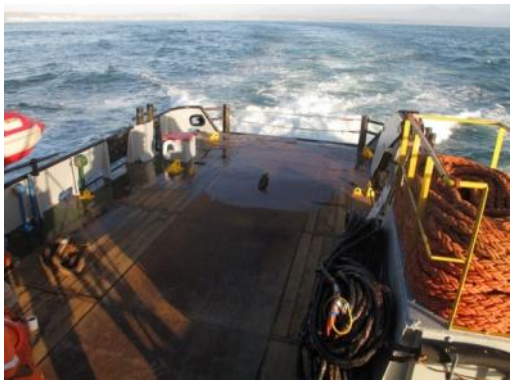
Coastal Systems Research Group
Ecosystem Services Competence Area

Final Report

Assessment of the inshore subtidal environment in the vicinity of the PetroSA Vleesbaai pipeline: November 2011 survey

July 2012


Prepared for

The Petroleum Oil and Gas Corporation of South Africa (SOC) Ltd

Herein referred to as "PetroSA"

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Executive Summary

Effluents from the PetroSA, Mossel Bay refinery are discharged into Vleesbaai marine waters through a subtidal pipeline extending approximately 1.3 km offshore at a depth of ~ 22 m. Prior to discharge the effluent is treated to ensure various harmful components remain within limits as specified in the relevant discharge permit. The discharged effluent, however, still contains a range of contaminants, at reduced concentrations, that have the potential to impair the ecological functioning of the receiving environment. Prior to the pipeline becoming active in 1991/1992, PetroSA commissioned two environmental baseline studies (1986 and 1989), and in 2000 and 2003, impact assessment studies were conducted. Each of these previous studies in Vleesbaai employed different survey methods such that potential impacts over time cannot be accurately assessed. In 2011 PetroSA commissioned the South African Environmental Observation Network (SAEON) in collaboration with the Council for Scientific and Industrial Research (CSIR) to develop and implement a long-term environmental monitoring programme designed to determine potential impact of the effluent discharge on the receiving environment in Vleesbaai.

Three components of the Vleesbaai ecosystem were assessed for potential impact resulting from the effluent discharge. These were 1) the seabed sediment quality, 2) the invertebrate community living within the sediment (macrofauna and meiofauna) and 3) the quality of the water in the vicinity of the outlet pipeline (using data supplied by PetroSA). *In situ* sampling of the sediment and invertebrate community took place in November 2011. The quality of the sediment was assessed by analysing grain size, total organic content, fifteen metals and 23 hydrocarbons (total petroleum hydrocarbons and polycyclic aromatic hydrocarbons) at seven 'Test' sites and eight 'Control' sites. The abundance and biomass of macrofauna (> 0.5 mm) were recorded at these same 15 sites, whilst the Nematode/Copepod ratio of meiofauna (> 45µm) was determined at nine of the sites (six 'Test' and three 'Control') for possible comparisons with previous studies. Sediment analysis was also conducted for an additional nine sites randomly sampled from the greater Mossel Bay area to provide adequate data for defining baseline metal concentrations. Data from water samples collected and analysed by PetroSA from 2008-2010 in the vicinity of the pipeline diffuser were assessed.

The grain size of sediment in the study area was classified as sand and muddy-sand with more than 70% of the sediment being fine-grained (0.125-0.250mm). Less than 10% of the sediment was classified as mud which is typical of high-energy environments such as Vleesbaai. The total organic content (TOC) of the sediment in the study area was low (1.39%) with a higher than expected TOC being recorded at only one site. This higher TOC is not considered to be a result of effluent discharge from the Vleesbaai pipeline. Baseline models for metal concentrations in sediment samples were normalised using aluminium concentrations, except for cadmium, for which a baseline was defined using a probability plot. Only one of the sites within the pipeline vicinity (the 'Control' site furthest west of the diffuser) revealed slightly elevated cadmium concentrations in the sediment. The sediment in the Vleesbaai area is not considered to be metal contaminated. Low concentrations of total petroleum hydrocarbons were detected at all but one site in the study area whilst the polycyclic aromatic hydrocarbon isomer naphthalene was detected at a concentration only marginally exceeding the method detection limit (i.e. very low) at one site in the study area. The total petroleum hydrocarbons detected are relatively 'light' hydrocarbons, possibly originating from the effluent discharged through the pipeline.

The benthic macrofauna community sampled was characteristic of such marine environments in the southern Cape region. Control sites had significantly higher abundances and lower evenness (spread of numbers among species) and diversity indices of benthic macrofauna than Test sites. These differences in univariate measures were not considered indicative of impacts resulting from effluent discharge. Furthermore, typical pollution indicator species (e.g. polychaetes *Capitella capitata* and *Prionospio* spp.) were not detected in greater abundance closer to the pipeline. Multivariate analyses also revealed significant differences in macrofauna composition between Control and Test sites in both abundance and biomass measures, however, the level of significance was very small. The difference in macrofauna

occurring at Control vs. Test sites was as a result of subtle differences in a wide range of taxa and not driven by typical pollution indicator species. Taking the measured environmental variables (grain size, organic content, metals and hydrocarbons) into account in the macrofauna composition, it is evident that metal and hydrocarbon concentrations do not influence the macrofauna community composition and differences detected between Control and Test sites are most likely due to variations in natural parameters and not as a result of pollution.

Meiofauna numbers recorded in this survey were much higher than any of the previous surveys conducted in Vleesbaai and harpacticoid copepods were detected in seven of the nine sites sampled. Previous impact assessment surveys (2000 and 2003) reported concern at not detecting any harpacticoid copepods during surveys, attributing this to evidence of pollution. The nematode/copepod ratios in close proximity to the pipeline in this study were generally lower than the two impact assessment surveys (2000 and 2003), but slightly higher than the baseline survey conducted in 1989. Analysis of the influence of environmental parameters on meiofaunal abundances indicate that the meiofauna community patterns detected in this study were strongly influenced by sediment grain size and that the possible influence of pollution was likely to be minimal.

Investigation of the water quality data provided by PetroSA from 2008 to 2010 elicited some concerns about interpretation of these data, including missing data and zero values. Preliminary data exploration also suggests that the concentrations of several parameters, especially the metals, are extremely high and far exceed the South African Water Quality Guidelines for Coastal Marine Waters. It is however proposed that these elevated values probably represent an analytical or method interpretation error rather than highly contaminated water. Results of the sediment and faunal community from the November 2011 survey do not reflect severe contamination implied by the water quality data provided by PetroSA. Further investigation of these data, analytical methods and processing is highly recommended.

Results from the samples collected and analysed during the November 2011 survey of the Vleesbaai marine environment indicate that the discharge of effluent through the pipeline is not significantly adversely impacting on the receiving marine environment in Vleesbaai.

Based on the results of this survey, recommendations for future monitoring include downscaling the sampling design whilst not compromising the statistical requirements of the study. It is proposed that macrofauna, sediment grain size and total organic carbon be monitored at six, rather than 15 sites, meiofauna should also be monitored at these six sites for comparison continuity and the sediment chemistry analysis (metals and hydrocarbons) should be monitored at a total of 10 sites. It is proposed that a greater focus should be placed on the lower molecular weight hydrocarbons, including volatile hydrocarbons, in future monitoring. *In situ* water quality monitoring should be conducted at the same 10 sites as sediment chemistry and parameters monitored should include, at a minimum, temperature, salinity, dissolved oxygen, pH and turbidity. A revision of the analytical process and objective of the quarterly *in situ* water quality monitoring conducted by PetroSA is recommended. Should PetroSA desire continuation of in-house *in situ* water quality monitoring, it is suggested that duplicate samples be analysed by an alternative marine accredited laboratory to promote future accuracy and comparability of resulting data. Should *in situ* water quality monitoring be continued, it is also suggested that consideration be given to collecting the samples at mid-water level rather than on the surface, if the density of the effluent is established to be less dense than seawater (this should first be confirmed). The above recommended sampling design should be conducted once per year for at least two consecutive years, following which, further revision of long-term environmental monitoring requirements can be made.

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1. Introduction

PetroSA discharges effluent through a submerged pipeline into the marine environment at Vleesbaai, located just westwards of Mossel Bay. The effluent contains a range of contaminants that have the potential to impair the ecological functioning of the receiving environment, including ammonia, metals and oil. Whether the discharge of effluent impairs the ecological functioning of the receiving environment depends on the receiving waters capacity to receive effluent or toxic materials without deleterious effects to aquatic life, termed "assimilative capacity". The assimilative capacity can be considered as the receiving waters 'pollution diet' - too much pollutant loading will result in the manifestation of deleterious effects. Assimilative capacity differs between receiving waters depending on the nature of the effluent and the characteristics of the receiving water in terms of its ability to dilute, disperse and degrade contaminants. Not surprisingly, the voluminous and high-energy marine environment has a higher assimilative capacity compared to smaller volume, sheltered waters, such as estuaries. The volume and duration of effluent discharge is also important to consider. While absolute concentrations of contaminants in effluent at any moment in time might be low and elicit no acute toxic effects, the persistent loading of the contaminants over time may overwhelm the assimilative capacity of the receiving water in the long-term, resulting in chronic toxicity.

Prior to the pipeline becoming active in 1991/1992, PetroSA commissioned two environmental baseline studies which were conducted by the Council for Scientific and Industrial Research in 1986 and 1989. These studies focussed on beach and subtidal meiofaunal communities (reportedly retained on 500 µm sieve[1]), water column surf-zone nutrients and sulphate levels and heavy metal content of intertidal mussels and oysters. In 2000 and 2002, PetroSA commissioned the Centre for Marine Studies (CMS) to assess for any pollution impacts by comparison with the earlier baseline studies (CMS 2001, CMS 2003). The study conducted in 2000 analysed meiofaunal communities (retained on a 150 µm sieve) at four beach sites and three subtidal sites. A modified sample design was employed in 2002 where 10 subtidal sites were assessed for meiofaunal communities (retained on a 63 µm sieve) and sediment grain size. Both the latter studies (conducted in 2000 and 2002) detected considerably fewer meiofauna than the baseline surveys, however, the different sampling protocol and data analysis methods used in each of the studies conducted thus far, preclude any meaningful interpretation of these findings (CMS 2001, CMS 2003). PetroSA have expressed their intention to develop and implement a long term standardised environmental monitoring program to assess potential inshore pollution impacts in the marine environment in the vicinity of the Vleesbaai effluent pipeline.

To ensure that the integrity of the environment into which effluent is discharged is not unacceptably compromised, the South African government issues effluent discharge licenses[2] that stipulate conditions under which the discharge is authorised. One of the conditions is that the discharger must implement and report on an environmental monitoring programme designed to determine potential impact of the effluent discharge on the receiving environment. To this end, PetroSA commissioned the South African Environmental Observation Network (SAEON) with expertise provided by the Council for Scientific and Industrial Research (CSIR) to fulfil this requirement. This report discusses the findings of a survey conducted in November 2011 to assess any potential impact of effluent discharge through the PetroSA Vleesbaai pipeline on the receiving environment. The report provides PetroSA with strategic information for managing the discharge and for informing the public on the status of the receiving environment. Although

[1] Accurate methods employed in the previous studies are not adequately documented in the monitoring reports viewed by the authors of this proposal and replication may not be appropriate.

[2] In the past, the Department of Water Affairs was the government agency mandated with the control of effluent discharges to all surface waters of South Africa in terms of the National Water Act (Act 36 of 1998). With the promulgation of the National Environmental Management: Integrated Coastal Management Act (Act 24 of 2008), the responsibility of regulating effluent discharges to the marine environment transferred to the Department of Environmental Affairs. Therefore, in future licensing of marine effluent discharges will become the responsibility of Department of Environmental Affairs under the Integrated Coastal Management Act. However, the issuing of effluent discharge licenses for freshwater receiving waters remains the responsibility of the Department of Water Affairs under the National Water Act.

this report deals with technical issues, where possible these are discussed and presented in a simplified manner for the benefit of non-specialist audiences. A glossary of terms has also been included for this purpose, and wherever possible the use of acronyms is avoided.

2. Brief Description of the Marine Receiving Environment

Effluent is discharged through the PetroSA pipeline pipeline into Vleesbaai (the receiving environment), situated to the west of Mossel Bay on the southern Cape coastline of South Africa (Figure 1). Vleesbaai is situated within the warm-temperate Agulhas marine ecoregion of the South African coastline (Sink et al. 2012). Although the Agulhas Current is the dominant oceanographic feature along this coastline the core of the current is situated some distance offshore and the local oceanography is undoubtedly influenced more by localised wind driven flows than the Agulhas Current. Upwelling is a significant feature of this coastline, wherein cold nutrient rich water is welled up from deeper areas to replace surface water advected offshore by strong winds.

Figure 1: Sampling design and site locations sampled for the PetroSA pipeline monitoring programme in 2011 depicting entire study area; red triangles = biota and sediment chemistry, green circles 1-9 = sediment chemistry only, Biological sampling sites and pipeline diffuser (D) section, additional 4 Test sites (dw 1 – dw 4 were sampled immediately west (within 200 m) of the D, and 3 Test sites de 1 – de 3 were sampled immediately east (within 200 m) of D. Aerial views reproduced from Google Earth©.

Recent oceanographic monitoring conducted in Mossel Bay as a specialist study for an Environmental Impact Assessment for a seawater desalination plant (Aurecon 2011) provides some perspective on the oceanography of the area, although not in particular to Vleesbaai. The average current speeds experienced in Mossel Bay are lower than those along other parts of the South Africa coast, and range from 0.0565 ms^{-1} at a depth of -1.1 m to 0.0390 ms^{-1} at -7.1 m. The general current direction is north to south. The bay often experiences current reversals (bottom current is different to the surface current). The average temperature

recorded during the Environmental Impact Assessment study period (31 July - 7 September 2010) was 15.39^{o}C, with a mean salinity of 35.10 PSU (Aurecon 2011).

3. Pipeline Design and Nature of the Effluent

The PetroSA Vleesbaai pipeline extends about 1.3 km offshore and discharges effluent at a depth of about 22 m. In addition to monitoring water quality in the marine environment in the vicinity of the Vleesbaai pipeline outlet, PetroSA are also required to monitor several physical and chemical water quality parameters in the effluent prior to discharge on a daily basis and closely record the volumes of effluent being discharged per month. These water samples were collected by PetroSA staff and processed by in-house facilities. Data resulting from this monitoring were provided to the scientists from October, November and December 2010 ('Effluent to Sea') for the following parameters: pH, oil content, ammonium, fluorides, suspended solids, absorbed oxygen, conductivity, chemical oxygen demand and faecal coliforms, which are summarised in Table 1. The primary purpose for PetroSA to monitor the effluent prior to discharge is to ensure the various parameter concentrations are within the permit specified limits. These data were the only information on effluent quality prior to discharge provided to the researchers and is thus considered to represent the overall existing effluent quality. The quality of the effluent was broadly explored to provide an indication of effluent content being released into the receiving environment.

The effluent is assessed to have, on average, a relatively low pH. However, occasional significant increases in pH are evident. The total suspended solids concentration is also highly variable and on average, exceeds the licence limit (Table 1). The chemical oxygen demand is relatively modest although it has exceeded the permit limit on occasion. The ammonium concentration is, on average, high, but does not exceed the permit limit. The coliform count is also considered high, but remains below the general wasterwater limit (1000 per 100 ml) as defined in the National Water Act (no. 36 of 1998).
Knowledge of the effluent content and concentrations enabled further interpretation of the findings during the study.

Table 1. Summary statistics of various physical and chemical parameters analysed in effluent prior to discharge through the PetroSA pipeline for the period October to December 2010 (data provided by PetroSA).

Parameter	n	Average	Minimum	Maximum	Median	License Limit
pH	43	6.4	4.5	11.4	6	5.5-9.5
Conductivity (µS.cm^{-1})	43	5910	1658	11210	5320	waived
Total suspended solids (mg.l^{-1})	43	116	38	358	92	80
Oxygen adsorbed (mg O_2.l^{-1})	43	64	16	108	65.6	120
Chemical oxygen demand (mg O_2.l^{-1})	43	3224	212	9810	2450	7000
Ammonium (mg.l^{-1})	43	5.7	0.7	12.5	4.9	35
Fluoride (mg.l^{-1})	43	0.9	0.2	3.1	0.7	10
Oil (mg.l^{-1})	43	2.7	0.1	7.5	2.4	8
Coliforms	26	1163	135	6100	508	1000*

* Refers to a General limit applied to any wastewater discharge into a water resource (National Water Act 1998, No. 36 of 1998).

4. Monitoring Programme Components

The impact of effluent discharge on the receiving environment can be assessed through measuring certain physical and chemical parameters that provide a tracer (or signal) of the effluent component within water, sediment and/or biological tissue samples and through evaluating the structure and composition of biological communities characteristic of the habitat. Various physical, chemical and biological indicators of environmental condition were analysed for the 2011 survey of the PetroSA Vleesbaai pipeline monitoring programme. Taking results of these analyses into account best professional judgement is applied to reach a conclusion on the impact of the discharge. A brief rationale and frame of reference for the components of

the monitoring programme and associated indicators is provided below.

4.1. Sediment quality

Sediment is the predominant sink for many contaminants that are anthropogenically introduced in solution to surface waters. This is because many contaminants have low water solubility and once introduced in solution to surface waters (especially marine) they rapidly adsorb onto suspended sediment and organic matter. In this way, the contaminants are 'scavenged' from the water column through flocculation, coagulation and sedimentation. Under certain conditions, depending on the rate of loading and degree of deposition, contaminants may accumulate in sediment to such high concentrations that they adversely affect bottom-dwelling organisms directly through toxicity or indirectly through alterations in community structure and composition. In addition to these environmental concerns there are pragmatic reasons for focusing attention on contaminants in sediment rather than in the water column. The concentrations of contaminants in the water column are usually low and often highly variable due to variations in water column turbulence and mixing. Furthermore the volume and concentration of anthropogenic inputs also vary over time. A sample of the water column only provides a "snapshot" of water quality information pertinent only to the time of sampling. Important contamination events are likely to be missed when only evaluating water column samples. Sediment, and the communities living therein, accumulates contaminants over time and analysis thereof provides a far more realistic, spatially and temporally integrated measure of possible contamination. Furthermore, contaminant concentrations in sediment are usually orders of magnitude higher than in the overlying water column (up to a million times more) making detection and measurement in the laboratory more feasible.

4.2. Benthic invertebrates

An important concern in any situation where effluent is discharged is whether the ecology of the receiving environment is being unacceptably compromised. Effluent discharge can impact the ecology of the receiving environment in numerous ways, including changes in water column primary productivity, changes in benthic invertebrate community structure and composition, and the accumulation of contaminants in the tissue of fish and shellfish, which not only affects the health of these organisms but may also affect the health of animals and humans that consume them.

Measuring sediment chemistry provides a screening level assessment of potential adverse effects while monitoring biological communities provides a direct measure of effects. The structure and composition of benthic meiofaunal and macrofaunal communities in the study area was used as an indicator of the ecological impact of effluent discharge. This is a typical component of marine pipeline monitoring programmes in many parts of the world. Marine benthos refers to invertebrate fauna that live in or on the surface of the sediments. In contrast to the pelagic groups (e.g. fish and plankton) which can move in and out of an area avoiding temporarily contaminated waters, the benthos, by virtue of their relatively sedentary nature, have to adapt to the prevailing conditions or perish (Warwick 1993).

The difference between benthic macrofauna and meiofauna is largely a human artefact. Simply put, macrofauna and larger than meiofauna. Meiofauna are benthic invertebrates retained on sieve mesh sizes of 150 µm or less, while macrofauna are usually regarded as invertebrates retained on sieve sizes of 500 or 1000 µm. Internationally both meio- and macrofauna are used in programmes monitoring marine pipelines. They often complement one another as biomonitoring indicator assemblages. However, macrofauna have emerged as the most widely used indicator group (Ballesteros et al. 2007, Ranasinghe et al. 2009). Macrofauna tend to have generation times that extend over months or years and are therefore particularly useful in integrating the effects of an impact over the relatively long inter-survey time frames (e.g. one year as proposed for this monitoring programme). Benthic macrofauna typically include a wide variety of taxa

with varying sensitivities to particular impacts. Response to pollution is therefore species specific, but inevitably the overall species response is reflected at the community level. Chronic exposure to contamination may cause sensitive species to die and allow more tolerant, opportunistic species to proliferate. The net effect would be a skewing of the community structure that can be interpreted to reflect the general state of the environment. Pollution impacts then are reflected by shifts in the abundance of macrofauna species, reductions in diversity, or a relative proliferation of tolerant and opportunistic species.

While many of these attributes are also true of the meiofauna, they have much shorter generation times, and can therefore recover from the effects of pollution events more rapidly. Most importantly in South Africa, are very real practical challenges posed by the lack of appropriate taxonomic resolution and skills available when working with meiofauna. Most assessments that have used meiofauna have worked at very coarse taxonomic resolution. Advances in statistical approaches now make it possible to analyse multi species community arrays and detect subtle changes at the community level. These techniques are now standard practice in marine pollution assessment studies, but cannot be fully exploited on datasets which have very poor taxonomic resolution e.g. meiofauna.

The structure of marine benthic invertebrate communities is influenced by many factors. These include abiotic factors, such as sediment conditions, salinity and temperature, as well as biotic factors such as food availability, competition and predation. A major challenge in environmental monitoring is to distinguish between naturally occurring and anthropogenically induced changes to benthic invertebrate communities. This is best achieved through comparison of communities from impacted sites to those from reference sites. While benthic invertebrate community data have limitations, with appropriate replication and analysis they remain the most ecologically relevant source of evidence regarding possible impacts on the benthos (McPherson et al. 2008).

Although both macro- and meiofauna were sampled as part of this programme, the former formed the basis of the biological assessment. Previous impact surveys of the Vleesbaai pipeline conducted by the Centre for Marine Studies (in 2000 and 2002) recorded an absence of harpaticoid copepods in meiofaunal samples, suggesting that these sensitive species were affected by the pipeline effluent and were no longer present in the immediate vicinity (CMS 2001, CMS 2003). The meiofaunal assessment conducted as part of the present survey was limited to a few selected sites with the purpose being to check if this was indeed still the case.

4.3. *In situ* water column data assessment (PetroSA provided data 2008-2010)

As part of the monitoring programme documented in this report, PetroSA requested our assessment of physical and chemical data resulting from analysis of water samples collected by contracted divers at and near the pipeline diffuser which are analysed by PetroSA laboratories. Data from samples collected between three and five times per year (weather and schedule permitting) for 2008, 2009 and 2010 were interrogated for trends. The effluent being discharged from the pipeline into the water column is the first interaction between the natural environment and the potentially harmful effluent. The effluent will become considerably diluted as it enters the marine environment and potential impacts thereof on the natural environment are required to be monitored by PetroSA in accordance with their effluent discharge permit regulations. Careful, regular monitoring of contaminants (metals, hydrocarbons, suspended solids, oil etc.) in the water column present an excellent likelihood of detecting any environmental hazard well before this negatively impacts on the biota in the region. Such regular monitoring should be encouraged as good environmental practice.

5. Materials and Methods

5.1. Sampling design

The sampling design for the monitoring programme sought to address three key questions, namely:

1. Is there a measureable impact from effluent discharge?
2. What is the spatial extent of the effluent discharge impact?
3. What is the magnitude of the effluent discharge impact?

Initial sampling locations were adjusted once researchers were in the field as the true location of the pipeline diffuser differed from that on which the sampling design was originally based. Nevertheless, the original sampling principle was retained in sampling sites immediately adjacent to the pipeline diffuser ('Test' sites - where impacts might be expected) and sites at increasing distances away from the pipeline diffuser ('Control' sites - where impacts should not be expected). Coordinates of sites sampled in November 2011 are provided in Table 2.

Table 2. Details of sites sampled during November 2011 survey of Vleesbaai and Mossel Bay environment.

Sample	Site code	Latitude	Longitude	Depth (m)	Time	Date
Test	dw1	34 13.87'	021 58.76'	24	11h17	7-11-2011
Test	dw2	34 13.88'	021 58.78'	25	12h15	7-11-2011
Test	dw3	34 13.88'	021 58.80'	26	12h45	7-11-2011
Test	dw4	34 13.88'	021 58.84'	26	08h12	8-11-2011
Test	de1	34 13.86'	021 58.92'	25	07h45	7-11-2011
Test	de2	34 13.88'	021 58.93'	27	08h45	7-11-2011
Test	de3	34 13.91'	021 58.96'	28	09h40	7-11-2011
Control	E1	34 13.81'	021 59.02'	26	08h40	8-11-2011
Control	E2	34 13.78'	021 59.32'	27	09h29	8-11-2011
Control	E3	34 13.65'	021 59.74'	28	10h33	8-11-2011
Control	E4	34 13.55'	022 00.35'	30	11h06	8-11-2011
Control	E5	34 13.15'	022 01.53'	26	11h48	8-11-2011
Control	W1	34 13.93'	021 58.70'	25	07h35	8-11-2011
Control	W2	34 14.18'	021 58.24'	26	15h20	7-11-2011
Control	W3	34 14.58'	021 57.69'	28	13h53	7-11-2011
Sediment 1	MB1	34 13.05	022 03.28'	27	12h36	8-11-2011
Sediment 2	MB2	34 12.86'	022 05.33'	28	12h57	8-11-2011
Sediment 3	MB3	34 12.17'	022 08.63'	29	13h12	8-11-2011
Sediment 4	MB4	34 09.87'	022 09.65'	18	13h54	8-11-2011
Sediment 5	MB5	34 08.47'	022 08.45'	22	14h20	8-11-2011
Sediment 6	MB6	34 08.22'	022 07.81'	18	14h38	8-11-2011
Sediment 7	MB7	34 09.23'	022 07.57'	13	15h08	8-11-2011
Sediment 8	MB8	34 09.67'	022 08.15'	11	15h14	8-11-2011
Sediment 9	MB9	34 09.98'	022 08.43'	9	15h18	8-11-2011

A total of seven 'Test' sites were sampled; four immediately westwards of the diffuser (dw1 – dw4) and three eastwards of the diffuser (de1 – de3), aligned perpendicular to the shore (Figure 1, Table 2). The *a priori* hypothesis was that any chemical contamination of sediment and associated adverse effects to benthic invertebrate communities due to effluent discharge would likely be most pronounced at these sites in close proximity to the discharge point. A total of eight 'Control' sites were sampled; five sites at increasing distance eastwards of the diffuser parallel to the shore (E1 – E5) and similarly, three sites at increasing distance, westwards of the diffuser (W1 – W3, Figure 1, Table 2). The influence of contaminant dispersion as a result of current flow would be accounted for in the sampling design implemented.

