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Field trial at Sleipner Vest Alfa Nord: Effects of drilling activities on benthic communities

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Sammendrag / Summary

In connection with the ERMS project a field trial was carried out at Sleipner Vest Alfa Nord (SVAN). This report summarises the results of the benthic survey that was carried out after completion of drilling activities. The aim of the project was to evaluate the influence of cuttings and mud on the benthic communities, and thereby provide data to be used for validation purposes in the development of ERMS for drilling discharges.

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Preface

As a part of the ERMS project (*ERMS = Environment Risk and Management System*) a field trial was carried out at the Sleipner Vest Alfa Nord (SVAN) field in the south-western part of Region II on the Norwegian side of the North Sea. This report summarises the results of benthic monitoring that was carried out after completion of drilling activities. In addition to the results from the *ParTrack* model carried out by SINTEF, the results are to be used for validation in the ERMS-project.

All background data are available in the appendices and on the CD-ROM enclosed with this report.

Akvaplan-niva AS carried out the survey in co-operation with the following research institutes and consultancies:

- Unilab Analyse AS, Tromsø
- GeoGruppen AS, Tromsø
- NIVA, Oslo
- MUST AS, Porsgrunn

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List of abbreviations

AAS	Atomic absorption spectrometry
Ba	Barium
CA	Correspondence analysis
CCA	Canonical correspondence analysis
Cd	Cadmium
CDI	Community Disturbance Index
Cr	Chromium
Cu	Copper
CVAAS	Cold vapour atomic absorption spectrometry
EAAS	Atomic absorption spectrometry using a graphite oven
ES_{100}	Expected number of species in a 100 specimen sample
F-PNEC	Field Based Predicted No Effect Concentration
FTV	Field Threshold Value
GC/FID	Gas chromatography with flame ionisation detector
GC/MS	Gas chromatography with mass selective detector
H’	Shannon-Wiener diversity
He	Helium
Hg	Mercury
ICP-AES	Inductive coupled plasma atomic emission spectrometry
J	Pielou’s measure of evenness
LOD	Limit of detection
LOQ	Limit of quantification
MDS	Multidimensional scaling
NPD	Naphthalene, Phenathrene/Anthracene, Dibenzothiophene and their C_1-C_3 homologues
NS	Norwegian Standard
PAH	Polycyclic Aromatic Hydrocarbons, includes NPDs and 3-6 ring aromatics
Pb	Lead
PLS	Partial Least Squares
SD	Standard deviation
THC	Total Hydrocarbon Content
TOM	Total Organic Material
Zn	Zinc

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1 Introduction

A field trial was carried out at the Sleipner Vest Alfa Nord (SVAN) field as a part of the ERMS project (*ERMS = Environment Risk and Management System*). The purpose of the ERMS project is to develop a risk assessment tool for discharges of drill cuttings and mud. An important part of the project is to use field measurements to validate/calibrate the ERMS model (including the *ParTrack* simulation), where the described field trial represents one essential study. The results are to be used for validation of the fate and effects of the discharge, i.e. both the PEC (Predicted Environmental Concentration) and the PNEC (Predicted No Effect Concentration) values. The main focus of this report is to provide input to the PNEC values, while SINTEF is responsible for activities related to the PECs.

So far, four PNEC's have been identified; effects of contamination, changed sediment composition, reduced oxygen content and burial. In the present field trial all except the last of these are directly measured in the sediment. However, burial is modelled through the *ParTrack* simulation, which means that all the four PNEC's may be quantified and compared. The field trial represents a unique opportunity for studying fate and effects of discharge of water based drilling mud.

The SVAN field is located in the south-western part of Region II in the Norwegian part of the North Sea, and it consists of 4 wells drilled from the same sub sea template. The drilling activities started up in September 2003 and were completed in April 2004. Data on reported drilling activities and discharges at SVAN are given in Table 1 (received from L. Aasberg, Statoil). During the drilling 709 m^3 (1038 tons) oil-based mud was used in the lower sections. The oil based mud was recovered and shipped to land.

Table 1: Summary of recent wells drilled and discharges that may have influenced the chemical and biological conditions at the SVAN field.

	2003	2004
No of wells drilled	3	1
Barite (tonnes)	1402	533
Cuttings (m^3)	1935	689
Oil-based drilling mud (m^3)	0	0
Synthetic drilling mud (m^3)	0	0
Water-based drilling mud (m^3,	308	178
Cementing chemicals (tonnes)	0	0
Kompletteringskjemikalier (tonnes)	10.4	38.1
Oil in produced water	0	0
Accidental discharges	0	0

When the drilling started, SINTEF carried out a comprehensive field study which included sampling of water and sediment. After completion of drilling, Akvaplan-niva sampled sediment to evaluate the changes in chemical and biological parameters. Biological samples were also collected during the fieldwork in the autumn 2003 to analyse the composition of the undisturbed communities. In addition, data from the baseline survey of the field, carried out in 2002 (Eriksen *et al*., 2003), are used.

2 Methods

Field sampling and analyses were performed according to The Norwegian offshore HSE regulations; Activity Regulation Appendix 1: Requirements for Environmental Monitoring of the Petroleum Activities on the Norwegian Continental Shelf and Akvaplan-niva's internal procedures, with some modifications for the purpose of this particular study. In using these standardised guidelines, the results can be compared with the results from other environmental surveys in the Norwegian sector.

2.1 Station network

The station network from the sampling in 2003 and 2004 is shown in Table 2 and Figure 1.

Table 2: Station information for the SVAN field, 2003 and 2004. The volume is the sum of the replicate grab samples at each station.

St. no.	Degrees	Distance	Year	Position (WGS 84)		Volume (l)
				Latitude	Longitude	
Centre				58° 29,784'N	1° 43,268'E	
ALF-3	10	1000	2004	58° 30,316'N	1° 43,448'E	38
ALF-2	10	500	2004	58° 30,050'N	1° 43,358'E	41
ALF-1	10	250	2003	58° 29,946'N	1° 43,422'E	37
			2004	58° 29,917'N	1° 43,313'E	50
ALF-17	10	175	2004	58° 29,877'N	1° 43,300'E	52,5
ALF-16	10	125	2003	58° 29,874'N	1° 43,380'E	33
			2004	58° 29,850'N	1° 43,291'E	48
ALF-15	10	75	2004	58° 29,824'N	1° 43,282'E	53
ALF-5		250	2003	58° 29,799'N	1° 43,611'E	44
ALF-20	100	125	2003	58° 29,804'N	1° 43,485'E	40,5
			2004	58° 29,772'N	1° 43,395'E	41
ALF-19	100	75	2004	58° 29,777'N	1° 43,345'E	41
ALF-22	190	125	2003	58° 29,719'N	1° 43,320'E	40,5
			2004	58° 29,718'N	1° 43,246'E	39
ALF-21	190	75	2004	58° 29,744'N	1° 43,255'E	72
ALF-11		250	2003	58° 29,835'N	1° 43,112'E	42
ALF-24	280	125	2004	58° 29,796'N	1° 43,141'E	42,5
ALF-23	280	75	2004	58° 29,791'N	1° 43,192'E	15
ALF-ref			2003	58° 29,300'N	1° 43,361'E	36

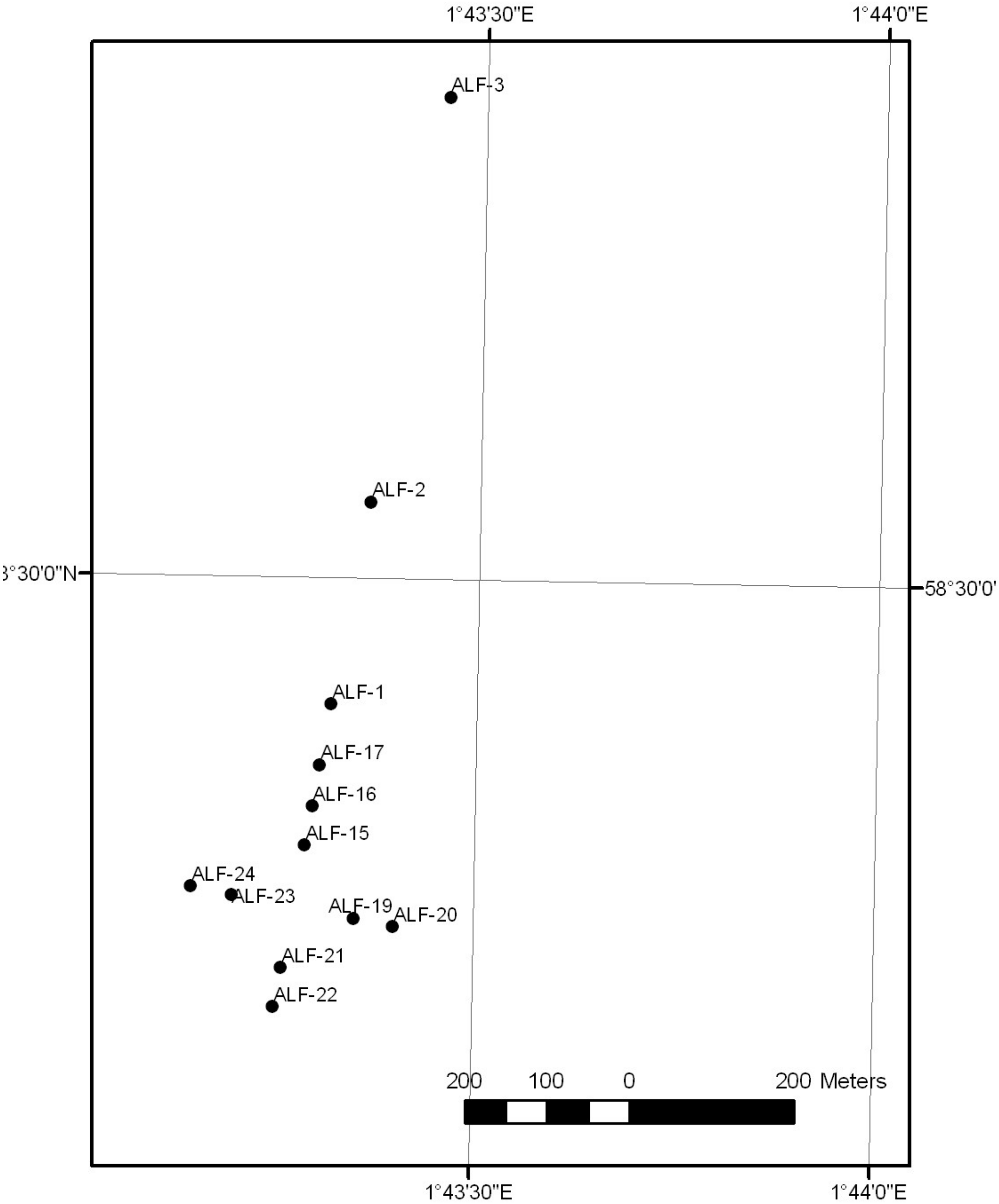


Figure 1: Station network at SVAN, 2004.

Originally, it was decided to sample at 1000, 500, 350, 250, 175, and 125 m in the main current direction and at 125 and 175 m in the other directions in the 2004 sampling. However, after a discussion with Henrik Rye (SINTEF), who is responsible for the *ParTrack* model, it was agreed to sample at closer distances based on the visual impression of the spreading of the discharge. At the same time, the number of sampled stations was not supposed to exceed 12 due to the costs associated with the sampling.

The sampling started in the main current direction (10°), at 1000 m distance from the well. From the 500 m station the ship went directly to the 250 m station, where some drill cuttings particles were observed, but an otherwise apparently undisturbed sediment. Then the 175 and 125 m stations were sampled, where more signs of the discharge were observed. However, to ensure that a possible gradient in the fauna could be detected, it was decided to sample at the 75 m station instead of the 350 m station in this direction. In the other directions, sampling started at the 125 m stations. Here, there were fewer signs of disturbance compared to the 125 m station in the main current direction. Based on this, it was decided to sample the 75 m station instead of the 175 m stations in these directions also.

As it was decided to sample closer to the centre in 2004 compared to 2003, there are fewer stations available for direct comparisons. However, it was considered more important to make an attempt to "capture" the transitional zones between the impacted and not impacted areas.

2.2 Fieldwork

In 2003, the fieldwork was carried out between 4 and 11 September with the vessel "Polarbas". In total 35 0.1 m^2 van Veen grab samples were collected from 12 stations. All samples were taken for chemical and biological analyses. For a more detailed description of the fieldwork, see the field report (Jensen et al., 2003).

In 2004, the fieldwork was carried out between 19 and 21 April, using the vessel M/S "Siggbas". In total 96 0.1 m^2 van Veen grab samples were collected from 12 stations. Of these, 60 samples were taken for biological analyses and 36 samples for physical/chemical analyses. During sampling, the ship was held within $\pm$ 25 m of the station coordinates. Positioning was done using a differential GPS with accuracy better than 10 m. A more detailed description of the field work is presented in the field report (appendix).

The entire sampling programme was followed and sampling was conducted without deviating from the guidelines.

2.3 Sampling and sample treatment

Sampling was carried out with a 0.1 m^2 lead weighted, modified van Veen grab. The grab had hinged and lockable inspection flaps constructed of 0.5 mm mesh, each covered by an additional rubber flap. This construction allows water to pass freely through the grab during lowering, but prevents disturbance of the sediment surface by water currents during hauling. While lowering and hauling the grab, the wire was positioned close to the side of the boat. This allowed the controller to manually determine when the grab had reached the seabed. The grab was lowered at less than 1.5 m/s. At 5-10 m above the sediment surface, speed was reduced to less than 0.2 m/s. Each grab sample was visually inspected to ensure there was no disturbance of the sediment surface. Disturbed samples were discarded.

At each station 3 replicates were taken for analyses of hydrocarbons, metals, grain size and total organic matter. The hydrocarbon and metal samples were taken with suitable equipment from the upper sediment layer (0-1 cm), while sediment for grain size analysis was taken from the upper 5 cm layer. All samples were labelled and immediately frozen at -20°C.

5 biological replicates were collected at each station. After the sample volume was recorded, the sediment was gently sieved through a 1 mm round mesh sieve immersed in seawater. The fauna retained on the sieve was preserved in a 4 – 10 % formaldehyde solution, neutralised with borax.

On deck, each sample was described with respect to sediment type, smell, colour, larger living animals and other prominent features (i.e. traces of oil, cuttings etc.). In one sample per station, a transparent PVC-corer was pressed down in the sediment through the top opening of the grab. The colour profile was determined using a Munsell Soil Colour Chart.

2.4 Electrode measurements

Redox potential (E_h) is an electrical measurement that shows the tendency of a solution to transfer electrons to or from a reference electrode. From this measurement it is possible to estimate whether the sediment is oxic, suboxic or anoxic. In the marine environment E_h varies from +400mV in atmospheric equilibrated surface water to –200 mV in anoxic marine sediments or bottom water poor water exchange. A measurement of hydrogen sulphide ion activities (E_s) was also included to investigate if sulphate-reducing bacteria were present.

Redox potentials were determined by insertion of a Radiometer P101 platinum electrode into the submersed sediments. Potentials were measured against an Ag|AgCl reference electrode placed in seawater. Before the measurement started and in the middle of the sampling the redox circuit was checked in a ZoBell Fe(II)-Fe(III) redox-buffer solution. The E_h of the samples was obtained by adding the half-cell potential of the reference electrode to the potential recorded on the Pt-electrode.

E_s, potentials were measured with a silver-silver sulphide electrode against the same reference electrode. The response of the Ag|AgS electrode is selective to S^{2-}-ions, and negative deviations from control show presence of free hydrogen sulphide in the pore water.

The electrode measurements were carried out according to NS 9410 (Environmental monitoring of marine fish farms). At each station measurements of E_h and E_s were carried out *in situ* on three replicate samples at the surface and at 5 cm sediment depth. According to NS9410 the readings are supposed to be taken when the E_h drift is less than 0.2 mV/s, or be read after five minutes. In practice, stable E_h values were very time-consuming to obtain. As it was considered more valuable to spend the time on more than one replicate at each station, the measurement was stopped and the value read after a couple of minutes. In these cases it was noted whether the value was decreasing or increasing. For the sulphide measurements, on the other hand, it was not necessary to read the values before they were stable.

2.5 Laboratory analyses

The laboratories involved are accredited by Norsk Akkreditering; Akvaplan-niva with TEST 079, Unilab Analyse AS with TEST 061 and Norwegian Institute for Water Research (NIVA), with TEST 009.

