CORRIB OFFSHORE GAS FIELD DEVELOPMENT

CORRIB OFFSHORE FIELD ENVIRONMENTAL SURVEY 2008

September 2009

CONTENTS

Tables

Figures

Appendices

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**.

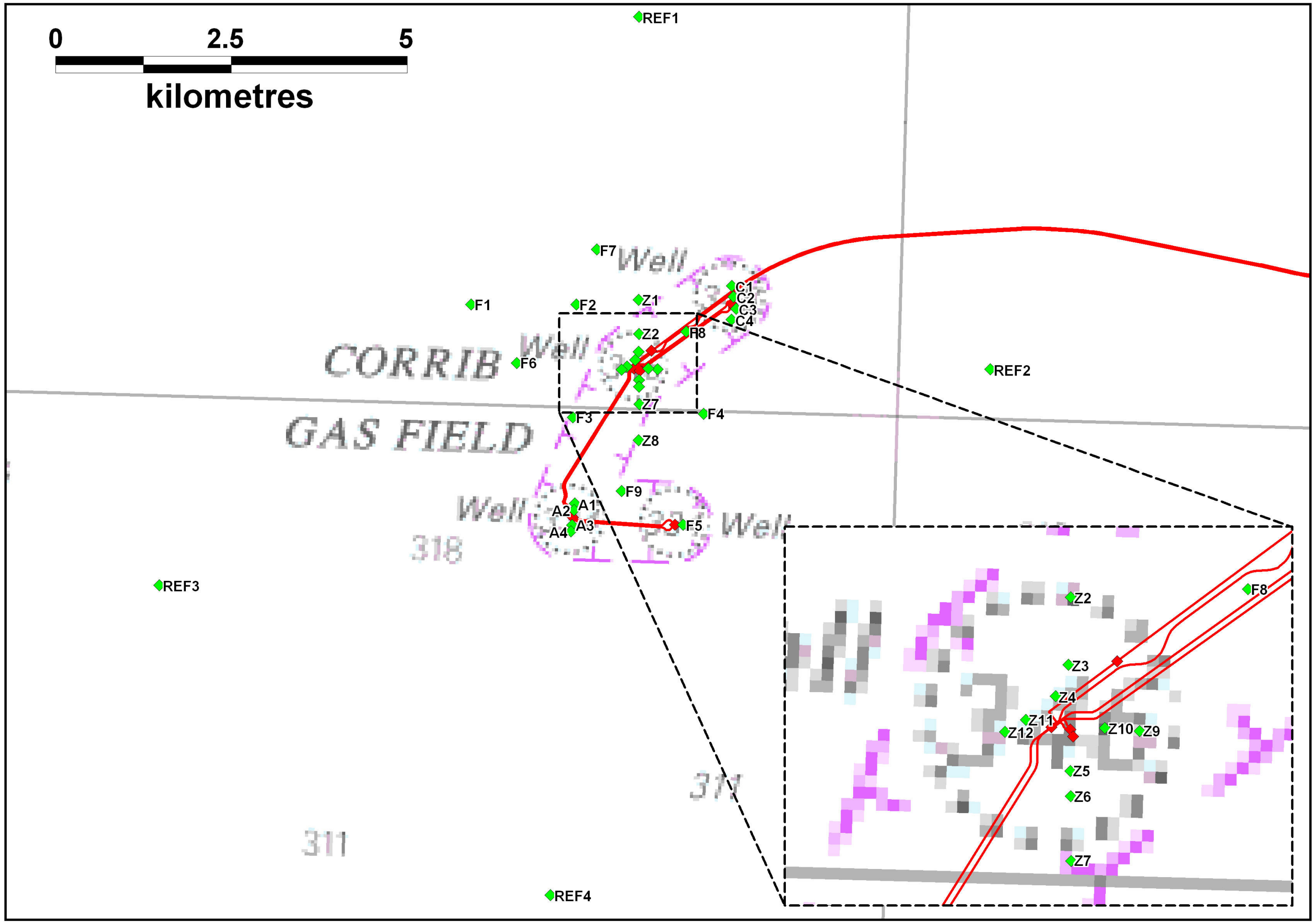


Figure 2.1: Overview map of planned locations in the Corrib field for summer 2008

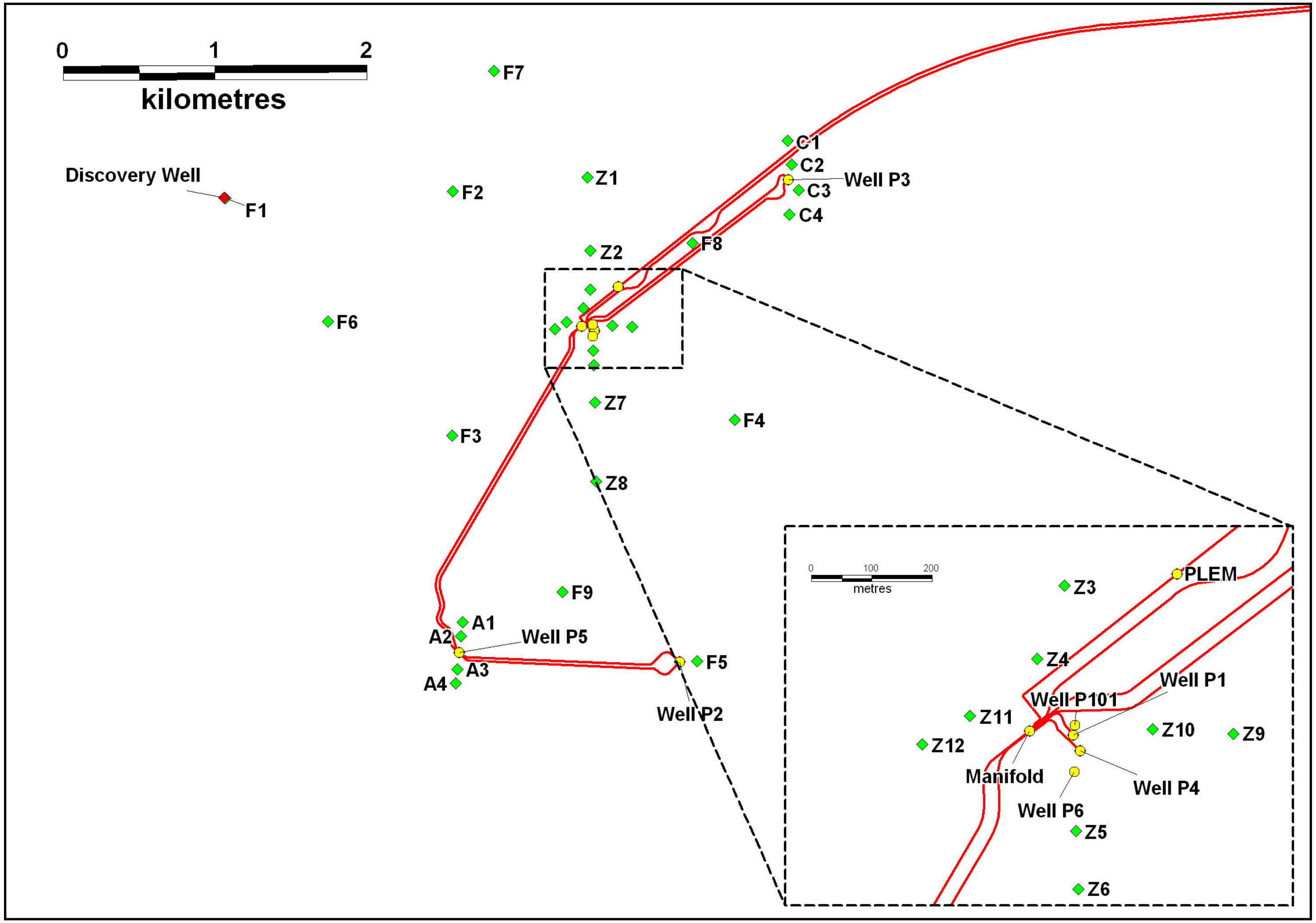


Figure 2.2: Detailed map of planned stations in the Corrib field.

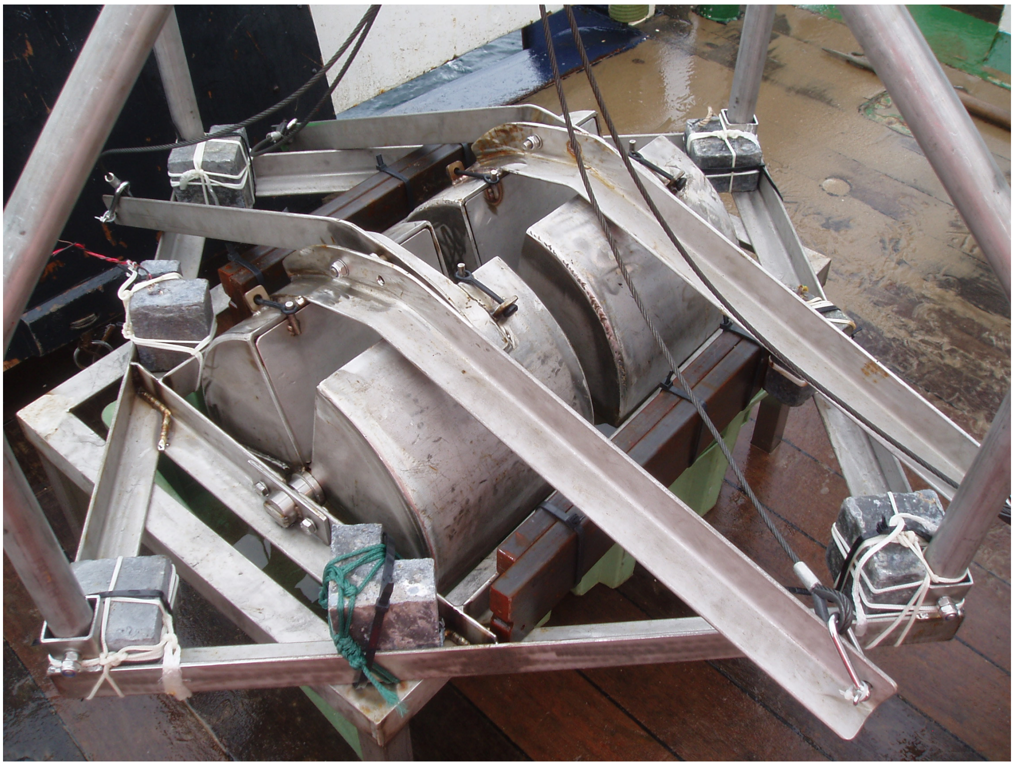


Figure 2.3: Double Van Veen grab used for sediment sampling

Table 2.2: Sediment quality sub-samples collected

<table>
<tr><th>Parameter</th><th>Weight/ Volume</th><th>Container</th><th>Preservation</th><th>Analysis</th></tr>
<tr><td>Particle size analysis</td><td rowspan="4">c.1kg</td><td rowspan="4">Double-labelled plastic tub or Ziploc bag</td><td rowspan="4">Frozen</td><td>Full particle size distribution (phi scale, includes the <63µm fraction)</td></tr>
<tr><td>Total organic carbon</td><td>Complete levels of organic carbon present</td></tr>
<tr><td rowspan="2">Inorganic chemistry (hydrocarbons and saturates)</td><td>Solvent extraction to produce a total organic extract (TOE), qualitative and quantitative analysis of the total hydrocarbon fraction by GC-FID.</td></tr>
<tr><td>Polycyclic aromatic hydrocarbons (2-6 ring EPA16 PAH and NPD (naphthalenes, phenanthrenes, dibenzothiophenes + alkylated homologues));</td></tr>
<tr><td>Metals</td><td>c.300ml (duplicate taken)</td><td>Double-labelled aluminium tins or glass jars</td><td>Frozen</td><td>Heavy and trace metals (totals following aqua regia digest)
Insoluble Ba (following sodium fusion)</td></tr>
</table>

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 F8 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	0.097	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	6.65	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	156	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.

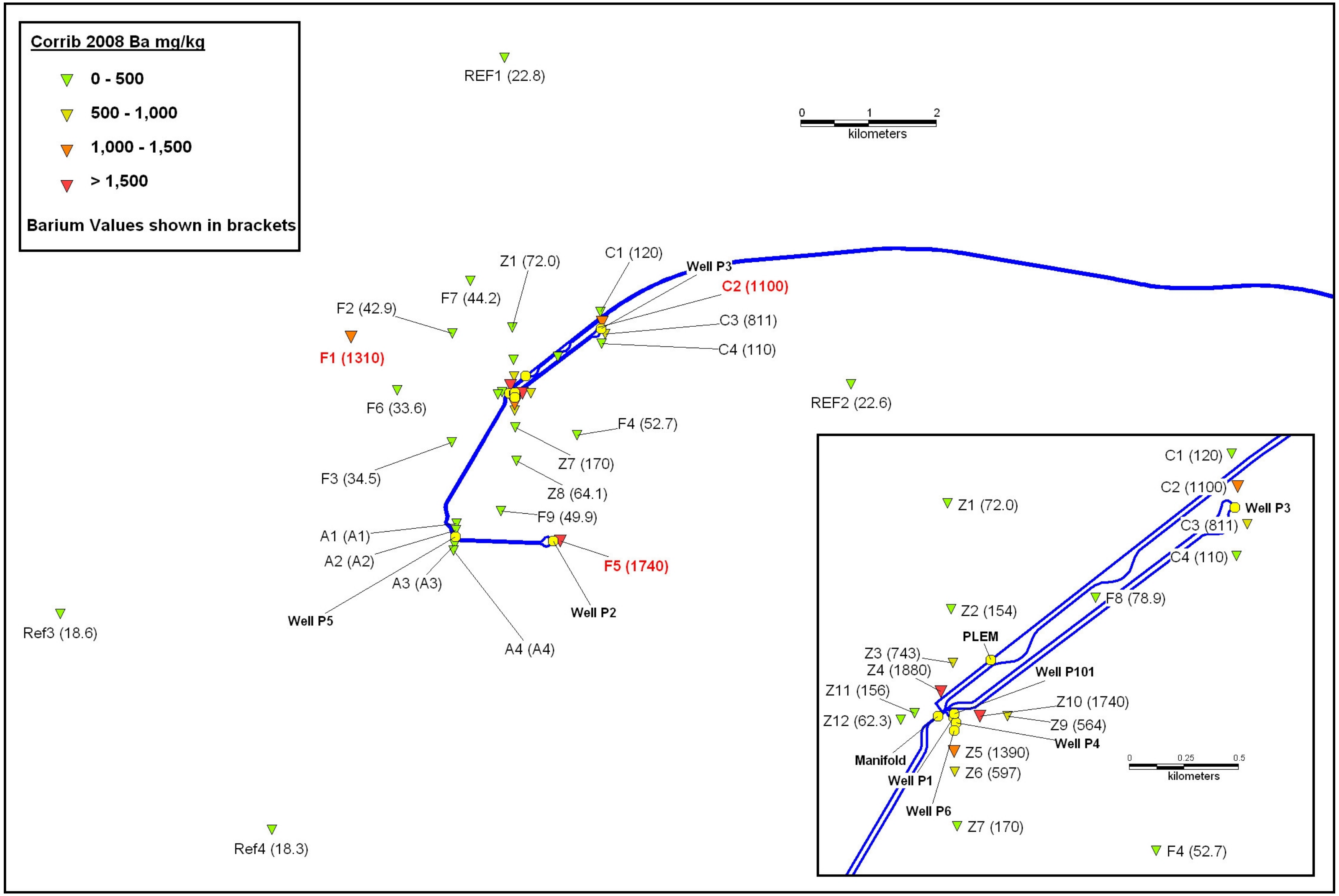


Figure 3.1: Barium concentrations (mg/kg) in sediment from the 2008 Corrib field survey

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:	(yellow)	*Shows maximum value recorded*				
	(green)	*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.

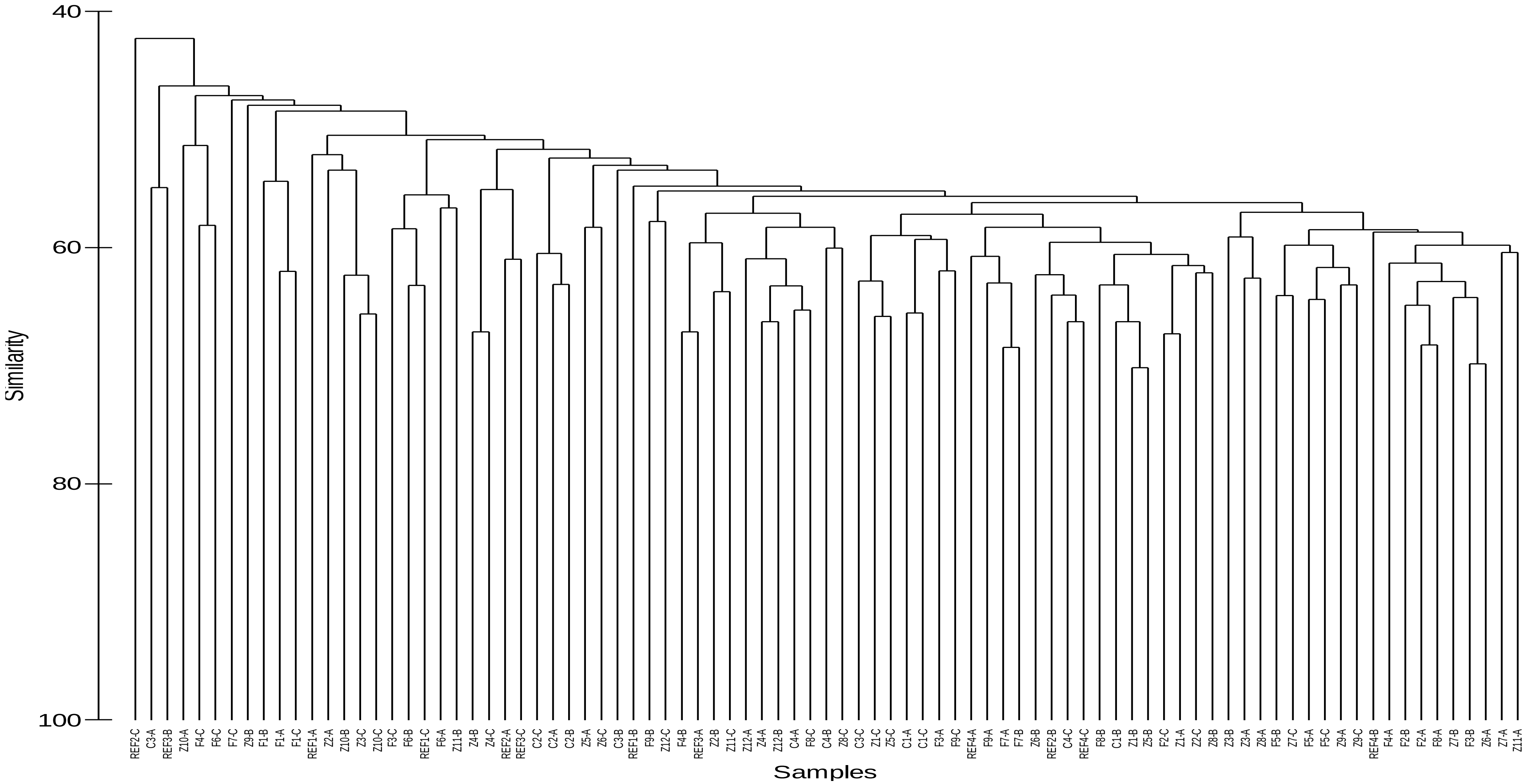


Figure 3.2: Dendrogram showing clustering of communities (per replicate) from sites at the Corrib field (square root transformed data)

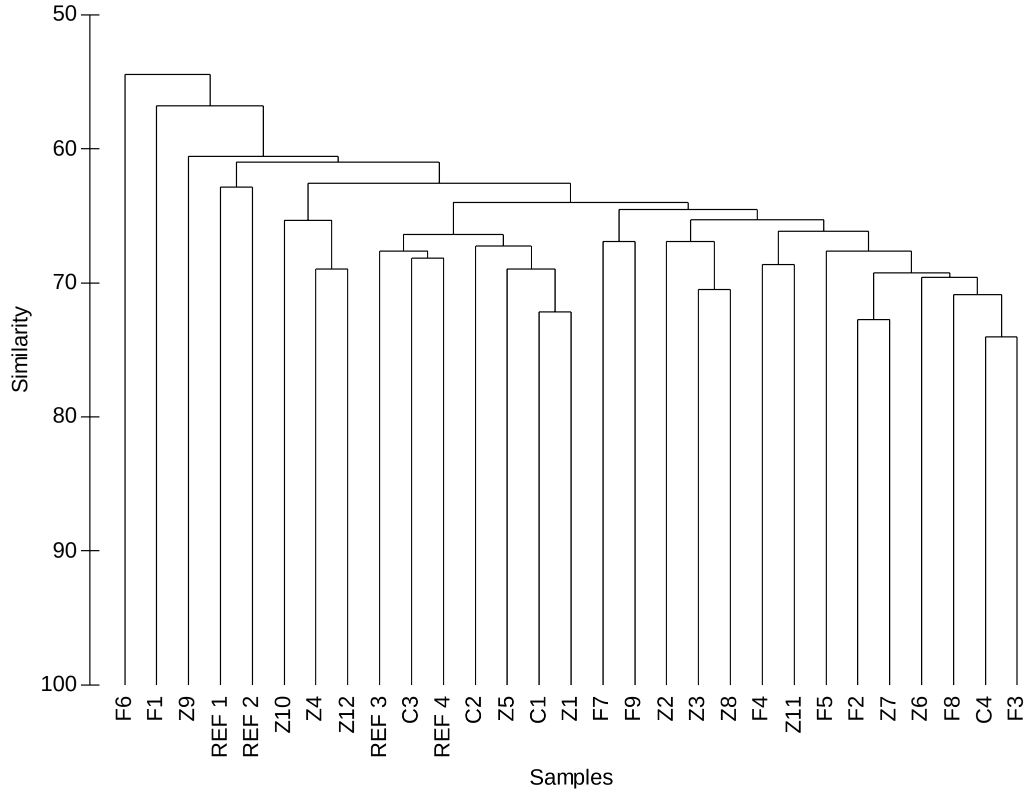


Figure 3.3: Dendrogram showing clustering of communities (per site) at the Corrib field (square root transformed data)

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.