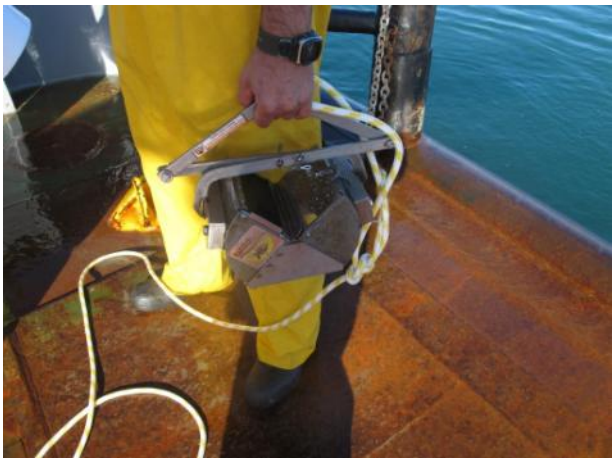
5.2. Field procedures

At each site a van Veen grab, sampling an area of 0.084 m^2 of seabed, was deployed six times to collect sediment and fauna from the seabed. One of these replicates was processed for grain size, total organic content, metal and hydrocarbon analysis. Subsamples of sediment from this grab replicate were transferred either to high-density polyethylene containers for grain size, total organic content and metal analysis, or to glass containers for hydrocarbon analysis. Where appropriate, the samples were frozen (-4°C) in the laboratory until analysis.

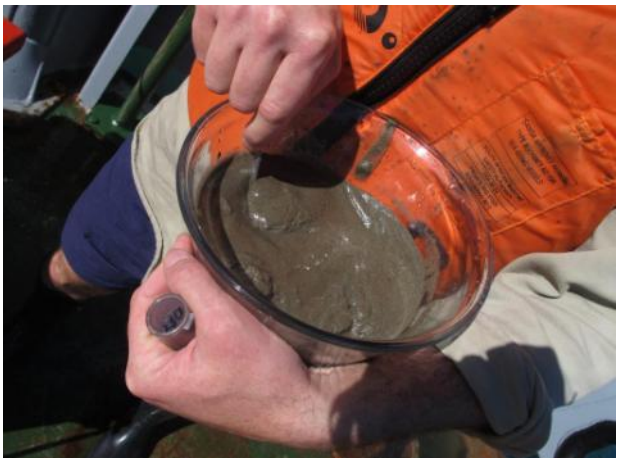
The five remaining grab replicates were processed for macrofauna. In the field the sediment was sieved through a 500 µm mesh size sieve. All macrofauna retained by the 500 µm mesh were transferred into high-density polyethylene containers with seawater and preserved immediately with formaldehyde to which the dye Phloxine had been added to stain all biotic matter a red-brown colour which aids in sample processing in the laboratory.

At nine selected sites (six 'Test' and three 'Control') an additional sediment grab was taken with a smaller Ponar grab, sampling an area of 0.023 m^2 of seabed. This sample was also preserved with formaldehyde and retained for analysis of meiofauna in the laboratory.

Sediment for grain size, total organic content, metal and hydrocarbon analysis was collected from an additional nine sites positioned arbitrarily to the east of the study area, including offshore of the town of Mossel Bay (MB1-9). The primary purpose of this sampling was to provide sufficient data for the definition of baseline metal concentrations and to identify whether sources of anthropogenic contaminants offshore of Mossel Bay were significant for the broader study area.



A) Ponar grab for sampling meiofauna



B) Ensuring the sediment sample is well mixed for further analysis

C) Various containers prepared for different sediment property analyses: grain size, organic carbon, hydrocarbons and metals

D) SMIT Amandla vessel crew assisting with retrieval of the Van Veen grab to obtain a macrofauna sample

E) Sieving the macrofauna sample through 0.5 mm mesh sieve bag.

F) Ensuring all the macrofauna sample is processed through the sieve bag

Plate 1: Photographs showing various field sampling processes employed during the November 2011 survey.

5.3. Laboratory procedures

5.3.1. Grain size composition

Sediment grain size composition was determined by wet and dry sieving into seven grain size classes, namely mud (<0.063 mm), very fine-grained sand (0.063 - 0.125 mm), fine-grained sand (0.125 - 0.250 mm), medium-grained sand (0.25 - 0.50 mm), coarse-grained sand (0.5 - 1.0 mm), very coarse-grained sand (1.0 - 2.0 mm) and gravel (>2.0 mm). Grain size class contribution is expressed as a fraction of bulk sediment dry weight.

5.3.2. Total organic content

Sediment was oven dried, weighed, and organic matter then degraded using hydrogen peroxide. The sediment was washed in distilled water, re-dried and re-weighed. The difference in dry weights before and after organic matter degradation is used to determine total organic content. Total organic content is expressed as a fraction of bulk sediment dry weight.

5.3.3. Metals

The sediment was freeze dried and ball milled. Approximately 1 g of dried sediment was digested with HNO_3-HCl-H_2O_2 according to USEPA method 3050B. This is a 'near-total' digestion procedure that dissolves most elements that could become 'environmentally available' but is not designed to dissolve metals tightly bound in silicate structures. The concentrations of 15 metals (Table 3) were detected and quantified using Inductively Coupled Plasma Optical Emission and Mass Spectroscopy. The exception to the above method was mercury, which was analysed using a direct mercury analyser. Metal concentrations are presented as $mg.g^{-1}$ or $\mu g.g^{-1}$ dry weight.

Precision and method extraction efficiency of the digestion and concentration determination procedures were evaluated by analysing marine sediment reference standard PACS-2 (National Research Council of Canada) with each batch of 10 sediment samples. Since the reference material is certified for total digestion the recovery for several refractory metals (e.g. aluminium, chromium) was, as expected, somewhat below 100%. The lower recovery of certain metals compared to recoveries achieved using aggressive acids does not invalidate the data since the relationships between metal concentrations, sediment grain size and total organic content are likely to be as strong using different acids, but the slopes and intercepts of the relationships will differ.

The reader should note that while arsenic is technically a metalloid (i.e. semi-metal), in the interests of simplicity it is referred to as a metal in this report.

5.3.4. Hydrocarbons

The sediment samples were freeze dried and ball milled. A sodium sulphate blank accompanied the sediment samples through the entire preparation and analysis procedure to monitor for detection quality. Before solvent extraction the sediment was spiked with a deuterated standard mix (deuterium added) to monitor recovery. Sediment and sodium sulphate blank samples were subjected to enhanced solvent extraction using methylene chloride, concentrated under nitrogen and purified by size exclusion liquid chromatography to remove biogenic co-extractives of large molecular size. The eluent (substance used as a solvent in separating materials) was collected in vessels containing activated elemental copper to remove co-extracted sulphur. Purified extracts were reduced in volume and purified on 2 g silica gel solid-phase extraction columns to retain polar biogenic compounds. Total petroleum hydrocarbon and polycyclic aromatic hydrocarbons (Table 2) were analysed on a high resolution gas chromatograph.

Method extraction efficiency was evaluated by analysing National Institute of Standards and Technology standard reference material 1944. Extraction efficiencies were within the data quality objectives of 75 – 125 % recovery.

Table 3. Physical and chemical parameters analysed in sediment samples collected for the 2011 survey of the PetroSA pipeline monitoring programme.

Class	Parameter	Class	Parameter
Conventional	Sediment grain size	*Total petroleum hydrocarbons*	C10-C12
			C12-C16
Organic indicators	Total organic content		C16-C21
			C21-C30
Metals	Aluminium		C30-C35
	Iron		C35-C40
	Arsenic		C10-C40
	Barium	*Polycyclic aromatic hydrocarbons*	Naphthalene
	Beryllium		Acenaphthylene
	Cadmium		Acenaphthene
	Cobalt		Fluorene
	Copper		Phenanthrene
	Chromium		Anthracene
	Manganese		Fluoranthene
	Mercury		Pyrene
	Nickel		Benzo(a)anthracene
	Lead		Chrysene
	Vanadium		Benzo(b)fluoranthene
	Zinc		Benzo(k)fluoranthene
			Benzo(a)pyrene
			Dibenzo(ah)anthracene
			Benzo(ghi)perylene
			Indeno(123cd)pyrene

5.3.5. Benthic invertebrates

In the laboratory macrobenthic samples were washed gently and all matter retained by sieves decanted into sorting trays. Organisms were individually removed from the matter with fine forceps and the aid of magnifying glasses. The composite fauna for each site was preserved in 70% ethanol and subsequently identified to the lowest level of taxonomic resolution practicable and enumerated under stereomicroscope.

In the laboratory, meiofauna were extracted from the sediment using a modified Oostenbrink separator (Fricke 1979) and a 45 µm mesh sieve. Sub-samples were then counted and converted so as to be expressed as meiofauna per 100 ml sediment for each of the nine sites sampled. Counts were made of each meiofaunal group distinguishable at 63x magnification under a stereomicroscope.

5.4. Data analysis

5.4.1. Sediment quality

5.4.1.1. Definition of baseline metal concentrations

Determining whether sediment is contaminated by certain chemicals is easy since these only have an anthropogenic origin (e.g. polychlorinated biphenyls); the mere presence of these chemicals in the natural environment is thus indicative of contamination. Determining whether sediment is metal contaminated is, in contrast, far more complicated. This is because metals are a ubiquitous, naturally occurring component of all sediment. The mere presence of metals in sediment does not, therefore, imply that the sediment is contaminated. Metal concentrations in uncontaminated sediment can also vary naturally by orders of magnitude over relatively small spatial scales depending on sediment mineralogy, granulometry and organic content amongst other factors (Loring and Rantala 1992, Kersten and Smedes 2002). High metal concentrations in sediment thus do not automatically imply that the sediment is metal contaminated but may simply reflect the natural mineralogical composition of the sediment parent material, and

granulometry and organic content of the host sediment.

To meaningfully interpret metal concentrations the factors that influence the natural variation of metal concentrations in sediment must be compensated for before natural concentrations can be differentiated from anthropogenically enhanced (i.e. contaminated) concentrations (Kersten and Smedes 2002). This can be accomplished through the procedure of normalisation, which mathematically normalises metal concentrations to a co-occurring conservative element (the normaliser) that provides a tracer of crustal decomposition (Kersten and Smedes 2002). This is used to define baseline metal concentration models (or simply baseline models), which are then used to interpret whether sediment is metal enriched and possibly metal contaminated. Since previously defined baseline metal concentrations are not readily available for the Mossel Bay area one objective of this study was to define these concentrations for a suite of major, minor and trace metals from sediment samples collected at random locations in and around Mossel Bay.

The basis for geochemical normalisation is that while the absolute concentrations of naturally occurring metals vary between regions the relative proportions of metals from a particular region tend to be fairly constant (e.g. Turekian and Wedepohl 1961, Taylor and McLennan 1981, Martin and Whitfield 1983, Wedepohl 1995, Kersten and Smedes 2002). Since there is relatively little fractionation between metals and aluminosilicates during the weathering of parent material (Schropp and Windom 1988), metal concentrations in uncontaminated sediment tend to reflect the relative proportions of metals in the material from which they are derived.

The use of a metal as a proxy for the natural metal-bearing phases of sediment requires that the metal meet several assumptions, namely that it:

1. is highly refractory (i.e. is resistant to weathering),
2. is structurally combined to one or more of the major metal-bearing phases of sediment,
3. co-varies in proportion to the naturally occurring concentrations of metals of interest,
4. is insensitive to inputs from anthropogenic sources, and
5. is stable and not subject to environmental influences such as reduction/oxidation, adsorption/desorption and other diagenetic processes that may alter sediment concentrations (Luoma 1990).

Two metals in the data set, namely aluminium and iron, meet all or most of these assumptions and are widely used as normalisers of metal concentrations in sediment. Aluminium is generally considered the better normaliser and was used as a normaliser for baseline model definition in this study. The use of iron as a normaliser could also have been used yielding very similar results. The only metal for which aluminium is not used as a normaliser is that of cadmium (see below).

Scatter plots were generated to explore the relationship between each metal and the co-occurring aluminium concentrations, usually resulting in linear relationships becoming evident (i.e. with an increase in the metal, the aluminium also increased). Outliers were eliminated from the data and linear regressions with 99 % prediction limits were fitted. These baseline models do not result in a definitive line beyond which the metal accumulation is considered contaminated, but provides a range of likely, uncontaminated metal concentrations that may naturally occur in the region. Should metal concentrations occur outside of the 99 % prediction limit, it is likely to reflect anthropogenically derived contamination in excess of what is naturally occurring in the region.

5.4.1.2. Cadmium

Cadmium concentrations were weakly correlated to co-occurring aluminium concentrations, even after the trimming of outliers. Thus, variation in the concentration of aluminium is not able to explain variation in cadmium concentrations. Similarly weak relationships between cadmium and aluminium concentrations have been reported by other researchers (e.g. Schropp and Windom 1988, Windom et al. 1989, Daskalakis

and O'Connor 1995, Summers et al. 1996, Newman and Watling 2007; but see Schropp et al. 1990, Trimble et al. 1999). Some researchers (Windom et al. 1989 and Hanson et al. 1993), suggest that variability in analytical detection at low cadmium concentrations, diagenetic remobilisation and binding to other phases in sediment, such as organic matter, may decrease the sensitivity of the linear regression approach for cadmium (and indeed other metals such as mercury in many cases).

A variety of other approaches have been recommended for defining baseline concentrations for metals in sediment (e.g. Matschullat et al. 2000), including the iterative mean + 2 standard deviations, the geometric mean + 2 standard deviations and the calculated distribution function. These approaches were applied in this study but proved to be of little use, primarily because of the small data set. The baseline cadmium concentration above which enrichment of sediment from the study area can be inferred, was consequently defined using a probability plot (Figure 2). The theory on the use of probability plots for defining baseline concentrations is that natural and contaminated samples have different underlying distributions. Marked gaps and/or inflections in the data distribution are taken as representing different populations, including outliers (i.e. contamination). Data points that form a continuous distribution (i.e. approximate a straight line) are considered to represent a (single) population and are likely to represent natural conditions, while those beyond gaps and inflections represent a different (contaminated) population.

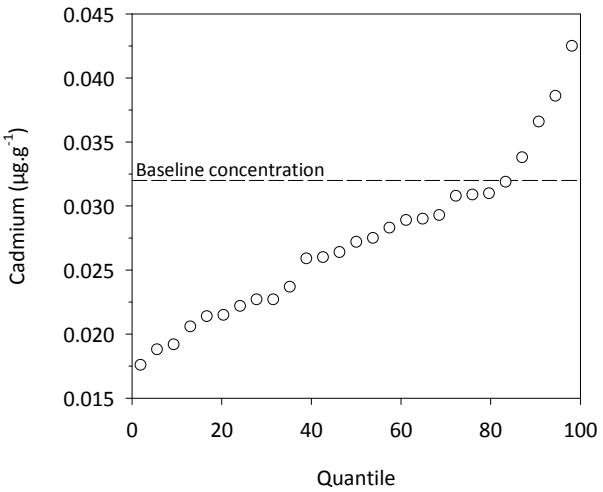


Figure 2. Probability plots for cadmium in sediment in the Mossel Bay area. The baseline concentration is indicated. Concentrations below the method detection limit were replaced with a concentration equivalent to the method detection limit.

5.4.1.3. Sediment metal concentrations: Data interpretation

The manner in which baseline models are used to interpret metal concentrations in sediment is best conveyed using a theoretical example based on the baseline model for chromium in sediment from the study area (Figure 3). Metal concentrations from collected samples are superimposed on the baseline model. In Figure 3, four hypothetical chromium concentrations are superimposed on the baseline model. Concentrations that fall within the baseline model upper and lower 99% prediction limits (i.e. hypothetical concentration 1) are considered to fall within the baseline concentration range. Concentrations that exceed the baseline model upper prediction limit (i.e. hypothetical concentrations 2, 3, and 4) are interpreted as enriched. Metal concentrations that exceed the upper prediction limit do not necessarily imply that the enrichment has an anthropogenic source, but rather that the concentrations are atypical of the data set used to define the baseline model (Horowitz et al. 1991). Several reasons in addition to anthropogenic contributions may lead to a metal concentration exceeding the baseline model upper prediction limit, including analytical errors, poor model assumptions and natural enrichment that is not captured by the data set used to define the baseline model (Schropp et al. 1990, Rae and Allen 1993). Interpretation of metal enrichment, and ultimately whether this reflects contamination, therefore requires consideration of additional factors, including (a) possible (bio)geochemical processes leading to natural enrichment, (b) the

absolute difference between a metal concentration and the baseline model upper prediction limit, (c) the number of metals at a sampling site that exceed baseline model upper prediction limits and (d) the proximity of the metal enriched sediment relative to known or potential anthropogenic sources of metals. The greater the difference between a metal concentration and a baseline model upper prediction limit, the greater the number of metals enriched in sediment at a particular site, and the nearer a metal enriched site is to a known or strongly suspected anthropogenic source of metals the greater is the likelihood that the metal concentrations are enhanced through anthropogenic contributions and thus reflect contamination.

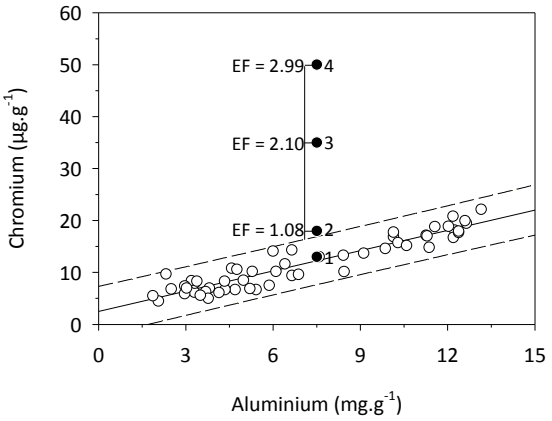


Figure 3. Baseline model for chromium in sediment from the Mossel Bay area. Open symbols are chromium concentrations used to define the baseline model while numbered solid symbols represent four hypothetical scenarios: 1. concentration falls within the baseline model upper and lower prediction limits (dashed lines) and is not enriched; 2, 3 and 4. concentrations exceed baseline model upper prediction limit and reflect various levels of enrichment that can broadly be defined from low (2) through to high (4). Situations 3 and 4 would be interpreted as reflecting enrichment through contamination with a high level of confidence. Enrichment Factors for two of the scenarios are indicated.

As portrayed in Figure 3, the hypothetical concentration 2 would be interpreted as slightly enriched, but whether this reflects contamination can only be decided on following an assessment of whether the concentrations of other metals in this sample are also enriched and the proximity of the sample site to known or suspected anthropogenic sources of chromium. Hypothetical concentrations 3 and 4, greatly exceed the upper prediction limit and these concentrations would be interpreted as enriched (contaminated with chromium) due to an anthropogenic contribution.

Interpreting the concentration of cadmium in the sediment is conducted differently due to the different method of assessing this (see above). The cadmium concentrations detected in the sediment samples are compared to the baseline cadmium concentration and concentrations above baseline are considered further. The procedure used to define the baseline *cadmium* concentration is more subjective than the geochemical normalisation approach a measure of professional judgement is necessary for deciding whether a high cadmium concentrations (i.e. those that exceed the baseline cadmium concentration) reflect contamination. This is done by considering the above-mentioned additional factors.

5.4.2. Benthic invertebrates

Investigating for any impact on the biological community required testing for differences between 'Control' and 'Test' site using appropriate statistical routines, namely PRIMER v6 software (Clarke and Warwick 2001). Where appropriate data were either 4^{th} square root or log (X + 1) transformed prior to analysis to down-weight the abundance of dominant or large species (Field et al. 1982).

The following PRIMER software routines were used to analyse the data.

DIVERSE indices: This routine calculates a range of univariate community parameters and diversity indices

for each sample. These are key ecological measures that can provide an indication of the status of an ecosystem (Magurran 1988). In this study, five univariate indices are reported on, these being 1) total number of taxa, 2) total number of individuals, 3) species richness (Margalef), 4) species evenness (spread of numbers among species) and 5) diversity (Shannon-Weiner). Average indices were compared amongst sites using one-way Analysis of Variance (ANOVA), followed where appropriate by a Tukey multiple comparison test (Zar 1996).

CLUSTER dendrogram: This multivariate routine measures the relative similarity of each sample within a group of samples resulting in a dendrogram that displays samples similar in faunal composition to be more closely related within the group. It is particularly useful in delineating clusters of similar sites. Abundance data were 4^{th} root transformed to reduce the dominance of disproportionately high counts. A stronger (logarithmic) transformation was used for biomass data as some samples were heavily influence by the presence of single occurrences of large e.g. starfish. The Bray-Curtis coefficient was used as a measure if similarity.

MDS (Multi-Dimensional Scaling) Plot: This multivariate routine is linked to the CLUSTER dendrogram, and depicts similarities amongst samples within a multidimensional framework, projected onto a two dimensional ordination plot.

ANOSIM (Analysis of similarities): This routine tests for the statistical differences between pre-defined groups. The ANOSIM routine results in a test statistic (R) and level of significance (Clarke and Green 1988). The test statistic R reflects the degree of similarity between the groups being tested (e.g. between Control and Test site) and ranges between 1 and -1. Typically:

- R = 1 only if all site within groups are more similar to each other than to sites from other groups.
- R approaches zero if the null hypothesis is true, i.e. all sites are similar and there is no significant different between the groups.
- R = -1 only if all sites within groups are more similar to sites from other groups.

SIMPER (Similarity of percentages): This routine assesses which species contribute the most to differences between groups as detected by the dendrogram, MDS and ANOSIM. It is particularly useful for identifying faunal markers (indicator species) that may be indicative of impact.

BEST: This routine links biological patterns detected with physical and chemical measurements. By cross correlating the data sets, this routine defines which of the measured physical and chemical parameters are most likely 'driving' the biological trends detected. It provides a information towards understanding cause and effect.

Previous meiofaunal analysis conducted at Vleesbaai, relied on the use of the Nematode/Copepod ratio (N/C). To allow comparisons with previous studies, the same analysis was applied to meiofauna for this study. The N/C ratio is very simply calculated as the number of nematodes divided by the number of harpacticoid copepods. Where there were no copepods the number of nematodes was divided by 1.

5.4.3. *In situ* water column data assessment (PetroSA provided data 2008-2010)

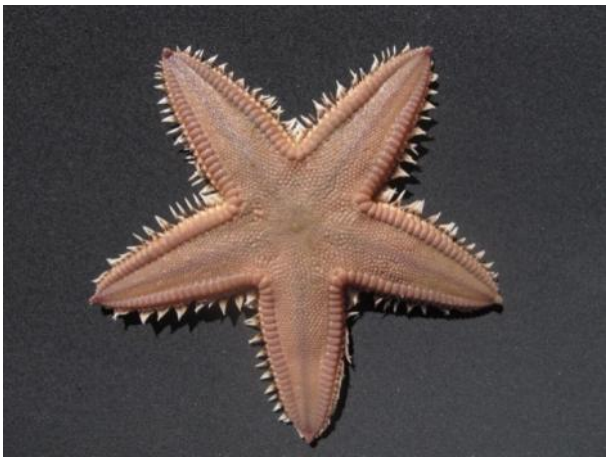
PetroSA contract divers collect *in situ* water samples from six sites within the immediate vicinity of the Vleesbaai pipeline. A day or two before the divers are scheduled to collect water samples, the discharge is halted and divers collect the first water sample from above the diffuser. This sample is considered to represent ambient water conditions representative of natural conditions in the area. Once this sample is collected, the divers notify the plant and effluent discharge re-commences for approximately 30 to 60

minutes. Water samples are then collected from the surface of the water directly above each of the two diffuser ports and 200m east and west of the diffuser outlet. Additionally a mid-water sample is collected approximately 2 m from the seabed above each of the diffuser ports. Water samples to be analysed for faecal coliforms are collected in sterile glass bottles. All glass sample bottles are returned to PetroSA laboratories for analysis.

