Environmental monitoring survey of oil and gas fields in Region II, 2000

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Sammendrag / Summary

An environmental monitoring survey was carried out in Region II in the central North Sea. This report presents the results from the chemical and biological analyses performed on samples from a total of 230 stations at 15 fields and 9 regional stations in the area. The status of the conditions in the region is given at the end of the report.

Emneord:	Key words:
Region II	Region II
Hydrokarboner	Hydrocarbons
Tungmetaller	Heavy metals
Makrofauna	Macro fauna

Prosjektleder / Project manager	Kvalitetskontroll / Quality control
Hans-Petter Mannvik	Sabine Cochrane

Preface

The report presents the results from the environmental monitoring survey of Region II. After the introduction and chapters describing the fieldwork and methods used, the results of the regional stations are presented and discussed. In the following chapters each field is described separately with details on its history, sampling network and a presentation and discussion of the results in relation to previous investigations and results form the regional stations. A status of environmental conditions and regional trends is given as a separate chapter, followed by a presentation of the survey conclusions and recommendations for follow-up.

In addition to this main report, summary reports in English and Norwegian are available. All background data are available in the appendices on the CD-ROM included with this report.

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

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

The work was commissioned by Statoil (Contract Agreement no. VMS135236) on behalf of the operators in this region.

Statoil	Glitne, Sleipner Øst and Sleipner Vest fields
Norsk Hydro	Varg and Heimdal fields
Elf Petroleum	Frigg, Nordøst Frigg, Øst Frigg, Lille Frigg and Frøy fields
Esso Norge	Ringhorne, Sigyn, Balder, Jotun and Odin fields

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We also like to thank the master and crew of the vessel “Seaway Invincible”.

Table of Content

1 Summary

Statoil commissioned Akvaplan-niva AS to carry out the regional environmental survey of the Region II in the North Sea (contract agreement VMS135236). The fields included in the survey are Glitne, Sleipner Øst, Sleipner Vest (Statoil), Varg, Heimdal (Norsk Hydro) Frigg, Nordøst Frigg, Øst Frigg, Lille Frigg, Frøy (Elf Petroleum) Ringhorne, Sigyn, Balder, Jotun, and Odin (Esso Norge). Samples from a total of 230 stations in the regional survey were collected. In addition samples from the Oseberg Øst field and cutting piles at Frigg, Nordøst Frigg, Øst Frigg, Lille Frigg and Frøy were collected. Separate reports with these results will be produced.

There is a great variation in the sediment structure over the region. The sediments at Frigg, Nordøst Frigg, Sigyn, Odin, Varg and Sleipner Øst all have relatively low amounts of pelite (< 5 %) and TOM (< 1 %) while the highest values are found at Jotun (> 15 and 2 %, respectively). The average value of fine sand are, for most of the field, around 80 % or higher, with the exceptions of Nordøst Frigg and Varg where the average is 40 and 60 %, respectively.

Overall, there is a general trend of finer sediments the region in the present survey compared to the survey carried out in 1997.

Since the previous survey in 1997, the contents of THC are almost unchanged or reduced at fields with no drilling activity in recent years (Frigg, Nordøst Frigg, Heimdal, Odin, Øst Frigg and Frøy). At Frøy, olefins are about to disappear from the sediments, but traces are still present at the innermost stations. The changes in barium contents are more unsystematic at these fields. The content of barium, in sediments from Nordøst Frigg, Øst Frigg and Odin are almost unchanged or reduced compared to the 1997 results, while the amounts of barium have increased at Lille Frigg. There has been no drilling activity at Lille Frigg in recent years, but discharges of barite occurred during the permanent plugging of the wells immediately before the year 2000 survey. Increased barium contents are also found at the Frigg, Frøy and Heimdal fields, even though there has been no plan for discharges that can explain these increases in barium contents.

In the southern part of the region the highest concentrations of THC and barium are found at Varg and Sleipner Vest, where the general levels have increased since 1997 following acute discharges of both oil-based mud and barite in 1999 and 2000. At Sleipner Øst, generally elevated levels of THC are found at the innermost stations at Loke and SLA, while barium is contaminated at all except one station. Compared to the results in the 1997 survey, the THC level are unchanged or only slightly increased at most of the Sleipner Øst stations, while the contents of barium are unchanged or reduced. Exceptions are found north and west of Loke where both THC and barium have increased in addition to south of SLE where both THC and barium have decreased. At Sleipner Øst, Petrofree ester was discharged in the time period from 1994 to 1996. The amount of Petrofree ester has decreased considerable since 1997, but traces are still present at the Loke stations. Because of reported discharges of olefins at Loke and SLA, sediments from the seabed around these locations were analysed for traces of olefins. As expected from discharge history, the sediments from Loke contained higher amount of olefins than the sediments from SLA.

The largest areas contaminated with THC and barium are found at Jotun in the central part of the region. At Jotun, the centre position has been changed approximately 400 m north to north west since the baseline survey in 1996and direct comparison of THC and barium levels is not possible, but the amounts of THC and barium have increased in the area. At the Balder field, the average THC and barium contents are almost unchanged compared to the 1997 results. The area contaminated with THC has switched from south and south east of well templates A, B and C, to north west of well-templates A and D. The amount of olefins have decreased, but traces are still present at several stations. The area contaminated with barium has decreased around well-templates A and B and increased in the main-current direction from well-templates C and D. The total area contaminated with barium has increased at Balder. The increase might be explained by discharges of barite and water-based mud at Balder in 1998.

All three fields where baseline surveys were carried out (Glitne, Ringhorne and Sigyn) were unaffected by petroleum activities.

Through the evaluation of the results from the different analyses carried out on the data from each field, the fauna at each station is classified into groups according to disturbance levels. Eight of the fields (Ringhorne, Sigyn, Glitne, Jotun, Lille Frigg, Øst Frigg, Nordøst Frigg and Sleipner Øst) are found to have only undisturbed fauna (group A), four fields (Odin, Varg, Heimdal and Sleipner Vest) have undisturbed and slightly disturbed fauna (group B), while three fields (Frigg, Frøy and Balder) have undisturbed, slightly disturbed and disturbed fauna (group C).

The calculated minimum area of faunal disturbance and contaminated sediments in the present survey in Region II is shown in the table below. The total area of slightly disturbed fauna (group B) in Region II has decreased from 1.72 km^2 in the 1997 survey to 1.21 km^2 in the present survey while the area of disturbed fauna (group C) has increased from 0.18 km^2 in 1997 to 0.24 km^2 in 2000. This means that the total area of disturbed fauna has decreased while the intensity has increased during these years. But it should be mentioned that the group C fauna only is found at three of the fifteen fields and that the total area of disturbed fauna is relatively small.

Comparisons of single fields show that the area of faunal disturbance has decreased while the intensity has increased at the Frigg and Balder fields. At Varg and Sleipner Vest no faunal disturbance was detected in the previous survey, while slightly disturbed fauna is seen at these fields in the present survey. At Heimdal the area of faunal disturbance has increased while the intensity has decreased. At Øst Frigg, Lille Frigg and Sleipner Øst, where faunal disturbance was detected in 1997, the fauna is now found to be undisturbed. At Jotun and Nordøst Frigg the fauna was found to be undisturbed in both surveys.

Field	Faunal group B	Faunal group C	THC	Olefins/ ester	Ba	Other metals
Frigg	0.12	0.10	0.06	n.a.	0.08	0.36
Nordøst Frigg	0	0	0	n.a.	0	0
Øst Frigg	0	0	0.07	n.a.	0.18	0
Lille Frigg	0	0	0.15	n.a.	0.33	0.07
Frøy	0.29	0.07	0.07	0.29/n.a.	1.18	0.15
Ringhorne	0	0	0	n.a.	0	0
Sigyn	0	0	0	n.a.	0	0
Balder	0.37	0.07	0.54	1.13/n.a.	4.21	0.15
Glitne	0	0	0	n.a.	0	0
Jotun	0	0	1.77	n.a.	5.30	0.07
Odin	0.03	0	0.02	n.a.	0	0.03
Varg	0.15	0	1.33	n.a.	1.77	0.25
Heimdal	0.18	0	0.12	n.a.	0.43	0.29
Sleipner Vest	0.07	0	0.74	n.a.	3.14	0.74
Sleipner Øst	0	0	0.40	1.10/0.37	2.43	0
Total area 2000	1.21	0.24	5.27	2.89	17.87	2.11
Total area 1997	1.72	0.18	4.15	15.67	22.81	2.11

n.a. Not analysed.

2 Introduction

Statoil, Norsk Hydro, Elf Petroleum and Esso Norge commissioned Akvaplan-niva to carry out the regional monitoring survey in Region II in the North Sea (contract no. VMS135236). The programme for the regional monitoring survey was designed in accordance with the guidelines SFT 99:01 (Nilssen 1999). Samples were collected from a total of 208 field stations and 9 regional and 13 reference stations in the region. In addition to the usual physical, chemical and biological analyses, samples were collected for analysis of synthetic drilling mud at some of the fields. Samples were also collected at the Oseberg Øst field and cutting piles at the Frigg, Nordøst Frigg, Øst Frigg, Lille Frigg and Frøy. Separate reports with the results from these will be produced.

The fields included in the survey in Region II were:

Statoil	Glitne, Sleipner Øst and Sleipner Vest
Norsk Hydro	Varg and Heimdal
Elf Petroleum	Frigg, Nordøst Frigg, Øst Frigg, Lille Frigg and Frøy
Esso Norge	Ringhorne, Sigyn, Balder, Jotun and Odin

Region II is situated in the central part of the North Sea (Figure 2-1) and the depth varies from approximately 90 m in the south (Sigyn, Varg and Sleipner Øst area) to approximately 130 m in the central part of the region. The current directions differ somewhat in the region. In the Frigg area the residual current direction is in the south east direction, in the Balder area mainly in the south east and east direction and i the Varg area in north to north east direction.

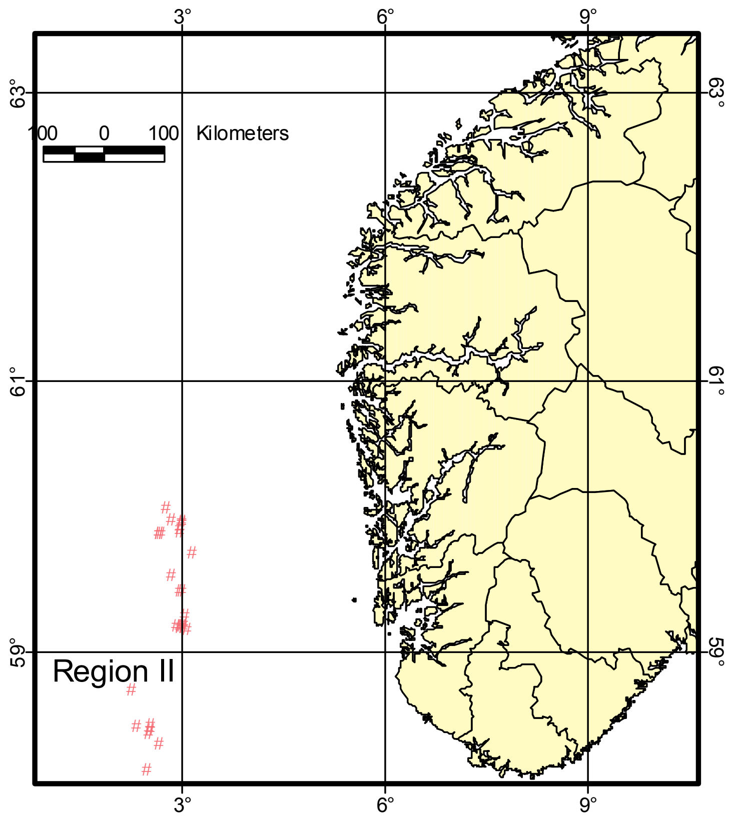

Figure 2-1: Location of Region II.

Offshore activities have been going on since the late 1970'ies in Region II when the Frigg field started the production. A summary of the operational and accidental discharges that may have influenced the current chemical and biological conditions is provided in the relevant field chapters (section 5 and further).

This is the second regional survey in Region II, but before regional surveys were introduced, environmental conditions have been monitored at single fields. The conclusions from these previous surveys are summarised in the field chapters.

The survey was carried out by Akvaplan-niva AS in co-operation with the following laboratories:

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

3 Methods

Station selection, field sampling and laboratory analyses of the samples were performed in accordance with the Norwegian guidelines for environmental monitoring of petroleum activities on the Norwegian shelf (Nilssen 1999).

3.1 Station network

The selection of the stations at each field is based on the results from the previous surveys and the drilling and discharge history since that survey. Generally, samples from three to four stations on the main transect and two to three stations on the other transects were collected. Baseline surveys are in accordance with the guidelines. The locations of the regional stations are selected to get information about the natural geographical and topographical variations in the sediment conditions in the area. Map showing the location of fields in Region II is shown in Figure 3-1.

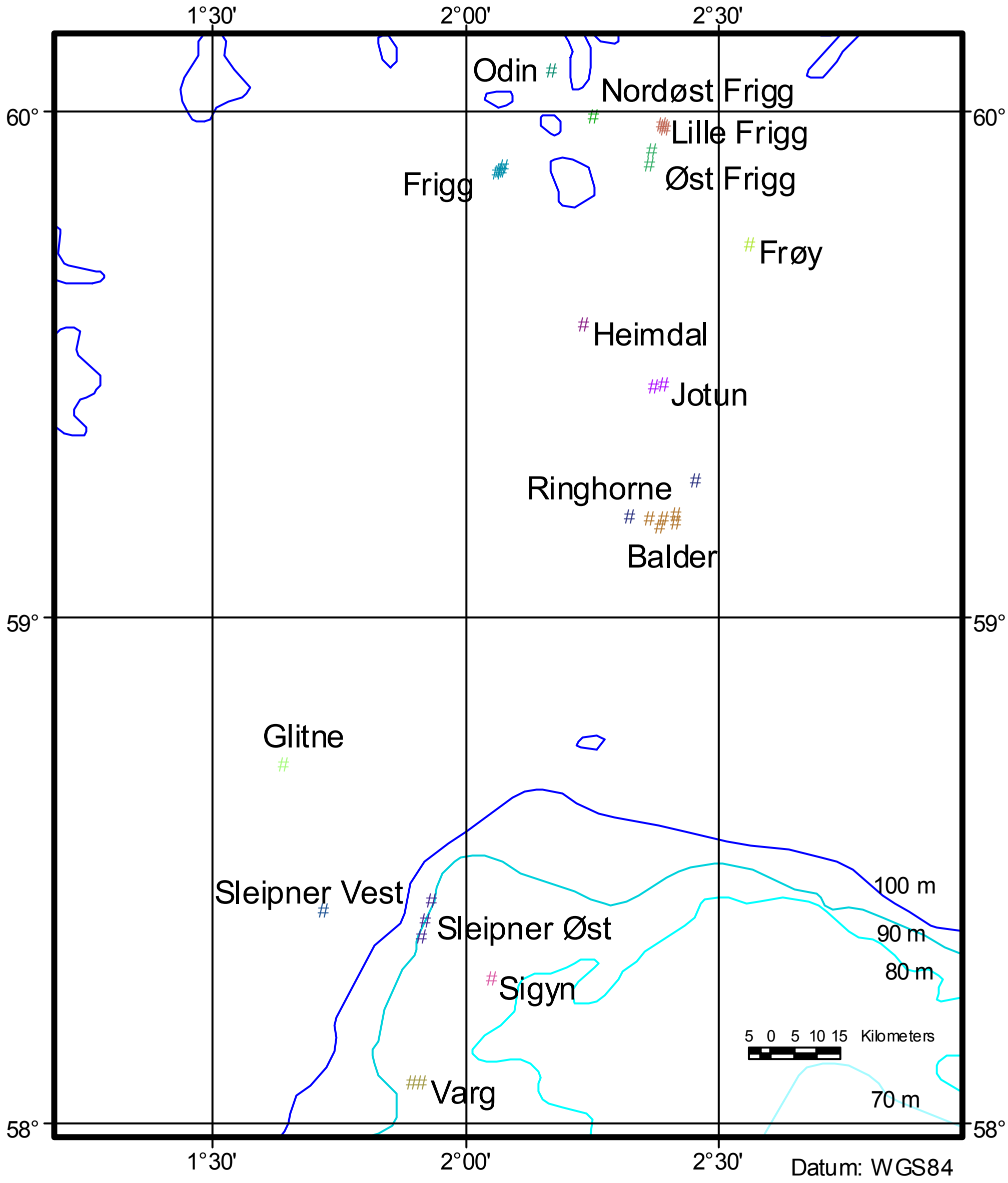

Figure 3-1: Location of the fields and regional stations included in the survey in Region II, 2000.

3.2 Fieldwork

The fieldwork was carried out between 23.05. and 13.06. 2000, using MS "Seaway Invincible" (Stolt Offshore). The samples were collected at 9 regional stations, 13 reference stations and 208 field stations. At the regional and field stations three and five chemical and biological samples were collected, while at the reference stations five chemical and ten biological samples were collected. In addition, samples from the Oseberg Øst field and cutting piles at the Frigg, Nordøst Frigg, Øst Frigg, Lille Frigg and Frøy fields were collected. A separate report with these results will be produced. A total of 2104 samples from 251 stations were collected during the field work.

During sampling, the ship's officers held the vessel within $\pm$ 50 m of the station coordinates. Positioning was done using a differential GPS with accuracy better than 10 m and the vessel was held in position with a dynamic positioning system (DP).

The entire sampling programme was followed and sampling was conducted without deviating from the guidelines. Sampling positions, distances from the field centre and information on the samples retrieved are presented in the result chapters in the main report and the field report in the appendix.

Due to inaccurate echo sounder, the depths at the stations were not recorded.

3.3 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 wire in use was marked at the depths of the stations. 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 sediment disturbance. Disturbed samples were discarded.

Samples for analyses of hydrocarbons, metals, grain size and total organic matter were taken from the same grab sample. The hydrocarbon and metal samples were taken with suitable implements from the upper sediment layer (0 - 1 cm) while sediment for grain size analysis was taken from the upper 5 cm layer. At designated stations sub samples were taken for analysis of the vertical distribution of selected parameters. This was done by pressing a metal cylinder (10 cm long and approx. 7 cm in diameter) down in the sediment through the top opening of the grab. The samples were cut into sub samples at 1, 3 and 6 cm depths. All samples were marked and immediately frozen at -20°C.

Biological samples were taken from separate grab samples. 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 % formaldehyde solution, neutralised with borax.

The colour of the sediment profile was described from a sub sample, which was taken from one of the biological samples. The sample was gently washed out of the corer and combined with the sediment it originated from.

3.4 Sample analyses

3.4.1 Physical analyses

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.

The amount of total organic material (TOM) was determined as loss by 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.

Analysis of grain size distribution was carried out in accordance with the methodology given in Buchanan (1984). From each station three sub samples from separate grab samples were collected, mixed and thoroughly homogenised. The homogenised sample was split into 2 fractions using wet-sieving. Following, the sandy fraction (particle size larger than 0.063 mm) was further analysed using dry-sieving.

All samples were analysed without deviation from the guidelines

3.4.2 Chemical analyses

Three grab samples were taken at each station for chemical analyses. At the reference stations, two additional grab samples were collected.

The vertical distribution of hydrocarbons and metals were determined in vertical sections of core samples from selected stations. Sediments from the 0-1, 1-3 and 3-6 cm layers were analysed. At each field, core samples were collected at the field specific reference station and at the innermost and outermost stations on the main transect.

Sediments from stations with an average THC content at or above twice the value of the calculated limit of significant contamination for THC ($2xLSC_{97-00RegII}$) were analysed for NPD, 3-6-ring aromatics and decalins.

3.4.2.1 Hydrocarbons

The hydrocarbons 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.

THC was determined by gas chromatography, GC/FID, using an external standard for quantification. The base oil HDF 200 was used as reference oil and external standard for the whole region. THC was determined in all samples.

NPD, 3-6-ring aromatics and decalins in the hydrocarbon extract were analysed using gas chromatography/mass spectrometry, GC/MS, using a deuterium labelled internal standard for quantification.

Olefins in the hydrocarbon extract were identified in the gas chromatogram by comparing the profile of the sediment extract with the profile of the base oil used at the field. The amounts of olefins were quantified by GC/FID using a pure sample of the olefin-based base oil as external standard.

Esters, which are degenerated during the standard work-up procedure for hydrocarbons, were extracted from the sediment using a Soxhlet-extractor with dichloromethane as an extraction solvent. Further purification was accomplished by adsorption chromatography on a silica column. The amount of esters in the sediment was quantified by GC/FID using a pure sample of the ester-based base oil as external standard.

3.4.2.2 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).

The sediments from the regional stations were in addition analysed for Cd, Pb, Zn, Cu, Ba, Cr, aluminium (Al) and lithium (Li) using "total" digestion with hydrofluoric acid and aqua regia.

All chemical samples were analysed without deviating from the guidelines.

3.4.2.3 Calculation of Limits of Significant contamination (LSC)

Prior to the calculation of background levels and Limits of Significant Contamination (LSC), a multivariate analysis of the chemical data from all regional and reference stations was performed on the current year's data and on the data from both the present and previous regional survey(s). The results of these multivariate analyses clarify the need for a subdivision of the region into sub region(s) and indicate other "outliers".

The average background levels of chemical parameters were calculated across:

- the whole region (all reference and regional stations)
- any sub-regions (based on the chosen reference and regional stations)
- each field reference station

By comparing the background values obtained by the calculations described above, a selection of suitable background levels for calculation of LSC for this region can be performed.

The final selection of background levels and calculation of LSC are described in the results and discussion chapter for regional and reference stations. The LSC values were calculated from the chosen 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.

3.4.3 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 was carefully removed from the sediment under a magnifying glass (10x) and sorted in a limited number of main 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. If juveniles appeared among the ten most dominant organisms in the data set, the statistical analysis was conducted both with and without these in order to evaluate their importance.

All biological samples were analysed without deviation from the guidelines.

Based on the statistical analyses the following information was provided:

- ten most prevalent species for every station
- diversity index of "Shannon Wiener index" on $\log_2$ basis (McArthur & McArthur 1961)
- evenness expressed as Pielou's "J" (Pielou 1966)
- expected number of species per 100 individuals (Hulbert's ES_{100})
- cluster-analysis based on "Bray-Curtis dissimilarity index" (Bray & Curtis 1957), followed by "Group Average Sorting"
- ordination by "Multidimensional Scaling"
- species/area curves (for the 10 replicates taken at the reference stations only).

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

Multivariate analyses was performed both on the set of data from the replicate samples and on the totals for each station.

In addition to the above-mentioned (required) methods, a canonical correspondence analyses (CCA) were carried out as well:

Criteria for faunal impacts are based on a combination of multivariate analyses comprising cluster analysis and multidimensional scaling (MDS) and an evaluation of the faunal data (number of species and individuals, diversity indices, dominant taxa etc.) at each station. In this way the following four faunal groups are defined in this report:

Group A: Undisturbed fauna, generally with low dominance (no taxa present in very high numbers) and a wide range of taxa from a variety of taxonomic groups, including polychaetes, molluscs, echinoderms and crustacea, are present. Taxa indicating disturbed sediments are absent or occur in very low individual numbers.

Group B: Slightly disturbed fauna: generally with higher dominance, number of taxa and total abundance. Taxa indicating disturbed sediments, usually including polychaetes and molluscs, increase in individual numbers, but are not usually dominant.

Group C: Disturbed fauna: generally with high dominance and lower number of taxa. Taxa indicating disturbed sediments, usually including polychaetes and molluscs, occur among the dominant taxa, echinoderms rare.

Group D: Highly disturbed fauna: small deposit feeding worms totally predominate (usually polychaetes). Echinoderms absent and molluscs and crustaceans rare or absent. Low number of taxa, high total abundance.

Natural variation might occur within each group.

The most familiar taxa that occur in disturbed sediments are the polychaetes *Capitella capitata*, *Chaetozone* sp., *Cirratulus* sp., *Opryotrocha* sp. and *Ditrupa arietina* and the molluscs *Thyasira sarsi* and *T. flexuosa*, while the echinoderm *Amphiura filiformis* disappears under such conditions.

The CCA analyses combine the environmental and biological parameters and the plots presented show the biological variance between the stations and those environmental parameters that explains the variance.

The estimated area of contaminated sediments and disturbed fauna is based on a calculation of the area of an asymmetric ellipse. The radius varies from field to field and between transects within each field. In calculation, the distance to contaminated/disturbed station is used. In cases with contamination/disturbance at one to three transects, 125 m was used at non contaminated/undisturbed transects.

3.4.4 Quality control

Sampling and sample analyses were preformed by field personnel and laboratories accredited for these activities in accordance with the Norwegian Guideline and EN-45001. Copies of the accreditation documents are included 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 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 grab speed exceeded 0.2 m/sec immediately before reaching the bottom, the sample was discarded.

The limit of detection (LOD) and the limit of quantitation (LOQ) for hydrocarbons were determined to be 0.2 mg/kg and 0.4 mg/kg, respectively. The LOD and LOQ 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 standard oil. The recovery of total hydrocarbons was 85%. Reproducibility was checked with house standard sediment. The relative standard deviation over the time period was 14 %. Accuracy of the aromatic analyses was determined using the standard reference sediment SRM 1941a. The results from this analysis 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 four reference samples BCSS-1, MESS-2 and BCR-320 by the same procedure as for the samples. The results are given in the Appendix.

In order to assess sorting efficiency, a minimum of 10 % of the biological samples was subjected to control sorting. If more than 15 individuals were found in the residual sediment, all samples sorted by the same person are re-sorted. A similar control procedure is used to check the transfer of species lists to the database. A minimum of 10% of the species records for each field is checked. If the error is 1% or more, all records are checked and corrected, and a new check is conducted.

3.4.5 Storage of sample material

Analysed samples are stored at the laboratory that conducted the analyses for at least five years after the client has accepted the environmental monitoring report. Reference collections are maintained for at least ten 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.

4 Regional and reference stations

4.1 Introduction

Samples from 9 regional and 13 field reference stations were collected in the present survey. Two of the regional stations, stations RII07 and RII08, are also reference stations at the Glitne and Sleipner Vest fields, respectively. More information on these stations is shown in Figure 4-17 and Table 4-10, which can be found on the foldout page at the end of this chapter (page 4-23). The first regional survey was carried out in this region in 1997 (Mannvik *et al*., 1998). This survey did not reveal contaminated sediments or disturbed benthos communities at any regional or reference stations. Prior to 1997 single field surveys have been carried out at the different fields in the region.

4.2 Results and discussion

4.2.1 Physical characteristics

The amounts (%) of pelite, fine sand, median phi value, and total organic material (TOM) in the sediment from the present and previous survey are shown in Table 4-1 and Figure 4-1. 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 variation of the sediment structure in the region is great with a median value ranging from 1.59 (medium sand) at the Odin reference station to 4.47 (silt) at the Jotun reference station. The amount of pelite varies from 1.9 % at regional station RII06 and the reference station at Sleipner Øst (SLE41R) to19.3 % at the reference station at Jotun (JOT30R), the amount of fine sand from 5.2 % at the reference station at Odin (ODI14R) to 92.1 % at the reference station at Sigyn (SIG17R), while the TOM varies from 0.63 % at RII06 to 2.57 at JOT30R. This shows a tendency of coarser sediments in the shallower, southern part of the region (Sleipner Øst-, Sigyn- and Varg area) where the depths are less than 90 m.

Compared with the results from the 1997 survey, there is a general trend of finer sediments in the region in the present survey. This is shown by an increase in the median and pelite values at most of the stations surveyed. This is specially seen in the Balder – Heimdal area (including regional stations RII03 and RII10 and the reference stations at Balder, Jotun and Heimdal) where the TOM value as well has increased.

The results from the reference station at Odin need special attention as they differ greatly from those obtained in the previous surveys (see also chapter 14 where the results from the Odin field are presented). The median value at this station has decreased from 3.53 in 1997 to 1.59 in 2000, while the amount of pelite and fine sand in the sediment comprise less than 10 % in the present survey compared to more than 95 % in the 1997 survey. The most possible explanation for this is that the positions, where samples were collected in the two surveys, are different resulting in a different type of sediments collected.

Table 4-1: The median (phi and amount (%) of pelite, fine sand and TOM in the sediments at the regional and reference stations in Region II, 2000 (minimum and maximum values are indicated with bold text).

Station	Median	Classification	Pelite	Fine sand	TOM
RII01	3.46	Fine sand	3.2	80.2	1.11
RII02	4.04	Silt	9.1	63.4	0.94
RII03	3.83	Fine sand	9.7	77.0	1.60
RII04	2.65	Fine sand	3.0	31.5	0.73
RII06	3.48	Fine sand	**1.9**	89.5	**0.63**
RII07	3.53	Fine sand	6.8	74.3	1.38
RII08	3.68	Fine sand	11.5	80.9	1.92
RII09	3.93	Fine sand	8.4	91.0	1.78
RII10	4.22	Silt	12.4	81.5	1.96
FRI10R	3.68	Fine sand	6.3	82.0	1.18
NEF20R	3.52	Fine sand	5.6	74.4	0.99
PSB13R	3.60	Fine sand	6.5	85.5	0.97
LFR01R	3.51	Fine sand	5.5	72.0	1.08
FRY18R	3.79	Fine sand	9.3	76.5	1.50
RIN29R	4.06	Silt	14.0	85.4	2.35
SIG17R	3.50	Fine sand	2.3	**92.1**	0.68
BAL27R	4.10	Silt	14.7	84.9	2.38
JOT30R	**4.47**	Silt	**19.3**	80.3	**2.57**
ODI14R	**1.59**	Medium sand	2.7	**5.2**	0.64
VAR14R	3.48	Fine sand	2.7	84.1	0.93
HEM22R	4.14	Silt	14.4	81.6	2.02
SLE41R	3.48	Fine sand	**1.9**	90.3	0.75
Average.	3.62		7.8	75.6	1.37
St. dev.	0.59		5.0	20.1	0.62

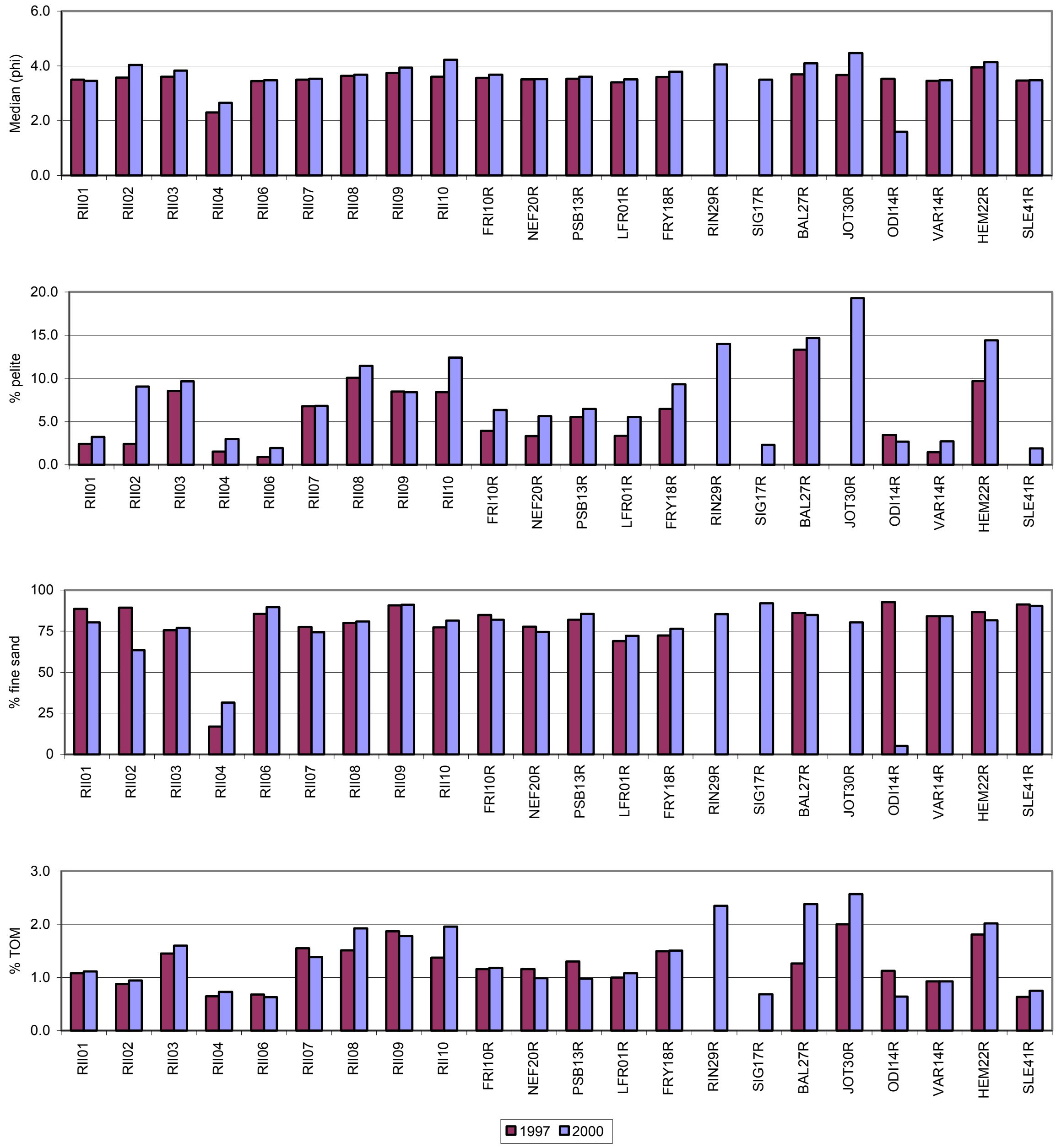

Figure 4-1: Sediment characteristics at the regional and reference stations in Region II, 2000 and the previous survey.

4.2.2 Chemical characteristics

Altogether 9 regional and 13 field reference stations are sampled in this survey. Two of the regional stations, stations RII07 and RII08, are also reference stations at the Glitne and Sleipner Vest fields respectively. Three replicate sediment samples from each of the regional stations and five from the field-specific reference stations are analysed for hydrocarbons and selected metals. The results of the chemical analyses are summarised in Table 4-2 and Table 4-3. Chemical values from 2000 are compared with those from previous years in Figure 4-4 to Figure 4-10. The full data set of replicate measurements and data from previous years are given in the Appendix.

Table 4-2: Minimum- and maximum concentrations of hydrocarbons and selected metals in sediments from reference and regional stations in Region II, 2000. All values in mg/kg dry sediment.

Parameter	Min	Station	Max	Station
THC	2.2 ± 0.4	ODI14R	8.9 ± 2.0	RII08/GLI
Cd	0.004 ± 0.002	SIG17R and SLE41R	0.035 ± 0.017	FRY18R
Hg	<0.005	RII01, RII04, SIG17R and SLE41R	0.008 ± 0.001	JOT30R
Cu	<0.6	RII06	2.1 ± 0.2	RIN29R and JOT30R
Zn	0.9 ± 0.4	RII06	9.3 ± 1.2	RIN29R and JOT30R
Ba	8 ± 1	RII06	215 ± 30	RII08/GLI
Cr	3.8 ± 0.1	RII02	9.1 ± 0.3	SLE41R
Pb	3.1 ± 0.2	RII02	6.7 ± 0.6	RII08/GLI, JOT30R and VAR14R

The chemical results show large variation in both THC and metal contents between the stations (Table 4-2 and Table 4-3.) The average concentration of zinc is ten times higher at the stations with the highest contents than at the station with the lowest content. Even bigger variations are found for barium where the average concentrations range from 8 ± 1 to 215 ± 30 mg/kg dry sediment.

The general picture of the region is that the lowest amounts of THC and selected metals are found at stations situated south in the region. These stations are RII06, VAR14R, SIG17R and SLE41R, which also are the stations with the lowest contents of pelite and TOM. The highest concentration of THC and metals are found in the central part of the region, at stations with high amounts of pelite and TOM (RIN22R, BAL27R, JOT30R, HEIM22R, RII08/GLI, RII09 and RII10.)

Comparison with previous survey (s)

Compared with the results from the 1997 survey, the general picture of the region is that the status at the regional and reference stations are almost unchanged (Figure 4-4 to Figure 4-10.) However, there is a tendency of decreased (4 mg/kg) amounts of THC north to north east in the region (including regional stations RII01, RII02 and RII03.) The THC content has also decreased (5 mg/kg) at the Balder reference station where the concentration is back to the 1996 level (see also Balder survey.) At the remaining of the regional and reference stations, the THC levels are almost unchanged since 1997. For the selected metals, the largest changes are seen at RII10 where the amount of cadmium has doubled and the amounts of lead, copper and barium have increased with 50-60% since the previous survey. Increased barium content (approximately 50%, 20-40 mg/kg) are in addition found at the Frigg, Nordøst Frigg, Lille Frigg, Heimdal and Glitne reference stations.

As mentioned earlier, the sediments sampled at the field-specific reference station at Odin contains higher proportions of medium and coarse sand than the sediments sampled in 1997 (Mannvik *et al.,* 1998.) As expected changes in THC and metal contents are found at this station (see also Odin survey where changes in chemical results at the field-specific reference station are further discussed.)

Since the last survey at the Jotun field was carried out (Jensen *et al*., 1997); the content of zinc has decreased from 15 to 9 mg/kg at the field-specific reference station. The concentrations of THC and the remaining metals are almost unchanged (for further information see Jotun survey, 2000.)

Table 4-3: The concentrations of THC and metals in sediments from the regional and reference stations in Rregion II, 2000. All values in mg/kg dry sediment.

Station	THC		Cd		Hg		Cu		Zn		Ba		Cr		Pb	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
RII01	3.1	0.9	0.023	0.003	<0.005	-	1.0	0.1	2.2	0.6	34	6	5.3	0.3	3.2	0.2
RII02	2.5	0.8	0.012	0.001	0.003	0.001	0.9	0.1	1.7	0.2	51	8	3.8	0.1	3.1	0.2
RII03	3.7	0.4	0.019	0.002	0.007	0.002	1.3	0.1	5.0	0.6	82	12	5.7	0.4	5.3	0.2
RII04	3.5	0.4	0.011	0.002	<0.005	-	0.7	0.1	3.2	0.2	23	10	5.6	0.2	5.0	0.2
RII06	2.4	0.1	0.007	0.001	0.006	0.007	<0.6	-	0.9	0.4	8	1	6.5	0.4	4.6	0.1
RII07/SLV	5.5	2.0	0.017	0.002	0.005	0.003	1.1	0.1	7.0	0.6	90	8	9.0	0.3	6.6	0.2
RII08/GLI	8.9	2.0	0.014	0.003	0.006	0.002	1.4	0.2	7.4	2.1	215	30	8.4	0.8	6.7	0.6
RII09	6.8	1.5	0.022	0.005	0.007	0.002	1.3	0.1	5.6	0.2	111	17	7.1	0.2	4.8	0.6
RII10	5.8	1.8	0.022	0.001	0.006	0.001	1.5	0.1	5.9	0.3	90	12	6.4	0.2	4.9	0.1
FRI10R	4.5	1.2	0.015	0.003	0.004	0.001	1.0	0.1	5.4	0.2	67	10	4.4	0.2	3.7	0.1
NEF20R	6.2	1.0	0.014	0.007	0.004	0.002	0.9	0.2	2.5	0.6	78	16	4.7	0.2	3.4	0.2
PSB13R	6.0	0.7	0.013	0.001	0.004	0.002	1.4	0.6	2.6	0.5	60	18	4.1	0.2	3.6	0.1
LFR01R	7.9	0.8	0.017	0.002	0.003	0.001	1.0	0.0	5.1	0.1	74	25	5.0	0.1	3.6	0.1
FRY18R	5.3	1.3	0.035	0.017	0.005	0.001	1.6	0.0	5.3	0.3	80	13	5.9	0.2	4.9	0.4
RIN29R	8.2	1.2	0.029	0.004	0.007	0.001	2.1	0.2	9.3	1.2	86	21	8.7	0.7	6.9	0.5
SIG17R	2.9	1.0	0.004	0.002	<0.005	-	0.5	0.2	3.7	0.3	13	2	7.8	0.3	5.5	0.2
BAL27R	6.0	1.4	0.026	0.004	0.007	0.001	1.9	0.2	8.9	0.8	123	14	8.2	0.5	6.5	0.5
JOT30R	5.1	1.5	0.029	0.004	0.008	0.001	2.1	0.2	9.3	1.1	93	24	8.7	0.8	6.7	0.6
ODI14R	2.2	0.4	0.015	0.003	0.005	0.005	0.9	0.2	3.6	0.7	51	13	5.7	0.5	4.8	0.3
VAR14R	4.7	0.7	0.006	0.001	0.004	0.002	0.8	0.1	5.2	0.1	34	6	7.9	0.2	6.7	0.1
HEM22R	8.5	1.4	0.026	0.002	0.007	0.000	2.0	0.2	7.7	0.8	131	20	6.7	0.5	6.0	0.4
SLE41R	5.4	1.4	0.004	0.002	<0.005	-	1.0	1.2	4.3	0.9	18	9	9.1	0.3	6.3	0.1

Background levels and calculated limits of significant contamination

Natural background levels of THC, NPD´s, 3-6 ring aromatics, decalins and metals will always be present in the sediments. Different natural background levels of chemical parameters reflect differences in sediment characteristics across the region.

As a basis for dividing Region II into possible sub regions, PCA analyses are performed on the chemical results. Figure 4-2 shows a PCA-plot based on this year's results and Figure 4-3 shows the PCA-plot of both the 1997 and 2000 data. In Figure 4-2, regional and reference stations in the shallow area located south in the region, in addition to RII04, separate out with the lowest concentrations of barium and cadmium. In Figure 4-3, the same stations separate out with the lowest concentrations of THC, barium and copper. The granulometric composition of the sediments at RII04, located north east of the shallow area, differs from the general structure found across shallow area. When the lower contents of THC, copper and barium in sediments from the shallow area are taken in account, it seems reasonable to split the background material into a sub region consisting of RII06, VAR14R, SIG17R and SLE41R. The cluster and MSD analyses (Figure 4-14 and Figure 4-15) carried out on the whole data set from the regional and reference stations support this choice of sub region.

The background levels of THC and metals across Region II are calculated from the analyses results obtained at the 9 regional and 13 reference stations in the present (2000) and previous (1997) surveys in the region. The levels are compiled in Table 4-4 together with the background levels of THC and metals across the shallow sub region ($Backgr_{97\text{-}00\ shallow\ RegII}$) calculated from the1997 and 2000 data at RII06, VAR14R, SIG17R and SLE41R.

Table 4-4: Background levels (mean ± st.dev.) and calculated Limits of Significant Contamination (LSC) of sediments in Region II and the shallow subregion, 2000. All values in mg/kg dry sediment.

	THC	Cd	Hg	Cu	Zn	Ba	Cr	Pb
$Backgr_{97\text{-}00\ RegII}$	5.9 ± 2.3	0.015 ± 0.008	0.005 ± 0.002	1.2 ± 0.5	4.9 ± 2.3	69 ± 45	6.6 ± 1.7	4.5 ± 1.4
$Backgr_{97\text{-}00\ shallow\ RegII}$	3.7 ± 1.4	0.005 ± 0.001	0.003 ± 0.001	0.6 ± 0.3	3.8 ± 2.0	17 ± 10	7.8 ± 1.1	5.4 ± 0.9
$LSC_{97\text{-}00\ RegII}$	9.8	0.029	0.008	2.0	8.9	146	9.6	7.0
$LSC_{97\text{-}00\ shallow\ RegII}$	6.6	0.008	0.006	1.2	8.1	38	10.2	7.4

Statistical treatment of the analytical results 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 in Region II ($LSC_{97\text{-}00\ RegII}$) and in the shallow sub region ($LSC_{97\text{-}00\ shallow\ RegII}$) are given in Table 4-4. 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:

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

where: mean = mean value over the stations investigated, t= students t-value from statistical tables and N = number of stations

At each field, the criteria for using the $LSC_{97\text{-}00\ RegII}$ to assess the contaminated area is that the background levels across the Region II are representative for natural variation in the field-area. The fields located in the central part of the region, Jotun, Ringhorne, Balder and Glitne have higher sediment concentrations of pelite than the general level found across Region II. Higher background levels of metals reflect this dissimilarity in sediment composition. The naturally higher background levels of metals are taken in to account when the areas contaminated with metals are described at these fields. The $LSC_{97\text{-}00\ shallow\ RegII}$ are used to assign areas contaminated with THC and metals in the shallow sub region.

Synthetic base oils as esters and olefins that are included in synthetic drilling muds, are not present in uncontaminated sediments. If these compounds are found in the sediments, the sediments are considered as contaminated.

The regional stations are not analysed for aromatic hydrocarbons and decalins. The stations considered contaminated with these compounds are therefore assigned by using the LSC values calculated from the results of the chemical analyses at the field-specific reference station. The LSC values are calculated from the LSC formula (1):

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

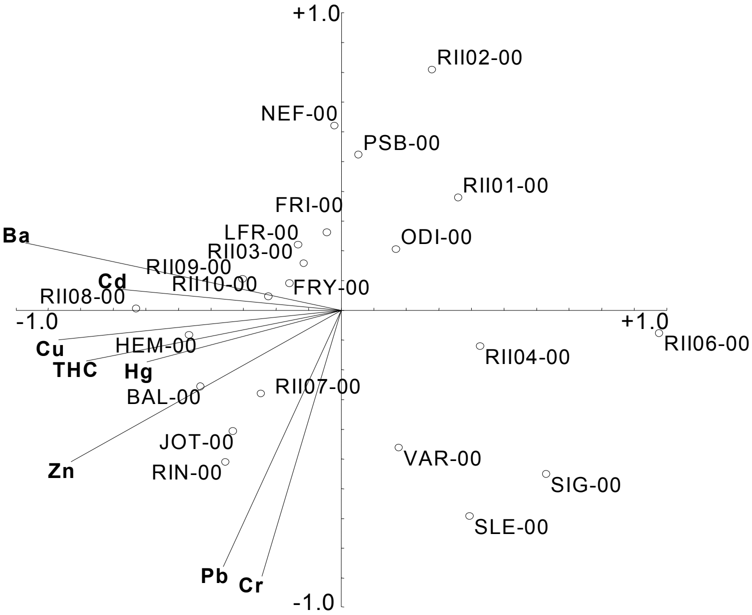

Figure 4-2: PCA plot based on the chemical data from the regional and reference stations form Region II, 2000.

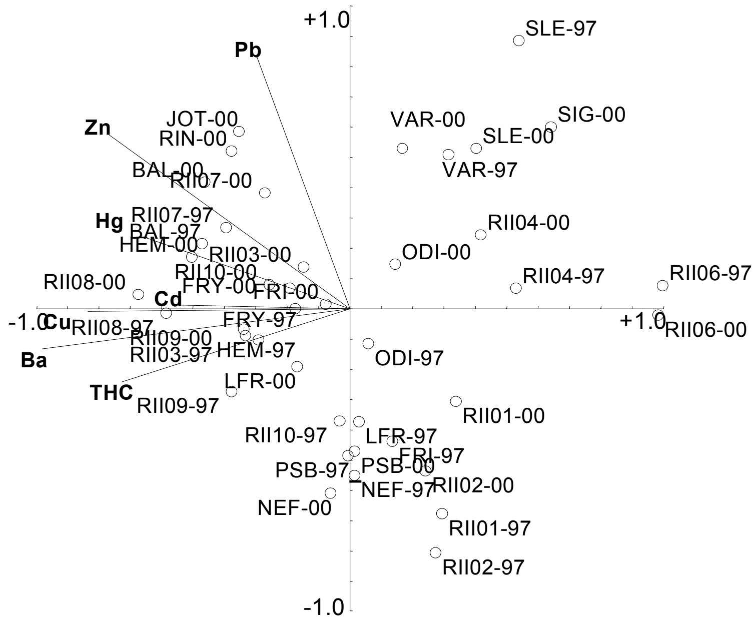

Figure 4-3: PCA plot based on the chemical data from the regional and reference stations from Region II, 1997-2000.

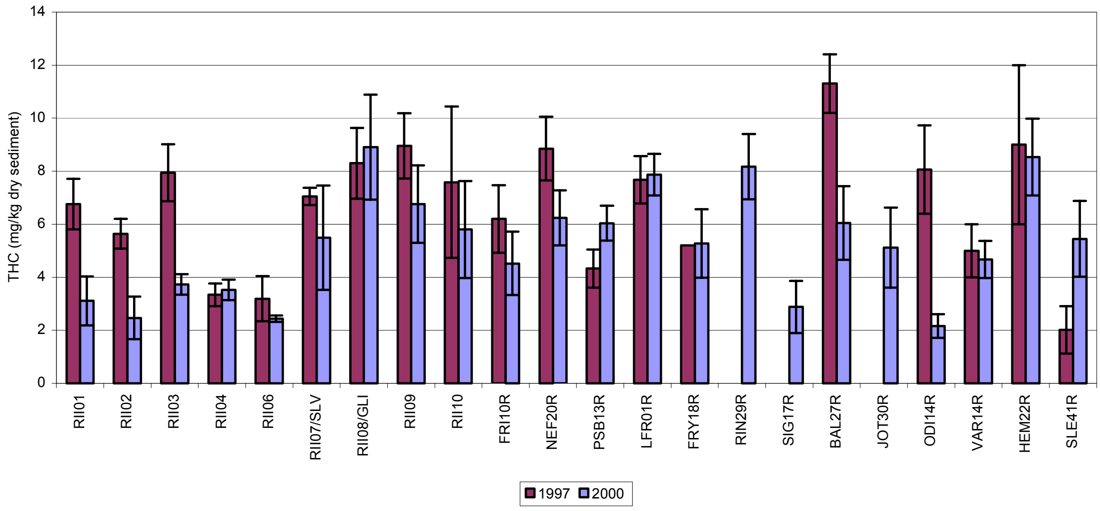

Figure 4-4: THC levels in sediment from regional and reference stations from the present (2000) and previous surveys in Region II.

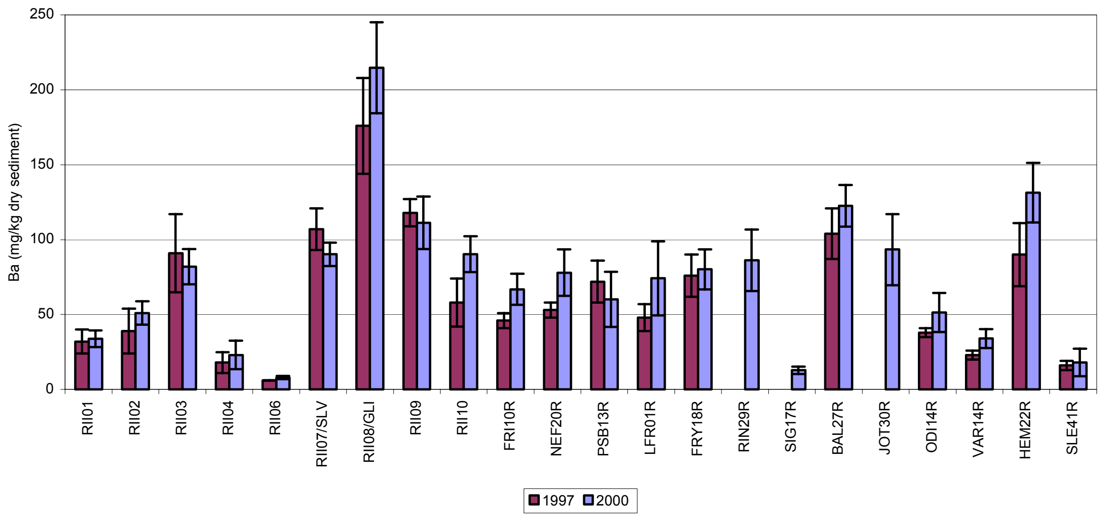

Figure 4-5:Barium levels in sediment from regional and reference stations from the present (2000) and previous surveys in Region II.

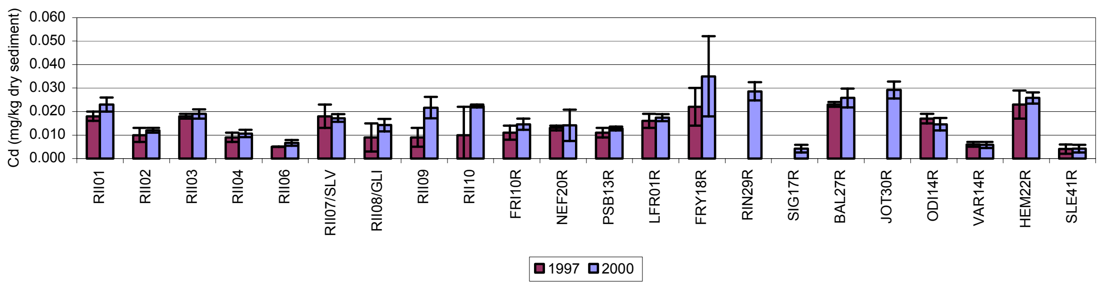

Figure 4-6: Cadmium levels in sediment from regional and reference stations from the present (2000) and previous surveys in Region II.

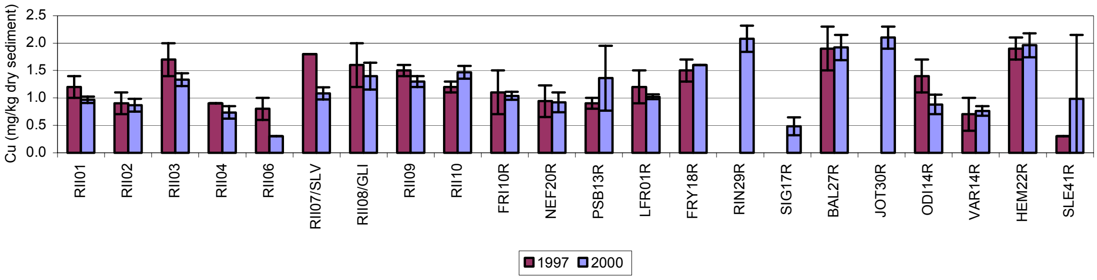

Figure 4-7 : Copper levels in sediment from regional and reference stations from the present (2000) and previous surveys in Region II.

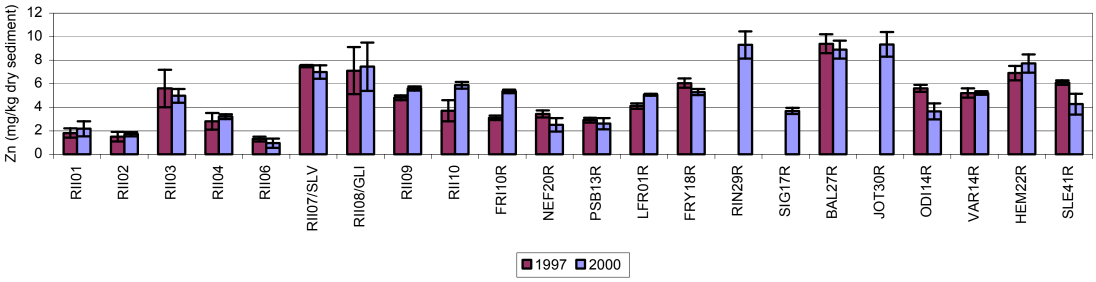

Figure 4-8: Zinc levels in sediment from regional and reference stations from the present (2000) and previous surveys in Region II.

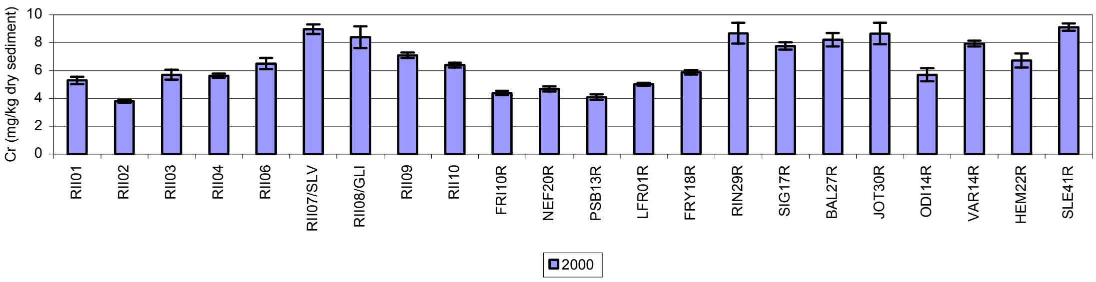

Figure 4-9: Chrome levels in sediment from regional and reference stations from the present (2000) and previous surveys in Region II.

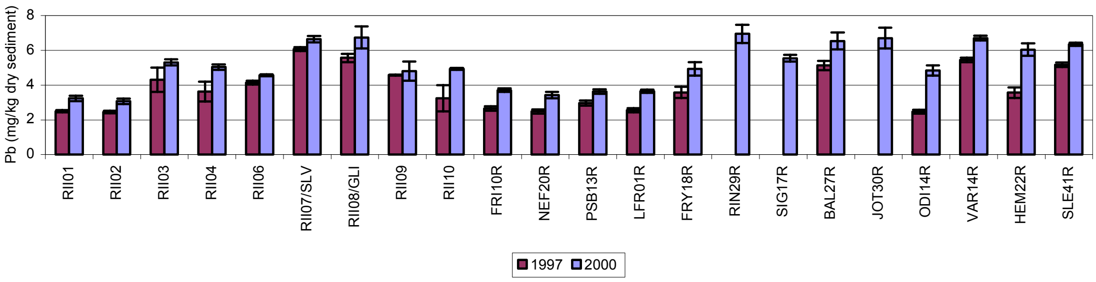

Figure 4-10: Lead levels in sediment from regional and reference stations from the present (2000) and previous surveys in Region II.

The sediments from the regional stations are analysed for metals by two different analytical procedures. The sediment samples are first analysed for cadmium, mercury, copper, zinc, barium, chromium and lead by extraction of metals from the sediments by using nitric acid (NS 4770.) However, this procedure does not compensate for inherent differences in metal content related to the granulometric composition of the sediments.

Digestion with hydrofluoric acid (HF) and aqua regia is an improved extraction technique that results in larger yield of a metal compared to the total amount of an element in a sediment sample. The sediments from the regional stations digested with HF/aqua regia are, in addition to cadmium, copper, zinc, barium, lead and chromium, analysed for lithium and aluminium. The lithium and aluminium concentrations can be used to normalise the metal values. By using this method, it is to a larger extent possible to compare metal values from areas with different sediment composition and thus different natural metal content (Loring 1990). The average content of metals found by analyses of three replicate sediment samples from each regional station by using HF/aqua regia are summarised in Table 4-5 together with the average concentrations of metals found in the same three replicate sediment samples by using nitric acid. The full data set of replicate measurements is given in the Appendix.

As expected, the concentrations found by digestion with HF/aqua regia are higher than the concentrations found by using nitric acid. The relative amount of an element found by “partial” digestion with nitric acid, and by “total” digestion HF/aqua regia varies depending upon the sediment structure/mineralogy at the station. This is illustrated by the concentrations of barium found at the regional stations RII06 and RII08/GLI. At station RII06 the mean barium content are 8 mg/kg (NS1470) and 260 mg/kg (HF/aqua regia) whereas the concentrations at RII08/GLI are 215 mg/kg (NS1470) and 497 mg/kg (HF/aqua regia.) Thus a change in extraction method from digestion with nitric acid to “total” digestion results in 33 and 2 times higher concentrations of barium. For the remaining metals, except cadmium, the concentrations found by “total” digestion range from 1.6 to 12 times the levels found by digestion with nitric acid.

The concentrations of barium and lead are plotted against the concentration of lithium and aluminium in Figure 4-11. A certain correlation between increased concentrations of barium and increased concentrations of aluminium might be seen. The points are more random distributed for barium against lithium and for lead against both lithium and aluminium. Principally, anthropogenic trace metal input to sediments shall give an anomalous point in a scatter plot. The number of measurements is limited and anomalous points in a plot may also rise if the normalisation method is unsuitable for the sediment.

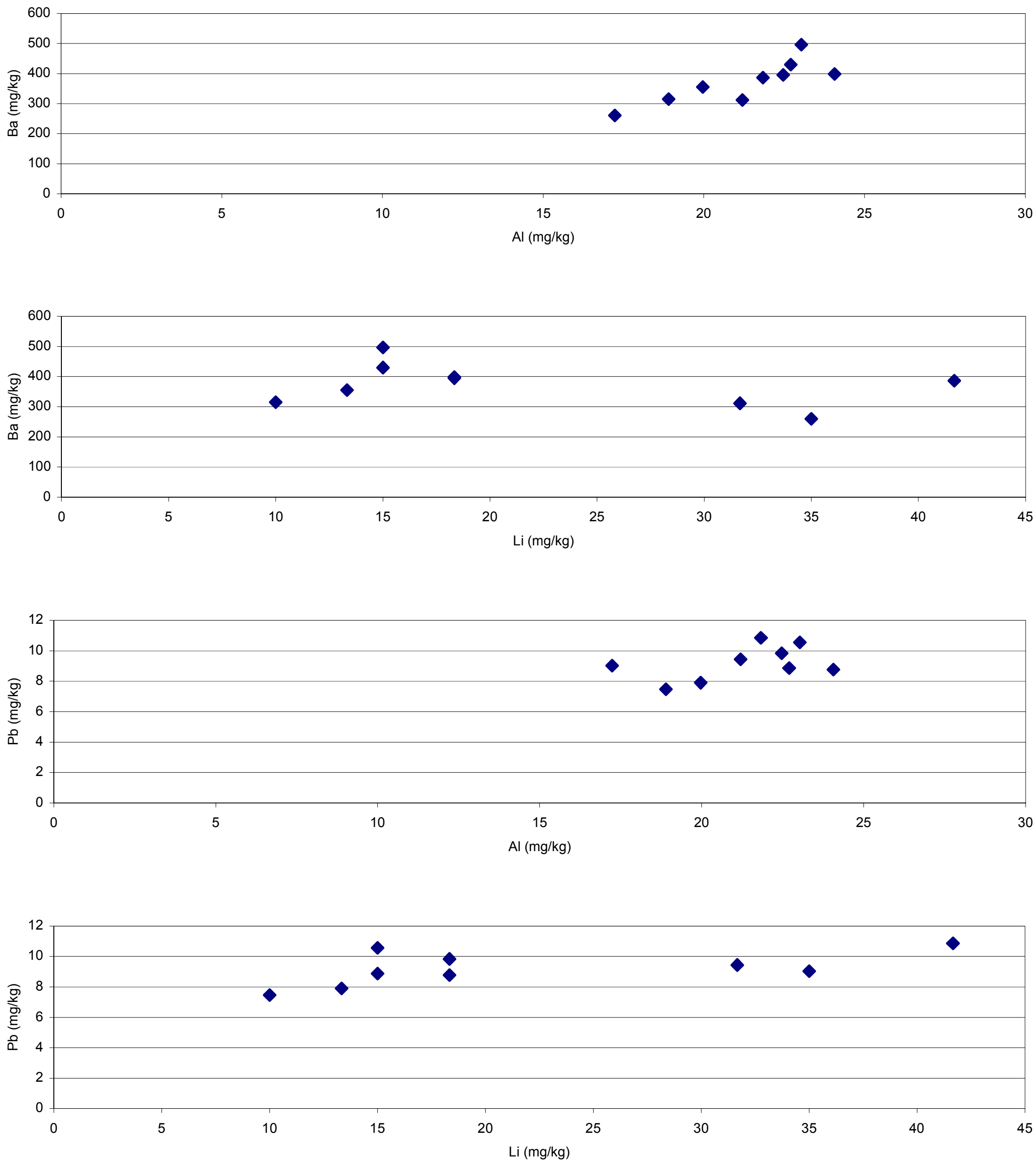

Figure 4-11: Scatter plot of concentrations of some selected metals in sediments against the concentration of lithium at the regional stations in Region II, 2000.

Table 4-5: The average concentrations of metals found by analysis of three replicate sediment samples at the regional stations in Region II, 2000, after digestion with nitric acid (NS 4770) and HF/ aqua regia. All values in mg/kg dry sediment.

Station	Cd		Cu		Zn		Ba		Cr		Pb		Al	Li
	NS4770	total	NS4770	total	NS4770	total	NS4770	total	NS4770	total	NS4770	total	total	total
RII01	0.023	0.025	1.0	1.9	2.2	14.0	34	315	5.3	10.0	3.2	7.5	18.9	10
RII02	0.012	<0.03	0.9	1.9	1.7	13.0	51	355	3.8	7.5	3.1	7.9	20.0	13
RII03	0.019	<0.03	1.3	2.4	5.0	15.0	82	395	5.7	10.5	5.3	9.8	22.5	18
RII04	0.011	<0.03	0.7	1.5	3.2	13.3	23	312	5.6	10.3	5.0	9.4	21.2	32
RII06	0.007	<0.03	<0.6	1.1	0.8	9.7	8	260	6.5	11.8	4.6	9.0	17.2	35
RII07/SLV	0.018	<0.03	1.1	3.4	7.0	18.7	95	387	9.0	15.3	6.6	10.9	21.8	42
RII08/GLI	0.014	<0.03	1.3	2.3	7.5	18.0	215	497	8.2	15.7	6.6	10.6	23.0	15
RII09	0.022	0.025	1.3	2.2	5.6	17.7	111	430	7.1	13.3	4.8	8.9	22.7	15
RII10	0.022	0.030	1.5	2.4	5.9	13.3	90	398	6.4	13.0	4.9	8.8	24.1	18

4.2.3 Biology

The distribution of individuals and taxa within the main taxonomic groups are given in Table 4-6.A total of 23353 individuals from 368 taxa were registered at the regional and reference stations in Region II in the present survey (excluding juveniles). The polychaetes dominate the fauna with 69 % of the individuals and 55 % of the taxa recorded.

Table 4-6: Distribution of taxa and individuals within the main taxonomic groups at the regional and reference stations in Region II, 2000.

Main taxonomic groups	Individuals		Taxa	
	Number	%	Number	%
Polychaeta	16147	69	201	55
Mollusca	2500	11	63	17
Crustacea	1413	6	72	20
Echinodermata	1647	7	13	4
Diverse groups	1646	7	19	5
Total	23353	100	368	100

The number of individuals and taxa at each station, together with selected community indices are presented in Table 4-7 and Figure 4-12. The number of individuals varies from 236 at VAR14R to 2994 at RII02, the number of taxa from 46 at SLE41R to 149 at FRY18R, the diversity index H’ from 3.4 at RII02 to HEM22R, the evenness index J from 0.50 at RII02 to 0.81 at ODI14R and HEN22R while the ES100 varies from 21 at RII02 to 44 at ODI14R and HEM22R. The number of individuals and taxa are lowest in the coarser, southern part of the region (Sleipner Øst, Sigyn and Balder).

Compared with the results from 1997, the numbers of individuals and taxa have decreased at most of the stations, with the exception of regional station RII02 and the reference stations at Frøy, Balder and Jotun. The diversity index H’ and the ES_{100} have also decreased at most of the station between 1997 and 2000.

Table 4-7: Number of individuals and taxa and selected community indices for each station (0.5 m^2) sampled at the regional and reference stations, 2000. (Minimum and maximum values are indicated with bold text.)