2.5.1 Physical analyses

Total organic material

The amount of total organic matter (TOM) was determined as loss in weight after combustion at 480 °C. At this temperature carbonates are not oxidised and pre-treatment of the samples with HCl can be avoided. Treatment with HCl (including washing of the sample) removes some organic matter, particularly the more labile and soluble components, from the sediment (Byers *et al*., 1978). Samples with a known amount of carbonates were used as controls.

Grain size distribution

Analysis of grain size distribution was carried out in accordance with the methodology given in Buchanan (1984). From each station the three samples from the separate grab samples were mixed and homogenized, and a sub sample of this mixed sample analysed.

2.5.2 Chemical analyses

Three grab samples were taken at each station for the chemical analyses.
A short description of the methods is described below, while a more detailed description is given in the Appendix.

Hydrocarbons (THC, NPDs, 16 EPA-PAHs and decalins)
Hydrocarbons (THC, NPDs, 16 EPA-PAHs and decalins) were extracted from the sediment using saponification followed by solvent extraction. Concentration and isolation of the hydrocarbon fraction was accomplished by adsorption chromatography on a silica column. (UNESCO, 1982; Klungsøyr *et al.***,** 1988).

THC was determined by gas chromatography/ flame ionisation detection (GC/FID) using an external standard for quantification. The base oil HDF 200 was used as reference oil and external standard.

NPD, 16EPA and decalins in the hydrocarbon extract were analysed using gas chromatography/ mass spectrometry (GC/MS) using a deuterium labelled internal standard for quantification.

Metals
The sediment was dried, homogenised and sieved prior to extraction in accordance with Norsk Standard 4770 (nitric acid digestion). Barium (Ba), copper (Cu), chromium (Cr) and zinc (Zn) were analysed by inductive coupled plasma atomic emission spectrometry (ICP-AES). Quantitative analysis of lead (Pb) and cadmium (Cd) was carried out by atomic absorption spectrometry (AAS). Mercury (Hg) was determined by cold vapour atomic absorption spectrometry (CVAAS).

All chemical samples were analysed without deviation from the guidelines.

2.5.3 PCA, environmental variables

A PCA was conducted on the environmental variables. Prior to the analysis, the variables were ln-transformed. They were also centred and standardised, which means that all variables get a mean = 0 and the same dispersion, i.e. standard deviation = 1. This procedure ensures that all variables are given equal weight in the analysis, and is recommended when they are measured in different units.

2.5.4 Biological analyses

In the laboratory, each replicate sample was washed in freshwater on a submerged sieve with 1 mm round mesh prior to sorting. Sorting was conducted in water, in white shallow containers. All fauna were carefully removed from the sediment under a magnifying glass (10x) and sorted into main taxonomic groups. The animals were preserved in 75 % ethanol and identified to the lowest possible taxa.

Statistical analyses were performed on the entire set of benthos data. The statistical analyses were conducted both with and without juveniles in order to evaluate their importance.

The following analyses were conducted:

- ten most prevalent species for every station (not an analysis)
- diversity index; "Shannon Wiener index" on $\log_2$ basis (Shannon & Weaver 1963)
- evenness; Pielou's "J" (Pielou 1966)
- expected number of species per 100 individuals; Hulbert's ES_{100} (Hurlbert 1971)
- cluster-analysis based on "Bray-Curtis dissimilarity index" (Bray & Curtis 1957), followed by "Group Average Sorting"
- ordination by "Multidimensional Scaling" (MDS)
- ABCD classification
- CDI (Community Disturbance Index) (Massart et al. 1996)
- Canonical correspondence analysis (CCA)
- BIOENV (Clarke & Ainsworth, 1993)

The formulas used for calculation of the indices are provided in the appendix.

The CDI classification is at present not included in the routine statistical analyses performed in the offshore monitoring. The CDI is an index developed to classify communities according to degree of disturbance. The index has a multivariate basis, and by a multivariate F-test (at 95% confidence level) the method gives the communities a value, where values > 1 indicates disturbance and values < 1 indicates that the community is not disturbed (i.e. only contain natural variation). The higher the value is over 1, the more disturbed the community is.

Also a qualitative classification was performed by the ABCD classification method. This method is used by Akvaplan-niva in the offshore monitoring. The criteria for impact in this classification system are based on a combination of multivariate analyses such as cluster analysis and MDS (Multidimensional scaling), evaluation of the numerical faunistic data (number of species and individuals, diversity indices etc.), and abundance of selected disturbance-tolerant species at each station. The various ways of categorising groups in the past at the different fields throughout the region have been reviewed and the following four broad groupings have been recognised:

- Group A: Undisturbed communities, with low dominance (no species present in very high numbers) and a wide range of species from a variety of taxonomic groups, including molluscs, echinoderms and crustaceans. Moderate species numbers and total abundance, high biomass.
- Group B: Slightly disturbed communities: increased numbers of smaller polychaetes and molluscs, fewer echinoderms. Higher species numbers and abundance, lower biomass.
- Group C: Distinctly disturbed communities: small deposit feeding polychaetes predominate together with a few small bivalve molluscs and small deposit feeding crustaceans, echinoderms rare. High species numbers, abundance and biomass.
- Group D: Highly disturbed communities: small deposit feeding worms totally predominate (polychaetes, oligochaetes, nematodes). Echinoderms absent and molluscs and crustaceans rare or absent. Low species numbers and biomass, high total abundance.

Natural variation can affect several of the faunal parameters within each group. The classification is therefore based on an over-all interpretation of the fauna. For example, at stations with undisturbed fauna, certain taxa can be present in high numbers, resulting in a lowered diversity.

CCA combines the environmental parameters with the faunal composition and in particular seeks to identify patterns in the faunal composition that can be related to gradients in those parameters. The analysis also calculates how much of the variance in the biological data can be described by the individual or collective environmental parameters. This gives a measure of the extent to which those parameters represent or correlate to factors that influence the fauna.

As the name implies, BIOENV is another method to link community structure to environmental variables. It is based on matching the MDS-plots of the biota to the MDS-plots of the environmental variables. This is done by comparing the Bray-Curtis values for the biota with the Euclidean distance of the environmental variables through a rank correlation coefficient (weighted Spearman rank correlation). The environmental variables or the combination of different variables that give the highest rank correlations, are then assumed to be the most important explanatory variables for the fauna.

The cluster analysis and the MDS ordination were performed both on the set of data from the replicate samples and on the totals for each station. Furthermore, these analyses were performed with the results from 2003 included in order to investigate the change in the faunal composition from 2003 to 2004.

The calculated area having contaminated sediment and disturbed fauna is based on the area of an asymmetric ellipse. The radius varies between the different transects. In cases where contamination was only recorded along one to three transects, 32.5 m was used as the radius of the non-contaminated transect(s) as contamination reached to somewhere between 0 and 75 m.

2.5.5 Quality control

Sampling and sample analyses were preformed by field personnel and laboratories accredited for these activities in accordance with NS-EN ISO/IEC 17025. Copies of the accreditation documents are enclosed in the Appendix. During fieldwork and laboratory treatment of the samples, detailed checklists and logbooks were kept in order to check whether all procedures had been followed, to allow a sample to be traced through and to document the accuracy and reliability of the results. Full documentation on the QA results from the chemical laboratories is included in the Appendix.

In the field, all disturbed samples are rejected. Also, if the grab speed exceeds 0.2 m/sec immediately before reaching the bottom, the sample is discarded.

The limit of detection (LOD) and the limit of quantification (LOQ) for hydrocarbons were determined to be 0.7 mg/kg and 1 mg/kg respectively. The limits for the aromatic compounds are provided in the Appendix. Recovery of the hydrocarbon extraction was checked using non-contaminated sediments spiked with 20 ppm of oil standard. The recovery of total hydrocarbons was 85 %. Reproducibility was checked with a standard sediment. The relative standard deviation over the time period was 12 %. Accuracy of the aromatic analyses was determined using the standard reference sediment SRM 1941a. The results from these analyses are given in the Appendix.

Detection limits and the blind values for the metals are given in the Appendix. Precision of the analyses was checked using several sets of three parallel samples. Accuracy was examined by analysing reference samples MESS 3 and GBW 07307 by the same procedure as for the samples. The results are given in the Appendix.

In order to assess sorting efficiency of biological samples, a minimum of 10% of the samples is controlled by another approved sorter. Any additional organisms which are encountered, are removed and presented to the initial sorter, and placed in the respective glasses. A similar control procedure is used to check the transfer of species lists to the database. Ten percent of the species records for each field are checked. If the error is 1% or more for one group of species, all the records belonging to this group are checked and corrected.

In the processing of the biological samples there was one minor deviation from the guidelines. The handwritten sheet for the polychaeta recordings from 2003 disappeared, and thus it was not possible to control these recordings. When controlling the polychaeta recordings from 2004, analysed and punched by the same person, no mistakes were found. Thus, the deviation is not assumed to have had any influence on the results. All the other biological analyses were performed without deviating from the guidelines.

2.5.6 Storage of sample material

Analysed samples and reference collections are stored at the laboratory that conducted the analyses for at least six months after the environmental monitoring report has been accepted by the client. Reference collections are maintained for at least five years. Analytical results (at replicate level) are kept for at least ten years in a database at Akvaplan-niva. During the period of storage, the material and results can be made available to the client.

3 Results and discussion

3.1 Physical characteristics

The median phi value and the amounts (%) of pelite and total organic material (TOM) in the sediment from the present surveys are shown in Table 3. The same data are shown visually in Figure 2, together with the results from 2002. Sampling of physical parameters was not performed in 2003. Detailed data on sediment characteristics such as colour, smell and a full set of analytical data, including TOM content and grain size distribution (with standard deviation, evenness and kurtosis) can be found in the Appendix.

The sediments are classified as silt or fine sand having median phi/µm-values between 4.88 phi/34.0 µm (ALF-21) and 3.88 phi/67.9 µm (ALF-24). The amount of pelite ranged from 11.6 (ALF-20) to 47.1 % (ALF-21). The content of TOM was relatively high, and varied from 1.8 (ALF-3, ALF-2 and ALF-19) to 6.4 % (ALF-16 and ALF-15). In the main current direction it is evident that the pelite content increased with decreasing distance to the discharge point. The pelite content was also high in the opposite direction at the 75 m station (ALF-21). The seabed at this station had a surface layer (1-2 cm) of light grey sediment containing some larger drill cuttings particles. The same stratification was evident at ALF-15 and ALF-16, and partly on ALF-23. It is likely that this layer originates from the top hole section, while only the larger drill cuttings particles are assumed to come from the discharge to the water column. The reason for this assumption is that the particle size according to *ParTrack* is assumed to decrease with increasing distances from the discharge point, and that the grain size of particles at the inner locations (closer than 100 m) are supposed to be 1 mm or more (Henrik Rye, pers. com.). Furthermore, the thickness of this layer is generally thicker than modelled by the *ParTrack* model (Table 9).

At the three stations that also were sampled in 2002, the pelite content was very similar to what was observed in 2004. However, the TOM content was higher in 2002 compared to 2004. The reason for this is not clear, but different timing of the field work with regard to the spring bloom and a different magnitude of sedimentation of organic matter from the spring bloom may be one possible explanation.

Table 3: Median grain size (phi and µm) and amount (%) of pelite (silt and clay) and TOM in the sediments from SVAN, 2004.

	Distance	Degrees	Median (phi)	Median (µm)	Classification	Pelite	TOM
ALF-3	1000	10	4.17	55.6	Silt	12.9	**1.8**
ALF-2	500	10	4.28	51.5	Silt	13.1	**1.8**
ALF-1	250	10	4.14	56.7	Silt	12.6	2.3
ALF-17	175	10	4.07	59.5	Silt	16.8	4.1
ALF-16	125	10	4.33	49.7	Silt	22.7	**6.4**
ALF-15	75	10	4.54	43.0	Silt	31.9	**6.4**
ALF-20	125	100	3.94	65.2	Fine sand	**11.6**	2.1
ALF-19	75	100	3.98	63.4	Fine sand	13.6	**1.8**
ALF-22	125	190	3.99	62.9	Fine sand	16.4	4.6
ALF-21	75	190	**4.88**	**34.0**	Silt	**47.1**	4.7
ALF-24	125	280	**3.88**	**67.9**	Fine sand	12.2	2.1
ALF-23	75	280	4.09	58.7	Silt	19.5	4.9
Average			4.19	55.7		19.2	3.6
St. dev.			0.29	9.8		10.5	1.8

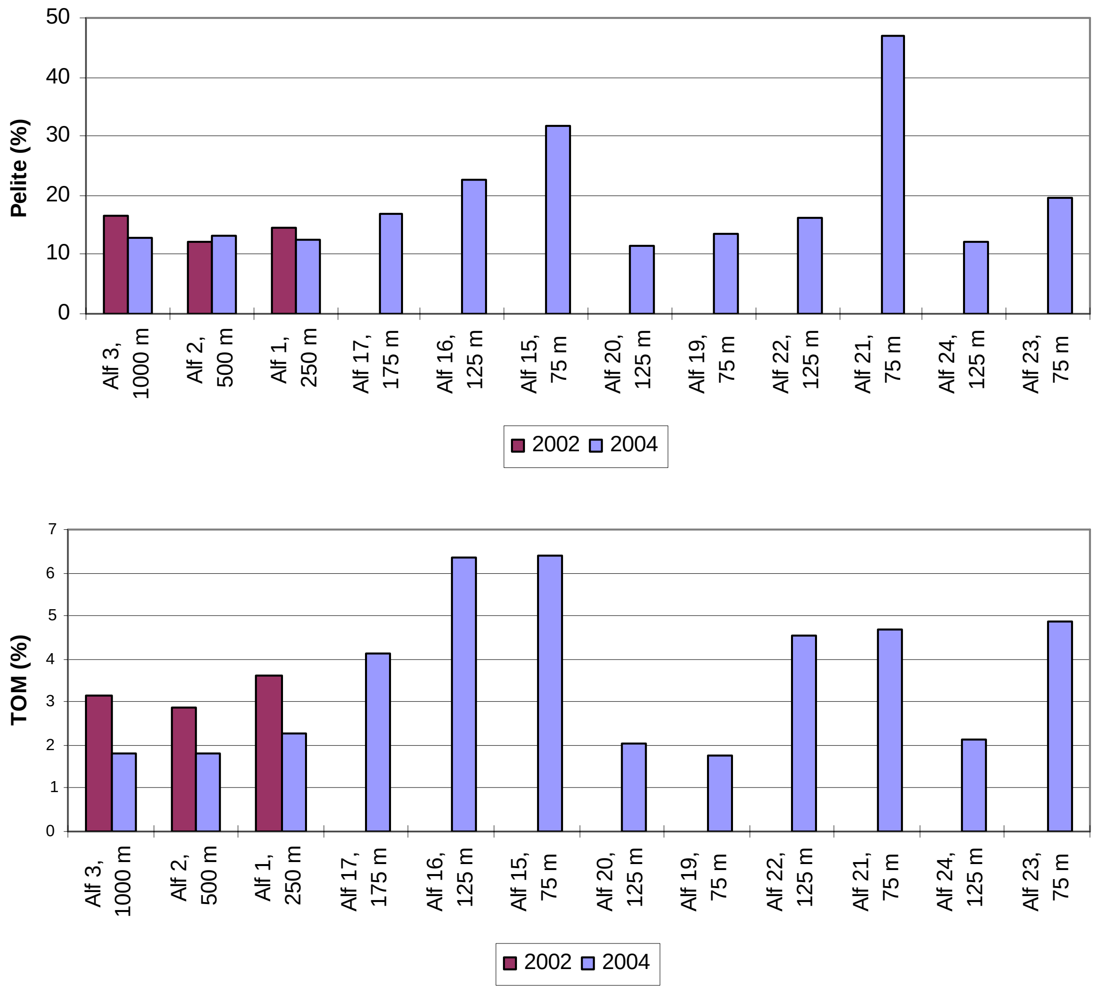


Figure 2: Pelite and TOM content in sediments from the SVAN field in 2004 and 2002.

3.2 Chemical characteristics

The chemical substances found in marine sediments are either naturally present or the result of anthropogenic (i.e. man-made) inputs. It is therefore important to distinguish between the natural background concentrations and fluxes of these substances and the extent to which these are augmented by human activities. Different natural background levels of chemical parameters reflect differences in sediment characteristics across a region.