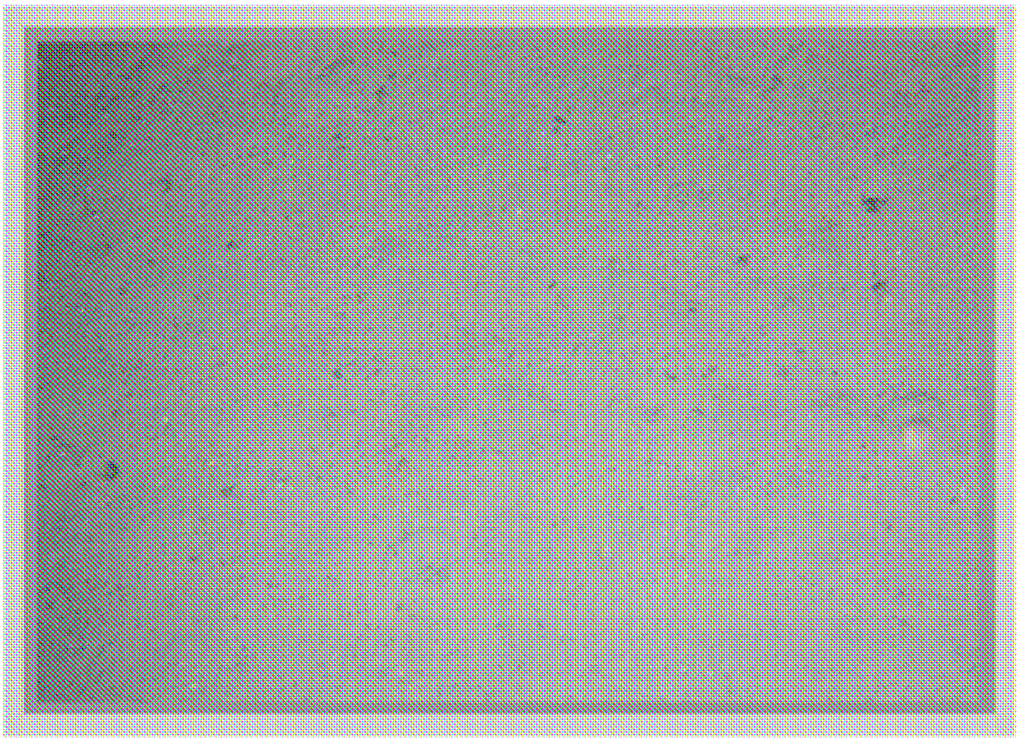


Figure 3.6: Seabed surface photograph, station F1

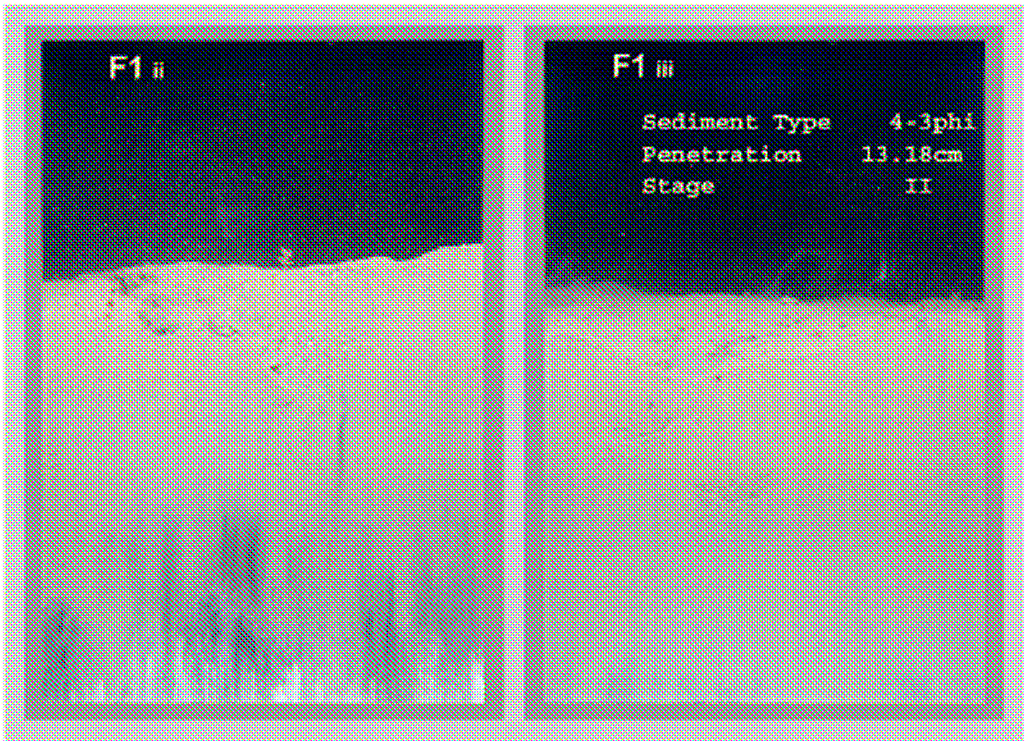


Figure 3.7: Seabed SPI at station F1, ARPD visible

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

Aqua-Fact, 2000a. Sediment Profile Imagery (SPI) Survey: Corrib Field, July 2000. Prepared by Aqua-Fact International Services Ltd, Ireland. 49 pages

Aqua-Fact, 2000b. A report on the marine environment in the vicinity of the Corrib Natural Gas Field and pipeline route to a land-based terminal close to Broadhaven Bay, Co. Mayo. Prepared by Aqua-Fact International Services Ltd, Ireland on behalf of RSK Environment Ltd., 55 pages

Aqua-Fact, 2007. Sediment Profile Imagery Survey, Corrib Field Development, proposed pipeline route and field. August 2007. On behalf of RSK Environment Ltd. 17 pages plus appendices.

CCME, 1999. Canadian sediment quality guidelines for the protection of aquatic life: Summary tables. In: *Canadian environmental quality guidelines*, 1999, Canadian Council of Ministers for the Environment, Winnipeg.

Corrib EIS. 2001. Submission to the Department of the Marin and Natural Resources, Environmental Impact Statement for the Corrib Field Development (Offshore Field to Terminal). Prepared on behalf of Enterprise Energy Ireland by RSK Environment Ltd.

Eleftheriou, A., and N.A. Holme. 1984. Macrofauna techniques. In Methods for the Study of Marine Benthos. (ed. N.A. Holme, A.D. McIntyre), pp. 140-216. Blackwell Scientific Publications, Oxford.

International Association of Oil & Gas Producers. 2003. *Environmental aspects of the use and disposal of non aqueous drilling fluids associated with offshore oil & gas operations*, Report No. 342, May.

Nicolaidou, A., A. Zenetos, M.A. Pancucci, and N. Simboura. 1993. Comparing ecological effects of two different types of pollution using multivariate techniques. *P.S.Z.N.I: Marine Ecology* 14: 113–128.

Nixon, E. 1995. Report on Irish Sea Monitoring as part of Albright and Wilson's European Union LIFE Programme (UK/006). Fisheries Research Centre, Dublin.

NSTF. 1993 North Sea Quality Status Report 1993. North Sea Task Force. Oslo and Paris Commissions. International Council for the Exploration of the Sea. Olsen & Olsen, Fredensborg.

OSPAR Commission. 2000. Quality Status Report 2000. OSPAR Commission, London.

Pielou, E.C. 1966. The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology* 13**:** 131–144.

Shannon, C.E., and W. Weaver. 1963. The mathematical theory of communication. Urbana, IL: University of Illinois Press.

Simpson, E.H. 1949. Measurement of diversity. *Nature* (London) 163: 688.

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.

Wilson, I. 2007. Offshore environmental work scope for benthic and water quality sampling at the Corrib Field Development and along the proposed pipeline route corridor and outfall location – project briefing document. Prepared for RSK Environment Ltd.

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	Taxon	Qualifier	C1-A	C1-B	C1-C
	Cnidaria				
D0617	Virgularia	juvs			
D0618	Virgularia mirabilis				
D0662	Actinaria				
D0662	Actiniaria	burrowing			
D0759	Edwardsiidae				
	Nemertea				
G0001	Nemertea	indet	6	1	3
G0034	Tubulanus polymorphus		2	2	2
G0039	Cerebratulus	indet			1
	Nematoda				
HD001	Nematoda	indet	1		
	Chaetognatha				
L0001	Chaetognatha				
	Sipuncula				
N0011	Golfingiidae	juvs			
N0014	Golfingia elongata				
N0037	Onchnesoma steenstrupi				
N0047	Aspidosiphon muelleri				
	Annelida				
P0017	Aphroditidae	juvs	1		1
P0025	Polynoidae	juvs/scale-less			
P0052	Harmothoe antilopes				
-	Malmgreniella arenicolae				
P0062	Malmgreniella glabra				
P0078	Lepidasthenia argus				
P0087	Panthalis oerstedi				
P0100	Neoleanira tetragona				
P0107	Sthenelais	juvs			
P0109	Sthenelais limicola		3		1
P0116	Eteone				
P0141	Anaitides groenlandica				
P0142	Anaitides lineata				
P0143	Anaitides longipes				
P0144	Anaitides maculata				
P0146	Anaitides rosea			1	
-	Paranaitis uschakovi				
P0190	Sige	indet			
P0255	Glycera	juvs/damaged			
P0256	Glycera alba				
P0260	Glycera lapidum		5	5	1
P0263	Glycera rouxii		2		
P0266	Goniadidae	juvs			
P0268	Glycinde nordmanni				
P0271	Goniada maculata			1	
P0284	Sphaerodoridium claparedii				
P0313	Ophiodromus flexuosus				
P0319	Podarkeopsis capensis			1	
P0338	Ancistrosyllis groenlandica		1	1	
P0340	Glyphohesione klatti		2	1	
P0342	Litocorsa stremma				
P0421	Exogone hebes				
P0423	Exogone verugera				
P0458	Nereididae	juvs			
P0494	Nephtys	juvs	4	2	
P0499	Nephtys hombergii				
P0500	Nephtys hystricis		1		1
P0502	Nephtys kersivalensis		1		
P0518	Paramphinome jeffreysii		1	1	
P0545	Nothria conchylega				
P0564	Marphysa bellii				
P0579	Lumbrineris gracilis		1	2	
P0580	Abyssoninoe hibernica		1		
P0583	Scoletoma cf. magnidentata				
P0590	Drilonereis brattstroemi				
P0598	Dorvilleidae	indet			
P0607	Dorvillea erucaeformis				
P0613	Ophryotrocha				1
P0643	Schistomeringos rudolphi				
P0668	Orbinia grubei				
P0672	Scoloplos armiger		1		
P0675	Aricidea	head only	2		
P0678	Aricidea wassi		10	1	2
P0680	Aricidea albatrossae				
P0682	Aricidea suecica				
P0684	Aricidea catherinae			1	
P0686	Aricidea laubieri			1	2
P0691	Cirrophorus furcatus				
P0693	Levinsenia gracilis		27	20	14
P0701	Paraonides myriamae		2		1
P0711	Apistobranchus tenuis		3	1	
P0718	Poecilochaetus serpens				
P0720	Spionidae	head regenerating			
P0721	Aonides	juvs			
P0723	Aonides paucibranchiata			2	
P0725	Atherospio distincta				
P0731	Laonice	head regenerating			
P0733	Laonice bahusiensis		1		1
P0735	Laonice sarsi				
P0747	Minuspio cirrifera		4	1	1
P0750	Polydora caeca				
P0763	Prionospio	juvs			
P0764	Prionospio dubia				2
P0765	Prionospio fallax		21	12	10
P0771	Pseudopolydora				
P0777	Scolelepis	damaged/juvs			
P0785	Scolelepis tridentata				
P0794	Spiophanes bombyx				
P0796	Spiophanes kroyeri		7	3	5
P0795	Spiophanes ?wigleyi				
P0805	Magelona filiformis				
P0806	Magelona minuta				2
P0810	Chaetopteridae	damaged			
P0818	Spiochaetopterus				
P0822	Cirratulidae	juvs			
P0824	Aphelochaeta		1	3	1
-	Aphelochaeta	sp. 'A'			
P0834	Chaetozone setosa				
-	Cirratulus caudatus				
P0844	Monticellina dorsobranchialis				
P0845	Tharyx		2		
P0846	Tharyx killariensis		1		2
P0878	Diplocirrus glaucus				
P0889	Macrochaeta		2		1
P0907	Capitella	agg.			
P0914	Dasybranchus caducus				
P0919	Mediomastus fragilis				
P0920	Notomastus				
P0925	Peresiella clymenoides		10	3	6
P0938	Maldanidae	juvs			
P0940	Lumbriclymene	head only			
P0944	Praxillura longissima				
P0947	Chirimia biceps				
P0955	Clymenura				
-	Clymenura tricirrata				
P0960	Euclymene				
P0971	Praxillella affinis				
P0991	Rhodine loveni				
P1013	Ophelina abranchiata		1		1
P1015	Ophelina cylindricaudata		1	2	1
P1027	Scalibregma inflatum				
P1093	Galathowenia oculata		172	108	66
P1095	Myriochele danielsseni				
P1098	Owenia fusiformis		1	1	
P1100	Pectinariidae	juvs			1
P1102	Amphictene auricoma				
P1125	Ampharetinae	juvs/damaged	2		
P1142	Amphicteis gunneri				
P1145	Amythasides macroglossus				
P1147	Anobothrus gracilis				
P1149	Eclysippe vanelli		4	1	1
P1157	Mugga wahrbergi		2	1	1
P1163	Samytha sexcirrata				
P1169	Sosanopsis wireni				
P1175	Terebellides stroemi		1	1	1
P1178	Trichobranchus roseus				
P1180	Amphitritinae	juvs/damaged			
P1195	Lanice conchilega				
P1211	Nicolea zostericola				
P1213	Paramphitrite tetrabranchia				
P1218	Pistella lornensis				
P1229	Amaeana trilobata				
P1235	Polycirrus	damaged		1	1
P1242	Polycirrus medusa				
P1257	Sabellidae	juvs			
P1264	Chone	damaged		1	2
P1265	Chone acustica				
P1266	Chone collaris				
P1267	Chone duneri				
P1281	Euchone ?southerni				
-	Euchone cf. incolor		5	5	2
P1290	Jasmineira elegans				
P1328	Ditrupa arietina				
P1334	Hydroides norvegica				
P1340	Pomatoceros lamarcki				
	Chelicerata				
-	Nymphon cf. laterospinum				
	Crustacea				
R0142	Copepoda		4	2	4
R2412	Ostracoda				
	Hypererythrops serriventer				
S0056	Pseudomma affine				
S0109	Eusirus longipes				
S0131	Perioculodes longimanus				
S0138	Synchelidium maculatum				
S0140	Westwoodilla caecula				
S0178	Leucothoe lilljeborgi		1		
S0213	Stenothoe marina				
S0248	Urothoe elegans				
S0254	Harpinia antennaria		1	1	1
S0255	Harpinia crenulata				
S0271	Lysianassidae				
S0274	Acidostoma nodiferum		1		2
S0296	Hippomedon denticulatus				
S0334	Sophrosyne robertsoni		1		
S0374	Epimeria cornigera				
S0406	Nicippe tumida				
-	Halice cf. walkeri				
S0423	Ampelisca	juvs			
S0424	Ampelisca aequicornis				
S0431	Ampelisca gibba				
S0432	Ampelisca macrocephala				
S0436	Ampelisca spinifer				
S0438	Ampelisca spinipes				
S0440	Ampelisca tenuicornis		1		1
S0442	Ampelisca typica				
S0443	Byblis				
S0503	Cheirocratus	females			
S0510	Eriopisa elongata				
S0538	Gammaropsis	damaged			
S0565	Ericthonius ?rubricornis				
S0793	Gnathia	praniza			
S0844	Natatolana borealis				
S0856	Eurydice truncata				
S0911	Paramunna bilobata				
S0931	Pseudarachna hirsuta				
S1099	Tanaidacea				
S1183	Cumacea	tail only			
S1201	Iphinoe serrata				
S1208	Eudorella truncatula		2		
S1213	Leucon nasica				
S1215	Campylaspis				
S1257	Diastyloides biplicata				
S1266	Meganyctiphanes norvegica				
S1269	Stylocheiron				
S1278	Penaeoidea	damaged			
S1293	Caridea	juvs/damaged			
S1362	Processa	damaged			
S1367	Processa nouveli				
S1373	Pandalina	indet			
S1374	Pandalina brevirostris				
S1404	Thalassinoidea	juvs			
S1445	Paguridae	juvs			
	Munida				
-	Munida intermedia				
S1504	Ebalia	juvs			
S1555	Atelecyclus rotundatus		1		1
-	Decapoda	larvae		1	
	Mollusca				
W0002	Caudofoveata	damaged			
W0009	Chaetoderma nitidulum		3		
W0011	Falcidens crossotus		1	2	1
W0012	Solenogastres				
W0019	Lepidomeniidae			1	1
W0088	Gastropoda	damaged			
W0431	Aporrhais serresianus				
W0482	Naticidae	juvs		1	
W0489	Polinices fuscus				
W0494	Euspira pallida				
W0702	Buccinidae	juvs			
W0771	Turridae	juvs			
-	Gymnobela subarenosa				
W0985	Turbonilla crenata				
W1006	Acteon tornatilis				
-	Scaphander punctostriatus				
-	Cylichna alba			2	
W1028	Cylichna cylindracea				
W1068	Haminoea hydatis				
W1077	Retusa obtusa		2		
W1169	Limacina retroversa				
-	Entalina tetragona	indet			
W1554	Gadila subfusiformis				
-	Dentalium agile		4	1	
W1560	Pelecypoda	damaged/juvs			
W1563	Nuculidae	juvs			
W1566	Nucula	juvs			
W1577	Nuculoma tenuis		1		
W1624	Yoldiella lenticula				
-	Yoldiella jeffreysi				
-	Limatula bisecta				
W1747	Limatula subovata				
W1803	Similipecten similis				
W1835	Thyasira	juvs			
W1837	Thyasira flexuosa				
W1845	Axinulus croulinensis		6	8	4
W1851	Mendicula ferruginosa		3	3	
W1852	Adontorhina similis		6	6	3
-	Kelliella abyssicola		9		8
W1902	Tellimya ferruginosa				
W1911	Epilepton clarkiae				
W1937	Cardiacea	juvs			
W2058	Abra	juvs	10	5	4
W2061	Abra nitida				
W2104	Timoclea ovata				
W2166	Hiatella arctica				
W2226	Thraciidae	juvs			
W2277	Cuspidaria	juvs	4	4	1
W2286	Cuspidaria rostrata				
W2289	Cardiomya costellata				
W2294	Cuspidaria abbreviata			2	
	Bryozoa				
Y0017	Crisia eburnea				
Y0080	Alcyonidium mytili				
Y0279	Scrupocellaria scruposa				
	Phoronida				
ZA003	Phoronis	indet			
	Echinodermata				
ZB018	Asteroidea	juvs	4	2	3
ZB026	Astropecten irregularis				
ZB105	Ophiuroidea	juvs	6		2
ZB149	Amphiura	juvs			
ZB154	Amphiura filiformis				
ZB167	Ophiocten affinis				
ZB181	Echinoidea	smashed/juvs	4	3	4
ZB212	Echinocyamus pusillus				
ZB222	Echinocardium	juvs			
ZB224	Echinocardium flavescens				
ZB228	Brissopsis lyrifera				
ZB257	Pseudothyone raphanus				
ZB290	Synaptidae	juvs	2		
ZB299	Labidoplax buskii		1	2	
ZB300	Labidoplax digitata				
	Hemichordata				
ZC001	Hemichordata	indet	1	2	2
	Pisces				
ZG007	Teleostei	juvs			
	No. Species		64	49	48
	No. Individuals		394	235	180

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).