A) Sieved macrofauna sample transferred to jar with label.

B) Adding formalin preservative to the macrofauna sample.

C) Buoy marker for the seaward end of pipeline diffuser (PLEM).



D) Starfish species sampled as component of macrofauna, *Astropecten antares* ~ 70 mm diameter.

E) Burrowing urchin species sampled as component of macrofauna, *Echinocardium chordatum* ~ 40 mm diameter.

Plate 2. Photographs of field sampling, pipeline diffuser marker buoy and large individuals of macrofauna occurring in samples.

6. Results and Discussion[3]

6.1. Sediment quality

6.1.1. Sediment grain size

Sediment grain size is one of the most important variables that influence natural and anthropogenic concentrations of metals in sediment. Anthropogenic metals also tend to preferentially associate with fine-grained sediment due to the large surface area for adsorption by the fine-grained particles and surface electric charges that render the particles reactive. Anthropogenic metals are also preferentially transported with (i.e. adsorbed onto) fine-grained particles and are ultimately deposited and accumulate in depositional zones (i.e. zones dominated by fine-grained sediment, typically mud). There are of course exceptions, such as coarse-grained sediment having high metal concentrations due, for example, to the introduction of metal flecks and metal-infused paint flakes near vessel construction and maintenance facilities. An understanding of the grain size composition of sediment thus provides important information for identifying areas that are potentially susceptible to the accumulation of anthropogenic contaminants.

The grain size composition of sediment also provides important information for understanding factors that influence the composition and structure of benthic macrofaunal communities (discussed in a subsequent section of this report).

From a textural perspective sediment in the study area can be divided into two classes, namely sand and muddy-sand, with sand being the dominant textural class (Figure 4). Of the various grain size classes that comprise sand, fine-grained sand was dominant at all sites, usually comprising in excess of 70% of the bulk sediment weight. The lowest contribution of fine-grained sand was generally evident at sites MB4 to MB8, situated offshore of Mossel Bay. Coarse fractions, namely gravel, very coarse-grained and coarse grained sand were poorly represented, usually comprising less than 1% of the bulk sediment weight. Although mud was present at all sites the contribution was usually less than 10% of the bulk sediment weight. The low mud fraction of sediment thus theoretically implies that there is a low probability for the accumulation of particle reactive contaminants in the study area.

The sediment at the majority of sites is very well- to well-sorted. Well-sorted sediment is characteristic of high-energy environments, where currents, waves and other forms of turbulence are of sufficient velocity to winnow fine grains (e.g. mud) from the sediment, but not coarser grains. Poorly sorted sediment is characteristic of low energy environments (e.g. estuaries), where turbulence velocity is insufficient to winnow even very fine grains of sediment. The implication then is that the same currents that are sorting sediment in the study area will also be efficiently dispersing effluent discharged through the pipeline.

[3] Raw data are provided as appendices to this report.

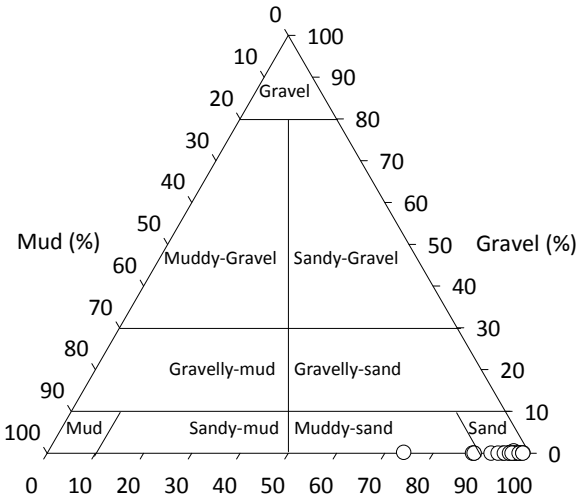


Figure 4. Ternary plot illustrating the proportional contribution of gravel, sand and mud to bulk sediment in the study area.

6.1.2. Total organic content

Organic matter in sediment provides an additional binding site for metals. Metals are also commonly transported and introduced to aquatic systems bound to particulate organic matter. Because of its fine grain size, particulate organic matter is deposited on and winnowed from sediment along with mud, depending on prevailing hydrodynamic conditions. Thus, mud and particulate organic matter tend accumulate in the same areas. An understanding of the total organic content of sediment thus provides important information for identifying the major sources to depositional zones of particulate organic matter in the study area and thus for identifying areas potentially susceptible to the accumulation of anthropogenic contaminants, including metals, but particularly organic contaminants (e.g. hydrocarbons).

The total organic content of sediment across the study area was low, reaching a maximum of only 1.39 %. A scatter plot of the mud versus total organic content of sediment revealed a positive linear relationship between these variables at the majority of sites (Figure 5). A baseline model for total organic content was defined using the same approach described previously for the definition of baseline models for metals. The total organic content of sediment at a single site (DE1) is anomalously high (Figure 5). The probability that the particulate organic material in this sample was derived from effluent is, however, unlikely considering that none of the other sediment samples collected near the pipeline diffuser were enriched.

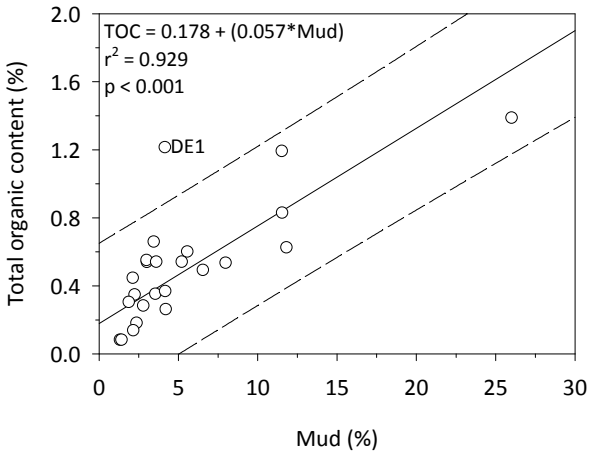


Figure 5. Baseline model for total organic content in sediment in the study area. Sites at which the total organic content is enriched are superimposed and denoted by identifiers. Fitted parameters, coefficient of determination and statistical significance for the baseline model are provided.

6.1.3. Metals

6.1.3.1. Relationship between aluminium and mud fraction of sediment

There is usually a strong positive correlation between concentrations of most metals and the mud fraction of sediment in unimpacted coastal systems in most areas of the South African coastline. The results from this study, however, reveal that the correlation between the mud fraction and aluminium concentrations was very weak and not statistically significant ($r = 0.104$, $p = 0.606$), with similar results for iron concentrations ($r = 0.104$, $p = 0.045$). However, aluminium and iron concentrations were strongly positively correlated with the very fine-grained sand fraction (Al: $r = 0.758$, $p < 0.001$; Fe: $r = 0.752$, $p < 0.001$). This implies that aluminium and iron are more closely associated with the very-fine grained sand fraction rather than mud, which is generally the major metal-bearing phase of sediment. The positively correlated relationship between aluminium and the very-fine grained sand fraction enabled the use of aluminium as a normaliser.

6.1.3.2. Baseline metal concentration models

The aluminium normalised baseline model parameters are presented in Table 4. The concentrations of five of the metals were strongly positively correlated (defined as a coefficient of determination $r^2 > 0.80$) to co-occurring aluminium concentrations, which is sufficient for baseline model definition (Table 4). The remaining metals showed two patterns of correlation. Arsenic, cobalt, copper, lead and vanadium showed a moderate correlation to co-occurring aluminium concentrations as a result of scatter in the data, which reflects the natural variation in the study area (Table 4). There was substantial data scatter for barium and beryllium, whilst cadmium was inversely correlated to aluminium concentrations. The baseline models for beryllium and cadmium were also not statistically significant (Table 4). The baseline models for barium, beryllium and cadmium were not considered suitable for interpreting concentrations in sediment from the study area and no further interpretation on the status of these metals was made for this study other than that the test site results were no different to the control or background sites and contamination as a result of the effluent is unlikely.

Table 4. Regression parameters for aluminium normalised baseline models for the Mossel Bay area. Metal concentrations in $\mu g.g^{-1}$ with the exception of aluminium and iron, which are in $mg.g^{-1}$. n = sample size on which the regression is based, r^2 = coefficient of determination, p = statistical significance.

Metal	Baseline model parameters	n	r^2	p
Iron	Fe = 0.447 + (0.978*Al)	51	0.995	<0.001
Arsenic	As = 3.439 + (0.241*Al)	53	0.435	<0.001
Barium	Ba = -34.222 + (8.564*Al)	24	0.519	<0.001
Beryllium	Be = 0.0878 + (0.0294*Al)	24	0.116	0.104
Cadmium	Cd = 0.0374 - (0.00103*Al)	27	0.232	0.026
Cobalt	Co = 0.00424 + (0.286*Al)	32	0.452	<0.001
Copper	Cu = 0.982 + (0.176*Al)	32	0.452	<0.001
Chromium	Cr = 2.516 + (1.301*Al)	54	0.885	<0.001
Manganese	Mn = 1.363 + (9.185*Al)	46	0.903	<0.001
Nickel	Ni = -0.424 + (0.612*Al)	53	0.950	<0.001
Lead	Pb = 2.829 + (0.562*Al)	46	0.632	<0.001
Vanadium	V = -0.480 + (1.604*Al)	24	0.614	<0.001
Zinc	Zn = 4.761 + (1.772*Al)	52	0.886	<0.001

6.1.3.3. Cadmium baseline concentration probability plot

The baseline cadmium concentration was defined using a probability plot (Figure 2, previously explained). The cadmium baseline concentration was defined as 0.032 $\mu g.g^{-1}$ in this study. This concentration represents the point at which the data distribution distinctly inflects (Figure 2).

6.1.3.4. Metal enrichment of sediment results

Figure 6 presents metal concentrations in sediment collected for the present study superimposed on the aluminium normalised baseline models. Metal concentrations that exceed the baseline model upper prediction limit (or baseline cadmium concentration), indicated by dashed lines in Figure 6, are considered to be enriched. This does not necessarily imply that the enrichment is a consequence of the anthropogenic introduction of metals (i.e. contamination) and several additional factors are considered before conclusions are drawn. As is evident in Figure 6 only two manganese concentrations and two arsenic concentrations exceed the baseline model upper prediction limit and three cadmium concentrations exceed the baseline cadmium concentration. In all of these cases the magnitude of exceeding the limit was minimal and only one control site (W4) where the baseline cadmium concentration was exceeded was located within the vicinity of the pipeline outlet. All remaining sites that exceed the respective limits were located within the broader Mossel Bay area and served as sites from which to gain background environmental information. The results from the sediment metal concentration analysis indicate that there is no evidence that sediment within the Vleesbaai area is metal enriched.

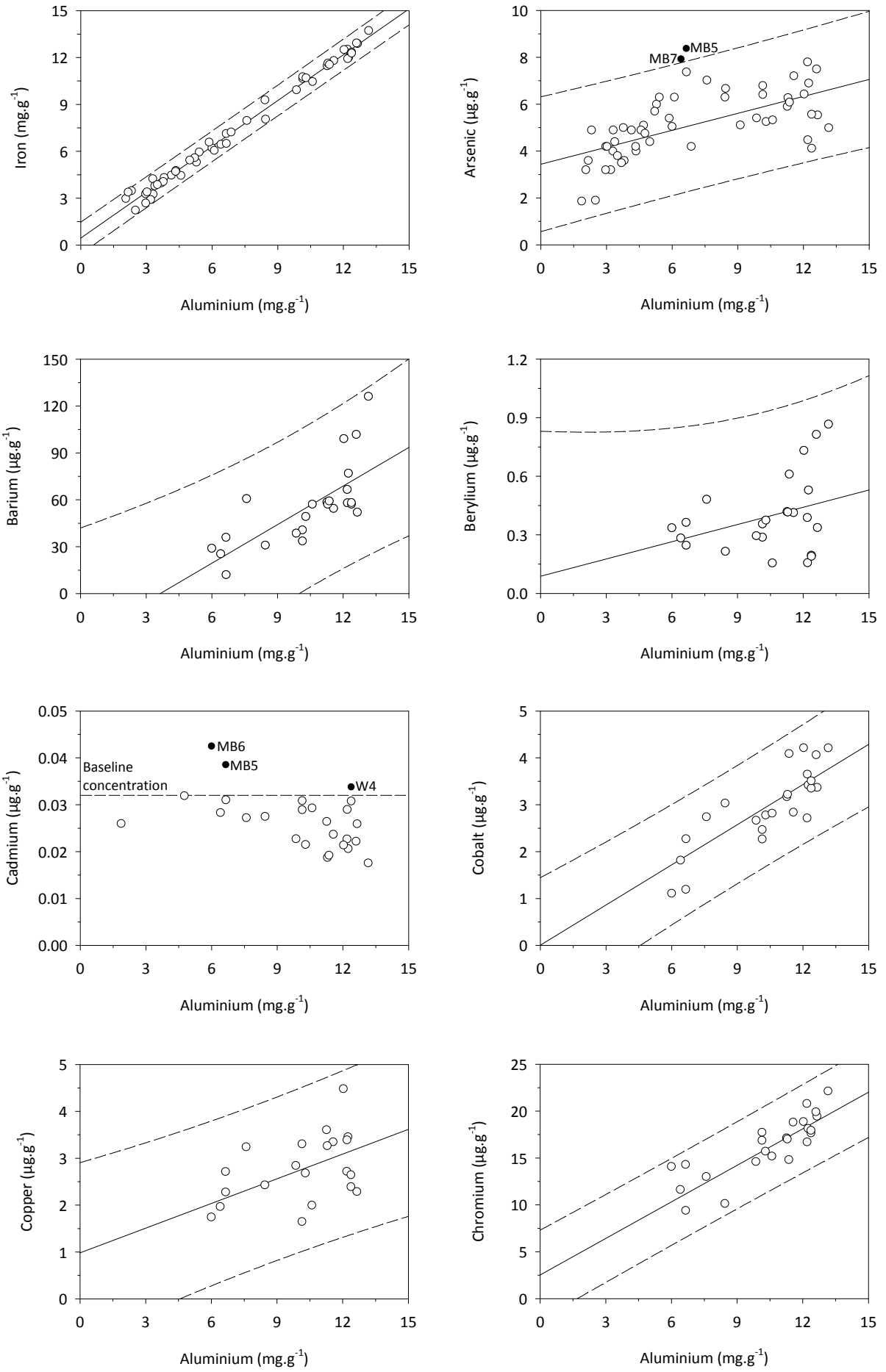


Figure 6. Aluminium normalised baseline models for metals in sediment in the Mossel Bay area, with concentrations identified as outliers superimposed and denoted by site identifiers.

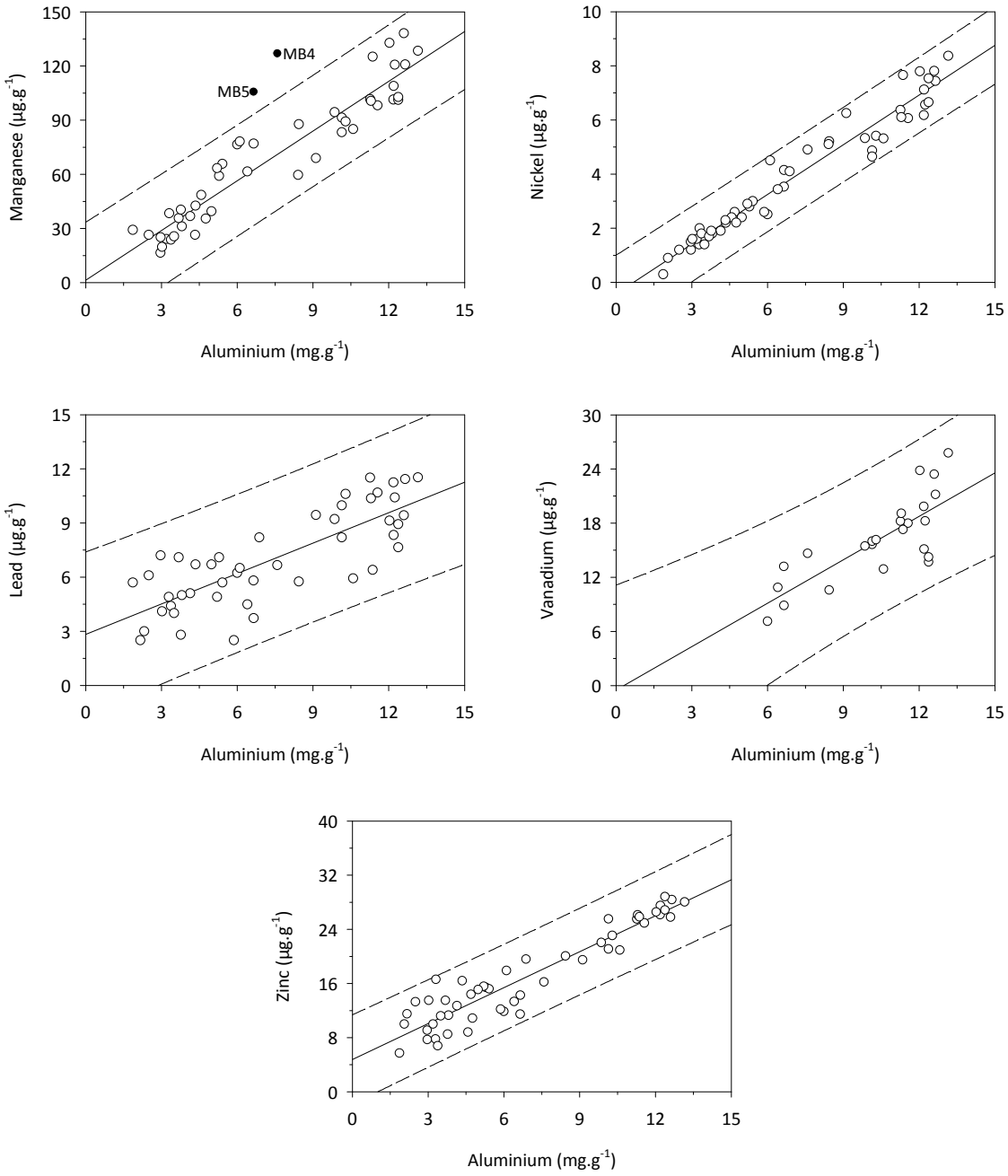


Figure 6 continued. Aluminium normalised baseline models for metals in sediment in the Mossel Bay area, with concentrations identified as outliers superimposed and denoted by site identifiers.

6.1.4. Hydrocarbons

Concentrations of total petroleum hydrocarbons were detected in sediment at all but one site (Figure 7). The concentrations detected were however, very low and almost exclusively restricted to carbon ranges C10-C12 and C12-C16, which are considered to be relatively 'light' hydrocarbons (Figure 7). The only polycyclic aromatic hydrocarbon isomer detected was naphthalene, at concentrations only marginally exceeding the method detection limit in sediment at three sites: DE1, MB5 and MB6 (see Appendix 3).

The results from this study and analysis show no evidence that sediment within the study area is significantly contaminated by hydrocarbons. The source of the 'light' petroleum hydrocarbons to the study area is uncertain, but effluent discharged through the PetroSA pipeline cannot be discounted.

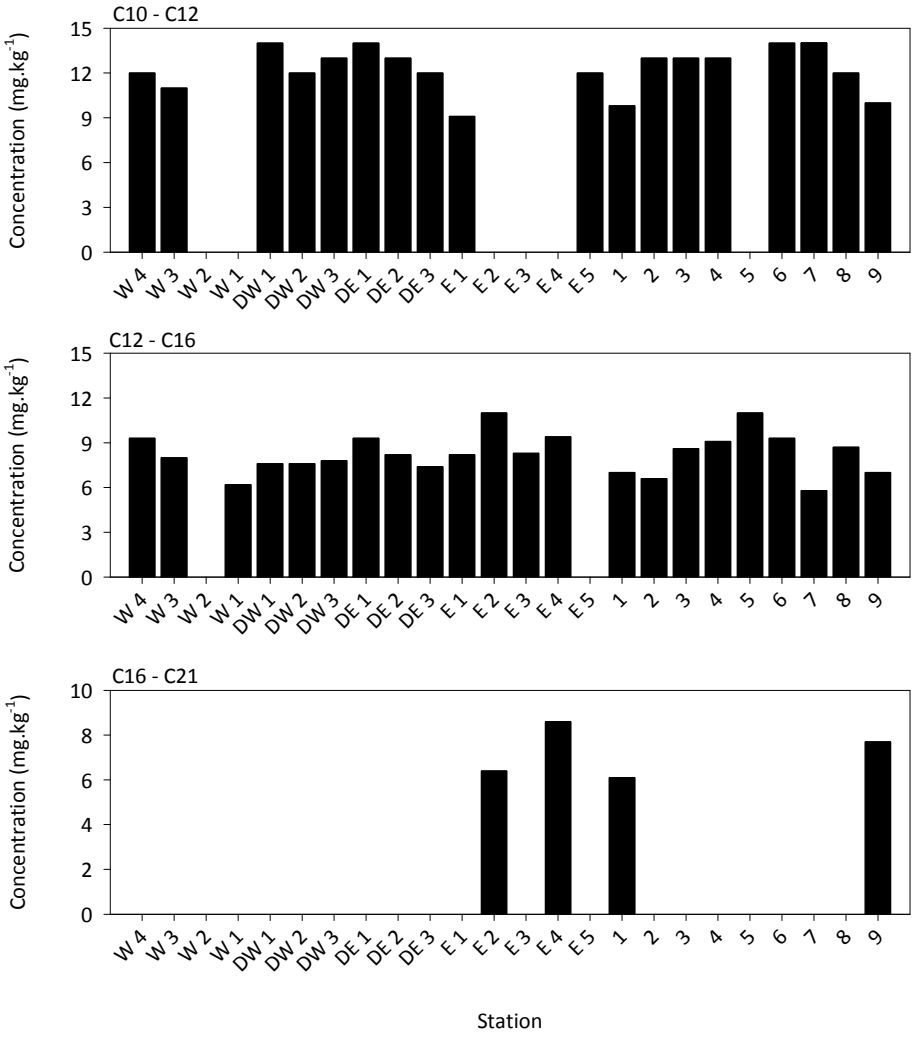


Figure 7. Concentrations of total petroleum hydrocarbon carbon equivalents in sediment in the Mossel Bay area. Concentrations of all other carbon equivalents analysed were below the method detection limit.

6.2. Benthic invertebrates

6.2.1. Macrofauna

A good array of macrofauna species were sampled from the vicinity of the PetroSA pipeline in Vleesbaai in 2011. The benthic community was generally dominated, in terms of abundance, by bristle worms (polychaetes) and small crustaceans (amphipods and isopods) (Appendix 4). Echinoderms (starfish and urchins, Plate 2) and hermit crabs were the main contributors to benthic biomass sampled (Appendix 5). This is typical of the shallow water marine environment in the southern Cape, and elsewhere on the South African coast.

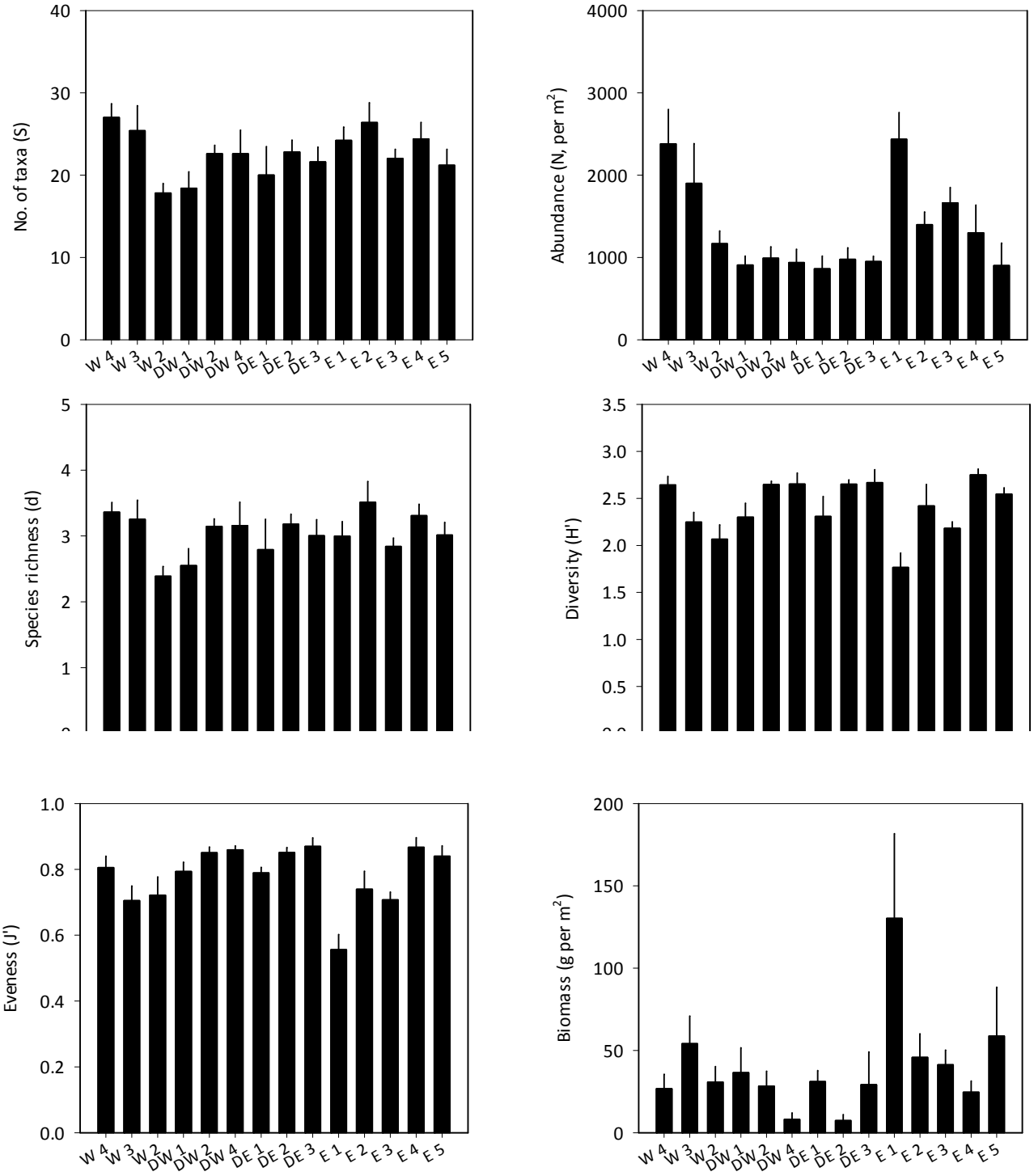


Figure 8. Univariate indices of macrobenthic community structure for the 2011 survey of the PetroSA outfalls monitoring programme.