In the baseline survey at SVAN in 2002 the sediments were found to be unaffected by the oil activity in the area. It was also concluded that the field stations had a naturally higher content of hydrocarbons and metals than the field specific reference station, and that a new reference station should be established in prospective surveys. As baseline data existed and as it was considered more important to sample stations closer to the well within the available budget of the present survey, a separate reference station was not included. The naturally background levels of the chemical parameters at SVAN 2004 (Table 4) are therefore calculated from the analytical results from 2002, and field stations instead of the reference station are used.

Statistical treatment of the analytical results from 2002 allows the determination of specific limits above which a sediment sample might be said to contain higher levels than the natural background levels. The statistical limits with respect to detection of significant contamination at SVAN (LSC_{SVAN}) are given in Table 4. The LSC values are calculated from the corresponding background levels by using a one-tailed student t-test at 95% significant level according to the formula given in the NIVA-notat O-99218:

$$LSC = mean + t \times st.dev. \times \sqrt{1 + 1/N}$$

where: mean = mean value at the reference station, t= students t-value from statistical tables and N = number of replicate measurements

Based on analysis results of the SVAN field the LSC_{SVAN} is regarded as representative for the field.

Table 4: Background levels and Limits of Significant Contamination for the SVAN field, 2004. All values in mg/kg dry sediment.

	THC	NPD	16EPA	Decalins	Hg	Ba
$Background_{SVAN}$	6.9 ± 1.8	0.075 ± 0.038	0.128 ± 0.044	<0.005	0.003 ± 0.001	186 ± 40
LSC_{SVAN}	10.1	0.158	0.224	-	0.004	254

	Cd	Cr	Cu	Pb	Zn
$Background_{SVAN}$	0.031 ± 0.014	10.0 ± 1.0	2.6 ± 1.0	6.6 ± 1.0	12.7 ± 1.7
LSC_{SVAN}	0.056	11.7	4.4	8.2	15.6

The results of analyses of the hydrocarbons are summarised in Table 5. A full data set of replicate measurements and data from previous years are given in the Appendix. THC concentrations from 2004 are compared with those from previous years in Figure 3, which very clearly indicates that a THC-contamination has taken place.

Table 5: The concentrations of hydrocarbons in sediments from SVAN Field in 2004. All values in mg/kg dry sediment. (Minimum and maximum values for each parameter are indicated with bold text.)

Station	THC		NPDs		16 EPA		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
ALF-3	**7.5**	2.3	na	-	na	-	na	-
ALF-2	21	6.1	na	-	na	-	na	-
ALF-1	160	15.6	na	-	na	-	na	-
ALF-17	164	47	na	-	na	-	na	-
ALF-16	91	64	**1.10**	0.39	**0.21**	0.10	**12.7**	9.16
ALF-15	155	70	**2.73**	0.77	**0.24**	0.04	**18.1**	6.68
ALF-20	484	171	na	-	na	-	na	-
ALF-19	268	43	na	-	na	-	na	-
ALF-22	212	76	na	-	na	-	na	-
ALF-21	90	21	na	-	na	-	na	-
ALF-24	**532**	101	na	-	na	-	na	-
ALF-23	165	46	na	-	na	-	na	-
$Mean_{04}$	196		-		-		-	

na Not analysed

The average content of THC varied from background level (ALF-3) to 532 ± 101 mg/kg dry sediment (ALF-24). According to the calculated LSC all stations except ALF-3 were contaminated with THC. The gas chromatographic profile of the sediment extracts from stations contaminated with THC indicates the presence of mineral oil (Figure 4). On the 10°-axis THC concentrations above 100 mg/kg dry sediment are found out to 250 m. On the 100°-, 190°- and 280°-axes the 125 m stations have higher concentrations of THC than the 75 m stations. The reason for this is not clear.

The two innermost stations (ALF-15 and ALF-16) on the main transect (10°-axis) were investigated for NPD, PAHs (16 EPA) and decalins. For NPDs and decalins both stations were contaminated, while for 16 EPA-PAH, the concentrations were close to the limit of significant contamination. The reason why only two stations were analysed for these compounds, was that the field was not assumed to be contaminated by hydrocarbons and that it therefore was considered more important to carry out other analysis within the available budget.

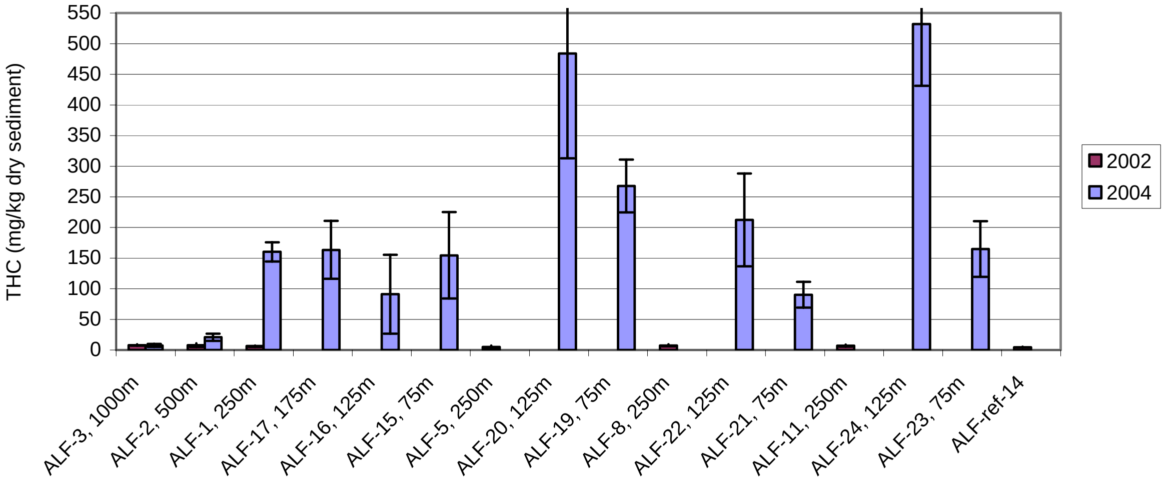
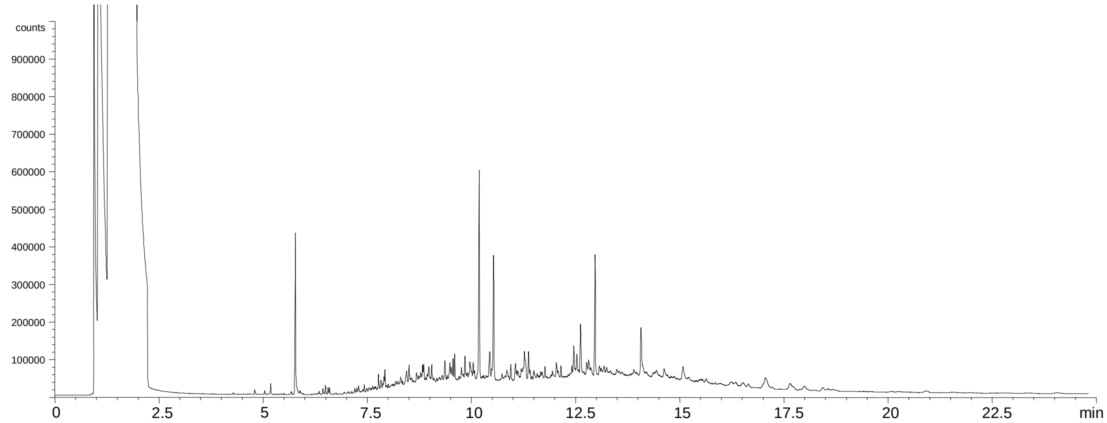
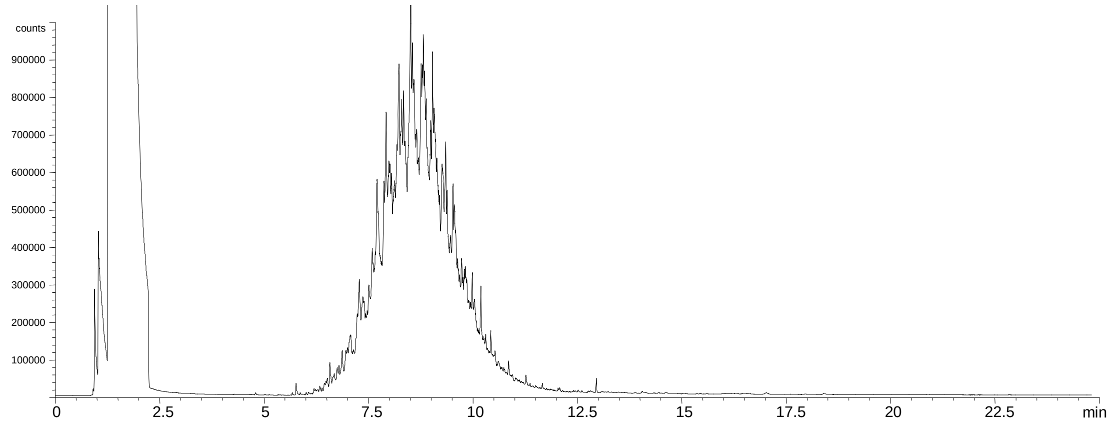


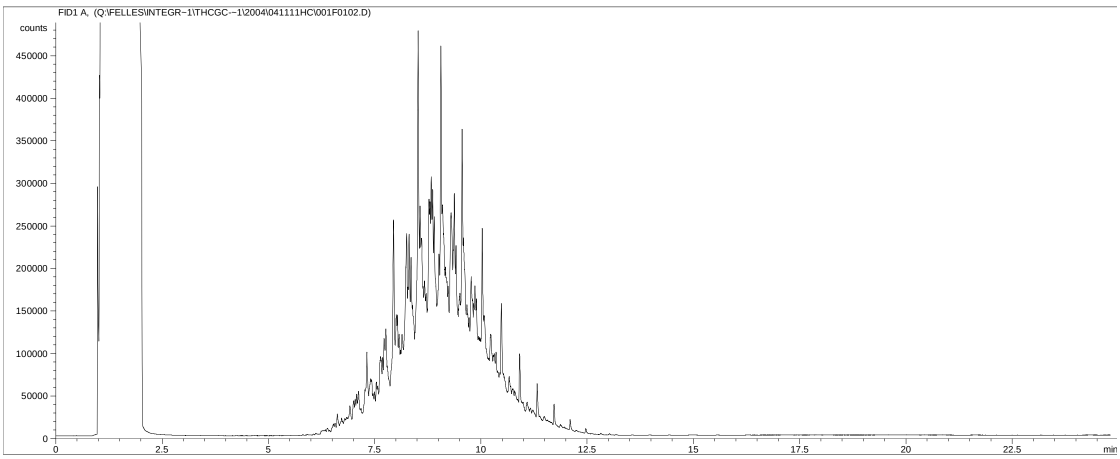
Figure 3: Average THC concentrations in sediments from the present (2004) and previous survey (2002) at SVAN field.



UA446/hcs/008, 1000 m ALF 3-7 THC= 8,0 mg/kg TS



UA446/hcs/002, 250 m ALF 1-7 THC=32 mg/kg TS



EDC 95/11

Figure 4: Gas chromatogram of hydrocarbon extract of sediments sampled at SVAN, 2004 (upper plot) and the mineral oil EDC 95/11 (lower plot).

The results of the metal analyses for SVAN are summarised in Table 6. The full data set of replicate measurements are given in the Appendix. Metal values from 2004 are presented as histograms in Figure 5 to Figure 10.

Table 6: The concentrations of selected metals in sediments from SVAN field in 2004. All values in mg/kg dry sediment. (Minimum and maximum values for each parameter are indicated with bold text.)

Station	Ba		Cd		Cr		Cu		Hg		Pb		Zn	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
ALF-3	**484**	175	0.025	0.003	10.2	1.3	**2.4**	0.4	na	-	5.9	1.1	12.3	2.5
ALF-2	509	157	0.025	0.003	**9.7**	0.3	2.8	0.6	na	-	5.3	0.5	**12.3**	1.2
ALF-1	1270	72	0.028	0.002	9.9	0.9	4.1	1.8	na	-	**4.8**	0.5	13.8	4.4
ALF-17	2690	227	0.094	0.043	24.5	6.8	26.4	13.1	na	-	9.5	1.7	50.9	22.5
ALF-16	3197	369	**0.198**	0.121	30.2	3.5	30.0	4.6	**0.044**	0.012	14.0	0.0	62.8	8.2
ALF-15	2763	204	0.177	0.031	**36.3**	1.8	33.8	5.8	**0.036**	0.002	**16.0**	4.6	74.7	13.1
ALF-20	1513	310	**0.021**	0.001	10.5	1.3	2.9	0.6	na	-	5.9	1.0	14.7	1.2
ALF-19	3480	1414	0.053	0.009	14.3	1.2	9.9	2.3	na	-	7.0	0.2	32.7	7.6
ALF-22	4337	1771	0.065	0.019	19.6	4.8	19.0	11.6	na	-	7.6	1.8	41.9	25.9
ALF-21	2590	584	0.125	0.009	36.1	0.6	**41.1**	3.2	na	-	10.3	0.6	**68.9**	9.0
ALF-24	**4987**	1003	0.030	0.006	10.7	0.2	6.0	1.4	na	-	6.1	0.4	17.3	2.3
ALF-23	4127	900	0.093	0.010	26.8	3.1	26.9	7.0	na	-	11.0	1.0	51.2	12.1
$Mean_{04}$	2662		0.078		19.9		17.1		-		8.6		37.8	

na Not analysed

The average concentrations of barium ranged from 484 ± 175 (ALF-3) to 4987 ± 1003 mg/kg (ALF-24). According to the calculated LSC all stations were contaminated with barium. Gradients of decreasing concentrations of barium with increasing distance from the centre were found from 125 m and out 500 m on the 10°-axis. On the 190°- and 280°-axes the 125 m stations had higher concentrations of barium than the innermost station. As for the THC, the reason for this is not clear.

For the other heavy metals gradients of decreasing concentrations with increasing distance from the centre were found. The concentrations of other metals reached background levels at the 250 m station on the 10°- and 190°-axes and at the 125 m stations on the 100°- and 280°-axes. The concentrations of cadmium, chromium, copper, lead and zinc varied from background levels to 0.198 ± 0.121 mg/kg (ALF-16), 36.1 ± 0.6 mg/kg (ALF-21), 41.1 ± 3.2 mg/kg (ALF-21), 16.0 ± 4.6 mg/kg (ALF-15) and 68.9 ± 9.0 mg/kg (ALF-21). Stations ALF-15, ALF-16, ALF-17, ALF-19, ALF-21, ALF-22 and ALF-23 were contaminated with these metals. The two innermost stations (ALF-15 and-ALF16) on the main transect were investigated for mercury and both stations were contaminated. It is clear that the contamination pattern at the field is very similar for the various metals, which clearly indicates that they have the same source, i.e. the drill cuttings.

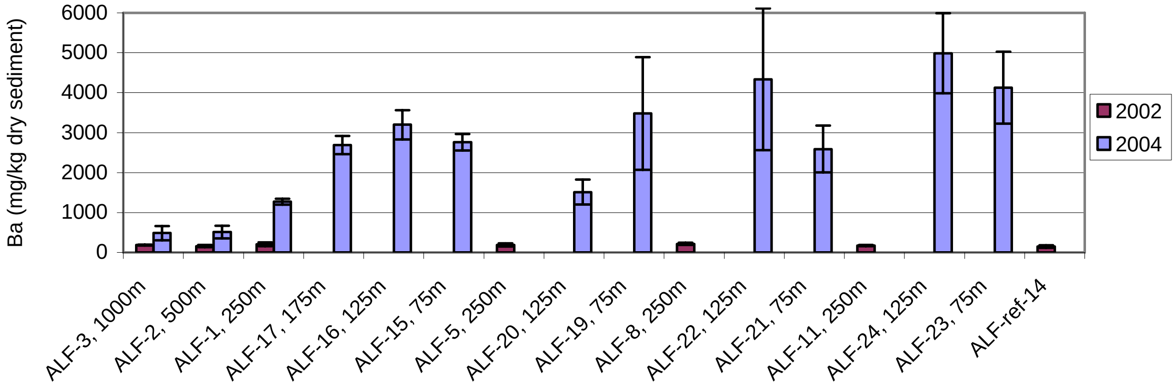


Figure 5: Average barium concentrations in sediments from the present (2004) and previous survey (2002) at SVAN field.