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

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

CCME, 1999. Canadian sediment quality guidelines for the protection of aquatic life: Summary tables. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers for the Environment, Winnipeg.

Clarke, K.R. & Warwick R.M. (2001). Changes in marine communities: An approach to Statistical Analysis and Interpretation. 2nd Edition. Plymouth Marine Laboratory.

Eleftheriou, A. and Basford, D.J., 1989. The macrofauna of the offshore northern North Sea. *Journal of the Marine Biological Association of the UK.,* **69:**123–143.

Grimwood, M.J., Dixon, E., 1997. Assessment of risks posed by list II metals to Sensitive Marine Areas (SMA's) and adequacy of existing environmental quality standards (EQSs) for SMA protection. Report by WCR to English Nature.

Kruskal, J.B., Wish, M., 1978. Multidimensional scaling. Sage Publications, Beverly Hills, California.

Lance, G.N., Williams, W.T., 1967. A general theory of classificatory sorting strategies: 1 Hierarchical Systems. *Computer Journal.* **9:** 373-380.

Newell, R.C.; Seiderer, L.J.; Simpson, N.M., and Robinson, J.E., 2004. Impacts of marine aggregate dredging on benthic macrofauna off the south coast of the United Kingdom. *Journal of Coastal Research,* **20(1):** 115–125.

Pielou, E.C., 1966. The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology.* **13:** 131-144.

Shannon & Weaver, 1963. The mathematical theory of communication. University of Illinois press. 117pp.

Simpson, E.H., 1949. Measurement of diversity. *Nature* (London). **163:** 688.

	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.

	S	N	N/m^2	J'	H	λ	% of each phyla: 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	75.58	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.

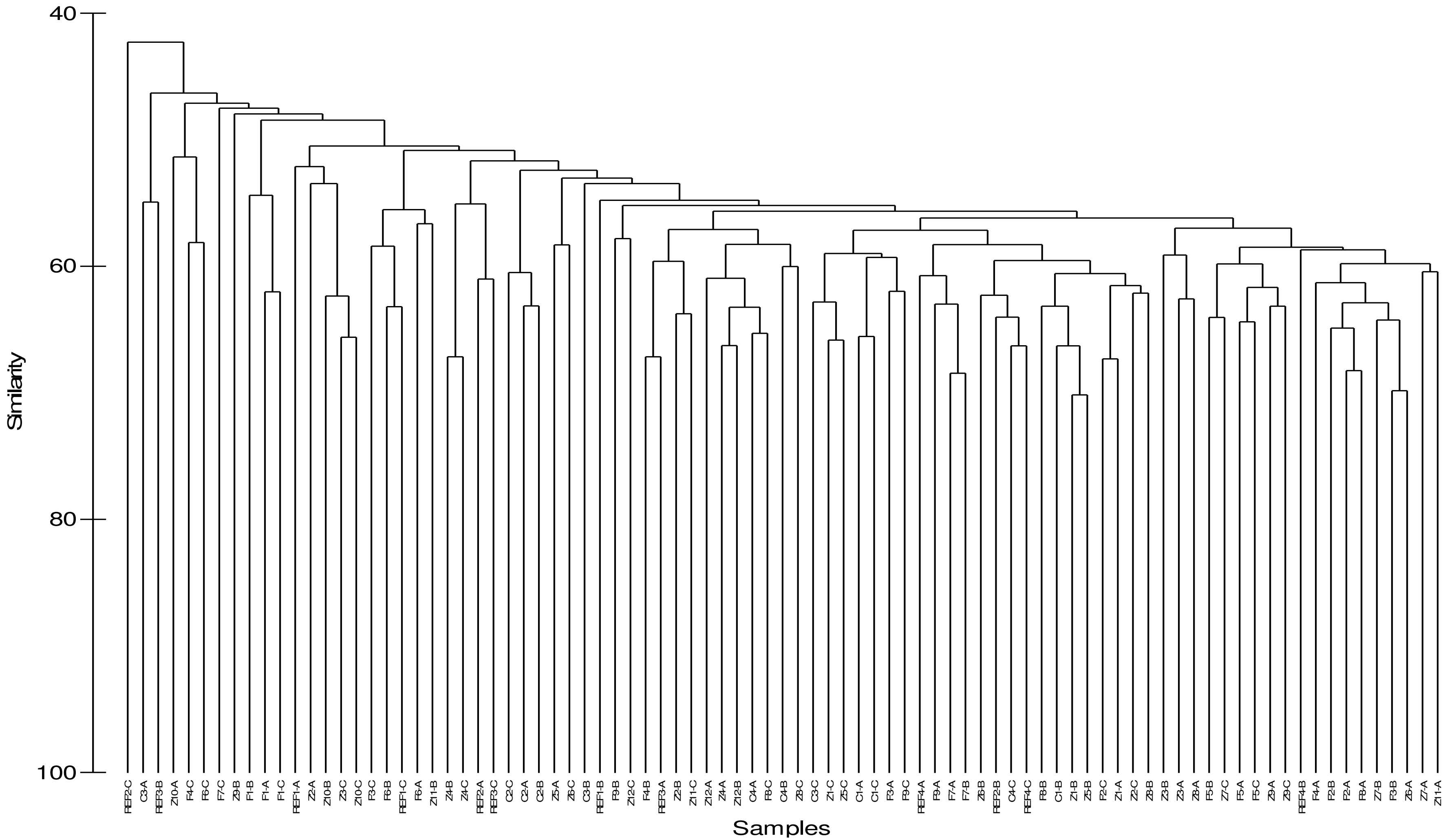


Figure 1. Dendrogram showing clustering of communities using per replicate sample data from sites around the gas field.

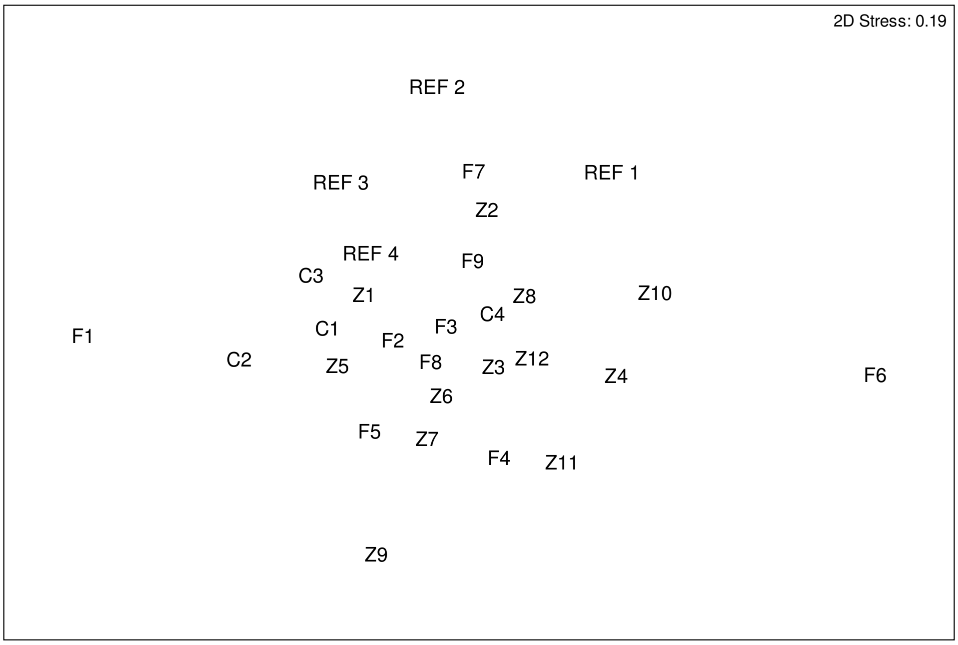


Figure 4. MDS plot of sample sites (per site data) around the gas field.

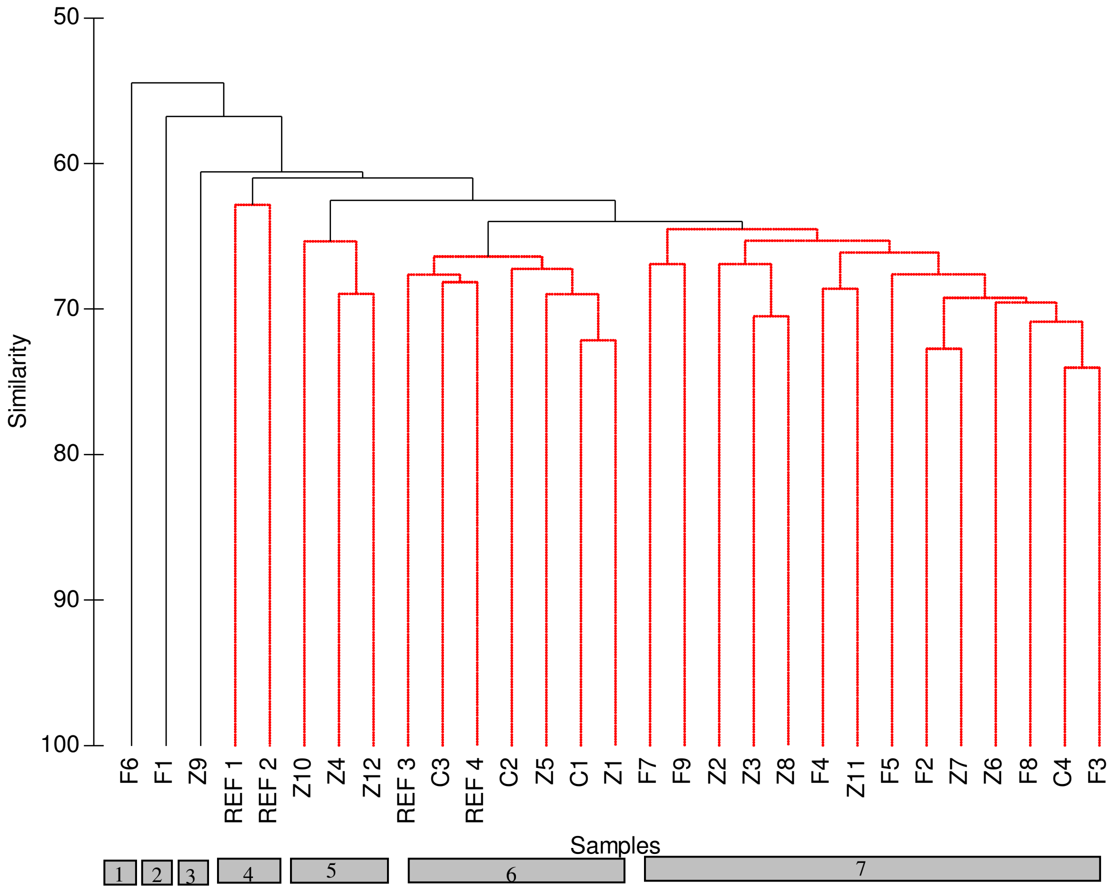


Figure 5. Dendrogram showing clustering of communities using pooled replicate (per site) data taken from sites around the gas field. Black lines indicate where significant differences lie and red dashed lines show sites that are not significantly different.

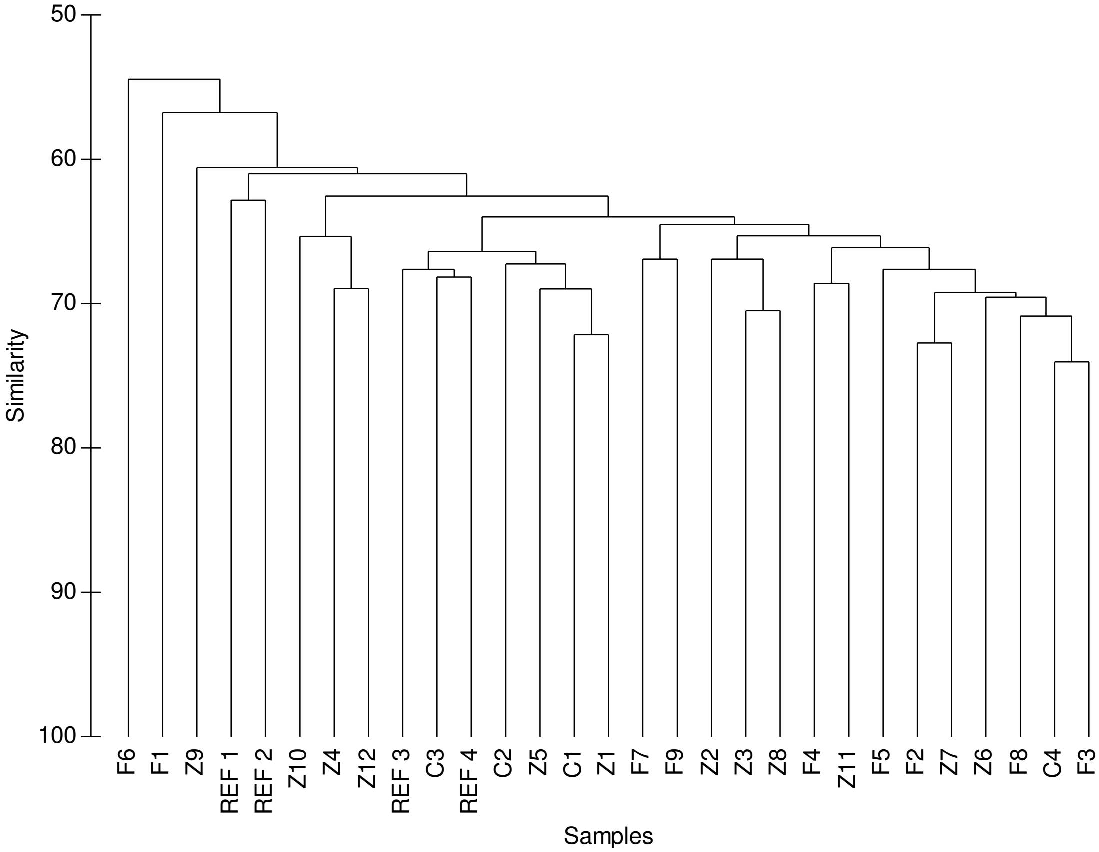


Figure 2. Dendrogram showing clustering of communities using pooled replicate (per site) data taken from sites around the gas field.

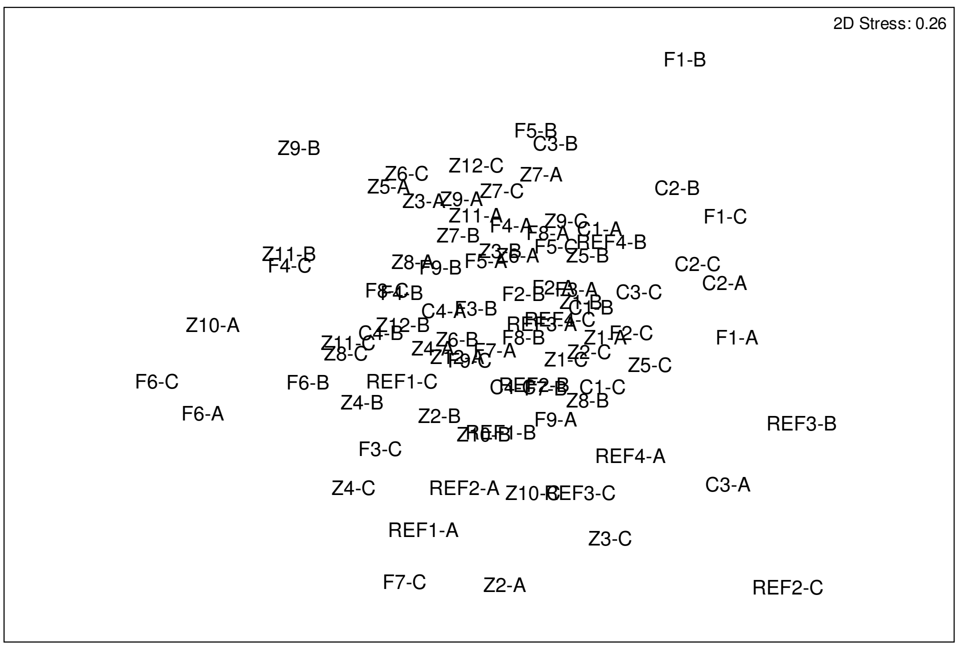


Figure 3. MDS plot of sample sites (per replicate data) around the gas field.

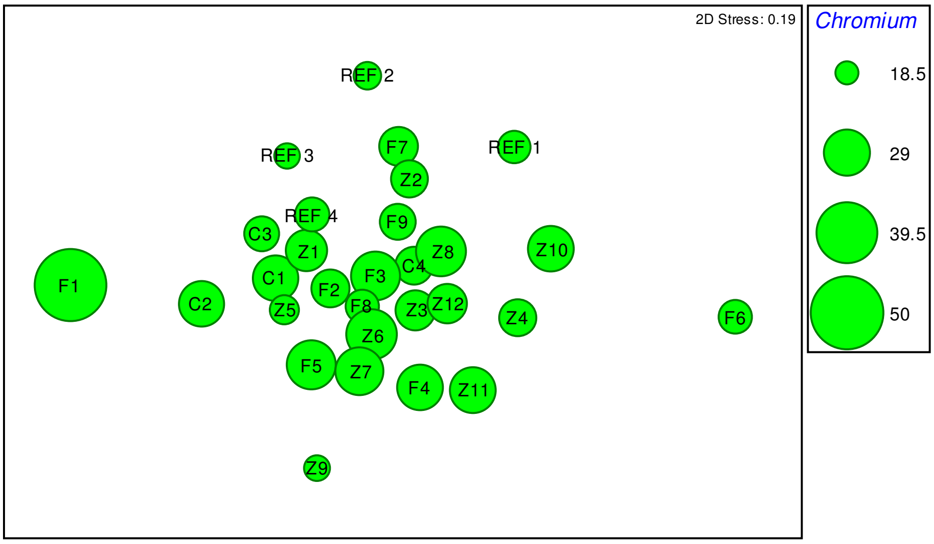


Figure 6. MDS plot of sites around the gas field with superimposed bubbles representing the concentration of chromium ($mgkg^{-1}$) at each site.

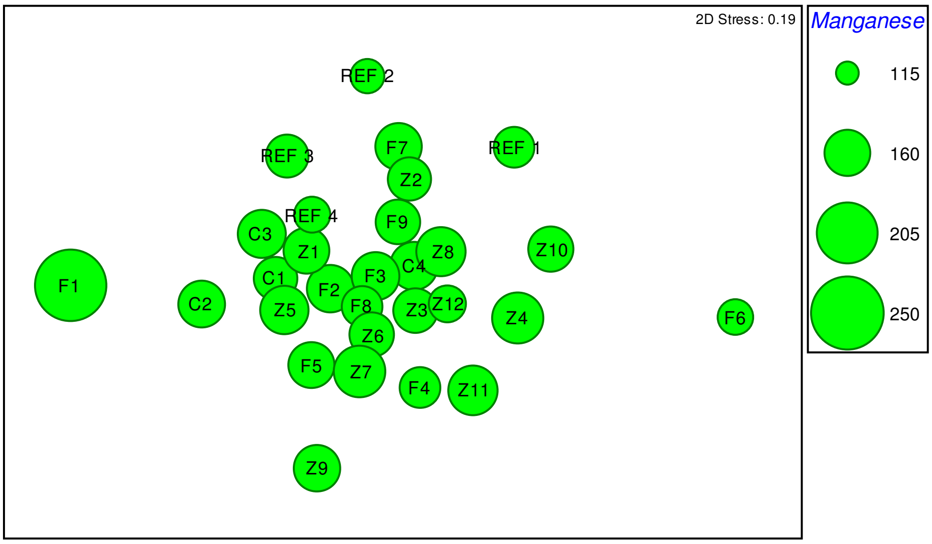


Figure 7. MDS plot of sites around the gas field with superimposed bubbles representing the concentration of manganese ($mgkg^{-1}$) at each site.