Univariate measures of community structure essentially condense the data for each sample into a single index/measure. These measures are based on the number of different taxa recorded and the number of individual animals sampled and provides insight into community composition. Conventional wisdom in assessing marine macrobenthic communities is that a 'healthy' community is characterised by high diversity and an even spread of numbers amongst species. A superabundance of one species in combination with reduced diversity often indicates that the community is stressed.

Figure 8 presents the average univariate index values for sites samples. The highest numbers of taxa were found at Control sites W3, W2 and E2. These differences were however, not statistically significant. There appeared to be a trend of increasing abundance of benthos with increasing distance to the west of the pipeline. Average abundance at Sites W3 and E1 were significantly higher than abundances at many other sites, ($F = 4.699$, $p < 0.001$). There were no differences in Margalef's species richness (d) among sites and differences in Pielou's evenness (J', $F = 6.645$, $p < 0.001$) and Shannon-Weiner diversity (H', $F = 4.779$, $p < 0.001$) were related to low index values at Site E1.

Statistical testing of differences between all Control sites and all Test sites together indicated that Control sites had significantly higher abundances of benthic macrofauna than Test sites ($H = 15.527$ ($P < 0.001$)), and lower evenness ($H = 9.521$, $P < 0.01$) and diversity ($H = 5.466$, $P < 0.05$) indices.

Univariate analyses of the benthic community comparing samples taken in close proximity to the Vleesbaai pipeline outlet with samples taken further away, do not provide evidence of marked impacts that might be caused by effluent discharge. This is further supported by the fact that no marked abundance of typical pollution indicator species (such as the polychaetes *Capitella capitata* and *Prionospio* spp.) were reported from the Test sites.

Multivariate analysis is a powerful analytical tool for developing an understanding of ecological impact because it allows a combined analysis of biological community characteristics and univariate physico-chemical measures.

The results of two non-metric Multi-Dimensional Scaling (MDS) plots of abundance and biomass data respectively, are presented in Figure 9. For the purpose of presentation and interpretation, these multi-dimensional plots are forced in two dimensions. This process results in a 2D stress value (depicted in the bottom left hand corner of each plot, Figure 9). The higher the stress value, the greater the general scatter of data in multi-dimensions and the less similar the sites are. Although both plots show fairly high stress values, the general trends are confirmed by cluster analysis (Figure 10), showing a separation of Test and Control assemblages. This separation is more distinct in faunal abundance than the biomass (Figure 9 & 10).

Statistical testing between Test and Control communities (using ANOSIM) indicates that there are significant abundance and biomass differences between Test and Control samples ($p < 0.001$ in both cases). The returned R values for both tests were low ($R = 0.207$ and $R = 0.122$ respectively) indicating that although the differences were consistent enough to be statistically significant, they were very small.

SIMPER analyses indicated that dissimilarities between Test and Control samples were the result of subtle differences in a wide range of taxa. In terms of abundance and biomass there were no strong indications of taxa with known tolerances or sensitivities to pollution contributing disproportionately to differences between Test and Control samples. SIMPER analysis was not able to definitely any particular species that was driving the differences detected between Test and Control sites.

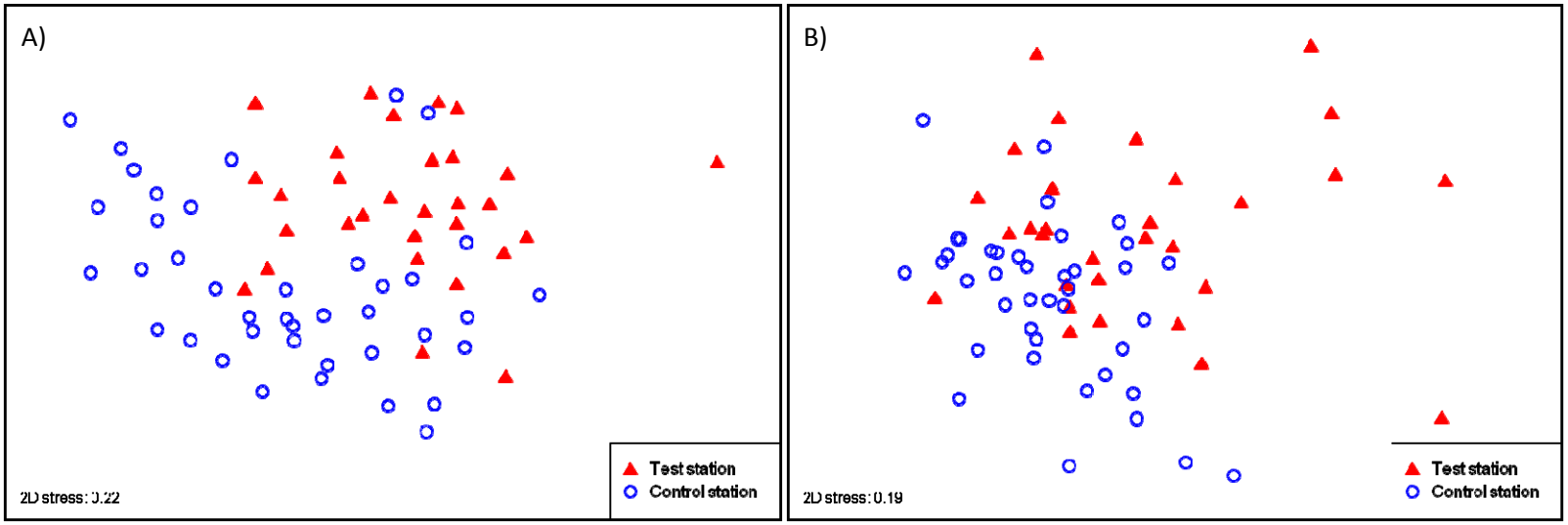


Figure 9. Multi-dimensional scaling plots of macrobenthic samples taken from all Test and Control sites at the PetroSA pipeline in Vleesbaai, November 2011 (A - abundance, B - biomass).

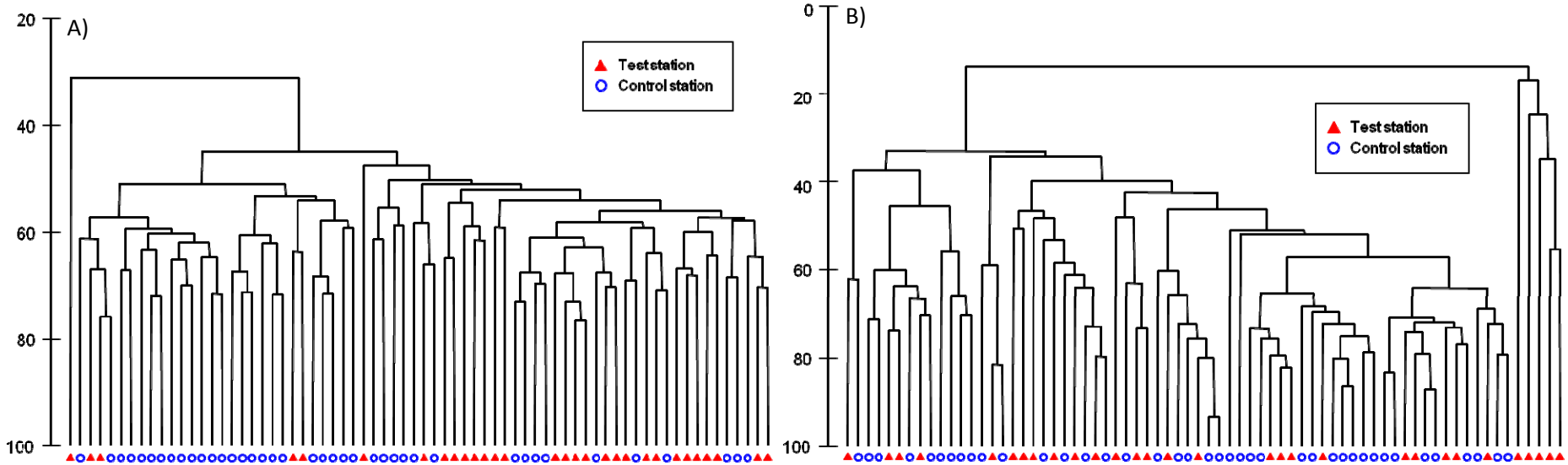


Figure 10. Dendrograms of macrobenthic samples taken from all Test and Control sites at the PetroSA pipeline in Vleesbaai, November 2011 (A - abundance, B - biomass)

BEST analyses were performed incorporating a range of measured factors potentially influencing the benthic communities in Vleesbaai. These included sediment characteristics (granulometry and total organic content) and a suite of trace metal and hydrocarbon concentrations. BEST analyses using abundance data indicated that a set of five parameters combined (% fine sand, % very fine sand, sediment organic content, manganese and hydrocarbons in the carbon ranges or C16-C21)showed the highest Spearman correlation of ρ = 0.373 . BEST analyses using biomass data indicated that for a set of five parameters combined (% gavel, % very coarse sand, % very fine sand, arsenic and lead) showed the highest Spearman correlation of ρ = 0.355.In both cases correlations were low, suggesting that the major drivers of biological communities at the sampled sites were not represented in those measured in this study. Factors that may contribute more to driving the differences in biological communities might be physico-chemical, hydrodynamic (e.g. current strength) or biological (e.g. competition, larval supply).Of the measured variables included in the analysis, natural factors related to sediment granulometry and organic content were the most influential in 'driving' biological variability. This was verified by conducted a BEST analysis using only natural parameters (granulometry and organic content) which resulted in slightly lower correlations than the full analyses, indicting the low contribution made by trace metal and hydrocarbon concentrations in explaining measured biological variability. It is therefore concluded that differences in macrofauna community composition between Control and Test sites is most likely due to variations in natural parameters and not as a result of pollution.

6.2.2. Meiofauna

Numbers of meiofauna per 100 ml sediment and Nematode/Copepod ratios from the nine sites sampled in 2011 are shown in Table 5. As was the case in previous studies of meiofauna from the area in 1989 (EMATEK 1989), 2000 (CMS 2001) and in 2002 (CMS 2003) there was variability in total numbers of meiofauna. This probably relates to the patchy nature of meiofauna distribution in marine sediments (Armenteros et al. 2008) and differences in sediment grain size.

Table 5. Average numbers of meiofauna per 100 ml of sediment collected for the 2011 survey of the PetroSA pipeline monitoring programme.

Taxa	W4	DW1	DW2	DW3	DE1	DE2	DE3	E4	E5
Turbellaria		102	48	36	221	138	58	336	20
Nematoda	12210	1974	2448	1064	3178	1572	1141	6256	1631
Rotifera						6			
Gastrotricha		30		12	134	610	45		29
Kinorhyncha									
Annelida	1	16		4		12	3	3	
Tardigrada						4	3		
Acarina						2			
Ostracoda	1	2				4	6		3
Copepod nauplii				12	10	6		32	
Harpacticoida		30		24	240	66	96	608	80
Amphipoda			2			2			
Sarcomastigophora	57	72	36	36	134	42	29	192	20
Insecta									
Total	**12268**	**2226**	**1267**	**1188**	**3917**	**1864**	**1381**	**7427**	**1783**
No. of Taxa	4	7	4	7	6	12	8	6	6
Nematode/Copepod ratio	12210	65	2448	44.33	13.24	23.81	11.88	10.29	20.39

The pre-pipeline survey conducted by the CSIR in 1989 (EMATEK 1989) returned numbers of meiofauna ranging from 661 to 2624 individuals per 100 ml sediment. After the installation of the Vleesbaai pipeline, two subsequent studies by the University of Cape Towns' Centre for Marine studies (CMS 2001, CMS 2003) revealed lower numbers of meiofauna in proximity to the diffuser section of the pipeline, (ranges were 344

to 613 and 134 to 430 respectively). The current study produced numbers per 100 ml of sediment ranging from 1188 to 12210 individuals.

These differences are marked, but undoubtedly relate to a large extent on differences in sampling and sample processing techniques. The initial survey (EMATEK 1989) used a Shipek grab from which cores were removed for meiofauna analysis. The surface area of sediment sampled and analysed is not clear in the report, as the cores used were not described. The mesh size used to retain meiofauna is also, unfortunately, not specified in the report.

The subsequent survey (CMS 2001) used a Ponar grab, as did the current survey (although sizes might differ) from which 100 ml sediment was removed for meiofauna analysis after mixing the sediment. A 150 µm mesh was used to retain the meiofauna.

The 2002 survey (CMS 2003) employed divers to collect the samples with 4 cm diameter cores to a depth of 15 cm. They then also mixed the sediment and removed 100 ml of sediment for meiofauna analysis using a 63 µm mesh.

The depth of sediment analysed plays an important role abundance of meiofauna sampled (when expressed per unit volume of sediment). The majority of the meiofauna are found in the top few centimeters of sublittoral sediment. Mazzola et al. (2000) for example, found approximately 60 % of meiofauna in the upper 1 cm of sublittoral sediment sampled, and approximately 97 % in the upper 5 cm. Using a 15 cm core and mixing the sediment before extracting 100 ml for meiofauna analysis, probably resulted in a dilution of meiofauna by approximately 66% compared to the present study. The CMS survey of 2003 used cores with a surface area of 12.6 cm^2 (diameter of 4 cm). Therefore broader shallower cores would collect many times more meiofauna per 100 ml sediment than narrow deep cores.

In the current (2011) survey a Ponar grab was used, which has a bite area of 225 cm^2. Slightly different volumes were collected each time the grab was deployed so the volume of sediment for each sample was measured prior to separation. The meiofauna from the whole sample were extracted using a modified Oostenbrink separator (Fricke 1979) and a 45 µm mesh. Sub samples were then counted and converted so as to be expressed as meiofauna per 100 ml sediment.

The meiofauna numbers collected for the current survey were much higher than any previous surveys at this area and ranged from 1188 to 3917 per 100 ml sediment in all the samples collected in close proximity to the pipeline diffusers. At one of the Control sites (W3) an extremely high number of 12268 meiofauna per 100 ml sediment was recorded (Table 5).

A concern noted from previous surveys in 2000 and 2002 was the complete lack of harpacticoid copepods in meiofauna sampled at most sites in the vicinity of the Vleesbaai pipeline. This was regarded (justifiably so) as evidence of pollution impact from effluent discharge from the pipeline. (along with the nematode/copepod ratio, see below). The 2011 study however, resulted in the presence of harpacticoid copepods at all but one of the six Test sites sampled. One of the three Control sites sampled, however, also yielded no harpacticoid copepods (Table 5).

Previous surveys made use of a nematode/copepod ratio (N/C) as a tool for detecting pollution effects. The most recent of these surveys (CMS 2003) demonstrated a decreasing trend in the N/C ration with distance away from the pollution source. The current survey showed no such pattern (Table 5).

N/C ratios in close proximity to the diffuser section of the pipeline in the present survey were generally lower than those of the two previous surveys (CMS 2001, CMS 2003) but were slightly higher than the pre-pipeline survey (EMATEK 1989). The reduction in the N/C ratio in relation to the most recent previous

survey at least would have been influenced by the fact that a larger surface area but shallower depth of sediment was sampled in the 2011 survey. Nematodes are less sensitive to anoxia than other meiofauna groups and are found at greater depths in the sediment (Bodin 1988). Harpacticoid copepods on the other hand remain in the upper, more oxygenated part of the sediment (Ansari et al. 1993). Therefore a greater number of harpacticoid copepods relative to nematodes would have been collected per sample for the current survey.

Harpacticoid copepod abundance and the (related) N/C ratio is not only affected by pollution but is also directly influenced by granulometry. Nematodes have a broad preference for muddy sediments while copepods prefer sands (McLachlan et al. 1981; Warwick 1981, Vinx and Heip 1991). According to McLachlan et al. (1981), proportions of nematodes decrease and harpacticoid copepods increase with increasing particle size above the range of 0.2 to 0.9 mm. From these studies it is suggested by McLachlan et al. (1981) that nematodes should disappear above a mean particle size of 1.34 mm and harpacticoid copepods should disappear below 0.07 mm mean particle size.

Mean sediment grain size measured in the 2011 survey ranged from 0.12 – 0.20 mm, suggesting that sediment conditions should not exclude either nematodes or harpacticoid copepods. However, sediment granulometry was a major influence on the Vleesbaai meiofauna sampled in 2011. A BEST analysis on meiofauna abundance data and environmental parameters measured for this project suggest that the proportions of fine sand and very fine sand contributed the most to the community structure composition of the sites sampled. The correlation between parameters measured and benthic meiofauna was $\rho = 0.779$. This suggests that the meiofauna community patterns were strongly influenced by sediment grain size and that the possible influence of pollution was likely to be minimal.

6.3. *In situ* water column data assessment (PetroSA provided data 2008 -2010)

In analysing the data provided by PetroSA from the *in situ* water column samples, several issues became evident. Of greatest concern was that data for certain parameters/sampling events are missing or accorded a value/concentration of zero. In the latter case the reason for the zero value is uncertain since the majority of laboratory analytical methods have a minimum method detection limit below which there is no confidence in the measurement. Consequently, a value of zero cannot actually be measured and measurements that cannot be made in the laboratory with a stated confidence are rather indicated as being lower than the method detection limit. For our interpretive purposes, values/concentrations denoted as being lower than the method detection limit were substituted with a value equivalent to the method detection limit and zero values were simply included in plots as they were reported in the data provided.

The simplest approach to providing a broad understanding of water quality in the vicinity of the pipeline is through the use of cumulative probability plots. The plots, which are presented in Figures 11-14, are based on data collected between 2008 - 2010 at six positions near the pipeline, namely:

- 200 m east of diffuser,
- 200 m west of diffuser,
- at port #1 on diffuser,
- at port #2 on diffuser,
- at water surface above port #1 on diffuser, and
- at water surface above port #2 on diffuser.

Two key components in the data distribution are assessed, namely its shape and presence of distinct inflections and gaps (either as raw data or when log transformed), and whether the data for a sampling position were clumped or interspersed between data for other sampling positions. The shape and presence of distinct inflections and gaps in the data distribution provides a general appreciation of whether any of the data is distinctly anomalous. A data distribution that approximates a linear shape, such as the

distribution for total suspended solids in Figure 11, suggests the data is from a single population and is consequently reflective of 'baseline' conditions (note that this is notwithstanding the fact that the total suspended solids concentrations reported are extremely high and suggestive of an analytical/reporting error). Distinct inflections and/or gaps in the data denote separate populations, as is the case for fluoride and oil in Figure 12 and chromium and copper in Figure 13. The consistent clumping or skewing of data, particularly to the extremes of the data distribution, suggests that water quality at the relevant sampling position is, on average, different to other sampling positions. An example of a skewed distribution is ammonium, for which the highest concentrations were commonly measured in water collected near ports on the diffuser. This strongly implies that discharged effluent is the source of the elevated ammonium concentrations in water samples collected at these positions. The more the data for a particular sampling position are interspersed with that for other sampling positions the greater the likelihood that this represents a single ('baseline') population.

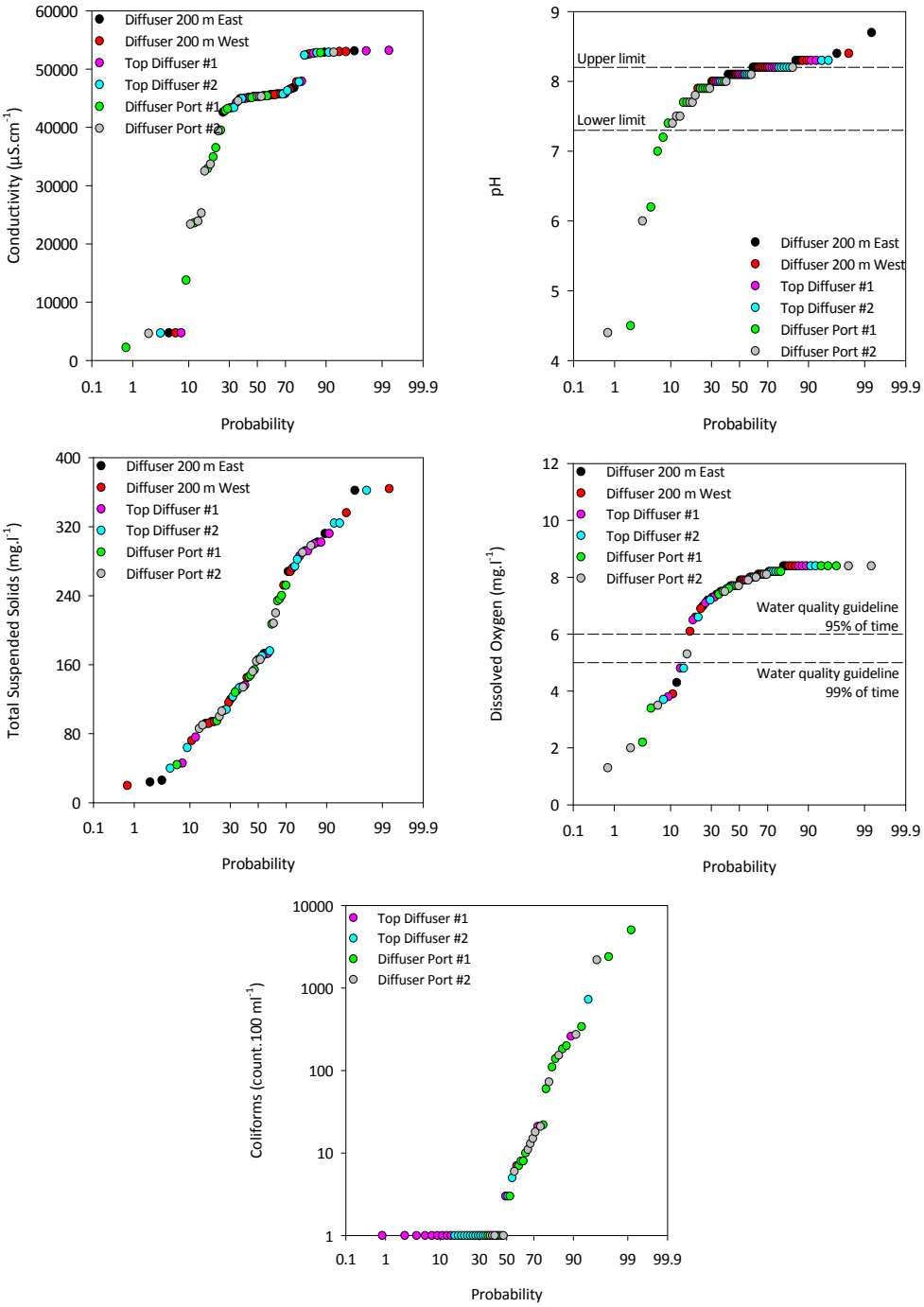


Figure 11. Cumulative distribution of parameters analysed in water samples collected at and near the diffuser for the PetroSA outfall between 2008 - 2010 (data provided by PetroSA).

Preliminary exploration of the data provided, however, alludes to significant concerns with regards to data quality (or water quality which is of even greater concern), in that the values/concentrations of several parameters, especially the metals, are extremely high and far exceed relevant South African Water Quality Guidelines for Coastal Marine Waters (DWAF 1995). It is the opinion of the scientists that compiled this report that these elevated values probably represent an analytical error rather than highly contaminated water. The source of the error is uncertain however there are two likely possibilities. The most likely scenario is that analytical methods developed for the analysis of freshwater and/or effluent samples may have been used to analyse these marine samples. If so then this presents a significant problem as the high sodium chloride (salt) content in marine water acts as a confounding variable. Freshwater analytical methods are, in the majority of cases, not suitable for the analysis of marine water samples. The high total suspended solids concentrations suggest that filtered samples were not (adequately) rinsed with deionised water and the resulting concentration reflects, in part, the weight of sodium chloride (salt). Second, but less likely is that the measurement units are incorrectly reported (e.g. reported as $mg.l^{-1}$ rather than $\mu g.l^{-1}$). PetroSA staff have confirmed that the measurement units reported in the data are milligrams per litre ($mg.l^{-1}$) and that the most likely reason for the anomalous data is due to non-marine analytical methods.