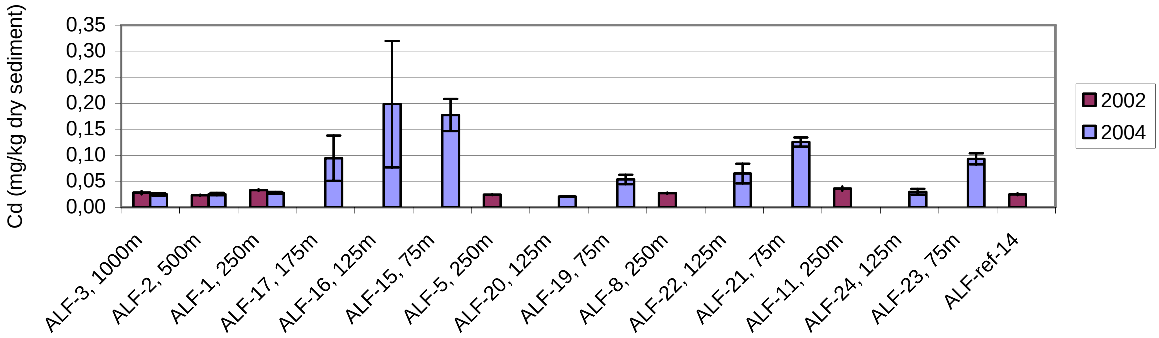


Figure 6: Average cadmium concentrations in sediments from the present (2004) and previous survey (2002) at SVAN field.

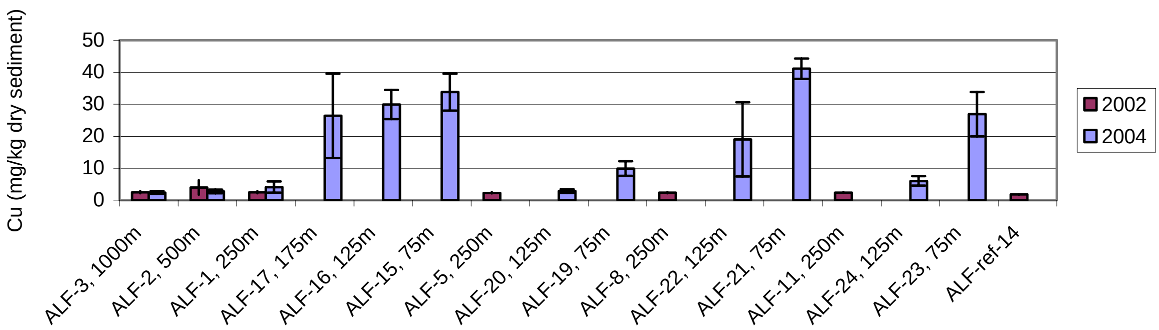


Figure 7: Average copper concentrations in sediments from the present (2004) and previous survey (2002) at SVAN field.

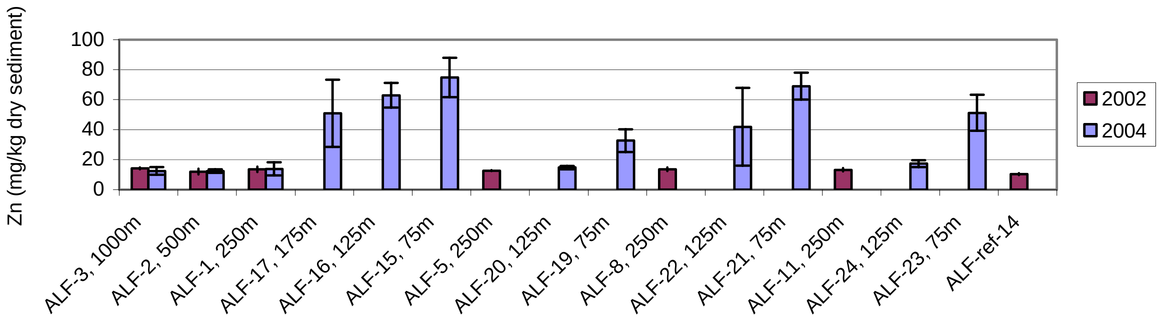


Figure 8: Average zinc concentrations in sediments from the present (2004) and previous survey (2002) at SVAN field.

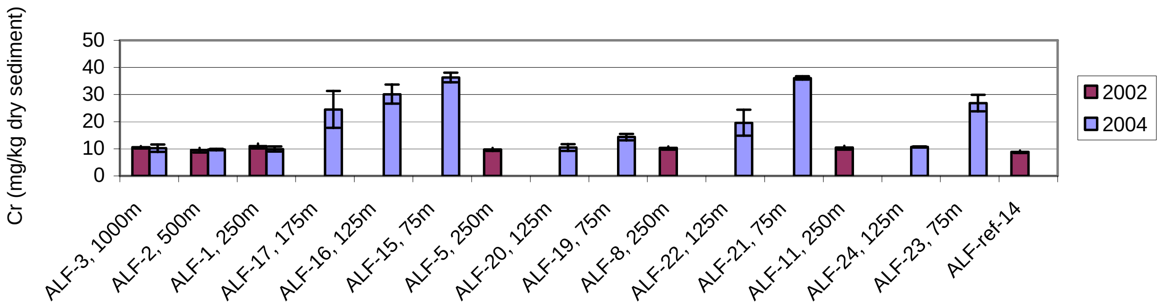


Figure 9: Average chromium concentrations in sediments from the present (2004) and previous survey (2002) at SVAN field.

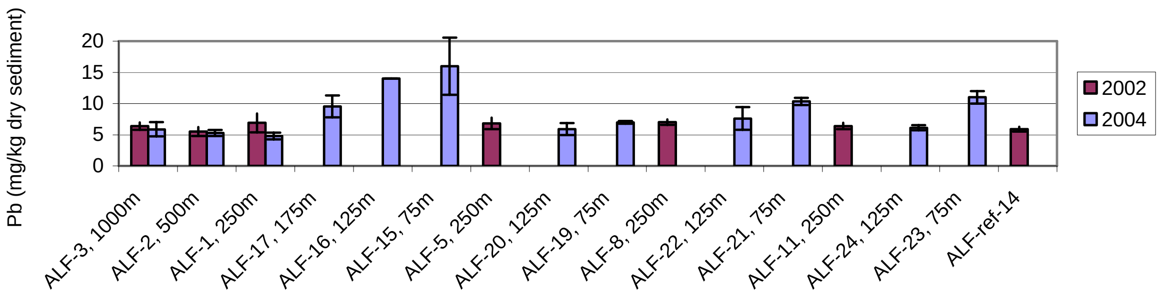


Figure 10: Average lead concentrations in sediments from the present (2004) and previous survey (2002) at SVAN field.

<u>Comparison with previous survey</u>

During the baseline survey at SVAN in 2002, sediments from 250 m and out to 1000 - 2000 m from the centre were investigated. The sediments were found to have background concentrations of all hydrocarbons and metals analysed.

In the present survey new sampling points closer to the centre (75 m, 125 m and 175 m) are included. The 1000 m, 500 m and 250 m stations on the main transect (10°-axis) are the only stations also investigated in 2002. Compared with the chemical results found in 2002, the THC content is unchanged at the 1000 m station while the THC content has increased by 13 mg/kg at the 500 m station and by 154 mg/kg at the 250 m station. The field history does not include discharges of oil-based drilling mud, but according to the operator, 709 tonnes of the oil based mud Versavert (containing more than 60% of the base oil EDC 95/11) was used in the lowest sections and shipped to land. However, the similarity of the gas chromatogram between the THC found in the sediments and the EDC 95/11 indicates that oil-based mud has been discharged at the field.

The amount of barium has increased at the 1000 m, 500 m and 250 m stations on the main transect. The concentrations of other heavy metals are almost unchanged. According to data on recent drilling and discharges at SVAN, 1953 tonnes of barite and 486 m^3 of water-based drilling mud have been discharged since the previous survey was performed.

3.3 Redox measurements

The results of the redox measurements are given in Table 7. The redox at the surface was positive at all stations. At station ALF-15 and ALF-21 the mean redox potential was less than 100 mV 5 cm down in the sediment, which indicates suboxic conditions. All the other sediments are characterised as oxic. As expected, the redox potential was generally lower 5 cm down in the sediment compared to the surface. There was also a tendency for lowered redox potentials towards the centre in the 10º direction. In the other directions the redox potential was slightly lower at the 75 m station compared to the 125 m station. The lowered potentials closer to the centre may indicate higher biodegradation rates or reduced diffusion/bioturbation due to sedimentation.

Table 7: Summary of results from the measurement of redox potentials (E_h) and hydrogen sulphide ion activities (Es).

St. no	Sed. layer	E_h (mV) 1	2	3	average	E_s (mV) 1	2	3	average
ALF-3, 1000m	surface	406	406	401	404	-57	-	-70	-64
	5 cm	223*	196*	166	195	-50*	-63*	-67	-60
ALF-2, 500m	surface	176	343	340	286	-77	-82	-86	-82
	5 cm	137	160	186	161	-78	-84	-85	-82
ALF-1, 250m	surface	419	341	331	364	-97	-101	-108	-102
	5 cm	151	147	131	143	-90	-104	-105	-100
ALF-17, 175m	surface	311	367	299	326	-104	-109	-112	-108
	5 cm	156	156	131	148	-101	-109	-114	-108
ALF-16, 125m	surface	164	177	206	182	-112	-113	-114	-113
	5 cm	168	121*	104	131	-115	-116*	-112	-114
ALF-15, 75m	surface	101	250	249	200	-118	-122	-114	-118
	5 cm	101	-	77	89	-122	-	-126	-124
ALF-20, 125m	surface	306	333	313	317	-141	-140	-142	-141
	5 cm	196	137	266	200	-141	-151	-143	-145
ALF-19, 75m	surface	271	279	281	277	-134	-136	-135	-135
	5 cm	142	174	189	168	-134	-138	-121	-131
ALF-22, 125m	surface	266	264	339	290	-118	-118	-119	-118
	5 cm	113	131	130	125	-125	-124	-124	-124
ALF-21, 75m	surface	308	143	276	242	-117	-154	-140	-137
	5 cm	-	-	81	81	-	-	-145	-145
ALF-24, 125m	surface	389	341	331	354	-180	-172	-166	-173
	5 cm	71	223	161	152	-180	-173	-166	-173
ALF-23, 75m	surface	256	326	241	274	-153	-151	-149	-151
	5 cm	129	201	136	155	-155	-151	-150	-152

* 3 cm

The results from the measurement of sulphide activity indicated very low sulphide concentrations at all stations. At station ALF-21 the potential decreased from the first to the second replicate, indicating some sulphide activity in the second replicate. When the sulphide electrode has been in contact with sulphide, it takes some time before it shows normal values, and the measurement at the second replicate at ALF-21 may at least partly explain the apparent lowered potential that was recorded at the third replicate at station ALF-21 and at ALF-24 and ALF-23, which were sampled after ALF-21.

3.4 PCA of environmental variables

A PCA was conducted on the environmental data to analyse how the variables were correlated to each other and how the stations are placed in this pattern, see Figure 11. The first axis represents 72.3% of the variation in the dataset and the second axis 22.9%, which means that almost all of the variation is explained in two dimensions.

It is evident that the trace metals, except from Ba, were strongly correlated with pelite and TOM. This is as expected as trace metals often are adsorbed to organic coatings of particles, and as finer sediments have a larger surface/volume-ratio. The stations ALF-15, ALF-16 and ALF-21 show the highest content of pelite and trace metals. Ba showed a perfect correlation to the drill cuttings, which accords with the fact that barite is the main constituent in the drilling mud. THC showed a different contamination pattern compared to the trace metals, which indicates that it may have been discharged differently from the other components in the drilling mud. The redox potential showed a negative correlation to the pelite and trace metal gradient. This means that more negative potentials, i.e. less oxygen available, are found in finer and more metal-contaminated sediments. Since THC, which is the only degradable component of the discharge, was not associated with the gradient in pelite/trace metals, the lowered redox potentials are not assumed to be caused by the chemicals in the drilling mud, but rather the higher pelite/TOM content at the closer stations.

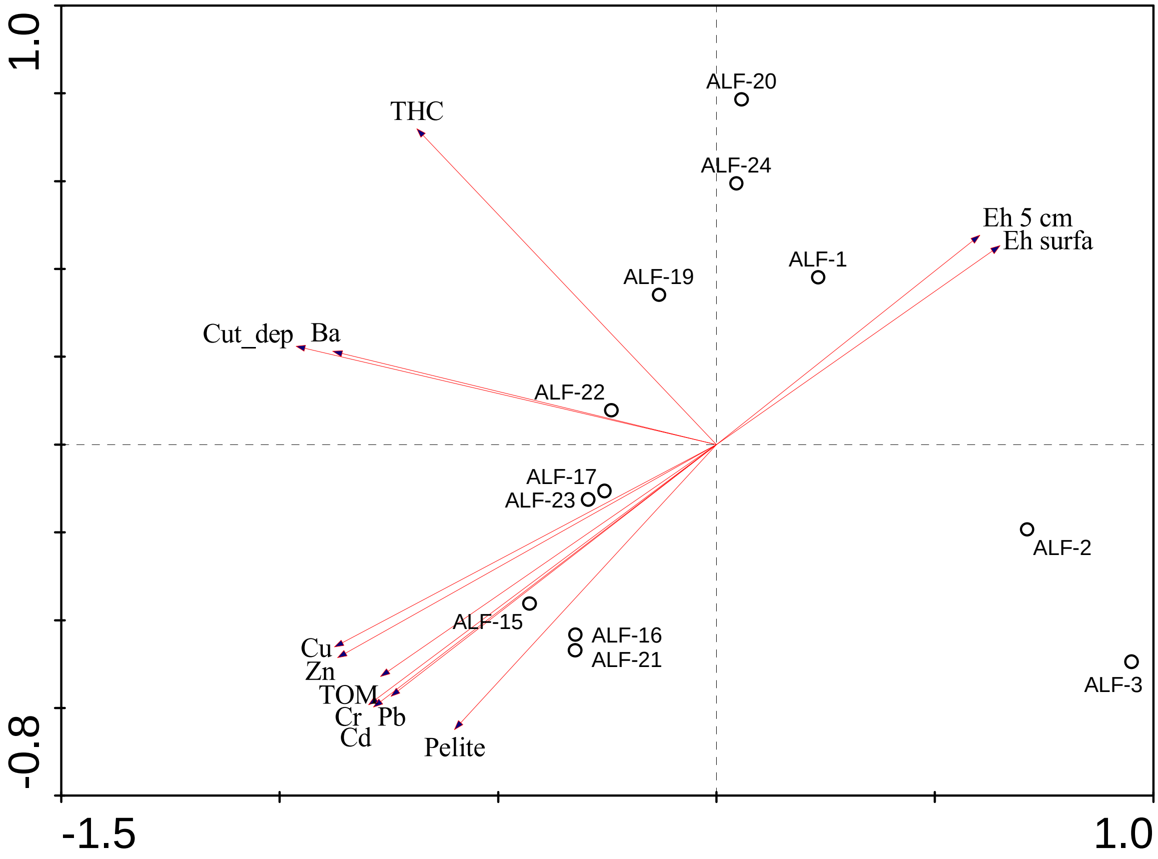


Figure 11. PCA of environmental variables, SVAN 2004.

3.5 Biology

3.5.1 Univariate measures

3910 individuals from 199 taxa were recorded at the SVAN field in 2004 and 5758 individuals from 225 taxa in 2003 (excluding juveniles). The number of individuals and taxa at each station, together with selected community indices, are presented in Table 8. The same data, except for the evenness, are presented in Figure 12, together with the results from 2002. The 2002 calculations, carried out by Rogalandsforskning, were based on the species list including juveniles, and to ensure that the dataset are comparable, juveniles were included in the plots shown in the figure. The density of juveniles often shows large variation both within the year and between years because of differences in settlement and survival, and may also have a patchy distribution within an area. Juveniles are therefore most often excluded from statistical analysis. The number of individuals and number of species was higher in 2003 than in 2002 and 2004, but regarding the diversity measures no trends were observed.

The number of individuals in the 03/04-survey ranged from 118 (ALF-21, 04) to 1036 (ALF-ref, 03; note that there is no reference station from 2004), the number of taxa from 37 (ALF-21, 04) to 115 (ALF1, 03/ALF16, 03), the Shannon-Wiener diversity (H') from 3,9 (ALF-15, 04) to 5,5 (ALF-22, 03), the evenness (J') from 0.71 (ALF-15, 04) to 0.88 (ALF-2, 04) and the Hurlbert diversity (ES_{100}) from 28 (ALF-15, 03) to 44 (ALF-3, 03). The diversity indices were, with a few exceptions, generally high. At station ALF-16 the diversity indices (H' and ES_{100}) decreased from 2003 to 2004. A reduction in H' was also evident at ALF-22, but here the change in ES_{100} was only very minor.