Station	No. of ind.	No. of taxa	H'	J	ES_{100}
RII01	377	69	4.5	0.74	35
RII02	**2994**	123	**3.4**	**0.50**	**21**
RII03	1523	127	4.7	0.67	37
RII04	676	98	5.2	0.78	41
RII06	245	54	4.6	0.80	34
RII07	692	90	5.1	0.78	39
RII08	647	96	5.0	0.76	38
RII09	1221	118	5.2	0.76	38
RII10	1200	128	5.4	0.77	40
FRI10R	1591	126	4.9	0.71	35
NEF20R	1221	68	4.0	0.66	25
PSB13R	1457	118	4.9	0.72	34
LFR01R	1523	119	4.9	0.71	35
FRY18R	2289	**149**	5.4	0.74	40
RIN29R	824	104	5.0	0.75	37
SIG17R	266	59	4.6	0.77	35
BAL27R	1073	118	5.4	0.78	41
JOT30R	1219	116	5.2	0.76	39
ODI14R	697	103	5.4	**0.81**	**44**
VAR14R	**236**	53	4.6	0.80	34
HEM22R	1032	119	**5.6**	**0.81**	**44**
SLE41R	340	**46**	4.0	0.73	28
Sum	23343				
Average.	1061	100	4.9	0.74	36
St. dev.	684	29	0.5	0.07	6

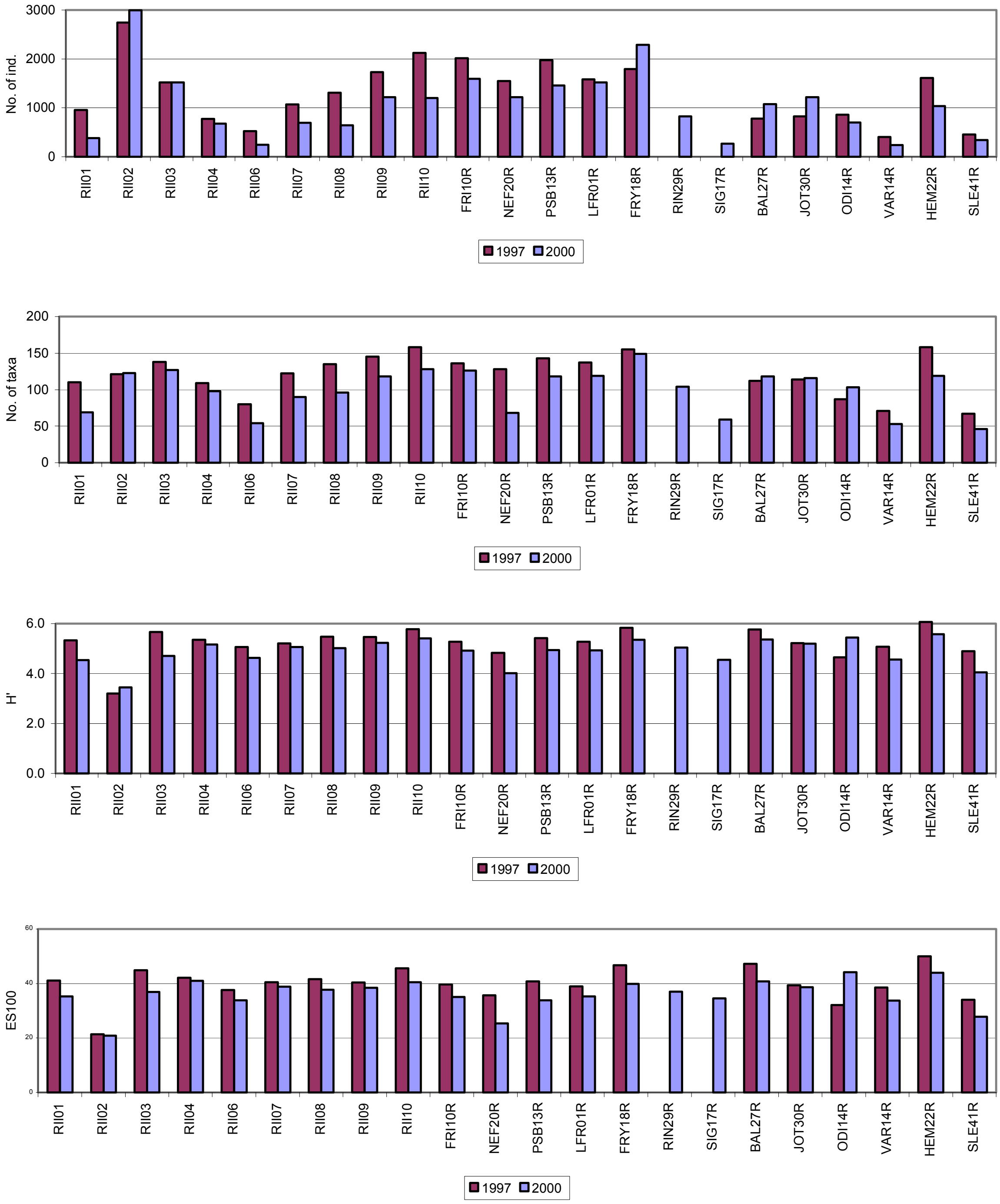

Figure 4-12: Biological characteristics from the regional and reference stations in Region II, 2000 and the previous survey.

The distribution of taxa in geometrical classes at each station is shown in Figure 4-13. Regional station RII02 has taxa in class 11 (1024 – 2047 individuals), regional station RII03 has taxa in class 10 (512 – 1023 individuals), while four stations (the reference stations at Frigg, Nordøst Frigg, Lille Frigg and Frøy) have taxa in class 9 (256 – 511 individuals) and the rest of the stations have taxa in class 8 and lower (< 256 individuals). Occurrence of taxa in high classes might indicate faunal disturbance.

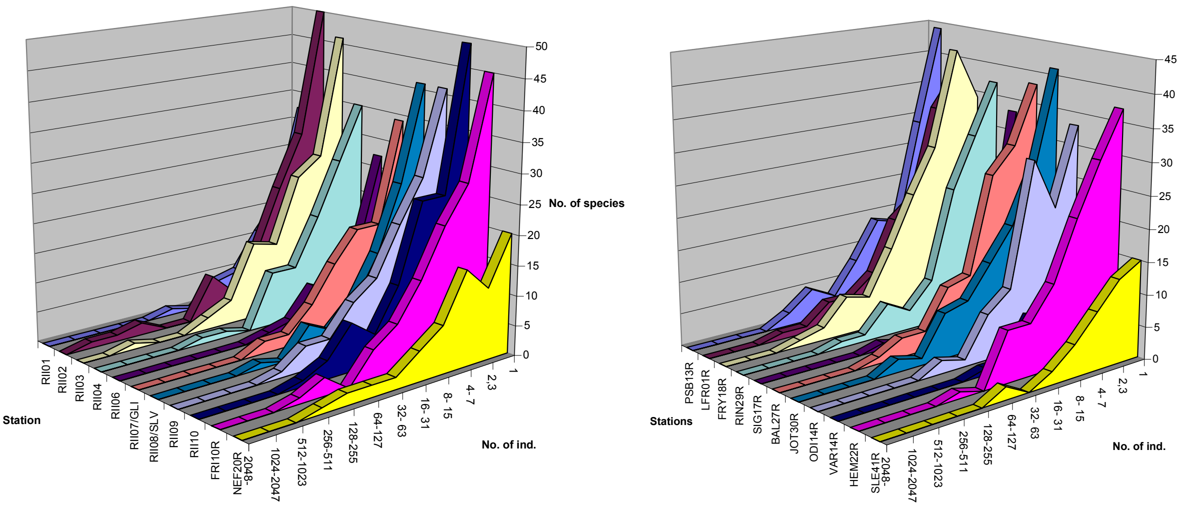

Figure 4-13: Distribution of taxa in geometrical classes for the regional stations in Region II, 2000.

The ten most dominant taxa at each of the 22 regional and reference station are shown in Table 4-9 at the end of this chapter. A total of 53 taxa, inclusive three juvenile groups, are among the ten most dominant taxa at one or more of the stations. These 53 taxa comprise 82 % of the total number of individuals and 14 % of the total number of taxa registered at the regional and reference stations in the present survey.

The most dominant taxa among the adult forms are the polychaetes *Galathowenia oculata*, *Owenia fusiformis*, *Spiophanes bombyx*, *S. kroyeri*, *Myriochele fragilis* and *Paramphinome jeffreysii*, the brittle star *Amphiura filiformis* and the phoronid *Phoronis* sp. The polychaetes *G. oculata* and *S. bombyx* are among the most dominant taxa at 18 of the 22 stations, while the other taxa mentioned above have such status at 10 or more of the stations. The polychaete *Chaetozone* sp. occur among the ten most dominant at regional station RII01, RII02 and RII07. At regional station RII02 it is present with 50 individuals.

The ten most dominant taxa comprise between 48 % (at HEM22R) and 83 % (at RII02) of the total number of individuals registered at the respective station.

Figure 4-14 shows the dendrogram from the cluster analysis for the regional and reference stations in Region II while Figure 4-15 shows the 2-D plot from the MDS analysis.

In the cluster analysis, regional stations RII01 and RII06 and the reference stations at Sleipner Øst, Varg and Sigyn are separated out at approximately 69 % dissimilarity level. These stations are further separated from each other at dissimilarity levels between 56 and 35 %. Among the other stations, the Odin reference station is separated out at 66 % level, regional stations RII08 and RII04 at 55 and 53 %, respectively, while the remaining stations are separated into two main groups at 49 % dissimilarity levels. Within these groups the stations are separated from each other at dissimilarity levels between 48 and 27 %.

The result indicates highest faunal similarity between the reference stations at Balder, Jotun, Ringhorne, Heimdal and regional station RII10, all located in the central part of Region II. Other stations forming groups are regional station RII03 and the Frøy reference station and the reference stations at Frigg, Lille Frigg and Øst Frigg.

The 2-D plot from the MDS analyses isolates the Odin reference station in the upper, central part of the plot and the regional station RII06 together with the reference stations at Varg, Sigyn and Sleipner Øst in the right part.

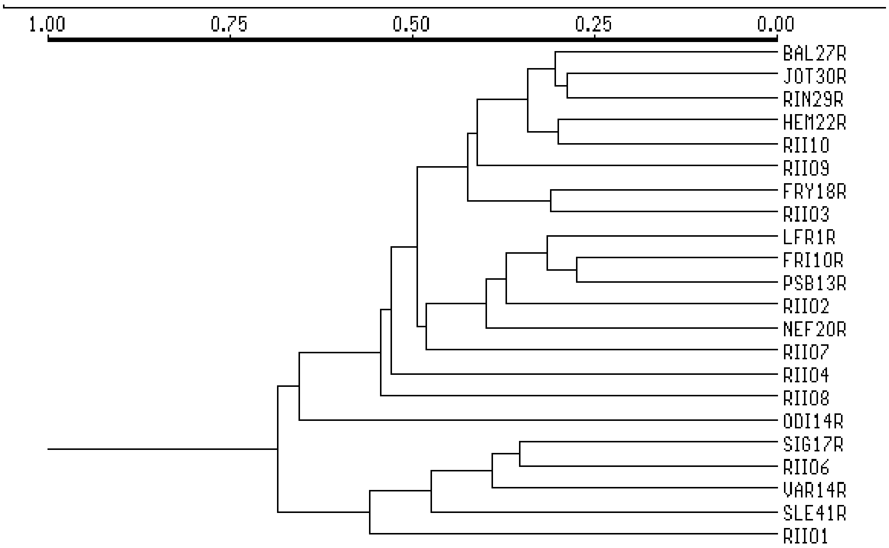

Figure 4-14: Cluster analysis of the regional and reference stations in Region II, 2000.

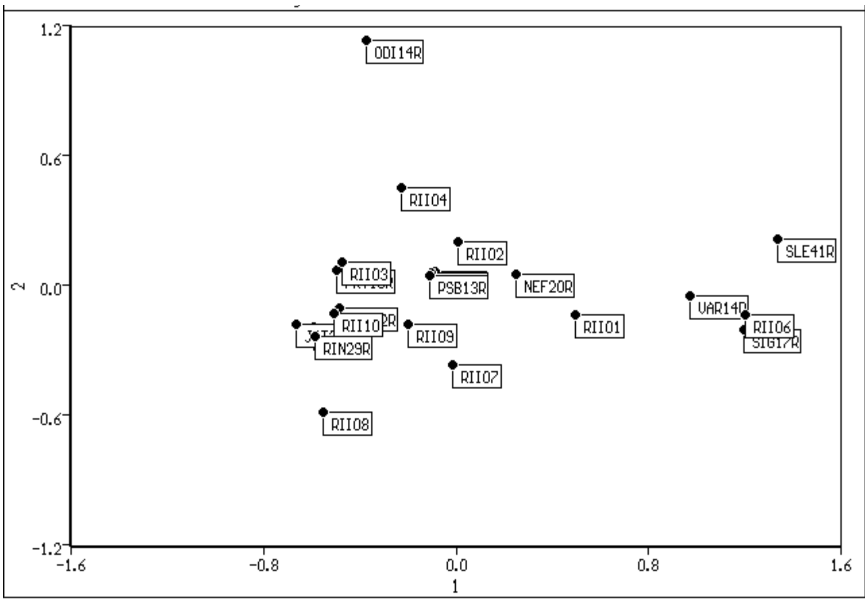

Figure 4-15: 2-D plot form the MDS analysis carried out on the data from the regional and reference stations in Region II, 2000.

A Canonical Correspondence Analysis (CCA) of the data from the regional and reference stations was carried out to examine the association between the biological data and the measured environmental variables in these areas. The analysis was carried out excluding the data from Odin reference station due to the differences revealed in the cluster analysis for the whole region. CCA including Odin reference station is given in the Appendix.

Through the forward selection procedure in CANOCO, three of ten variables gave the best fit and were significant. 32.5 % of the biological variance was explained by the first two axes of the ordination space which is constrained by these environmental variables.

Figure 4-16 shows a biplot from the analysis using zinc (Zn), chromium (Cr) and pelite (Pel) as the constraining environmental variables. The first axis shows a gradient from regional station RII02 on the positive end to regional station RII07 on the negative end and is negatively correlated with the amount of zinc (- 0.88) and chromium (- 0.88) in the sediments. Stations on the positive end of this axis have lower Zn and Cr content in the sediment than those on the negative end. The taxa with highest contribution on this axis are the polychaetes *Owenia fusiformis* (30.2 %), *Myriochele danielsseni* (19.9 %), *Paramphinome jeffreysii* (7.4 %) and *Myriochele fragilis* (4.8 %).

The second axis shows a gradient from the Sleipner Øst reference station SLE41R on the positive end to the Jotun reference station JOT30R on the negative end and is negatively correlated with the amount of pelite (- 0.84) in the sediments. Stations on the positive end of this axis have lower pelite content in the sediments than those on the negative end. The taxa with highest contribution on this axis are the brittle star Amphiura filiformis (12.9 %) and the bivalve Thyasira croulinensis (3.6 %).

All taxa that occur with high contribution on the first and second axes are known to abundant in undisturbed sediments, indicating that the faunal distribution on the regional and reference stations are a result of natural variation in the sediment structure.

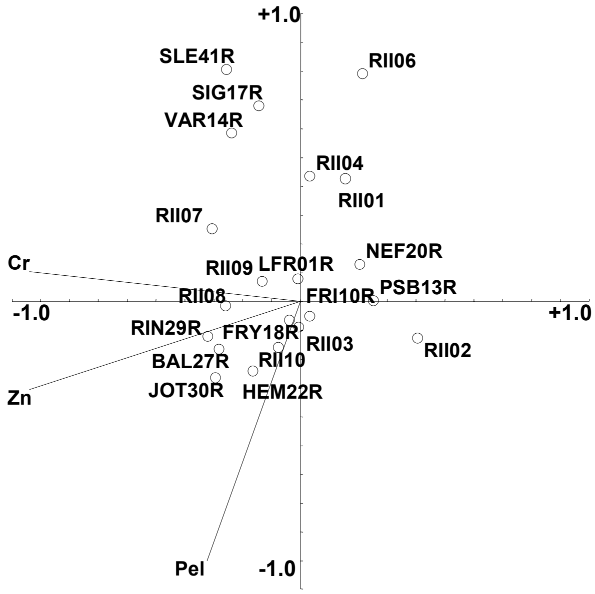

Figure 4-16: Biplot from the CCA analysis for the regional and reference stations in Region II, 2000.

On the basis of the results from the uni- and multivariate analyses carried out on the data from the regional and reference stations in Region II, all stations are classified as group A stations (undisturbed fauna). Some biological statistics from the stations are summarised in Table 4-8. As can be seen from the table, a great variation in species composition occurs among the stations. The regional station RII01 and RII06 together with the reference stations at Varg, Sigyn and Sleipner Øst have very low numbers of individuals and taxa while regional station RII02 and the reference station at Frøy have high numbers.

The polychaetes *Galathowenia oculata* and *Spiophanes bombyx* are the most dominant taxa occurring among the ten most dominant taxa at 18 of the 22 stations. The polychaete *Owenia fusiformis* is recorded with 1085 individuals at regional station RII02. At the same station the polychaete *Chaetozone* sp., known to increase in abundance in disturbed sediments, is registered with 50 individuals. However, all measured chemical parameters and the TOM has low values, indicating that these results can not be related to the petroleum activity in the Region.

The CCA show significant correlation between the faunal distribution and the amount of zinc, chromium and pelite in the sediments. As mentioned above, the amount of zinc and chromium are low, and it is believed that the faunal distribution is related to natural variation in the sediment structure.

Table 4-8: Biological statistics for the regional and reference stations in Region II, 2000 (the species occurrence among top 10 at the stations are marked with bold figures).

Station	Statistics			No. of individuals										
	No. ind.	No. taxa	H'	Goc	Ofu	Sbo	Skr	Mfr	Pje	Tcr	Afi	Psp	Cca	Csp
RII01	377	69	4.5	**16**	**11**	**29**	**24**	1	5	0	**114**	**17**	**8**	**8**
RII02	2994	123	3.4	**302**	**1085**	34	**40**	**270**	2	2	**62**	**36**	0	**50**
RII03	1523	127	4.7	**520**	**31**	**54**	**50**	**73**	1	**96**	25	20	1	1
RII04	676	98	5.2	**69**	**22**	**144**	**19**	**19**	**19**	0	10	**21**	0	4
RII06	245	54	4.6	2	0	**11**	**10**	0	3	0	**47**	**13**	0	0
RII07	692	90	5.1	**92**	0	14	**36**	0	**58**	0	**113**	**18**	0	**19**
RII08	647	96	5.0	**36**	15	0	**42**	2	**132**	**32**	**35**	8	0	1
RII09	1221	118	5.2	**176**	**74**	**103**	25	2	**66**	10	**115**	**49**	0	7
RII10	1200	128	5.4	**142**	3	**106**	33	5	**58**	**102**	33	**44**	0	1
FRI10R	1591	126	4.9	**256**	**62**	**216**	45	**48**	25	14	**146**	**160**	0	13
NEF20R	1221	68	4.0	**301**	**227**	**149**	**70**	0	8	2	**68**	23	0	19
PSB13R	1457	118	4.9	**223**	**98**	**121**	**65**	**116**	12	19	**132**	37	0	28
LFR01R	1523	119	4.9	**312**	**115**	**55**	44	**105**	20	6	**156**	**66**	2	17
FRY18R	2289	149	5.4	**400**	54	**111**	79	**141**	2	**101**	60	**90**	0	11
RIN29R	824	104	5.0	**49**	1	**151**	**29**	0	**80**	**30**	5	0	1	0
SIG17R	266	59	4.6	0	**7**	**13**	**8**	0	6	0	**72**	**11**	0	1
BAL27R	1073	118	5.4	**59**	1	**94**	23	1	**72**	**49**	16	**147**	0	0
JOT30R	1219	116	5.2	**55**	1	**191**	**39**	0	**157**	**46**	6	**49**	11	0
ODI14R	697	103	5.4	**112**	2	5	14	0	8	0	1	5	0	0
VAR14R	236	53	4.6	2	1	**13**	**12**	0	**10**	0	**56**	**13**	0	0
HEM22R	1032	119	5.6	**61**	1	**46**	**32**	11	**35**	**143**	**41**	**58**	0	0
SLE41R	340	46	4.0	0	4	**16**	7	0	7	0	**75**	**14**	0	0

Goc = *Galathowenia oculata*, Ofu = *Owenia fusiformis*, Sbo = *Spiophanes bombyx*, Skr = *S. kroyeri*, Mfr = *Myriochele oculata*, Pje = *Paramphinome jeffreysii*, Csp = *Chaetozone* sp. (incl. *C. setosa*), Cca = *Capitella capitata*, Afi = *Amphiura filiformis*, Psp = *Phoronis* sp., Tcr = *Thyasira croulinensis*.

4.3 Summary and conclusions

The sediment structure varies greatly at the regional and reference stations in Region II. There are coarser sediments in the shallower, southern part of the region (Sleipner Øst-, Sigyn- and Varg area) where the depths are less than 90 m compared to that found in the central part of the region (Jotun, Heimdal and Balder area).

Compared with the results from the 1997 survey, there is a general trend of finer sediments in the region in the present survey. This is shown by an increase in the median and pelite values at most of the stations that are included. This is specially seen in the Balder – Heimdal area (including regional stations RII03 and RII10 and the reference stations at Balder, Jotun and Heimdal) where the TOM value as well has increased.

The results from the reference station at Odin need special attention as they differ greatly from those obtained in the previous surveys (see also chapter 14 where the results from the Odin field are presented). The median value at this station has decreased from 3.53 in 1997 to 1.59 in 2000, while the amount of pelite and fine sand in the sediment comprise less than 10 % in the present survey compared to more than 95 % in the 1997 survey. The most possible explanation for this is that the positions, where samples were collected in the two surveys, are different resulting in a different type of sediments collected.

The total hydrocarbon content (THC) at the regional and reference stations range from 2.2 to 8.9 mg/kg dry sediment. The mean barium concentrations range from 8 to 215 mg/kg. The amounts of cadmium, mercury and copper range from levels below the detection limits to 0,035, 0.008 and 2.1 mg/kg respectively. For zinc, the average concentration is ten times higher at the stations with the highest contents (9.3 mg/kg) than at the station with the lowest content (0.9 mg/kg.) The amounts of chromium and lead ranges from 3.8 to 9.1 mg/kg and 3.1 to 6.7 mg/kg respectively. In general, the highest amounts of THC and metals are found at stations with high contents of pelite and TOM. These stations are located in the central part of the region. The lowest amounts of THC, metals pelite and TOM are found at stations in shallow area south in the region (RII06, VAR14R, SIG17R and SLE41R).

Compared with the results from the 1997 survey, the general picture of the background material of Region II is almost unchanged. The content of THC has decreased somewhat north to north east in the region, while the barium content has increased in the Frigg-Heimdal and Glitne areas.

Prior to the calculation of background levels and Limits of Significant Contamination (LSC), a multivariate analysis of the chemical data from all regional and reference stations was performed on the current year's data and on the data from both the present and previous regional survey(s). The results of these multivariate analyses clarified that the background material for the shallow area differed from the remaining of the region. To take in account naturally lower levels of THC and metals in sediments from the shallow Sleipner Øst, Varg and Sigyn area separate background levels are calculated for this area based on 2000 and 1997 results. Background levels for the remaining of the fields in Region II are calculated from the analyses results obtained at all regional and reference stations in the present and previous (1997) survey.

All regional and reference stations in Region II are classified as group A stations (undisturbed fauna) in the present survey. The number of individuals and taxa recorded are lowest in the shallower, southern part of the region and highest in the central and northern part. The regional station RII01 and RII06 together with the reference stations at Varg, Sigyn and Sleipner Øst have very low numbers of individuals and taxa while regional station RII02 and the reference station at Frøy have high numbers. Compared with the results from 1997, the numbers of individuals and taxa have decreased at most of the stations, with the exception of regional station RII02 and the reference stations at Frøy, Balder and Jotun. The diversity index H' and the ES100 have also decreased at most of the station between 1997 and 2000.

A great variation in species composition occurs among the stations. The polychaetes *Galathowenia oculata* and *Spiophanes bombyx* are the most dominant taxa occurring among the ten most dominant taxa at 18 of the 22 stations. The polychaete *Owenia fusiformis* is recorded with more than 1000 individuals at regional station RII02. At the same station the polychaete *Chaetozone* sp., known to increase in abundance in disturbed sediments, is registered with 50 individuals. However, all measured chemical parameters and the TOM have low values at this station, indicating that these results can not be related to the petroleum activity in the region.

The CCA show significant correlation between the faunal distribution and the amount of zinc, chromium and pelite in the sediments. However, the amount of zinc and chromium are low, and it is believed that the faunal distribution is related to natural variation in the sediment structure over the region.

Table 4-9: Number of individuals and the accumulative abundance for the most predominant taxa at each regional and reference station in Region II, 2000.

RII01	No. ind.	Acc. %	RII02	No. ind.	Acc. %	RII03	No. ind.	Acc. %	RII04	No. ind.	Acc. %	RII06	No. ind.	Acc. %
Amphiura filiformis	114	27%	Owenia fusiformis	1085	35%	Galathowenia oculata	520	33%	Spiophanes bombyx	144	21%	Amphiura filiformis	47	19%
Ophiuroidea indet. juv.	39	36%	Myriochele danielsseni	646	56%	Thyasira croulinensis	96	39%	Galathowenia oculata	69	31%	Goniada maculata	29	31%
Spiophanes bombyx	29	42%	Galathowenia oculata	302	65%	Myriochele fragilis	73	43%	Aonides paucibranchiata	23	34%	Eudorellopsis deformis	16	37%
Spiophanes kroyeri	24	48%	Myriochele fragilis	270	74%	Spiophanes bombyx	54	47%	Lanice conchilega	22	37%	Mysella sp.	14	43%
Phoronis sp.	17	52%	Amphiura filiformis	62	76%	Spiophanes kroyeri	50	50%	Owenia fusiformis	22	40%	Phoronis sp.	13	48%
Galathowenia oculata	16	56%	Ophiuroidea indet. juv.	51	78%	Laonice sarsi	35	52%	Phoronis sp.	21	43%	Spiophanes bombyx	11	52%
Pholoe baltica	12	59%	Chaetozone sp.	50	79%	Pseudopolydora	35	54%	Myriochele fragilis	19	46%	Scoloplos armiger	10	56%
Owenia fusiformis	11	61%	Thyasira flexuosa	50	81%	Owenia fusiformis	31	56%	Paramphinome jeffreysii	19	49%	Spiophanes kroyeri	10	60%
Nemertini indet.	10	63%	Spiophanes kroyeri	40	82%	Eclysippe vanelli	30	58%	Spiophanes kroyeri	19	51%	Bathyporeia sp.	8	63%
Capitella capitata	8	65%	Phoronis sp.	36	83%	Mugga wahrbergi	28	60%	Nematoda indet.	17	54%	Nephtys longosetosa	8	67%
Chaetozone sp.	8	67%												
RII07	**No. ind.**	**Acc. %**	**RII08**	**No. ind.**	**Acc. %**	**RII09**	**No. ind.**	**Acc. %**	**RII10**	**No. ind.**	**Acc. %**	**FRI10R**	**No. ind.**	**Acc. %**
Amphiura filiformis	113	16%	Paramphinome jeffreysii	132	19%	Galathowenia oculata	176	13%	Galathowenia oculata	142	11%	Pectinaria sp. juv.	588	22%
Galathowenia oculata	92	29%	Nothria hyperborea	50	27%	Amphiura filiformis	115	22%	Spiophanes bombyx	106	19%	Owenia fusiformis juv.	395	36%
Paramphinome jeffreysii	58	37%	Spiophanes kroyeri	42	33%	Spiophanes bombyx	103	29%	Thyasira croulinensis	102	27%	Galathowenia oculata	256	46%
Spiophanes kroyeri	36	42%	Galathowenia oculata	36	38%	Owenia fusiformis	74	35%	Timoclea ovata	64	32%	Spiophanes bombyx	216	54%
Laonice sarsi	22	45%	Amphiura filiformis	35	43%	Paramphinome jeffreysii	66	40%	Paramphinome jeffreysii	58	37%	Phoronis sp.	160	60%
Ampharete falcata	19	48%	Thyasira croulinensis	32	48%	Pectinaria sp. juv.	53	44%	Lanice conchilega	49	41%	Amphiura filiformis	146	65%
Chaetozone sp.	19	51%	Ophiuroidea indet. juv.	31	52%	Phoronis sp.	49	47%	Ophiuroidea indet. juv.	48	44%	Ophiuroidea indet. juv.	90	68%
Phoronis sp.	18	53%	Polydora coeca	26	56%	Thyasira flexuosa	40	50%	Phoronis sp.	44	48%	Owenia fusiformis	62	71%
Anobothrus gracilis	16	55%	Laonice sarsi	25	60%	Prionospio cirrifera	39	53%	Amphiura chiajei	38	51%	Myriochele danielsseni	49	72%
Pectinaria auricoma	16	58%	Terebellides stroemi	20	63%	Lanice conchilega	33	56%	Eudorella emarginata	37	54%	Myriochele fragilis	48	74%
NEF20R	**No. ind.**	**Acc. %**	**PSB13R**	**No. ind.**	**Acc. %**	**LFR01R**	**No. ind.**	**Acc. %**	**FRY18R**	**No. ind.**	**Acc. %**	**RIN29R**	**No. ind.**	**Acc. %**
Pectinaria sp. juv.	346	21%	Pectinaria sp. juv.	402	19%	Owenia fusiformis juv.	598	22%	Galathowenia oculata	400	13%	Spiophanes bombyx	151	17%
Galathowenia oculata	301	39%	Owenia fusiformis juv.	251	30%	Pectinaria sp. juv.	493	40%	Owenia fusiformis juv.	315	24%	Paramphinome	80	27%
Owenia fusiformis	227	52%	Galathowenia oculata	223	40%	Galathowenia oculata	312	51%	Pectinaria sp. juv.	291	34%	Lanice conchilega	54	33%
Spiophanes bombyx	149	61%	Amphiura filiformis	132	46%	Amphiura filiformis	156	57%	Mugga wahrbergi	144	39%	Galathowenia oculata	49	38%
Owenia fusiformis juv.	77	66%	Spiophanes bombyx	121	52%	Owenia fusiformis	115	61%	Myriochele fragilis	141	43%	Eudorella emarginata	47	44%
Spiophanes kroyeri	70	70%	Myriochele fragilis	116	57%	Myriochele fragilis	105	65%	Spiophanes bombyx	111	47%	Thyasira equalis	43	49%
Amphiura filiformis	68	74%	Pectinaria koreni	107	62%	Ophiuroidea indet. juv.	96	68%	Laonice sarsi	110	51%	Diplocirrus glaucus	32	52%
Pectinaria koreni	51	77%	Owenia fusiformis	98	67%	Myriochele danielsseni	69	71%	Pseudopolydora	106	54%	Thyasira croulinensis	30	56%
Ophiuroidea indet. juv.	34	79%	Spiophanes kroyeri	65	70%	Phoronis sp.	66	73%	Thyasira croulinensis	101	58%	Spiophanes kroyeri	29	59%
Anobothrus gracilis	32	81%	Ophiuroidea indet. juv.	52	72%	Spiophanes bombyx	55	75%	Phoronis sp.	90	61%	Eriopisa elongata	24	62%

Table 4-9 cont.

SIG17R	No. ind.	Acc. %	BAL27R	No. ind.	Acc. %	JOT30R	No. ind.	Acc. %	ODI14R	No. ind.	Acc. %	VAR14R	No. ind.	Acc. %
Amphiura filiformis	72	26%	Phoronis sp.	147	13%	Spiophanes bombyx	191	14%	Owenia fusiformis juv.	171	19%	Amphiura filiformis	56	22%
Goniada maculata	16	32%	Spiophanes bombyx	94	21%	Paramphinome jeffreysii	157	25%	Galathowenia oculata	112	31%	Scoloplos armiger	17	29%
Eudorellopsis deformis	15	37%	Paramphinome jeffreysii	72	27%	Pectinaria sp. juv.	146	35%	Poecilochaetus serpens	64	39%	Eudorellopsis deformis	13	34%
Scoloplos armiger	13	42%	Eudorella emarginata	70	33%	Eudorella emarginata	65	40%	Spio sp.	34	42%	Phoronis sp.	13	39%
Spiophanes bombyx	13	47%	Galathowenia oculata	59	39%	Galathowenia oculata	55	43%	Aonides paucibranchiata	31	46%	Spiophanes bombyx	13	44%
Mysella sp.	12	51%	Thyasira croulinensis	49	43%	Phoronis sp.	49	47%	Pista sp.	31	49%	Goniada maculata	12	49%
Bathyporeia sp.	11	55%	Thyasira equalis	38	46%	Thyasira croulinensis	46	50%	Nemertini indet.	27	52%	Spiophanes kroyeri	12	54%
Phoronis sp.	11	59%	Lanice conchilega	28	49%	Spiophanes kroyeri	39	53%	Edwardsia sp.	21	55%	Paramphinome	10	57%
Spiophanes kroyeri	8	62%	Pectinaria sp. juv.	27	51%	Abyssoninoe scopa	38	56%	Aricidea cerrutii	18	57%	Abra prismatica	8	61%
Ophiuroidea indet. juv.	7	65%	Eriopisa elongata	26	53%	Diplocirrus glaucus	36	58%	Glycera lapidum	17	58%	Nemertini indet.	7	63%
Owenia fusiformis	7	67%				Thyasira equalis	32	60%	Thracia villosiuscula	17	60%			

HEM22R	No. ind.	Acc. %	SLE41R	No. ind.	Acc. %
Thyasira croulinensis	143	13%	Mysella sp.	83	23%
Galathowenia oculata	61	18%	Amphiura filiformis	75	44%
Phoronis sp.	58	24%	Bathyporeia sp.	16	48%
Ophiuroidea indet. juv.	48	28%	Spiophanes bombyx	16	52%
Spiophanes bombyx	46	32%	Phoronis sp.	14	56%
Amphiura filiformis	41	36%	Eudorellopsis deformis	13	60%
Timoclea ovata	38	39%	Goniada maculata	12	63%
Laonice sarsi	36	42%	Ophiuroidea indet. juv.	12	67%
Paramphinome jeffreysii	35	46%	Nephtys longosetosa	10	69%
Spiophanes kroyeri	32	48%	Nemertini indet.	9	72%
Mugga wahrbergi	30	51%			

Table 4-10: Station information for the regional station in Region II, 2000.

St. no.	E UTM 31 (ED50)	N UTM 31 (ED50)	Volume (litres)
RII01	463281	6688937	60
RII02	490795	6651639	30
RII03	490702	6614517	33
RII04	485867	6577412	30
RII06	460684	6429120	39
RII07	421831	6457534	43
RII08	422936	6513198	25
RII09	433551	6568688	30
RII10	443670	6609362	50

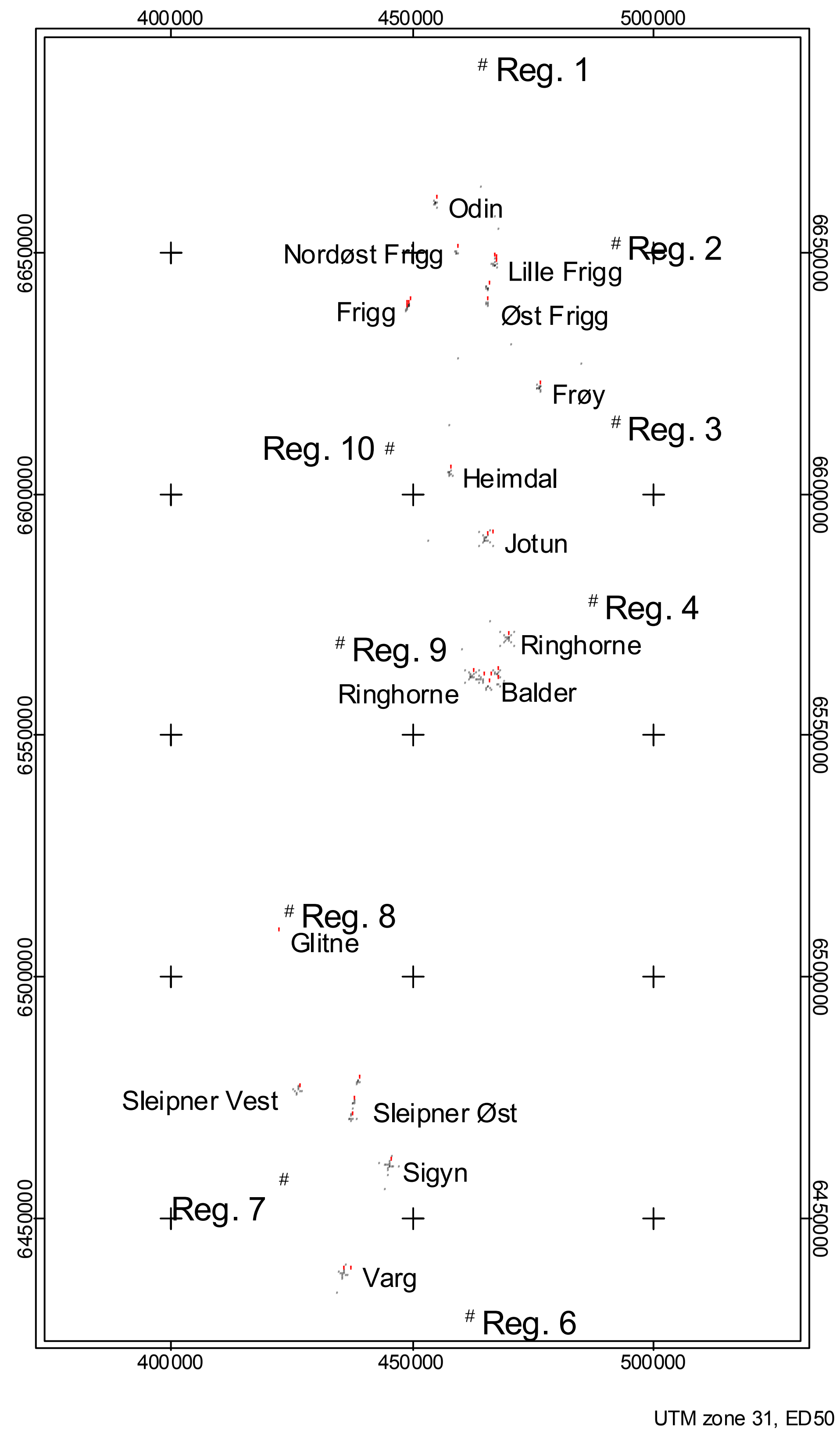

Figure 4-17: Map of sampling positions for the regional stations and the fields in Region II, 2000.

5 Frigg field

5.1 Introduction

The Frigg field is located in blocks 25/1 and 30/10 in Region II. Production at the field started in 1977. There has been no drilling activity at the field since the previous survey. Recent discharges are summarised in Table 5-1. The accidental discharges in 1997 and 1998 all occur at the TCP2 installation and were related to the produced water system. It is believed that this oil quickly dispersed into the water masses. The drilling rig at the DP2 installation was removed during summer and autumn in 1999 and was cleaned during the operation. Sandy particles contaminated with hydrocarbons were released during this event.

In 1997 none of the sediment samples from Frigg were judged significantly contaminated by hydrocarbons. Sediments from the station situated 200 m in the 350° direction relative to TCP2 were contaminated by barium, cadmium, zinc, lead and copper, while sediments sampled 200 m in the 70° direction relative to TCP2 were contaminated by barium, zinc, lead and copper. Lead, zinc and copper contaminated sediments at the remaining stations, except the one situated 330 m at 70° relative to DP2. The fauna was found to be relatively undisturbed, although some minor signs of disturbance could be seen at the stations close to TCP2 and TP1. Therefore, the same set of stations is included in the present survey.

Information on the sampling stations is shown in Figure 5-13 and Table 5-13, both on the foldout page at the end of this chapter (page 5-19). In addition, samples from the cutting piles at the field were collected by use of a van Veen grab (biology) and box corer (chemistry). A separate report with these results will be produced.

Table 5-1: Summary of recent operational and accidental discharges at the Frigg field (all discharges in tonnes).

	1997	1998	1999	2000	Comments
Oil in produced water	42.5	36.0	13.5	2.5	
Accidental discharges	25.7	18.3	1.0	0.7	

5.2 Results and discussion

5.2.1 Physical characteristics

Th median phi value and the amounts (%) of pelite, fine sand and total organic material (TOM) in the sediments from the present and previous surveys are shown in Table 5-2 and Figure 5-1. 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 in the area are classified as fine sand with median values varying from 3.46 to 3.50. The amount of pelite in the sediment varies from 1.51 % (station FRI02) to 2.55 % (station FRI04), the fine sand from 85.6 % (station FRI25) to 91.1 % (station FRI02) while the TOM varies from 0.67 % (station FRI02) to 1.04 % (station FRI04). The sediment is finer at the reference station where the pelite content is 6.32 % and the TOM 1.18 %. At the field stations the pelite and TOM values are highest at stations south west of TP1 and DP2 (FRI04 and 11).

The pelite content has increased at all stations since the previous survey in 1997, while the TOM is more or less similar between the two surveys, with the exception of station FRI04 where an increase has occurred. Between 1992 and 1997, the pelite content has decreased at most of the stations. The median value has had a stable level throughout the period, with a small increase at the reference station between 1997 and 2000.

Table 5-2: The median (phi) and amount of pelite, fine sand and TOM in the sediments from stations at the Frigg field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	Distance (m)	Direction (degr.)	Median	Classification	Pelite	Fine sand	TOM
FRI01	200	350	3.48	Fine sand	1.83	89.6	0.92
FRI02	200	70	3.48	Fine sand	**1.51**	**91.1**	**0.67**
FRI03	330	194	**3.46**	Fine sand	1.62	86.0	0.77
FRI04	200	249	**3.50**	Fine sand	**2.55**	89.6	**1.04**
FRI11	500	350	3.49	Fine sand	2.28	87.4	0.96
FRI24	250	170	**3.46**	Fine sand	1.78	85.8	0.68
FRI25	250	350	**3.46**	Fine sand	1.71	**85.6**	0.76
FRI27	250	70	3.49	Fine sand	1.90	90.3	0.72
FRI10R	14686	135.4	3.68	Fine sand	6.32	82.0	1.18
Average. *			3.48		1.90	88.2	0.81
St. dev. *			0.02		0.35	2.2	0.14

* Excluding the reference station.

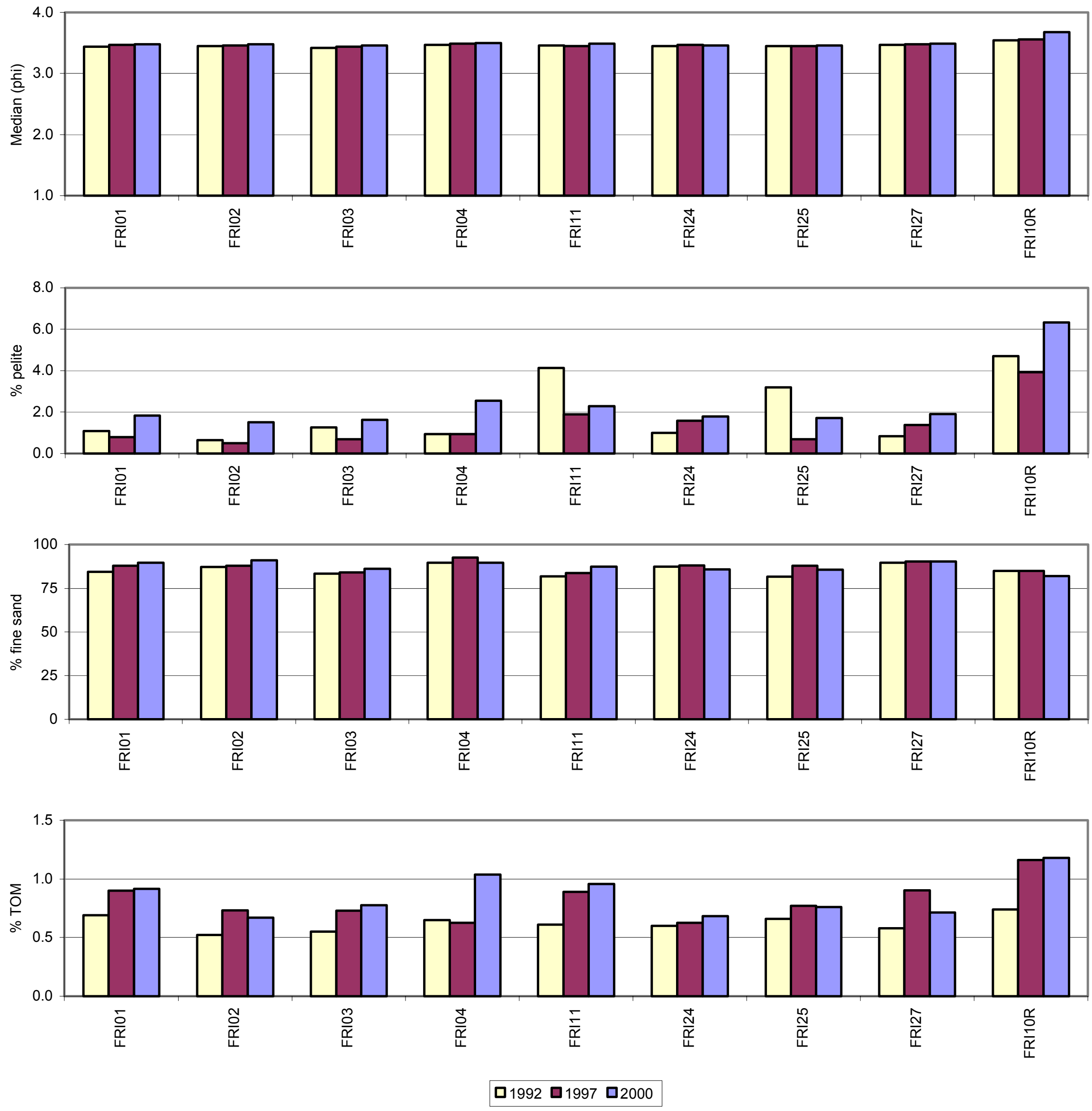

Figure 5-1: Sediment characteristics at the Frigg field, 2000 and previous surveys.

5.2.2 Chemical characteristics

The calculated limits of significant contamination for selected hydrocarbons and metals in sediments from Region II ($LSC_{97\text{-}00\ RegII}$) are presented previously in the chapter that deals with the regional and reference stations. In addition to the regional limits, field-specific limits of significant contamination are calculated from the field reference station ($LSC_{00\ FRI10R}$). Both sets of data are presented in Table 5-3. Based on analysis results of the Frigg field the $LSC_{97\text{-}00\ RegII}$ is regarded as representative of the entire region and will therefore be used as further basis for discussion of the contamination status of this field. Those limits will hereafter simply be referred to as LSC.

The results of analyses of the hydrocarbons are summarised in Table 5-4. Concentrations of selected compounds in the vertical sediment sections are presented in Table 5-5. The full data set of replicate measurements and date from previous years are given in the Appendix. THC values from 2000 are compared with those from previous years in Figure 5-3.

Table 5-3: Background levels and Limits of Significant Contamination for the Frigg field, 2000. All values in mg/kg dry sediment.

	THC	NPD's	3-6 ring	Decalins	Cd	Hg	Cu	Zn	Ba	Cr	Pb
$LSC_{00\ FRI10R}$	7.3	0.018	0.058	0.062	0.020	0.007	1.2	5.7	91	4.8	4.0
$LSC_{97\text{-}00\ Region\ II}$	9.8	*	*	*	0.029	0.008	2.0	8.9	146	9.6	7.0

*) Regional stations not analysed for NPD's, 3-6 ring aromatics and decalins.

Table 5-4: Concentrations of hydrocarbons in sediments from the Frigg field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between LSC_{FRI10R} and $LSC_{97\text{-}00\ RegII}$ light shaded.

Station	THC		NPD's		3-6 ring		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
FRI01	13.2	3.7	n.a.		n.a.		n.a.	
FRI02	4.1	0.9	0.011	0.002	0.019	0.001	0.028	0.007
FRI03	7.4	2.1	n.a.		n.a.		n.a.	
FRI04	9.2	3.0	n.a.		n.a.		n.a.	
FRI11	7.6	1.6	n.a.		n.a.		n.a.	
FRI24	5.8	0.9	n.a.		n.a.		n.a.	
FRI25	9.2	1.1	n.a.		n.a.		n.a.	
FRI27	3.5	0.7	n.a.		n.a.		n.a.	
FRI10R	4.5	1.2	0.013	0.002	0.044	0.006	0.032	0.013

n.a. Not analysed.

Table 5-5: Concentrations of hydrocarbons in vertical sections of sediment samples from the Frigg field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between LSC_{FRI10R} and $LSC_{97\text{-}00\ RegII}$ light shaded.

Station	Layer (cm)	THC	NPD's	3-6 ring	Decalins
FRI02	0-1	5.2	0.012	0.019	0.022
	1-3	2.5	0.010	0.014	0.052
	3-6	4.0	0.009	0.018	0.069
FRI10R	0-1	6.5	0.016	0.048	0.045
	1-3	3.8	0.019	0.076	0.018
	3-6	5.4	0.022	0.087	0.032

n.a. Not analysed.

THC values range from 3.5 ± 0.7 mg/kg dry sediment to 13.2 ± 3.7 mg/kg at Frigg (Table 5-4). THC contaminates sediments at FRI01, with an average concentration of 13.2 mg/kg dry sediment. Sediments at FRI04 and FRI25 have THC concentrations at LSC with 9.2 ± 3.0 mg/kg and 9.2 ± 1.1 mg/kg respectively. Chromatograms of sediment extracts from these stations indicate mineral oil (Figure 5-2). THC levels in sediments at the other stations are well below the LSC of the region. The concentrations of NPD's, 3-6 ring aromatics and decalins in sediments at station FRI02 are all below the LSC's for these parameters (Table 5-4). Vertical core samples at station FRI02 reveal no concentration gradients or concentrations above LSC for THC, NPD's, or 3-6 ring aromatics with depth (Table 5-5). The concentration of decalins is increasing with depth, values just above LSC are found in the 3-6 cm layer (0.069 mg/kg).

In general low total hydrocarbon contents are found in the sediments at Frigg. THC levels above LSC are found in sediments at one station, situated 250 m in the 350° direction relative to TCP2.

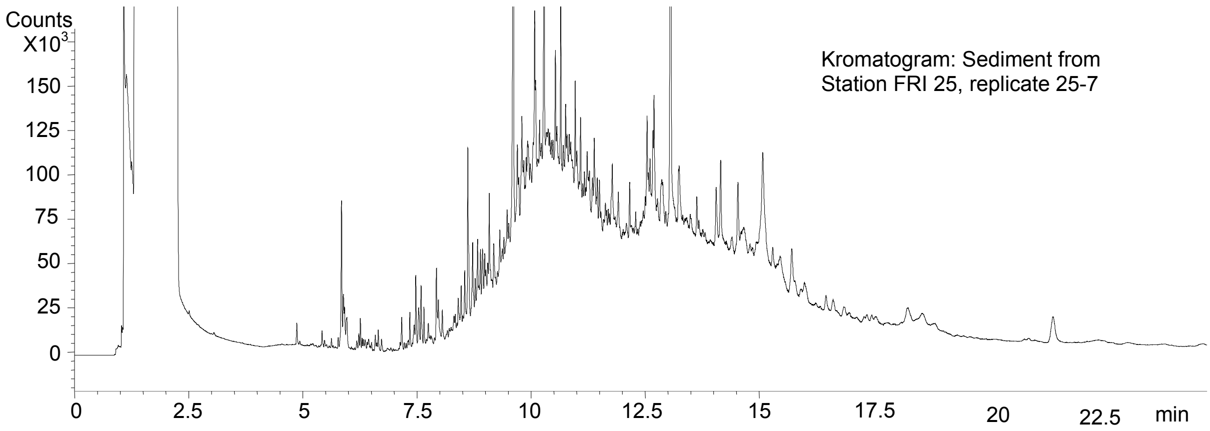

Figure 5-2: Gas chromatogram of a sediment extract from the Frigg field, 2000.

The results of the metal analyses for the Frigg field are summarised in Table 5-6. Concentrations of the selected metals in the vertical sediment sections are presented in Table 5-7. The full set of replicate measurements, including selected data from previous years is given in the Appendix. Metal values from 2000 are compared with those from previous years in Figure 5-4 and Figure 5-5.

Table 5-6: Concentrations of selected metals in sediments from the Frigg field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between LSC_{FRI10R} and $LSC_{97\text{-}00\ RegII}$ light shaded.

	Cd		Hg		Cu		Zn		Ba		Cr		Pb	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	Sd.
FRI01	0.027	0.009	n.a.		12.0	2.3	133	8.4	124	45	8.0	1.0	31.0	1.1
FRI02	0.011	0.003	<0.005	-	4.8	1.9	39.8	11.5	64	25	5.0	1.0	11.6	1.9
FRI03	0.037	0.017	n.a.		12.5	2.7	122	20.4	102	16	9.0	1.4	28.1	3.4
FRI04	0.039	0.019	n.a.		10.0	4.7	102	39.6	135	27	8.1	2.4	23.2	6.3
FRI11	0.018	0.002	n.a.		6.5	1.2	47.4	10.0	110	90	6.6	1.2	17.7	1.6
FRI24	0.017	0.004	n.a.		5.9	3.3	36.5	19.0	272	33	5.9	0.8	15.1	4.3
FRI25	0.026	0.009	n.a.		9.9	3.7	74.8	10.2	311	138	6.9	1.0	23.1	4.5
FRI27	0.007	0.001	n.a.		1.5	0.2	8.7	0.5	106	15	4.0	0.2	7.6	2.6
FRI10R	0.015	0.003	0.004	0.001	1.0	0.1	5.4	0.2	67	10	4.4	0.2	3.7	0.1

n.a. Not analysed.

Table 5-7: Concentrations of selected metals in vertical sections of the sediment samples from the Frigg field. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between LSC_{FRI10R} and $LSC_{97\text{-}00\ RegII}$ light shaded.

Station	Layer (cm)	Cd	Hg	Cu	Zn	Ba	Cr	Pb
FRI02	0-1	0.014	<0.005	7.0	52.7	40	6.1	13.7
	1-3	0.016	<0.005	7.1	56.7	88	7.1	13.5
	3-6	0.017	0.013	4.8	51.9	72	5.0	11.5
FRI10R	0-1	0.013	0.005	1.0	5.4	74	4.6	3.6
	1-3	0.020	<0.005	1.2	5.8	112	4.6	4.4
	3-6	0.028	0.005	1.3	6.7	113	4.8	3.8

n.a. Not analysed.

The barium values range from 64 ± 25 mg/kg to 311 ± 139 mg/kg dry sediment, cadmium from 0.006 ± 0.001 mg/kg to 0.039 ± 0.019 mg/kg, copper from1.5 ± 0.2 mg/kg to 12.5 ± 2.7 mg/kg, lead from 7.6 ± 2.6 mg/kg to 31.0 ± 1.1 mg/kg, zinc from 8.7 ± 0.5 mg/kg to 132.7 ± 8.4 mg/kg and chromium from 4.0 ± 0.1 to 9.0 ± 1.4 mg/kg.

Barium concentrations above LSC are found in sediments at FRI24 and FRI25, the highest concentrations found at FRI25 with 311 ± 139 mg/kg dry sediment. At the other field stations no sediment concentrations above LSC are measured. However, contamination by lead is found in sediments at all field stations. Contamination by copper and zinc are found in sediments at all stations except FRI27. Cadmium contamination is found in sediments at stations FRI03 and FRI04. The highest concentrations are found at station FRI01, with 12 mg copper /kg dry sediment, 133 mg zinc/kg and 31 mg lead/kg. No chromium or mercury contamination is found in sediments at Frigg.

Vertical core samples reveal elevated levels of copper, zinc and lead in all layers at FRI02 (Table 5-7). No distinct gradients are seen. Contamination with mercury is also found in the 3-6 cm layer on this location (0.013-mg/kg dry sediment).

In general low sediment concentrations of barium are found at Frigg. Contrary to this finding are the elevated levels of copper, zinc and lead with contamination at most stations sampled. No changes in mercury levels are observed.

<u>Comparison with previous survey(s)</u>

At the reference station sediment levels of THC, aromatics, decalins and selected metals except barium are comparable with the levels found in 1997. A minor increase in the barium level is found. Elevated levels of NPD's and 3-6 ring aromatics are found in the 1-3 cm and 3-6 cm sediment layers on this location.

Contamination by hydrocarbons is only found in sediments at the station situated 200 m in the 350° direction relative to TCP2. The hydrocarbon levels in sediments at this station and at the one situated 330 m in the194° direction relative to TCP2 are a little higher in 2000 than in 1997 (Figure 5-3). This is also the case for sediments from the station situated 200 m in the 350° direction relative to DP2. Chromatograms of sediment extracts from these locations indicate mineral oil. This is in accordance with the field history, with spill of 92 tons oil in produced water and accidental discharges of 45 tons oil between 1997 and 1999. At the other field stations THC levels are comparable with those reported in 1997. The concentrations of NPD's, 3-6 ring aromatics and decalins in sediments at the station situated 200 m in the 70° direction relative to TCP2 have decreased to about half of what were found in 1997 and the values are below LSC of the region. However, average THC concentrations in sediments at Frigg have increased from 6.6 mg/kg dry sediment to 7.5 mg/kg since 1997 (Figure 5-3).

Barium concentrations above LSC are found in sediments at two stations, situated 200 m in the 170° and 350° directions relative to DP2 (Figure 5-4). However, contamination by lead is found in sediments at all field stations (Figure 5-5). Contamination by copper and zinc are found in sediments at all field stations minus the one situated 330 m in the 70° direction relative to DP2. The highest concentrations of copper, zinc and lead are found 200 m in the 350° direction relative to TCP2, with 12 mg copper/kg, 133 mg zinc/kg and 31 mg lead/kg dry sediment. Cadmium contamination is found in sediments from position 330 m in the 194° direction relative to TCP2 and 200 m in the 249° direction relative to TP1. No chromium or mercury contamination is found in sediments at Frigg.

Sediment barium concentrations are higher in this survey than in 1997 at all stations except 200 m in the 70° and 350° directions relative to TCP2 (Figure 5-4). At stations situated 200 m in the 170°and 350° directions relative to DP2 the sediment concentrations of barium have increased about four times, bringing the levels above LSC of the region. The same pattern is seen for cadmium, copper, zinc and lead, with contamination in sediments at the majority of stations (Figure 5-5). The field history does not indicate anything that may explain this rise in metal concentrations.

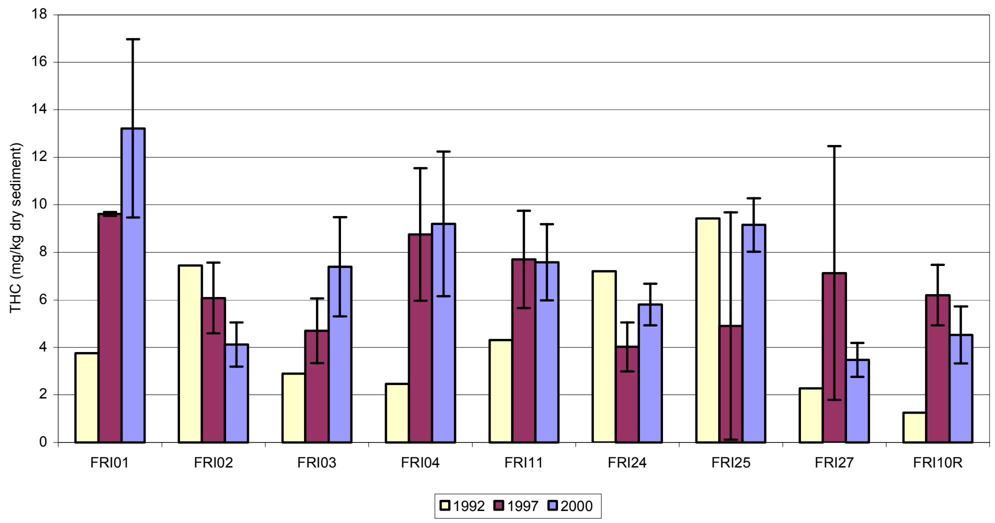

Figure 5-3: THC levels in sediment from the present (2000) and previous surveys, Frigg field.

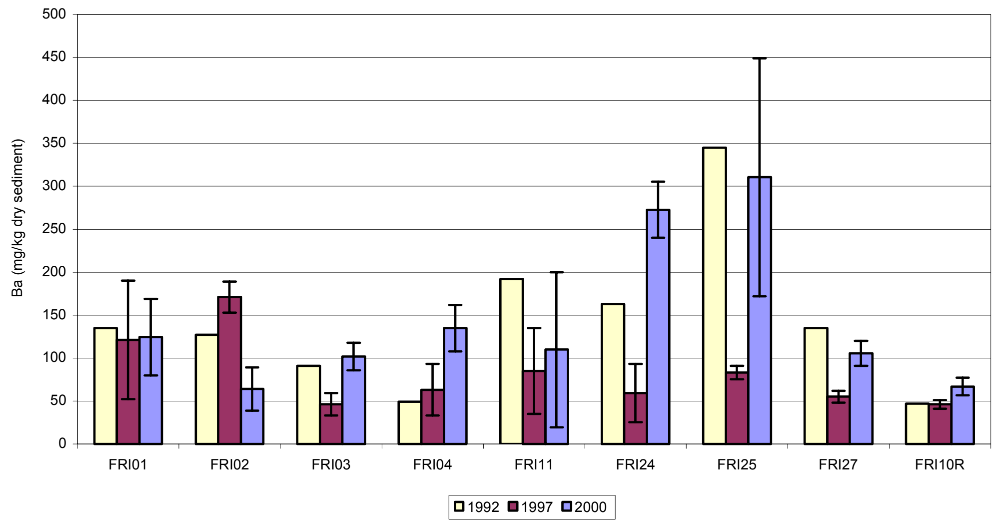

Figure 5-4: Barium levels in sediment from the present (2000) and previous survey, Frigg field.

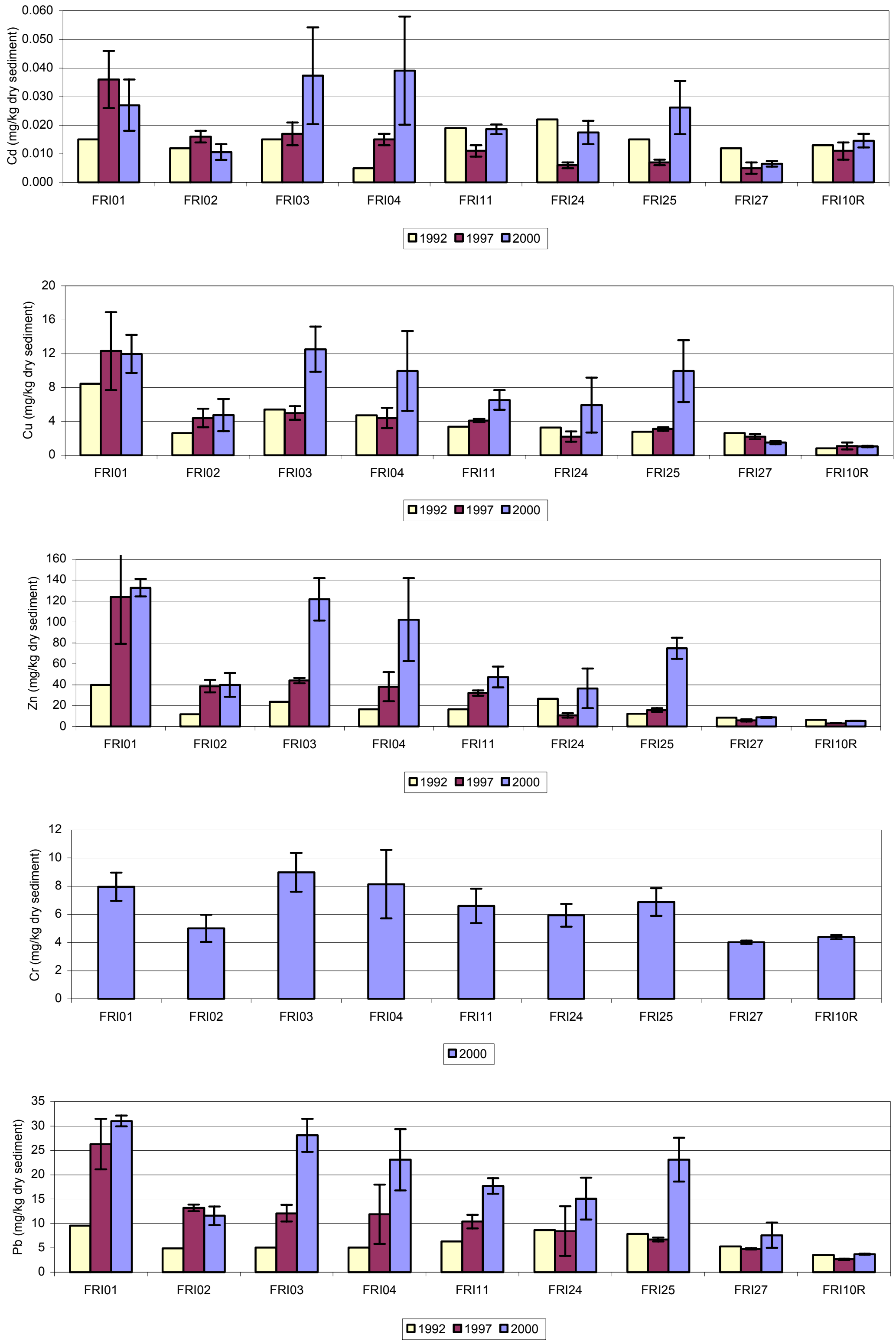

Figure 5-5: Levels of selected metals in sediments from the present (2000) and previous surveys, Frigg field.

5.2.3 Biology

The distribution of individuals and taxa within the main taxonomic groups are given in Table 5-8. A total of 13299 individuals within 240 taxa were recorded at the Frigg field in the present survey (excluding juveniles). The polychaetes dominate the fauna with 76 % of the individuals and 50 % of the taxa recorded.

Table 5-8: Distribution of individuals and taxa within the main taxonomic groups at Frigg, 2000 (excluding juveniles).

Main taxonomic groups	Individuals		Taxa	
	Number	%	Number	%
Polychaeta	10173	76	120	50
Mollusca	665	5	38	16
Crustacea	804	6	55	23
Echinodermata	625	5	13	5
Diverse groups	1032	8	14	6
Total	13299	100	240	100

The species/area curve for the field reference station is shown in Figure 5-6. A total of 160 taxa were taken in the 10 grab samples of which 73 (45.6 %) were registered in the first sample and 128 (80.0 %) in the five first samples. The curve indicates that not all taxa in the area are represented in 10 samples, but the representativity of five samples is considered to be relatively good.

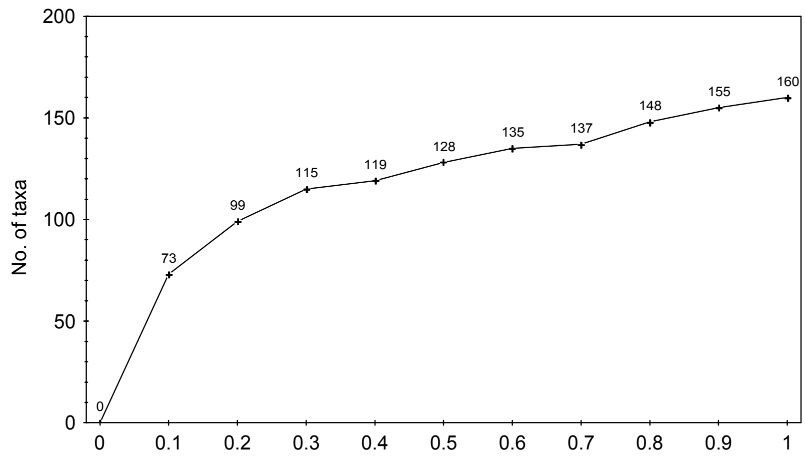

Figure 5-6: Species/area curve for the reference station at the Frigg field (area in m^2).

The number of individuals and taxa at each station, together with selected community indices, are presented in Table 5-9 while a comparison with the previous surveys is shown in Figure 5-7. The number of individuals in the present survey varies from 863 (station FRI25) to 2635 (FRI04), the number of taxa from 84 (FRI03) to 114 (FRI11), the diversity index H' from 3.1 to 4.8, the evenness index J from 0.46 to 0.73 while the ES_{100} varies from 20 to 35. The H', J and ES100 values were all lowest at station FRI04 (south west of TP1) and highest at station FRI25 (north of DP2). With the exception of the number of individuals, which is highest at FRI04, the values for all other parameters are higher at the reference station than at the field stations.

Compared with the results from the previous surveys, there is a general trend for lower values for all parameters analysed in the present survey. The most dramatic change occurred between 1992 and 1997, when the number of individuals decreased at most of the stations. This is best seen at the reference station FRI10R. Between 1997 and 2000 the number of individuals are more or less similar. The number of taxa has also decreased in the period, resulting in lower diversity at the stations.

Table 5-9: Number of individuals and taxa and selected community indices for each station (0.5 m^2) at the Frigg field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	No. of ind.	No. of taxa	H'	J	ES_{100}
FRI01	1278	103	4.3	0.65	32
FRI02	1176	93	3.9	0.60	28
FRI03	1165	**84**	4.2	0.66	28
FRI04	**2635**	102	**3.1**	**0.46**	**20**
FRI11	1398	**114**	4.4	0.64	32
FRI24	1482	99	3.6	0.55	26
FRI25	**863**	93	**4.8**	**0.73**	**35**
FRI27	1704	99	3.7	0.56	25
FRI10R	1598	128	4.9	0.71	35
Sum *	11701				
Average. *	1463	98	4.0	0.61	28
St. dev. *	535	9	0.5	0.08	5

* Excluding the reference station.