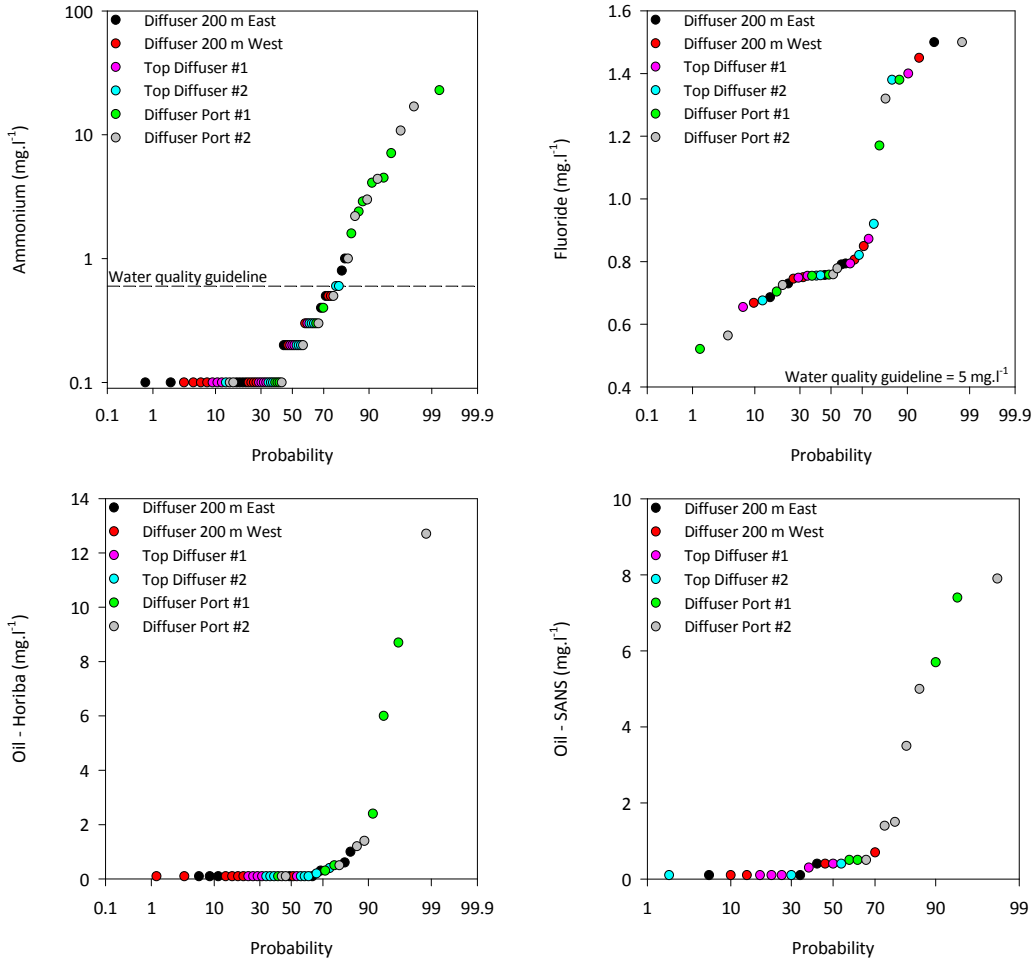


Figure 12. Cumulative distribution of parameters analysed in water samples collected at and near the diffuser for the PetroSA outfall between 2008 - 2010 (data provided by PetroSA).

Due to the abovementioned limitations and uncertainties, further detailed analysis of the data was not deemed feasible. A few points are, however, worth mentioning for future consideration.

1) Assuming that the data, even if inaccurate, are reflective of a consistent error then the only parameters that appear to provide a distinct tracer of effluent in the receiving water are pH, ammonium and oil, and to a lesser degree manganese. As is evident in Figure 11 the pH of water samples collected at ports #1 and #2 on the diffuser are usually lower than water samples collected at other positions (note that the pH scale is logarithmic and a single unit difference therefore represents a fairly large difference in reality). The concentrations of ammonium and oil, and to a lesser degree manganese, in water samples collected at ports #1 and #2 on the diffuser are higher compared to water samples collected at other positions. As stated previously this implies that the low pH and elevated ammonium, oil and manganese concentrations detected at ports #1 and #2 are attributable to effluent discharge. When comparing these *in situ* water quality data with the data provided by PetroSA on the effluent parameters before discharge (Table 1), it is evident that the effluent typically has a low pH and often elevated ammonium and oil concentrations. Concentrations of manganese in the effluent are also typically higher than concentrations measured in the receiving water. Obviously, dilution of the effluent after its discharge means that the pH and ammonium and oil concentrations are not unusual at the other sampling positions, which are situated at modest distances from the diffuser (either vertically or horizontally).

2) There is some evidence that the effluent discharge induces lower conductivity and dissolved oxygen concentration in water samples collected at ports #1 and #2 on the diffuser, but this is confounded by one or two low conductivity and dissolved oxygen concentration events recorded at other sampling positions. Nevertheless, based on the greater frequency of such events for water samples collected at ports #1 and #2 on the diffuser this is probably attributable to effluent discharge.

3) One of the most efficient tracers of effluent is faecal coliforms and/or *E. coli*. Effluent discharged through the PetroSA pipeline has, on average, a modest faecal coliform count for effluent, but which is nevertheless sufficient to act as a reliable tracer of effluent in the receiving marine water. As is evident in Figure 11, coliforms were far more numerous in water samples collected immediately at the diffuser ports compared to at the surface above the diffusers. It is however, likely that the effluent is being dispersed alongshore at depth, rather than surfacing. Unfortunately, water samples for faecal coliform analysis were not collected to the east and west of the diffuser, as for other parameters, and should be a consideration for future sampling.

4) A further issue of concern is that the concentrations of most parameters, but particularly metals, usually far exceed the relevant South African Water Quality Guidelines for Coastal Marine Waters (DWAF 1995, Figure 13 - 14). The concentrations, if accurately measured, analysed and reported, are in fact amongst the highest reported for coastal waters anywhere in South Africa – in many cases the concentrations represent severe contamination. As discussed previously this may be due to an inappropriate analytical method or incorrect measurement units in the data sheets and no conclusions in this context can be made. There was no evidence for metal contamination in any of the sediment or faunal samples in the vicinity of the pipeline, which suggests a possible analytical error.

In conclusion, it is our interpretation that little can be deduced from the water quality data provided by PetroSA except to state that it is imperative that appropriate analytical methods are used for sample analysis and the objective of future sample analysis should be re-evaluated. There is little value in continuing the monitoring based on inappropriate analytical methods as further data interpretation is invalid.

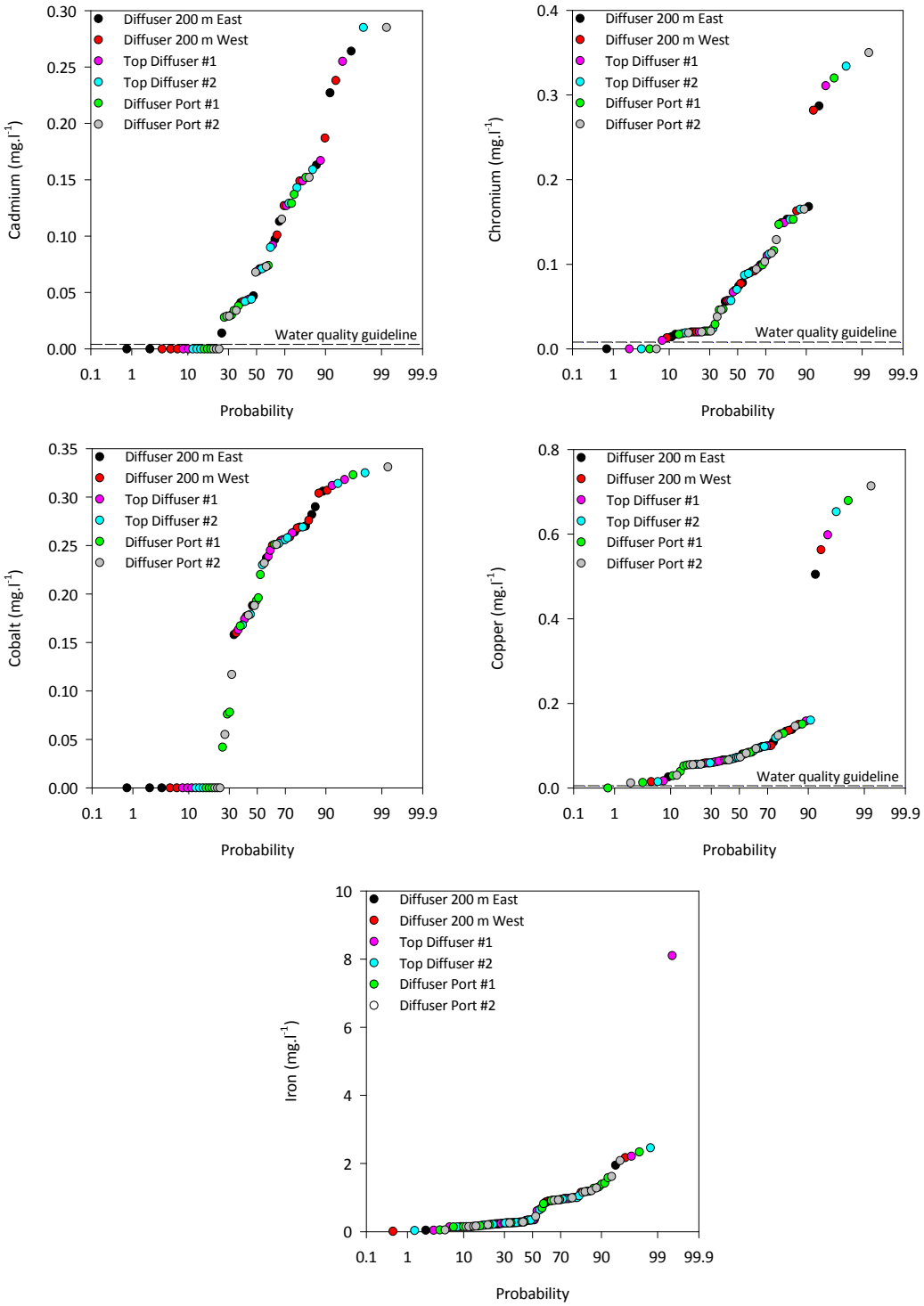


Figure 13. Cumulative distribution of parameters analysed in water samples collected at and near the diffuser for the PetroSA outfall between 2008 - 2010 (data provided by PetroSA).

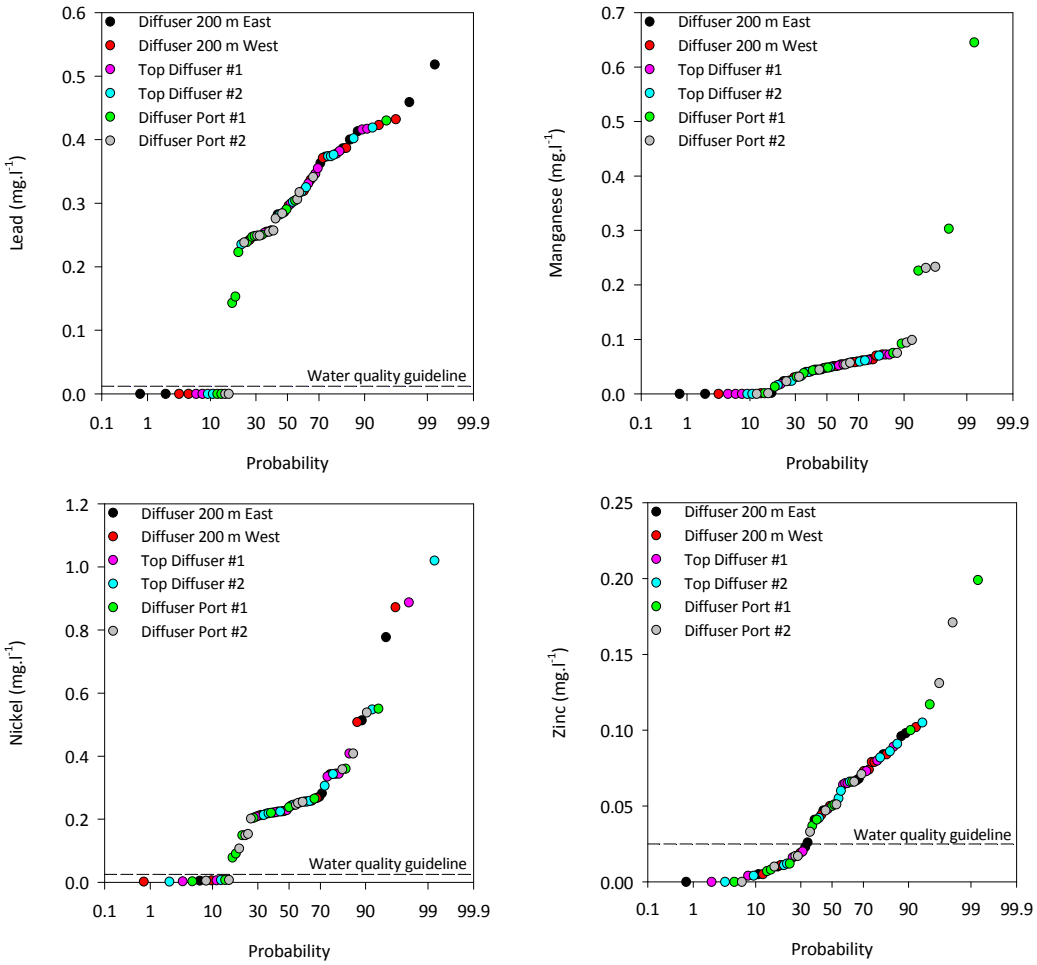


Figure 14. Cumulative distribution of parameters analysed in water samples collected at and near the diffuser for the PetroSA outfall between 2008 - 2010 (data provided by PetroSA).

7. Conclusions

The results obtained from the samples collected during this study (November 2011) in the vicinity of the PetroSA Vleesbaai outlet pipeline, following analyses of sediment chemistry and benthic invertebrate communities , indicate that the discharge of effluent through the pipeline is not significantly adversely impacting on the receiving environment in Vleesbaai. The various indicators measured in the receiving environment within the vicinity of the pipeline outlet in this study do not reflect a significant adverse effect on the natural environment.

8. Recommendations for future monitoring

Based on the finding from this study that effluent discharge through the PetroSA Vleesbaai outlet pipeline is not significantly adversely impacting the ecology of the receiving environment it is recommended that the sample design for the benthic invertebrate component of the survey be downscaled for future monitoring. A conceptual sampling design is outlined below demonstrating the proposed downscaling possible whilst not compromising the statistical credibility and value of the monitoring:

Macrofauna, meiofauna, grain size and total organic carbon:

Two impact sites positioned immediately east and west of the pipeline diffuser and two reference sites positioned at distances of about 500 m and 1000 m to both the east and west of the diffuser are considered adequate for future monitoring. This represents a decrease from 15 sites to six sites. Five replicate samples should be collected for benthic macrofauna community analysis. This represents a decrease from 75

replicate samples to 30 replicate samples. Differences in sampling procedures aside, meiofauna sampled over different years in the vicinity of the pipeline appear to have shown a high degree of variability. This needs to be monitored, for a limited period of two more years at least. A single meiofauna sample should be collected and analysed at each of the six sites.

Sediment chemistry:

A single sediment sample at each of the six benthic invertebrate community sites plus two additional sites to the east and west (at 2000 m) is adequate for chemical analysis. This represents a decrease from 15 to eight sites for sediment chemistry analysis. The baseline metal concentrations for the area have now been adequately defined and there is no need to collect samples from the surrounding area of Mossel Bay. The findings of metal analyses of future monitoring can be used to refine the baseline models.

The range of chemicals that should be analysed for in the sediment should be based on the predominant constituents in the effluent and importantly on toxicity information available for these constituents. This information will need to be supplied in as much detail as possible by PetroSA. The low concentrations of polycyclic aromatic hydrocarbons and total petroleum hydrocarbon carbon equivalents C16-C40 that were detected in the sediment in this study imply that these are not important constituents of the effluent. However, lower molecular weight hydrocarbons were detected in all sediment samples and it may be necessary to focus on these compounds, including volatile hydrocarbons, in future monitoring.

Water quality sampling:

The monitoring of water quality *in situ* is also recommended. This monitoring should take place at the ten sites where sediment is proposed to be collected for metal and hydrocarbon analysis (see above). Parameters measured during *in situ* water quality monitoring should include temperature, salinity, dissolved oxygen, pH and turbidity. Although *in situ* water quality monitoring at the time of benthic community monitoring provides only a snapshot of water quality, this type of monitoring is beneficial in that it provides an understanding of vertical trends in key water quality parameters through the water column.

The analysis of water samples collected near the pipeline by PetroSA each quarter has the potential to provide extremely valuable information provided that there is clarity on whether the methods used for the analyses are appropriate for *marine* samples. If not then appropriate methods must be implemented or the samples should be sent to a laboratory that is accredited by the South African National Accreditation System specifically for the analysis of *marine* samples (or appropriate accreditation system in the case of an international laboratory). In order to confirm the appropriateness of PetroSA laboratory analyses, it is recommended that duplicate water column samples be collected as soon as possible and the duplicate samples be analysed at a private marine accredited laboratory. Results can then be compared for clarity and modifications made as necessary.

Collection and analysis of water samples at the water surface above the diffusers (e.g. site 97/47) can be reconsidered. Analysis of surface water samples is only appropriate if there is clear evidence that the effluent frequently reaches the surface above the diffuser. If there is no such evidence then this sampling effort should be redirected, as discussed below.

Water samples collected at a distance of 200 m to the east and west of the pipeline should be collected at the mid-water level. Additionally, mid-water level samples should be collected at distances of 500 m east and west of the diffuser. Samples should be collected from the mid-water level because the effluent discharged through the pipeline is probably less dense than seawater (this should first be confirmed). The effluent will thus ascend through the water column until it reaches neutral buoyancy. During this rise the

effluent will be advected by currents, either to the east or west of the pipeline (presuming these being the dominant current directions in Vleesbaai). Only in the case of very low current velocities is it likely that the effluent will surface. Sampling at the mid-water point will consequently increase the probability of detecting an effluent signal, if this exists, at moderate distances from the pipeline.

The sampling design outlined above should be conducted at least once annually for at least two consecutive years (2012 and 2013) at the same time of year as the 2011 sampling (i.e. November). Pending results and interpretation of such monitoring data, it is possible that additional future monitoring may only be required every two or three years.

9. Acknowledgements

The South African Environmental Observation Network and The Council for Scientific and Industrial Research would like to acknowledge the cooperation and assistance of the captain and crew of the tender vessel “Pentow Malgas” and the SMIT Amandla dive team, led by Mr Durant de Wet and Mr Terian Wallis, who competently assisted in the field sampling. The parataxonomist team from SAEON Elwandle Node in Grahamstown are thanked for their macrofauna sorting expertise and Dr Nina Steffani of Steffani Marine Environmental Consultant is thanked for her expertise in identifying, enumerating and weighing all macrofauna.

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11. Appendices

Appendix 1: Grain size composition and total organic content of sediment collected for the 2011 survey of the PetroSA outfall monitoring programme. VCS = very coarse-grained sand, CS = coarse-grained sand, MS = medium-grained sand, FS = fine-grained sand, VFS = very fine-grained sand, TOC = total organic content.

Site	Gravel (%)	VCS (%)	CS (%)	MS (%)	FS (%)	VFS (%)	Mud (%)	Mean (mm)	Median (mm)	Sorting	TOC (%)
DE1	0.10	0.15	0.81	11.35	75.86	7.58	4.15	0.19	0.20	0.35	1.22
DE2	0.00	0.04	0.25	7.48	75.40	11.28	5.55	0.18	0.19	0.57	0.60
DE3	0.54	0.35	0.84	20.37	67.38	7.50	3.01	0.20	0.21	0.41	0.54
DW1	0.00	0.05	0.36	3.33	83.13	10.13	2.99	0.18	0.19	0.30	0.55
DW2	0.00	0.00	0.09	3.26	84.01	9.19	3.44	0.18	0.19	0.29	0.66
DW3	0.00	0.05	0.36	3.12	84.98	9.38	2.11	0.18	0.19	0.30	0.45
E1	0.00	0.06	0.67	20.31	67.46	7.95	3.55	0.19	0.20	0.41	0.35
E2	0.00	0.08	0.13	5.30	73.75	9.20	11.53	0.18	0.18	0.55	0.83
E3	0.00	0.04	0.46	5.58	81.19	8.54	4.19	0.17	0.18	0.31	0.26
E4	0.00	0.08	0.77	22.30	64.11	4.76	7.97	0.20	0.21	0.69	0.54
E5	0.00	0.00	0.06	2.81	81.67	8.93	6.53	0.17	0.17	0.54	0.49
DW4	0.00	0.08	0.61	14.59	73.19	6.33	5.21	0.19	0.20	0.58	0.54
W1	0.00	0.00	0.21	4.93	74.16	8.90	11.81	0.19	0.18	0.54	0.63
W2	0.00	0.02	0.54	4.62	71.40	11.90	11.51	0.19	0.17	0.52	1.19
W3	0.14	0.21	1.30	8.61	45.73	18.01	26.00	0.12	0.14	1.08	1.39
MB1	0.00	0.15	0.18	3.02	84.93	8.94	2.78	0.17	0.17	0.29	0.28
MB2	0.00	0.00	0.05	10.16	81.80	5.63	2.36	0.18	0.18	0.36	0.18
MB3	0.00	0.02	0.07	1.49	88.52	7.66	2.23	0.17	0.16	0.28	0.35
MB4	0.00	0.14	1.23	25.59	69.88	1.29	1.86	0.22	0.21	0.49	0.31
MB5	0.00	0.11	1.32	39.33	52.17	2.90	4.17	0.22	0.23	0.48	0.37
MB6	0.00	0.16	1.87	36.14	54.57	3.65	3.60	0.22	0.23	0.47	0.54
MB7	0.00	0.21	1.89	30.32	64.33	1.09	2.15	0.22	0.22	0.48	0.14
MB8	0.07	0.37	2.04	34.21	61.12	0.87	1.32	0.23	0.23	0.51	0.08
MB9	0.00	0.05	0.32	21.57	76.08	0.58	1.41	0.21	0.21	0.39	0.08

Appendix 2: Metal concentrations (mg.g^{-1} for aluminium and iron, µg.g^{-1} for all other metals; dry weight) in sediment collected for the 2011 survey of the PetroSA outfall monitoring programme. Al = aluminium, Fe = iron, As = arsenic, Ba = barium, Be = beryllium, Cd = cadmium, Co = cobalt, Cu = copper, Cr = chromium, Hg = mercury, Mn = manganese, Ni = nickel, Pb = lead, V = vanadium, Zn = zinc. < symbol denotes that the concentration was below the method detection limit, as indicated by the value following the symbol.