Table 8: Number of individuals and taxa and selected community indices for each station (0.5 m²) sampled at SVAN in 2003 and 2004. (Minimum and maximum values for each parameter are indicated with bold text.)

station	Year	no. of ind.	no. of taxa	H'	J	ES_{100}
ALF-3	03	493	99	5.2	0.79	**44**
ALF-2	04	252	65	5.3	**0.88**	43
ALF-1	03	835	**115**	5.3	0.77	40
	04	378	76	5.1	0.82	39
ALF-17	04	550	86	5.1	0.79	38
ALF-16	03	756	**115**	5.5	0.80	42
	04	265	51	4.5	0.79	33
ALF-15	04	241	44	**3.9**	**0.71**	**28**
ALF-5	03	796	101	5.2	0.78	39
ALF-20	03	897	111	5.2	0.77	39
	04	293	73	5.4	0.87	43
ALF-19	04	432	75	4.8	0.77	36
ALF-22	03	627	107	**5.5**	0.81	43
	04	188	56	4.9	0.85	40
ALF-21	04	**118**	**37**	4.1	0.79	34
ALF-11	03	811	94	5.1	0.78	38
ALF-24	04	394	77	5.0	0.80	39
ALF-23	04	306	54	4.7	0.81	32
ALF-ref	03	**1036**	114	5.3	0.77	40
Average		*509*	*82*	*5.0*	*0.80*	*38*

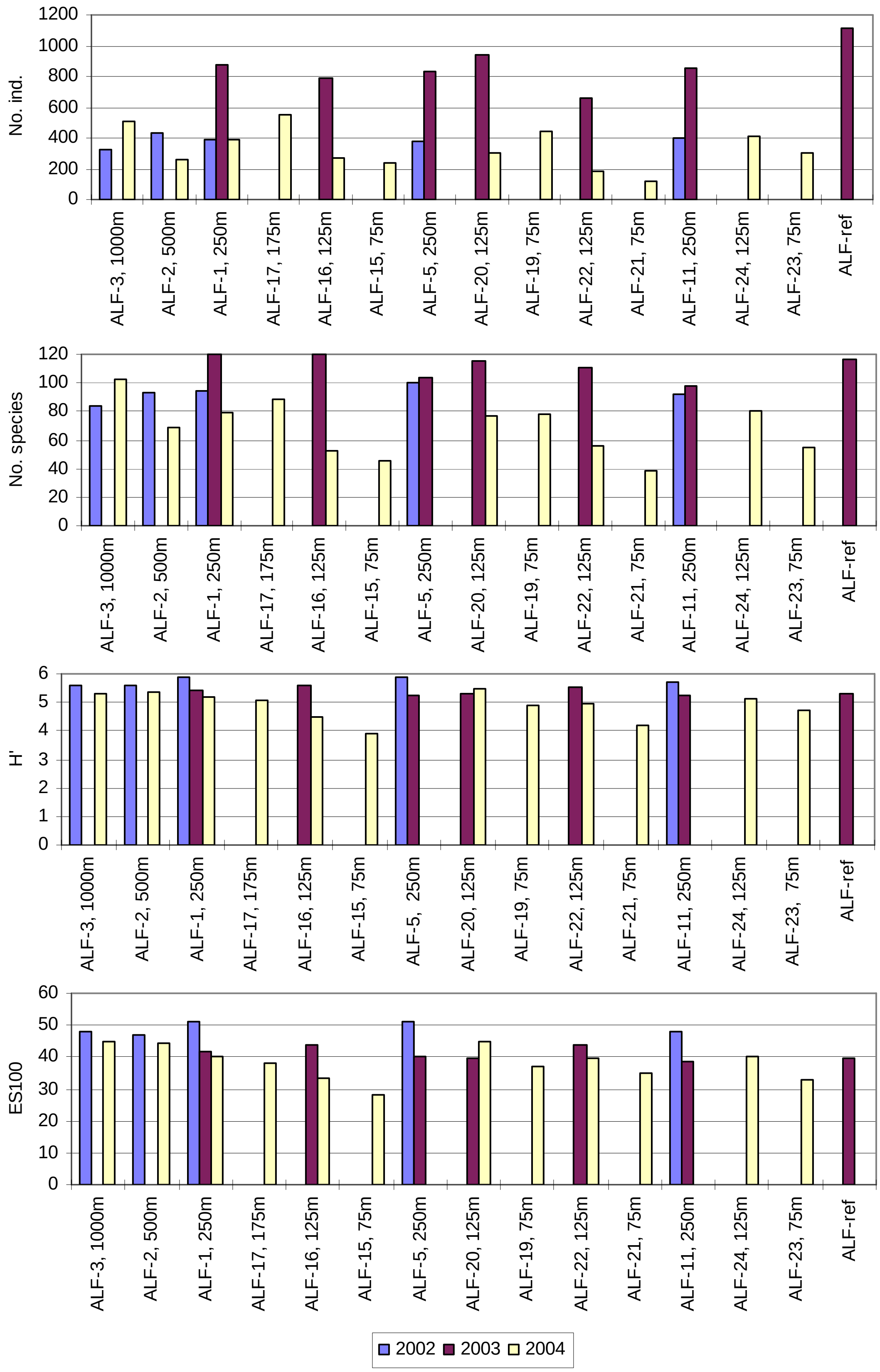
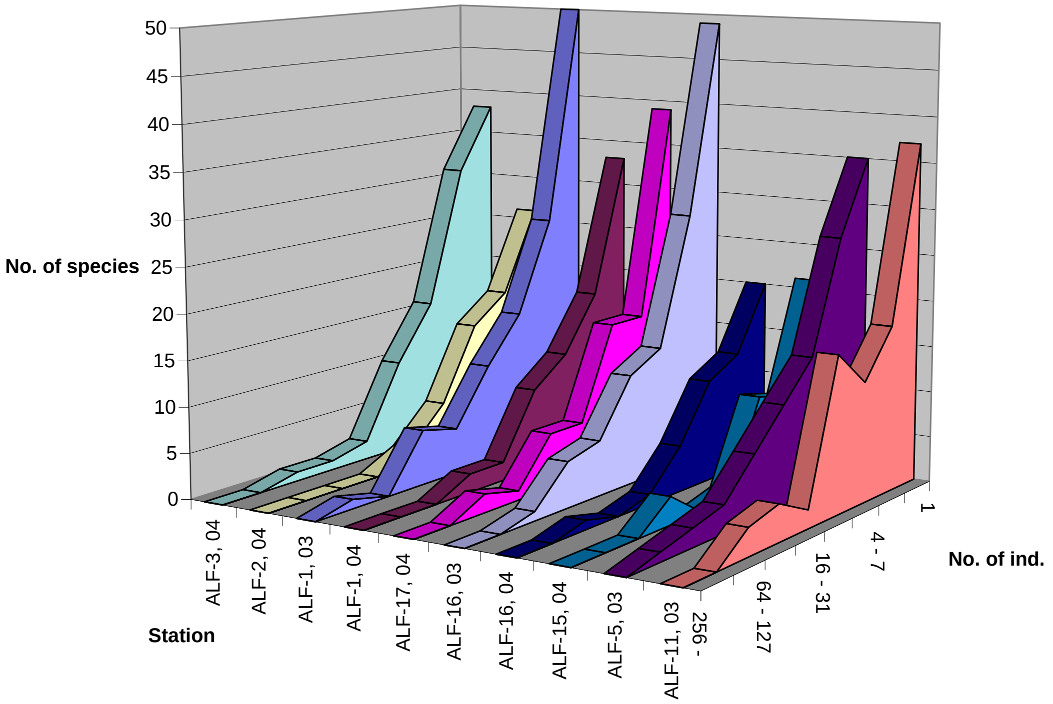


Figure 12: Biological characteristics of the stations at SVAN, 2002, 2003 and 2004.

3.5.2 Log-normal distribution

The distribution of taxa in geometrical classes is shown in Figure 13. The curves from stations ALF-15, 16, 21 and 23 are lowered compared to the curves from the other stations, which reflect the reduced number of individuals and taxa that was recorded at these stations. None of the curves stretched towards higher classes, which means that there are no taxa having particularly high abundances as often is the case in strongly polluted sediments.



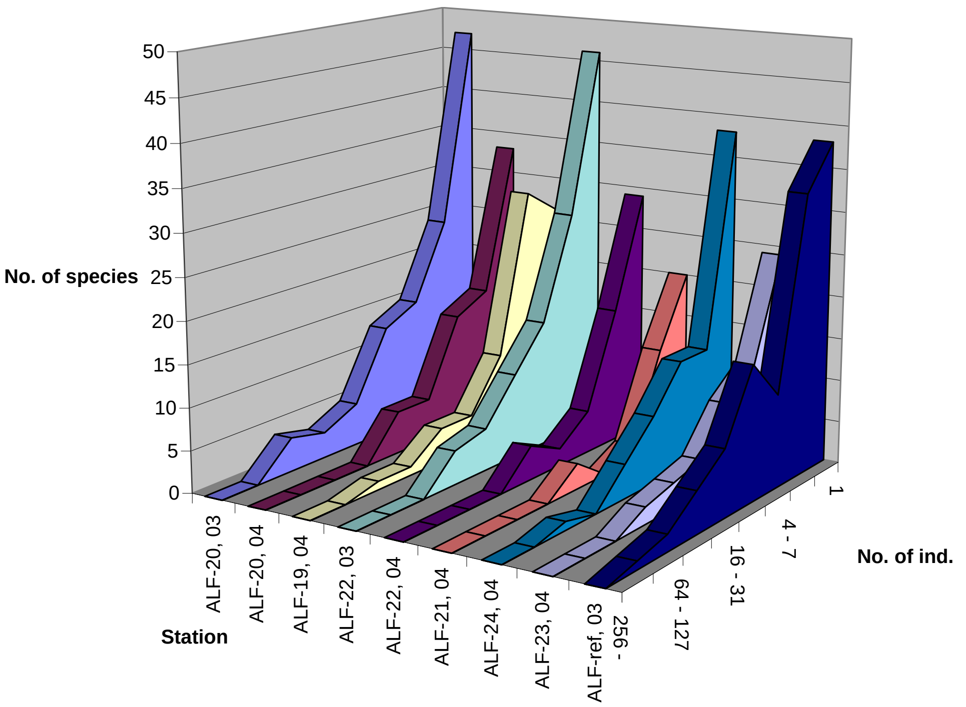


Figure 13: Distribution of taxa in geometrical classes, SVAN 2003 and 2004.

3.5.3 Faunal composition

The ten predominant taxa at each station are shown in Table 14 at the end of the report. At the field as a whole, the tube-building polychaete *Galathowenia oculata* was the most common taxon in 2004, while in 2003 the small carnivorous polychaete *Paramphinome jeffreysii* dominated the communities. Biological communities show natural variation from year to year, depending on e.g. the recruitment success of juveniles, that will act as a "background noise" when evaluating the effect of disturbance.

At ALF-15, ALF-16 (04), ALF-17, ALF-19 and ALF-23 the bivalve *Parvicardium minimum* was the most predominant taxon. Interestingly, this taxon also showed higher abundance at disturbed stations at Goliat (Trannum *et al*., 2004). At ALF-21 the carnivorous polychaete *Glycera alba* and Nemertini indet. were the most dominant taxa, and these are generally tolerant to disturbances. ALF-15 had a higher abundance of the tube-building polychaete *Pseudopolydora paucibranchiata* compared to the other stations, which also is interpreted as disturbance as this species typically increases in abundance in disturbed habitats. At both ALF-21 and ALF-15 *Galathowenia oculata* was almost absent (recorded by one individual at each station). This species is known to be sensitive to physical disturbance of the sediment. Also the tube-building polychaete *Terebellides stroemi,* which is considered a highly sensitive species, was absent at these stations, in addition to stations ALF-16 (04) and ALF-23. At ALF-23 the strongly opportunistic polychaete *Capitella capitata* had a relatively high abundance.

3.5.4 Cluster analysis and MDS ordination

Figure 14 shows the dendrogram from the cluster analysis, while Figure 15 shows the 2-D plot from the MDS analysis. At dissimilarity level of 60-65% the cluster analysis separated two stations, ALF-15 and ALF-21, both 75 m from the discharge point, from the other stations. At dissimilarity level of approximately 50%, the analysis separated the stations from 2003 and 2004 from each other. The 2004 stations are further separated into two groups at 45 % dissimilarity level with stations ALF-16, ALF-19, ALF-22 and ALF-23 (75-125 m from discharge) in one group and the rest of the stations (125-1000 m from discharge) in the other group.

In the 2-D MDS plot the stations from 2003 are aggregated on the right side of the plot, while the stations from 2004 are spread out in the left side of the plot. Stations ALF-15 and ALF-21, which were isolated in the cluster-analysis, are placed on the very left side. Changes in faunal composition over time are natural, which means that the change from 2003 to 2004 cannot directly be interpreted as disturbance. However, the placing of the stations from 2004 indicates that a pollution-induced gradient is affecting the faunal composition. The stress test for the MDS-plot revealed that minimum stress for the 2-D plot was achieved at a value of 0.14, indicating a good fit to the data.

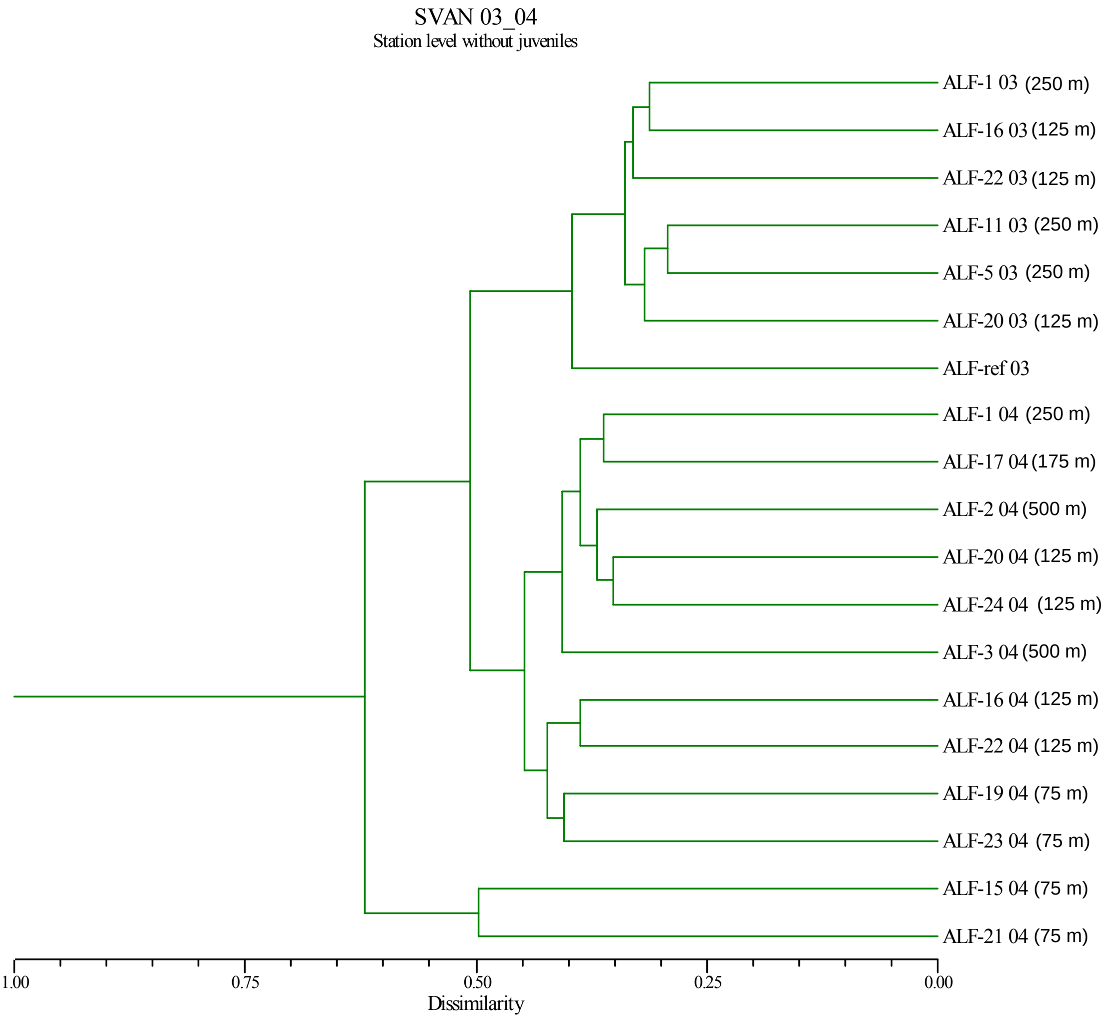


Figure 14: Cluster analysis of the station data from SVAN, 2003 and 2004.