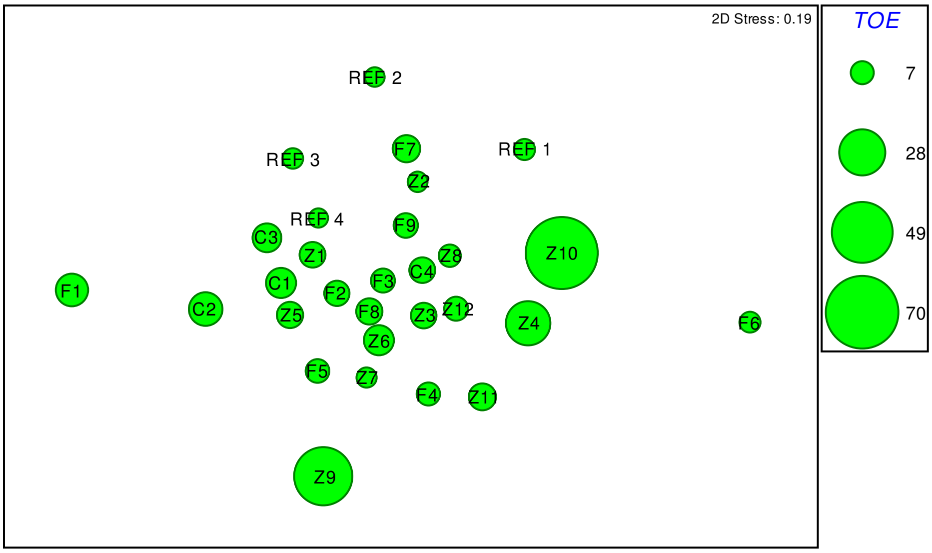


Figure 8. MDS plot of sites around the gas field with superimposed bubbles representing the concentration of total organic esters (ppm) at each site.

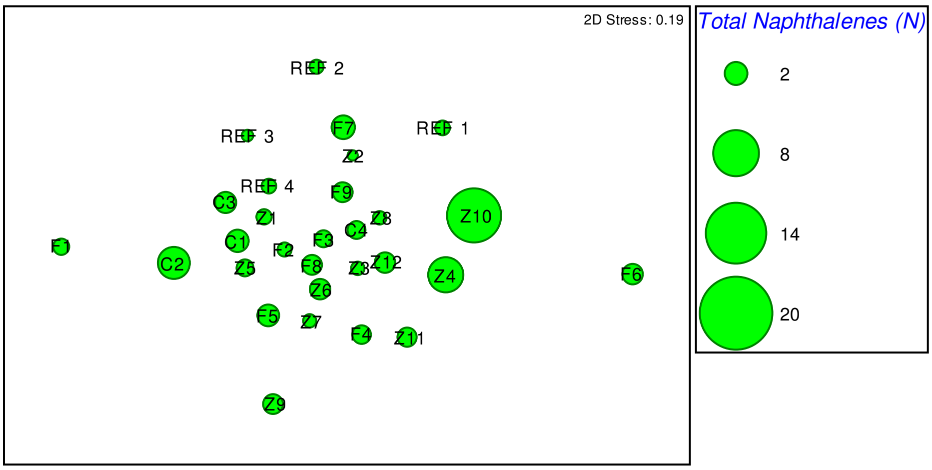


Figure 9. MDS plot of sites around the gas field with superimposed bubbles representing the concentration of total naphthalenes (ppm) at each site.

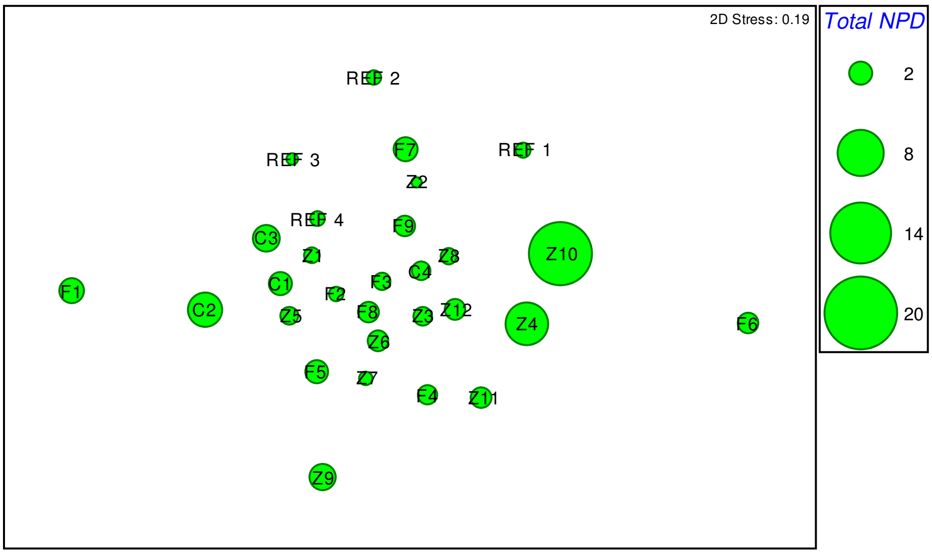


Figure 10. MDS plot of sites around the gas field with superimposed bubbles representing the concentration of total naphthalenes, phenanthrenes and dibenzothiophenes (ppm) at each site.

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

AQUAFACT INTERNATIONAL SERVICES ltd
12 KILKERRIN park
TUAM rd
GALWAY city
www.AQUAFACT.ie

info@AQUAFACT.ie

tel +353 (0) 91 756812
fax +353 (0) 91 756888

Table of Contents

List of Figures

List of Tables

List of Appendices

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.

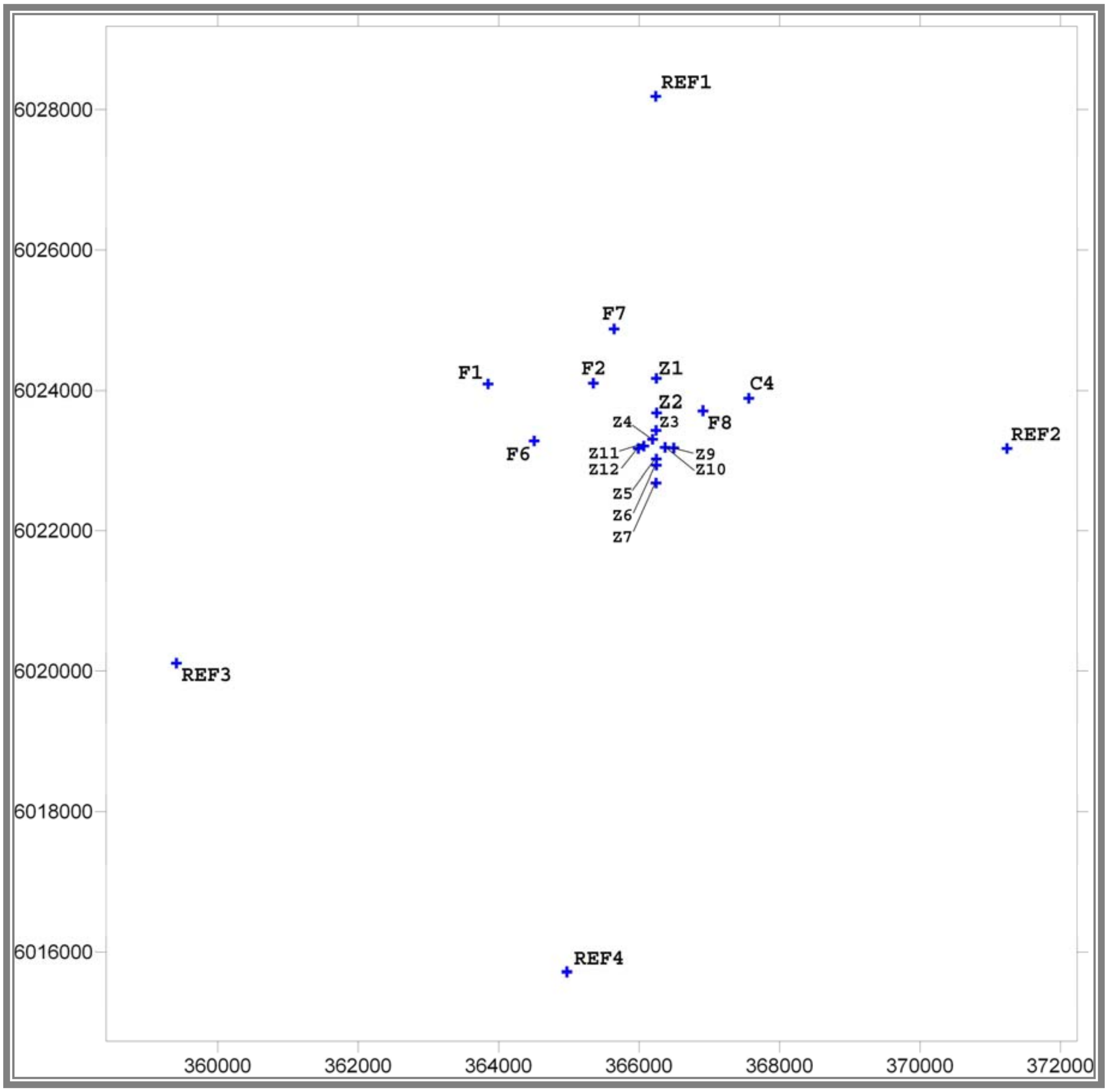


Figure 2 Layout of stations surveyed using SPI on the Corrib Gas Field, July 2008

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.

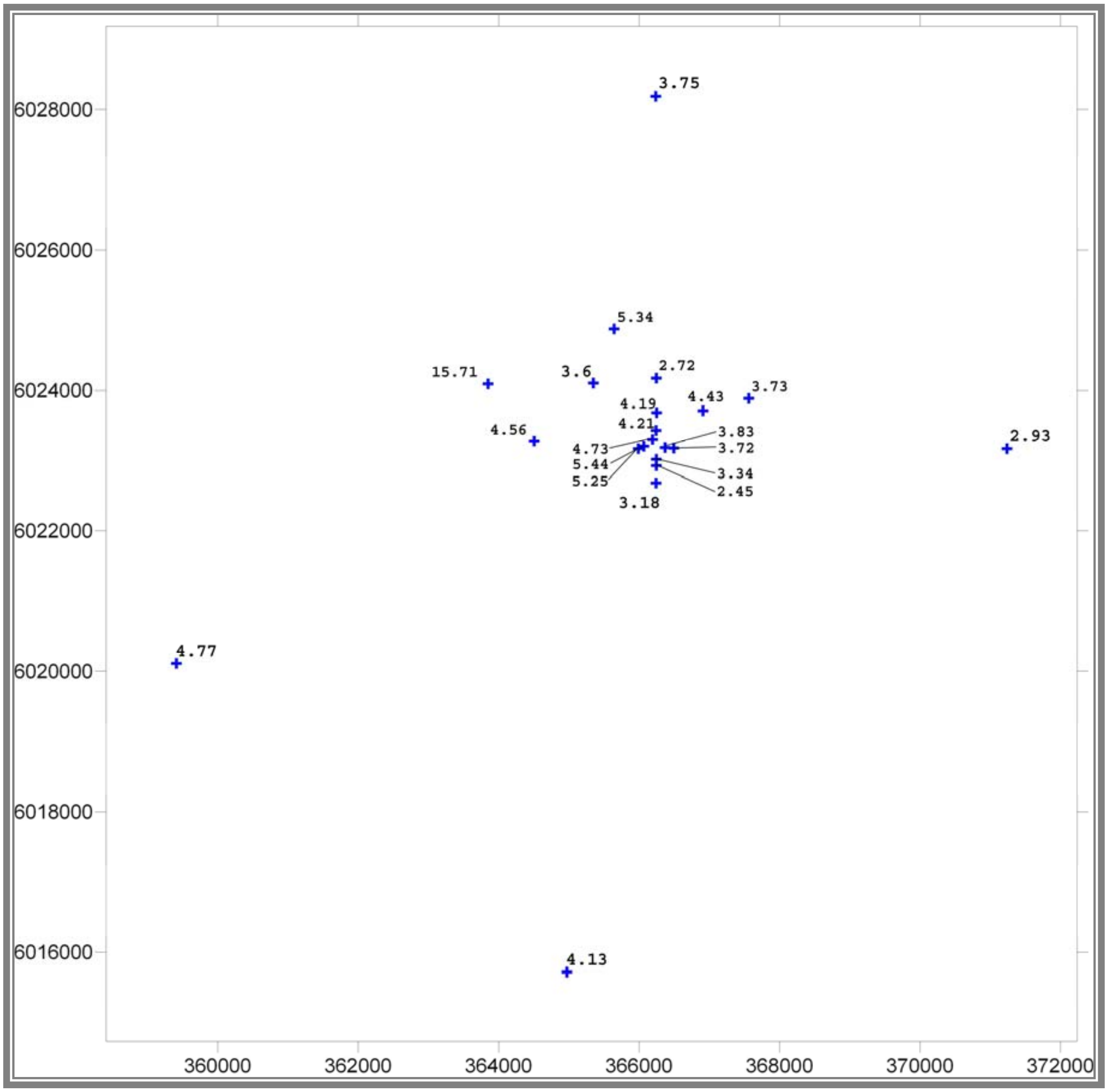


Figure 3 Maximum prism penetration in centimetres achieved in a single deployment at stations surveyed using SPI on the Corrib Gas field, July 2008.

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.

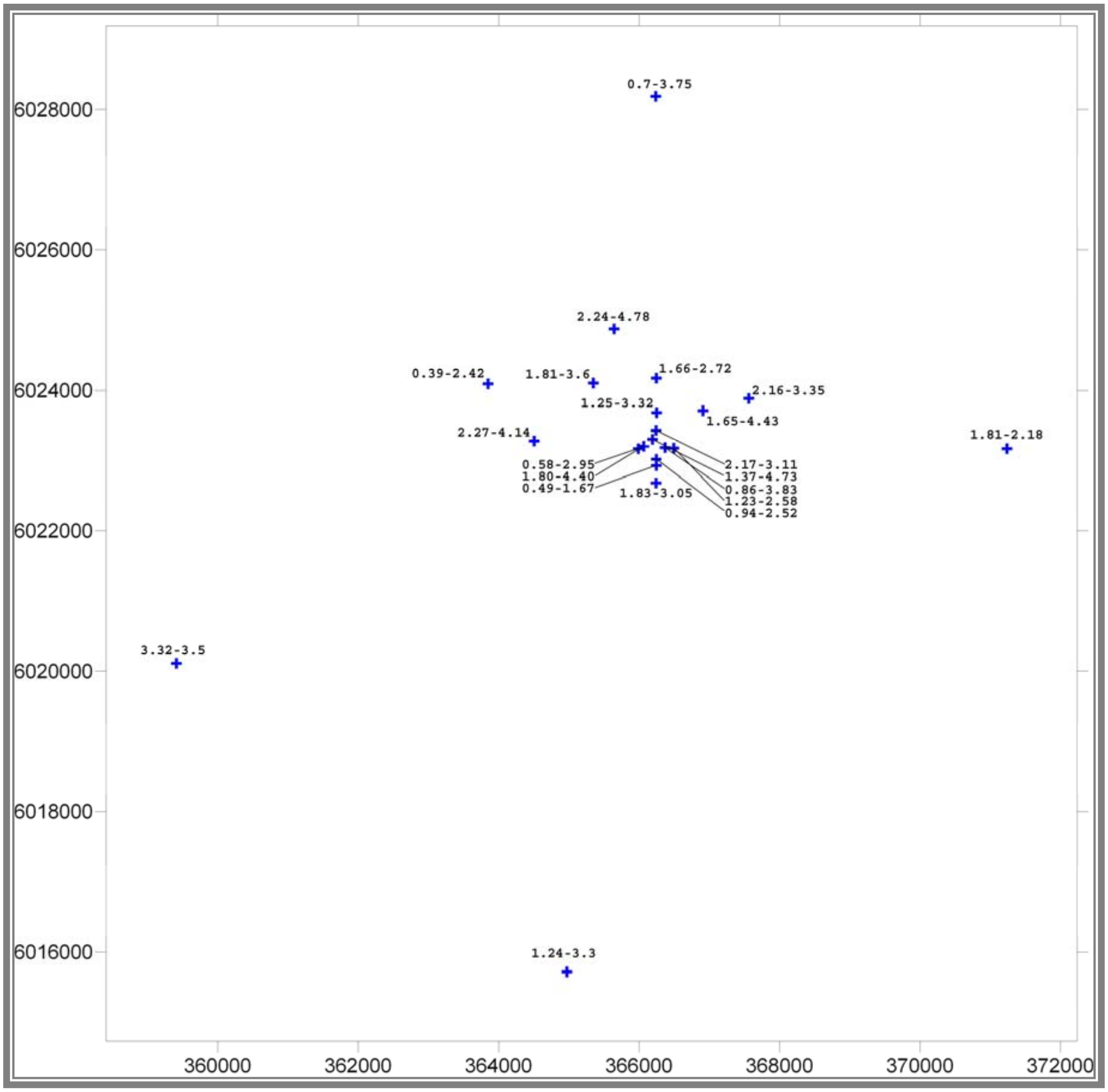


Figure 4 Sediment boundary roughness SBR (ranges in Centimetres) recorded on the Corrib gas field, July 2008.

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.

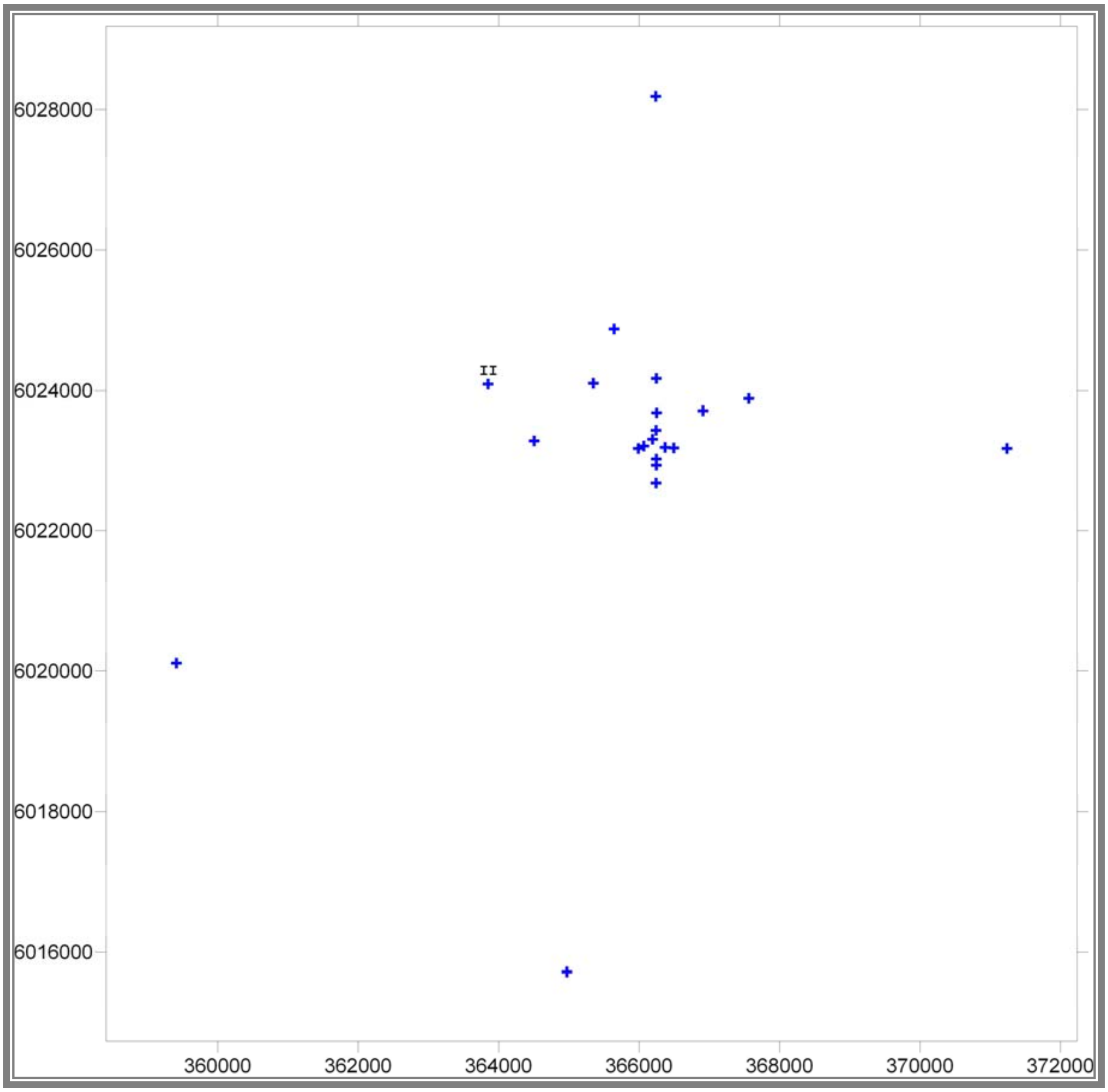


Figure 5 Successional stage recorded by SPI on the Corrib Gas Field. All stations but one (shown) returned a Stage III (healthy/mature) community status.