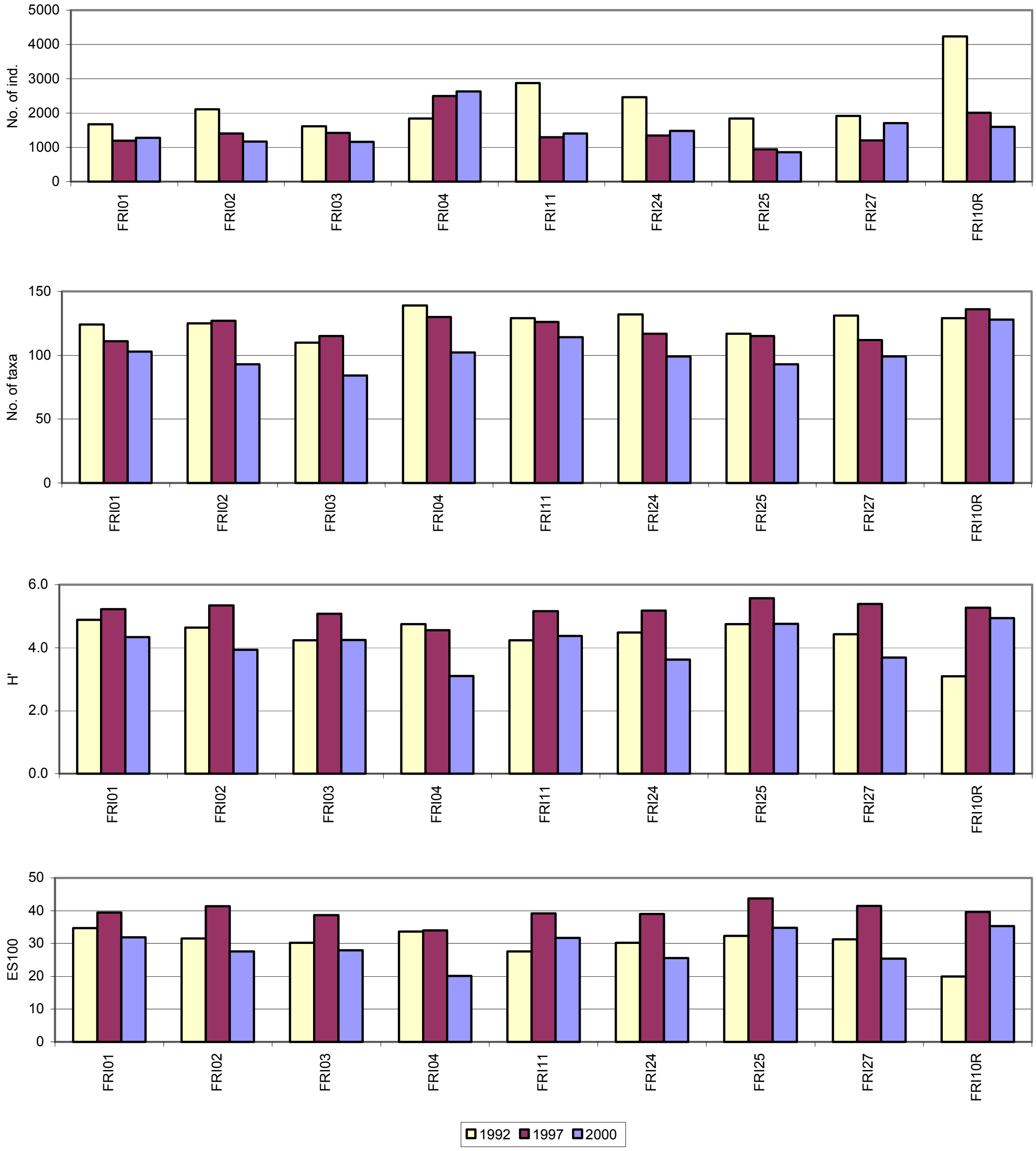

Figure 5-7: Biological characteristics of the stations at Frigg, 2000 and previous surveys.

The distribution of taxa in geometrical classes at each station is shown in Figure 5-8. Station FRI04 has one taxon in class 11 (1024 – 2047 individuals), station FRI24 one taxon in class 10 (512 – 1023 individuals), four stations (inclusive the reference station FRI10R) have taxa in class 9 (256 – 511 individuals), while the two remaining stations have taxa in class 8 and lower (< 256 individuals). These results might indicate faunal disturbance at some of the stations.

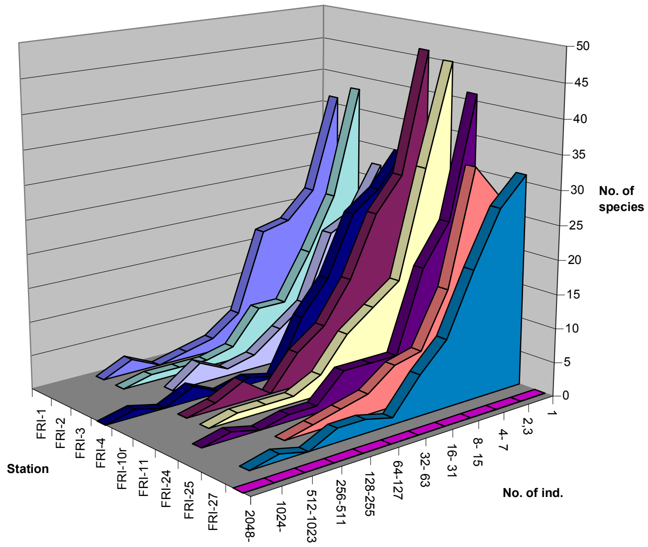

Figure 5-8: Distribution of taxa in geometrical classes from the stations at Frigg, 2000.

The ten most dominant taxa at each station are shown in Table 5-12 at the end of this chapter. A total of 26 taxa, inclusive five juvenile groups, are among the ten most dominant taxa at one or more stations. These 26 taxa comprise 84 % of the total number of individuals and 10 % of the total number of taxa registered at the Frigg field in the present survey.

The most dominant taxa among the adult forms are the polychaetes *Galathowenia oculata*, *Spiophanes bombyx*, *Ditrupa arietina* and *Chaetozone setosa*, the brittle star *Amphiura filiformis* and the phoronid *Phoronis* sp. The polychaetes *G. oculata* and *S. bombyx* are among the five most dominant taxa at eight and nine stations, respectively, while *D. arietina* and *C. setosa* have the same status at two and one stations, respectively. The brittle star *A. filiformis* is not among the ten most dominant taxa at stations FRI01, FRI03 and FRI04, where *C. setosa* is among the five most dominants. These results might indicate some faunal disturbance, at least at the three stations mentioned.

The ten most abundant taxa at the stations comprise between 64 % (station FRI25) and 84 % (station FRI04) of the total number of individuals registered at the respective stations. The corresponding value at the reference station FRI10R is 74 %.

Figure 5-9 shows the dendrogram from the cluster analysis for the field stations and selected regional and reference stations while Figure 5-10 shows the 2-D plot from the MDS analysis.

The cluster analysis separates all the regional and reference stations from the Frigg field station at approximately 49 % dissimilarity level. Within the field stations, two main groups are separated at 40 % dissimilarity level, one containing stations FRI01, FRI03 and FRI04 and the other the remaining field stations. The Product Moment correlation coefficient shows a very good fit to the data (r = 0.89).

The MDS analyses supports the results from the cluster analysis with the regional and reference stations separated from the field stations and the field stations FRI01, 03, and 04 separated from the other stations. The stress test for the 2-D plot shows a fair fit to the data (0.19).

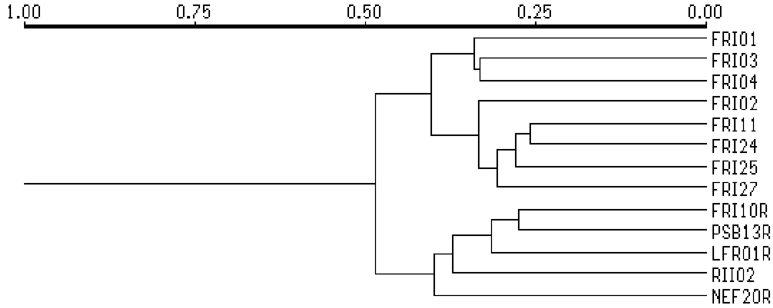

Figure 5-9: Cluster analysis of the Frigg field stations and selected regional and reference stations from Region II, 2000.

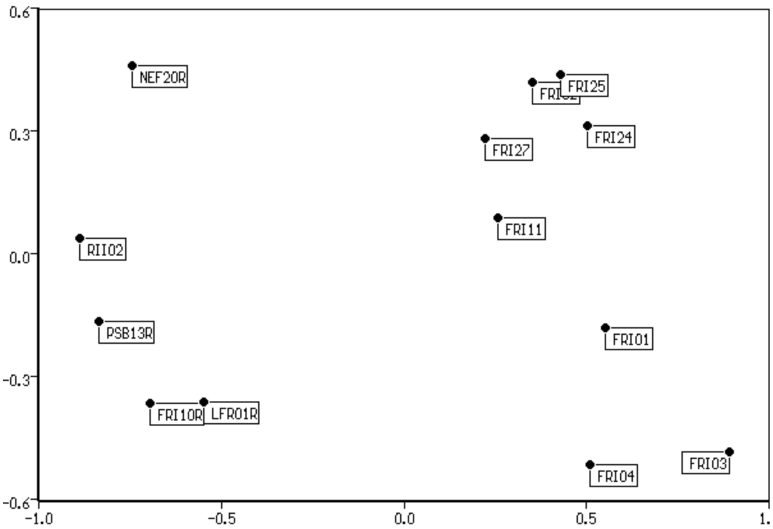

Figure 5-10: 2-D plot from the MDS analysis carried out on the station data form the Frigg field and selected regional and reference stations from Region II, 2000.

A Canonical Correspondence Analysis (CCA) of the data from the field stations and selected regional and reference stations was carried out to examine the association between the biological data and the measured environmental variables in these areas.

Through the forward selection procedure in CANOCO, three of ten variables, cadmium, fine sand and lead, gave the best fit and were significant. 53.2 % of the biological variance was explained by the first two axes of the ordination space which is constrained by these environmental variables.

Figure 5-11 shows a biplot from the analysis using fine sand (FS), cadmium (Cd) and lead (Pb) as the constraining environmental variables together with a plot of the species with the highest contribution on the two axes. The first axis shows a gradient from field station FRI04 at the positive end to regional station RII02 at the negative end and is positively correlated with the amount of cadmium (+ 0.85), lead (+ 0.85) and fine sand (+ 0.77) in the sediment. Species with high contribution on this axis are the polychaetes *Ditrupa arietina* (36.4 %), *Owenia fusiformis* (21.7 %), *Myriochele danielsseni* (11.4 %) and *Chaetozone setosa* (11.0 %).

The second axis shows a gradient from field station FRI27 at the positive end to field station FRI04 at the negative end and is weakly correlated with the amount of cadmium (- 0.40) and fine sand (+ 0.53) in the sediment. Species with high contribution on this axis are the polychaetes *Ditrupa arietina* (24.3 %), *Owenia fusiformis* (17.2 %), *Galathowenia oculata* (15.7 %) and *Spiophanes bombyx* (7.5 %).

The polychaetes *D. arietina*, *C. setosa*, together with *Cirratulus incertus*, all known as indicator species in disturbed sediments, are associated with the field stations FRI03 and FRI04 located at the right side of the plot. On the other hand the polychaetes *Owenia fusiformis*, *Myriochele danielsseni* and *M. fragilis* are associated with the regional and reference stations RII02, LFR01R and NEF20R located at the left side of the plot. The sediment at field stations FRI03 and FRI04 have higher concentrations of lead and cadmium than regional station RII02.

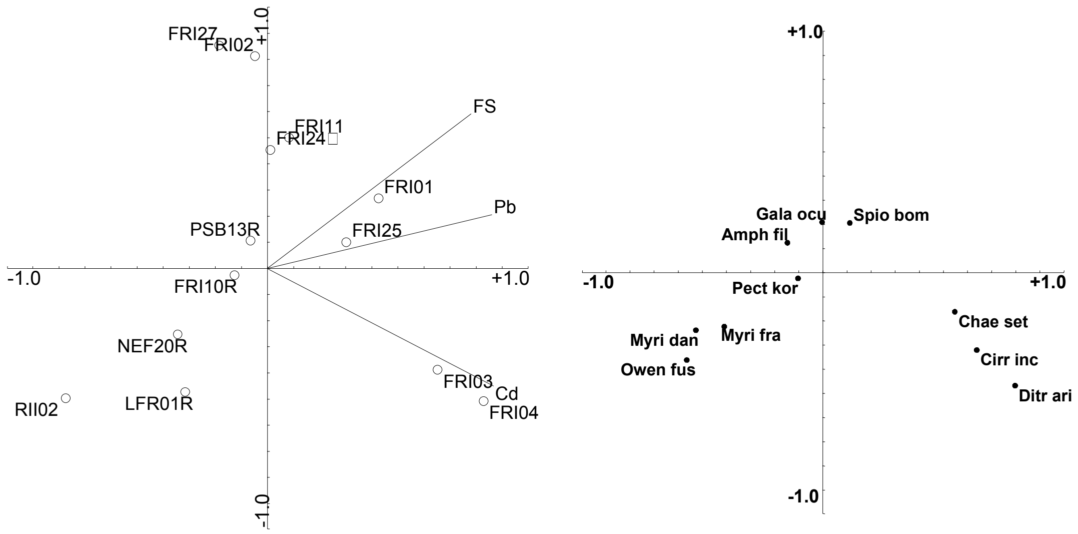

Figure 5-11: Biplot from the CCA analysis for the Frigg field and selected regional and reference stations from Region II, 2000 (left) and species with highest contribution on two axis (right).

On the basis of the results from the uni- and multivariate analyses, the stations at Frigg are classified into three different faunal groups (see Table 5-10). Field stations FRI03 and FRI04 are placed in group C (disturbed fauna), field station FRI01 is placed in group B (slightly disturbed fauna), while the rest of the stations are placed in group A (undisturbed fauna).

The stations that are classified as group B and C stations were separated from the other stations in the multivariate analyses. At these three stations, the polychaetes *Ditrupa arietina*, *Chaetozone* sp. (inclusive *C. setosa*) and *Cirratulus incertus* occur in relatively high individual numbers while the brittle star *Amphiura filiformis* occurs in low numbers or is absent. The latter species is known to react negatively to disturbed conditions in the sediment while the polychaetes mentioned increase in abundance under such conditions. The stations classified into group B and C are located at 200 – 330 m distances from the TP1 and TCP2 installations. These stations have relatively high concentrations of cadmium and lead in the sediments while the THC levels are low. The faunal disturbance, therefore, can be seen in connection with sediments contaminated by heavy metals in the vicinity of the TP1 and TCP2 installations.

In the 1997 survey, the fauna was found to be relatively undisturbed, although some minor signs of faunal disturbance could be seen at the stations close to the TP1 and TCP2 installations. At stations FRI01, FRI02, FRI03 and FRI04 the polychaetes *Chaetozone setosa* and *Ditrupa arietina* occurred in relatively high numbers and, at least stations FRI03 and FRI04, might have been placed in group B (slightly disturbed fauna). However, these stations were not separated from the other field stations in the multivariate analyses in that survey, as is the case in the present survey. Compared to this, faunal disturbance has increased at the field during the last three years. According to the information given in Table 5-1, discharges at the field have decreased in the recent years and no drilling has taken place. Accidental discharges occur at TCP2 in 1997 and 1998, but it is believed that this oil quickly dispersed into the water masses. On the other hand, the amount of pelite, TOM and most of the heavy metals have increased at station FRI04 and might explain the increased faunal disturbance.

Table 5-10: Classification in impact groups, distance to installation and biological statistics for the field stations at Frigg field, 2000.

Station.	Impact group	Dist. (m)	Statistics			No of individuals								
			No. ind	No. taxa	H'	Goc	Sbo	Afi	Psp	Mda	Dar	Csp	Cin	Tfl
FRI01	B	200	1278	103	4.3	263	344	8	26	6	47	122	15	1
FRI02	A	200	1176	93	3.9	427	199	67	52	5	0	61	0	5
FRI03	C	330	1165	84	4.2	59	220	0	23	0	134	239	126	8
FRI04	C	200	2635	102	3.1	474	71	18	15	4	1226	363	14	30
FRI11	A	500	1398	114	4.4	423	236	51	56	23	5	92	2	4
FRI24	A	250	1482	99	3.6	675	183	56	33	86	0	22	1	6
FRI25	A	250	863	93	4.8	110	192	46	38	8	0	36	0	17
FRI27	A	250	1704	99	3.7	728	212	150	79	64	1	16	0	4
FRI10R	A	14686	1598	128	4.9	256	216	146	160	49	0	13	0	30
RII02	A	-	2994	123	3.4	302	34	62	36	646	0	50	0	50
NEF20R	A	-	1221	68	4.0	301	149	68	23	7	0	19	0	25
PSB13R	A	-	1457	118	4.9	223	121	132	37	48	0	28	0	29
LFR01R	A	-	1523	119	4.9	312	55	156	66	69	0	17	0	19

Goc = *Galathowenia oculata*, Sbo = *Spiophanes bombyx*, Afi = *Amphiura filiformis*, Psp = *Phoronis* sp., Mda = *Myriochele danielsseni*, Dar =*Ditrupa arietina,* Csp = *Chaetozone sp. (incl. C. setosa)*, Cin = *Cirratulus incertus*, Tfl = *Thyasira flexuosa*.

5.3 Summary and conclusions

The sediments at Frigg are classified as fine sand with a relatively low amount of pelite (1.5 – 2.5 %) and TOM (0.7 – 1.0 %). The changes in the sediment characteristics since the previous survey is largest at the field station FRI04 for the amount of pelite and TOM in the sediment. The value for both these parameters have increased since 1997, which indicate an increased input of fine material at the location. This station is situated at 250 m distance from TP1 in south west direction, while the main current direction in the area is to the south east. There is also recorded an increase in the amount of pelite at the reference station FRI10R in the same period, while the amount of TOM is similar. It is therefore uncertain if this increase in the pelite is caused by natural variation or by the petroleum activity in the area.

Contamination by hydrocarbons is found in sediments at one station, situated 200 m in the 350° direction relative to TCP2.

Sediments from the station mentioned above and at the one situated 330 m in the194° direction relative to TCP2 have slightly higher THC levels in 2000 than 1997. This is also the case for sediments from the station situated 200 m in the 350° direction relative to DP2. Chromatograms of sediment extracts from these stations indicate mineral oil. This is in accordance with the discharge history of the field. At the other field stations THC levels are comparable with those found in 1997. However, the average THC concentrations in sediments at Frigg have increased from 6.6 mg/kg dry sediment to 7.5 mg/kg since 1997.

Barium concentrations above the limit of significant contamination are found in sediments at two stations, situated 200 m in the 170° and 350° directions relative to DP2. However, contamination by lead is found in sediments at all field stations. Contamination by copper and zinc are found in sediments at all field stations minus the one situated 330 m in the 70° direction relative to DP2. Cadmium contamination is found in sediment 330 m in the 194° direction relative to TCP2 and 200 m in the 249° direction relative to TP1. No chromium or mercury contamination is found in sediments at Frigg.

Sediment barium concentrations are higher in this survey than in 1997 at all stations except 200 m in the 70° and 350° directions relative to TCP2. At stations situated 200 m in the 170°and 350° directions relative to DP2 the sediment concentrations of barium have increased about four times, bringing the levels above the limit of significant contamination. The same pattern is seen for cadmium, copper, zinc and lead. Mercury levels are unchanged in sediments on station FRI05.

Like the Frøy and Heimdal fields, the field history at Frigg does not reveal any discharges that can explain the rise in metal concentrations since the last survey. The proportion of pelite in sediments at Frigg has increased with about 3% at the reference station, with a concomitant increase at the field stations. At the reference station minor increases in barium concentrations are measured, not explaining the general rise of barium concentrations in the field.

The number of individuals at the stations in this and the previous survey is relatively similar, while the number of taxa has decreased somewhat. This has resulted in a decrease in the diversity at all stations. Fauna disturbance is registered at three of the stations in the present survey. Station FRI01 is classified as faunal group B (slightly disturbed fauna), stations FRI03 and FRI04 are classified as faunal group C (disturbed fauna) while the rest of the stations at the field have undisturbed fauna. The stations FRI01, FRI03 and FRI04 are situated at 250 – 330 m from the TP1 and TCP2 installations. At these stations the polychaetes *Ditrupa arietina*, *Chaetozone* sp. and *Cirratulus incertus* are recorded with relatively high individual numbers, while the brittle star *Amphiura filiformis* is absent or recorded with a few individuals. The mentioned polychaetes are often abundant in organic enriched or disturbed sediments, while the brittle star decrease in individual numbers with increasing disturbance. The same stations are also separated from the other stations in the multivariate analyses and the CCA show significant correlations between the faunal distribution and the amount of cadmium and lead in the sediment. At these stations also high levels of most of the heavy metals (i.e. cadmium, lead, copper and zinc) are recorded, while the amount of THC is similar to, or somewhat higher, than the LSC value in the present survey. The faunal disturbance can therefore be seen in connection with the contaminated sediments in the vicinity of the installations TP1 and TCP2.

Although minor signs of faunal disturbance could be seen at the stations in the vicinity of TP1 and TCP2 in the previous survey, it was concluded that the fauna at the field was relatively undisturbed. It is possible that at least stations FRI03 and FRI04 should have been classified as faunal group B (slightly disturbed fauna) due to the relatively high number of individuals of the polychaetes *Ditrupa arietina* and *Chaetozone* sp. However, these stations were not separated from the other field stations in the multivariate analyses in that survey, as is the case in the present survey. Anyhow, it can be concluded that the faunal disturbance has increased in intensity since 1997. In the same period the concentrations of some of the heavy metals have increased at the same stations. Discharges at the field have decreased in the recent years and no drilling has taken place. Accidental discharges occur at TCP2 in 1997 and 1998, but it is believed that this oil quickly dispersed into the water masses. On the other hand, the amount of pelite, TOM and most of the heavy metals have increased at station FRI04 and might explain the increased faunal disturbance.

The calculated minimum area and spatial extent of contaminated sediments and disturbed fauna at the Frigg field is shown in Table 5-11 and Figure 5-12. The THC level at one station at Frigg has increased with 3 mg/kg dry sediment since 1997 and the THC level has just exceeded the LSC in the present survey. However the result is increased area contaminated with THC since 1997.

Table 5-11: Distance along the transects and calculated minimum area of contaminated sediments and disturbed fauna at the Frigg field, 2000 and previous survey.

Frigg TP1/TCP2	N	NE	S	W	Km^2 (2000)	Km^2 (1997)
Group B	200	100	330	200	0.12	0.13
Group C	100	100	330	200	0.10	0.00
THC	200	100	165	100	0.06	0.00
Ba	0	0	0	0	0.00	0.08
Other metals	500	200	330	200	0.26	0.26
Frigg DP2	SE	SW	NE	NW	Km^2 (2000)	Km^2 (1997)
Group B	0	0	0	0	0.00	0.00
Group C	0	0	0	0	0.00	0.00
THC	0	0	0	0	0.00	0.00
Ba	200	330	100	0	0.08	0.00
Other metals	200	330	200	0	0.10	0.10
Sum Frigg					Km^2 (2000)	Km^2 (1997)
Group B					0.12	0.13
Group C					0.10	0.00
THC					0.06	0.00
Ba					0.08	0.08
Other metals					0.36	0.36

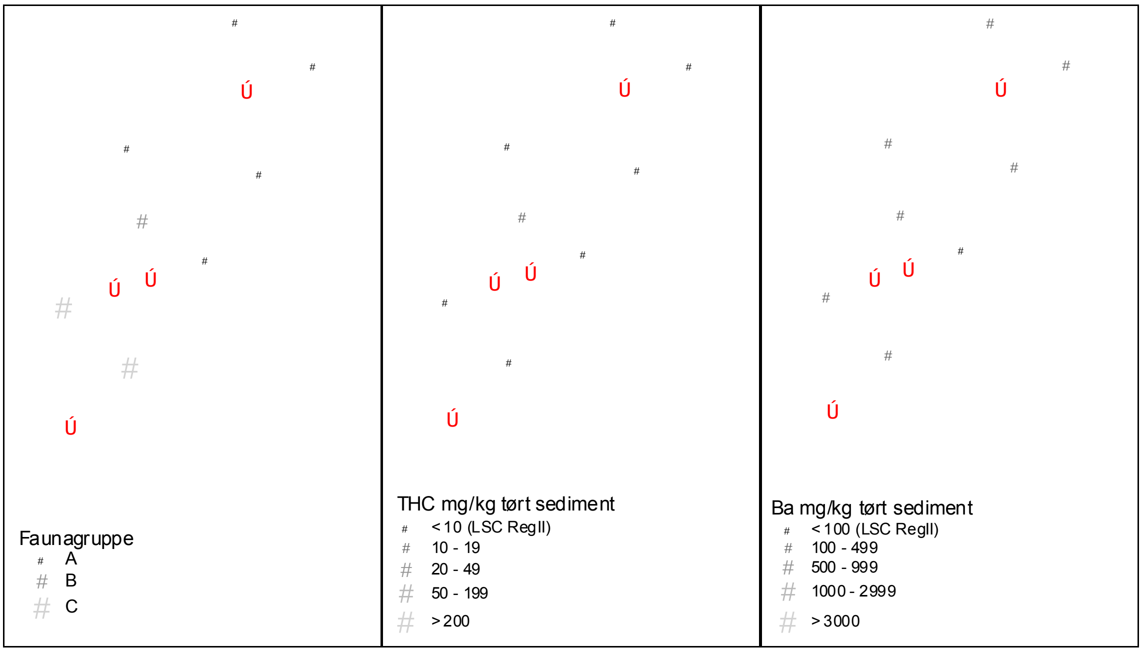

Figure 5-12: Distribution of faunal groups and amounts of THC and barium at the Frigg field, 2000.

Table 5-12: Number of individuals and the accumulative abundance for the ten most dominant taxa at each station at the Frigg field, 2000.

FRI01 (350°/200 m)	No. ind.	Acc. %	FRI02 (70°/200 m)	No. ind.	Acc. %	FRI03 (194°/330 m)	No. ind.	Acc. %	FRI04 (249°/200 m)	No. ind.	Acc. %	FRI011 (350°/500 m)	No. ind.	Acc. %
Spiophanes bombyx	344	22%	Galathowenia oculata	427	29%	Chaetozone setosa	228	16%	Ditrupa arietina	1226	42%	Galathowenia oculata	423	22%
Galathowenia oculata	263	38%	Spiophanes bombyx	199	43%	Spiophanes bombyx	220	31%	Galathowenia oculata	474	58%	Pectinaria sp. juv.	293	37%
Chaetozone setosa	114	45%	Ophiuroidea indet. juv.	95	49%	Pectinaria sp. juv.	141	41%	Chaetozone setosa	350	70%	Spiophanes bombyx	236	49%
Pectinaria sp. juv.	106	52%	Pectinaria sp. juv.	71	54%	Ditrupa arietina	134	50%	Pectinaria sp. juv.	212	77%	Ophiuroidea indet. juv.	106	54%
Ophiuroidea indet. juv.	76	57%	Amphiura filiformis	67	58%	Cirratulus incertus	126	59%	Spiophanes bombyx	71	79%	Chaetozone setosa	80	58%
Owenia fusiformis juv.	48	60%	Cerianthus lloydi juv.	56	62%	Ophiuroidea indet. juv.	63	63%	Cerianthus lloydi juv.	34	80%	Cerianthus lloydi juv.	64	62%
Ditrupa arietina	47	63%	Phoronis sp.	52	66%	Galathowenia oculata	59	67%	Thyasira flexuosa	30	81%	Phoronis sp.	56	64%
Siphonoecetes kroyeranus	35	65%	Chaetozone setosa	45	69%	Siphonoecetes kroyeranus	38	70%	Ophiuroidea indet. juv.	29	82%	Amphiura filiformis	51	67%
Cerianthus lloydi juv.	34	67%	Owenia fusiformis juv.	35	71%	Cerianthus lloydi juv.	37	72%	Hydroides norvegicus	22	83%	Edwardsia sp.	44	69%
Phoronis sp.	26	69%	Nemertini indet.	26	73%	Glycera lapidum	23	74%	Eumida ockelmanni	21	84%	Owenia fusiformis juv.	42	71%
			Spiophanes kroyeri	26	75%	Nemertini indet.	23	76%	Spiophanes sp. juv.	21	84%			
						Phoronis sp.	23	77%						

FRI24 (170°/250 m)	No. ind.	Acc. %	FRI25 (350°/250 m)	No. ind.	Acc. %	FRI27 (70/°250 m)	No. ind.	Acc. %	FRI10R (135.4°/14686 m)	No. ind.	Acc. %
Galathowenia oculata	675	38%	Spiophanes bombyx	192	17%	Galathowenia oculata	728	33%	Pectinaria sp. juv.	588	22%
Spiophanes bombyx	183	48%	Galathowenia oculata	110	27%	Spiophanes bombyx	212	43%	Owenia fusiformis juv.	395	36%
Myriochele danielsseni	86	53%	Pectinaria sp. juv.	88	35%	Pectinaria sp. juv.	162	50%	Galathowenia oculata	256	46%
Ophiuroidea indet. juv.	79	57%	Lucinoma borealis	72	41%	Amphiura filiformis	150	57%	Spiophanes bombyx	216	54%
Cerianthus lloydi juv.	76	61%	Ophiuroidea indet. juv.	58	46%	Owenia fusiformis juv.	130	63%	Phoronis sp.	160	60%
Pectinaria sp. juv.	73	66%	Cerianthus lloydi juv.	55	51%	Ophiuroidea indet. juv.	90	67%	Amphiura filiformis	146	65%
Amphiura filiformis	56	69%	Amphiura filiformis	46	55%	Phoronis sp.	79	71%	Ophiuroidea indet. juv.	90	68%
Owenia fusiformis juv.	37	71%	Phoronis sp.	38	58%	Myriochele danielsseni	64	74%	Owenia fusiformis	62	71%
Lucinoma borealis	34	73%	Owenia fusiformis juv.	34	61%	Cerianthus lloydi juv.	58	77%	Myriochele danielsseni	49	72%
Bathyporeia sp.	33	74%	Chaetozone setosa	32	64%	Spiophanes kroyeri	36	78%	Myriochele fragilis	48	74%
Eudorellopsis deformis	33	76%									
Phoronis sp.	33	78%									

Table 5-13: Station information for Frigg field, 2000.

St. no.	Installation	Distance (m)	Direction (degr.)	Volume (litres)
FRI01	TCP2	200	350	40
FRI02	TCP2	200	70	35
FRI03	TCP2	330	194	37
FRI04	TP1	200	249	36
FRI11	TCP2	500	350	36
FRI24	DP2	250	170	30
FRI25	DP2	250	350	30
FRI27	DP2	250	70	30
FRI10R	TCP2	14686	135.4	30 *

* The additional five grab samples gave 30 litres of sediment.

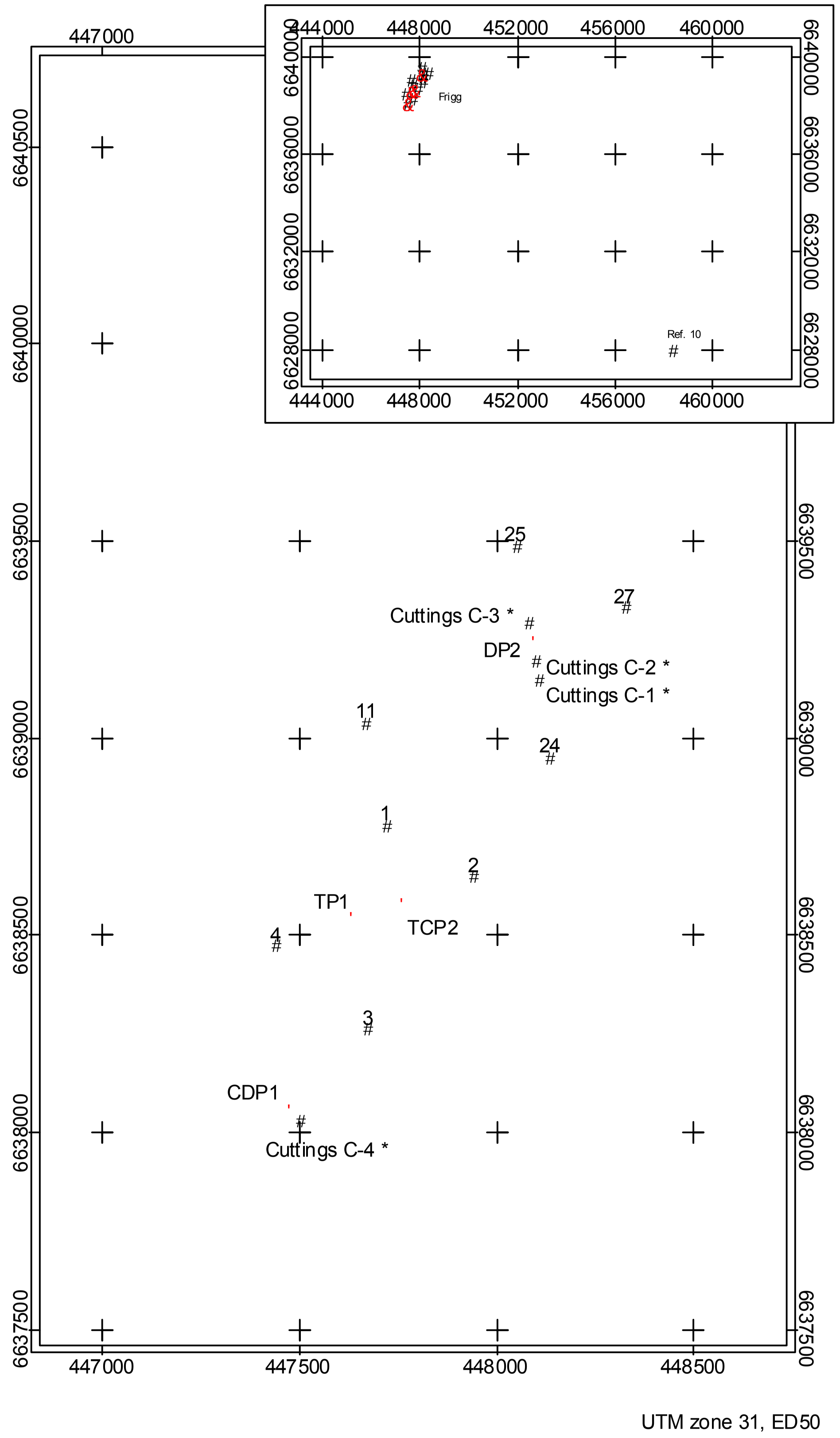

Figure 5-13: Map of sampling positions for Frigg field, 2000

6 Nordøst Frigg field

6.1 Introduction

The Nordøst Frigg field is located in block 25/11 and 30/10. Production at the field started in 1983 and ceased in 1993. No activity has taken place at the field in the recent years. The present survey is the second survey after removal of the installation.

In the monitoring survey at the field in 1997, no hydrocarbon or metal contamination of the sediments or effects on the fauna was detected and the same set of stations is therefore included in the present survey.

Information on the sampling stations is shown in Figure 6-11 and Table 6-11, both on the foldout page at the end of this chapter (page 6-15). In addition, samples from the cutting piles at the field were collected by use of a van Veen grab (biology) and box corer (chemistry). A separate report with these results will be produced.

6.2 Results and discussion

6.2.1 Physical characteristics

The median phi value and amounts (%) of pelite, fine sand, and total organic material (TOM) in the sediment from the stations at Nordøst Frigg are shown in Table 6-1 and Figure 6-1. 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 in the area are classified as fine sand with median values varying from 2.75 at station NEF22 to 3.14 at station NEF23. The amount of pelite in the sediment varies from 2.07 % at station NEF22 to 2.27 % at station NEF06, the fine sand from 31.7 (station NEF22) to 55.2 % (station NEF23) while the TOM varies between 0.63 % at station NEF22 to 0.77 % at station NEF23. All these values were lower at the field stations than that recorded at the reference station NEF20R.

Compared with the previous survey, the results are more or less similar, with the exception of an increase of the amount of pelite at the reference station and a decrease in the amount of fine sand at the field stations NEF05, 06 and 22. Between 1992 and 1997, there was a general increase in the median, fine sand and TOM content while the pelite value has decreased during the same period.

Table 6-1: The median (phi) and amount (%) of pelite, fine sand and TOM in the sediment from stations at the Nordøst Frigg field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	Distance (m)	Direction (degr.)	Median	Classification	Pelite	Fine sand	TOM
NEF05	250	150	2.86	Fine sand	2.12	40.0	0.64
NEF06	250	330	2.81	Fine sand	**2.27**	35.9	0.70
NEF22	250	285	**2.75**	Fine sand	**2.07**	**31.7**	**0.63**
NEF23	250	105	**3.14**	Fine sand	2.23	**55.2**	**0.77**
NEF20R	10000	60	3.52	Fine sand	5.64	74.4	0.99
Average *			2.89		2.17	40.7	0.69
St. dev. *			0.17		0.09	10.3	0.06

* Excluding the reference station.

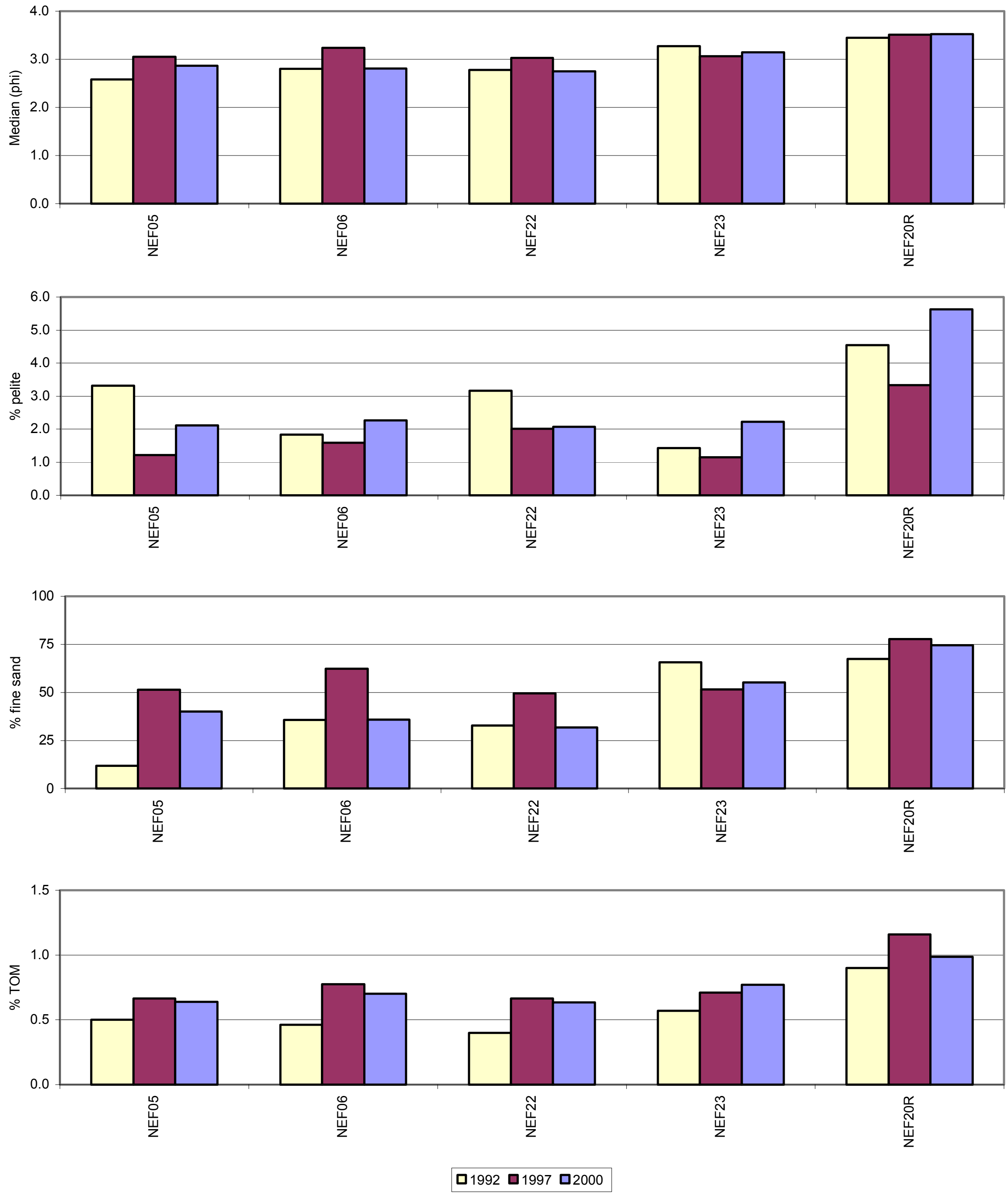

Figure 6-1: Sediment characteristics at the Nordøst Frigg field, 2000 and previous surveys.

6.2.2 Chemical characteristics

The calculated limits of significant contamination for selected hydrocarbons and metals in sediments from Region II ($LSC_{97\text{-}00\ RegII}$) are presented previously in the chapter that deals with the regional and reference stations. In addition to the regional limits, field-specific limits of significant contamination are calculated from the field reference station ($LSC_{00\ NEF20R}$). Both sets of data are presented in Table 6-2. Based on analysis results of the Nordøst Frigg field the $LSC_{97\text{-}00\ RegII}$ is regarded as representative of the entire region and will therefore be used as further basis for discussion of the contamination status of this field. Those limits will hereafter simply be referred to as LSC.

The results of analyses of the hydrocarbons are summarised in Table 6-3. Concentrations of selected compounds in the vertical sediment sections are presented in Table 6-4. The full data set of replicate measurements and date from previous years are given in the Appendix. THC values are compared with those from previous years in Figure 6-2.

Table 6-2: Background levels and Limits of Significant Contamination for the Nordøst Frigg field, 2000. All values in mg/kg dry sediment.

	THC	NPD's	3-6 ring	Decalins	Cd	Hg	Cu	Zn	Ba	Cr	Pb
$LSC_{00\ NEF20R}$	8.7	0.021	0.049	0.050	0.030	0.009	1.3	3.8	114	5.1	3.8
$LSC_{97\text{-}00\ Region\ II}$	9.8	*	*	*	0.029	0.008	2.0	8.9	146	9.6	7.0

*) Regional stations not analysed for NPD's, 3-6 ring aromatics and decalins.

Table 6-3: Concentrations of hydrocarbons in sediments from the Nordøst Frigg field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between $LSC_{00NEF20R}$ and $LSC_{97\text{-}00\ RegII}$ light shaded.

Station	THC		NPD's		3-6 ring		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
NEF05	2.6	0.5	0.008	0.003	0.013	0.001	0.024	0.013
NEF06	3.2	0.7	n.a.		n.a.		n.a.	
NEF22	3.2	0.1	n.a.		n.a.		n.a.	
NEF23	4.8	3.1	n.a.		n.a.		n.a.	
NEF20R	6.2	1.0	0.008	0.005	0.024	0.011	0.018	0.013

n.a. Not analysed.

Table 6-4: Concentrations of hydrocarbons in vertical sections of sediment samples from the Nordøst Frigg field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between $LSC_{00NEF20R}$ and $LSC_{97\text{-}00\ RegII}$ light shaded.

Station	Layer (cm)	THC	NPD's	3-6 ring	Decalins
NEF05	0-1	2.4	0.005	0.012	0.015
	1-3	3.6	0.008	0.017	0.023
	3-6	4.0	0.011	0.026	0.013
NEF20R	0-1	8.0	0.016	0.038	0.034
	1-3	4.1	0.017	0.044	0.026
	3-6	8.0	0.028	0.069	0.074

n.a. Not analysed.

The THC values range from 2.6 ± 0.5 mg/kg to 6.2 ± 1.0 mg/kg dry sediment at Nordøst Frigg (Table 6-3). Sediments at all field stations have low THC values, all of them well beyond LSC. Low concentrations of NPD's, 3-6 ring aromatics and decalins are found in sediments at station NEF 05, which is the only field station analyzed for selected aromatics and decalins (Table 6-3). None of the values exceed LSC for these parameters.

Vertical core samples from station NEF05 reveal an almost uniform distribution of THC with depth and no values are above the LSC (Table 6-4). Low concentrations of aromatics and decalins are also found in these samples.

In general, no hydrocarbon contamination of sediments at Nordøst Frigg is found in this year's survey.

The results of the metal analyses for the Nordøst Frigg field are summarised in Table 6-5. Concentrations of selected metals in the vertical sediment sections are presented in Table 6-6. The full set of replicate measurements, including selected data from previous years is given in the Appendix. Metal values from 2000 are compared with those from previous years in Figure 6-3 and Figure 6-4.

Table 6-5: Concentrations of selected metals in sediments from the Nordøst Frigg field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between $LSC_{00NEF20R}$ and $LSC_{97\text{-}00\ RegII}$ light shaded.

	Cd		Hg		Cu		Zn		Ba		Cr		Pb	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
NEF05	0.004	0.001	<0.005	-	0.6	0.4	0.9	0.8	20	3	6.1	0.2	3.7	0.0
NEF06	0.006	0.002	n.a.		0.8	0.2	1.7	1.0	31	10	6.2	0.1	3.6	0.2
NEF22	0.009	0.006	n.a.		0.5	0.4	2.1	1.0	38	44	5.4	0.6	3.3	0.3
NEF23	0.007	0.001	n.a.		0.6	0.3	0.9	0.4	24	8	5.4	0.2	3.2	0.1
NEF20R	0.014	0.007	0.004	0.002	0.9	0.2	2.5	0.6	78	16	4.7	0.2	3.4	0.2

n.a. Not analysed.

Table 6-6: Concentrations of selected metals in vertical sections of the sediment samples from the Nordøst Frigg field. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between $LSC_{00NEF20R}$ and $LSC_{97\text{-}00\ RegII}$ light shaded.

Station	Layer (cm)	Cd	Hg	Cu	Zn	Ba	Cr	Pb
NEF05	0-1	<0.005	<0.005	<0.6	<1.0	18	5.9	3.7
	1-3	0.008	<0.005	0.8	<1.0	35	6.2	3.9
	3-6	0.018	<0.005	1.0	1.2	93	6.2	3.7
NEF20R	0-1	0.018	<0.005	0.8	2.4	83	4.7	3.2
	1-3	0.018	0.005	1.1	2.7	120	4.6	3.8
	3-6	0.021	0.005	1.0	3.0	184	5.0	4.0

n.a. Not analysed.

The barium values range from 20 ± 3 mg/kg to 78 ± 16 mg/kg dry sediment, cadmium from 0.004 ± 0.001 mg/kg to 0.014 ± 0.007 mg/kg, copper from 0.5 ± 0.4 mg/kg to 0.8 ± 0.2 mg/kg, lead from 3.2 ± 0.1 mg/kg to 3.7 ± 0.0 mg/kg, zinc from 0.9 ± 0.4 mg/kg to 2.5 ± 0.6 mg/kg and chromium from 4.7 ± 0.2 to 6.2 ± 0.1 mg/kg (Table 6-5).

All selected metals reveal sediment values below LSC. For the metals, as for the hydrocarbons, the highest concentrations are found in sediments from the reference station. Chromium and lead are exceptions to this tendency. These metals reveal a uniform distribution in the field, the reference station included. Hg-measurements are conducted in sediments from two stations. In both cases concentrations at background levels are found.

Vertical sections of core samples reveal slight increases in metal concentrations with depth at the reference station and a relatively uniform distribution down to 6 cm at station NEF05 (Table 6-6). Barium concentrations above LSC are found in the 3-6 cm section at the reference station. In general, low metal contents are found in sediments at the field stations and no parts of the field can be characterised as contaminated by metals.

<u>Comparison with previous survey(s)</u>

Sediments at the reference station contain the highest concentrations of both hydrocarbons and selected metals at Nordøst Frigg, though well beyond the limits of significant contamination. There is an obvious difference in grain sizes between the reference- and field stations, which may explain the results. Sediments from the reference station have higher content of pelite and fine sand than sediments at the field stations. When comparing to the 1997 survey minor increases in barium and lead concentrations in sediments at the reference station are found. Concentrations of aromatics, decalins and barium above LSC are found in the 3-6 cm layer of vertical core samples at the reference station.

In 2000 no contamination of sediments at Nordøst Frigg is found. According to field history the field was closed down in 1993. From 1992 to 1997 there were slight increases in sediment hydrocarbon and metal concentrations at Nordøst Frigg. From 1997 to 2000 we find minor decreases in hydrocarbon levels expressed as THC (Figure 6-2), aromatics and decalins. The average THC concentration has gone down from 4.8 mg/kg dry sediment to 3,5 mg/kg. For the selected metals we find minor increases in sediment concentrations of barium and lead, unchanged or lower levels of the other specimen (Figure 6-3, Figure 6-4).

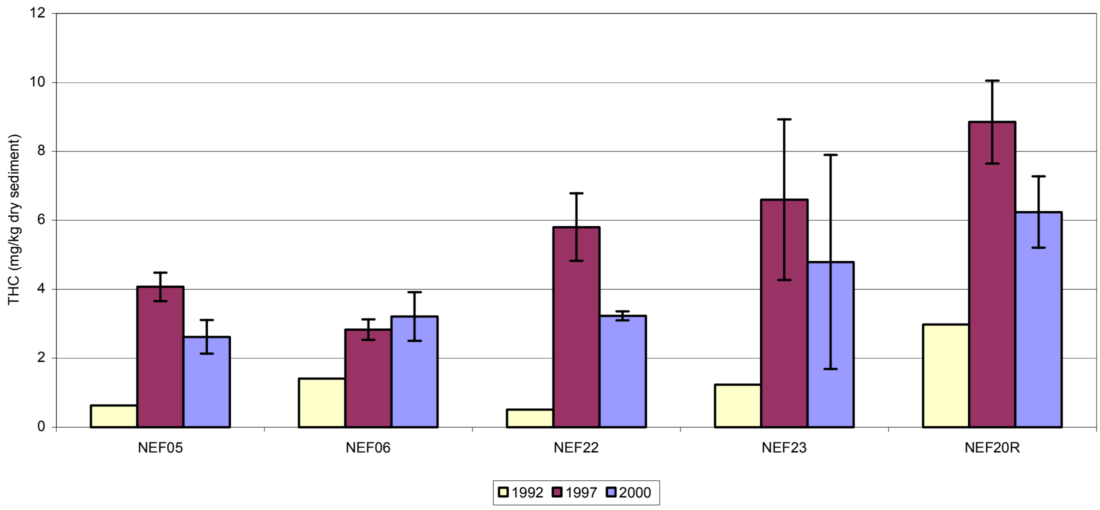

Figure 6-2: THC levels in sediment from the present (2000) and previous surveys, Nordøst Frigg field.

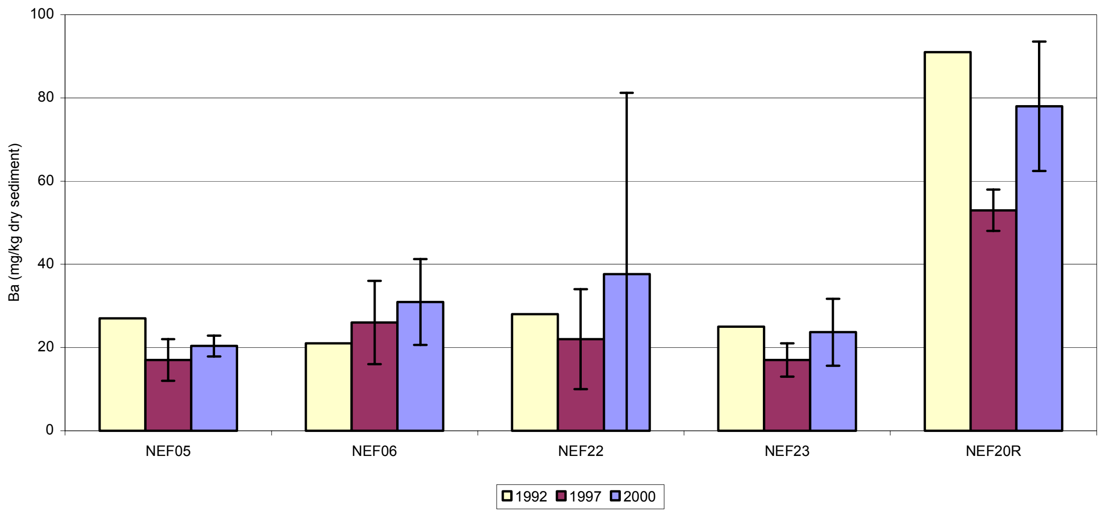

Figure 6-3: Barium levels in sediment from the present (2000) and previous survey, Nordøst Frigg field.

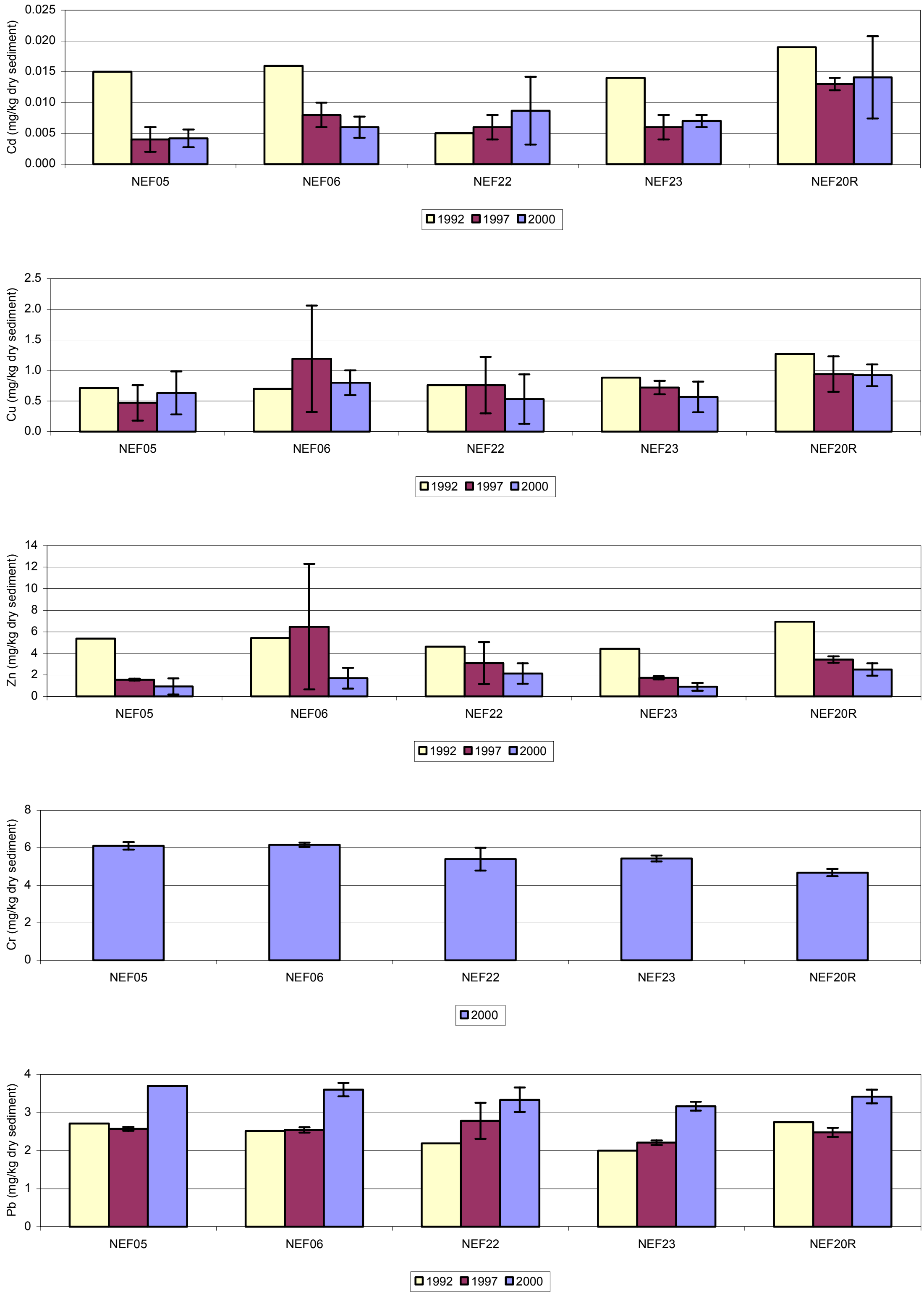

Figure 6-4: Levels of selected metals in sediments from the present (2000) and previous surveys, Nordøst Frigg field.

6.2.3 Biology

The distribution of individuals and taxa within the main taxonomic groups are given in Table 6-7. A total of 3563 individuals within 170 taxa were registered at the Nordøst Frigg field in the present survey (excluding juveniles). The polychaetes dominate the fauna with 63 % of the individuals and 54 % of the taxa recorded.

Table 6-7: Distribution of individuals and taxa within the main taxonomic groups at Nordøst Frigg, 2000 (excluding juveniles).

Main taxonomic groups	Individuals		Taxa	
	Number	%	Number	%
Polychaeta	2240	63	92	54
Mollusca	298	8	27	16
Crustacea	283	8	33	19
Echinodermata	511	14	8	5
Diverse groups	231	6	10	6
Total	3563	100	170	100

The species/area curve for the field reference station is shown in Figure 6-5. A total of 95 taxa are recorded in the ten grab samples, of which 43 (45.3 %) occur taken in the first sample and 68 (71.6 %) occur in the first five samples. The shape of the curve indicates that not all taxa in the area are present in the ten grab samples and the representativity of five samples seems to be relatively low compared with the curves form other reference stations in the region.

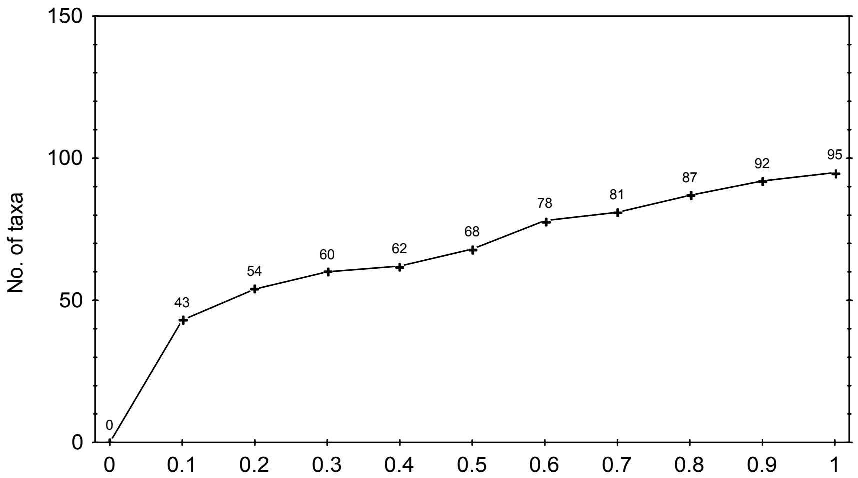

Figure 6-5: Species/area curve for the reference station at the Nordøst Frigg field, 2000 (area in m^2).

The number of individuals and taxa at each station, together with selected community indices is presented in Table 6-8 and Figure 6-6. The number of individuals in the present survey varies from 493 at station NEF22 to 639 at station NEF05, the number of taxa varies between 86 (NEF06) and 98 (NEF23), the diversity index H' between 4.7 and 5.1, the evenness index J between 0.73 and 0.79 and the ES_{100} between 35 and 41. The indices H', J and ES_{100} have highest and lowest values at station NEF06 and NEF22, respectively. At the reference station NEF20R, the number of individuals is higher while all other values are lower than at the field stations.

These values are equal to or lower than those recorded in the previous surveys. The number of taxa at the reference station decreased from 128 to 68 between 1997 and 2000, which resulted in a drop in the H' and ES_{100} values at that station.

Table 6-8: Number of individuals and taxa and selected community indices for each station (0.5 m^2) at the Nordøst Frigg field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	No. of ind.	No. of taxa	H'	J	ES_{100}
NEF05	**639**	87	5.0	0.78	38
NEF06	573	**86**	**4.7**	**0.73**	**35**
NEF22	**493**	89	**5.1**	**0.79**	**41**
NEF23	637	**98**	5.0	0.76	38
NEF20R	1221	68	4.0	0.66	25
Sum *	2342				
Average *	586	90	5.0	0.76	38
St. dev. *	69	5	0.2	0.03	3

* Excluding the reference station.

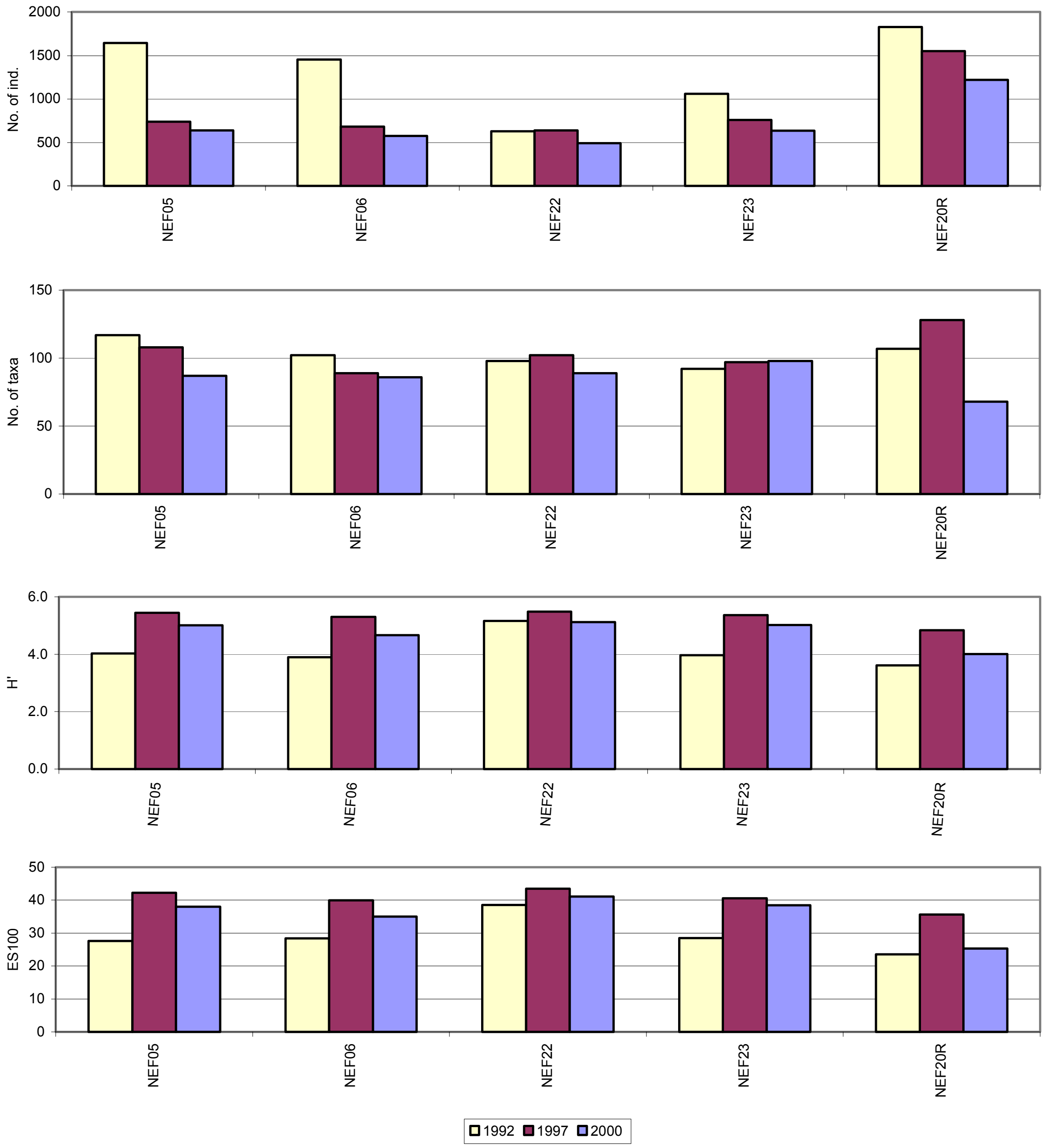

Figure 6-6: Biological characteristics at the Nordøst Frigg field, 2000 and previous surveys.

The distribution of taxa in geometrical classes at each station is shown in Figure 6-7. The reference station has one taxon in class 9 (256 – 511 individuals) while the field stations all have taxa in class 7 (64 – 127) and lower. At the same time there are relatively few taxa in geometrical class 1 (1 individual) at the reference station compared with the field stations. The results do not indicate any faunal disturbance at the field.

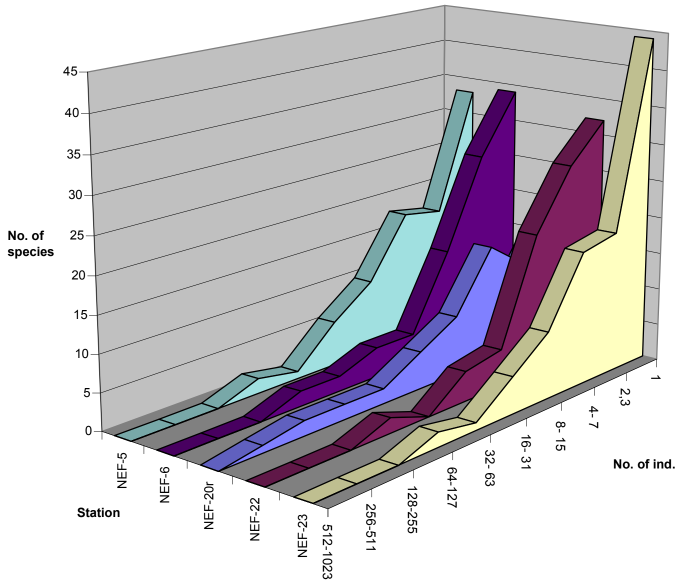

Figure 6-7: Distribution of taxa in geometrical classes for the stations at the Nordøst Frigg field, 2000.

The ten most dominant taxa at each station are shown in Table 6-10 at the end of this chapter. A total of 15 taxa, including four juvenile groups, are among the ten most dominant taxa at one or more stations. These 15 taxa comprise 75 % of the total number of individuals and 9 % of the total number of taxa found at the Nordøst Frigg in the present survey.

The most dominant taxa among the adult forms are the polychaete *Spiophanes bombyx* and the brittle star *Amphiura filiformis*. These two species are among the five most dominant taxa at five and four stations, respectively. Dominance of *A. filiformis* indicate a lack of faunal disturbance at the localities. The polychaetes *Galathowenia oculata* and *Owenia fusiformis* are among the most dominant taxa only at the reference station.

The ten most dominant taxa at the stations comprise between 61 % (NEF05) and 72 % (NEF06 and 23) of the total number of individuals recorded at the respective field station. The corresponding value at the reference station is 81 %. The results indicate a uniform distribution of undisturbed fauna in the area.

Figure 6-8 shows the dendrogram from the cluster analysis for the field stations and selected regional and reference stations.

The cluster analysis separates all regional and reference stations from the field stations at 50 % dissimilarity level. Within the field station group, the stations separate from each other at dissimilarity levels between 36 and 32 %. In the other group, the reference station at Nordøst Frigg separates from the remaining stations at 40 % dissimilarity level. The correlation coefficient shows a very good fit to the data (r = 0.95).

Due to the large differences between the field stations and the regional and reference stations, the MDS analyses are not informative (the plots from this analyses are shown in the Appendix). A 2-D plot from the analysis including only field stations and field reference station is shown in Figure 6-9. The field stations are evenly distributed in the plot.

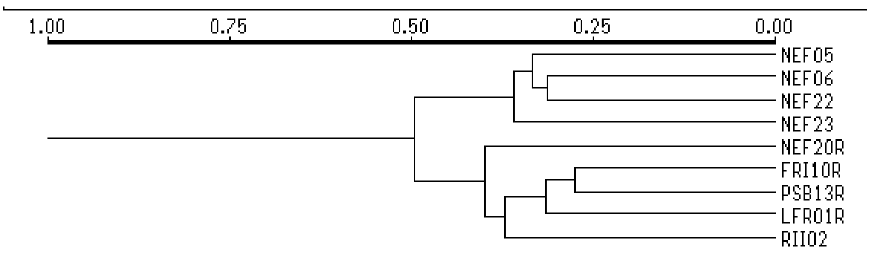

Figure 6-8: Cluster analysis of the Nordøst Frigg field stations and selected regional and reference stations in Region II, 2000.

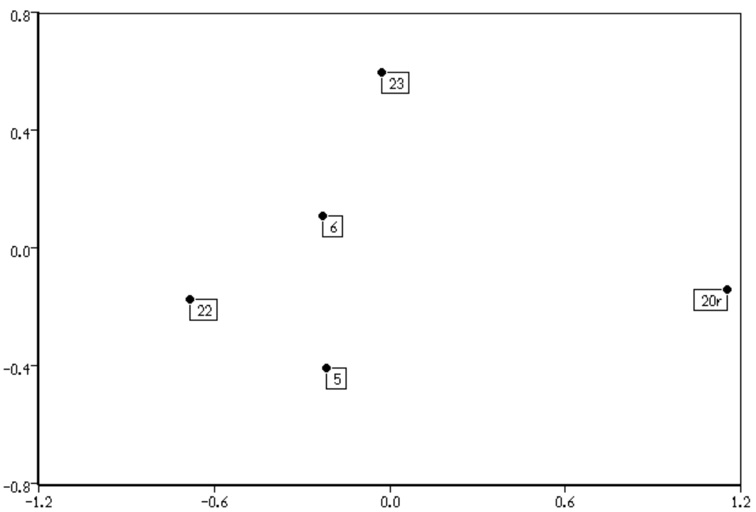

Figure 6-9: 2-D plot from the MDS analysis carried out on Nordøst Frigg field stations, 2000.

A Canonical Correspondence Analysis (CCA) of the data from the field stations and selected regional and reference stations was carried out to examine the association between the biological data and the measured environmental variables in these areas.