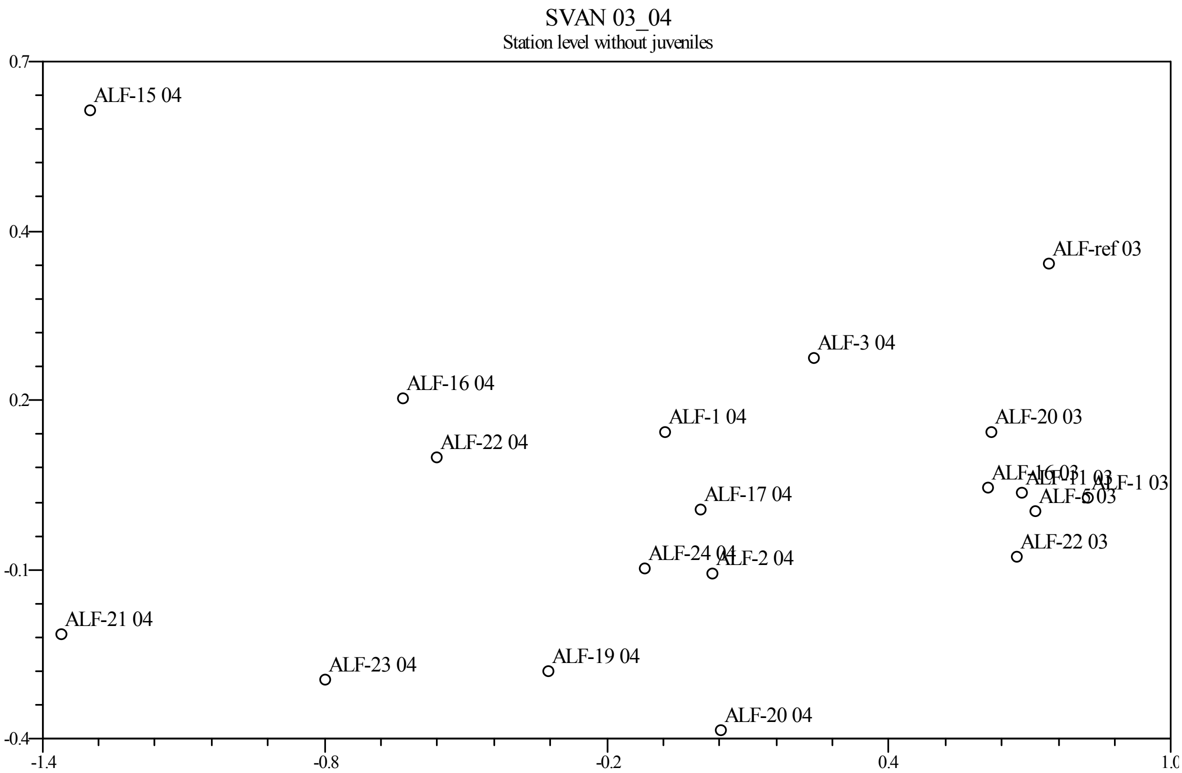


Figure 15: 2-D plot from the MDS analysis carried out on the station data form the SVAN field, 2003 and 2004.

3.5.5 ABCD classification

ALF-15 and ALF-21 were clearly separated from the other stations in both the MDS and cluster analyses. The diversity was lower at these stations compared to the other stations. The stations were also characterised by the absence of *Galathowenia oculata* and other tube-building polychaetes (with the exception from *Pseudopolydora paucibranchiata*, which is tolerant towards disturbances) and crustaceans, which is interpreted as a response towards disturbance. Station ALF-23, placed in the lower left part of the MDS plot, has a high abundance of the polychaete *Capitella capitata*, known to increase in abundance with increasing organic enrichment/contamination of the sediment. Thus, on the basis of the multivariate results and the faunal data, ALF-15, ALF-21 and ALF-23 appear to be slightly disturbed and are classified in group B. All the other stations are classified in group A. At some of these stations (ALF-16, ALF-19 and ALF-22) the faunal composition seems to very slightly altered, but at the same time the stations cannot be interpreted as disturbed.

3.5.6 Community Disturbance Index (CDI)

An analysis of CDI (Community Disturbance Index) was also performed on the field.
Since the sampling of benthic fauna was performed at different times of the year in 2003 and 2004, the data was slightly changed to remove those species that only contributed to separate the data according to year of sampling. This tuning was based on station ALF-2, which is considered to not be disturbed, to ensure that the change which is due to the discharge is still captured. The method used was to simultaneously observe the score plot and loadings plots from the correspondence analysis and remove the "year dependent" species from the loading plot until the ALF-2 sample felled into the 2003 group in the score plot. The calculated CDIs are given in Figure 16.

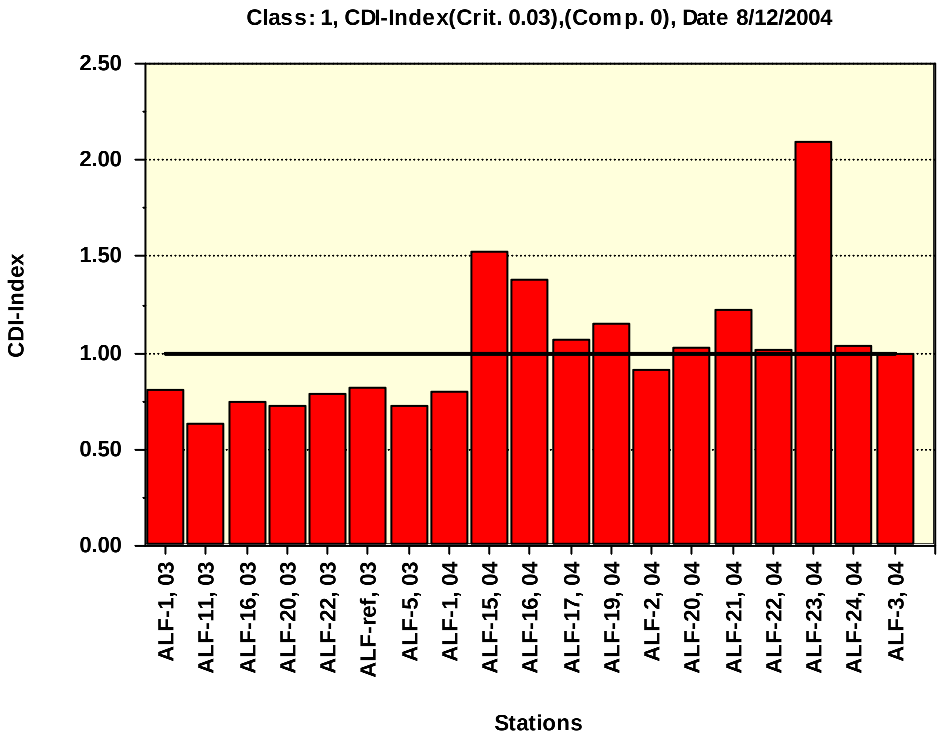


Figure 16: CDIs of stations at SVAN, 2003 and 2004.

As expected all samples from the 2003 survey are classified as undisturbed. In 2004 the three outermost stations (ALF-3, ALF-2 and ALF-1) also have CDI-values below 1, indicating that these are unaffected as well. However, at ALF-3, the value is very close to 1 (0.998). This is caused by this station being located at some distance from the other stations, and naturally has a faunal composition that differ slightly from the other stations. This hypothesis was confirmed when a separate Correspondence Analysis was performed on the data (not shown), and thus ALF-3 is defined as an outlier. All the 75 and 125 m stations have CDI's higher or slightly higher than 1.The highest CDI-value is observed at ALF-23, having a CDI higher than 2. At ALF-15 the CDI value is approximately 1.5, followed by ALF-16 having a CDI-value of approximately 1.4. ALF-21, which was identified as slightly disturbed in the other analyses, had a moderate CDI-value of 1.2.

The observation from the CDI analysis that ALF-23, ALF-15 and ALF-21 were influenced by the discharge is in accordance with the observations from the traditional biologically analysis (see above). However, in CDI, ALF-23 appeared to be the most disturbed station, which is not in accordance with the other statistical analyses and the chemical results. In addition, ALF-16 was disturbed according to the CDI, while it was not classified as disturbed in the ABCD-classification.

3.5.7 Correlation between fauna and environmental variables

When investigating the relationship between biological and environmental variables it is important to be aware that the results refer to correlations, and not necessarily real causality. Therefore, to increase the robustness of the conclusions, several methods were used to investigate such correlations.

Of the physical data, only the pelite content was used as this fraction will represent the fine fraction of the sediment. In order to obtain a measure on burial of the drill cuttings, the results from the *ParTrack* simulation were used, see Table 9. The *ParTrack* model quantifies the deposition in kg/m^2 at the end of the drilling period. 1 kg/m^2 deposited cuttings corresponds to approximately 1 mm thickness. The sedimentation was therefore maximum 1 cm during the drilling period (ALF-15). *ParTrack* produces a range of depositional rates for each station, and the mean value for each was used. As for the other variables, the values were ln-transformed prior to the analysis.

Table 9: Modelled sediment deposition at SVAN, from the ParTrack *model.*

Station	Sediment deposition (kg/m^2)
ALF-3	0,05
ALF-2	0,20
ALF-1	2,00
ALF-17	6,50
ALF-16	6,50
ALF-15	10,00
ALF-20	6,50
ALF-19	6,50
ALF-22	6,50
ALF-21	6,50
ALF-24	2,00
ALF-23	6,50

In the field, the cuttings are discharged discontinuously, while the *ParTrack* results represent the sedimentation that takes place during the drilling operation as a whole. Thus, *ParTrack* will not fully represent how the benthos experiences the burial, but represents the best picture of the situation and offer a unique possibility to compare the effect of burial with the other disturbance factors associated with drilling activities.

Correlation between CDI and environmental variables

A correlation analysis was performed to evaluate the linear correlation between the environmental variables and the CDI, and also between the various environmental variables, see Table 10. The correlations between the environmental variables generally confirm the results of the PCA, and are not discussed any further in this section.

As expected, the correlations between the toxic stressors and CDI are mostly positive, which supports the validity of the calculated CDIs. However, THC is an exception (-0.1 is close to no correlation at all), indicating that the hydrocarbon contamination observed at the field has not influenced the fauna at the time of sampling. This conclusion is in accordance with the fact that the station ALF-24 had the highest concentration of THC, at the same time as it appeared to be undisturbed.

Table 10: Correlation coefficients between environmental variables and between environmental variables and CDI (CDI/environmental variables in bold).

	g.size (µm)	Eh surf.	Eh 5 cm	TOM	THC	Ba	Cd	Cr	Cu	Pb	Zn	Cut-dep	CDI
grain size (um)	1	-	-	-	-	-	-	-	-	-	-	-	-
Eh surface	0.557	1	-	-	-	-	-	-	-	-	-	-	-
Eh 5 cm	0.716	0.643	1	-	-	-	-	-	-	-	-	-	-
TOM	-0.528	-0.785	-0.731	1	-	-	-	-	-	-	-	-	-
THC	0.648	0.207	0.27	-0.287	1	-	-	-	-	-	-	-	-
Ba	0.285	-0.303	-0.335	0.399	0.48	1	-	-	-	-	-	-	-
Cd	-0.622	-0.853	-0.708	0.936	-0.327	0.305	1	-	-	-	-	-	-
Cr	-0.702	-0.781	-0.806	0.916	-0.321	0.338	0.916	1	-	-	-	-	-
Cu	-0.663	-0.737	-0.812	0.892	-0.306	0.395	0.876	0.987	1	-	-	-	-
Pb	-0.558	-0.82	-0.654	0.933	-0.259	0.335	0.964	0.915	0.857	1	-	-	-
Zn	-0.623	-0.804	-0.796	0.922	-0.281	0.417	0.926	0.988	0.98	0.922	1	-	-
Cut-dep	-0.229	-0.712	-0.511	0.731	0.147	0.471	0.696	0.755	0.732	0.752	0.808	1	-
CDI	**-0.213**	**-0.538**	**-0.257**	**0.63**	**-0.106**	**0.445**	**0.57**	**0.635**	**0.602**	**0.696**	**0.622**	**0.55**	**1**

Response modelling

As the CDI has so far been in accordance with the observations from the other biological analyses and the chemistry, a response modelling was carried out to explore and quantify the relationship between the CDI and the environmental variables. As the number of variables is relatively large and as they are correlated to each other, the response modelling is performed by a Partial Least Squares regression method (Sjöström et al., 1983). Prior to the response modelling, a correspondence analysis was performed with the data from 2004, see Figure 17. The CDI-value is used to express the biological variation, and is included in the analysis in the same way as the environmental variables. All variables were standardized prior to the analysis, i.e. that each value is divided by the standard deviation of the variable. This transformation gives all variables equal weight in the analysis.

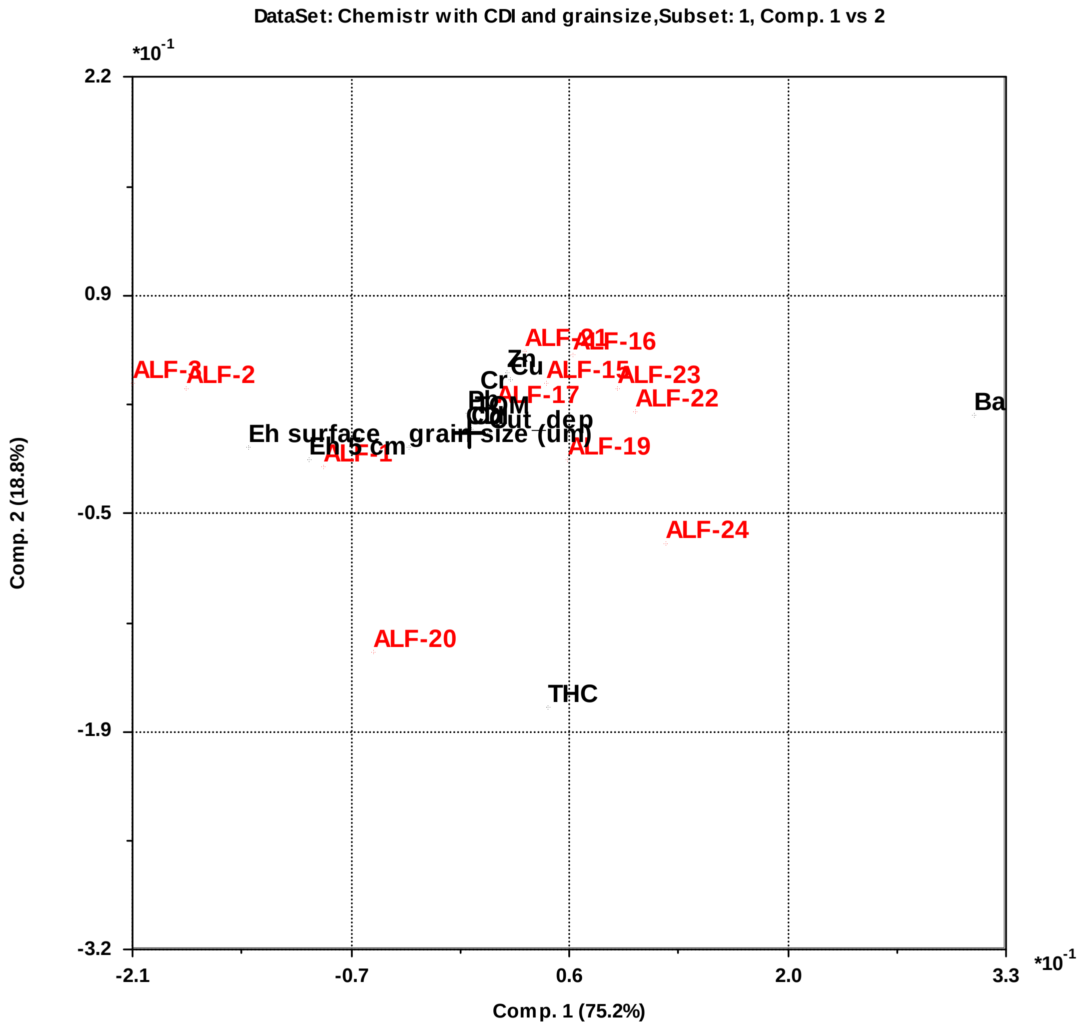


Figure 17: Biplot from the correspondence analysis of the CDI and environmental variables.

