached to a piece of fine rope, so that it could be removed remotely when the bottle was held at the correct depth. The Winchester bottles were pre-cleaned by acid washing before the survey, with a new bottle used at each station. To collect the required volume of sample, the Winchester bottle needed to be deployed twice.

Samples of the seawater close to the seabed were collected using the second piece of equipment: a five-litre Niskin water sampler. The Niskin sampler was thoroughly cleaned before its initial deployment and between each station. The Niskin sampler was deployed at each station in the open position and lowered to the required depth then a messenger was sent down the wire to trigger closing of the sampler, thus taking the sample.

At stations where deep-water samples were taken, a CTD was deployed directly below the Niskin sampler using the same wire on the hydrographic winch.

2.6.4 Mussel Sampling

A total of five sampling locations for mussels were selected prior to sampling (presented in Figure 2-6) based on their relative proximity to the outfall and to previous sampling events. Sampling was timed to coincide with low water during full daylight.

Four of the five locations were sampled successfully. Due to rough weather conditions and the exposed nature of the site, the foreshore at Annagh Head could not be sampled safely. Sampling locations were recorded on a hand-held GPS and photographed, although the digital camera was dropped into the sea and lost at Gubastuckaun.

Mussels (*Mytilus edulis*) were picked off the rocks by hand and placed into a clean plastic bag, which was placed into a second bag with internal labelling. With the exception of larger mussels (4–8cm) at station M6 (Rossport), all mussels were small (4cm or less) and likely to have been spatfall from the previous spring.

Figure 2-6: Mussel sampling sites

2.7 Sample Processing

2.7.1 Macrofaunal Samples

The three samples retained for macrofaunal analysis were sieved aboard the vessel using a Wilson Autosiever. This equipment sieves macrofaunal samples gently using a regulated curtain of seawater. The samples were sieved through a mesh of 500µm. The retained material was transferred into appropriate containers for preservation and storage on board the vessel. Samples were preserved using a solution of 10–20% buffered formaldehyde in seawater. The samples were then stored securely aboard the vessel at ambient temperature. A range of sizes of containers was used for the storage of macrofaunal samples, the size being dependent on the degree of reduction of the samples when sieved. An internal identification tag was placed inside the sample container and an additional ID label was fixed to the outside. At the end of the survey, the samples were transferred according to chain-of-custody procedures to the analytical laboratory (Hebog Environmental Ltd) for identification and enumeration.

2.7.2 Physico-chemical Samples

The fourth replicate collected for physico-chemical analysis was sub-sampled as follows:

- Two aliquots were taken for analysis of organic chemistry and sub-sampled into two acid-washed 300ml aluminium tins. These samples were taken directly into the tins from the top surface of the sediment in the grab, without using other sampling implements. The containers had an identifying label fixed to the outside.

- Two replicates were taken for particle size analysis. These sub-samples were taken from the top 5cm of the sediment in the grab sampler using a disposable plastic spoon and stored in a small, polythene Ziploc bag. The samples were then double bagged and an internal identification tag put between the two bags.

- A single replicate was taken for analysis of inorganic chemistry (trace metals and TOC). The sample was taken from the surface of the sediment in the grab using a disposable plastic spoon and stored in a 500ml plastic tub. An identification label was fixed to the outside of the container.

- A single additional replicate was taken as a separate sample for the analysis of mercury. This sample followed the same procedure as that of the inorganic chemistry sample.

All physico-chemical samples were taken by the same surveyor on each watch, who wore a pair of nitrile gloves (disposed of after each station, to avoid cross contamination). A new disposable plastic spoon was used for each sub-sample, with the exception of the organic chemistry sample.

All samples were taken from sediment that had not been in contact with the metal of the grab sampler. Between each deployment, the grab sampler was thoroughly rinsed and scrubbed clean to limit cross contamination between sampling locations.

All samples taken from the fourth grab replicate were frozen immediately following their processing. At the end of the survey, the samples were transferred to cold boxes containing ice packs. These samples were then transferred under chain-of-custody procedures to the various analytical laboratories.

The grain size, total organic carbon and metal analyses were undertaken by the UK Environment Agency Laboratory in Llanelli using UKAS or MCerts accredited methods. Sample analysis for organic compounds was undertaken by M-Scan Ltd, via a subcontract through Benthic Solutions Ltd. Mussel flesh analysis was also undertaken by the Environment Agency laboratory.

2.7.3 Water

Seawater samples were sub-sampled a number of times for a range of different analyses. A total of eight subsamples were taken for each surface and seabed water sample; the sampling regime, storage, preservation and pre-cleaning requirements of the containers are detailed in Table 2-1.

Care was taken to ensure that there was no contamination during water sampling. All personnel involved directly with sub-sampling wore a new pair of nitrile gloves at each station. Where the sub-sample containers were not pre-spiked with preservative, they were rinsed with sample water before being filled completely. Sub-sample containers were kept closed until the moment they were required and great care was taken to avoid contamination sources from the vessel while sub-sampling and direct water sampling.

Table 2-1: Water quality sub-samples

Analysis	Sample container	Preservative	Storage	Pre-cleaned?
Phenols	250ml glass	1-M H_2SO_4	Chilled	Yes
BTEX	250ml PET	-	Chilled	Yes
Suspended solids	1 litre PET	-	Chilled	Yes
Metals	125ml Polypropylene	-	Chilled	Yes
PAHs	1 litre glass	-	Chilled	Yes
Mercury	125ml Schott glass	1ml of 2.5% K-Dichromate in 50% HNO_3	Chilled	Yes
Ammoniacal N	125ml Polypropylene	-	Chilled	Yes
Arsenic	125ml Polypropylene	-	Chilled	Yes

2.7.4 *Mussels*

Mussels collected in the field were placed immediately into an insulated cool box containing ice packs. These were then delivered back to storage facilities in Belmullet and placed in a freezer within three hours of collection.

At the end of the two-day sampling period, all frozen mussel samples were packed into a cool box and surrounded with ice packs. These were delivered by the sampling team to a courier in Galway for next-day despatch to the Environment Agency laboratory in Llanelli, South Wales. All appropriate documentation was included in the shipment (letters of consents from Sea Fisheries Protection Authority and National Parks and Wildlife Service-Ireland, and DEFRA Animal Health Import Licence, UK).

3. Operations

In some areas, the sediments were of a nature that prevented the Van-Veen grab penetrating sufficiently. In these instances, it was necessary to use the day grab.

Samples were collected from all proposed stations for water and sediment.

It was not possible to collect mussels from one of the proposed locations due to poor weather conditions leading to unsafe access. An alternative “reference” location will be sought for future mussel sampling, which is less exposed to prevailing winds.

4. Results

4.1 Sediment Physical Data

Results from the grain size analysis of samples taken near the outfall are summarised in Table 4-1. Percentages present in all fractions sampled are presented graphically in Appendix A.

Table 4-1: Outfall grain size data summary

Sample	%			Median Grain Size (mm)	Mean Grain Size (mm)	Sediment Description (Udden-Wentworth)	Total Organic Carbon (%)
	Gravel	Sand	Mud				
S1	48.3	48.98	0	2.11	3.75	Very Coarse Sand	0.3
S2	8.23	91.84	0	0.12	1.29	Very Coarse Sand	1.7
S4	6.24	93.75	0	0.29	0.55	Medium Sand	0.33
S5	24.17	75.89	0	1.45	1.74	Very Coarse Sand	7.4
S5R	1.08	99.01	0	0.95	0.96	Coarse Sand	4.9
S6	7.23	92.69	0	0.51	0.82	Medium Sand	0.79
S6R	0	99.99	0	0.26	0.29	Medium Sand	0.32
S9	0	99.93	0	0.38	0.41	Fine Sand	0.69
S10	7.89	93.21	0.01	0.21	0.43	Medium Sand	0.28
S10 - *DUPLICATE*	0	100.04	0	0.19	0.21	Medium Sand	0.28
S11	8.87	91.13	0	0.70	1.02	Coarse Sand	1.6
S15	4.87	95.14	0	0.47	0.64	Medium Sand	5.1
S17	0	100.12	0	0.33	0.35	Medium Sand	0.63

NB. Udden-Wentworth descriptions calculated on mean of 16, 50 and 84 percentiles.

Grain size at the sampled sites ranged from fine sand through to very coarse sand. Mud was only recorded from one site (S10), and here only 0.01% of the sediment was <63µm. The majority of the sites contained "Medium Sand" as defined by the Udden-Wentworth scale (mean of 16, 50 and 84th percentiles is between 0.25 and 0.5µm), with S9 being the only one where the sediment can be described as fine (mean of 16, 50 and 84th percentiles is between 0.125 and 0.25µm). At all other sites, the sediment was coarse or very coarse sand. The exposed nature of the seabed off this area of the Mayo coastline dictates that most of the fine material is moved by tides and currents to more sheltered locations.

Total organic carbon levels are generally low (Table 4-1), as would be expected in sediments where there are very low levels of fine material (mud), with which organic material is usually associated. Most sites contain less than 1% organic material by weight, though site S5 (and the duplicate from this site, S5R) do contain 7.4 and 4.9% respectively, and site S15 contains 5.1%.

4.2 Sediment Chemical Data

4.2.1. Metals

Metal concentrations in sediments taken around the outfall during the 2007 survey are presented in Table 4-2.

Table 4-2: July/August 2007 results for metals in sediments

Station	Hg	Cd	Cr	Pb	As	Zn	Ba	Ni	Cu	LOI
S1	0.0053	0.198	12.7	12.9	14.9	16.5	10.2	9.75	6.06	0.89
S2	0.026	0.102	8.1	4.3	3.7	5.6	13.3	1.73	2.73	3.31
S4	0.007	1.780*	21.5	6.6	<1.0	11.2	3.31	1.23	3.37	1.69
S5	0.0056	0.268	7.6	5.8	5.7	5.3	13.9	1.48	2.49	3.07
S5R	0.0036	0.13	7.0	5.7	3.4	8.4	11.0	0.82	3.21	2.95
S6	0.0032	0.127	11.1	7.6	13.2	7.3	5.76	1.40	2.45	2.00
S6R	0.024	0.285	18.7	7.1	1.8	11.3	7.82	2.04	3.83	1.87
S9	0.0022	0.271	8.5	8.0	3.6	10.5	7.68	1.35	3.94	1.36
S10	0.0033	0.194	18.7	8.0	4.3	30.4	2.59	3.1	3.33	0.79
S11	0.011	0.31	9.1	6.5	10.4	6.7	6.6	2.13	3.04	3.19
S15	0.0018	0.082	9.6	8.0	2.4	11.8	7.91	1.32	3.95	1.60
S17	0.027	0.141	24.1	9.2	2.6	16.5	11.1	1.76	5.96	1.15

Note: All results expressed as mg/kg dry weight. NB. The cadmium concentration at station S4 is much higher than expected and the sample is being re-analysed.

Mercury

All reported mercury concentrations are very low (0.002–0.027mg/kg) and are similar to the lowest reported values for the North Sea and Cumbria coast. They are somewhat lower than typical background concentrations cited by OSPAR.

Cadmium

Although the cadmium concentrations do not appear to be anthropogenically impacted, the range 0.08–0.31mg/kg (S4 value of 1.78mg/kg is discussed below) is somewhat higher than for material from the central North Sea that has values as low as 0.01mg/kg and a mean of 0.050mg/kg. The observed range brackets the OSPAR BC (0.2mg/kg) and is well below levels anticipated that may give rise to any biological effect. The result from site S4 of 1.78mg/kg appears to be anomalous, though checks through the analytical information do not provide any indication of analytical error. If it is valid, the level of contamination present is above the upper limit of OSPAR's Environmental Assessment Criteria, but below the probable effects limit as proposed by Environment Canada (Table 4-3). The sample is being re-analysed to enable confirmation of the value. Duplicate samples will be taken from site S4 in the next pre-commissioning baseline survey to provide more robust information on the concentrations of cadmium there.

Chromium

The chromium results (7.0–24.1mg/kg) are consistent with the low end of the ranges reported by Taylor and Nixon for the Dee Estuary, Liverpool Bay and the Cumbria coast and lower than sediments collected off the west coast of Scotland. All results are below the accepted OSPAR BC by a factor of at least two.

Lead

Most lead values were <10mg/kg, generally lower than published values for other sea areas and apparently lower than the OSPAR BC by a factor of two.

Arsenic

Arsenic concentrations were typically <5mg/kg with a few stations exceeding 10mg/kg reflecting a situation similar to the central North Sea. Both data sets are consistent with the BC of 15mg/kg. Concentrations of arsenic in the sediments of Donegal Bay are known to be higher than most other areas around Ireland due to the local geological conditions.

Zinc

With the exception of Station S10 (30.4mg/kg), most zinc values were <10mg/kg, which are similar to the lowest reported findings for Liverpool Bay (which receives contaminated run-off from the Mersey and was formerly a site for sea disposal of sewage sludge and dredging spoil) and the North Sea. The data are well below the accepted BC (90mg/kg).

Barium

Data for other near-shore sea areas are sparse, making comparisons difficult. Barium is used as an indicator of the presence of drilling muds used in the oil and gas industry, and the observed range (2.59–13.9mg/kg) in the vicinity of the proposed outfall is similar to that recorded from sites along the pipeline route (0.67–11mg/kg) (Corrib Offshore EIS supplementary report 2008), and much lower than those observed in the Corrib Field itself (25–4550mg/kg – 2001 Offshore EIS).

Nickel

With the exception of Station S1 (9.75mg/kg), most sites had nickel values <2mg/kg consistent with the low end of the ranges reported for allegedly non-impacted locations. All values were significantly lower than the BC (30mg/kg).

Copper

Most sites fall into the range 2–4mg/kg with two sites *c*. 6mg/kg. Again, these finding are in accord with the lowest values reported by others and are below the BC (20mg/kg).

To put these results into context, Table 4-3 presents a comparison of the range of concentrations found near the proposed outfall with OSPAR and Environment Canada guidelines. The 2007 results are compared further with data from other locations around Ireland and Britain (Table 4-4).

The sediments collected around the proposed outfall were fairly coarse: none of the sites had material <63µm, the fraction that is frequently chosen in studies to determine the extent of anthropogenic impact. Under these circumstances, it is to be expected that contaminant concentrations would be quite low and this in general was found to be the case.

Table 4-3: Observed range around proposed Corrib Outfall and guideline concentrations

Metal mg/kg	Corrib Outfall range 2007	OSPAR *BC	OSPAR EAC lower limit	OSPAR EAC upper limit	Environment Canada TEL	Environment Canada PEL
Hg	0.002-0.027	0.05	0.05	0.50	0.13	0.70
Cd	0.08-0.31	0.2	0.10	1.00	0.676	4.21
Cr	7.0-24.1	60	5.00	50.00	52.3	160
Pb	5.8-12.9	25	5.00	50.00	30.3	112
As	<1.0-14.9	15	1.00	10.00	7.24	41.6
Zn	5.3-30.4	90	10.00	100.00	124	271
Ba	2.59-13.9	-	-	-	-	-
Ni	1.23-9.75	30	5.00	50.00	15.9	42.8
Cu	2.45-6.06	20	5.00	50.00	18.7	108

Note: *BC Background Concentration. OSPAR Agreement 2005–6. – formerly termed Background Reference Concentration (BRC). OSPAR EAC – Ecotoxicological Assessment Criteria (provisional); TEL – Threshold Effects Limit; PEL – Probable Effects Limit

Table 4-4: Comparison of published data for metals in sediments from UK and Irish coastal waters (mg/kg).

Author(s)	Locality	Hg	Cd	Cr	Pb	As	Zn	Ba	Ni	Cu
Corrib 2007	Erris Head	0.002–0.027	0.08–0.31	7.0–24.1	5.8–12.9	<1.0–14.9	5.3–30.4	2.59–13.9	1.23–9.75	2.45–6.06
Taylor, 1986	Urr Water	0.03–0.17	0.8–1.3	3.8–7.5	11.5–34.1	No data	24.8–65.0	No data	6.1–14.3	1.9–12.1
	Dee	0.02–1.0	0.1–1.2	2.9–66.2	6.0–15.2	No data	27.6–3480	No data	3.0–34.9	0.9–56.8
	Liverpool Bay	0.01–1.44	0.3–2.1	0.5–35.9	6.9–101	No data	9.4–327	No data	1.2–16.5	1.8–33.7
Nixon, 1995	Cumbria Coast	0.005–0.17	0.007–0.46	10.7–85.8	10.3–69.7	No data	22.4–129.4	No data	No data	1.8–49.4
FRS & SEPA 1998	Scottish waters Minches	0.05	0.018	57	24	4.3	45	No data	6.4	7.3
NSTF, 1993	North Sea	75% of samples <0.025	0,010–0.38 mean 0.050	No data	1.7–288 mean 21	1.2–33 mean 11	3–510 mean 39	No data	1.5–113 mean 23	0.1–87 mean 14

With the exception of the cadmium result at Station S4 (1.78mg/kg), possibly the zinc value (30.4mg/kg) at Station S10 and the nickel (9.75 mg/kg) at Station S1, the data

reflect conditions that would be expected for a site with little or no anthropogenic impact.

Quality Control

A certified reference material (CRM) was provided to the Environment Agency laboratory with the outfall area sediment samples. The CRM contained documented levels of various trace metals, and was analysed at the same time as the field samples. The results from the analysis of the CRM, together with the documented levels from the material are presented in Table 4-5, the similarity between the results obtained and the certified levels show that we can be confident in the results reported from the outfall area samples.

Table 4-5: Analyses of certified reference materials (supplied by National Research Council Canada)

Sediment (MESS-3) mg/kg		
Metal	EA data	Reference value
As	19.3	21.2
Cd	0.325	0.24
Cr	86.3	105
Cu	No data	33.9
Pb	21.5	21.1
Ni	36.6	46.9
Zn	134	159
Ba	8.53	No data
Al	43400	No data
Ag	<10	0.18
Hg	0.079	0.091

4.2.1. Hydrocarbons

Total Organic Extracts (TOE)

The total organic extracts were analysed to detect any saturate hydrocarbons (including anthropogenic hydrocarbons such as drilling related base-oils) that may be present in the sediment. The concentrations of TOE have been calculated from the GC analyses and are shown in Table 4-6. TOE concentrations ranged from 0.69µg/g at Station S17 to 13µg/g at Station S10 (duplicate). Concentrations of TOE in these samples are considered consistent with 'background' levels as previously seen in the offshore Corrib field (Benthic Solutions Limited, 2006). Benthic Solutions Limited was responsible for analysis and reporting of the organics data for the current project, and the complete report is attached as Appendix B to this document. References to appendices in the following paragraphs relate to appendices to the Benthic Solutions report.

Comparison with similar data, from surveys in the North Sea oil and gas fields (including both baseline studies and reference background stations from around fields where drilling operations have taken place), suggests that the background concentration of total hydrocarbons typically ranges between 1ppm and 10ppm (1–10mg/kg). This agrees with data from the North Sea Task Force (NSTF 1993) and Law (Law *et al.*, 1982), although other studies have shown higher concentrations (e.g. McIntosh *et al.*, 1983; 10–60ppm in sediments between the Firth of Forth and the Forties field).

Apart from the internal standards, the GC traces show clear evidence for the presence of a number of resolved peaks. The TOE of sample S2 was further analysed by GC-MS to characterise these components. They include a range of fatty acids (dominated by C_{14} (myristic), C_{16} (palmitic) and C_{18} (stearic) acids), sterols, long chain alcohols and long-chain ($C_{39–42}$) ketones, which have been previously identified in the North Sea sediments and in the marine coccolithophore *Emiliana huxleyi*. These are all considered to be of biogenic rather than petrogenic origin, and confirm a very low level of petrogenic contamination within the sediments.

The GC traces preclude the presence of the three synthetic base oils previously identified in the Corrib field development ("Ecosol", "Ecomul" and "Esterkleen"). The base oil "Ecomul" comprises almost entirely of paraffins, while "Esterkleen" is based upon 45–70% 2-ethyl-hexyloleate. The base oil "Ecosol" is 60% paraffins, 20% poly-alpha olefins and 20% linear alpha olefins. For comparison, a GC trace of the "Ecosol" base oil from previous analyses is included as *Appendix 1*. This base oil was spiked into a portion of a sample from along the pipeline route (Station 25) at 52.7ppm. This was extracted and analysed in parallel with the other samples, and the trace is shown as *Figure 22 (Appendix II)*. The measured concentration of the base oil in the extracted sediment was 49.9ppm.

There was also no evidence in the sediments for the presence of base oils of mineral origin (e.g. "low-tox" or diesel).

A portion of pre-extracted sediment was utilised as a "trip" blank. This sediment was extracted and the data included for comparison with a portion of pre-extracted sediment retained within the laboratory. The chromatograph for the trip blank sample showed evidence for a series of resolved peaks between 22 and 30 minutes, and a narrow-range UCM (unresolved complex mixture) between 30 and 34 minutes. Inspection of the GC-MS data of the aromatic fraction for this sample indicates that the UCM comprises mixed long-chain phthalates, which are widely used as plasticisers. The source of this contamination is unclear. However, these components were not detected in the sediments analysed, and so they are not considered significant in this context.

Table 4-6: Concentrations of total organic extractables (TOE)

Station	TOE (µg/g; ppm)
S1	2.2
S2	8.2
S4	10
S5	5.9
S5R	9.5
S6	2.7
S6R	4.5
S9	1.1(0.89)
S10	8.1
S10 D	13
S11	6.6
S15	0.96
S17	0.69
Pre-extract	1.2
Trip Blank	30

4.2.3. Polycyclic Aromatic Hydrocarbons (PAHs)

Concentrations of PAHs in the sediments are given in Table 4-7 includes naphthalenes, phenanthrenes and dibenzothiophenes (NPD) and the sixteen priority PAHs defined by the US EPA.

Table 4-7: Concentrations of 2-6 ring PAHs (ng/g (ppb); dry weight basis)

Station No.	S1	S2	S4	S5	S5R	S6	S6R	S9	S10	S10 D	S11	S15	S17
Naphthalene	0.23	0.04	0.21	Nd	Nd	2.3	0.62	1.6	Nd	0.01	Nd	0.11	0.04
C_1-Naphthalenes	Nd	0.17	0.28	0.09	0.12	4.7	2	3.9	Nd	0.37	Nd	0.16	Nd
C_2-Naphthalenes	Nd	Nd	1.2	Nd	1	4.3	2.3	3.4	Nd	1.5	Nd	Nd	Nd
C_3-Naphthalenes	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
C_4-Naphthalenes	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Total Naphthalenes	0.23	0.21	1.7	0.09	1.1	11	4.9	8.9	Nd	1.9	Nd	0.27	0.04
Phenanthrene	0.02	0.04	0.08	0.03	0.02	0.27	0.13	0.08	Nd	0.11	0.1	Nd	0.06
C_1-Phenanthrenes	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
C_2-Phenanthrenes	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
C_3-Phenanthrenes	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Total Phenanthrenes	0.02	0.04	0.08	0.03	0.02	0.27	0.13	0.08	Nd	0.11	0.1	Nd	0.06
Dibenzothiophene	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
C_1-Dibenzothiophenes	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
C_2-Dibenzothiophenes	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
C_3-Dibenzothiophenes	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Total DBT	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Total NPD	0.25	0.25	1.8	0.12	1.1	11	5	9	Nd	2	0.1	0.27	0.1
Acenaphthylene	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Acenaphthene	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Fluorene	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Anthracene	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Fluoranthene	0.1	0.04	0.17	0.1	0.09	Nd	0.12	Nd	0.1	0.16	0.13	Nd	0.08
Pyrene	0.04	0.03	0.11	0.05	0.06	Nd	0.04	Nd	0.07	0.08	0.18	Nd	0.15
C_1-Fluoranthenes/ Pyrenes	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
C_2-Fluoranthenes/ Pyrenes	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
C_3-Fluoranthenes/ Pyrenes	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Benzo(a)anthracene	Nd	Nd	0.05	0.05	0.06	Nd	Nd	Nd	Nd	0.1	0.04	Nd	Nd
Chrysene	Nd	Nd	0.09	0.1	0.08	Nd	Nd	Nd	Nd	0.07	0.11	Nd	Nd
C_1-Benanthracenes/ Chrysenes	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
C_2- Benanthracenes/ Chrysenes	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Benzo(b)fluoranthene	0.07	0.04	0.12	0.15	0.1	Nd	0.1	Nd	0.15	0.38	0.31	Nd	Nd
Benzo(k)fluoranthene	0.06	0.01	0.19	0.08	0.04	Nd	0.04	Nd	0.1	0.09	0.05	Nd	Nd
Benzo(a)pyrene	0.01	Nd	0.08	0.09	0.04	Nd	0.03	Nd	0.07	0.11	0.07	Nd	Nd
C_1-Benzofluoranthenes/ Benzpyrenes	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
C_2-Benzofluoranthenes/ Benzpyrenes	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Indeno(1,2,3-cd)pyrene	0.07	Nd	0.24	0.16	0.16	Nd	0.14	Nd	0.29	0.3	0.17	Nd	Nd
Dibenzo(a,h)anthracene	0.02	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	0.05	Nd	Nd	Nd
Benzo(ghi)perylene	0.11	Nd	0.22	0.16	0.29	Nd	0.14	Nd	0.25	0.27	0.13	Nd	Nd
Total EPA 16	0.73	0.21	1.6	0.97	0.93	2.6	1.4	1.7	1.03	1.7	1.3	0.11	0.33
4-6 Ring PAH/NPD	2.92	0.84	0.89	8.08	0.85	0.24	0.28	0.19	Nd	0.85	13	0.41	3.3

PAHs and their alkyl derivatives have been recorded in a wide range of marine sediments (Laflamme & Hites, 1978) with the majority of compounds produced from what are thought to be pyrolytic sources. They are the combustion products of organic material from processes such as forest fires (Youngblood & Blumer, 1975), the burning of fossil fuels and, in the case of offshore oilfields, flare stacks, etc. The resulting PAHs, rich in the heavier weight 4-6 ring aromatics, are normally transported to the sediments via atmospheric fallout or river run-off. Another PAH source is petroleum hydrocarbon, often associated with localised drilling activities. These are rich in the lighter, more volatile 2 and 3 ring PAHs (NPD; naphthalene (128), phenanthrene, anthracene (178) and dibenzothiophene (DBT) with their alkyl derivatives).

The concentrations of NPD range from not detectable to 11ng/g (Station S6) (Table 4-7). The concentrations of NPD in these samples are considered consistent with 'background' levels previously seen in the sediments around the Corrib field development (Benthic Solutions Limited, 2006), which are generally similar to the background levels observed in the North Sea (Davies *et al*., 1984).

The concentrations of the EPA 16 PAHs range from 0.11ng/g (Station 15) to 1.7ng/g (Station S9). These values, again, are generally similar to those observed in the 'background' levels previously seen around the Corrib Field development (Benthic Solutions Limited 2006), and are also generally similar to the background levels observed in North Atlantic sediments. Data from surveys around North Sea fields and the North Atlantic suggest that the background concentrations of the EPA16 PAH concentrations typically range up to 50ng/g.

The above findings are in accord with the latest OSPAR background concentrations (OSPAR, 2005–6) (see Table 4-8) and, in general, are lower than the quoted values.

Table 4-8: BCs and provisional BACs for PAHs in sediments (OSPAR, 2005–6)

PAH	Sediment (µg kg^{-1} dry weight normalised to 2.5% organic carbon)	
	BC	*BAC*
Naphthalene	5	8
Phenanthrene	17	32
Anthracene	3	5
Fluoranthene	20	39
Pyrene	13	24
Benz[*a*]anthracene	9	16
Chrysene	11	20
Benoz[*a*]pyrene	15	30
Benzo[*ghi*]perylene	45	80
Indeno[123-*cd*]pyrene	50	103

4.3 Seawater Monitoring and Seawater Quality Results

4.3.1. CTD Profiles

Data recorded during the conductivity, temperature and depth (CTD) meter deployments at each of the sampling sites are summarised in Table 4-9. The range in depths across the sites was 50–90m, with site W1 being located in the deepest water, and sites 15 and 17 being located at the shallowest water. Appendix C presents the temperature and salinity profiles for each site surveyed.

Table 4-9: Depth profiles at water quality sampling locations

Site	Depth (m)	Temp		Salinity	
		Surface*	Seabed	Surface*	Seabed
W1	89.5	15.83	12.14	35.16	35.24
W2	57.0	15.22	14.78	35.05	35.03
W3	78.000	15.08	13.97	35.05	35.11
W4	58.5	14.80	13.35	35.06	35.11
W5	68.5	15.11	14.71	35.05	35.07
W6	66.6	15.16	14.72	35.05	35.07
W7	69.0	14.54	13.03	35.07	35.12
W8	83.5	15.05	13.42	35.04	35.15
W9	54.0	15.27	14.32	35.06	35.07
W10	77.1	15.25	14.12	35.05	35.11
W11	72.5	15.33	14.48	35.05	35.08
W12	72.0	15.39	14.64	35.06	35.07
W13	70.0	15.10	14.20	35.06	35.10
W14	59.0	15.26	14.70	35.05	35.07
W15	50.5	15.15	14.71	35.05	35.07
W16	59.0	15.38	14.78	35.05	35.06
W17	51.0	14.87	14.73	35.06	35.07

* Surface readings are taken from 5m below surface

Salinity

As would be expected in a coastal area with little freshwater run-off, there was no evidence of any significant salinity differences in the surface waters or through the water column at each station (see Appendix C). The range in salinities recorded was 34.6 to 35.4ppt.

Temperature

This was not the case for the observed temperatures both at the surface but more significantly over depth at each site. Unfortunately, due to the prevailing weather conditions, it was not possible to carry out this aspect of the work synoptically. The data were captured over a five-day period (2nd August and 5th/6th August).

At station W1, marked thermal stratification was evident: at this deepest of all sites, the maximum temperature (15.82°C) at the surface and lowest temperature (12.13°C) at the seabed were recorded. The temperature profile (Figure 4-1**)** is typical of summer conditions in temperate latitudes (Open University, 1989). It is notable that below 40m the water at this location was approximately 1°C colder than observed in the slightly shallower water around the outfall site. The profiles at W4 and W7 were taken soon after that collected from S1 (within two hours). At these locations, there was also significant thermal structure with both sites having similar temperatures at the surface (*c*.14.8°C) and discernibly cooler water at the seabed. It is noteworthy that the surface water was significantly cooler (*c*.1°C) than observed shortly earlier, 14 miles to the West at Station S1. With the weather deteriorating, no further observations could be made.

Data for the remaining stations were collected approximately 72 hours later. Over this period, the tidal range had decreased from 3.1m to 2.1m with a corresponding decrease in the tidal streams. There had also been a spell of adverse weather requiring the vessel to suspend survey work. On 3rd August, the wind strength increased to SW Force 9. It is difficult to judge to what extent these factors influenced the findings. In general, relative to the stations that were worked three days earlier, most of the sites to the east

showed considerably smaller temperature differences through the water column. It was also observed that the surface waters were marginally cooler (*c*.0.5°C). This may be related either to wind-induced turbulence or perhaps to greater tidal mixing, albeit with smaller tides, at the sites closer to Erris Head.

Although these data were collected a few weeks later in the year than the EcoServe survey carried out in July 2005, water temperatures were 1–1.5°C higher.

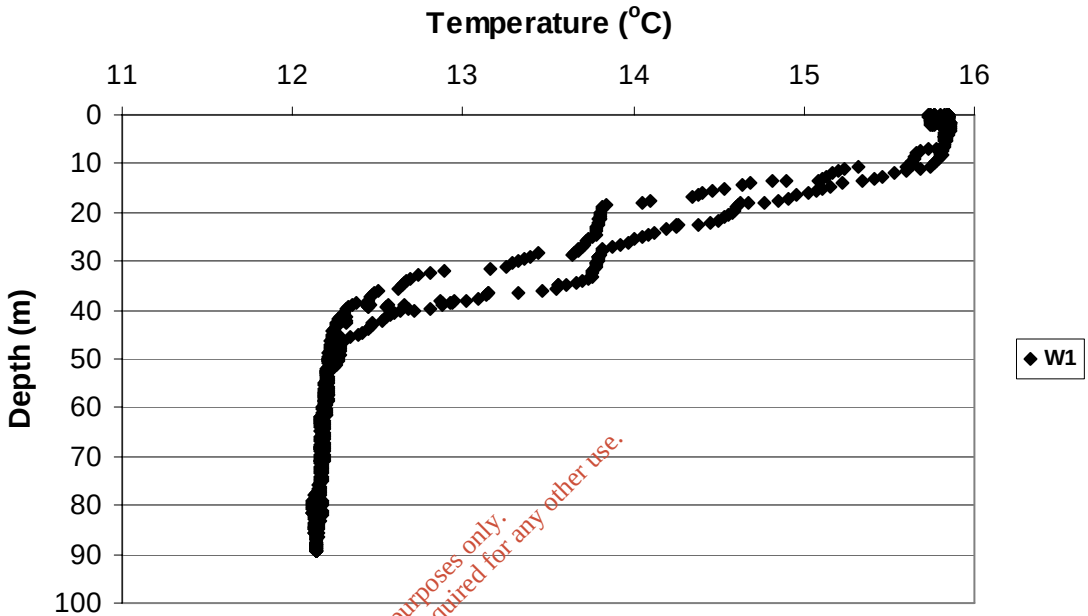

Figure 4-1: Temperature – depth profile from site W1

4.3.2. *Water Samples*

Water samples were collected from the surface at all sites, and from near the seabed at 5 of the 17 water sampling sites. The results of all analyses are presented in Appendix D.

Suspended Particulate Matter (SPM)

Most of the sites had concentrations at the surface less than the MRV (minimum reporting level) – 3 $mg.l^{-1}$, which provide an indication of the high clarity of these coastal waters.

Ammoniacal Nitrogen

In situations with significantly elevated concentrations of reduced nitrogen (NH_3), such as estuaries and harbours, the concern is with respect to the concentration of un-ionised ammonia: the chemical species that is toxic to fish. To determine whether the Environmental Quality Standard (EQS, 21$\mu g.l^{-1}$) is exceeded demands precise measurements of salinity, temperature and pH to compute the equilibrium concentrations from the total concentration routinely determined analytically. In the

open sea, total concentrations are much smaller than those found in inshore waters and, consequently, toxicity from un-dissociated ammonia is not an issue in such locations.

The concentrations of ammoniacal nitrogen in the vicinity of the outfall are presented in Table 4-10.

Table 4-10: Ammoniacal nitrogen (µg/l) concentrations at water sampling locations

Station	NH_3 ($\mu g.l^{-1}$)		Station	NH_3 ($\mu g.l^{-1}$)
W1	<10.0		W9	15.0
W1(bottom)	<10.0		W9(bottom)	<10.0
W2	10.0		W10	<10.0
W3	<10.0		W11	12.0
W4	60.0		W12	<10.0
W4(bottom)	<10.0		W13	20.0
W5	16.0		W13(bottom)	<10.0
W6	<10.0		W14	106.0
W7	33.0		W15	31.0
W7(bottom)	<10.0		W16	28.0
W8	12.0		W17	<10.0

Surface water at five of the stations had concentrations lower than the MRV ($10\mu g.l^{-1}$) as did all the bottom samples (Table 4-10). The other samples ranged from $10\mu g.l^{-1}$ to a maximum of $106\mu g.l^{-1}$. No obvious pattern could be discerned in the distribution, possibly indicating natural patchiness even over such relatively small distances, rather than an artefact of the analytical difficulties at these low levels.

It seems unlikely that the reduced nitrogen is influenced by land run-off and could possibly be generated *in situ* as excretion products from grazing zooplankton (autochthonous rather than allochthonous inputs). None of the bottom waters had concentrations exceeding the MRV ($10\mu g.l^{-1}$) possibly, as with the temperature profiles, indicative of limited exchange from the surface.

Data in the literature are sparse but values as low as 0.2µM (*c*.$3\mu g.l^{-1}$) have been reported (UKNMMP, 2004). Winter concentrations < $10\mu g.l^{-1}$ have been observed off the Cumbrian coast (UK Environment Agency – unpublished). The "summer" values reported here almost certainly reflect the situation that these waters are not significantly anthropogenically perturbed.

Metals

The results reported here refer to unfiltered seawater. It should be noted that published data are usually derived from samples filtered immediately after collection or later, prior to analysis (UK NMMP, 2004). As these waters have very low SPM concentrations, the difference between "total" and "dissolved" concentrations would be expected to be minimal.

The observed ranges in the vicinity of the outfall are presented in Table 411. With the exception of arsenic, copper, lead nickel, zinc and mercury, all the reported values were less than their respective (certified) MRVs as indicated in Table 411.

Table 4-11: Minimum reporting values in relation to background/guideline concentrations

Metal	Observed Range (µg.l^{-1})	Typical Atlantic Ocean (µg.l^{-1})	MRV (µg.l^{-1})	EQS (µg.l^{-1})	BRC (µg.l^{-1})	EAC(µg.l^{-1})
Arsenic	1.09–1.56	1.4	1	25	–	
Cadmium	All < 0.04	0.005–0.01	0.04	2.5	0.004–0.025	0.01–0.10
Copper	< 0.2–2.45	0.07–0.15	0.2	5	0.05–0.36	0.005–0.05
Lead	< 0.04–0.545	0.001–0.014	0.04	25	0.005–0.02	0.5–5.0
Mercury	<0.01–0.01*	0.0001–0.0004	0.01	0.3	0.0001–0.0005	0.005–0.50
Zinc	0.97–8.42	0.1	0.25	40	0.03–0.45	0.5–5.0
Nickel	<0.25–1.10	0.2	0.4	30	0.16–0.26	0.1–1.0
Chromium	All < 0.5	0.3	0.5	15	0.09–0.12	1.0–10
Silver	All <1.0	0.002	1	-	-	
Barium	All <100	20	100	-	-	

* - range quoted above is from accredited Environment Agency method. IAEA range from non-accredited method was 0.0048–0.0215µg.l^{-1}

Although the reported values (Table 411) are above the very low levels reported for oceanic waters by a number of academic and governmental organisations, in no instance were any concentrations observed that would give rise to concern, all being significantly less than the respective EQSs. At some sites, however, the results for copper, and to a lesser extent for zinc, exceed the provisional OSPAR Ecotoxicological Assessment Criteria. Assessments made using current EACs, however, should be treated with extreme caution (UKNMMP, 2004). (It should be noted that OSPAR is reviewing these guidelines, which have been renamed 'environmental assessment criteria'.)

Mercury

With the exception of one station (W10), all mercury concentrations reported by the UK Environment Agency Laboratory were below the MRV (0.01µg.l^{-1}) and even at this site the concentration was only just detectable, i.e. 0.01µg.l^{-1}. Consequently, duplicate samples were sent to International Atomic Energy Agency (IAEA) Laboratory in Monaco. Whilst this laboratory was able to achieve a lower MRV, their analytical method for mercury is not accredited. The reported values from the IAEA analyses were in the range 0.0048 to 0.0215µg.l^{-1}.

Whilst these values are not disturbing, they should be considered in context with recently reported data from the Celtic Sea and north of Scotland (0.0002–0.0005µg.l^{-1}) and the North Atlantic (0.0001–0.0004 µg.l^{-1} – MON, 1998).

Arsenic

All stations had positive arsenic concentrations in the range 1.09–1.56µg.l^{-1}. There was no clear spatial distribution readily evident but at several sites, the bottom water had slightly higher concentrations. Reported background concentrations for Atlantic waters are of the order of 1.4µg.l^{-1} (OSPAR, 1993)

Cadmium

All stations had cadmium concentrations < MRV (0.04µg.l^{-1}). Reported values for Atlantic waters are typically 0.004–0.012µg.l^{-1} (MON, 1998).

Copper

Most sites had copper concentrations between 0.25 and 0.4µg.l^{-1}. Again, it was difficult to discern any clear spatial coherence in the data. The elevated values in both surface and bottom water at the reference station (S1), 2.45 and 2.08µg.l^{-1} respectively should be viewed with some circumspection given consistently lower results from what is effectively a continuous water mass. There a few reported observations for the west of Ireland but these results are consistent with data from Bantry Bay where a mean value of 0.31µg.l^{-1} has been recorded at similar salinities (Marine Institute, 1999).

Lead

Only one station (W3) had a lead concentration below the MRV (0.04µg.l^{-1}). It is interesting to note that the value at W1 (0.545µg.l^{-1}) is an order of magnitude greater than at the adjacent stations in the outfall grid W2 (0.055µg.l^{-1}) and W3 (<0.04µg.l^{-1}). These data, however, are somewhat higher than expected: reported observations for stations in the Celtic Sea and Bristol Channel are generally less than 0.05µg.l^{-1} (Marine Institute, 1999). Atmospheric deposition is often suggested as the mechanism giving rise to patchiness in dissolved lead concentrations: clearly, over the small area around the outfall, this not a plausible explanation.

Nickel

As was the case for lead, only one station (W3) had a nickel concentration below the MRV (0.25µg.l^{-1}). All other samples were in the range 0.3–0.4µg.l^{-1} with a maximum of 1.10µg.l^{-1} recorded at the far field station W1. The values are in reasonable accord with reported concentrations for background levels in Atlantic waters (Marine Institute, 1999).

Zinc

Zinc concentrations ranged from < 1.0 to a maximum of 8.42µg.l^{-1} at site W4. At this location, there was apparently a significant difference between the surface and bottom water (1.8µg.l^{-1}). This was also the case at station W7 but not so at stations W1, W9 and W13. As most of the depth profiles indicate a well-mixed water column with respect to salinity, it is difficult to explain these anomalies. In general, the concentrations were higher than reported levels from the Celtic Sea (typically <1 µg.l^{-1}, Marine Institute, 1999).

Chromium

All chromium concentrations were below the MRV (0.5µg.l^{-1}) background Atlantic values are reported to be in the range 0.090–0.120 µg.l^{-1} (OSPAR, 2006).

Silver

All silver concentrations were below the MRV (1.0µg.l^{-1}). This is well above background values for oceanic waters that are reported to be 0.002µg.l^{-1}

Barium

All barium concentrations were below the MRV (100 µg.l^{-1}) Again, this is above the values for oceanic waters that are reported to be *c*.20µg.l^{-1}

Quality Control

A certified reference material (CRM) was provided to the Environment Agency laboratory with the outfall area water samples. The CRM contained documented levels

of various trace metals, and was analysed at the same time as the field samples. The results from the analysis of the CRM, together with the documented levels from the material are presented in Table 4-12, the similarity between the results obtained and the certified levels show that we can be confident in the results reported from the outfall area samples.

Table 4-12: Analyses of CRM (supplied by National Research Council Canada)

		Water (SLEW-3) µg.l^{-1}
Metal	EA data	Reference value
As	1.55	1.39
Cd	0.05	0.048
Cr	<0.5	0.183
Cu	1.34	1.55
Pb	<0.04	0.009
Ni	1.26	1.23
Zn	<0.40	0.201
Ag	<1.00	0.003

As part of its QC procedures, the IAEA laboratory used reference material BCR 579, issued by the Institute for Reference Materials and Measurements (IRMM). The IAEA obtained results within 10% of the certified value for that reference material. Again, this gives confidence that the results provided by the IAEA for mercury analyses are close to their true value.

4.4 Mussel Flesh Analyses

Mussels collected from four sites (M2, M3, M4 and M6) around Broadhaven Bay (Figure 2-6) have been analysed to determine tissue levels of a range of heavy metals and polycyclic aromatic hydrocarbons.

The analytical data are presented in Table 4-13 and Table 4-14. In all cases, the results were very low, reflecting, in common with the water and sediment results, the pristine nature of the local environment.

Metals

With the exception of silver, all determinands had concentrations above the MRV.

In general, the findings were consistent with published background reference concentrations (BRCs) (OSPAR, 2005–6) and in accord with levels reported for Irish waters (Table 4-15, Marine Institute, 1999).

As a note of caution, Bryan *et al.* (1985) reported that mussels are “unreliable” indicator species for copper, zinc, arsenic, and silver, and have “moderate” usefulness for nickel. Mussel body burdens of these metals should therefore be interpreted carefully.

Table 4-13: Metal concentrations in mussels (*Mytilus edulis*) from Broadhaven Bay area

	MRV*	Guidance	OSPAR BRC	Rinroe Point		Sruwaddacon		North Inver		Gubastuckaun	
Analyte	mg/kg DW	mg/kg WW	mg/kg WW	mg/kg DW	mg/kg WW**	mg/kg DW	mg/kg WW**	mg/kg DW	mg/kg WW**	mg/kg DW	mg/kg WW**
Arsenic	0.1			11.2	2.03	8.77	1.74	14.6	2.18	15.40	2.49
Mercury	0.001		0.005–0.010	0.04	0.01	0.043	0.01	0.087	0.01	0.074	0.01
Barium	0.3			1.06	0.19	1.700	0.34	2.66	0.40	2.38	0.39
Lithium	0.1			1.15	0.21	0.880	0.17	2.93	0.44	1.84	0.30
Silver	0.1			< 0.1	N/A	< 0.1	N/A	< 0.1	N/A	< 0.1	N/A
Iron	0.3			196	35.48	358	70.88	860	128.14	679	110
Sulphate	0.1			33200	6009	29700	5881	37800	5632	40600	6577
Sulphur	0.1			11100	2009	9900	1960	126	1877	13500	2187
Cadmium	0.01	1[a]	0.07–0.11	0.76	0.14	0.33	0.07	2.12	0.32	0.67	0.11
Chromium	0.05			2.88	0.52	3.05	0.60	4.19	0.62	7.99	1.29
Copper	0.1		0.76–1.10	4.85	0.88	4.09	0.81	6.14	0.91	7.6	1.23
Lead	0.2	1.5[a]	0.010–0.19	0.41	0.07	0.26	0.05	1.15	0.17	2.48	0.4
Manganese	0.2			22.2	4.02	24.7	4.89	52.5	7.82	27.6	4.47
Nickel	0.3			1.66	0.30	1.05	0.21	3.71	0.55	3.23	0.52
Zinc	0.2		11.6–30.0	82.9	15.00	57.9	11.46	91.7	13.66	96	15.55

* MRV=Minimum reporting value (i.e. limit of detection)
**Data reported in dry weight (DW); wet weight (WW) derived from conversion factors from analysing laboratory based on % dry solids of sample
[a] Maximum permitted levels in bivalve molluscs for human consumption, as per EC 1881 (2006)

Table 4-14: PAH concentrations in mussels (*Mytilus edulis*) from Broadhaven Bay area

	MRV*	Guidance		OSPAR BRC	Rinroe Point		Sruwaddacon		North Inver		Gubastuckaun	
Analyte	mg/kg WW	mg/kg WW	mg/kg DW	mg/kg WW	mg/kg WW	mg/kg DW**	mg/kg WW	mg/kg DW**	mg/kg WW	mg/kg DW**	mg/kg WW	mg/kg DW**
Acenaphthene	0.0005				< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A
Acenaphthylene	0.0005				< 0.0005	N/A	< 0.000930	N/A	< 0.000610	N/A	< 0.000880	N/A
Anthracene	0.0005		0.005–0.05[b]	0.001	< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A
B(a)anthracene	0.0005			0.0015	< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A
B(a)pyrene	0.0005	0.01[a]	5–50[b]	0.001	< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A
B(b)anthracene	0.0005				< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A
B(b)fluoranthene	0.0005				< 0.000880	N/A	< 0.000760	N/A	< 0.0005	N/A	< 0.0005	N/A
B(e)pyrene	0.0005				< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A
B(ghi)perylene	0.0005			0,0025	< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A
B(k)fluoranthene	0.0005				< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A	0.000500	0.0031
Chrysene	0.0005			0.0065	0.000850	0.0047	0.000850	0.0043	0.000580	0.0039	0.000660	0.0041
DiB(ah)anthracene	0.0005				< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A
Dibenzothiophene	0.0005				< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A
Fluoranthene	0.0005		1–10[b]	0.007	< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A
Fluorene	0.0005				0.000570	0.0031	< 0.0005	N/A	0.001300	0.0087	< 0.0005	N/A
I(123cd)pyrene	0.0005			0.002	< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A
Naphthalene	0.001		0.5–5[b]	0.001	< 0.01060	N/A	< 0.01250	N/A	0.01360	0.0913	< 0.00616	N/A
Perylene	0.0005				< 0.000520	N/A	< 0.000660	N/A	< 0.0005	N/A	< 0.0005	N/A
Phenanthrene	0.001		5–50[b]	0.0045	< 0.00100	N/A	< 0.00100	N/A	< 0.00100	N/A	< 0.00100	N/A
Pyrene	0.0005		1–10[b]	0.0055	< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A	< 0.0005	N/A

* MRV=Minimum reporting value (i.e. limit of detection)
**Data reported in wet weight (WW); dry weight (WW) derived from conversion factors from analysing laboratory based on % dry solids of sample
[a] Maximum permitted levels in bivalve molluscs for human consumption, as per EC 1881 (2006)
[b] OSPAR Ecotoxicological Assessment Criteria levels (these values are provisional).

Table 4-15: Concentrations of metals from Irish shellfish growing areas

Metal	Mean concentrations +/- standard deviation mg/kg wet weight
Mercury	0.02 +/- 0.01
Cadmium	0.15 +/- 0.04
Lead	0.15 +/- 0.12
Copper	1.45 +/- 0.16
Zinc	17.6 +/- 3.4
Chromium	0.25 +/- 0.12

Individual metal results

Arsenic

There are few reported results for Irish waters. In 1994, Nixon *et al*. reported that average concentrations were 0.66mg/kg, somewhat lower than those presented here (1.74–2.49 mg/kg).

This may well be due to local geological factors as similar, slightly elevated, concentrations were found in sediments (see Section 4.2.1).

In UK waters, tissue concentrations in the range 0.94 to 7.47mg/kg have been found (UKNMMP, 2004).

Mercury

Regular monitoring has shown that concentrations rarely exceed 0.1mg/kg around the Irish coast, below standards set to protect public health. Mussels in the Broadhaven area have even lower levels and are consistent with the recognised BRC (0.005–0.010mg/kg).

Silver

Specimens from all four sites had values <MRV (0.1mg/kg).

Cadmium

Three sites had levels as anticipated for background locations (0.07–0.11mg/kg). At North Inver, levels were slightly higher (0.32mg/kg) but still below concentrations that would give for concern.

Copper

Typical background concentrations (0.76–1.10mg/kg) were found at each site.

Lead

Although the concentration at Gubastuckaun (0.40mg/kg) was somewhat higher, the background levels (0.010–0.19 mg/kg), this is still below values that would be of concern.

Zinc

All values were consistent with established background values (11.6–30mg/kg).

Polycyclic Aromatic Hydrocarbons

The majority of results were <MRV. Only four determinands (benzo(k)fluoranthene, chrysene, fluorine and naphthalene) had positive results. Chrysene was recorded in mussels from every sampling station. Other PAHs were recorded at concentrations above the MRV at only one or two locations.

The concentrations were all very low and there was no exceedance of the OSPAR Environmental Advisory Concentrations (EAC) for those PAHs for which these have been proposed. Likewise, the results are all below OSPAR BRCs (Table 4-14).

Table 4-16: BCs and provisional BACs for PAHs in mussels (OSPAR, 2005–6)

PAH	Mussel (µg kg^{-1} dry weight)	
	BC	*BAC*
Naphthalene	1	81,2
Phenanthrene	4,5	12,6
Anthracene	1	2,7
Fluoranthene	7	11,2
Pyrene	5,5	10,1
Benz[*a*]anthracene	1,5	3,6
Chrysene	6,5	21,8
Benoz[*a*]pyrene	1	2,1
Benzo[*ghi*]perylene	2,5	7,2
Indeno[123-*cd*]pyrene	2	5,5

Summary

Analyses of mussel tissue confirm the findings from other matrices that this locality is free from significant anthropogenic influences.

4.5 Biological Data

4.5.1 Univariate Analysis

A number of common ecological indices were calculated for replicate and pooled replicate (per site) data. These summarise, by means of a single number, information about some aspect of community structure.

Species numbers and abundances for macrofauna are shown on a replicate (Table 4-17) and site (Table 4-18) basis. The percentage of each phylum that makes up the community at each site is also shown in Table 4-18. Species that are encrusting and/or colonial are included in the number of species per replicate and site but were excluded from abundance counts.

Table 4-17: Univariate indices by replicate for sample sites around the Corrib outfall

Station	No. species (including encrusting species)	No. individuals	Pielou's Evenness	Shannon-Weiner Diversity (log_e)	Simpson's Dominance index
1-A	63	259	0.90	3.69	0.03
1-B	69	262	0.86	3.56	0.05
1-C	69	255	0.85	3.55	0.05
2-A	42	2035	0.41	1.54	0.39
2-B	44	2128	0.35	1.29	0.52
2-C	39	1100	0.48	1.73	0.32
4-A	58	216	0.81	3.28	0.07
4-B	51	181	0.85	3.32	0.06
4-C	54	198	0.80	3.18	0.08
5-A	91	1325	0.64	2.89	0.12
5-B	77	1108	0.60	2.62	0.17
5-C	63	545	0.69	2.86	0.15
5R-A	50	750	0.59	2.30	0.23
5R-B	51	901	0.45	1.77	0.44
5R-C	54	968	0.41	1.63	0.46
6-A	49	445	0.79	3.07	0.07
6-B	76	443	0.82	3.48	0.05
6-C	66	414	0.83	3.49	0.05
6R-A	99	1326	0.67	3.07	0.11
6R-B	92	897	0.76	3.36	0.06
6R-C	57	141	0.85	3.43	0.06
9-A	59	204	0.87	3.49	0.05
9-B	64	279	0.80	3.31	0.07
9-C	58	290	0.81	3.28	0.07
10-A	63	338	0.77	3.20	0.08
10-B	83	398	0.78	3.46	0.07
10-C	72	385	0.79	3.37	0.08
11-A	50	229	0.87	3.38	0.05
11-B	42	139	0.86	3.23	0.06
11-C	50	387	0.80	3.11	0.07
15-A	43	177	0.83	2.89	0.08
15-B	53	300	0.81	3.17	0.07
15-C	51	321	0.78	2.99	0.08
17-A	24	61	0.84	2.60	0.12
17-B	25	86	0.86	2.75	0.09
17-C	39	117	0.91	3.27	0.05

Species numbers and abundances were high at the majority of sites. Per site, the number of species ranged from 55 to 172 per $0.1m^2$, whilst abundances ranged from 88 to 1754 individuals per $0.1m^2$.

Diversity was moderate to high at all sites, ranging from 1.53 at site 2 to 3.98 at site 1. Diversity at sites 2 and 5R was the lowest throughout the sampling area due to the high numerical dominance of the polychaete *Spio filicornis* as reflected in the relatively high dominance values for this site (0.42 and 0.38 respectively). Dominance by a single or small group of species was not observed in the rest of the dataset, with values for Pielou's evenness being approximately 0.6 or more and all dominance scores being less that 0.15.

Table 4-18: Univariate indices by replicate for sample sites adjacent to the proposed outfall

						% of each phyla				
	S	N	J'	H'	λ	Annelida	Crust	Mollusca	Echino	Other
1	125	259	0.84	3.98	0.03	59.28	16.88	4.90	5.41	13.53
2	73	1754	0.36	1.53	0.42	81.85	1.58	1.67	0.08	14.82
4	93	198	0.78	3.50	0.06	34.96	24.20	27.39	9.24	4.20
5	117	993	0.61	2.90	0.13	47.48	7.49	3.56	12.39	29.08
5R	83	873	0.45	2.00	0.38	86.37	2.37	4.01	1.53	5.73
6	109	434	0.77	3.58	0.05	67.28	7.22	8.29	6.14	11.06
6R	172	788	0.68	3.48	0.07	71.24	7.40	3.64	3.13	14.59
9	100	258	0.79	3.61	0.05	24.77	29.70	33.59	8.69	3.24
10	123	374	0.73	3.51	0.07	53.97	8.12	15.08	5.08	17.75
11	93	252	0.81	3.66	0.04	61.19	13.25	8.48	5.30	11.79
15	88	266	0.75	3.22	0.07	40.73	23.43	18.55	8.27	9.02
17	55	88	0.83	3.24	0.07	22.35	47.73	17.05	9.47	3.41

S = Number of species (including encrusting species)
N = Number of individuals
J' = Pielou's Evenness
H'= Shannon-Weiner Diversity ($\log_e$)
λ = Simpson's Dominance index

Ranked taxa illustrating the 10 most abundant species at each site are shown in Table 4-19. Annelids comprised the highest percentage of animals at the majority of sites in the sampling area with the maximum being recorded at site 5R (86%). However, at sites 4, 9 and 17 no one phyla dominated as high contributions to community composition from Annelida, Mollusca and Crustacea were observed. For example at site 4 although annelids made up approximately 35% of the community, crustaceans and molluscs contributed 24% and 27% respectively. Animals from the phyla Mollusca and Crustacea were also found to make up more than 10% of the community at four sites. Additionally, throughout the dataset, other phyla such as Nematoda and Nemertea proved to be important components, occurring at all sites and comprising 29% at site 5.

Numerically, the most dominant animal was the spionid polychaete *Spio filicornis*, but this was due to its extremely high densities at sites 2 and 5R - it was found in much lower abundances (or was absent) at other sites. At seven of the sites (1, 2, 5, 5R, 6, 6R and 11), nematodes and the interstitial polychaetes *Polygordius* and *Pisione remota* were found in high abundances. At the other sites (4, 9, 10, 15 and 17), organisms such as the molluscs *Abra prismatica* and *Moerella pygmaea* and the sea urchin *Echinocyamus pusillus*, more typical of finer, sandy environments, were present.

Table 4-19: Top 10 ranked taxa list for sites adjacent to the Corrib outfall (taxa comprising the top 50% (approx.) of the population are in bold. Abundances are per 0.1m^2)

1		2		4		5		5R		6	
Nematoda	**26**	**Spio filicornis**	**1102**	**Abra prismatica**	**29**	**Nematoda**	**271**	**Spio filicornis**	**529**	**Pisione remota**	**48**
Galathea intermedia	**17**			**Aonides paucibranchiata**	**27**	**Polygordius sp. indet**	**218**			**Polygordius sp. indet**	**43**
Polygordius sp. Indet	**13**	Nematoda	239	**Moerella pygmaea**	**15**	**Ophiuroidea**	**56**	Pisione remota	62	**Nematoda**	**33**
Protodorvillea kefersteini	**11**	Pisione remota	97	**Bathyporeia elegans**	**13**			Nematoda	33	**Streptosyllis bidentata**	**24**
Pisione remota	**10**	Polygordius sp. indet	68	**Argissa hamatipes**	**10**	Amphipholis squamata	50	Moerella pygmaea	24	**Moerella pygmaea**	**23**
Glycera lapidum	**9**	Protodorvillea kefersteini	61	**Echinocyamus pusillus**	**8**	Polygordius appendiculatus	33	Opisthodonta pterochaeta	19	**Spio filicornis**	**19**
Atylus vedlomensis	**9**	Polygordius appendiculatus	39			Sphaerosyllis bulbosa	25	Enchytraeidae	19	**Enchytraeidae**	**18**
Aonides paucibranchiata	**8**	Hesionura elongata	19	Copepoda	8	Pisione remota	25	Polygordius sp. indet	16	**Opisthodonta pterochaeta**	**17**
Mediomastus fragilis	**8**	Moerella pygmaea	16	Echinocardium flavescens	6	Guernea coalita	25	Hesionura elongata	16		
Polynoidae	**7**	Glycera lapidum	13	Nephtys juvs.	5	Glycera lapidum	23	Polygordius appendiculatus	13	Polygordius appendiculatus	14
		Copepoda	12	Glycera oxycephala	4	Syllis ?'H'	19	Protodorvillea kefersteini	11	Protodorvillea kefersteini	11
No. of individuals	259	No. of individuals	1754	No. of individuals	198	No. of individuals	993	No. of individuals	873	No. of individuals	434
50% of individuals	129	50% of individuals	103	50% of individuals	99	50% of individuals	497	50% of individuals	437	50% of individuals	217

6R		9		10		11		15		17	
Polygordius sp. indet	**156**	**Abra prismatica**	**30**	**Spiophanes bombyx**	**77**	**Polygordius sp. indet**	**22**	**Copepoda**	**39**	**Copepoda**	**15**
Nematoda	**100**	**Argissa hamatipes**	**28**	**Edwardsiidae**	**39**	**Copepoda**	**21**	**Moerella pygmaea**	**37**	**Bathyporeia elegans**	**13**
Sphaerosyllis bulbosa	**59**	**Aonides paucibranchiata**	**22**	**Myriochele danielsseni**	**30**	**Nematoda**	**20**	**Streptosyllis bidentata**	**21**	**Spiophanes bombyx**	**5**
Aonides paucibranchiata	**45**	**Moerella pygmaea**	**21**	**Spiophanes kroyeri**	**18**	**Pisione remota**	**18**	**Nematoda**	**20**	**Moerella pygmaea**	**4**
Pisione remota	**33**	**Copepoda**	**12**	**Phoronis**	**16**	**Protodorvillea kefersteini**	**15**	**Hesionura elongata**	**19**	**Abra prismatica**	**3**
		Bathyporeia elegans	**9**	**Abra prismatica**	**13**	**Aonides paucibranchiata**	**10**			**Echinocardium flavescens**	**3**
Glycera lapidum	30	**Echinocyamus pusillus**	**9**			**Hesionura elongata**	**10**	Echinocyamus pusillus	13		
Mediomastus fragilis	28			Philine scabra	12	**Spio filicornis**	**9**	Polygordius sp. indet	11	Echinocyamus pusillus	3
Syllis ?'H'	28	Echinocardium flavescens	9	Spio decorata	10	**Polygordius appendiculatus**	**9**	Enchytraeidae	10	Polycirrus medusa	3
Trypanosyllis coeliaca	25	Spiophanes bombyx	7	Aonides paucibranchiata	10			Atylus falcatus	9	Eurydice truncata	3
Copepoda	18	Enchytraeidae	7	Echinocyamus pusillus	8	Echinocyamus pusillus	8	Glycera lapidum	6	Siphonoecetes kroyeranus	2
No. of individuals	788	No. of individuals	257	No. of individuals	374	No. of individuals	252	No. of individuals	266	No. of individuals	88
50% of individuals	14	50% of individuals	128.5	50% of individuals	187	50% of individuals	126	50% of individuals	133	50% of individuals	44

4.5.2 Multivariate Analysis

The results of per replicate group average clustering analysis using Bray Curtis similarity are shown per replicate (Figure 4-2) and per site (Figure 4-3).

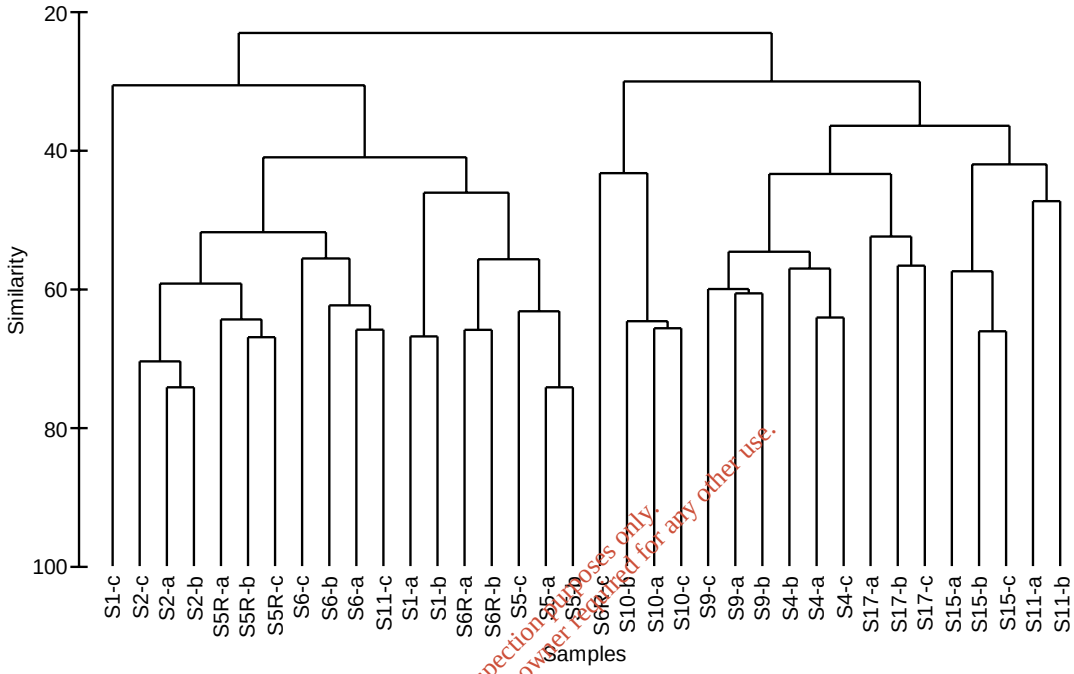

Figure 4-2: Dendrogram showing clustering of communities using per replicate sample data from sites around the proposed outfall (data was square root transformed)

Variability was found to be low at the majority of sites; replicates of each site had a 50% or more similarity with each other. The exceptions were sites 1, 6R and 11, all of which exhibited one replicate that clustered separately from the other two and showed only a 30% similarity. One possible explanation for this is that field sampling protocols allowed for replicate grabs to be taken within 50m of the target location, such that in a worst-case scenario two replicates could be as much as 100m apart from each other.

The dendrograms showed that throughout the sampling area communities had a degree of homogeneity, as the initial separation of sites did not occur until a 30% similarity level as indicated on Figure 4-3. The formation of two major clusters was then observed: sites 4, 9, 10 and 17, and sites 1, 2, 5, 5R, 6, 6R, 11 and 15.

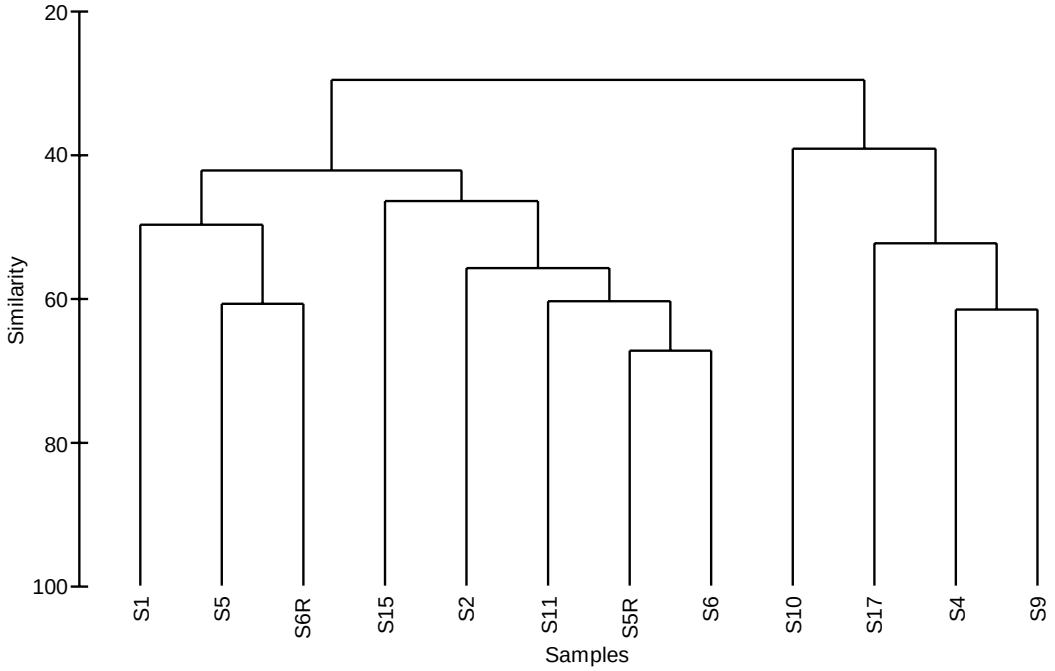

Figure 4-3: Dendrogram showing clustering of communities using pooled replicate (per site) data taken from sites around the proposed outfall (data was square root transformed)

The results of multi-dimensional scaling using the similarity matrices derived from cluster analysis are plotted two dimensionally for each replicate in Figure 4-4 and for each site in Figure 4-5. Stress values were low (0.09 and 0.06 respectively), indicating that the two-dimensional MDS diagram is a very good representation of how sites are related to each other. Together with the dendrograms, it was seen that there were four clusters at a similarity threshold of approximately 50% (shown as superimposed bubbles on figures 3 and 4). Cluster 1 comprised sites 1, 5 and 6R, cluster 2 sites 2, 5R, 6, 11 and 15, cluster 3 site 10 and cluster 4 sites 4, 9 and 17.

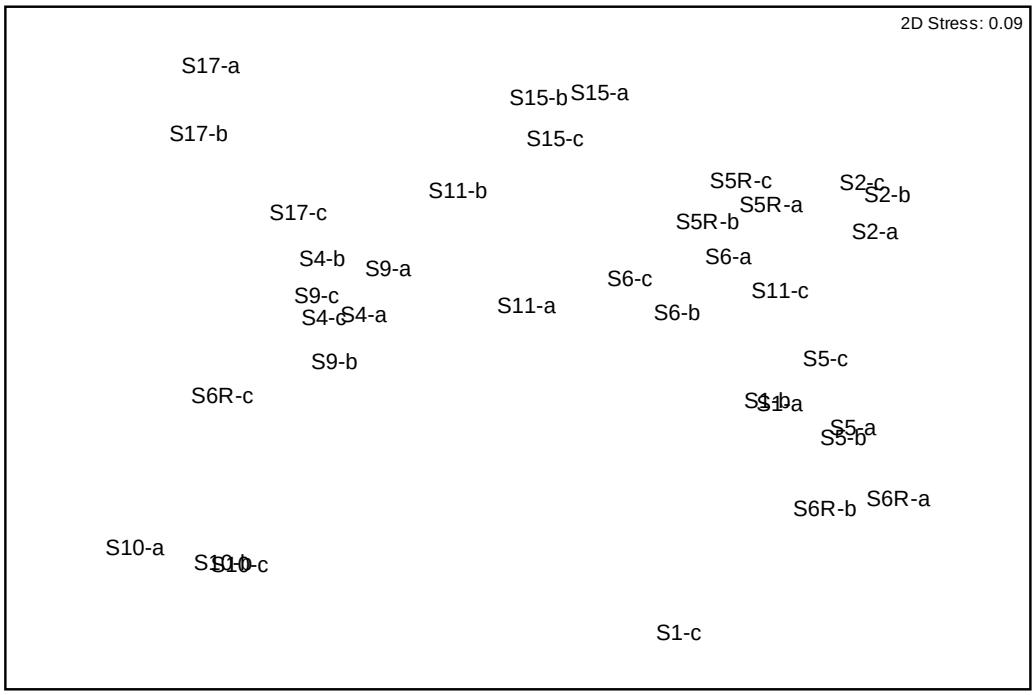

Figure 4-4: MDS plot of sample sites (per replicate data) around the proposed outfall with superimposed bubbles showing the four clusters

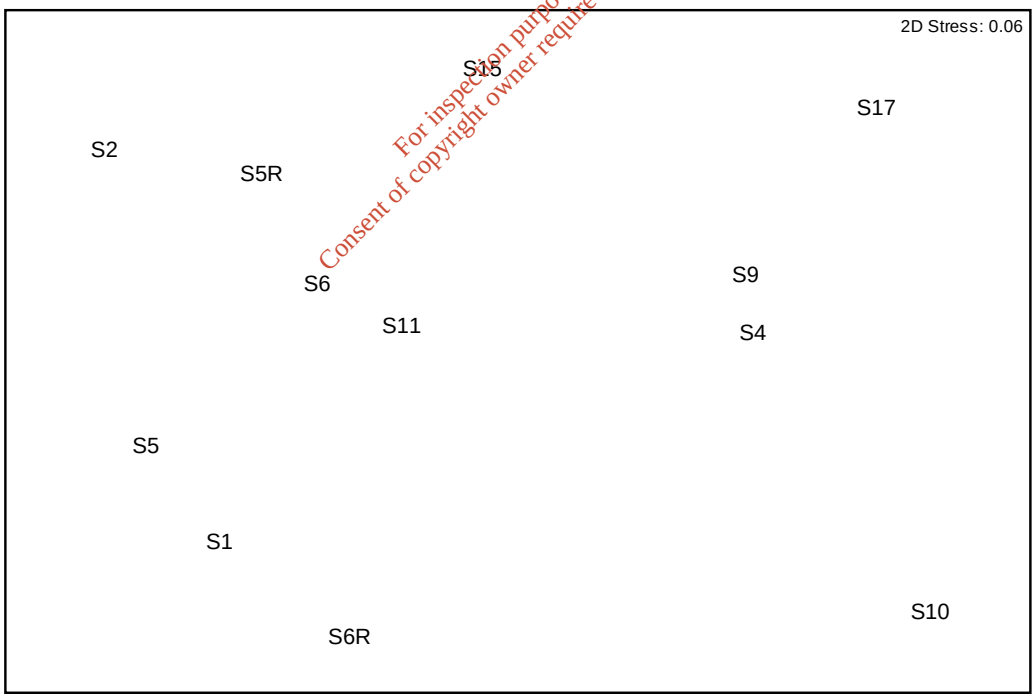

Figure 4-5: MDS plot of sample sites (pooled replicate data) around the proposed outfall with superimposed bubbles showing the four clusters

A SIMPER was performed to discover which species contributed most to each cluster, and which species contributed most to the differences seen between clusters. The

results for this are shown in Table 4-20 (the columns shown give the average abundance, the average contribution to the similarity, the percentage contribution to overall similarity and the cumulative contribution to similarity).