Site	Al	Fe	As	Ba	Be	Cd	Co	Cu	Cr	Mn	Hg	Ni	Pb	V	Zn
DE1	10.14	10.66	6.79	40.72	0.36	0.029	2.47	3.31	16.88	83.33	<0.03	4.87	9.98	15.64	25.54
DE2	11.56	11.81	7.21	54.50	0.41	0.024	2.84	3.35	18.82	98.24	<0.03	6.07	10.69	17.98	24.93
DE3	10.14	10.78	6.41	33.66	0.29	0.031	2.27	1.65	17.75	91.44	<0.03	4.65	8.20	15.99	21.10
DW1	10.29	10.70	5.26	49.35	0.38	0.022	2.78	2.68	15.73	89.29	<0.03	5.41	10.61	16.15	23.08
DW2	11.26	11.47	5.91	58.55	0.42	0.026	3.17	3.61	17.15	101.75	<0.03	6.37	11.52	18.22	25.53
DW3	11.29	11.64	6.28	57.20	0.42	0.019	3.22	3.27	17.02	100.64	<0.03	6.10	10.37	19.08	26.14
E1	9.85	9.94	5.41	38.61	0.30	0.023	2.67	2.85	14.61	94.43	<0.03	5.33	9.22	15.45	22.06
E2	12.65	12.90	5.54	52.11	0.34	0.026	3.37	2.29	19.46	120.87	<0.03	7.44	11.43	21.17	28.38
E3	12.24	11.99	6.90	76.96	0.53	0.021	3.42	3.46	18.15	120.71	<0.03	6.56	10.41	18.25	26.80
E4	12.19	12.54	7.81	66.62	0.39	0.023	2.72	2.72	20.82	101.41	<0.03	6.18	11.25	19.85	26.16
E5	13.15	13.73	5.00	126.21	0.87	0.018	4.21	7.05	22.15	128.44	<0.03	8.37	11.53	25.77	28.04
DW4	10.59	10.46	5.33	57.17	0.16	0.029	2.82	2.00	15.20	85.08	<0.03	5.31	5.93	12.92	20.94
W1	12.19	11.93	4.48	57.99	0.16	0.029	3.65	3.39	16.71	108.96	<0.03	7.12	8.33	15.12	27.52
W2	12.37	12.35	5.57	57.19	0.20	0.031	3.35	2.65	17.68	101.17	<0.03	6.65	7.65	13.69	26.87
W3	12.38	12.28	4.12	58.20	0.19	0.034	3.51	2.39	17.95	102.77	<0.03	7.53	8.93	14.24	28.84
MB1	12.60	12.93	7.50	101.81	0.81	0.022	4.07	5.58	19.93	138.19	<0.03	7.81	9.43	23.43	25.81
MB2	11.36	11.55	6.09	59.21	0.61	0.019	4.09	5.31	14.82	125.22	<0.03	7.66	6.40	17.28	25.84
MB3	12.03	12.51	6.43	99.12	0.73	0.021	4.22	4.48	18.89	132.82	<0.03	7.79	9.13	23.84	26.56
MB4	7.59	7.97	7.02	60.73	0.48	0.027	2.74	3.24	13.02	127.07	<0.03	4.90	6.66	14.65	16.23
MB5	6.64	7.14	8.38	36.01	0.36	0.039	1.19	2.72	14.32	105.81	<0.03	3.53	5.81	13.21	11.48
MB6	5.99	6.22	5.05	29.01	0.34	0.043	1.11	1.75	14.10	76.51	<0.03	2.51	6.24	7.13	11.87
MB7	6.40	6.45	7.93	25.41	0.28	0.028	1.82	1.97	11.64	61.59	<0.03	3.44	4.49	10.87	13.34
MB8	6.65	6.50	7.38	12.06	0.25	0.031	2.28	2.28	9.41	77.04	<0.03	4.15	3.72	8.87	14.27
MB9	8.44	8.06	6.67	31.00	0.22	0.028	3.03	2.43	10.15	87.83	<0.03	5.21	5.75	10.58	20.06

Appendix 3: Concentrations of total petroleum hydrocarbons (mg.kg^{-1}) and polycyclic aromatic hydrocarbons (µg.kg^{-1}) in sediment samples collected for the 2011 survey of the PetroSA outfall monitoring programme. < symbol denotes that the concentration was below the method detection limit, as indicated by the value following the symbol.

	Site																							
Sample	DE1	DE2	DE3	DW1	DW2	DW3	E1	E2	E3	E4	E5	DW4	W1	W2	W3	MB1	MB2	MB3	MB4	MB5	MB6	MB7	MB8	MB9
C10-C12	14	13	12	14	12	13	9.1	<3.0	<3.0	<3.0	12	<3.0	<3.0	11	12	9.8	13	13	13	<3.0	14	14	12	10
C12-C16	9.3	8.2	7.4	7.6	7.6	7.8	8.2	11	8.3	9.4	<5.0	6.2	<5.0	8	9.3	7	6.6	8.6	9.1	11	9.3	5.8	8.7	7
C16-C21	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	6.4	<6.0	8.6	<6.0	<6.0	<6.0	<6.0	<6.0	6.1	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	7.7
C21-C30	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12
C30-C35	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0
C35-C40	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0
C10-C40	<38	<38	<38	<38	<38	<38	<38	<38	<38	<38	<38	<38	<38	<38	<38	<38	<38	<38	<38	<38	<38	<38	<38	<38
Naphthalene	11	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	13	12	<10	<10	<10
Acenaphthylene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Acenaphthene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Fluorene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Phenanthrene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Anthracene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Fluoranthene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Pyrene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Benzo(a)anthracene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Chrysene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Benzo(b)fluoranthene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Benzo(k)fluoranthene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Benzo(a)pyrene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Dibenzo(ah)anthracene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Benzo(ghi)perylene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Indeno(123cd)pyrene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10

Appendix 4: Benthic macrofauna abundance (animals/m^2) in sediment samples collected for the 2011 survey of the PetroSA outfall monitoring programme.

Taxa	DE1A	DE1B	DE1C	DE1D	DE1E	DE2A	DE2B	DE2C	DE2D	DE2E	DE3A	DE3B	DE3C	DE3D	DE3E
Anemone															
Ampelisca brevicornis													1		
Ampelisca spp.													1		
Amphioplus integer ?									1						
Ancilla marmorata						1									
Anthuridae			2			1				1	2				2
Arabella spp.															
Astropecten antares	1														
Bivalvia A															
Bodotriidae	2	3		3	2	2	7	4	2	2	8	4	4	3	4
Branchiostoma capensis	1	1	1			1		1			4	3	3		4
Bullia annulata															
Capitella capitata											1				
Caridea															
Caulleriella spp.															
Chaetognatha				1			2		1		2		5		
Chaetozone setosa															
Cirratulidae								1							
Cirolana hirtipes															
Copepoda															
Corophiidae A			1												
Corophiidae B															
Cunicus profundus		3									3				
Decapoda larva													3	1	
Diastylidae		1		1											
Diogenes extricatus															1
Diopatra cuprea punctifera															
Diopatra neapolitana capensis			12				3			2					2
Drilonereis spp.															
Echinocardium cordatum															
Eulalia spp.															
Exogone clavator															
Fasciolaria spp.															
Glycera spp.			1	5											
Glycera subaenea ?															
Glycera unicornis							1								

Taxa	DE1A	DE1B	DE1C	DE1D	DE1E	DE2A	DE2B	DE2C	DE2D	DE2E	DE3A	DE3B	DE3C	DE3D	DE3E
Glycinde spp. (kameruniana ?)			1	2			1			1			1	2	
Goniada spp.															
Gyptis capensis		1	1	2	1			1					1	1	3
Harmothoe spp.															
Harmothoe lunulata				1	2			1		1	1		3		
Heterophoxus opus		1	2			2	3	5	3	2	12	6			8
Hippomedon longimanus	1	1	1	1		6	1	3	1		11				3
Holothuroidea	12	16	10	29	24	2		8	3	12	4	1	12	3	2
Hymenosoma orbiculare															
Iphinoe stebbingi			1												
Lanice conchilega															
Lumbrineris spp.															
Lumbrineris hartmani					1										
Macoma crawfordi															
Magelona cincta				2	1	1	2		1				1	2	6
Magelona debeerei	2	2	1		1	2		2	1	6	3	1	5		
Maldanidae															
Mediomastus capensis		2		1	1	2		2		5	7	3	7	2	5
Megaluropus namaquaeensis				5		5	2	4	1	4	3	2	4	1	3
Mesochaetopterus capensis							2		1	1					
Microarcturus similis							1	1					3		
Monoculodopsis longimana										2				3	
Mysidacea			1	2				2		1	1				
Nassarius cf. plicatellus															
Nassarius speciosus															
Nemertea (red banded)		3	1	6		2					1				
Nemertea ?			2				5	1		2	2	2	5	4	1
Nephtys hombergi															
Nephtys sphaerocirrata	8	16	13	19	9	15	30	11	9	24	11	14	8	20	7
Nereis spp. (succinea ?)		1	3				2	1	1	2				1	1
Notanthura caeca													2		
Nucula nucleus															
Oligochaeta															
Opheliidae															
Ophiuroidea (Amphiura capensis ?)		2	1		3				1		2		2		1
Ostracoda		2	3			4	7	1	4	2	2	1	1		
Paguridae															
Paramoera capensis															
Paraonidae											2	3	2		2

Taxa	DE1A	DE1B	DE1C	DE1D	DE1E	DE2A	DE2B	DE2C	DE2D	DE2E	DE3A	DE3B	DE3C	DE3D	DE3E
Paraonides lyra capensis															
Pectinaria capensis															
Pennatulacea															
Perna perna															
Perioculodes longimanus		10	2	5	3	12	20	9	1	5	3	3	3	15	4
Pherusa swakopiana		1									1				
Photis longidactylus		1		1			5	4					1	2	1
Philine aperta		1													
Philyra punctata															
Platyhelminthes															
Poecilochaetus sp.															
Polydora spp.				1											
Prionospio spp.		1		8	1		1			2			1	1	
Processa austroafricana															
Pseuodmalacoceros gilchristi			1	1	2	1	3	1			1				
Pterygosquilla armata capensis															
Sabellides capensis															
Sabellides luderitzi				1	1	1	1								
Scolaricia dubia			3				1		1	1	2	1			
Sigalion capense	1		1			1		1		1					
Sigambra parva												1			
Sipunculida A							2								
Spiophanes soederstromi				1			1					1			
Sthenelais boa		1													
Syllidae															
Synidotea hirtipes			1	2	1		4	1				3			
Synopiidae (Tiron australis ?)												6			1
Tanaidacea								1			1	2			4
Tellina spp. (gilchristi)			1	2						1				3	
Urothoe grimaldi		17	7	2	11	13	4	10	5	12	6	29	2	6	7
Urothoe spp.				2	1	2	1		3		2	2			
Virgularia spp. (mirabilis ?)			2	1		1	5	2	5	4	1				

Appendix 4 continued: Benthic macrofauna abundance (animals/m^2) in sediment samples collected for the 2011 survey of the PetroSA outfall monitoring programme.

Taxa	DW1A	DW1B	DW1C	DW1D	DW1E	DW2A	DW2B	DW2C	DW2D	DW2E	W3A	W3B	W3C
Anemone													
Ampelisca brevicornis										1	4	3	7
Ampelisca spp.													
Amphioplus integer ?							1			1			
Ancilla marmorata													
Anthuridae					1				1				
Arabella spp.													
Astropecten antares													
Bivalvia A	1					2	4			4			
Bodotriidae		3	4		3	3	2				12	52	28
Branchiostoma capensis		1		1	1		1	1	1				
Bullia annulata													
Capitella capitata													
Caridea													
Caulleriella spp.													
Chaetognatha				2		2			1	2	1	7	
Chaetozone setosa													
Cirratulidae		1											
Cirolana hirtipes													
Copepoda												2	
Corophiidae A											10		3
Corophiidae B													
Cunicus profundus					1								
Decapoda larva											2		2
Diastylidae											8	3	7
Diogenes extricatus											1		
Diopatra cuprea punctifera													
Diopatra neapolitana capensis		2			1		1				8		9
Drilonereis spp.													
Echinocardium cordatum		1						1					
Eulalia spp.													
Exogone clavator													
Fasciolaria spp.													
Glycera spp.		1				2				4	3	3	
Glycera subaenea ?												1	
Glycera unicornis													14

Taxa	DW1A	DW1B	DW1C	DW1D	DW1E	DW2A	DW2B	DW2C	DW2D	DW2E	W3A	W3B	W3C
Glycinde spp. (kameruniana ?)							1			3	7	4	10
Goniada spp.													
Gyptis capensis		2		1	1		1	1	1	2			
Harmothoe spp.						1	1						
Harmothoe lunulata		3	1			1		1	1	1	1	2	1
Heterophoxus opus		1	1	1	1	4	1		2				
Hippomedon longimanus	1	1	1			1	1	2	1				
Holothuroidea	28	35	12	17	11	5	28	11	12	34	3	3	43
Hymenosoma orbiculare													
Iphinoe stebbingi													
Lanice conchilega													
Lumbrineris spp.													
Lumbrineris hartmani													
Macoma crawfordi													1
Magelona cincta								1		1	2		1
Magelona debeerei		2	3	1	3		3	4	3				
Maldanidae													1
Mediomastus capensis	2	5	1	5	2	2	2		2	4			3
Megaluropus namaquaeensis	2	6	2		4	1	5		5	6	1	6	4
Mesochaetopterus capensis										1			
Microarcturus similis												1	
Monoculodopsis longimana	1	1	1			2			1				
Mysidacea									1			2	
Nassarius cf. plicatellus													
Nassarius speciosus		1											1
Nemertea (red banded)	2	3	5			2	2	2		1			
Nemertea ?				2	1			1	1		1	2	2
Nephtys hombergi													
Nephtys sphaerocirrata	15	14	16	16	9	8	10	8	9	9	7	17	15
Nereis spp. (succinea ?)							2						2
Notanthura caeca				2									
Nucula nucleus												4	
Oligochaeta													3
Opheliidae													
Ophiuroidea (Amphiura capensis ?)		3	1	1	1			2					
Ostracoda	2	5		2	5	1	2	3	5	12	12	6	27
Paguridae													
Paramoera capensis													
Paraonidae												1	2

Taxa	DW1A	DW1B	DW1C	DW1D	DW1E	DW2A	DW2B	DW2C	DW2D	DW2E	W3A	W3B	W3C
Paraonides lyra capensis													
Pectinaria capensis													
Pennatulacea													
Perna perna										1	1		1
Perioculodes longimanus	4	7	1	2	3	11	5	2	4	11	9	9	11
Pherusa swakopiana						2	1				12		8
Photis longidactylus							1					3	3
Philine aperta													
Philyra punctata	1												
Platyhelminthes													
Poecilochaetus sp.													
Polydora spp.													
Prionospio spp.				1		7	5		3	8	2	2	7
Processa austroafricana													
Pseuodmalacoceros gilchristi						1							
Pterygosquilla armata capensis													
Sabellides capensis													1
Sabellides luderitzi													
Scolaricia dubia								1			8	3	
Sigalion capense		1	1		2		1	2	1	1			
Sigambra parva													
Sipunculida A													
Spiophanes soederstromi						2		1	1		14	7	4
Sthenelais boa													
Syllidae													
Synidotea hirtipes		2					1			3	11		78
Synopiidae (Tiron australis ?)								1					
Tanaidacea											10	17	9
Tellina spp. (gilchristi)	2		2			6			2	7	2	7	1
Urothoe grimaldi	1	9	13	8	13	2	11	10	13	3	1		
Urothoe spp.		2	1	2	2			1	2				
Virgularia spp. (mirabilis ?)			8	3	3		1		5	5			

Appendix 4 continued: Benthic macrofauna abundance (animals/m^2) in sediment samples collected for the 2011 survey of the PetroSA outfall monitoring programme.

Taxa	W3D	W3E	W2A	W2B	W2C	W2D	W2E	W1A	W1B	W1C	W1D	W1E	DW4A	DW4B
Anemone														
Ampelisca brevicornis	6	3					4							
Ampelisca spp.		1				3								
Amphioplus integer ?										1		2		
Ancilla marmorata														
Anthuridae														4
Arabella spp.			1											
Astropecten antares														
Bivalvia A	2					1	1						1	4
Bodotriidae	6		6	4	4	7	13	2	2	1	3	1	1	1
Branchiostoma capensis														1
Bullia annulata				1										
Capitella capitata					2									
Caridea														
Caulleriella spp.					1									
Chaetognatha	2	2	5			2	1	2	2	9	2		5	2
Chaetozone setosa											1			
Cirratulidae														
Cirolana hirtipes														
Copepoda	1			2							2			
Corophiidae A							1							3
Corophiidae B														
Cunicus profundus														
Decapoda larva	1	20					4		1					
Diastylidae	1	6	10			5	7						1	
Diogenes extricatus														
Diopatra cuprea punctifera			1											
Diopatra neapolitana capensis		13					14					4		1
Drilonereis spp.														
Echinocardium cordatum						1								
Eulalia spp.							3							
Exogone clavator		2												
Fasciolaria spp.														
Glycera spp.			14	4		4	4					4		
Glycera subaenea ?														
Glycera unicornis	7	8				1	1							1

Taxa	W3D	W3E	W2A	W2B	W2C	W2D	W2E	W1A	W1B	W1C	W1D	W1E	DW4A	DW4B
Glycinde spp. (kameruniana ?)	6	4	1	2		3	7			1			2	
Goniada spp.														
Gyptis capensis				2				2	2	3	1	2		
Harmothoe spp.				1	1									
Harmothoe lunulata	3		3			8	7	5	1	7	2	7		1
Heterophoxus opus									4	3	6	1	1	4
Hippomedon longimanus		1							13	1	2		1	2
Holothuroidea	33	7	74	41	5	97	131	59	13	27	25	88	1	4
Hymenosoma orbiculare								1				1		
Iphinoe stebbingi														
Lanice conchilega		1												
Lumbrineris spp.														
Lumbrineris hartmani														
Macoma crawfordi	6													
Magelona cincta	1		1	1	1	1	1			1				
Magelona debeerei													2	3
Maldanidae														
Mediomastus capensis	1		1	4	5	2	2	2		1	2		1	2
Megaluropus namaquaeensis	1	1	1	3	6	1	12	2	4	2	2	1	3	12
Mesochaetopterus capensis			1			1	1							
Microarcturus similis		5					6							
Monoculodopsis longimana					1	1								
Mysidacea														
Nassarius cf. plicatellus														
Nassarius speciosus			1											
Nemertea (red banded)	1			2		1	1	1				2		
Nemertea ?		1	1						1					1
Nephtys hombergi														
Nephtys sphaerocirrata	10	11	5	9	10	7	30	13	16	7	16	12	7	30
Nereis spp. (succinea ?)		1					1					2		1
Notanthura caeca					1					1		1		
Nucula nucleus	1													
Oligochaeta	3	1					1							
Opheliidae					1									
Ophiuroidea (Amphiura capensis ?)		1			1	2	1	1	1					
Ostracoda	10	25	1			2	6	1	2	2	4	3	1	7
Paguridae														
Paramoera capensis														
Paraonidae	1	1											1	

Taxa	W3D	W3E	W2A	W2B	W2C	W2D	W2E	W1A	W1B	W1C	W1D	W1E	DW4A	DW4B
Paraonides lyra capensis														
Pectinaria capensis			1								1			
Pennatulacea									1					
Perna perna		2		2										6
Perioculodes longimanus	4	4	4	9	4	10	19	3	6	2	9	3	6	13
Pherusa swakopiana		10					1					1		
Photis longidactylus	3	6	1	3		1	2					1		3
Philine aperta														
Philyra punctata														
Platyhelminthes														
Poecilochaetus sp.							1							
Polydora spp.														
Prionospio spp.	7	5	14	10		4	4			1	2	1		1
Processa austroafricana		1												
Pseuodmalacoceros gilchristi							4							2
Pterygosquilla armata capensis														
Sabellides capensis														
Sabellides luderitzi		3		1	1									
Scolaricia dubia		2					1		1				1	1
Sigalion capense						1			3		2	1		
Sigambra parva							2							
Sipunculida A														
Spiophanes soederstromi	6	13	2	3		4	6							
Sthenelais boa														
Syllidae														
Synidotea hirtipes	2	109	1	3	1									5
Synopiidae (Tiron australis ?)								1	1					
Tanaidacea	3	9			2		2							
Tellina spp. (gilchristi)		2	2	1		3	1							
Urothoe grimaldi				2	15	1	2	5	10	4	11	5	14	7
Urothoe spp.	1					3								
Virgularia spp. (mirabilis ?)					1	2	3	6	3	3		2	2	3

Appendix 4 continued: Benthic macrofauna abundance (animals/m^2) in sediment samples collected for the 2011 survey of the PetroSA outfall monitoring programme.

Taxa	DW4C	DW4D	DW4E	E1A	E1B	E1C	E1D	E1E	E2A	E2B	E2C	E2D	E2E	E3A
Anemone													1	
Ampelisca brevicornis		1			2				3					
Ampelisca spp.														
Amphioplus integer ?				2					1	6			1	
Ancilla marmorata														
Anthuridae		1		1	1								1	
Arabella spp.							1							
Astropecten antares					1									
Bivalvia A		1			3				2	1				
Bodotriidae	1	3	3	1	1	2		2	10	2	2	3	2	2
Branchiostoma capensis	1		5					1						
Bullia annulata														
Capitella capitata														
Caridea													2	
Caulleriella spp.	2			1	1									1
Chaetognatha	1	4		9	1	2	2	3	2	5	3	8	3	4
Chaetozone setosa														
Cirratulidae														
Cirolana hirtipes						1								
Copepoda									1					
Corophiidae A	2							1		1				2
Corophiidae B				1										
Cunicus profundus														
Decapoda larva				3	1				1		1	2	1	1
Diastylidae		1		2	3	2	1					1		
Diogenes extricatus														
Diopatra cuprea punctifera														
Diopatra neapolitana capensis		1	1		1		2			4				
Drilonereis spp.					1									
Echinocardium cordatum											1	1		
Eulalia spp.														
Exogone clavator														
Fasciolaria spp.														
Glycera spp.			1	1	6	3	3	1	3	1			2	
Glycera subaenea ?									2					

Taxa	DW4C	DW4D	DW4E	E1A	E1B	E1C	E1D	E1E	E2A	E2B	E2C	E2D	E2E	E3A
Glycera unicornis	1	5			1					1				
Glycinde spp. (kameruniana ?)		3	3	1	2		3		3	2		1	1	
Goniada spp.														
Gyptis capensis			1		4		1			1	1	4	1	
Harmothoe spp.														
Harmothoe lunulata				4	13	12	13	7	2		5	7	12	3
Heterophoxus opus	1							1			3		1	
Hippomedon longimanus	3													3
Holothuroidea	5	2		48	178	141	153	88	9	17	49	58	76	23
Hymenosoma orbiculare														
Iphinoe stebbingi										1				
Lanice conchilega														
Lumbrineris spp.													1	
Lumbrineris hartmani														
Macoma crawfordi														
Magelona cincta		3			2				2			1		2
Magelona debeerei	3	1	6			1	1	1			1	1	1	
Maldanidae														
Mediomastus capensis	5	1	3	1	1	4	1	2	4		2	7	1	3
Megaluropus namaquaeensis	4	5	2	1	1	1	1	4	2	1	1	4	5	1
Mesochaetopterus capensis							1		1				1	
Microarcturus similis		1		1						1				1
Monoculodopsis longimana		1						1			1	1		
Mysidacea	1			1									1	
Nassarius cf. plicatellus														
Nassarius speciosus														
Nemertea (red banded)	2	1					1	2		1		1		
Nemertea ?		2	4						2					1
Nephtys hombergi	1													
Nephtys sphaerocirrata	14	20	17	18	22	27	18	22	14	19	10	14	16	7
Nereis spp. (succinea ?)		1		2	1	1	2			3			2	1
Notanthura caeca												2		
Nucula nucleus														
Oligochaeta														
Opheliidae														
Ophiuroidea (Amphiura capensis ?)					2	4	1	1			1	1		
Ostracoda		5	1	2	1			1	3				2	
Paguridae							2							
Paramoera capensis													1	

Taxa	DW4C	DW4D	DW4E	E1A	E1B	E1C	E1D	E1E	E2A	E2B	E2C	E2D	E2E	E3A
Paraonidae		1							1	2				
Paraonides lyra capensis														
Pectinaria capensis							2					1	1	
Pennatulacea														
Perna perna										1				
Perioculodes longimanus	3	6	2	12	10	9	7	5	10	4		6	9	3
Pherusa swakopiana		1						1	1	3	1			
Photis longidactylus									4	9			6	1
Philine aperta														
Philyra punctata														
Platyhelminthes														
Poecilochaetus sp.									1					
Polydora spp.														
Prionospio spp.		5			7	1	1	1	5	5		1	2	
Processa austroafricana				1										
Pseuodmalacoceros gilchristi	1	1						1	2	1				
Pterygosquilla armata capensis														
Sabellides capensis														
Sabellides luderitzi		1			1			1	1	1		1	1	
Scolaricia dubia	4		4	1				1	1		1			
Sigalion capense				1	1	3	1						1	2
Sigambra parva														
Sipunculida A														
Spiophanes soederstromi				7	3	17	8	2	6	3			2	
Sthenelais boa						1						1		
Syllidae										1				
Synidotea hirtipes		2		4						2	1		2	2
Synopiidae (Tiron australis ?)	1				1									
Tanaidacea									2					
Tellina spp. (gilchristi)		5		4					8	4				
Urothoe grimaldi	2	2	8	3		7	2	3	1	1	5	6	3	22
Urothoe spp.	2	3	2								2	1		
Virgularia spp. (mirabilis ?)	5	11		6	1	6		5		1	1	8	3	2

Appendix 4 continued: Benthic macrofauna abundance (animals/m^2) in sediment samples collected for the 2011 survey of the PetroSA outfall monitoring programme.