The main axis (CA factor 1) explains 75% of the variation, separating the stations ALF-2 and ALF-3 from the others. These stations have lower levels of contaminants and larger E_h values. In the CA-plot the sample ALF-23 is placed together with most of the other stations, despite of its high CDI-value. It is therefore assumed that the high CDI-value at this station at least partly is caused by other factors than pollution. On this background, this station is excluded from the response modelling.

In the response modelling all data are scaled to unit variance (i.e. standardised). There is one statistically significant PLS (Partial Least Squares) component, explaining 75% of the variation in CDI. The relative importance of the environmental variables to the pollution induced disturbance of the benthic fauna is shown in Figure 18. As expected, grain size and E_h are significantly negatively correlated to the CDI, while the TOM and the trace metals are positively correlated. The THC is, as already observed, of no importance to the observed CDI. The importance of interactions (i.e. crossterms) among the environmental variables to the CDI was found to be neglectable.

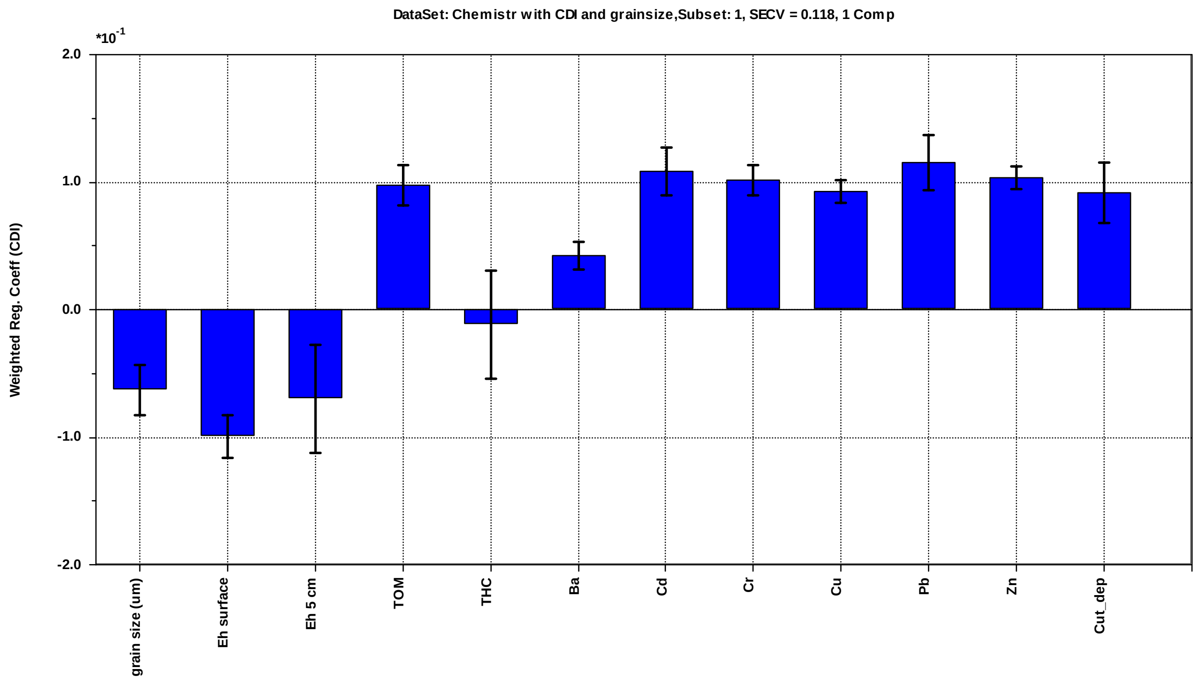


Figure 18: The relative importance (weighted regression coefficients) to the environmental variables for the explanation of the disturbance of the benthic fauna (CDI).

Another way to look at the correlation between the measured CDI's (i.e. the ones calculated directly from the benthic fauna) and the predicted CDI's (i.e. from the chemistry, the E_h and the grain size), is by plotting these as two lines, see Figure 19. There is a very good correlation between the measured levels of chemistry and the observed CDI's. This again confirms the validity of the calculated CDI's, with the exception of station ALF-23, which was excluded from the analysis.

Figure 19: The CDI from the benthic fauna (blue line) plotted versus the CDI predicted from the environmental variables (red line).

Canonical Correspondence Analysis (CCA)

The first procedure in the CCA is to identify and remove the variables that show a high correlation with other variables with regard to the explanation of the biological variation and Cr, Zn, Cd and THC were excluded from analysis on this background. Of the remaining 8 variables, only the pelite content ($p = 0.004$) and the cuttings deposition ($p = 0.004$) were identified as significant variables. 34.8% of the biological variance was explained by the first two axes of the ordination space which is constrained by these two environmental variables. This is a normal variance explanation which documents that there are clear gradients in the fauna.

The plots from the analysis are shown in Figure 20. In the plot with stations and environmental variables, the variables not identified as significant are also included in order to show how they correlate with the other variables. These are treated as passive variables, which mean that they are projected on the plot *a posteriori*. The first canonical axis in Figure 20 shows a gradient from ALF-21 and ALF-15 at the positive end of the axis to ALF-3, ALF-2 and ALF-20 at the negative end, and has a positive correlation with pelite (0.85) and cuttings deposition (0.78). The second axis shows a gradient from ALF-21 at the positive end to ALF-20 at the negative end. This axis has a negative correlation with cuttings deposition (-0.56) and a positive correlation with pelite (0.46). The conclusion from the other analysis that stations ALF-15 and ALF-21 are disturbed is thus also supported by the CCA.

The taxa that contribute most to the variance in the analysis are also included in the plot in Figure 20. The taxa on the left side of the plot are generally associated with undisturbed sediments, like the tube-building polychaetes *Euclymene affinis* and *Galathowenia oculata* and the amphipods *Ampelisca tenuicornis* and *Harpinia antennaria*. Several of the taxa on the right side of the plot are known to be associated with disturbed sediments, like the polychaetes *Capitella capitata* and *Pseudopolydora paucibranchiata* and the mollusc *Thyasira sarsi*.

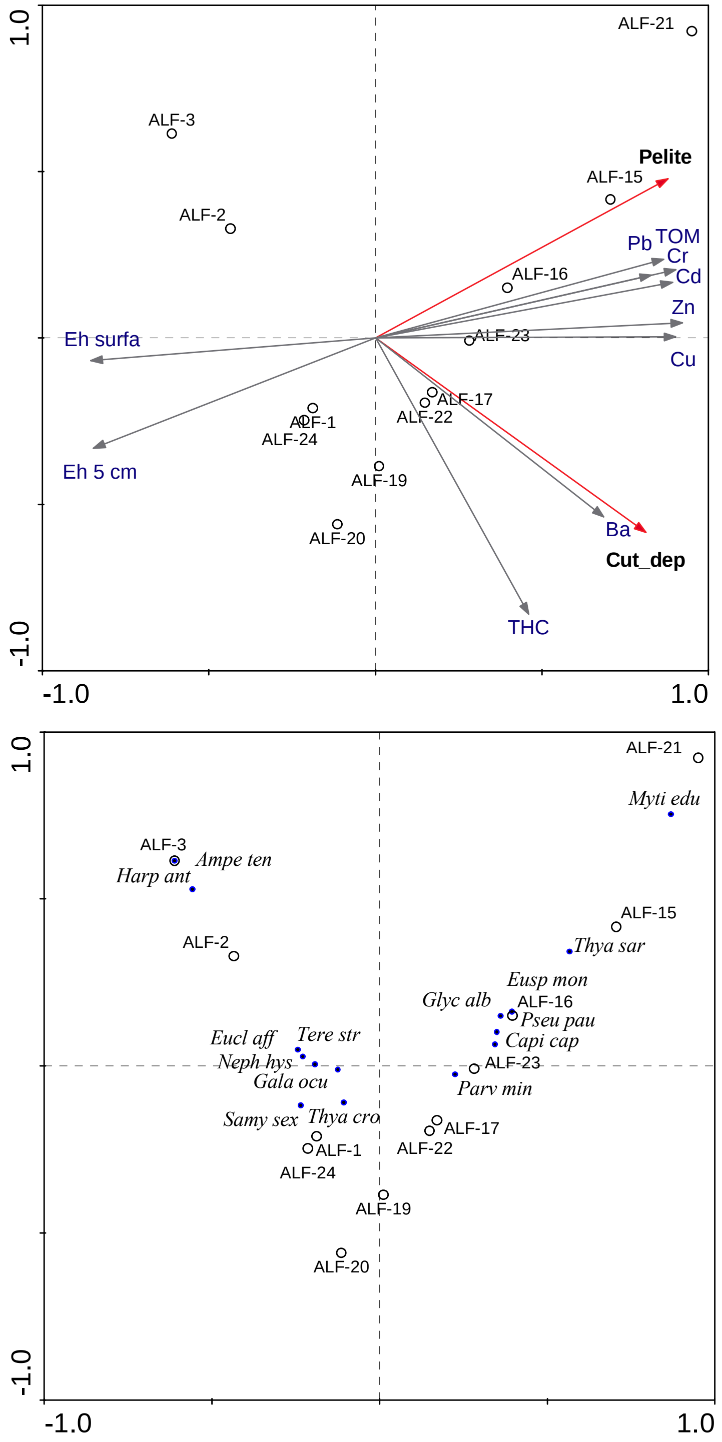


Figure 20: Plots from the CCA analysis for the SVAN field, 2004, with the ParTrack *results included. Upper plot stations and environmental variables (significant variables red arrows, non-significant variables grey arrows), lower plot stations and species.*

BIOENV

The results of BIOENV are presented in Table 11. In this analysis, the pelite content seems to be the most important variable for the faunal composition, which is in accordance with the CCA. According to BIOENV also E_h seems to be an important variable. The trace metals Zn, Pb, Cu and Cd were highly correlated with each other, which is the reason why their combination with the pelite and $E_{h\ 5cm}$ gives approximately the same result in BIOENV. This means that it is very difficult to isolate the possible individual effect of each of these metals. Anyway, pelite alone or pelite and $E_{h\ 5cm}$ give the best correlation in the analysis, and the correlation is reduced when including trace metals, indicating that trace metals not are of importance.

Table 11: Correlation coefficients (ρw) from the BIOENV-analysis.

Variables	Correlation
Pelite and Eh 5 cm	0.715
Pelite	0.715
Pelite, Eh 5 cm and Zn	0.708
Pelite, Eh 5 cm and Pb	0.703
Pelite, Eh 5 cm and Cu	0.700
Pelite, Eh 5 cm, Cu and Pb	0.696
Pelite, Eh 5 cm and Cd	0.696
Pelite, Eh surface and Eh 5 cm	0.696
Pelite, Eh surface, Eh 5 cm, Pb and Zn	0.695
Pelite, Eh surface, Eh 5 cm and Pb	0.695

Conclusion from the correlation analyses

To discuss the results of the correlation analyses we use the PNEC-values that have been derived during the ERMS-project. Regarding the trace metals, we use the work presently carried out by Bjørgesæter (2006) and Grung et al (2005), both based on MOD (database containing results from the offshore benthic monitoring). Bjørgesæter used the SSDs (Species Sensitivity Distributions) approach to find the lethal concentration for 5% of the species, which is then the F-PNEC (Field Based Predicted No Effect Concentration) value. Grung et al (2005) used an alternative approach, and for each chemical found the highest concentration where no effect (predicted by CDI) was observed. This value then corresponds to the FTV (Field Threshold Value). Both studies developed different F-PNEC/FTV for different grain size intervals.

The F-PNEC and FTV values for the grain size interval that is relevant for SVAN are presented in Table 12, together with the maximum concentration at SVAN. When using these values it is important to be aware that the F-PNEC-values may be influenced by correlations with other variables, i.e. that other variables may have contributed to the effects, and that the FTV-values always are below the true effect concentration.

Table 12: Overview of F-PNEC/FTV values derived by Bjørgesæter et al (2006)and Grung et al (2005), together with max concentrations recorded at the SVAN field..

	THC mg/kg	Cd µg/g	Pb µg/g	Ba µg/g	Cr µg/g	Cu µg/g	Zn µg/g
FTV	9.7	0.05	12.9	921	9.04	3.8	17.9
F-PNECs	71.2	0.05	18.7	2645	14.1	7.37	34.0
$SVAN_{max}$	532	0.198	16	4987	36.3	41.1	74.7

The highest concentration of THC was 532 mg/kg, which is two orders of magnitudes larger than the FTV and one order of magnitude larger than the F-PNEC. Despite of this, THC was not identified as a significant variable in any of the analyses. The fact that the highest concentration of THC occurred at station ALF-24, which was not identified as disturbed, strengthens the conclusion that the fauna did not respond to the THC. However, since the drilling activity was ceased just some weeks before the sampling was carried out, it is possible that the fauna has not yet responded to the THC-contamination and that some effects may be evident after longer time.

As evident in Table 12, all trace metals were expected to affect the benthic fauna, with the possible exception from lead. In the correlation analysis that was carried out between the CDI and environmental variables, the trace metals, together with TOM, generally showed higher correlation with the CDI than cuttings deposition and pelite (0,37, not shown), indicating an effect of these metals, while this not was the case in the CCA or BIOENV. The polychaete *Pseudopolydora pauibranchiata* has been identified as sensitive to contamination by copper (Olsgard, 1999; Trannum et al., 2004), and the fact that this species was not affected at the most contaminated stations, indicates that at least copper has not had any effect.

Neither in CCA nor BIOENV was Ba identified as a significant factor. Furthermore, in the analysis of the correlation between the CDI and the environmental variables, the correlation between CDI and Ba was not particularly high. Based on the correlative analysis, therefore Ba does therefore not seem to influence the fauna, despite of the fact that the maximum concentration was much higher than the F-PNEC and FTV values. Ba is not assumed to be toxic as it is highly inert. Apparent effects of Ba are therefore assumed to be related to the physical effects, i.e. burial, as Ba is the main constituent as barite in the drilling mud. In this study the effects of the deposition of the cuttings were analysed separately, which may explain why no effects of Ba were evident.

The deposition of the cuttings was identified as an important variable by CCA, and the correlation between the CDI and cuttings was quite high (0.55). For burial the PNEC has instead been denoted PNET (Predicted No Effect Threshold) as the factor is not a concentration, but an amount. As the extent and effect of burial is not investigated in traditional monitoring, there do not exist field-based PNET values. From literature surveys Holtaus *et al*. (2003) calculated a PNET value for exotic sediments of 0.65 cm. This was exceeded at the innermost stations at SVAN, which supports the conclusion that the deposition of cuttings has influenced the fauna. However, the values do not take into account a time aspect, which makes it difficult using them (Kjeilen-Eilertsen *et al*., 2004). It should therefore be derived a PNET expressed as mm deposition /day. Due to lack of literature data it has been proposed to use SSD (Species Sensitivity Distribution) derived from monitoring data with Ba as indicator variable. As the PCA shows (Figure 11), Ba shows a perfect correlation with the drill cuttings, which makes this approach promising.

The effects of burial may be related to disruption of feeding and respiration, where particularly filter feeders are sensitive. Hyland et al. (1994) found a significant negative correlation between the abundance of two species of sabellids and the flux of drilling mud particles. Sabellids have also shown decreased abundances in other environments influenced by large particle fluxes (e.g. Holte, 1998). In the present study species belonging to the order Sabellida were absent at ALF-15, ALF-21 and ALF-23, but present at all other stations. Small infaunal and epifaunal crustaceans may also be particularly sensitive towards burial (J. Neff, pers. com). In the CCA plot in Figure 20 there are two amphipods in the upper left corner, clearly showing a negative correlation with the drill cuttings deposition. Thus the gradient in faunal composition at the SVAN field agrees well with what is expected when an area is influenced by sediment accumulation, and clearly indicates that the deposition of drill cuttings is an important factor.