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

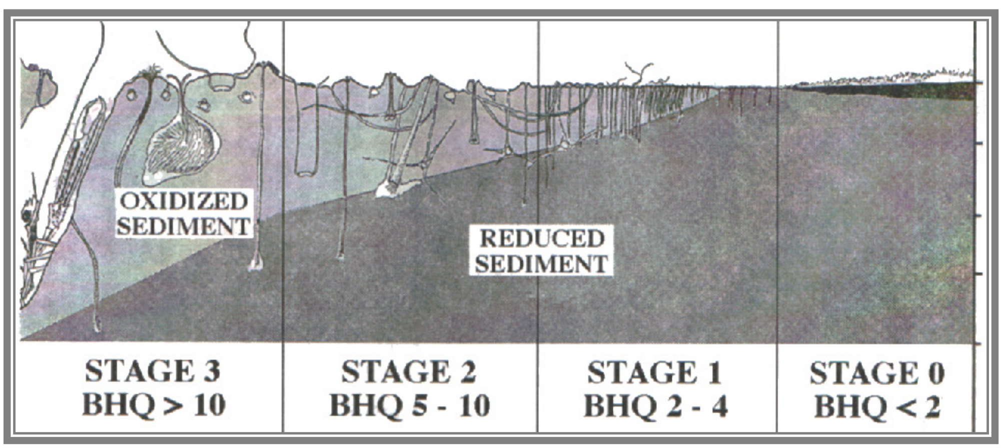


Figure 6 The distribution of benthic infaunal successional stages along a gradient of increased environmental disturbance from left to right (from Nilsson and Rosenberg, 1997 – after Pearson and Rosenberg, 1978) and the associated Benthic Habitat Quality index (described in table 3-1 above. The successional 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.

5. References

AQUAFACT, 2007. Sediment Profile Imagery Survey, Corrib Field Development, proposed pipeline route and field. August 2007. On behalf of RSK Environment Ltd. 17 pages plus appendices.

AQUAFACT, 2000a. Sediment Profile Imagery (SPI) Survey: Corrib Field, July 2000. Prepared by AQUAFACT International Services Ltd., 12 Kilkerrin Park, Liosbaun, Galway, Ireland. 49 pages

AQUAFACT, 2000b. A report on the marine environment in the vicinity of the Corrib Natural Gas Field and pipeline route to a land-based terminal close to Broadhaven Bay, Co. Mayo. Prepared by AQUAFACT International Services Ltd., 12 Kilkerrin Park, Liosbaun, Galway, Ireland on behalf or RSK Environment Ltd., 172 Chester Road, Heisby Cheshire, England. 55 pages

Eleftheriou, A. and Holme, N.A. (1984). Macrofauna techniques. In Methods for the study of marine benthos. (ed. N.A. Holme, A.D. McIntyre), pp. 140-216. Blackwell Scientific Publications, Oxford.

Nicolaidou, A., A. Zenetos, M.A. Pancucci and N. Simboura, 1993. Comparing ecological effects of two different types of pollution using multivariate techniques. P.S.Z.N.I: Marine Ecology, 14: 113-128

Nilsson, H.C. and R. Rosenberg, 1997. Benthic habitat quality assessment of an oxygen stressed fjord by surface and sediment profile images. Journal of Marine Systems, Vol. 11, pages 249-264.

Pearson, T.H. and R. Rosenberg, 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr. Mar. Biol. Annu. Rev., Vol. 16, pages 229-311.

Rhoads, D.C. and J.D. Germano, 1990. The use of REMOTS technology for disposal site selection and monitoring). Geotechnical engineering of ocean waste disposal. American Society for Testing and Materials STP 1087, 1916 Race Street, Philadelphia, PA 19103

Rhoads, D.C. and J.D. Germano, 1986. Interpreting long-term changes in benthic community structure: a new protocol. Hydrobiologia, Vol. 142, pages 291-308.

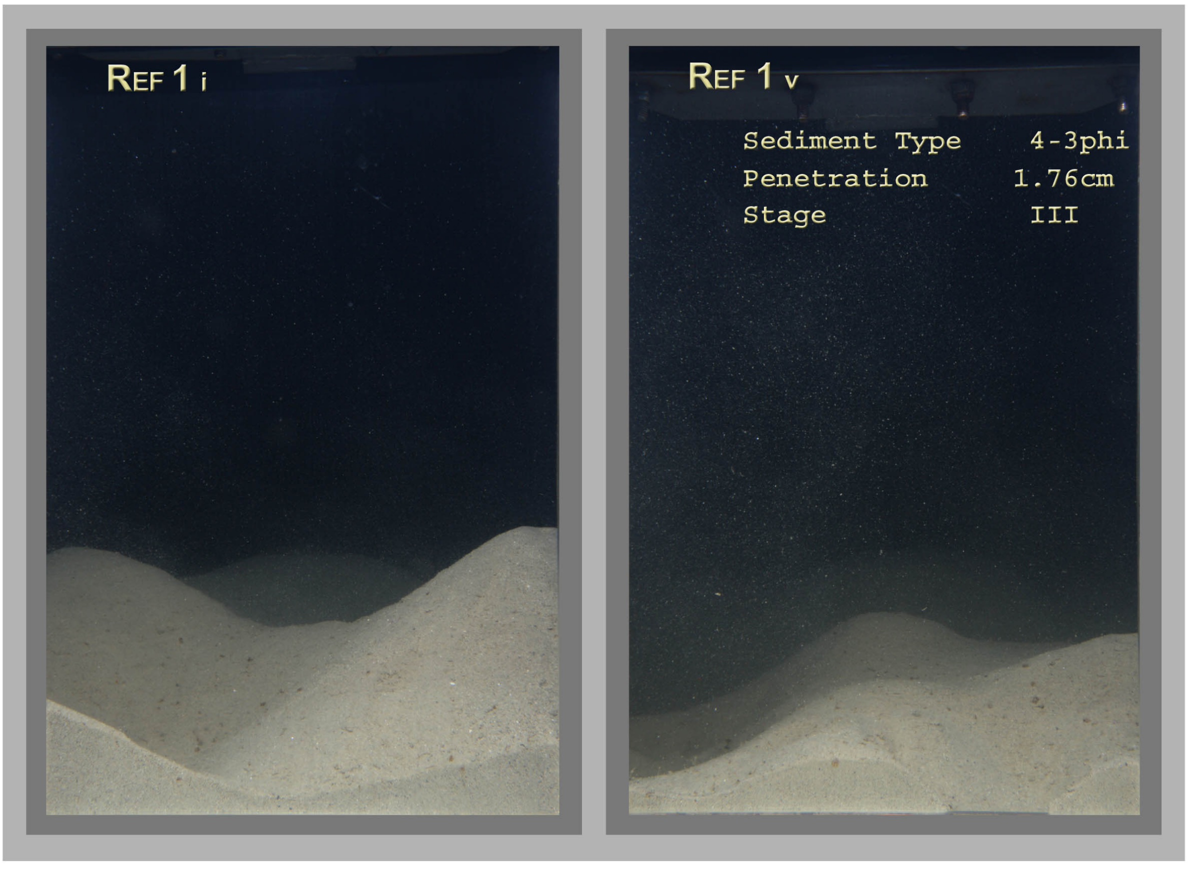
Wilson, I., 2007. Offshore environmental work scope for benthic and water quality sampling at the Corrib Field Development and along the proposed pipeline route corridor and outfall location – project briefing document. Prepared for RSK Ltd. by Ian Wilson. 18 pages.

Solan, M., B.D. Wigham, I.R. Hudson, R. Kennedy, C.H. Coulon, K. Norling, H.C. Nilsson and R. Rosenberg, 2004. In situ quantification of bioturbation using time-lapse fluorescent sediment profile imaging (f-SPI), luminophore tracers and model simulation. Marine Ecology Progress Series, Vol. 271: pages 1-12.

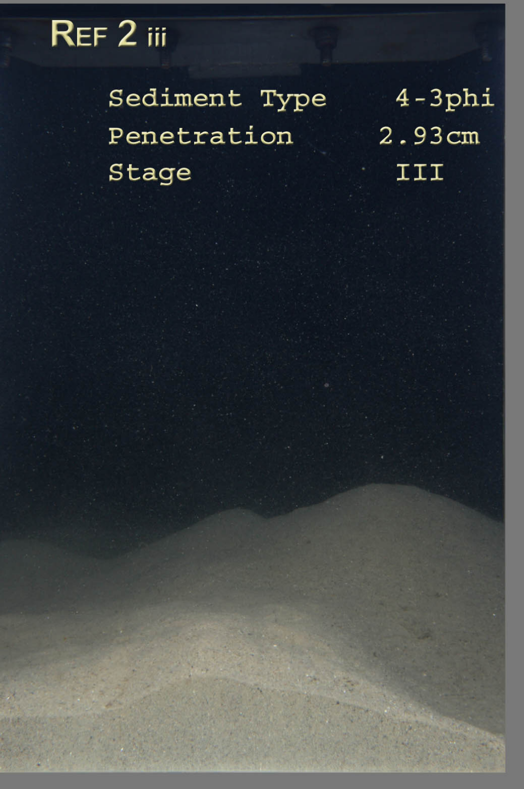
APPENDIX I

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

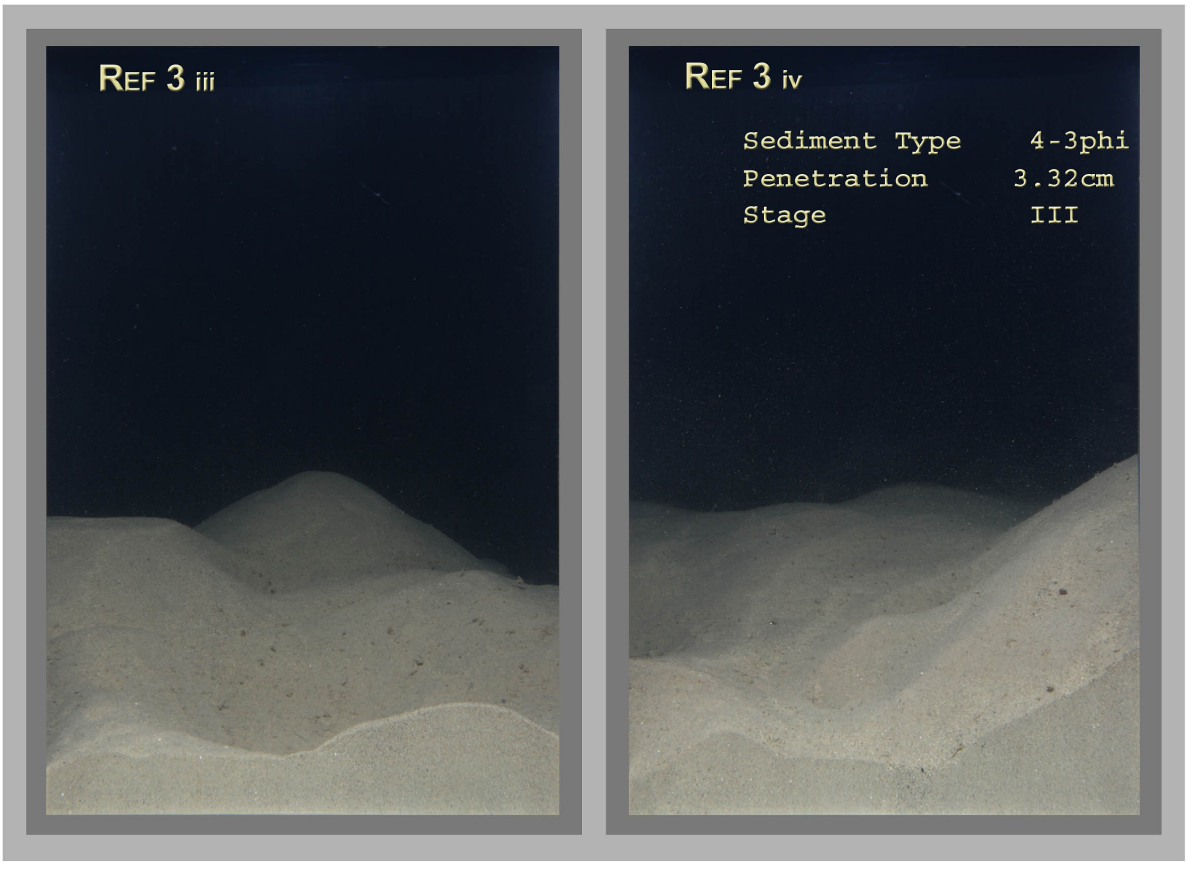
JULY 2008



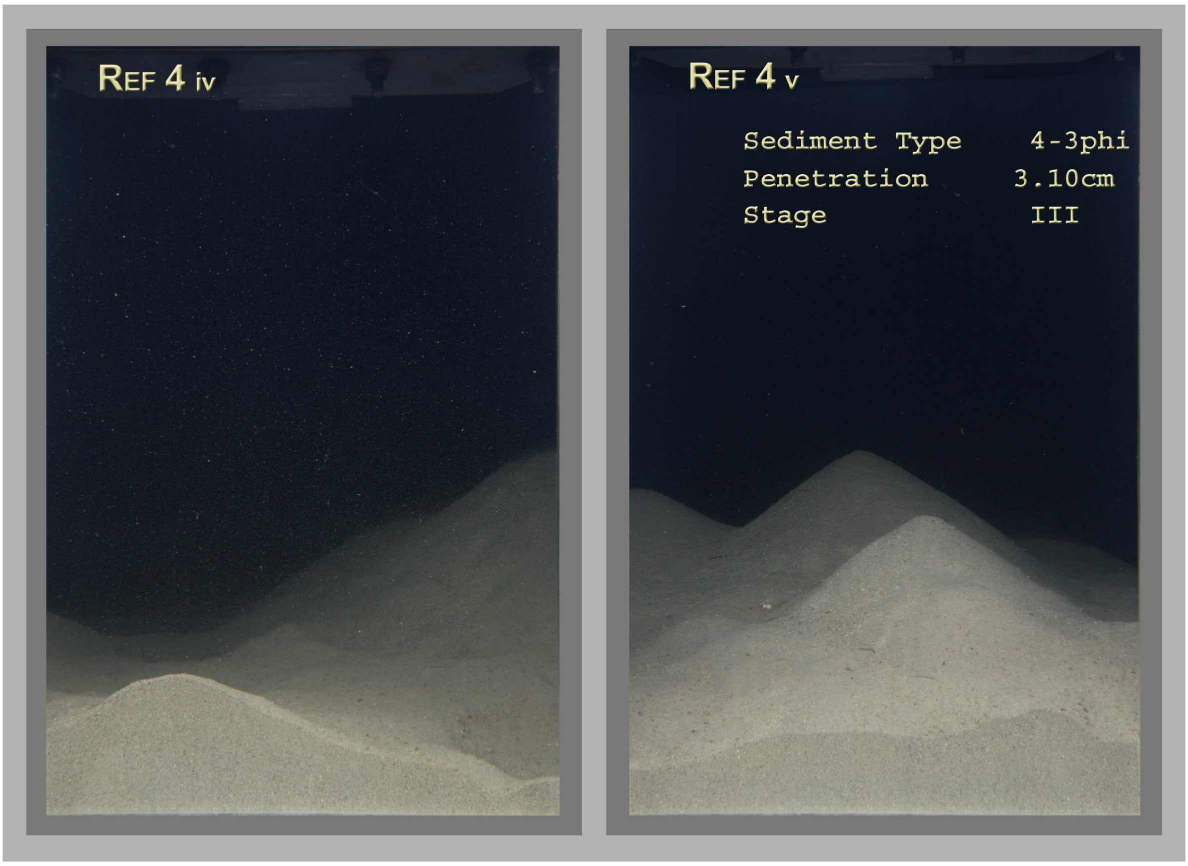
Station Ref 1: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.



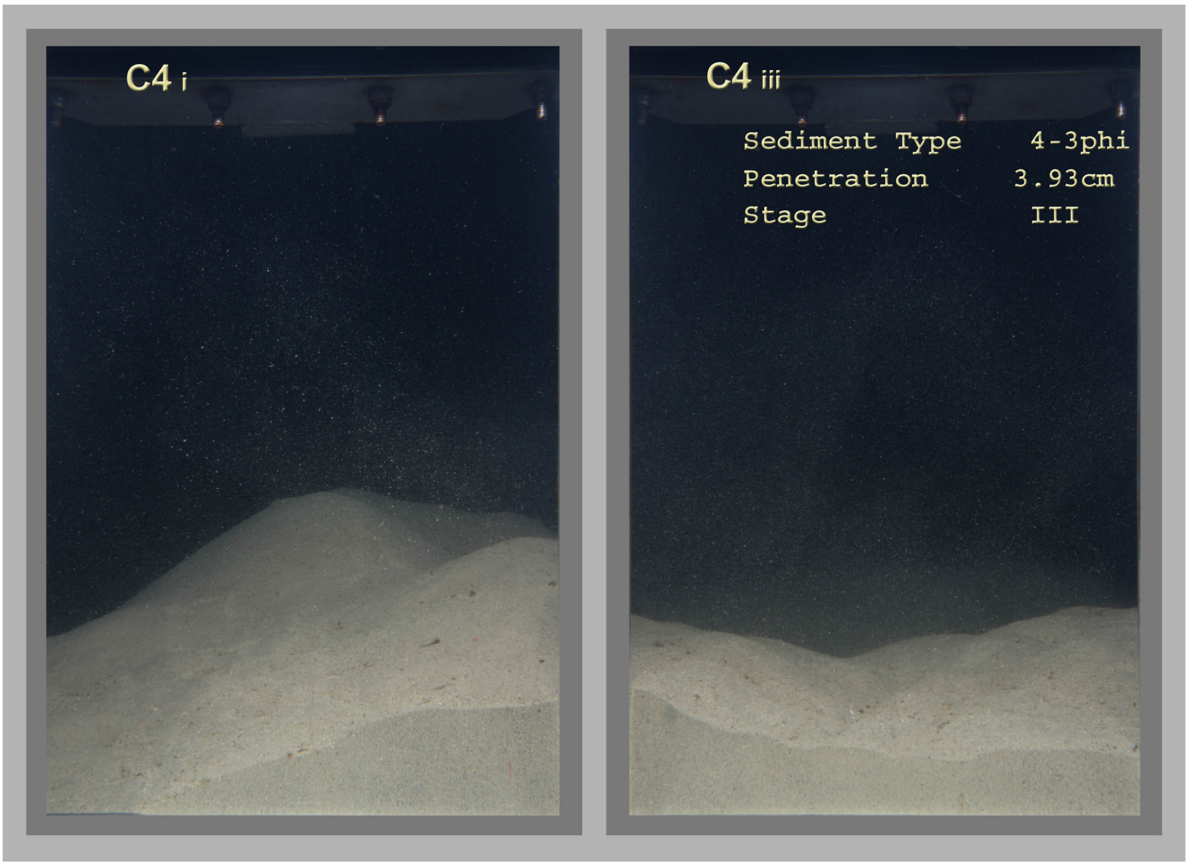
Station Ref 2: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