Through the forward selection procedure in CANOCO, two of ten variables, TOM and chrome gave the best fit and are significant. 52.9 % of the biological variance is explained by the first two axes of the ordination space which is constrained by these environmental variables.

Figure 6-10 shows a biplot from the analysis using TOM and chrome (Cr) as the constraining environmental variables. The first axis shows a gradient from field station NEF05 at the positive end to regional station RII02 at the negative end and is correlated with the amount of chrome (+ 0.92) and TOM (- 0.59) in the sediments. The species with the highest contribution on this axis are the polychaetes *Owenia fusiformis* (19.9 %), *Myriochele danielsseni* (11.5 %), *Spiophanes bombyx* (6.8 %) and *M. fragilis* (5.0 %) and the brittle star *Amphiura filiformis* (7.2 %).

The second axis shows a gradient from field station NEF22 on the positive end to reference station FRI10R on the negative end and is negatively correlated with the amount of TOM (- 0.72) in the sediments. The species with the highest contribution on this axis are the polychaetes *Owenia fusiformis* (11.9 %), *Galathowenia oculata* (11.4 %), *Myriochele danielsseni* (10.4 %) and the phoronid *Phoronis* sp. (8.6 %).

These analyses do not indicate any disturbed conditions at the stations included, as only taxa that are abundant in clean sediments are associated with the distribution of the stations on the two axes. Stations on the right side of the biplot have higher concentrations of chrome in the sediments than those appearing on the left side, but the levels are low (< 6.2 mg/kg on the field stations) and within the LSC value for the region. All measurements of the other heavy metals and THC from the stations have values below the LSC level. Stations on the right side of the plot have lower TOM values than those on the left side and also these values are low, the highest value being recorded at the reference station FRI10R (1.18 %).

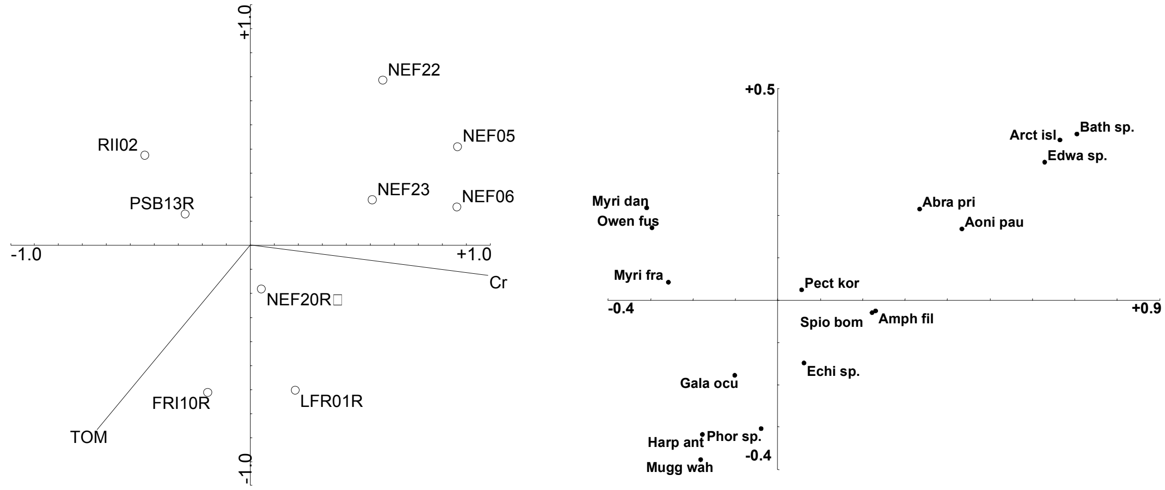

Figure 6-10: Biplot from the CCA analysis for the Nordøst Frigg field stations and selected regional and reference stations in Region II, 2000 (left) and species with highest contribution on the two axes (right).

On the basis of the results from the uni- and multivariate analyses carried out, all stations from the Nordøst Frigg are classified as belonging to faunal group A (undisturbed fauna, see Table 6-9). The number of individuals of the polychaetes *Galathowenia oculata* and *Owenia fusiformis* are much higher at the regional and reference stations than at the field stations. The differences seen in the faunal composition between the field stations and the regional and reference stations, and which is shown in the multivariate analysis, are believed to be a result of differences in the sediment structure between the stations. The sum of the amount of pelite and fine sand at the field stations is between 33 and 57 % while the value at the regional and reference stations included in Table 6-9 is 72 - 92 %. This is also reflected in the amount of TOM in the sediment, which is highest at the regional and reference stations. All measured chemical parameters, including heavy metals and hydrocarbons, are low at the field stations. Further, none of the known indicator species, that are abundant in disturbed sediment, occur in high numbers at the field stations.

The fauna also was found to be undisturbed in the previous survey in 1997. Similar differences in faunal composition between the field and reference stations, with dominance of the above mentioned polychaetes at the reference station, also were registered in that survey.

Table 6-9: Classification into impact groups, distance to installation and biological statistics for the field stations at Nordøst Frigg field and selected regional and reference stations in Region II, 2000.

Station	Impact group	Dist. (m)	Statistics			No. of individuals							
			No. of ind	No. of taxa	H'	Afi	Apr	Spb	Goc	Ofu	Skr	Csp	Cca
NEF05	A	250	639	87	5.0	99	29	104	12	2	19	9	0
NEF06	A	250	573	86	4.7	111	39	111	8	5	35	1	1
NEF22	A	250	493	89	5.1	80	17	80	1	2	23	5	2
NEF23	A	250	637	98	5.0	97	31	111	4	1	45	11	1
NEF20R	A	10000	1221	68	4.0	68	7	149	301	227	70	19	0
RII02	A	-	2994	123	3.4	62	34	34	302	1085	40	50	0
FRI10R	A	-	1591	126	4.9	146	6	216	256	62	45	13	0
PSB13R	A	-	1457	118	4.9	132	21	121	223	98	65	28	0
LFR01R	A	-	1523	119	4.9	156	8	55	312	115	44	17	2

Afi = *Amphiura filiformis*, Apr = *Abra prismatica*, Spb = *Spiophanes bombyx*, Skr = *S. kroyeri*, Goc = *Galathowenia oculata*, Ofu = *Owenia fusiformis*, Csp = *Chaetozone* sp., Cca = *Capitella capitata*.

6.3 Summary and conclusions

The sediments at Nordøst Frigg are classified as fine sand with relatively low amount of pelite (2.0 – 2.3 %) and TOM (0.6 – 0.8 %). The changes in the sediment characteristics since the previous survey is largest at the reference station NEF20R (increase in the amount of pelite from 3.3 to 5.6 %) and field station NEF06 (decrease in the amount of fine sand from 62.4 to 35.9 %). On the regional basis there is a general trend of finer sediments. The amount of TOM in the sediment at the field stations is between 0.5 and 1.0 % and is relatively similar to that found in the previous survey.

In 2000 no contamination of sediments at Nordøst Frigg is found. According to field history the field was closed down in 1993. From 1992 to 1997 there were slight increases in sediment hydrocarbon and metal concentrations at Nordøst Frigg. From 1997 to 2000 we find minor decreases in hydrocarbon levels expressed as total hydrocarbons, aromatics and decalins. The average total hydrocarbon concentration has gone down from 4.8 mg/kg dry sediment to 3,5 mg/kg. Among the selected metals minor increases in sediment concentrations of barium and lead are found, while the levels of the other are unchanged or lower.

The number of individuals and taxa are relatively similar in the present and previous survey, with the exception of the reference station NEF20R where the number of taxa is almost half of earlier record (128 to 68). It is not registered any faunal disturbance at the surveyed stations from Nordøst Frigg in 2000. The differences in the faunal composition between the field stations and the regional and reference stations, which are seen in the multivariate analyses, is believed to be a result of the differences found in the sediment structure at the stations. The sediment is coarser at the field stations and this also results in differences in the amount of TOM in the sediment, which are highest at the regional and reference stations. All measured chemical parameters, including the THC and heavy metals, are low at the field stations. None of the known indicator species, which are abundant in disturbed sediments, occur in high numbers at the field.

The fauna was also found to be undisturbed in the previous survey so that the environmental conditions are unchanged at the field in this second survey after removal of the installation.

Table 6-10: Number of individuals and the accumulative abundance for the ten most dominant taxa at each station at the Nordøst Frigg field, 2000.

NEF05 (170/250 m)	No. ind.	Acc. %	NEF06 (330/250 m)	No. ind.	Acc. %	NEF22 (285/250 m)	No. ind.	Acc. %	NEF23 (105/250 m)	No. ind.	Acc. %	NEF20R (60/10000 m)	No. ind.	Acc. %
Spiophanes bombyx	104	12	Pectinaria sp. juv.	121	15	Pectinaria sp. juv.	142	19	Pectinaria sp. juv.	257	23	Pectinaria sp. juv.	346	21
Amphiura filiformis	99	24	Amphiura filiformis	111	28	Amphiura filiformis	80	29	Owenia fusiformis juv.	123	34	Galathowenia oculata	301	39
Ophiuroidea indet. juv.	70	33	Spiophanes bombyx	111	41	Spiophanes bombyx	80	40	Spiophanes bombyx	111	44	Owenia fusiformis	227	52
Owenia fusiformis juv.	58	40	Owenia fusiformis juv.	60	48	Ophiuroidea indet. juv.	58	48	Amphiura filiformis	97	53	Spiophanes bombyx	149	61
Pectinaria sp. juv.	43	45	Ophiuroidea indet. juv.	56	55	Owenia fusiformis juv.	43	53	Ophiuroidea indet. juv.	71	59	Owenia fusiformis juv.	77	66
Bathyporeia sp.	35	49	Abra prismatica	39	60	Bathyporeia sp.	23	56	Spiophanes kroyeri	45	63	Spiophanes kroyeri	70	70
Aonides paucibranchiata	30	53	Spiophanes kroyeri	35	64	Spiophanes kroyeri	23	60	Cerianthus lloydi juv.	32	66	Amphiura filiformis	68	74
Abra prismatica	29	56	Pectinaria koreni	25	67	Abra prismatica	17	62	Abra prismatica	31	68	Pectinaria koreni	51	77
Cerianthus lloydi juv.	22	59	Cerianthus lloydi juv.	19	69	Cerianthus lloydi juv.	17	64	Aonides paucibranchiata	26	71	Ophiuroidea indet. juv.	34	79
Edwardsia sp.	20	61	Aonides paucibranchiata	18	72	Edwardsia sp.	16	66	Bathyporeia sp.	18	72	Anobothrus gracilis	32	81

Table 6-11: Station information for Nordøst Frigg field, 2000.

St. no.	Distance (m)	Direction (degr.)	Volume (litres)
NEF05	250	150	50
NEF06	250	330	37
NEF22	250	285	46
NEF23	250	105	45
NEF20R	10000	60	32 [1]

[(1)] The additional five grab samples taken gave 31 litres of sediment.

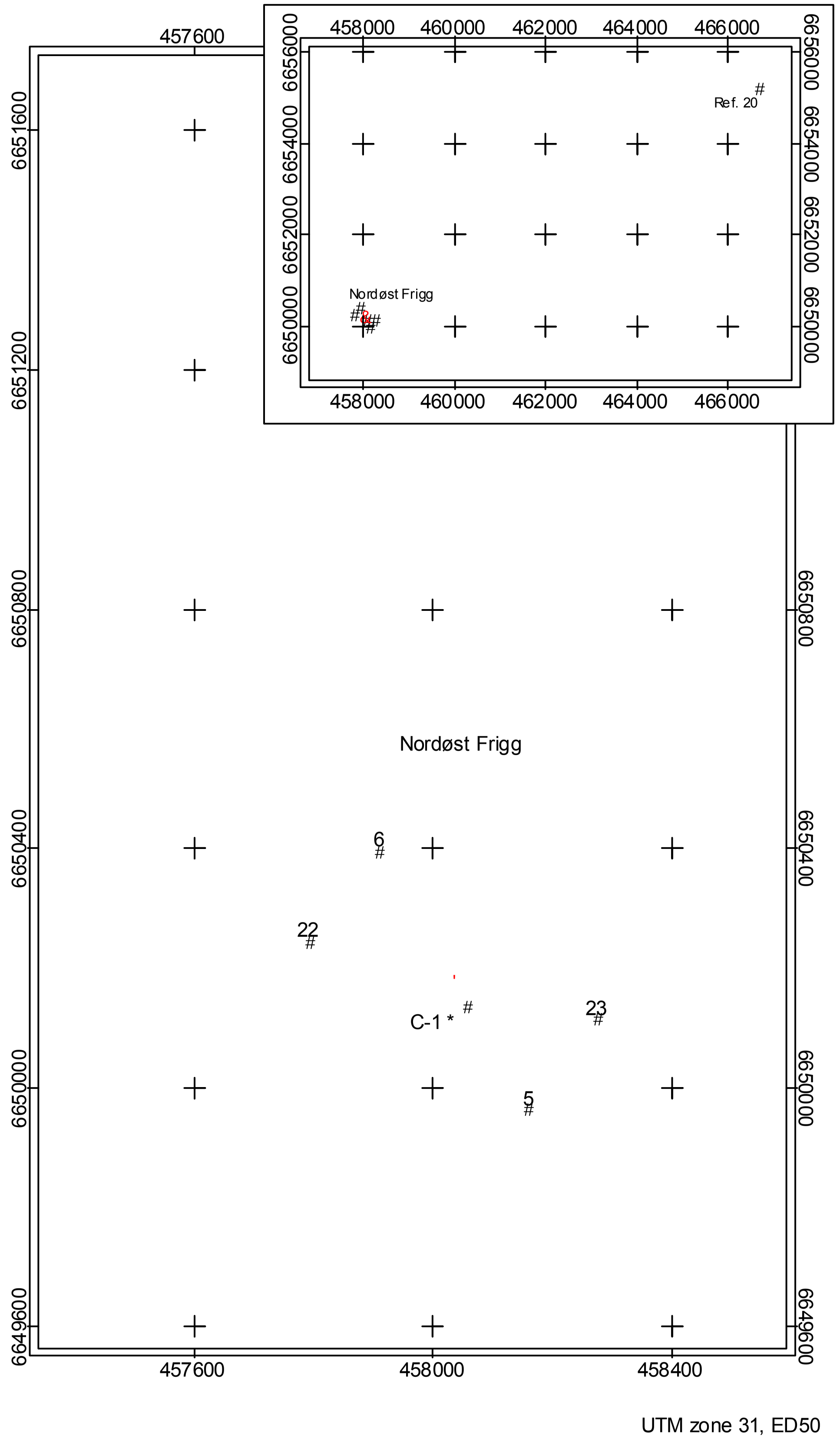

Figure 6-11: Map of sampling positions for Nordøst Frigg field, 2000

7 Øst Frigg field

7.1 Introduction

The Øst Frigg field is located in block 25/1 and 25/2 in the Region II. Production at the field started in 1988 and the field was closed down in 1997. There has been no drilling activity at the field since the previous survey. The wells were permanently plugged and abandoned in 1999 and the discharges given in Table 7-1 occur during this operation. Some parts of the well head equipment have been removed while the frame will be removed in 2001.

In the monitoring survey at the field in 1997 the stations situated 500 m in the 330°direction relative to PSA and 250 m in directions 150° and 240° were contaminated by hydrocarbons. The area contaminated with barium extended 500 m in the 330° direction and 250 m in directions 150° and 60° relative to PSA, in addition to the stations situated 250 m in directions 150°and 240°relative to PSB. Sediments contaminated by the other selected metals were not found in 1997. The fauna was found to be slightly disturbed at 250 m distance south east of PSA. Based on the results obtained in 1997, five field stations at 500 m and one of the reference stations were excluded from the present survey.

Information on the sampling stations is shown in Figure 7-13 and Table 7-13, both on the foldout page at the end of this chapter (page 7-19). In addition, samples from the cutting piles at the field were collected by use of a van Veen grab (biology) and box corer (chemistry). A separate report with these results will be produced.

Table 7-1: Summary of recent operational and accidental discharges at the Øst Frigg field (all discharges in tonnes).

	1997	1998	1999	2000	Comments
Barite	0	0	81	-	
Water-based drilling mud	0	0	804	-	
Cementing chemicals	0	0	310	-	

7.2 Results and discussion

7.2.1 Physical characteristics

The median phi value and the amounts (%) of pelite, fine sand and total organic material (TOM) in the sediment from the present and previous surveys are shown in Table 7-2 and Figure 7-1. 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 in the area are classified as fine sand with a median value varying from 3.36 to 3.58. The amount of pelite in the sediment varies from 3.59 % (station PSA09) to 5.57 % (station PSA08), the fine sand from 65.4 % (station PSA08) to 90.6 % (station PSB17) while the TOM varies from 0.91 % (station PSB08) to 1.25 % (station PSB16). The median and pelite values are higher at the reference station PSB13R than at the field stations, while the fine sand and TOM values are within the range for the field stations.

Compared with the previous surveys, there is a general trend for finer sediments at the stations, while the amount of TOM in the sediment has decreased since 1997, with the exception of station PSB16.

Table 7-2: The median (phi) and amount (%) of pelite, fine sand and TOM in the sediment from stations at the Øst Frigg field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	Distance (m)	Direction (degr.)	Median	Classification	Pelite	Fine sand	TOM
PSA06	500	330	3.53	Fine sand	3.96	86.5	0.99
PSA07	250	330	**3.58**	Fine sand	4.75	90.3	1.07
PSA08	250	150	3.39	Fine sand	**5.57**	**65.4**	0.96
PSA09	500	150	3.37	Fine sand	**3.59**	69.0	1.00
PSA19	250	60	**3.36**	Fine sand	4.11	65.7	0.94
PSA20	250	240	3.53	Fine sand	5.17	82.6	0.96
PSB06	350	330	3.56	Fine sand	5.23	86.8	1.04
PSB07	250	150	3.54	Fine sand	5.10	84.3	1.04
PSB08	500	150	3.51	Fine sand	4.66	80.5	**0.91**
PSB16	250	60	3.55	Fine sand	4.65	85.9	**1.25**
PSB17	250	240	3.57	Fine sand	4.64	**90.6**	0.97
PSB13R	10000	150	3.60	Fine sand	6.47	85.5	0.97
Average *			3.50		4.67	80.7	1.01
St. dev. *			0.08		0.60	9.5	0.09

* Excluding the reference station.

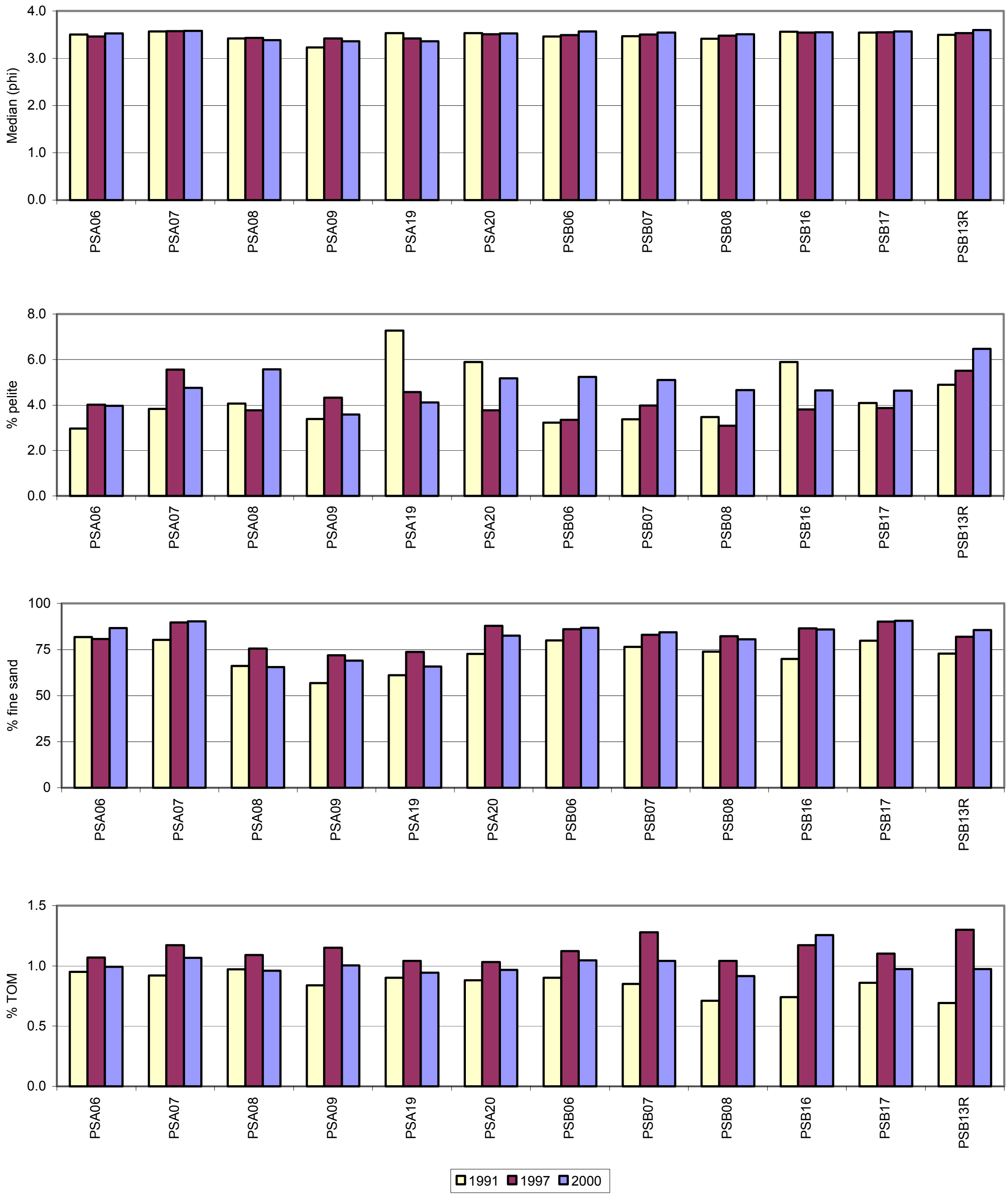

Figure 7-1: Sediment characteristics at the Øst Frigg field, 2000 and previous surveys.

7.2.2 Chemical characteristics

The calculated limits of significant contamination for selected hydrocarbons and metals in sediments from Region II ($LSC_{97\text{-}00\ RegII}$) are presented previously in the chapter that deals with the regional and reference stations. In addition to the regional limits, field-specific limits of significant contamination are calculated from the field reference station ($LSC_{00\ PSB13R}$). Both sets of data are presented in Table 7-3. Based on analysis results of the Øst Frigg field the $LSC_{97\text{-}00\ RegII}$ is regarded as representative of the entire region and will therefore be used as further basis for discussion of the contamination status of this field. Those limits will hereafter simply be referred to as LSC.

The results of analyses of the hydrocarbons are summarised in Table 7-4. Concentrations of THC in vertical sediment sections are presented in Table 7-5. The full data set of replicate measurements and date from previous years are given in the Appendix. THC values from 2000 are compared with those from previous years in Figure 7-2.

Table 7-3: Background levels and Limits of Significant Contamination for the Øst Frigg field, 2000. All values in mg/kg dry sediment.

	THC	NPD's	3-6 ring	Decalins	Cd	Hg	Cu	Zn	Ba	Cr	Pb
$LSC_{00PSB13R}$	7.6	0.015	0.039	0.064	0.015	0.009	2.7	3.7	103	4.5	3.9
$LSC_{97\text{-}00\ Region\ II}$	9.8	*	*	*	0.029	0.008	2.0	8.9	146	9.6	7.0

*) Regional stations not analysed for NPD's, 3-6 ring aromatics and decalins.

Table 7-4: Concentrations of hydrocarbons in sediments from the Øst Frigg field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between $LSC_{00PSB13R}$ and $LSC_{97\text{-}00\ RegII}$ light shaded.

Station	THC		NPD's		3-6 ring		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
PSA06	7.3	0.4	n.a.		n.a.		n.a.	
PSA07	11.4	1.6	n.a.		n.a.		n.a.	
PSA08	7.4	0.8	0.014	0.001	0.033	0.003	0.019	0.004
PSA09	7.5	2.6	n.a.		n.a.		n.a.	
PSA19	6.3	1.0	n.a.		n.a.		n.a.	
PSA20	12.3	0.9	n.a.		n.a.		n.a.	
PSB06	10.3	0.4	n.a.		n.a.		n.a.	
PSB07	10.3	1.3	0.014	0.002	0.036	0.002	0.041	0.009
PSB08	6.9	0.7	n.a.		n.a.		n.a.	
PSB16	6.7	0.3	n.a.		n.a.		n.a.	
PSB17	7.0	1.0	n.a.		n.a.		n.a.	
PSB13R	6.0	0.7	0.013	0.001	0.033	0.003	0.042	0.009

n.a. Not analysed.

Table 7-5: Concentrations of hydrocarbons in vertical sections of the sediment samples from the Øst Frigg field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between $LSC_{00PSB13R}$ and $LSC_{97\text{-}00\ RegII}$ light shaded.

Station	Layer (cm)	THC	NPD's	3-6 ring	Decalins
PSA08	0-1	6.7	0.013	0.030	0.023
	1-3	10.3	0.027	0.059	0.051
	3-6	9.2	0.026	0.069	0.046
PSB07	0-1	11.4	0.012	0.038	0.031
	1-3	12.7	0.055	0.050	0.044
	3-6	13.0	0.028	0.047	0.066
PSB13R	0-1	6.6	0.012	0.030	0.042
	1-3	7.9	0.018	0.039	0.030
	3-6	6.7	0.021	0.047	0.023

n.a. Not analysed.

At Øst Frigg samples are taken in the vicinity of two installations, PSA and PSB. The THC values range from 6.3 ± 1.0 mg/kg dry sediment to 12.3 ± 0.9 mg/kg (Table 7-4). Sediments at station PSA20 reveal THC levels just above the limit of significant contamination with concentrations of 12.3 ± 0.9 mg/kg dry sediment. At station PSA07 sediment concentrations of 11.4 ± 1.6 mg/kg are found, standard deviation defining this as borderline values. At stations PSB06 and PSB07 concentrations around 10 mg/kg dry sediment are found. None of the remaining field stations at Øst Frigg reveal sediment THC levels above LSC of the region. The concentrations of NPD's, 3-6 ring aromatics and decalins in sediments at stations PSB07 and PSA08 are slightly above the background of the field (Table 7-4).

Vertical core samples from station PSA08 reveal a THC concentration of 6.7 mg/kg dry sediment in the 0-1 cm layer, increasing to concentrations near LSC in the 1-3 cm and 3-6 cm layers (Table 7-5). At station PSB07 a rather uniform distribution of THC is found down the layers with concentrations just above the limit of significant contamination. The 1-3 cm and 3-6 cm layers at both stations are regarded as contaminated by NPD's and 3-6 ring aromatics, while the surface layers are relatively undisturbed. The 3-6 cm layer at station PSB07 has elevated level of decalins.

In general, low total hydrocarbon contents are found in sediments at Øst Frigg. No distinct THC gradients are seen. Sediments contaminated by THC are found 250 m in the 240° direction relative to PCA. Concentrations above background levels are found out to 250 m in the 330° direction relative to PSA and 250 m in the 330° and 150° directions relative to PSB, though without defining these sediments as contaminated. Deeper layers of the sediments at the stations situated 250 m in the 150° direction relative to PSA and PSB reveal slight contamination of THC and aromatics.

The results of the metal analyses for the Øst Frigg field are summarised in Table 7-6. Concentrations of selected metals in the vertical sediment sections are presented in Table 7-7. The full set of replicate measurements, including selected data from previous years is given in the Appendix. Metal values from 2000 are compared with those from previous years in Figure 7-3 and Figure 7-4.

Table 7-6: Concentrations of selected metals in sediments from the Øst Frigg field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between $LSC_{00PSB13R}$ and $LSC_{97\text{-}00\ RegII}$ light shaded.

	Cd		Hg		Cu		Zn		Ba		Cr		Pb	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
PSA06	0.010	0.001	n.a.		1.0	0.0	1.7	0.1	71	23	4.3	0.1	3.8	0.3
PSA07	0.012	0.001	n.a.		1.3	0.2	2.3	0.2	118	34	4.7	0.1	3.6	0.1
PSA08	0.011	0.001	<0.005	-	1.2	0.1	2.4	0.0	84	5	5.0	0.1	3.5	0.1
PSA09	0.010	0.001	n.a.		1.0	0.2	2.1	0.8	45	5	5.1	0.2	3.6	0.2
PSA19	0.014	0.003	n.a.		1.1	0.1	2.2	0.7	98	42	4.7	0.3	3.5	0.4
PSA20	0.017	0.002	n.a.		1.1	0.1	2.1	0.4	226	22	4.3	0.1	3.6	0.2
PSB06	0.015	0.001	n.a.		1.1	0.1	2.7	0.3	78	21	4.4	0.3	3.5	0.1
PSB07	0.016	0.001	<0.005	-	1.1	0.2	2.6	0.4	190	30	4.4	0.1	3.8	0.3
PSB08	0.016	0.002	n.a.		1.1	0.1	2.2	0.3	89	38	4.4	0.2	3.4	0.3
PSB16	0.018	0.001	n.a.		1.2	0.0	2.6	0.2	230	90	4.5	0.2	3.7	0.1
PSB17	0.016	0.001	n.a.		1.3	0.3	2.4	0.1	119	39	4.5	0.2	3.5	0.2
PSB13R	0.013	0.001	0.004	0.002	1.4	0.6	2.6	0.5	60	18	4.1	0.2	3.6	0.1

n.a. Not analysed.

Table 7-7: Concentrations of selected metals in vertical sections of the sediment samples from the Øst Frigg field. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between $LSC_{00PSB13R}$ and $LSC_{97\text{-}00\ RegII}$ light shaded.

Station	Layer (cm)	Cd	Hg	Cu	Zn	Ba	Cr	Pb
PSA08	0-1	0.012	<0.005	1.2	2.4	89	5.0	3.4
	1-3	0.016	<0.005	1.4	2.8	164	5.2	3.6
	3-6	0.037	0.006	1.4	3.7	787	5.5	4.7
PSB07	0-1	0.015	<0.005	1.0	2.2	177	4.3	3.5
	1-3	0.015	<0.005	1.2	2.6	193	4.8	3.6
	3-6	0.032	0.006	1.2	3.3	369	4.9	4.5
PSB13R	0-1	0.013	<0.005	1.2	2.6	67	4.4	3.8
	1-3	0.018	<0.005	1.1	3.3	111	4.4	3.8
	3-6	0.027	0.008	1.2	3.5	113	4.7	4.1

n.a. Not analysed.

At Øst Frigg the barium values range from 45 ± 5 mg/kg to 230 ± 90 mg/kg dry sediment, cadmium from 0.010 ± 0.001 mg/kg to 0.018 ± 0.001 mg/kg, copper from1.0 ± 0.2 mg/kg to 1.3 ± 0.3 mg/kg, lead from 3.4 ± 0.3 mg/kg to 3.8 ± 0.3 mg/kg, zinc from 1.7 ± 0.1 mg/kg to 2.7 ± 0.3 mg/kg and chromium from 4.1 ± 0.2 to 5.1 ± 0.2 mg/kg (Table 7-6). Only a few stations, PSA20, PSB07 and PSB16, reveal sediments with barium concentrations above LSC. The highest concentrations, 230 ± 90 mg/kg dry sediment, are found at station PSB16. Vertical core samples reveal an increase in sediment barium concentrations down in the sediments at stations PSA08 and PSB07 (Table 7-7), exceeding LSC in the deeper layers. The other metals, including mercury, reveal no sediment concentrations over LSC of the region.

In general, low metal contents are found in sediments at Øst Frigg. Elevated levels of barium are found at the stations situated 250 m in the 240°direction relative to PSA and 250 m in the 60° and 150° directions relative to PSB. No contamination by the other selected metals is found.

<u>Comparison with previous survey(s)</u>

This year's hydrocarbon content at the reference station was comparable to the amount found in 1997. The average THC level is 6.0 mg/kg dry sediment in 2000, while it was 4.3 mg/kg in 1997. NPD's are at the1997 level, while the concentrations of 3-6 rings aromatics and decalins have decreased in the sediments on this location. Minor increases in lead concentrations in sediments at the reference station are found. Virtually no changes in levels of barium, cadmium, mercury, zinc and copper are registered here.

Minor increases in values of THC in sediments at the stations situated 250 m in the 330°direction, 250 m in the 240°direction and 500 m in the 150°direction relative to PSA are found when comparing with the 1997 survey (Figure 7-2). Sediments at these sampling spots have THC levels just above LSC in 2000. However, decreases to levels below LSC are found in sediments at 500 m distance in the 330°direction relative to PSA. At the station situated 250 m in the 150° direction relative to PSB the average sediment concentration have decreased from 26.1 mg/kg dry sediment in 1997 to 10.3 mg/kg in this year survey. Sediments from the other field stations reveal unchanged and lower THC concentrations in 2000 than in 1997. Sediment concentrations of NPD's, 3-6 ring aromatics and decalins at the two stations examined are two to six times lower in this survey than in 1997. Discharges of 804 tons water based drilling mud and 310 tons cementing chemicals took place in 1999. However, the average sediment THC level at Øst Frigg has decreased from 10 mg/kg in 1997 to 8.8 mg/kg in 2000. Hydrocarbon levels must on this background be characterised as lower at Øst Frigg in 2000 than they were in 1997.

Concentrations of selected metals in sediments at Øst Frigg have also decreased since 1997 (Figure 7-3, Figure 7-4). The average sediment barium level was measured to 177 mg/kg dry sediment in the field in 1997, while an average of 123 mg/kg is found in 2000. The declining tendency is found for zinc and cadmium too, while lead and copper show minor increases. It must be emphasised that all metals except barium have no values above LSC of the region.

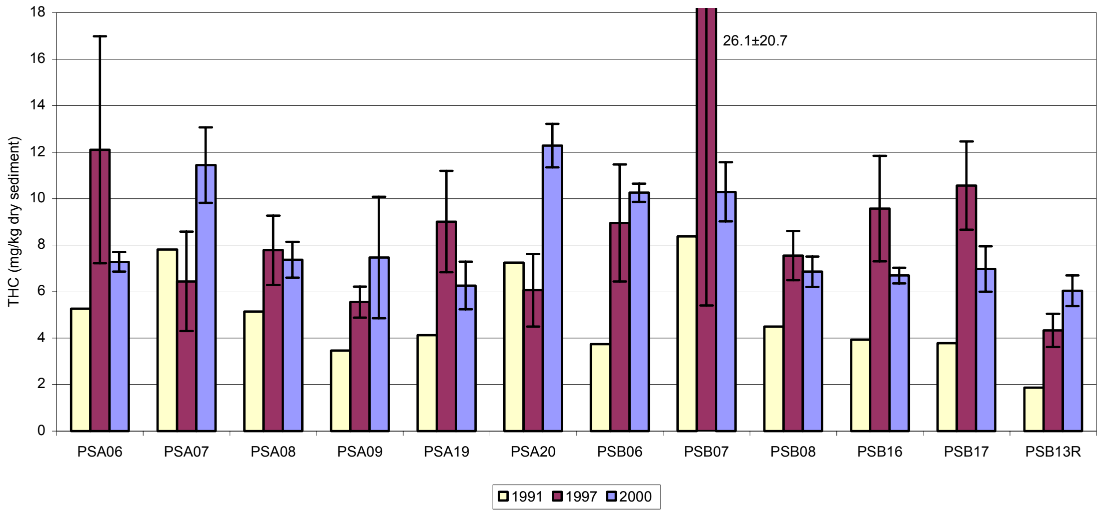

Figure 7-2: THC levels in sediment from the present (2000) and previous surveys, Øst Frigg field.

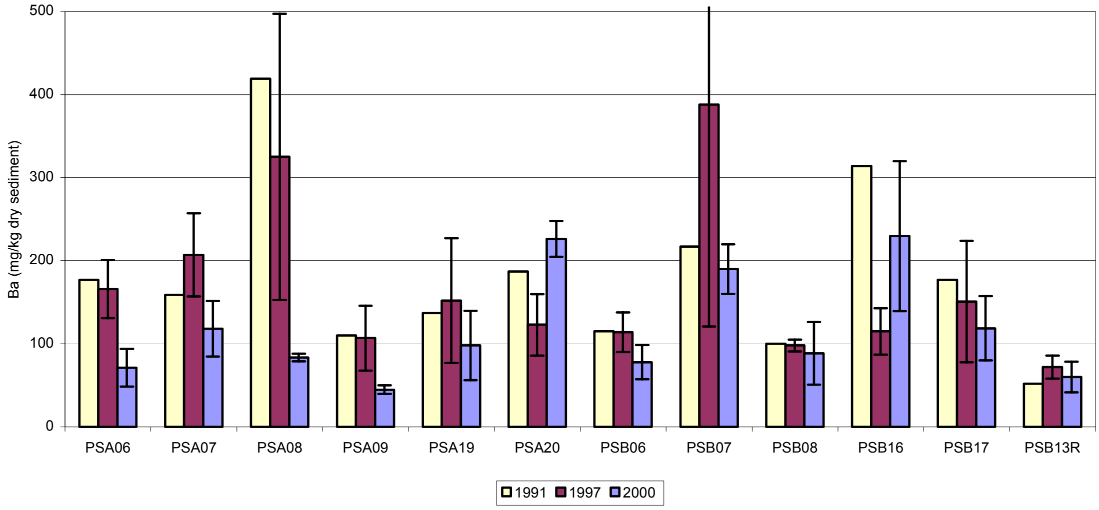

Figure 7-3: Barium levels in sediment from the present (2000) and previous survey, Øst Frigg field.

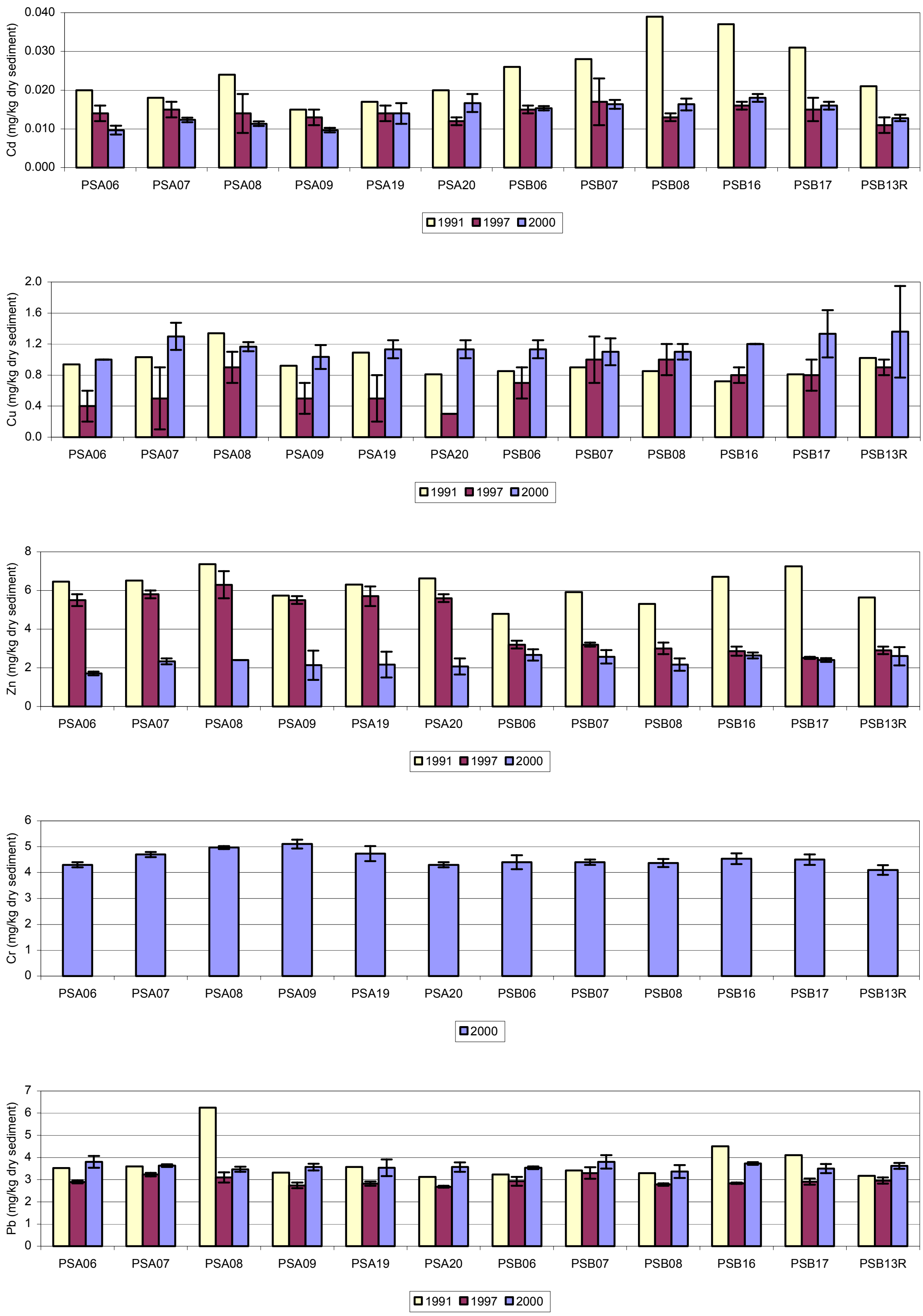

Figure 7-4: Levels of selected metals in sediments from the present (2000) and previous surveys, Øst Frigg field.

7.2.3 Biology

The distribution of individuals and taxa within the main taxonomic groups are given in Table 7-8. A total of 13431 individuals within 279 taxa were recorded at the Øst Frigg field in the present survey (excluding juveniles). The polychaetes dominate the fauna with 67 % of the individuals and 51 % of the taxa recorded.

Table 7-8: Distribution of individuals and taxa within the main taxonomic groups at Øst Frigg, 2000 (excluding juveniles).

Main taxonomic groups	Individuals		Taxa	
	Number	%	Number	%
Polychaeta	8945	67	142	51
Mollusca	1541	11	46	16
Crustacea	937	7	58	21
Echinodermata	1338	10	19	7
Diverse groups	670	5	14	5
Total	13431	100	279	100

The species/area curve for the field reference station is shown in Figure 7-5. A total of 144 taxa are present in the ten grab samples, of which 64 (44.4 %) occur in the first sample and 120 (83.3 %) in the five first samples. The shape of the curve indicates that not all taxa in the area are present in the ten grab samples, but the representativity of five samples is considered as good.

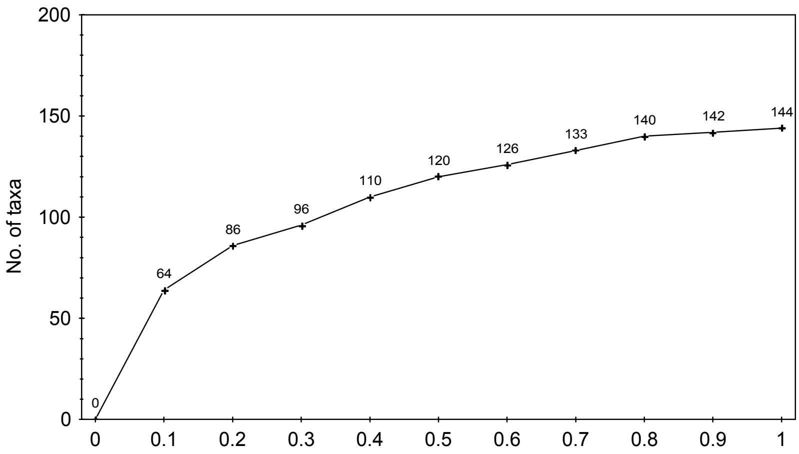

Figure 7-5: Species/area curve for the reference station at the Øst Frigg field, 2000 (area in m^2).

The number of individuals and taxa at each station, together with selected community indices is presented in Table 7-9 and Figure 7-6. The number of individuals in the present survey varies from 805 (station PSA06) to 1561 (station PSA20), the number of taxa from 74 (PSB08) to 154 (PSA09), the diversity index H' from 4.4 (PSB08) to 5.9 (PSA09), the evenness index J from 0.68 (PSA20) to 0.81 (PSA09) while the ES_{100} varies from 29 (PSB08) to 49 (PSA09). The values at the reference station PSB13R are within these ranges.

The number of individuals has decreased dramatically at some of the stations since the 1991 survey, while the number of taxa was highest in 1997 at most of the stations. The diversity thereby increased from 1991 till 1997 and thereafter, with a few exceptions, had a slight drop in 2000.

Table 7-9: Number of individuals and taxa and selected community indices for each station (0.5 m^2) at the Øst Frigg field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	No. of ind.	No. of taxa	H'	J	ES_{100}
PSA06	**805**	100	4.9	0.73	36
PSA07	1129	116	5.1	0.74	37
PSA08	1080	106	4.8	0.71	35
PSA09	1090	**154**	**5.9**	**0.81**	**49**
PSA19	812	91	4.8	0.73	34
PSA20	**1561**	121	4.7	**0.68**	34
PSB06	1177	102	4.7	0.70	32
PSB07	1226	111	5.0	0.74	35
PSB08	812	**74**	**4.4**	0.71	**29**
PSB16	1206	105	4.6	0.69	32
PSB17	1081	91	4.5	0.69	30
PSB13R	1459	121	4.9	0.72	34
Sum *	11979				
Average *	1089	106	4.8	1	35
St. dev. *	223	20	0.4	0	5

* Excluding the reference station.

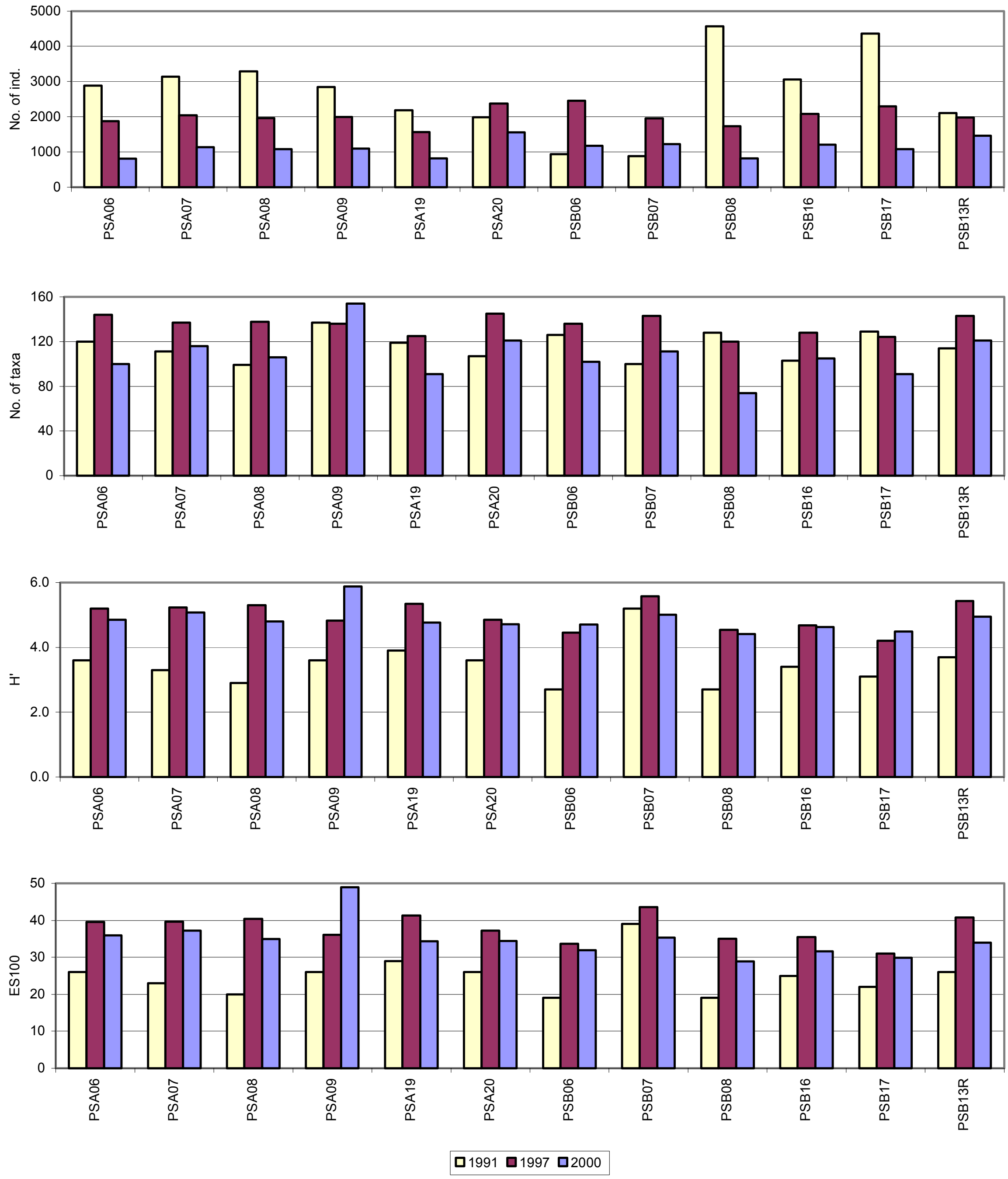

Figure 7-6: Biological characteristics at the Øst Frigg field, 2000 and previous surveys.

The distribution of taxa in geometrical classes at each station is shown in Figure 7-7. Station PSA20 has one taxon in class 9 (256 – 511 individuals) while the rest of the stations have taxa in class 8 and lower (< 256 individuals). These results do not indicate any faunal disturbance at the stations included in the present survey.

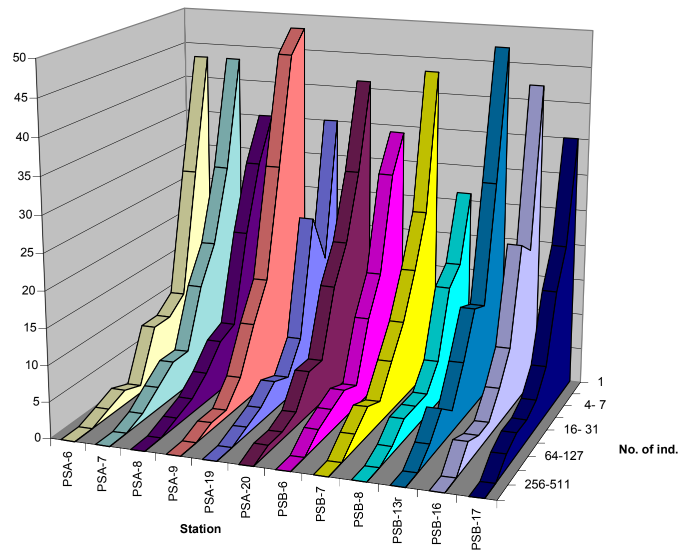

Figure 7-7: Distribution of taxa in geometrical classes for the stations at the Øst Frigg field, 2000.

The ten most dominant taxa at each station are shown in Table 7-12 at the end of this chapter. A total of 17 taxa, inclusive three juvenile groups, are among the ten most dominant taxa at one or more stations. These 17 taxa comprise 81 % of the total number of individuals and only 6 % of the total number of taxa registered at the Øst Frigg field in the present survey.

The most dominant taxa among the adult forms are the polychaetes *Galathowenia oculata*, *Pectinaria koreni*, *Spiophanes bombyx* and *S. kroyeri* and the brittle star *Amphiura filiformis*. These five species are among the ten most dominant taxa at all, or almost all, stations, indicating a uniform distribution of the dominant taxa over the surveyed area. All these taxa are typical for relatively undisturbed sediment conditions in the area. One exception from this is the brittle star *Ophiactis balli*, which was the tenth most dominant taxa at station PSA09 (recorded with 28 individuals) and not found at any of the other stations. At this station, some stones occurred in the sediment and this explains the occurrence of this hard bottom species.

The ten most dominant taxa at the stations comprise between 63 % (station PSA09) and 79 % (station PSB06) of the total number of individuals at the respective stations. The corresponding value at the reference station PSB13R is 72 %.

Figure 7-8 shows the dendrogram from the cluster analysis for the field stations and selected regional and reference stations while Figure 7-9 shows the 2-D plot from the MDS analysis.

In the cluster analysis, the field station PSA09 is separated from the other stations at 44 % dissimilarity level, regional station RII02 and reference station NEF20R at 40 %, reference stations FRI10R and LFR01R at 37 % and the remaining field stations are separated from each other at 36 % dissimilarity level or lower. This indicates a high faunal similarity between the field stations, with the exception of PSA09, and no discernible trends relating to distance from field centre. The correlation coefficient for the cluster analysis shows a good fit to the data (r = 0.86).

The MDS analyses support the results from the cluster analysis separating the field station PSA09 from the rest of the Øst Frigg stations. The stress test for the 2-D plot shows a fair fit to the data (0.26).

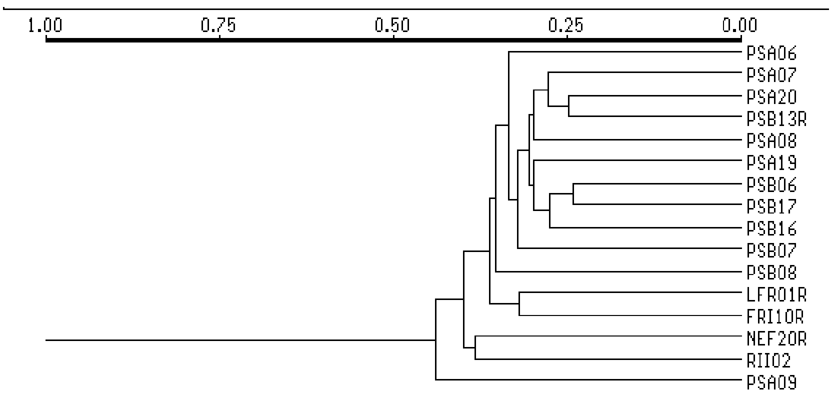

Figure 7-8: Cluster analysis of the Øst Frigg field stations and selected regional and reference stations in Region II, 2000.

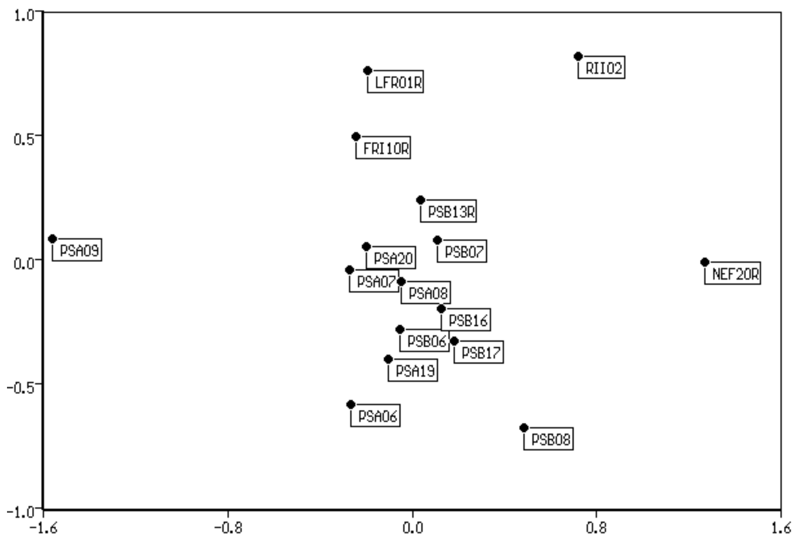

Figure 7-9: 2-D plot from the MDS analysis carried out on the Øst Frigg field stations and selected regional and reference stations in Region II, 2000.

A Canonical Correspondence Analysis (CCA) of the data from the field stations and selected regional and reference stations was carried out to examine the association between the biological data and the measured environmental variables in these areas.

Through the forward selection procedures in CANOCO, two of ten variables, gave the best fit and were significant. 38.9 % of the biological variance was explained by the first two axes of the ordination space which is constrained by the environmental variables pelite and zinc.

Figure 7-10 shows a biplot from the analysis using pelite (Pel) and zinc (Zn) as the constraining environmental variables, while Figure 7-11 shows a plot of the species with the highest contribution on the two axes. The first axis shows a gradient from regional station RII02 on the positive end to field station PSA09 on the negative end and is positively correlated with the amount of pelite in the sediment (0.91). The species with the highest contributions on this axis are the polychaetes *Owenia fusiformis* (34.6 %), *Myriochele danielsseni* (26.7 %) and *Myriochele fragilis* (6.4 %). The distribution on the first axis clearly reflects a natural variation in the sediment structure.

The second axis shows a gradient from the reference station FRI10R on the positive end to field station PSA06 on the negative end and is positively correlated with the amount of zinc in the sediment (0.87). However, the amount of zinc is lower than the LSC value at all field stations and the distribution of the station on this axis as well reflects the natural variation in the sediments. The taxa with the highest contributions on this axis are the phoronid *Phoronis* sp. (7.7 %) and the polychaetes

Pectinaria koreni (5.1 %) and *Spiophanes bombyx* (3.5 %). The polychaete *Chaetozone setosa*, which often is abundant in disturbed sediments, is associated with the positive end of the second axis. However, the species is only represented by a total of 29 individuals at the stations included in the analysis, and does not reflect a disturbance gradient.

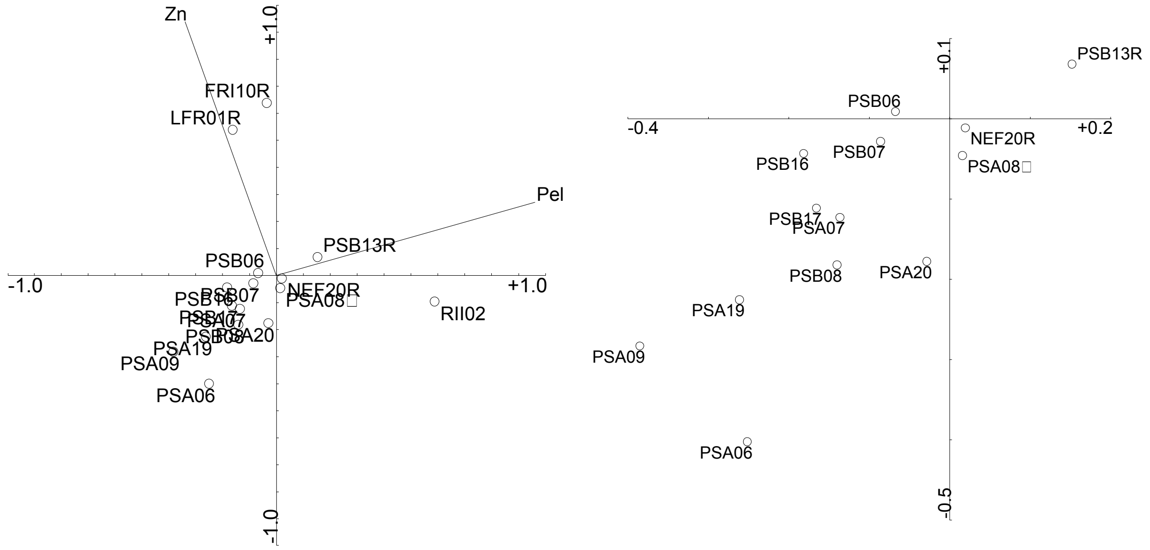

Figure 7-10: Biplot from the CCA analysis for the Øst Frigg field stations and selected regional and reference stations in Region II, 2000 (left) and detail of the stations in the centre of the plot (right).

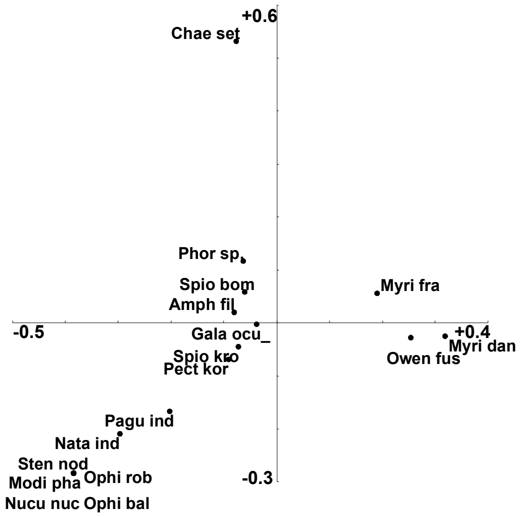

Figure 7-11: Plot of taxa with highest contribution on two axis in the CCA for Øst Frigg, 2000.

On the basis of the results from the uni- and multivariate analyses, all stations included in the present survey are placed in faunal group A (undisturbed fauna, see Table 7-10). The field station PSA09, which was separated from the other stations in the multivariate analyses, does not show any greater differences in the dominant species composition. Further, the THC and heavy metal concentrations in the sediment are low at all stations. Therefore, the separation, therefore, is believed to be a result of natural variation over the surveyed area.

In the 1997 survey, it was concluded that field station PSA08 was slightly disturbed (classified as faunal group B) due to the relatively high occurrence of the polychaetes *Pseudopolydora paucibranchiata* and *Capitella capitata* at that station. These two species do not occur in high numbers at any of the stations in the present survey. In conclusion, the biological results indicate that the environmental conditions at the field have improved during the last three years.

Table 7-10: Classification into impact groups, distance to installation and biological statistics for the field stations at Øst Frigg field and selected regional and reference stations in Region II, 2000.

Station	Impact group	Dist. (m)	Statistics			No. of individuals								
			No. ind	No. taxa	H'	Goc	Pko	Afi	Sbo	Skr	Ofu	Psp	Tfl	Csp
PSA06	A	500	805	100	4.9	190	15	79	25	70	21	32	16	24
PSA07	A	250	1129	116	5.1	201	77	124	23	78	51	43	21	11
PSA08	A	250	1080	106	4.8	243	124	106	52	47	21	25	36	13
PSA09	A	500	1090	154	5.9	148	45	87	54	40	13	33	25	24
PSA19	A	250	812	91	4.8	166	80	90	51	46	16	32	23	10
PSA20	A	250	1561	121	4.7	452	144	84	53	83	44	54	42	19
PSB06	A	350	1177	102	4.7	192	178	124	56	67	80	34	52	9
PSB07	A	250	1226	111	5.0	191	128	111	67	79	72	36	40	8
PSB08	A	500	812	74	4.4	79	80	72	180	41	60	23	35	10
PSB16	A	250	1206	105	4.6	217	160	113	67	52	144	27	51	15
PSB17	A	250	1081	91	4.5	222	144	115	72	54	83	35	36	8
PSB13R	A	10000	1459	121	4.9	223	107	132	121	65	98	37	29	28
RII02	A	-	2994	123	3.4	302	3	62	34	40	1085	36	50	50
FRI10R	A	-	1591	126	4.9	256	26	146	216	45	62	160	30	13
NEF20R	A	-	1221	68	4.0	301	51	68	149	70	227	23	25	19
LFR01R	A	-	1523	119	4.9	312	2	156	55	44	115	66	19	17

Goc = *Galathowenia oculata*, Pko = *Pectinaria koreni,* Afi = *Amphiura filiformis*, Sbo = *Spiophanes bombyx*, Skr = *S. kroyeri,* Ofu =*Owenia fusiformis, Psp = Phoronis* sp., Tfl = *Thyasira flexuosa,* Csp = *Chaetozone sp. (incl. C. setosa)*

7.3 Summary and conclusions

The sediments at Øst Frigg are classified as fine sand with a relatively moderate amount of pelitt (3.6 – 5.6 %) and TOM (0.9 – 1.3 %). There is a general trend for finer sediments in the area, also at the reference station, as the amount of pelite has increased while the amount of finer sand is more or less similar in the present and previous survey. On the other hand, the amount of TOM has decreased somewhat at most of the stations. It is believed that this is a result of natural variation in the sediments.

In 2000 sediments at the station situated 250 m in the 240°direction relative to PSA have THC levels just above the limit of significant contamination. Borderline values are found at the stations situated 250 m in the 330° direction relative to PSA and 250 m in the 330° and 150° directions relative to PSB. Minor increases in THC values are found in sediments at these stations when comparing to the 1997 survey. However, sediments from the other field stations generally reveal lower THC concentrations in 2000 than in 1997. In addition to the total hydrocarbons, sediment concentrations of NPD's, 3-6 ring aromatics and decalins at the two stations examined are lower in this survey than in 1997. In sum, the average sediment THC level at Øst Frigg has gone down from 10 mg/kg in 1997 to 8.8 mg/kg in 2000. Hydrocarbon levels must on this background be characterised as lower at Øst Frigg in 2000 than they were in 1997.

Elevated levels of barium are found at the stations situated 250 m in the 240°direction relative to PSA and 250 m in the 60° and 150° directions relative to PSB. No contamination by the other selected metals is found.

Concentrations of selected metals in sediments at Øst Frigg have decreased since 1997. The average sediment barium level at Øst Frigg was measured to 177 mg/kg dry sediment in 1997, while an average of 123 mg/kg is measured in 2000. The declining tendency is found for zinc and cadmium too, while lead and copper show minor increases. It must be emphasised that no metals except barium have values above the limit of significant contamination.

The number of individuals has decreased at all stations since 1997 and is relatively similar over the whole field. With the exception of station PSA09 the number of taxa as well has decreased. The most dominant taxa at the stations are typical for undisturbed sediments and all stations are classified as faunal group A (undisturbed fauna). Station PSA09 (situated 500 m south east of PSA) was separated from the other stations in the multivariate analyses, but the dominant taxa at this station do not show greater differences compared with the other stations. The concentrations of THC and heavy metals are low at all stations. The differences in faunal composition are therefore believed to be a result of natural variation over the area in the present survey, and do not represent any clear gradients associated with the petroleum activity.

In the 1997 survey, it was concluded that field station PSA08 (situated 250 m south east of PSA) was slightly disturbed (classified as faunal group B) due to the relatively high abundance of the polychaetes *Pseudopolydora paucibranchiata* and *Capitella capitata* at that station. These two species do not occur in high numbers at any of the stations in the present survey. The results indicate that the environmental conditions at the field have improved during the last three years, most likely due to the low activity at the field since 1997.

The calculated minimum area and spatial extent of contaminated sediments at the Øst Frigg field is shown in Table 7-11 and Figure 7-12.

Table 7-11: Distance along the transects and calculated minimum area of contaminated sediments at the Øst Frigg field, 2000 and previous survey.

Øst Frigg PSA	NE	SE	SW	NW	Km^2 (2000)	Km^2 (1997)
THC	125	125	250	125	0.07	0.00
Ba	125	125	250	125	0.07	0.22
Øst Frigg PSB	NE	SE	SW	NW	Km^2 (2000)	Km^2 (1997)
THC	0	0	0	0	0.00	0.11
Ba	250	250	125	125	0.11	0.11
Sum Øst Frigg					Km^2 (2000)	Km^2 (1997)
THC					0.07	0.11
Ba					0.18	0.33

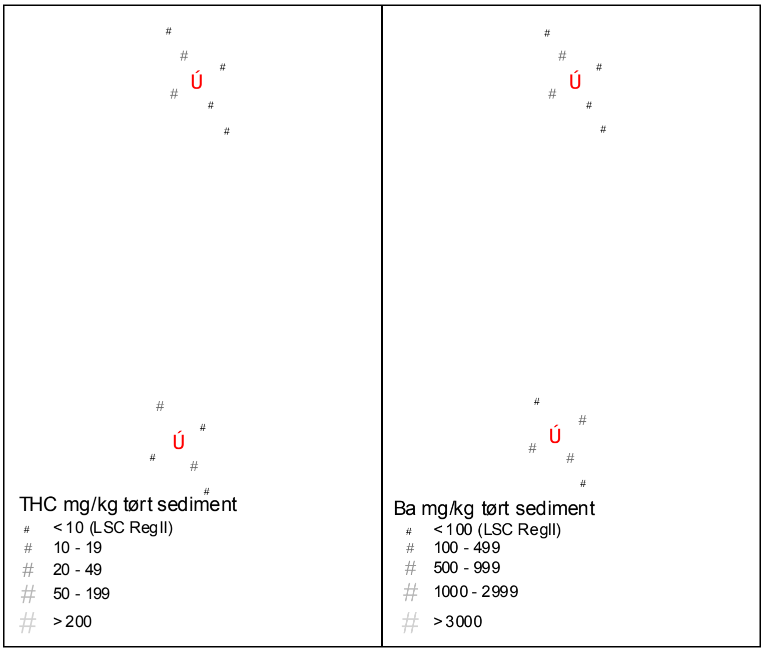

Figure 7-12: Distribution of the amounts of THC and barium at the Øst Frigg field, 2000.

Table 7-12: Number of individuals and the accumulative abundance for the ten most dominant taxa at each station at the Øst Frigg field, 2000.