Table 4-20: SIMPER output of species that contribute (top 30%) to the similarity between sites around the proposed outfall using Bray-Curtis similarity on standardised square root transformed data

Cluster 1 (Sites 1, 5 & 6R)				
Average similarity:	53.38			
Species	Av. Abund	Av. Sim	Contrib%	Cum%
Nematoda	10.51	3.34	6.25	6.25
Polygordius (sp. indet)	10.29	3.17	5.95	12.19
Pisione remota	4.63	1.90	3.56	15.75
Glycera lapidum	4.38	1.78	3.34	19.09
Protodorvillea kefersteini	3.38	1.70	3.19	22.27
Aonides paucibranchiata	4.50	1.63	3.05	25.33
Sphaerosyllis bulbosa	4.90	1.48	2.77	28.10
Syllis 'H'	3.86	1.37	2.57	30.67
Cluster 2 (Sites 2,5R,6,11&15)				
Average similarity:	54.09			
Species	Av. Abund	Av. Sim	Contrib%	Cum%
Nematoda	7.17	3.51	6.48	6.48
Pisione remota	6.20	3.01	5.57	12.05
Polygordius (sp.indet)	5.36	2.96	5.48	17.53
Spio filicornis	12.86	2.96	5.48	23.01
Moerella pygmaea	4.51	2.74	5.07	28.08
Hesionura elongata	3.80	2.52	4.66	32.74
Cluster 3 (Site 10)				
Average similarity:	64.97			
Species	Av. Abund	Av. Sim	Contrib%	Cum%
Spiophanes bombyx	8.79	6.47	9.95	9.95
Edwardsiidae	6.21	4.60	7.08	17.03
Myriochele danielsseni	5.24	3.19	4.90	21.94
Phoronis	3.96	2.97	4.58	26.52
Spiophanes kroyeri	4.17	2.90	4.46	30.98
Cluster 4 (Sites 4, 9 & 17)				
Average similarity:	55.37			
Species	Av. Abund	Av. Sim	Contrib%	Cum%
Bathyporeia elegans	3.44	3.52	6.35	6.35
Copepoda	3.37	3.28	5.93	12.28
Abra prismatica	4.24	3.00	5.43	17.71
Moerella pygmaea	3.50	2.76	4.99	22.70
Aonides paucibrancihata	3.68	2.28	4.11	26.81
Echinocyamus pusillus	2.54	2.20	3.98	30.79

All clusters had average similarities of 50% or more. Throughout the sampling area, communities were found to be typical of subtidal sands, ranging from species generally found in stable, fine sand to those found in more exposed coarse sand with gravel.

Species typical of communities in a medium to coarse sand and gravely sand such as nematodes, and the polychaetes *Pisione remota*, *Polygordius* and *Glycera lapidum* were found to contribute highly to the similarity between sites of cluster 1 (sites 1, 5 and 6R). These species were also found to be important contributors to communities of cluster 2 (sites 2, 5R, 6, 11 and 15). In addition, sites in cluster 2 contained the polychaete *Spio filicornis* and the bivalve *Moerella pygmaea*, also typical of this habitat type.

Cluster 3, site 10, had an average similarity of 64.97%. Those species that contributed most to this similarity were tube dwelling organisms such as the polychaetes *Spiophanes bombyx*, *Spiophanes kroyeri* and *Myriochele danielsseni*, *Phoronids* and the burrowing anemone *Edwardsia*.

The communities from sites 4, 9 and 17, which made up cluster 4, were more typical of fine sand habitats. The amphipod *Bathyporeia elegans* and the bivalve *Abra prismatica* both contributed highly to the similarity between these sites.

Dissimilarities between clusters were high throughout the dataset, as those species that characterised communities in each defined cluster were found to be in reduced numbers or absent in the others. For example, cluster 4 (sites 4, 9 and 17) and 1 (sites 1, 5 and 6R) had a dissimilarity of 73.64%. The polychaetes, *Polygordius*, *Sphaerosyllis bulbosa*, *Pisione remota* and *Glycera lapidum* contributed highly to this dissimilarity as there was a high average abundance in cluster 1 but they were absent in cluster 4.

A BIO-ENV was performed for all sites. This looks at the best correlation between the biological and environmental data and endeavours to show which set of chemical and/or physical variables best explains the variation observed in the biological communities. Water depth, particle size, total organic carbon and heavy metals were included in the analysis.

The BIO-ENV analysis showed that no one variable measured was responsible for the observed variance between sites. However, there were strong correlations, the best being with four variables (r = 0.707). These were sediment grain size of medium size sand (250–499µm), fine sand (125–249µm) and very fine sand (63–125µm) and depth. The values for each of these environmental variables at each site are shown in Table 4-21 and MDS overlays of these environmental variables are plotted for 250–499µm in Figure 4-6, 125–249µm in Figure 4-7, and 63–125µm in Figure 4-8 and water depth in Figure 4-9.

When transposing these values onto MDS plots, patterns between clustering of sites and variables were observed. Depth varied by 40m throughout the area, but when plotted showed no distinct patterns between clusters. Sediment grain size was found to be an important environmental variable for these communities. Sites 4, 9 and 17 from cluster 4, on average, were comprised of the highest proportion of medium sand (250–499µm) whilst site 10 (cluster 3) had the highest proportion of fine and very fine sand (63–249µm). The other sites had variable percentages of these grain size fractions but were overall coarser.

Table 4-21: Physical and chemical variables found to best correlate with biological data for sites around the proposed outfall

	% sediment fraction			
	250–499µm	125–249µm	63–125µm	Depth (m)
1	33.3	9.32	0.13	90
2	4.04	0	0	58
4	50.3	36.2	0.86	73
5	5.3	0.99	0	74
5R	19.7	0.61	0	69
6	38.6	10.4	0.05	71
6R	44.8	43.5	3.66	67
9	63.7	12.1	0	61
10	22.9	60.7	9.24	81
11	29.7	5.33	0	77
15	51	5.62	0	50
17	63.8	23.4	0.02	48

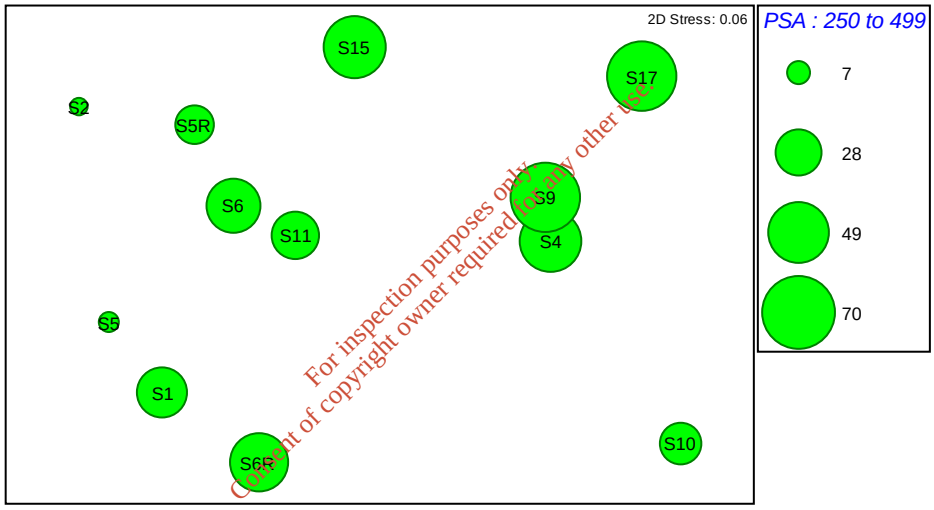

Figure 4-6: MDS plot of sites around the proposed outfall with superimposed bubbles representing the percent of sediment fraction 499–250µm (medium sand) at each site

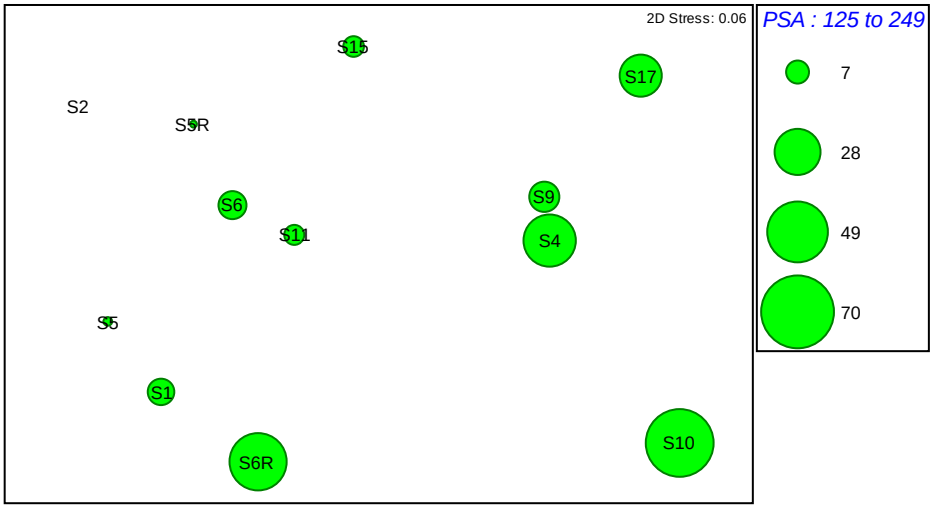

Figure 4-7: MDS plot of sites around the proposed outfall with superimposed bubbles representing the percent of sediment fraction 249–125µm (fine sand) at each site

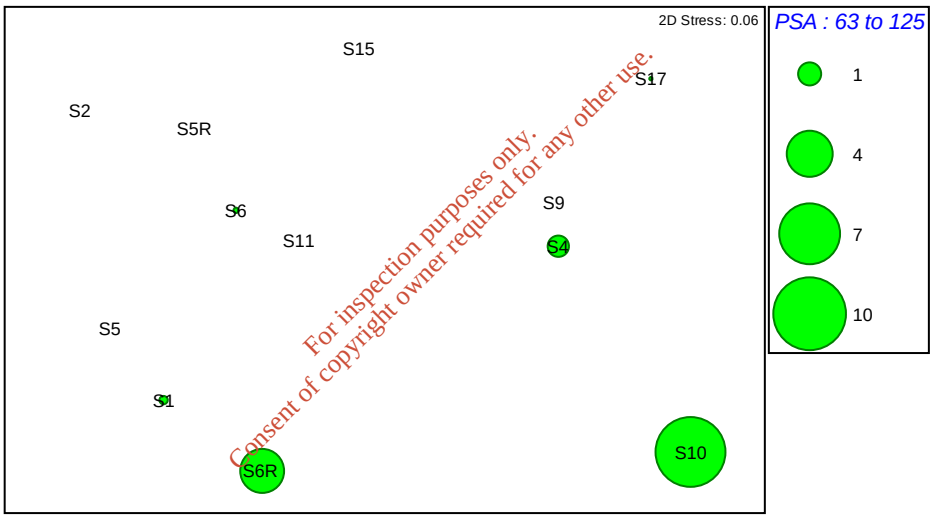

Figure 4-8: MDS plot of sites around the proposed outfall with superimposed bubbles representing the percent of sediment fraction 125–63µm (very fine sand) at each site

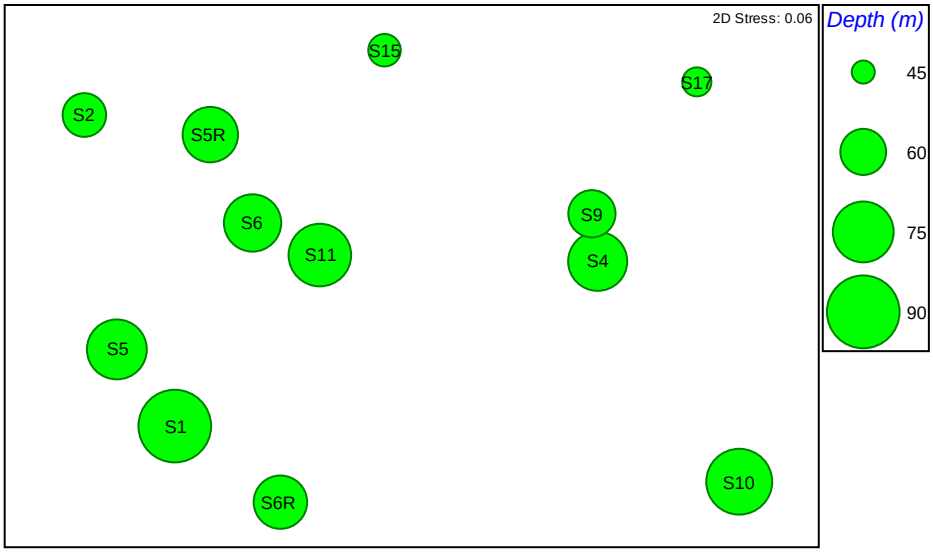

Figure 4-9: MDS plot of sites around the proposed outfall with superimposed bubbles representing water depth (m) at each site

Influence of grain size was investigated further and sediments were separated into coarse (500–2000µm), medium (250–500µm) and fine sand (63–250µm) and values were superimposed onto MDS plots. There was little change for the graphical representations of medium and fine sand but coarse sand showed a distinct pattern (Figure 4-10). It was seen that there were higher proportions of coarse sands in sites 1, 5, 6R (cluster 1) and 2, 5R, 6, 11, 15 (cluster 2).

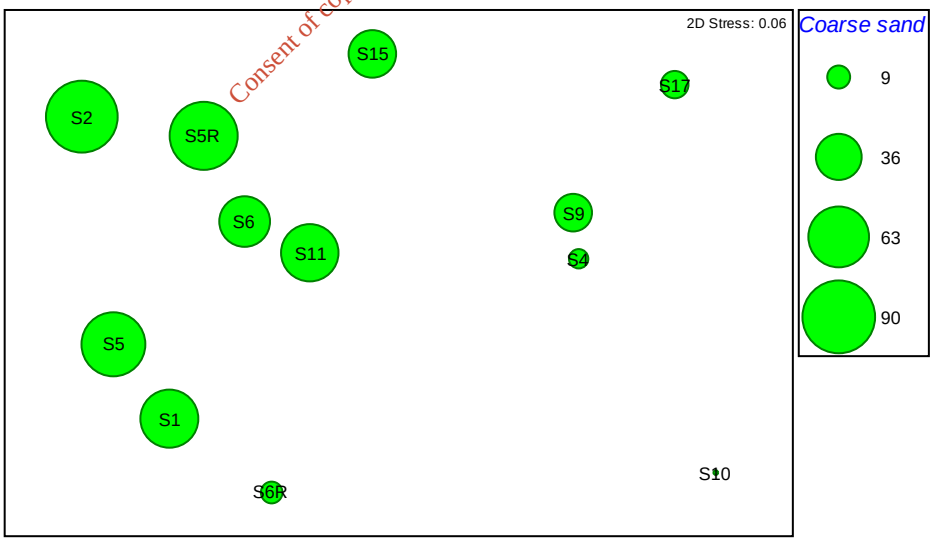

Figure 4-10: MDS plot of sites around the proposed outfall with superimposed bubbles representing the percent of sediment fraction 500–2000µm (coarse and very coarse sand) at each site

Other correlations found that along with the sediment grain size and depth, the heavy metals zinc and chromium were also important in explaining community variability. MDS overlays of these environmental variables are plotted for concentration of zinc ($mgkg^{-1}$) in Figure 4-11 and concentration of chromium ($mgkg^{-1}$) in Figure 4-12. It can be seen that, on average, clusters 1 and 2 have lower concentrations of these heavy metals than clusters 3 and 4.

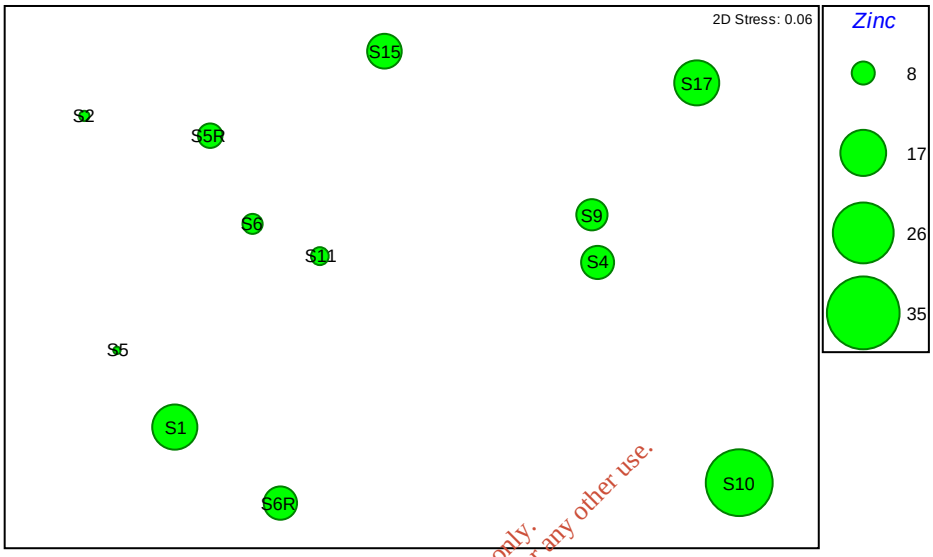

Figure 4-11: MDS plot of sites around the proposed outfall with superimposed bubbles representing the concentration of zinc ($mgkg^{-1}$) at each site

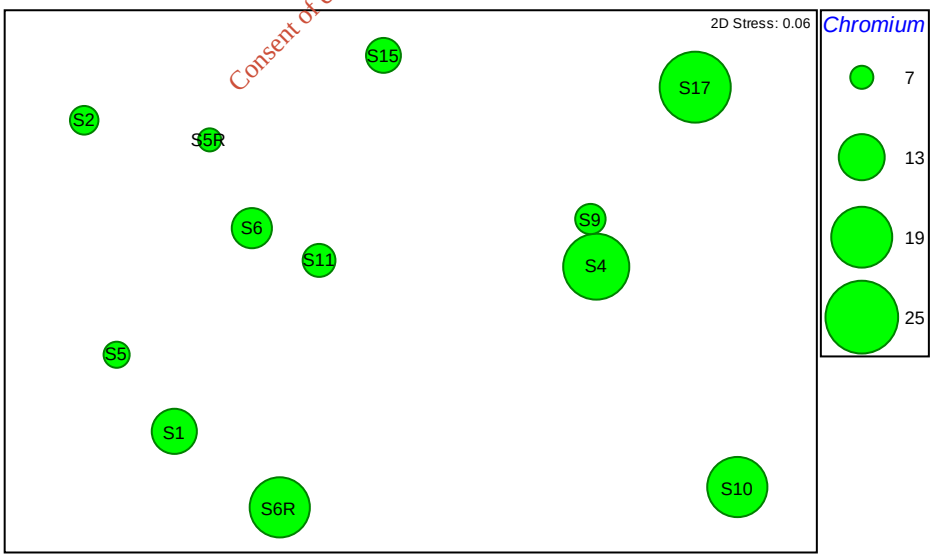

Figure 4-12: MDS plot of sites around the proposed outfall with superimposed bubbles representing the concentration of chromium ($mgkg^{-1}$) at each site

In summary, the faunal communities observed in the current survey were of moderate to high diversity and generally exhibited high evenness and low dominance. Some communities proved exceptions to this, especially at sites 2 and 5R where high numbers of the polychaete *Spio filicornis* decreased diversity and increased dominance values. Although there were obvious differences in the community composition at sites throughout the sampling area, a degree of homogeneity was observed as sites did not initially separate until a similarity level of 30%. The species found were typical of a subtidal sandy habitats, ranging from those found in coarse sand and gravel to those preferring more stable fine sand.

When analysed, the data generally showed low intra-site variance, except at sites 1, 6R and 11 where replicates only had a similarity of 30%. Sites clustered well into four distinct clusters, each exhibiting a relatively high intra-cluster similarity in their community structure. Between-cluster differences were high, with species typical of one community being less abundant or rare in the others.

Good correlations were observed with regard to species distribution and physical and chemical parameters. The combination of the four variables medium sand (250–499µm), fine sand (125–249µm), very fine sand (63–125µm) and depth were found to correlate best. Though there were no obvious patterns between depth and community composition, a relationship with sediment composition was observed. Sites containing the polychaetes *Polygordius*, *Spio filicornis* and *Pisione remota* and nematodes were associated with coarser sand habitats and sites containing the amphipod *Bathyporeia elegans*, the bivalve *Abra prismatica* and the polychaete *Spiophanes bombyx* were associated with finer sand habitats. Concentrations of chromium and zinc were also found to be important in explaining variability in community composition, those sites with coarser sediment were generally found to have lower concentrations of these heavy metals.

There was no definite influence of geographical position on community composition. Sites that were less than a kilometre apart clustered well in some cases but not in others. For example, sites 4 and 11 were found to have little similarity whilst, site 1 that was approximately 10km away from the rest of the sites clustered well with sites 5 and 6R.

5. Summary and Conclusion

The summer 2007 Corrib outfall area survey was completed successfully, with data collected for water and sediment quality, invertebrate abundance and bio-monitoring analyses. The methods used are appropriate and can be used to collect further data in the forthcoming years.

5.1 Physico-chemical

Sediments

Typically, the sediments collected in the area around the outfall consist of varying grades of sand, with five sites being medium sand, and the others being coarse or very coarse, with the exception of one site that had fine sand. These results are as expected given the previous sampling which has taken place in the area.

Total organic carbon concentrations are generally low, and this is related to the coarse nature of the sediments.

Trace metal and organic chemical concentrations are generally low, reflecting the coarse nature of the sediments in the area, and the lack of anthropogenic influences. Arsenic is the only metal that is present close to the EAC levels, and this metal is known to be present at relatively high levels throughout Donegal Bay.

Water

Profiles of salinity and temperature were taken at all water sampling stations and reveal a relatively well-mixed water body in the area. Evidence from the first sites sampled showed that a weak thermocline may have existed; however, this was not present at the sites sampled towards the end of the cruise, following a force 9 gale, which appears to have removed any trace of stratification.

Water temperatures and salinities recorded were in line with expectations for the area and timing of the survey.

Trace metal, organics and nutrient concentrations were relatively low, reflecting the pristine nature of the area.

5.2 Fauna

Macrofauna

The benthic macrofaunal communities present at the sites sampled had moderate to high diversity, generally with high degree of evenness and low dominance by single species. The communities present at the various sites tended to be correlated with the grain size and depth. Zinc and chromium concentrations also appear to have an influence on community type; however, the concentrations of these metals is also dependent upon the grain size.

Biomonitoring

Mussels collected from four locations around Broadhaven Bay contained low levels of metals and PAHs. Concentrations of all contaminants measured were well within the background and guidance levels where these have been set.

5.3 Conclusion

The data sets for metals and hydrocarbons in sediments, water and mussels reflect a pristine environment. With the limitations of differing pre-treatment and subsequent analytical methods, the data are in accord with other published work. No determinand was found at concentrations that would give rise to concern regarding potential biological impacts.

6. References

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Appendix A: Particle Size Graphs

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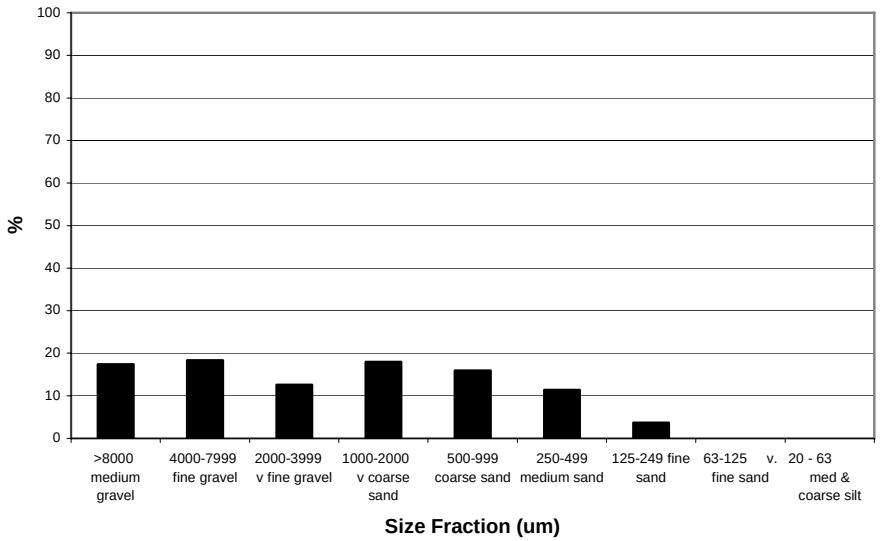

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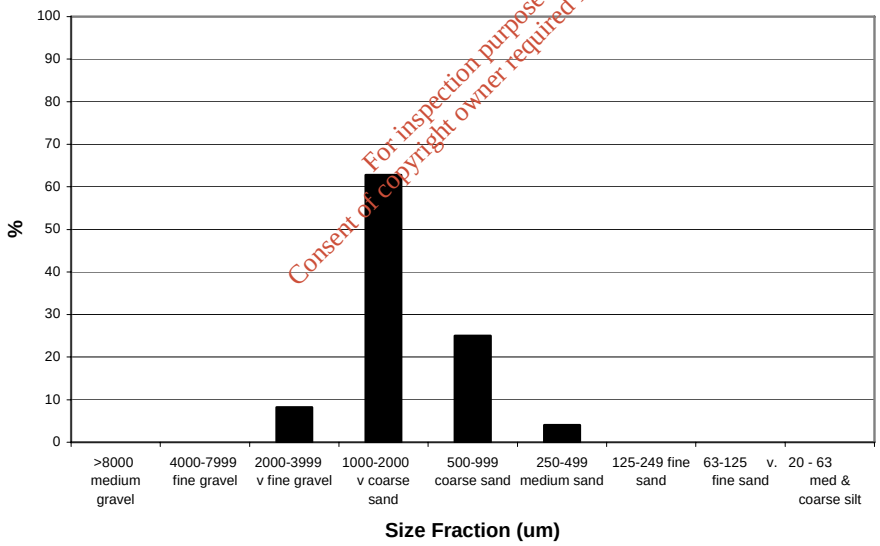

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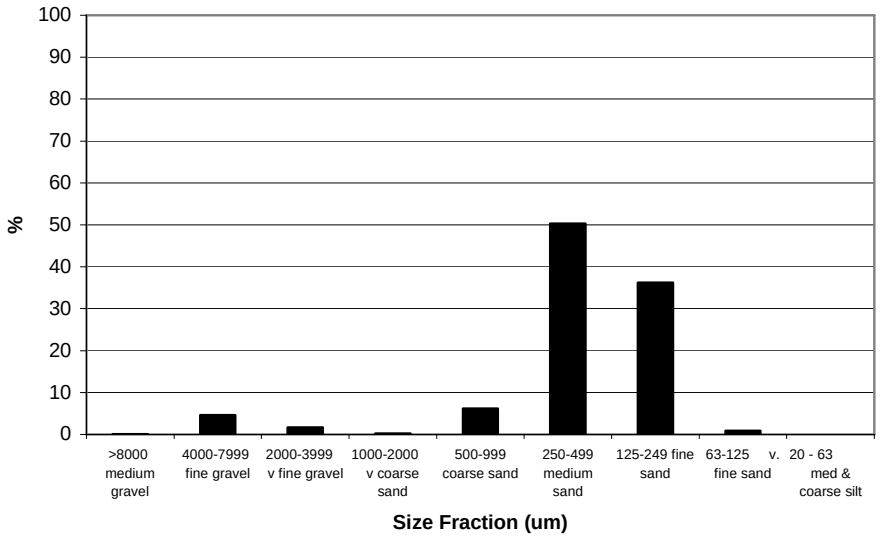

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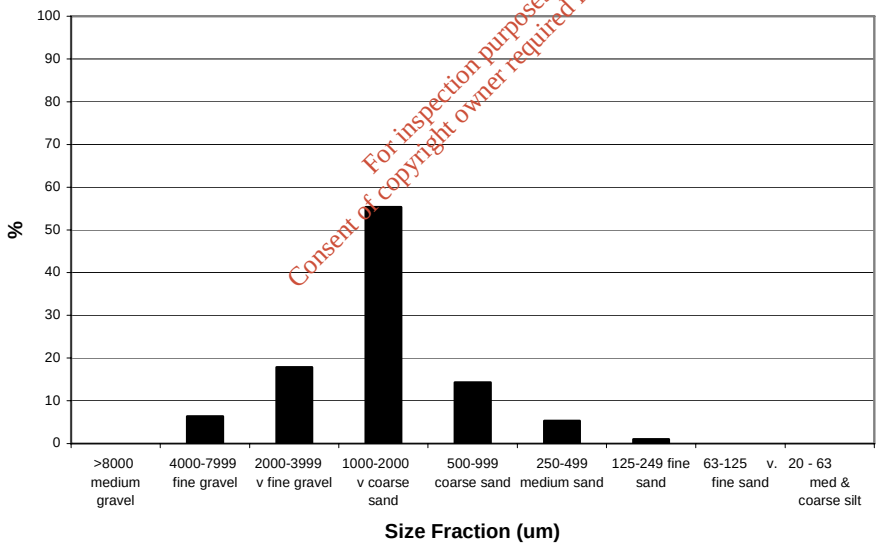

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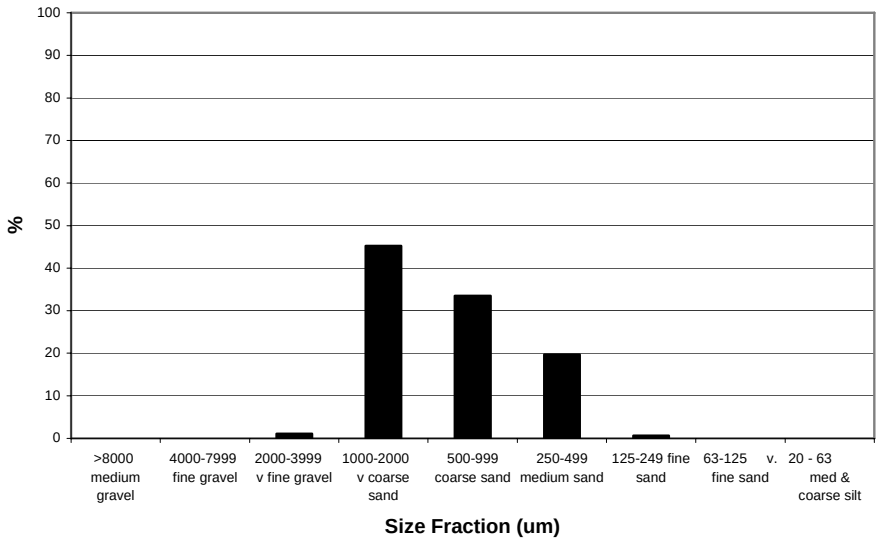

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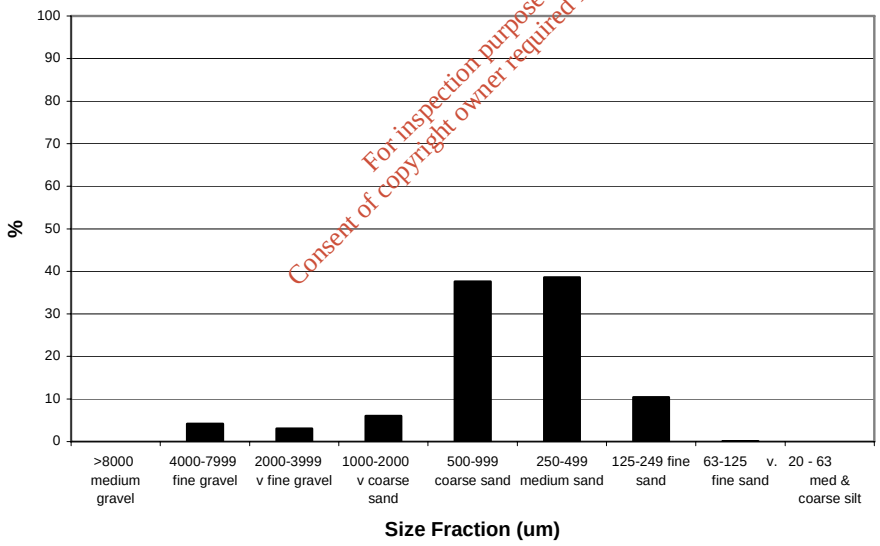

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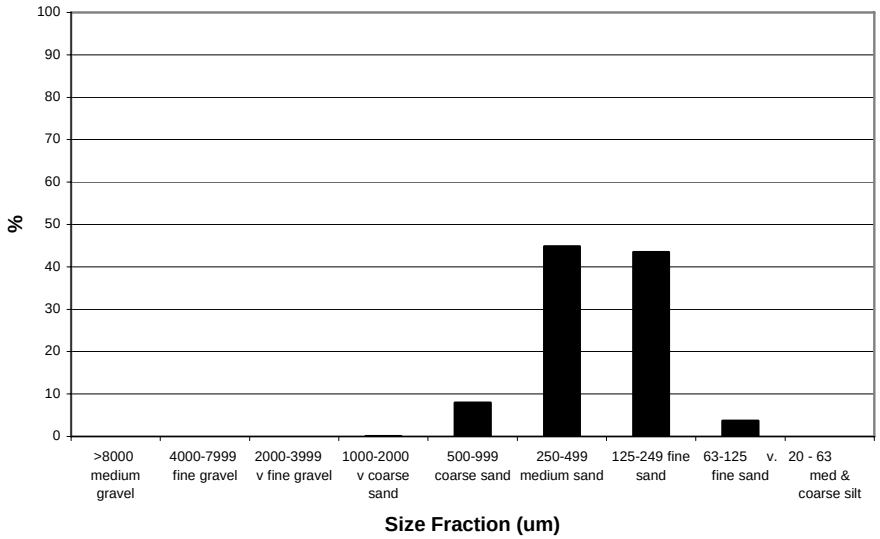

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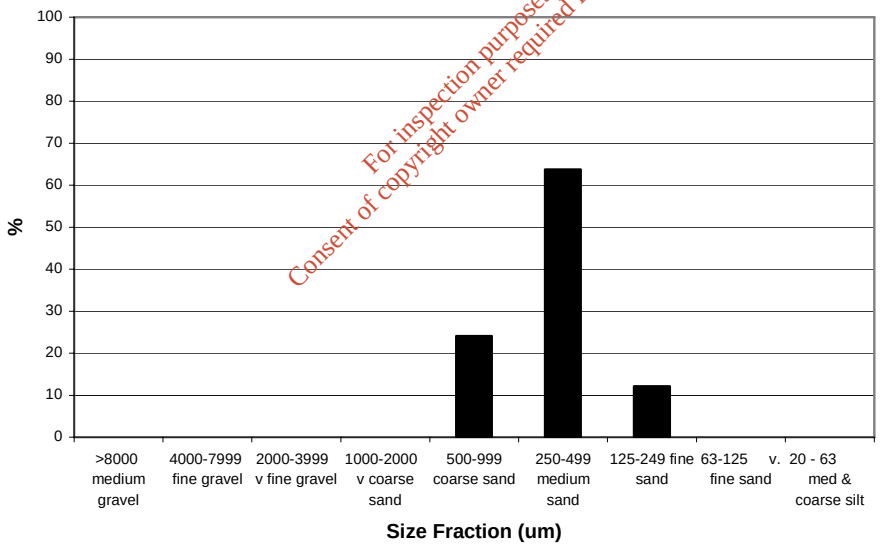
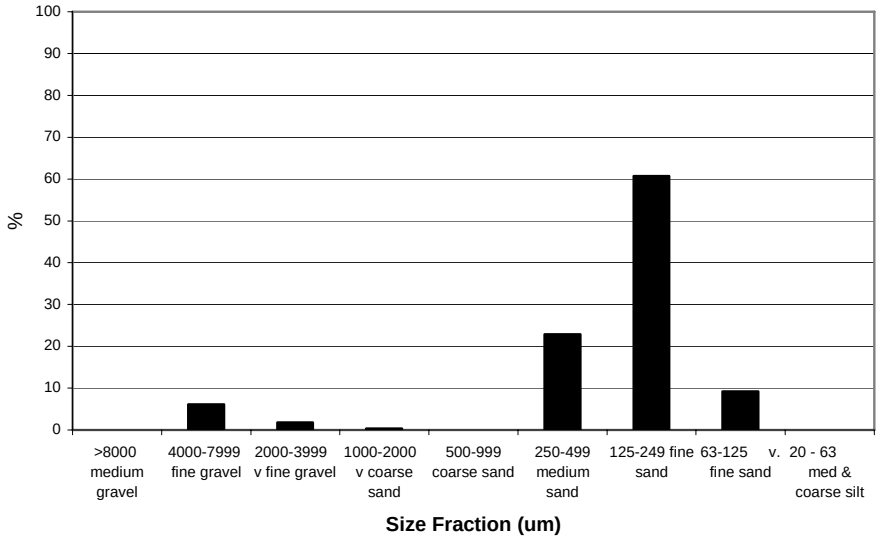
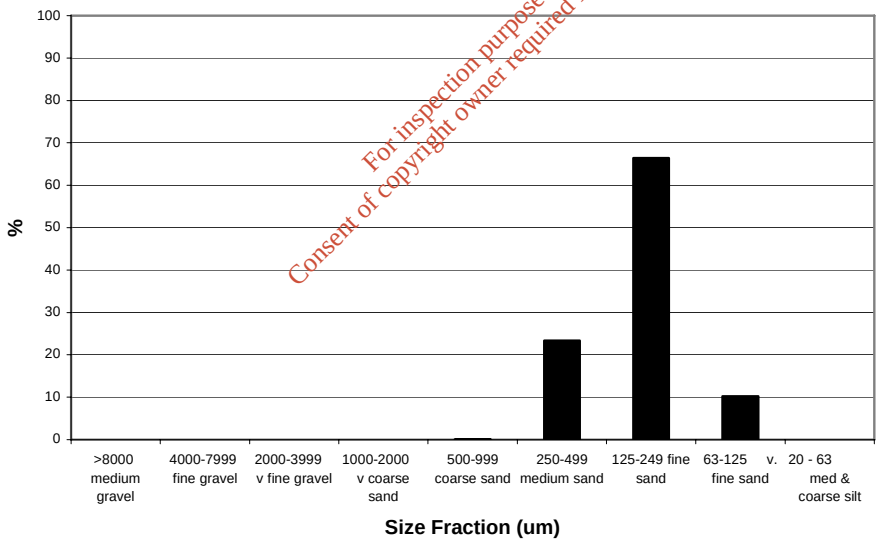


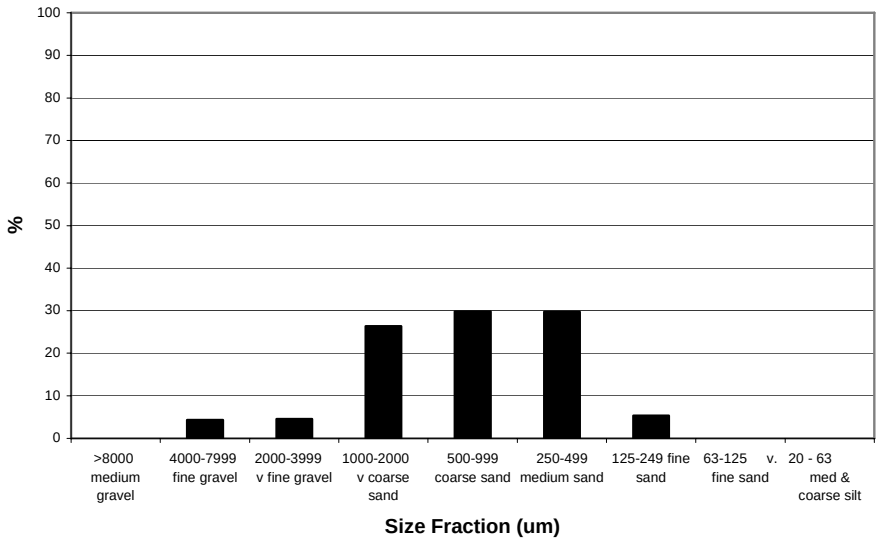
S10



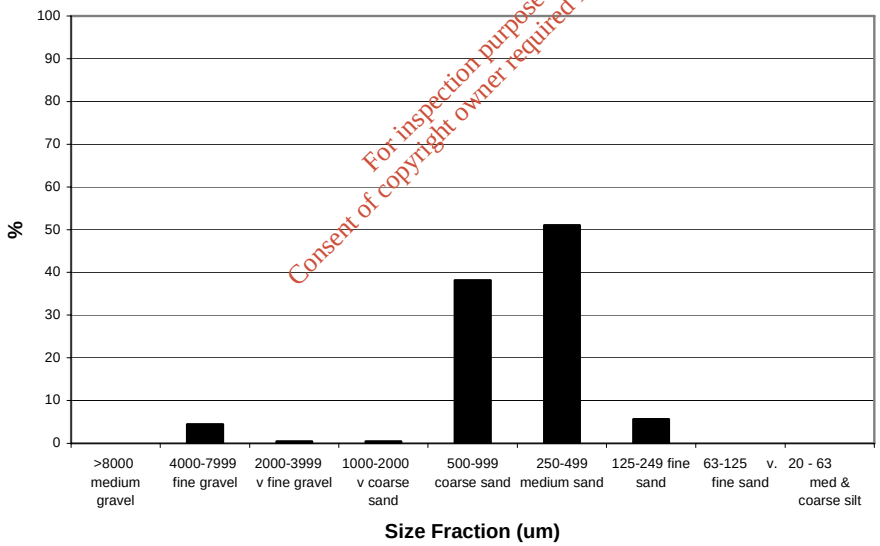
S10 Duplicate



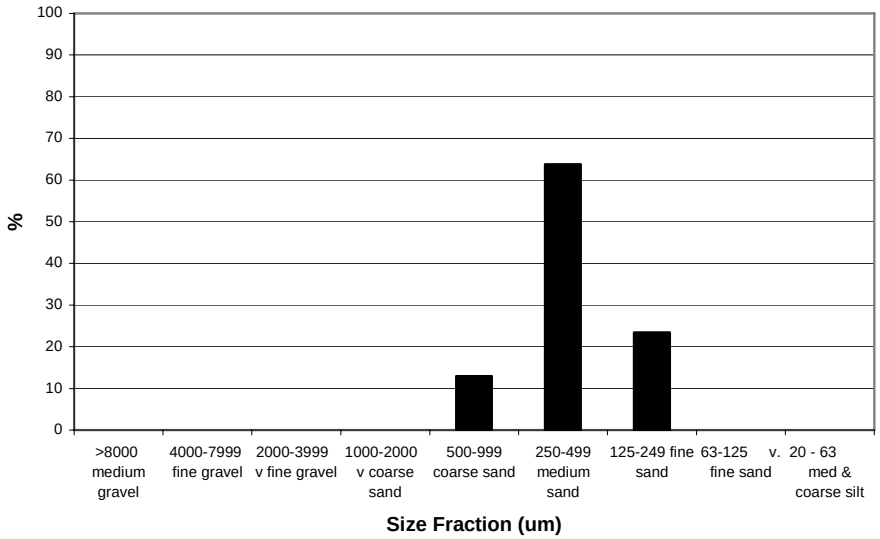
S11



S15



S17



Appendix B: BenthicSolutions Report on hydrocarbon concentrations in sediments from the offshore pipeline route and outfall area

An Examination of Hydrocarbons in Seabed Sediments Collected from the Proposed Corrib Outfall & Pipeline Route Corridor, County Mayo Ireland.

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Project Reference: BSL0707
Survey Dates: 29.07.2007 to 10.08.2007
Date of Report: 03.10.2007

1. Organic Analysis Aims

1.1 To extract twenty-one seabed sediments to determine the concentrations of total organic extractables (TOE) therein using gas chromatography (GC), with particular reference to identify any type of base oils present.

1.2 To determine the concentrations of a range of polyaromatic hydrocarbons (PAH), including naphthalenes, phenanthrenes and dibenzothiophenes (NPD) and the EPA 16 polyaromatic hydrocarbons in the twenty-one sediment samples.

2. Sample Details

Twenty-one sediment samples from the proposed outfall location and Corrib Pipeline Route Corridor, off the Irish West coast, were received delivered to the analytical laboratory (M-Scan) on the 14th August 2007. All samples were stored at -18°C immediately after sampling in the field, remaining frozen at all times prior to analysis. On receipt, each sample was given a unique processing reference number, as follows:

Sample (Date)	Reference No
08 (02/08/07)	80136
20 (01/08/07)	80137
25 (02/08/07)	80138
26 (01/08/07)	80139
27 (01/08/07)	80140
25A (02/08/07)	80141
25B (02/08/07)	80142
32A (01/08/07)	80143
S1 (06/08/07)	80144
S10 (02/08/07)	80145
S10 Duplicate (08/08/07)	80146

Sample (Date)	Reference No
S11 (08/08/07)	80147
S15 (07/08/07)	80148
S17 (02/08/07)	80149
S2 (08/08/07)	80150
S4 (08/08/07)	80151
S5R (08/08/07)	80152
S5 (08/08/07)	80153
S6 (08/08/07)	80154
S6R (07/08/07)	80155
S9 (02/08/07)	80156

Parenthesis: Date sample recovered from the seabed.

3. Analytical Methodology

3.1 Extraction of Hydrocarbons

Samples were stored in metal cans at -18°C prior to extraction and analysis. In the laboratory, the samples were defrosted, homogenised and sub-samples weighed out for analysis. Known amounts of heptamethylnonane (HMN), chlorooctadecane (COD), squalane (Sq), d_8-naphthalene (d_8-N), d_{10}-phenanthrene (d_{10}-P) and d_{10}-pyrene (d_{10}-Py) were added to each sediment prior to extraction as internal standards, and the sample re-homogenised. After the addition of 100ml of isopropanol/hexane (4:1), the sediments were extracted using ultra-sonication (2 x 5 min, stirring in between) and then centrifuged at 2000rpm for 10 minutes. The supernatant extract was then decanted and partitioned between water and pentane. The resulting organic fractions were collected in pre-cleaned 500ml round bottom flasks. The extraction procedure was then repeated with a further 100ml of isopropanol/hexane (4:1), omitting the addition of internal standards. Organic fractions were combined and re-washed to give a total organic extract (TOE). This TOE was reduced under vacuum to *ca*. 2ml, and was analysed by gas chromatography (GC) to obtain quantification of any saturate organics present (including drilling related base-oils, if found). Following the GC analysis, the TOE was further processed though a silica chromatography column (silica, 60-230 mesh). 40ml of pentane were used to elute the aliphatic fraction, followed by 50ml of DCM to elute the aromatic fraction. The fractions were collected in pre-cleaned 100ml round bottom flasks. Each fraction was reduced under vacuum (<30°C) to *ca*.1ml, transferred to a glass vial and further concentrated using dry nitrogen blow-down. The aromatic hydrocarbon fractions were then analysed by GC-mass spectrometry (GC-MS).

The analysis of a procedural blank, along with a duplicate sample and a pre-extracted trip blank were carried out in parallel with the field samples.

3.2 Gas Chromatography (GC)

An aliquot (1µl) of the TOE fraction was analysed by GC under the following conditions:

GC	
Instrument	Hewlett Packard 6890
Columns	30m x 0.32mm i.d. x 0.25µm d.f DB5-MS (J&W)
Injection	Splitless at 325°C
Temperature Prog.	40°-325°C at 8°C/min, 325°C (10 min)
Carrier Gas	Helium at 2ml/min; constant flow
Data handling	Hewlett Packard Chemstation Series 7.1

Quantification of total organic extractables (TOE) was carried out against the internal standard squalane.

3.3 Gas Chromatography- Mass Spectrometry (GC-MS)

Aliquots (1.0µl) of the sediment aromatic fractions, dissolved in dichloromethane, were analysed by GC-MS using a Perkin Elmer Turbomass Gold mass spectrometer with Turbomass version 4.4 data system, under the following conditions:

GC	
Column	30m x 0.32mm i.d x 0.25µm d.f. DB5-MS (J&W)
Injection	Splitless at 325°C
Temperature Prog.	40°-100°C at 45°C/min, 100°-325°C at 8°C/min, 325°C (10 min)
Carrier Gas	Helium at 1.5ml/min; constant flow
MS	
Ionisation Voltage	70eV
Mass Range	90-350 amu
Scan Rate	ca. 0.5 second cycle
MS Resolution	Unit

4. Results And Discussion

4.1 GC Analysis of Total Organic Extracts (TOE)

The total organic extracts (TOE) of the sediments were analysed by gas chromatography (GC) to detect any saturate hydrocarbons (including anthropogenic hydrocarbons such as drilling related base-oils) that may be present in the sediment. This is the same procedure as previously used in earlier survey undertaken in and around the Corrib field development since 1997.

The TOE GC traces of the sediments are given in *Figures 1-24*, while that of the procedural blank is shown in *Figure 25*. The concentrations of TOE have been calculated from the GC analyses and are shown in *Table 1*. TOE concentrations range from 0.69µg/g at Station 17 to 13µg/g at Stations 25B and the S10 Duplicate. Concentrations of TOE in these samples are considered consistent with 'background' levels as previously seen in the offshore Corrib field (Benthic Solutions Limited 2006).

Table 1 Concentrations of Total Organic Extractables (TOE)

Station	TOE (µg/g; ppm)
08	7.0
20	4.7
25	5.8
25A	6.7
25B	8.6(13)
26	10
27	6.5
32A	10
S1	2.2
S2	8.2
S4	10
S5	5.9

Station	TOE (µg/g; ppm)
S5R	9.5
S6	2.7
S6R	4.5
S9	1.1(0.89)
S10	8.1
S10 D	13
S11	6.6
S15	0.96
S17	0.69

Pre-extract	1.2
Trip Blank	30

Parenthesis: Duplicate analysis

Comparison with similar data, previously analysed from surveys in the North Sea Oil and Gas fields (including both baseline studies and reference background stations from around fields where drilling operations have taken place) suggests that the background

concentration of total hydrocarbons typically ranges between 1-10ppm. This agrees with data from the North Sea Task Force (NSTF 1993), and Law (Law et al, 1982), although other studies have shown higher concentrations (e.g. McIntosh et al, 1983; 10-60ppm in sediments between the Firth of Forth and the Forties field).

Apart from the internal standards, the GC traces show clear evidence for the presence of a number of resolved peaks. The TOE of sample S2 was further analysed by GC-MS to characterise these components. They include a range of fatty acids (dominated by C_{14} (myristic), C_{16} (palmitic) and C_{18} (stearic) acids), sterols, long chain alcohols and long-chain (C_{39-42}) ketones, which have been previously identified in the North Sea sediments and in the marine coccolithophore *Emiliana huxleyi*. These are all considered to be of biogenic rather than petrogenic origin, and confirm a very low level of petrogenic contamination within the sediments.

The GC traces preclude the presence of the three synthetic base oils previously identified in the Corrib field development ("Ecosol", "Ecomul" and "Esterkleen"). The base oil "Ecomul" comprises almost entirely of paraffins, while "Esterkleen" is based upon 45-70% 2-ethyl-hexyloleate. The base oil "Ecosol" is 60% paraffins, 20% poly-alpha olefins and 20% linear alpha olefins. For comparison a GC trace of the "Ecosol" base oil from previous analyses is included as *Appendix 1*. This base oil was spiked into a portion of the sample from Station 25 at 52.7ppm; this was extracted and analysed in parallel with the other samples, and the trace is shown as *Figure 22 (Appendix II)*. The measured concentration of the base oil in the extracted sediment was 49.9ppm.

There was also no evidence in the sediments for the presence of base oils of mineral origin (e.g. "low-tox" or diesel).

A portion of pre-extracted sediment was utilised as a "trip" blank. This sediment was extracted and the data included for comparison with a portion of pre-extracted sediment retained within the laboratory. The data are included as *Figures 23* and *24 (Appendix II)*. The trip blank sample shows evidence for a series of resolved peaks between 22-30 minutes, and a narrow-range UCM between 30-34 minutes. Inspection of the GC-MS data of the aromatic fraction for this sample indicates that the UCM comprises mixed long-chain phthalates, which are widely used as plasticisers. The source of this contamination is unclear. However, these components were not detected in the sediments analysed, and so they are not considered significant in this context.

4.2 GC-MS Analysis of Polycyclic Aromatic Hydrocarbons (PAHs)

Total ion current traces for the sediment aromatic fractions are given in *Figures 26-46*, whilst that of the procedural blank is given in *Figure 47 (Appendix III)*. Concentrations of PAHs in the sediments are given in *Table 2* and include naphthalenes, phenanthrenes and dibenzothiophenes (NPD) and the sixteen PAHs defined by the US EPA.

Polyaromatic hydrocarbons and their alkyl derivatives have been recorded in a wide range of marine sediments (Laflamme & Hites, 1978) with the majority of compounds produced from what is thought to be pyrolytic sources. These are the combustion of organic material such as forest fires (Youngblood & Blumer, 1975), the burning of fossil fuels and, in the case of offshore oilfields, flare stacks, etc. The resulting PAHs, rich in the heavier weight 4-6 ring aromatics, are normally transported to the sediments via atmospheric fallout or river runoff. Another PAH source is petroleum hydrocarbon, often associated with localised drilling activities. These are rich in the lighter, more volatile 2 and 3 ring PAHs (NPD; naphthalene (128), phenanthrene, anthracene (178) and dibenzothiophene (DBT) with their alkyl derivatives).

The concentrations of NPD (*Table 2*), range from 0.03ng/g (ppb; Station 26) to 11ng/g (Station S6). The concentrations of NPD in these samples are considered consistent with 'background' levels previously seen in the sediments around the Corrib field development (Benthic Solutions Limited 2006), which are generally similar to the background levels observed in the North Sea (Davies *et al*., 1984).

The concentrations of the EPA 16 PAHs range from 0.11ng/g (Station 15) to 2.8ng/g (Station 32A). These values, again, are generally similar to those observed in the 'background' levels previously seen around the Corrib field development (Benthic Solutions Limited 2006), and are also generally similar to the background levels observed in North Atlantic sediments. Previous data from surveys around North Sea fields and the North Atlantic suggest that the background concentrations of the EPA16 PAH concentrations typically range up to 50ng/g, whilst NPDs are typically in the region of 10ng/g.

Table 2a. *Concentrations of 2-6 ring **Polycyclic** Aromatic **Hydrocarbons** (ng/g (ppb); dry weight basis)*

Station No.	8	20	25	26	25A	25B	27
Naphthalene	nd	0.02	0.06	nd	0.08	nd	0.52
C1-Naphthalenes	nd	nd	0.04	nd	nd	nd	0.31
C2- Naphthalenes	nd	nd	nd	nd	0.95	nd	nd
C3- Naphthalenes	nd	1.2	nd	nd	nd	nd	nd
C4- Naphthalenes	nd	nd	nd	nd	nd	nd	nd
Total Naphthalenes	nd	1.2	0.10	nd	1.0	nd	0.83
Phenanthrene	nd	0.06	0.09	0.03	0.01	nd	0.07
C1-Phenanthrenes	nd	nd	nd	nd	nd	nd	nd
C2- Phenanthrenes	nd	nd	nd	nd	nd	nd	nd
C3- Phenanthrenes	nd	nd	nd	nd	nd	nd	nd
Total Phenanthrenes	nd	0.06	0.09	0.03	0.01	nd	0.07
Dibenzothiophene	nd	nd	nd	nd	nd	nd	nd
C1-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd
C2-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd
C3-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd
Total DBT	nd	nd	nd	nd	nd	nd	nd
Total NPD	nd	1.3	0.19	0.03	1.0	nd	0.90
Acenaphthylene	nd	nd	nd	nd	nd	nd	nd
Acenaphthene	nd	nd	nd	nd	nd	nd	nd
Fluorene	nd	nd	nd	nd	nd	nd	nd
Anthracene	nd	nd	nd	nd	nd	nd	nd
Fluoranthene	0.08	0.16	0.08	0.17	0.07	0.10	0.12
Pyrene	nd	nd	nd	0.13	0.05	0.05	0.09
C_1-Fluoranthenes/Pyrenes	nd	nd	nd	nd	nd	nd	nd
C_2-Fluoranthenes/Pyrenes	nd	nd	nd	nd	nd	nd	nd
C_3-Fluoranthenes/Pyrenes	nd	nd	nd	nd	nd	nd	nd
Benzo(a)anthracene	nd	0.05	0.04	0.11	0.03	nd	0.08
Chrysene	nd	0.09	0.07	0.11	0.05	nd	0.06
C_1-Benanthracenes/Chrysenes	nd	nd	nd	nd	nd	nd	nd
C_2- Benanthracenes/Chrysenes	nd	nd	nd	nd	nd	nd	nd
Benzo(b)fluoranthene	0.01	0.11	nd	0.37	0.13	0.17	0.22
Benzo(k)fluoranthene	0.14	0.24	nd	0.12	0.04	0.08	0.08
Benzo(a)pyrene	nd	0.07	nd	0.12	0.06	0.06	0.09
C_1-Benzofluoranthenes/Benzpyrenes	nd	nd	nd	nd	nd	nd	nd
C_2- Benzofluoranthenes/Benzpyrenes	nd	nd	nd	nd	nd	nd	nd
Indeno(1,2,3-cd)pyrene	0.12	0.33	nd	0.30	0.21	0.17	0.24
Dibenzo(a,h)anthracene	nd	0.10	nd	0.03	0.03	nd	nd
Benzo(ghi)perylene	0.11	0.25	nd	0.24	0.15	0.18	0.18
Total EPA 16	0.46	1.5	0.40	1.7	0.91	0.80	1.8
4-6 Ring PAH/NPD	-	1.15	2.11	56.67	0.91	-	2.00

nd = not detected

Table 2b. *Concentrations of 2-6 ring* ***Polycyclic*** *Aromatic* ***Hydrocarbons*** *(ng/g (ppb); dry weight basis)*

Station No.	32A	S1	S2	S4	S5	S5R	S6
Naphthalene	0.43	0.23	0.04	0.21	nd	nd	2.3
C1-Naphthalenes	nd	nd	0.17	0.28	0.09	0.12	4.7
C2- Naphthalenes	0.95	nd	nd	1.2	nd	1.0	4.3
C3- Naphthalenes	nd	nd	nd	nd	nd	nd	nd
C4- Naphthalenes	nd	nd	nd	nd	nd	nd	nd
Total Naphthalenes	1.4	0.23	0.21	1.7	0.09	1.1	11
Phenanthrene	0.03	0.02	0.04	0.08	0.03	0.02	0.27
C1-Phenanthrenes	nd	nd	nd	nd	nd	nd	nd
C2- Phenanthrenes	nd	nd	nd	nd	nd	nd	nd
C3- Phenanthrenes	nd	nd	nd	nd	nd	nd	nd
Total Phenanthrenes	0.03	0.02	0.04	0.08	0.03	0.02	0.27
Dibenzothiophene	nd	nd	nd	nd	nd	nd	nd
C1-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd
C2-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd
C3-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd
Total DBT	nd	nd	nd	nd	nd	nd	nd
Total NPD	1.4	0.25	0.25	1.8	0.12	1.1	11
Acenaphthylene	nd	nd	nd	nd	nd	nd	nd
Acenaphthene	nd	nd	nd	nd	nd	nd	nd
Fluorene	nd	nd	nd	nd	nd	nd	nd
Anthracene	nd	nd	nd	nd	nd	nd	nd
Fluoranthene	0.17	0.10	0.04	0.17	0.10	0.09	nd
Pyrene	0.10	0.04	0.03	0.11	0.05	0.06	nd
C_1-Fluoranthenes/Pyrenes	nd	nd	nd	nd	nd	nd	nd
C_2-Fluoranthenes/Pyrenes	nd	nd	nd	nd	nd	nd	nd
C_3-Fluoranthenes/Pyrenes	nd	nd	nd	nd	nd	nd	nd
Benzo(a)anthracene	0.05	nd	nd	0.05	0.05	0.06	nd
Chrysene	0.08	nd	nd	0.09	0.10	0.08	nd
C_1-Benanthracenes/Chrysenes	nd	nd	nd	nd	nd	nd	nd
C_2- Benanthracenes/Chrysenes	nd	nd	nd	nd	nd	nd	nd
Benzo(b)fluoranthene	0.64	0.07	0.04	0.12	0.15	0.10	nd
Benzo(k)fluoranthene	0.15	0.06	0.01	0.19	0.08	0.04	nd
Benzo(a)pyrene	0.10	0.01	nd	0.08	0.09	0.04	nd
C_1-Benzofluoranthenes/Benzpyrenes	nd	nd	nd	nd	nd	nd	nd
C_2- Benzofluoranthenes/Benzpyrenes	nd	nd	nd	nd	nd	nd	nd
Indeno(1,2,3-cd)pyrene	0.58	0.07	nd	0.24	0.16	0.16	nd
Dibenzo(a,h)anthracene	0.07	0.02	nd	nd	nd	nd	nd
Benzo(ghi)perylene	0.38	0.11	nd	0.22	0.16	0.29	nd
Total EPA 16	2.8	0.73	0.21	1.6	0.97	0.93	2.6
4-6 Ring PAH/NPD	2.00	2.92	0.84	0.89	8.08	0.85	0.24

nd = not detected

Table 2c. *Concentrations of 2-6 ring **Polycyclic** Aromatic **Hydrocarbons** (ng/g (ppb); dry weight basis)*

Station No.	S6R	S9	S10	S10 D	S11	S15	S17
Naphthalene	0.62	1.6	nd	0.01	nd	0.11	0.04
C1-Naphthalenes	2.0	3.9	nd	0.37	nd	0.16	nd
C2- Naphthalenes	2.3	3.4	nd	1.5	nd	nd	nd
C3- Naphthalenes	nd	nd	nd	nd	nd	nd	nd
C4- Naphthalenes	nd	nd	nd	nd	nd	nd	nd
Total Naphthalenes	4.9	8.9	nd	1.9	nd	0.27	0.04
Phenanthrene	0.13	0.08	nd	0.11	0.10	nd	0.06
C1-Phenanthrenes	nd	nd	nd	nd	nd	nd	nd
C2- Phenanthrenes	nd	nd	nd	nd	nd	nd	nd
C3- Phenanthrenes	nd	nd	nd	nd	nd	nd	nd
Total Phenanthrenes	0.13	0.08		0.11	0.10	nd	0.06
Dibenzothiophene	nd	nd	nd	nd	nd	nd	nd
C1-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd
C2-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd
C3-Dibenzothiophenes	nd	nd	nd	nd	nd	nd	nd
Total DBT	nd	nd	nd	nd	nd	nd	nd
Total NPD	5.0	9.0	nd	2.0	0.10	0.27	0.10
Acenaphthylene	nd	nd	nd	nd	nd	nd	nd
Acenaphthene	nd	nd	nd	nd	nd	nd	nd
Fluorene	nd	nd	nd	nd	nd	nd	nd
Anthracene	nd	nd	nd	nd	nd	nd	nd
Fluoranthene	0.12	nd	0.10	0.16	0.13	nd	0.08
Pyrene	0.04	nd	0.07	0.08	0.18	nd	0.15
C_1-Fluoranthenes/Pyrenes	nd	nd	nd	nd	nd	nd	nd
C_2-Fluoranthenes/Pyrenes	nd	nd	nd	nd	nd	nd	nd
C_3-Fluoranthenes/Pyrenes	nd	nd	nd	nd	nd	nd	nd
Benzo(a)anthracene	nd	nd	nd	0.10	0.04	nd	nd
Chrysene	nd	nd	nd	0.07	0.11	nd	nd
C_1-Benanthracenes/Chrysenes	nd	nd	nd	nd	nd	nd	nd
C_2- Benanthracenes/Chrysenes	nd	nd	nd	nd	nd	nd	nd
Benzo(b)fluoranthene	0.10	nd	0.15	0.38	0.31	nd	nd
Benzo(k)fluoranthene	0.04	nd	0.10	0.09	0.05	nd	nd
Benzo(a)pyrene	0.03	nd	0.07	0.11	0.07	nd	nd
C_1-Benzofluoranthenes/Benzpyrenes	nd	nd	nd	nd	nd	nd	nd
C_2- Benzofluoranthenes/Benzpyrenes	nd	nd	nd	nd	nd	nd	nd
Indeno(1,2,3-cd)pyrene	0.14	nd	0.29	0.30	0.17	nd	nd
Dibenzo(a,h)anthracene	nd	nd	nd	0.05	nd	nd	nd
Benzo(ghi)perylene	0.14	nd	0.25	0.27	0.13	nd	nd
Total EPA 16	1.4	1.7	1.03	1.7	1.3	0.11	0.33
4-6 Ring PAH/NPD	0.28	0.19	-	0.85	13.00	0.41	3.30

nd = not detected

5. Conclusions

- TOE concentrations in the sediments range from 0.69µg/g at Station 17 to 13µg/g at Stations 25B and the S10 Duplicate. Concentrations of TOE in these samples are considered consistent with 'background' levels previously seen further offshore around the Corrib field development.

- The GC traces preclude the presence of the synthetic base oils previously identified in the Corrib field ("Ecosol", "Ecomul" and "Esterkleen). There was also no evidence for the presence of base oils of mineral origin (such as "low toxicity Oil Based Muds" or diesel related hydrocarbons from shipping related activities).

- The concentrations of naphthalenes, phenanthrenes and dibenzothiophenes (NPDs) in the sediments, which are generally thought to be of petrogenic origin, range from 0.03ng/g (ppb; Station 26) to 11ng/g (Station S6). The concentrations of the EPA 16 PAHs range from 0.11ng/g (Station 15) to 2.8ng/g (Station 32A). These concentrations are generally similar to those previously observed in the 'background' sample taken around the Corrib field development, and are also generally similar to the background levels found in North Atlantic sediments.