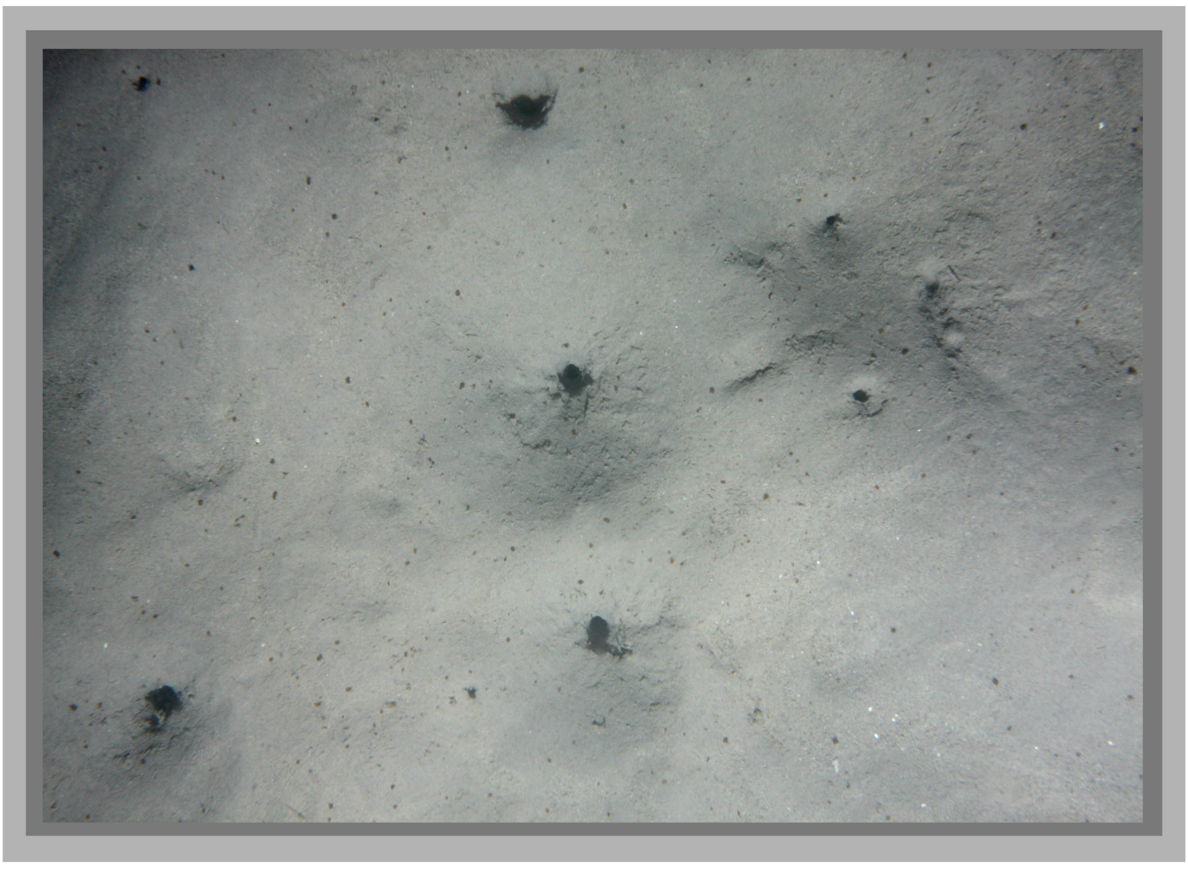


Station Ref 3: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

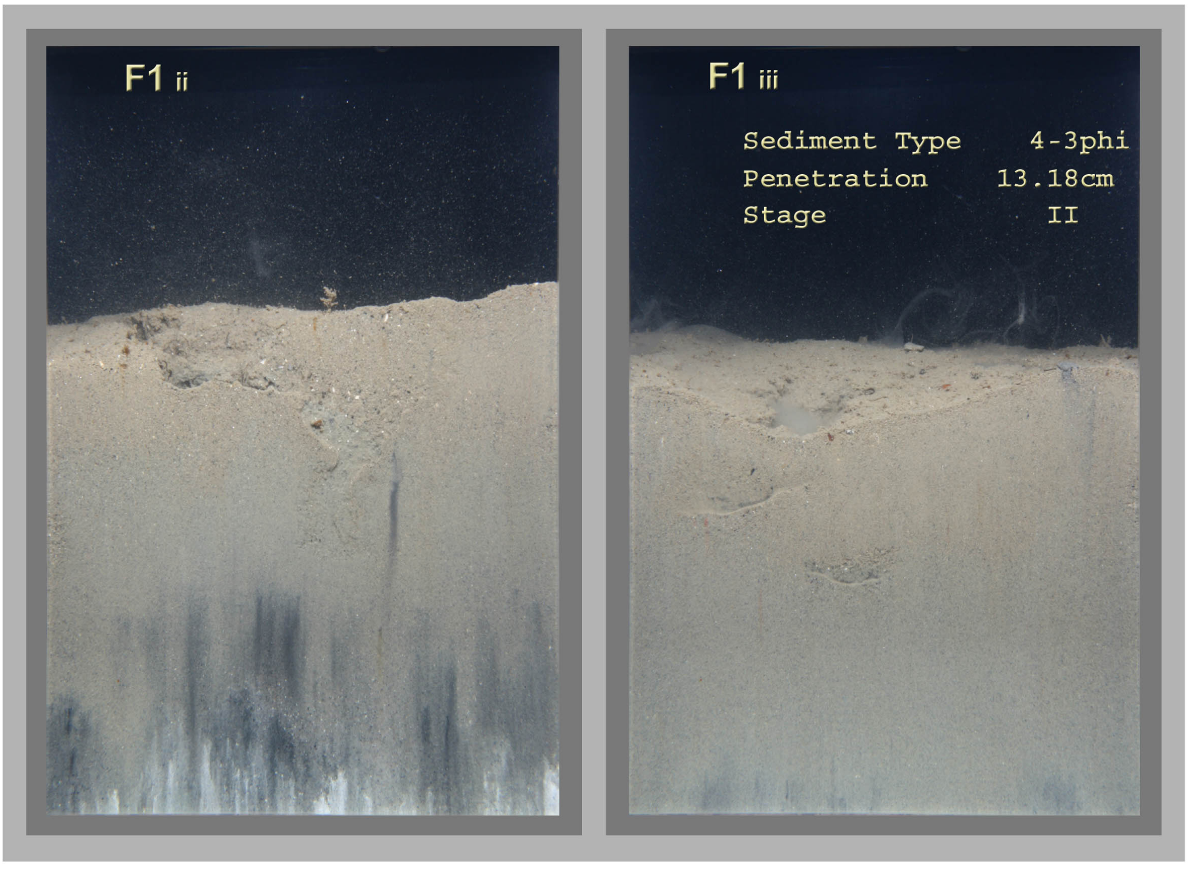


Station Ref 4: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

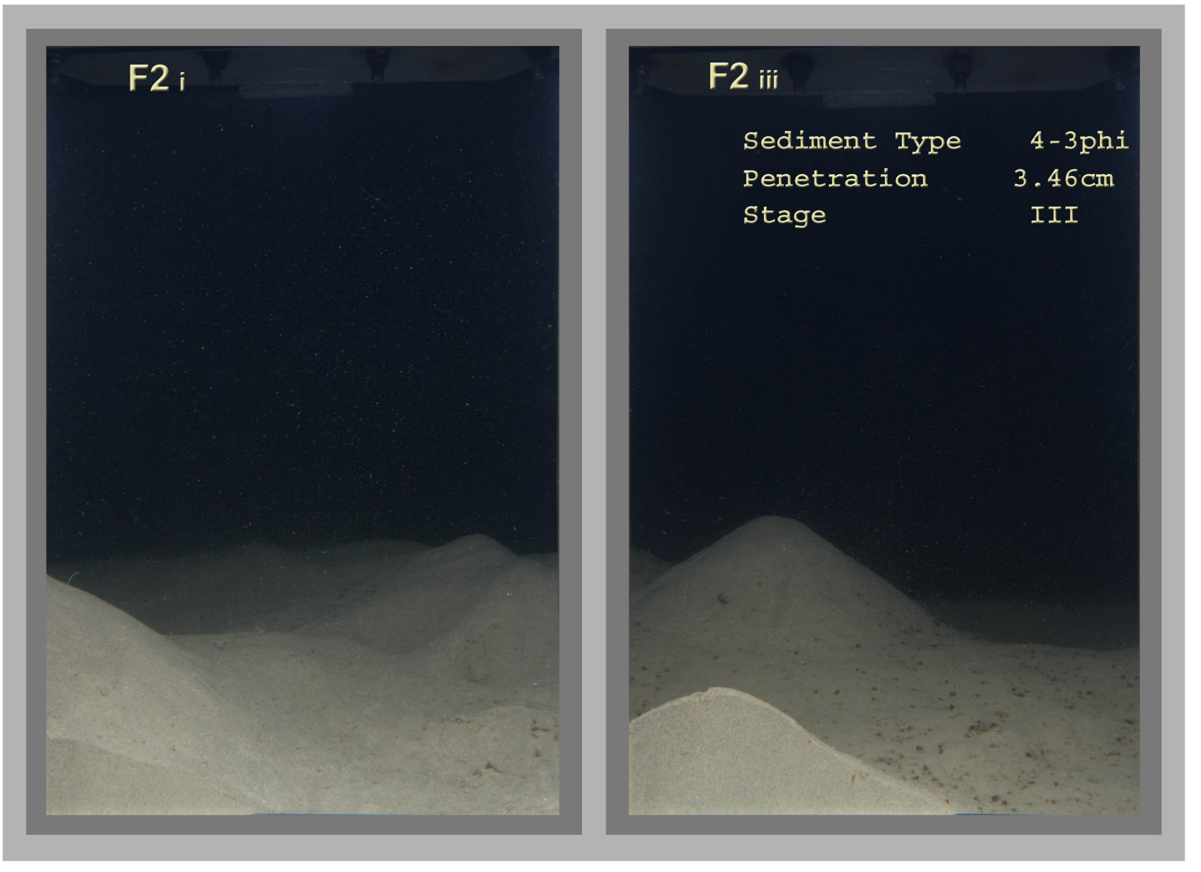




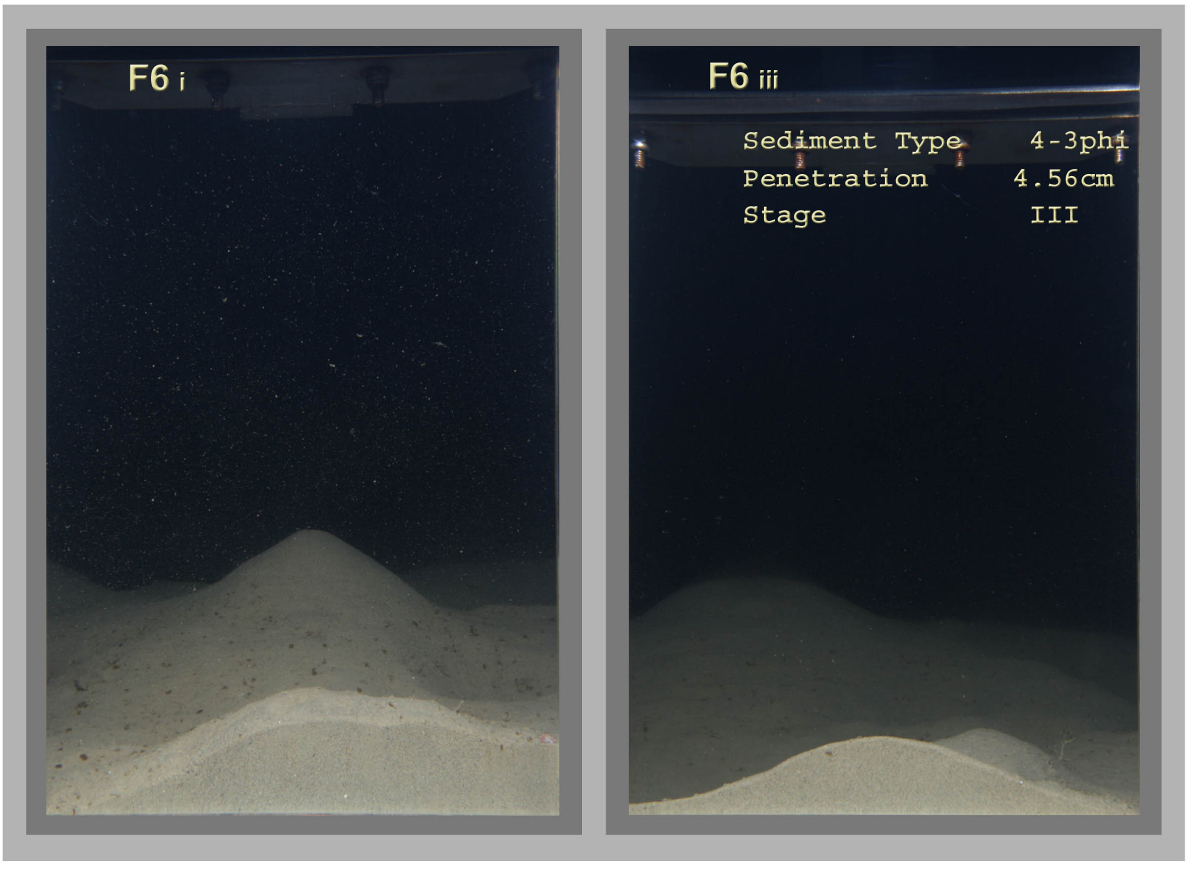
Station C4: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.



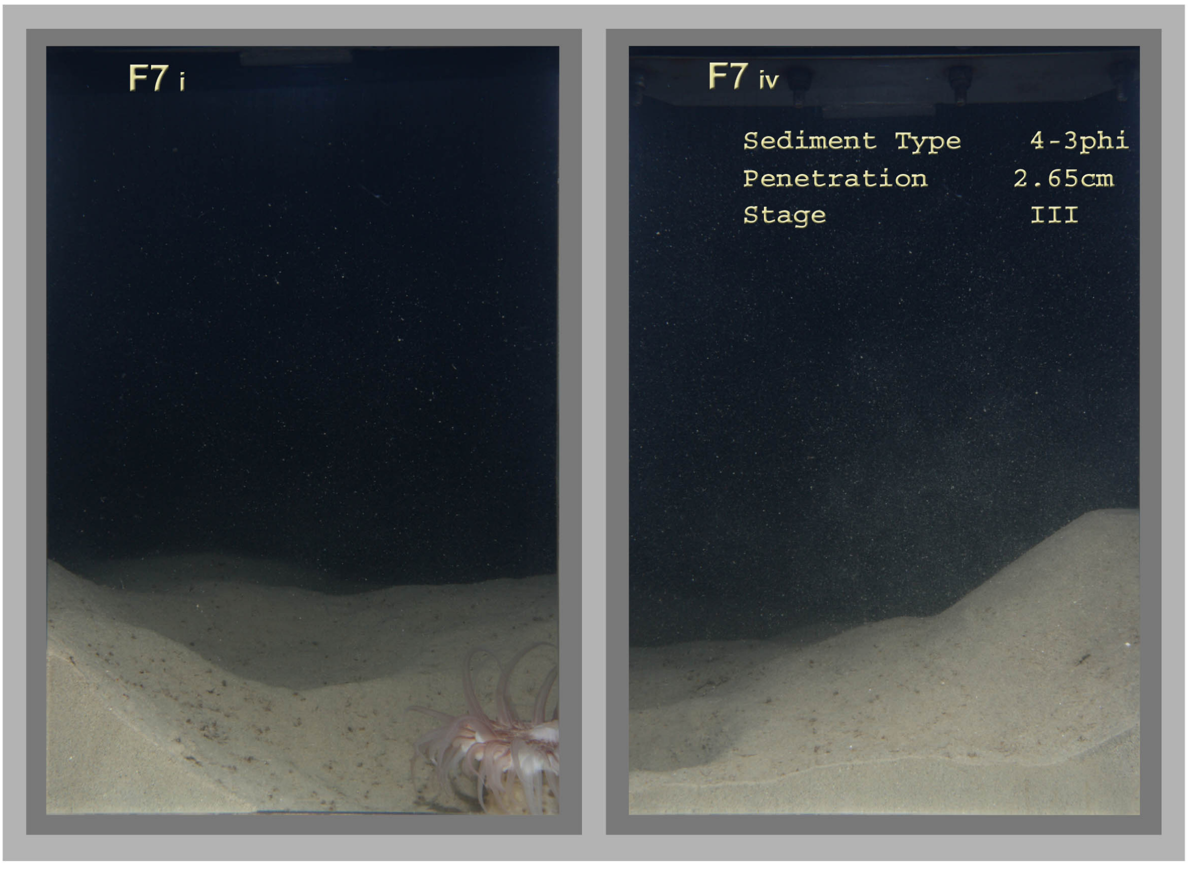
Station F1: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.



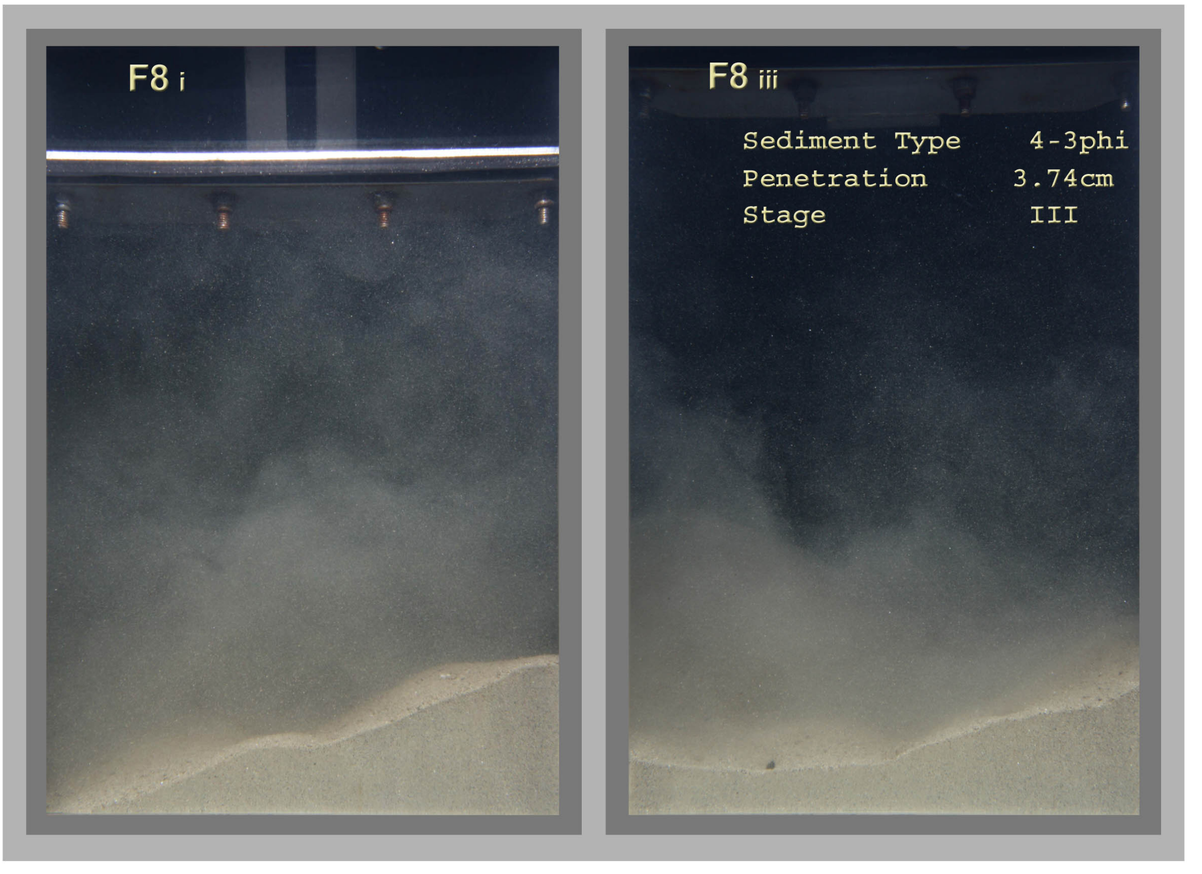
Station F2: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.