PSA06 (330°/500 m)	No. ind.	Acc. %	PSA07 (330°/250 m)	No. ind.	Acc. %	PSA08 (150°/250 m)	No. ind.	Acc. %	PSA09 (150°/500 m)	No. ind.	Acc. %	PSA19 (60°/250 m)	No. ind.	Acc. %
Pectinaria sp. juv.	196	17%	Pectinaria sp. juv.	691	35%	Owenia fusiformis juv.	375	20%	Owenia fusiformis juv.	341	19%	Pectinaria sp. juv.	334	26%
Galathowenia oculata	190	33%	Galathowenia oculata	201	45%	Pectinaria sp. juv.	342	38%	Pectinaria sp. juv.	219	31%	Galathowenia oculata	166	38%
Owenia fusiformis juv.	106	42%	Amphiura filiformis	124	51%	Galathowenia oculata	243	50%	Galathowenia oculata	148	39%	Amphiura filiformis	90	45%
Amphiura filiformis	79	49%	Owenia fusiformis juv.	89	55%	Pectinaria koreni	124	57%	Ophiuroidea indet. juv.	133	47%	Owenia fusiformis juv.	80	51%
Spiophanes kroyeri	70	55%	Spiophanes kroyeri	78	59%	Amphiura filiformis	106	62%	Amphiura filiformis	87	52%	Pectinaria koreni	80	57%
Ophiuroidea indet. juv.	50	59%	Ophiuroidea indet. juv.	77	63%	Ophiuroidea indet. juv.	100	68%	Spiophanes bombyx	54	55%	Ophiuroidea indet. juv.	70	63%
Phoronis sp.	32	62%	Pectinaria koreni	77	67%	Spiophanes bombyx	52	70%	Pectinaria koreni	45	57%	Spiophanes bombyx	51	67%
Spiophanes bombyx	25	64%	Myriochele danielsseni	52	70%	Spiophanes kroyeri	47	73%	Spiophanes kroyeri	40	59%	Spiophanes kroyeri	46	70%
Urothoe elegans	25	66%	Owenia fusiformis	51	72%	Thyasira flexuosa	36	75%	Phoronis sp.	33	61%	Abra prismatica	34	73%
Chaetozone sp.	24	68%	Phoronis sp.	43	74%	Urothoe elegans	32	76%	Ophiactis balli	28	63%	Phoronis sp.	32	75%

PSA20 240°/250 m)	No. ind.	Acc. %	PSB06 (330°/350 m)	No. ind.	Acc. %	PSB07 (150°/250 m)	No. ind.	Acc. %	PSB08 (150°/500 m)	No. ind.	Acc. %	PSB16 (60°/250 m)	No. ind.	Acc. %
Owenia fusiformis juv.	674	23%	Pectinaria sp. juv.	708	34%	Pectinaria sp. juv.	583	30%	Pectinaria sp. juv.	225	20%	Pectinaria sp. juv.	336	19%
Pectinaria sp. juv.	601	43%	Galathowenia oculata	192	43%	Galathowenia oculata	191	39%	Spiophanes bombyx	180	35%	Galathowenia oculata	217	32%
Galathowenia oculata	452	59%	Pectinaria koreni	178	52%	Pectinaria koreni	128	46%	Pectinaria koreni	80	43%	Pectinaria koreni	160	41%
Pectinaria koreni	144	64%	Amphiura filiformis	124	58%	Amphiura filiformis	111	52%	Galathowenia oculata	79	49%	Owenia fusiformis	144	49%
Ophiuroidea indet. juv.	95	67%	Ophiuroidea indet. juv.	107	63%	Spiophanes kroyeri	79	56%	Amphiura filiformis	72	56%	Amphiura filiformis	113	56%
Amphiura filiformis	84	70%	Owenia fusiformis	80	67%	Owenia fusiformis juv.	73	59%	Owenia fusiformis	60	61%	Owenia fusiformis juv.	103	62%
Spiophanes kroyeri	83	72%	Owenia fusiformis juv.	69	70%	Owenia fusiformis	72	63%	Owenia fusiformis juv.	47	65%	Ophiuroidea indet. juv.	81	66%
Phoronis sp.	54	74%	Spiophanes kroyeri	67	73%	Spiophanes bombyx	67	67%	Ophiuroidea indet. juv.	46	69%	Spiophanes bombyx	67	70%
Spiophanes bombyx	53	76%	Spiophanes bombyx	56	76%	Ophiuroidea indet. juv.	58	69%	Spiophanes kroyeri	41	73%	Spiophanes kroyeri	52	73%
Myriochele fragilis	47	78%	Thyasira flexuosa	52	79%	Thyasira flexuosa	40	72%	Thyasira flexuosa	35	76%	Thyasira flexuosa	51	76%

PSB17 (240°/250 m)	No. ind.	Acc. %	PSB13R (150°/10000 m)	No. ind.	Acc. %
Pectinaria sp. juv.	360	22%	Pectinaria sp. juv.	402	19%
Galathowenia oculata	222	35%	Owenia fusiformis juv.	251	30%
Pectinaria koreni	144	44%	Galathowenia oculata	223	40%
Amphiura filiformis	115	51%	Amphiura filiformis	132	46%
Owenia fusiformis juv.	108	58%	Spiophanes bombyx	121	52%
Ophiuroidea indet. juv.	89	63%	Myriochele fragilis	116	57%
Owenia fusiformis	83	68%	Pectinaria koreni	107	62%
Spiophanes bombyx	72	72%	Owenia fusiformis	98	67%
Spiophanes kroyeri	54	76%	Spiophanes kroyeri	65	70%
Thyasira flexuosa	36	78%	Ophiuroidea indet. juv.	52	72%

Table 7-13: Station information for Øst Frigg field, 2000.

St. no.	Distance (m)	Direction (degr.)	Volume (litres)
PSA06	500	330	36
PSA07	250	330	39
PSA08	250	150	38
PSA09	500	150	39
PSA19	250	60	34
PSA20	250	240	40
PSB06	350	330	34
PSB07	250	150	34
PSB08	500	150	34
PSB16	250	60	33
PSB17	250	240	33
PSB13R	10000	150	34

* The additional five grab samples taken gave 30 litres of sediment

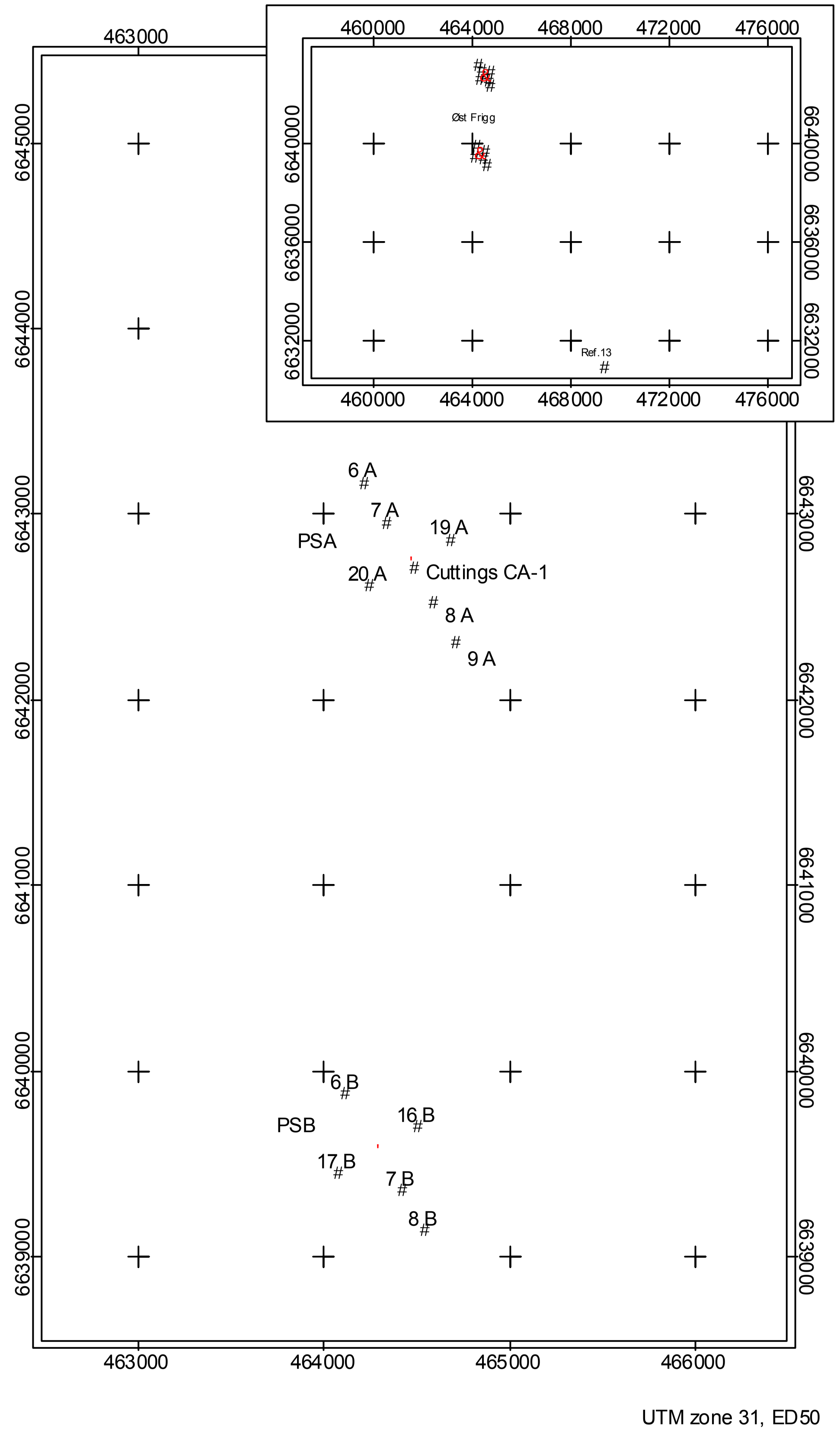

Figure 7-13: Map of sampling positions for Øst Frigg field, 2000.

8 Lille Frigg field

8.1 Introduction

The Lille Frigg field is located in block 25/2 in Region II. Production at the field started in 1994 and ceased in April 1999. The field is a sub-sea development situated north of the East Frigg field. All wells were drilled with water based mud. There has been no drilling activity at the field in the recent years. The wells were permanently plugged in June 2000 and the discharges given in Table 8-1 occurred during this operation.

In the monitoring survey at the field in 1997 no sediment from field stations at Lille Frigg were contaminated by hydrocarbons. On the other hand, sediments at all stations were contaminated by barium. Lead contamination was measured 250 m in direction 150° relative to C1. Slightly elevated levels of cadmium were measured 250 m in directions 60° and 240° relative to C2. The fauna was found to be slightly disturbed at some stations close to C1 and C2. Therefore, some additional stations were included in the present survey.

Information on the sampling stations is shown in Figure 8-12 and Table 8-13, both on the foldout page at the end of this chapter (page 8-19). In addition, samples from the cutting piles at the field were collected by use of a van Veen grab (biology) and box corer (chemistry). A separate report with these results will be produced.

Table 8-1: Summary of recent operational and accidental discharges at the Lille Frigg field (all discharges in tonnes).

	1997	1998	1999	2000*	Comments
Barite	0	0	0	140	
Water-based drilling mud	0	0	0	375	
Cementing chemicals	0	0	0	13	
Accidental discharges	0	0	0	0.50	Hydraulic oil.

* 1.st quarter.

8.2 Results and discussion

8.2.1 Physical characteristics

The median phi value and the amounts (%) of pelite, fine sand and total organic material (TOM) in the sediment from the present and previous surveys are shown in Table 8-2 and Figure 8-1. 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 in the area are classified as fine sand with median phi values varying from 3.55 to 3.67. The amount of pelite in the sediment varies from 4.4 % (station LFR11) to 8.7 % (station LFR12), fine sand from 77.6 % (station LFR24) to 91.6 % (station LFR13) and the TOM varies from 0.95 % (station LFR03) to 1.63 % (station LFR12). The sediment was somewhat coarser at the reference station, where the pelite content was 5.5 %, fine sand 72.0 % and the TOM 1.08 %. At the field stations the pelite and TOM values are highest at stations north east of C1 (LFR12, LFR13) and east of C2 (LFR19).

The pelite content has increased at all stations since the previous survey in 1997, whereas the fine sand and TOM are more or less similar in the two surveys.

Table 8-2: The median (phi) and amount (%) of pelite, fine sand and TOM in the sediments from stations at Lille Frigg field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	Distance (m)	Direction (degr.)	Median	Classification	Pelite	Fine sand	TOM
LFR03	500	150	**3.55**	Fine sand	5.1	85.5	**0.95**
LFR04	250	150	3.60	Fine sand	6.0	89.6	1.12
LFR11	250	240	**3.55**	Fine sand	**4.4**	89.9	0.96
LFR12	250	60	3.65	Fine sand	**8.7**	81.7	**1.63**
LFR13	500	60	**3.67**	Fine sand	6.6	**91.6**	1.18
LFR17	500	240	**3.55**	Fine sand	4.5	90.1	1.01
LFR18	250	240	3.63	Fine sand	6.1	89.9	1.02
LFR19	250	60	3.66	Fine sand	7.0	90.1	1.26
LFR24	250	60	3.58	Fine sand	5.5	**77.6**	1.11
LFR1R	10150	0	3.51	Fine sand	5.5	72.0	1.08
Average *			3.60		6.0	87.3	1.14
St. dev. *			0.05		1.4	4.8	0.21

* Excluding the reference station.

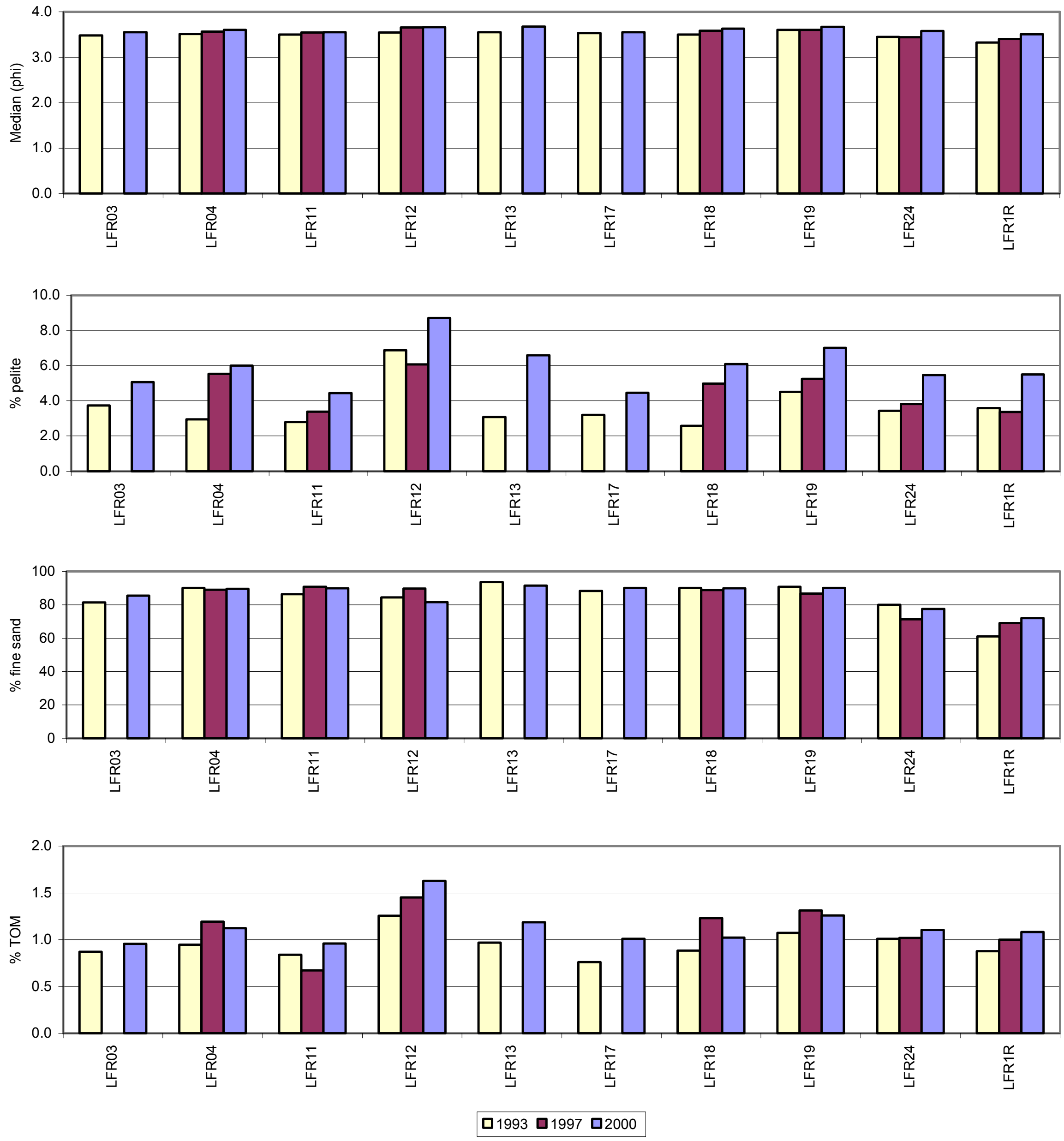

Figure 8-1: Sediment characteristics at the Lille Frigg field, 2000 and previous years.

8.2.2 Chemical characteristics

The calculated limits of significant contamination for selected hydrocarbons and metals in sediments from Region II ($LSC_{97\text{-}00\ RegII}$) are presented previously in the chapter that deals with the regional and reference stations. In addition to the regional limits, field-specific limits of significant contamination are calculated from the field reference station ($LSC_{00\ LFR01R}$). Both sets of data are presented in Table 8-3. Based on analysis results of the Lille Frigg field the $LSC_{97\text{-}00\ RegII}$ is regarded as representative of the entire region and will therefore be used as further basis for discussion of the contamination status of this field. Those limits will hereafter simply be referred to as LSC.

The results of analyses of the hydrocarbons are summarised in Table 8-4. Concentrations of selected compounds in the vertical sediment sections are presented in Table 8-5. The full data set of replicate measurements and date from previous years are given in the Appendix. THC values from 2000 are compared with those from previous years in Figure 8-2.

Table 8-3: Background levels and Limits of Significant Contamination for the Lille Frigg field, 2000. All values in mg/kg dry sediment.

	THC	NPD's	3-6 ring	Decalins	Cd	Hg	Cu	Zn	Ba	Cr	Pb
$LSC_{00\ LFR01R}$	9.7	0.030	0.082	0.079	0.021	0.006	1.1	5.3	132	5.3	3.8
$LSC_{97\text{-}00\ Region\ II}$	9.8	*	*	*	0.029	0.008	2.0	8.9	146	9.6	7.0

*) Regional stations not analysed for NPD's, 3-6 ring aromatics and decalins.

Table 8-4: Concentrations of hydrocarbons in sediments from the Lille Frigg field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between $LSC_{00LFR10R}$ and $LSC_{97\text{-}00\ RegII}$ light shaded.

Station	THC		NPD's		3-6 ring		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
LFR03	5.3	1.6	n.a.		n.a.		n.a.	
LFR04	7.2	2.0	0.045	0.022	0.047	0.023	0.032	0.013
LFR11	7.0	1.5	n.a.		n.a.		n.a.	
LFR12	15.1	2.2	n.a.		n.a.		n.a.	
LFR13	10.4	5.1	n.a.		n.a.		n.a.	
LFR17	7.5	0.3	n.a.		n.a.		n.a.	
LFR18	7.2	0.1	n.a.		n.a.		n.a.	
LFR19	11.2	0.7	n.a.		n.a.		n.a.	
LFR24	7.7	0.1	n.a.		n.a.		n.a.	
LFR01R	7.9	0.8	0.017	0.006	0.048	0.015	0.033	0.020

n.a. Not analysed.

Table 8-5: Concentrations of hydrocarbons in vertical sections of sediment samples from the Lille Frigg field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between $LSC_{00LFR10R}$ and $LSC_{97\text{-}00\ RegII}$ light shaded.

Station	Layer (cm)	THC	NPD's	3-6 ring	Decalins
LFR04	0-1	7.5	0.070	0.049	0.034
	1-3	13.0	0.048	0.066	0.047
	3-6	14.7	0.039	0.079	0.038
LFR01R	0-1	6.9	0.025	0.074	0.065
	1-3	8.4	0.016	0.047	0.030
	3-6	9.4	0.021	0.059	0.025

n.a. Not analysed.

At Lille Frigg, stations LFR03, LFR13 and LFR17 are new sampling points of the year. The THC values range from 5.3 ± 1.6 mg/kg (background level) to 15.1 ± 2.2 mg/kg (Table 8-4). Hydrocarbon values above the calculated LSC are shaded in (Table 8-4). The concentrations of 3-6 ring aromatics and decalins in sediments from LFR04 are below the LSC of the area, while the concentration of NPD's is slightly above the LSC.

Vertical core samples from station FRI04 reveal increases in THC concentrations with depth (Table 8-5). The 1-3 and 3-6 cm layers have THC concentrations above the LSC, with 13.0 mg/kg and 14.7 mg/kg dry sediment respectively. NPD values above the LSC are found in all layers at station FRI04. The highest concentration of NPD's is found in the top layer, with a concentration of 0.070 mg/kg.

In general, THC values above LSC are found in sediments from the stations situated 250 m and 500 m in the 60° direction relative to C1 and in sediments from the station situated 250 m in the 60° direction relative to C2. The THC results from the 500 m station on the C1 60°-axis has a relatively large standard deviation (10.4 ± 5.1 mg/kg), classifying this as a borderline value. Sediments from remaining stations at Lille Frigg have THC values below the LSC. Vertical core samples from position 250 m at 150° reveal increasing hydrocarbon levels with depth, values above LSC are measured in the 1-3 cm and 3-6 cm layers. Mineral oil profiles are not found in gas chromatograms of sediment extracts from Lille Frigg.

The results of the metal analyses for the Lille Frigg field are summarised in Table 8-6. Concentrations of selected metals in the vertical sediment sections are presented in Table 8-7. The full set of replicate measurements, including selected data from previous years is given in the Appendix. Metal values from 2000 are compared with those from previous years in Figure 8-3 and Figure 8-4.

Table 8-6: Concentrations of selected metals in sediments from the Lille Frigg field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between $LSC_{00LFR10R}$ and $LSC_{97\text{-}00\ RegII}$ light shaded.

	Cd		Hg		Cu		Zn		Ba		Cr		Pb	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
LFR03	0.017	0.007	n.a.		1.0	0.0	3.8	0.3	330	140	4.3	0.3	4.4	0.5
LFR04	0.021	0.003	0.005	0.001	2.0	0.9	6.8	2.5	727	181	5.1	0.6	7.9	1.1
LFR11	0.013	0.001	n.a.		1.0	0.0	4.3	0.1	391	52	4.2	0.2	5.6	0.3
LFR12	0.042	0.007	n.a.		3.3	0.6	12.9	5.1	3942	165	8.9	2.7	11.8	1.5
LFR13	0.018	0.001	n.a.		1.3	0.1	4.9	0.1	695	153	4.9	0.1	5.3	0.3
LFR17	0.016	0.001	n.a.		1.0	0.0	3.9	0.1	192	10	4.5	0.1	4.2	0.0
LFR18	0.018	0.001	n.a.		1.3	0.1	5.9	0.5	530	65	4.5	0.1	5.5	0.1
LFR19	0.023	0.003	n.a.		1.5	0.2	7.0	0.2	1005	183	5.1	0.1	7.4	0.9
LFR24	0.019	0.002	n.a.		1.1	0.1	5.3	0.2	435	173	5.2	1.0	4.6	0.6
LFR01R	0.017	0.002	0.003	0.001	1.0	0.0	5.1	0.1	74	25	5.0	0.1	3.6	0.1

n.a. Not analysed.

Table 8-7: Concentrations of selected metals in vertical sections of the sediment samples from the Lille Frigg field. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between $LSC_{00LFR10R}$ and $LSC_{97\text{-}00\ RegII}$ light shaded.

Station	Layer (cm)	Cd	Hg	Cu	Zn	Ba	Cr	Pb
LFR04	0-1	0.019	0.005	1.4	5.1	569	4.7	6.9
	1-3	0.027	0.005	1.4	5.7	882	5.1	7.3
	3-6	0.045	0.006	1.6	6.8	4108	5.4	8.0
LFR01R	0-1	0.015	0.005	1.0	5.2	42	5.0	3.6
	1-3	0.016	<0.005	1.0	5.1	69	5.1	3.9
	3-6	0.030	0.005	1.2	6.0	135	5.4	4.2

n.a. Not analysed.

Barium values range from 192 ± 10 mg/kg to 3942 ± 165 mg/kg dry sediment, cadmium from 0.013 ± 0.001 mg/kg to 0.042 ± 0.007 mg/kg, copper from1.0 ± 0.0 mg/kg to 3.3 ± 0.6 mg/kg, lead from 3.6 ± 0.1 mg/kg to 11.8 ± 1,5 mg/kg, zinc from 3.8 ± 0.3 mg/kg to 12.9 ± 5.1 mg/kg and chromium from 4.2 ± 0.2 to 8.9 ± 2.7 mg/kg (Table 8-6).

The highest barium concentrations, 3942 ± 165 mg/kg dry sediment, are found at station LFR12. LFR 13 also reveal sediments with high concentrations of barium, values of 695 ± 153 mg/kg being measured. At station LFR 19 sediment barium concentrations are found to be 1005 ± 183 mg/kg. Station LFR 24, positioned relative to C3, have sediments with barium concentrations of 435 ± 173 mg/kg. Barium concentrations are lower in sediments at the other field stations, though above LSC of the region. Sediments at station LFR 12 are contaminated with cadmium (0.042 ± 0.007 mg/kg), copper (3.3 ± 0.6 mg/kg), zinc (12.9 ± 5.1 mg/kg) and lead (11.8 ± 1.5 mg/kg). Sediments at stations LFR04 and LFR19 are contaminated by lead (7.9 ± 1.1 mg/kg and 7.4 ± 0.9 mg/kg respectively).

Vertical core samples from station LFR04 reveal increases in sediment concentrations of cadmium, copper, zinc, barium, chromium and lead down in the sediments (Table 8-7). Only barium reveals concentrations above LSC in the top layer. No mercury contamination is found in sediments at LFR04.

All the stations investigated are regarded as contaminated with barium. The barium concentrations are especially high in sediments at stations situated 250 and 500 m in the 60° direction relative to C1 and 250 m in the 60° direction relative to C2. Sediments from the station located 250m/60° relative to C1 are also contaminated with the other selected metals. In addition contamination by lead is found at 250m/150° relative to installation C1 and at 250m/60° relative to installation C2.

Comparison with previous survey(s)

The THC level at the reference station is comparable to level found in the 1997 survey. However, the level is three times above the background levels found in 1992 (Figure 8-2). Minor increases in levels of zinc and lead are found. Concentrations of the other selected metals are at the same level as in the previous surveys and seem to reflect the natural background in the field area (Figure 8-3 and Figure 8-4). Minor increases in THC, cadmium, zinc, chromium and lead concentrations with depth are measured in vertical core samples from the reference station, though none of the measured values exceed the calculated LSC.

Compared to the 1997 results, the hydrocarbon levels have increased at the 250 m stations in the 60° directions relative to C1, C2 and C3 (Figure 8-2), while the THC contents are almost unchanged at the remaining stations. The discharge history includes an acute spill of 0,5 tons hydraulic oil and 13 tons of cementing chemicals immediately before the survey in 2000.

Compared to the 1997 results increased in barium concentrations are found at the innermost stations in the 60° direction relative to C1, C2 and C3 (Figure 8-3). The most pronounced increase (+3345 mg/kg) in barium content is found at the 250 m station on the C1 60°-axis. At this station, the levels of cadmium, copper, zinc and lead also have increased, and the highest values measured in the present survey are found in sediments from the station last mentioned (Figure 8-4). At the other stations the levels of the selected metals are at the same level or a little lower than in the 1997 survey. The discharge history of 140 tons of barite in year 2000 may explain the increased amounts of the selected metals in sediments at Lille Frigg.

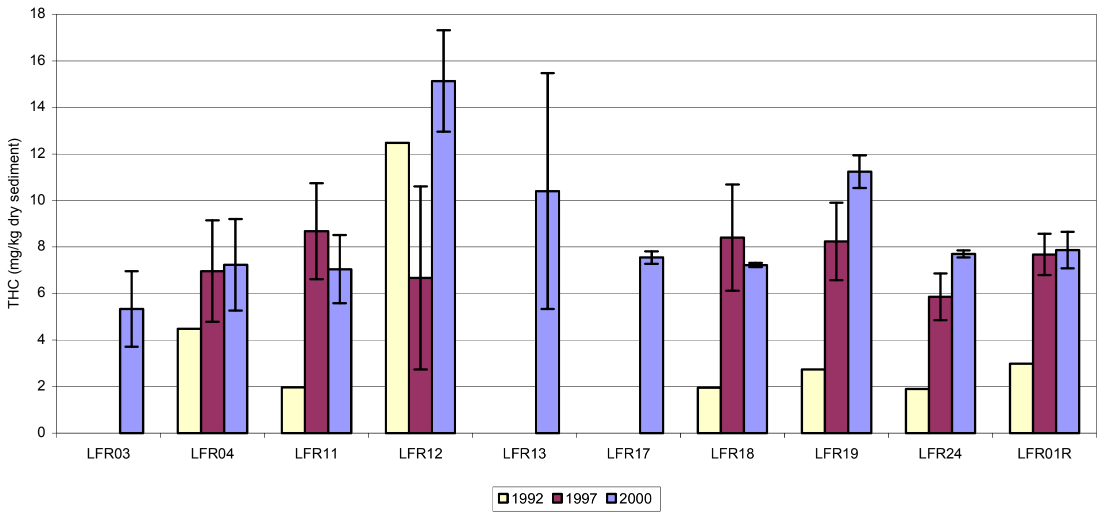

Figure 8-2: THC levels in sediment from the present (2000) and previous surveys, Lille Frigg field.

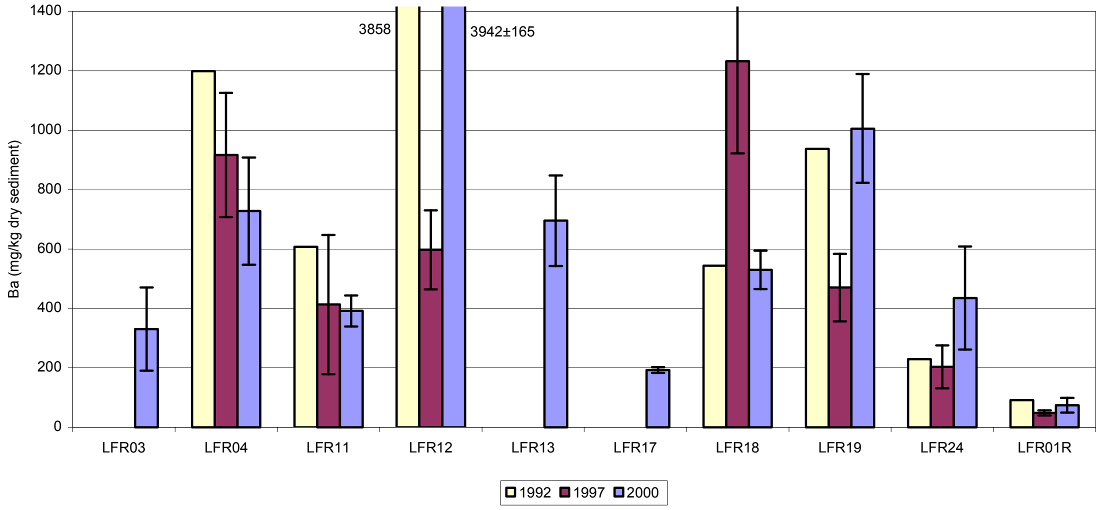

Figure 8-3: Barium levels in sediment from the present (2000) and previous survey, Lille Frigg field.

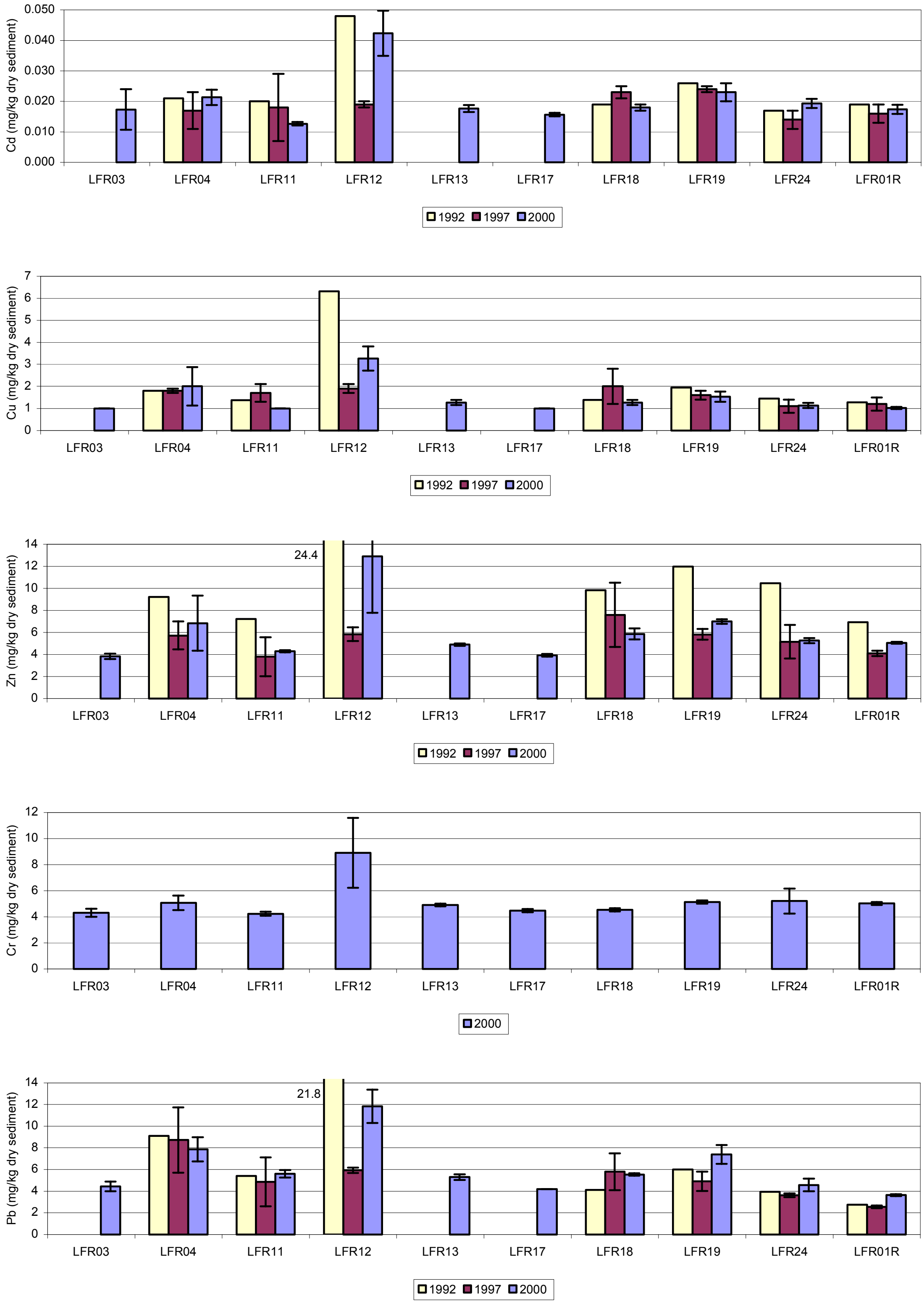

Figure 8-4: Levels of selected metals in sediments from the present (2000) and previous surveys, Lille Frigg field.

8.2.3 Biology

The distribution of individuals and taxa within the main taxonomic groups are given in Table 8-8. A total of 16359 individuals within 238 taxa were registered at the Lille Frigg field in the present survey (excluding juveniles). The polychaetes dominate the fauna with 72 % of the individuals and 53 % of the taxa recorded.

Table 8-8: Distribution of individuals and taxa within the main taxonomic groups at Lille Frigg, 2000 (excluding juveniles).

Main taxonomic groups	Individuals		Taxa	
	Number	%	Number	%
Polychaeta	11747	72	125	53
Mollusca	1246	8	42	18
Crustacea	664	4	48	20
Echinodermata	1365	8	11	5
Diverse groups	1337	8	12	5
Total	16359	100	238	100

The species/area curve for the field reference station is shown in Figure 8-5. A total of 141 taxa are present in the 10 grab samples of which 62 (44 %) occur in the first sample and 119 (84 %) in the five first samples. The curve indicates that not all taxa in the area are recorded in 10 samples, but the representativity of five samples is considered to be relatively good.

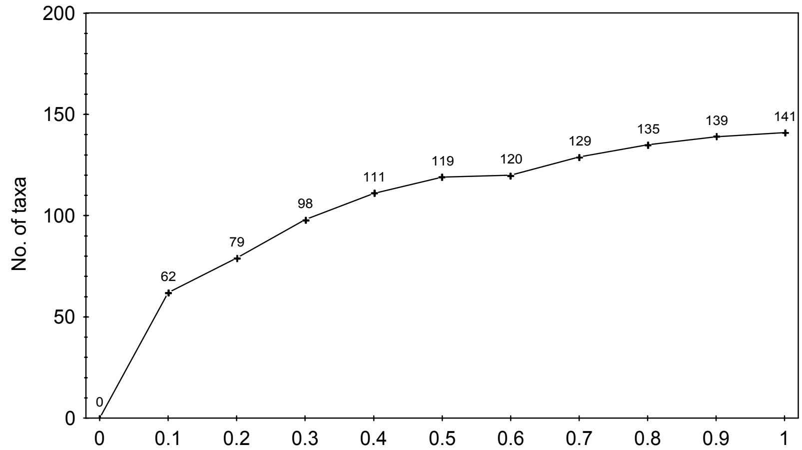

Figure 8-5: Species/area curve for the reference station at the Lille Frigg field (area in m^2).

The number of individuals and taxa at each station, together with selected community indices is presented in Table 8-9, while a comparison with the previous surveys is shown in Figure 8-6. The number of individuals in the present survey varies from 1062 (station LFR03) to 2337 (LFR19), the number of taxa from 98 (LFR17) to 138 (LFR12), the diversity index H' from 3.9 to 4.9, the evenness index J from 0.57 to 0.73 while the ES_{100} varies from 26 to 37. The H', J and ES100 values are all lowest at station LFR13 (500 m north east of C1) and highest at station LFR12 (250 m north east of C1). The values for all parameters, with exception of number of individuals, are higher at the reference station LFR01R than the average values for the field stations.

Compared with the results from the previous surveys, there is a general trend for lower values for all parameters assessed in the present survey, with the exception of station LFR24 where the number of individuals has increased. The largest decrease in number of individuals is at station LFR18 where it is reduced from 3748 to 1458 in the period between the two surveys.

Table 8-9: Number of individuals and taxa and selected community indices for each station (0.5 m^2) at the Lille Frigg field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	No. of ind.	No. of taxa	H’	J	ES_{100}
LFR03	**1062**	99	4.5	0.68	32
LFR04	1473	107	4.3	0.63	29
LFR11	1384	101	4.5	0.67	30
LFR12	1717	**138**	**4.9**	0.70	**37**
LFR13	2310	112	**3.9**	**0.57**	**26**
LFR17	1071	**98**	4.8	**0.73**	34
LFR18	1458	102	4.4	0.66	30
LFR19	**2337**	114	4.3	0.62	29
LFR24	2024	111	4.1	0.60	27
LFR1R	1523	119	**4.9**	0.71	35
Sum *	14836				
Average *	1648	109	4.4	0.65	31
St. dev. *	484	12	0.3	0.05	3

* Excluding the reference station.

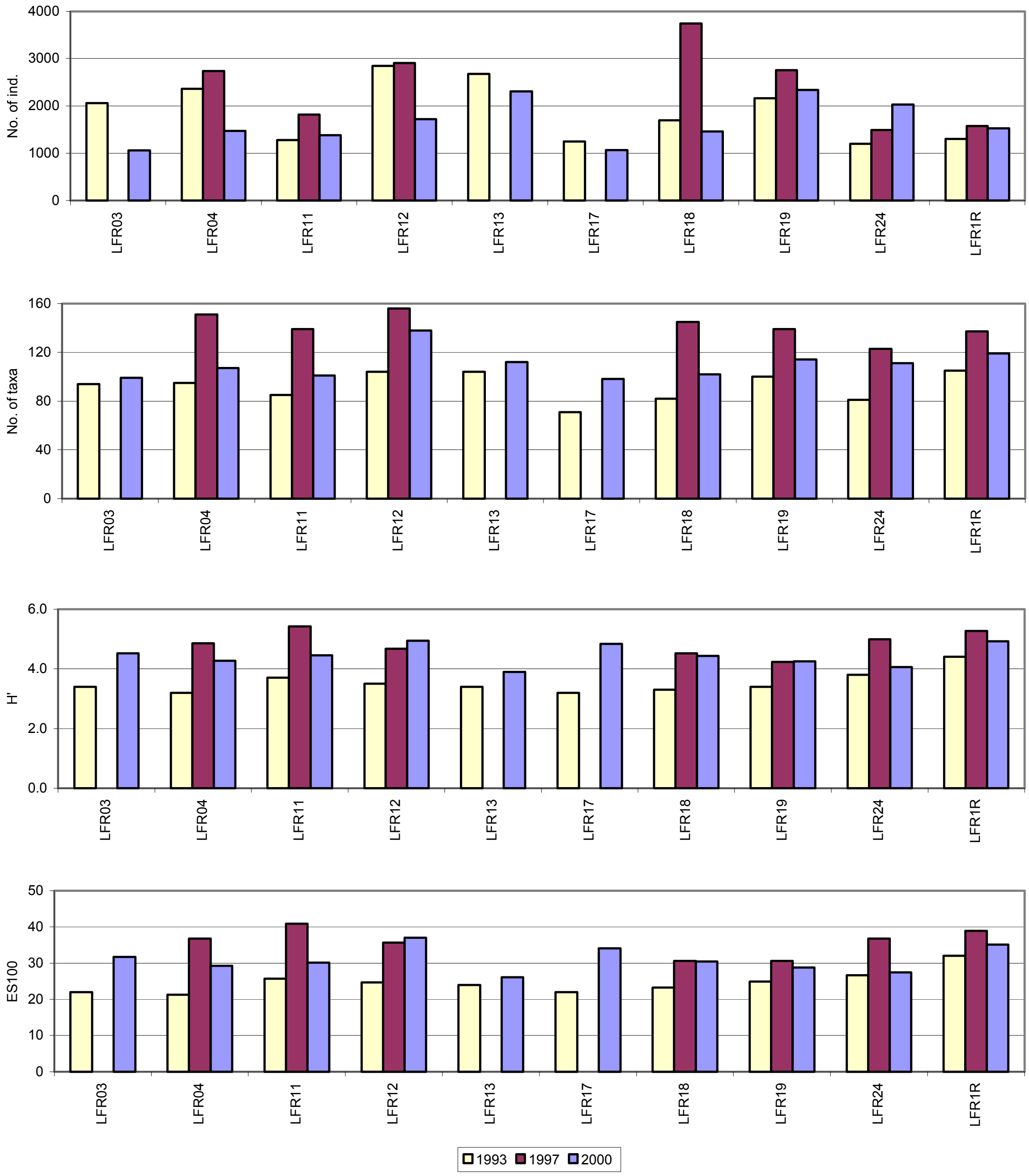

Figure 8-6: Biological characteristics of the stations at Lille Frigg field, 2000 and previous surveys.

The distribution of taxa in geometrical classes at each station is shown in Figure 8-7. Three stations (LFR13, LFR19 and LFR24) have taxa in class 10 (512- 1023 individuals) while the remaining stations (including the reference station LFR01R) have taxa in class 9 (256 – 511 individuals) or lower. These results do not indicate faunal disturbance at any of the stations.

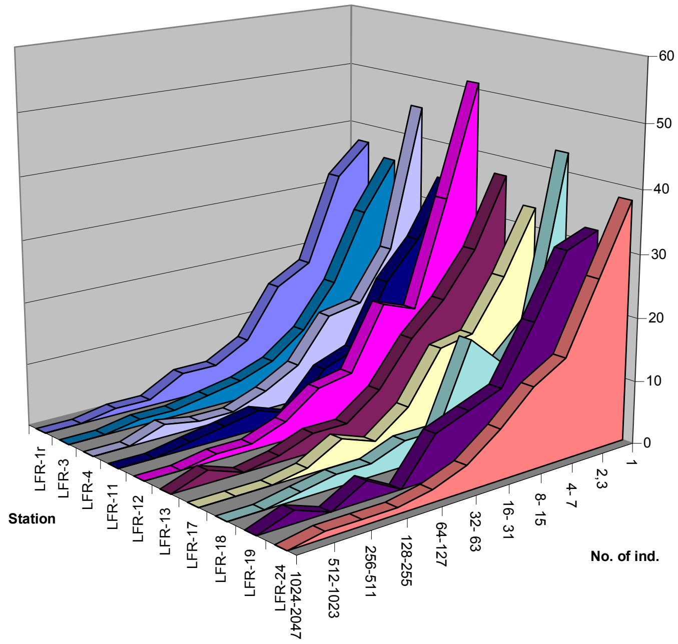

Figure 8-7: Distribution of taxa in geometrical classes for the stations at the Lille Frigg field, 2000.

The ten most dominant taxa at each station are shown in Table 8-12 at the end of this chapter. A total of 15 taxa (including three juvenile forms) are among the ten most dominant taxa at one or more stations. These 15 taxa comprise 82 % of the total number of individuals and 6 % of the total number of taxa recorded at the Lille Frigg field in the present survey.

The most dominant taxa among the adult forms are the polychaetes *Galathowenia oculata* and *Owenia fusiformis*, the brittle star *Amphiura filiformis* and the phoronid *Phoronis* sp. These four taxa are among the ten most dominant at all stations at Lille Frigg. The ten most dominant taxa at the stations comprise between 66 % (LFR12) and 82 % (LFR11, 18 and 24) of the total number of individuals recorded at the respective stations. The corresponding value at the reference station is 75 %. The results indicate a uniform distribution of undisturbed fauna in the area.

Figure 8-8 shows the dendrogram from the cluster analysis for the field stations and selected regional and reference stations, while Figure 8-9 shows the 2-D plot from the MDS analysis.

The cluster analysis separates out the reference station at Nordøst Frigg (NEF20R) at 40 % dissimilarity level, regional station RII02 at 38 % and the rest of the stations in smaller groups at 34 % dissimilarity level and lower. These stations include the reference stations at Lille Frigg (LFR01R), Øst Frigg (PSB13R) and Frigg (FRI10R). The correlation coefficient shows a good fit to the data (r = 0.83).

The MDS analyses support the results from the cluster analysis of the station data. In the 2-D plot, regional station RII02 and reference station NEF20 R are somewhat separated from the group of stations that are scattered in the middle part of the plot. The stress test revealed that minimum stress for the 2-D plot was achieved at a value of 0.20, indicating a fair fit to the data.

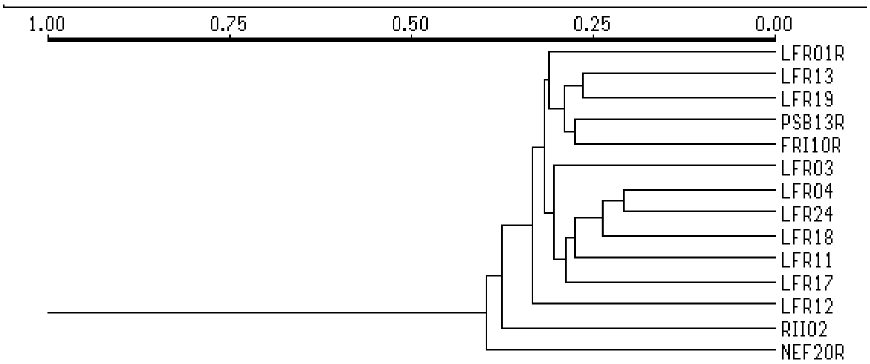

Figure 8-8: Cluster analysis of the Lille Frigg field stations and selected regional and reference stations in Region II, 2000.

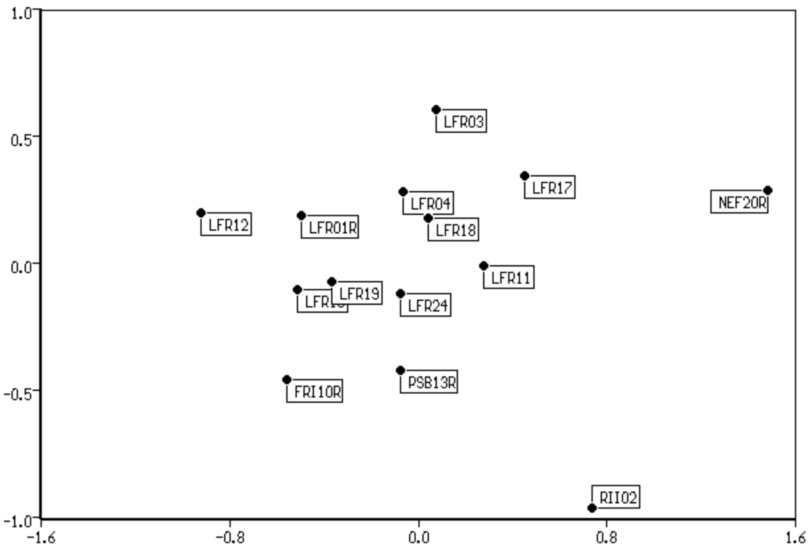

Figure 8-9: 2-D plot from the MDS analysis carried out on the Lille Frigg field stations and selected regional and reference stations in Region II, 2000.

A Canonical Correspondence Analysis (CCA) of the data from the field stations and selected regional and reference stations was carried out to examine the association between the biological data and the measured environmental variables in these areas.

Through the forward selection procedure in CANOCO, three of ten variables (pelite, barium and zinc) gave the best fit and were significant. The first two axes of the ordination space, which is constrained by these environmental variables, explained 41 % of the biological variance.

Figure 8-10 shows a biplot from the analysis using pelite (Pel), barium (Ba) and zinc (Zn) as the constraining environmental variables. The first canonical axis shows a gradient from regional station RII02 at the positive end of the axis to field station LFR17 at the negative end and has a positive correlation with the amount of pelite in the sediment (0.77) and a negative correlation with the amount of zinc (- 0.60). Species with the highest contribution on this axis are the polychaetes *Myriochele danielsseni* (35.0 %), *Owenia fusiformis* (13.6 %) and *M. fragilis* (9.4 %) and the brittle star *Amphiura filiformis* (4.5 %).

The second axis shows a gradient from field station LFR12 at the positive end to reference station LFR01R at the negative end and is positively correlated with the amount of barium (0.88) and zinc (0.63) in the sediment. Species with highest contribution on this axis are the polychaetes *Owenia fusiformis* (12.8 %), *Spiophanes bombyx* (11.8 %), *Pectinaria koreni* (9.5 %) and *Myriochele fragilis* (7.5 %) and the bivalve *Thyasira ferruginea* (6.8 %).

None of the species with high contribution on the two axes are known as indicator species for disturbed fauna.

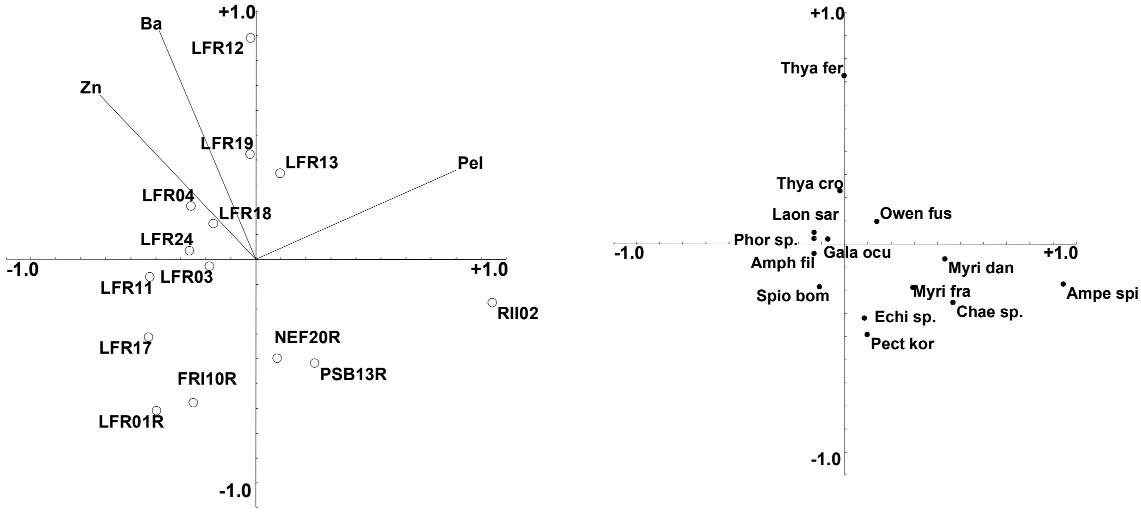

Figure 8-10: Biplot from the CCA analysis for the Lille Frigg field stations and selected regional and reference stations in Region II, 2000 (left) and taxa with highest contribution on the two axes (right).

On the basis of the results from the uni- and multivariate analyses, all stations are classified as faunal group A (undisturbed fauna, see Table 8-10). The results indicate a uniform distribution of undisturbed fauna in the surveyed area. The low diversity index at regional station RII02 (H' = 3.4) is caused by the high abundance of the polychaete *Owenia fusiformis* at that station. This species, together with *Galathowenia oculata*, predominates at most of the stations included in Table 8-10.

Although elevated levels of barium and some other heavy metals are recorded at many of the field stations, this has not resulted in faunal disturbance. In 1997 stations LFR04, LFR12 and LFR18 were classified as group B stations (slightly disturbed fauna) due to the relatively high abundance of the polychaete *Pseudopolydora paucibranchiata* (188 – 386 individuals at these three stations). In the present survey the same species is registered with only 9 – 26 individuals at the surveyed field stations. The largest decrease in number of individuals is seen at station LFR18 where it is reduced from 3748 to 1458 in the period between the two surveys. The main reason for this is the reduced abundance of the polychaetes *Owenia fusiformis*, *Galathowenia oculata* and *Myriochele danielsseni*, each of which were represented by more than 500 individuals at the same station in 1997.

Table 8-10: Classification into faunal groups, distance to installation and biological statistics for the field stations at Lille Frigg field, 2000.

Station	Impact group	Dist. (m)	Statistics			No. of individuals								
			No. ind	No. taxa	H'	Goc	Ofu	Afi	Psp	Sbo	Mda	Tfl	Csp	Cca
LFR03	A	500	1062	99	4.5	264	139	109	59	66	18	33	8	4
LFR04	A	250	1473	107	4.3	366	298	140	77	62	29	15	13	3
LFR11	A	250	1384	101	4.5	289	246	135	85	88	33	24	1	5
LFR12	A	250	1717	138	4.9	243	389	115	74	22	64	42	5	11
LFR13	A	500	2310	112	3.9	538	726	98	143	81	19	54	5	2
LFR17	A	500	1071	98	4.8	178	102	119	92	87	20	23	11	5
LFR18	A	250	1458	102	4.4	369	218	142	75	70	40	39	12	3
LFR19	A	250	2337	114	4.3	555	517	137	191	49	135	28	20	9
LFR24	A	250	2024	111	4.1	572	465	139	124	64	45	18	14	3
LFR1R	A	10150	1523	119	4.9	312	115	156	66	55	69	19	17	2
RII02	A	-	2994	123	3.4	302	1085	62	36	34	646	50	50	0
FRI10R	A	-	1591	126	4.9	256	62	146	160	216	49	30	13	0
NEF20R	A	-	1221	68	4.0	301	227	68	23	149	7	25	19	0
PSB13R	A	-	1457	118	4.9	223	98	132	37	121	48	29	28	0

Goc = *Galathowenia oculata*, Ofu = *Owenia fusiformis*, Afi = *Amphiura filiformis*, Psp = *Phoronis* sp., Sbo = *Spiophanes bombyx*, Mda = *Myriochele danielsseni*, Tfl = *Thyasira flexuosa*, Csp = *Chaetozone* sp. (incl. *C. setosa*), Cca = *Capitella capitata*.

8.3 Summary and conclusions

The sediments at Lille Frigg are classified as fine sand with relatively moderate amounts of pelite (4.4 – 8.7 %) and TOM (0.9 – 1.6 %). The amount of pelite has increased at all stations since 1997 and is largest at station LFR12 (situated 250 m north west of C1) and the reference station LFR1R. The amount of fine sand and TOM is nevertheless relatively similar between the two surveys. The recorded changes are believed to be a result of natural variation as they occur at both the reference and the field stations.

At Lille Frigg contamination with hydrocarbons are found in the sediments at two stations situated 250 m in the 60° directions relative to C1 and C2. Borderline value of THC is found in the sediments from the 500 m station in the 60° direction relative to C1. Gas chromatograms of sediment extracts from Lille Frigg do not show mineral oil profiles. The vertical core samples reveal increasing hydrocarbon levels with depth on the 250 m station on the 150°-axis relative to C1. Compared to the 1997 results, the hydrocarbon levels have increased at the 250 m stations in the 60° directions relative to C1, C2 and C3, while the THC contents are almost unchanged at the remaining stations.

All the stations investigated are regarded as contaminated with barium. Sediments at the station situated 250m in the 60° direction relative to C1 also are contaminated by the other selected metals. Contamination by lead is found 250m at 150° relative to installation C1 and 250m at 60° relative to installation C2. Compared to the 1997 results increases in barium concentrations are found at the innermost stations in the 60° direction relative to the three installations C1, C2 and C3. The most pronounced increase in barium level is found near the C1 installation. Here the level has increased from 597 to 3942 mg/kg dry sediment. At this station, the levels of cadmium, copper, zinc and lead have also increased, and in the present survey the highest values is found at 250m in the 60° direction relative to C1. At the other stations, the levels of the selected metals are at the same level or a little lower than in the 1997 survey.

The discharge history at Lille Frigg states an acute spill of 0,5 tons hydraulic oil, 13 tons of cementing chemicals and 140 tons of barite in 2000, immediately before the 2000 survey. These discharges may explain the rises in hydrocarbons and selected metals at the field.

The number of individuals and taxa has decreased at all stations since 1997. Station LFR18 has the largest decrease of the number of individuals with a reduction from 3748 to 1458. The main reason for this is the reduced abundance of the polychaetes *Owenia fusiformis*, *Galathowenia oculata* and *Myriochele danielsseni*. Even though relatively high levels of barium and other heavy metals are recorded, faunal disturbance is not registered at any stations in the present survey. There is a uniform distribution of the fauna in the surveyed area.

In 1997 stations LFR04, LFR12 and LFR18 were classified as group B stations (slightly disturbed fauna) due to the relatively high abundance of the polychaete *Pseudopolydora paucibranchiata*. This species is recorded with relatively low individual numbers in the present survey. The results show that the faunal conditions have improved at the field in the recent years.

The calculated minimum area and spatial extent of contaminated sediments at the Lille Frigg field is shown in Table 8-11 and Figure 8-11.

Table 8-11: Distance along the transects and calculated minimum area of contaminated sediments the Lille Frigg field, 2000 and previous survey.

Lille Frigg C1	NE	SE	SW	NW	Km^2 (2000)	Km^2 (1997)
THC	250	125	125	125	0.07	0.00
Ba	500	500	250	125	0.37	0.15
Other metals	0	0	0	0	0.00	0.00
Lille Frigg C2	NE	SE	SW	NW	Km^2 (2000)	Km^2 (1997)
THC	250	125	125	125	0.07	0.00
Ba	250	125	500	125	0.15	0.10
Other metals	250	125	125	125	0.07	0.00
Lille Frigg C3	NE	SE	SW	NW	Km^2 (2000)	Km^2 (1997)
THC	0	0	0	0	0.00	0.00
Ba	250	125	125	125	0.07	0.07
Other metals	0	0	0	0	0.00	0.00
Sum Lille Frigg					Km^2 (2000)	Km^2 (1997)
THC					0.15	0.00
Ba					0.59	0.32
Other metals					0.07	0.00

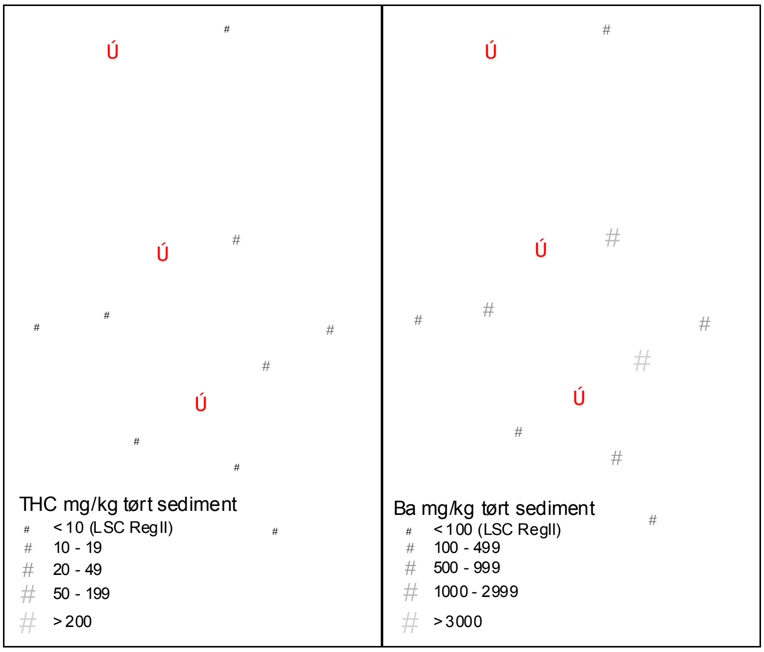

Figure 8-11: Distribution of the amounts of THC and barium at the Lille Frigg field, 2000.

Table 8-12: Number of individuals and the accumulative abundance for the ten most dominant taxa at each station at the Lille Frigg field, 2000.

LFR03 (150°/500 m)	No. ind.	Acc. %	LFR04 (150°/250 m)	No. ind.	Acc. %	LFR11 (240°/250 m)	No. ind.	Acc. %	LFR12 (60°/250 m)	No. ind.	Acc. %	LFR13 (60°/500 m)	No. ind.	Acc. %
Galathowenia oculata	264	18%	Galathowenia oculata	366	19%	Owenia fusiformis juv.	948	35%	Owenia fusiformis	389	17%	Owenia fusiformis	726	22%
Pectinaria sp. juv.	250	35%	Owenia fusiformis	298	34%	Galathowenia oculata	289	46%	Pectinaria sp. juv.	368	33%	Pectinaria sp. juv.	552	39%
Owenia fusiformis	139	44%	Pectinaria sp. juv.	273	48%	Owenia fusiformis	246	55%	Galathowenia oculata	243	44%	Galathowenia oculata	538	55%
Amphiura filiformis	109	51%	Amphiura filiformis	140	55%	Pectinaria sp. juv.	239	64%	Owenia fusiformis juv.	135	50%	Owenia fusiformis juv.	312	65%
Owenia fusiformis juv.	106	59%	Owenia fusiformis juv.	100	60%	Amphiura filiformis	135	69%	Amphiura filiformis	115	55%	Phoronis sp.	143	69%
Spiophanes bombyx	66	63%	Ophiuroidea indet. juv.	89	65%	Spiophanes bombyx	88	72%	Phoronis sp.	74	58%	Amphiura filiformis	98	72%
Phoronis sp.	59	67%	Phoronis sp.	77	69%	Phoronis sp.	85	75%	Myriochele danielsseni	64	61%	Abra prismatica	90	75%
Ophiuroidea indet. juv.	47	70%	Spiophanes bombyx	62	72%	Ophiuroidea indet. juv.	81	79%	Ophiuroidea indet. juv.	42	63%	Spiophanes bombyx	81	77%
Spiophanes kroyeri	33	72%	Spiophanes kroyeri	46	74%	Spiophanes kroyeri	64	81%	Thyasira flexuosa	42	65%	Ophiuroidea indet. juv.	74	80%
Thyasira flexuosa	33	75%	Urothoe elegans	38	76%	Myriochele danielsseni	33	82%	Thyasira croulinensis	41	66%	Thyasira flexuosa	54	81%
LFR17 (240°/500 m)	No. ind.	Acc. %	SLFR18 (240°/250 m)	No. ind.	Acc. %	LFR19 (60°/250 m)	No. ind.	Acc. %	LFR24 (60°/250 m)	No. ind.	Acc. %	LFR01R (0°/10150 m)	No. ind.	Acc. %
Owenia fusiformis juv.	810	35%	Owenia fusiformis juv.	947	32%	Owenia fusiformis juv.	601	17%	Owenia fusiformis juv.	844	25%	Owenia fusiformis juv.	598	22%
Pectinaria sp. juv.	349	50%	Pectinaria sp. juv.	452	47%	Galathowenia oculata	555	33%	Galathowenia oculata	572	43%	Pectinaria sp. juv.	493	40%
Galathowenia oculata	178	57%	Galathowenia oculata	369	60%	Pectinaria sp. juv.	523	47%	Owenia fusiformis	465	57%	Galathowenia oculata	312	51%
Amphiura filiformis	119	62%	Owenia fusiformis	218	67%	Owenia fusiformis	517	62%	Pectinaria sp. juv.	363	67%	Amphiura filiformis	156	57%
Owenia fusiformis	102	67%	Amphiura filiformis	142	72%	Phoronis sp.	191	67%	Amphiura filiformis	139	72%	Owenia fusiformis	115	61%
Phoronis sp.	92	71%	Phoronis sp.	75	75%	Amphiura filiformis	137	71%	Phoronis sp.	124	75%	Myriochele fragilis	105	65%
Spiophanes bombyx	87	74%	Spiophanes bombyx	70	77%	Myriochele danielsseni	135	75%	Spiophanes bombyx	64	77%	Ophiuroidea indet. juv.	96	68%
Ophiuroidea indet. juv.	84	78%	Ophiuroidea indet. juv.	59	79%	Ophiuroidea indet. juv.	67	77%	Ophiuroidea indet. juv.	62	79%	Myriochele danielsseni	69	71%
Spiophanes kroyeri	46	80%	Myriochele danielsseni	40	80%	Spiophanes bombyx	49	78%	Spiophanes kroyeri	55	81%	Phoronis sp.	66	73%
Abra prismatica	35	81%	Spiophanes kroyeri	40	82%	Spiophanes kroyeri	43	79%	Myriochele danielsseni	45	82%	Spiophanes bombyx	55	75%

Table 8-13: Station information for Lille Frigg field, 2000.

St. no.	Distance (m)	Direction (degr.)	Volume (litres)
LFR03	500	150	37
LFR04	250	150	37
LFR11	250	240	31
LFR12	250	60	47
LFR13	500	60	32
LFR17	500	240	30
LFR18	250	240	30
LFR19	250	60	30
LFR24	250	60	30
LFR1R	10150	0	30 *

*) The additional five grab samples gave 28 litres of sediment.

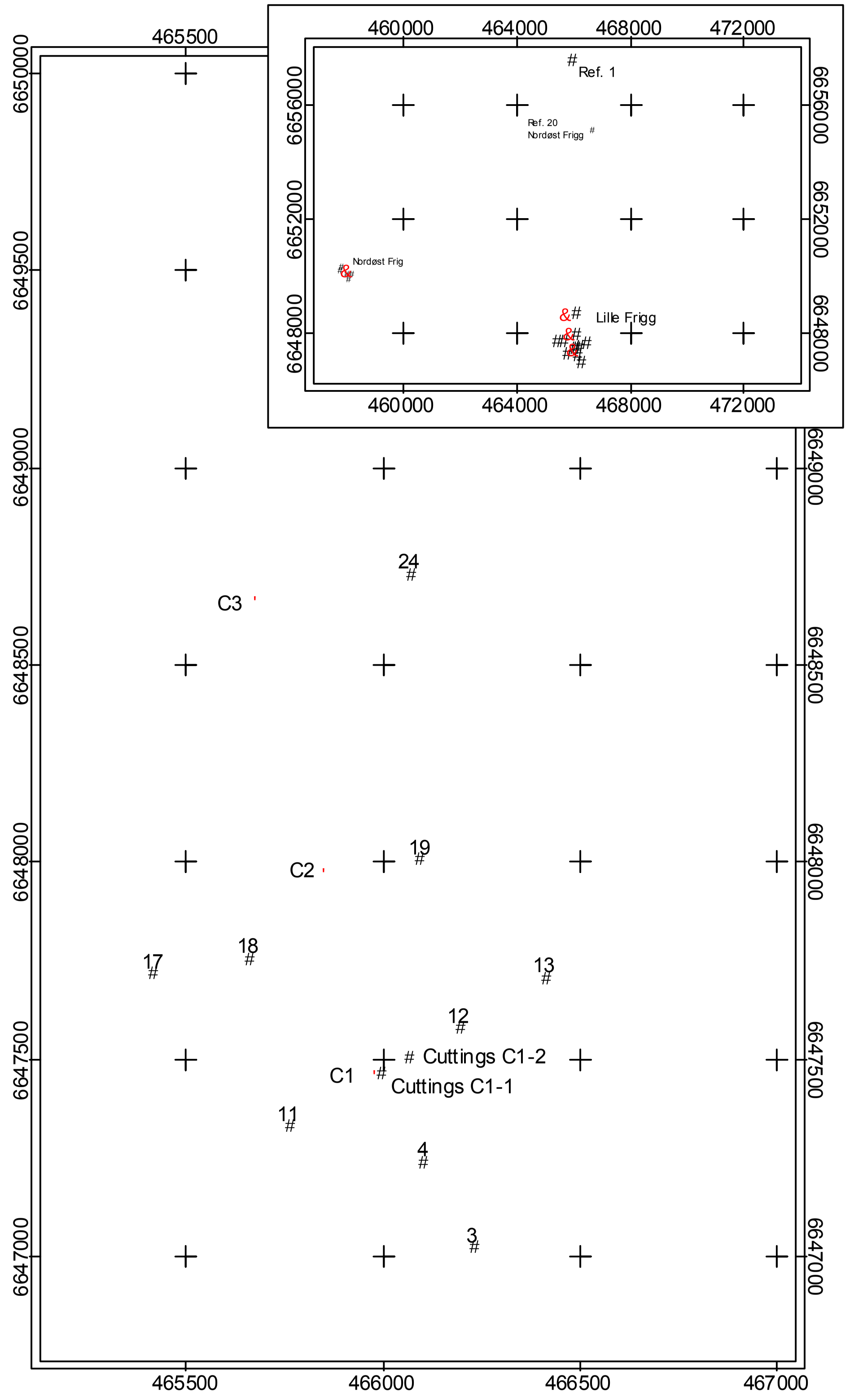

Figure 8-12: Map of sampling positions for Lille Frigg field, 2000

9 Frøy field

9.1 Introduction

The Frøy field is located in block 25/2 and 25/5 in Region II. Production at the field started in 1995 and the field is closed down during March 2001. There has been no drilling activity at the field since 1997. Recently discharges are summarised in Table 9-1.