6. References

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APPENDIX I

Total Organic Extractables (TOE)

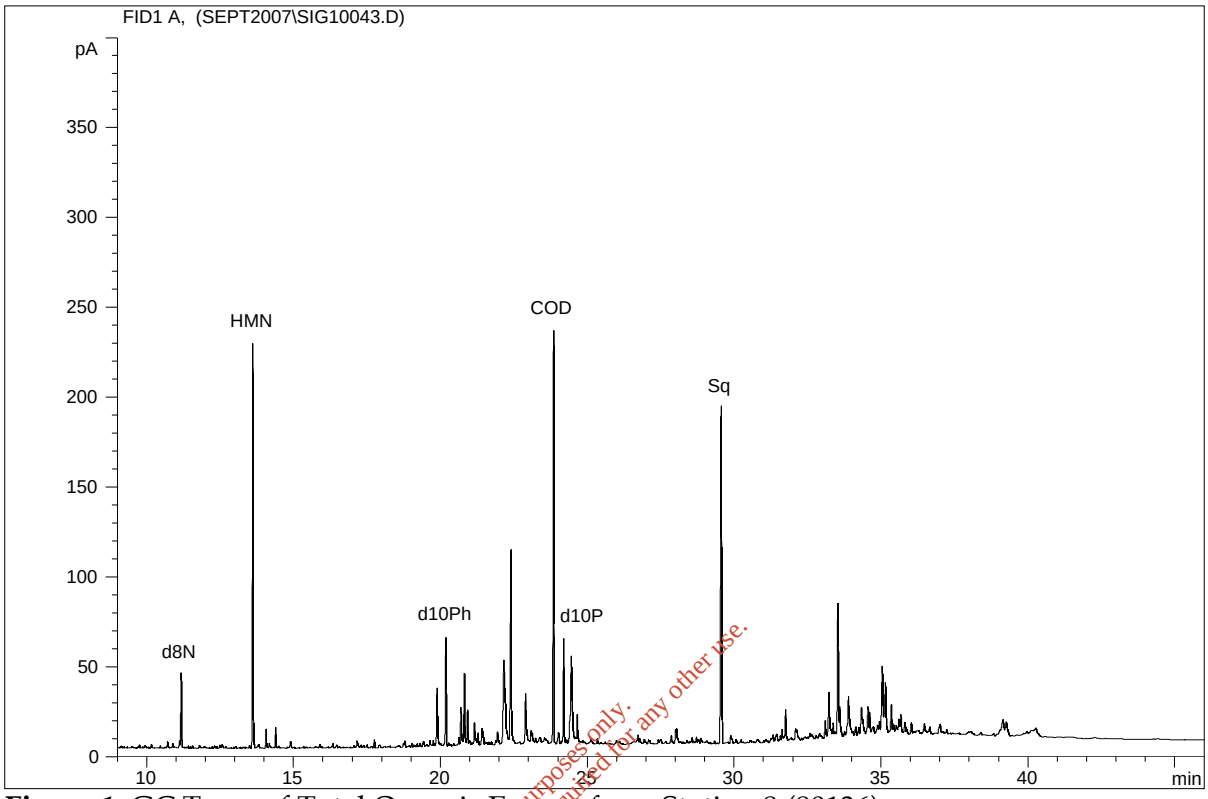


Figure 1: GC Trace of Total Organic Extract from Station 8 (80136)

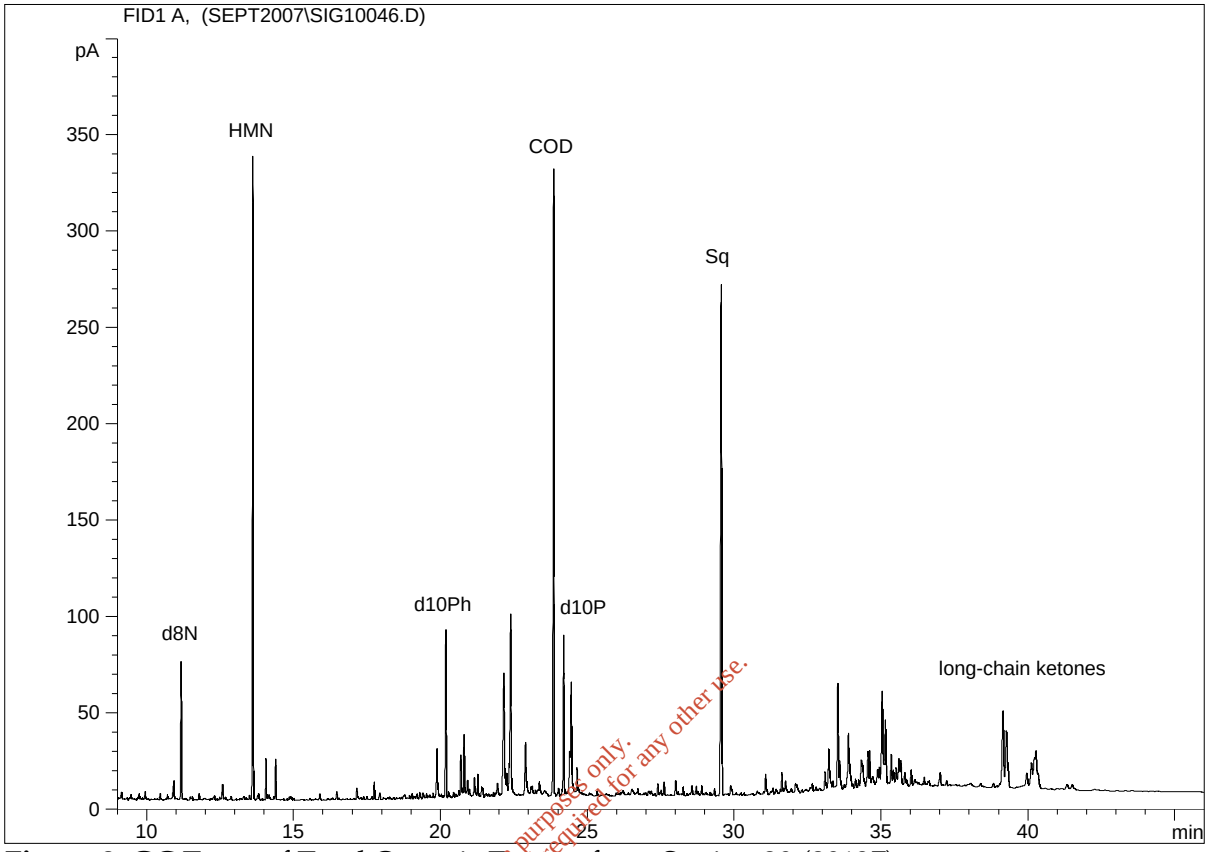


Figure 2: GC Trace of Total Organic Extract from Station 20 (80137)

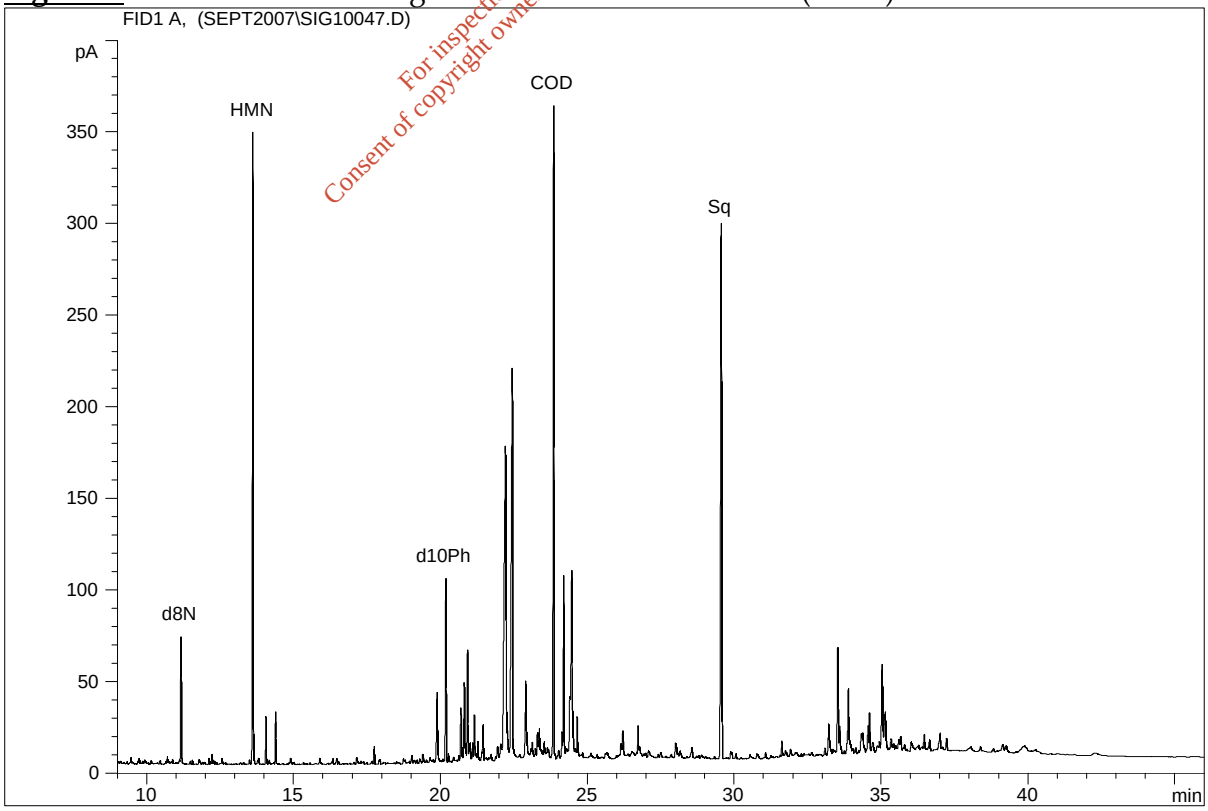


Figure 3: GC Trace of Total Organic Extract from Station 25 (80138)

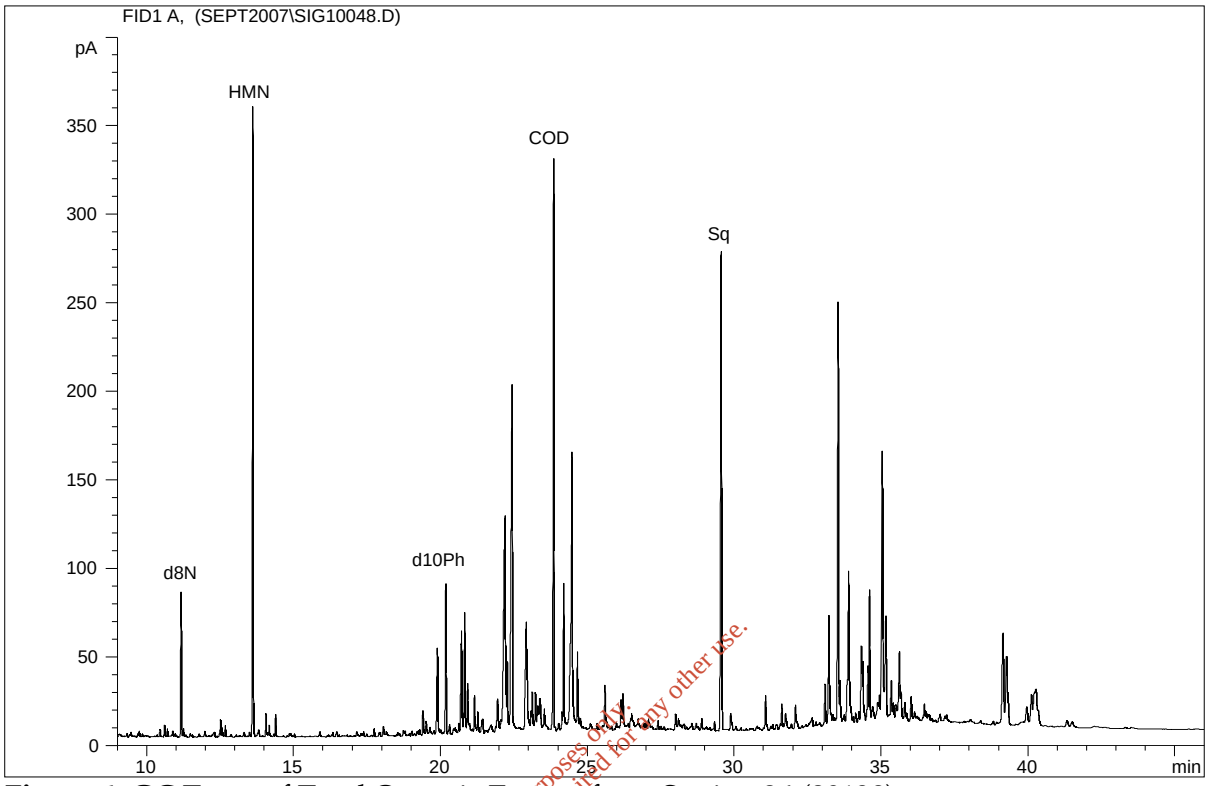


Figure 4: GC Trace of Total Organic Extract from Station 26 (80139)

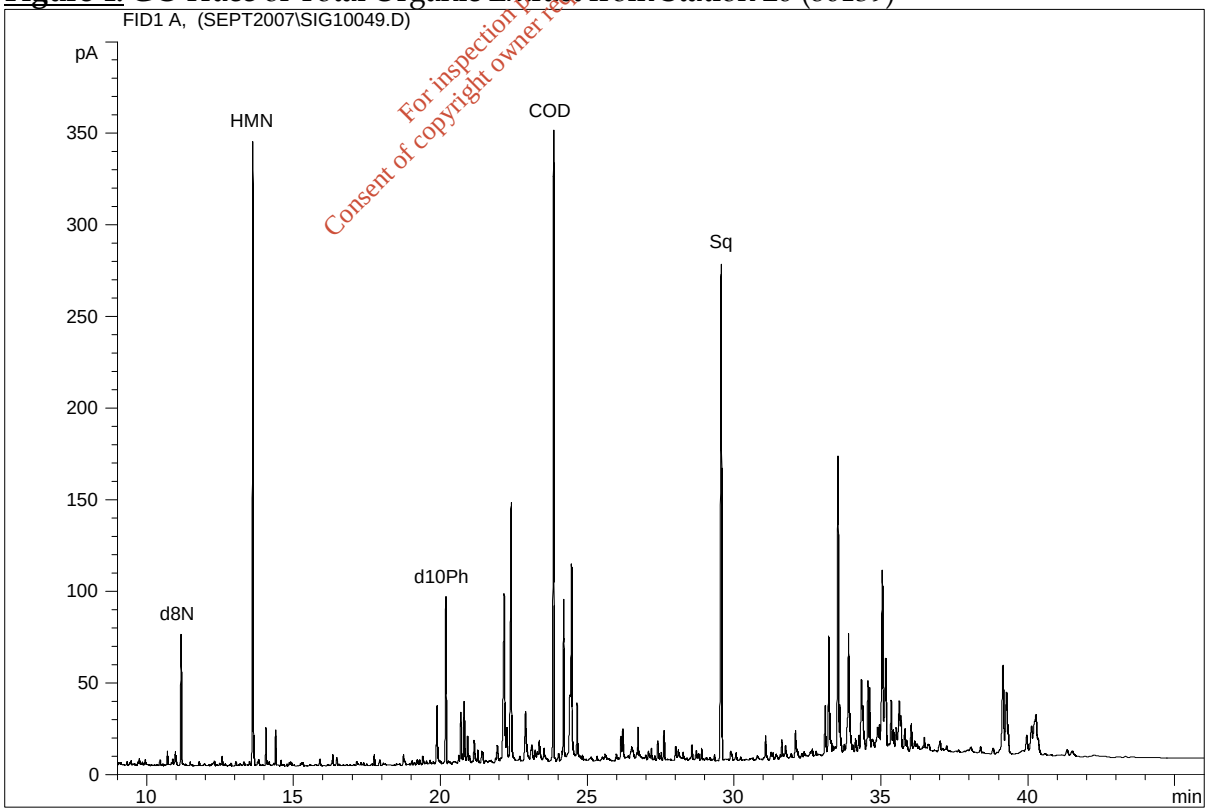


Figure 5: GC Trace of Total Organic Extract from Station 27 (80140)

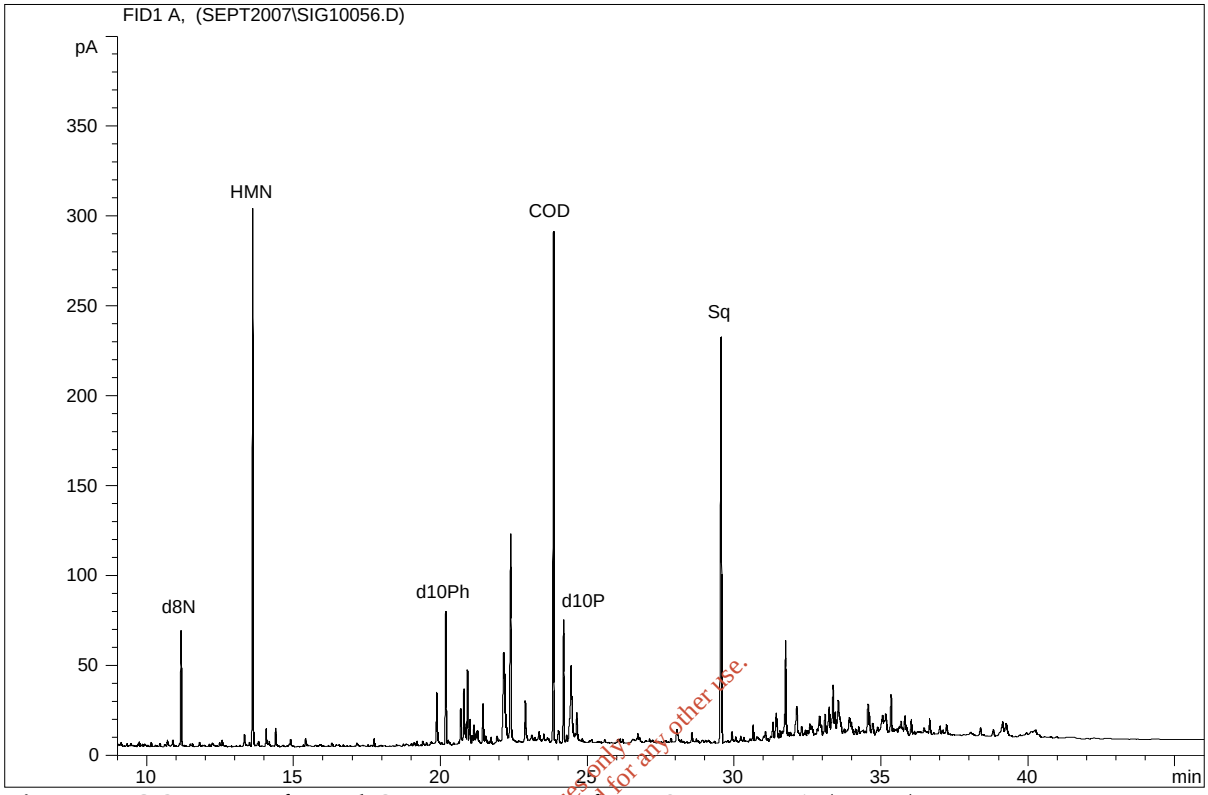


Figure 6: GC Trace of Total Organic Extract from Station 25A (80141)

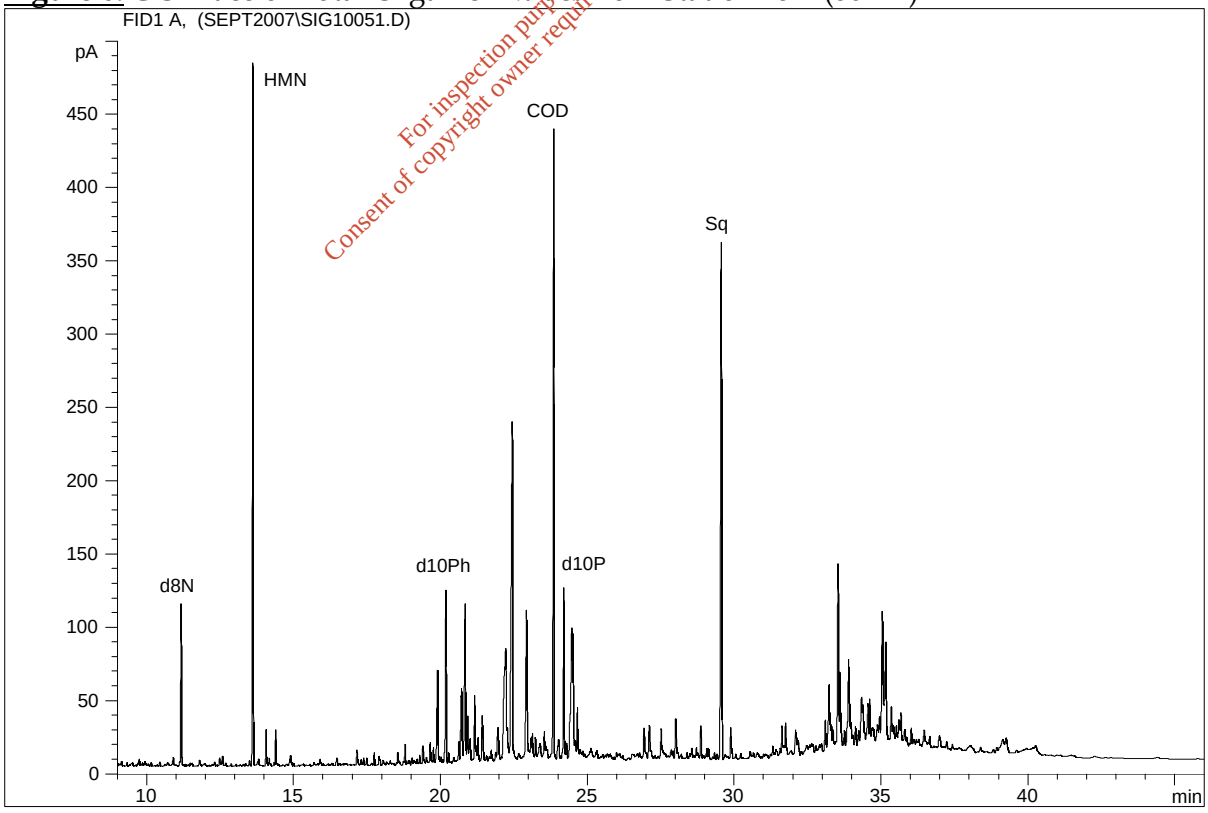


Figure 7: GC Trace of Total Organic Extract from Station 25B (80142)

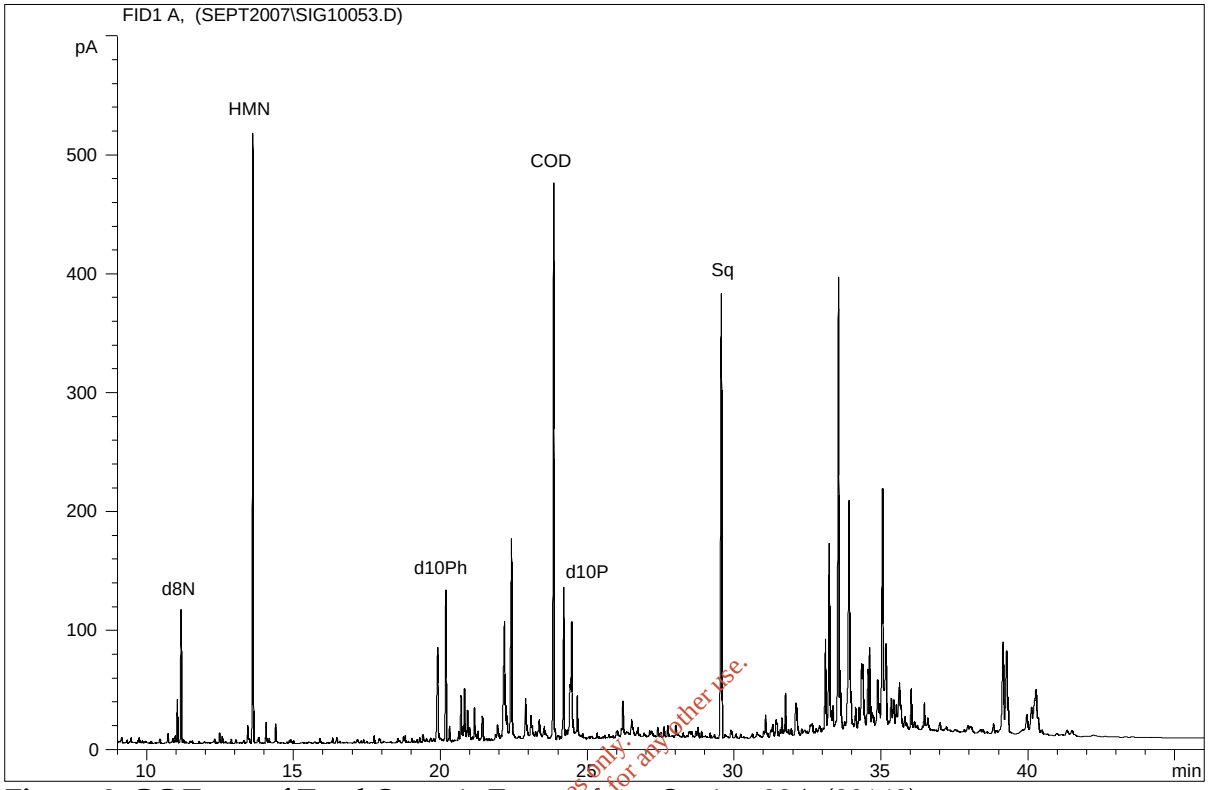


Figure 8: GC Trace of Total Organic Extract from Station 32A (80143)

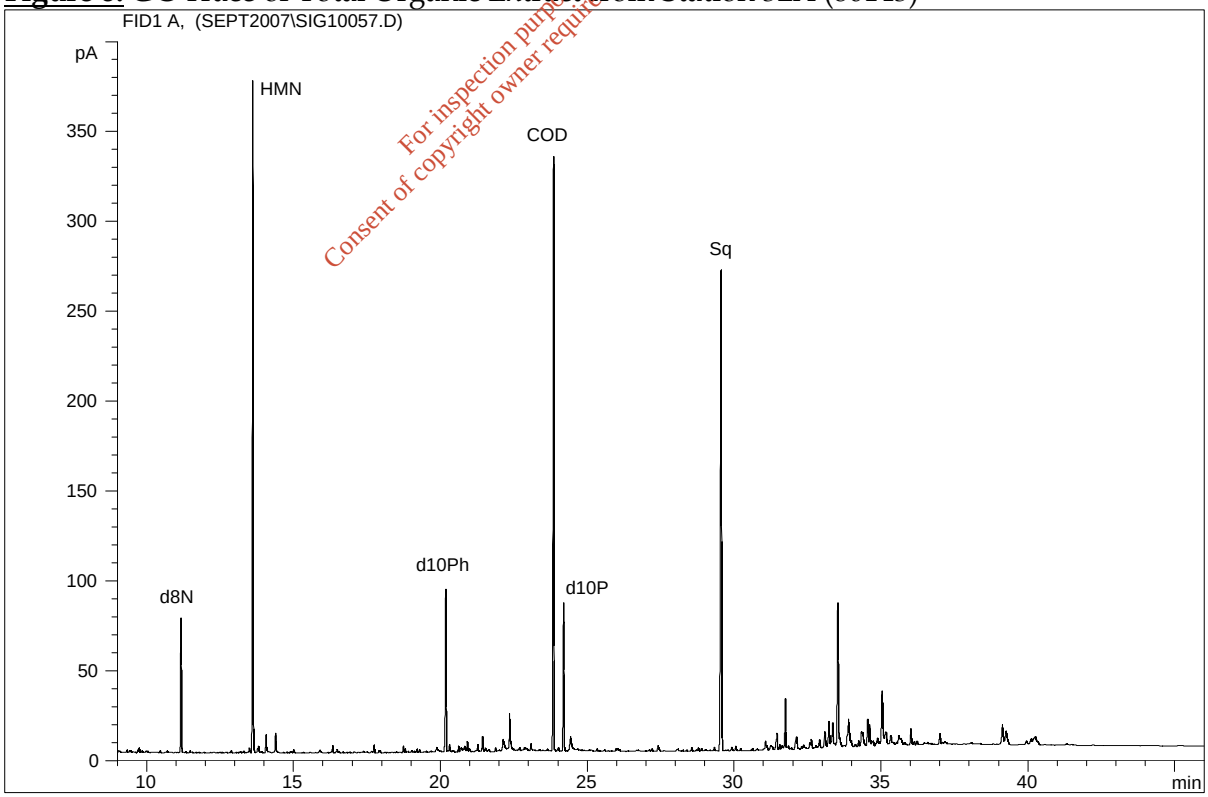


Figure 9: GC Trace of Total Organic Extract from Station 1 (80144)

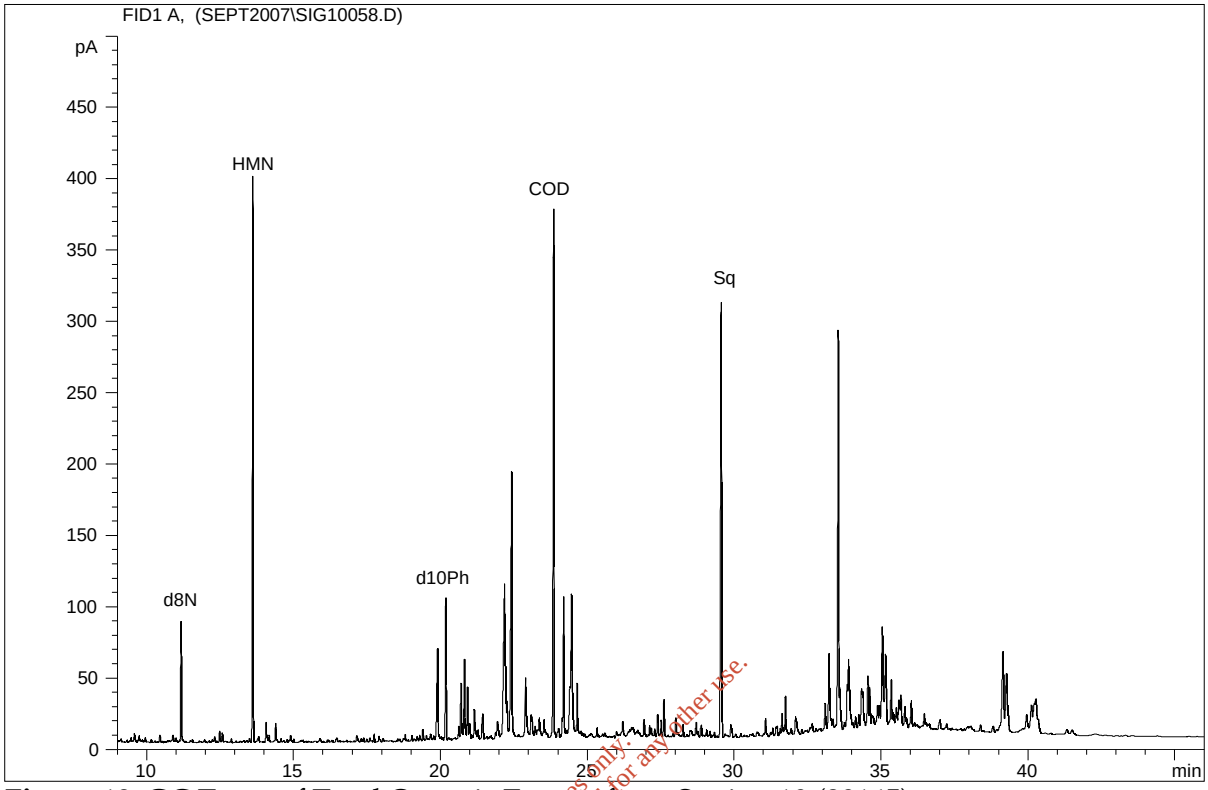


Figure 10: GC Trace of Total Organic Extract from Station 10 (80145)

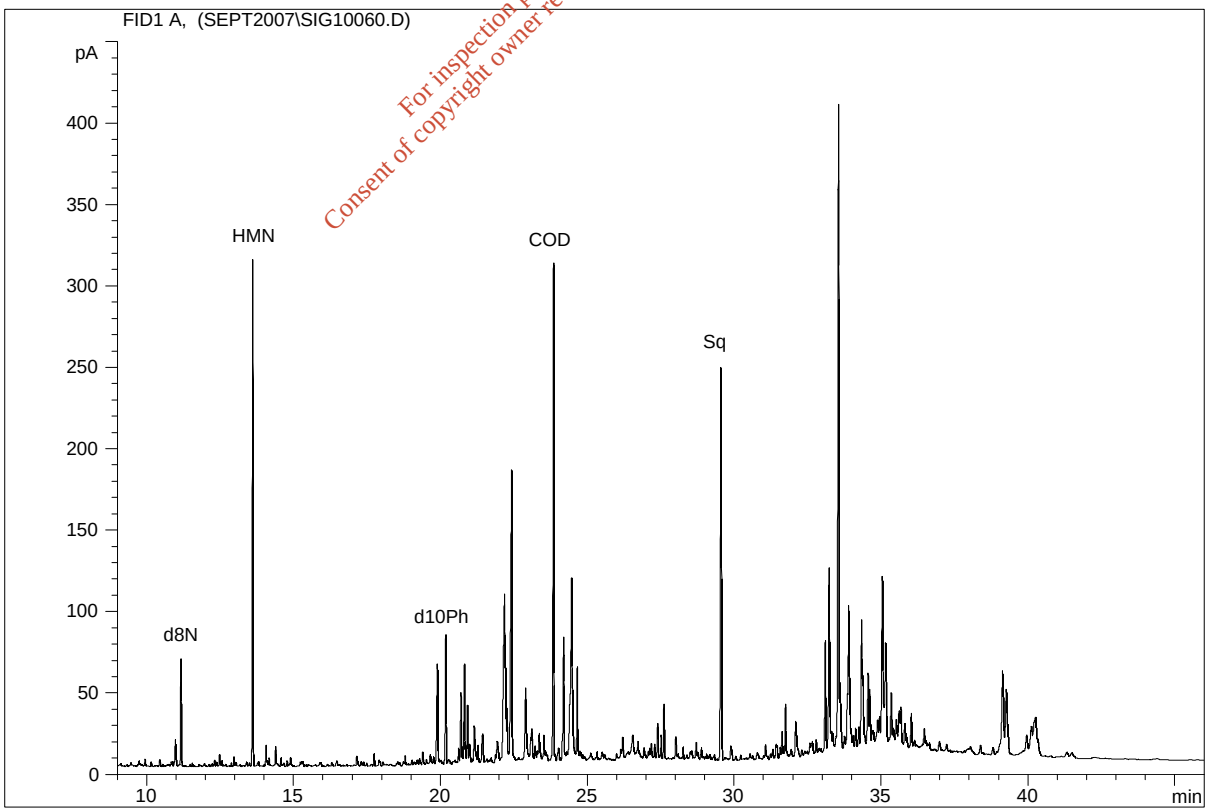


Figure 11: GC Trace of Total Organic Extract from Station 10 Duplicate (80146)

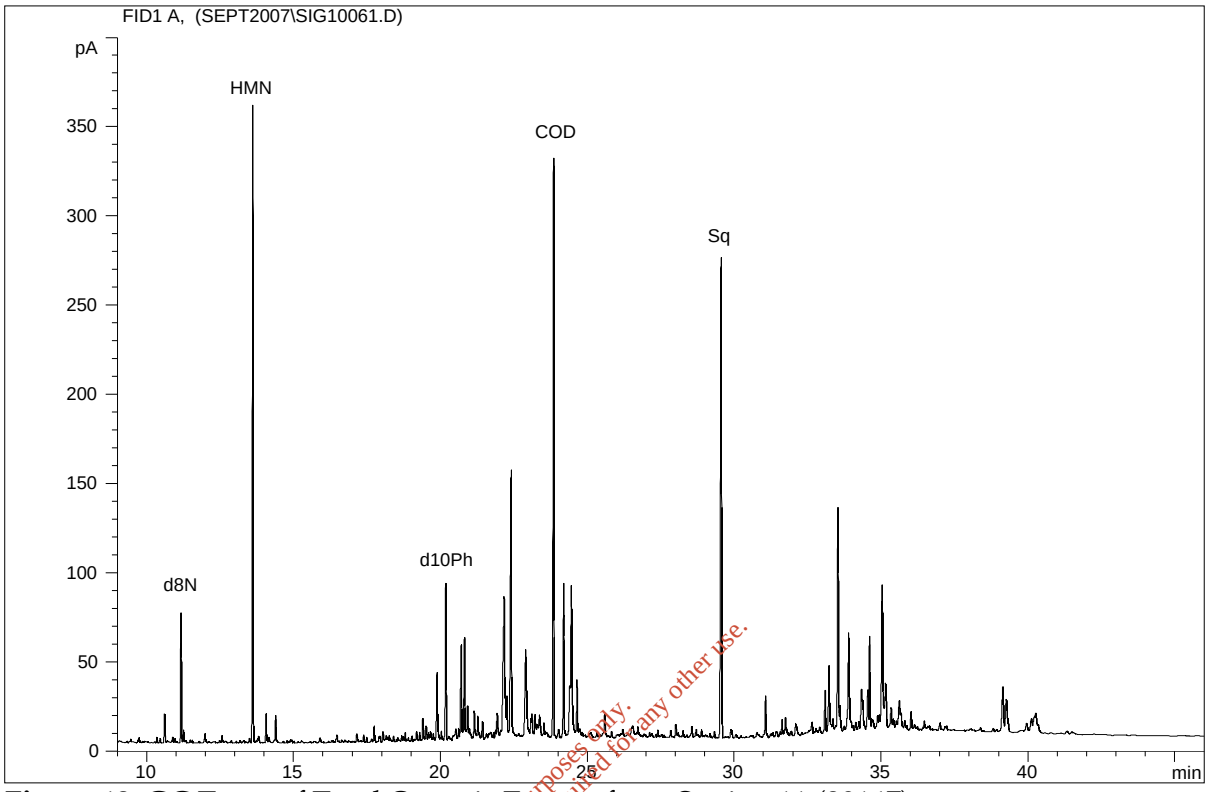


Figure 12: GC Trace of Total Organic Extract from Station 11 (80147)

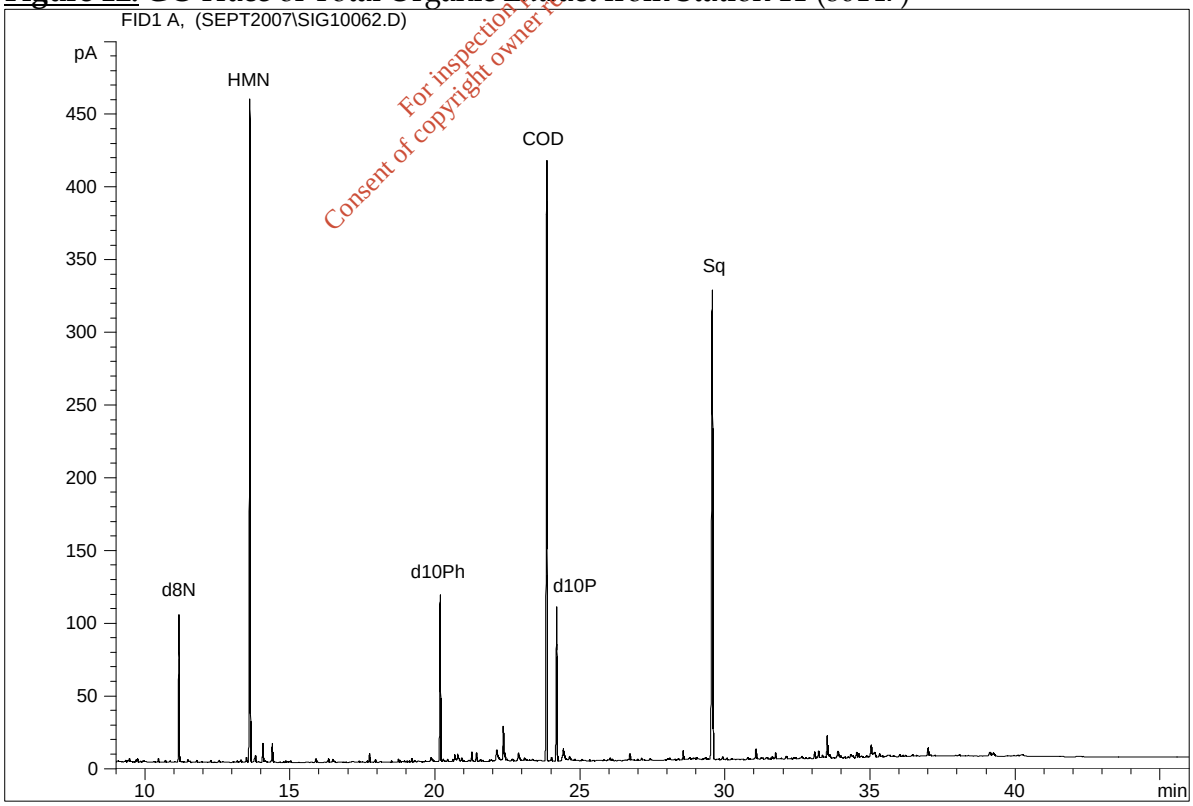


Figure 13: GC Trace of Total Organic Extract from Station 15 (80148)

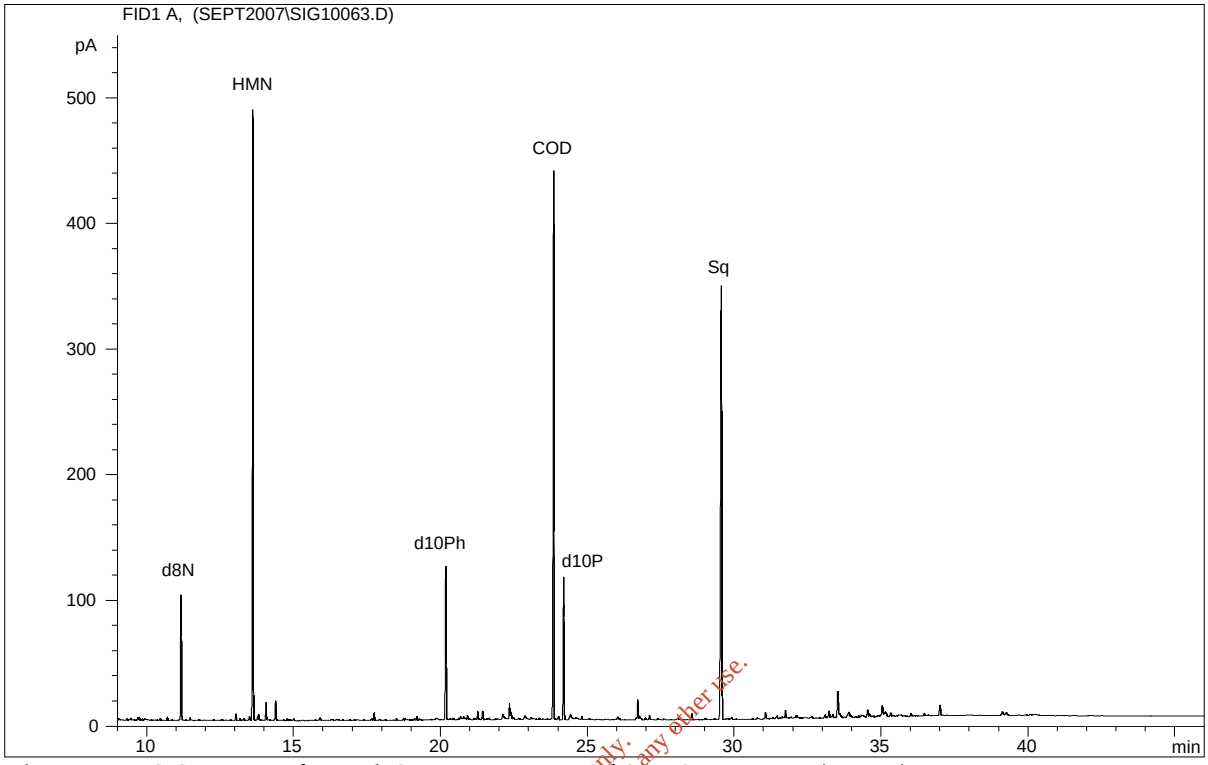


Figure 14: GC Trace of Total Organic Extract from Station 17 (80149)

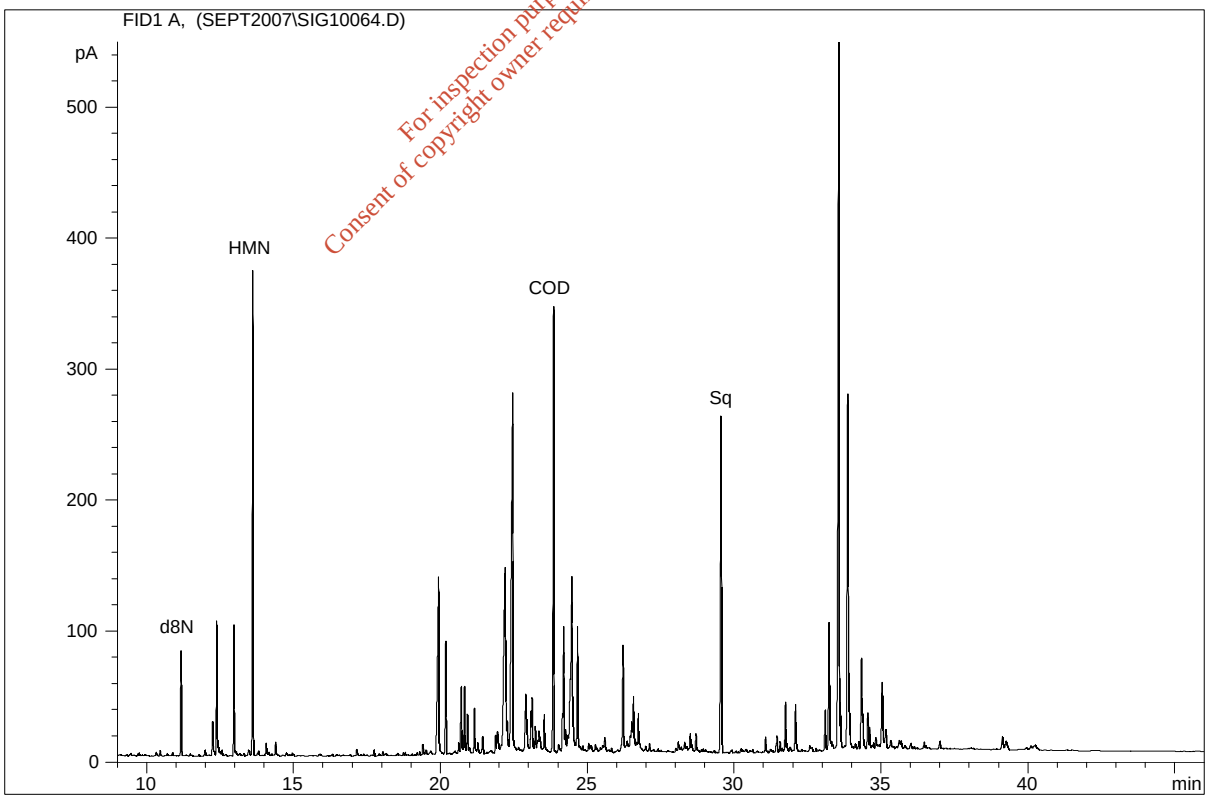


Figure 15: GC Trace of Total Organic Extract from Station 2 (80150)

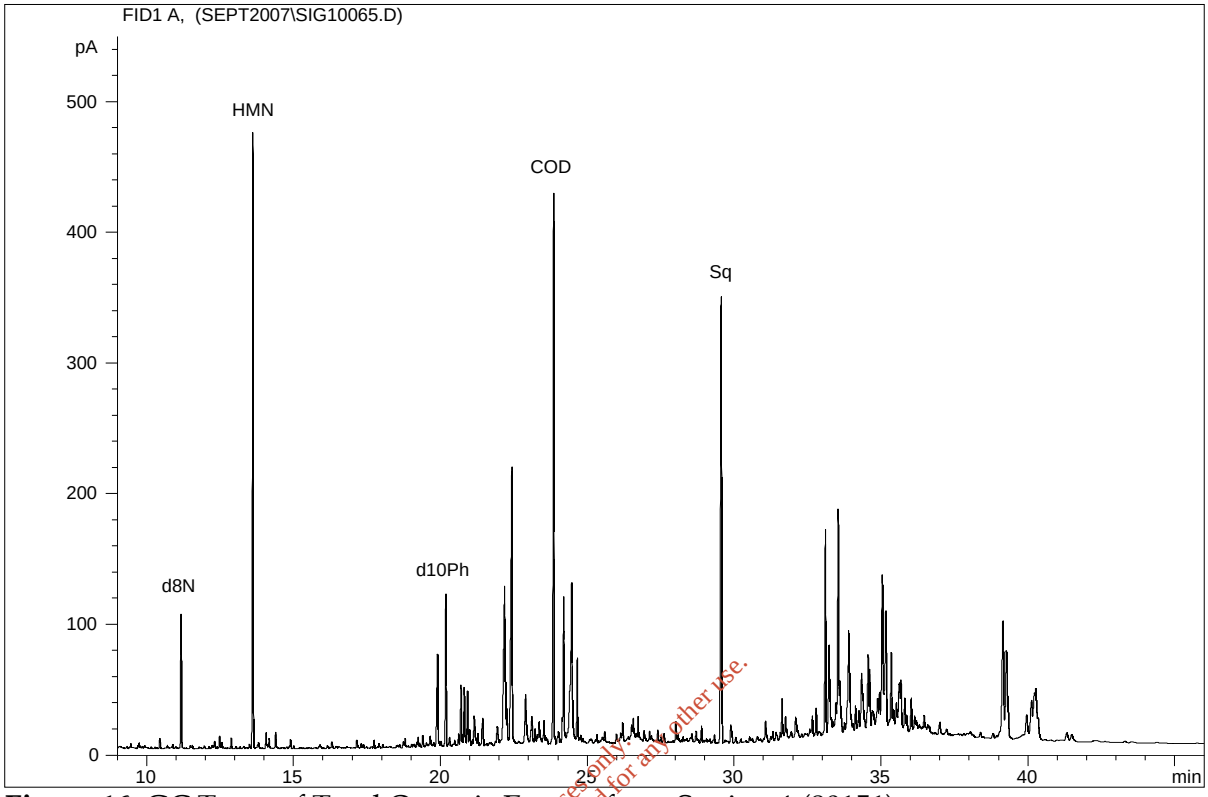


Figure 16: GC Trace of Total Organic Extract from Station 4 (80151)

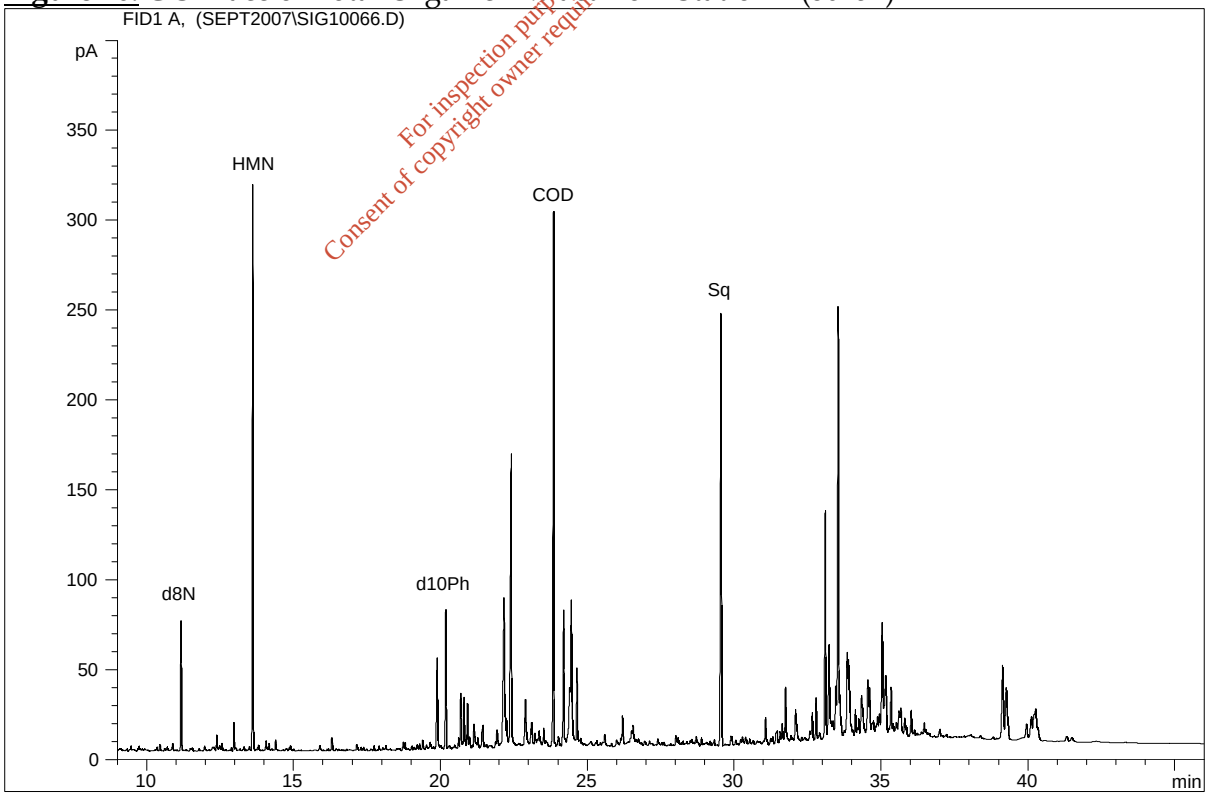


Figure 17: GC Trace of Total Organic Extract from Station 5R (80152)

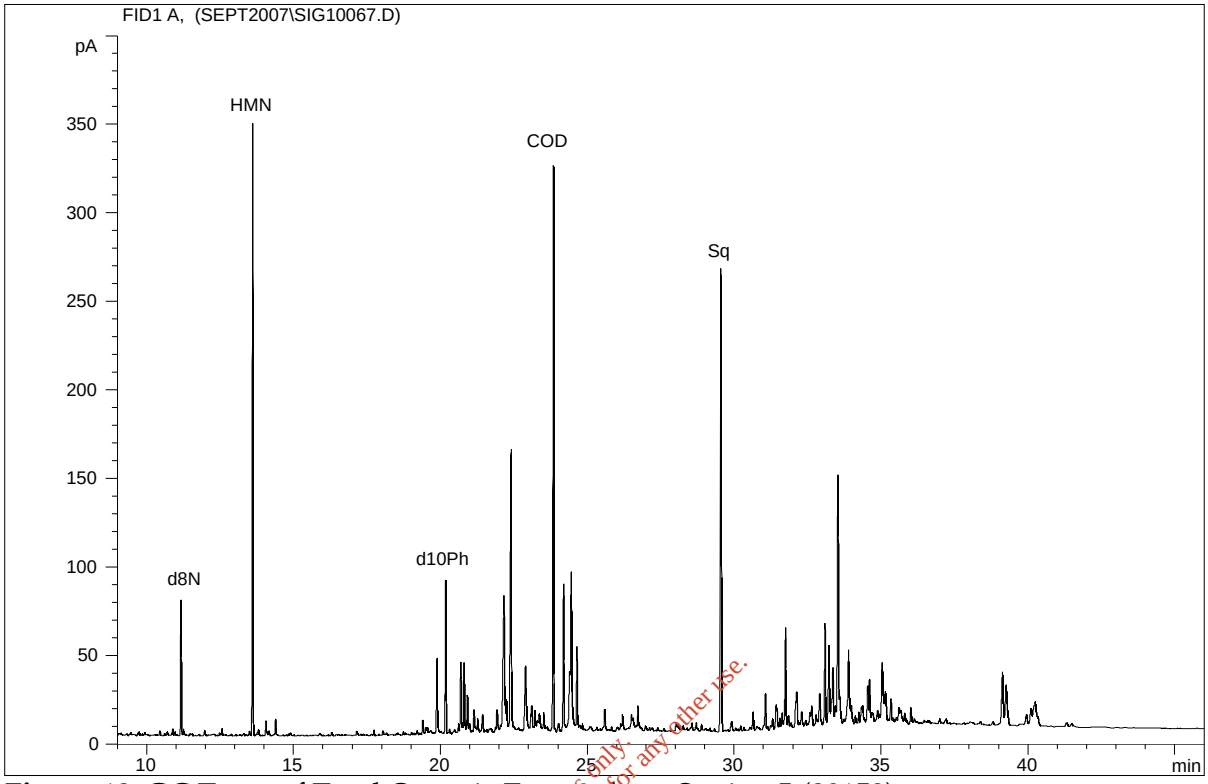


Figure 18: GC Trace of Total Organic Extract from Station 5 (80153)

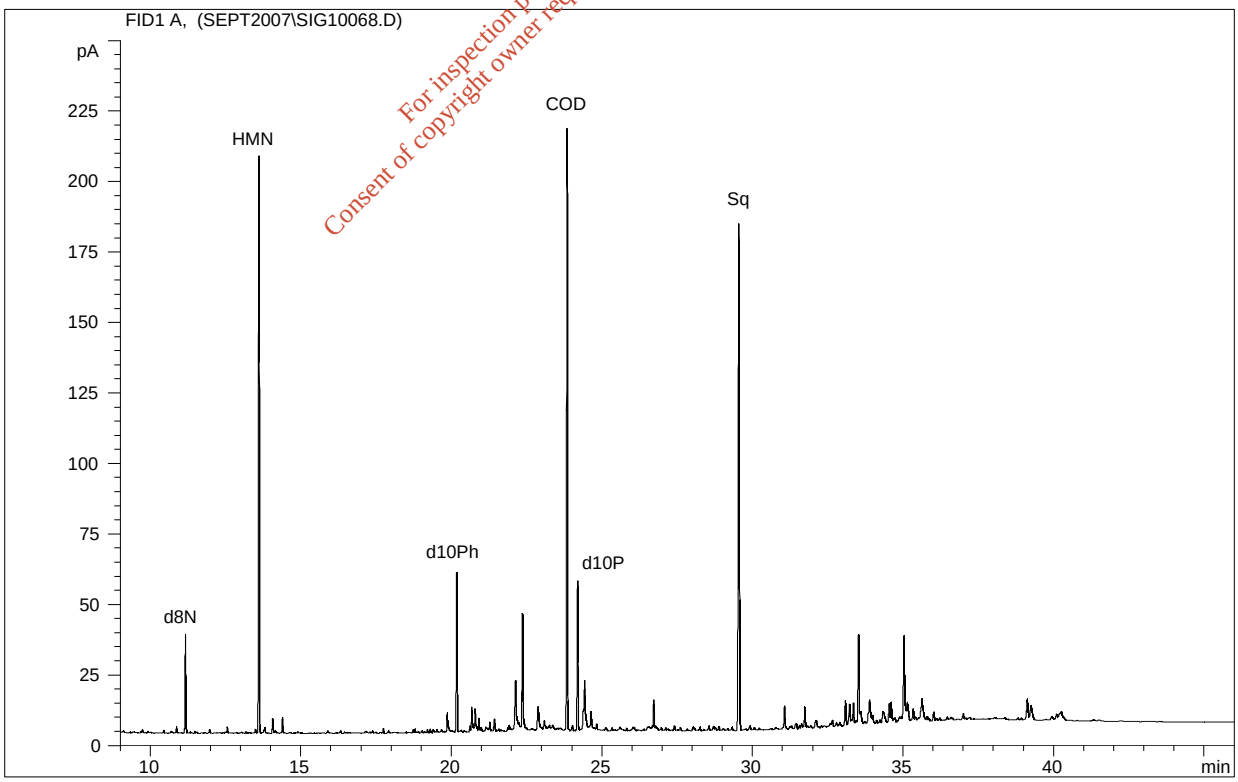


Figure 19: GC Trace of Total Organic Extract from Station 6 (80154)

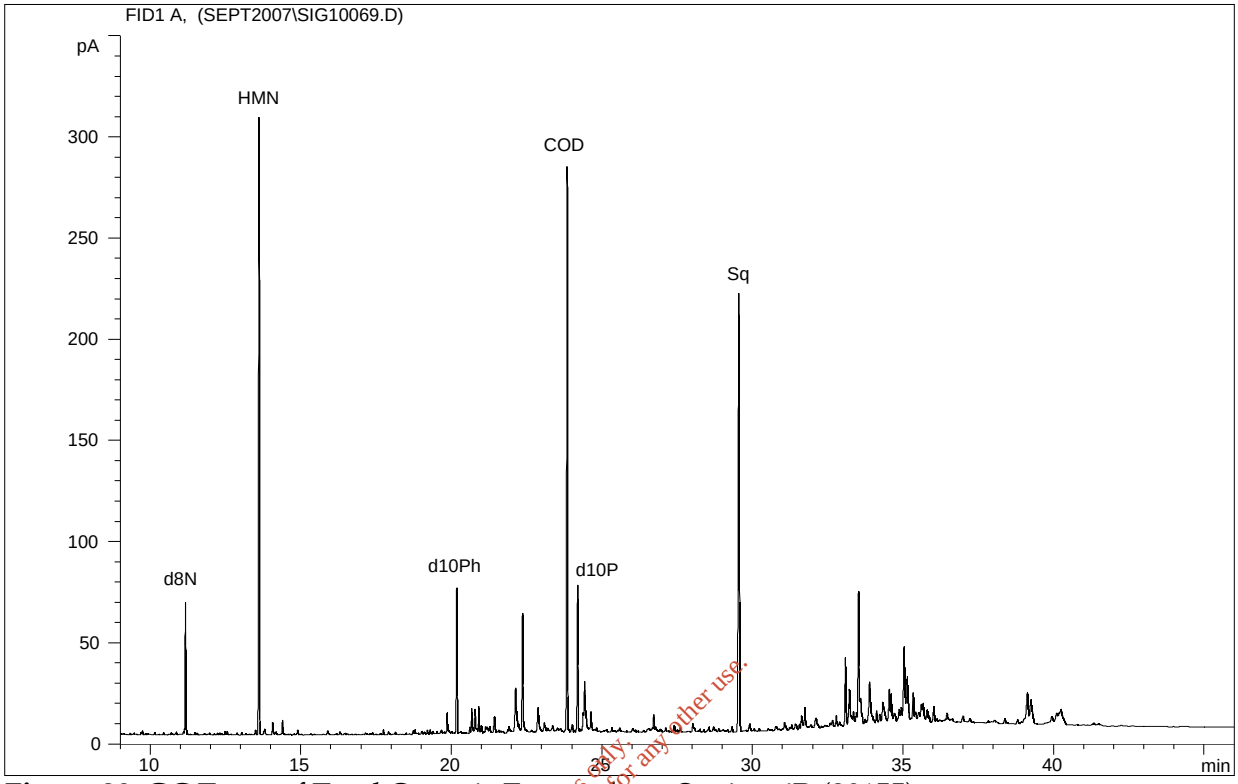


Figure 20: GC Trace of Total Organic Extract from Station 6R (80155)

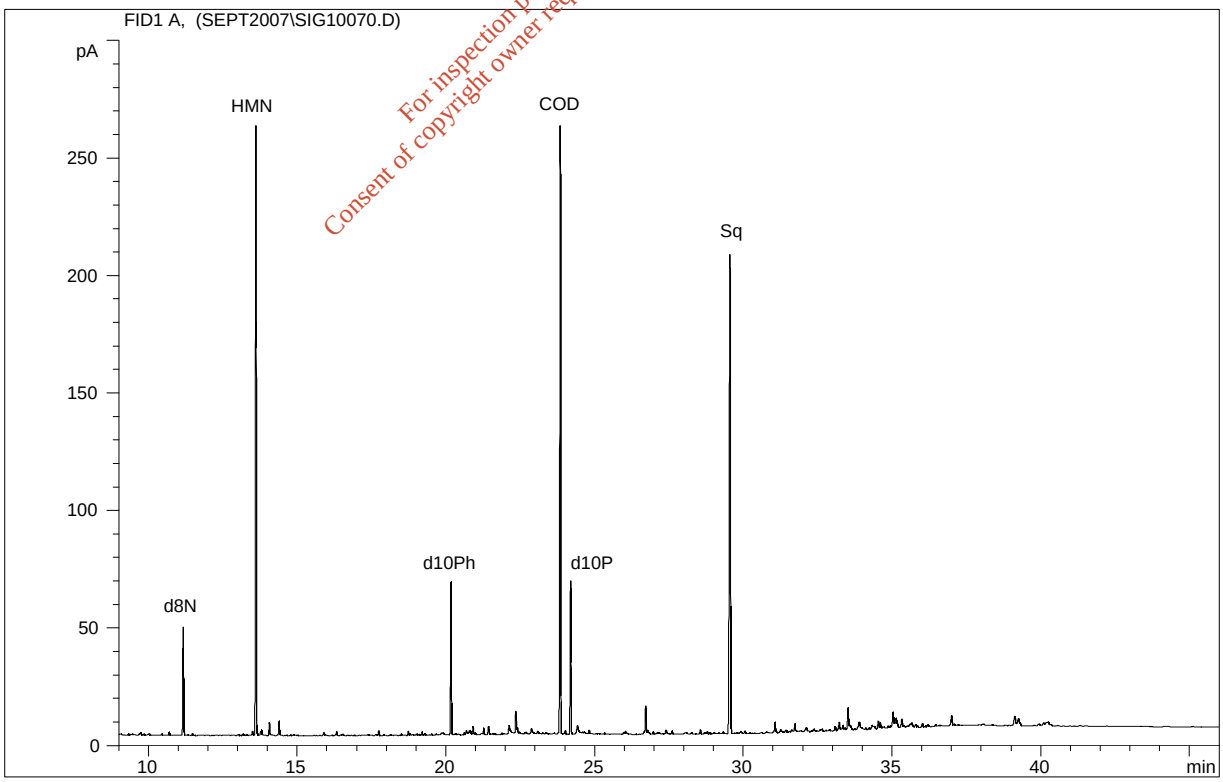


Figure 21: GC Trace of Total Organic Extract from Station 9 (80156)

APPENDIX II

Quality Assurance Analysis for

Total Organic Extractables (TOE)

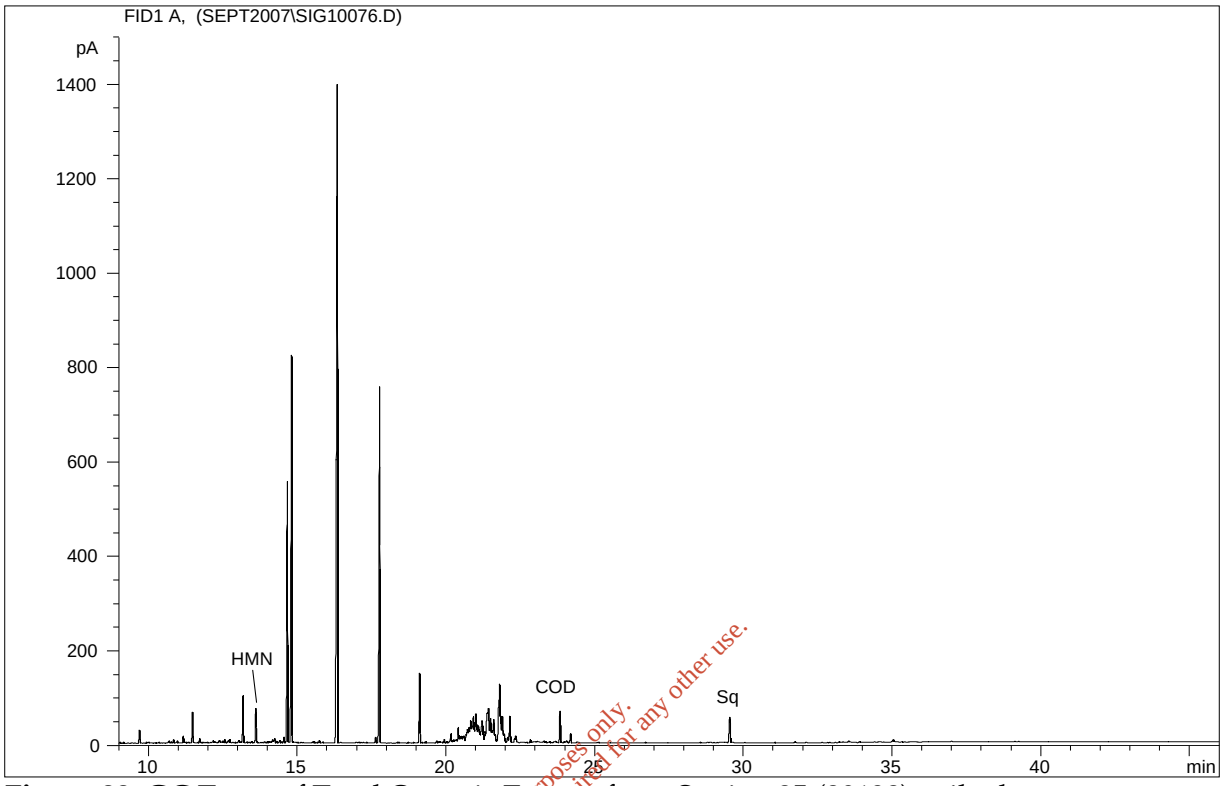


Figure 22: GC Trace of Total Organic Extract from Station 25 (80138) spiked with Ecosol Base Oil

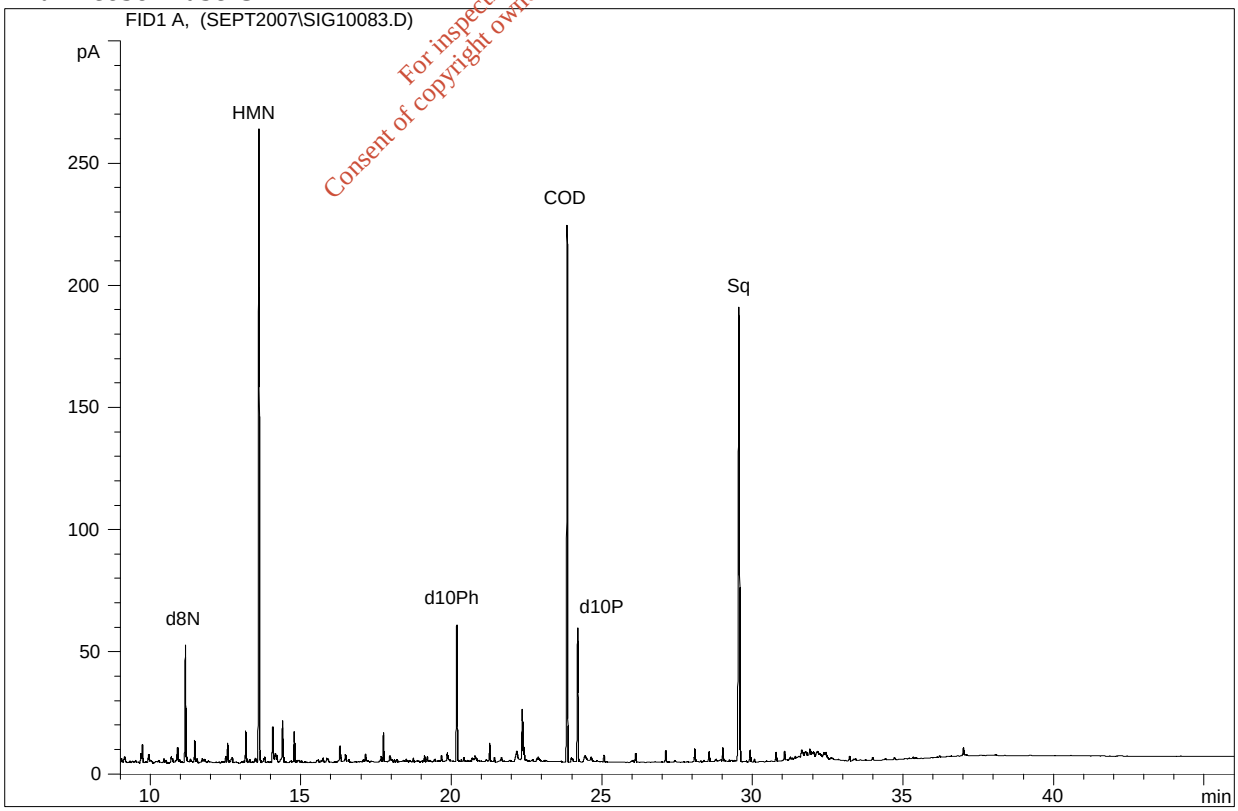


Figure 23: GC Trace of Total Organic Extract from Pre-Extracted Sediment 1

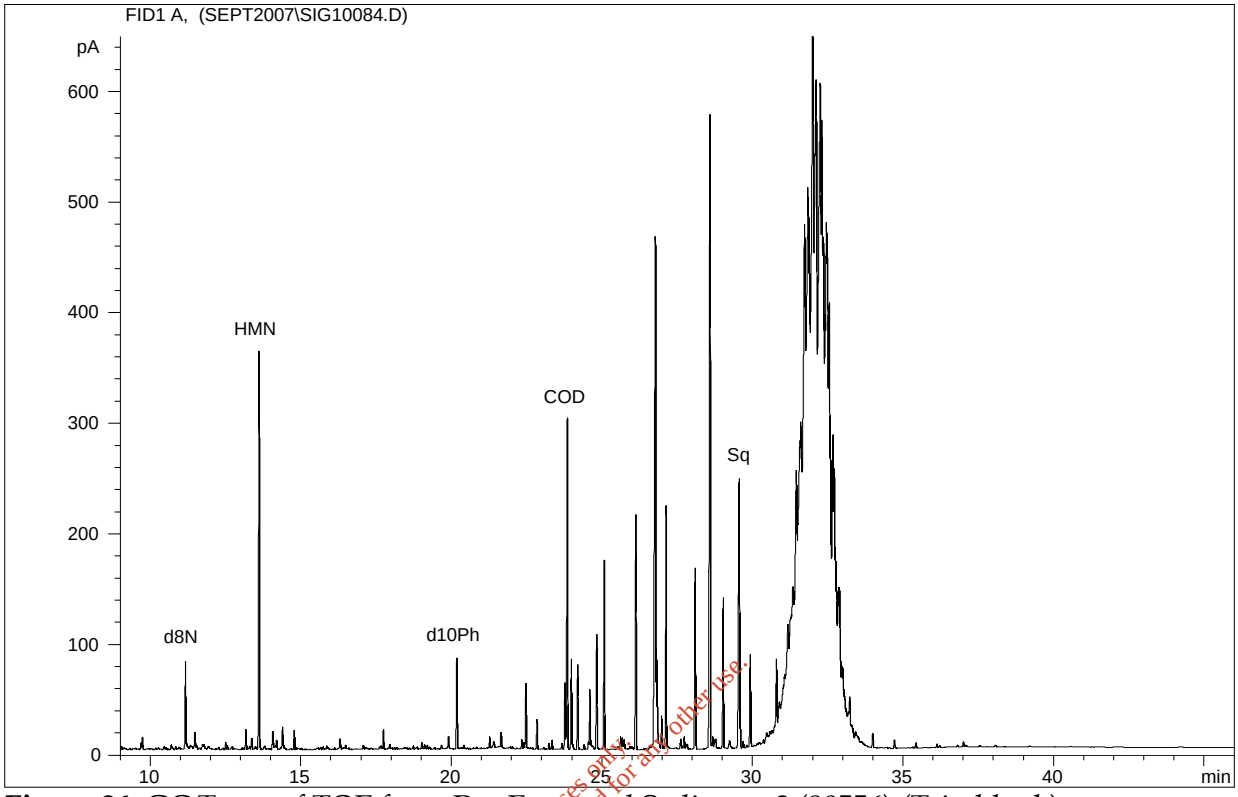


Figure 24: GC Trace of TOE from Pre-Extracted Sediment 2 (80556) (Trip blank)