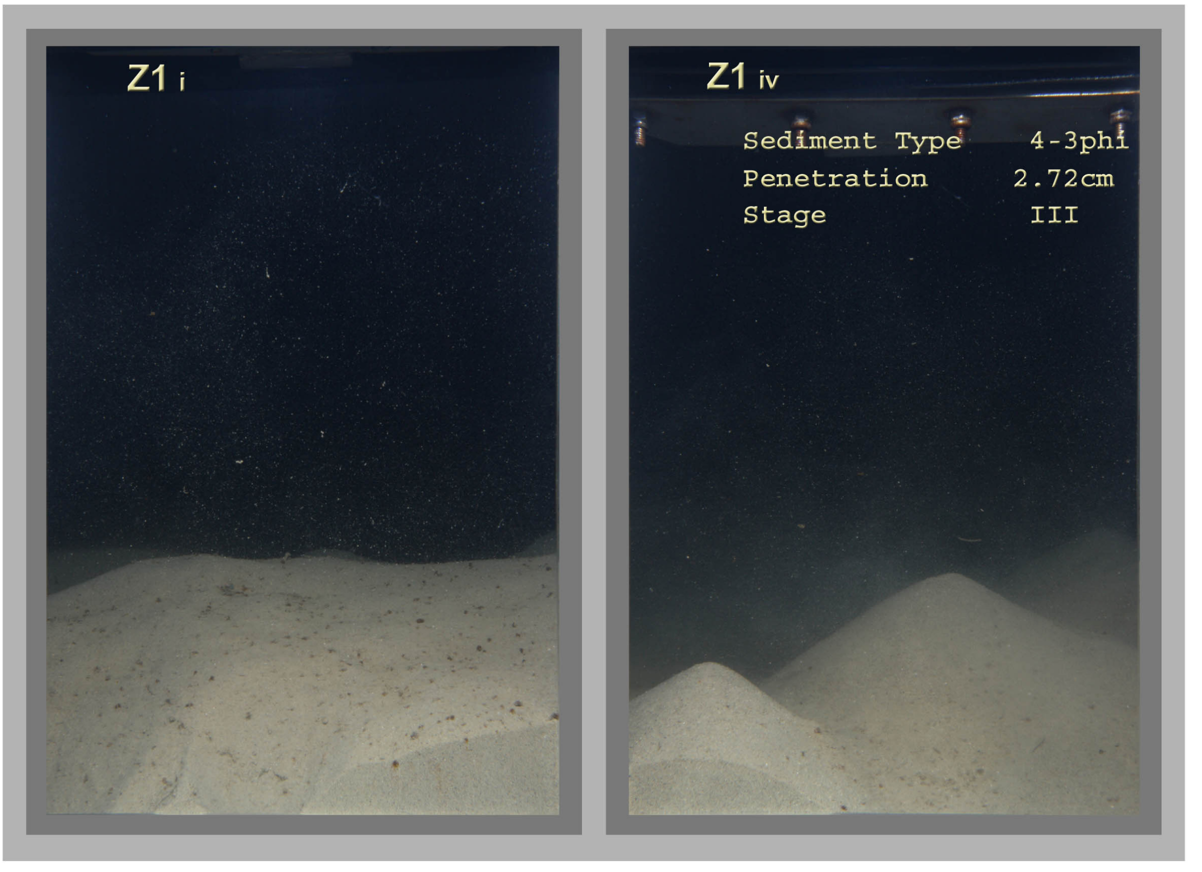
Station F6: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

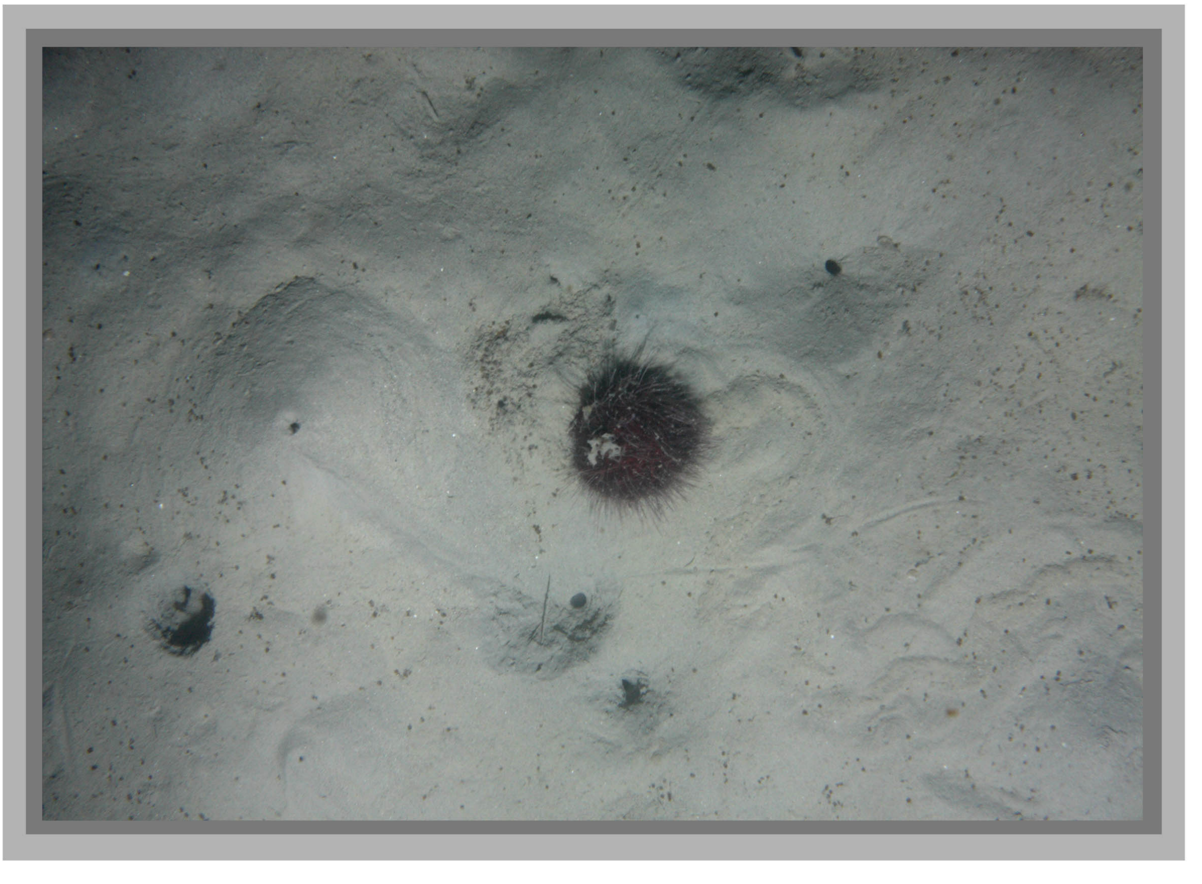


Station F7: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

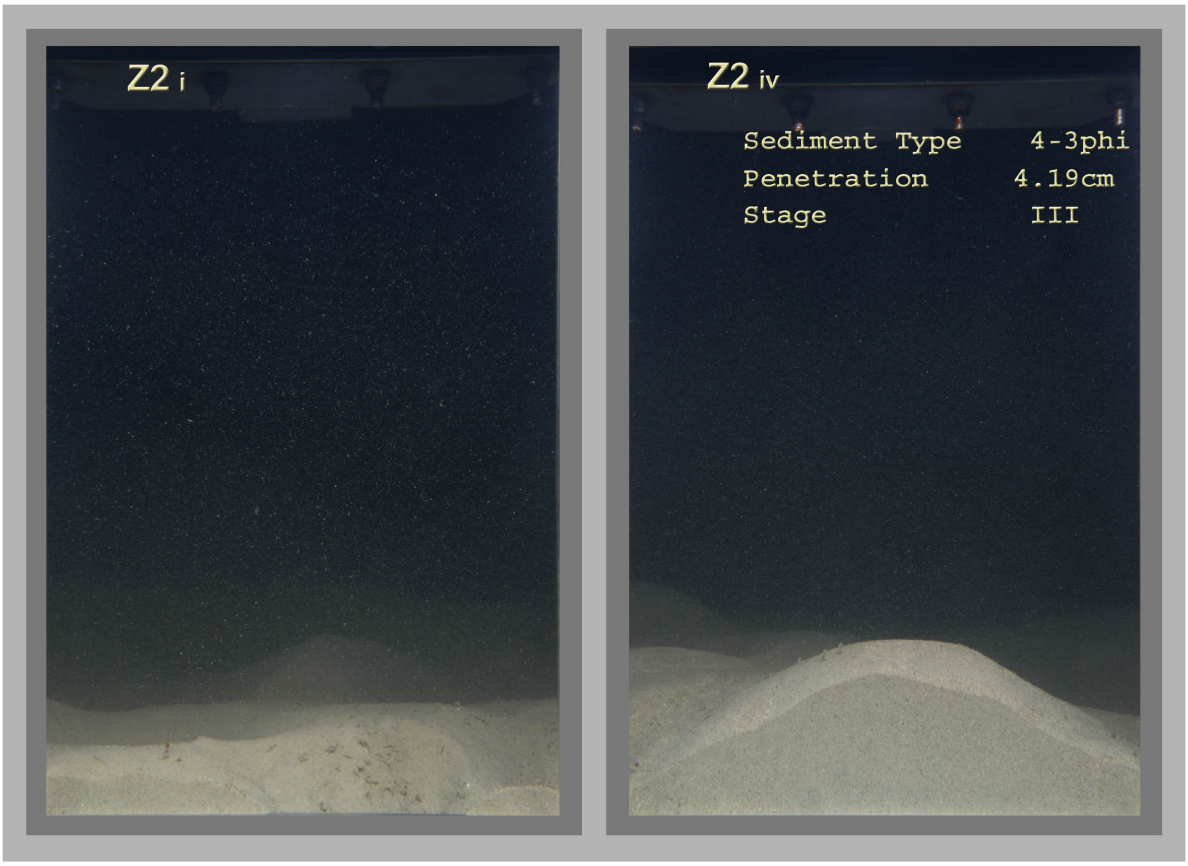


Station F8: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

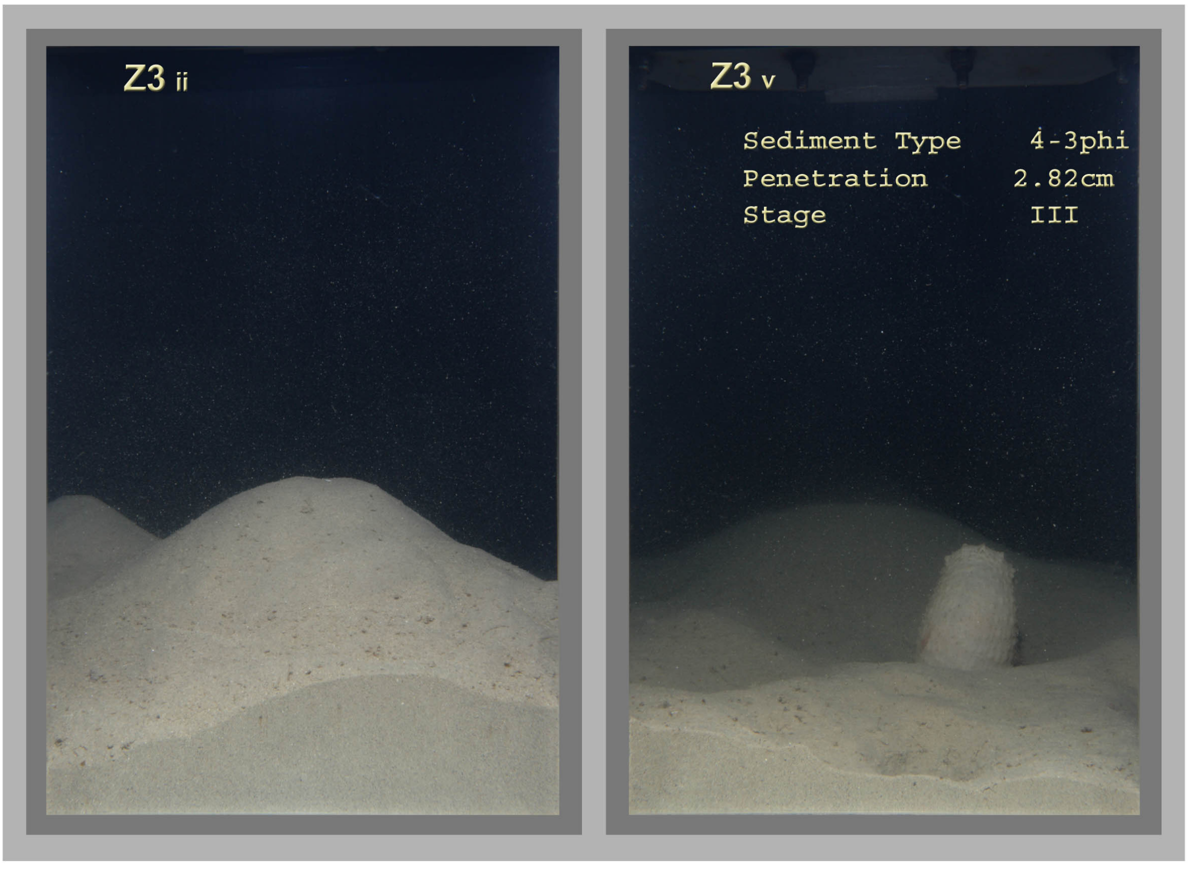




Station Z1: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

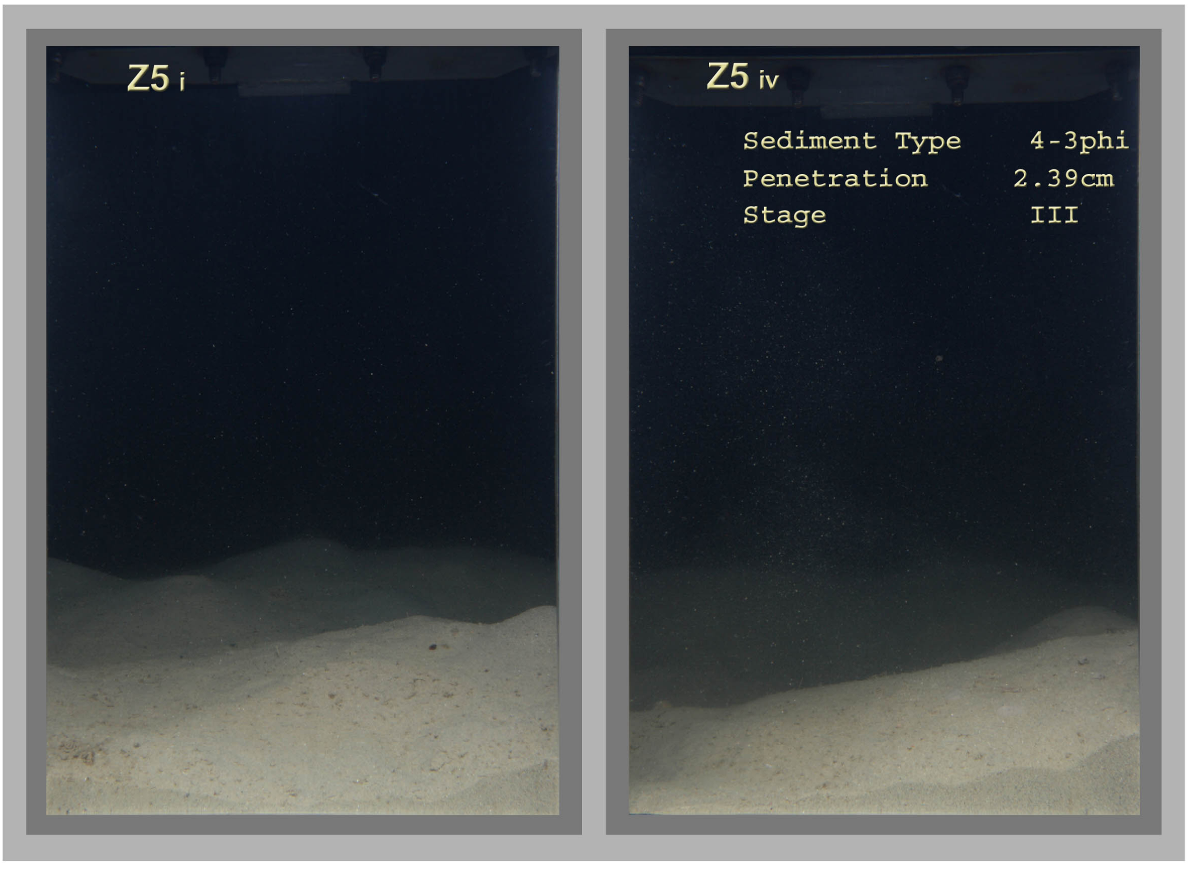


Station Z2: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

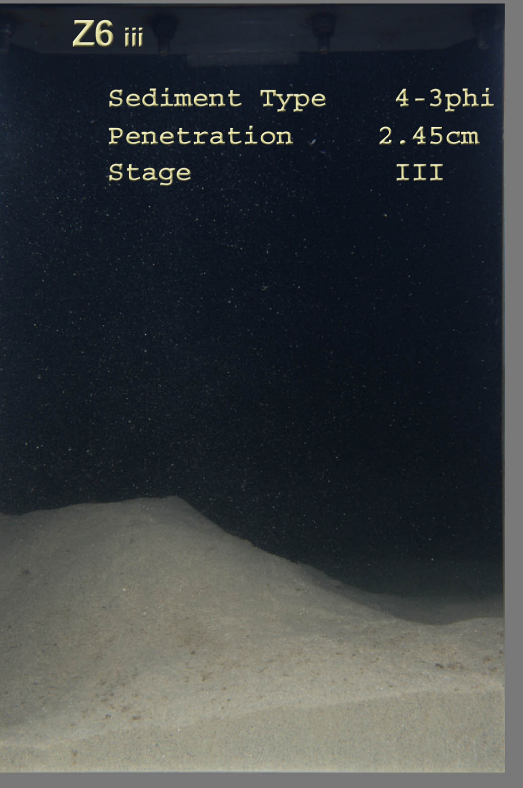


Station Z3: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

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.

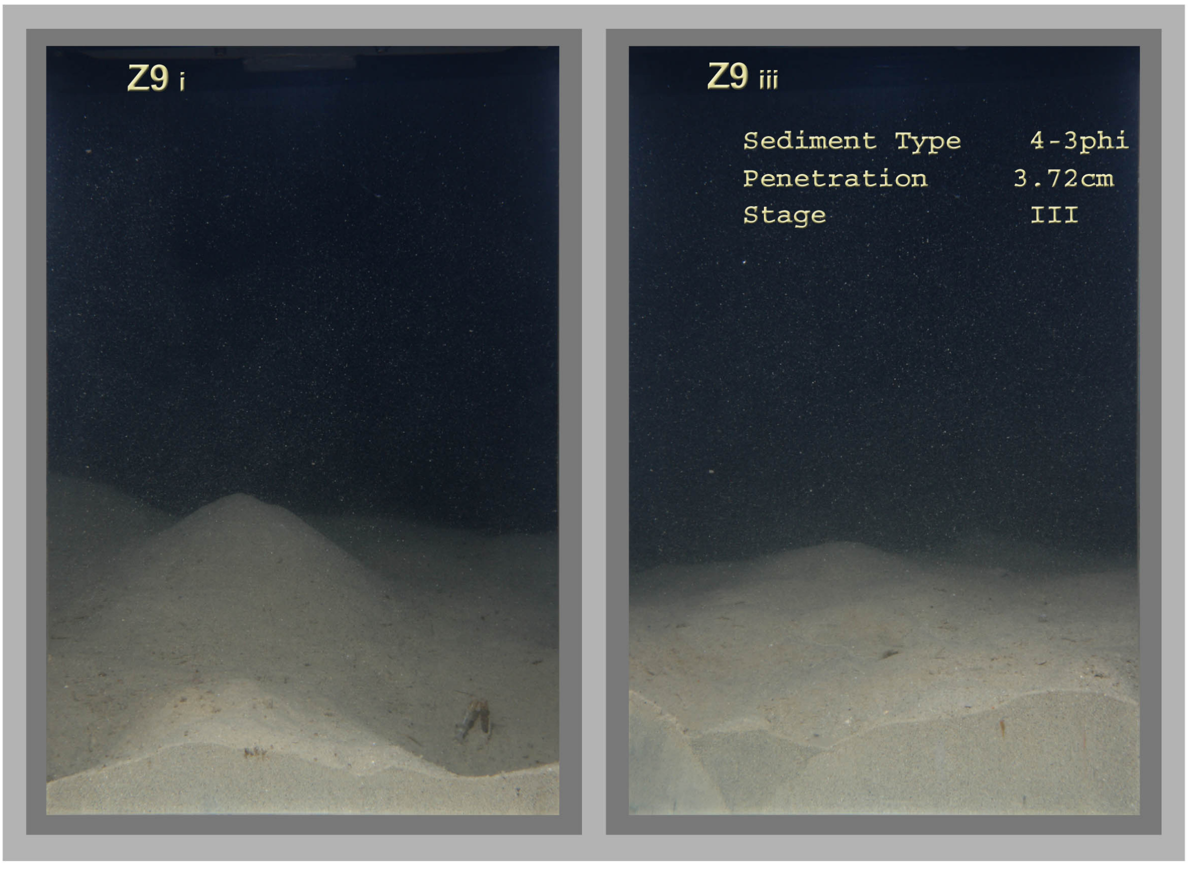


Station Z5: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

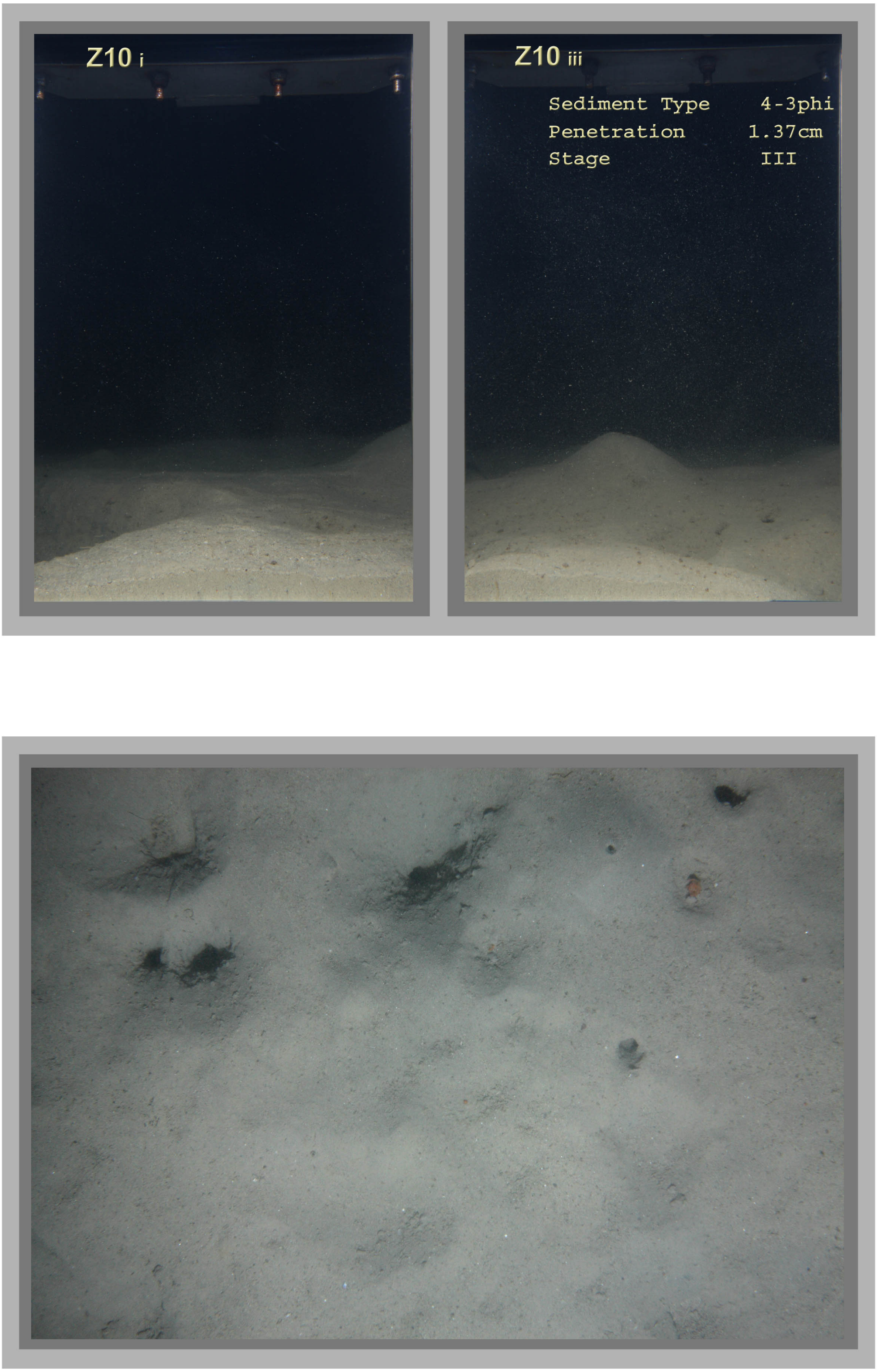


Station Z6: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.