Taxa	E3B	E3C	E3D	E3E	E4A	E4B	E4C	E4D	E4E	E5A	E5B	E5C	E5D	E5E
Anemone		1				1								
Ampelisca brevicornis												2		1
Ampelisca spp.		1						1						
Amphioplus integer ?						1								
Ancilla marmorata														
Anthuridae	1		1		1						1		2	
Arabella spp.														
Astropecten antares														1
Bivalvia A						2		3				1		
Bodotriidae	5	1	5	1	3	6	2	5	2	1		1	1	
Branchiostoma capensis					4	1	3							
Bullia annulata														
Capitella capitata														
Caridea														
Caulleriella spp.	2		1					1		3	2	2	3	1
Chaetognatha	3	1	3		3	8	1	7		5	3	60	7	2
Chaetozone setosa														
Cirratulidae										1				1
Cirolana hirtipes														
Copepoda	1		1	1		2		1	1			2		3
Corophiidae A	1			6		8		2						
Corophiidae B								6			1			
Cunicus profundus														
Decapoda larva	2				2	2		5		1		15		
Diastylidae	2			1		1		2						
Diogenes extricatus									1			1		
Diopatra cuprea punctifera														
Diopatra neapolitana capensis	1			7		7	2	2	5					
Drilonereis spp.														
Echinocardium cordatum			1							1		1		
Eulalia spp.														
Exogone clavator														
Fasciolaria spp.														
Glycera spp.	5	7	3	1		2		13	1					
Glycera subaenea ?														
Glycera unicornis								2	2			3		

Taxa	E3B	E3C	E3D	E3E	E4A	E4B	E4C	E4D	E4E	E5A	E5B	E5C	E5D	E5E
Glycinde spp. (kameruniana ?)								1						
Goniada spp.														
Gyptis capensis	2		2			2						1	1	1
Harmothoe spp.														
Harmothoe lunulata	4	6	6	4					1	1	1	9	1	6
Heterophoxus opus	1	2			6	2	2				1			
Hippomedon longimanus							1					1		
Holothuroidea	66	81	66	23	9	7	6	15	7	2	7	58	9	20
Hymenosoma orbiculare										1	1			
Iphinoe stebbingi														
Lanice conchilega														
Lumbrineris spp.														
Lumbrineris hartmani														
Macoma crawfordi														
Magelona cincta	1	4		2	1	4	2	8	6				1	
Magelona debeerei					4		4		2		3		1	1
Maldanidae														
Mediomastus capensis	1	2	2			1		1		1	3	5	2	3
Megaluropus namaquaeensis		1	3	1	4	6	3	2	2	2		4	2	2
Mesochaetopterus capensis	1											1		
Microarcturus similis			1			2								3
Monoculodopsis longimana					1							1		
Mysidacea								1		1				
Nassarius cf. plicatellus														
Nassarius speciosus														
Nemertea (red banded)									1			2	3	1
Nemertea ?							1							
Nephtys hombergi														
Nephtys sphaerocirrata	23	21	20	18	8	24	8	26	11	10	8	27	6	13
Nereis spp. (succinea ?)	1	1		1		2		3	3	1	1	2	1	
Notanthura caeca		2			1					3				
Nucula nucleus														
Oligochaeta														
Opheliidae														
Ophiuroidea (Amphiura capensis ?)	1	1								1	1	1		
Ostracoda					1	1					1			1
Paguridae														
Paramoera capensis														
Paraonidae					2	4	2	2	2					

Taxa	E3B	E3C	E3D	E3E	E4A	E4B	E4C	E4D	E4E	E5A	E5B	E5C	E5D	E5E
Paraonides lyra capensis														
Pectinaria capensis				1										
Pennatulacea														
Perna perna			1			5								
Perioculodes longimanus	6	4	6	9	5	11	2	8	1	3	4	10		4
Pherusa swakopiana	1		1	1		2		2						
Photis longidactylus	1		3	3		3		4	11			7	1	
Philine aperta														
Philyra punctata				1										
Platyhelminthes							1							
Poecilochaetus sp.														
Polydora spp.														
Prionospio spp.	2	5	3		1	11		64	6			9		
Processa austroafricana														
Pseuodmalacoceros gilchristi			1		1		1		3					
Pterygosquilla armata capensis								2						
Sabellides capensis														
Sabellides luderitzi						1								
Scolaricia dubia					3				1	1	1			
Sigalion capense	5		6	1	1		1			1	2	1		
Sigambra parva					1									
Sipunculida A														
Spiophanes soederstromi	1	11	6	5		6		6	5	1		1	1	
Sthenelais boa					1								2	
Syllidae						1		1						
Synidotea hirtipes			13	43	2	29	2	2	1			3		
Synopiidae (Tiron australis ?)		1								1				
Tanaidacea				1	1									
Tellina spp. (gilchristi)						6		9		1		2	1	
Urothoe grimaldi	12	12	14	2	3		6		4	7	3	8	5	4
Urothoe spp.		1	3							10	1		2	2
Virgularia spp. (mirabilis ?)	2		2	1			1			3		2		3

Appendix 5: Benthic macrofauna biomass (g/m2) in sediment samples collected for the 2011 survey of the PetroSA outfall monitoring programme.

Taxa	DE1A	DE1B	DE1C	DE1D	DE1E	DE2A	DE2B	DE2C	DE2D	DE2E	DE3A	DE3B	DE3C	DE3D	DE3E
Anemone															
Ampelisca brevicornis													0.0024		
Ampelisca spp.													0.0002		
Amphioplus integer ?									0.0203						
Ancilla marmorata						0.0963									
Anthuridae			0.0006			0.001				0.0007	0.0007				0.0008
Arabella spp.															
Astropecten antares	3.5381														
Bivalvia A															
Bodotriidae	0.0009	0.0002		0.0003	0.0009	0.0003	0.001	0.0007	0.0002	0.0003	0.0015	0.0004	0.003	0.0003	0.0009
Branchiostoma capensis	0.0174	0.0201	0.0611			0.0251		0.0226			0.2794	0.0177	0.211		0.1615
Bullia annulata															
Capitella capitata											0.0007				
Caridea															
Caulleriella spp.															
Chaetognatha				0.0002			0.0003		0.0007		0.0008		0.0019		
Chaetozone setosa															
Cirratulidae								0.0014							
Cirolana hirtipes															
Copepoda															
Corophiidae A			0.0002												
Corophiidae B															
Cunicus profundus		0.0022									0.0026				
Decapoda larva													0.0002	0.0001	
Diastylidae		0.0005		0.0014											
Diogenes extricatus															7.8893
Diopatra cuprea punctifera															
Diopatra neapolitana capensis			0.9356				0.0133			0.4267					0.3018
Drilonereis spp.															
Echinocardium cordatum															
Eulalia spp.															
Exogone clavator															
Fasciolaria spp.															
Glycera spp.			0.0006	0.003											
Glycera subaenea ?															

Taxa	DE1A	DE1B	DE1C	DE1D	DE1E	DE2A	DE2B	DE2C	DE2D	DE2E	DE3A	DE3B	DE3C	DE3D	DE3E
Glycera unicornis							0.0161								
Glycinde spp. (kameruniana ?)			0.0012	0.0089			0.0032			0.0018			0.0027	0.0065	
Goniada spp.															
Gyptis capensis		0.0009	0.0003	0.002	0.001			0.001					0.0002	0.0006	0.0049
Harmothoe spp.															
Harmothoe lunulata				0.0034	0.0048			0.0034		0.0044	0.0017		0.0024		
Heterophoxus opus		0.0001	0.0004			0.0112	0.001	0.0009	0.0131	0.0009	0.0034	0.0036			0.012
Hippomedon longimanus	0.0039	0.0012	0.0018	0.0082		0.0051	0.0036	0.0011	0.0037		0.0028				0.0059
Holothuroidea	0.4118	0.5351	0.2844	1.0025	1.8447	0.0222		0.301	0.1779	1.2745	0.2058	0.0388	0.6302	0.1122	0.1233
Hymenosoma orbiculare															
Iphinoe stebbingi			0.0033												
Lanice conchilega															
Lumbrineris spp.															
Lumbrineris hartmani					0.0109										
Macoma crawfordi															
Magelona cincta				0.009	0.0011	0.0026	0.0031		0.0006				0.0012	0.002	0.035
Magelona debeerei	0.0032	0.0136	0.0033		0.0014	0.009		0.0069	0.0035	0.0173	0.0048	0.0014	0.0028		
Maldanidae															
Mediomastus capensis		0.0007		0.0007	0.001			0.0016		0.0023	0.0033	0.0005	0.0035	0.001	0.0028
Megaluropus namaquaeensis				0.0016		0.0016	0.0004	0.0013	0.0003	0.0009	0.001	0.0002	0.0003	0.0002	0.0006
Mesochaetopterus capensis							0.0816		0.0219	0.0088					
Microarcturus similis							0.0081	0.0016					0.0084		
Monoculodopsis longimana										0.0023				0.0009	
Mysidacea			0.0012	0.0018				0.0057		0.0011	0.0016				
Nassarius cf. plicatellus															
Nassarius speciosus															
Nemertea (red banded)		0.0114	0.0084			0.0002					0.0008				
Nemertea ?			0.0009			0.0007	0.0042	0.0027		0.0047	0.0167	0.001	0.0133	0.0023	0.0036
Nephtys hombergi															
Nephtys sphaerocirrata	0.0052	0.0071	0.011	0.0123	0.0044	0.0089	0.0167	0.008	0.007	0.0214	0.0054	0.0037	0.0024	0.0167	0.0038
Nereis spp. (succinea ?)		0.0003	0.0013				0.001	0.0008	0.0039	0.0015		0.0044		0.003	0.0045
Notanthura caeca													0.031		
Nucula nucleus															
Oligochaeta															
Opheliidae															
Ophiuroidea (Amphiura capensis ?)		0.2668	0.0219		1.5161				0.0385		1.1297		0.3391		0.4597

Taxa	DE1A	DE1B	DE1C	DE1D	DE1E	DE2A	DE2B	DE2C	DE2D	DE2E	DE3A	DE3B	DE3C	DE3D	DE3E
Ostracoda		0.0011	0.0003			0.0008	0.0017	0.0002	0.0003	0.0008	0.0006	0.0001	0.0001		
Paguridae															
Paramoera capensis															
Paraonidae											0.0002	0.0009	0.0008		0.0012
Paraonides lyra capensis															
Pectinaria capensis															
Pennatulacea															
Perna perna															
Perioculodes longimanus		0.0013	0.001	0.001	0.0011	0.0033	0.0029	0.0019	0.0003	0.0016	0.001	0.0005	0.0003	0.003	0.0013
Pherusa swakopiana		0.0003									0.0004				
Photis longidactylus		0.0002		0.001			0.0011	0.001					0.0003	0.0003	0.0003
Philine aperta		2.1689													
Philyra punctata															
Platyhelminthes															
Poecilochaetus sp.															
Polydora spp.				0.0004											
Prionospio spp.		0.0002		0.0015	0.0002		0.0006			0.0004			0.0003	0.0002	
Processa austroafricana				0.004											
Pseuodmalacoceros gilchristi			0.0004	0.001	0.0048	0.0029	0.0065	0.0006			0.0007				
Pterygosquilla armata capensis															
Sabellides capensis															
Sabellides luderitzi				0.0006	0.0002	0.0003	0.0007								
Scolaricia dubia			0.0039				0.0053		0.0129	0.0089	0.0136	0.0046			
Sigalion capense	0.0174		0.0575			0.0105		0.0404		0.0694					
Sigambra parva															
Sipunculida A							0.0361								
Spiophanes soederstromi				0.0013			0.0006					0.0004			
Sthenelais boa		0.0594													
Syllidae															
Synidotea hirtipes			0.0302	0.0133	0.0094		0.0473	0.0033				0.0258			
Synopiidae (Tiron australis ?)												0.0006			0.0003
Tanaidacea								0.0003			0.001	0.0003			0.0006
Tellina spp. (gilchristi)			0.0004	0.0003						0.0007				0.0004	
Urothoe grimaldi		0.0131	0.0051	0.0003	0.0098	0.0071	0.0008	0.006	0.0034	0.0052	0.0065	0.0061	0.0004	0.0023	0.008
Urothoe spp.				0.0003	0.0005	0.0002	0.0001		0.0005		0.0009	0.0003			
Virgularia spp. (mirabilis ?)			0.0024	0.0002		0.0002	0.0051	0.0027	0.0131	0.0062	0.0009				

Appendix 5 continued: Benthic macrofauna biomass (g/m^2) in sediment samples collected for the 2011 survey of the PetroSA outfall monitoring programme.

Taxa	DW1A	DW1B	DW1C	DW1D	DW1E	DW2A	DW2B	DW2C	DW2D	DW2E	W3A	W3B	W3C
Anemone													
Ampelisca brevicornis										0.0014	0.0032	0.001	0.0016
Ampelisca spp.													
Amphioplus integer ?							0.0131			0.0117			
Ancilla marmorata													
Anthuridae					0.0005				0.0003				
Arabella spp.													
Astropecten antares													
Bivalvia A	0.0029					0.0008	0.0018			0.002			
Bodotriidae		0.0013	0.0011		0.001	0.0006	0.0006				0.0017	0.0108	0.0033
Branchiostoma capensis		0.0505		0.037	0.01		0.0137	0.0525	0.0261				
Bullia annulata													
Capitella capitata													
Caridea													
Caulleriella spp.													
Chaetognatha				0.0003		0.0005			0.0004	0.0012	0.0007	0.0022	
Chaetozone setosa													
Cirratulidae		0.0057											
Cirolana hirtipes													
Copepoda												0.0002	
Corophiidae A											0.0064		0.0026
Corophiidae B													
Cunicus profundus					0.0018								
Decapoda larva											0.0002		0.0002
Diastylidae											0.0059	0.0019	0.0032
Diogenes extricatus											0.029		
Diopatra cuprea punctifera													
Diopatra neapolitana capensis		0.59			0.0152		0.2309				0.0893		0.8687
Drilonereis spp.													
Echinocardium cordatum		2.2605						3.3709					
Eulalia spp.													
Exogone clavator													
Fasciolaria spp.													

Taxa	DW1A	DW1B	DW1C	DW1D	DW1E	DW2A	DW2B	DW2C	DW2D	DW2E	W3A	W3B	W3C
Glycera spp.		0.0005				0.0005				0.0146	0.0033	0.0024	
Glycera subaenea ?												0.045	
Glycera unicornis													0.0979
Glycinde spp. (kameruniana ?)							0.0018			0.011	0.0145	0.0108	0.0189
Goniada spp.													
Gyptis capensis		0.0011		0.0015	0.002		0.001	0.0012	0.0009	0.0014			
Harmothoe spp.						0.0001	0.0009						
Harmothoe lunulata		0.0146	0.0009			0.0015		0.0015	0.0024	0.0023	0.0015	0.0195	0.0012
Heterophoxus opus		0.0002	0.0029	0.0004	0.004	0.0014	0.0009		0.0017				
Hippomedon longimanus	0.0004	0.0008	0.0012			0.0004	0.0012	0.0026	0.0023				
Holothuroidea	1.7986	2.8964	1.0172	1.378	1.391	0.3553	2.7547	1.0126	1.1164	2.1187	0.1014	0.3885	1.7383
Hymenosoma orbiculare													
Iphinoe stebbingi													
Lanice conchilega													
Lumbrineris spp.													
Lumbrineris hartmani													
Macoma crawfordi													0.1528
Magelona cincta								0.0089		0.0006	0.005		0.0001
Magelona debeerei		0.0049	0.0046	0.0017	0.0073		0.0033	0.0035	0.0071				
Maldanidae													0.0049
Mediomastus capensis	0.0008	0.0024	0.0007	0.0032	0.0014	0.0004	0.0011		0.001	0.0017			0.0006
Megaluropus namaquaeensis	0.0006	0.001	0.0009		0.0008	0.0003	0.0011		0.0006	0.0024	0.0003	0.0016	0.0008
Mesochaetopterus capensis										0.0008			
Microarcturus similis												0.0002	
Monoculodopsis longimana	0.0004	0.0009	0.0003			0.0006			0.0005				
Mysidacea									0.0014			0.0016	
Nassarius cf. plicatellus													
Nassarius speciosus		1.8867											0.2678
Nemertea (red banded)		0.0136	0.0148			0.007	0.0028	0.0016		0.0034			
Nemertea ?	0.0046			0.0079	0.0118			0.0037	0.0018		0.0014	0.0019	0.001
Nephtys hombergi													
Nephtys sphaerocirrata	0.0096	0.0087	0.0094	0.0119	0.0067	0.0036	0.0042	0.0025	0.0058	0.0055	0.0064	0.0168	0.01
Nereis spp. (succinea ?)							0.001						0.0003
Notanthura caeca				0.0247									
Nucula nucleus												0.0024	
Oligochaeta													0.0008

Taxa	DW1A	DW1B	DW1C	DW1D	DW1E	DW2A	DW2B	DW2C	DW2D	DW2E	W3A	W3B	W3C
Opheliidae													
Ophiuroidea (Amphiura capensis ?)		0.3519	0.2935	0.2525	0.5744			0.2245					
Ostracoda	0.0003	0.0007		0.0004	0.0008	0.0003	0.0008	0.0008	0.001	0.0033	0.0053	0.0261	0.0098
Paguridae													
Paramoera capensis													
Paraonidae												0.0019	0.0037
Paraonides lyra capensis													
Pectinaria capensis													
Pennatulacea													
Perna perna										0.0351	0.0763		0.8138
Perioculodes longimanus	0.0018	0.001	0.0003	0.0009	0.0008	0.0036	0.0013	0.0013	0.0009	0.0039	0.0024	0.0023	0.0028
Pherusa swakopiana						0.0004	0.1029				0.4899		0.2467
Photis longidactylus							0.0007					0.0005	0.0006
Philine aperta													
Philyra punctata	0.0519												
Platyhelminthes													
Poecilochaetus sp.													
Polydora spp.													
Prionospio spp.				0.0003		0.0011	0.0009		0.0006	0.0024	0.0004	0.0008	0.001
Processa austroafricana													
Pseuodmalacoceros gilchristi						0.001							
Pterygosquilla armata capensis													
Sabellides capensis													0.0018
Sabellides luderitzi													
Scolaricia dubia								0.0013			0.0445	0.0266	
Sigalion capense		0.0164	0.0193		0.1068		0.0215	0.0884	0.0116	0.0157			
Sigambra parva													
Sipunculida A													
Spiophanes soederstromi						0.0003		0.0008	0.0003		0.0041	0.0076	0.0012
Sthenelais boa													
Syllidae													
Synidotea hirtipes		0.016					0.0012			0.0325	0.225		0.4844
Synopiidae (Tiron australis ?)								0.0008					
Tanaidacea											0.0009	0.0014	0.0008
Tellina spp. (gilchristi)	0.0029		0.0019			0.0032			0.0008	0.017	0.0482	0.0025	0.0717
Urothoe grimaldi	0.0024	0.0066	0.0103	0.0128	0.0138	0.0009	0.0069	0.0078	0.0094	0.0041	0.0002		

Taxa	DW1A	DW1B	DW1C	DW1D	DW1E	DW2A	DW2B	DW2C	DW2D	DW2E	W3A	W3B	W3C
Urothoe spp.		0.0003	0.0004	0.0008	0.0003			0.0002	0.0003				
Virgularia spp. (mirabilis ?)			0.0146	0.0037	0.0034		0.0029		0.0122	0.0083			

Appendix 5 continued: Benthic macrofauna biomass (g/m^2) in sediment samples collected for the 2011 survey of the PetroSA outfall monitoring programme.

Taxa	W3D	W3E	W2A	W2B	W2C	W2D	W2E	W1A	W1B	W1C	W1D	W1E	DW4A	DW4B
Anemone														
Ampelisca brevicornis	0.0094	0.0014					0.0079							
Ampelisca spp.		0.0006				0.0016								
Amphioplus integer ?										0.1369		0.0892		
Ancilla marmorata														
Anthuridae														0.0014
Arabella spp.			0.0382											
Astropecten antares														
Bivalvia A	0.0015					0.0012	0.001						0.0003	0.0035
Bodotriidae	0.001		0.0013		0.0018	0.0012	0.0015	0.0005	0.0016	0.0003	0.0008	0.0001	0.0003	0.0009
Branchiostoma capensis														0.0131
Bullia annulata														
Capitella capitata					0.001									
Caridea														
Caulleriella spp.					0.0078									
Chaetognatha	0.0008	0.0003	0.0009			0.0007	0.0002	0.0006	0.0005	0.0037	0.0003		0.0008	0.0006
Chaetozone setosa											0.0002			
Cirratulidae														
Cirolana hirtipes														
Copepoda	0.0002										0.0001			
Corophiidae A							0.0003							0.0017
Corophiidae B														
Cunicus profundus														
Decapoda larva	0.0002	0.0009					0.0002		0.0001					
Diastylidae	0.0005	0.0039	0.0093			0.0024	0.0035						0.001	
Diogenes extricatus														
Diopatra cuprea punctifera			0.2383											
Diopatra neapolitana capensis		0.4773					0.7201					0.0371		1.4727
Drilonereis spp.														

Taxa	W3D	W3E	W2A	W2B	W2C	W2D	W2E	W1A	W1B	W1C	W1D	W1E	DW4A	DW4B
Echinocardium cordatum						0.9372								
Eulalia spp.							0.0011							
Exogone clavator		0.0005												
Fasciolaria spp.														
Glycera spp.			0.0072			0.0031	0.0012					0.0008		
Glycera subaenea ?														
Glycera unicornis	0.006	0.0312				0.4484	0.014							0.0451
Glycinde spp. (kameruniana ?)	0.0056	0.0092	0.0023			0.0084	0.0208			0.0049			0.0038	
Goniada spp.														
Gyptis capensis								0.0012	0.0008	0.0012	0.0008	0.0025		
Harmothoe spp.					0.0007									
Harmothoe lunulata	0.01		0.0035			0.0212	0.0083	0.0144	0.001	0.01	0.0021	0.0081		0.0023
Heterophoxus opus									0.0022	0.0029	0.0024	0.0002	0.0005	0.0017
Hippomedon longimanus		0.0008							0.0016	0.0026	0.0007		0.003	0.0021
Holothuroidea	2.6873	0.2155	4.3232		0.2058	7.1269	4.5241	3.0117	0.8827	1.5115	1.2818	5.129	0.0365	0.2648
Hymenosoma orbiculare								0.0002				0.0005		
Iphinoe stebbingi														
Lanice conchilega		0.0336												
Lumbrineris spp.														
Lumbrineris hartmani														
Macoma crawfordi	0.0014													
Magelona cincta	0.0115		0.0007		0.0002	0.0067	0.0013			0.0003				
Magelona debeerei													0.0031	0.0086
Maldanidae														
Mediomastus capensis	0.0003		0.0003		0.0013	0.0009	0.0003	0.0016		0.0006	0.0014		0.0018	0.0013
Megaluropus namaquaeensis	0.0003	0.0003	0.0002		0.002	0.0002	0.0025	0.0006	0.0009	0.0015	0.0005	0.0002	0.0007	0.0031
Mesochaetopterus capensis			0.0002			0.0131	0.0002							
Microarcturus similis		0.0197					0.0017							
Monoculodopsis longimana					0.0007	0.0002								
Mysidacea														
Nassarius cf. plicatellus														
Nassarius speciosus			0.1883											
Nemertea (red banded)	0.0131					0.0009	0.0029	0.0014				0.0019		
Nemertea ?		0.0005	0.0002						0.0473					0.0022
Nephtys hombergi														
Nephtys sphaerocirrata	0.0074	0.01	0.0024		0.0032	0.0051	0.0156	0.007	0.0061	0.003	0.0053	0.0066	0.0036	0.0157

Taxa	W3D	W3E	W2A	W2B	W2C	W2D	W2E	W1A	W1B	W1C	W1D	W1E	DW4A	DW4B
Nereis spp. (succinea ?)		0.0027					0.0021					0.0074		0.0017
Notanthura caeca					0.0019					0.0061		0.0004		
Nucula nucleus	0.0019													
Oligochaeta	0.0003	0.0002					0.0001							
Opheliidae					0.0078									
Ophiuroidea (Amphiura capensis ?)		0.004			0.6293	0.3793	0.4328	0.2458	0.0955					
Ostracoda	0.0022	0.0084	0.0003			0.0003	0.0005	0.0003	0.0005	0.0004	0.0006	0.0006	0.0003	0.0024
Paguridae														
Paramoera capensis														
Paraonidae	0.0027	0.0006											0.0011	
Paraonides lyra capensis														
Pectinaria capensis			0.0027								0.0118			
Pennatulacea									0.0015					
Perna perna		0.1068												0.0025
Perioculodes longimanus	0.0008	0.0011	0.0023		0.0011	0.0035	0.004	0.0009	0.0013	0.0017	0.0023	0.0009	0.0008	0.0032
Pherusa swakopiana		0.5612					0.0008					0.0761		
Photis longidactylus	0.0006	0.0016	0.0002			0.0003	0.0007					0.0002		0.001
Philine aperta														
Philyra punctata														
Platyhelminthes														
Poecilochaetus sp.							0.0001							
Polydora spp.														
Prionospio spp.	0.0009	0.0007	0.002			0.0009	0.0005			0.0002	0.0002	0.0003		0.0008
Processa austroafricana		0.0022												
Pseuodmalacoceros gilchristi							0.0049							0.0038
Pterygosquilla armata capensis														
Sabellides capensis														
Sabellides luderitzi		0.0148			0.0004									
Scolaricia dubia		0.0093					0.0047		0.0014				0.002	0.0083
Sigalion capense						0.0101			0.0785		0.0553	0.0179		
Sigambra parva							0.0007							
Sipunculida A														
Spiophanes soederstromi	0.0079	0.009	0.0018			0.0027	0.0066							
Sthenelais boa														
Syllidae														
Synidotea hirtipes	0.0024	0.3531	0.0039		0.0305									0.1141

Taxa	W3D	W3E	W2A	W2B	W2C	W2D	W2E	W1A	W1B	W1C	W1D	W1E	DW4A	DW4B
Synopiidae (Tiron australis ?)								0.0001	0.0003					
Tanaidacea	0.0004	0.001			0.0006		0.0002							
Tellina spp. (gilchristi)		0.0008	0.0015			0.0108	0.0008							
Urothoe grimaldi					0.0237	0.0001	0.0015	0.0022	0.0199	0.0048	0.012	0.0025	0.0028	0.002
Urothoe spp.	0.0001					0.0002								
Virgularia spp. (mirabilis ?)					0.0006	0.0008	0.0011	0.0043	0.0035	0.0082		0.0013	0.0013	0.0008

Appendix 5 continued: Benthic macrofauna biomass (g/m^2) in sediment samples collected for the 2011 survey of the PetroSA outfall monitoring programme.