In the monitoring survey in 1997 hydrocarbon contamination extended out to 500 m on the 60°-axis and 250 m on the 150°-, 240°- and 330°-axes. All stations investigated had sediments contaminated with barium. No contamination with the other selected metals was found. Faunal disturbance was found out to 500 m in the 150° direction and 250 m in the other directions. Therefor the same set of stations was used in the present survey.

As Ultidrill has been used at this field during drilling operations, it was included in the analytical programme. Information on the sampling stations is shown in Figure 9-15 and Table 9-13, both on the foldout page at the end of this chapter (page 9-21). In addition, samples from the cutting piles at the field were collected by use of a van Veen grab (biology) and box corer (chemistry). A separate report with these results will be produced.

Table 9-1: Summary of recent accidental discharges at the Frøy field (all discharges in tonnes).

	1997	1998	1999	2000	Comments
Accidental discharges	1.4	0.09	0.4	0.1	

9.2 Results and discussion

9.2.1 Physical characteristics

The median phi value and the amounts (%) of pelite, fine sand and total organic material (TOM) in the sediments from the present and previous surveys are shown in Table 9-2 and Figure 9-1. 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 in the area are classified as silt and fine sand with median values varying from 3.67 to 4.05. The amount of pelite in the sediment varies from 6.1 % (FRY06) to 12.4 % (FRY13), the fine sand from 79.9 % (FRY02) to 91.2 % (FRY12) while the TOM varies from 1.06 % (FRY06) to 1.75 % (FRY13). The sediment is coarser at the reference station than at the field stations, with a pelite content of 9,3 %, fine sand of 76.5 % and TOM of 1.5 %. Among the field stations the pelite and TOM values are highest at the 250 m stations.

The pelite content has increased at most of the stations, including the reference station, since the previous survey in 1997. Between 1992 and 1997 the pelite content decreased at all stations. The largest increase since 1997 of the TOM value is registered at stations FRY04 and FRY13. The median value has increased at most of the stations between 1997 and 2000, indicating a general trend for finer sediments in the area.

Table 9-2: The median (phi) and amount (%) of pelite, fine sand and TOM in the sediments from stations at the Frøy field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	Distance (m)	Direction (degr.)	Median	Classification	Pelite	Fine sand	TOM
FRY02	1000	150	3.79	Fine sand	9.8	**79.9**	1.33
FRY03	500	150	3.74	Fine sand	8.1	82.8	1.32
FRY04	250	150	4.00	Silt	11.6	84.5	1.69
FRY05	250	330	4.01	Silt	11.4	83.4	1.48
FRY06	500	330	**3.67**	Fine sand	**6.1**	87.2	**1.06**
FRY12	500	240	3.74	Fine sand	6.2	**91.2**	1.28
FRY13	250	240	**4.05**	Silt	**12.4**	85.4	**1.75**
FRY14	250	60	**4.05**	Silt	11.9	84.0	1.58
FRY15	500	60	4.04	Silt	10.0	86.5	1.42
FRY18R	10000	60	3.79	Fine sand	9.3	76.5	1.50
Average *			3.90		9.7	85.0	1.44
St. dev. *			0.16		2.4	3.2	0.22

* Excluding the reference station.

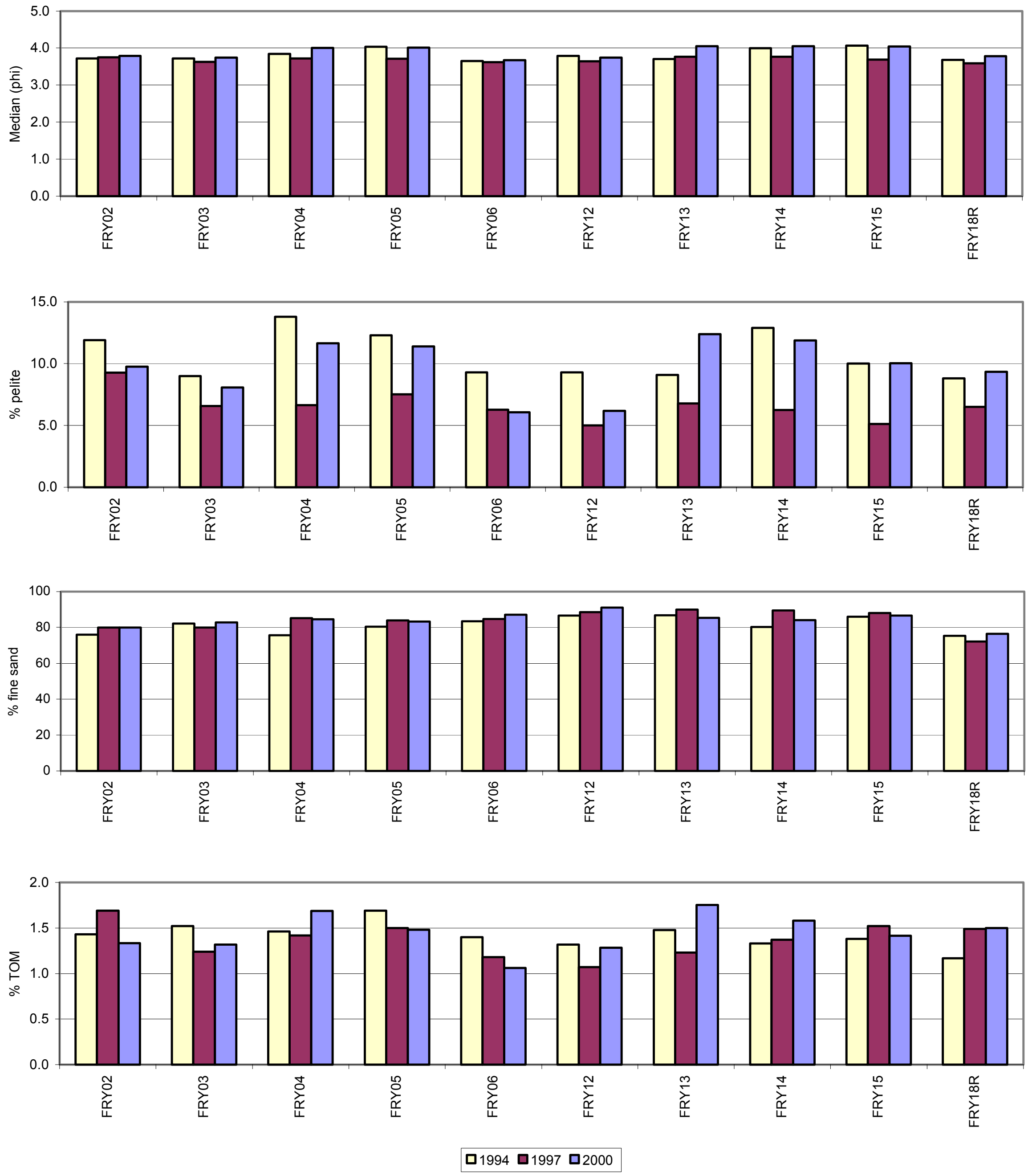

Figure 9-1: Sediment characteristics at the Frøy field, 2000 and previous surveys.

9.2.2 Chemical characteristics

The calculated limits of significant contamination for selected hydrocarbons and metals in sediments from Region II ($LSC_{97\text{-}00\ RegII}$) are presented previously in the chapter that deals with the regional and reference stations. In addition to the regional limits, field-specific limits of significant contamination are calculated from the field reference station ($LSC_{00\ FRY18R}$). Both sets of data are presented in Table 9-3. Based on analysis results of the Frøy field the $LSC_{97\text{-}00\ RegII}$ is regarded as representative of the entire region and will therefore be used as further basis for discussion of the contamination status of this field. Those limits will hereafter simply be referred to as LSC.

The results of analyses of the hydrocarbons are summarised in Table 9-4. Concentrations of selected compounds in the vertical sediment sections are presented in Table 9-5. The full data set of replicate measurements and date from previous years are given in the Appendix. THC values and content of synthetic base oil from 2000 are compared with those from previous years in Figure 9-3 and Figure 9-4 respectively.

Table 9-3: Background levels and Limits of Significant Contamination for the Frøy field, 2000. All values in mg/kg dry sediment.

	THC	NPD's	3-6 ring	Decalins	Cd	Hg	Cu	Zn	Ba	Cr	Pb
$LSC_{00\ FRY18R}$	8.3	0.024	0.082	0.084	0.075	0.008	1.6	5.9	111	6.3	5.8
$LSC_{97\text{-}00\ Region\ II}$	9.8	*	*	*	0.029	0.008	2.0	8.9	146	9.6	7.0

*) Regional stations not analysed for NPD's, 3-6 ring aromatics and decalins.

Table 9-4: Concentrations of hydrocarbons and synthetic base oil in sediments from the Frøy field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded, values between $LSC_{00FRY18R}$ and $LSC_{97\text{-}00\ RegII}$ are light shaded and olefin values at or above the limit of quantitation are dark shaded.

Station	THC		Olefins		NPD's		3-6 ring		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
FRY02	8.4	0.7	<0.1	-	0.028	0.015	0.063	0.025	0.048	0.008
FRY03	6.6	0.1	0.3	0.3	n.a.		n.a.		n.a.	
FRY04	10.6	3.5	2.4	1.0	0.141	0.064	0.062	0.012	0.040	0.014
FRY05	9.4	1.7	2.9	1.5	n.a.		n.a.		n.a.	
FRY06	6.0	1.8	<0.1	-	n.a.		n.a.		n.a.	
FRY12	7.5	1.7	<0.1	-	n.a.		n.a.		n.a.	
FRY13	6.9	3.1	1.7	0.3	n.a.		n.a.		n.a.	
FRY14	7.6	5.1	0.3	0.1	n.a.		n.a.		n.a.	
FRY15	9.0	1.7	<0.1	-	n.a.		n.a.		n.a.	
FRY18R	5.3	1.3	<0.1	-	0.018	0.003	0.065	0.007	0.036	0.020

n.a. Not analysed.

Table 9-5: Concentrations of hydrocarbons and synthetic base oil in vertical sections of the sediment samples from the Frøy field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded, values between $LSC_{00FRY18R}$ and $LSC_{97\text{-}00\ RegII}$ are light shaded and olefin values at or above the limit of quantification are dark shaded.

Station	Layer (cm)	THC	Olefins	NPD's	3-6 ring	Decalins
FRY02	0-1	7.9	<0.1	0.045	0.092	0.039
	1-3	8.2	<0.1	0.013	0.022	0.030
	3-6	11.7	<0.1	0.037	0.073	0.055
FRY04	0-1	13.8	2.9	0.191	0.071	0.050
	1-3	25.4	17.9	0.354	0.093	0.213
	3-6	32.7	27.0	0.388	0.099	0.365
FRY18R	0-1	3.6	<0.1	0.016	0.059	0.050
	1-3	7.1	<0.1	0.021	0.076	0.045
	3-6	8.4	<0.1	0.023	0.086	0.060

n.a. Not analysed.

At Frøy THC values range from 5.3 ± 1.3 mg/kg dry sediment to 10.6 ± 3.5 mg/kg (Table 9-4). Sediments at station FRY04 have THC concentrations of 10.6 ± 3.5 mg/kg. This is the only location at Frøy that have THC concentrations near LSC. However, one of the replicates at Frøy had a value as low as 6.9 mg/kg. Sediments at stations FRY05 and FRY15 have THC values just below LSC. Sediments elsewhere at Frøy have THC values well below LSC.

Field history shows that olefin based drilling fluid, Ultidrill, was used at Frøy before 1997. Sediment olefin levels are low at Frøy in the present survey, the highest values were found in sediments from stations FRY04 and FRY05 with 2.4 and 2.9 mg/kg dry sediment. Figure 9-2 is a gas chromatogram of a THC profile including olefins from Frøy. No mineral oil profiles are seen in chromatograms of sediment extracts from this field. Aromatics and decalins are measured in sediments from stations FRY02 and FRY04. Sediments at station FRY02 have NPD values near LSC and sediments at station FRY 04 are contaminated by NPD's with concentrations of 0.141 ± 0.064 mg/kg.

Vertical core samples of sediments from stations FRY 02 and FRY 04 reveal increasing THC concentrations with depth in the sediments (Table 9-5). At station FRY 04 sediment layers down to 6 cm all have THC concentrations over LSC, with the highest concentration found in the 3-6 cm layer with 32.7 mg/kg dry sediment. Increasing concentrations of Aromatics and decalins with depth are also found in sediments at station FRY04. Significant contamination of NPD's are found in all layers at this station and contamination by 3-6 ring aromatics and decalins are found in the 1-3 cm and 3-6 cm layers. Sediments at station FRY02 seem to have the lowest concentrations of aromatics and decalins in the mid layer, with elevated levels of NPD's and 3-6 ring aromatics in the top layer. On the same station olefin concentrations are increasing from 2.9 mg/kg in the top layer to 27 mg/kg in the 3-6 cm layer.

In general, low total hydrocarbon concentrations are found in sediments at Frøy. Sediments from the station situated at 250 m in the150° direction relative to the platform are contaminated by hydrocarbons. There are gradients towards higher hydrocarbon concentrations with depth in the sediments at station FRY 04 and FRY 02.

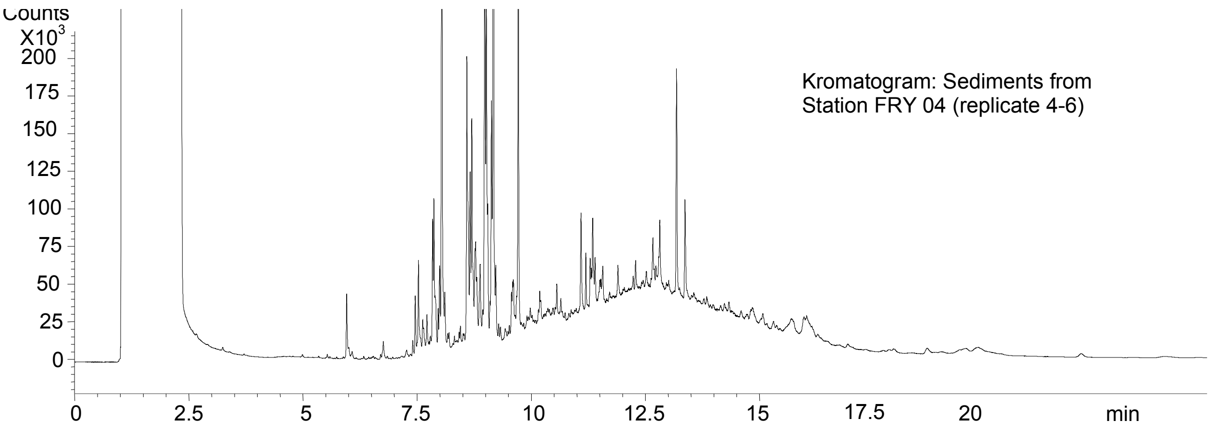

Figure 9-2: Gas chromatogram of a sediment extract from the Frøy field, 2000.

The results of the metal analyses for the Frøy field are summarised in Table 9-6. Concentrations of selected metals in the vertical sediment sections are presented in Table 9-7. The full set of replicate measurements, including selected data from previous years is given in the Appendix. Metal values from 2000 are compared with those from previous years in Figure 9-5 and Figure 9-6.

Table 9-6: Concentrations of selected metals in sediments from the Frøy field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between $LSC_{00FRY18R}$ and $LSC_{97\text{-}00\ RegII}$ are light shaded.

	Cd		Hg		Cu		Zn		Ba		Cr		Pb	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	Av.	sd.	av.	sd.	av.	sd.
FRY02	0.022	0.003	0.005	0.000	1.6	0.2	4.6	0.5	616	366	5.4	0.3	5.3	0.5
FRY03	0.015	0.002	n.a.		1.3	0.2	3.8	0.8	450	74	4.7	0.4	4.6	0.3
FRY04	0.025	0.005	0.005	0.002	2.4	0.4	6.4	0.9	1951	925	6.2	0.4	5.9	0.6
FRY05	0.028	0.011	n.a.		1.9	0.2	5.6	0.8	1678	357	5.7	0.6	5.1	0.5
FRY06	0.016	0.003	n.a.		1.2	0.1	3.5	0.9	333	40	4.4	0.4	4.1	0.2
FRY12	0.019	0.002	n.a.		1.5	0.2	4.1	0.4	392	170	5.0	0.3	4.8	0.2
FRY13	0.022	0.003	n.a.		2.3	0.1	6.4	0.5	1426	406	6.0	0.2	5.6	0.2
FRY14	0.025	0.003	n.a.		2.1	0.3	6.5	0.7	1455	695	6.1	0.3	5.7	0.3
FRY15	0.021	0.003	n.a.		1.4	0.2	4.4	0.8	395	165	5.4	0.3	4.8	0.2
FRY18R	0.035	0.017	0.005	0.001	1.6	0.0	5.3	0.3	80	13	5.9	0.2	4.9	0.4

n.a. Not analysed.

Table 9-7: Concentrations of selected metals in vertical sections of the sediment samples from the Frøy field. All concentrations in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between $LSC_{00FRY18R}$ and $LSC_{97\text{-}00\ RegII}$ light shaded.

Station	Layer (cm)	Cd	Hg	Cu	Zn	Ba	Cr	Pb
FRY02	0-1	0.025	0.005	1.8	5.0	571	5.6	5.8
	1-3	0.031	0.007	1.8	6.1	950	5.9	6.9
	3-6	0.045	0.007	2.1	7.6	515	6.7	6.3
FRY04	0-1	0.024	0.006	2.8	7.3	2860	6.6	6.6
	1-3	0.051	0.008	3.4	9.1	3325	7.3	7.7
	3-6	0.039	0.007	2.4	11.4	1131	6.5	6.7
FRY18R	0-1	0.061	<0.005	1.6	5.0	62	6.0	4.4
	1-3	0.038	<0.005	1.6	4.9	85	5.8	4.9
	3-6	0.032	0.007	1.9	6.7	140	6.3	5.9

n.a. Not analysed.

At Frøy the barium values range from 333 ± 40 mg/kg to 1951 ± 925 mg/kg dry sediment, cadmium from 0.015 ± 0.002 mg/kg to 0.035 ± 0.017 mg/kg, copper from 1.2 ± 0.1 mg/kg to 2.4 ± 0.4 mg/kg, lead from 4.1 ± 0.2 mg/kg to 5.9 ± 0.6 mg/kg, zinc from 3.5 ± 0.9 mg/kg to 6.5 ± 0.7 mg/kg and chromium from 4.4 ± 0.4 to 6.2 ± 0.4 mg/kg. The highest barium concentrations are found in sediments at the stations situated 250 m from the field centre, ranging from 1426 mg/kg to 1961 mg/kg. A barium gradient seems to exist along all transects between 250 and 500 m from the installation, with concentrations ranging from 333 mg/kg to 450 mg/kg in sediments at the stations situated 500 m from the installation. In addition to barium, copper contamination is found at all 250 m stations except at FRY05, which is situated in the 330° direction. Mercury levels are measured in sediments from stations FRY02 and FRY04. Levels are low, 0.005 mg/kg in the 0-1 cm layers, increasing to 0.008 mg/kg in the 1-3 cm layer at FRY04.

Vertical core samples at FRY02 and FRY 04 reveal the highest barium levels in the 1-3 cm layers, with concentrations of 950 mg/kg and 3325 mg/kg dry sediment. Lower barium concentrations are found in the 0-1 cm and 3-6 cm layers. At both stations all layers are contaminated by lead, at FRY04 also by copper. The 1-3 and 3-6 cm layers at stations FRY02 and FRY04 are also contaminated by cadmium.

In general, sediments from all field stations in the Frøy field are contaminated with barium. Contamination with copper is found in sediment 250 m from the field centre in directions 150°, 240°

and 60°. No contamination by the other selected metals is found. Vertical sediment samples reveal higher barium concentrations in 1-3 cm layers than in 0-1 and 3-6 cm layers.

<u>Comparison with previous survey(s)</u>

THC concentrations for 1997 are previously reported as the sum of mineral oil and olefins (Mannvik *et al.*, 1998.) The THC values for 1997 presented in the histogram in Figure 9-3 are the recalculated THC values found by substraction of olefin-concentrations (adjusted for response factor) from the THC values reported in 1997. This year's THC content in sediments at the reference station was comparable with concentrations found in 1997, both years being somewhat higher than background levels from 1992 (Figure 9-3). NPD's and 3-6 ring aromatics concentrations are also similar to 1997 values, while the concentration of decalins is about half of what was found in 1997. No changes in levels of barium, copper, zinc and mercury are found, while sediments reveal minor increases in levels of lead (Figure 9-5, Figure 9-6). Relatively high concentrations of cadmium, 0.035 ± 0.17 mg/kg, are found at the reference station. Here, one of the replicates has a concentration of 0.061 mg/kg. This explains the rather high average sediment concentration of cadmium at this station. However, high cadmium levels are found in all sediment layers down to 6 cm in vertical core samples, with the highest concentration measured in the top layer.

Hydrocarbon levels are lower in sediments at Frøy in 2000 than they were in 1997 (Figure 9-3 and Figure 9-4). The field history reveals acute spills of 1.9 tons oil since 1997. However, both THC and olefin levels have fallen at virtually all field stations. One of the five stations that revealed sediment THC values over LSC in 1997, situated 250 m in the 150° direction relative to the platform, also have values above LSC in 2000. Results from vertical core samples support these findings, with increasing hydrocarbon concentrations with depth. Metal concentrations do not reveal the same declining tendency from 1997 to 2000 as do the hydrocarbons (Figure 9-5 and Figure 9-6). Increased barium concentrations are found in sediments at Frøy. At the station situated 250 m in the 150°direction the barium concentration has increased from 1048 mg/kg dry sediment to 1951 mg/kg. The highest barium concentrations were nevertheless found in the1-3 cm layers in vertical core samples and not in the top layer. Cadmium and lead also reveal slight increases. Copper and zinc concentrations seem to be similar to the concentrations found in the 1997 survey. Copper levels just above LSC are found in sediments at three stations in 2000. Chromium was not measured in 1997. Sediment levels of mercury are relatively unchanged. The field history gives no explanation of the increase in barium levels in the field. The tendency of increased barium concentrations in sediments is also found in the neighbour field Heimdal. Field history does not reveal discharges in this field either. The discrepancies of the results in 2000 and 1997 are too large to be explained only by laboratory errors, especially considering that the same laboratory performed the analyses on both occasions. The proportion of pelite in sediments at Frøy has increased from 6.5 % to 9.3 % at the reference station with a concomitant increase at the field stations.

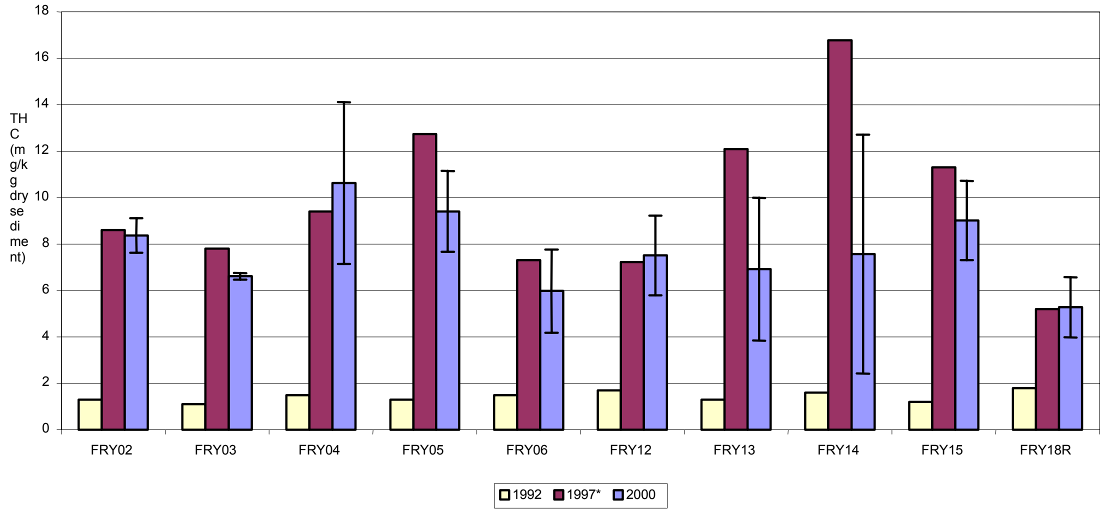

Figure 9-3: THC levels in sediment from the present (2000) and previous surveys, Frøy field.

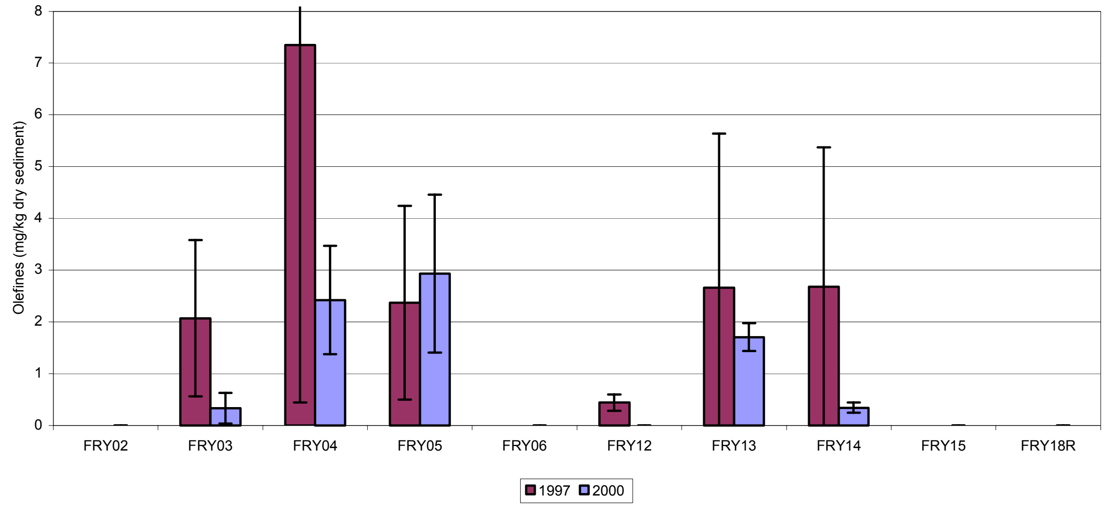

Figure 9-4: Synthetic base oil levels in sediments from the present (2000) and previous surveys, Frøy field.

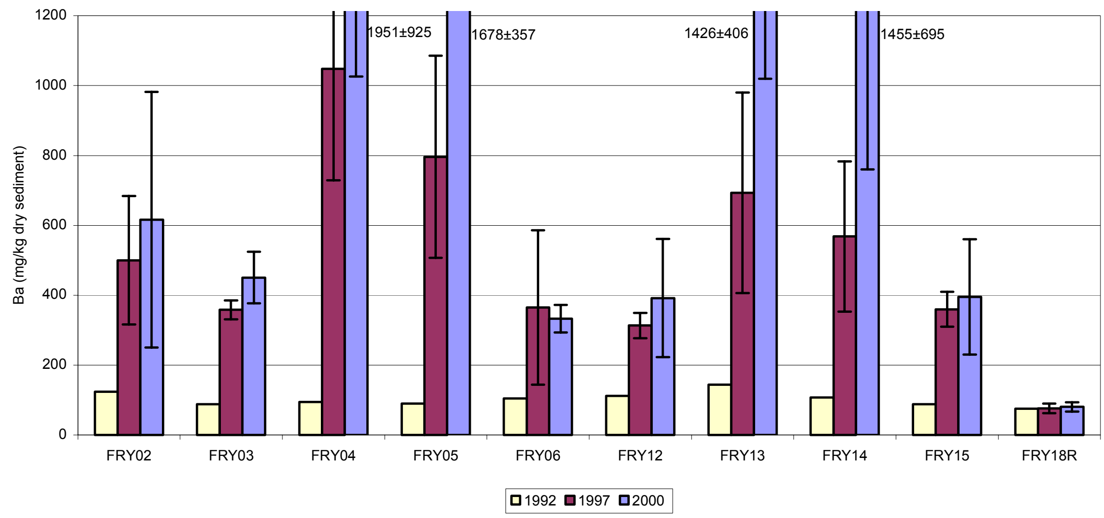

Figure 9-5: Barium levels in sediment from the present (2000) and previous survey, Frøy field.

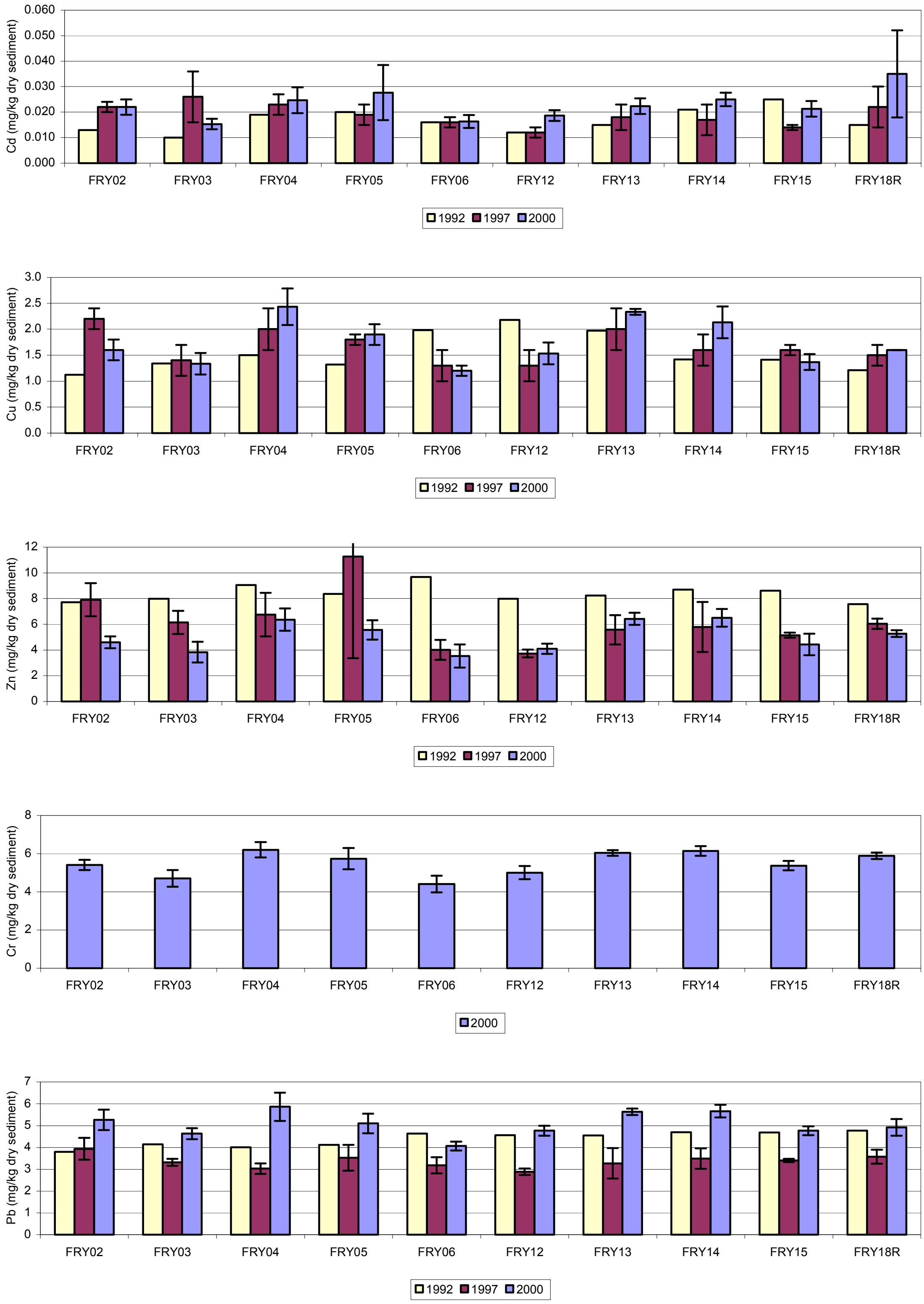

Figure 9-6: Levels of selected metals in sediments from the present (2000) and previous surveys, Frøy field.

9.2.3 Biology

The distribution of individuals and taxa within the main taxonomic groups are given in Table 9-8. A total of 16874 individuals within 264 taxa were registered at the Frøy field in the present survey (excluding juveniles). The polychaetes dominate the fauna with 66 % of the individuals and 53 % of the taxa recorded.

Table 9-8: Distribution of individuals and taxa within the main taxonomic groups at Frøy, 2000 (excluding juveniles).

Main taxonomic groups	Individuals		Taxa	
	Number	%	Number	%
Polychaeta	11109	66	141	53
Mollusca	2500	15	47	18
Crustacea	858	5	50	19
Echinodermata	829	5	12	5
Diverse groups	1578	9	14	5
Total	16874	100	264	100

The species/area curve for the field reference station is shown in Figure 9-7. A total of 176 taxa are present in the 10 grab samples of which 88 (50 %) occur in the first sample and 149 (85 %) in the five first samples. The curve indicates that not all taxa in the area are present in 10 samples, but the representativity of five samples is considered to be good.

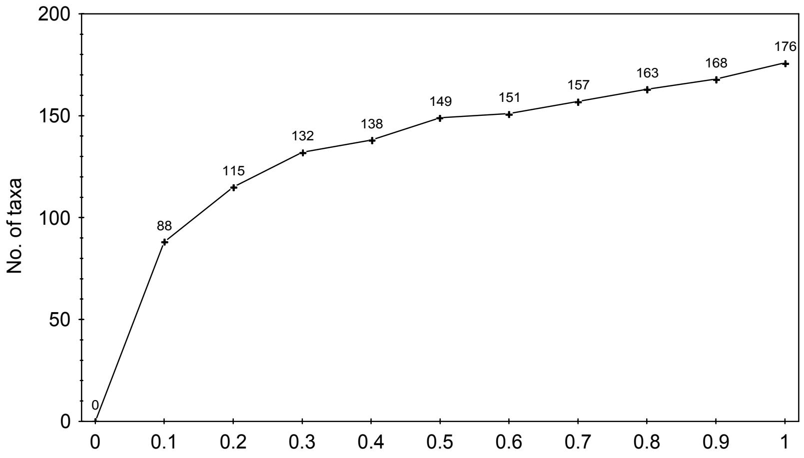

Figure 9-7: Species/area curve for the reference station at the Frøy field (area in m^2).

The number of individuals and taxa at each station, together with selected community indices, is presented in Table 9-9 while a comparison with the previous surveys is shown in Figure 9-8. The number of individuals in the present survey varies from 1195 (FRY06) to 2537 (FRY05), the number of taxa from 119 (FRY06) to 144 (FRY12), the diversity index H' from 4.6 to 5.5, the evenness index J from 0.65 to 0.79 while the ES_{100} varies from 33 to 43. The H', J and ES_{100} values are lowest at station FRY05 (250 m north west of field centre) and highest at station FRY03 (500 m south east). The corresponding values at the reference station FRY18R are within the variation at the field sta6tions with the exception of the number of taxa, which are a little, higher.

Compared with the results from the previous surveys, there is a general trend for lower values for all parameters in the present survey. At FRY04 and FRY13 the number of individuals is approximately half the value recorded in 1997.

Table 9-9: Number of individuals and taxa and selected community indices for each station (0.5 m^2) at the Frøy field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	No. of indiv	No. of taxa	H'	J	ES_{100}
FRY02	1789	126	4.8	0.69	35
FRY03	1214	127	**5.5**	**0.79**	**43**
FRY04	1526	125	5.1	0.73	37
FRY05	**2537**	138	**4.6**	**0.65**	**33**
FRY06	**1195**	**119**	5.3	0.77	40
FRY12	1850	**144**	5.1	0.72	38
FRY13	1551	130	5.2	0.74	39
FRY14	1521	141	**5.5**	0.77	42
FRY15	1402	133	**5.5**	0.78	42
FRY18R	2289	149	5.4	0.74	40
Sum *	14585				
Average *	1621	131	5.2	0.74	39
St. dev. *	409	8	0.3	0.05	3

* Excluding the reference station.

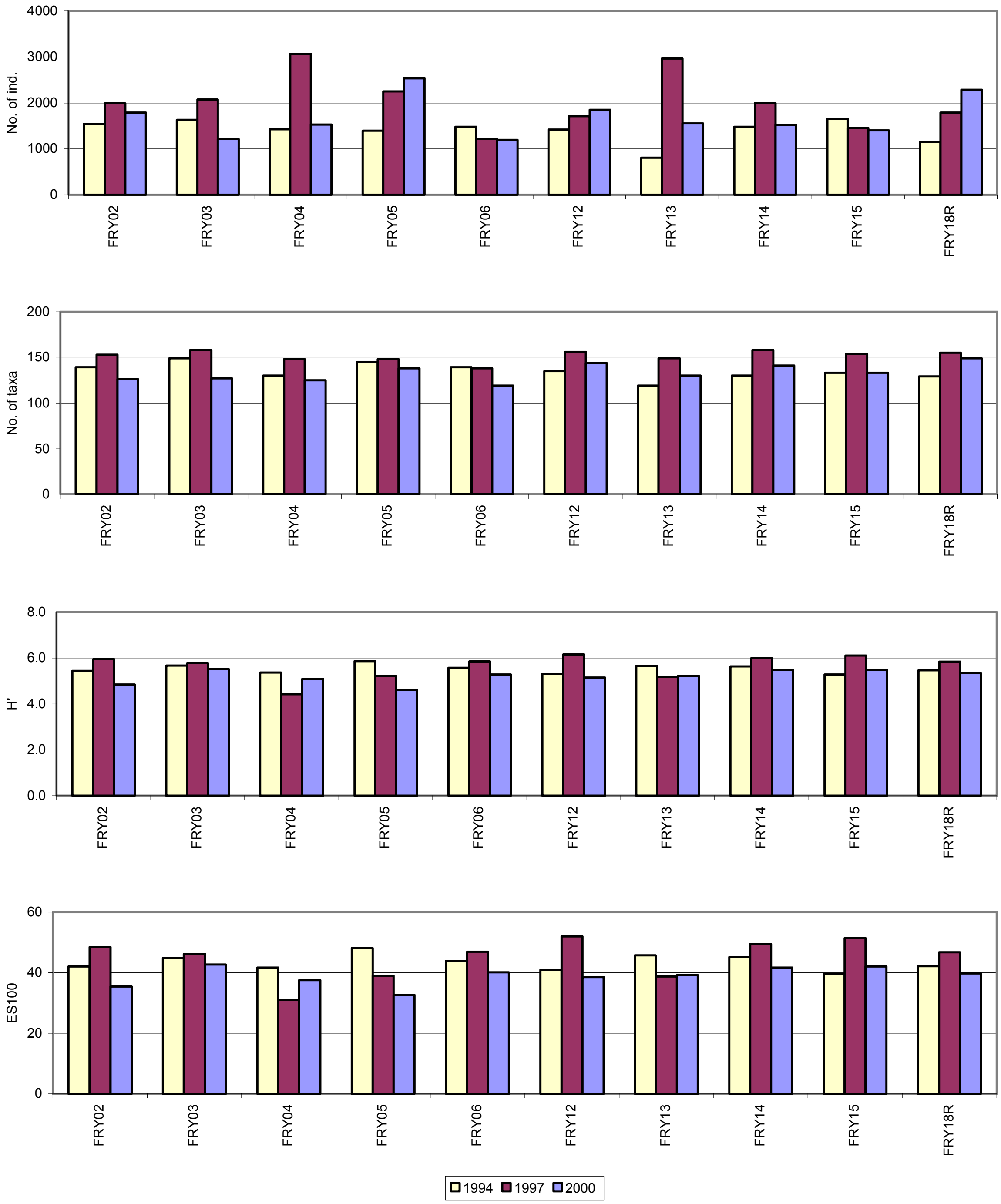

Figure 9-8: Biological characteristics at the Frøy field, 2000 and previous surveys.

The distribution of taxa in geometrical classes at each station is shown in Figure 9-9. Station FRY05 has taxa in class 10 (512-1023 individuals), station FRY02, FRY12 and FRY18R taxa in class 9 (256-511 individuals), while the rest of the stations have taxa in class 8 or lower (< 256 individuals). Occurrence of taxa in high classes might indicate faunal disturbance, but need to be examined closer.

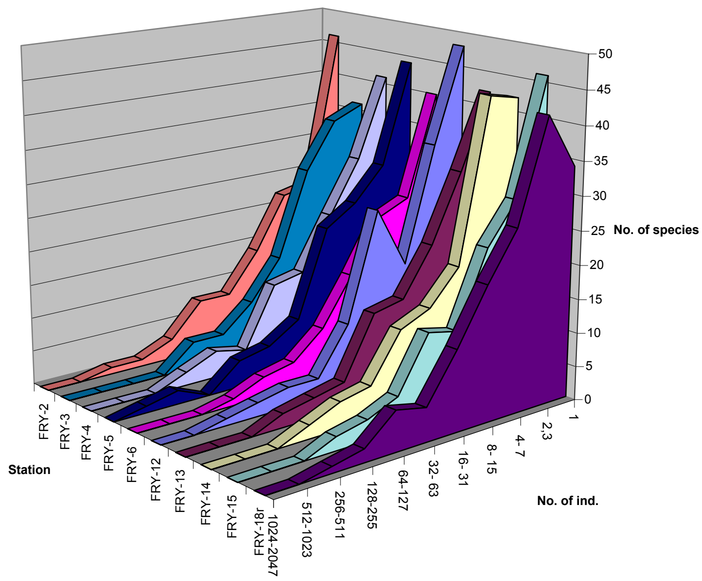

Figure 9-9: Distribution of taxa in geometrical classes from the stations at the Frøy field, 2000.

The ten most dominant taxa at each station are shown in Table 9-12 at the end of this chapter. A total of 20 taxa, inclusive three juvenile forms, are among the ten most dominant taxa at one or more stations. These 20 taxa comprise 74 % of the total number of individuals and 7 % of the total number of taxa registered at the Frøy field in the present survey.

The most dominant taxa among the adult forms are the polychaetes *Galathowenia oculata*, *Spiophanes bombyx* and *S. kroyeri*, the bivalve *Thyasira flexuosa* and the phoronid *Phoronis* sp. The polychaetes *Capitella capitata*, *Chaetozone* sp. and *Ditrupa arietina*, known indicator species for faunal disturbance, are among the ten most dominant at one station each (FRY05, FRY12 and FRY14). The brittle star *Amphiura filiformis* do not occur among the ten most dominant taxa at five of the ten stations.

The ten most abundant taxa at the stations comprise between 60 % (FRY03 and FRY04) and 74 % (FRY05) of the total number of individuals at the respective stations. The corresponding value at the reference station FRY18R is 61 %.

Figure 9-10 shows the dendrogram from the cluster analysis for the field stations and selected regional and reference stations. The analysis separates the regional and reference stations, including the field reference station FRY18R, from the field stations at 35 – 42 % dissimilarity levels. The field stations are further separated from each other at dissimilarity level from 31 % and lower, indicating a relatively uniform distribution of the fauna over the Frøy field. The correlation coefficient shows a good fit to the data for this analysis (r = 0.85).

Due to the dissimilarity between the field stations and most of the regional and reference stations in the cluster analysis, the 2-D MDS plot is presented with only field stations included (Figure 9-11). The reference station FRY18R is seen in the upper right part of the plot while station FRY05 is located in the left part. Between these two most different stations, stations FRY04, FRY12, FRY13 and FRY14 are somewhat separated from the remaining stations located in the lower right part of the plot. The stress test for the 2-D plot shows a fair fit to the data (0.24).

MDS plots including the other stations are presented in the Appendix.

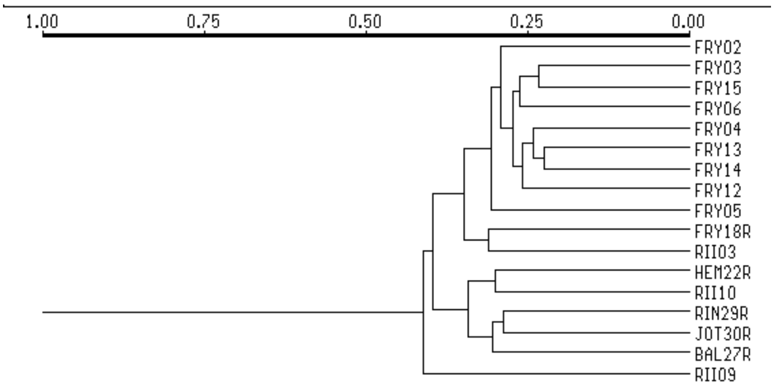

Figure 9-10: Cluster analysis of the Frøy field stations and selected regional and reference stations in Region II, 2000.

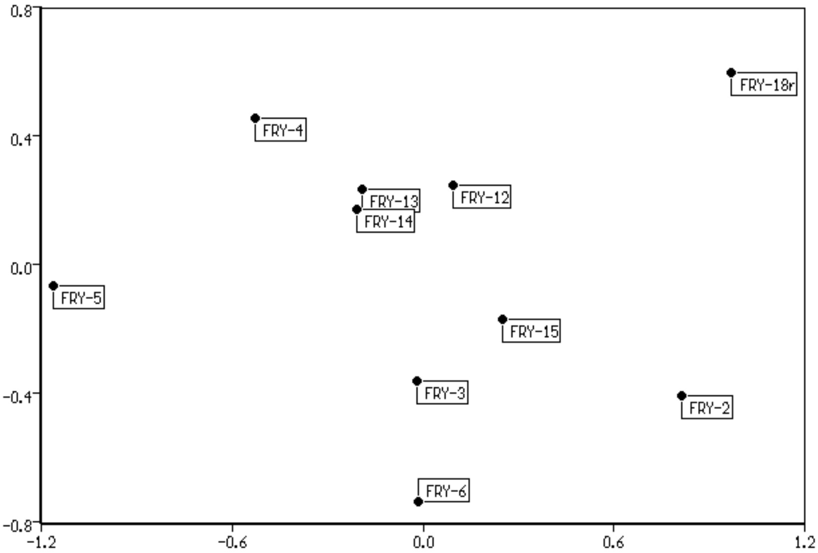

Figure 9-11: 2-D plot from the MDS analysis carried out on the Frøy field stations, 2000.

A Canonical Correspondence Analysis (CCA) of the data from the field stations and selected regional and reference stations was carried out to examine the association between the biological data and the measured environmental variables in these areas. Through the forward selection procedure in CANOCO, three of ten variables, barium, pelite and fine sand, gave the best fit and were significant. 31.7 % of the biological variance was explained by the first two axes of the ordination space which is constrained by these environmental variables.

Figure 9-12 shows a biplot from the analysis using barium (Ba), pelite (Pel) and fine sand (FS) as the constraining environmental variables together with a plot of the taxa with highest contribution on the two axes. The first axis shows a gradient from reference station JOT30R on the positive end to field station FRY05 at the negative end and is negatively correlated with the amount of barium in the sediment (- 0.80). The two other environmental parameters have low correlation with this axis. Species with highest contribution on this axis are the bivalve *Thyasira flexuosa* (13.3 %), *T. equalis* (6.4 %) and *T. croulinensis* (5.5 %), the polychaetes *Capitella capitata* (12.0 %) and *Lanice conchylega* (5.2 %) and the cumacean *Eudorella emarginata* (9.3 %).

The second axis shows a gradient from the field reference station FRY18R at the positive end to field station FRY13 at the negative end and is negatively correlated with the amount of pelite in the sediment (- 0.63). The two other environmental parameters have low correlation with this axis. Species with highest contribution on this axis are the polychaetes *Myriochele fragilis* (11.7 %), *Capitella capitata* (11.2 %), *Galathowenia oculata* (6.6 %) and *Paramphinome jeffreysii* (6.3 %) and the bivalve *Thyasira flexuosa* (10.8 %).

These results indicate faunal disturbance at least at the stations located in the lower left part of the plot with which the species *C. capitata*, *Chaetozone*. sp and *Thyasira flexuosa* are associated.

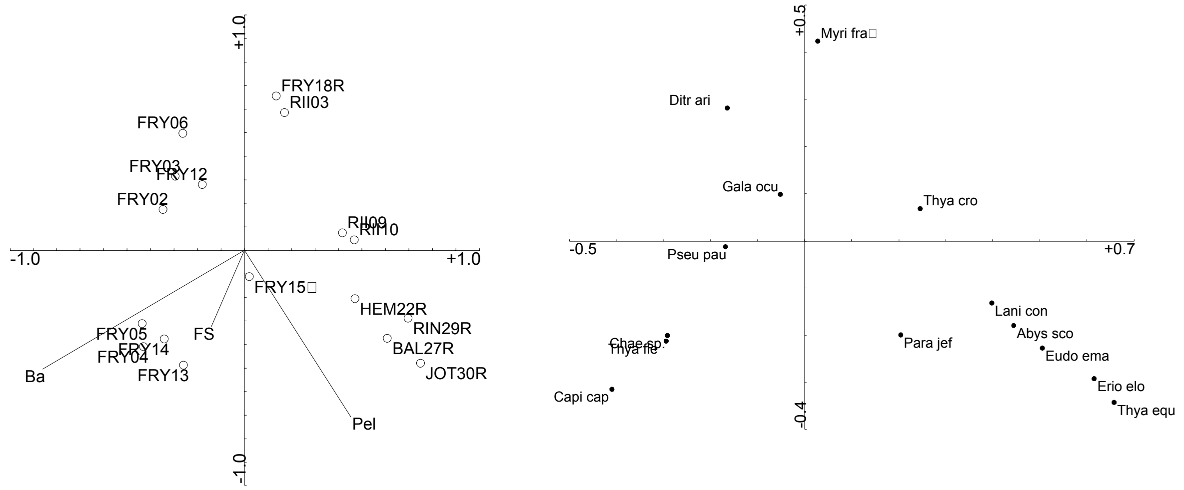

Figure 9-12: Biplot from the CCA analysis for the Frøy field stations and selected regional and reference stations in Region II, 2000 (left) and species with highest contribution on two axes (right).

A second CCA was carried out including olefins among the environmental parameters. As olefin was not measured at the regional and regional stations, only field stations and the field reference station together with the reference station at Balder, were included. Through the forward selection procedure in CANOCO, two of ten variables, olefins and lead, gave the best fit and were significant. 37.5 % of the biological variance was explained by the first two axes of the ordination space which is constrained by these environmental variables.

Figure 9-13 shows a biplot from the analysis using olefins (Ole) and lead (Pb) as the constraining environmental variables together with a plot of the taxa with highest contribution on the two axes. The first axis shows a gradient from field station FRY05 on the positive end to the Balder reference station BAL27R on the negative end and is positively correlated with the amount of olefins in the sediments (+ 0.88). The taxa with the highest contribution on this axis are the *Capitella capitata* (46.5 %) and *Spiophanes bombyx* (6.2 %) and the bivalve *Thyasira flexuosa* (11.6 %). *C. capitata* and *T. flexuosa*, which are known to be abundant in disturbed sediments, are associated with the stations on the positive end of the first axis. These stations (FRY04, FRY05 and FRY13) have the highest concentrations of olefins in the sediments.

The second axis shows a gradient from field station FRY06 at the positive end to the Balder reference station on the negative end and is negatively correlated with the amount of lead in the sediments (-0.84). The taxa with the highest contribution on this axis are the bivalve *Thyasira flexuosa* (6.1 %) and the polychaete *Ditrupa arietina* (5.7 %), both known to be abundant in disturbed sediments. The cumacean *Eudorella emarginata* also have high contribution (9.9 %) on this axis, but is represented with a relatively low individual number. The amount of lead in the sediments is below the LSC value at all stations and it is believed that this axis shows a gradient of variation in the sediment structure.

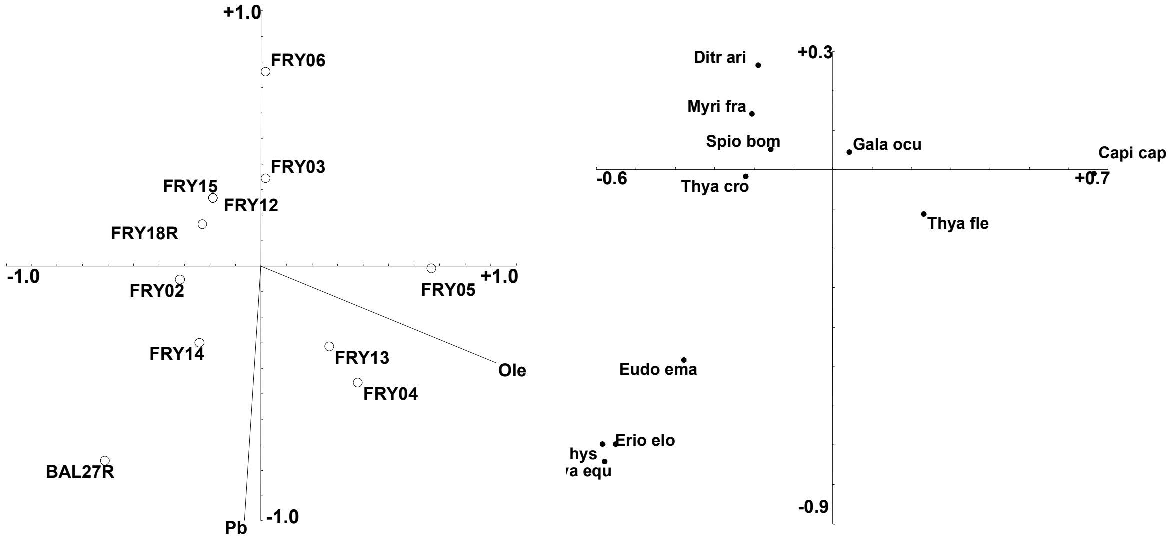

Figure 9-13: Biplot from the analysis for the Frøy field stations including olefins (left) and taxa with highest contribution on the two axes (right).

On the basis of the results from the uni- and multivariate analyses the stations at Frøy field are classified into three stations groups. Station FRY05 is placed in group C (disturbed fauna), stations FRY04, FRY12, FRY13 and FRY14 are placed in group B (slightly disturbed fauna) while the rest of the stations are placed in group A (undisturbed fauna). The stations in group B and C are separated from the other field stations in the multivariate analyses, and they have relatively high abundance of the polychaetes *Capitella capitata*, *Chaetozone* sp. and *Ditrupa arietina* and the bivalve *Thyasira flexuosa* in some combinations. The CCA show correlation between the faunal distribution and the amount of barium and olefins in the sediments. However, the olefin and THC levels are low at the stations, while the amount of barium is relatively high. The stations in group B and C are situated at 250 m distance on all transects and 500 m south west of the centre.

Compared to the previous survey in 1997, the intensity of faunal disturbance has decreased while the area is more or less similar.

Table 9-10: Classification in impact groups, distance to installation and biological statistics for the field stations at Frøy field, 2000.

Station.	Impact group	Dist. (m)	Statistics			No of individuals								
			No. ind	No. taxa	H'	Goc	Sbo	Skr	Afi	Tfl	Cca	Ppa	Csp	Dar
FRY02	A	1000	1789	126	4.8	157	456	110	76	57	0	18	12	0
FRY03	A	500	1214	127	5.5	115	119	50	50	68	0	25	6	0
FRY04	B	250	1526	125	5.1	224	31	91	42	250	0	69	44	0
FRY05	C	250	2537	138	4.6	421	81	62	47	304	582	101	38	0
FRY06	A	500	1195	119	5.3	197	103	50	77	57	0	25	10	0
FRY12	B	500	1850	144	5.1	365	140	61	64	63	0	17	14	203
FRY13	B	250	1551	130	5.2	232	38	90	41	214	0	75	29	0
FRY14	B	250	1521	141	5.5	184	66	74	51	137	2	54	72	0
FRY15	A	500	1402	133	5.5	177	147	83	67	37	0	25	6	0
FRY18R	A	10000	2289	149	5.4	400	111	79	60	19	0	106	11	3
RII03	A	-	1523	127	4.7	520	54	50	25	2	1	35	1	2
RII09	A	-	1221	118	5.2	176	103	25	115	40	0	2	7	0
RII10	A	-	1200	128	5.4	142	106	33	33	3	0	6	1	0
RIN29R	A	-	824	104	5.0	49	151	29	5	1	1	2	0	1
BAL27R	A	-	1073	118	5.4	59	94	23	16	6	0	6	0	0
JOT30R	A	-	1219	116	5.2	55	191	39	6	0	11	1	0	0
HEM22R	A	-	1032	119	5.6	61	46	32	41	15	0	14	0	1

Goc = *Galathowenia oculata*, Sbo = *Spiophanes bombyx*, Skr =*S. kroyeri*, Afi = *Amphira filiformis*, Tfl = *Thyasira flexuosa*, Cca = *Capitella capitata*, Ppa = *Pseudopolydora paucibranchiata*, Csp = *Chaetozone* sp. (incl. *C. setosa*), Dar = *Ditrupa arietina*.

9.3 Summary and conclusions

The sediments at the field are classified as silt and fine sand with a relatively high amount of pelite (6.0 – 12.5 %) in the sediment. The pelite content has increased at most of the stations since 1997 while the TOM has increased at two station 250 m south east and south west of the centre.

Hydrocarbon levels are lower in sediments at Frøy in 2000 than 1997. The field history includes acute spills of 1.9 ton oil since 1997. However, both total hydrocarbon and olefin levels have fallen at virtually all field stations. Sediments from the station situated 250 m in the 150° direction relative to the field centre contain hydrocarbons just above limit of significant contamination in 2000. In 1997 sediments out to 500 m on the 60°-axis and 250 m in the other directions were contaminated by hydrocarbons. Vertical core samples support these findings with increasing hydrocarbon concentrations with depth.

Metal concentrations do not reveal the same declining tendency from 1997 to 2000 as do the hydrocarbons. Increased barium concentrations are found in sediments at Frøy. At the station situated 250 m in the 150°direction the barium concentration has increased from 1048 mg/kg dry sediment to 1951 mg/kg. The highest barium concentrations were nevertheless found in the 1-3 cm layers and not in the top layer of vertical core samples. Cadmium and lead also reveal slight increases. Copper and zinc seem to at level with the 1997 survey. In 2000 copper levels just above the limit of significant contamination in sediments at three stations are found. Chromium was not measured in 1997. Sediment levels of mercury are relatively unchanged.

The field history gives no explanation for the increase in barium levels at the field. The tendency of increased barium concentrations in sediments, with no supporting field history, is also found in the adjacent fields Frigg and Heimdal. The discrepancies of the results between 2000 and 1997 are too large to be explained only by laboratory errors, especially considering that the same laboratory performed the analyses on both occasions. The proportion of pelite in sediments at Frøy has increased by about 3% at the reference station, with a concomitant increase at the field stations. However, at the reference station minor increases in zinc and lead levels are found, with the other selected metals being unchanged.

The number of individuals has its largest decrease at station FRY04 and FRY13, while the number of taxa has a slight decrease at all stations. On the basis of the results from the uni- and multivariate analyses the stations at Frøy field are classified into three stations groups. Station FRY05 is placed in group C (disturbed fauna), stations FRY04, FRY12, FRY13 and FRY14 are placed in group B (slightly disturbed fauna) while the rest of the stations are placed in group A (undisturbed fauna). The stations in group B and C are separated from the other field stations in the multivariate analyses, and they have relatively high abundance of the polychaetes *Capitella capitata*, *Chaetozone* sp. and *Ditrupa arietina* and the bivalve *Thyasira flexuosa* in some combinations. These taxa are known to increase in abundance in disturbed sediments.

The CCA show correlation between the faunal distribution and the amount of barium and olefins in the sediments. However, the olefin and THC levels are low at the stations, while the amount of barium is relatively high. The stations in group B and C are situated at 250 m distance on all transects and 500 m south west of the centre.

Compared to the previous survey in 1997, the intensity of faunal disturbance has decreased while the area is more or less similar.

The calculated minimum area and spatial extent of contaminated sediments and disturbed fauna at the Frøy field is shown in Table 9-11 and Figure 9-14.

Table 9-11: Distance along the transects and calculated minimum area of contaminated sediments and disturbed fauna at the Frøy field, 2000 and previous survey.

Frøy	NE	SE	SW	NW	Km^2 (2000)	Km^2 (1997)
Group B	250	250	500	250	0.29	0.29
Group C	125	125	125	250	0.07	0.10
THC	125	250	125	125	0.07	0.29
Olefiner	250	500	250	250	0.29	0.44
Ba	500	1000	500	500	1.18	1.18
Other metals	250	250	250	125	0.15	0.00

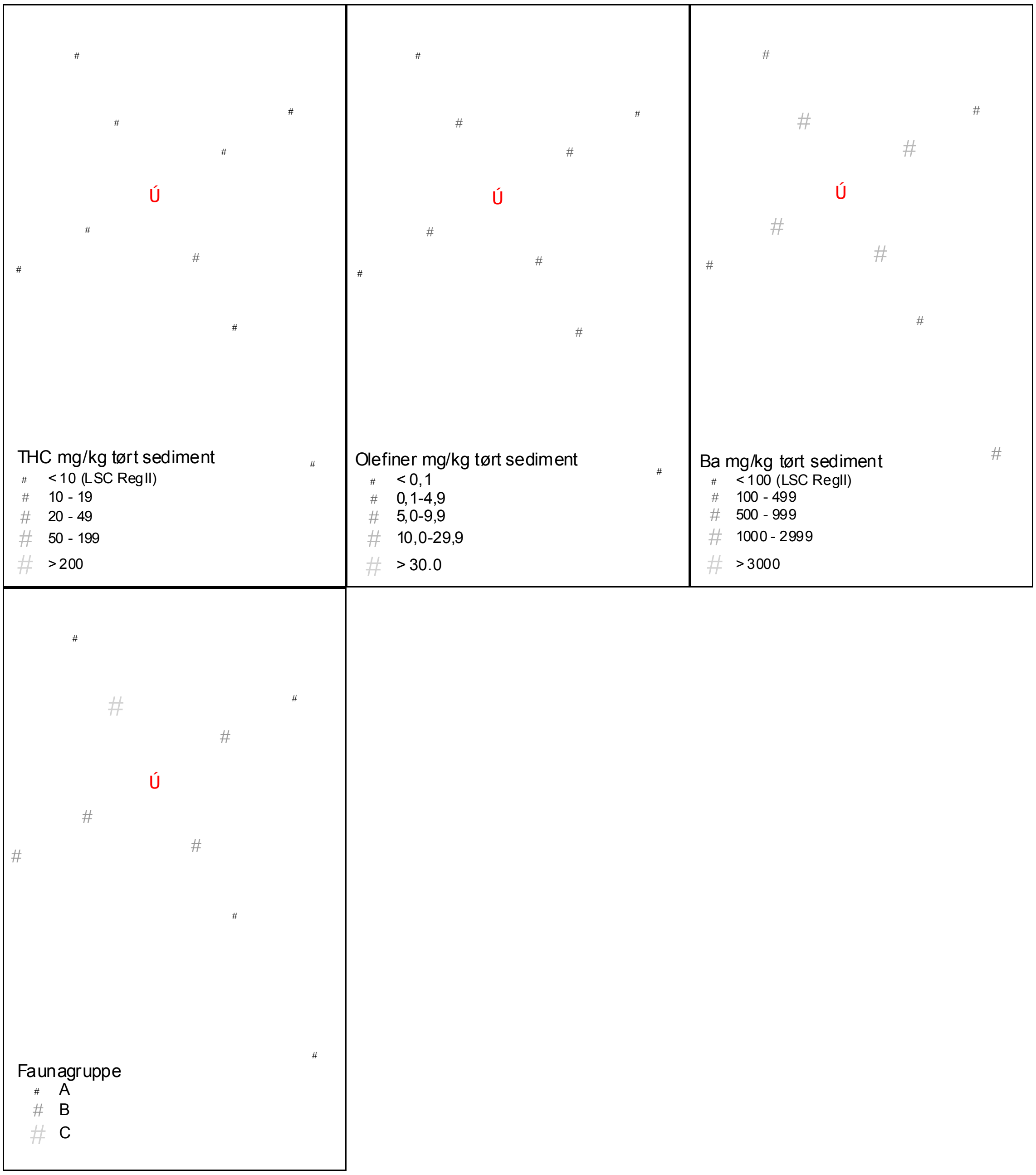

Figure 9-14: Distribution of disturbed fauna and the amounts of THC and barium in the sediments at the Frøy field, 2000.

Table 9-12: Number of individuals and the accumulative abundance for the ten predominant taxa at each station at the Frøy field, 2000.

FRY02 (150°/1000 m)	No. ind.	Acc. %	FRY03 (150°/500 m)	No. ind.	Acc. %	FRY04 (150°/250 m)	No. ind.	Acc. %	FRY05 (330°/250 m)	No. ind.	Acc. %	FRY06 (330°/500 m)	No. ind.	Acc. %
Spiophanes bombyx	456	19	Pectinaria sp. juv.	185	12	Thyasira flexuosa	250	14	Pectinaria sp. juv.	660	18	Pectinaria sp. juv.	345	19
Pectinaria sp. juv.	365	33	Spiophanes bombyx	119	20	Galathowenia oculata	224	26	Capitella capitata	582	35	Owenia fusiformis juv.	236	31
Owenia fusiformis juv.	222	42	Galathowenia oculata	115	27	Pectinaria sp. juv.	189	36	Galathowenia oculata	421	46	Galathowenia oculata	197	42
Galathowenia oculata	157	49	Phoronis sp.	112	34	Spiophanes kroyeri	91	41	Thyasira flexuosa	304	55	Spiophanes bombyx	103	48
Phoronis sp.	123	54	Thyasira flexuosa	68	39	Phoronis sp.	73	45	Owenia fusiformis juv.	297	63	Phoronis sp.	83	52
Spiophanes kroyeri	110	58	Owenia fusiformis juv.	65	43	Pseudopolydora paucibranchiata	69	49	Pseudopolydora	101	66	Amphiura filiformis	77	56
Ophiuroidea indet. juv.	79	61	Ophiuroidea indet. juv.	60	47	Paramphinome jeffreysii	66	52	Spiophanes bombyx	81	68	Ophiuroidea indet. juv.	57	59
Amphiura filiformis	76	65	Paramphinome jeffreysii	51	50	Ophiuroidea indet. juv.	52	55	Phoronis sp.	77	70	Thyasira flexuosa	57	62
Thyasira flexuosa	57	67	Amphiura filiformis	50	53	Mugga wahrbergi	51	58	Ophiuroidea indet. juv.	73	72	Spiophanes kroyeri	50	65
Timoclea ovata	50	69	Mugga wahrbergi	50	56	Owenia fusiformis juv.	45	60	Paramphinome jeffreysii	71	74	Mugga wahrbergi	40	67
			Spiophanes kroyeri	50	60									
FRY12 (240°/500 m)	No. ind.	Acc. %	FRY13 (240°/250 m)	No. ind.	Acc. %	FRY14 (60°/250 m)	No. ind.	Acc. %	FRY15 (60°/500 m)	No. ind.	Acc. %	FRY18R (60°/10000 m)	No. ind.	Acc. %
Galathowenia oculata	365	15	Pectinaria sp. juv.	257	13	Pectinaria sp. juv.	589	26	Pectinaria sp. juv.	311	16	Galathowenia oculata	400	13
Owenia fusiformis juv.	337	28	Galathowenia oculata	232	24	Galathowenia oculata	184	34	Galathowenia oculata	177	25	Owenia fusiformis juv.	315	24
Pectinaria sp. juv.	221	37	Thyasira flexuosa	214	35	Thyasira flexuosa	137	40	Spiophanes bombyx	147	33	Pectinaria sp. juv.	291	34
Ditrupa arietina	203	45	Phoronis sp.	100	40	Phoronis sp.	121	46	Owenia fusiformis juv.	128	40	Mugga wahrbergi	144	39
Spiophanes bombyx	140	51	Owenia fusiformis juv.	94	45	Spiophanes kroyeri	74	49	Phoronis sp.	85	44	Myriochele fragilis	141	43
Mugga wahrbergi	91	54	Spiophanes kroyeri	90	49	Chaetozone sp.	72	52	Spiophanes kroyeri	83	49	Spiophanes bombyx	111	47
Phoronis sp.	86	58	Ophiuroidea indet. juv.	83	54	Owenia fusiformis juv.	68	55	Amphiura filiformis	67	52	Laonice sarsi	110	51
Ophiuroidea indet. juv.	82	61	Pseudopolydora	75	57	Spiophanes bombyx	66	58	Ophiuroidea indet. juv.	66	55	Pseudopolydora	106	54
Amphiura filiformis	64	63	Mugga wahrbergi	51	60	Ophiuroidea indet. juv.	65	61	Mugga wahrbergi	44	58	Thyasira croulinensis	101	58
Thyasira flexuosa	63	66	Paramphinome jeffreysii	47	62	Pseudopolydora paucibranchiata	54	63	Thyasira flexuosa	37	60	Phoronis sp.	90	61
									Urothoe elegans	37	62			

Table 9-13: Station information for Frøy field, 2000.