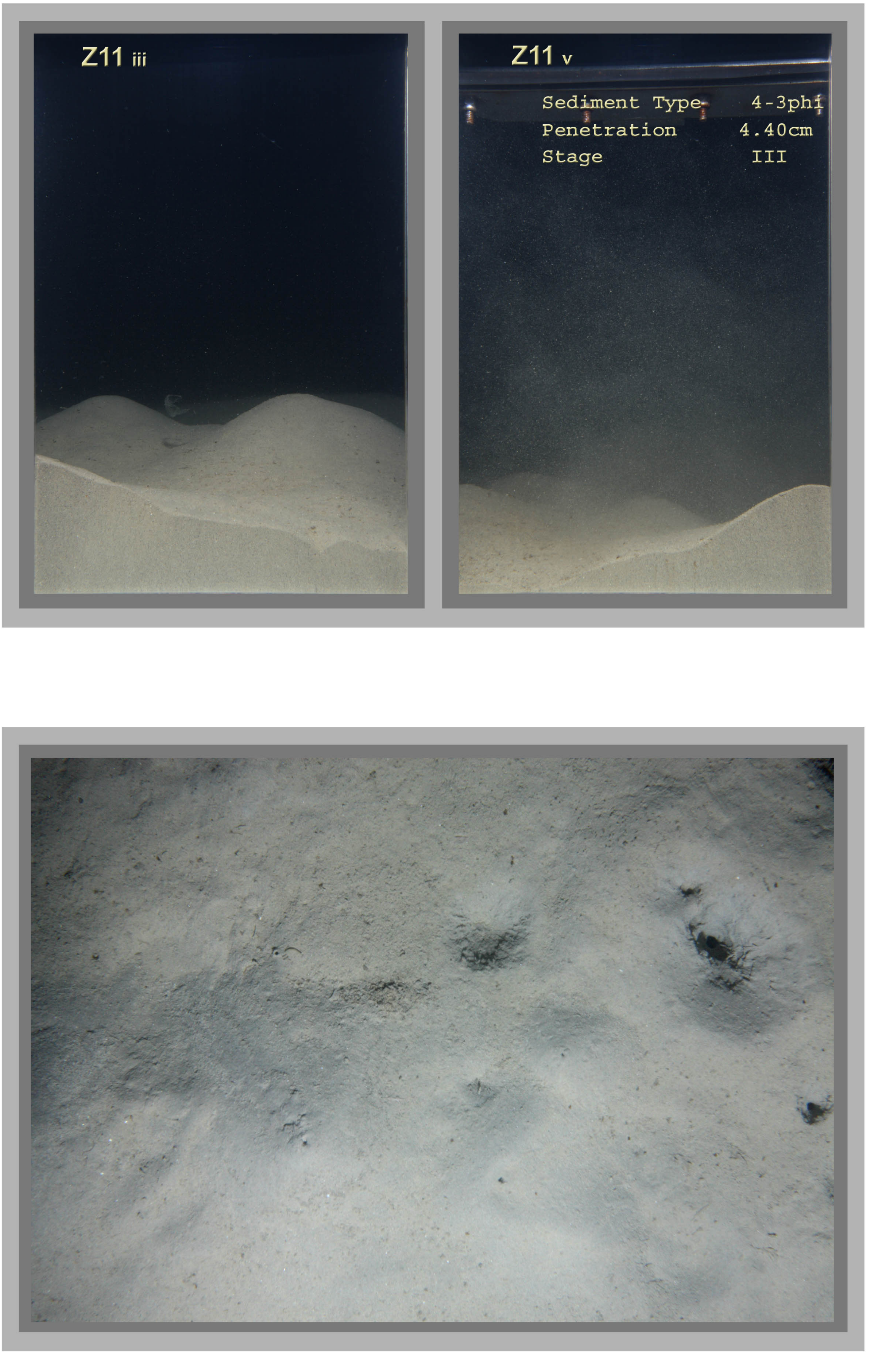
Station Z7: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.



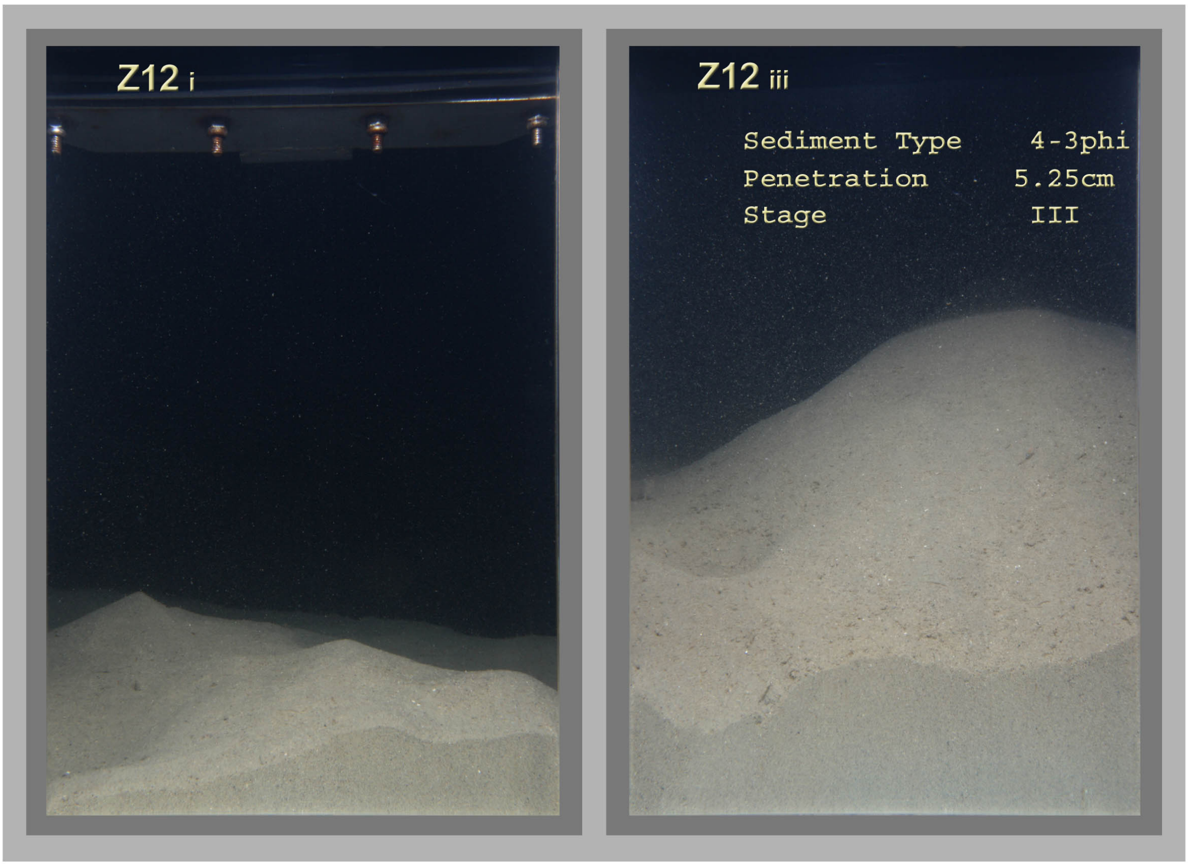
Station Z9: Sediment profile images and representative surface shot. Measured parameters are presented in the table superimposed on the profile shots. See Figure 2 for Station locations.



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.

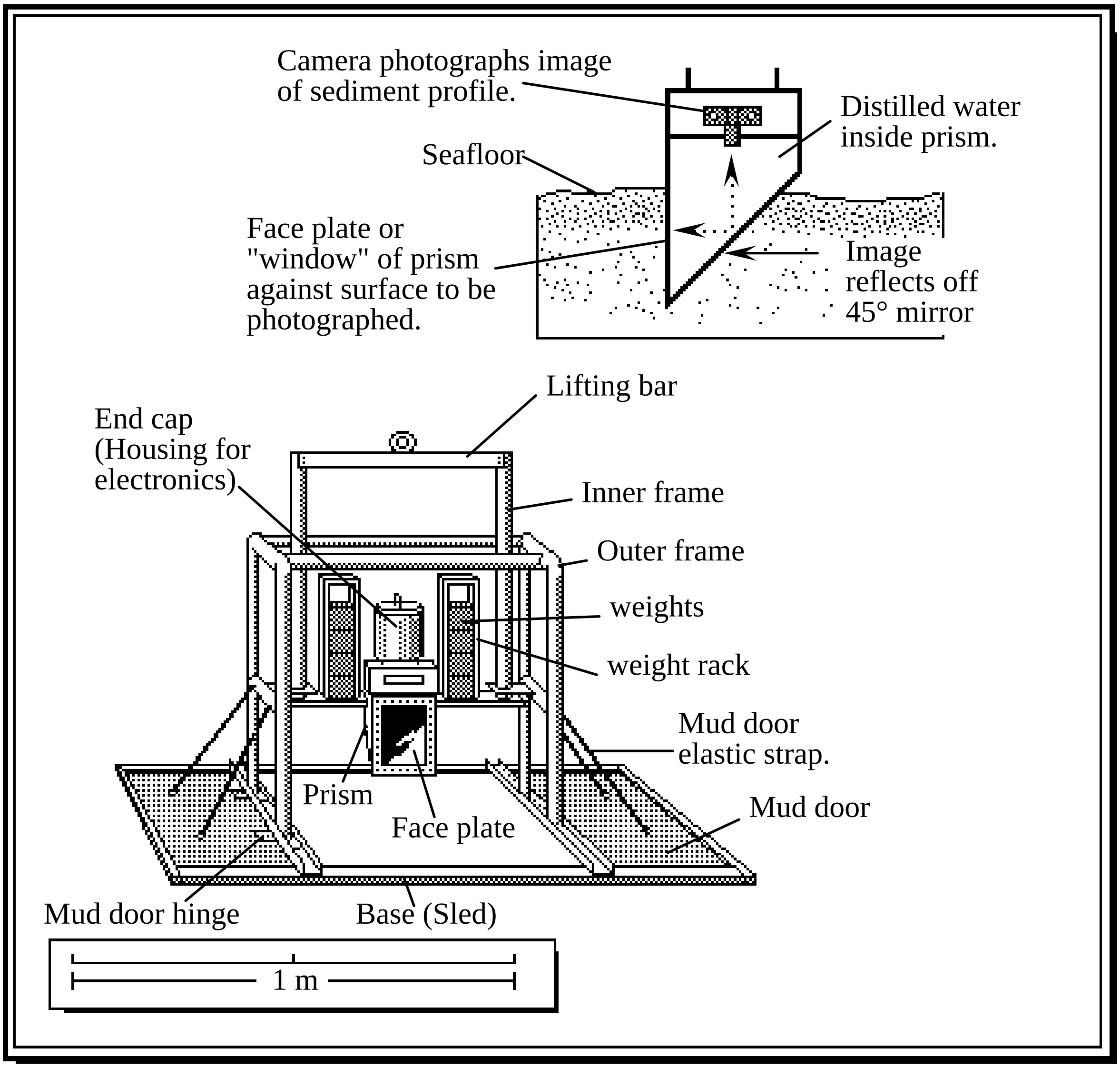


Figure 1. Representation of the remotely operated **S**ediment **P**rofile **I**magery camera.

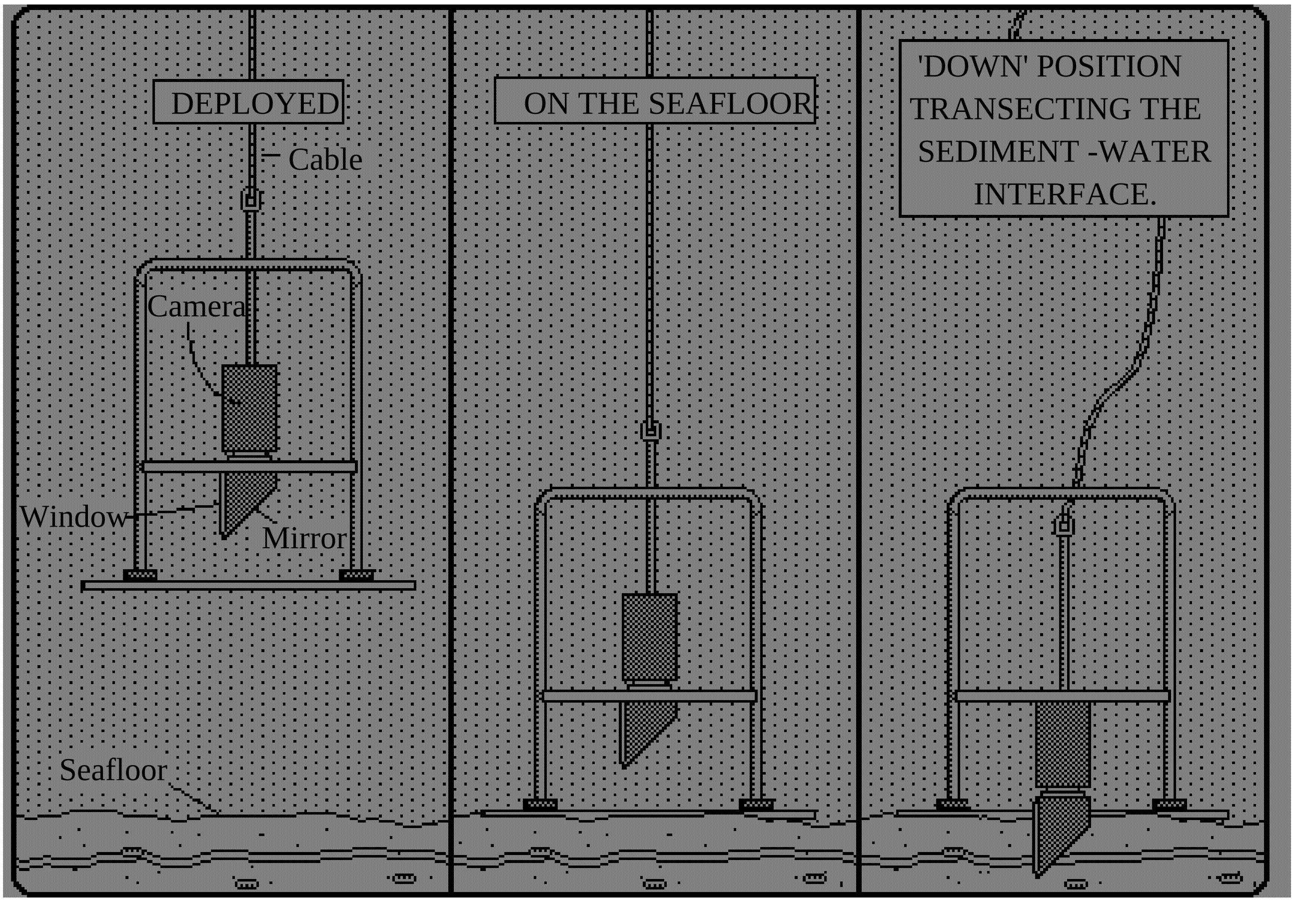


Figure 2. **S**ediment **P**rofile **I**magery (SPI): camera deployment on the seafloor.

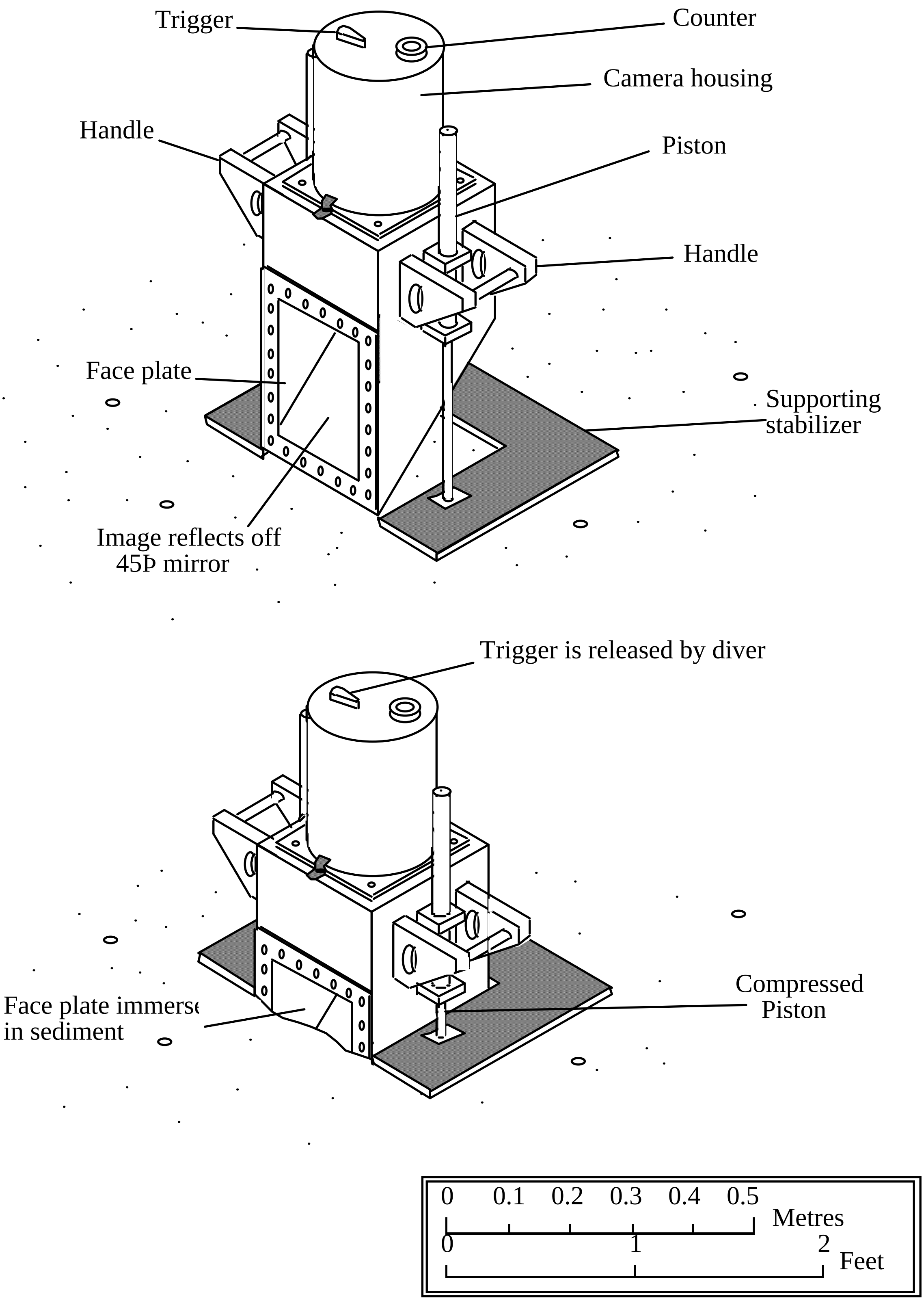


Figure 3. Details of the diver operated **S**ediment **P**rofile **I**magery (SPI) camera.

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