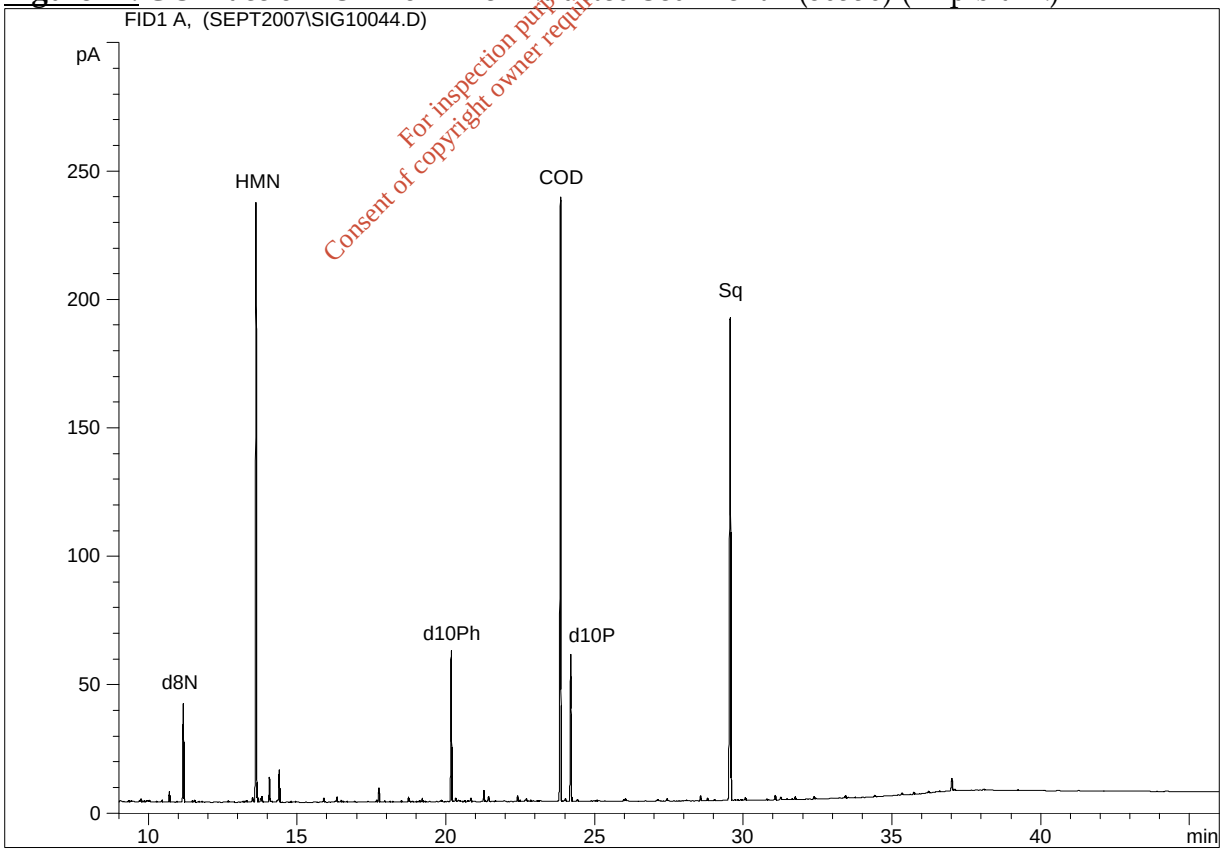


Figure 25: GC Trace of Total Organic Extract from Procedural Blank

APPENDIX III

Polycyclic Aromatic Hydrocarbons Total Ion Current (TIC)

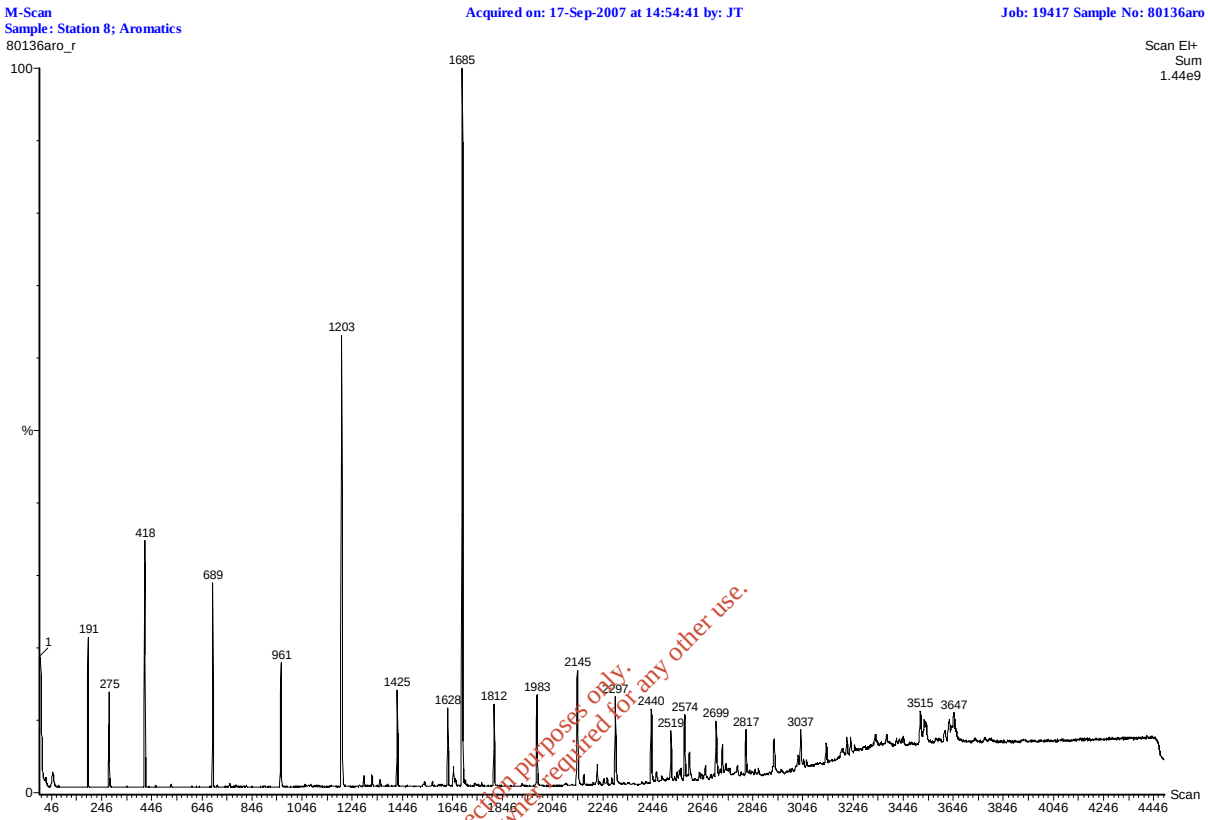


Figure 26: GC-MS TIC trace for aromatic hydrocarbon fraction, Station 8 (80136)

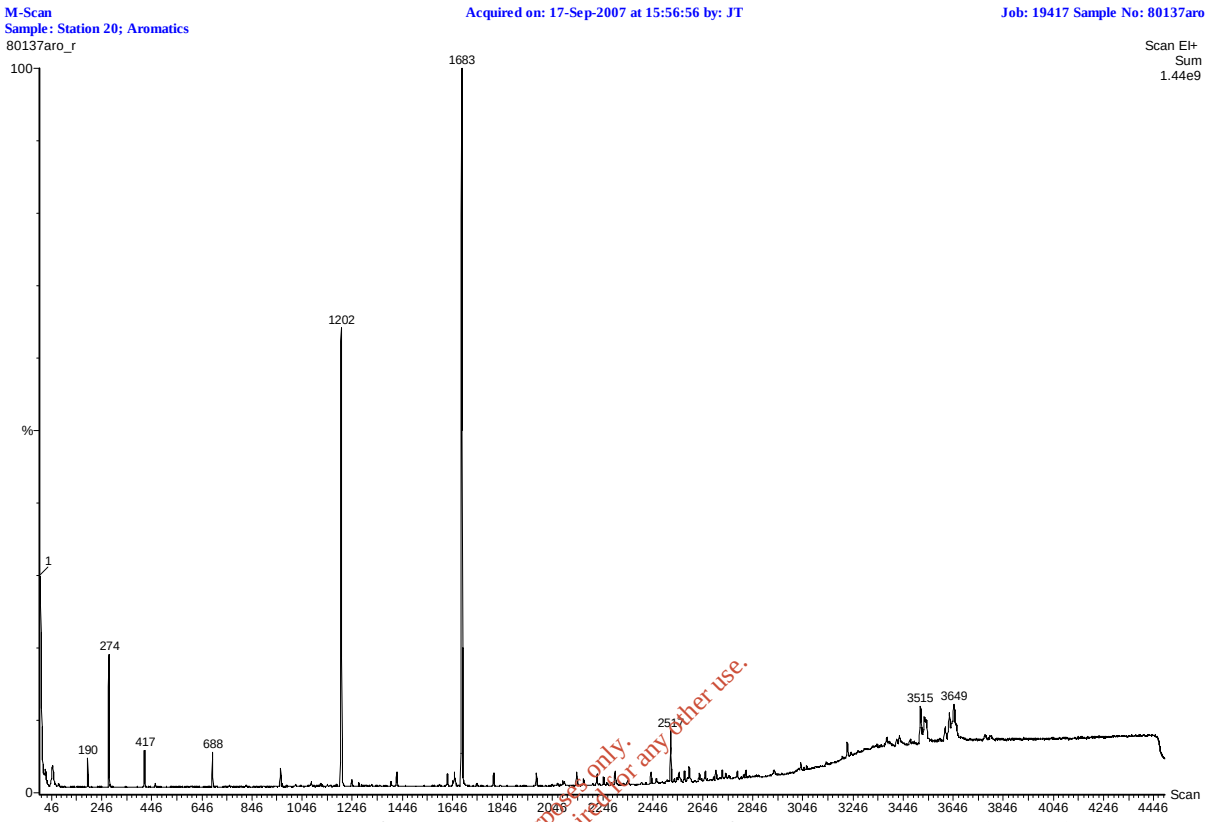


Figure 27: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 20 (80137)

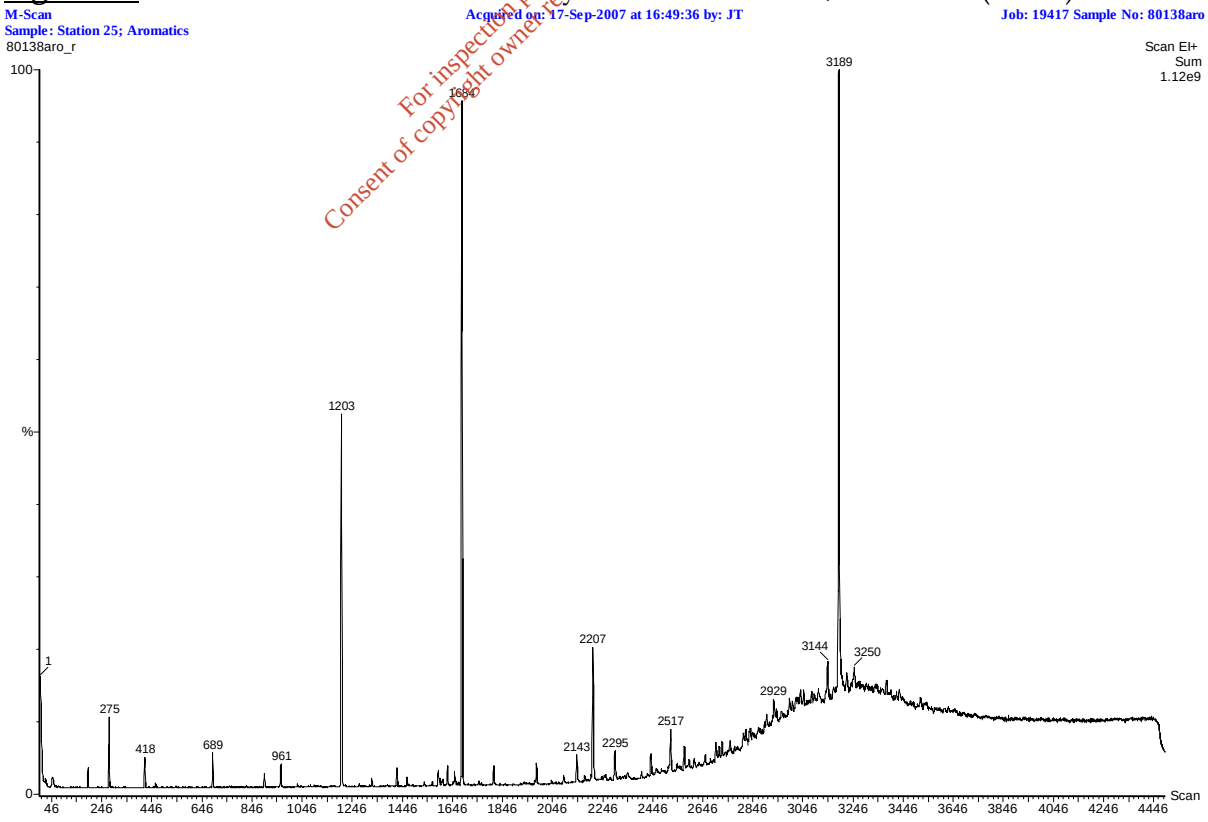


Figure 28: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 25 (80138)

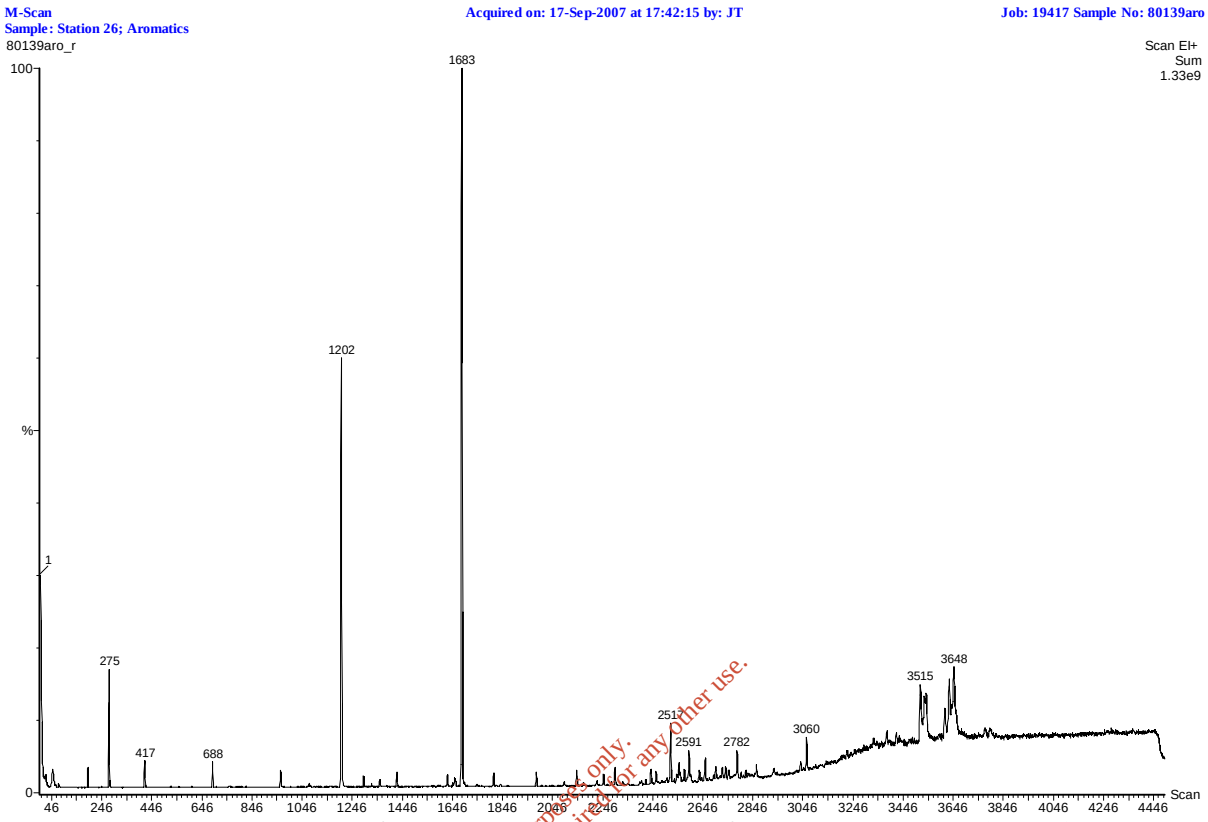


Figure 29: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 26 (80139)

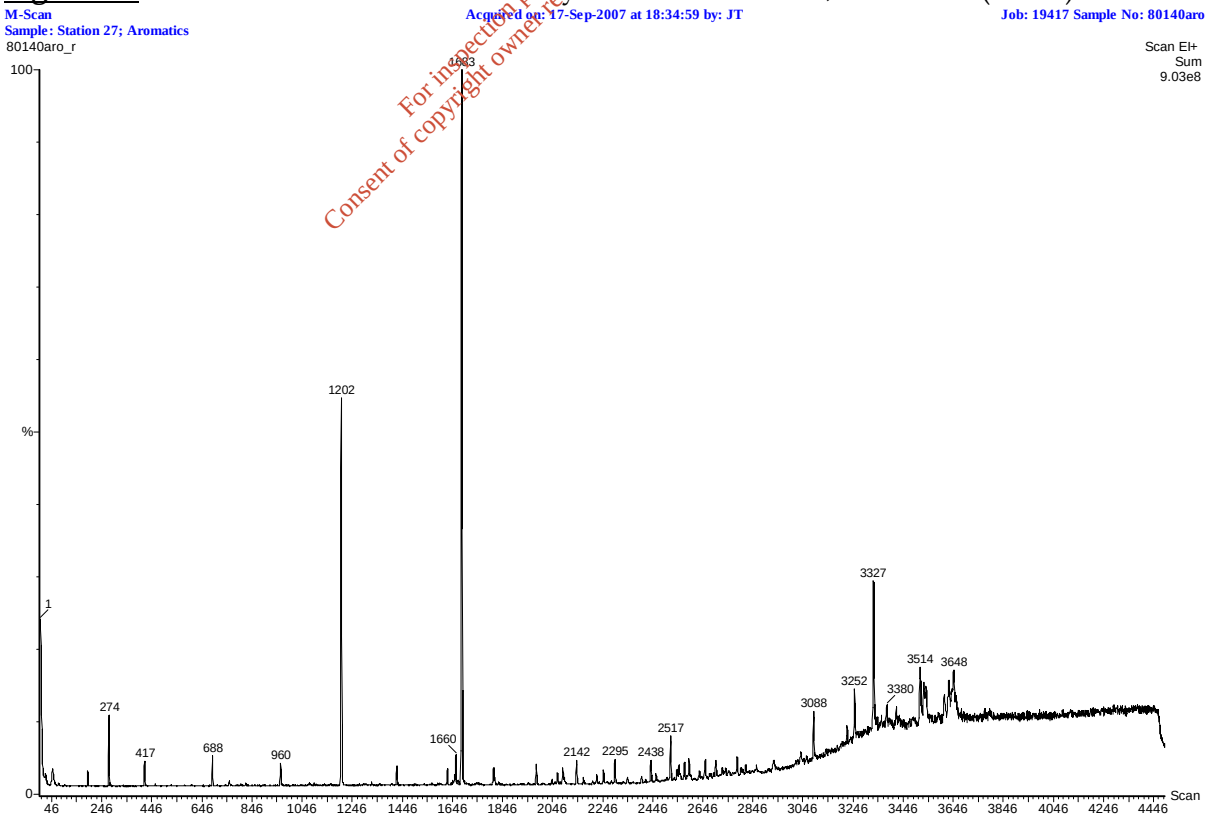


Figure 30: GC-MS TIC trace for aromatic hydrocarbon fraction, Station 27 (80140)

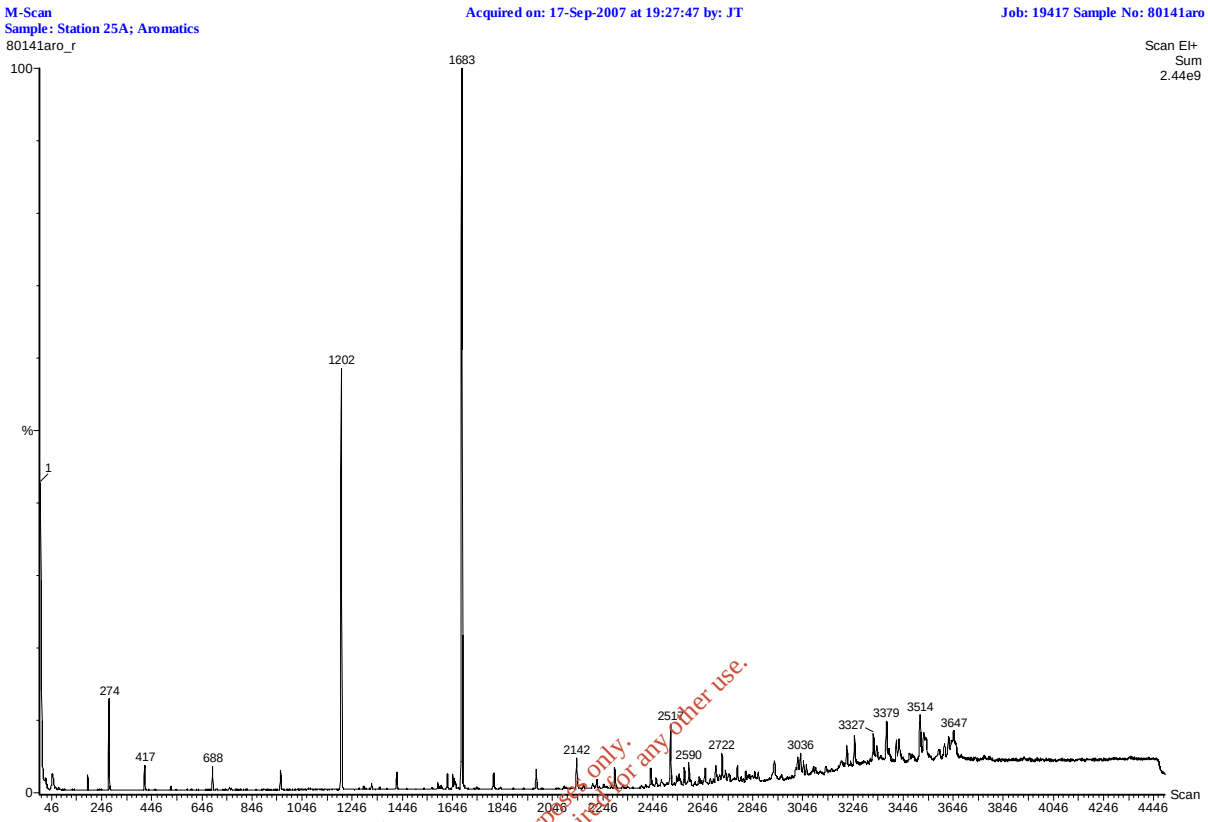


Figure 31: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 25A (80141)

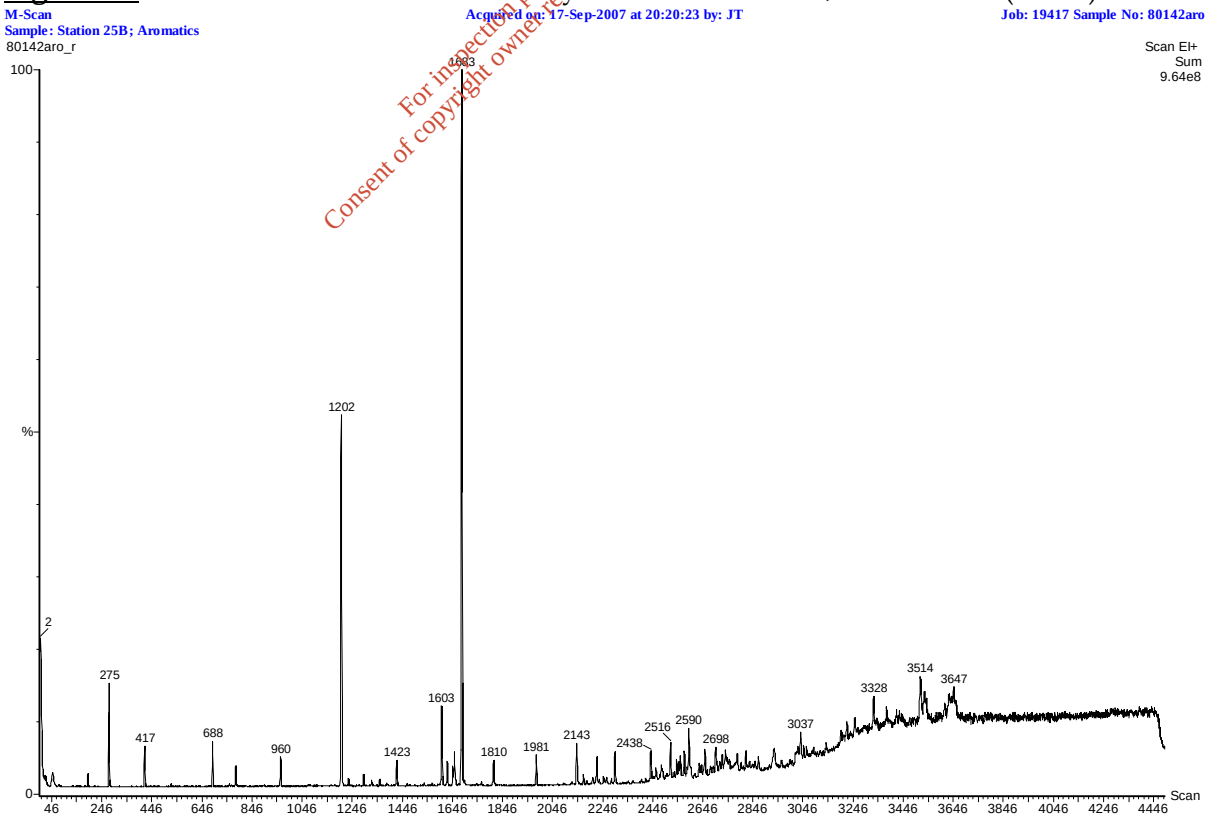


Figure 32: GC-MS TIC trace for aromatic hydrocarbon fraction, Station 25B (80142)

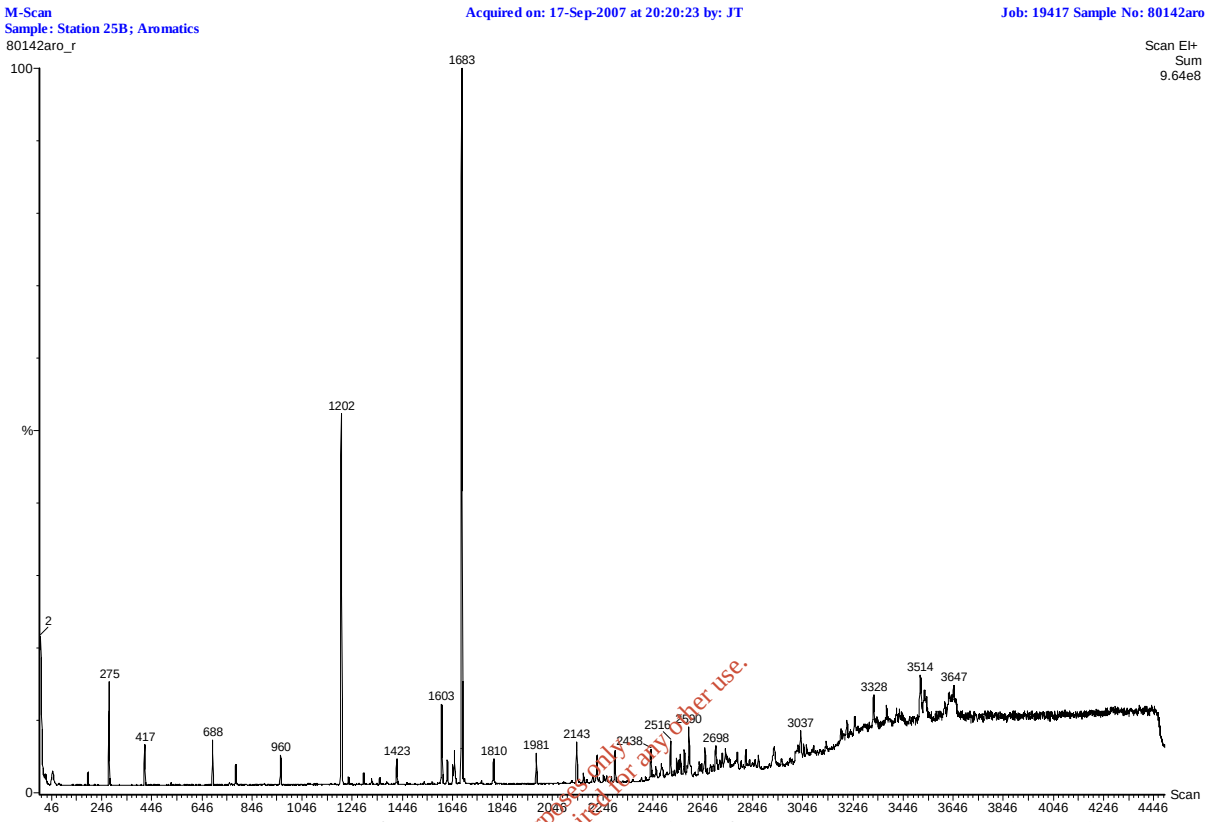


Figure 33: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 32A (80143)

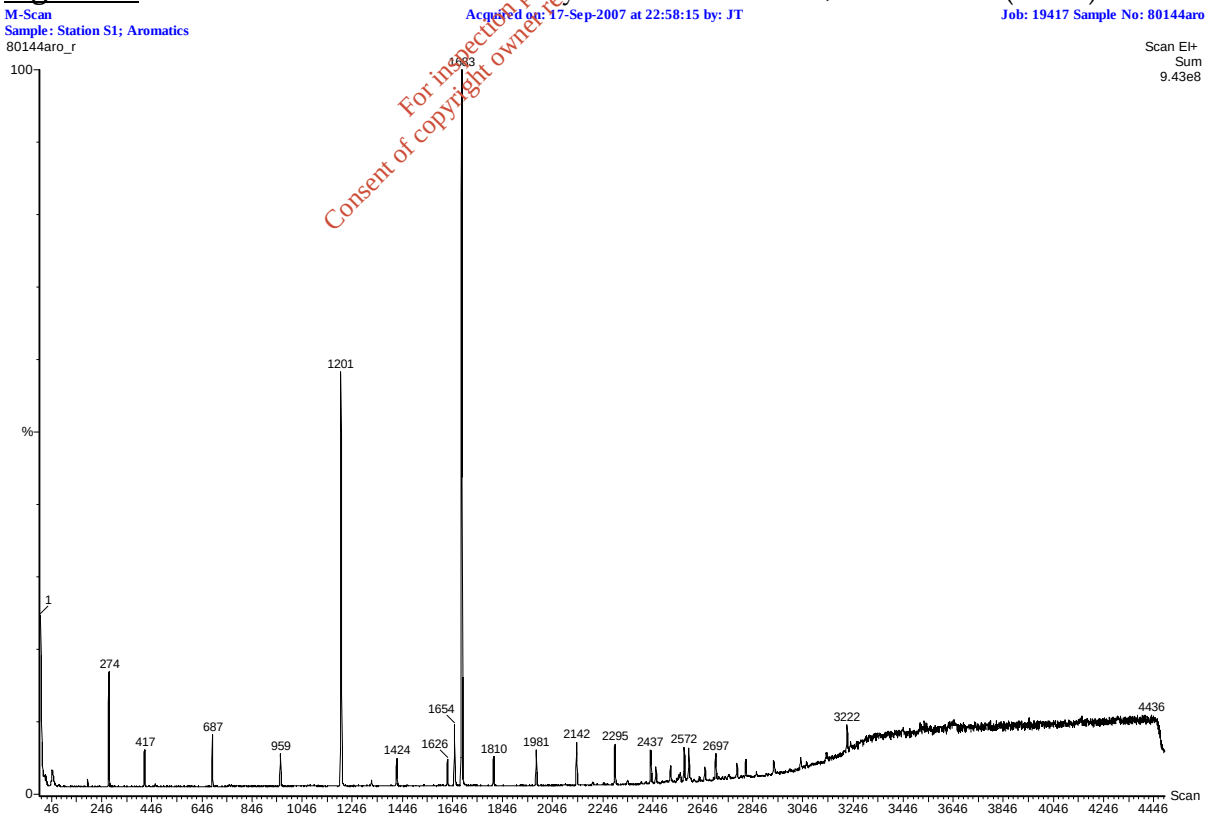


Figure 34: GC-MS TIC trace for aromatic hydrocarbon fraction, Station 1 (80144)

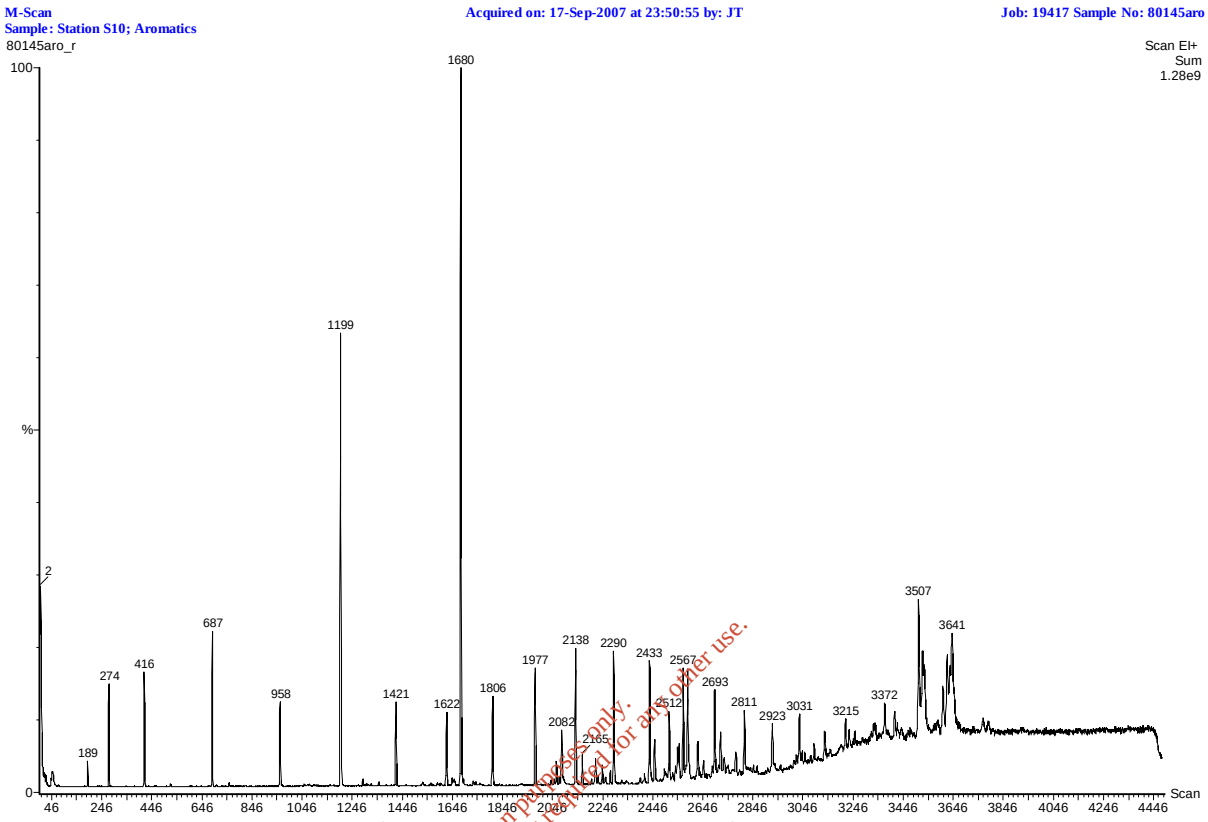


Figure 35: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 10 (80145)

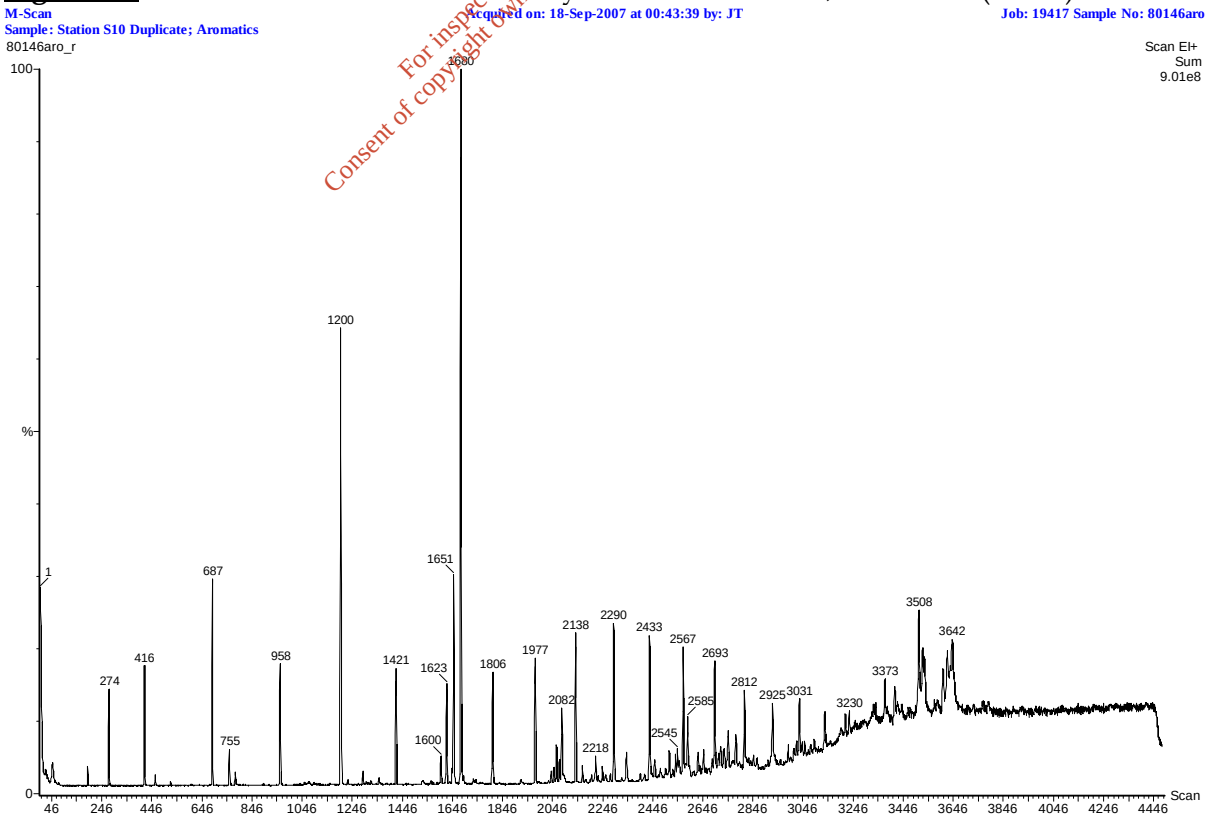


Figure 36: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 10 (80146)

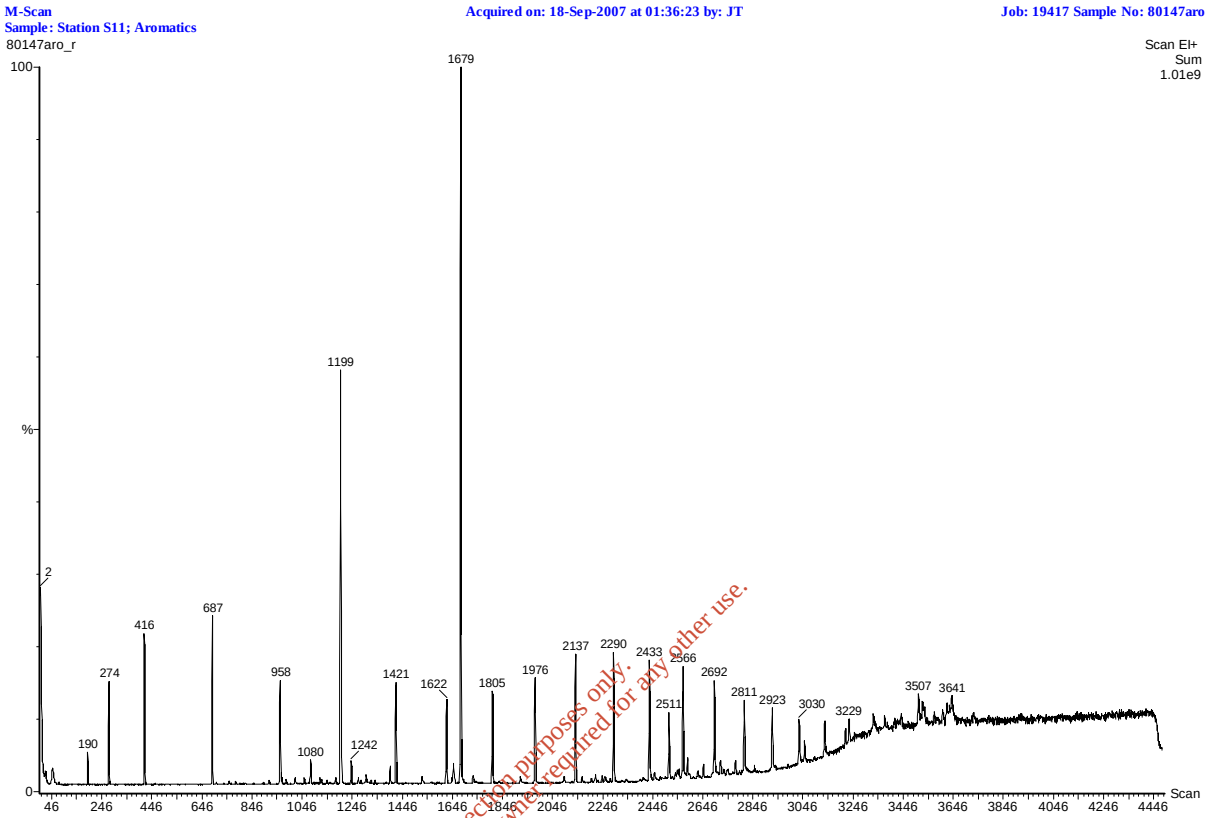


Figure 37: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 11 (80147)

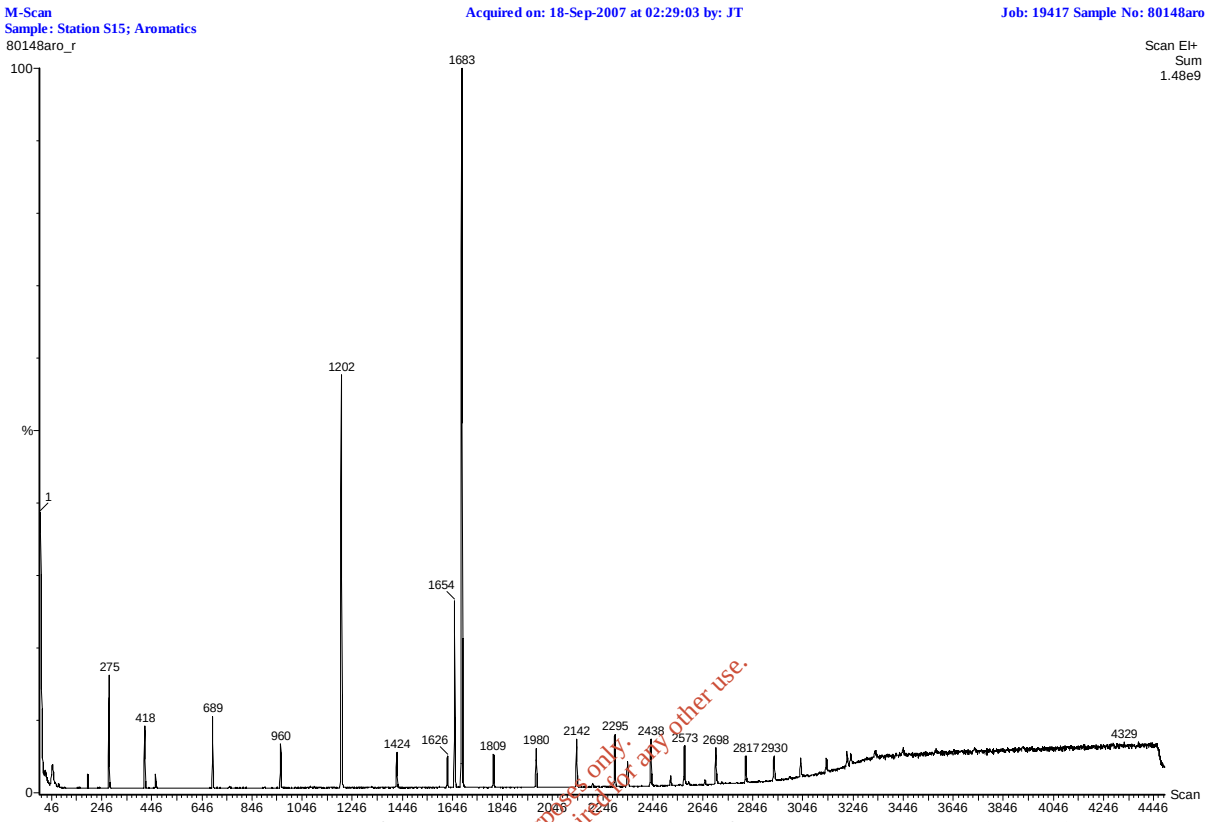


Figure 38: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 15 (80148)

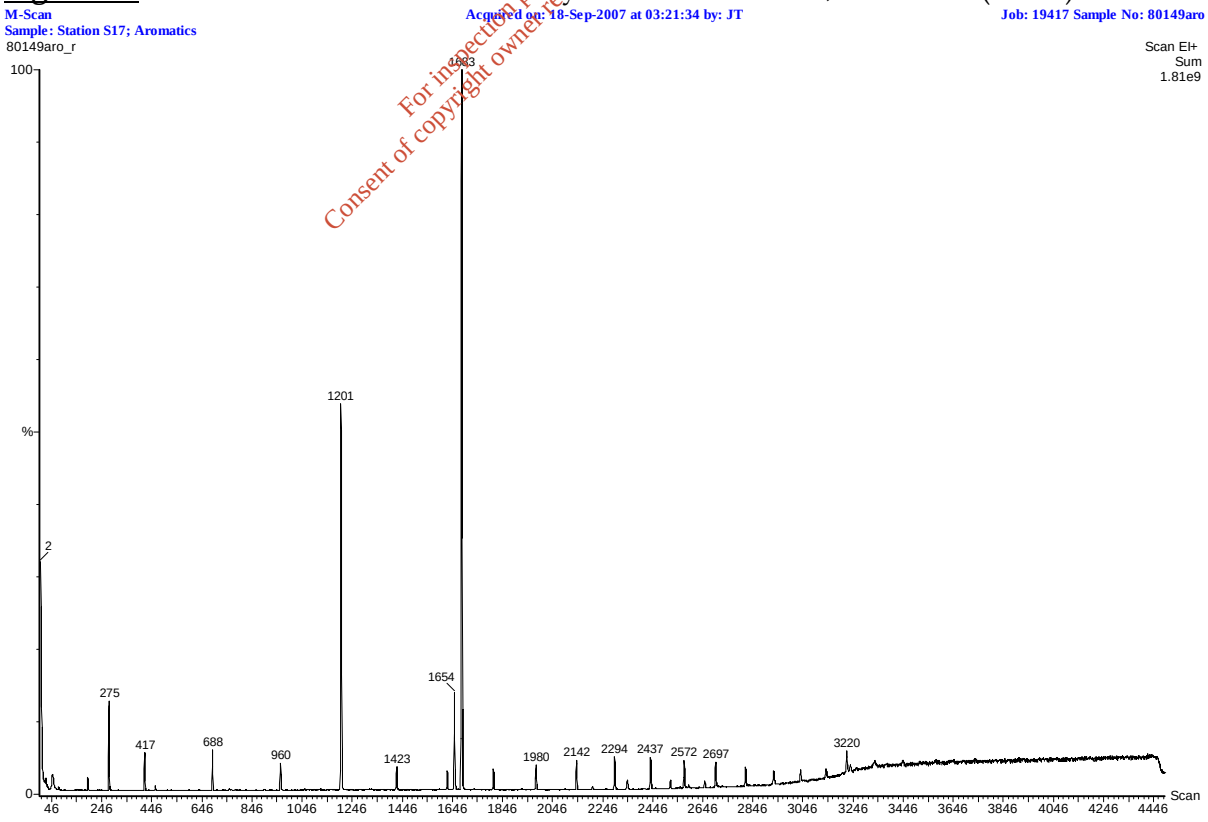


Figure 39: GC-MS TIC trace for aromatic hydrocarbon fraction, Station 17 (80149)

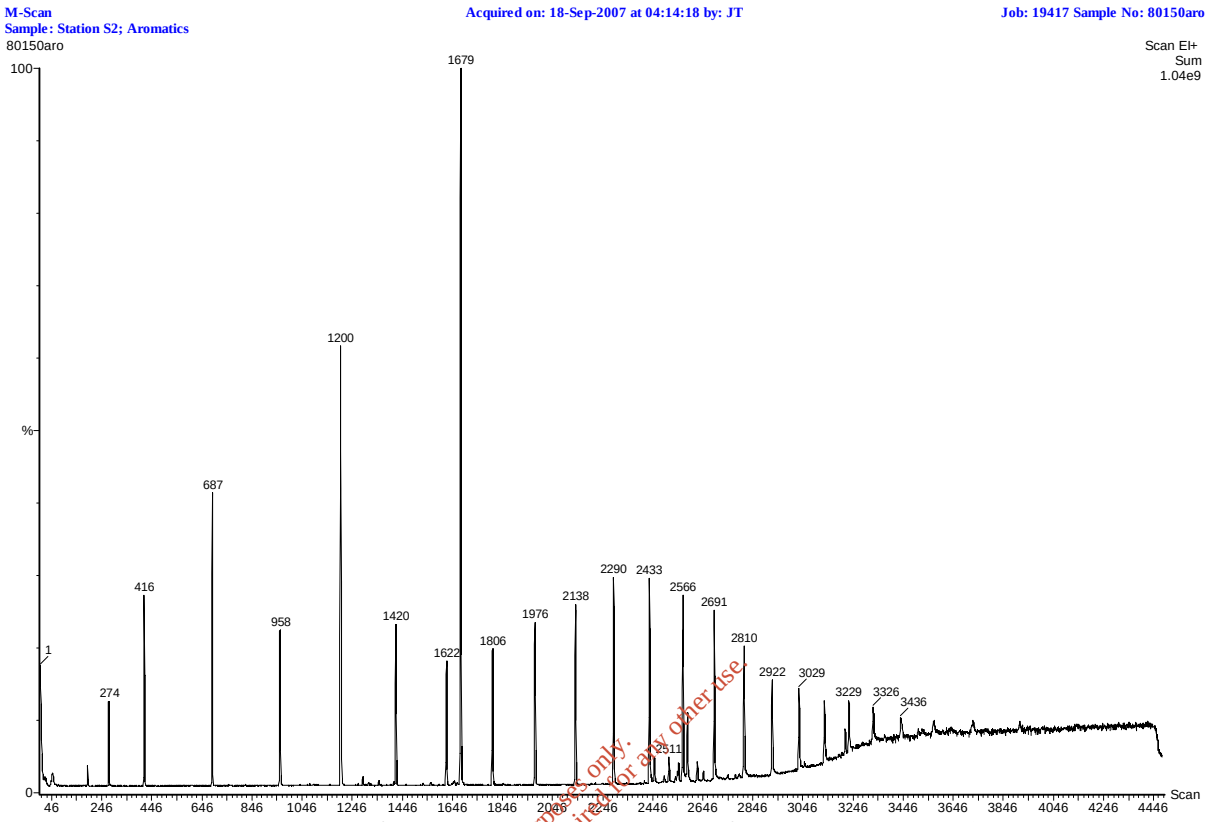


Figure 40: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 2 (80150)

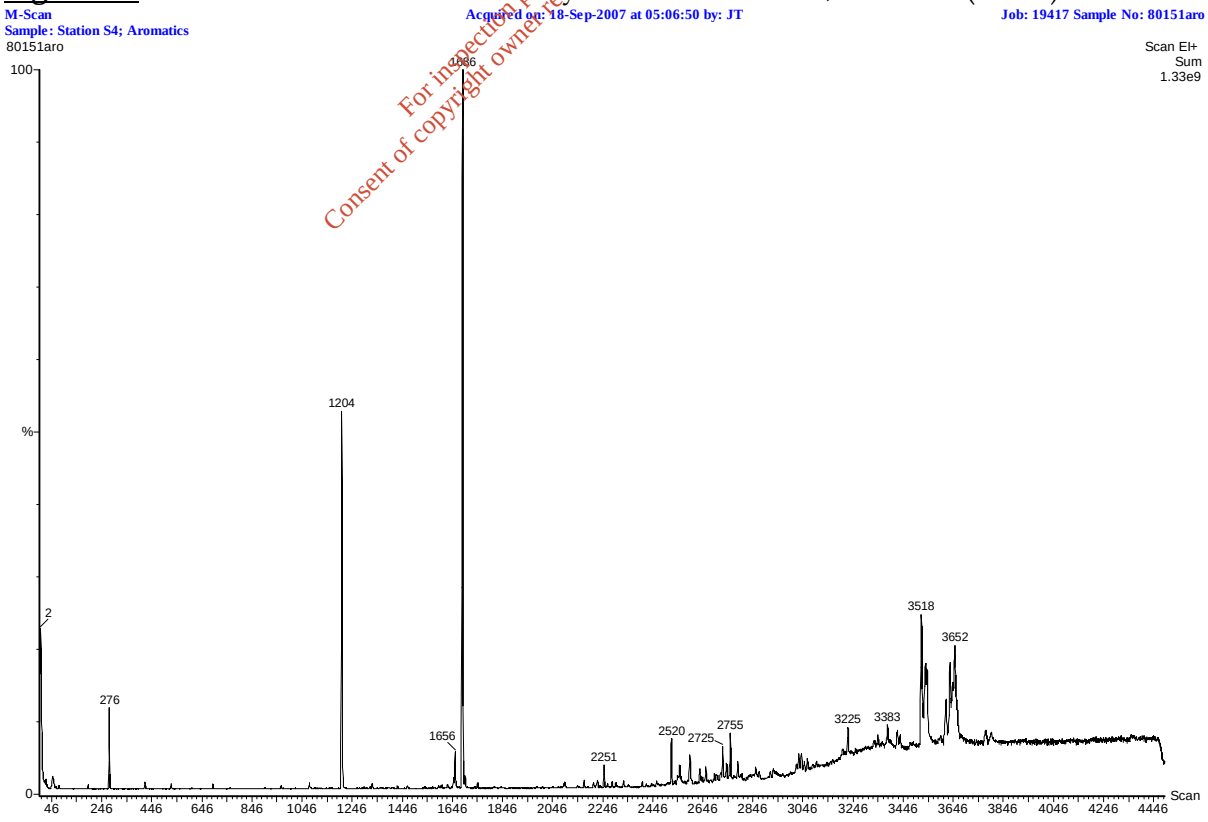


Figure 41: GC-MS TIC trace for aromatic hydrocarbon fraction, Station 4 (80151)

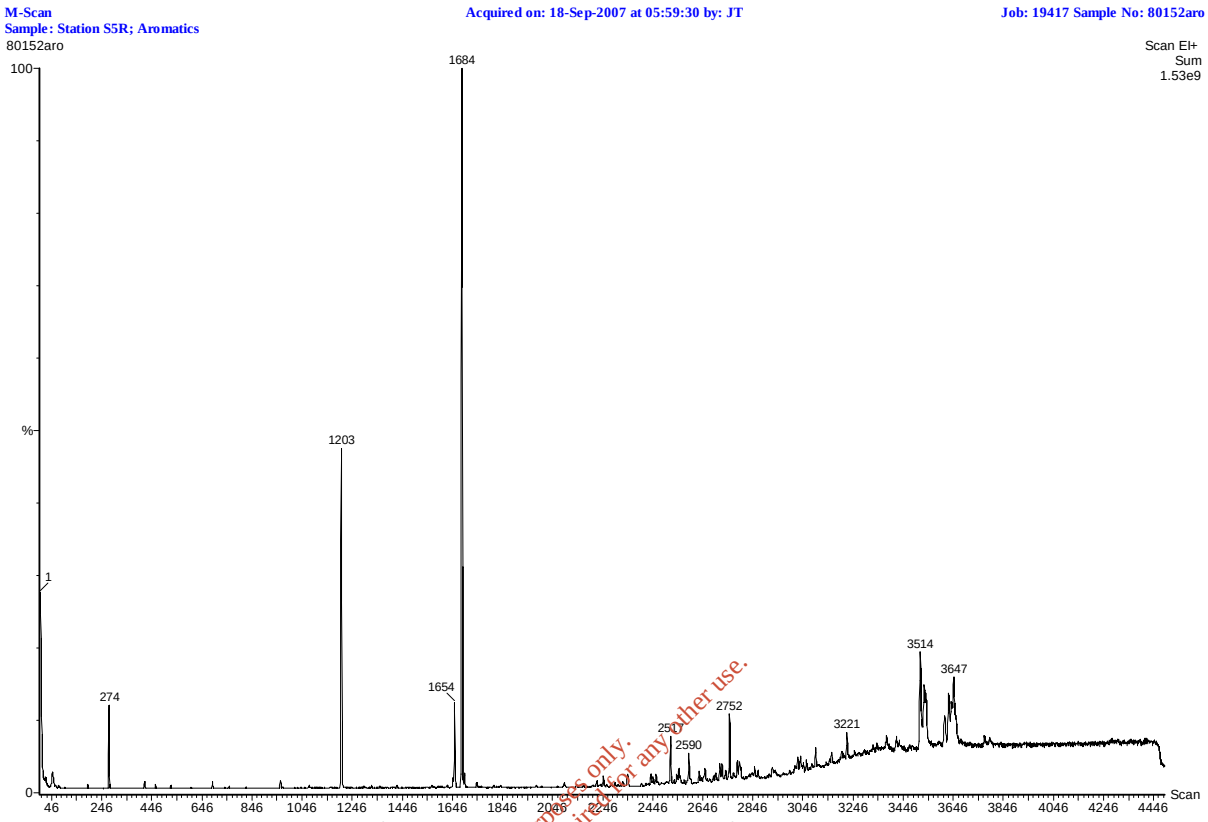


Figure 42: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 5R (80152)

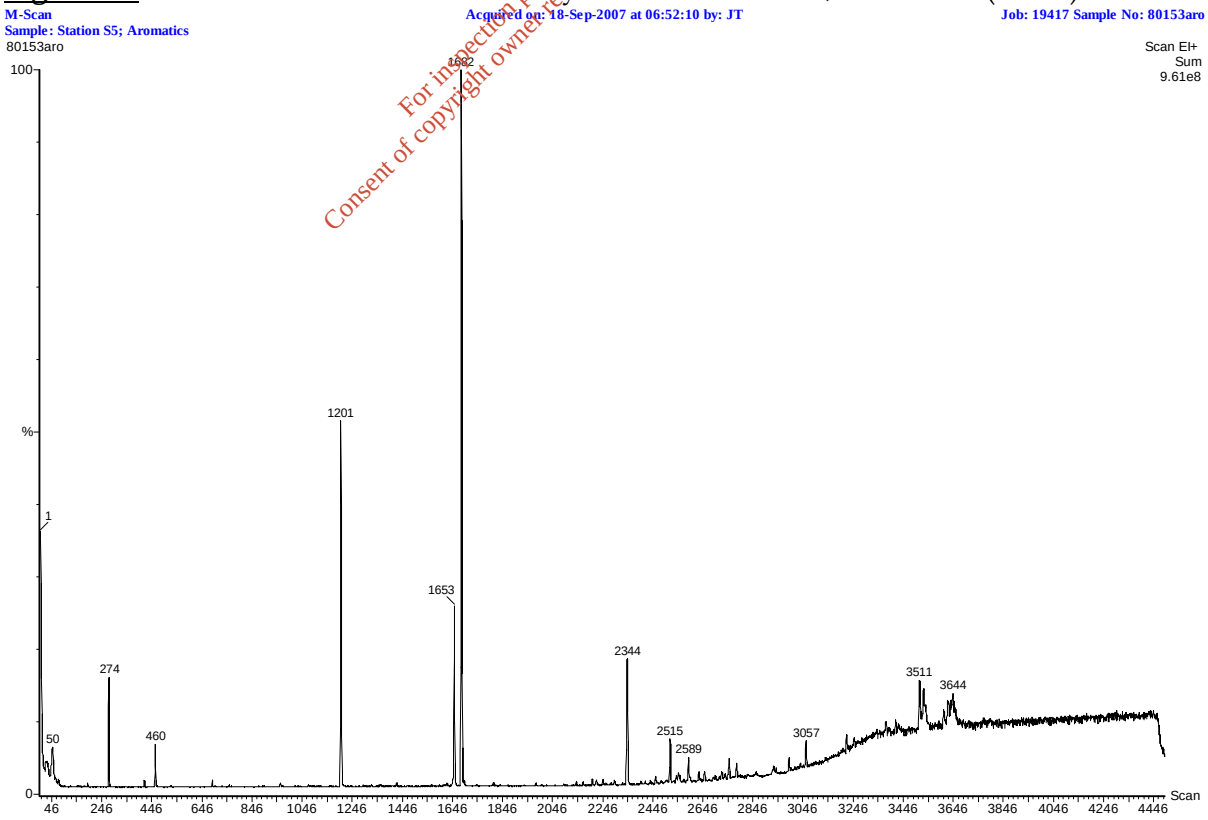


Figure 43: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 5 (80153)

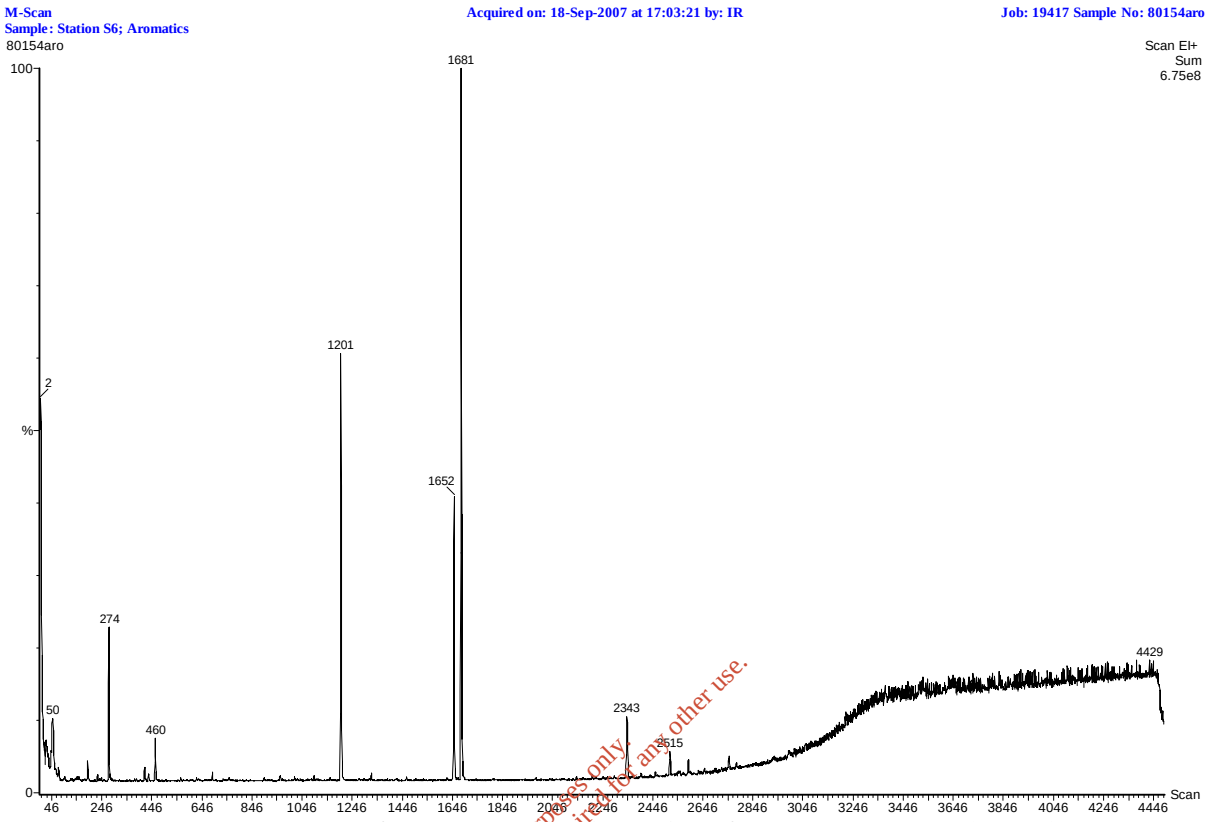


Figure 44: GC-MS TICtrace for aromatic hydrocarbon fraction, Station 6 (80154)

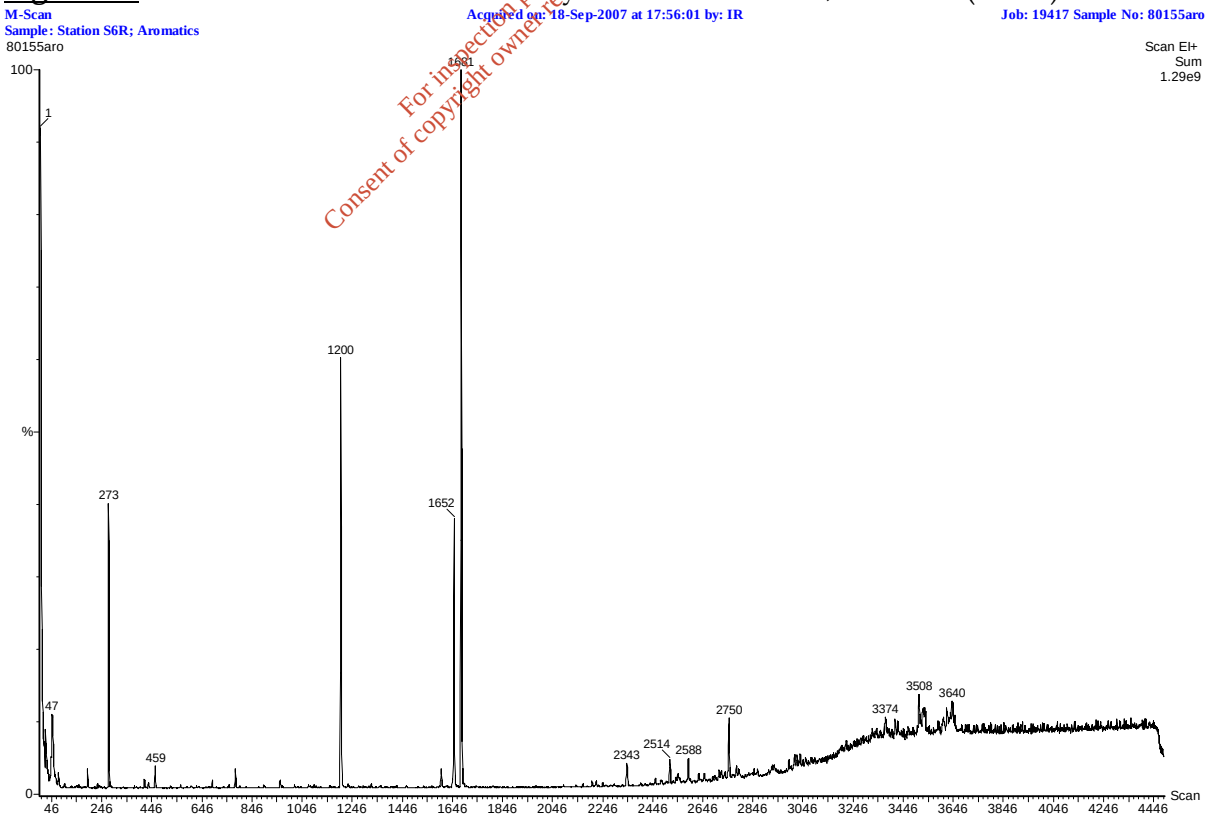


Figure 45: GC-MS TIC trace for aromatic hydrocarbon fraction, Station 6R (80155)

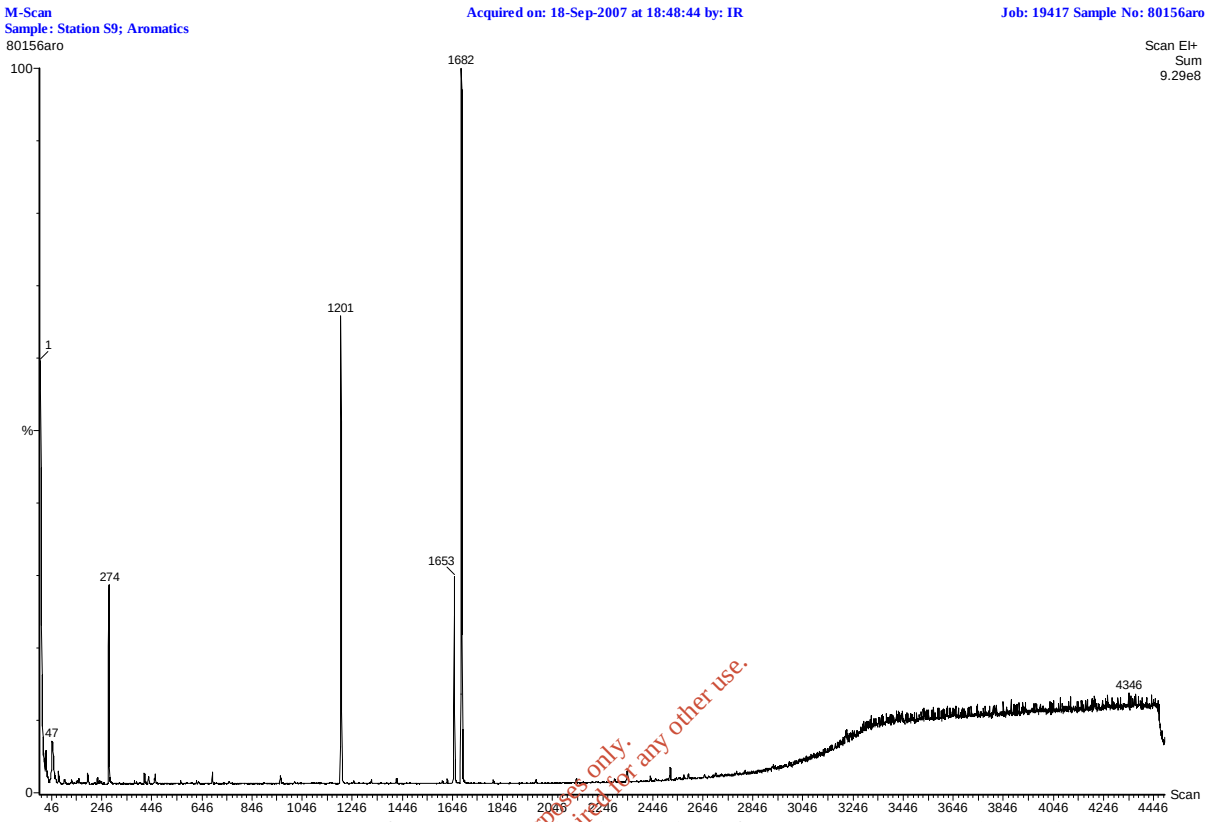


Figure 46: GC-MS TIC trace for aromatic hydrocarbon fraction, Station 9 (80156)

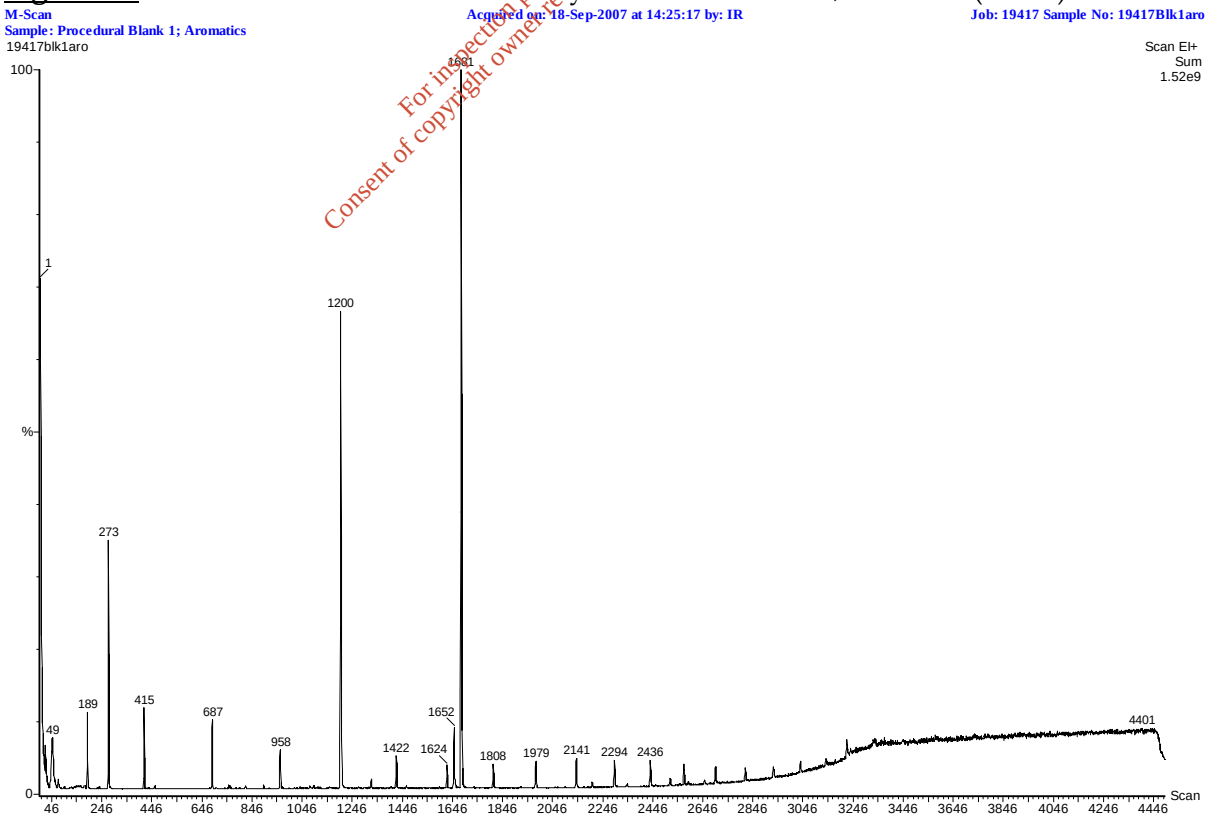
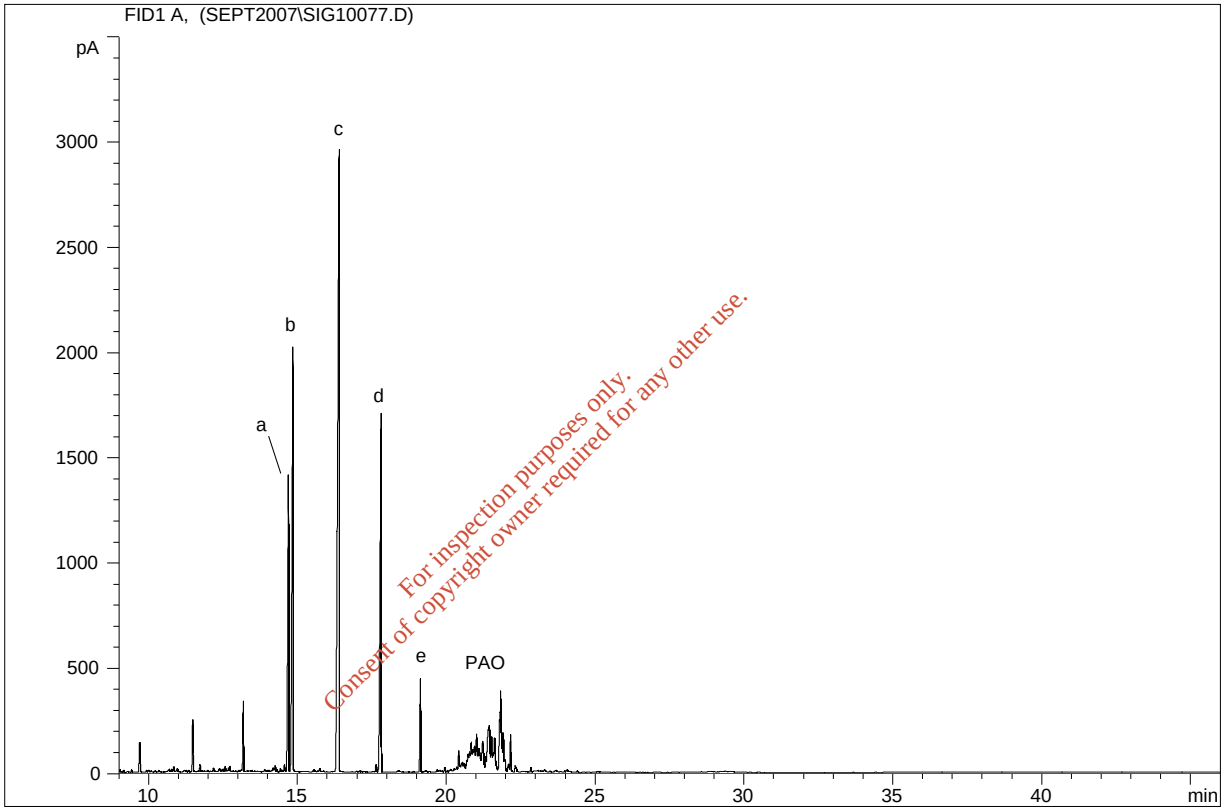


Figure 47: GC-MS TIC trace for aromatic hydrocarbon fraction, Procedural Blank

APPENDIX IV

GC Trace of the "Ecosol" Base Oil



b-e n-alkanes
POA poly-alpha olefins

APPENDIX V: Service Warranty

This report, with its associated works and services, has been designed solely to meet the requirements of the contract agreed with you, our client. If used in other circumstances, some or all of the results may not be valid and we can accept no liability for such use. Such circumstances include different or changed objectives, use by third parties, or changes to, for example, site conditions or legislation occurring after completion of the work. In case of doubt, please consult Benthic Solutions Limited.