Burial may also inhibit the settlement of larvae (e.g. Hyland et al., 1994) as the sediment surface gets more unstable. Menzie et al. (1980) and Gillmor et al. (1985) suggested that physical alterations of sediments around an exploratory drilling rig might have resulted in diminished recruitment as evidenced by localized reductions in abundance of a number of taxa and shift in the size frequency distribution of brittlestars and by bioassays indicating that the drilling discharges had low toxicity. The present study was not designed to investigate settlement processes, so there is not sufficient data to make any conclusion related to a possible effect on the larval stages. A sieve with 1 mm mesh size was used, which means that the larvae and juveniles to a large degree are lost. Furthermore, the field work may have been carried out too early in the year with regard to sampling of newly settled larvae. Lastly, it is expected that effects related to the survival of larvae first will be evident after some time.

In the North Sea natural sedimentation is in a range of 0.5-3.5 mm/year, and the accumulation during the drilling period at SVAN exceeded this at several stations. There was a storm in February 2004, which may also have influenced the sediments at the SVAN field. In the North Sea, large storms can cause substantial bed transport at water depths of more than 200 m, resulting in erosion and deposition. Thus, it is likely that benthos at such depths are more tolerant towards burial than benthos at deeper waters. Anyway, burial by cuttings seems to have induced some effects on the benthic communities.

E_h was identified as an important variable in the BIOENV-analysis, which agrees with the moderately negative correlation between redox and CDI (-0.53). As redox potential is not measured in traditional monitoring, a F-PNEC or NOEC for this variable does not exist. Based on a study by Schaanning & Bakke (2005), a PNEC for oxygen is set to 20% change in E_h, which clearly is exceeded at the SVAN-field. The redox potential at SVAN was positive at all stations, but suboxic 5 cm down in the sediment at ALF-15 and ALF-21 for reasons discussed in section 2.5.3. This may have affected the fauna at these two stations, but is not assumed to have caused serious effects.

There is also a PNEC for grain size (HC_5), defined as a 52.7 μm (Smit et al., 2006). In the present dataset the maximum difference in grain size was 34 μm, which indicates that the change in grain size not should have an effect on the fauna. This is not in accordance with the CCA and BIOENV-results, which identified pelite as an important factor for the faunal composition. Pelite rather than the average grain size was used in these analyses as this is assumed to be more relevant for the fauna than the grain size as such. This is because pelite has strong influence on e.g. the amount of organic matter, i.e. food, and metal partitioning in the sediment. The correlation coefficient for CDI/pelite is 0.37 (not shown in Table 10) and for CDI/grain size is -0.21, which suggests that pelite rather than grain size should be used when evaluating changes in faunal composition. (Note that there is an inverse relationship between pelite and grain size, which leads to different signs of the correlation coefficients.) The correlation coefficient for CDI/TOM was 0.63, and higher than for pelite, indicating the importance of TOM. In CCA and BIOENV the effect of TOM is assumed to be reflected through the pelite content. Thus, the effect of changed sediment structure seems to be very clear in our study.

4 Summary and conclusions

The SVAN field is situated in the south-western part of Region II on the Norwegian Continental Shelf. Drilling was performed between September 2003 and April 2004. In connection with the ERMS project a comprehensive field trial has been carried out at the field. The results will be used for validation purposes of both fate and effects of the discharges, i.e. the PECs and the PNECs. Regarding the effects, four disturbance factors are taken into consideration; effects of toxic compounds, effects of changed sediment composition (e.g. grain size), effects of hypoxia, and effects of burial. The present survey was conducted according to the Norwegian guidelines for the offshore monitoring, which includes a measurement of various chemical compounds and the grain size, in addition to the benthic communities. Also a measurement of redox was included. The monitoring results therefore provide a possibility for quantification of effects of toxic compounds, grain size and hypoxia. In order to obtain a measure of burial, the results of the *ParTrack* model are used. The field trial therefore represents a unique case study for obtaining a holistic picture on which factors in the discharge influence the benthic communities most.

The average concentrations of THC range from background level to 532 mg/kg dry sediment. The average concentrations of barium range from 484 to 4987 mg/kg dry sediment. The lowest concentrations of THC and barium are found at the outermost station 1000 m NE and the highest concentrations at the 125 m station NW of the discharge point.

In 2002 hydrocarbons and metals in the sediments at SVAN were at background level concentrations. In the present survey the minimum area contaminated with THC is 0.12 km^2 (Table 13). However, as contamination was recorded out the 750 m in the NE direction, it seems likely that the contamination reached further than 175 m in other directions. This means that the true area that is contaminated is assumed to be larger than 0.12 km^2. The field history does not include discharges that can explain the THC contamination, but our data suggest that oil-based mud that has been used at the field has been discharged.

The minimum area contaminated with barium has increased to 0.46 km^2 as a result of discharges of barite as weight material in the water-based drilling mud. Again, the true area is assumed to be larger as all stations were contaminated, indicating that the border zone between contaminated and uncontaminated stations was not captured. For the other metals the contaminated area was 0.05 km^2. Also here the true area may be larger as contamination was recorded on the outermost stations in the SE and SW directions.

The benthic communities at ALF-15, ALF-21 and ALF-23 were classified in group B, which means that they are slightly disturbed. These stations are situated 75 m from the discharge point; ALF-15 in the NE, ALF-21 in the SE and ALF-23 in the NW direction. The area that is classified as slightly disturbed according to the ABCD classification is estimated to 0.01 km^2, much less than the area that is chemically contaminated (see Table 13). According to the CDI, disturbance was recorded at three of the 75 m stations and at all the 125 m stations, which gives a disturbed area of 0.05 km^2. As for the chemicals, the true area may have been larger as disturbance was identified out to 125 m. As the monitoring at SVAN was carried out only some days after completion of drilling activities, it is possible that the fauna has not yet fully responded to the discharges, and that the extent of biological effect may have increased in intensity and area after the sampling. The results of the CDI show a better correlation with the chemical results than the ABCD classification, but it is important to bear in mind that the extent of biological disturbance is usually much less than chemical contamination.

Table 13: Calculated minimum area of contaminated sediment and slightly disturbed fauna at SVAN 04. Note that the area contaminated by THC/Ba/metals (shaded with grey colour) is assumed to be larger than calculated as contamination was recorded at t he outermost stations.

	SE	SW	NW	NE	Area m^2	Area km^2
THC	125	125	125	500	122,718	0.12
Ba	125	125	125	1000	220,893	0.22
Other metals	125	125	75	175	47,124	0.05
Faunal group B	75	32.5	75	75	12,665	0.01
CDI	125	125	125	125	47,124	0.05

Several analyses were carried out to examine the correlation between the fauna and the environmental variables. There was a strong correlation among pelite, TOM, trace metals, and Eh, which makes it difficult the isolate the individual effect of each of these factors. Despite this, it can be concluded that sediment texture was the most important factor for separating the stations. The deposition of cuttings seems to be of some importance as well. Trace metals and changed redox conditions are assumed to have less effect, but at the same time, it cannot be excluded that some effect is evident. THC, on the other hand, did not appear to have any effects in this short-term study.

With regard to the chemical analyses, the station grid was not ideal. In three of four directions the outer station was located only 125 m from the centre, and they were all chemical contaminated. Thus the calculated area of contaminated sediments has been underestimated. This also makes it difficult to use the results in a validation of PEC values. However, the main focus of this survey was to study the biological responses, and for this purpose the selected station grid is considered to be better adapted as the transitional zone between impacted and unimpacted area seems to have been identified.

One of the reasons why the SVAN-field was chosen as a test field in ERMS, was that only WBM was supposed to have been discharged at the field. The contamination by THC was therefore unexpected and not ideal with regard to using the results for validation purposes. However, despite high concentrations, THC has apparently not had any significant effect on the fauna composition. We therefore conclude that the field trial has provided valuable information for evaluating and comparing disturbance factors related to discharge of water based drilling mud.

Table 14: The numerical and cumulative abundance of the ten most dominant taxa at each station at SVAN in 2003 and 2004.

ALF-3, 04	No. ind.	Cum.	ALF-2, 04	No. ind.	Cum.	ALF-1, 03	No. ind.	Cum.
Galathowenia oculata	100	20 %	Galathowenia oculata	31	12 %	Paramphinome jeffreysii	138	16 %
Nephtys hystricis	61	32 %	Nephtys hystricis	21	20 %	Nephtys hystricis	62	23 %
Terebellides stroemi	22	36 %	Nemertini indet.	13	25 %	Ampharete falcate	50	29 %
Thyasira croulinensis	20	40 %	Paramphinome jeffreysii	13	30 %	Galathowenia oculata	44	34 %
Harpinia antennaria	14	43 %	Levinsenia gracilis	11	34 %	Nemertini indet.	44	39 %
Nemertini indet.	14	46 %	Thyasira croulinensis	10	38 %	Phoronis sp.	39	43 %
Thyasira equalis	12	48 %	Abyssoninoe scopa	9	41 %	Terebellides stroemi	37	48 %
Euclymene affinis	11	50 %	Terebellides stroemi	8	44 %	Ampelisca tenuicornis	29	51 %
Parvicardium minimum	10	52 %	Euclymene affinis	7	47 %	Thyasira croulinensis	25	54 %
Ampelisca tenuicornis	9	54 %	Thyasira ferruginea	7	50 %	Ophiuroidea indet. juv.	23	56 %
ALF-1, 04	No. ind.	Cum.	ALF-17, 04	No. ind.	Cum.	ALF-16, 03	No. ind.	Cum.
Galathowenia oculata	54	14 %	Parvicardium minimum	77	14 %	Paramphinome jeffreysii	89	11 %
Nephtys hystricis	42	25 %	Galathowenia oculata	74	27 %	Ampharete falcata	54	18 %
Parvicardium minimum	27	31 %	Nephtys hystricis	46	36 %	Nephtys hystricis	52	25 %
Nemertini indet.	24	38 %	Thyasira equalis	23	40 %	Terebellides stroemi	42	30 %
Abyssoninoe scopa	12	41 %	Abyssoninoe scopa	22	44 %	Galathowenia oculata	37	35 %
Euclymene affinis	12	44 %	Pseudopolydora paucibranchiata	22	48 %	Thyasira croulinensis	34	39 %
Terebellides stroemi	12	47 %	Paramphinome jeffreysii	18	51 %	Phoronis sp.	29	43 %
Thyasira croulinensis	12	50 %	Glycera alba	17	54 %	Ampelisca tenuicornis	28	46 %
Levinsenia gracilis	11	53 %	Terebellides stroemi	17	57 %	Nemertini indet.	24	49 %
Ophiuroidea indet. juv.	11	55 %	Ampharete falcata	15	60 %	Harpinia antennaria	23	52 %
ALF-16, 04	No. ind.	Cum.	ALF-15, 04	No. ind.	Cum.	ALF-5, 03	No. ind.	Cum.
Parvicardium minimum	68	25 %	Parvicardium minimum	58	24 %	Paramphinome jeffreysii	130	16 %
Galathowenia oculata	30	37 %	Pseudopolydora paucibranchiata	50	45 %	Terebellides stroemi	70	24 %
Thyasira equalis	15	42 %	Glycera alba	38	60 %	Ampharete falcata	65	32 %
Glycera alba	14	48 %	Levinsenia gracilis	8	64 %	Nephtys hystricis	46	37 %
Nemertini indet.	14	53 %	Thyasira ferruginea	6	66 %	Phoronis sp.	43	43 %
Abyssoninoe scopa	9	56 %	Thyasira sarsi	6	69 %	Nemertini indet.	32	47 %
Thyasira croulinensis	9	60 %	Ampharete falcata	5	71 %	Thyasira croulinensis	27	50 %
Levinsenia gracilis	7	62 %	Nemertini indet.	5	73 %	Ophiuroidea indet. juv.	25	53 %
Pseudopolydora paucibranchiata	7	65 %	Paramphinome jeffreysii	5	75 %	Spiophanes kroyeri	24	56 %
Capitella capitata	6	67 %	Abyssoninoe scopa	4	76 %	Harpinia antennaria	19	58 %
ALF-20, 03	No. ind.	Cum.	ALF-20, 04	No. ind.	Cum.	ALF-19, 04	No. ind.	Cum.
Paramphinome jeffreysii	94	10 %	Galathowenia oculata	28	9 %	Parvicardium minimum	89	20 %
Ampharete falcata	92	20 %	Nephtys hystricis	23	17 %	Galathowenia oculata	56	33 %
Terebellides stroemi	87	29 %	Thyasira croulinensis	18	23 %	Thyasira croulinensis	29	39 %
Nephtys hystricis	69	36 %	Nemertini indet.	17	28 %	Nemertini indet.	26	45 %
Nemertini indet.	49	42 %	Thyasira ferruginea	16	33 %	Nephtys hystricis	21	50 %
Phoronis sp.	48	47 %	Parvicardium minimum	14	38 %	Thyasira equalis	17	54 %
Thyasira croulinensis	34	50 %	Abyssoninoe scopa	12	42 %	Glycera alba	15	57 %
Ampelisca tenuicornis	29	54 %	Amphiura chiajei	8	44 %	Thyasira ferruginea	13	60 %
Ophiuroidea indet. juv.	28	57 %	Glycera alba	8	47 %	Abyssoninoe scopa	10	62 %
Abyssoninoe scopa	20	59 %	Thyasira equalis	8	50 %	Westwoodilla caecula	9	64 %

Table 14: Continued.

ALF-22, 03	No. ind.	Cum.	ALF-22, 04	No. ind.	Cum.	ALF-21, 04	No. ind.	Cum.
Nephtys hystricis	58	9 %	Galathowenia oculata	20	11 %	Glycera alba	29	24 %
Paramphinome jeffreysii	58	18 %	Glycera alba	20	21 %	Nemertini indet.	17	38 %
Terebellides stroemi	54	26 %	Parvicardium minimum	18	31 %	Parvicardium minimum	16	51 %
Ampharete falcata	40	32 %	Nemertini indet.	16	39 %	Thyasira equalis	4	55 %
Galathowenia oculata	30	36 %	Pseudopolydora paucibranchiata	11	45 %	Thyasira ferruginea	4	58 %
Ampelisca tenuicornis	29	41 %	Hemilamprops roseus	9	50 %	Abyssoninoe scopa	3	60 %
Thyasira croulinensis	25	45 %	Thyasira ferruginea	7	54 %	Capitella capitata	3	63 %
Nemertini indet.	20	48 %	Nephtys hystricis	5	56 %	Levinsenia gracilis	3	65 %
Ophiuroidea indet. juv.	20	51 %	Paramphinome jeffreysii	5	59 %	Pogonophora indet.	3	68 %
Harpinia antennaria	18	53 %	Dipolydora coeca	4	61 %	Diplocirrus glaucus	2	69 %

ALF-11, 03	No. ind.	Cum.	ALF-24, 04	No. ind.	Cum.	ALF-23, 04	No. ind.	Cum.
Paramphinome jeffreysii	108	13 %	Galathowenia oculata	74	18 %	Parvicardium minimum	41	13 %
Ampharete falcata	65	20 %	Nephtys hystricis	29	25 %	Galathowenia oculata	38	26 %
Nephtys hystricis	65	28 %	Thyasira croulinensis	29	32 %	Capitella capitata	30	35 %
Phoronis sp.	58	35 %	Abyssoninoe scopa	22	37 %	Glycera alba	21	42 %
Galathowenia oculata	57	41 %	Nemertini indet.	19	42 %	Nemertini indet.	21	49 %
Terebellides stroemi	48	47 %	Terebellides stroemi	15	46 %	Thyasira ferruginea	15	54 %
Nemertini indet.	44	52 %	Thyasira ferruginea	14	49 %	Thyasira croulinensis	12	58 %
Ophiuroidea indet. juv.	27	55 %	Thyasira equalis	13	52 %	Ampharete falcata	10	61 %
Ampelisca tenuicornis	19	58 %	Ophiuroidea indet. juv.	10	54 %	Thyasira equalis	10	64 %
Spiophanes kroyeri	17	60 %	Parvicardium minimum	9	57 %	Aricidea catherinae	7	67 %

ALF-ref, 03	No. ind.	Cum.
Galathowenia oculata	145	13 %
Paramphinome jeffreysii	127	24 %
Ampharete falcata	86	32 %
Ophiuroidea indet. juv.	72	39 %
Phoronis sp.	50	43 %
Nephtys hystricis	41	47 %
Terebellides stroemi	38	50 %
Nemertini indet.	36	53 %
Amphiura filiformis	33	56 %
Pseudopolydora paucibranchiata	21	58 %

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