St. no.	Distance (m)	Direction (degr.)	Volume (litres)
FRY02	1000	150	30
FRY03	500	150	30
FRY04	250	150	41
FRY05	250	330	38
FRY06	500	330	27
FRY12	500	240	27
FRY13	250	240	35
FRY14	250	60	35
FRY15	500	60	30
FRY18R	10000	60	29 *

* The additional five grab samples gave 30 litres of sediment.

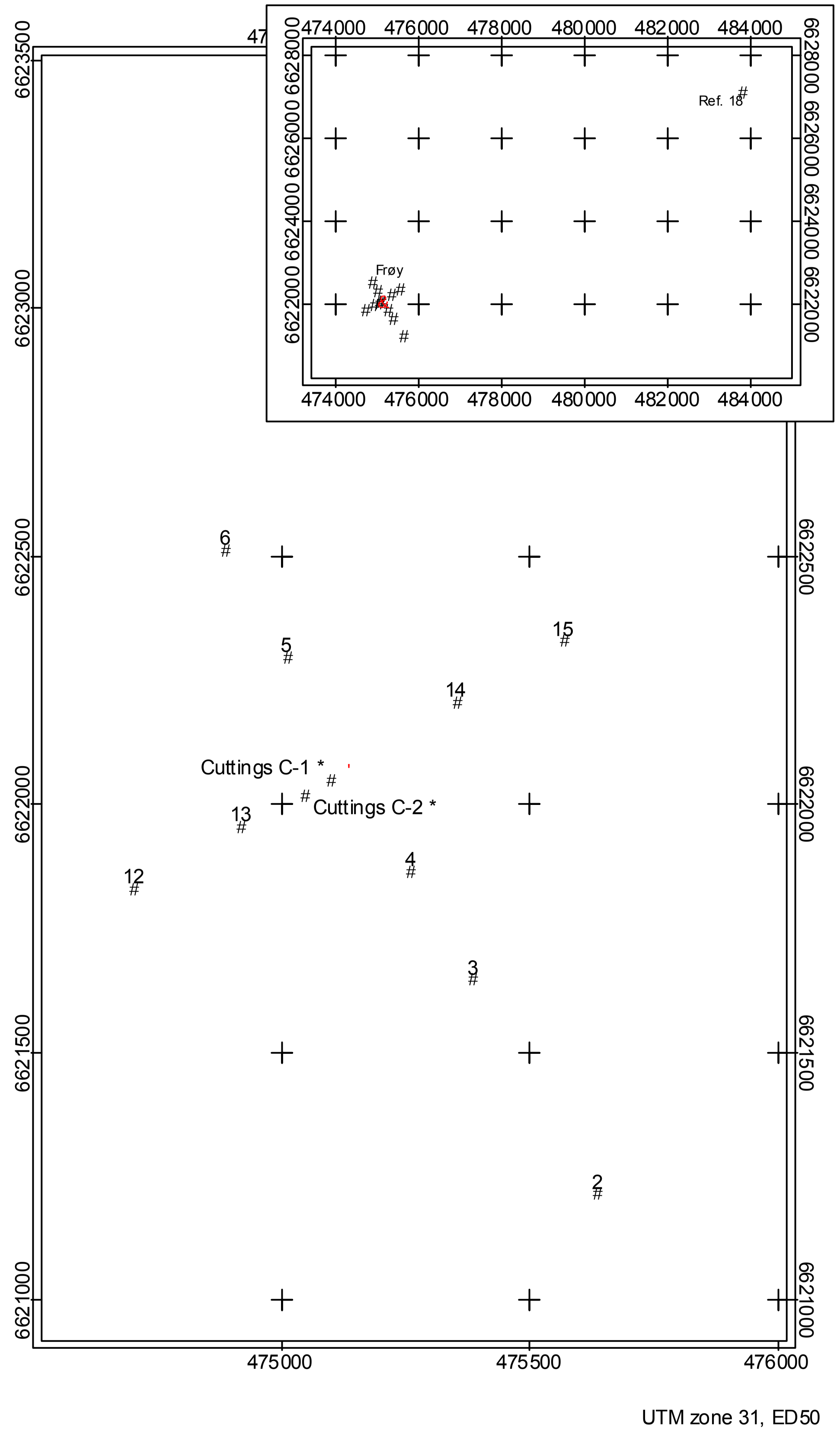

Figure 9-15: Map of sampling positions for Frøy field, 2000.

10 Ringhorne field

10.1 Introduction

The baseline survey at Ringhorne field includes two separate locations, which constitutes a well head platform and one sub-sea installation. Ringhorne is located in Block 25-10 in the middle of Region II, situated west and north east of the Balder field. The production at the field has not started yet, but a PDQ-device (Processing/Drilling/Living-Quarters) will most likely be used. Based on information from Exxon, it is most likely that the production will be transported in flowlines to Balder for processing and storage before shipping.

One well was drilled in 1997 and two wells were drilled in 1999. The sampling plan in 2000 included a separate reference station for the Ringhorne field. Data on recent drilling and discharges are given in Table 10-1.

There has only been discharged water based drilling muds in drilling the three wells at this field. Information on the sampling stations is shown in Figure 10-12 and Table 10-12, both on the foldout page at the end of this chapter (page 10-25).

Table 10-1: Summary of recent operational and accidental discharges at the Ringhorne field (all discharges in tonnes).

	1997	1998	1999	2000	Comments
No of wells drilled	1	0	2	0	
Barite	216	0	61	0	
Cuttings	250	0	340	0	Only cuttings from water based drilling mud
Water-based drilling mud	800	0	767	0	
Cementing and other chemicals	13	0	18.9	0	

10.2 Results and discussion

10.2.1 Physical characteristics

The median phi value and the amount (%) of pelite, fine sand and total organic matter (TOM) in the sediment from the present and previous surveys are shown in Table 10-2 and Figure 10-1. 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 in the Ringhorne field area are classified as fine sand with median values varying from 4.23 at station RIN25 to 3.63 at station RIN06 and RIN13. The amount of pelite in the sediment varies from 14% (RIN06) to 9.7% (RIN18), the fine sand from 88.9 % (RIN18) to 85.5 % (RIN16) and the TOM from 2.6 % (RIN32) to 1.63 % (RIN04). The average for all these parameters were lower at the field stations than at the reference station RIN29R, with the exception of fine sand, where the average of the field stations were higher than the reference station, both with values above 85 %.

The sediment characteristics are similar to those recorded at the neighbouring Balder field.

Table 10-2: The median (phi) and amount of pelite, fine sand and TOM in the sediment from stations at the Ringhorne field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	Distance (m)	Direction (degr.)	Median	Classification	Pelite	Fine sand	TOM
RIN01	2000	45	3.78	Fine sand	12.18	87.4	1.96
RIN02	1000	45	3.67	Fine sand	11.17	88.3	1.90
RIN03	500	45	3.68	Fine sand	12.03	87.6	1.89
RIN04	250	45	3.68	Fine sand	10.83	88.8	**1.63**
RIN05	250	135	3.69	Fine sand	13.30	86.1	2.05
RIN06	500	135	3.71	Fine sand	12.72	86.6	2.23
RIN07	1000	135	**3.63**	Fine sand	12.19	86.5	2.33
RIN08	2000	135	3.73	Fine sand	10.89	85.9	1.65
RIN09	2000	225	3.64	Fine sand	12.14	87.5	1.91
RIN10	1000	225	3.64	Fine sand	11.21	88.0	1.73
RIN11	500	225	3.65	Fine sand	11.54	88.0	2.25
RIN12	250	225	3.73	Fine sand	12.38	87.1	2.22
RIN13	250	315	**3.63**	Fine sand	11.37	88.2	1.79
RIN14	500	315	3.66	Fine sand	11.26	88.3	2.19
RIN15	1000	315	3.64	Fine sand	12.14	87.5	1.95
RIN16	2000	315	3.81	Fine sand	**13.95**	**85.5**	2.26
RIN17	2000	225	3.67	Fine sand	10.01	88.5	1.77
RIN18	1000	225	3.70	Fine sand	**9.74**	**88.9**	1.95
RIN19	500	225	3.70	Fine sand	11.57	87.3	1.85
RIN20	250	225	3.73	Fine sand	11.34	87.1	2.19
RIN21	250	315	3.81	Fine sand	13.23	86.1	2.19
RIN22	500	315	3.97	Fine sand	12.11	87.0	2.00
RIN23	1000	315	3.89	Fine sand	11.29	88.1	1.89
RIN24	2000	315	3.76	Fine sand	11.54	87.8	1.96
RIN25	250	135	**4.30**	Silt	11.93	87.4	2.15
RIN26	500	135	3.83	Fine sand	13.02	85.9	2.00
RIN27	1000	135	4.28	Silt	12.14	87.1	2.16
RIN28	2000	135	3.77	Fine sand	12.27	87.3	2.32
RIN30	250	45	3.73	Fine sand	12.56	86.8	2.13
RIN31	500	45	3.69	Fine sand	11.95	87.3	2.07
RIN32	1000	45	3.75	Fine sand	11.99	87.2	**2.60**
RIN33	2000	45	3.83	Fine sand	13.09	86.4	2.48
RIN29R	5000	315	4.06	Silt	14.00	85.4	2.35
Average*			3.76		11.91	87.3	2.05
St.dev.*			0.16		0.91	0.9	0.23

* Excluding the reference station

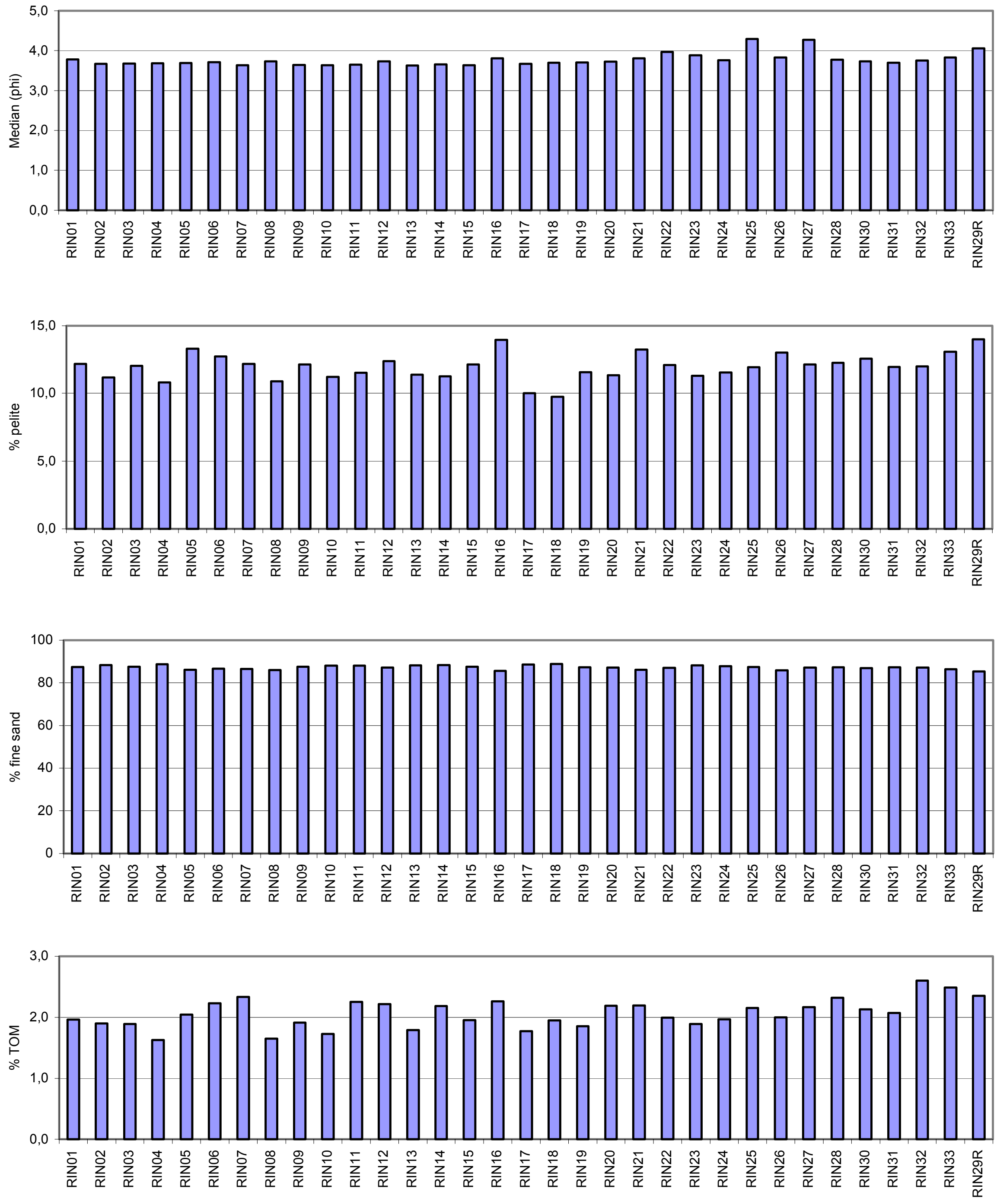

Figure 10-1: Sediment characteristics at the Ringhorne field, 2000.

10.2.2 Chemical characteristics

The calculated limits of significant contamination for selected hydrocarbons and metals in sediments from Region II ($LSC_{97\text{-}00\ RegII}$) are presented previously in the chapter that deals with the regional and reference stations. In addition to the regional limits, field-specific limits of significant contamination are calculated from reference station ($LSC_{00\ RIN29R}$). Both sets of data are presented in Table 10-3. Ringhorne has somewhat higher levels of THC and metals than most of the other fields in Region II (see Regional and reference stations chapter). The limits of significant contamination based on sediments from the reference station are therefore correspondingly higher than the limits calculated for the whole region. Based on the analysis results of the Ringhorne field, both LSC´s will hereafter be used as a basis by which to assign areas contaminated with the chemical parameters.The results of analyses of the hydrocarbons are summarised in Table 10-4. Concentrations of selected compounds in the vertical sediment sections are presented in Table 10-5. The full data set of replicate measurements is given in the Appendix. THC values from 2000 are presented as histogram in Figure 10-3.

Table 10-3: Background levels and Limits of Significant Contamination for the Ringhorne field, 2000. All values in mg/kg dry sediment.

	THC	NPD's	3-6 ring	Decalins	Cd	Hg	Cu	Zn	Ba	Cr	Pb
$LSC_{00RIN29R}$	11.0	0.075	0.281	0.163	0.038	0.009	2.6	12.0	134	10.4	8.1
$LSC_{97\text{-}00\ RegII}$	9.8	*	*	*	0.029	0.008	2.0	8.9	146	9.6	7.0

*) Regional stations not analysed for NPD's, 3-6 ring aromatics and decalins.

Table 10-4: Concentrations of hydrocarbons in sediments from the Ringhorne field, 2000. All concentrations in mg/kg dry sediment. Values above $LSC_{00\ RIN29R}$ are dark shaded and values between $LSC_{00RIN29R}$ and $LSC_{97\text{-}00\ RegII}$ are light shaded.

Station	THC		NPD's		3-6 ring		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
RIN01	7.1	1.1	n.a.		n.a.		n.a.	
RIN02	6.2	1.1	n.a.		n.a.		n.a.	
RIN03	10.0	4.1	n.a.		n.a.		n.a.	
RIN04	7.7	1.0	n.a.		n.a.		n.a.	
RIN05	6.3	2.6	0.035	0.006	0.104	0.014	0.049	0.012
RIN06	10.4	5.8	n.a.		n.a.		n.a.	
RIN07	11.0	3.2	n.a.		n.a.		n.a.	
RIN08	8.0	2.5	0.024	0.003	0.073	0.010	0.039	0.018
RIN09	7.7	1.5	n.a.		n.a.		n.a.	
RIN10	4.8	2.8	n.a.		n.a.		n.a.	
RIN11	6.4	1.5	n.a.		n.a.		n.a.	
RIN12	8.7	2.5	n.a.		n.a.		n.a.	
RIN13	8.8	1.0	n.a.		n.a.		n.a.	
RIN14	8.9	2.9	n.a.		n.a.		n.a.	
RIN15	7.8	1.4	n.a.		n.a.		n.a.	
RIN16	9.7	2.4	n.a.		n.a.		n.a.	
RIN17	10.8	0.3	n.a.		n.a.		n.a.	
RIN18	11.2	2.0	n.a.		n.a.		n.a.	
RIN19	8.2	2.7	n.a.		n.a.		n.a.	
RIN20	9.6	2.1	n.a.		n.a.		n.a.	
RIN21	11.0	2.3	n.a.		n.a.		n.a.	
RIN22	14.3	2.5	n.a.		n.a.		n.a.	
RIN23	12.2	2.5	n.a.		n.a.		n.a.	
RIN24	12.5	2.8	n.a.		n.a.		n.a.	
RIN25	11.2	2.1	0.031	0.009	0.105	0.014	0.056	0.005
RIN26	11.7	2.0	n.a.		n.a.		n.a.	
RIN27	10.9	1.4	n.a.		n.a.		n.a.	
RIN28	11.3	3.1	0.036	0.002	0.110	0.008	0.072	0.010
RIN30	10.1	1.9	n.a.		n.a.		n.a.	
RIN31	9.7	1.3	n.a.		n.a.		n.a.	
RIN32	9.3	0.3	n.a.		n.a.		n.a.	
RIN33	7.8	0.4	n.a.		n.a.		n.a.	
RIN29R	8.2	1.2	0.039	0.016	0.147	0.058	0.077	0.037
Mean*	9.4	2.8	-		-		-	

n.a. Not analysed.
* Excl. reference station.

Table 10-5: Concentrations of hydrocarbons in vertical sections of the sediment samples from the Ringhorne field, 2000. All concentrations in mg/kg dry sediment. Values above $LSC_{00\ RIN29R}$ are dark shaded and values between $LSC_{00\ RIN29R}$ and $LSC_{97\text{-}00\ RegII}$ are light shaded.

Station	Layer (cm)	THC	NPD's	3-6 ring	Decalins
RIN05	0-1	7.9	0.041	0.110	0.062
	1-3	9.7	0.046	0.131	0.090
	3-6	9.5	0.054	0.160	0.084
RIN08	0-1	9.1	0.025	0.078	0.042
	1-3	12.0	0.049	0.175	0.087
	3-6	11.7	0.048	0.180	0.080
RIN25	0-1	9.9	0.037	0.121	0.061
	1-3	14.5	0.045	0.120	0.055
	3-6	14.5	0.045	0.116	0.088
RIN28	0-1	11.0	0.036	0.105	0.060
	1-3	13.3	0.042	0.124	0.072
	3-6	12.8	0.041	0.119	0.078
RIN29R	0-1	7.3	0.026	0.091	0.063
	1-3	8.9	0.043	0.141	0.056
	3-6	13.3	0.050	0.174	0.091

n.a. Not analysed.

In the 2000 baseline survey of the Ringhorne field, the THC content at the field-specific reference station (RIN29R) is 8.2 ± 1.2 mg/kg dry sediment *i.e*. somewhat higher than the amount found across the Region II (5.9 ± 2.3 mg/kg). The THC content at RIN29R is comparable to the amounts found at the Glitne reference station (8.6 ± 1.7 mg/kg) and in the 1-3 and 3-6 cm sediment layers at the Balder reference station (see Balder survey). The amounts of NPD's, 3-6 ring aromatics and decalins are higher at the Glitne reference station (see Glitne survey), but comparable to the amounts found at the Balder reference station. The sediment concentrations (Table 10-6) of cadmium, zinc and copper are considerable higher (75-90%) at RIN29R than the corresponding values found across Region II (see Regional and reference stations). The amounts of metals in sediments from RING29 are comparable to the amounts found at the Balder reference station. In the sectioned sediment samples from RIN29R, the highest amounts of hydrocarbons are found in the 1-3 and 3-6 cm layers, while the 0-1 and 1-3 cm layers have slightly higher contents of copper, zinc, barium and chromium than the 3-6 cm layer (Table 10-7).

The THC values range from values below the background level across Region II (5.9 mg/kg) to 14.3 ± 2.5 mg/kg dry sediment. According to the calculated $LSC_{97\text{-}00\ RegII}$ elevated levels of THC are found at several stations (Table 10-4), but by using the $LSC_{00RIN29R}$ elevated levels of THC are found at the three outermost stations on the sub sea 315°-axis (RIN22, RIN23 and RIN24) and at the 500 m station on the sub sea 135°-axis (RIN26). The elevated levels of THC might be a result of contamination in the sediments, or more probably occasional higher values due to natural variations in the sediment texture. Gradients of decreasing THC content with increasing distance are not found along any of the sub sea. axes. In addition, the THC levels on the 135°-axis are comparable to the amounts found in the 3-6 cm layer at tRIN29R and in the 1-3 and 3-6 cm layers at the Glitne and Balder reference stations. Generally, the vertical distribution of hydrocarbons determined from core samples from selected stations at Ringhorne and Glitne shows that the 1-3 and 3-6 cm layers contains somewhat higher amounts of THC, aromatics and decalins than the top layer (Table 10-5). In accordance with data on recent drilling and discharges on Ringhorne, the gas chromatogram profiles of the sediment extracts (Figure 10-2) show no indications of mineral oil or olefin-based synthetic base oils (used at Balder).

The sediments around the sub sea installation contain slightly more THC (8-14 mg/kg) than the sediments around the well head platform (5-11 mg/kg). Naturally higher levels of THC seems to be found along the sub sea 315°-axis. Sediments from Ringhorne are regarded as uncontaminated with THC, aromatics and decalins. The average THC content across the Ringhorne field (9.4 ± 2.9 mg/kg) is comparable to the content found across the Glitne field (8.6 ± 1.7 mg/kg) and in uncontaminated sediments at the Balder field.

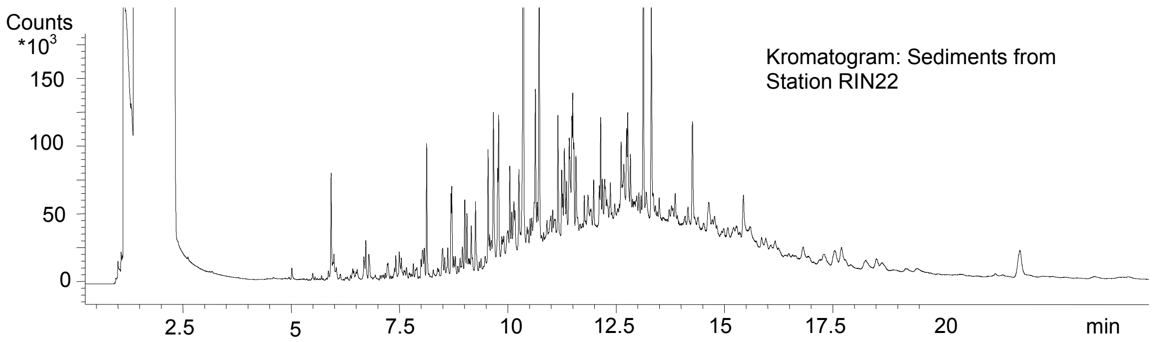

Figure 10-2: Gas chromatogram of a sediment extract from the Ringhorne field, 2000.

The results of the metal analyses for the Ringhorne field are summarised in Table 10-6. Concentrations of selected metals in the vertical sediment sections are presented in Table 10-7. The full data set of replicate measurements is given in the Appendix. Metal values from 2000 are presented as histograms in Figure 10-4 and Figure 10-5.

Table 10-6: Concentrations of selected metals in sediments from the Ringhorne field, 2000. All concentrations in mg/kg dry sediment. Values above LSC_{00}RIN29R are dark shaded and values between LSC_{00}RIN29R and LSC_{97-00} RegII are light shaded.

	Cd		Hg		Cu		Zn		Ba		Cr		Pb	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
RIN01	0.022	0.005	n.a.		1.6	0.1	7.1	0.3	71	3	6.9	0.1	6.2	0.0
RIN02	0.020	0.004	n.a.		1.6	0.1	7.0	0.4	65	1	6.9	0.2	6.5	0.4
RIN03	0.023	0.001	n.a.		1.8	0.1	7.7	0.6	93	2	7.4	0.2	6.8	0.6
RIN04	0.021	0.001	n.a.		1.8	0.2	7.0	0.7	70	14	7.0	0.4	6.4	0.3
RIN05	0.033	0.011	0.007	0.001	2.0	0.2	8.0	0.7	81	18	8.0	0.5	6.4	0.6
RIN06	0.022	0.003	n.a.		1.9	0.1	7.9	0.3	84	10	7.6	0.2	7.0	0.3
RIN07	0.024	0.003	n.a.		2.1	0.1	8.5	0.6	95	9	8.0	0.2	7.2	0.2
RIN08	0.020	0.002	0.005	0.002	2.0	0.3	7.7	1.1	79	16	7.0	0.3	6.8	0.5
RIN09	0.023	0.002	n.a.		1.7	0.1	7.2	0.7	80	14	7.4	0.3	6.2	0.2
RIN10	0.021	0.006	n.a.		1.7	0.4	7.1	1.4	71	23	7.4	0.7	5.5	0.6
RIN11	0.020	0.001	n.a.		2.3	0.7	7.9	0.7	86	9	7.7	0.4	5.9	0.4
RIN12	0.022	0.004	n.a.		2.0	0.3	7.8	1.0	81	19	7.6	0.4	5.8	0.4
RIN13	0.020	0.006	n.a.		1.6	0.2	7.0	1.4	72	18	7.0	0.6	5.8	0.9
RIN14	0.023	0.001	n.a.		2.4	0.5	8.8	0.5	89	6	8.0	0.3	6.7	0.3
RIN15	0.021	0.003	n.a.		1.9	0.4	7.3	1.0	76	7	7.4	0.5	5.5	0.2
RIN16	0.024	0.003	n.a.		2.3	0.3	8.8	0.7	92	3	8.3	0.4	6.3	0.4
RIN17	0.020	0.001	n.a.		1.9	0.1	7.1	0.1	92	3	7.2	0.0	6.1	0.1
RIN18	0.028	0.006	n.a.		1.8	0.2	7.2	0.6	81	14	7.4	0.4	5.3	0.6
RIN19	0.032	0.010	n.a.		1.9	0.2	7.9	0.9	72	32	7.8	0.5	5.3	0.7
RIN20	0.029	0.007	n.a.		2.1	0.3	8.4	1.6	114	28	8.0	0.9	6.5	0.9
RIN21	0.032	0.008	n.a.		2.4	0.4	9.9	1.5	107	47	8.6	0.8	6.6	1.5
RIN22	0.031	0.013	n.a.		2.1	0.1	8.3	0.5	100	18	7.9	0.1	6.3	0.6
RIN23	0.027	0.006	n.a.		2.0	0.0	8.6	0.2	107	7	8.3	0.1	6.3	0.5
RIN24	0.022	0.003	n.a.		1.9	0.1	7.9	0.2	96	6	7.8	0.1	5.9	0.2
RIN25	0.027	0.004	0.007	0.001	2.1	0.5	8.9	1.7	136	18	8.5	0.9	6.3	1.0
RIN26	0.024	0.001	n.a.		1.7	0.1	7.1	0.3	123	25	7.3	0.1	5.6	0.3
RIN27	0.025	0.003	n.a.		1.9	0.3	8.5	1.0	131	28	8.1	0.5	6.0	0.7
RIN28	0.028	0.005	0.007	0.000	2.1	0.1	8.7	0.5	114	19	8.4	0.4	6.3	0.4
RIN30	0.025	0.003	n.a.		2.1	0.1	9.2	1.2	116	19	8.5	0.7	6.4	0.9
RIN31	0.024	0.003	n.a.		1.8	0.2	7.5	0.9	85	14	7.5	0.6	5.7	0.6
RIN32	0.029	0.001	n.a.		2.1	0.3	9.1	1.5	122	23	8.5	0.8	6.8	0.9
RIN33	0.031	0.004	n.a.		2.3	0.1	9.8	0.2	142	9	9.1	0.1	6.9	0.1
RIN29R	0.029	0.004	0.007	0.001	2.1	0.2	9.3	1.2	86	21	8.7	0.7	6.9	0.5
Mean*	0.025	0.006			2.0	0.3	8.0	1.1	95	26	7.8	0.7	6.2	0.7

n.a. Not analysed.
* Excl. reference station.

Table 10-7: Concentrations of selected metals in vertical sections of the sediment samples from the Ringhorne field. All concentrations in mg/kg dry sediment. Values above LSC_{00}RIN29R are dark shaded and values between LSC_{00}RIN29R and $LSC_{97\text{-}00}$ RegII are light shaded.

Station	Layer (cm)	Cd	Hg	Cu	Zn	Ba	Cr	Pb
RIN05	0-1	0.045	0.006	2.0	7.8	64	8.2	5.8
	1-3	0.034	0.006	2.0	8.4	84	7.8	7.0
	3-6	0.032	0.008	2.2	9.0	94	8.2	8.0
RIN08	0-1	0.017	<0.005	2.2	8.3	89	7.0	6.8
	1-3	0.026	0.006	2.2	8.7	101	7.7	7.9
	3-6	0.031	0.007	2.0	8.6	98	7.8	8.2
RIN25	0-1	0.024	0.007	2.4	9.7	149	8.7	6.9
	1-3	0.035	0.008	2.2	9.3	180	8.7	7.1
	3-6	0.032	0.009	2.2	9.3	170	8.5	7.5
RIN28	0-1	0.024	0.007	2.0	8.2	94	8.0	5.8
	1-3	0.025	0.006	2.0	7.9	101	8.3	5.6
	3-6	0.029	0.007	1.9	7.8	99	8.2	5.8
RIN29R	0-1	0.029	0.008	2.4	10.6	110	9.8	7.4
	1-3	0.034	0.009	2.8	11.3	121	9.5	8.1
	3-6	0.036	0.007	2.2	9.6	82	9.0	7.4

n.a. Not analysed.

The concentrations of barium range from 65 ± 1 to 136 ± 18 mg/kg, cadmium from 0.020 ± 0.001 to 0.033 ± 0.011 mg/kg, copper from 1.6 ± 0.1 to 2.4 ± 9.9 mg/kg, lead from 5.3 ± 0.7 to 7.2 ±0.2 mg/kg, zinc from 7.0 ± 0.4 to 9.9 ± 1.5 mg/kg and chromium from 6.9 ± 0.1 to 9.1 ± 0.1 mg/kg dry sediment. According to the calculated $LSC_{97\text{-}00\ RegII}$ elevated levels of cadmium, copper, zinc and lead are found at several stations (Table 10-6), but by using the $LSC_{00\ RIN29R}$ none of these stations are contaminated with metals. The selected metals are uniform distributed down in the cores collected at selected stations. At RING25 elevated level of barium are found down to 6 cm.

The selected metals are very evenly distributed over the Ringhorne field. Generally, the sediments around the sub sea installation contain slightly more cadmium, zinc and barium than those collected nearby the well head. The sediments at Ringhorne are regarded as uncontaminated with metals. The amounts of metals found in sediments across Ringhorne are comparable to the concentrations found in sediments from uncontaminated stations at Balder. The Ringhorene field is located north east of the Glitne field. Generally, the sediments from the Ringhorne field contains 40-50% more cadmium and copper and only half as much barium as the sediments form the Glitne field stations.

The mercury concentrations in the replicate sediment samples from the field stations analysed for mercury, ranges from 0.005-0.008 mg/kg dry sediment. The five replicate mercury concentrations at the field-specific reference station ranges between 0.006 and 0.008 mg/kg dry sediment. At the stations investigated mercury is detected down to 6 cm depth (Table 10-7).

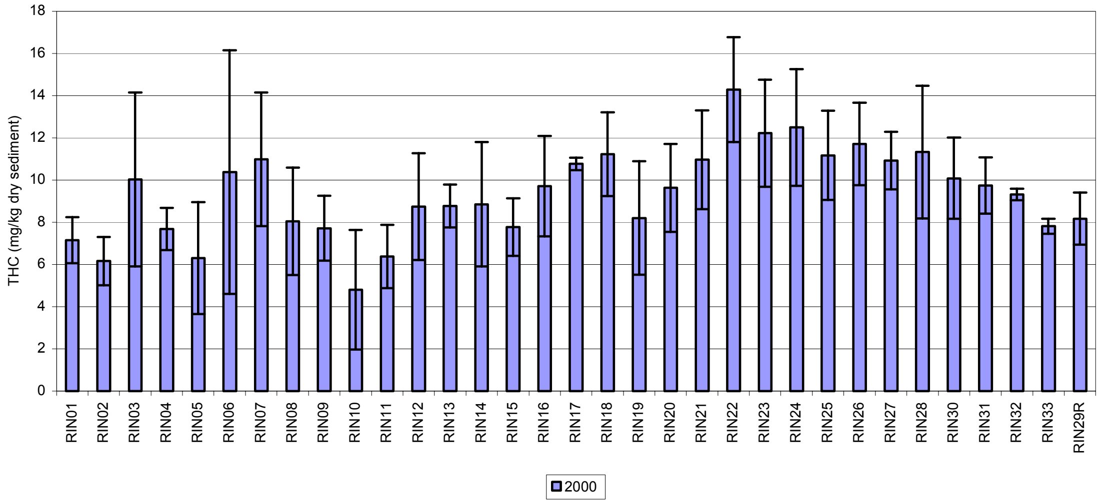

Figure 10-3: THC levels in sediment from the present (2000) survey, Ringhorne field.

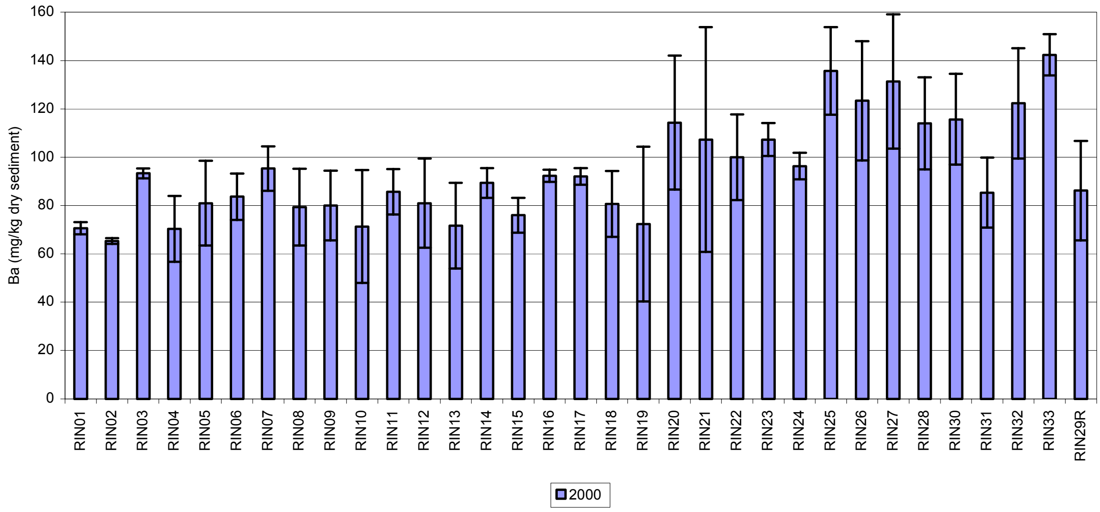

Figure 10-4: Barium levels in sediment from the present (2000), Ringhorne field.

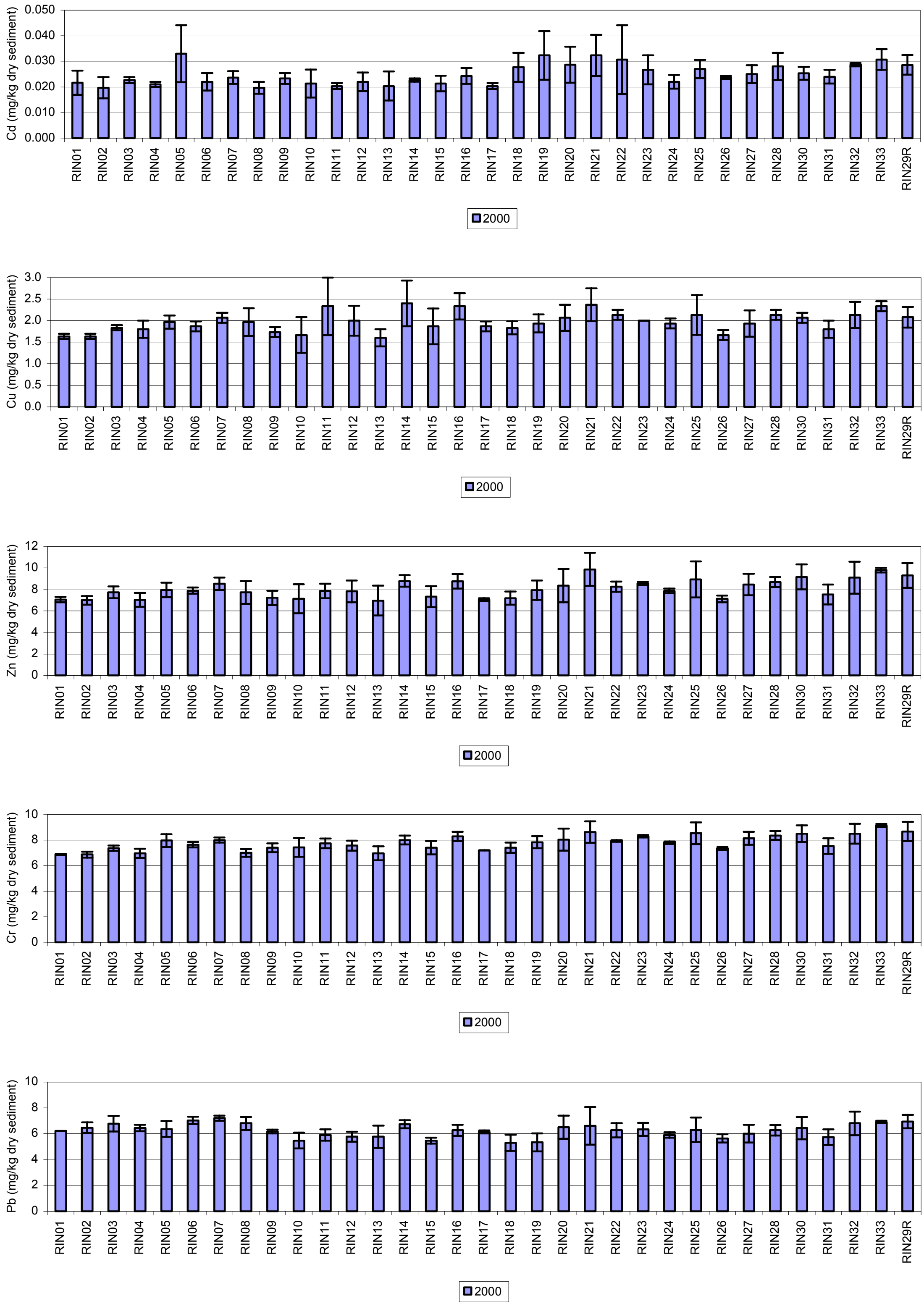

Figure 10-5: Levels of selected metals in sediments from the present (2000) survey, Ringhorne field.

10.2.3 Biology

The distribution of individuals and taxa within the main taxonomic groups are given in Table 10-8. A total of 26942 individuals within 279 taxa were registered at the Ringhorne field in the present survey (excluding juveniles). The polychaetes dominate the fauna with 60 % of the individuals and 51 % of the taxa recorded.

Table 10-8: Distribution of individuals and taxa within the main taxonomic groups at Ringhorne, 2000 (excluding juveniles).

Main taxonomic groups	Individuals		Taxa	
	Number	%	Number	%
Polychaeta	16099	60	141	51
Mollusca	4386	16	52	19
Crustacea	4382	16	58	21
Echinodermata	1434	5	10	4
Diverse groups	641	2	18	6
Total	26942	100	279	100

The species/area curve for the field reference station is shown in Figure 10-6. A total of 132 taxa are registered in the ten grab samples, of which 57 (31 %) are registered in the first sample and 104 (78 %) in the first five samples. The shape of the curve indicates that not all taxa in the area are present in the ten grab samples, but the representativity of five samples is considered to be relatively good.

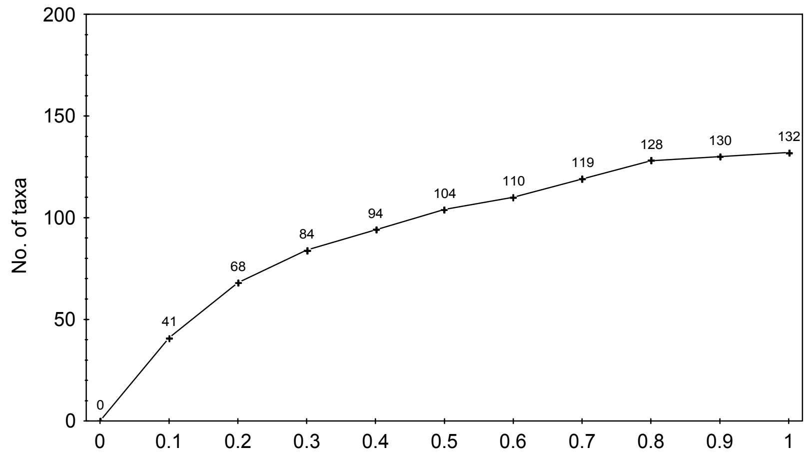

Figure 10-6: Species/area curve for the reference station at the Ringhorne field (area in m^2).

The number of individuals and taxa at each station, together with selected community indices are presented in Table 10-9 and Figure 10-7. The number of individuals varies from 1122 (RIN24) to 431 (RIN11), the number of taxa from 73 (RIN11) to 123 (RIN24), the diversity index H' from 4.4 (RIN09) to5.5 (RIN27), the evenness index J from 0.68 (RIN04) to 0.80 (RIN27, RIN16, RIN12) and the ES_{100} from 33 (RIN13, RIN09 and RIN02) to 43 (RIN27). The indices H', J and ES_{100} have highest values at station RIN27. At the reference station RIN29R the corresponding values are within the variation at the field stations.

Table 10-9: Number of individuals, taxa and selected community indices for each station (0.5 m^2) at the Ringhorne field 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	No. of ind	No. of taxa	H'	J	ES100
RIN01	1016	108	4.7	0.69	35
RIN02	845	93	4.6	0.71	**33**
RIN03	1013	111	4.8	0.71	35
RIN04	1030	101	4.5	**0.68**	34
RIN05	772	110	4.9	0.72	37
RIN06	685	101	4.8	0.72	36
RIN07	914	107	5.1	0.76	39
RIN08	812	97	4.8	0.72	36
RIN09	685	85	**4.4**	0.69	**33**
RIN10	548	90	5.1	0.79	39
RIN11	**431**	**73**	4.9	0.79	37
RIN12	471	86	5.1	**0.80**	40
RIN13	643	86	4.6	0.71	**33**
RIN14	635	94	4.9	0.75	36
RIN15	557	80	4.9	0.77	36
RIN16	578	99	5.3	**0.80**	41
RIN17	966	105	4.7	0.71	35
RIN18	855	109	5.2	0.77	38
RIN19	827	117	5.4	0.78	41
RIN20	749	101	5.3	0.79	39
RIN21	893	114	5.4	0.79	41
RIN22	1087	121	5.3	0.76	40
RIN23	993	119	5.3	0.77	40
RIN24	**1122**	**123**	5.4	0.78	41
RIN25	805	115	5.4	0.79	41
RIN26	790	106	5.2	0.78	39
RIN27	936	116	**5.5**	**0.80**	**43**
RIN28	717	97	5.1	0.78	37
RIN30	830	97	5.0	0.76	36
RIN31	813	102	5.2	0.78	38
RIN32	1002	114	5.3	0.78	41
RIN33	1098	113	**5.4**	0.79	41
RIN29R	824	104	5.0	0.75	37
Sum*	26942				
Average*	816	103	5.05	0.76	38
St.dev*	186	13	0.30	0.04	3

* Excluding the reference station

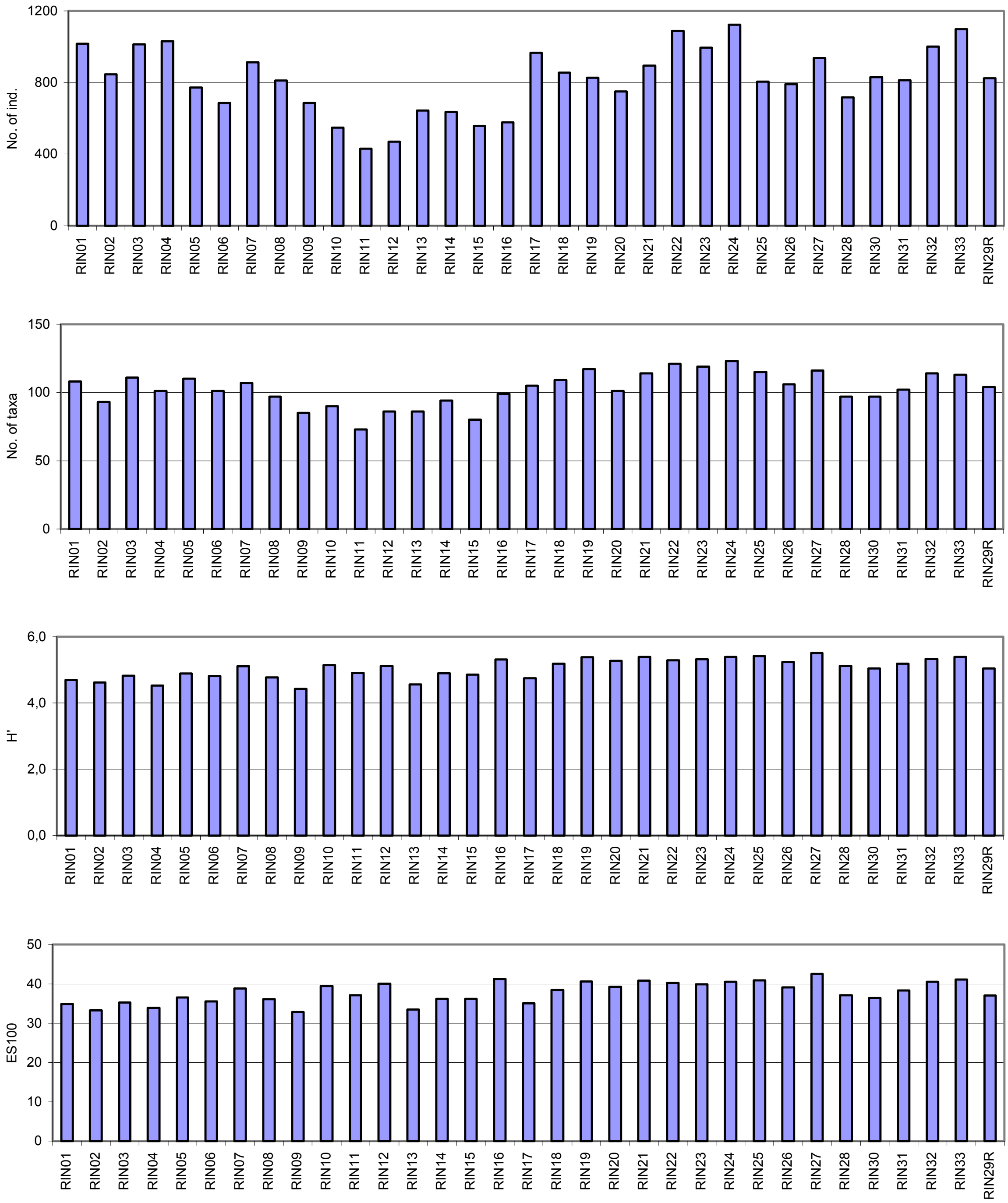

Figure 10-7: Biological characteristics of the stations at Ringhorne, 2000.

The distribution of taxa in geometrical classes is in shown in Figure 10-8. Three stations (RIN01, RIN04 and RIN17) have taxa in class 9 (256 – 511 individuals), 13 stations have taxa in class 8 (128 – 255 individuals) while the rest (17 stations) have taxa in class 7 or lower (< 128 individuals). The results indicate no disturbance of the fauna at the stations surveyed.

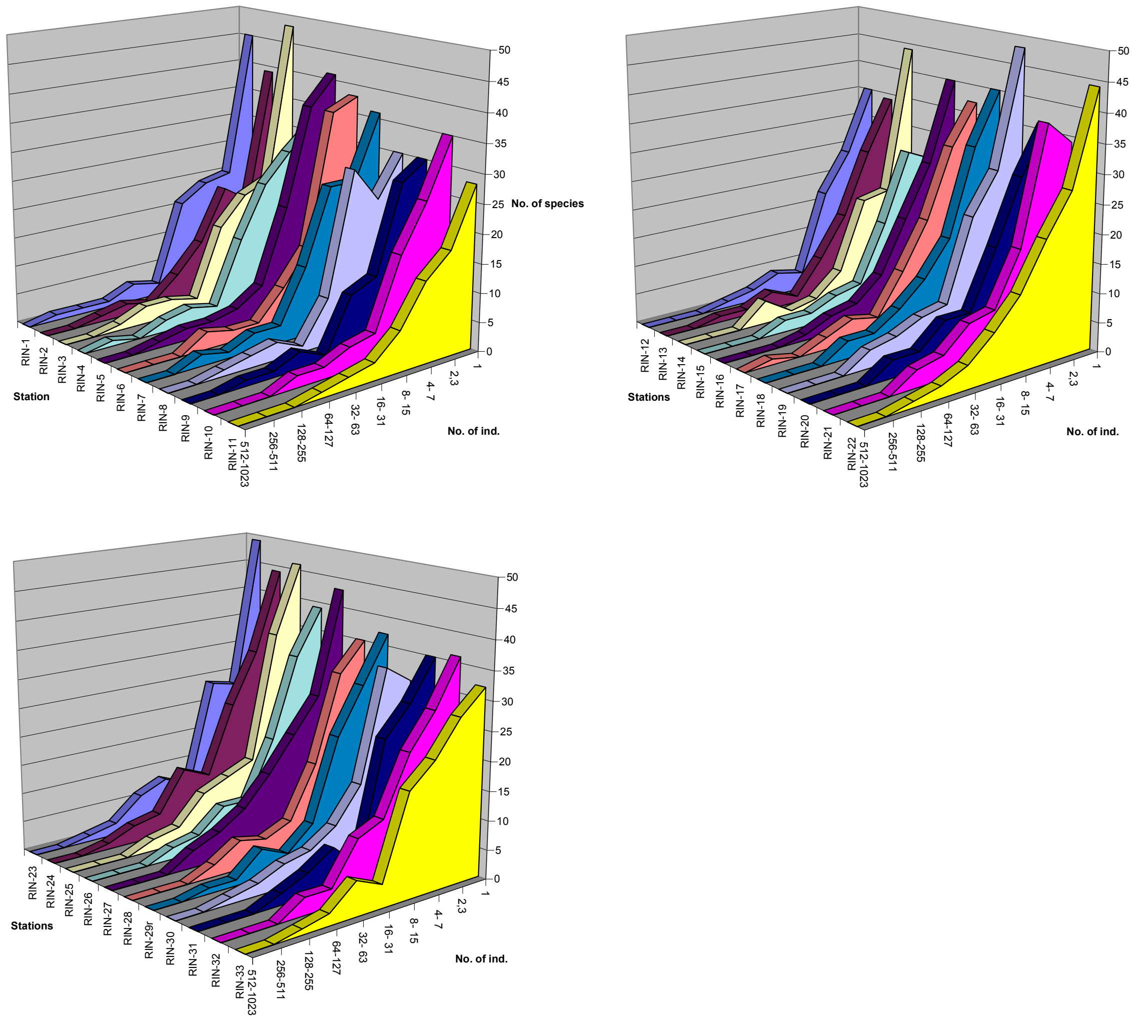

Figure 10-8: Distribution of taxa in geometrical classes at Ringhorne 2000.

The ten most dominant taxa at each station are shown in Table 10-11 at the end of this chapter. A total of 28 taxa, inclusive four juvenile groups, are among the ten most dominant taxa at one or more stations. These 28 taxa comprise 75 % of the total number of individuals and 10 % of the total number of taxa registered at the Ringhorne field in the present survey.

The most dominant taxa among the adult forms are the polychaetes *Spiophanes bombyx, Paramphinome jeffreysii, Lanice conchilega,* the mollusca *Thyasira croulinensis* and the cumacean *Eudorella emarginata*. The polychaetes *S. bombyx* and *P. jeffreysii* are among the five most dominant taxa at all stations while *L. conchilega* is among the five most dominant taxa at 31 stations. The cumacean *E. emarginata* and the mollusc *T. croulinensis* are among the ten most dominants at all 33 stations. These results indicate a uniform distribution of the fauna in the surveyed area.

The ten most abundant taxa at the stations comprise between 49 % (station RIN27) and 69 % (station RIN01 and RIN04) of the total number of individuals registered at the respective stations. The corresponding value at the reference station RIN29R is 62 %.

Figure 10-9 shows the dendrogram from the cluster analysis for the field stations and regional and reference stations while Figure 10-10 shows the 2-D plot from the MDS analysis.

In the cluster analysis the regional stations RII03, RII09 and RII10 together with the reference stations at Heimdal and Frøy, are separated out at 43 % dissimilarity level, field station RIN17 at 35 % level while the remaining stations are separated into two main groups at 34 % dissimilarity level. One of the groups contains all but one Well head stations (RIN02 – RIN16) which are further separated from each other at dissimilarity levels between 33 and 25 %. In the other main group the reference stations at Balder, Jotun, Ringhorne and field station RIN01 (Well head station) are separated form the remaining Sub Sea template stations (RIN18 – RIN28 and RIN30 – RIN33) at approximately 32 % level. The results indicate a fairly uniform distribution of the fauna in the area with differences between the two station groups that are a based on geographical variation. The correlation coefficient shows a good fit to the data (r = 0.82).

Due to the differences between the field and regional/reference stations, only the 2-D plot from the MDS analyses of field stations are shown in Figure 10-10. Analyses including the other stations are given in the Appendix.

The MDS analyses supports the cluster analysis by separating the stations situated around the well head installation (RIN01 – RIN16) from those around the sub sea template (RIN17 – RIN33). The field reference station RIN29R is seen together with the well head stations in the plot. The stress test shows a poor fit to the data (0.50).

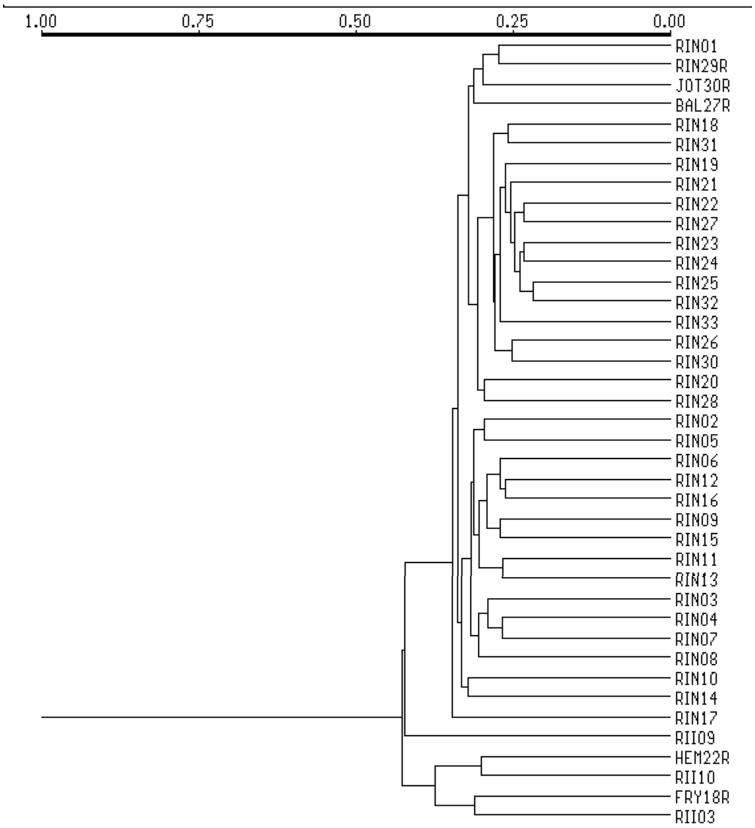

Figure 10-9: Cluster analysis of the Ringhorne field stations and selected regional and reference stations from Region II, 2000.

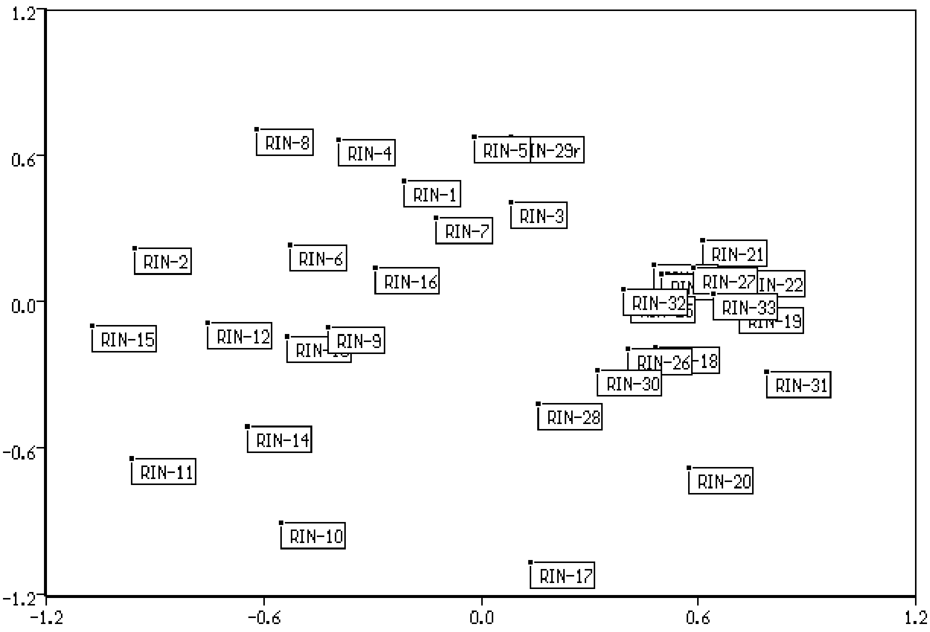

Figure 10-10: 2-D plot from the MDS analysis carried out on the Ringhorne field stations, 2000.

A Canonical Correspondence Analysis (CCA) of the data from the Ringhorne field stations and selected regional and reference stations was carried out to examine the association between the biological data and the measured environmental variables in these areas.

Through the forward selection procedure in CANOCO, seven of ten variables gave the best fit and were significant. 23.6 % of the biological variance was explained by the first two axes of the ordination space which is constrained by these environmental variables.

Figure 10-11 shows a biplot from the analysis using copper (Cu), barium (Ba), chromium (Cr), lead (Pb), THC, pelite (Pel) and fine sand (FS) as the constraining environmental variables. The first axis shows a gradient from regional station RII10 on the positive end to field station RIN02 on the negative end and is positively correlated with the amount of barium in the sediments (+ 0.65). The correlation with the other parameters are low (< ± 0.5). Taxa with the highest contribution on this axis are the polychaetes *Spiophanes bombyx* (17.4 %), *Lanice conchylega* (14.4 %) and *Galathowenia oculata* (4.9 %), the phoronid *Phoronis* sp. (6.6 %), the bivalve *Timoclea ovata* (4.7 %) and the brittle star *Amphiura filiformis* (3.9 %).

The second axis shows a gradient from the Heimdal reference station HEM22R on the positive end to field station RIN23 on the negative end and is correlated with the amount of chromium (- 0.67) and THC (- 0.55) in the sediments. The correlation with the other parameters are low (< ± 0.5). Taxa with highest contribution on this axis are the phoronid *Phoronis* sp. (13.8 %), the polychaetes *Spiophanes bombyx* (6.8 %), *Eriopis elongata* (5.2 %) and the bivalve *Thyasira equalis* (6.1 %).

All taxa with high contributions on the two axes in the CCA are known to be relatively abundant in undisturbed sediments. The correlation with the chemical parameters, which have concentrations similar to or below their calculated LSC values at the stations, are believed to be a result of natural variations in the sediment structure over he field.

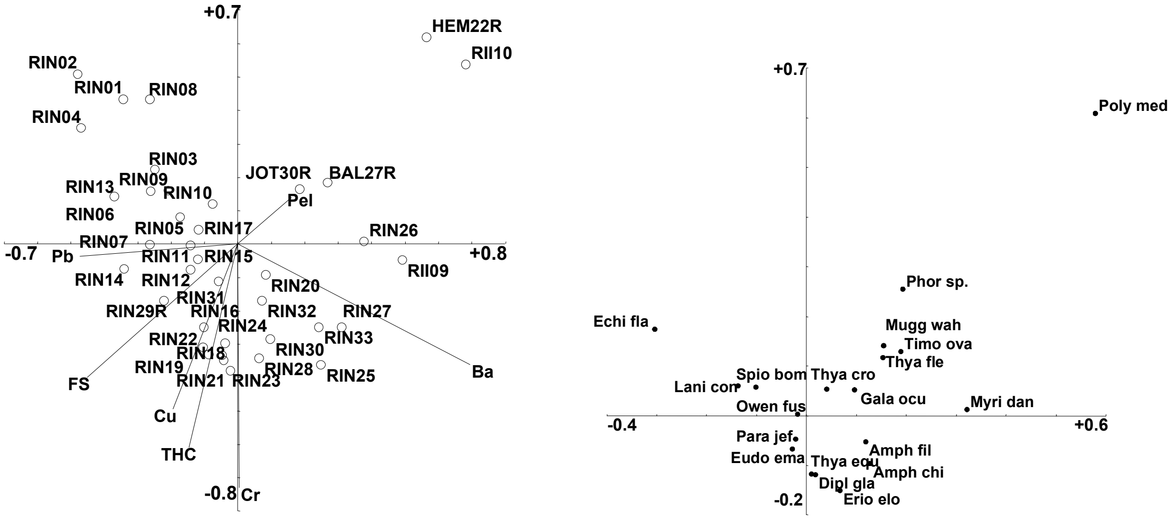

Figure 10-11: Biplot from the CCA analysis for the Ringhorne field stations and selected regional and reference stations from Region II, 2000 (left) and taxa with high contribution on two axes (right).

On the basis of the results from the uni- and multivariate analyses all stations at Ringhorne field are classified as group A stations (undisturbed fauna). The multivariate analyses indicate a uniform distribution of the fauna, although separations of the stations around the sub sea installation and well head template occur. This is believed to be a result of geographical variation in the area. The faunal composition at the field is relatively similar to that found in undisturbed sediments at the neighbouring fields (i.e. Balder).

The CCA shows significant correlation between the faunal distribution and the sediment structure and amount of THC and some heavy metals (Cu, Ba, Cr and Pb). Some of these correlations, however, were weak. The correlation with the chemical parameters, which have concentrations similar to or below their calculated LSC values at the stations, are believed to be a result of natural variations in the sediment structure over he field. All taxa with high contributions on the two axes in the CCA are known to be relatively abundant in undisturbed sediments.

Table 10-10: Classification into impact groups, distance to installation and biological statistics for the field stations at Ringhorne field, 2000.

Station	Impact group	Dist. (m)	Statistics			No. of individuals								
			No. ind	No. taxa	H'	Afi	Sbo	Skr	Eem	Pje	Lco	Tcr	Goc	Teq
RIN01	A	2000	1016	108	4,7	0	259	0	45	93	131	40	47	0
RIN02	A	1000	845	93	4,6	0	206	0	63	80	94	30	0	30
RIN03	A	500	1013	111	4,8	0	229	35	76	85	112	49	36	0
RIN04	A	250	1030	101	4,5	0	330	19	56	72	89	40	58	0
RIN05	A	250	772	110	4,9	0	129	28	50	83	120	45	17	28
RIN06	A	500	685	101	4,8	0	105	20	47	68	123	41	28	0
RIN07	A	1000	914	107	5,1	0	134	21	54	75	133	32	58	25
RIN08	A	2000	812	97	4,8	0	203	0	49	64	60	34	79	0
RIN09	A	2000	685	85	4,4	0	206	0	33	49	83	44	0	0
RIN10	A	1000	548	90	5,1	0	51	22	37	65	73	23	0	18
RIN11	A	500	431	73	4,9	0	60	11	26	35	67	18	0	22
RIN12	A	250	471	86	5,1	0	36	16	31	72	52	26	9	23
RIN13	A	250	643	86	4,6	0	162	21	39	54	82	47	0	13
RIN14	A	500	635	94	4,9	0	87	0	69	76	76	33	0	21
RIN15	A	1000	557	80	4,9	21	95	21	46	81	37	21	0	20
RIN16	A	2000	578	99	5,3	0	61	20	45	70	26	23	37	30
RIN17	A	2000	966	105	4,7	47	256	0	48	99	66	37	25	0
RIN18	A	1000	855	109	5,2	31	73	27	100	113	45	51	0	0
RIN19	A	500	827	117	5,4	27	79	25	69	92	33	54	0	38
RIN20	A	250	749	101	5,3	0	51	23	71	80	22	42	0	65
RIN21	A	250	893	114	5,4	0	97	33	82	93	36	31	35	43
RIN22	A	500	1087	121	5,3	0	176	41	73	111	60	45	50	27
RIN23	A	1000	993	119	5,3	34	139	0	89	91	41	34	40	36
RIN24	A	2000	1122	123	5,4	41	144	0	82	106	51	43	71	0
RIN25	A	250	805	115	5,4	0	81	31	56	74	27	44	0	53
RIN26	A	500	790	106	5,2	0	84	29	55	98	29	46	0	60
RIN27	A	1000	936	116	5,5	33	97	0	72	92	26	34	42	35
RIN28	A	2000	717	97	5,1	28	55	0	81	88	31	41	0	34
RIN30	A	250	830	97	5,0	29	70	0	85	131	40	37	0	52
RIN31	A	500	813	102	5,2	0	60	0	79	113	34	40	0	61
RIN32	A	1000	1002	114	5,3	0	124	0	85	115	30	31	62	39
RIN33	A	2000	1098	113	5,4	0	69	35	120	137	0	48	42	55
RIN29R	A	5000	824	104	5,0	0	151	29	47	80	54	30	49	43
RII03	A	-	1523	127	4,7	0	54	50	0	0	0	96	520	0
RII09	A	-	1221	118	5,2	115	103	0	0	66	33	0	176	0
RII10	A	-	1200	128	5,4	0	106	0	37	58	49	102	142	0
BAL27R	A	-	1073	118	5,4	0	94	0	70	72	28	49	59	38
JOT30R	A	-	1221	117	5,2	0	191	39	65	157	0	46	55	0

Afi = *Amphiura filiformis,* Sbo = *Spiophanes bombyx*, Skr = *Spiophanes kroyeri,* Eem = *Eudorella emarginata*, Pje = *Paramphinome jeffreysii*, Lco = *Lanice conchilega*, Tcr = *Thyasira crouliensis*, Goc = *Galatowenia oculata*, Teq = *Thyasira equalis*.

10.3 Summary and conclusions

The sediment at the Ringhorne field is classified as fine sand with relatively high amount of pelite (9 – 14 %) and TOM (1.5 – 2.5 %). The sediment is similar to that found at the neighbouring Balder field.

The sediments around the sub sea installation contain slightly more THC (8-14 mg/kg) than the sediments around the well head platform (5-11 mg/kg). Naturally higher levels of THC (11-14 mg/kg) seems to be found along the sub sea 315^{o}-axis. The average THC content across the Ringhorne field (9.4 ± 2.9 mg/kg) is comparable to the content found across the Glitne field (8.6 ± 1.7 mg/kg), which is located south west of Ringhorne, and to the content in uncontaminated sediments at the Balder field. Ringhorne is regarded as uncontaminated with THC, aromatic hydrocarbons and decalins.