Appendix C: Temperature and Salinity Profiles

Temperature Profiles at 17 Outfall Stations

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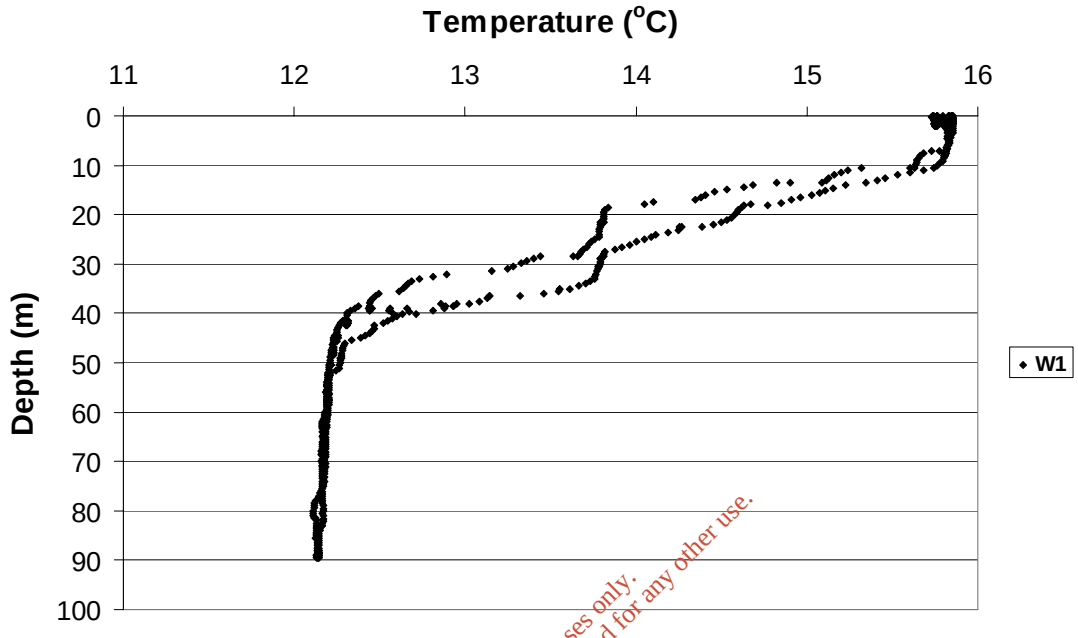

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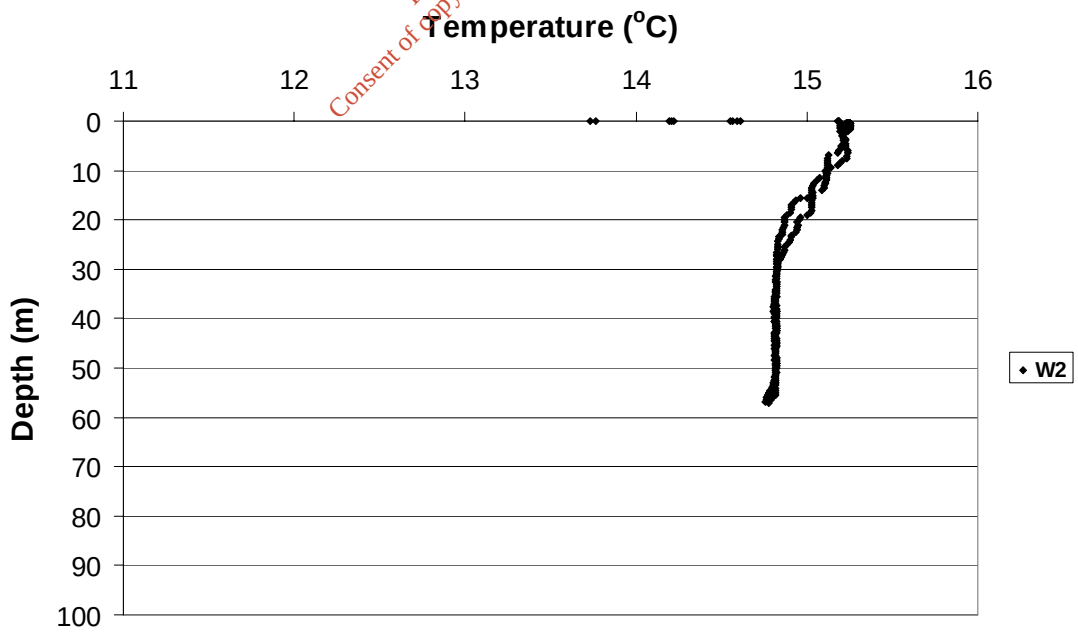

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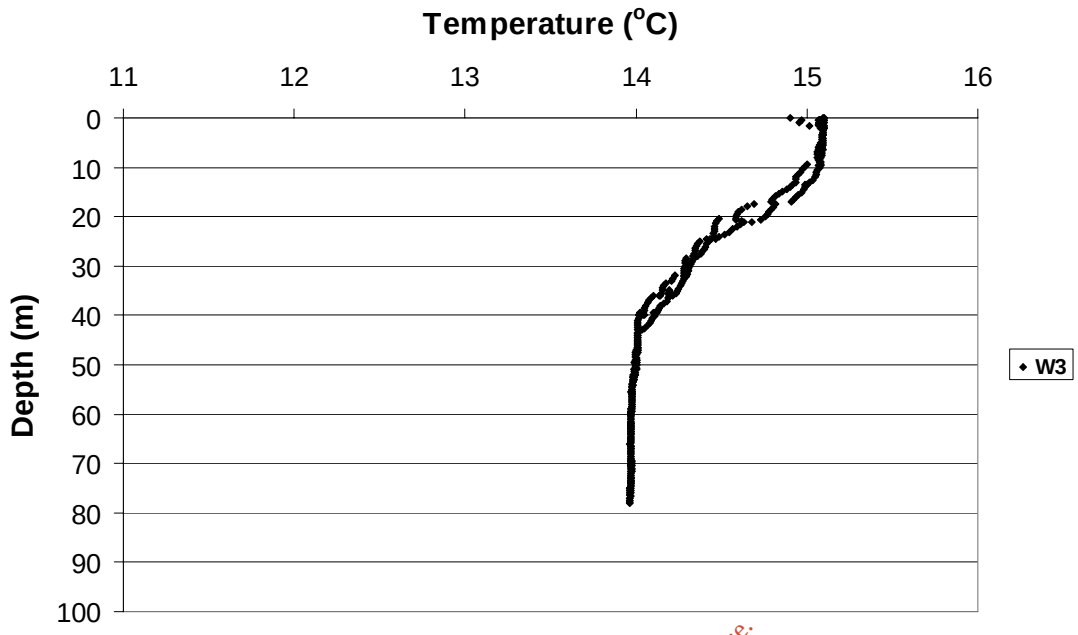

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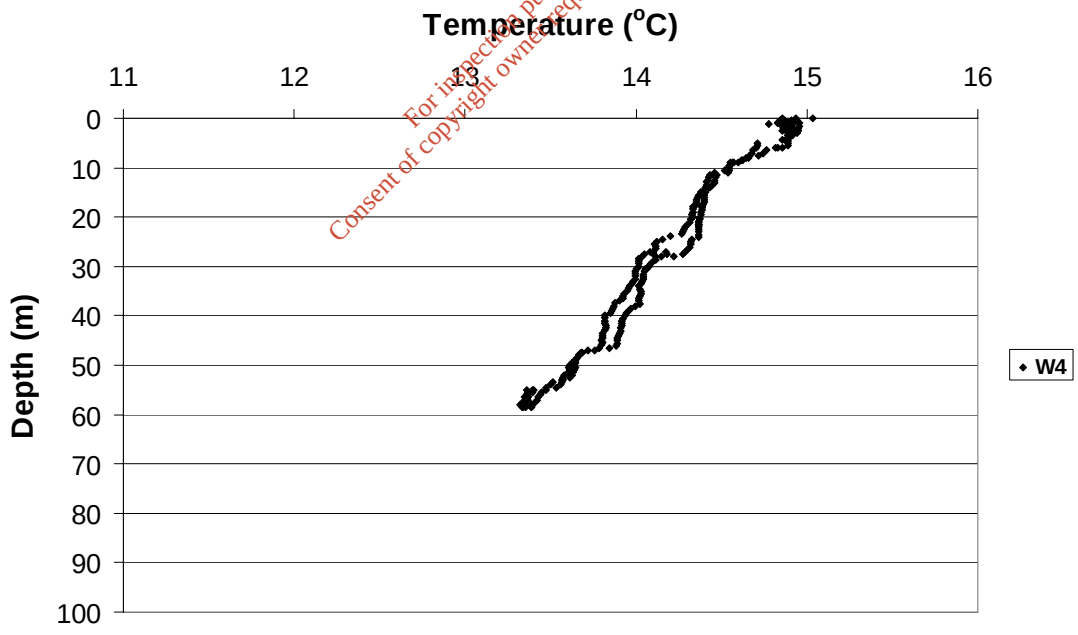

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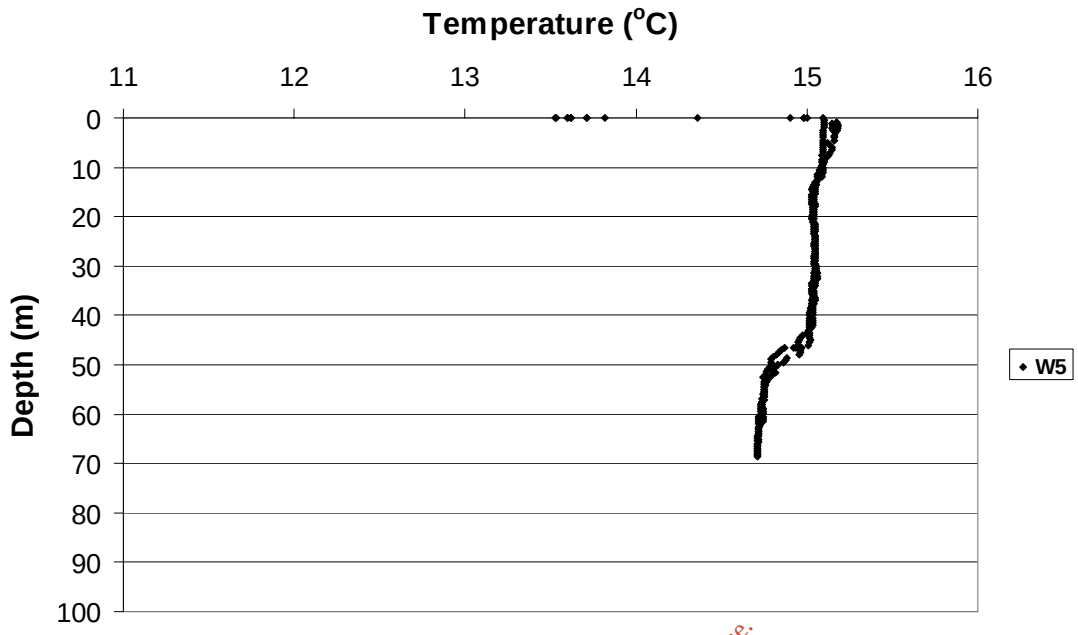

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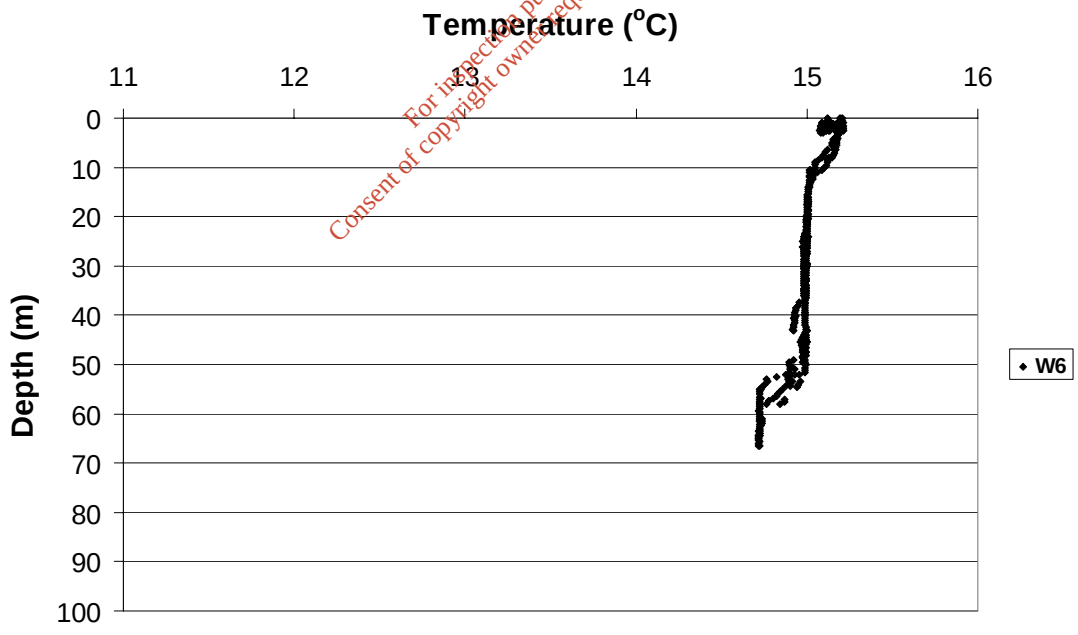

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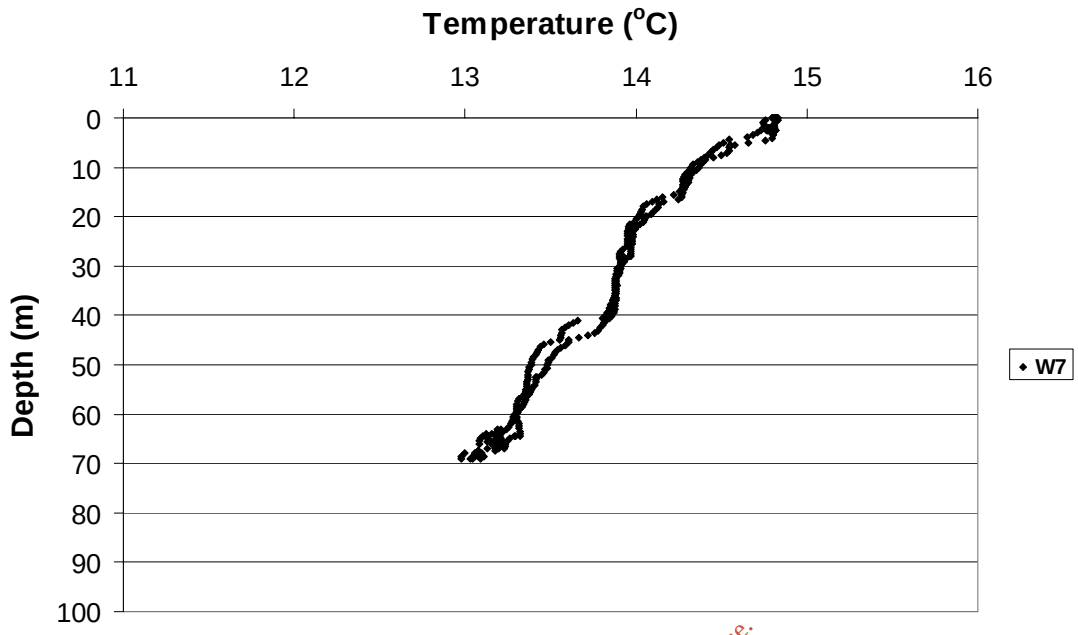

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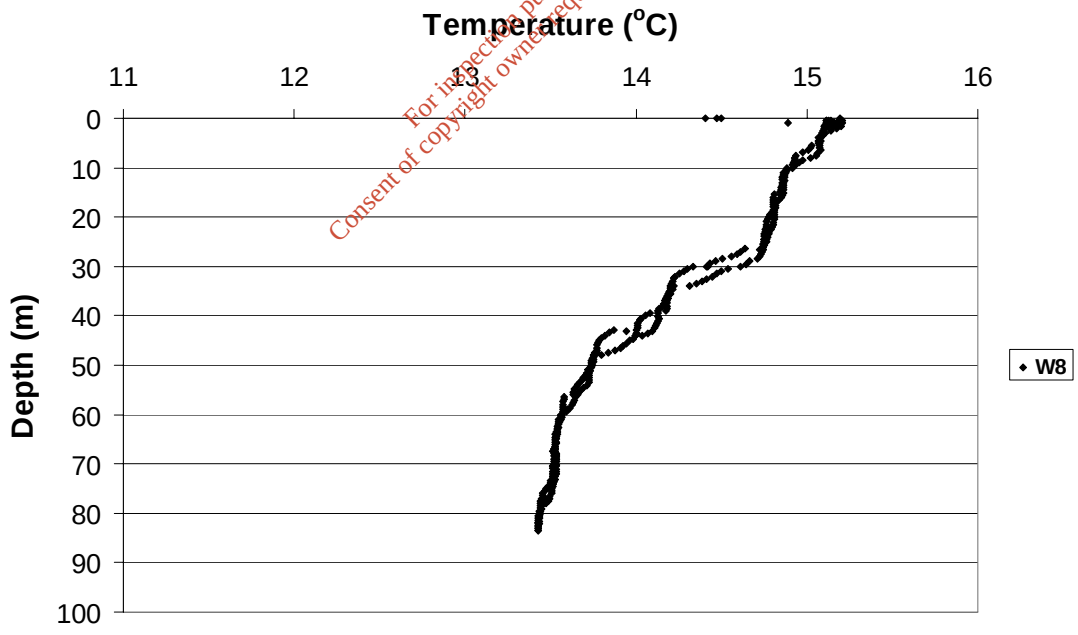

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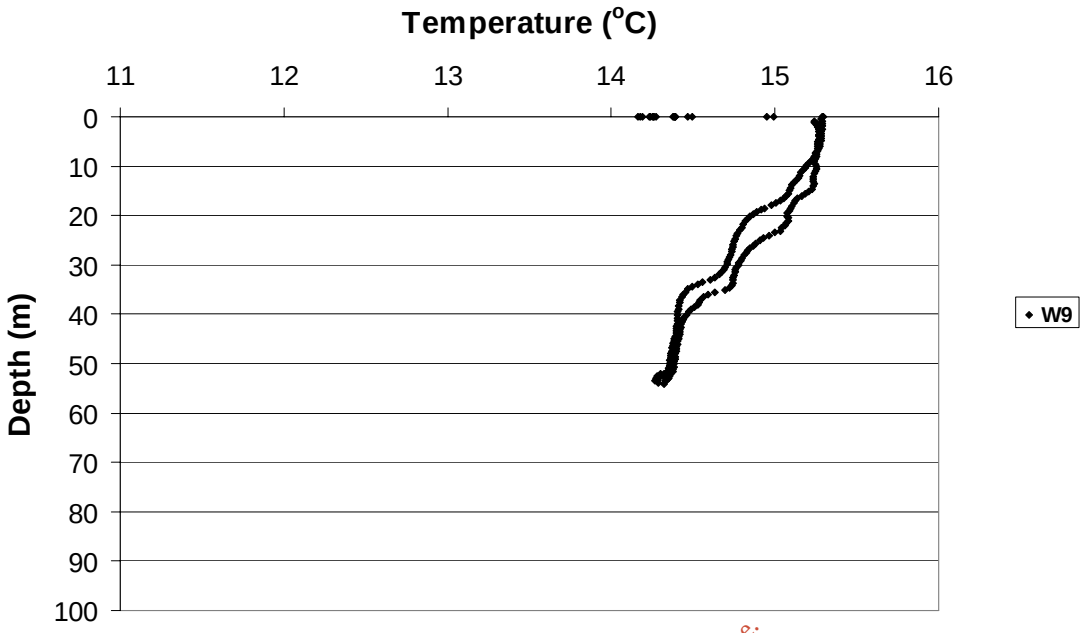

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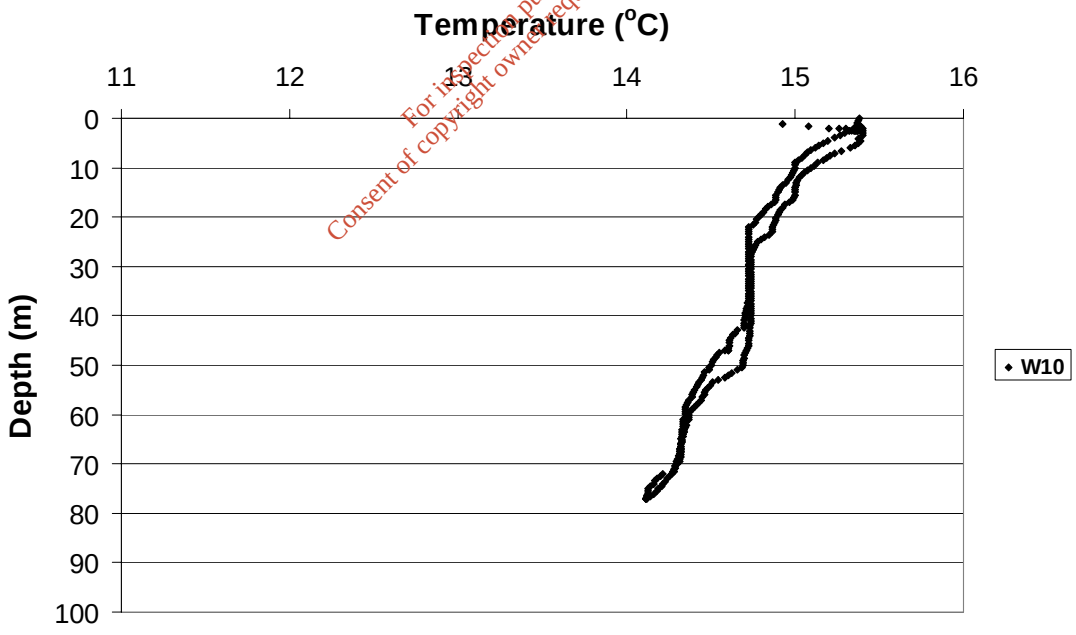

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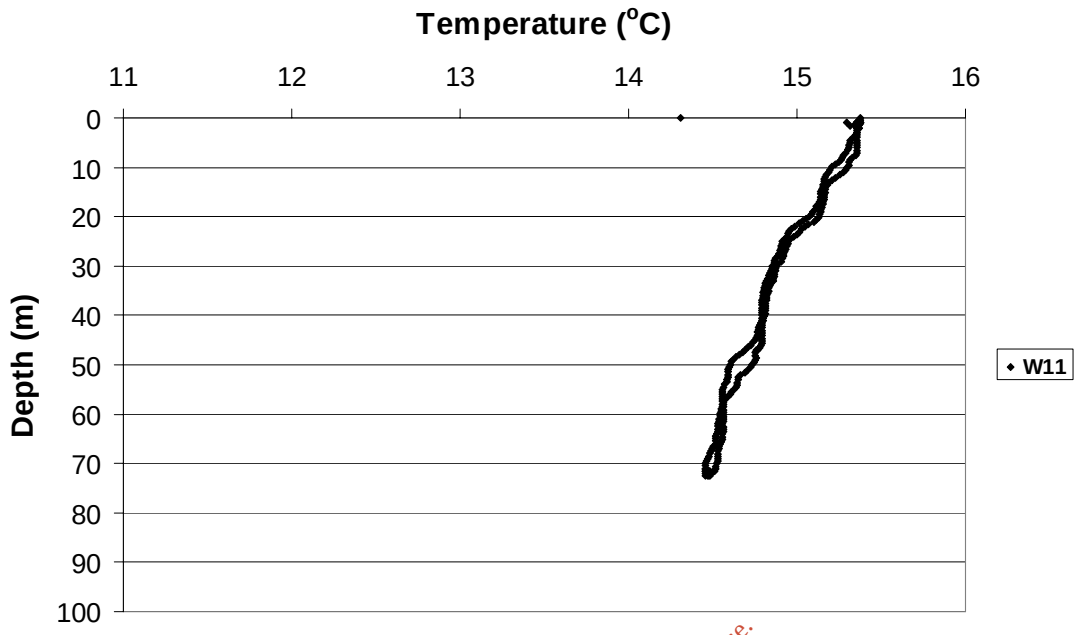

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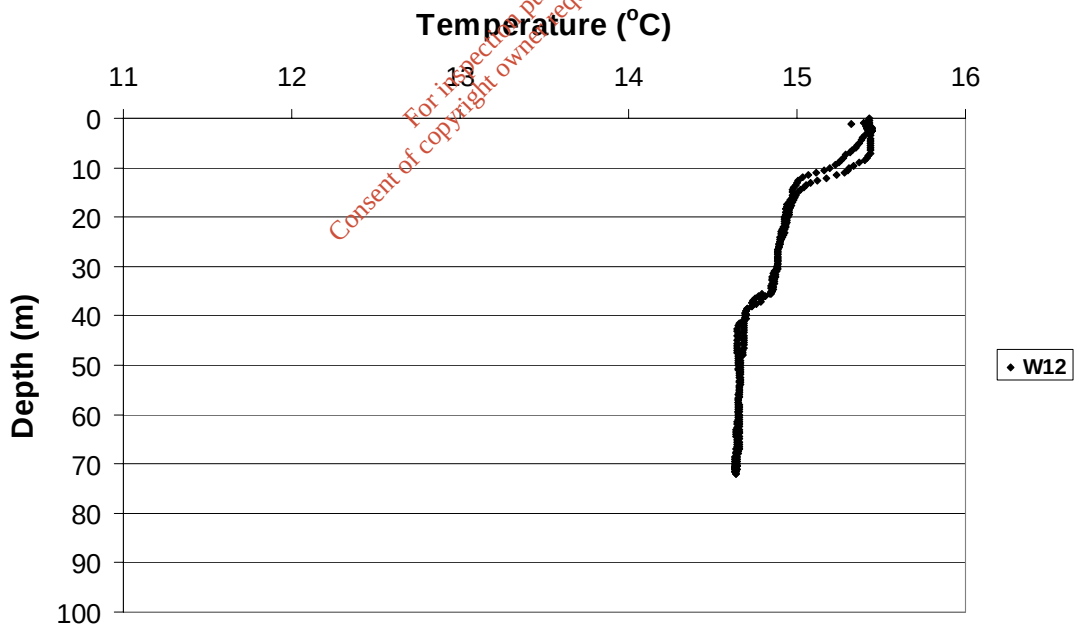

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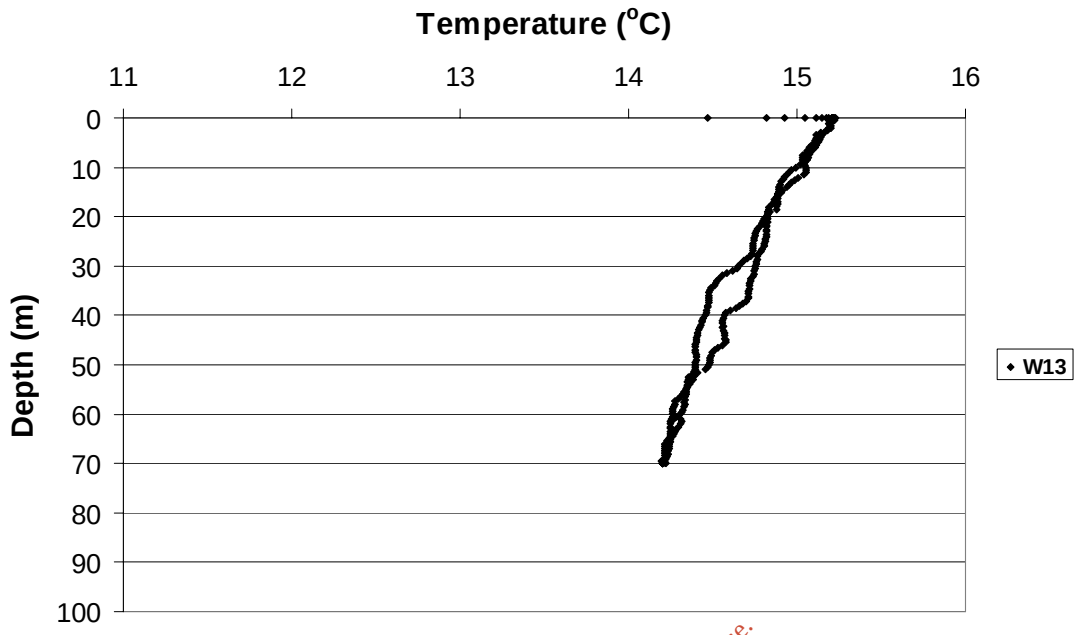

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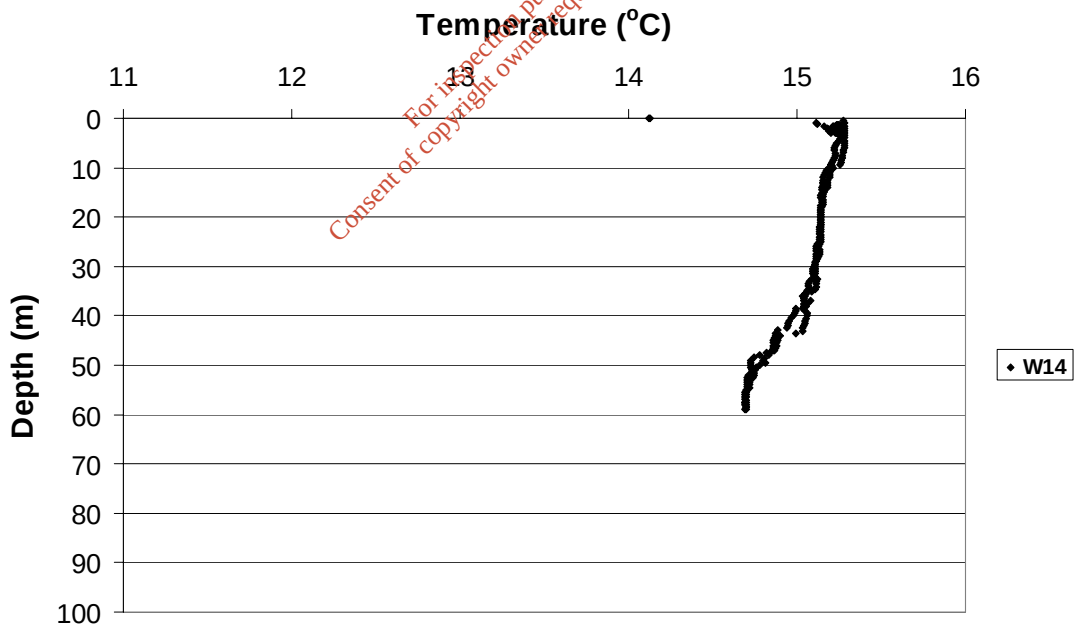

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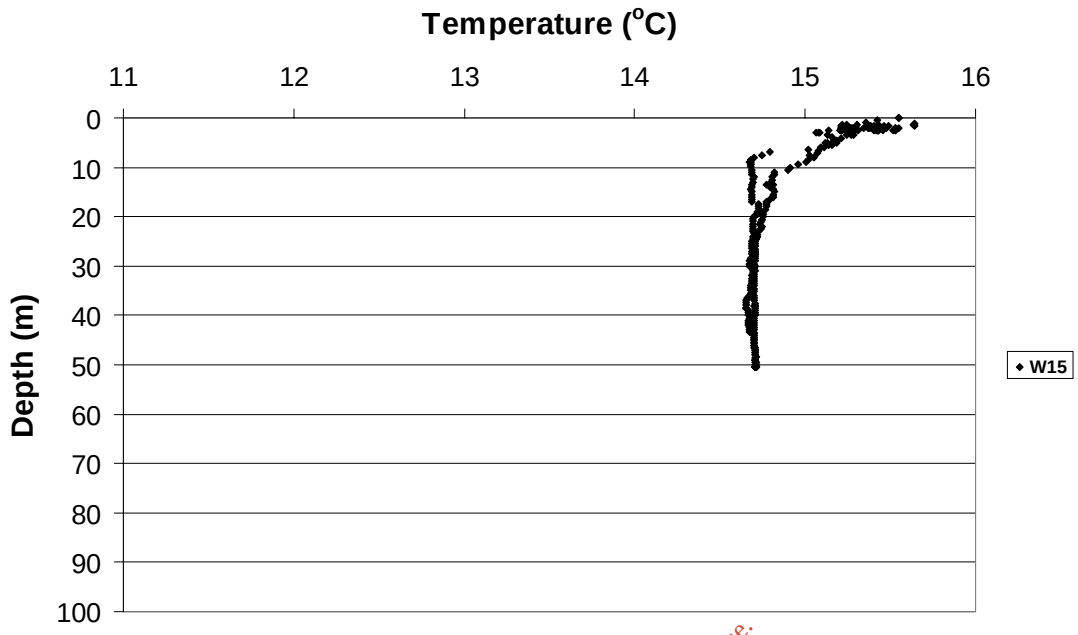

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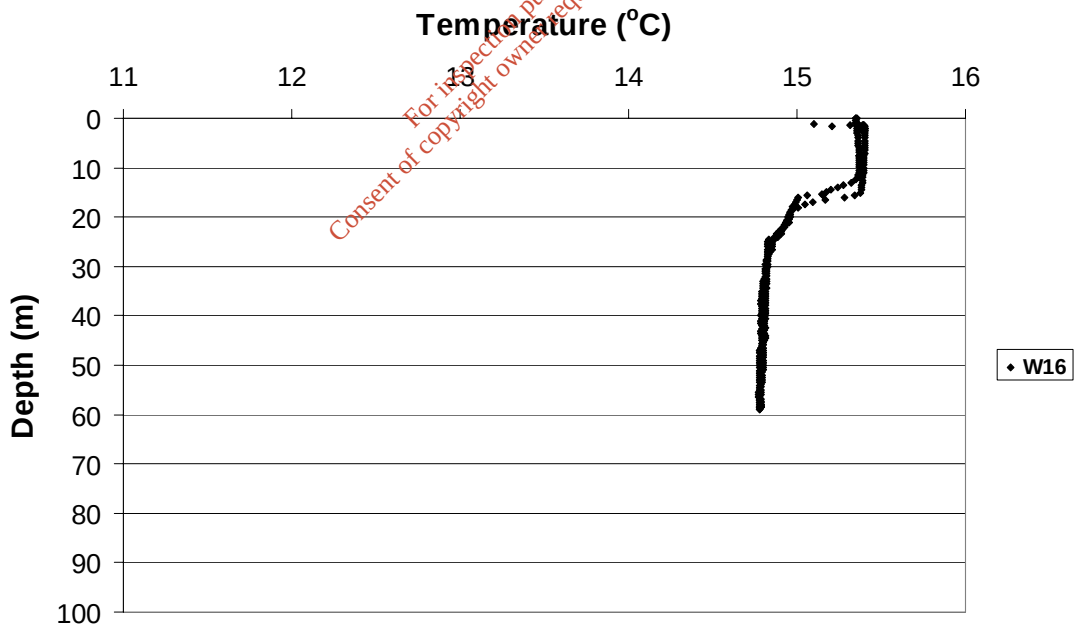

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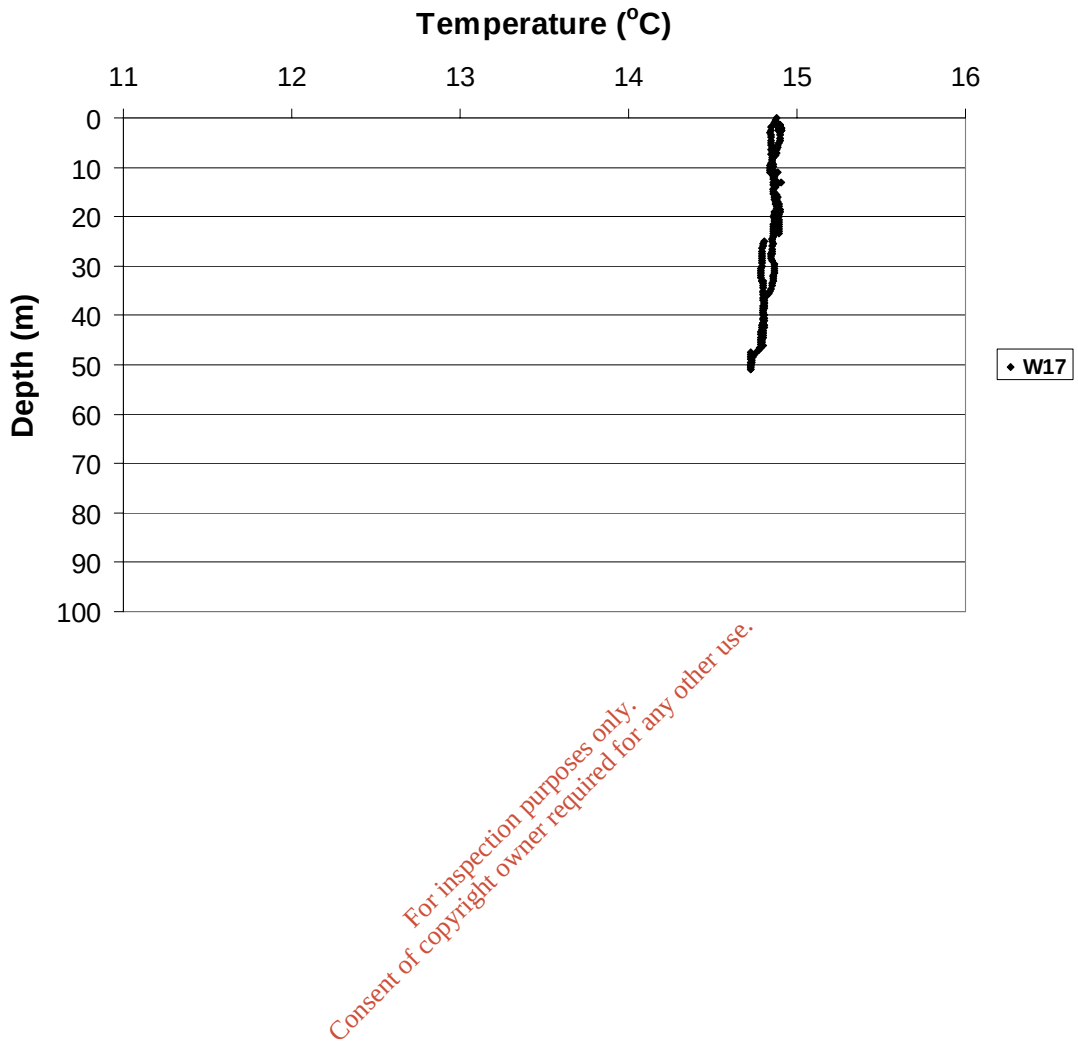

Salinity Profiles at 17 Outfall Stations

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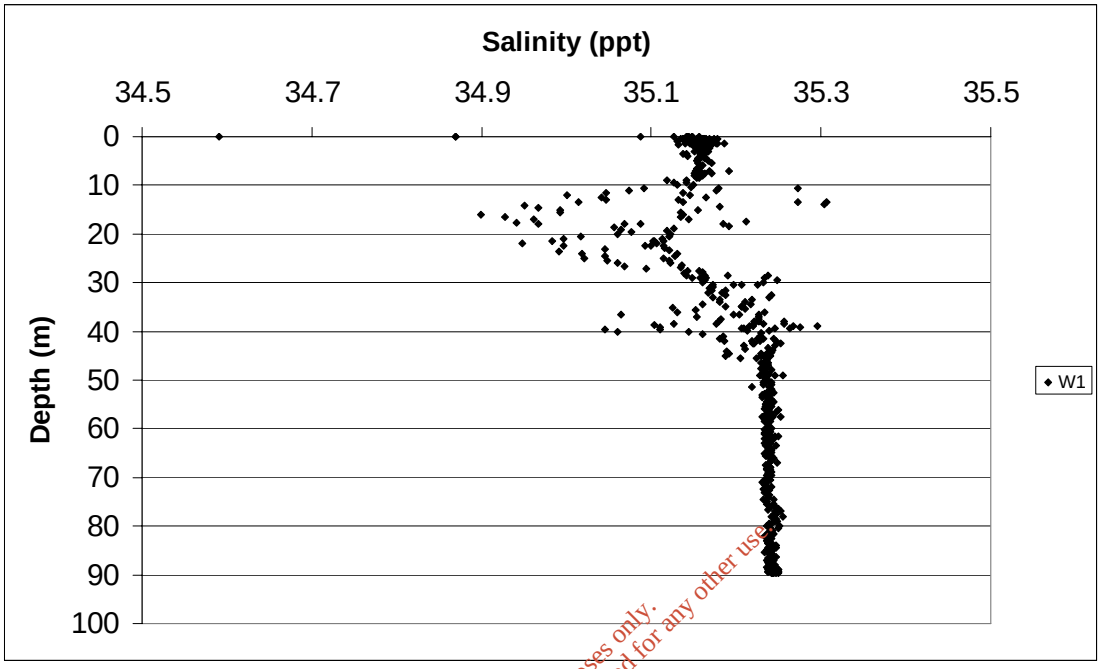

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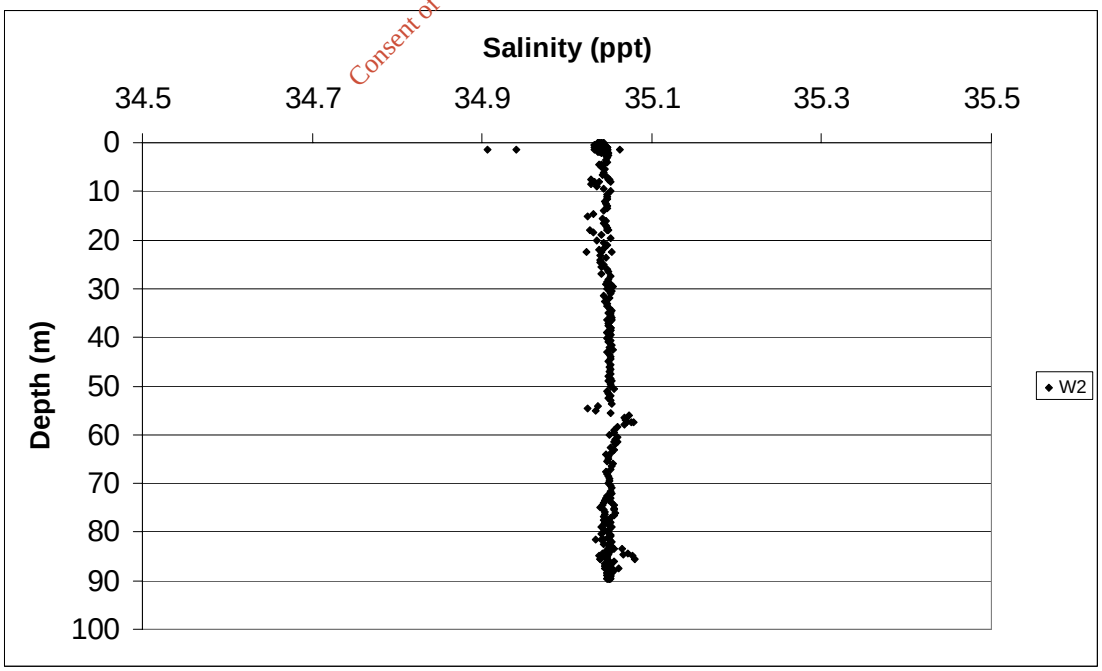

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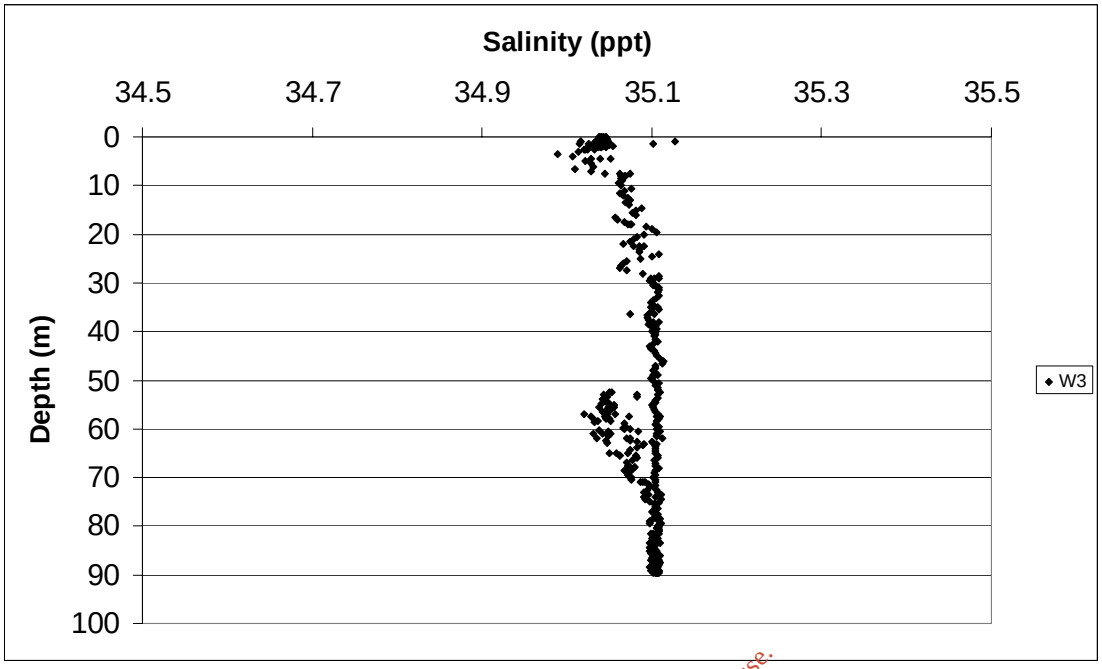

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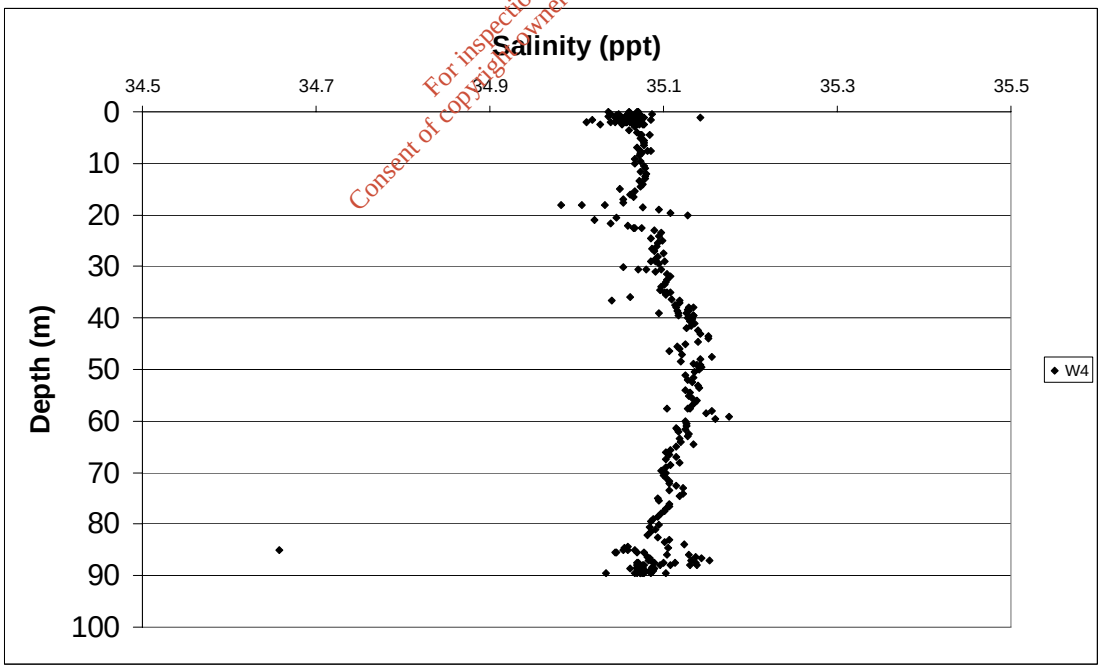

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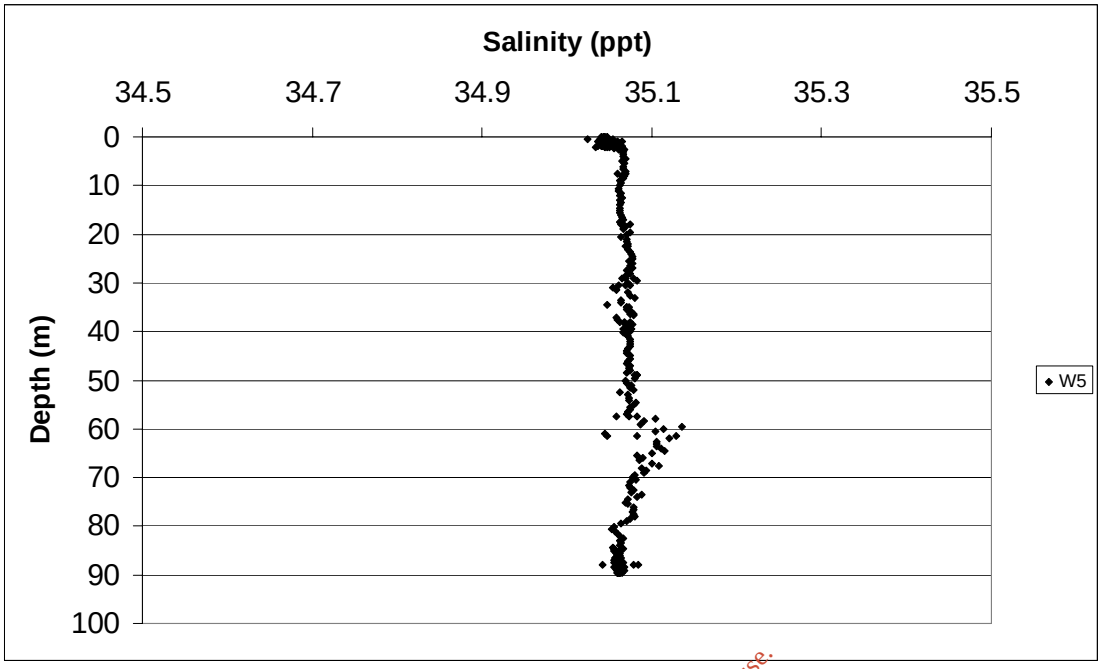

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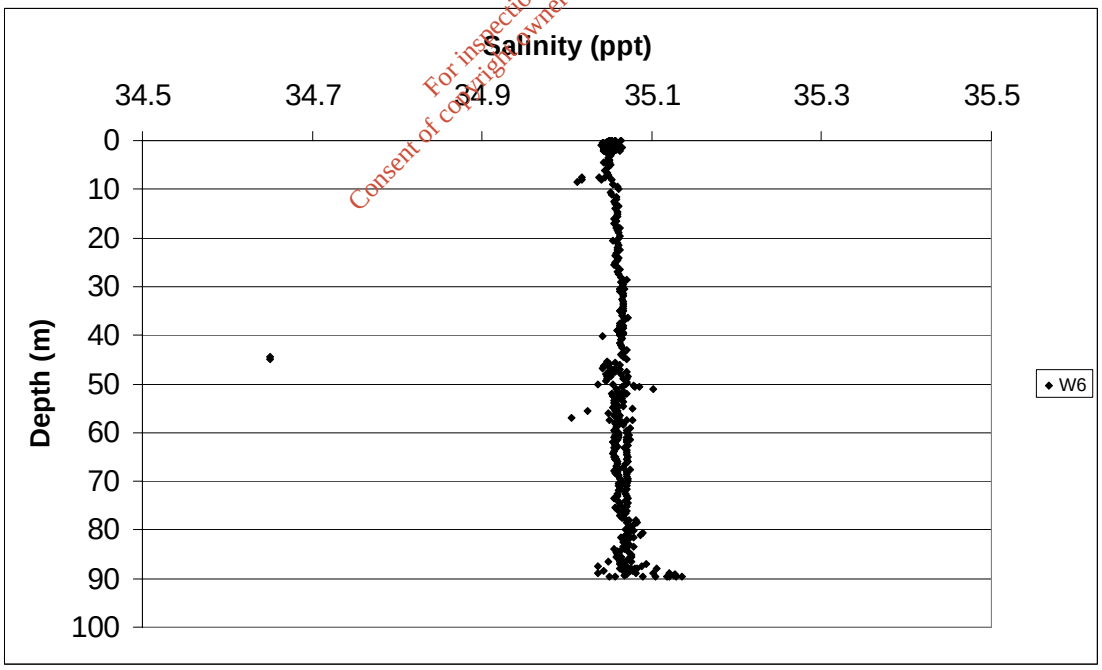

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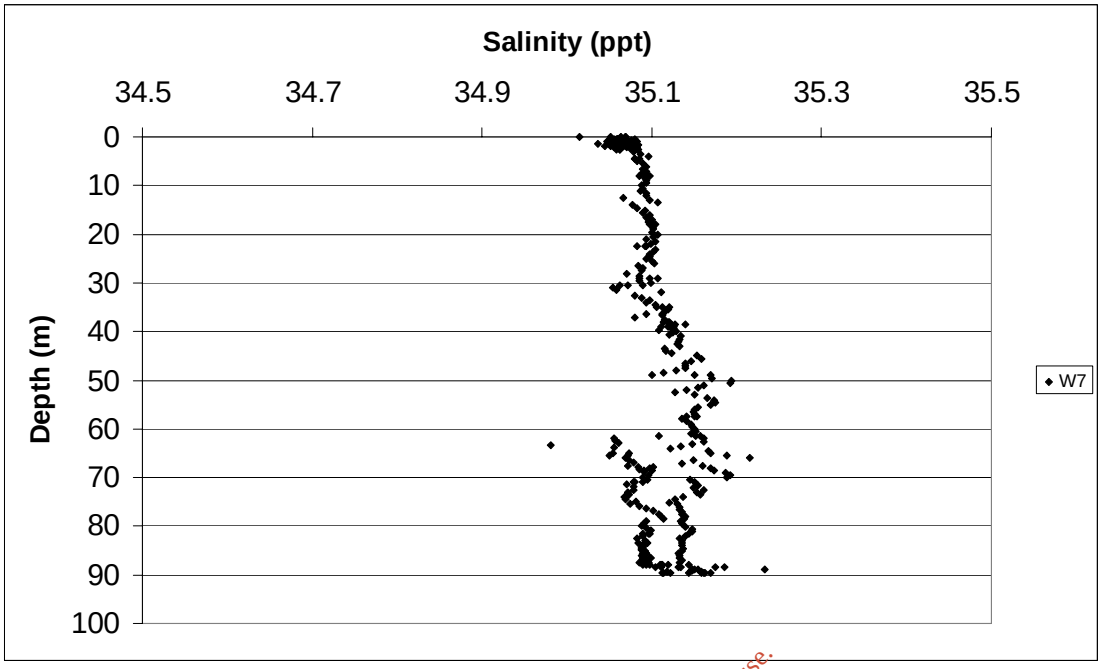

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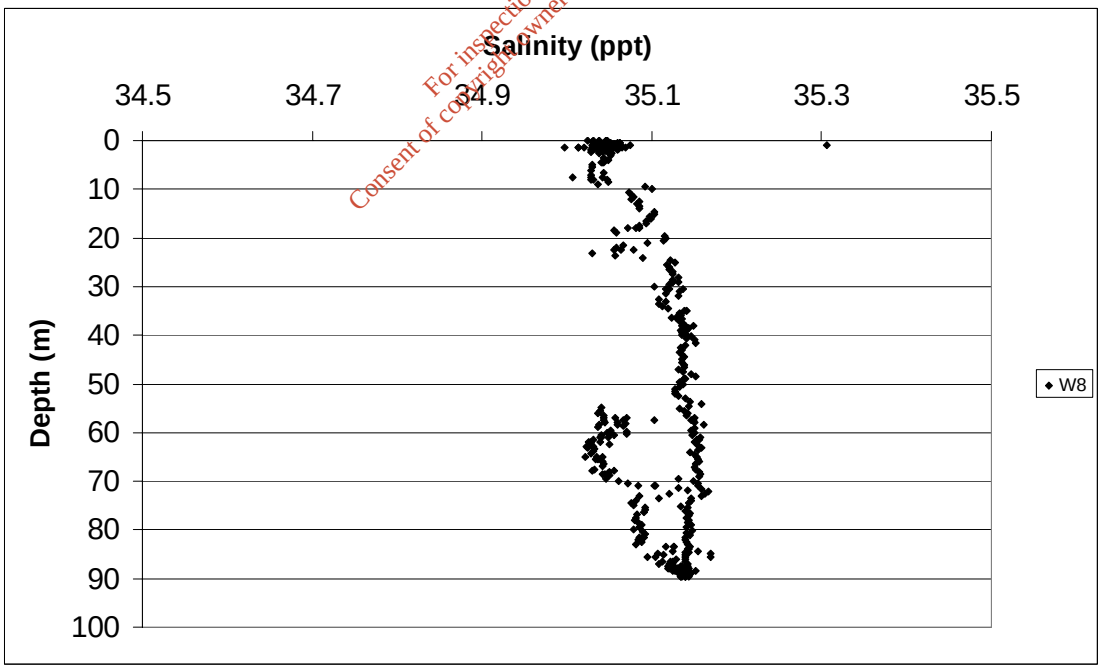

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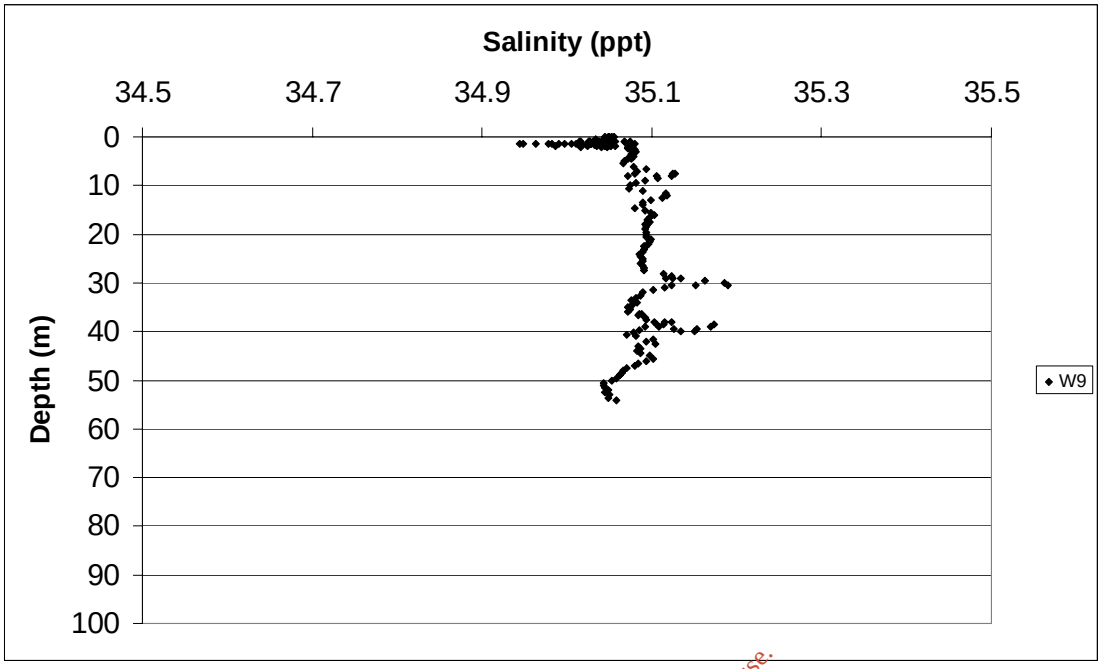

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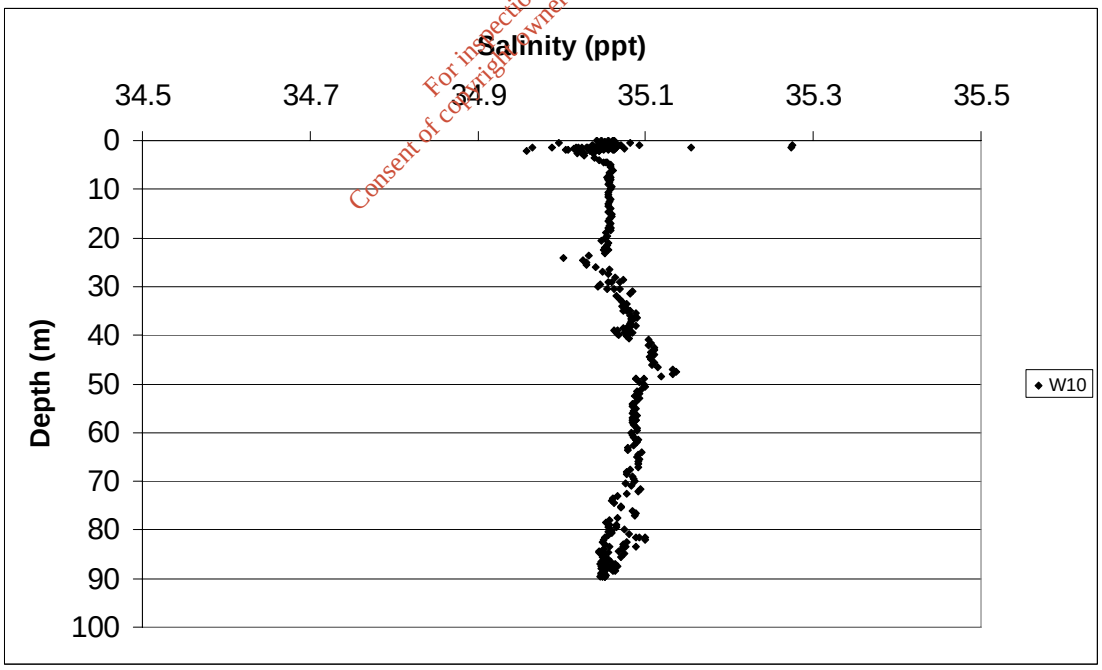

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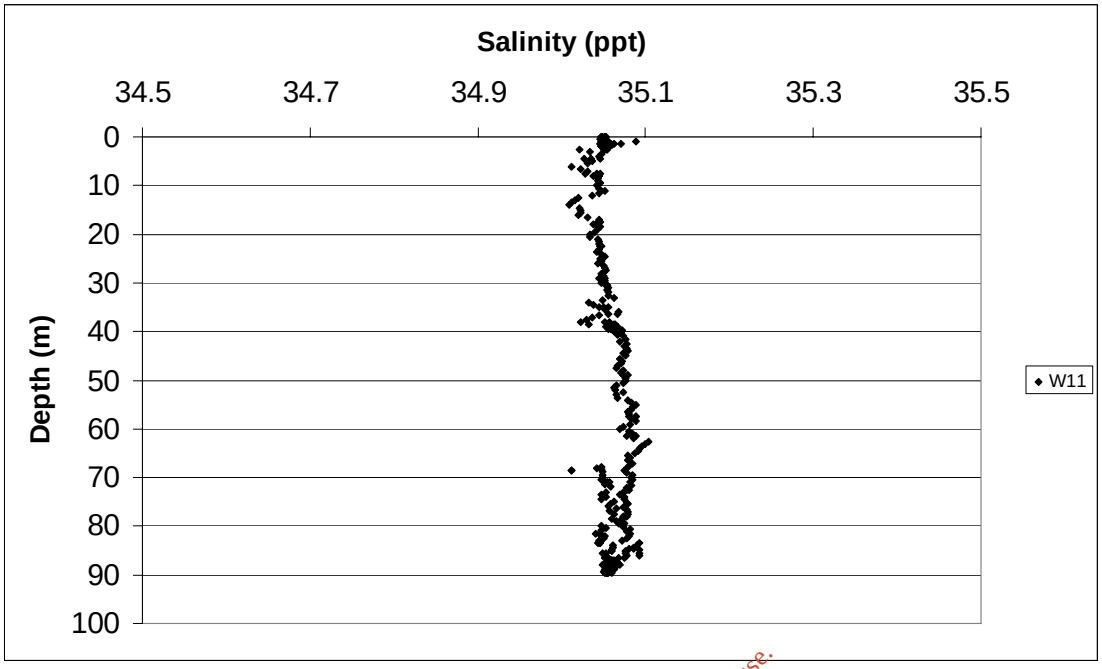