Taxa	DW4C	DW4D	DW4E	E1A	E1B	E1C	E1D	E1E	E2A	E2B	E2C	E2D	E2E	E3A
Anemone													0.0182	
Ampelisca brevicornis		0.0006			0.0018				0.0028					
Ampelisca spp.														
Amphioplus integer ?				0.168						0.0282			0.0109	
Ancilla marmorata														
Anthuridae		0.0002		0.0004	0.0004								0.0008	
Arabella spp.							0.0652							
Astropecten antares					11.44									
Bivalvia A		0.0009			0.0012				0.0003	0.0027				
Bodotriidae	0.0006	0.0008	0.0006	0.0003	0.0004	0.0005		0.0003	0.0006	0.0003	0.0007	0.0004	0.0006	0.0004
Branchiostoma capensis	0.0014		0.0848					0.011						
Bullia annulata														
Capitella capitata														
Caridea													0.0012	
Caulleriella spp.	0.0083			0.0017	0.001									0.0024
Chaetognatha	0.0004	0.0012		0.0025	0.0004	0.0007	0.0012	0.001	0.0003	0.0008	0.0004	0.0016	0.0015	0.0009
Chaetozone setosa														
Cirratulidae														
Cirolana hirtipes						0.0162								
Copepoda									0.0001					
Corophiidae A	0.0004							0.0002		0.0004				0.0006
Corophiidae B				0.001										
Cunicus profundus														
Decapoda larva				0.0002	0.0001				0.0002		0.0001	0.0003	0.0001	0.0002
Diastylidae		0.0008		0.0021	0.0028	0.0022	0.0008					0.0004		
Diogenes extricatus														

Taxa	DW4C	DW4D	DW4E	E1A	E1B	E1C	E1D	E1E	E2A	E2B	E2C	E2D	E2E	E3A
Diopatra cuprea punctifera														
Diopatra neapolitana capensis		0.0049	0.0266		0.0028		0.0341			0.3743				
Drilonereis spp.					0.004									
Echinocardium cordatum											1.9246	2.3164		
Eulalia spp.														
Exogone clavator														
Fasciolaria spp.														
Glycera spp.			0.0009	0.0002	0.0012	0.0008	0.0012	0.0004	0.0005	0.0003			0.0006	
Glycera subaenea ?									0.0111					
Glycera unicornis	0.0371	0.162			0.1442					0.0118				
Glycinde spp. (kameruniana ?)		0.0289	0.0044	0.0045	0.0006		0.0087		0.0003	0.0034		0.0029	0.0004	
Goniada spp.														
Gyptis capensis			0.0003		0.0022		0.0022			0.0007	0.0003	0.0019	0.0006	
Harmothoe spp.														
Harmothoe lunulata				0.0057	0.012	0.013	0.0153	0.0087	0.0151		0.0056	0.0055	0.0101	0.0036
Heterophoxus opus	0.0004							0.001			0.0011		0.0004	
Hippomedon longimanus	0.0074													0.0014
Holothuroidea	0.3956	0.234		2.023	13.6473	7.3629	11.7125	4.6213	0.5681	0.6314	3.1332	3.2812	5.9982	1.5501
Hymenosoma orbiculare														
Iphinoe stebbingi										0.0011				
Lanice conchilega														
Lumbrineris spp.													0.0003	
Lumbrineris hartmani														
Macoma crawfordi														
Magelona cincta		0.0049			0.0456				0.0038			0.0001		0.0006
Magelona debeerei	0.0098	0.0007	0.0156			0.0027	0.0004	0.0004			0.001	0.0002	0.0003	
Maldanidae														
Mediomastus capensis	0.0027	0.0005	0.001	0.0002	0.001	0.0017	0.0006	0.0005	0.0006		0.0012	0.0037	0.0011	0.0009
Megaluropus namaquaeensis	0.0008	0.0015	0.0004	0.0003	0.0005	0.0005	0.0003	0.001	0.0005	0.0003	0.0004	0.0006	0.0013	0.0003
Mesochaetopterus capensis							0.0012		0.0126				0.0004	
Microarcturus similis		0.0003		0.0012						0.0023				0.0055
Monoculodopsis longimana		0.0004						0.0004			0.001	0.0006		
Mysidacea	0.002			0.0017									0.001	
Nassarius cf. plicatellus														
Nassarius speciosus														
Nemertea (red banded)	0.0096	0.0147					0.0033	0.0094		0.0006		0.0029		

Taxa	DW4C	DW4D	DW4E	E1A	E1B	E1C	E1D	E1E	E2A	E2B	E2C	E2D	E2E	E3A
Nemertea ?		0.0036	0.0122						0.0014					0.0015
Nephtys hombergi	0.1025													
Nephtys sphaerocirrata	0.008	0.0099	0.0119	0.0099	0.015	0.0155	0.0115	0.0085	0.0092	0.0098	0.0034	0.0064	0.0075	0.0027
Nereis spp. (succinea ?)		0.0062		0.0014	0.0054	0.0026	0.0012			0.003			0.0098	0.0143
Notanthura caeca												0.0269		
Nucula nucleus														
Oligochaeta														
Opheliidae														
Ophiuroidea (Amphiura capensis ?)					1.4865	0.7217	0.4091	0.1021			0.268	0.2422		
Ostracoda		0.0007	0.0003	0.0002	0.0002			0.0002	0.0006				0.0005	
Paguridae							0.1067							
Paramoera capensis													0.0018	
Paraonidae		0.0011							0.0005	0.0012				
Paraonides lyra capensis														
Pectinaria capensis							0.091					0.0117	0.0055	
Pennatulacea														
Perna perna										0.0063				
Perioculodes longimanus	0.0012	0.0018	0.0004	0.0017	0.0017	0.0014	0.002	0.0012	0.0018	0.0011		0.0012	0.0031	0.0006
Pherusa swakopiana		0.0008						0.0008	0.0004	0.0389	0.0026			
Photis longidactylus									0.0016	0.0027			0.0019	0.0002
Philine aperta														
Philyra punctata														
Platyhelminthes														
Poecilochaetus sp.									0.0004					
Polydora spp.														
Prionospio spp.		0.0006			0.0015	0.0004	0.0005	0.0003	0.0004	0.0006		0.0006	0.0002	
Processa austroafricana				0.0014										
Pseuodmalacoceros gilchristi	0.0025	0.0019						0.0045	0.0006	0.0013				
Pterygosquilla armata capensis														
Sabellides capensis														
Sabellides luderitzi		0.0006			0.0002			0.0005	0.0004	0.0003		0.0003	0.0002	
Scolaricia dubia	0.0216		0.0183	0.0075				0.0023	0.0037		0.0007			
Sigalion capense				0.0331	0.0239	0.0813	0.003						0.0344	0.0601
Sigambra parva														
Sipunculida A														
Spiophanes soederstromi				0.0026	0.0016	0.0169	0.0087	0.0012	0.0015	0.0004			0.0003	

Taxa	DW4C	DW4D	DW4E	E1A	E1B	E1C	E1D	E1E	E2A	E2B	E2C	E2D	E2E	E3A
Sthenelais boa						0.0006						0.001		
Syllidae										0.0002				
Synidotea hirtipes		0.0196		0.0228						0.0014	0.0031		0.0016	0.0018
Synopiidae (Tiron australis ?)	0.0003				0.0004									
Tanaidacea									0.0003					
Tellina spp. (gilchristi)		0.0026		0.0033					0.0102	0.004				
Urothoe grimaldi	0.0013	0.0026	0.0077	0.0011		0.0059	0.0026	0.0014	0.0006	0.0004	0.0029	0.0073	0.0014	0.0393
Urothoe spp.	0.0007	0.0007	0.0004								0.0003	0.0002		
Virgularia spp. (mirabilis ?)	0.002	0.0074		0.0035	0.001	0.0071		0.0037		0.0002	0.0005	0.0117	0.0029	0.0003

Appendix 5 continued: Benthic macrofauna biomass (g/m^2) in sediment samples collected for the 2011 survey of the PetroSA outfall monitoring programme.

Taxa	E3B	E3C	E3D	E3E	E4A	E4B	E4C	E4D	E4E	E5A	E5B	E5C	E5D	E5E
Anemone		0.024				0.0604								
Ampelisca brevicornis												0.0005		0.0004
Ampelisca spp.		0.0003						0.0005						
Amphioplus integer ?						0.0015								
Ancilla marmorata														
Anthuridae	0.0004		0.0006		0.0007						0.0004		0.0008	
Arabella spp.														
Astropecten antares														13.27
Bivalvia A						0.0019		0.0004				0.0007		
Bodotriidae	0.0004	0.0003	0.0007	0.0002	0.0018	0.0007	0.0008	0.0009	0.0003	0.0002		0.0003	0.0002	
Branchiostoma capensis					0.3976	0.0012	0.2425							
Bullia annulata														
Capitella capitata														
Caridea														
Caulleriella spp.	0.0021		0.0013					0.0039		0.0022	0.0061	0.0051	0.0036	0.0017
Chaetognatha	0.0007	0.0003	0.0015		0.0007	0.0009	0.0003	0.0008		0.0012	0.0004	0.0191	0.0008	0.0005
Chaetozone setosa														
Cirratulidae										0.0006				0.0005
Cirolana hirtipes														
Copepoda	0.0001		0.0001	0.0001		0.0003		0.0001	0.0002			0.0003		0.0003
Corophiidae A	0.0002			0.0012		0.0026		0.0004						
Corophiidae B								0.0013			0.0002			

Taxa	E3B	E3C	E3D	E3E	E4A	E4B	E4C	E4D	E4E	E5A	E5B	E5C	E5D	E5E
Cunicus profundus														
Decapoda larva	0.0012				0.0004	0.0003		0.0002		0.0002		0.0015		
Diastylidae	0.0015			0.0006		0.0009		0.0015						
Diogenes extricatus									3.3171			0.444		
Diopatra cuprea punctifera														
Diopatra neapolitana capensis	0.0071			0.4588		0.1955	0.5629	0.3601	0.206					
Drilonereis spp.														
Echinocardium cordatum			0.0027							1.3512		1.4796		
Eulalia spp.														
Exogone clavator														
Fasciolaria spp.														
Glycera spp.	0.0015	0.0014	0.0006	0.001		0.0011		0.0041	0.001					
Glycera subaenea ?														
Glycera unicornis								0.5005	0.1446			0.0366		
Glycinde spp. (kameruniana ?)								0.0005						
Goniada spp.														
Gyptis capensis	0.0018		0.0009			0.0015						0.0007	0.0011	0.0005
Harmothoe spp.														
Harmothoe lunulata	0.0024	0.0692	0.0077	0.0042					0.0016	0.0018	0.0012	0.0155	0.0007	0.0059
Heterophoxus opus	0.0003	0.0019			0.0026	0.0008	0.0035				0.0007			
Hippomedon longimanus							0.0011					0.0021		
Holothuroidea	4.0474	4.813	3.069	0.9061	0.7418	0.5623	0.6234	0.9048	0.5305	0.1236	0.4531	4.0662	0.4757	0.7108
Hymenosoma orbiculare										0.0003	0.0004			
Iphinoe stebbingi														
Lanice conchilega														
Lumbrineris spp.														
Lumbrineris hartmani														
Macoma crawfordi														
Magelona cincta	0.0137	0.0096		0.0021	0.0003	0.0035	0.0047	0.0357	0.0199				0.0008	
Magelona debeerei					0.0027		0.012		0.0017		0.0056		0.0004	0.0004
Maldanidae														
Mediomastus capensis	0.0006	0.0014	0.0015			0.0008		0.0002		0.0006	0.0017	0.0019	0.001	0.0017
Megaluropus namaquaeensis		0.0005	0.0007	0.0004	0.002	0.0013	0.0005	0.0007	0.0007	0.0005		0.0004	0.0003	0.0005
Mesochaetopterus capensis	0.0007											0.001		
Microarcturus similis			0.0024			0.0017								0.0006
Monoculodopsis longimana					0.0002							0.0003		

Taxa	E3B	E3C	E3D	E3E	E4A	E4B	E4C	E4D	E4E	E5A	E5B	E5C	E5D	E5E
Mysidacea								0.0005		0.0006				
Nassarius cf. plicatellus														
Nassarius speciosus														
Nemertea (red banded)									0.0014			0.0057	0.0068	0.0019
Nemertea ?							0.0024							
Nephtys hombergi														
Nephtys sphaerocirrata	0.0091	0.0115	0.0065	0.0094	0.0035	0.0125	0.006	0.0187	0.0068	0.0047	0.0032	0.0134	0.0021	0.0041
Nereis spp. (succinea ?)	0.0004	0.0066		0.0006		0.0031		0.021	0.0096	0.001	0.0006	0.0097	0.0009	
Notanthura caeca		0.0209			0.0039					0.0308				
Nucula nucleus														
Oligochaeta														
Opheliidae														
Ophiuroidea (Amphiura capensis ?)	0.4086	0.4376								1.2976	0.3447	0.2161		
Ostracoda					0.0007	0.0004					0.0003			0.0002
Paguridae														
Paramoera capensis														
Paraonidae					0.0015	0.0067	0.0016	0.0025	0.0038					
Paraonides lyra capensis														
Pectinaria capensis				0.0109										
Pennatulacea														
Perna perna			0.0656			0.0534								
Perioculodes longimanus	0.0014	0.0008	0.0008	0.0025	0.0013	0.0024	0.0008	0.0009	0.0002	0.0007	0.001	0.0022		0.0006
Pherusa swakopiana	0.1414		0.1316	0.0012		0.2118		0.0466						
Photis longidactylus	0.0002		0.002	0.0007		0.0005		0.0006	0.0024			0.0014	0.0003	
Philine aperta														
Philyra punctata				0.1152										
Platyhelminthes							0.0075							
Poecilochaetus sp.														
Polydora spp.														
Prionospio spp.	0.0003	0.0009	0.0006		0.0003	0.0018		0.0153	0.0017			0.0021		
Processa austroafricana														
Pseuodmalacoceros gilchristi			0.0007		0.0007		0.0013	0.0006	0.0017					
Pterygosquilla armata capensis														
Sabellides capensis														
Sabellides luderitzi						0.0006								
Scolaricia dubia					0.0144				0.0028	0.0005	0.0004			

Taxa	E3B	E3C	E3D	E3E	E4A	E4B	E4C	E4D	E4E	E5A	E5B	E5C	E5D	E5E
Sigalion capense	0.1566		0.1945	0.0167	0.0043		0.0136			0.0329	0.0555	0.0262		
Sigambra parva					0.0012									
Sipunculida A														
Spiophanes soederstromi	0.0012	0.0022	0.0011	0.0012		0.0014		0.0021	0.0021	0.0002		0.0026	0.0004	
Sthenelais boa					0.0005								0.0364	
Syllidae						0.0005		0.0001						
Synidotea hirtipes			0.0248	0.2815	0.0025	0.1869	0.0065	0.0018	0.0656			0.0181		
Synopiidae (Tiron australis ?)		0.0006								0.0002				
Tanaidacea				0.0002	0.0003									
Tellina spp. (gilchristi)						0.0068		0.0059		0.0006		0.0024	0.0007	
Urothoe grimaldi	0.0094	0.009	0.0103	0.0019	0.0011		0.0108		0.0057	0.0055	0.0049	0.0026	0.0032	0.001
Urothoe spp.		0.0002	0.0003							0.0008	0.0002		0.0002	0.0003
Virgularia spp. (mirabilis ?)	0.0281		0.0007	0.0003			0.0005			0.0089		0.0034		0.0086

Appendix 6: Scientific details of various analytical procedures as conducted in this study.

Detailed reporting is previded as an Appendix for purposes of future replication or detailed enquiry of the scientific rationale or methods used in this study.

Addendum to 5.4.1.1 Definition of baseline metal concentrations

Metal concentrations generated through the present study and through studies in the Port of Mossel Bay were used for baseline model definition (latter data used with permission of Transnet National Ports Authority). The data were first examined by generating scatter plots of the relationship between each metal and co-occurring aluminium concentrations. Although there was substantial scatter of data for many metals, linear relationships were nevertheless usually evident between concentrations at most of the sites. This suggested that the relationships could be described by some form of linear regression after the trimming of anomalous data (i.e. outliers). Although several forms of regression have been used to define baseline models the most common form is simple linear regression. Linear regressions and 99% prediction limits were fitted to the data. Data falling outside the prediction limits were deemed outliers and sequentially trimmed, starting with the data point furthest from a prediction limit, until all data fell within the prediction limits. For a few metals linear regression assumptions of a normal data distribution and constant variance of error terms was violated. From a strict (parametric) statistical point of view this precludes use of the raw data for regression analysis. Transformation was not, however, used to approximate these assumptions. This is consistent with the geochemical model on which normalisation is based, that is, a linear relationship between metal and normaliser concentrations rather than a curvilinear relationship assumed through some data transformations commonly applied (e.g. ln transformation). In general, the lack of variance homogeneity does not result in biased estimates of the regression parameters, although it does result in an increase in variance about these estimates (Hanson et al. 1993).

While the above approach to the definition of baseline models is geochemically and statistically valid there is nevertheless still an element of subjectivity involved. First, 99% rather than 95% prediction limits were used for the purposes of this study. This is a subjective decision as there is no convention on which of these levels of confidence is more appropriate. The use of 95% prediction limits would have led to the trimming of more data than is the case using 99% prediction limits and is probably more appropriate in situations where data are collected from a highly anthropogenically impacted system. However, analysis of the data showed that the study area is not significantly metal contaminated and 99% prediction limits were thus considered appropriate. Second, there is no convention on the strength of the relationship between a normaliser and metal for the baseline model to be considered ‘adequate’ for interpretive purposes. Third, if deviations from a regression line follow a normal distribution then 1% of the data will naturally tend to lie outside the 99% prediction limits. There is thus no reason to flag the data as outliers since they are as much a part of the normal distribution as data within the prediction limits. There is no statistical procedure that cleanly separates normally distributed data from outliers.

12. Glossary of Terms[4]

Abiotic factors	The non-living factors that affect the ability of living organisms to survive in an environment (e.g. temperature, salinity).
Adsorption	Bonding of metals and nutrients onto the surfaces of suspended particles by way of physical, chemical and biological processes.
Aliquot	A sub-sample of the original sample.
Analysis of Variance (ANOVA)	A statistical procedure used to compare the average condition between three or more treatments.
Anthropogenic	Made and/or introduced into the environment by humans, especially pertaining to contaminants/pollutants.
Assimilative capacity	The amount of contaminant load that can be discharged to a specific water body without exceeding water quality standards or criteria. Assimilative capacity is used to define the ability of a water body to naturally absorb and use a discharged substance without impairing water quality or harming aquatic life.
Benthic	Pertaining to the environment inhabited by organisms living on or in the ocean bottom.
Benthos	Living organisms (e.g. algae and animals) associated with the sea bottom.
Biota	The living organisms within a habitat or region.
Biotic	Relating to life or living things.
Community	Any group of organisms belonging to a number of different species that co-occur in the same habitat or area. An association of interacting assemblages in a given water body.
Concentration	The quantifiable amount of a substance in water, food or sediment.
Contaminants	Biological or chemical substances or entities, not normally present in a system, capable of producing an adverse effect in a biological system, seriously injuring structure or function.
Control site	A geographic location that is far enough from a known pollution source (e.g. pipeline) to be considered representative of an undisturbed environment. Information collected within control sites is used as a reference and compared to impacted sites.
Crustacea	A group (Phylum) of marine invertebrates characterised by jointed legs and an exoskeleton (e.g. crabs, shrimps, and crayfish).
Dendrogram	A tree-like diagram used to represent hierarchal relationships from a multivariate analysis where results from several monitoring parameters are compared among sites.
Diversity	A measurement of community structure that describes the abundances of different species within a community, taking into account their relative rarity or commonness.
Ecosystem	An interrelating complex of plant and animal communities and their associated non-living environment.
Effluent	The discharge to a body of water from a defined or point source, generally consisting of a mixture of waste and water from industrial or municipal facilities.
Gas Chromatograph-Mass Spectrometry (GC/MS)	An instrumental analysis especially useful in analysing for specific PCB congeners. The instrument consists of is a gas chromatograph coupled with a mass spectrometer to produce a 3-D dataset that is not

[4] This glossary of terms was compiled from numerous sources, which are available from the CSIR on request.

	available with traditional GC detectors (i.e. GC-ECD). The gas chromatography separates samples into fractions, and the mass spectrometer produces characteristic spectra. GC/MS operates under scan mode or selective ion monitoring mode (SIM). The scan mode produces the maximum qualitative information of the mass data, while SIM samples at a predetermined mass value to give maximum quantitative information.
Grab	A mechanical device designed to collect bottom sediment samples. The device consists of a pair of hinged jaws and a release mechanism that allows the opened jaws to close and entrap a 0.25 m^2 sediment sample once they touch bottom.
Guideline	A numerical concentration limit or narrative statement recommended to support and maintain a designated water use.
Habitat	A place where the physical and biological elements of ecosystems provide an environment and elements of the food, cover and space resources needed for plant and animal survival.
Heavy metal	An imprecise term with no sound terminological or scientific basis, used loosely to refer to metals that are toxic.
Impact	A change in the chemical, physical or biological quality or condition of a waterbody caused by external sources.
Indicator	Characteristics for the environment, both abiotic and biotic, that can provide quantitative information on environmental conditions.
Infauna	Those animals that live within the sediments of the sea floor.
Intraspecific variability	Differences between individuals of a single species.
Invertebrate	An animal without a backbone (e.g. a starfish, crab, or worm).
Macrofauna	Epifaunal or infaunal benthic invertebrates that are visible with the naked eye. These animals inhabit soft-bottom marine habitats and are retained on a 1 mm mesh screen.
Meiofauna	Small interstitial (i.e. occurring between sediment particles) animals that pass through a 1 mm mesh sieve but are retained by a 0.045 mm mesh.
Metalloid	A non-metallic element that has some of the chemical properties of a metal and that can form an alloy with metals. Metalloids are often referred to as semi-metals. An example is arsenic.
Multivariate analysis	Statistical methods (e.g. ordination or discriminant analysis) for analysing physical and biological community data using multiple variables.
Normalise	Perform a data calculation in order to express results in terms of a reference parameter or characteristic.
Ordination	A two-dimensional scatter plot, generated through multivariate community analysis, which depicts the relative taxonomic similarities amongst a group of faunal samples.
Physico-chemical	Measurement of both physical properties (e.g. temperature, salinity) and chemical determinants (e.g. metals and nutrients) to characterise the state of an environment.
Population	An aggregate of interbreeding individuals of a biological species within a specified location.
Pollution	The Paris Convention defines pollution as the introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects

	as hazards to human health, harm to living resources and to marine ecosystems, damage to amenities or interference with other legitimate uses of the sea.
Polychaeta	A taxonomic group (Class) of, mainly marine, invertebrates characterised by having wormlike features, segments, and bristles or hairs. They are very variable in form and lifestyle and are good environmental indicators.
Receiving water	A river, stream, lake or other body of surface water into which effluent or treated effluent is discharged.
Replicate	Taking more than one sample or performing more than one analysis.
Sediment	Mud, sand, silt, clay, shell debris, and other particles that settle on the bottom of rivers, lakes, estuaries, and oceans.
Significance	Used in terms of statistics; statistical significance is a mathematical tool used to determine whether the outcome of an experiment is the result of a relationship between specific factors or due to chance.
Species	A category of biological classification ranking immediately below the genus, comprising related organisms potentially capable of interbreeding. A species is identified by a two part name; the name of the genus followed by a Latin or Latinised un-capitalised noun agreeing grammatically with the genus name.
Species richness	The number of species per unit area. A metric used to evaluate the health of macrofauna and meiofauna communities.
Site	A sampling location within a study area or site, where physical, chemical, or biological sampling and/or testing occurs.
Ternary plot	A diagram that depicts the ratios of three variables as positions in an equilateral triangle. It is used in sediment granulometry to show the relative proportions of the fine, coarse and silt/clay of size fractions in a sediment sample.
Trace metal	A metal found in low concentration, in mass fractions of ppm (µg) or less, in some specified source (e.g. sediment, tissue).
Taxon (taxa)	Any group of organisms considered to be sufficiently distinct from other such groups to be treated as a separate unit (e.g. species, genera, families).
Toxic	Poisonous, carcinogenic, or otherwise directly harmful to life.
Toxicity	A measure of the impact on a chosen biological process or condition.
Weight-of-evidence approach	Use of multiple lines of evidence to evaluate an issue or risk; evidence can be scientific in nature or inclusive of other disciplines; e.g., socio-economic, political and legal
Zone of impact	The area around a physical or chemical disturbance in the environment that has a significantly changed ecology or chemistry, compared to natural conditions; the changes to species, populations or communities are often considered adverse
Zone of Initial Dilution (ZID)	An area in the immediate vicinity of a marine pipeline discharge where there is rapid mixing of the effluent with sea water as a result of jetting and buoyant rise. An allocated impact area, or mixing zone, in a water body where numeric water quality criteria can be exceeded as long as acutely toxic conditions are prevented.