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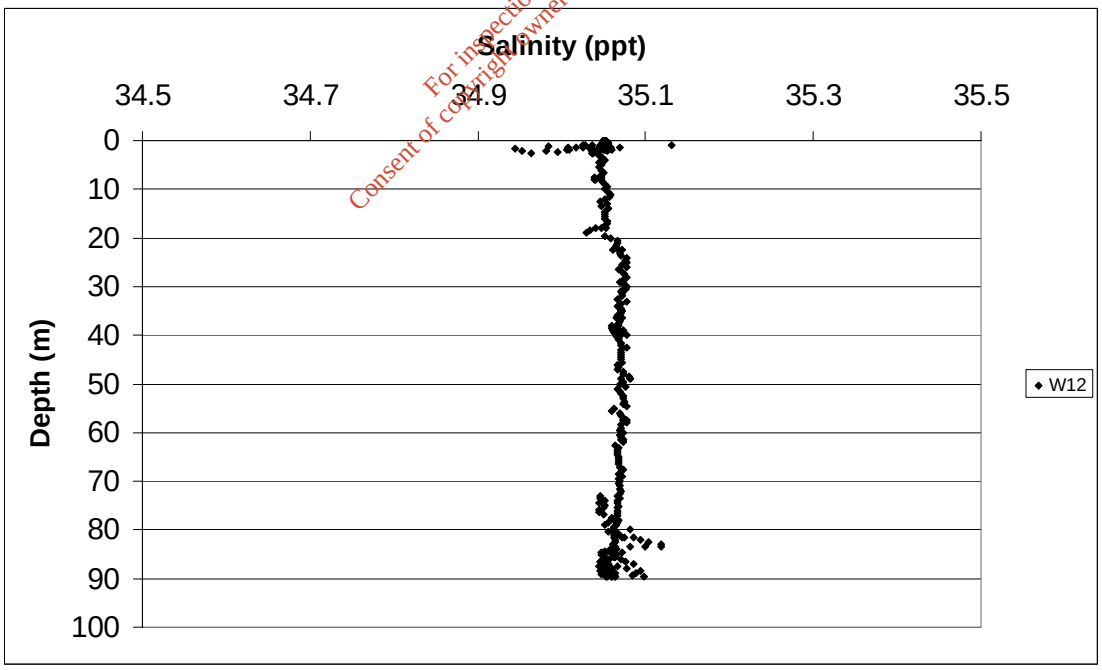

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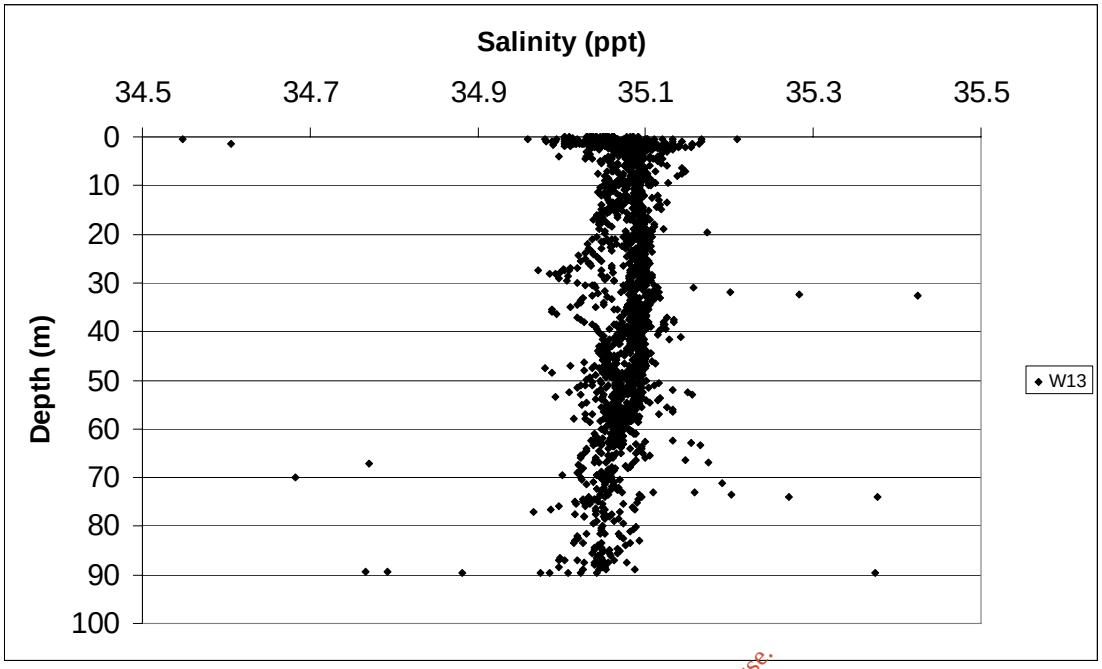

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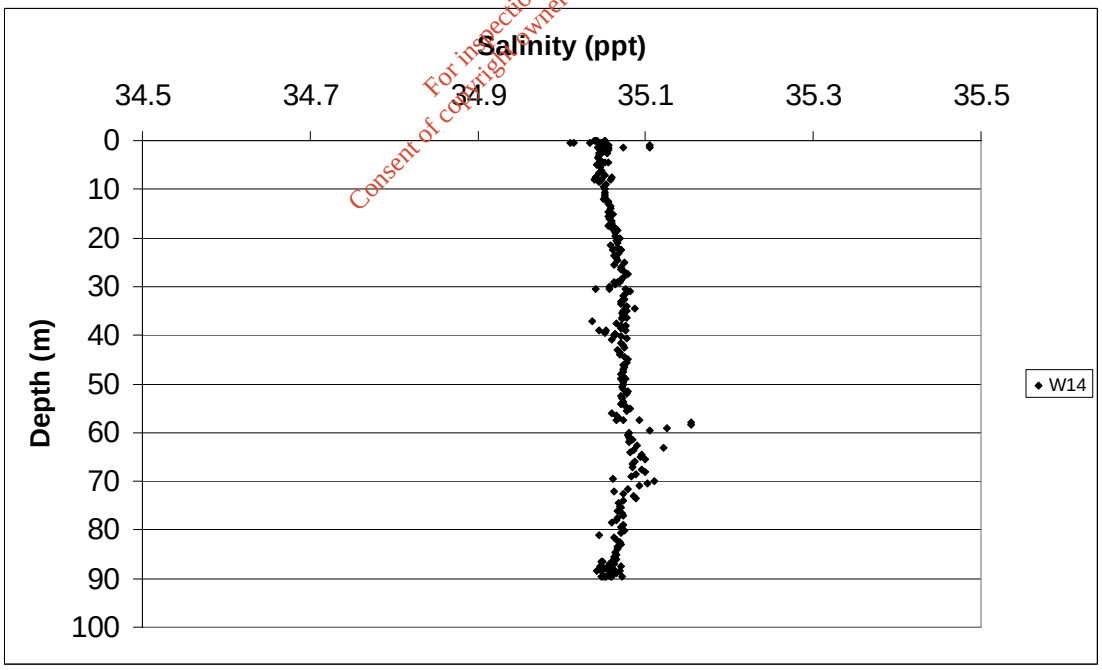

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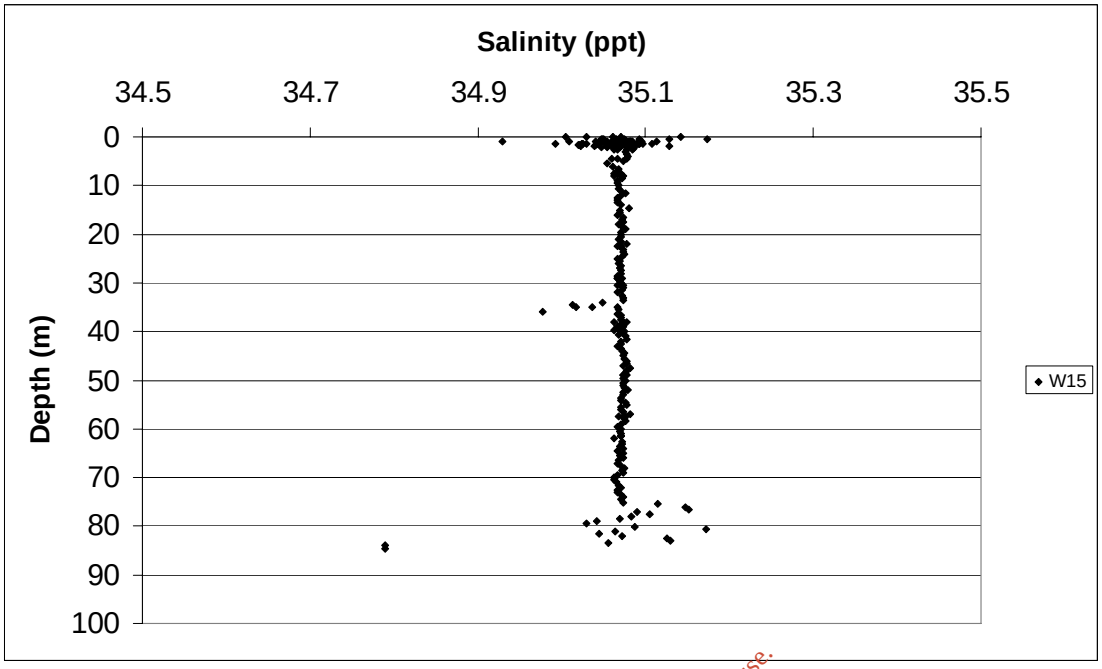

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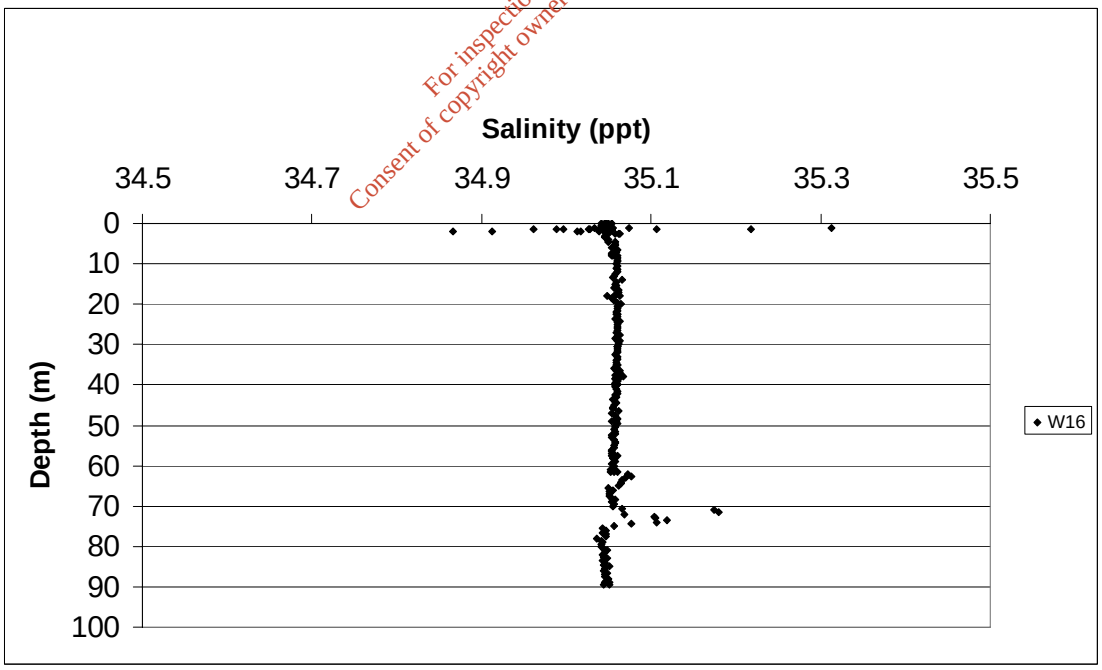

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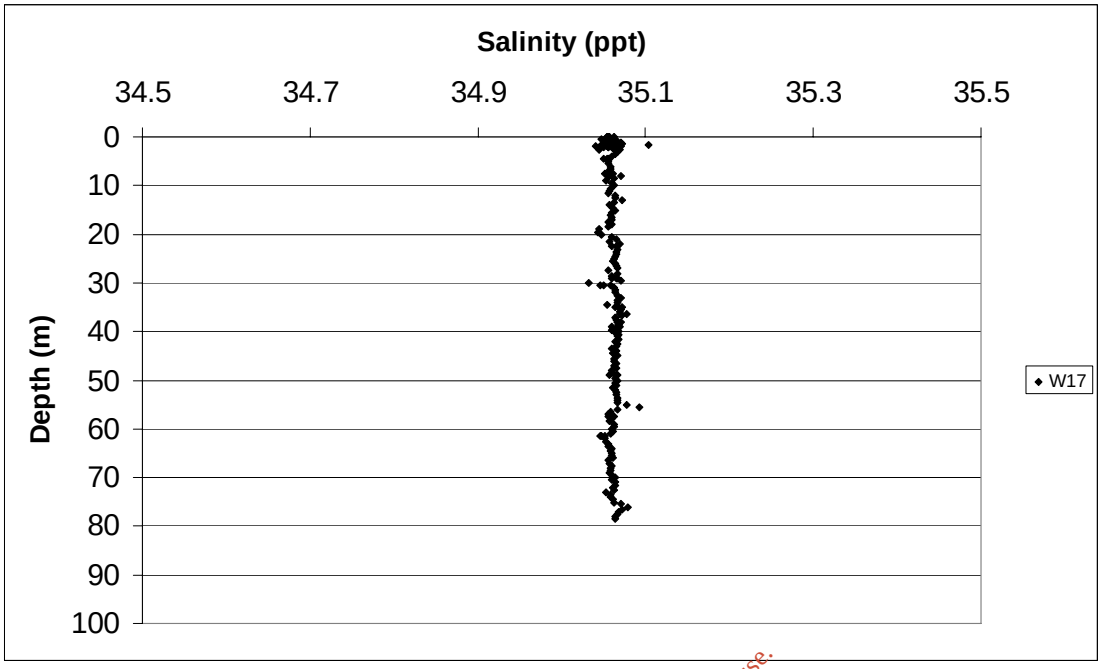

Appendix D: Water Quality Results

				W1 Outfall surf	W1 Outfall bot	W2 Outfall surf	W3 Outfall surf	W4 Outfall surf	W4 Outfall bot	W5 Outfall surf	W6 Outfall surf	W7 Outfall surf	W7 Outfall bot	W8 Outfall surf
		date		2-Aug-07	2-Aug-07	6-Aug-07	6-Aug-07	2-Aug-07	2-Aug-07	5-Aug-07	5-Aug-07	2-Aug-07	2-Aug-07	6-Aug-07
Ammoniacal Nitrogen as N	MRV 0.01 mg/l	UKAS	ug/l	< 10.0000	< 10.0000	10.0000	< 10.0000	60.0000	< 10.0000	16.0000	< 10.0000	33.0000	< 10.0000	12.0000
Arsenic	MRV 1.0 ug/l	UKAS	ug/l	1.14	1.56	1.09	1.34	1.17	1.29	1.12	1.16	1.28	1.31	1.30
Benzene	MRV 0.1 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
Toluene :- {Methylbenzene}	MRV 1 ug/l	UKAS	ug/l	< 2.00	< 2.00	< 2.00	< 2.00	< 2.00	< 2.00	< 2.00	< 2.00	< 2.00	< 2.00	< 2.00
Ethylbenzene	MRV 0.1 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
1,2-Dimethylbenzene :- {o-Xylene}	MRV 0.1 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
DiMeBenzene 13+14	MRV 0.1 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
Pentachlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
4-Chloro-2-methylphenol :- {p-Chloro-o-cresol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
4-Chloro-3-methylphenol :- {p-Chloro-m-cresol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,4-Dimethylphenol :- {2,4-Xylenol}	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
3,5-Dimethylphenol :- {3,5-Xylenol}	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
4-Methylphenol :- {p-cresol}	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
3-Methylphenol :- {m-Cresol}	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2-Methylphenol :- {o-Cresol}	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,3,5,6-Tetrachlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,6-Dimethylphenol :- {2,6-Xylenol}	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
3,4-Dimethylphenol :- {3,4-Xylenol}	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
4-Chloro-3,5-dimethylphenol :- {PCMX}	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,5-Dichlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,5-Dimethylphenol :- {2,5-Xylenol}	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
Phenol	MRV 0.4 ug/l	UKAS	ug/l	< 0.200	0.213	< 0.200	< 0.200	< 0.200	< 0.200	< 0.200	< 0.200	< 0.200	< 0.200	< 0.200
3-Chlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2-Chlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
4-Chlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,4-Dichlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,6-Dichlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,4,5-Trichlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,4,6-Trichlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,3-Dimethylphenol :- {2,3-Xylenol}	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,3-Dichlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2-Ethylphenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
Cadmium	MRV 0.04 ug/l	UKAS	ug/l	< 0.0400	< 0.0400	< 0.0400	< 0.0400	< 0.0400	< 0.0400	< 0.0400	< 0.0400	< 0.0400	< 0.0400	< 0.0400
Copper	MRV 0.2 ug/l	UKAS	ug/l	2.450	2.080	0.320	0.430	0.310	0.530	0.390	0.270	0.380	0.280	0.250
Lead	MRV 0.04 ug/l	UKAS	ug/l	0.5450	0.3890	0.0550	< 0.0400	0.1900	0.3960	0.1120	0.0970	0.0660	0.2220	< 0.0400
Mercury	MRV 0.01 ug/l		ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
Nickel	MRV 0.25 ug/l	UKAS	ug/l	1.100	0.370	0.290	< 0.250	0.440	0.290	0.440	0.310	0.310	0.270	0.370
Zinc	MRV 0.4 ug/l	UKAS	ug/l	59.600	5.900	1.160	1.010	8.420	1.800	5.880	3.820	3.320	1.000	1.510
Chromium	MRV 0.5 ug/l	UKAS	ug/l	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	1.000	< 0.500	< 0.500	< 0.500	< 0.500
Silver	MRV 1.0 ug/l	UKAS	ug/l	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00
Barium	MRV 100 ug/l	None	ug/l	< 100.	< 100.	< 100.	< 100.	< 100.	< 100.	< 100.	< 100.	< 100.	< 100.	< 100.
Acenaphthylene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0110	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
Acenaphthene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0110	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
Fluorene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0110	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
Phenanthrene	MRV 0.011 ug/l	UKAS	ug/l	< 0.0110	< 0.0110	< 0.0110	< 0.0110	< 0.0110	< 0.0110	< 0.0110	< 0.0110	< 0.0110	< 0.0110	< 0.0110
Anthracene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0110	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
Fluoranthene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0110	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
Pyrene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0110	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
B(a)anthracene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0110	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
Chrysene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0110	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
B(b)fluoranthene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0110	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
B(k)fluoranthene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0110	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
B(a)pyrene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0110	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
Indeno123cdPyrene	MRV 0.02 ug/l	UKAS	ug/l	< 0.0200	< 0.0200	< 0.0200	< 0.0200	< 0.0200	< 0.0200	< 0.0200	< 0.0200	< 0.0200	< 0.0200	< 0.0200
DiB(ah)anthracene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0110	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
B(ghi)perylene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0110	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
Naphthalene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	0.0660	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
Double Paper Solids, Suspended at 105 C	MRV 3.0 mg/l	UKAS	ug/l	< 3000.00	< 3000.00	< 3000.00	4000.00	< 3000.00	< 3000.00	< 3000.00	< 3000.00	4000.00	< 3000.00	4000.00

				W9 Outfall surf	W9 Outfall bot	W10 Outfall surf	W11 Outfall surf	W12 Outfall surf	W13 Outfall surf	W13 Outfall bot	W14 Outfall surf	W15 Outfall surf	W16 Outfall surf	W17 Outfall surf
		date		5-Aug-07	5-Aug-07	5-Aug-07	5-Aug-07	5-Aug-07	5-Aug-07	5-Aug-07	5-Aug-07	5-Aug-07	5-Aug-07	5-Aug-07
Ammoniacal Nitrogen as N	MRV 0.01 mg/l	UKAS	ug/l	15.0000	< 10.0000	< 10.0000	12.0000	< 10.0000	20.0000	10.0000	106.0000	31.0000	28.0000	< 10.0000
Arsenic	MRV 1.0 ug/l	UKAS	ug/l	1.22	1.24	1.33	1.33	1.26	1.21	1.20	1.27	1.27	1.28	1.27
Benzene	MRV 0.1 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
Toluene :- {Methylbenzene}	MRV 1 ug/l	UKAS	ug/l	< 2.00	< 2.00	< 2.00	< 2.00	< 2.00	< 2.00	< 2.00	< 2.00	< 2.00	< 2.00	< 2.00
Ethylbenzene	MRV 0.1 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
1,2-Dimethylbenzene :- {o-Xylene}	MRV 0.1 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
DiMeBenzene 13+14	MRV 0.1 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
Pentachlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
4-Chloro-2-methylphenol :- {p-Chloro-o-cresol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
4-Chloro-3-methylphenol :- {p-Chloro-m-cresol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,4-Dimethylphenol :- {2,4-Xylenol}	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
3,5-Dimethylphenol :- {3,5-Xylenol}	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
4-Methylphenol :- {p-cresol}	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
3-Methylphenol :- {m-Cresol}	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2-Methylphenol :- {o-Cresol}	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,3,5,6-Tetrachlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,6-Dimethylphenol :- {2,6-Xylenol}	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
3,4-Dimethylphenol :- {3,4-Xylenol}	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
4-Chloro-3,5-dimethylphenol :- {PCMX}	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,5-Dichlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,5-Dimethylphenol :- {2,5-Xylenol}	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
Phenol	MRV 0.4 ug/l	UKAS	ug/l	< 0.200	0.243	< 0.200	< 0.200	< 0.200	0.223	< 0.200	< 0.200	< 0.200	0.275	0.298
3-Chlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2-Chlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
4-Chlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,4-Dichlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,6-Dichlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,4,5-Trichlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,4,6-Trichlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,3-Dimethylphenol :- {2,3-Xylenol}	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2,3-Dichlorophenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
2-Ethylphenol	MRV 0.2 ug/l	UKAS	ug/l	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
Cadmium	MRV 0.04 ug/l	UKAS	ug/l	< 0.0400	< 0.0400	< 0.0400	< 0.0400	< 0.0400	< 0.0400	< 0.0400	< 0.0400	< 0.0400	< 0.0400	< 0.0400
Copper	MRV 0.2 ug/l	UKAS	ug/l	< 0.200	0.260	0.260	0.770	0.280	0.330	1.250	0.780	1.110	0.400	0.240
Lead	MRV 0.04 ug/l	UKAS	ug/l	0.2680	0.2950	0.0720	0.0700	0.0660	0.1070	0.4340	0.0590	0.0860	0.0770	0.0810
Mercury	MRV 0.01 ug/l		ug/l	< 0.0100	< 0.0100	0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
Nickel	MRV 0.25 ug/l	UKAS	ug/l	0.290	0.310	0.320	0.320	0.260	0.290	0.290	0.300	0.290	0.320	0.290
Zinc	MRV 0.4 ug/l	UKAS	ug/l	2.850	0.970	2.020	1.580	1.630	2.840	1.460	2.100	4.570	2.150	1.740
Chromium	MRV 0.5 ug/l	UKAS	ug/l	1.090	< 0.500	0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500	< 0.500
Silver	MRV 1.0 ug/l	UKAS	ug/l	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00
Barium	MRV 100 ug/l	None	ug/l	< 100.	< 100.	< 100.	< 100.	< 100.	< 100.	< 100.	< 100.	< 100.	< 100.	< 100.
Acenaphthylene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	0.0550	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
Acenaphthene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 1.0000	< 0.0100	0.0390	< 0.0100	0.0980	< 0.0100	< 0.0100	< 0.0100	< 0.0100
Fluorene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	0.2280	< 0.0100	0.0140	< 0.0100	0.0460	< 0.0100	< 0.0100	< 0.0100	< 0.0100
Phenanthrene	MRV 0.011 ug/l	UKAS	ug/l	< 0.0110	< 0.0110	0.2150	< 0.0110	< 0.0110	< 0.0110	0.0440	< 0.0110	< 0.0110	< 0.0110	< 0.0110
Anthracene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	0.2480	< 0.0100	0.0140	< 0.0100	0.0610	< 0.0100	< 0.0100	< 0.0100	< 0.0100
Fluoranthene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
Pyrene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
B(a)anthracene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
Chrysene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
B(b)fluoranthene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
B(k)fluoranthene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
B(a)pyrene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
Indeno123cdPyrene	MRV 0.02 ug/l	UKAS	ug/l	< 0.0200	< 0.0200	< 0.0200	< 0.0200	< 0.0200	< 0.0200	< 0.0200	< 0.0200	< 0.0200	< 0.0200	< 0.0200
DiB(ah)anthracene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
B(ghi)perylene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100	< 0.0100
Naphthalene	MRV 0.01 ug/l	UKAS	ug/l	< 0.0100	< 0.0100	< 1.0000	< 0.0100	< 1.0000	< 0.0100	< 1.0000	< 0.0100	< 0.0100	< 0.0100	< 1.0000
Double Paper Solids, Suspended at 105 C	MRV 3.0 mg/l	UKAS	ug/l	< 3000.00	< 3000.00	< 3000.00	< 3000.00	< 3000.00	3000.00	5000.00	< 3000.00	< 3000.00	< 3000.00	< 3000.00

CORRIB OFFSHORE GAS FIELD DEVELOPMENT

ERRIS HEAD OUTFALL ENVIRONMENTAL SURVEY 2008

August 2009

CONTENTS

Tables

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1 Introduction

The Corrib gas field lies in approximately 350m of water, approximately 65km off the coast of County Mayo. The gas in the field is to be brought ashore using a 20-inch-diameter pipeline, which will landfall at Dooncarton in Broadhaven Bay. From there, the pipeline will be routed to the terminal at Bellanaboy Bridge. The plan of development for the field was approved in 2002, subject to various conditions.

Processing of the gas at the terminal will result in the production of waste water, which will be discharged back to sea through a pipeline (consented under an IPPC licence).

The proposed discharge location lies approximately 2km north of Erris Head in water depths of approximately 70m below chart datum. A baseline survey of biological and chemical parameters in seawater and sediment was undertaken around the proposed Corrib outfall in June–August 2005 (EcoServe, 2006). In addition, a second baseline survey was undertaken in July 2007 (RSK, 2008). This report documents a third baseline survey of water and sediment around the outfall in summer 2008.

After the completion of the 2008 baseline survey, Shell agreed to route the produced water back through some spare umbilical cores, and toe release it in the Corrib field itself. The proposed outfall, which is the subject of this report, will be engaged solely for the discharge of treated surface water run-off from the terminal.

2 Methods

2.1 Vessel

Sampling operations were carried out from the M/V *Deepworker*, a 70-metre dynamically positioned salvage/survey/research vessel, licensed for survey operations in waters of the continental shelf.

Osiris Projects provided an onboard positioning package and helmsman display from which to position the vessel during survey operations. The following equipment was mobilised aboard the vessel for the survey: CSI dGPS Max receiver; high-specification navigation PC supporting Quincy V8 (spare PC); TSS Meridian gyro; Simrad HPR 400 subsea positioning system over-the-side mount and Simrad 60 series single-beam echo sounder. The vessel's existing Trimble dGPS navigation system was used as a secondary resource.

2.2 Personnel

SEPIL commissioned RSK Environment Ltd (RSK) to manage the environmental survey cruise. RSK contracted Osiris Projects to act as vessel operators for the offshore survey work and to provide navigational services for the duration of the project.

During the survey operations, the scientific crew aboard worked according to two 12-hour shifts to enable sampling operations to continue over 24 hours. Each watch comprised three scientists, the most senior being the dedicated shift leader.

2.3 Survey dates

Table 2.1 presents key dates of the survey.

Table 2.1: Dates of 2008 Erris Head environmental survey

Date (July 2008)	Task	Location
11	Mobilisation	Foynes
12–13	Depart/transit (30 hours), Navigation calibration	Foynes/en route
13–21	Survey operations (outwith this report)	Corrib field
21–22	**Survey operations**	**Erris Head outfall**
22–23	Survey operations (outwith this report)	Stations at 12nm limit alternative outfall
23–26	Transit (to Foynes), partial demobilisation, remobilisation, transit (to alternative outfall stations off Erris Head)	Foynes/en route/alternative stations off Erris Head
26–29	Survey operations (outwith this report)	Stations at alternative outfall off Erris Head
30	Transit, complete demobilisation	Alternative outfall, Foynes

*Partial demobilisation only. Survey continued to sample 'Alternative outfall' stations; see separate report.

2.4 Sampling locations

Twenty stations were planned for sampling and these are presented in. Stations included those both with sediment (S) and water (W) sampling elements (nine stations) and those with only water (eight stations) and only sediment (three stations) elements.

The target accuracy for benthic samples was within 30m of the position.

Table 2.2: Coordinates of sites (WGS84 datum)

Site	Latitude N	Longitude W
S1 and W1	54.294696	-10.183642
S2 and W2	54.320796	-10.017542
S4	54.328996	-10.023142
W4	54.324834	-9.998042
W6	54.326687	-9.989278
S5	54.333900	-9.987600
S5R	54.327996	-9.986942
S6 and W11	54.332500	-9.993100
S6R and W5	54.326596	-9.992442
W7	54.330676	-9.983941
S9 & W9	54.332296	-9.952242
S10 &W8	54.356496	-9.986242
W10	54.337643	-9.996132
S11 and W3	54.332496	-10.027042
W12	54.329328	-9.990907
W13	54.328220	-9.990162
W14	54.323598	-9.986581
S15 and W15	54.319296	-9.982042
W16	54.327586	-9.972536
S17 and W17	54.320696	-9.956342

Blank cell: sediment and water; Brown: sediment only; Blue: water only

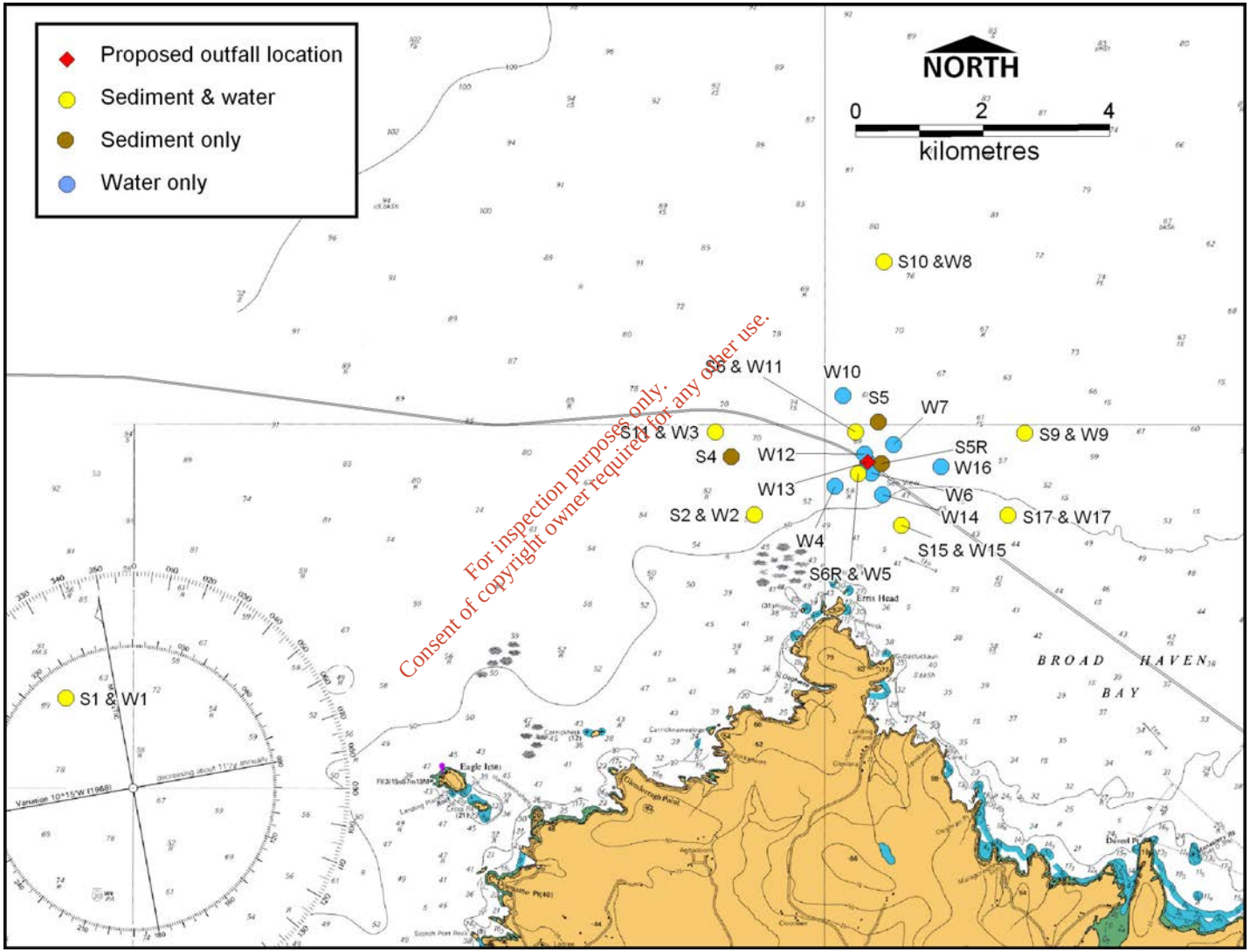

Figure 2.1: Planned sampling stations, Erris Head outfall survey (July 2008)

2.5 Sampling methods

Survey operations at the Erris Head outfall locations consisted of sampling:

a) **Water quality parameters:**
   a. Collection of surface and near-bottom samples for laboratory chemical analysis
   b. Measurement of parameters using a conductivity, temperature and depth (CTD) probe.

b) **Seabed sediments** using a grab sampler for:
   a. Physico-chemistry (particle size and total organic carbon, TOC)
   b. Chemistry (metals, hydrocarbons)
   c. Benthic macroinvertebrates.

2.5.1 Water quality

Surface water samples were obtained by means of a surface-deployed Winchester bottle using a 4.5m pole. The bottle was opened remotely at a depth of one metre. Once full, the bottle was recovered and transferred to subsample bottles for various analytes. A new Winchester bottle was used for each of the surface water stations.

For near-bottom water samples (including water column CTD profiling), a Richter and Weise Niskin bottle was deployed from the deck winch on a 4mm stainless steel wire along with a Valeport Monitor CTD profiler, both of which were positioned two metres above a sinker weight. The CTD was allowed to equilibrate in the surface waters for three minutes before it was lowered through the water column. When the weight at the bottom of the cable reached the seabed, the bottle-closing mechanism was triggered by a messenger sent down the cable. Upon retrieval of the Niskin bottle, subsamples were poured into appropriate containers from the release tap.

During all water quality sampling, care was taken to avoid any contamination from the survey vessel. Therefore, all vessel outlets (deck scupper, bilge pump, water maker outlets etc.) were identified and avoided during the water sampling operations.

2.5.2 Sediment

A double Van Veen grab comprising twin buckets, each sampling a surface area of 0.1m^2, was used. The grab was constructed of stainless steel. The double Van Veen was used in place of ordinary single-grab samplers to reduce the number of deployments necessary at each station.

To limit cross-contamination and maximise consistency, all physico-chemical and chemical sediment samples were taken by the same surveyor on each watch, who wore a pair of nitrile gloves (disposed of after each station). Samples were taken from sediment that had not been in direct contact with the surface of the grab, and the grab was scrubbed clean and rinsed with seawater between each deployment.

2.6 Sample processing

2.6.1 Water quality processing and analysis

Processing and analysis details of water samples collected are present in Table 2.3.

Table 2.3: Water quality sample processing and analysis details

Parameter	No./Volume	Container	Preservation	Lab
Total suspended solids	1000ml	PET	-	Environment Agency
Ammoniacal N	125ml	Polypropylene	-	
Metals Cd, Cu, Pb, Ni, Zn, Ba, Cr	125ml	Polypropylene		
Arsenic	125ml	Polypropylene		
Mercury	125ml	Glass	1ml of 2.5% K-dichromate in 50% HNO_3	
Phenol	250ml	Glass	1 molar H_2SO_4	
BTEX	250ml	PET	-	

All samples were transferred to cold boxes containing ice packs at the end of the survey and couriered under chain-of-custody procedures to the analytical laboratory.

2.6.2 Metals in water QA/QC

A certified reference material (CRM) containing known levels of metals, was provided to the Environment Agency (EA) along with other samples in order to determine their analytical accuracy.

The CRM used was SLEW-3 specification (estuarine waters), produced by the National Research Council of Canada (NRCC).

Results of the analysis of the CRM by the EA are presented in 3.2.3.

2.6.3 Sediment processing & analysis

Details of sediment samples collected are presented in Table 2.4.

Table 2.4: Sediment sample processing and analysis details

Parameter	No./Volume	Container	Preservation	Lab
Benthic macro-invertebrates	3x1 complete (separate) grab buckets	Double-labelled plastic bucket	4–10% buffered formaldehyde solution	Hebog Environmental
Particle size analysis (PSA)	~1kg	Double-labelled plastic	Frozen	Environment Agency

Parameter	No./Volume	Container	Preservation	Lab
Total organic carbon (TOC)		tub/Ziploc bag		
Organics: total organic extract (TOE)	~300ml	Double-labelled aluminium tins/glass jars	Frozen	M-Scan (subcontractor to Benthic Solutions)
Organics: polycyclic aromatic hydrocarbons (2-6 ring EPA16 PAH and NPD (naphthalenes, phenanthrenes, dibenzothiophenes + alkylated homologues)				
Metals: Al, Ag, As, Ba, Cd, Cr, Cu, Fe, Hg, Li, Mn, Ni, Pb, Se, V, Zn	~1kg	Double-labelled plastic tub/Ziploc bag	Frozen	Environment Agency

At the end of the survey, samples were transferred to cold boxes containing ice packs (with the exception of benthic samples). All samples were then transferred under chain-of-custody procedures to analytical laboratories.

2.6.4 *Metals in sediment QA/QC*

To assess the accuracy of one of the analytical laboratories in determining levels of metals, a CRM of marine sediment containing certified levels of metals, was provided to the Environment Agency (EA) along with other samples.

The CRM used was the MESS-3 specification (marine sediment), produced by the National Research Council of Canada (NRCC).

Results of the analysis of the CRM by the EA are presented in 3.4.2.

2.6.5 *Sediment macrofaunal analysis*

After sieving over a 0.5mm-mesh sieve, macrofaunal invertebrates were identified and enumerated. These data were then used to collate a number of ecological indices as follows:

- *Species richness* (S): the number of species present;
- *Abundance* (N): the number of individuals present;
- *Diversity* (Shannon-Wiener, H'): an integrated index of species richness and relative abundance;
- *Evenness* (Pielou's, J'): evenness of the distribution of individuals amongst different species in each sample; and
- *Dominance* (Simpsons, λ): dominance, essentially the reverse of evenness.

In addition, numerical data were then used in multivariate analyses to calculate a number of indices. These were:

- *Cluster analysis*: determination of inherent groupings within species and station data. In this study Bray-Curtis similarity was calculated using the PRIMER statistical package;
- *Multi-dimensional scaling* (MDS): using similar data to cluster analysis, this presents groupings on a 2-D map;
- *SIMPER*: this identifies those species most responsible for the defining similarities in each group; output is given as a percentage of similarity/dissimilarity and ranks those species that contribute most to this value; and
- *BIOENV*: performed within PRIMER, this incorporates physical or chemical data from each station (e.g. water depth, sediment size fraction) to determine the degree of correlation between this and the communities present.

3 Results

3.1 Planned and actual sample collection

All planned samples were successfully taken; planned and actual samples are presented in Table 3.1. At 10 of the 12 grab sites, a minimum of two deployments was used to collect samples, and at only two sites (S1 and S10) were more than two required; these were due to the grab not firing. All grab samples were within 1.0–8.5m (mean 4.3m) of the target location.

All water samples were collected successfully and without issue.

Table 3.1: Planned and actual sediment and water samples taken

Station	Sediment				Water		
	Macrofauna	PSA/TOC	Chem	Organics	Surface water	Near-bottom water	CTD profile
S1 and W1	3	1+1	1	1+1	1	1	1
S2 and W2	3	1+1	1	1+1	1	-	-
S4	3	1+1	1	1+1	-	-	-
W4	-	-	-	-	1	1	1
W6	-	-	-	-	1	-	-
S5	3	1+1	1	1+1	-	-	-
S5R	3	1+1	1	1+1	-	-	-
S6 and W11	3	1+1	1	1+1	1	-	-
S6R and W5	3	1+1	1	1+1	1	-	-
W7	-	-	-	-	1	1	1
S9 and W9	3	1+1	1	1+1	1	1	1
S10 and W8	3	1+1	1	1+1	1	-	-
W10	-	-	-	-	1	-	-
S11 and W3	3	1+1	1	1+1	1	-	-
W12	-	-	-	-	1	-	-
W13	-	-	-	-	1	1	1
W14	-	-	-	-	1	-	-
S15 and W15	3	1+1	1	1+1	1	-	-
W16	-	-	-	-	1	-	-
S17 and W17	3	1+1	1	1+1	1	-	-
Planned	**36 (12x3)**	**12 + 12**	**12**	**12**	**17**	**5**	**5**
Actual	**36 (12x3)**	**12 + 12**	**12**	**12**	**17**	**5**	**5**
Not collected	**0**	**0**	**0**	**0**	**0**	**0**	**0**

3.2 Water quality

3.2.1 CTD profiles

3.2.1.1 Salinity

Salinity-depth profiles for the stations sampled are presented in Figure 3.1.

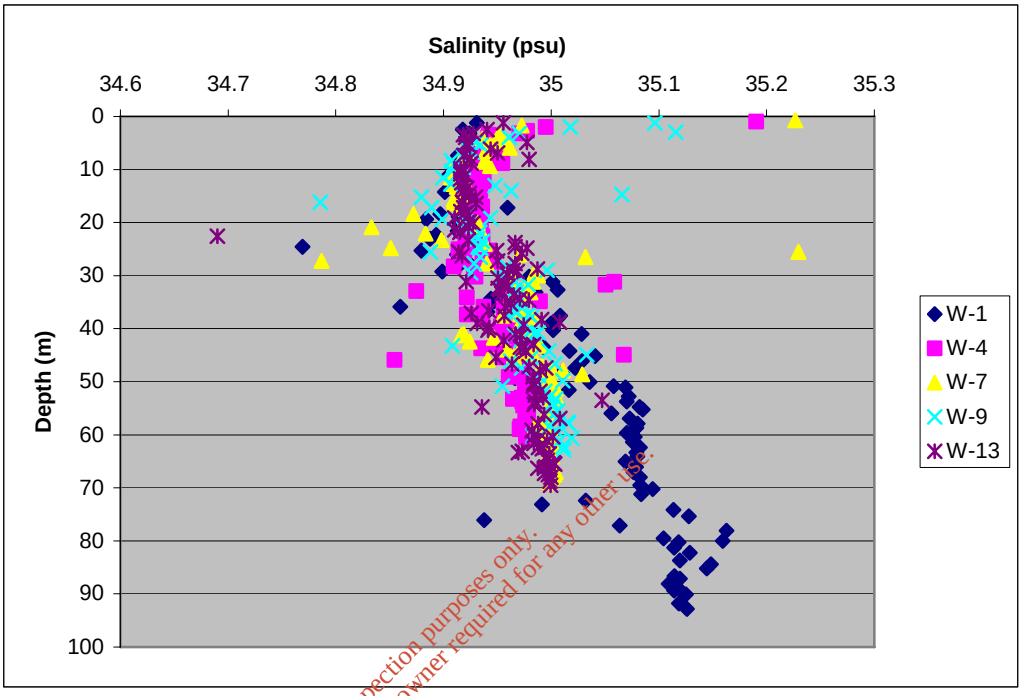

Figure 3.1: Salinity depth profiles

These data showed a gradual increase with salinity with depth, which was slightly more noticeable at reference station W1, the deepest station, located to the SW of the main survey area.

3.2.1.2 Temperature

A temperature-depth profile for the stations sampled is presented in Figure 3.2.

The overall range of temperatures recorded was approximately 3°C, ranging from *c*.11.34°C at 81m depth (W1) to *c*.14.23°C in surface waters at W9.

Recorded surface temperatures varied little, over a range of approximately 0.5°C from 13.81°C (W4) to 14.23°C. At depth, stations displayed a greater range of temperatures: at a comparable depth of 60m, five of the six stations were relatively similar (between 12.63 and 13.04°C), with station S1 marginally cooler than other stations, at 11.78°C.

All stations showed evidence of some degree of stratification throughout the water column. In general, there was a layer at the surface of a homogenous temperature (indicating mixing); this ranged in depth from *c*.13m at W9 to *c*.28m at W4. Below this, there was a gradual decrease in water temperature with water depth. A second layer of water of homogenous temperature was then recorded, commencing at around 50m depth. This continued to beyond 60m for shallower stations (W9, W4), and to 70m depth at the deeper stations

(W1, W7, W13). At the deepest station (W1), below this depth there was a further slight decrease in temperature (with the lowest recorded temperature, 11.34°C at around 85m depth). Temperatures beyond 85m were fairly homogenous and possibly slightly higher than those around 80–85m.

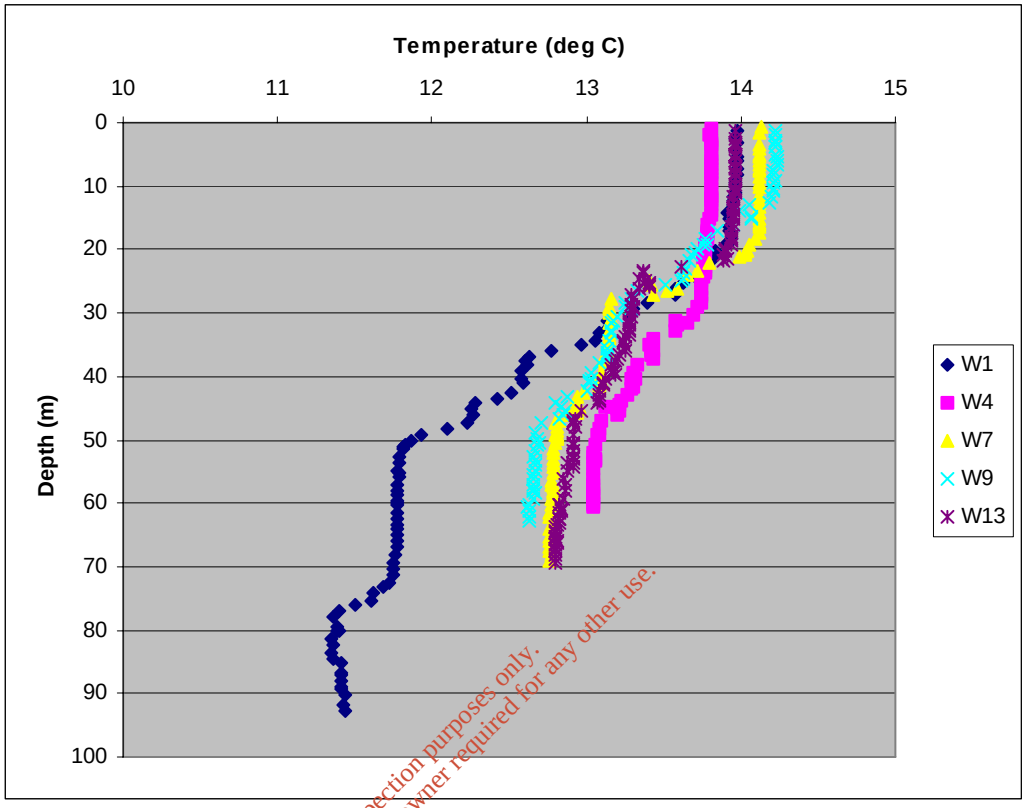

Figure 3.2: Temperature depth profile

3.2.2 Water samples

Results for suspended particulate matter (SPM) and ammoniacal nitrogen from discrete water samples are presented in Table 3.2.

Table 3.2: Suspended particulate matter (SPM) and ammoniacal nitrogen in seawater results

Station	Depth	Suspended particulate matter (SPM)	Ammoniacal nitrogen as N
		mg/l	
W1	Surface	<3.00	<0.01
	Bottom	<3.00	**0.022**
W2	Surface	<3.00	<0.01
W3	Surface	<3.00	<0.01
W4	Surface	<3.00	<0.01
	Bottom	<3.00	<0.01
W5	Surface	<3.00	<0.01
W6	Surface	<3.00	<0.01
W7	Surface	<3.00	<0.01
	Bottom	<3.00	<0.01
W8	Surface	<3.00	<0.01
W9	Surface	<3.00	<0.01

Station	Depth	Suspended particulate matter (SPM)	Ammoniacal nitrogen as N
		mg/l	
	Bottom	<3.00	<0.01
W10	Surface	<3.00	<0.01
W11	Surface	<3.00	<0.01
W12	Surface	<3.00	<0.01
W13	Surface	<3.00	<0.01
	Bottom	<3.00	<0.01
W14	Surface	<3.00	<0.01
W15	Surface	**4.00**	<0.01
W16	Surface	<3.00	<0.01
W17	Surface	<3.00	<0.01

3.2.2.1 Suspended particulate matter (SPM)

With the exception of a single station, all stations had SPM levels below that of the detection limit, i.e. <3.00mg/l. Station W15 recorded a value of 4mg/l, which is considered to be low.

3.2.2.2 Ammoniacal nitrogen

With the exception of a single sample (W1 bottom, 0.022mg/l), all stations had results below that of the detection limit, i.e. <0.01mg/l. The EQS for ammoniacal nitrogen is 0.021mg/l. Given that the other results were below the detection limit, it may be the case that the result from W1 is erroneous, though checks on the sampling and analytical procedure show no problems.

3.2.2.3 Metals

Results for metals in discrete seawater samples are presented in Table 3.3. Concentrations of barium, cadmium and chromium were all below their respective limits of detection.

Four of the readings for arsenic were below the detection limits and all samples had concentrations less than 1.45µg/l. No patterns in the distribution of concentrations of arsenic are evident.

Eight of the results for copper were below the limit of detection, and all samples contained less than 1.21µg/l. There is no apparent pattern in the distribution of copper concentrations, although the highest concentration was recorded at the most westerly sampling station.

Lead concentration range from 0.056 – 40.8µg/l. Four of the five samples taken from close to the seabed have concentrations >2µg/l, while only one of the other seventeen surface samples is above 0.14µg/l. There is no apparent reason for this difference between surface and seabed concentrations, sample dilution was investigated as a possible cause, but was eliminated. Notably, the highest concentration was again found in the most westerly sampling station.

Nickel concentrations were all below the limits of detection, except in those samples taken from site W1, which were marginally above the limit. The concentration at W1 close to the surface was greater than that close to the seabed. Site W1 is the most westerly station.

The range of zinc concentrations recorded was 1.39-29.5µg/l, with a tendency for lower concentrations to be found in samples taken close to the seabed rather than near the surface. Samples from the surface at stations W3 and W2 had the highest concentrations, these sites are located to the north west of Erris Head. The zinc concentration at site W4, located between W2 and W3 was close to the average for the other sites, indicating that there is unlikely to be a pattern in zinc concentrations.

Only four samples had mercury concentrations above the limit of detection. The maximum concentration, 0.019µg/l is less than twice the limit of detection, indicating that all concentrations are low. All positive readings were collected from surface samples, but no geographic pattern in the distribution of concentrations is evident.

Table 3.3: Metals in seawater results

Station		As	Cd	Cu	Pb	Ni	Zn	Ba	Hg	Cr
		µg/l								
W1	Surface	1.02	<0.0400	<0.200	0.082	0.350	11.0	<100	<0.010	<0.500
	Bottom	<1.00	<0.0400	1.21	40.8	0.320	8.72	<100	<0.010	<0.500
W2	Surface	1.31	<0.0400	0.200	0.138	<0.300	21.6	<100	<0.010	<0.500
W3	Surface	<1.00	<0.0400	0.670	0.251	<0.300	29.5	<100	<0.010	<0.500
W4	Surface	<1.00	<0.0400	0.300	0.067	<0.300	4.97	<100	<0.010	<0.500
	Bottom	1.27	<0.0400	<0.200	8.80	<0.300	1.39	<100	<0.010	<0.500
W5	Surface	1.06	<0.0400	0.400	0.088	0.300	7.32	<100	<0.010	<0.500
W6	Surface	1.00	<0.0400	<0.200	0.065	<0.300	3.26	<100	<0.010	<0.500
W7	Surface	<1.00	<0.0400	0.480	2.67	<0.300	1.63	<100	<0.010	<0.500
	Bottom	1.09	<0.0400	0.340	0.082	<0.300	4.00	<100	<0.010	<0.500
W8	Surface	1.25	<0.0400	<0.200	0.085	<0.300	5.44	<100	0.011	<0.500
W9	Surface	1.14	<0.0400	<0.200	0.056	<0.300	3.02	<100	0.016	<0.500
	Bottom	1.45	<0.0400	0.420	2.18	<0.300	2.15	<100	<0.010	<0.500
W10	Surface	1.20	<0.0400	<0.200	0.068	<0.300	4.81	<100	<0.010	<0.500
W11	Surface	1.26	<0.0400	0.210	0.063	<0.300	3.38	<100	0.019	<0.500
W12	Surface	1.24	<0.0400	<0.200	0.107	<0.300	4.27	<100	<0.010	<0.500
W13	Surface	1.15	<0.0400	0.240	0.087	<0.300	5.56	<100	<0.010	<0.500
	Bottom	1.36	<0.0400	<0.200	5.32	<0.300	2.16	<100	<0.010	<0.500
W14	Surface	1.02	<0.0400	0.210	0.065	<0.300	4.45	<100	<0.010	<0.500
W15	Surface	1.10	<0.0400	0.330	0.081	<0.300	3.11	<100	<0.010	<0.500
W16	Surface	1.08	<0.0400	0.560	0.077	<0.300	3.32	<100	<0.010	<0.500
W17	Surface	1.09	<0.0400	0.320	0.095	<0.300	5.64	<100	0.014	<0.500

Orange: highest result; green: lowest result

3.2.3 *Metals in water QA/QC*

Results from the EA analytical laboratory as compared to the pre-determined levels in the SLEW-3 CRM are presented in Table 3.4. All differences between certified and EA laboratory results are less than 12.5%, with the exception of zinc, where EA results were much higher than the certified value.

Discussions with the EA laboratory have revealed that all of the quality checks were passed during the analytical run for the zinc samples, including measurements of the internal laboratory standard. The zinc reading was close to the minimum reporting value (detection limit), around which any "uncertainty of measure" is at it's maximum. This uncertainty decreases as the concentrations of a metal move more into the centre of the analytical working range (between the minimum and maximum reporting values). The readings from the field samples were all much higher than the CRM, and therefore

subject to less uncertainty than the CRM result. All results for zinc were lower than the EQS for marine waters.

Table 3.4: Comparison of analytical results for metals in seawater from EA laboratory against Certified Reference Material (CRM) values

Metal	EA result	CRM value	%difference
Ag	<1.00	0.003	N/A
As	1.52	1.36	11.76
Cd	0.054	0.048	12.50
Cr	<0.5	0.183	N/A
Cu	1.36	1.55	-12.26
Ni	1.18	1.23	-4.07
Pb	<0.04	0.009	N/A
Zn	0.86	0.201	327.86

3.2.4 Organics

Results for organic compounds in seawater are presented in Table 3.5. The majority of results are reported as less than the minimum reporting value. Of the 46 compounds tested for, only four were detected (phenol; 1,2-di-methylbenzene {o-Xylene}; di-Mebenzene 13+14; and ethylbenzene), although these were only present in low concentrations.

Table 3.5: Organic compounds in seawater (S=Surface, B=near-bottom)

Compound	Station												
	W1 S	W1 B	W2 S	W3 S	W4 S	W4 B	W5 S	W6 S	W7 S	W7 B	W8 S	W9 S	W9 B
Acenaphthene	<0.0100	<0.0120	0.0150	<0.0110	<0.0120	<0.0110	<0.0120	<0.0120	<0.0110	<0.0110	<0.0110	<0.0110	<0.0110
Acenaphthylene	<0.0100	<0.0120	<0.0120	<0.0110	<0.0120	<0.0110	<0.0120	<0.0120	<0.0110	<0.0110	<0.0110	<0.0110	<0.0110
Anthracene	<0.0100	<0.0120	<0.0120	<0.0110	<0.0120	<0.0110	<0.0120	<0.0120	<0.0110	<0.0110	<0.0110	<0.0110	<0.0110
B(a)anthracene	<0.0100	<0.0120	<0.0120	<0.0110	<0.0120	<0.0110	<0.0120	<0.0120	<0.0110	<0.0110	<0.0110	<0.0110	<0.0110
B(a)pyrene	<0.0100	<0.0120	<0.0120	<0.0110	<0.0120	<0.0110	<0.0120	<0.0120	<0.0110	<0.0110	<0.0110	<0.0110	<0.0110
B(b)fluoranthene	<0.0100	<0.0120	<0.0120	<0.0110	<0.0120	<0.0110	<0.0120	<0.0120	<0.0110	<0.0110	<0.0110	<0.0110	<0.0110
B(ghi)perylene	<0.0100	<0.0120	<0.0120	<0.0110	<0.0120	<0.0110	<0.0120	<0.0120	<0.0110	<0.0110	<0.0110	<0.0110	<0.0110
B(k)fluoranthene	<0.0100	<0.0120	<0.0120	<0.0110	<0.0120	<0.0110	<0.0120	<0.0120	<0.0110	<0.0110	<0.0110	<0.0110	<0.0110
Chrysene	<0.0100	<0.0120	<0.0120	<0.0110	<0.0120	<0.0110	<0.0120	<0.0120	<0.0110	<0.0110	<0.0110	<0.0110	<0.0110
DiB(ah)anthracene	<0.0100	<0.0120	<0.0120	<0.0110	<0.0120	<0.0110	<0.0120	<0.0120	<0.0110	<0.0110	<0.0110	<0.0110	<0.0110
Fluoranthene	<0.0100	<0.0120	<0.0120	<0.0110	<0.0120	<0.0110	<0.0120	<0.0120	<0.0110	<0.0110	<0.0110	<0.0110	<0.0110
Fluorene	<0.0100	<0.0120	<0.0120	<0.0110	<0.0120	<0.0110	<0.0120	<0.0120	<0.0110	<0.0110	<0.0110	<0.0110	<0.0110
Indeno123cdPyrene	<0.0100	<0.0120	<0.0120	<0.0110	<0.0120	<0.0110	<0.0120	<0.0120	<0.0110	<0.0110	<0.0110	<0.0110	<0.0110
Naphthalene	<0.0100	<0.0120	<0.0120	<0.0110	<0.0120	<0.0110	<0.0120	<0.0120	<0.0110	<0.0110	<0.0110	<0.0110	<0.0110
Phenanthrene	<0.0100	<0.0120	<0.0120	<0.0110	<0.0120	<0.0110	<0.0120	<0.0120	<0.0110	<0.0110	<0.0110	<0.0110	<0.0110
Pyrene	<0.0100	<0.0120	<0.0120	<0.0110	<0.0120	<0.0110	<0.0120	<0.0120	<0.0110	<0.0110	<0.0110	<0.0110	<0.0110
2,3,5,6-Tetrachlorophenol	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
2,3-Dichlorophenol	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
2,3-Dimethylphenol {2,3-Xylenol}	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
2,4,5-Trichlorophenol	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
2,4,6-Trichlorophenol	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
2,4-Dichlorophenol	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
2,4-Dimethylphenol {2,4-Xylenol}	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
2,5-Dichlorophenol	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100

Compound	Station												
	W1 S	W1 B	W2 S	W3 S	W4 S	W4 B	W5 S	W6 S	W7 S	W7 B	W8 S	W9 S	W9 B
2,5-Dimethylphenol {2,5-Xylenol}	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
2,6-Dichlorophenol	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
2,6-Dimethylphenol {2,6-Xylenol}	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
2-Chlorophenol	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
2-Ethylphenol	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
2-Methylphenol {o-Cresol}	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
3,4-Dimethylphenol {3,4-Xylenol}	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
3,5-Dimethylphenol {3,5-Xylenol}	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
3-Chlorophenol	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
3-Methylphenol {m-Cresol}	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
4-Chloro-2-methylphenol {p-Chloro-o-cresol}	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
4-Chloro-3,5-dimethylphenol {PCMX}	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
4-Chloro-3-methylphenol {p-Chloro-m-cresol}	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
4-Chlorophenol	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
4-Methylphenol {p-cresol}	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
Pentachlorophenol	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
Phenol	<0.200	<0.200	**0.207**	<0.200	<0.200	**0.222**	<0.200	<0.200	**0.220**	**0.340**	**0.293**	<0.200	<0.200
1,2-Dimethylbenzene {o-Xylene}	<0.100	**0.103**	<0.100	<0.100	<0.100	**0.127**	**0.103**	**0.142**	**0.119**	<0.100	<0.100	<0.100	**0.104**
Benzene	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
Di-Mebenzene 13+14	<0.200	**0.282**	**0.213**	<0.200	<0.200	**0.578**	**0.569**	**0.645**	**0.601**	**0.411**	**0.454**	**0.405**	**0.569**
Ethylbenzene	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
Toluene {Methylbenzene}	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00

Orange=highest value

Compound	W10 S	W11 S	W12 S	W13 S	W13 B	W14 S	W15 S	W16 S	W17 S
Acenaphthene	<0.0100	<0.0130	<0.0120	<0.0110	<0.0110	<0.0120	<0.0110	<0.0110	<0.0110
Acenaphthylene	<0.0100	<0.0130	<0.0120	<0.0110	<0.0110	<0.0120	<0.0110	<0.0110	<0.0110
Anthracene	<0.0100	<0.0130	<0.0120	<0.0110	<0.0110	<0.0120	<0.0110	<0.0110	<0.0110
B(a)anthracene	<0.0100	<0.0130	<0.0120	<0.0110	<0.0110	<0.0120	<0.0110	<0.0110	<0.0110
B(a)pyrene	<0.0100	<0.0130	<0.0120	<0.0110	<0.0110	<0.0120	<0.0110	<0.0110	<0.0110
B(b)fluoranthene	<0.0100	<0.0130	<0.0120	<0.0110	<0.0110	<0.0120	<0.0110	<0.0110	<0.0110
B(ghi)perylene	<0.0100	<0.0130	<0.0120	<0.0110	<0.0110	<0.0120	<0.0110	<0.0110	<0.0110
B(k)fluoranthene	<0.0100	<0.0130	<0.0120	<0.0110	<0.0110	<0.0120	<0.0110	<0.0110	<0.0110
Chrysene	<0.0100	<0.0130	<0.0120	<0.0110	<0.0110	<0.0120	<0.0110	<0.0110	<0.0110
DiB(ah)anthracene	<0.0100	<0.0130	<0.0120	<0.0110	<0.0110	<0.0120	<0.0110	<0.0110	<0.0110
Fluoranthene	<0.0100	<0.0130	<0.0120	<0.0110	<0.0110	<0.0120	<0.0110	<0.0110	<0.0110
Fluorene	<0.0100	<0.0130	<0.0120	<0.0110	<0.0110	<0.0120	<0.0110	<0.0110	<0.0110
Indeno123cdPyrene	<0.0100	<0.0130	<0.0120	<0.0110	<0.0110	<0.0120	<0.0110	<0.0110	<0.0110
Naphthalene	0.0150	<0.0130	<0.0120	<0.0110	<0.0110	<0.0120	<0.0110	<0.0110	<0.0110
Phenanthrene	<0.0100	<0.0130	<0.0120	<0.0110	<0.0110	<0.0120	<0.0110	<0.0110	<0.0110
Pyrene	<0.0100	<0.0130	<0.0120	<0.0110	<0.0110	<0.0120	<0.0110	<0.0110	<0.0110
2,3,5,6-Tetrachlorophenol	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
2,3-Dichlorophenol	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
2,3-Dimethylphenol {2,3-Xylenol}	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
2,4,5-Trichlorophenol	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
2,4,6-Trichlorophenol	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
2,4-Dichlorophenol	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
2,4-Dimethylphenol {2,4-Xylenol}	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
2,5-Dichlorophenol	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
2,5-Dimethylphenol {2,5-Xylenol}	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
2,6-Dichlorophenol	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
2,6-Dimethylphenol {2,6-Xylenol}	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200

Compound	W10 S	W11 S	W12 S	W13 S	W13 B	W14 S	W15 S	W16 S	W17 S
2-Chlorophenol	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
2-Ethylphenol	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
2-Methylphenol {o-Cresol}	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
3,4-Dimethylphenol {3,4-Xylenol}	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
3,5-Dimethylphenol {3,5-Xylenol}	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
3-Chlorophenol	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
3-Methylphenol {m-Cresol}	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
4-Chloro-2-methylphenol {p-Chloro-o-cresol}	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
4-Chloro-3,5-dimethylphenol {PCMX}	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
4-Chloro-3-methylphenol {p-Chloro-m-cresol}	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
4-Chlorophenol	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
4-Methylphenol {p-cresol}	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
Pentachlorophenol	<0.100	<0.100	<0.100	<0.200	<0.100	<0.100	<0.0200	<0.0200	<0.0200
Phenol	<0.200	<0.200	<0.200	<0.400	**0.544**	<0.200	**0.102**	**0.069**	**0.239**
1,2-Dimethylbenzene {o-Xylene}	<0.500	<0.100	<0.100	<0.100	**0.144**	<0.100	<0.100	<0.100	<0.100
Benzene	<0.500	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
Di-Mebenzene 13+14	<0.500	**0.427**	**0.365**	**0.401**	**0.588**	**0.426**	**0.389**	**0.343**	**0.343**
Ethylbenzene	<0.500	**0.365**	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
Toluene {Methylbenzene}	<10.0	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00

Orange=highest value

3.3 Sediment physico-chemistry

Summary results for particle size analysis (PSA) and total organic carbon (TOC) are presented in Table 3.6. Full PSA results are presented in Appendix 1.

Table 3.6: Sediment particle size and total organic carbon results

Station	%			Grain size (mm)		Sediment description (Udden Wentworth)	Total organic carbon (%)
	Gravel	Sand	Mud	Median	Mean		
S1	15.0	85.0	0.0	0.957	1.007	Coarse sand	1.63
S2	6.5	93.0	0.5	1.069	1.089	Very coarse sand	0.96
S4	2.4	97.6	0.0	0.440	0.361	Medium sand	3.03
S5	33.0	66.3	0.6	1.075	1.495	Very coarse sand	0.6
S5R	2.3	97.7	0.0	0.882	0.777	Coarse sand	2.56
S6	0.9	99.1	0.0	0.578	0.520	Coarse sand	2.9
S6R	23.3	76.8	0.0	1.486	1.381	Very coarse sand	1.52
S9	0.0	100.0	0.0	0.419	0.367	Medium sand	2.79
S10	0.0	96.4	3.6	0.223	0.196	Fine sand	0.45
S11	0.7	99.3	0.0	0.404	0.352	Medium sand	0.52
S15	0.3	99.7	0.0	0.548	0.485	Coarse sand	0.47
S17	0.3	99.7	0.0	0.415	0.364	Medium sand	0.45

Sand is the dominant sediment type, ranging from very coarse (S2, S5, S6R) to fine (S10), with medium and coarse sand both being the most frequently occurring classification. In most samples, the gravel fraction was not important, although it comprised a significant component at stations S5 (33%), S6R (23%) and to a lesser extent at S1 and S2. Fine sediment fractions (<63µm) were absent at all but three stations, with a maximum of 3.6% at S10.

TOC ranged from 0.45–3.03%. There was no clear pattern in the distribution of TOC levels, with for example stations with relatively high levels (S4, S6) adjacent to stations with lower levels (S11 and S5, respectively). There appeared to be no clear correlation between levels of TOC and grain size.

Together, the particle size and TOC data are consistent with a high-energy marine environment with no significant terrestrial (i.e. estuarine) inputs.

3.4 Sediment chemistry

3.4.1 Metals

Results are presented in Table 3.7, which indicate that no single station completely dominated in terms of relatively high, or low, levels of metals. Although there was considerable inter-station variability in levels of some metals (e.g. by more than an order of magnitude for arsenic), others varied within a relatively small range (e.g. copper). Samples and replicates from sites S5 and S6 show the local heterogeneity of the sediment metal concentrations too.

Aluminium concentrations ranged from 2850mg/kg to 33800mg/kg, indicating a wide range in sediment grain sizes across the survey sites. Aluminium is often used as a surrogate for grain size, with high concentrations indicating low grain sizes. Finer grained sediments have higher numbers of binding sites to which metal ions can attached, hence it is normal that finer grained sediments have higher concentrations of many metals than coarser sediments which have been exposed to the same metal inputs. Site S1, with an Al concentration of 33800mg/kg, also has highest concentrations of arsenic, iron, lithium, manganese, nickel and vanadium.

Sites S10 and S15, which had 3rd and 5th highest concentrations of aluminium respectively, between them had the highest concentrations of cadmium, chromium, copper, lead and zinc.

Conversely, highest concentrations of barium, mercury and selenium were recorded from site S5, from which the lowest concentration of aluminium was recorded. S5 also had the lowest level of organic carbon (0.6%), which also indicates that the number of potential binding sites for metals was low.

No highly elevated outliers, indicative of localised anthropogenic contamination, were recorded.

Comparison of the concentrations recorded against previous data from the outfall area, and international standards can be found in section 4.3.1.

Table 3.7: Sediment metals results

Station	Al	Ag	As	Ba	Cd	Cr	Cu	Fe	Hg	Li	Mn	Ni	Pb	Se	V	Zn
	mg/kg															
S1	33800	<10.0	17.1	12.7	0.058	8.69	2.91	9650	0.0032	7.95	354	6.96	12.4	<0.1	21.7	18.0
S2	8950	<10.0	1.76	16.6	0.061	4.82	1.96	3170	<0.001	4.57	158	2.21	3.47	<0.1	8.25	10.9
S4	14700	<10.0	3.50	8.6	0.031	6.02	1.88	3790	0.001	5.08	101	1.16	4.92	<0.1	7.44	11.2
S5	2850	<10.0	6.15	19.9	0.105	7.84	1.52	3340	0.0034	4.99	286	2.95	7.38	0.134	12.1	8.9
S5R	15900	<10.0	1.97	14.8	0.056	8.17	4.11	3260	0.0019	5.54	134	0.78	9.44	<0.1	7.78	16.8
S6	12400	<10.0	9.58	12.8	0.050	11.3	2.01	5550	0.0021	4.96	255	2.17	6.15	<0.1	16.5	10.7
S6R	14200	<10.0	0.43	15.7	0.045	3.84	2.61	3560	0.0018	4.02	128	0.93	6.65	0.115	7.77	11.6
S9	22400	<10.0	1.78	10.7	0.053	10.4	3.32	5090	0.0014	4.94	107	1.50	12.2	<0.1	9.06	16.2
S10	22700	<10.0	3.17	7.1	0.050	31.7	3.46	8270	0.0024	7.89	159	4.75	19.3	<0.1	13.7	19.0
S11	18000	<10.0	2.62	6.7	0.077	24.8	3.12	9470	0.0020	6.66	120	2.00	6.64	<0.1	14.7	14.3
S15	20700	<10.0	0.45	12.6	0.128	12.3	4.36	5960	<0.001	4.65	104	0.96	19.5	<0.1	10.5	18.1
S17	23600	<10.0	0.74	11.7	0.052	7.78	3.34	3830	0.0014	5.17	85	1.08	7.53	<0.1	7.37	17.9

Green: lowest result; Orange: highest result

3.4.2 Metals in sediment QA/QC

Table 3.8 presents the certified concentration data for the MESS-3 marine sediment CRM from the NRCC, together with the results of the analysis performed on the sample by the EA's National Laboratory Service.

The similarity between the certified and measured results shows confidence in the EA analysis of sediment samples at the Corrib alternative outfall sites. The sample analyses that do stand out, however, are the differences recorded for cadmium and vanadium.

The degree of error that is observed between the certified result and the EA laboratory result for cadmium is believed to be due to interference from tin oxide in the reference material. The EA has recently carried out an investigation into this issue and has determined that it appears to affect only the CRM, and can be overcome by analysing for the 114 isotope of cadmium only. Their investigations (using various spikes etc, also show that field samples tend to be unaffected by the tin oxide effects). Hence, it is not appropriate to use the CRM for quality checking the cadmium concentrations.

The degree of error observed in the results for vanadium are because the EA laboratory prepares its sediment samples for analysis using an aqua regia digestion, rather than a hydrofluoric acid digestion. Aqua regia is a significantly less vigorous digestion technique that achieves lower recoveries than hydrofluoric acid digestion, which is what the reference values for the CRM are based. The EA have stated that the reason they use aqua-regia is that it releases only the vanadium which is biologically available, rather than all of the metal in the sediment. Hence the results from the field samples reflect the biologically available vanadium.

Table 3.8: Analyses of marine sediment CRM

	Analysis of Marine Sediment CRM (MESS-3) (mg/kg)		
Determinand	**2008 EA results**	**NRCC Reference value**	**Difference (%)**
Ag	<10.0	0.18	N/A
Al	97,100	85,900	13.04%
As	22.1	21.2	4.25%
Cd	0.322	0.24	34.17%
Cr	98.3	105	-6.38%
Cu	37.5	33.9	10.62%
Fe	41,800	43,400	-3.69%
Hg	0.1004	0.091	10.29
Li	75.3	73.6	2.31%
Mn	325	324	0.31%
Ni	41.2	46.9	-12.15%
Pb	23.3	21.1	10.43%
Se	0.607	0.72	-15.69%
Vn	103	243	-57.61%
Zn	157	159	-1.26%

3.4.3 Hydrocarbons

3.4.3.1 Total organic extracts (TOE)/saturates

Results from analysis of TOE/saturates are presented in Table 3.9. They show that station S10 had a TOE concentration approximately three times greater than the next highest site. While the concentration at S10 is elevated above the other sites, it is generally within the background of concentrations recorded in and around the Corrib Field. Interestingly, S10 also had highest concentrations of TOE in the 2007 survey.

Ecomul, Ecosol and Esterkleen are components of drilling muds historically used in the Corrib field itself.

Table 3.9: Sediment TOE results

Station	TOE	Ecomul	Ecosol	Esterkleen
	µg/g; ppm			
S1	1.6	<0.1	<0.1	<0.01
S2	4.6	<0.1	<0.1	<0.01
S4	4.1	<0.1	<0.1	<0.01
S5	4.4	<0.1	<0.1	<0.01
S5R	1.3	<0.1	<0.1	<0.01
S6	1.4	<0.1	<0.1	<0.01
S6R	2.3	<0.1	<0.1	<0.01
S9	1.6	<0.1	<0.1	<0.01
S10	14	<0.1	<0.1	<0.01
S11	2.2	<0.1	<0.1	<0.01
S15	0.93	<0.1	<0.1	<0.01
S17	1.1	<0.1	<0.1	<0.01

Green: lowest result; Orange: highest result

3.4.3.2 Polycyclic aromatic hydrocarbons (PAHs)

Results are presented in Table 3.10. The majority of PAHs tested for were either not detected at all (i.e. dibenzothiophenes) or only detected at a few stations and in low concentrations. Naphthalenes were the only group that were detected at every station.

Table 3.10: PAHs in sediment results

Parameter	Station											
	S1	S2	S4	S5	S5R	S6	S6R	S9	S10	S11	S15	S17
	µg/kg (ppb); dry weight basis											
Naphthalene	0.12	0.11	0.08	0.17	0.34	0.19	0.31	0.29	0.27	0.22	0.12	0.49
C1-Naphthalenes	0.16	0.05	0.01	0.29	0.13	0.04	0.22	0.22	0.2	0.14	0.08	0.23
C2- Naphthalenes	0.22	0.21	0.28	0.24	0.06	0.25	0.51	0.19	2.7	0.23	0.12	0.24
C3- Naphthalenes	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C4- Naphthalenes	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total Naphthalenes	0.5	0.37	0.37	0.7	0.53	0.48	1.00	0.7	3.2	0.59	0.32	0.96
Phenanthrene	0.01	<0.01	0.02	0.04	<0.01	0.02	<0.01	<0.01	0.01	<0.01	0.02	<0.01
C1-Phenanthrenes	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C2- Phenanthrenes	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C3- Phenanthrenes	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total Phenanthrenes	0.01	<0.01	0.02	0.04	<0.01	0.02	<0.01	<0.01	0.01	<0.01	0.02	<0.01
Dibenzothiophene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C1-Dibenzothiophenes	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C2-Dibenzothiophenes	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Parameter	Station											
	S1	S2	S4	S5	S5R	S6	S6R	S9	S10	S11	S15	S17
C3-Dibenzothiophenes	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total DBT	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total NPD	0.51	0.37	0.39	0.74	0.53	0.5	1.00	0.7	3.3	0.59	0.34	0.96
Acenaphthylene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Acenaphthene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fluorene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Anthracene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fluoranthene	0.01	<0.01	<0.01	0.06	<0.01	<0.01	0.01	<0.01	0.05	<0.01	<0.01	<0.01
Pyrene	0.08	<0.01	0.02	0.06	<0.01	<0.01	0.01	<0.01	0.04	0.01	0.02	<0.01
C_1-Fluoranthenes/Pyrenes	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C_2-Fluoranthenes/Pyrenes	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C_3-Fluoranthenes/Pyrenes	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Benzo(a)anthracene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chrysene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C_1-Benanthracenes/Chrysenes	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C_2-Benanthracenes/Chrysenes	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Benzo(b)fluoranthene	0.02	<0.01	<0.01	0.1	<0.01	<0.01	<0.01	<0.01	0.18	<0.01	<0.01	<0.01
Benzo(k)fluoranthene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Benzo(a)pyrene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C_1-Benzofluoranthenes/Benzpyrenes	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C_2-Benzofluoranthenes/Benzpyrenes	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Indeno(1,2,3-cd)pyrene	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	<0.01	<0.01	0.13	<0.01	<0.01	<0.01
Dibenzo(a,h)anthracene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Benzo(ghi)perylene	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	0.13	<0.01	<0.01	<0.01
Total EPA 16	0.24	0.11	0.12	0.52	0.34	0.21	0.33	0.29	0.81	0.23	0.16	0.49

Orange=highest result

3.5 Sediment macrofauna

This section contains summary information on the analysis of benthic macrofauna samples. Full details are available in Appendix 2.

3.5.1 Diversity indices

Summary results for a range of univariate parameters, and percentage contribution of each phyla per station (replicates pooled), are presented in Table 3.11. Note that these data do not include encrusting species.

Table 3.11: Summary per-station sediment macrofauna results: univariate indices and taxonomic composition

Station	Species richness	Abundance	Evenness (Pielou's)	Diversity (Shannon-Wiener)	Dominance (Simpson's)	% abundance				
	S	N (m^{-2})	J'	H'	λ	Annelids	Crust.	Molluscs	Echino.	Other
S1	119	5,070	0.74	3.51	0.06	64.23	7.43	4.47	3.68	20.18
S2	104	10,540	0.58	2.70	0.14	89.06	3.86	3.07	0.92	3.10
S4	90	1,720	0.75	3.39	0.08	62.33	22.14	2.52	9.51	3.50
S5	135	11,590	0.59	2.88	0.14	51.38	3.62	7.02	7.16	30.81
S5R	83	9,580	0.55	2.42	0.18	73.84	2.50	3.44	2.16	18.05

Station	Species richness	Abundance	Evenness (Pielou's)	Diversity (Shannon-Wiener)	Dominance (Simpson's)	% abundance				
	S	N (m^{-2})	J'	H'	λ	Annelids	Crust.	Molluscs	Echino.	Other
S6	115	6,150	0.72	3.40	0.06	67.46	6.89	7.16	4.93	13.56
S6R	141	13,390	0.57	2.78	0.16	52.69	4.68	5.38	1.87	35.38
S9	74	1,460	0.83	3.55	0.04	28.47	28.47	26.42	11.85	4.78
S10	120	6,760	0.71	3.38	0.09	63.53	7.34	14.93	3.84	10.35
S11	79	1,170	0.83	3.64	0.04	54.42	16.24	11.68	12.54	5.13
S15	60	3,510	0.61	2.50	0.18	48.62	4.75	5.70	2.66	38.27
S17	59	1,050	0.87	3.55	0.03	39.05	33.33	10.16	16.19	1.27

Green: lowest result; Orange: highest result. Crust=crustaceans; echino=echinoderms
S: Species richness; **N**: abundance; J': evenness; H': Diversity

Species richness (S) was high for all sites, ranging from 59 species (station S17) to 141 per station (S6R).

Total abundance (N) was moderate throughout the dataset, but over 10,000 individuals per m^2 were found at S2, S5 and S6R.

Diversity (H') was high throughout the sampling area, ranging from 2.42 (S5R) to 3.64 (S11). Stations that had relatively lower diversity were generally those with a comparatively low evenness (J') and slightly higher dominance (λ) score, indicating a few dominant species present in the community. For example, S5R, where diversity was 2.42 and the lowest evenness of 0.55 was observed, the polychaete *Spio filicornis* numerically dominated the community.

3.5.2 *Taxonomic composition*

Throughout the sampling area, communities were found to be typical of subtidal sands, ranging from species characteristic of stable, fine sand to those species found in more exposed coarse sand with gravel.

At a broad taxonomic level, annelid polychaetes were the most dominant phyla at all sites with the maximum abundance recorded at S2 (89%). Crustaceans, molluscs and echinoderms made up small proportions of the fauna observed at most sites, on average comprising less than 25% of the community. However, at S4, S9 and S17 crustaceans made up more than 20% of the community. Additionally, molluscs were found to be abundant at S9 where they also made up more than 20% of the community. Tellinid bivalves such as *Moerella pygmaea* and *Abra pristmatica* were common throughout the sampling sites. Nematode worms were important at S5, S6R and S15 where they represented 30% or more of the community found there.

3.5.3 *Community clustering*

3.5.3.1 *Within stations*

Variability was low within stations, with a similarity of around 45% or more, indicating that each replicate at a station sampled a relatively similar community. Further details of this are presented in Appendix 3.

3.5.3.2 *Between stations*

Results of the group-average clustering analysis using Bray Curtis similarity (per station) are presented in Figure 3.3.

The fauna was dominated by two main communities, which were themselves split into two sub-groups. The first main group (clusters 1 and 2) was characterised by species typical of coarser sand and gravelly sediments. The second main group (clusters 3 and 4) was more typical of sandy sediments.

- **Cluster 1**: (S15): species typical of communities in a medium to coarse sand and gravelly sand. Nematode worms dominated, with contributions from syllid polychaetes such as *Streptosyllis bidentata* and *Opistodonta pterochaeta*.
- **Cluster 2:** (S1, S2, S5, S5R, S6 and S6R) a similar community composition to cluster 1; nematodes and the polychaetes *Pisione remota, Polygordius*, *Hesionura elongata* and *Glycera lapidum* were found to contribute highly to the similarity between these stations.
- **Cluster 3**: (S10) dominated by the spionid polychaetes *Spiophanes bombyx* and *Spio decorata*, and tellinid bivalves.
- **Cluster 4**: (S4, S9, S11 and S17) characterised by lower faunal abundance but higher diversity. Species that significantly contributed to community similarity were those associated with medium to fine sand sediments such as the amphipod *Bathyporeia elegans*, echinoids and spionid polychaetes such as *Nonides pauchibranchiata* and *Spiophanes bombyx.*

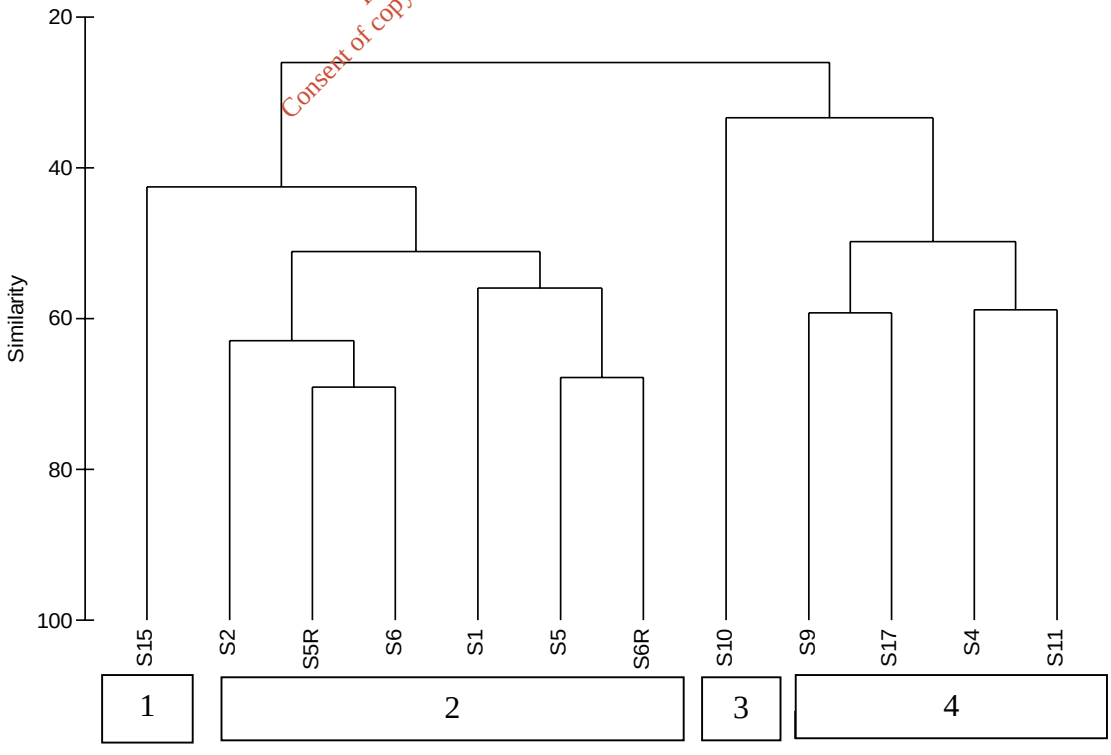

Figure 3.3: Dendrogram representation of clustering of benthic macrofauna communities (per station, replicates pooled)

Clusters were separated very discretely, with, for example, a similarity of less than 30% between clusters 2 and 3. Characterising species for each cluster were rare or absent in other clusters.

3.5.4 Environmental factors

Details of BIO-ENV analysis are presented in Appendix 3. In summary, BIO-ENV analysis showed that:

- No particular measured environmental variable was responsible for the observed variation between sites, although some strong correlations were found.
- Sediment grain size was found to be an important environmental variable for all the observed communities.
- Water depth was also important in explaining community variability. However, this relationship was not clearly defined.

Bubble plots showing the levels or concentrations of various environmental variables at each site, overlaying the MDS plots, are also included in Appendix 3.

4 Discussion

4.1 Water quality

4.1.1 CTD profiles

4.1.1.1 Salinity

The small level of variation in recorded salinity, and the minor increase in salinity with depth in the water column, is consistent with a fully marine environment, with little freshwater influence. Slightly reduced salinity levels at the surface are likely to be due to the natural buoyancy of freshwater, such as that from the small input of local rivers (e.g. the Sruwaddacon) or recent rain.

4.1.1.2 Temperature

Minor variation in temperature profiles across the survey area is likely to be due to the presence of different water masses moving through the area, and the influence of different tidal currents and water depths. Temperature differences may have also been influenced by sampling at different times of the day, and in different weather and tidal conditions.

Temperature profiles were sampled over similar dates (late July/early August) in 2007 and 2008 data, allowing comparison. In 2007, the highest temperature recorded (15.82°C at W1 surface) was around 1.5°C greater than the highest value recorded in 2008 (14.23°C, W9, surface), although such variations are to be expected as a result of diurnal temperature fluctuations (i.e. time of day of sampling) and the effect of other factors such as wind, tidal state and rainfall. Data for both 2007 and 2008 show stratification at around 50m water depth, most notably at station W1 (the deepest station), and both are typical for summer in temperate waters. The lowest temperature recorded in 2008 (11.34°C) was around 0.7°C lower than the lowest recorded in 2007 (12.13°C), both of which were near the seabed in around 90m at W1. This natural variation is likely to be a result of the movement of water masses and/or tidal streams.

4.1.2 Water samples

4.1.2.1 Suspended particulate matter

The non-detectable and low levels of SPM at all stations are indicative of the high clarity of the relatively deep coastal Atlantic waters sampled, with little local freshwater (and/or fine sediment) input.

4.1.2.2 Ammoniacal nitrogen

This parameter was non-detectable (i.e. <0.01mg/l) at all but one of the sampling points. The single detectable value from near-bottom water at station W2 (0.022mg/l) marginally exceeds the environmental quality standard (0.021mg/l); given the non-detectable levels throughout the survey area (indicating no anthropogenic influence, from, for example, fertiliser run-off), this is somewhat anomalous, and not a cause for concern.

4.1.2.3 *Metals*

Results from the 2007 and 2008 surveys were similar with no major discrepancies for any of the metals observed. A comparison of the results shows that the maximum levels recorded were lower in 2008 for arsenic, copper and nickel, while there were increases in the maxima for mercury, lead and zinc

Although the reported values are above the very low levels reported for oceanic waters by a number of academic and governmental organisations, in no instance were any concentrations observed that would give rise to concern, all being significantly less than the respective EQSs (with the exception of lead – discussed below). At many sites, however, the results for copper, and to a lesser extent for zinc, and lead exceed the provisional OSPAR Ecotoxicological Assessment Criteria. Assessments made using current EACs, however, should be treated with extreme caution (UKNMMP, 2004). (It should be noted that OSPAR is reviewing these guidelines, which have been renamed 'environmental assessment criteria'.)

Lead exceeded it's EQS at a single station. With measurement at such low detection limits, and even with stringent precautions, inadvertent contamination of samples may have occurred. This is the most likely explanation of anomalous results, such as that for lead from W12 (bottom), i.e. 40.8µg/l.

Table 4.1: 2008 Comparison of observed metals in water data with international standards

Metal	Outfall station ranges	EQS	BRC	EAC
	µg/l			
As	<1.00–1.45	25	No data	1–10
Cd	<0.0400	2.5	0.004–0.025	0.01–0.10
Cr	<0.500	15	0.09–0.12	1.0–10
Cu	<0.200–1.21	5	0.05–0.36	0.005–0.05
Hg	<0.010–0.019	0.3	0.0001–0.0005	0.005–0.05
Ni	<0.30–0.35	30	0.16–0.26	0.1–1.0
Pb	0.056–40.8	25	0.005–0.02	0.5–5.0
Zn	1.39–29.5	40	0.03–0.45	0.5–5.0

(EQS: EU Environmental Quality Standard for Dangerous Substances; BRC: OSPAR Background Reference Concentrations; EAC: OSPAR Ecotoxicological Assessment Criteria)

4.1.2.4 *Organics*

Whilst some persistent organic compounds were detected, these give no cause for concern at such low concentrations.

4.2 Sediment physico-chemistry

Comparison of results from 2008 with 2007 data shows that several stations retained the same classification (S2, S4, S5, S5R, S17), while others became slightly finer (S1: very coarse to coarse sand; S10: medium to fine sand; S11: coarse to medium sand) or slightly more coarse (S6: medium to coarse sand; S9: fine to medium sand; S15: medium to coarse sand). One station, S6R, increased from medium to very coarse sand. As no construction activities had taken place between the 2007 and 2008 surveys, these slight variations reflect

natural variability over time, patchiness of sediment and slight differences in the area sampled by the grab.

4.3 Sediment chemistry

4.3.1 Metals

Metals in sediment results for both 2007 and 2008 were very similar and low, as would be expected in an area with minimal anthropogenic activity.

To determine the degree of any anthropogenic contamination in marine sediments, it is useful to compare observed metal concentrations in sediment with the following values:

- OSPAR (Northeast Atlantic)
    - Background Reference (**BC**)
    - Ecotoxicological Assessment Criteria (**EAC**), with lower and upper limits.
- Environment Canada
    - Threshold effects level (**TEL**): the concentration above which metals may start to be harmful to organisms; and
    - Predicted effects level (**PEL**): the concentration above which metals are likely to become harmful to organisms.

Metal concentrations from the 2008 survey in comparison to these values are presented in Table 4.2.

Table 4.2: Comparison of observed sediment metals data to international standards

Metal	2008 Outfall station range	OSPAR			Upper limit exceeded?	Environment Canada		PEL exceeded?
		BC	EAC limits			TEL	PEL	
			Lower	Upper				
	mg/kg dry weight							
As	0.43–17.1	15	1	10	Yes	7.24	41.6	No
Cd	0.031–0.128	0.2	0.1	1	No	0.676	4.21	No
Cr	3.84–31.7	60	5	50	No	52.3	160	No
Cu	1.52–4.36	20	5	50	No	18.7	108	No
Hg	<0.001–0.0034	0.05	0.05	0.5	No	0.13	0.7	No
Ni	0.78–6.96	30	5	50	No	15.9	42.8	No
Pb	3.47–19.5	25	5	50	No	30.3	112	No
Zn	8.9–19	90	10	100	No	124	271	No

It is also informative to compare observed values with reference data available from the UK. These data are presented in Table 4.3.

Table 4.3 Comparison of observed sediment metals data to UK data

Metal	Outfall station range	Liverpool Bay[1]	Cumbrian coast[2]	Scottish Minches[3]	North Sea[4]
	mg/kg dry weight				
As	0.43–17.1	No data	No data	4.3	1.2–33 (mean 11)
Cd	0.031–0.128	0.3–2.1	0.007–0.46	0.018	0.01–0.38–(mean 0.05)
Cr	3.84–31.7	0.5–35.9	10.7–85.8	57	No data
Cu	1.52–4.36	1.8–33.7	1.8–49.4	7.3	0.1–87 (mean 14)
Hg	<0.001–0.0034	0.01–1.44	0.005–0.17	0.05	75% <0.025
Ni	0.78–6.96	1.2–16.5	No data	6.4	1.5–113 (mean 23)
Pb	3.47–19.5	6.9–101	10.3–69.7	24	1.7–288 (mean 21)
Zn	8.9–19	9.4–327	22.4–129.4	45	3–510 (mean 39)

Sources: [1] Taylor, 1986; [2] Nixon, 1985; [3] FRS/SEPA, 1998; [4] NSTF, 1993

Sediment metal results from the survey can be summarised as follows:

- Results reflect what would be expected for an area with both little or no anthropogenic impact and low levels of fine material (with which many metals are generally associated);
- Results are generally well below concentrations that could potentially give rise to any biological effects, and hence give no cause for concern.
- Arsenic levels at a single station (S1) exceed the OSPAR EAC upper limit, although this does not exceed the PEL. This result is not unexpected and is likely to reflect naturally elevated levels of this element present in Donegal Bay. Elevated levels of arsenic have also been found in intertidal sediment in Sruwaddacon Bay. As such, these data are not cause for concern;
- In general, results were either at the lower end of, or similar to, the ranges encountered around the UK coast;
- The results reflect a pristine environment with little evidence for departures from typical background levels.

4.3.2 Hydrocarbons

4.3.2.1 TOE/saturates

In general, the observed concentrations were consistent with the previous year's results, if anything, perhaps slightly lower. The concentration at station S10 (14.0µg/kg) was somewhat higher than nearby locations, a pattern that was also seen in 2007. There was no evidence of anthropogenically derived hydrocarbons.

4.3.2.2 *Polycyclic aromatic hydrocarbons (PAHs)*

Results from the present study are compared against reference criteria in Table 4.4. In most cases, PAH concentrations were below detection limits; where positive results were recorded, these were well below any levels of potential concern. Together these data indicate a pristine environment with little or no anthropogenic influence.

Table 4.4: Comparison of observed sediment PAH data to international standards

PAH	Environment Canada		OSPAR*		Outfall station max.
	TEL	PEL	*BC*	*BAC*	
	µg/kg				
Acenaphthene	6.7	88.9	-	-	-
Acenaphthylene	5.9	128	-	-	-
Anthracene	46.9	245	3	5	-
Benz(a)anthracene	74.8	693	9	16	-
Benzo(a)pyrene	88.8	763	15	30	-
Benzo(b)fluoranthene	No data	No data	-	-	0.22
Benzo(g,h,i)perylene	No data	No data	45	80	0.13
Benzo(k)fluoranthene	No data	No data	-	-	-
Chrysene	108	846	11	20	-
Dibenz(a,h)anthracene	6.2	135	-	-	-
Fluoranthene	113	1,494	20	39	0.05
Fluorene	21.2	144	-	-	-
Indeno(1,2,3,cd)pyrene	No data	No data	50	103	0.13
Naphthalene	34.6	391	5	8	0.49
Phenanthrene	86.7	544	17	32	0.04
Pyrene	153	1,398	13	24	0.08

***Note the BC and BAC sediment figures are listed as a dry weight normalised to 2.5% organic carbon, whereas the Corrib outfall samples were not normalised, however the majority of the data have organic carbons of <1%

(**TEL** = threshold effects level, **PEL** = probable effects level, **BC** = background concentration, **BAC** = background assessment concentration)

4.4 Sediment macrofauna

While there were differences in the community composition at stations throughout the sampling area, a degree of homogeneity was observed as sites did not initially separate below a similarity level of 25% (Figure 3.3). The species found were typical of a subtidal sandy habitats, ranging from those found in coarse sand and gravel to those preferring more stable fine sand.

4.4.1 Comparison between 2007 and 2008

The comparison between data from 2007 and 2008 can be summarised as follows:

- For all but one of the stations (S11), there was no notable difference in community composition between 2007 and 2008, with some sites demonstrating a very high degree of similarity (Figure 4.1).

- Between the two years, stations clustered in a similar pattern.
- Station S11 was unusual in that it shifted from a community of species typical of coarse sand/gravel (*Polygordius* and *Pisione remota*) to one more typical of finer sand (spionid polychaetes and echinoids); sediment composition had changed at this station.

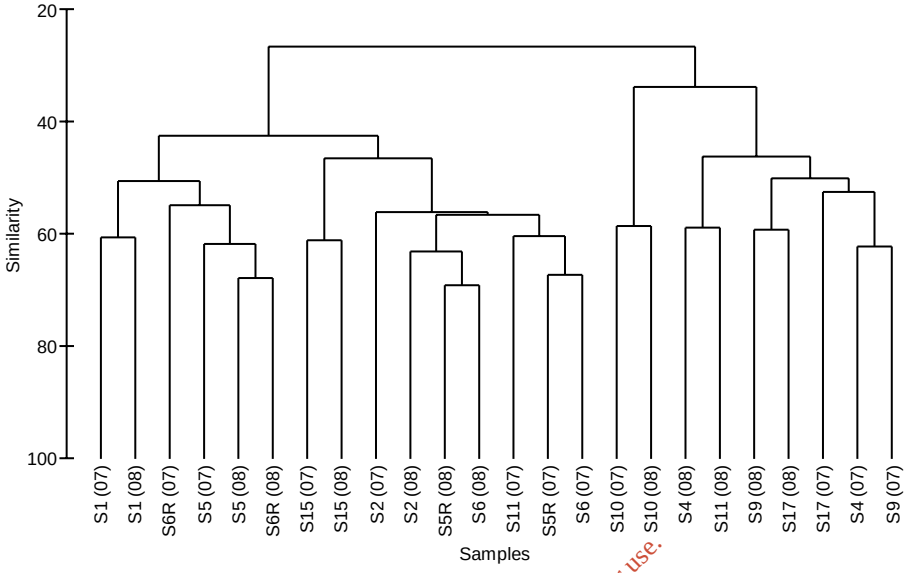

Figure 4.1: Dendrogram showing clustering of communities using pooled replicate (per site) data taken from sites around the proposed outfall in 2007 and 2008.

5 Summary

The summer 2008 outfall area survey was completed successfully, with data collected for water and sediment quality and macrofaunal diversity and abundance. The methods were the same as those used previously, and therefore the data are comparable with those collected in 2007.

5.1 Physico-chemical

5.1.1 Sediments

Typically, the sediments collected in the area around the outfall consist of varying grades of sand, with four sites being medium sand, and the others being coarse or very coarse, with the exception of one site that had fine sand. Whilst overall these results are almost identical to those from 2007, several individual results have changed.

Total organic carbon concentrations were generally low, and this is related to the coarse nature of the sediments.

Trace metal and organic chemical concentrations are generally low, and similar to those from 2007, reflecting the coarse nature of the sediments in the area, and the lack of anthropogenic influences. Arsenic was present at one site at a concentration above the EAC, however, this metal is known to be present at naturally relatively high levels throughout Donegal Bay.

5.1.2 Water

Profiles of salinity and temperature were taken at five water sampling stations and reveal a relatively well-mixed water body in the area. Evidence from these sites showed that a weak thermocline existed; with water temperature at the surface of around 14^{o}C, falling to less than 12^{o}C at the deepest site (W1), and to 13^{o}C at the other, shallower, sites.

Salinity levels increased very slightly with depth; the highest salinities being recorded at around 80m depth at site W1.

Water temperatures and salinities recorded were generally in line with expectations for the area and the time of year.

Trace metal, organics and nutrient concentrations were generally relatively low, however, the sample from close to the seabed at site W1 did contain a high concentration of lead. This appears to be a single anomalous result, and may have been the result of sample contamination.

5.2 Macrofauna

The benthic macrofaunal communities present at the sites sampled had moderate to high diversity, generally with moderate abundance and a high degree of evenness, with low dominance by single species, indicating a stable seabed ecosystem. No species of particular conservation value were recorded.

6 References

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Taylor, D. (1986). Changes in the distribution patterns of trace metals in sediments of the Mersey Estuary in the last decade. *Science of the Total Environment.* **49**, 257–295.

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Appendix 1: Raw sediment particle-size data

Aperture (mm)	8.000	4.000	2.000	1.000	0.710	0.500	0.355	0.250	0.180	0.125	0.090	0.063	0.044	0.032	0.022	0.016	0.011	0.008	0.006	0.004	0.002	0.001	<0.001
Grade	>8000	fine gravel	v fine gravel	v coarse sand	coarse sand		medium sand		fine sand		v. fine sand	med & coarse silt				clay & fine silt							
Station	**8.000**	**4.000**	**2.000**	**1.000**	**0.710**	**0.500**	**0.355**	**0.250**	**0.180**	**0.125**	**0.090**	**0.063**	**0.044**	**0.032**	**0.022**	**0.016**	**0.011**	**0.008**	**0.006**	**0.004**	**0.002**	**0.001**	**<0.001**
S1	4.89	4.52	5.64	31.46	23.93	16.94	7.37	2.75	1.35	0.91	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S2	0.00	0.25	6.24	47.99	26.15	13.17	2.96	0.13	0.67	1.24	0.64	0.05	0.00	0.08	0.18	0.17	0.06	0.00	0.00	0.00	0.00	0.00	0.00
S4	0.00	0.14	2.21	3.54	6.63	13.52	21.46	25.56	18.17	8.27	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S5	0.25	4.24	28.56	32.30	18.64	10.07	2.74	0.46	0.59	0.84	0.47	0.21	0.15	0.16	0.17	0.12	0.04	0.00	0.00	0.00	0.00	0.00	0.00
S5R	0.00	0.26	2.09	24.84	25.04	25.05	15.92	6.16	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S6	0.00	0.01	0.88	6.52	16.78	27.39	27.12	16.53	4.53	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S6R	0.55	4.96	17.74	38.34	23.01	11.42	2.42	0.15	0.45	0.72	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S9	0.00	0.00	0.00	0.00	4.49	18.06	29.32	28.88	15.06	4.12	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S10	0.00	0.00	0.00	0.00	0.00	0.13	4.44	20.05	32.75	29.48	8.92	0.64	0.00	0.20	1.16	0.91	0.38	0.21	0.29	0.30	0.14	0.00	0.00
S11	0.00	0.04	0.62	1.53	4.71	14.03	25.78	29.83	17.91	5.48	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S15	0.00	0.14	0.17	2.95	14.79	28.69	30.06	18.36	4.71	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S17	0.00	0.00	0.27	0.19	4.76	16.75	28.73	29.75	15.70	3.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 2: Raw benthic invertebrate data

MCS Code			S1-a	S1-b	S1-c	S2-a	S2-b	S2-c	S4-a	S4-b	S4-c	S5-a	S5-b	S5-c	S5R-a	S5R-b	S5R-c	S6-a	S6-b	S6-c	S6R-a	S6R-b	S6R-c	S9-a	S9-b	S9-c	S10-a	S10-b	S10-c	S11-a	S11-b	S11-c	S15-a	S15-b	S15-c	S17-a	S17-b	S17-c
	Porifera																																					
C0001	Porifera																						P															
	Cnidaria																																					
D0240	*Leuckartiara octona*																				P				P													
D0277	*Podocoryne carnea*													P																								
D0343	*Phialella quadrata*																										P											
D0618	*Virgularia mirabilis*	juvs																								2												
D0632	*Cerianthus lloydii*																						1	1			1		1		1							
D0662	Actiniaria																																					
D0759	Edwardsiidae	juvs			2											1		2	1	1				2		3	37	34	37	1	1				1		1	
D0776	Scleractinia	indet											P																									
	Platyhelminthes																																					
F0002	*Turbellaria*						1		1						1				1						1	1	1	1	2									
	Nemertea																																					
G0001	Nemertea		4	1	9	18	17	21			3	7	1	3	4	5	2	5	6			1	6		2	2	17	11	9	3	4		2		3			
G0034	*Tubulanus polymorphus*		5		4	4	4	6	2	4	2				4	5	3	2	4	8	1	2			2	1	4	5	3	3	1					1		1
G0039	*Cerebratulus*					1								1	1																							1
	Nematoda																																					
HD001	Nematoda		42	115	119	924	844	632			2	355	237	463	255	118	120	106	103	5	535	421	453	2		2						1	2	388	7			
	Chaetognatha																																					
L0001	Chaetognatha																																					
	Sipuncula																																					
N0001	Sipuncula	juvs	1		1	1						1																										
N0028	*Thysanocardia procera*																																					
N0034	*Phascolion strombus*			1		1														1																		
N0047	*Aspidosiphon muelleri*																	1			1																	
	Annelida																																					
P0015	*Pisione remota*		21	45	42	177	146	122	1		1	45	70	68	73	72	58	52	27	52	173	93	55							1			4	4	4			
P0017	Aphroditidae	juvs																																				
P0025	Polynoidae	juvs/scale-less	2	16	21	6	8	5			4	71	18	51	3	3	2	9	8	3	53	113	95			2	4	1							1			
P0052	*Harmothoe ?antilopes*																											1									
-	*Malmgreniella arenicolae*							1			1		1							1	1			1	1			1								1		
P0062	*Malmgreniella glabra*																	1																			1	
P0065	*Harmothoe impar*			2	2						1		1															3	3								
P0066	*Malmgreniella ?ljungmani*																									1											
P0094	*Pholoe inornata (sensu petersen)*					1						1																									
P0105	*Sigalion squamosus*							1																													
P0109	*Sthenelais limicola*									1						1								1	4	2		1	1	2					1		1	2
P0118	*Eteone longa*	agg																												1								
P0122	*Hesionura elongata*		7	18	22	102	47	57	10	2	2	6	28	2	19	22	28	19	45	43	24	25	15							5	2	3	7	36	16	1	6	
P0124	*Hypereteone foliosa*																															1						
P0130	*Mystides caeca*					19	3	5				1	1								1	2																
P0139	*Anaitides*	juvs/damaged																3											2		1				1			
P0142	*Anaitides lineata*		1	1	1		1	1	1				1		4	1		3		3				1	1		2			1	1	1			1	1	3	
P0144	*Anaitides maculata*					1	1	2							1		1									3										1		
P0146	*Anaitides rosea*							1			1													2			10	5	4									
P0150	*Eulalia*		1		1																																	

MCS Code			S1-a	S1-b	S1-c	S2-a	S2-b	S2-c	S4-a	S4-b	S4-c	S5-a	S5-b	S5-c	S5R-a	S5R-b	S5R-c	S6-a	S6-b	S6-c	S6R-a	S6R-b	S6R-c	S9-a	S9-b	S9-c	S10-a	S10-b	S10-c	S11-a	S11-b	S11-c	S15-a	S15-b	S15-c	S17-a	S17-b	S17-c
P0155	*Eulalia mustela*		4	13	20	4	3	2				4	4	7	1	4	2	5	3	6	19	11	17															
P0156	*Eulalia ornata*	small							1	2																												
P0163	*Eumida*	juvs				3	3	5			1			1	1	2	1	1					1				3	2	1						1			
P0164	*Eumida bahusiensis*																											2									
P0167	*Eumida sanguinea*			1							1	1	2									1															
P0195	*Lacydonia miranda*											3	3	6							2	3															
P0255	*Glycera*	juvs	8				5					10					3		5	5	17		17												10		
P0256	*Glycera alba*																										2		1			1					
P0257	*Glycera celtica*				1																																
P0260	*Glycera lapidum*		3	26	25	18	11	23				34	56	51	11	10	10	23	29	15	87	63	24					1				1			3	2	
P0262	*Glycera oxycephala*		14	1	1	17	20	10	3		2	5	8	3	6	6	8	6	7	3	6	3	47	1	2	1				4	4	2	12	7	3	1	5	1
P0265	*Glycera tridactyla*										1																										
P0266	Goniadidae	juvs																																			
P0268	*Glycinde nordmanni*		1							1					2	4	1			2							1				1						
P0271	*Goniada maculata*																										1	1	1								
P0275	*Goniadella bobretzkii*		4	7	14	3	12	6				6	7	8	10	8	7	10	8	14	10	9	12														
P0282	*Ephesiella peripatus*											9	3	5																							
P0288	*Sphaerodoropsis minuta*							2					2					1																			
P0291	*Sphaerodorum gracilis*																						1														
P0305	*Psamathe fusca*		1	4	9	3	4	4				10	4	4				1		2	5	7	4														
P0319	*Podarkeopsis capensis*													3						1		1	1				3	1				1					
P0340	*Glyphohesione klatti*																																				
P0349	*Syllis cornuta*			1																																	
P0362	*Trypanosyllis coeliaca*			1	3	1	2					7	1	5						1	1	10	11														
P0365	*Syllis armillaris*																																				
-	*Syllis* "species E"				1	1															1		3														
-	*Syllis* "species D"			1	2	14	2	2					2	5				1		3		5	6														
-	*Syllis* "species H"		4	9	4	18	16	8				4	19	27	4	7	4	4	1	6	30	31	38											1			
P0377	*Dioplosyllis cirrosa*																			1	1	1															
P0380	*Eusyllis blomstrandi*																						3				1		1								
P0388	*Odontosyllis gibba*				1							9		6									4														
P0390	*Opisthodonta*				2		3																														
P0391	*Opisthodonta pterochaeta*		12	12	10	28	27	24				1	1	2	11	17	18	16	11	22	1		2	1	2					2			26	8	14	1		
P0394	*Palposyllis prosostoma*		2	1				1							1	2																					
P0400	*Pionosyllis pulligera*				5																																
P0403	*Streptosyllis bidentata*					3	8	3							11	23	18	17	32	30	1	5								1	2	3	36	49	50			
P0405	*Streptosyllis websteri*		3	5	1					1																										1	1	
P0421	*Exogone hebes*								1	3					1				4	1					1					2			2		4		1	
P0422	*Exogone naidina*						1	5				3	3	1						1		15	6				1											
P0423	*Exogone verugera*								1																													
P0425	*Sphaerosyllis bulbosa*		9	4	15	11	5					28	60	40		2	2			1	41	27	12														
P0430	*Sphaerosyllis taylori*		1	5	4	1	1		1		1	7		10	2	1	1	7	14	8	6	3	3							1							
P0458	*Nereididae*	juvs																																			
P0475	*Nereis longissima*		1	1	2		1							1							1	1															
P0493	*Aglaophamus rubella*		1		1																																
P0494	*Nephtys*	juvs							4	6	10				4		2		1			1		1		3	2			2	1	1	5	6	8	9	8	
P0495	*Nephtys assimilis*																										1	1									
P0498	*Nephtys cirrosa*								3	2	1				2			1	1					2	2	1	2			1	3	2	1	3	2	2	2	4

MCS Code			S1-a	S1-b	S1-c	S2-a	S2-b	S2-c	S4-a	S4-b	S4-c	S5-a	S5-b	S5-c	S5R-a	S5R-b	S5R-c	S6-a	S6-b	S6-c	S6R-a	S6R-b	S6R-c	S9-a	S9-b	S9-c	S10-a	S10-b	S10-c	S11-a	S11-b	S11-c	S15-a	S15-b	S15-c	S17-a	S17-b	S17-c
S0528	*Euphrosine foliosa*											3	1	5								1																
P0539	*Aponuphis bilineata*		3	3	8	1			1		1	2	2	3		1			1	1	2		5	1						1								
P0545	*Nothria conchylega*																												1								
P0554	*Eunice*	juvs											1	2																							
P0563	*Marphysa*	juvs																					1														
P0564	*Marphysa bellii*																																				
P0573	*Lumbrineris agastos*				1	1						1	3		1	2	1		2	4			1										2					
P0577	*Scoletoma fragilis*											6	1																								
P0579	*Lumbrineris gracilis*				1															1						6	1	5									
P0633	*Parougia caeca*												1																								
P0638	*Protodorvillea kefersteini*		7	2	17	91	32	31				20	12	12	13	4	3	6	4	12	55	38	24														
P0661	*Orbinia*	juvs																							1	1											2
P0665	*Orbinia sertulata*																														1				2		
P0672	*Scoloplos armiger*								2	1	4													2	1		9	13	16								
P0678	*Aricidea wassi*																										3	3	2								
P0684	*Aricidea catherinae*																																				
P0685	*Aricidea cerrutii*		1					1	3						1	3	2	3		4		1			1	2	2	1		6	7	3	6	8	9			
P0688	*Aricidea simonae*																																				
P0699	*Paradoneis lyra*			1																1				1					1								
P0711	*Apistobranchus tenuis*																																				
P0718	*Poecilochaetus serpens*		2	2	2	2		2	1		2					2	1		1	1	1				1		5	9	16				1				
P0721	*Aonides*	juvs							1																												
P0722	*Aonides oxycephala*												1																								
P0723	*Aonides paucibranchiata*		12	11	35	16	10	6	17	16	15	11	15	11	6	35	11	16	12	14	12	24	27	18	13	8	29	24	27	15	27	7	2	5	2	4	5	10
P0732	*Laonice*	juvs																					1														
P0733	*Laonice bahusiensis*			1	3									4							2	2															
P0747	*Minuspio cirrifera*			2	5	3	1			4	3	3	6	2								5	15	2	1		15	11	8	1	1				1		
P0751	*Polydora caulleryi*			2																																	
P0763	*Prionospio*		2			6	1	6	5						5			4	2		4		10					3	3								
P0765	*Prionospio fallax*																										19	13	15								
P0773	*Pseudopolydora paucibranchiata*																											1									
P0779	*Scolelepis bonnieri*									1	1													1			1			2						1	
-	*Scolelepis gilchristi*		1		1									1									1		1					1							
P0787	*Spio*	damaged										1																									
P0789	*Spio decorata*				1				46	14	67				6	9	3	3	3	7				4	2	6	25	58	78	11	4	8		1			
P0790	*Spio filicornis*		28	8	1	266	277	337				8	8		387	386	238	58	67	34	8	3	3					4			5			3	1		
P0794	*Spiophanes bombyx*								3	3	9			1					1					2	2		172	151	196	5	3	4	1			5	2	1
P0796	*Spiophanes kroyeri*																	1									7	13	33								
P0804	*Magelona alleni*																										1	3									
P0805	*Magelona filiformis*									2																	42	38	65					2		1	1	
P0807	*Magelona mirabilis*								1	2																											
-	*Magelona johnstoni*																															1					
P0810	Chaetopteridae	juvs					1	1													3	10	2														
P0824	*Aphelochaeta* "species A"				1					1																1					1	1					
-	*Chaetozone christiei*								1																		2	1		1							
P0829	*Caulleriella alata*												1							1			1														
P0828	*Caulleriella*	sp. indet.																														1					
-	*Caulleriella viridis*																																				

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P0831	*Chaetozone zetlandica*				2						1																			1								
P0833	*Chaetozone gibber*																											1										
P0840	*Dodecaceria*																										2		1									
P0844	*Monticellina dorsobranchialis*																																					
P0846	*Tharyx killariensis*																																					
P0878	*Diplocirrus glaucus*			2																								2	2								
P0881	*Flabelligera affinis*											1															1										
P0889	*Macrochaeta helgolandica*											1	2									1															
P0907	*Capitella*	spp complex					1			1	6																1	3									
P0919	*Mediomastus fragilis*			1	6			1												1		9	19								1						
P0921	*Notomastus*		2	14	10	2	6	1		1		1		2	1	1	1	1	1	3	6	2	5	1	1	1				1							
P0925	*Peresiella clymenoides*																										8	5	12								
P0938	Maldanidae	no tail																																			
P0955	*Clymenura*	no tail											2																								
P0958	*Clymenura johnstoni*											3	5	2																							
P0973	*Praxillella praetermissa*																																					
-	*Isocirrus planiceps*																											1	1									
P0993	Opheliidae	juvs			2																								1								1
P1007	*Travisia forbesii*									1																			1		1	2					
P1011	*Armandia polyophthalma*														1																		1				
P1014	*Ophelina acuminata*																											1									
P1027	*Scalibregma inflatum*				1																																
P1062	*Polygordius*		54	55	86	106	251	219	3			90	534	78	120	164	94	89	83	119	242	259	216									1	20	32	46			
P1063	*Polygordius appendiculatus*		46			68					1												14							1								
P1093	*Galathowenia oculata*																												1								
P1095	*Myriochele danielsseni*																										4	2	4								
P1098	*Owenia fusiformis*										1	1	1	1	3		1			1	1			1		1					4		1		1	2		
P1100	Pectinariidae	juvs																																			
P1102	*Amphictene auricoma*																										6	4	4								
P1106	*Lagis koreni*																					1					1	3	6								
P1118	*Ampharetidae*	juvs/damaged																			2																
P1139	*Ampharete lindstroemi*												2														1	4	7								
P1142	*Amphicteis gunneri*																																				
P1160	*Sabellides octocirrata*			2																	2	1	1														
P1167	*Sosane sulcata*																																				
P1175	*Terebellides stroemi*																																				
P1179	Terebellidae	juvs																																			
P1185	*Amphitritides gracilis*			1																	1																
P1190	*Eupolymnia nesidensis*			2								2								1																	
P1195	*Lanice conchilega*																	1	1																		
P1213	*Paramphitrite tetrabranchia*										1																										
P1216	*Pista*	juvs									3									2							1				1						
P1217	*Pista cristata*																																				
P1218	*Pistella lornensis*			1																																	
P1233	*Lysilla loveni*																																				
P1235	*Polycirrus*	juvs																		3										2			2				14
P1242	*Polycirrus medusa*		3	8	2	17	6	4			1	13	12	8	3	3	3	13	12	10	5	17	15	3	5	3	1			2	1			4	8	8	
P1249	*Parathelepus collaris*		8	7	6																1	1	1														

MCS Code			S1-a	S1-b	S1-c	S2-a	S2-b	S2-c	S4-a	S4-b	S4-c	S5-a	S5-b	S5-c	S5R-a	S5R-b	S5R-c	S6-a	S6-b	S6-c	S6R-a	S6R-b	S6R-c	S9-a	S9-b	S9-c	S10-a	S10-b	S10-c	S11-a	S11-b	S11-c	S15-a	S15-b	S15-c	S17-a	S17-b	S17-c
P1260	*Bispira*	juvs																				1	1															
P1269	*Chone filicaudata*		1					2										1		1	9	8	5				4		1									
P1289	*Jasmineira caudata*					1			1							1			1			1						1										
P1329	*Ditrupa arietina*																																					
P1425	Tubificidae															4					1																	
P1501	Enchytraeidae			1	6	4	4	7	2			3	8		29	35	49	22	19	11	4	6	5	1						1	1		6	17	11	1	1	
	Chelicerata																																					
Q0044	*Anoplodactylus petiolatus*																																					
	Crustacea																																					
R0077	*Balanus crenatus*				P																																	
R0142	Copepoda				1	3			1		1	7	11		1			2			12	7			2	4		3			1			1			3	2
R2412	Ostracoda						1		3	1	3									1	2	2	1				1		2	1								
S0005	*Nebalia*										1																											
S0011	*Sarsinebalia typhlops*								5		1																											
S0041	*Gastrosaccus lobatus*		2								2								1	1											2	1						
S0048	*Erythrops elegans*																	1	1		1			1													
S0087	*Schistomysis ?ornata*													1																					1	1	
S0125	*Monoculodes carinatus*					1																															
S0131	*Perioculodes longimanus*								1															1			1	1	2			1				2		2
S0135	*Pontocrates arenarius*		2			2					1		2		1						1														1			
S0138	*Synchelidium maculatum*						1	1	1	2	2						1	1	2					2		1	1	1		4	3	3				2	1	
S0140	*Westwoodilla caecula*																																					
S0154	*Amphilochoides boecki*		1													1																					
S0159	*Amphilochus neapolitanus*																																					
S0164	*Gitana sarsi*			1	7																1		5															
S0170	*Paramphilochoides odontonyx*										1																1	1	3									
S0173	*Peltocoxa brevirostris*																					1																
S0177	*Leucothoe incisa*																																					
S0213	*Stenothoe marina*			1	1															1																	
S0248	*Urothoe elegans*																																					
S0254	*Harpinia antennaria*																										4		4									
S0265	*Parametaphoxus fultoni*			1								1										1																
S0274	*Acidostoma nodiferum*																																					
S0296	*Hippomedon denticulatus*					1		1	6	6	4			1	1	1		2	1	1				12	2	1				1	1	1			1	17	2	1
S0301	*Lepidepecreum longicorne*										1		1					1	4	1				1	1	2									1	2	
S0330	*Socarnes erythrophthalmus*																					26	43														
S0347	*Tryphosites longipes*																																					
S0360	*Argissa hamatipes*			1				1			1													2	4	3	2	1									2
S0399	*Listriella mollis*											3	2																									
S0409	*Atylus*	juvs	2				2		1		1		1							4	2									2	1						
S0410	*Atylus falcatus*					8	2	4							6	6	12	1	1	2	1		1		1							4	6		1		
S0413	*Atylus vedlomensis*			5	2	9	6	6			2	2	7	2	1	1	3	1	11	3	2	5	1														
S0418	*Guernea coalita*			7	3	9	4					20	31	11	2		1	1	5		11	17	13														
S0423	*Ampelisca*	juvs							1											1		1						3	6		1						
S0427	*Ampelisca brevicornis*					1					1								1						1	1	1									1		
S0438	*Ampelisca spinipes*			2		1																	2				3										
S0440	*Ampelisca tenuicornis*																										1	4	3								
S0442	*Ampelisca typica*																																					

MCS Code			S1-a	S1-b	S1-c	S2-a	S2-b	S2-c	S4-a	S4-b	S4-c	S5-a	S5-b	S5-c	S5R-a	S5R-b	S5R-c	S6-a	S6-b	S6-c	S6R-a	S6R-b	S6R-c	S9-a	S9-b	S9-c	S10-a	S10-b	S10-c	S11-a	S11-b	S11-c	S15-a	S15-b	S15-c	S17-a	S17-b	S17-c
S0451	*Bathyporeia*	juvs	1						20	2	9					1					1			8	3	5	3	7		4		8				2	3	
S0452	*Bathyporeia elegans*								13	8	8											1		1	5		5	2	6	7	6	18	2			10	4	9
S0456	*Bathyporeia pelagica*																											2	1									
S0489	*Megaluropus agilis*								1															2		1												
S0493	*Melphidippella macra*								2			1	1								1						3		2									
S0502	*Ceradocus semiserratus*																						1														
S0503	*Cheirocratus*	females/juvs	2		3																										1						
S0519	*Maera othonis*			1	3																																
S0539	*Gammaropsis cornuta*		5	5	6	9	10	6	2		2	3	3	3		1	2	6	3	5		3					1	1	3		1	1					
S0561	*Ericthonius punctatus*					1																															
S0577	Aoridae	females/juvs								1	2																2	1	11		1						
S0588	*Leptocheirus hirsutimanus*					2	9	1				1										1	1														
S0618	*Siphonoecetes kroyeranus*																								1	1							1	2	3	2	7	2
S0619	*Siphonoecetes striatus*								1		1																5	2	3									
S0639	Caprellidae	no legs																					2														
S0651	*Pariambus typicus*																											1									
S0657	*Phtisica marina*																																				
S0793	*Gnathia*	praniza/females												1													2										
S0796	*Gnathia oxyuraea*																																				
S0854	*Eurydice pulchra*											1	1																								
S0856	*Eurydice truncata*		3	1	1	4	2	7	2	1	1		1	1	8	11	6	19	22	13					3	1				4	1	3	7	4	12	5	4	4
S0911	*Paramunna bilobata*											11		5																							
S0955	*Astacilla longicornis*		1								1																										
S1099	Tanaidacea				3				1			12		4							2							4	6	1				1				
S1196	*Bodotria pulchella*																														1						
S1197	*Bodotria scorpioides*																		1	2																	
S1224	*Cumella pygmaea*		1		1							8		4							2	1	2														
S1236	*Pseudocuma longicornis*							1		1															2												
S1237	*Pseudocuma similis*						1		6	3	3					1	2	1	1	1				26	13	11	3	2	6	1		1			2	1	4	4
S1247	*Diastylis*	juvs																																			
S1248	*Diastylis bradyi*																																		1			
S1251	*Diastylis laevis*																										1										
S1254	*Diastylis rugosa*																										1	1	2	1	1						1
S1257	*Diastyloides biplicata*																																				
S1361	Processidae	damaged															1																				
S1374	*Pandalina brevirostris*				1							1																									
S1386	*Philocheras bispinosus*																											1									
S1445	Paguridae	juvs										1	1															1									
S1462	*Pagurus prideaux*				1																							4	1								
S1569	Portunidae	damaged/juvs					1																										1			1		
S1472	*Galathea intermedia*			13	22	1						4		4	1							2	2				1	1									
S1482	*Pisidia longicornis*											1																									
S1504	*Ebalia*	damaged												1									1														
S1506	*Ebalia granulosa*																											1									
S1535	*Eurynome*	juvs										1									1	1															
S1537	*Eurynome ?spinosa*																						1														
S1552	*Corystes cassivelaunus*																											1									
S1555	*Atelecyclus rotundatus*											1																									

MCS Code			S1-a	S1-b	S1-c	S2-a	S2-b	S2-c	S4-a	S4-b	S4-c	S5-a	S5-b	S5-c	S5R-a	S5R-b	S5R-c	S6-a	S6-b	S6-c	S6R-a	S6R-b	S6R-c	S9-a	S9-b	S9-c	S10-a	S10-b	S10-c	S11-a	S11-b	S11-c	S15-a	S15-b	S15-c	S17-a	S17-b	S17-c
S1582	*Liocarcinus marmoreus*					1		1					1									1												1				
S1584	*Liocarcinus pusillus*																				1															1		
-	Decapoda	megalopa				1																																
-	Decapoda	zoea																		1	1																	
	Mollusca																																					
W0029	Neomenia				1							5	3	8							3	2															
W0046	Polyplacophora	juvs			1																																	
W0088	Gastropoda	damaged	1	1									1	3					1		3	1	2															
W0157	*Gibbula*	juvs		1	2							2									1	32	11															
W0324	Rissoidae	juvs												1																								
W0418	*Caecum glabrum*											22	12	21				1			1	10	3															
W0488	*Polinices*	juvs										3																1										
W0491	*Polinices pulchellus*					1		2			1			2							1		1															
W0553	*Epitonium trevelyanum*																																					
W0603	*Eulima bilineata*																						1															
W0702	Buccinidae	juvs																																				
W0771	Turridae	juvs																																				
W0959	*Ondina diaphana*												1																								
W1006	*Acteon tornatilis*																											1									
W1019	*Scaphander lignarius*														2										1												
W1028	*Cylichna cylindracea*																	1									28	27	26								
W1036	*Philine*	juvs																								1											
W1044	*Philine quadrata*					5	4	2							2	2	1				2	1		3	7	7	2	2	3				1	1	2	3	6	2
W1045	*Philine scabra*																							1			26	16	15							1	1	
W1059	*Diaphana minuta*												1		1	1																				1	
W1077	*Retusa obtusa*				1	1						1	2	3	4				1	2	2	1	2														
W1243	Nudibranchia	juvs/indet										43	7					2	1	1		7															
W1414	Aeolidaiacea												2	4																							
W1519	*Antalis entalis*																																				
W1560	Pelecypoda	damaged/juvs																																	1		
W1688	*Glycymeris glycymeris*											1									1																
W1695	*Mytilus edulis*	juvs																					1												1		
W1703	*Modiolula phaseolina*	juvs												1							1	3	2														
W1746	*Limatula subauriculata*		1	1	1	1	1					1	2		1		1	1		2	2	2	1														
W1785	*Palliolum striatum*		3	4	1						1	3		2								1	2														
W1803	*Similipecten similis*																																					
W1829	*Lucinoma borealis*																										2		4								
W1837	*Thyasira flexuosa*																										8	7	11								
W1866	Galeommatacea	juvs																	1																		
W1892	*Montacuta substriata*												1							8																	
W1902	*Tellimya ferruginosa*					1						4	7	1						3	1																
W1906	*Mysella bidentata*																												1								
W1911	*Epilepton clarkiae*																														2						
W1929	*Goodallia triangularis*					3	1	1				4	2	2					1															1			
W1940	*Acanthocardia*	juvs										1									1		6		1		4	3	7								
W1959	*Laevicardium crassum*	juvs												1	1	1								1													
W1973	*Spisula*	juvs			18	17	2	2				5	5	5		2		2	4	4	8	7	1											2			
W1975	*Spisula elliptica*		1			6	2	1			1		3	1	3	6	8	2	5	3	3		1		3	4				1			1		5			1

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W1983	*Lutraria angustior*				1		3									1	1	1		2			1															
W1995	Pharidae	juvs																									1		2									
W1999	*Ensis ensis*					1	1	1									2			1														1	2			1
W2008	Tellinidae	juvs		5	3	3				1		2	5	3				4		4	1																	
W2015	*Arcopagia crassa*						1														1																	
W2023	*Moerella pygmaea*					6	5	14		2	1				16	4	30	22	18	15	1	2	7	1	1	6				3		1	2	18	20	3		2
W2044	*Gari*	juvs										2	4							1		29	10														
W2046	*Gari depressa*				1		1	2				1	2	8	2	1				1	12	1	2														
W2049	*Gari tellinella*																	1		1																	
W2058	*Abra*	juvs												1		1								16	27	8	18	11	7	5	19	1					3
W2062	*Abra prismatica*					1				4	2							2	9					2	11	5	11	19	10	3	2	2					
W2086	Veneridae	juvs												3								1															
W2095	*Gouldia minima*											2										1	1														
W2098	*Chamelea striatula*			1															1							1	1		3							
W2100	*Clausinella fasciata*											1		2							1	1															
W2104	*Timoclea ovata*													1		1					1	2												1			
W2126	*Dosinia*	juvs																			1										1						
W2131	*Dosinia lupinus*					1	1						1		1		1		1	1	1			2			4	3	5							1		2
W2157	*Corbula gibba*																											1	1								
W2166	*Hiatella arctica*																					1	1														
W2226	Thraciidae	juvs			17									1			1				2			2													
W2233	*Thracia villosiuscula*			1	1	2	1					2		4	1					1	3		1							1					1			
W2239	*Cochlodesma praetenue*																								3	2	6	1	5						1	3		1
W2247	*Lyonsia norwegica*																																				
W2277	*Cuspidaria*	juvs																																			
W2280	*Cuspidaria ?cuspidata*																																				
	Bryozoa																																				
Y0027	Tubulipora			P																																	
Y0054	*Entalophoroecia deflexa*			P																																	
Y0057	*Hornera lichenoides*																																				
Y0066	*Disporella hispida*			P																																	
Y0076	*Alcyonidium diaphanum*																					P															
Y0154	*Aetea anguina*																																			P	
Y0162	*Scruparia chelata*													P																							
Y0178	*Electra pilosa*																																		P		
Y0474	*Schizomavella linearis*			P																																	
Y0480	*Microporella ciliata*			P																																	
	Phoronida																																				
ZA003	Phoronis	indet								1		1															8	9	18	1	1						
	Echinodermata																																				
ZB018	Asteroidea	juvs		2	1									1		2		1	1	1				2		1		1		1					1		1
ZB105	Ophiuroidea	juvs		6	13			1				126	80	111					1		12		25				2	2	3								
ZB154	*Amphiura filiformis*													1														3									
ZB157	*Amphiura securigera*											3	2								1																
ZB161	*Amphipholis squamata*											47	20	70					2		4	5	1														
ZB167	*Ophiocten affinis*			1		1							2		1			1	2										2								
ZB181	Echinoidea	smashed/juvs		9	2	2	1		19	22	19	6	5	1	3	1		8	2	1		4	10	11	15	6	11	6	7	10	4	9	3	8	5	1	9	8
ZB212	*Echinocyamus pusillus*			6	14	4	1	4	7	4	24	10	15	18	14	21	9	12	15	16	6	2	2		2	9	1	5	11	5	9	3	1	3	2	9	6	3

MCS Code			S1-a	S1-b	S1-c	S2-a	S2-b	S2-c	S4-a	S4-b	S4-c	S5-a	S5-b	S5-c	S5R-a	S5R-b	S5R-c	S6-a	S6-b	S6-c	S6R-a	S6R-b	S6R-c	S9-a	S9-b	S9-c	S10-a	S10-b	S10-c	S11-a	S11-b	S11-c	S15-a	S15-b	S15-c	S17-a	S17-b	S17-c
ZB219	*Spatangus purpureus*																		1	2					2													
ZB224	*Echinocardium flavescens*					5	2	1	3	2	3				2	2	6	8	13	4				10	5	14	5	13	6		2	1	2		3	1	12	
ZB225	*Echinocardium pennatifidum*							1																													
ZB257	*Pseudothyone raphanus*																																				
ZB262	*Thyone fusus*				1	2	3						1		1						1	1															
ZB297	*Leptosynapta minuta*				1	1																															
ZB298	*Labidoplax*	juvs																						1											1		
ZB299	*Labidoplax buskii*																						1														
ZB300	*Labidoplax digitata*																								1												
	Hemichordata																																				
ZC001	Hemichordata	indet									3								1								5	3	4	1							
	Tunicata																																				
ZD109	*Cnemidocarpa mollis*																	1		1																	
	Cephalachordata																																				
-	*Branchiostoma lanceolatum*		3										2																								
	Pisces																																				
ZG007	Teleostei																	1																			
	Astrorhiza																																				
	No. Species		53	72	84	76	65	60	46	37	62	85	84	80	62	58	49	65	69	84	89	84	87	45	47	44	82	85	79	46	48	38	31	30	44	40	36	28
	No. Individuals		351	493	677	2082	1855	1628	212	130	254	1175	1402	1223	1083	1034	785	620	657	593	1499	1432	1382	160	164	142	643	625	788	132	144	102	160	621	272	111	118	86

Appendix 3: Benthic invertebrate statistical analysis

Table 1. Univariate Indices by replicate for sample sites around the proposed outfall.

	S	N	J'	H(loge)	λ
S1-a	53	351	0.79	3.14	0.07
S1-b	72	493	0.76	3.18	0.08
S1-c	84	677	0.77	3.41	0.06
S2-a	76	2082	0.53	2.29	0.23
S2-b	65	1855	0.49	2.05	0.26
S2-c	60	1628	0.52	2.12	0.22
S4-a	46	212	0.80	3.07	0.08
S4-b	37	130	0.85	3.08	0.06
S4-c	62	254	0.77	3.18	0.09
S5-a	85	1175	0.68	3.01	0.12
S5-b	84	1402	0.58	2.58	0.18
S5-c	80	1223	0.62	2.71	0.17
S5R-a	62	1083	0.55	2.28	0.20
S5R-b	58	1034	0.59	2.39	0.19
S5R-c	49	785	0.65	2.54	0.14
S6-a	66	621	0.75	3.16	0.07
S6-b	69	657	0.76	3.23	0.07
S6-c	84	593	0.78	3.44	0.07
S6R-a	89	1499	0.57	2.53	0.17
S6R-b	84	1432	0.63	2.78	0.14
S6R-c	87	1382	0.64	2.85	0.14
S9-a	45	160	0.83	3.15	0.06
S9-b	47	164	0.85	3.26	0.06
S9-c	44	142	0.91	3.43	0.04
S10-a	82	643	0.75	3.30	0.09
S10-b	85	625	0.75	3.35	0.08
S10-c	79	788	0.75	3.27	0.09
S11-a	46	132	0.90	3.44	0.04
S11-b	48	144	0.84	3.26	0.06
S11-c	38	102	0.87	3.16	0.06
S15-a	31	160	0.79	2.70	0.10
S15-b	30	621	0.49	1.66	0.40
S15-c	44	272	0.80	3.00	0.08
S17-a	40	111	0.87	3.19	0.05
S17-b	36	118	0.91	3.26	0.04
S17-c	28	86	0.88	2.93	0.06

S = Number of species (including encrusting species)
N = Number of individuals
J' = Pielou's Evenness
H'= Shannon-Weiner Diversity ($\log_e$)
λ = Simpson's Dominance index

Table 2: SIMPER output of those species that contribute (top 30%) to the similarity between sites around the proposed outfall using Bray-Curtis similarity on standardised square root transformed data (see Figure 2). The columns shown give the average abundance, the average contribution to the similarity, the percentage contribution to overall similarity and the cumulative contribution to similarity.

Cluster 1 (Site 15)				
Average similarity:	100			
Species	Av. Abund	Av. Sim.	Contrib%	Cum%
Nematoda	132.34	-	37.61	37.61
Cluster 2 (Sites 1,2,5,5R,6,6R)				
Average similarity:	55.64			
Species	Av. Abund	Av. Sim.	Contrib%	Cum%
Polygordius	12.29	5.17	9.28	9.28
Nematoda	12.35	3.98	7.16	16.44
Pisione remota	7.49	2.99	5.38	21.82
Spio filicornis	8.46	2.19	3.93	25.75
Hesionura elongata	5.18	2.11	3.78	29.53
Glycera lapidum	4.79	1.67	2.99	32.53
Cluster 3 (Site 10)				
Average similarity:	100			
Species	Av. Abund	Av. Sim	Contrib%	Cum%
Spiophanes bombyx	173	-	25.21	25.21
Spio decorata	54	-	7.87	33.09
Cluster 4 (Sites 4,9,11,17)				
Average similarity:	52.88			
Species	Av. Abund	Av. Sim	Contrib%	Cum%
Aonides paucibranchiata	3.54	3.75	7.09	7.09
Echinocyamus pusillus	2.54	2.62	4.96	12.04
Hippomedon denticulatus	2.03	1.97	3.72	15.77
Echinoidea juveniles	1.98	1.87	3.54	19.31
Bathyporeia elegans	2.11	1.83	3.46	22.77
Spiophanes bombyx	1.76	1.76	3.33	26.10
Echinocardium flavescens	1.96	1.69	3.19	29.30
Nephtys juveniles	1.82	1.65	3.12	32.41

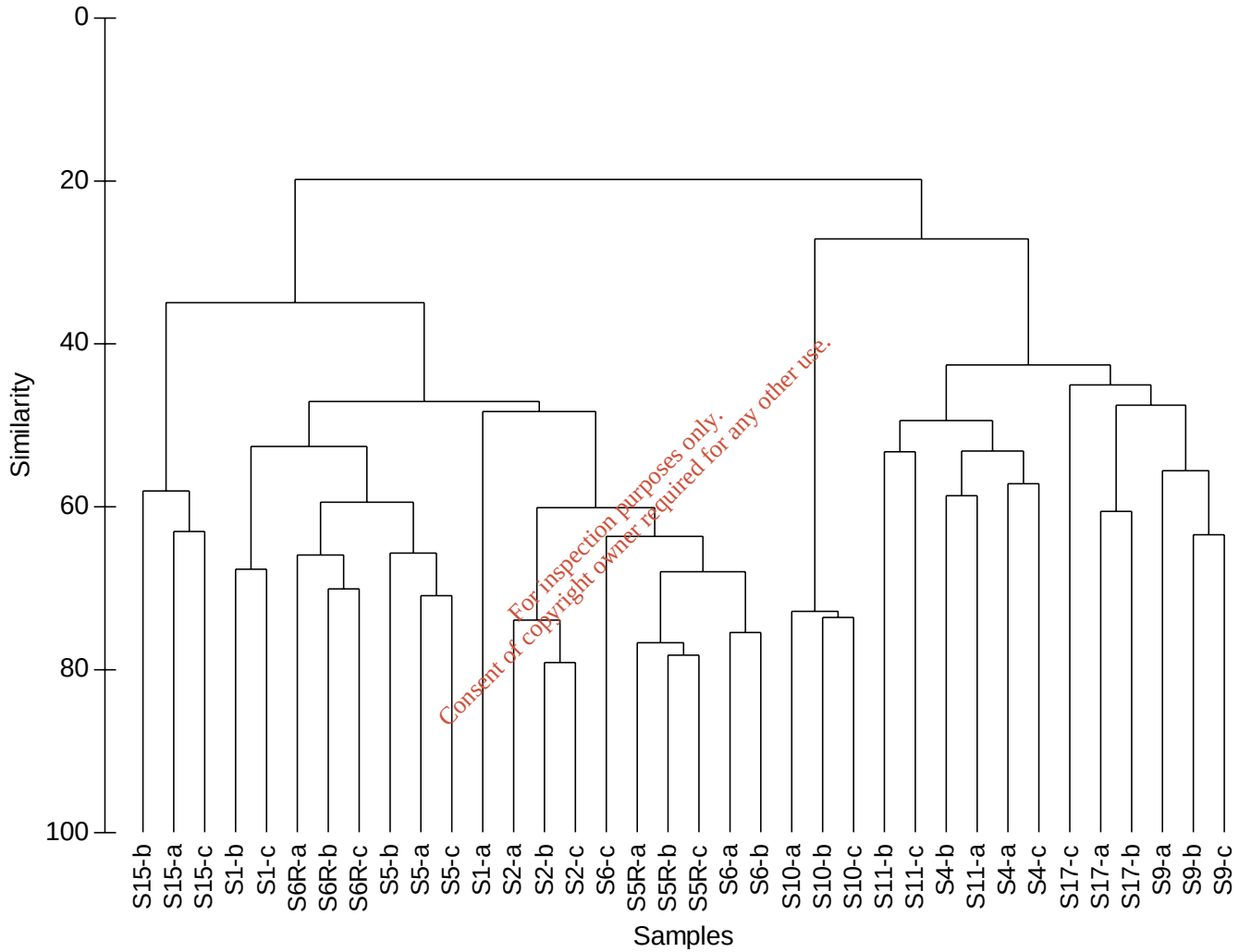

Figure 1. Dendrogram showing clustering of communities using per replicate sample data from sites around the proposed outfall.

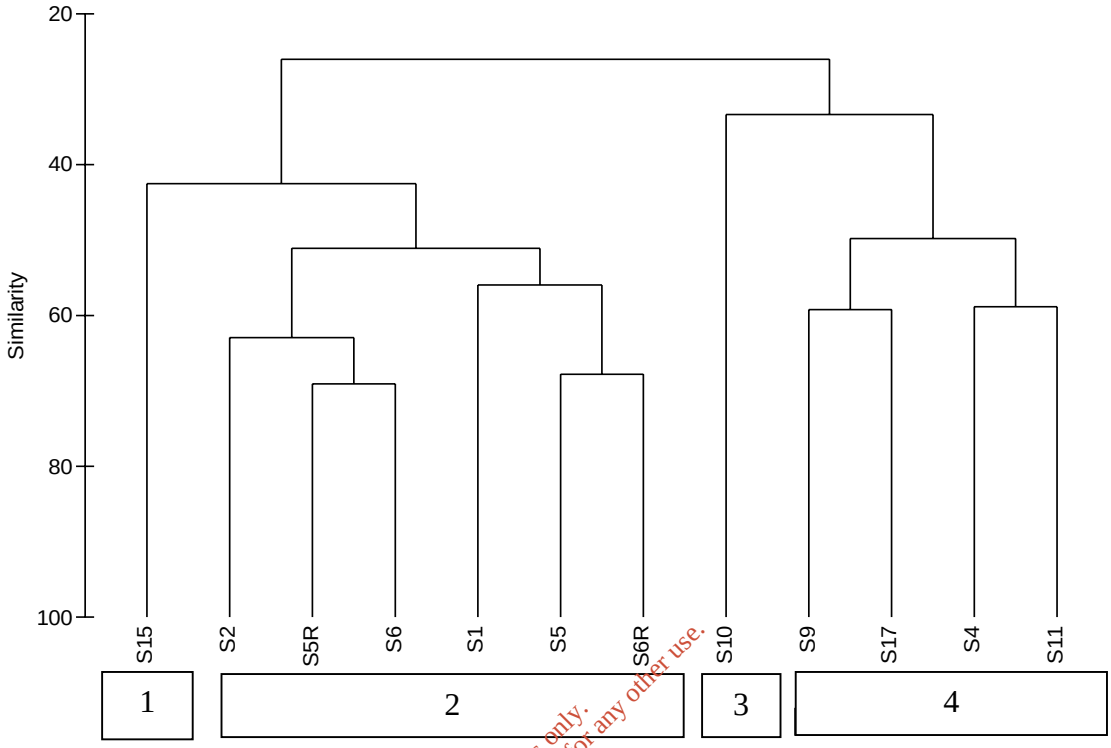

Figure 2: Dendrogram representation of clustering of benthic macrofauna communities (per station, replicates pooled)

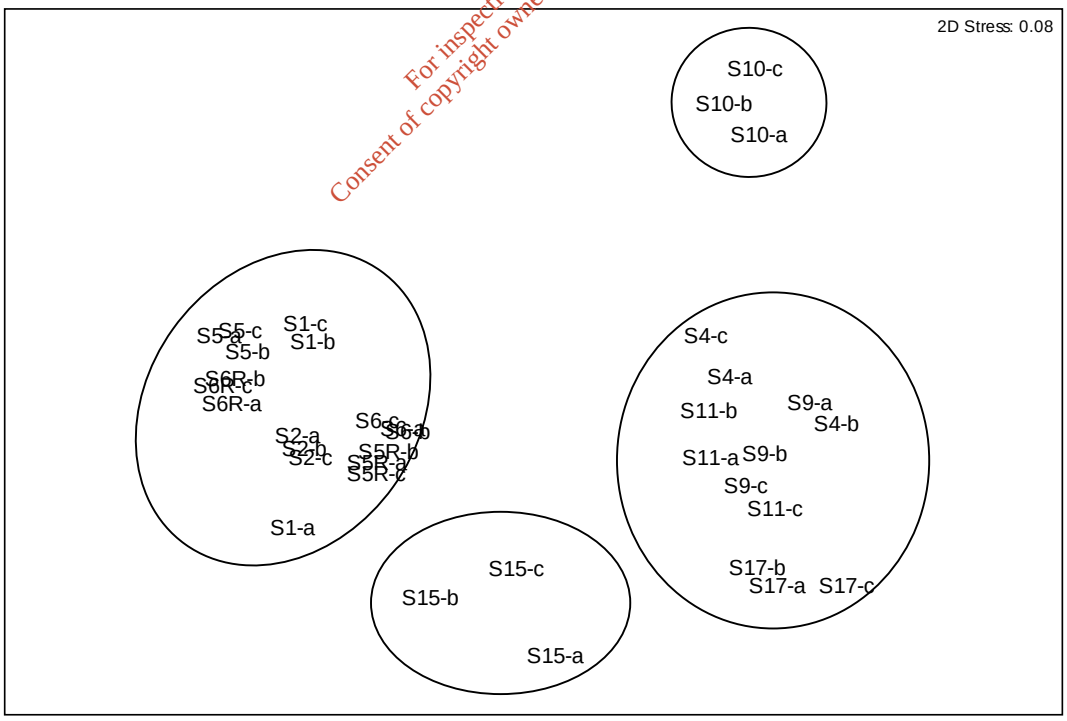

Figure 3. MDS plot of sample sites (per replicate data) around the proposed outfall with superimposed bubbles showing the four clusters.

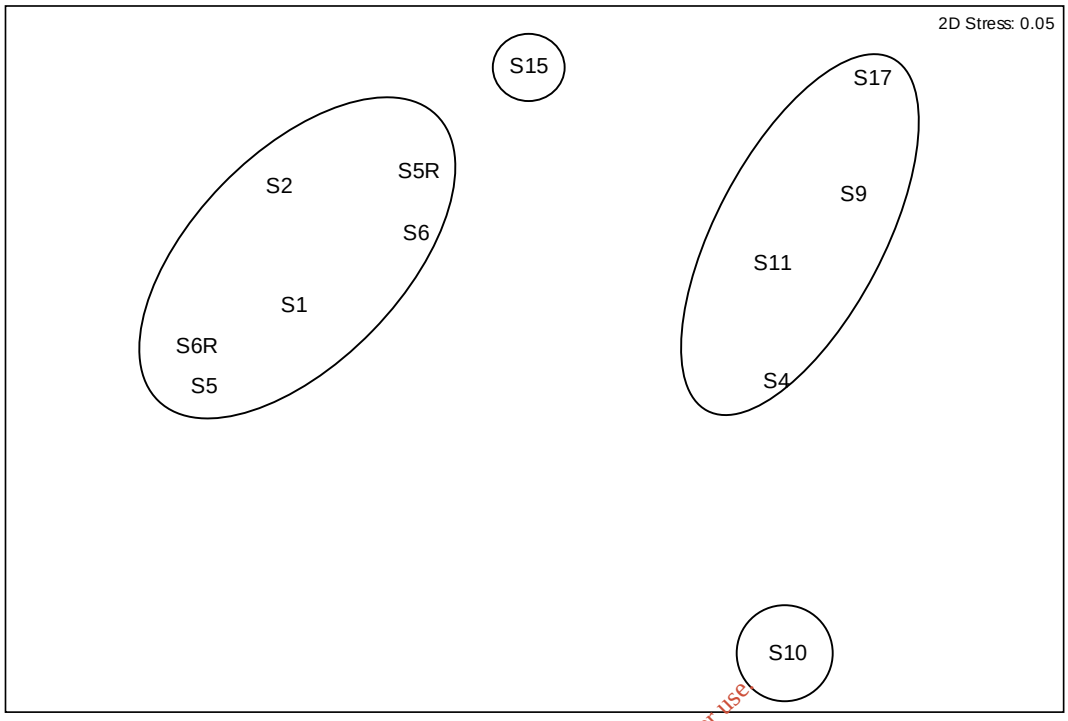

Figure 4. MDS plot of sample sites around the proposed outfall with superimposed bubbles showing the four clusters.

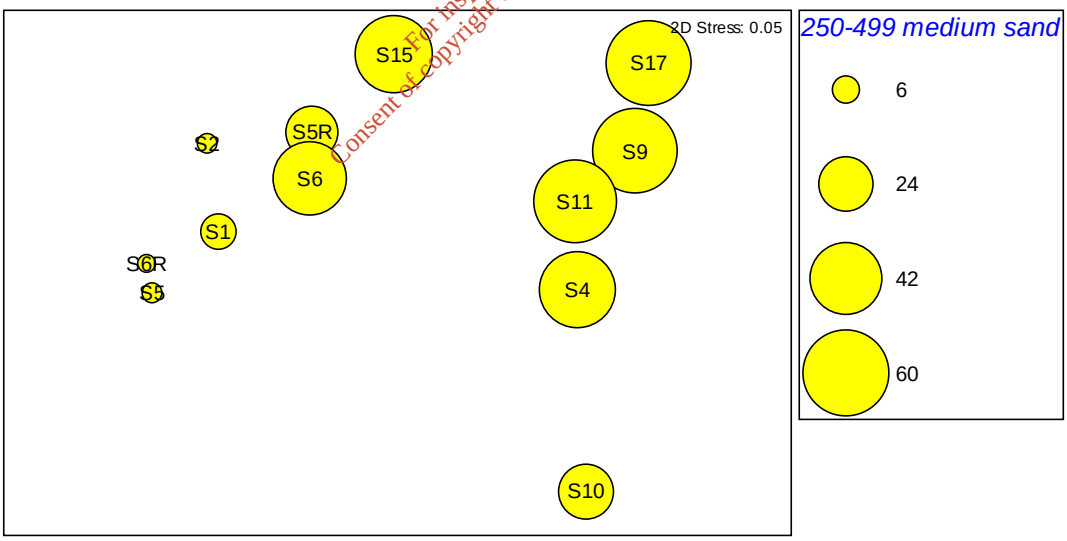

Figure 5. MDS plot of sites around the proposed outfall with superimposed bubbles representing the percent of sediment fraction 250-499µm (medium sand) at each site.

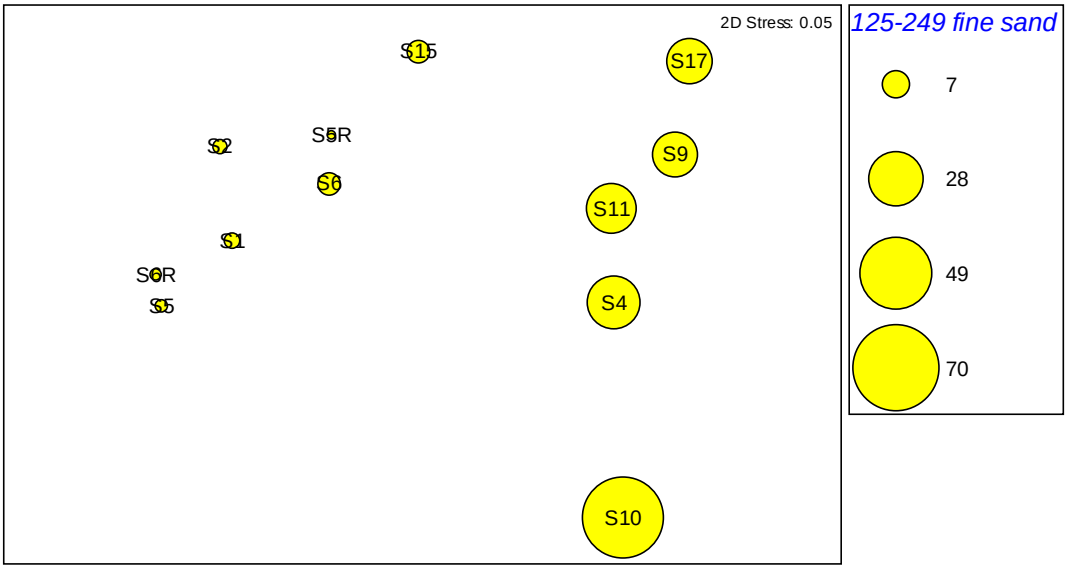

Figure 6. MDS plot of sites around the proposed outfall with superimposed bubbles representing the percent of sediment fraction 125-249µm (fine sand) at each site.

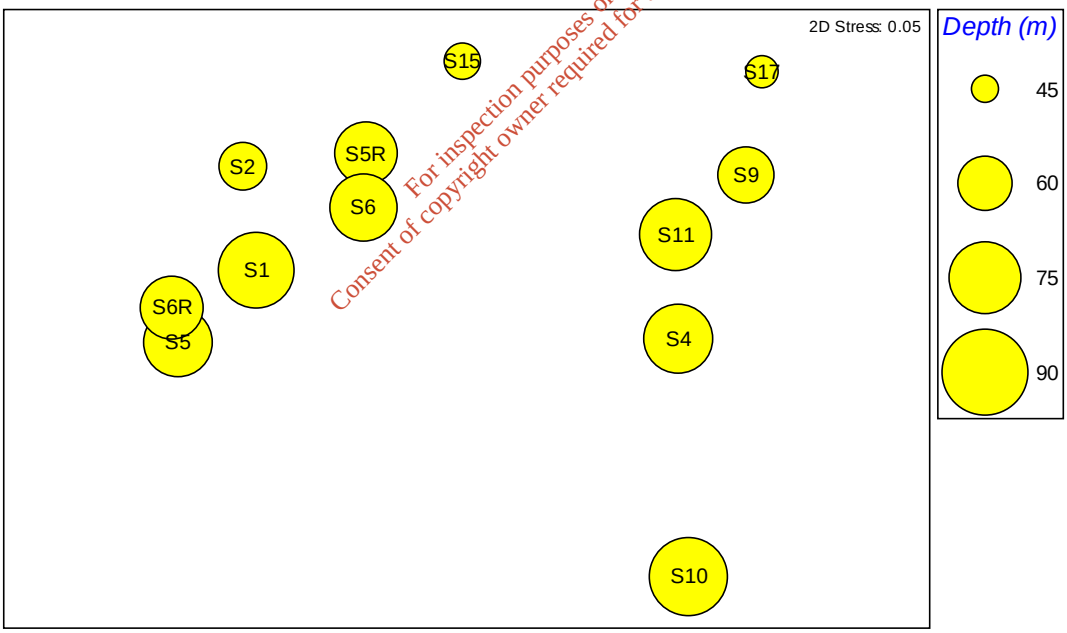

Figure 7. MDS plot of sites around the proposed outfall with superimposed bubbles representing the depth (m) at each site.

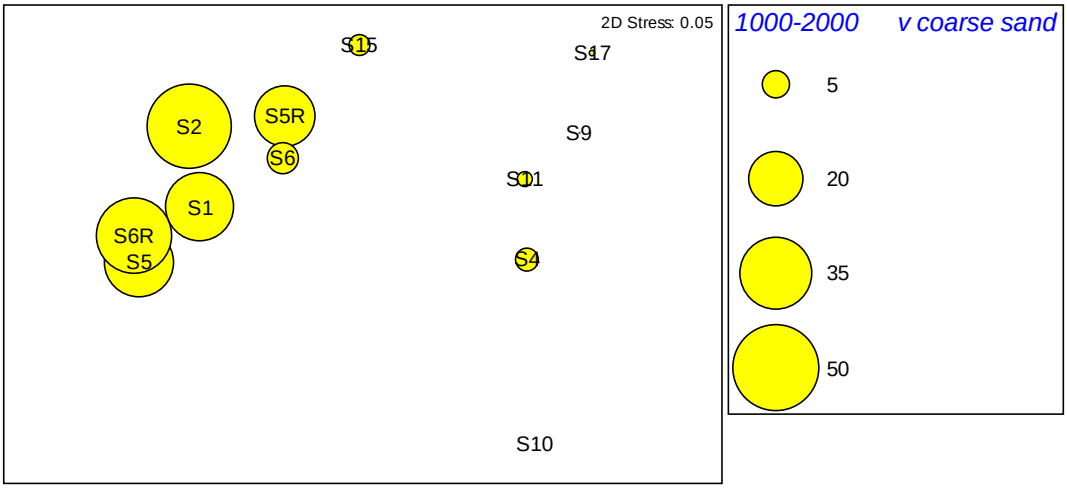

Figure 8. MDS plot of sites around the proposed outfall with superimposed bubbles representing the percent of sediment fraction 1000-2000µm (v coarse sand) at each site.

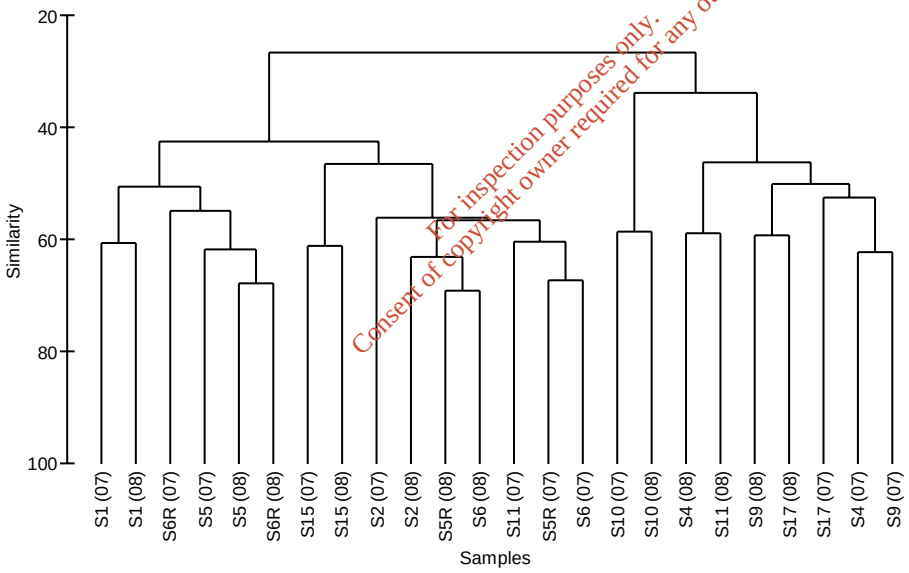

Figure 9. Dendrogram showing clustering of communities using pooled replicate (per site) data taken from sites around the proposed outfall in 2007 and 2008.

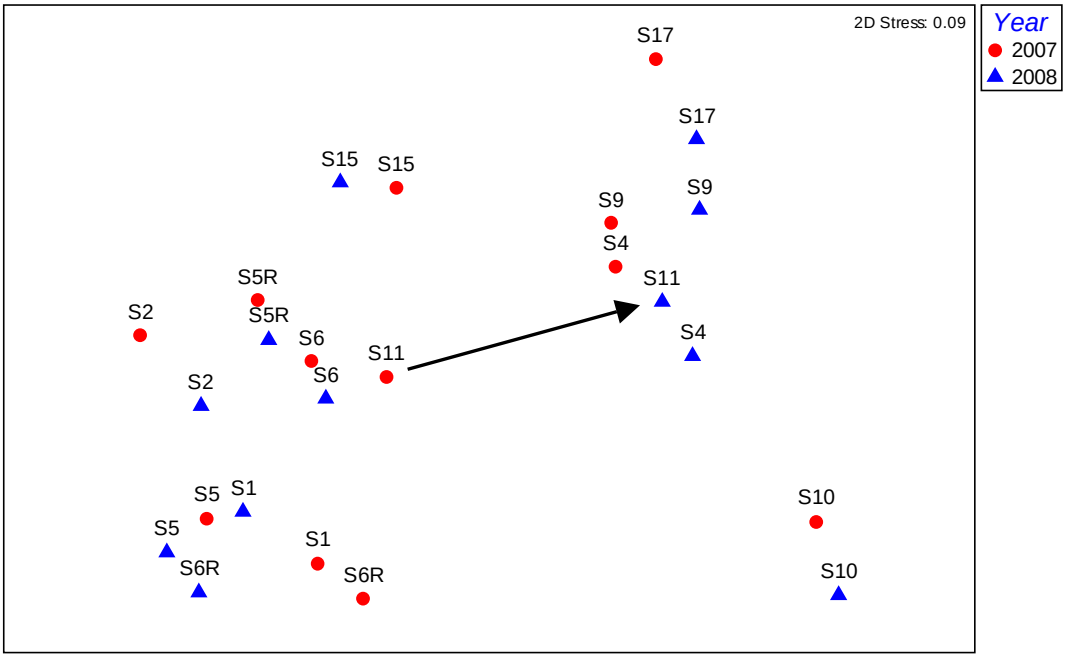

Figure 10. MDS plot of sample sites (per replicate data) around the proposed outfall in 2007 and 2008. The arrow indicates the movement of site 11.

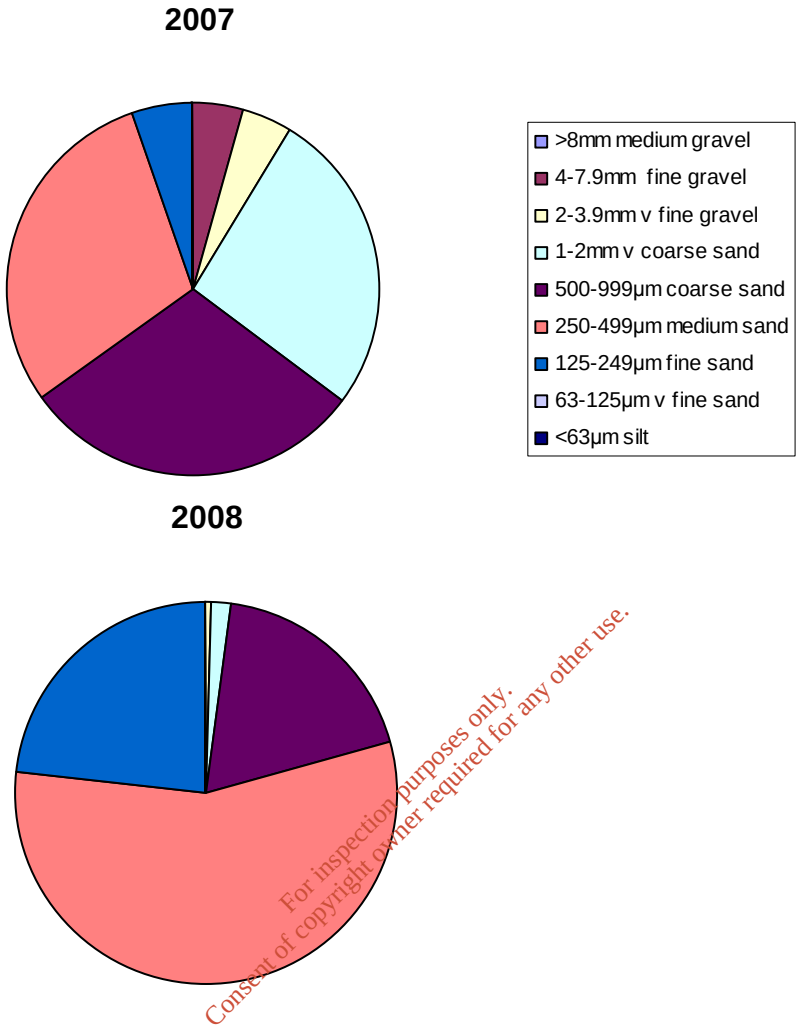

Figure 11. Pie charts showing the sediment composition at site 11 in 2007 and 2008.

Table 3. Ranked taxa list for site 11 in 2007 and 2008 based on average abundances per $0.1m^{2.}$

2007		2008	
Polygordius	22	*Aonides pauchibranchiata*	16
Copepoda	21	*Bathyporeia elegans*	10
Nematoda	20	*Abra* juveniles	8
Pisione remota	18	*Spio decorata*	8
Protodorvillea kefersteini	15	*Echinoidea* juveniles	8
Aonides pauchibranchiata	10	*Echinocyamus pusillus*	6
Hesionura elongata	10	*Aricidea cerruti*	5
Spio filicornis	9	*Spiophanes bombyx*	4
Polygordius appendiculatus	9	*Bathyporeia* juveniles	4
Echinocyamus pusillus	8	*Hesionura elongata*	3
		Glycera oxycephala	3
		Synchelidium maculatum	3

Marine benthic monitoring of the proposed Corrib Gas Pipeline

Pre construction survey

Report prepared for:
Enterprise Energy Ireland
Corrib House
Lower Lesson Street
Dublin

By:
Ecological Consultancy Services Ltd (EcoServe)
KCR Industrial Estate
Kimmage
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November 2002

CONTENTS

INTRODUCTION

Background

A gas pipeline will be laid from the Corrib Gas Field, situated approximately 65 km to the west of the Mullet Peninsula, to a landfall in Broadhaven Bay. Enterprise Energy Ireland Ltd (EEI), the operator of the pipeline has been requested by the Department of Communications, Marine and Natural Resources (DOCMNR), to carry out monitoring works, pre, during and post installation of the pipeline in the vicinity of the landfall.

The DOCMNR is concerned that the installation of the pipeline will create elevated levels of suspended solids that will be redistributed and in turn will cause impacts to the resident fauna of the area. The DOCMNR has requested that a series of surveys be undertaken by an independent contractor to establish the baseline conditions in the Bay, and provide comparable sets of data post construction.

Ecological Consultancy Services Limited (EcoServe) were commissioned by EEI to provide the initial baseline study of the marine fauna present in Broadhaven Bay which are likely to be impacted upon prior to the construction of the pipeline though the site. The survey will be followed with additional survey work one month, six months and twelve months after the pipeline has been constructed.

Study area

Broadhaven Bay is a large bay situated between the north-east side of the Mullet Peninsula and the north-west Mayo coast. It is exposed to prevailing winds and wave action diminishes from the mouth toward the head of the bay. The bay supports a range of marine habitats from extremely exposed bedrock at the entrance to sheltered sediments in the inner bay. However the majority of the seabed is sedimentary ranging from coarse sand in exposed areas to finer sand in more sheltered areas in the inner bay (Picton and Costello, 1999).

METHODOLOGY

The DOCMNR has requested that samples be taken from six locations on six transects which cross the pipeline route totalling 36 stations. The locations of these sites are shown in Appendix1, Figure 1, and are located at 10, 50 and 500m from the pipeline route on both sides.

Stations were located using a differential GPS and the survey boat was anchored over the station to minimise drift during sampling. At each station two sampling techniques were employed. Firstly a Remotely Operated Vehicle (ROV) was used to take video footage of the seabed and to identify the suitability of the site for grab sampling. Secondly grab samples were taken for infauna and sediment analysis.

Remotely Operated Vehicle (ROV)

A VideoRay ROV was used to visually survey each of the sample stations prior to grab samples being taken. The unit consisted of a full colour video camera, with twin variable illumination halogen lights, a depth gauge and a compass. Twin horizontal thrusters and a vertical thruster manoeuvred the ROV underwater. The unit was controlled from the surface via a video monitor, with footage recorded directly to video cassette. The high

manoeuvrability and portability of the ROV enabled a comprehensive survey of the marine flora and fauna within the area of each station.

The video samples were returned to the laboratory for examination to identify and describe the marine habitats and species present.

Infaunal grab samples

Three replicate samples were taken at each station using a $0.1m^2$ stainless steel van Veen grab fitted with 17 kg weights. Each replicate sample was then sieved separately through a 0.1cm stainless steel sieve and the material retained was preserved in 70% Industrial Methylated Spirits (IMS) and returned to the laboratory for identification.

Infaunal analysis

In the laboratory specimens were identified to the lowest possible taxonomic level, using:

Crothers and Crothers (1988)	crabs
Fauchald 1997	polychaete worms
Graham (1988), Tebble (1976) and Picton and Morrow (1994)	molluscs,
Hayward and Ryland (1995)	other taxa
Lincoln (1979)	amphipods
Makings (1977)	mysid crustaceans
Picton (1993)	echinoderms
Smaldon (1993)	shrimps and prawns
Wheeler (1978)	fish

A voucher collection of representative specimens was made. Species nomenclature follows Howson & Picton (1997).

Sediment grab samples

A sub sample of sediment was taken from the first successful grab sample at each station. This sample was labelled and retained in an unpreserved state for further analysis in the laboratory.

Granulometric analysis

Each sediment sample was dried, weighed and passed through a series of sieves of known mesh size. The amount of material retained on each sieve was weighed and the percentage of the total mass of the sample calculated.

The results were then compared with standard sediment scales (Wentworth, 1922 and Folk, 1954).

Loss on ignition

A sub sample of each dry sediment sample was taken and weighed. It was then placed in an oven at 815°C to burn off any organic matter. The sample was then reweighed and the mass of organic matter calculated as a percentage of the total sub sample.

RESULTS

Remotely Operated Vehicle (ROV)

Video samples were collected from all the stations and the results are supplied on the enclosed video cassette. During their examination the main substratum, habitats and species were noted (Appendix 2, Table 2). Still images of representative habitats and species made from the video at most of the sites (Appendix 4).

Infaunal grab samples

Grab samples were taken from each station identified from the video to be sedimentary (Appendix 2, Table 1).

Infaunal analysis

Currently 78 species or higher taxa have been identified (Appendix 2, Table 3). This number is likely to increase with further analysis of some groups, particularly the polychaete worm. The dominant taxa are polychaete worms (23 species or higher taxa), crustaceans (mostly amphipods) (21 species or higher taxa), molluscs (particularly bivalves) (20 species or higher taxa) and echinoderms (starfish, brittlestars and sea urchins) (11 species or higher taxa). The number of taxa appears to increase towards the entrance to the bay (Appendix 3, Figure 1) reaching a peak at Transects D and E.

The polychaetes were also the most numerically abundant taxa (837 individuals recorded), followed by the molluscs (485 individuals) and crustaceans (456 individuals). Echinoderms followed with 262 individuals and, although only one Anthozoa taxa was recorded 112 individuals were present. The number of individuals per station also appears to increase towards the entrance to the bay (Appendix 3, Figure 2) reaching a peak at Transect D despite only four stations being sampled on Transect B and only five stations on Transect C and F.

Sediment grab samples

Granulometric analysis

Analysis of the sediment grain size showed that the seabed of Broadhaven Bay is in general uniformly sand, when using the scale developed by Folk (Folk 1954, Appendix 6) although when using the more divided Wentworth scale (Wentworth (1992, Appendix 6) the seabed varies from very coarse sand to medium sand (Appendix 2, Table 4). The majority of the sites towards the inner bay (Transects A – D) are medium sand apart from site A1 which is very coarse sand. Towards the outer bay (Transects E and F) the sediment is predominantly coarse sand although medium sand occurs to the east of each transect.

The results of the granulometric analysis are given in full in Appendix 5. No sediment samples were analysed from stations B1, B6, D6, F6 and Ref 2, as the substratum was bedrock and boulders.

Loss on ignition

The organic component in the sediment varies between 0.02% at site D6 up to 21.41% at site E1 (Appendix 2, Table 5). Transect D across the centre of the bay has the lowest values of any transect whilst the south side of the bay (stations A1, C1 etc) are generally high than the north side of the bay (stations A6, D6 etc).

No sediment samples were analysed from stations B1, B6, D6, F6 and Ref 2 as the substratum was bedrock and boulders.

DISCUSSION

Remotely Operated Vehicle (ROV)

The video samples clearly indicate the extent of the sandy habitat within Broadhaven Bay. For many of the stations it was not possible to identify any infaunal species. However they did give an overview of the epifauna communities present including fish, crabs and starfish which would be unlikely to be recorded in the grab samples.

The video samples gave a good overview of the rock habitats encountered at stations A1, B1, B5, B6, C6 and Ref 2 which would otherwise not be sampled using grab techniques. The rock habitats varied from sand influenced infralittoral bedrock and boulders at the shallowers stations (A1, B1, B5, B6 and C6) to deep circalittoral bedrock at Ref 2. The shallower station supported kelp plants with a sparse understorey of red algae. The high water and sediment movement in this habitat possibly restricts the growth of foliose red algae on stable boulders and bedrock. Attached fauna, tunicates *Aplidium punctum*, dead mans fingers *Alcyonium digitatum* and the sponges *Cliona celata* and *Polymastia* sp. were restricted to areas of bedrock subject to less scouring. Mobile fauna such as the sea urchin *Echinus esculentus*, the sea cucumber *Holothuria forskali* and starfish *Asterias rubens* and *Marthasterias glacialis* were found on all areas of the rock but probably avoid areas of high scour when conditions prevail. At site B6 and C6 the water was deeper and the rock was most likely subject to less scour except during stormy conditions. At these sites the bedrock supported a kelp park with a more established understorey of brown and red algae. At station Ref 2 the water was in excess of 70m deep. At this depth it is unlikely that algae will occur due to the reduced light penetration through the water column. Therefore animals dominated the organisms that occurred there. Although it was not possible to examine the seabed closely due to limitations in the ROV it was possible to identify a number of echinoderm, species the sea urchin *Echinus esculentus*, the sea cucumber *Holothuria forskali* and starfish *Luidia ciliaris* and the sponge *Cliona celata*.

None of the species identified from the video samples are of specific nature conservation importance and are widespread in Ireland (Picton and Costello, 1999).

Infaunal grab samples

Broadhaven Bay is uniformly sandy and this is reflected in the faunal taxa recorded in the grab samples. None of the species identified are of specific nature conservation importance and are widespread in Ireland (Picton and Costello, 1999).

Infaunal analysis

The number of taxa recorded from each station appears to increase from Transect A at the head of the bay to Transects D and E towards the entrance to the bay. There is a slight decrease at Transect F. The number of taxa at station Ref 1 is comparable to stations along transects D and E. The granulometric analysis shows that there is a very slight gradient from medium sand to coarse sand towards the head of the bay. The exception being station A1, which was very coarse sand. At this station the number of taxa recorded was also low.

The number of individuals recorded from each station also shows a general increase from Transect A to Transect D before decreasing towards Transects E and F. Although these very general trends occur it is not possible to fully correlate the number of taxa and individuals to sediment type, depth or amount of organic matter (LOI). Further analysis will be carried out following the remaining sampling trips.

The dominant taxa occurring at every site were the polychaete worms with 23 species or higher taxa recorded. The polychaetes were more numerically abundant at Transects C, D and E towards the centre of the bay. Crustaceans (mostly amphipods) were also well represented with 21 species or higher taxa recorded. Unlike the polychaetes the crustaceans were more numerically abundant towards the head of the bay at transects A and B. The molluscan fauna which was dominated by bivalves particularly *Chamelea gallina* were also numerically dominant toward the middle of the bay (Transects C, D and E). Twenty species or higher taxa were recorded. The echinoderms (starfish, brittlestars and sea urchins) also followed this pattern. The number of taxa appears to increase towards the entrance to the bay (Appendix 3, Figure 1) reaching a peak at Transects D and E.

The species recorded from this survey are similar to those recorded during the benthic sampling for the Offshore Environmental Impact Statement (Enterprise Energy Ireland Ltd 2000).

Sediment grab samples

Granulometric analysis

The granulometric analysis shows that there is a very slight gradient from medium sand to coarse sand towards the head of the bay. The exception was station A1, which was 'very coarse sand'. This site is shallow (11.2 m BSL) and adjacent to bedrock outcrops on the south side of the bay. It is likely that the close proximity of the hard substratum locally intensifies the water movement from wind and waves causing an increase in mobility of the sediments. An increase in sediment movement may result in the loss of the finer sediment particles resulting in generally coarser sediment than the rest of the bay.

Sediments in the middle of the bay are 'medium sand' with very low or no 'silt' or 'mud' present. Towards the entrance of the bay along Transects E and F the sediment is 'coarse sand' also with little or no 'mud' or 'silt' present.

Loss on ignition

It is not easy to explain the patterns in the organic carbon content of the sediments. Organic content would arise from organisms and their by-products, from material washed into the bay from the open ocean and material transported down the river system for example wood and peat. However it is unclear as to the source of the low LOI value at Transect D or high LOI value at station D1.

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APPENDIX 1. MAP

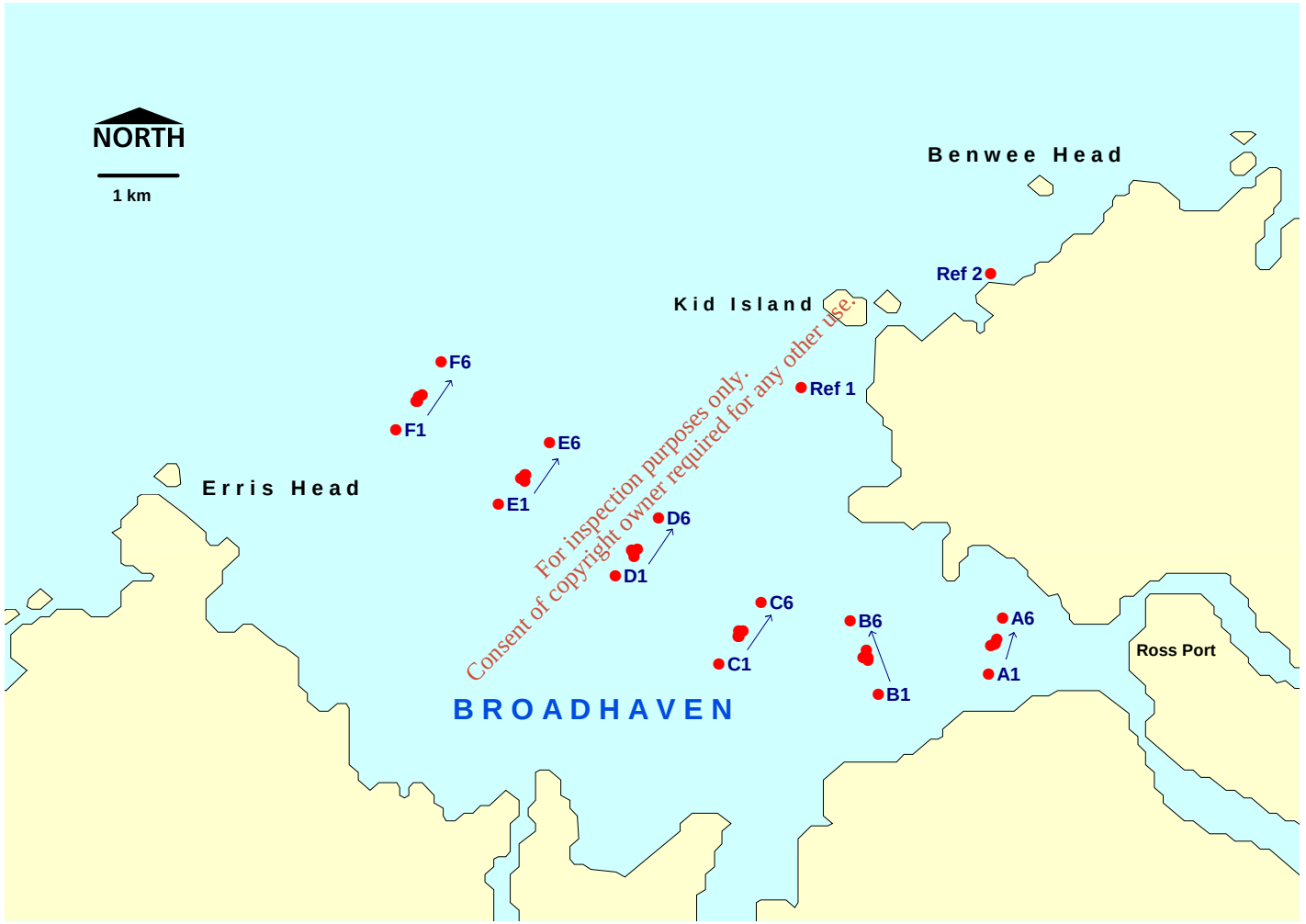


Figure 1. Map showing locations of the ROV and grab sample sites in Broadhaven Bay.

APPENDIX 2. TABLES

Table 1. Details of sublittoral grab and sediment sampling stations.

Station	Latitude and longitude	Depth (m)	Time	Grab	Sediment	Video	Date
A1	54.2821N 9.84133W	11.2	-	✓	✓	✓	01/06/02
A2	54.2848N 9.84053W	12.5	-	✓	✓	✓	01/06/02
A3	54.2851N 9.84043W	12.2	12:30	✓	✓	✓	01/06/02
A4	54.2853N 9.84037W	11.4	13:43	✓	✓	✓	01/06/02
A5	54.2857N 9.84027W	11.7	14:00	✓	✓	✓	01/06/02
A6	54.2883N 9.83947W	9.9	14:25	✓	✓	✓	01/06/02
B1	54.2797N 9.86354W	19.5	15:35	×	×	✓	01/06/02
B2	54.2835N 9.86579W	22.9	16:05	✓	✓	✓	01/06/02
B3	54.2838N 9.86599W	23	16:55	✓	✓	✓	01/06/02
B4	54.284N 9.86608W	23.5	17:20	✓	✓	✓	01/06/02
B5	54.2843N 9.86628W	24.2	17:45	✓	✓	✓	01/06/02
B6	54.2882N 9.86854W	23.4	18:10	×	×	✓	01/06/02
C1	54.283N 9.89506W	29.5	9:24	✓	✓	✓	02/06/02
C2	54.2863N 9.89099W	30	9:59	✓	✓	✓	02/06/02
C3	54.2866N 9.89063W	30	10:23	✓	✓	✓	02/06/02
C4	54.2867N 9.89045W	30.7	10:40	✓	✓	✓	02/06/02
C5	54.287N 9.89009W	29.9	11:08	✓	✓	✓	02/06/02
C6	54.2903N 9.88602W	22.4	11:21	×	×	✓	02/06/02
D1	54.292N 9.91643W	38	13:00	✓	✓	✓	02/06/02
D2	54.2953N 9.91238W	40.3	13:30	✓	✓	✓	02/06/02
D3	54.2955N 9.91202W	39.9	13:52	✓	✓	✓	02/06/02
D4	54.2957N 9.91184W	39.9	14:08	✓	✓	✓	02/06/02
D5	54.296N 9.91148W	39.8	14:24	✓	✓	✓	02/06/02
D6	54.2993N 9.90743W	42	14:42	✓	✓	✓	02/06/02
E1	54.3009N 9.93783W	45.7	16:00	✓	✓	✓	02/06/02
E2	54.3042N 9.93378W	45.6	16:16	✓	✓	✓	02/06/02
E3	54.3045N 9.93342W	45.5	16:28	✓	✓	✓	02/06/02
E4	54.3047N 9.93324W	45.6	16:48	✓	✓	✓	02/06/02
E5	54.305N 9.93288W	47.6	17:05	✓	✓	✓	02/06/02
E6	54.3082N 9.92882W	47.9	17:25	✓	✓	✓	02/06/02
F1	54.3099N 9.95918W	44	19:48	✓	✓	✓	02/06/02
F2	54.3132N 9.95517W	45.4	18:23	✓	✓	✓	02/06/02
F3	54.3135N 9.95481W	45.6	18:45	✓	✓	✓	02/06/02
F4	54.3136N 9.95463W	45.7	19:10	✓	✓	✓	02/06/02
F5	54.3139N 9.95427W	46	18:23	✓	✓	✓	02/06/02
F6	54.3172N 9.95025W	48.9	17:58	×	×	✓	02/06/02
Ref 1	54.3078N 9.86144W	47.3	12:30	✓	✓	✓	02/06/02
Ref 2	54.3281N 9.84086W	70		×	×	✓	11/07/02

Table 2. Details of ROV surveys.

Site	Substratum	Description
A1	A plain of coarse rippled sand adjacent to bedrock and boulders	Boulders and bedrock supported large kelp plants *Laminaria hyperborea* with red algae (*Dilsea carnosa*) forming a sparse understorey. Scour on more exposed rock likely due to the movement of the sand.
A2	Plain of rippled fine sand	Fine sand with drift algae and other organic debris. No obvious infauna or epifauna.
A3	Plain of rippled fine sand	Fine sand with drift algae and other organic debris. No obvious infauna or epifauna.
A4	Plain of rippled fine sand	Fine sand with drift algae and other organic debris. No obvious infauna or epifauna.
A5	Plain of rippled fine sand	Fine sand with drift algae and other organic debris. No obvious infauna or epifauna.
A6	Plain of rippled fine sand	Fine sand with dense drift algae and other organic debris. No obvious infauna or epifauna.
B1	Bedrock and boulders with patches of coarse sand and gravel	Bedrock supported sparse kelp with coralline crusts on the rock surface. Few red algae on or beneath the kelp, although some *Delesseria sanguinea*, probably due to the high scour caused by mobile cobbles and gravel. Shoal of saithe (*Pollachius virens*).
B2	Plain of rippled and ridged fine sand	Fine sand with sparse drift algae and other organic debris. No obvious infauna or epifauna.
B3	Plain of rippled and ridged fine sand	Fine sand with sparse drift algae and other organic debris. No obvious infauna or epifauna.
B4	Plain of rippled and ridged fine sand	Fine sand with sparse drift algae and other organic debris. No obvious infauna or epifauna.
B5	Plain of fine rippled sand adjacent to a large area of bedrock	Scoured bedrock with very sparse fauna including *Alcyonium digitatum*, *Calliostoma zizyphinum*, *Holothuria forskali* and the sponge *Polymastia* sp. The colonial tunicate *Aplidium punctatum* was quite common on the rock with small *Asterias rubens*. No obvious algal growth apart from coralline crusts on the rock surface. The more scoured parts of the rock had the keel worm *Pomatoceros* sp. Sediment supported no obvious infauna or epifauna although some filamentous green algae present which appeared to accumulate at the sediment rock interface.
B6	Bedrock and boulders	Scoured bedrock with sparse fauna including the sea urchin *Echinus esculentus*, dead man's fingers *Alcyonium digitatum*, the starfish *Marthasterias glacialis*, bryozoan crusts, and the sponge *Cliona celata*. The surface of the rock had dense coralline crusts with few other erect algae.
C1	Plain of mobile sand formed into large ripples	Fine sand with no obvious infauna or epifauna apart from one *Marthasterias glacialis*. Little drift material.
C2	Plain of mobile sand formed into large ripples	Fine sand with no obvious infauna or epifauna. Little drift material
C3	Plain of mobile sand formed into large ripples	Fine sand with no obvious infauna or epifauna. Little drift material.
C4	Plain of mobile sand formed into large ripples	Fine sand with no obvious infauna or epifauna. Little drift material.
C5	Plain of mobile sand formed into large ripples	Fine sand with no obvious infauna or epifauna. One small flatfish recorded. Little drift material.

Site	Substratum	Description
C6	Bedrock with small boulders and cobbles.	Bedrock supporting *Laminaria hyperborea* kelp park with a sparse understorey of red and brown algae including *Delesseria sanguinea* and *Cryptopleura ramosa.* The kelp fronds were covered with hydroids, possibly *Dynamena pumila*, and encrusting bryozoans with the occasional gastropod *Calliostoma zizyphinum.* The rock supported dense coralline and bryozoan crusts with *Echinus esculentus, Alcyonium digitatum and* the sponge *Cliona celata*,
D1	Rippled sand	No obvious infauna or epifauna. Very little drift material (no image).
D2	Rippled sand	No obvious infauna or epifauna. Very little drift material.
D3	Rippled sand	No obvious infauna or epifauna. Very little drift material. One starfish *Astropecten irregularis* (no image)
D4	Rippled sand	No obvious infauna or epifauna. Very little drift material. One starfish *Luidia ciliaris* and a small crab *Liocarcinus* sp.
D5	Rippled sand	No obvious infauna or epifauna. Very little drift material. One hermit crab possibly a *Pagurus bernhardus*.
D6	Rippled sand	No obvious infauna or epifauna. Very little drift material. One flatfish possibly a plaice *Pleuronectes platessa*.
E1	Rippled sand	No obvious infauna or epifauna. Very little drift material.
E2	Rippled sand	No obvious infauna or epifauna. Very little drift material.
E3	Rippled sand	No obvious infauna or epifauna. Very little drift material. One hermit crab possibly a *Pagurus bernhardus*.
E4	Rippled sand	No obvious infauna or epifauna. Very little drift material. One fish possibly a grey gurnard *Eutrigla gurnardus* part buried in the sand.
E5	Rippled sand	No obvious infauna or epifauna. Very little drift material. One edible crab *Cancer pagurus* part buried in the sand.
E6	Rippled sand	No obvious infauna or epifauna. Very little drift material. One edible crab *Cancer pagurus* and several hermit crabs probably *Pagurus bernhardus*.
F1	Rippled sand	No obvious infauna or epifauna. Very little drift material.
F2	Rippled sand	No obvious infauna or epifauna. Very little drift material.
F3	Rippled sand	No obvious infauna or epifauna. Very little drift material.
F4	Rippled sand	No obvious infauna or epifauna. Very little drift material. One starfish *Astropecten irregularis*.
F5	Rippled sand	No obvious infauna or epifauna. Very little drift material.
F6	Rippled sand	No obvious infauna or epifauna. Very little drift material.
Ref 1	Rippled sand	No obvious infauna or epifauna. Very little drift material.
Ref 2	Bedrock and boulders	Kelp free bedrock with the sea urchin *Echinus esculentus*, sea cucumber *Holothuria forskali*, the sponge *Cliona celata* and the starfish *Luidia ciliaris*

Table 3. Infaunal species and their abundance recorded from sublittoral grab samples. Numbers are the sum of three replicate 0.1m^2 van Veen samples.

Species	A1	A2	A3	A4	A5	A6	B2	B3	B4	B5	C1	C2	C3	C4	C5	D1	D2	D3	D4	D5	D6	E1	E2	E3	E4	E5	E6	F1	F2	F3	F4	F5	Ref1
ANTHOZOA (sea anemones)																																	
Edwardsiidae indet.	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	25	4	20	15	10	2	6	3	3	7	9	1	1	1	1	1	-	2
PLATYHELMINTHES (flat worms)																																	
Turbellaria indet.	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NEMERTEA (bootlace worms)																																	
Lineus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
SIPUNCULA (peanut worms)																																	
Sipuncula indet.	-	-	-	-	-	-	-	-	1	-	1	-	10	-	-	3	-	3	4	-	4	6	1	6	-	4	7	-	2	2	-	-	4
ANNELIDA (round worms)																																	
Aphroditoidea indet.	-	-	-	-	-	-	1	2	-	-	-	3	5	1	5	7	1	5	2	1	1	1	1	1	2	3	2	1	-	-	-	-	9
Phyllodocidae indet.	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	1	1	-	-	2	-	-	1	-	-	-	-	-	-	-
Pirakia punctifera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Glyceridae indet.	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	1	1	-	1	-	-	3	-	1	-	2	1	1	-	-
Glycera alba	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nereidae indet.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Neanthes fucata	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nephtys sp.	-	9	8	9	12	5	12	15	5	8	-	1	5	1	4	1	2	3	3	3	2	4	8	7	-	5	1	7	6	5	6	4	3
Nephtys caeca	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	1	1	-	-	-	-	-	-
Eunicidae indet.	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	1	1	-	2	1	-	2	2	1	3	-	2	2	-	-	-	2	1
Arabella iricolor	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Orbiniidae indet.	-	-	-	-	-	-	2	1	-	-	-	-	-	-	-	-	-	-	2	-	1	-	2	-	1	1	2	-	-	-	-	-	-
Spionidae indet.	-	-	10	-	-	-	1	4	-	-	1	-	-	1	2	-	-	1	3	1	3	2	3	-	1	1	-	4	6	7	2	4	2
Malacoceros fuliginosus	-	-	1	-	-	-	2	5	1	-	2	1	2	2	4	1	1	1	4	4	-	1	9	1	1	9	4	1	-	-	-	3	3
Magelona mirabilis	-	-	1	1	-	-	9	12	3	-	4	16	22	30	15	10	4	10	26	14	10	11	16	15	5	7	11	7	-	-	-	1	4
Cirratulidae indet.	-	-	-	-	1	-	1	2	1	-	5	8	3	8	9	12	12	15	5	8	4	1	1	2	2	1	7	8	1	1	2	1	8
Cirratulus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Species	A1	A2	A3	A4	A5	A6	B2	B3	B4	B5	C1	C2	C3	C4	C5	D1	D2	D3	D4	D5	D6	E1	E2	E3	E4	E5	E6	F1	F2	F3	F4	F5	Ref1
Cirriformia tentaculata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Opheliidae indet.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	5	-	1	1	-	-	1	1	-	-	-	-
Ophelina acuminata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Owenia fusiformis	-	-	-	-	-	2	5	2	2	-	2	1	-	-	1	-	2	-	1	-	-	-	-	1	-	-	-	1	-	-	-	-	-
Terebellidae indet.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Pomatoceros sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-
CRUSTACEA (crabs, shrimps and barnacles)																																	
Gastrosaccus sp.	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amphipoda indet.	1	1	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oedicerotidae indet.	-	-	1	2	2	1	2	1	2	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Hippomedon denticulatus	-	-	-	-	-	-	1	-	-	-	1	1	-	-	-	-	2	3	-	-	-	1	-	-	-	2	-	-	1	1	1	5	-
Lysianassidae indet.	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	1	-	2	-	-	-	-	-	-	-	-	-
Atylus vedlomensis	-	-	1	1	-	-	8	18	13	2	1	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Bathyporeia elegans	-	7	24	6	12	5	30	30	22	10	5	3	3	1	5	-	-	-	-	-	-	1	-	2	-	2	2	5	4	1	-	2	-
Corophium sp.	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Isopoda indet.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1
Eurydice sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Eurydice pulchra	1	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	2	-	-	-	-	1	-	-
Eurydice spinigera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	1	2	2	3	4	-	2	-	4	8	13	-	10	-
Cumacea indet.	-	-	-	-	-	-	8	1	3	-	3	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bodotriidae indet.	-	-	5	4	4	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iphinoe sp.	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iphinoe trispinosa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diastylis rugosa	-	-	1	1	-	1	17	13	10	12	-	1	2	3	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Euphausiacea indet.	-	4	1	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Inachus leptochirus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Macropodia tenuirostris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Corystes cassivelaunus	-	-	-	-	-	-	1	-	-	-	2	-	2	1	-	-	-	-	-	-	1	-	1	-	-	1	-	-	2	1	-	-	1
MOLLUSCA (snails, bivalves and sea slugs)																																	
Gastropoda indet.	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gibbula umbilicalis	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Species	A1	A2	A3	A4	A5	A6	B2	B3	B4	B5	C1	C2	C3	C4	C5	D1	D2	D3	D4	D5	D6	E1	E2	E3	E4	E5	E6	F1	F2	F3	F4	F5	Ref1
Polinices catena	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-
Acteon tornatilis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Cylichna cylindrica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Retusa truncatula	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	1
Mactra stultorum	-	-	-	-	-	-	-	-	-	-	1	1	17	-	3	1	2	3	2	2	2	7	1	2	4	2	2	1	-	-	-	1	-
Spisula subtruncata	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tellinacea indet.	-	-	-	-	-	-	-	-	-	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fabulina fabula	-	-	-	-	-	-	-	2	1	-	1	1	7	1	1	1	2	-	1	-	-	2	-	3	2	2	1	1	-	3	-	1	-
Moerella donacina	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Donax vittatus	-	-	1	-	-	2	2	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gari fervensis	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Abra sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Dosinia sp.	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	3	1	-	2	-	1	5	2	7	-	2	-	-	-	-	-	1
Dosinia lupinus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Dosinia exoleta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	2	2	2	1	-	-	1	-	-	-	-	-	1	-	-	4
Chamelea gallina	-	-	-	-	-	-	-	-	1	-	6	3	4	-	4	32	17	24	22	47	37	14	9	12	11	6	5	-	-	-	-	-	22
Thracia sp.	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	1	2	-	-	-	1	-	-	-	-	-	-	-	1	-
Cochlodesma praetenue	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	6	-	3	2	2	2	-	3	6	2	-
ECHINODERMATA (sea urchins and starfish)																																	
Astropecten irregularis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Henricia oculata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Amphiura brachiata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	2	4	4	3	1	1	1	1	-	-	-	-	-	-	-	-	8
Amphiura chiajei	-	-	-	-	-	1	-	3	1	1	2	4	5	3	5	11	6	9	12	23	13	3	2	2	3	4	4	-	1	1	-	2	30
Amphiura filiformis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Amphipholis squamata	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Echinocyamus pusillus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	12	8	6	4	12	2	2	2	3	8	4	-
Spatangus purpureus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-
Echinocardium sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Echinocardium cordatum	-	-	-	-	2	2	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	2
No. of taxa	**6**	**4**	**13**	**7**	**8**	**9**	**18**	**18**	**18**	**6**	**21**	**15**	**18**	**15**	**16**	**23**	**18**	**22**	**23**	**21**	**17**	**25**	**23**	**23**	**20**	**25**	**21**	**18**	**14**	**16**	**11**	**18**	**21**
No. of individuals	**6**	**21**	**56**	**24**	**36**	**20**	**104**	**118**	**72**	**34**	**44**	**51**	**92**	**58**	**63**	**117**	**68**	**112**	**116**	**130**	**87**	**91**	**87**	**77**	**63**	**82**	**61**	**51**	**38**	**45**	**30**	**47**	**111**

Table 4. Summary results of granulometric analysis for each station on each transect (- denotes no sediment sample taken) VCS = very coarse sand, CS = coarse sand, MS = medium sad, S = sand

	Station					
Transect	**1**	**2**	**3**	**4**	**5**	**6**
(a) Mean phi						
A	0.25	2.08	2.15	2.06	2.28	2.05
B	-	2.32	2.10	2.25	2.19	-
C	2.03	2.29	2.29	2.32	2.28	-
D	2.19	2.00	2.12	2.15	2.16	2.14
E	1.87	1.92	1.96	1.94	1.95	2.41
F	1.66	1.85	1.76	1.79	2.40	-
Ref 1	1.68					
Ref 2	-					
(b) Folk						
A	S	S	S	S	S	S
B	-	S	S	S	S	-
C	S	S	S	S	S	-
D	S	S	S	S	S	S
E	S	S	S	S	S	S
F	S	S	S	S	S	-
Ref 1	S					
Ref 2	-					
(c) Wentworth						
A	VCS	MS	MS	MS	MS	MS
B	-	MS	MS	MS	MS	-
C	MS	MS	MS	MS	MS	-
D	MS	MS	MS	MS	MS	MS
E	CS	CS	CS	CS	CS	MS
F	CS	CS	CS	CS	MS	-
Ref 1	CS					
Ref 2	-					

Table 5. Loss on ignition (% mass) sampling at 815ºC for each station on each transect (- denotes no sediment sample taken)

	Station					
Transect	**1**	**2**	**3**	**4**	**5**	**6**
A	12.98	12.02	2.72	12.25	5.67	10.04
B	-	11.2	18.36	11.23	7.84	-
C	8.92	8.89	11.65	10.44	10.74	-
D	5.12	8.7	5.93	5.79	6.84	0.02
E	21.41	19.08	17.76	16.59	13.15	8.97
F	11.43	8.33	11.98	12.21	7.79	-
Ref 1	11.32					
Ref 2	-					

APPENDIX 3. INFAUNA SUMMARIES

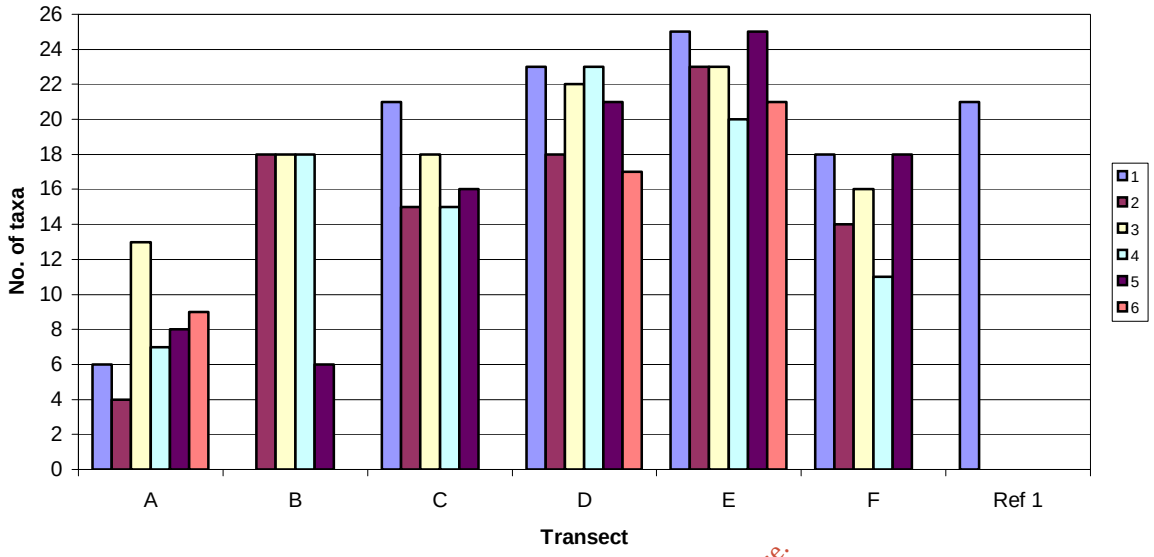


Figure 1. Total number of taxa per station by transect

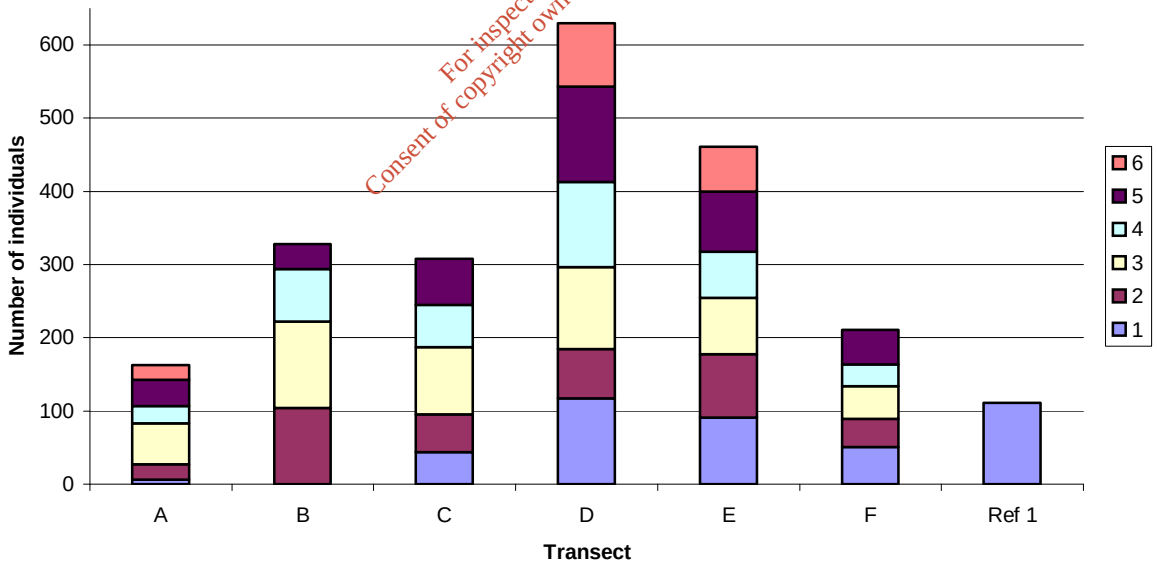
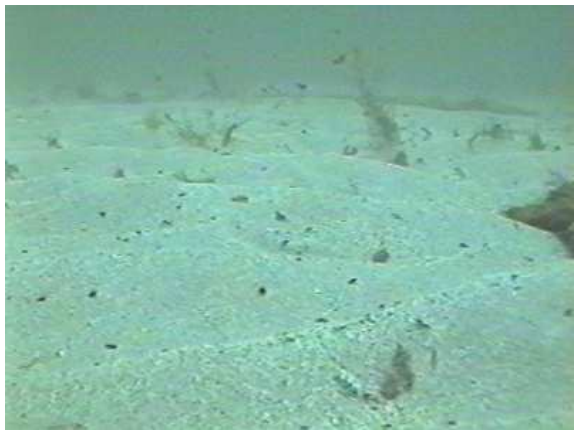


Figure 2. Total number of individuals per station by transects.

APPENDIX 4. PHOTOGRAPHS

Site A1. Coarse sand with kelp covered bedrock and boulders in the distance.



Site A2. Clean mobile sand with drift seaweed.

Site A3. Drift seaweed on clean rippled sand.

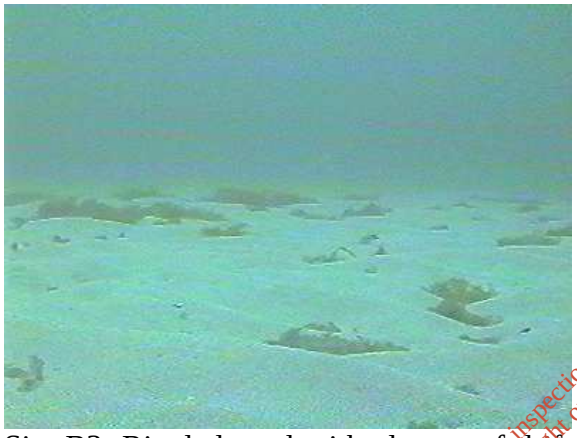
Site A4. Clean rippled sand with drift algae.

Site A5. Rippled sand and drift algae

Site A6. Lots of drift algae on rippled clean sand.

Site B1. Bedrock and boulders with sparse kelp plants.

Site B2. Drift algae on slightly rippled sand.



Site B3. Rippled sand with clumps of drift algae.

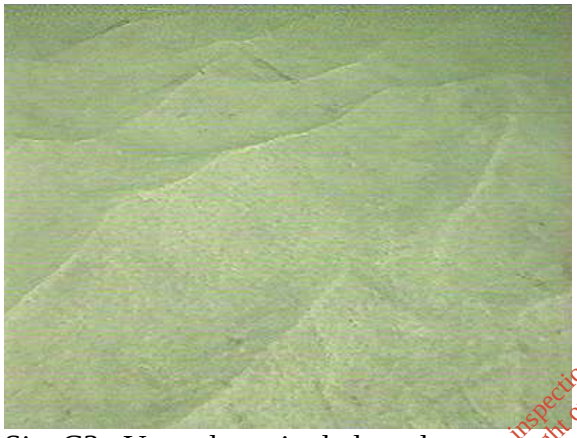
Site B4. Rippled sand with clumps of drift algae.

Site B5. ROV tender lying in front of an outcrop of scoured bedrock with clean sand in the foreground.

Site B6. Bedrock with the soft coral *Alcyonium digitatum* (back left), the sponge *Cliona celata* (middle right) and the sea urchin *Echinus esculentus* (front left).

Site C1. Rippled sand with no obvious infauna.

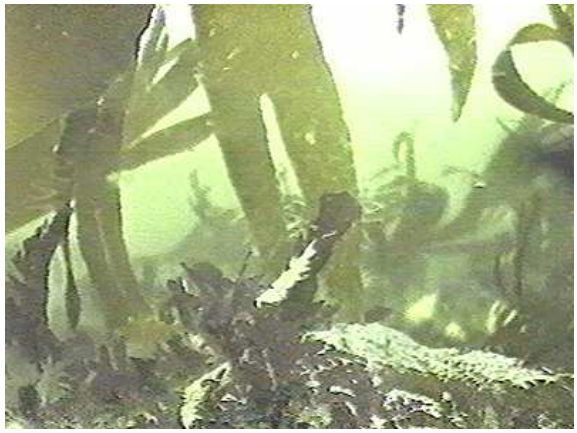
Site C2. Rippled sand with isolated pebble



Site C3. Very clean rippled sand.

Site C4. No picture available

Site C5. Rippled sand with no obvious infauna.



Site C6. Bedrock covered with kelp and an understorey of red and brown algae.

Site D1. No picture available

Site D2. Clean rippled sand

Site D3. No picture available

Site D4. The starfish *Luidia ciliaris* on rippled sand

Site D5. A hermit crab *Pagurus* spp. on clean rippled sand

Site D6. Clean rippled sand

Site E1. Coarse rippled sand with no obvious infaunal species

Site E2. Coarse rippled sand with no obvious infaunal species

Site E3. Coarse rippled sand with no obvious infaunal species

Site E4. Coarse rippled sand with no obvious infaunal species

Site E5. The edible crab *Cancer pagurus* on coarse rippled sand.

Site E6. A hermit crab *Pagurus* sp. on rippled sand.

Site F1. Coarse rippled sand with no obvious infaunal species

Site F2. Coarse rippled sand with no obvious infaunal species

Site F3. Coarse rippled sand with no obvious infaunal species

Site F4. Coarse rippled sand with no obvious infaunal species

Site F5. Coarse rippled sand with no obvious infaunal species

Site F6. Coarse rippled sand with no obvious infaunal species

Site Ref1. No picture available

Site Ref2. Bedrock at with the sea urchin *Echinus esculentus* (bottom centre) and sea cucumber *Holothuria forskali* (bottom right).

APPENDIX 5 GRANULOMETRIC DATA

Data from granulometric analysis showing the percentage of the total sample which passed through each sieve size.

	Station					
Sieve size µm	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**
2000	99.02	99.99	100	99.99	99.95	99.27
1180	91.61	99.64	99.83	99.79	99.89	98.94
850	72.41	99.2	99.49	99.28	99.76	98.38
600	28.51	98	98.61	98.02	99.48	97.04
425	8.29	96.06	97.31	95.76	98.97	94.17
300	2.87	87.73	91.84	88.38	98.42	87.41
212	1.46	67.57	72.85	65.87	77.13	67.73
150	0.74	20.75	21.89	16.51	35.04	21.19
62	0.47	0.01	0.43	0.04	0	0.14

Sieve size µm	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**
2000	-	99.94	99.77	99.98	100	-
1180	-	99.82	99.2	99.81	99.87	-
850	-	99.63	98.53	99.5	99.77	-
600	-	99.32	97.63	98.98	99.52	-
425	-	98.87	96.48	98.33	99.15	-
300	-	97.26	91.92	95.71	93.65	-
212	-	86.41	71.72	82.71	78.19	-
150	-	35.02	17.76	27.05	20.18	-
62	-	0	0	0	0.01	-

Sieve size µm	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
2000	99.91	99.95	100	99.96	99.97	-
1180	99.72	99.84	99.91	99.9	99.92	-
850	99.46	99.74	99.82	99.67	99.84	-
600	98.72	99.46	99.74	99.47	99.6	-
425	97.06	98.71	99.18	98.9	99.07	-
300	83.81	93.14	94.6	93.31	94.2	-
212	62.67	82.44	83.17	83.51	83.11	-
150	17.39	37.56	32.78	41.97	31.53	-
62	0.06	0.08	0.26	0.2	0.23	-

Sieve size µm	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**
2000	99.91	99.84	99.72	99.94	99.93	99.83
1180	99.82	99.65	99.48	99.85	99.85	99.68
850	99.7	99.35	99.37	99.77	99.73	99.52
600	99.45	98.55	99.2	99.59	99.5	99.24
425	99.1	95.95	97.95	99.2	98.73	98.64
300	91.32	85.86	90.12	91.93	91.92	90.39
212	68.53	63.58	64.72	65.18	69.14	69.09
150	32.06	10.54	25.72	26.59	25.2	23.89
62	0.1	0.08	0	0	0	0

Sieve size µm	E1	E2	E3	E4	E5	E6
2000	99.97	99.87	99.9	99.92	99.96	99.43
1180	99.77	99.68	99.73	99.72	99.81	99.05
850	99.4	99.32	99.41	99.37	99.55	98.85
600	98.01	98.21	98.4	98.36	98.82	97.83
425	92.86	94.46	95.42	94.1	96.17	97.56
300	78.12	81.26	83.54	81.9	83.16	95.51
212	46.64	50.73	55.26	53.05	52.27	90.94
150	12.69	12.56	13.84	13.58	12.54	55.07
62	0	0	0	0	0.2	0.89

Sieve size µm	F1	F2	F3	F4	F5	F6
2000	99.91	99.88	99.89	99.92	99.89	-
1180	99.65	99.72	99.69	99.71	99.68	-
850	99.25	99.41	99.31	99.38	99.5	-
600	97.44	98.55	98.06	98.19	99.11	-
425	90.15	94.91	93.56	93.89	98.57	-
300	64.66	80.78	76.44	77.57	96.51	-
212	27.62	41.53	31.61	34.66	86.28	-
150	6.47	8.8	6.61	7.22	54.13	-
62	0	0	0	0	0	-

Sieve size µm	Ref 1	Ref 2
2000	99.96	-
1180	99.64	-
850	98.97	-
600	96.4	-
425	88.27	-
300	67.37	-
212	31.49	-
150	5.92	-
62	0	-

APPENDIX 6 GRANULOMETRIC SCALES

Granulometric scales used in classifying sediments after Wentworth (1922) and Folk (1954).

phi	mm	µm	Wentworth	Folk
-8	256	256000	Boulders	Gravel
-7	128	128000	Cobbles	Gravel
-6	64	64000	Cobbles	Gravel
-5	32	32000	Pebbles	Gravel
-4	16	16000	Pebbles	Gravel
-3	8	8000	Pebbles/granules	Gravel
-2	4	4000	Granules	Gravel
-1	2	2000	Granules	Gravel
0	1	1000	Very coarse sand	Sand
1	0.5	500	Coarse sand	Sand
2	0.25	250	Medium sand	Sand
3	0.125	125	Fine sand	Sand
4	0.0625	63	Very fine sand	Sand
5	0.0312	31	Silt	Mud
6	0.0156	16	Silt	Mud
7	0.0078	8	Silt	Mud
8	0.0039	4	Silt	Mud
>8	<0.0039	<4	Clay	Mud