The selected metals are very evenly distributed over the Ringhorne field. The sediments around the sub sea installation contain generally slightly more cadmium, zinc and barium than those collected nearby the well head. The sediments are regarded as uncontaminated with metals. The amounts of metals found in sediments across Ringhorne are comparable to the concentrations found in sediments from uncontaminated stations at the neighbouring Balder field. Sediments from the Ringhorne field contain 40-50% more cadmium and copper and only half as much barium as sediments from Glitne.

A relatively high variation in the number of taxa and individuals are registered at the stations. However, the faunal composition at the field is relatively similar to that found in undisturbed sediments at the neighbouring fields (i.e. Balder). On the basis of the results from the uni- and multivariate analyses all stations at Ringhorne field are classified as group A stations (undisturbed fauna). The multivariate analyses indicate a uniform distribution of the fauna, although separations of the stations around the sub sea installation and well head template occur. This is believed to be a result of geographical variation in the area.

The CCA shows significant correlation between the faunal distribution and the sediment structure and amount of THC and some heavy metals (Cu, Ba, Cr and Pb). Some of these correlations, however, are weak. The correlation with the chemical parameters, which have concentrations similar to or below their calculated LSC values at the stations, are believed to be a result of natural variations in the sediment structure over he field. All taxa with high contributions on the two axes in the CCA are known to be relatively abundant in undisturbed sediments.

It is therefore concluded that the petroleum activity at the field so far has had no negative effects on the fauna.

Table 10-11: Number of individuals and the accumulative abundance for the ten predominant taxa at each station at the Ringhorne field, 2000.

RIN01 (45°/ 2000m)	No. ind	Acc. %	RIN02 (45°/ 1000m)	No. ind	Acc. %	RIN03 (45°/ 500m)	No. ind	Acc. %	RIN04 (45°/ 250m)	No. ind	Acc. %	RIN05 (135°/ 250m)	No. ind	Acc. %
Spiophanes bombyx	259	22 %	Spiophanes bombyx	206	23 %	Spiophanes bombyx	229	20 %	Spiophanes bombyx	330	28 %	Spiophanes bombyx	129	16 %
Pectinaria sp. juv.	140	33 %	Lanice conchilega	94	34 %	Lanice conchilega	112	30 %	Lanice conchilega	89	36 %	Lanice conchilega	120	30 %
Lanice conchilega	131	44 %	Paramphinome jeffreysii	80	43 %	Paramphinome jeffreysii	85	38 %	Pectinaria sp. juv.	76	43 %	Paramphinome jeffreysii	83	40 %
Paramphinome jeffreysii	93	52 %	Eudorella emarginata	63	50 %	Eudorella emarginata	76	45 %	Paramphinome jeffreysii	72	49 %	Eudorella emarginata	50	46 %
Galathowenia oculata	47	56 %	Phoronis sp.	31	54 %	Pectinaria sp. juv.	76	51 %	Galathowenia oculata	58	54 %	Thyasira croulinensis	45	52 %
Eudorella emarginata	45	59 %	Thyasira croulinensis	30	57 %	Thyasira croulinensis	49	56 %	Eudorella emarginata	56	59 %	Spiophanes kroyeri	28	55 %
Thyasira croulinensis	40	63 %	Thyasira equalis	30	60 %	Galathowenia oculata	36	59 %	Thyasira croulinensis	40	62 %	Thyasira equalis	28	58 %
Phoronis sp.	25	65 %	Pectinaria sp. juv.	22	63 %	Spiophanes kroyeri	35	62 %	Cerianthus lloydi juv.	32	65 %	Cerianthus lloydi juv.	21	61 %
Ophiuroidea indet. juv.	21	67 %	Antalis sp.	18	65 %	Harpinia antennaria	27	64 %	Owenia fusiformis	27	67 %	Pectinaria sp. juv.	19	63 %
Cerianthus lloydi juv.	16	68 %	Echinocardium flavescens	17	67 %	Phoronis sp.	25	66 %	Spiophanes kroyeri	19	69 %	Galathowenia oculata	17	65 %
Urothoe elegans	16	69 %												
RIN06 (135°/ 500m)	**No. ind**	**Acc. %**	**RIN07 (135°/ 1000m)**	**No. ind**	**Acc. %**	**RIN08 (135°/ 2000m)**	**No. ind**	**Acc. %**	**RIN09 (225°/ 2000m)**	**No. ind**	**Acc. %**	**RIN10 (225°/ 1000m)**	**No. ind**	**Acc. %**
Lanice conchilega	123	17 %	Spiophanes bombyx	134	13 %	Spiophanes bombyx	203	23 %	Spiophanes bombyx	206	28 %	Lanice conchilega	73	13 %
Spiophanes bombyx	105	31 %	Lanice conchilega	133	27 %	Galathowenia oculata	79	32 %	Lanice conchilega	83	40 %	Paramphinome jeffreysii	65	24 %
Paramphinome jeffreysii	68	40 %	Paramphinome jeffreysii	75	34 %	Paramphinome jeffreysii	64	39 %	Paramphinome jeffreysii	49	46 %	Spiophanes bombyx	51	33 %
Eudorella emarginata	47	46 %	Galathowenia oculata	58	40 %	Lanice conchilega	60	46 %	Thyasira croulinensis	44	52 %	Eudorella emarginata	37	39 %
Thyasira croulinensis	41	52 %	Eudorella emarginata	54	46 %	Eudorella emarginata	49	51 %	Eudorella emarginata	33	57 %	Thyasira croulinensis	23	43 %
Pectinaria sp. juv.	33	56 %	Pectinaria sp. juv.	32	49 %	Pectinaria sp. juv.	47	56 %	Pectinaria sp. juv.	24	60 %	Spiophanes kroyeri	22	47 %
Galathowenia oculata	28	60 %	Thyasira croulinensis	32	52 %	Thyasira croulinensis	34	60 %	Spiophanes kroyeri	16	63 %	Thyasira equalis	18	50 %
Spiophanes kroyeri	20	63 %	Thyasira equalis	25	55 %	Nothria conchylega	18	62 %	Antalis sp.	12	64 %	Timoclea ovata	16	53 %
Cerianthus lloydi juv.	14	65 %	Spiophanes kroyeri	21	57 %	Cerianthus lloydi juv.	17	64 %	Diplocirrus glaucus	12	66 %	Diplocirrus glaucus	13	55 %
Urothoe elegans	13	66 %	Antalis sp.	20	59 %	Hippomedon holbolli	15	66 %	Harpinia antennaria	12	67 %	Phaxas pellucidus	13	57 %
			Cerianthus lloydi juv.	20	61 %									

Continue Table 10-11

RIN11 (225°/ 500m)	No.ind	Acc. %	RIN12 (225°/ 250m)	No.ind	Acc. %	RIN13 (315°/ 250m)	No. ind	Acc. %	RIN14 (315°/ 500m)	No. ind	Acc. %	RIN15 (315°/ 1000m)	No. ind	Acc. %
Lanice conchilega	67	15 %	Paramphinome jeffreysii	72	15 %	Spiophanes bombyx	162	23 %	Spiophanes bombyx	87	12 %	Spiophanes bombyx	95	16 %
Spiophanes bombyx	60	28 %	Lanice conchilega	52	25 %	Lanice conchilega	82	35 %	Lanice conchilega	76	23 %	Paramphinome jeffreysii	81	30 %
Paramphinome jeffreysii	35	36 %	Spiophanes bombyx	36	33 %	Paramphinome jeffreysii	54	43 %	Paramphinome jeffreysii	76	34 %	Eudorella emarginata	46	38 %
Eudorella emarginata	26	42 %	Eudorella emarginata	31	39 %	Thyasira croulinensis	47	50 %	Eudorella emarginata	69	44 %	Lanice conchilega	37	44 %
Thyasira equalis	22	46 %	Thyasira croulinensis	26	44 %	Eudorella emarginata	39	56 %	Pectinaria sp. juv.	33	49 %	Amphiura filiformis	21	48 %
Thyasira croulinensis	18	50 %	Thyasira equalis	23	49 %	Cerianthus lloydi juv.	23	59 %	Thyasira croulinensis	33	54 %	Spiophanes kroyeri	21	51 %
Spiophanes kroyeri	11	53 %	Spiophanes kroyeri	16	52 %	Spiophanes kroyeri	21	62 %	Thyasira equalis	21	57 %	Thyasira croulinensis	21	55 %
Eriopisa elongata	10	55 %	Phaxas pellucidus	11	55 %	Pectinaria sp. juv.	19	65 %	Echinocardium flavescens	16	59 %	Thyasira equalis	20	58 %
Ophiuroidea indet. juv.	10	57 %	Harpinia antennaria	10	57 %	Thyasira equalis	13	67 %	Cerianthus lloydi juv.	15	61 %	Ophiuroidea indet. juv.	13	60 %
Nephtys hystricis	9	59 %	Galathowenia oculata	9	59 %	Harpinia antennaria	12	68 %	Harpinia antennaria	15	63 %	Phaxas pellucidus	13	63 %
Phaxas pellucidus	9	61 %												
RIN16 (315°/ 2000m)	No. ind	Acc. %	RIN17 (225°/ 2000m)	No. ind	Acc. %	RIN18 (225°/ 1000m)	No. ind	Acc. %	RIN19 (225°/ 500m)	No. ind	Acc. %	RIN20 (225°/ 250m)	No. ind	Acc. %
Paramphinome jeffreysii	70	10 %	Spiophanes bombyx	256	24 %	Paramphinome jeffreysii	113	12 %	Paramphinome jeffreysii	92	10 %	Paramphinome jeffreysii	80	10 %
Spiophanes bombyx	61	19 %	Paramphinome jeffreysii	99	33 %	Eudorella emarginata	100	23 %	Spiophanes bombyx	79	19 %	Eudorella emarginata	71	19 %
Natatolana borealis juv.	53	27 %	Lanice conchilega	66	40 %	Spiophanes bombyx	73	31 %	Eudorella emarginata	69	27 %	Thyasira equalis	65	27 %
Eudorella emarginata	45	34 %	Pectinaria sp. juv.	58	45 %	Thyasira croulinensis	51	36 %	Thyasira croulinensis	54	33 %	Spiophanes bombyx	51	34 %
Galathowenia oculata	37	39 %	Eudorella emarginata	48	49 %	Lanice conchilega	45	41 %	Thyasira equalis	38	37 %	Thyasira croulinensis	42	39 %
Thyasira equalis	30	44 %	Amphiura filiformis	47	54 %	Diplocirrus glaucus	38	45 %	Lanice conchilega	33	41 %	Diplocirrus glaucus	40	44 %
Lanice conchilega	26	47 %	Thyasira croulinensis	37	57 %	Amphiura filiformis	31	48 %	Diplocirrus glaucus	32	45 %	Eriopisa elongata	28	48 %
Thyasira croulinensis	23	51 %	Owenia fusiformis	32	60 %	Cerianthus lloydi juv.	29	51 %	Cerianthus lloydi juv.	30	48 %	Spiophanes kroyeri	23	51 %
Spiophanes kroyeri	20	54 %	Galathowenia oculata	25	63 %	Ophiuroidea indet. juv.	28	54 %	Amphiura filiformis	27	51 %	Lanice conchilega	22	54 %
Pectinaria sp. juv.	18	56 %	Diplocirrus glaucus	24	65 %	Harpinia antennaria	27	57 %	Spiophanes kroyeri	25	54 %	Harpinia antennaria	18	56 %
						Spiophanes kroyeri	27	60 %						

Continue Table 10-11

RIN21 (315°/ 250m)	No. ind	Acc. %	RIN22 (315°/ 500m)	No. ind	Acc. %	RIN23 (315°/ 1000m)	No. ind	Acc. %	RIN24 (315°/ 2000m)	No. ind	Acc. %	RIN25 (135°/ 250m)	No. ind	Acc. %
Spiophanes bombyx	97	10 %	Spiophanes bombyx	176	15 %	Spiophanes bombyx	139	13 %	Spiophanes bombyx	144	12 %	Spiophanes bombyx	81	10 %
Paramphinome jeffreysii	93	20 %	Paramphinome jeffreysii	111	24 %	Paramphinome jeffreysii	91	21 %	Paramphinome jeffreysii	106	20 %	Paramphinome jeffreysii	74	18 %
Eudorella emarginata	82	29 %	Eudorella emarginata	73	30 %	Eudorella emarginata	89	29 %	Eudorella emarginata	82	27 %	Eudorella emarginata	56	25 %
Thyasira equalis	43	33 %	Lanice conchilega	60	36 %	Cerianthus lloydi juv.	46	34 %	Galathowenia oculata	71	33 %	Thyasira equalis	53	31 %
Lanice conchilega	36	37 %	Galathowenia oculata	50	40 %	Lanice conchilega	41	37 %	Lanice conchilega	51	37 %	Thyasira croulinensis	44	36 %
Galathowenia oculata	35	41 %	Thyasira croulinensis	45	44 %	Galathowenia oculata	40	41 %	Thyasira croulinensis	43	41 %	Spiophanes kroyeri	31	40 %
Spiophanes kroyeri	33	44 %	Spiophanes kroyeri	41	47 %	Harpinia antennaria	36	44 %	Amphiura filiformis	41	44 %	Eriopisa elongata	29	43 %
Thyasira croulinensis	31	48 %	Cerianthus lloydi juv.	32	50 %	Thyasira equalis	36	48 %	Diplocirrus glaucus	33	47 %	Diplocirrus glaucus	27	47 %
Harpinia antennaria	24	50 %	Diplocirrus glaucus	29	52 %	Amphiura filiformis	34	51 %	Amphiura chiajei	31	49 %	Lanice conchilega	27	50 %
Eriopisa elongata	23	53 %	Ophiuroidea indet. juv.	27	54 %	Thyasira croulinensis	34	54 %	Pectinaria sp. juv.	31	52 %	Amphiura chiajei	26	53 %
Laonice sarsi	23	55 %	Thyasira equalis	27	57 %									
RIN26 (135°/ 500m)	No. ind	Acc. %	RIN27 (135°/ 1000m)	No. ind	Acc. %	RIN28 (135°/ 2000m)	No. ind	Acc. %	RIN30 (45°/ 250m)	No. ind	Acc. %	RIN31 (45°/ 500m)	No. ind	Acc. %
Paramphinome jeffreysii	98	12 %	Spiophanes bombyx	97	10 %	Paramphinome jeffreysii	88	12 %	Paramphinome jeffreysii	131	15 %	Paramphinome jeffreysii	113	13 %
Spiophanes bombyx	84	22 %	Paramphinome jeffreysii	92	19 %	Eudorella emarginata	81	22 %	Eudorella emarginata	85	25 %	Eudorella emarginata	79	22 %
Thyasira equalis	60	29 %	Eudorella emarginata	72	26 %	Spiophanes bombyx	55	29 %	Spiophanes bombyx	70	33 %	Thyasira equalis	61	29 %
Eudorella emarginata	55	35 %	Galathowenia oculata	42	30 %	Thyasira croulinensis	41	35 %	Thyasira equalis	52	38 %	Spiophanes bombyx	60	36 %
Thyasira croulinensis	46	41 %	Amphiura chiajei	36	33 %	Eriopisa elongata	38	40 %	Lanice conchilega	40	43 %	Thyasira croulinensis	40	41 %
Lanice conchilega	29	44 %	Thyasira equalis	35	37 %	Diplocirrus glaucus	36	44 %	Thyasira croulinensis	37	47 %	Lanice conchilega	34	45 %
Spiophanes kroyeri	29	47 %	Thyasira croulinensis	34	40 %	Thyasira equalis	34	49 %	Amphiura chiajei	35	51 %	Amphiura chiajei	28	48 %
Amphiura chiajei	24	50 %	Amphiura filiformis	33	44 %	Lanice conchilega	31	53 %	Diplocirrus glaucus	30	55 %	Eriopisa elongata	28	51 %
Diplocirrus glaucus	24	53 %	Lanice conchilega	26	46 %	Amphiura filiformis	28	57 %	Amphiura filiformis	29	58 %	Ophiuroidea indet. juv.	26	54 %
Harpinia antennaria	24	56 %	Cerianthus lloydi juv.	25	49 %	Ophiuroidea indet. juv.	23	60 %	Eriopisa elongata	24	61 %	Diplocirrus glaucus	25	57 %

Continue Table 10-11

RIN32 (45°/ 1000m)	No. ind	Acc. %	RIN33 (45°/ 2000m)	No. ind	Acc. %	RIN29R (315°/ 5000m)	No. ind	Acc. %
Spiophanes bombyx	124	12 %	Paramphinome jeffreysii	137	12 %	Spiophanes bombyx	151	17 %
Paramphinome jeffreysii	115	22 %	Eudorella emarginata	120	22 %	Paramphinome jeffreysii	80	27 %
Eudorella emarginata	85	30 %	Spiophanes bombyx	69	28 %	Lanice conchilega	54	33 %
Galathowenia oculata	62	36 %	Thyasira equalis	55	33 %	Galathowenia oculata	49	38 %
Thyasira equalis	39	40 %	Thyasira croulinensis	48	37 %	Eudorella emarginata	47	44 %
Eriopisa elongata	32	43 %	Eriopisa elongata	46	41 %	Thyasira equalis	43	49 %
Thyasira croulinensis	31	46 %	Diplocirrus glaucus	42	45 %	Diplocirrus glaucus	32	52 %
Lanice conchilega	30	49 %	Galathowenia oculata	42	49 %	Thyasira croulinensis	30	56 %
Cerianthus lloydi juv.	29	51 %	Spiophanes kroyeri	35	52 %	Spiophanes kroyeri	29	59 %
Amphiura chiajei	27	54 %	Laonice sarsi	29	54 %	Eriopisa elongata	24	62 %

Table 10-12:Station information for Ringhorne field, 2000.

St. no.		Distance (m)	Direction (degr.)	Volume (litres)
RIN01	Well head platform	2000	45	31
RIN02		1000	45	26
RIN03		500	45	37
RIN04		250	45	31
RIN05		250	135	33
RIN06		500	135	27
RIN07		1000	135	25
RIN08		2000	135	25
RIN09		2000	225	25
RIN10		1000	225	27
RIN11		500	225	32
RIN12		250	225	29
RIN13		250	315	27
RIN14		500	315	30
RIN15		1000	315	29
RIN16		2000	315	30
RIN17	Sub sea installation	2000	225	25
RIN18		1000	225	28
RIN19		500	225	43
RIN20		250	225	41
RIN21		250	315	36
RIN22		500	315	35
RIN23		1000	315	46
RIN24		2000	315	37
RIN25		250	135	46
RIN26		500	135	42
RIN27		1000	135	46
RIN28		2000	135	44
RIN30		250	45	51
RIN31		500	45	40
RIN32		1000	45	42
RIN33		2000	45	46
RIN29R	Well head platform	5000	315	46 *

* The additional five grab samples taken gave 51 litres of sediment.

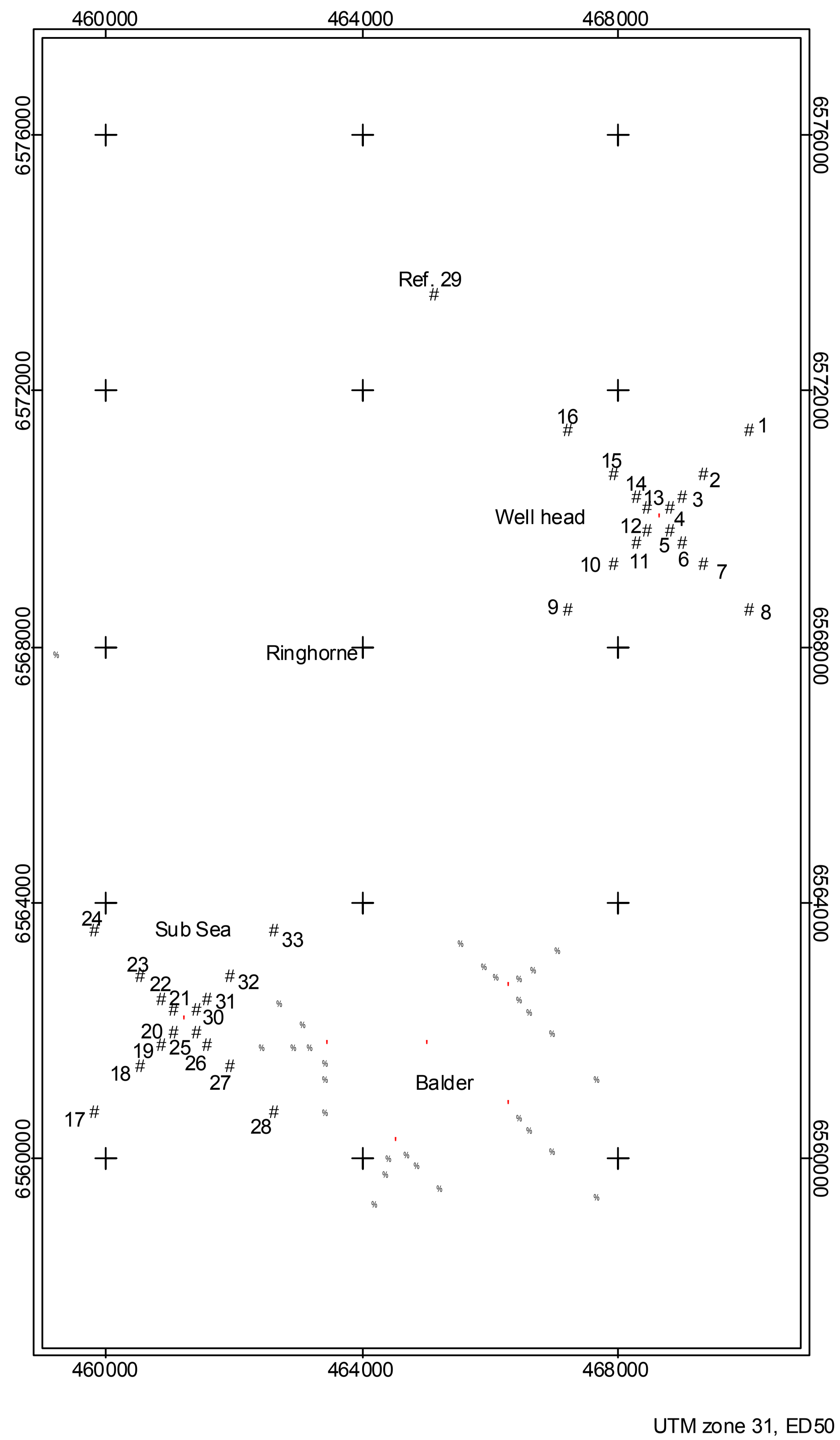

Figure 10-12: Map of sampling positions for Ringhorne field, 2000.

11 Sigyn field

11.1 Introduction

The Sigyn field is located in Block 16-7 in the southern part of Region II, situated south of the Sleipner Øst field. In 1997 two wells were drilled, and data on discharges are given in Table 11-1.

This is a baseline survey for Sigyn. Information on the sampling stations is shown in Figure 11-11 and Table 11-12 both on the foldout page at the end of this chapter.

Table 11-1: Summary of recent operational and accidental discharges at the Sigyn field (all discharges in tonnes).

	1997	1998	1999	2000	Comments
No of wells drilled	2	0	0	0	
Barite	432	0	0	0	
Cuttings	500	0	0	0	Only cuttings with water-based drilling mud was released
Water-based drilling mud	1600	0	0	0	
Cementing and other chemicals	26	0	0	0	

11.2 Results and discussion

11.2.1 Physical characteristics

The median phi value and the amount (%) of pelite, fine sand and total organic matter (TOM) in the sediment from the present survey is shown in Table 11-2 and Figure 11-1. 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 in the Sigyn field area are classified as fine sand with median values varying from 3.45 at station SIG13 and SIG14 to 3.52 at station SIG09. The amount of pelite in the sediment varies from 1.72 % (SIG11) to 2.2 % (SIG09), the fine sand from 85.6 % (SIG02) to 91.2 % (SIG09) while the TOM varies from 0.64 % (SIG03) to 0.73 % (SIG08 and SIG16). The amount of pelite and fine sand is higher at the reference station SIG17R than at the field stations. The sediment is relatively uniform over the surveyed area.

Table 11-2: The median (phi) and amount of pelite, fine sand and TOM in the sediments from stations at the Sigyn field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	Distance (m)	Direction (degr.)	Median	Classification	Pelite	Fine sand	TOM
SIG01	2000	10	3.50	Fine sand	1.76	89.5	0.65
SIG02	1000	10	3.46	Fine sand	1.84	**85.6**	0.67
SIG03	500	10	3.48	Fine sand	1.94	87.2	**0.64**
SIG04	250	10	3.47	Fine sand	2.06	87.4	0.65
SIG05	250	100	3.48	Fine sand	1.90	87.2	0.68
SIG06	500	100	3.47	Fine sand	1.83	86.6	0.70
SIG07	1000	100	3.48	Fine sand	1.74	87.0	0.70
SIG08	2000	100	3.47	Fine sand	1.91	87.8	**0.73**
SIG09	2000	280	**3.52**	Fine sand	**2.20**	**91.2**	0.68
SIG10	1000	280	3.48	Fine sand	1.89	88.8	0.68
SIG11	500	280	3.49	Fine sand	**1.72**	88.1	0.68
SIG12	250	280	3.46	Fine sand	1.82	86.2	0.68
SIG13	250	190	**3.45**	Fine sand	1.77	85.7	0.65
SIG14	500	190	**3.45**	Fine sand	1.77	85.8	0.67
SIG15	1000	190	3.47	Fine sand	1.87	87.8	0.67
SIG16	2000	190	3.47	Fine sand	2.04	87.4	**0.73**
SIG17R	5000	190	3.50	Fine sand	2.27	92.1	0.68
Average*			3.47		1.88	87.5	0.68
St.dev.*			0.02		0.13	1.47	0.03

*Excluding the reference station.

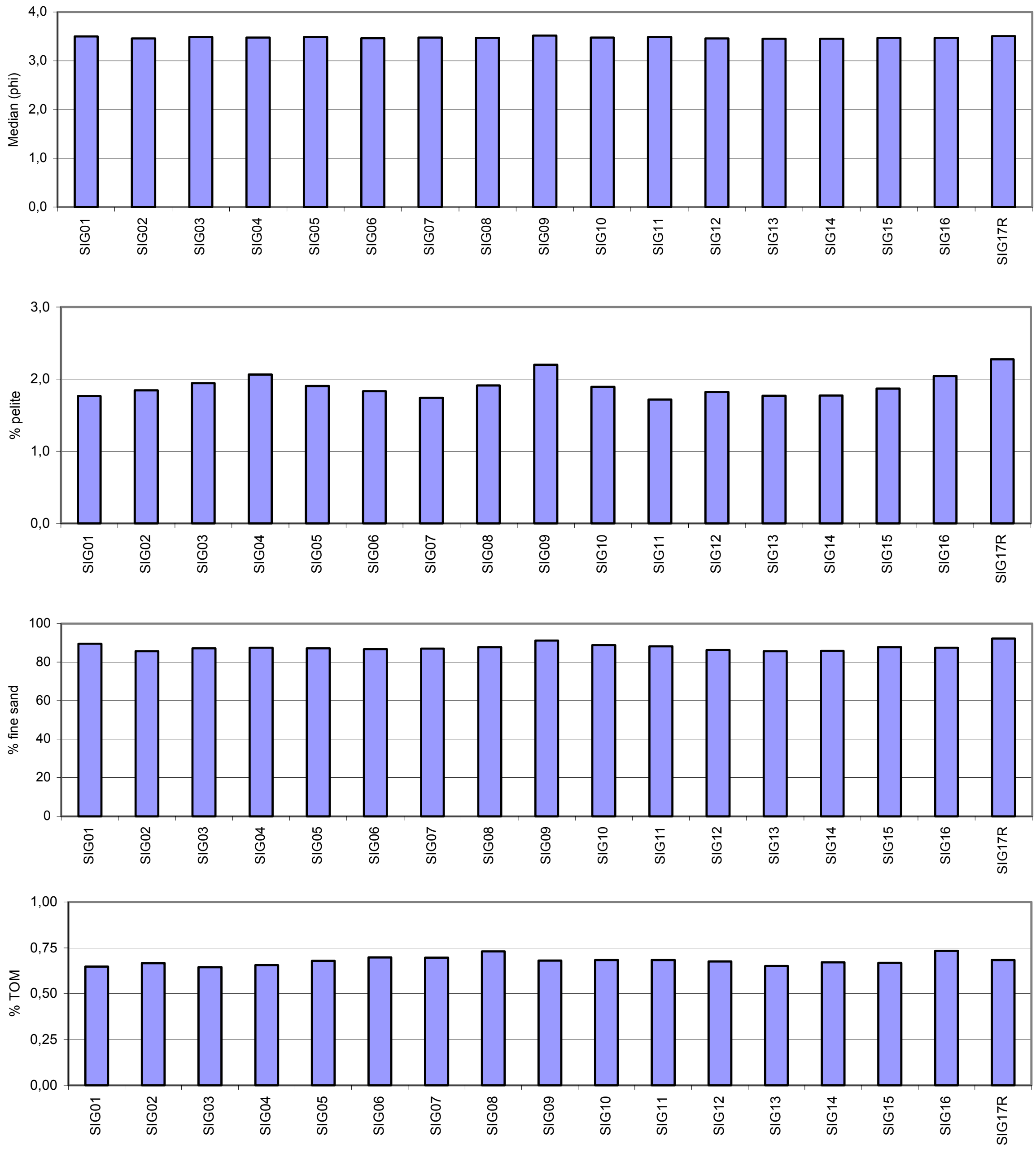

Figure 11-1: Sediment characteristics at the Sigyn field in 2000.

11.2.2 Chemical characteristics

The Sigyn field is located in shallow area south in Region II. The calculated limits of significant contamination for selected hydrocarbons and metals in sediments from the shallow area ($LSC_{97\text{-}00\ shallow\ RegII}$) are previously presented in the chapter that deals with the regional and reference stations. In addition to the sub-regional limits, field-specific limits of significant contamination are calculated by results from the reference station ($LSC_{00\ SIG17R}$). Both sets of data are presented in Table 11-3. Based on analysis results of the Sigyn field, the $LSC_{97\text{-}00\ shallow\ RegII}$ is regarded as representative and will therefore be used as further basis for discussion of the contamination status of this field. Those limits will hereafter simply be referred to as LSC.The results of analyses of the hydrocarbons are summarised in Table 11-4. Concentrations of selected compounds in the vertical sediment sections are presented in Table 11-5. The full data set of replicate measurements is given in the Appendix. THC values are presented as histograms in Figure 11-2.

Table 11-3: Background levels and Limits of Significant Contamination for the Sigyn field, 2000. All values in mg/kg dry sediment.

	THC	NPD's	3-6 ring	Decalins	Cd	Hg	Cu	Zn	Ba	Cr	Pb
$LSC_{00\ SIG17R}$	5.2	0.012	0.032	0.032	0.008	n.d.	0.9	4.3	19	8.4	6.0
$LSC_{97\text{-}00\ shallow\ RegII}$	6.6	*	*	*	0.008	0.006	1.2	8.1	38	10.2	7.4

*) Regional stations not analysed for NPD's, 3-6 ring aromatics and decalins.

n.d. Not detected at the reference station

Table 11-4: Concentrations of hydrocarbons in sediments from the Sigyn field, 2000. All values in mg/kg dry sediment.

Station	THC		NPD's		3-6 ring		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
SIG01	3.5	1.0	0.007	0.002	0.018	0.001	0.005	0.003
SIG02	3.6	0.9	n.a.		n.a.		n.a.	
SIG03	2.3	0.1	n.a.		n.a.		n.a.	
SIG04	3.9	0.2	0.005	0.000	0.015	0.001	0.010	0.008
SIG05	3.4	1.3	n.a.		n.a.		n.a.	
SIG06	5.4	2.1	n.a.		n.a.		n.a.	
SIG07	4.7	0.6	n.a.		n.a.		n.a.	
SIG08	5.2	0.4	n.a.		n.a.		n.a.	
SIG09	6.1	2.7	n.a.		n.a.		n.a.	
SIG10	3.9	0.4	n.a.		n.a.		n.a.	
SIG11	5.7	3.0	n.a.		n.a.		n.a.	
SIG12	1.6	1.0	n.a.		n.a.		n.a.	
SIG13	2.1	0.5	n.a.		n.a.		n.a.	
SIG14	3.3	0.4	n.a.		n.a.		n.a.	
SIG15	2.7	0.7	n.a.		n.a.		n.a.	
SIG16	4.1	1.7	n.a.		n.a.		n.a.	
SIG17R	2.9	1.0	0.007	0.002	0.022	0.004	0.018	0.006
Mean*	3.8	1.7	-		-		-	

n.a. Not analysed.
* Excl. reference station.

Table 11-5: Concentrations of hydrocarbons in vertical sections of the sediment samples from the Sigyn field, 2000. All concentrations in mg/kg dry sediment.

Station	Layer (cm)	THC	NPD's	3-6 ring	Decalins
SIG01	0-1	4.2	0.009	0.019	0.008
	1-3	6.1	0.011	0.016	0.031
	3-6	3.4	0.010	0.019	0.006
SIG04	0-1	4.0	0.005	0.014	0.004
	1-3	4.2	0.009	0.020	0.007
	3-6	3.2	0.009	0.019	0.010
SIG17R	0-1	2.9	0.010	0.021	0.028
	1-3	3.4	0.017	0.024	0.021
	3-6	3.6	0.019	0.032	0.033

n.a. Not analysed.

The THC values range from values below the background level across the shallow subregion (3.7 mg/kg) to 6.1 ± 2.7 mg/kg dry sediment (Table 11-4). None of the stations have THC contents above the calculated LSC. At SIG01 and SIG04 the hydrocarbon concentrations are at the same level as at the SIG17R down to 6 cm (Table 11-5). The highest amounts of aromatic hydrocarbons and decalins are found in the 3-6 cm layer at the field-specific reference station.

In general, low total hydrocarbon contents (2-6 mg/kg) are found in sediments from Sigyn. The amounts of THC, NPD´s, 3-6 ring aromatics and decalins are at the same level as those found in uncontaminated sediments from the neighbouring Sleipner Øst and Varg fields. The field is regarded as uncontaminated with THC, aromatic hydrocarbons and decalins.

The results of the metal analyses for the Sigyn field are summarised in Table 11-6. Concentrations of selected metals in the vertical sediment sections are presented in Table 11-7. The full data set of replicate measurements is given in the Appendix. Metal values are presented as histograms in Figure 11-3 and Figure 11-4.

Table 11-6: Concentrations of selected metals in sediments from the Sigyn field, 2000. All values in mg/kg dry sediment.

	Cd		Hg		Cu		Zn		Ba		Cr		Pb	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
SIG01	0.006	0.001	<0.005	-	0.4	0.2	4.0	0.2	16	4	9.7	0.3	6.2	0.2
SIG02	0.005	0.000	n.a.		<0.6	-	3.9	0.1	11	1	9.9	0.2	6.3	0.2
SIG03	0.007	0.004	n.a.		0.4	0.2	3.9	0.3	11	1	9.8	0.4	6.5	0.3
SIG04	0.005	0.001	<0.005	-	<0.6	-	4.0	0.2	11	2	9.8	0.2	6.3	0.3
SIG05	0.005	0.002	n.a.		<0.6	-	4.1	0.3	9	1	10.0	0.1	6.1	0.3
SIG06	0.007	0.006	n.a.		<0.6	-	3.9	0.3	11	3	9.7	0.2	6.0	0.1
SIG07	0.005	0.001	n.a.		<0.6	-	3.8	0.2	17	2	9.4	0.1	5.9	0.1
SIG08	<0.005	-	n.a.		<0.6	-	3.6	0.2	12	3	9.0	0.2	5.9	0.4
SIG09	0.004	0.002	n.a.		0.4	0.2	3.8	0.2	11	2	8.7	0.1	5.8	0.3
SIG10	0.005	0.002	n.a.		0.4	0.2	3.9	0.2	12	3	9.3	0.3	6.1	0.3
SIG11	0.003	0.001	n.a.		0.5	0.2	4.1	0.6	10	2	9.6	0.1	6.3	0.2
SIG12	0.004	0.001	n.a.		0.5	0.2	4.0	0.2	11	2	9.9	0.1	6.3	0.1
SIG13	<0.005	-	n.a.		0.4	0.2	3.8	0.2	11	2	10.0	0.2	6.4	0.2
SIG14	<0.005	-	n.a.		<0.6	-	3.7	0.1	13	4	9.5	0.2	5.9	0.2
SIG15	<0.005	-	n.a.		0.4	0.2	3.9	0.2	10	1	9.3	0.1	6.0	0.2
SIG16	<0.005	-	n.a.		0.5	0.2	3.6	0.3	23	8	8.6	0.3	5.8	0.2
SIG17R	0.004	0.002	<0.005	-	0.5	0.2	3.7	0.3	13	2	7.8	0.3	5.5	0.2
Mean*	0.004	0.002	<0.005	-	0.4	0.1	3.9	0.3	12	4	9.5	0.5	6.1	0.3

n.a. Not analysed.
* Excl. reference station.

Table 11-7: Concentrations of selected metals in vertical sections of the sediment samples from the Sigyn field. All concentrations in mg/kg dry sediment.

Station	Layer (cm)	Cd	Hg	Cu	Zn	Ba	Cr	Pb
SIG01	0-1	0.006	<0.005	<0.6	4.2	20	10.0	6.4
	1-3	<0.005	<0.005	<0.6	4.2	15	9.8	6.2
	3-6	0.007	<0.005	<0.6	4.0	22	9.7	6.5
SIG04	0-1	0.005	<0.005	<0.6	4.1	10	9.8	6.1
	1-3	0.007	<0.005	<0.6	4.6	12	10.0	5.9
	3-6	0.010	<0.005	<0.6	4.4	32	10.0	6.2
SIG17R	0-1	0.005	<0.005	0.6	4.0	16	8.0	5.8
	1-3	0.005	<0.005	0.6	3.8	20	7.7	5.5
	3-6	0.009	<0.005	0.6	3.8	52	7.8	5.8

n.a. Not analysed.

The content of cadmium, copper, zinc and barium range from values below to values barely above the corresponding background levels across the shallow sub region (see Regional and reference stations), while the contents of chromium and lead are slightly higher than the corresponding background levels. None of the stations have metal contents above the calculated LSC. At SIG01 the metals are even distributed down to 6 cm depth (Table 11-6). At SIG04 the 3-6 cm layer has higher content of cadmium and barium than the 0-1 and 1-3 cm layers, but the levels does not exceed the concentrations found in the sectioned sediment samples at the Sigyn reference station.

Mercury is not detected in any of the replicate sediment samples from the Sigyn reference station. Mercury is nor detected in sediments from SIG01 and SIG04 (Table 11-5 and Table 11-7.)

In general, the selected metals were very evenly distributed over the Sigyn field. The field is deemed uncontaminated with regard to metals.

In the 2000 baseline survey of the Sigyn field, the THC content at the field-specific reference station (SIG17R) is 2.9 ± 1.0 mg/kg dry sediment *i.e.* comparable to the amount found across the shallow sub region (3.7 ± 1.4 mg/kg). The content of NPD's, 3-6 ring aromatics and decalins comparable to the corresponding values found at the Sleipner Øst reference station (see Sleipner Øst survey.) The concentrations of selected metals are comparable to those found across the shallow sub region (see Regional and reference stations).

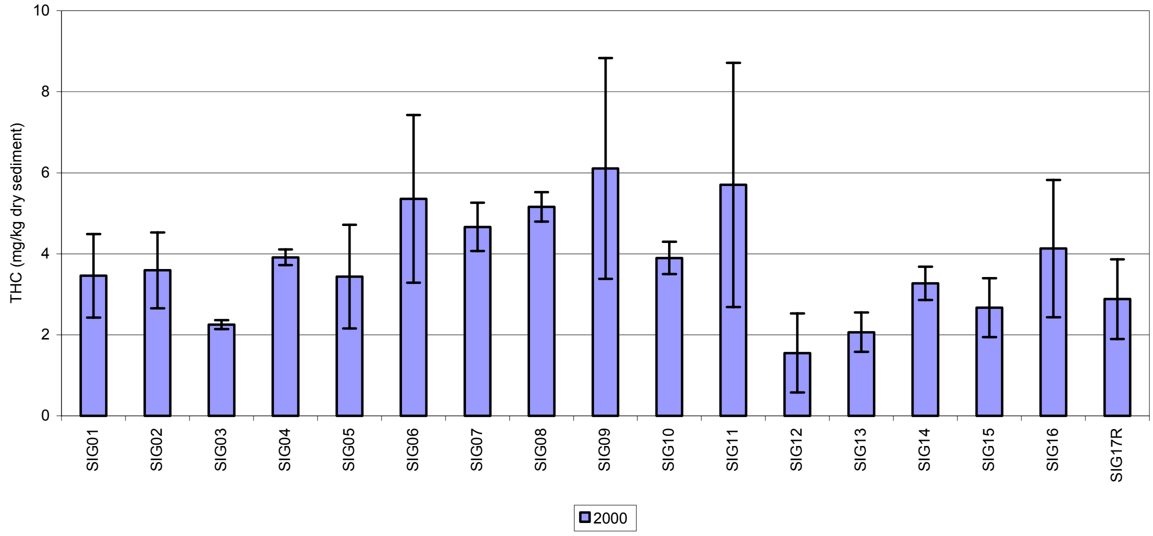

Figure 11-2: THC levels in sediment from the present (2000) survey, Sigyn field.

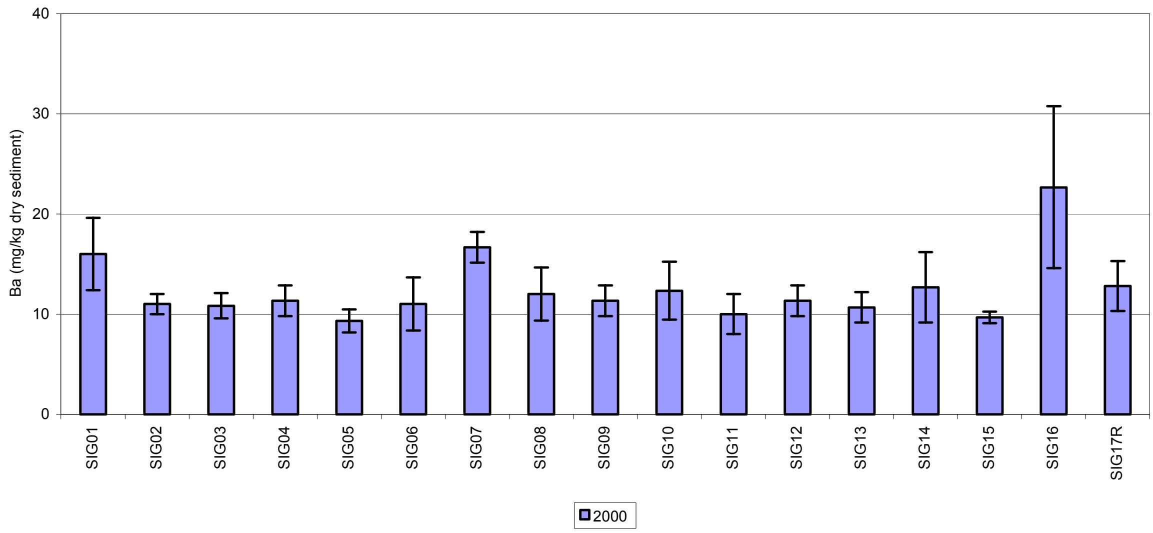

Figure 11-3: Barium levels in sediment from the present (2000) survey, Sigyn field.

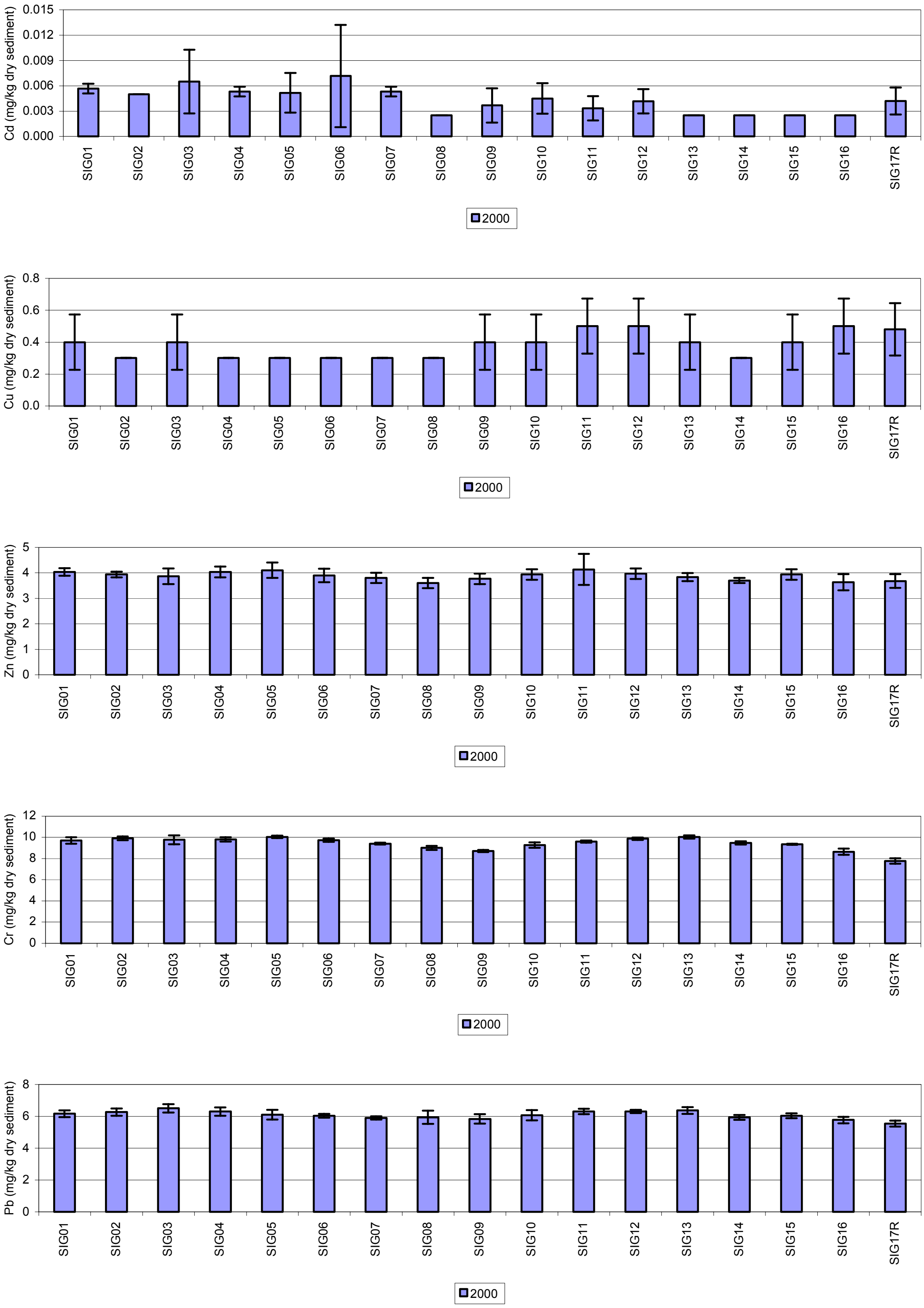

Figure 11-4: Levels of selected metals in sediments from the present (2000) survey, Sigyn field.

11.2.3 Biology

The distribution of individuals and taxa within the main taxonomic groups are given in Table 11-8. A total of 5467 individuals within 142 taxa are recorded at the Sigyn field in the present survey (excluding juveniles). The polychaetes dominate the fauna with 42 % of the individuals and 44 % of the taxa recorded.

Table 11-8: Distribution of individuals and taxa within the main taxonomic groups at Sigyn, 2000 (excluding juveniles).

Main taxonomic groups	Individuals		Taxa	
	Number	%	Number	%
Polychaeta	2302	42	62	44
Mollusca	677	12	30	21
Crustacea	889	16	30	21
Echinodermata	1150	21	5	4
Diverse groups	449	8	15	11
Total	5467	100	142	100

The species/area curve for the field reference station is shown in Figure 11-5. A total of 72 taxa are recorded in the ten grab samples, of which 24 (33 %) occur in the first sample and 59 (81 %) in the first five samples. The curve shows that not all taxa present in the area are represented in ten samples, but the representativity of five samples is considered to be relatively good.

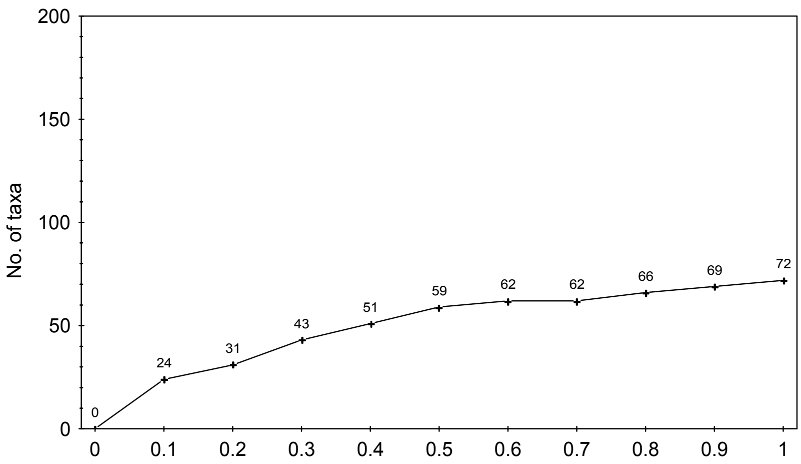

Figure 11-5: Species/area curve for the reference station at the Sigyn field (area in m^2).

The number of individuals and taxa at each station, together with selected community indices is presented in Figure 11-6 and Table 11-9. The number of individuals recorded at Sigyn varies from 219 (SIG11) to 414 (SIG08). The number of taxa varies from 37 (SIG11) to 65 (SIG08), the diversity index H' from 4.2 (SIG11) to 4.8 (SIG15, SIG08), the evenness index J from 0.76 (SIG12) to 0.82 (SIG15) and the ES_{100} between 27 (SIG11) to 35 (SIG15). The corresponding values at the reference station SIG17R lies within the variation at the field stations. The low number of individuals and taxa are comparable to those recorded at the neighbouring Varg and Sleipner Øst fields.

Table 11-9: Number of individuals, taxa and selected community indices for each station (0.5 m^2) at the Sigyn field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	No. of indiv.	No. of taxa	H'	J	ES100
SIG01	288	53	4.5	0.78	31
SIG02	326	55	4.7	0.80	32
SIG03	338	53	4.4	0.77	29
SIG04	353	51	4.5	0.79	30
SIG05	318	54	4.7	0.81	32
SIG06	356	56	4.5	0.78	31
SIG07	386	59	4.7	0.79	32
SIG08	**414**	**65**	**4.8**	0.79	34
SIG09	287	52	4.4	0.77	31
SIG10	275	46	4.4	0.80	29
SIG11	**219**	**37**	**4.2**	0.80	**27**
SIG12	320	54	4.4	**0.76**	30
SIG13	317	64	4.6	0.77	34
SIG14	302	51	4.5	0.79	30
SIG15	320	57	**4.8**	**0.82**	**35**
SIG16	382	58	4.6	0.79	31
SIG17R	266	59	4.7	0.77	35
Sum*	5467				
Average*	325,1	54	4.5	0.79	31
St. dev.*	47,6	7	0.16	0.02	2

*Excluding the reference station.

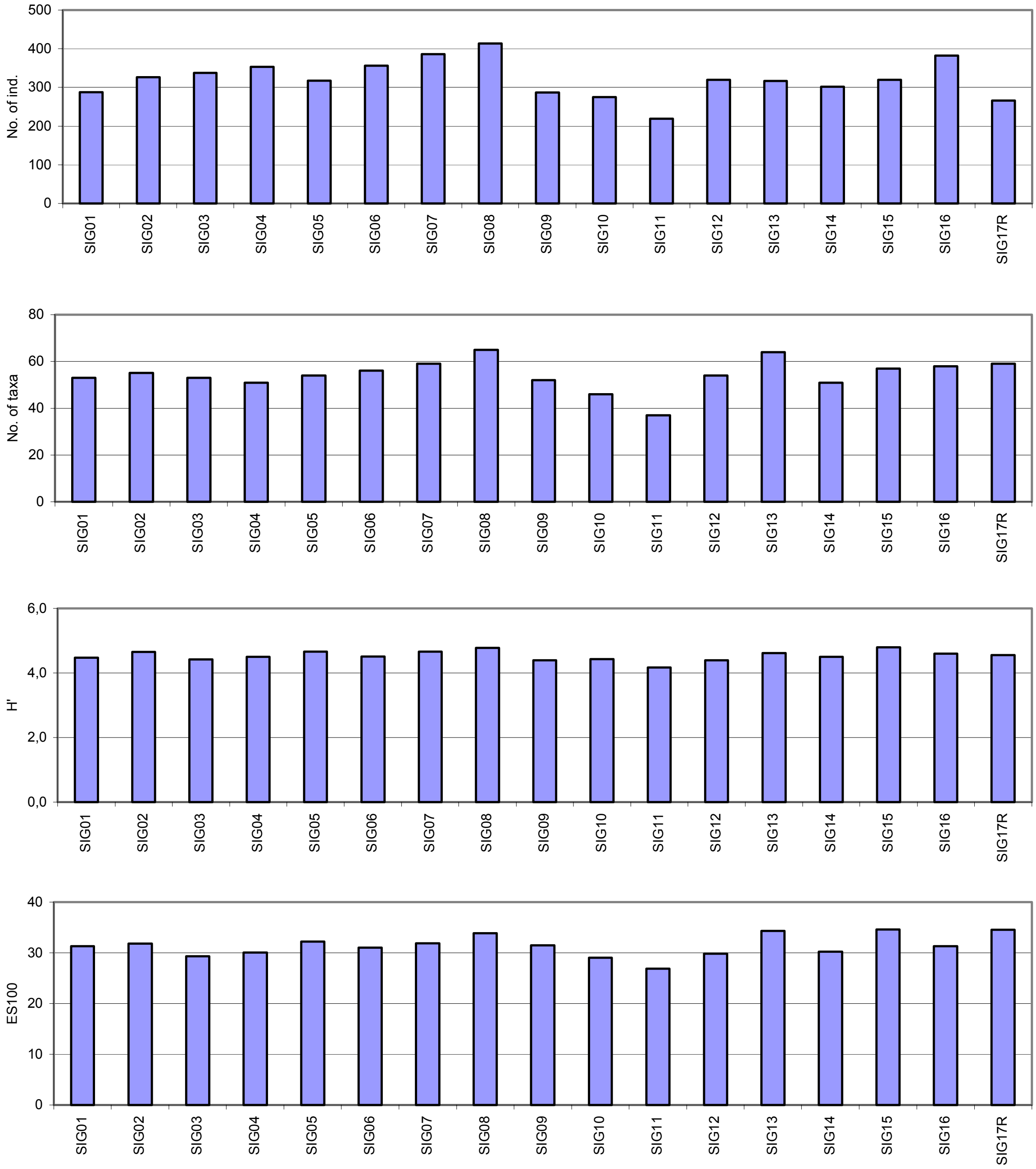

Figure 11-6: Biological characteristics at the Sigyn field, 2000.

The distribution of taxa in geometrical classes at each station is shown in Figure 11-7. Ten stations had taxa in class 7 (64-127) and the rest of the stations fell inn class 6 (32-63) or lower. These results do not indicate disturbance of the fauna at any of the stations.

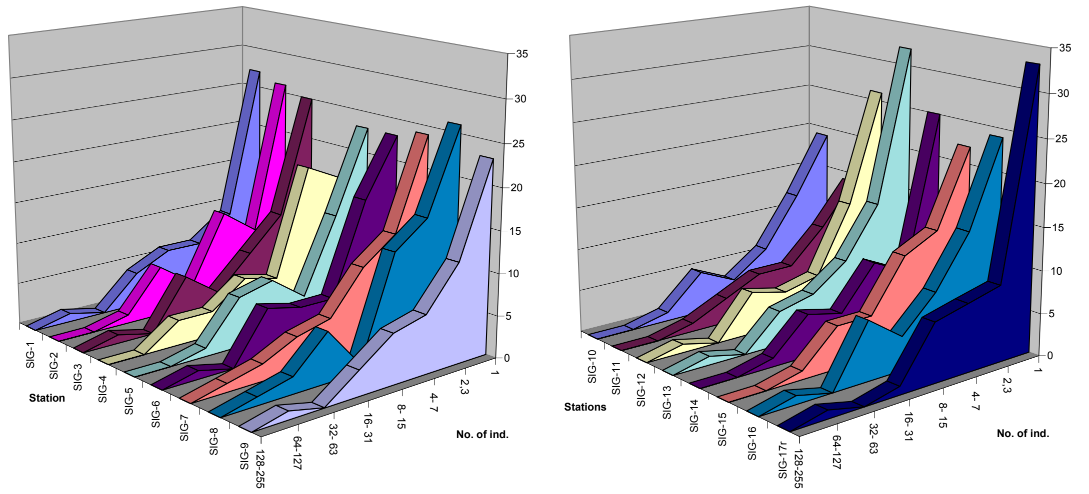

Figure 11-7: Distribution of taxa in geometrical classes from the stations at Sigyn,2000.

The ten most dominant taxa at each station are shown in Table 11-11 at the end of this chapter. A total of 19 taxa, including one juvenile group, are among the ten most dominant taxa at one or more stations. These 19 taxa comprise 87 % of the total number of individuals and 13 % of the total number of taxa recorded at the Sigyn field in the present survey.

The most dominant taxa among the adult forms are the brittle star *Amphiura filiformis,* the polychaetes *Spiophanes bombyx, Goniada maculata, Spiophanes kroyeri,* the crustacean *Eudorellopsis deformis* and *Bathyporeia* sp.*,* the bivalve *Mysella* sp. and the phoronid *Phoronis* sp. The brittle star *A. filiformis* is the most dominant species at all stations while the other above mentioned taxa are among the most dominant taxa at 13 to 17 stations. These results indicate a uniform distribution of undisturbed fauna over the field as a whole.

The ten most abundant taxa at the stations comprise between 62 % (station SIG15) and 76 % (station SIG10) of the total number of individuals recorded at the respective stations. The corresponding value at the reference station SIG17R is 67 %.

Figure 11-8 shows the dendrogram from the cluster analysis for the field stations and regional and reference stations while Figure 11-9 shows the 2-D plot from the MDS analysis.

In the cluster analysis, regional station RII06 and the reference stations at Varg and Sleipner Øst are separated out at dissimilarity levels between 40 and 45 %, the field stations SIG10 and SIG11 at 39 % while the remaining field stations are separated into two main groups at 35 % dissimilarity level. The correlation coefficient shows a good fit to the data (r = 0.82).

The MDS analyses supports the results from the cluster analysis with the reference stations at Varg and Sleipner Øst and regional station RII06 separated from the field stations where stations SIG10 and SIG11 are somewhat away from the other stations in the 2-D plot. The stress test shows a poor fit to the data.

These results indicate a fairly uniform distribution of the fauna over the field.

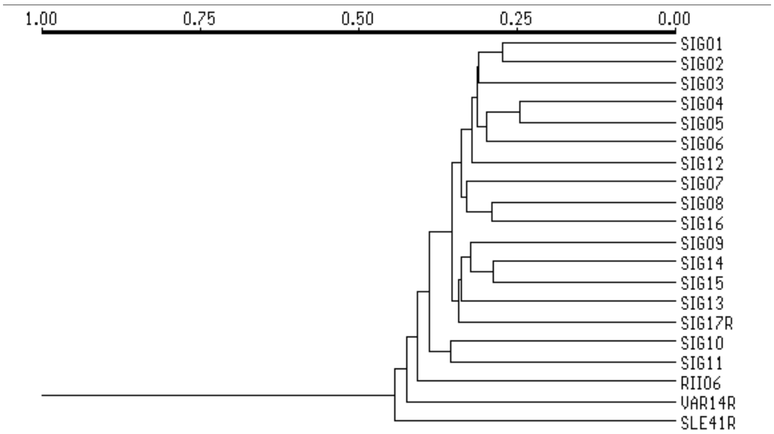

Figure 11-8: Cluster analysis of the Sigyn field stations and selected regional and reference stations from Region II, 2000.

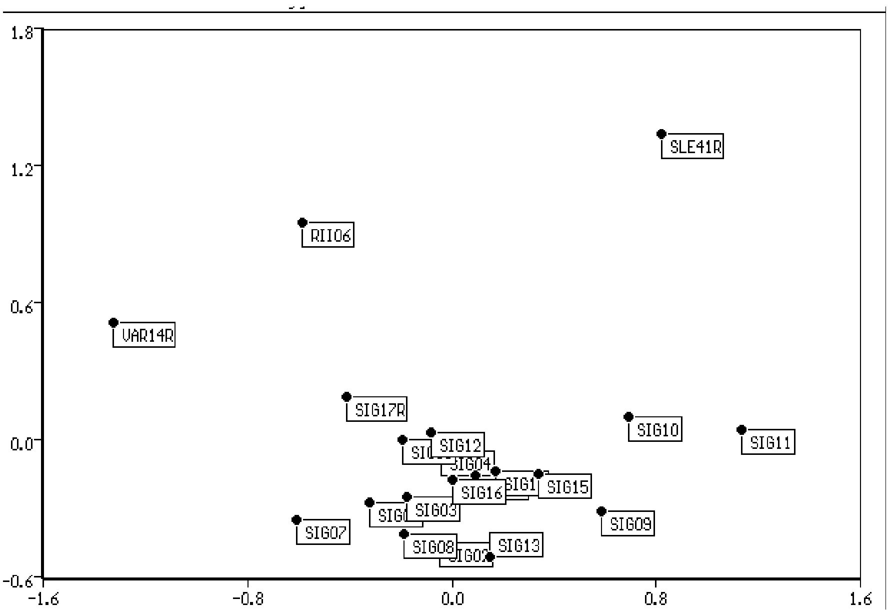

Figure 11-9: 2-D plot from the MDS analysis carried out on the station data form Sigyn field and selected regional and reference stations from Region II, 2000.

A Canonical Correspondence Analysis (CCA) of the data from the Sigyn field together with selected regional and reference stations was carried out to examine the association between the biological data and the measured environmental variables in these areas.

Through the forward selection procedure in CANOCO, four of ten variables gave the best fit and were significant. 22.6 % of the biological variance was explained by the first two axes of the ordination space which is constrained by these environmental variables.

Figure 11-10 shows a biplot from the analysis using copper (Cu), zinc (Zn), barium (Ba) and pelite (Pel) as the constraining environmental variables. The first axis shows a gradient from the reference station at Sleipner Øst on the positive end to field station SIG07 at the negative end and was positively correlated with the amount of copper in the sediments (+ 0.73). Taxa with highest contribution on this axis are the bivalve *Mysella* sp. (38.2 %) and the polychaete *Spiophanes kroyeri* (2.3 %). Many other taxa had also high contribution, but occurred in very low numbers and are therefore not significant.

The second axis shows a gradient from the reference station at Varg at the positive end to regional station RII06 at the negative end and is positive correlated with the amount of pelite (+ 0.91), barium

(+ 0.60) and copper (+ 0.52) in the sediments. None of the abundant taxa had high contribution on this axis.

The levels of the heavy metals at the field stations are lower than the LSC values for the area. Therefore, the minor differences that are seen in the faunal distribution are attributed to natural variations in the sediment structure.

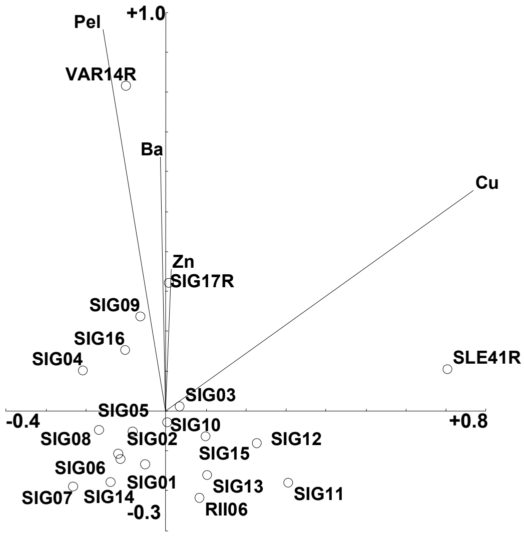

Figure 11-10: Biplot from the CCA analysis for the Sigyn field and selected regional and reference stations from Region II, 2000.

On the basis of the results from the uni- and multivariate analyses carried out, all stations at Sigyn are classified as group A (undisturbed fauna, see Table 11-10). The numbers of taxa and individuals are very low, but at a similar level as the neighbouring Varg and Sleipner Øst fields. The fauna has a uniform distribution over the field and the minor differences that occur are believed to be a result of natural variation in the sediments. All analysed chemical parameters are found at levels that are below the LSC value.

Table 11-10: Classification into impact groups, distance to installation and biological statistics for the field stations at Sigyn field, 2000.

Station	Impact group	Dist. (m)	Statistics			No. of individuals							
			No. ind	No. taxa	H'	Afi	Sbo	Skr	Ede	Psp	Gma	Sar	Bsp
SIG01	A	2000	288	53	4,47	68	29	12	17	13	17	19	10
SIG02	A	1000	326	55	4,65	56	27	0	18	14	24	20	23
SIG03	A	500	338	53	4,41	72	27	24	27	12	25	17	22
SIG04	A	250	353	51	4,49	60	35	15	29	12	24	25	35
SIG05	A	250	318	54	4,66	59	21	17	24	13	24	17	10
SIG06	A	500	356	56	4,51	81	23	24	22	0	21	10	11
SIG07	A	1000	386	59	4,66	67	25	35	32	22	23	11	24
SIG08	A	2000	414	65	4,77	72	38	22	25	32	23	18	21
SIG09	A	2000	287	52	4,39	78	22	16	15	13	12	11	9
SIG10	A	1000	275	46	4,43	44	21	24	23	10	13	13	20
SIG11	A	500	219	37	4,17	52	19	0	16	13	11	12	0
SIG12	A	250	320	54	4,40	71	30	14	29	0	14	17	18
SIG13	A	250	317	64	4,62	76	14	16	16	15	12	0	19
SIG14	A	500	302	51	4,49	59	25	22	18	14	26	11	20
SIG15	A	1000	320	57	4,80	57	17	11	24	15	22	11	11
SIG16	A	2000	382	58	4,60	71	26	25	29	25	21	15	30
SIG17R	A	5000	266	59	4,56	72	13	8	15	11	16	13	11
RII06	A	-	245	54	4.6	47	11	10	16	13	29	10	8
SLE41R	A	-	340	46	4.0	75	16	0	13	14	12	0	16
VAR14R	A	-	236	53	4.6	56	13	12	13	13	12	17	0

Afi = *Amphiura filiformis,* Sbo = *Spiophanes bombyx*, Skr = *Spiophanes kroyeri*, Ede = *Eudorellopsis deformis*, Psp = *Phoronis* sp., Gma = *Goniada maculata*, Sar = *Scoloplos armiger*, Bsp = *Bathyporeia* sp.

11.3 Summary and conclusions

The sediments at Sigyn are classified as fine sand and the sediment conditions are relatively uniform over the field with pelite values between 1.7 and 2.2 % and fine sand between 85 and 92 %. These values are similar to those recorded at the neighbouring Varg and Sleipner Øst fields.

The Sigyn field is located in shallow area south in Region II. Low total hydrocarbon contents (2-6 mg/kg) are found in sediments from Sigyn. The average amounts of THC across Sigyn are comparable to the levels found in uncontaminated sediments from the neighbouring Sleipner Øst and Varg fields. The content of cadmium, copper, zinc and barium range from values below to values barely above the corresponding background levels across the shallow sub region, while the contents of chromium and lead are slightly higher than the corresponding background levels. The Sigyn field is uncontaminated with hydrocarbons and selected metals.

The number of taxa and individuals are relatively low at all stations, but are at the same level as those recorded at the neighbouring fields. The analyses show that the field has a uniform distributed and undisturbed fauna. The minor differences that are detected are believed to be a result of natural variation in the sediment conditions over the area and do not indicate field-related disturbance.

Table 11-11: Number of individuals and the accumulative abundance for the ten most dominant taxa at each station at the Sigyn field, 2000.

SIG01 (10°/ 2000m)	No. ind	Acc. %	SIG02 (10°/ 1000m)	No. ind	Acc. %	SIG03 (10°/ 500m)	No. ind	Acc. %	SIG04 (10°/ 250m)	No. ind	Acc. %	SIG05 (100°/ 250m)	No. ind	Acc. %
Amphiura filiformis	68	23 %	Amphiura filiformis	56	17 %	Amphiura filiformis	72	21 %	Amphiura filiformis	60	16 %	Amphiura filiformis	59	18 %
Spiophanes bombyx	25	32 %	Spiophanes bombyx	29	25 %	Eudorellopsis deformis	27	28 %	Bathyporeia sp.	35	26 %	Eudorellopsis deformis	24	26 %
Scoloplos armiger	19	38 %	Goniada maculata	24	33 %	Spiophanes bombyx	27	36 %	Spiophanes bombyx	35	35 %	Goniada maculata	24	33 %
Eudorellopsis deformis	17	44 %	Bathyporeia sp.	23	39 %	Goniada maculata	25	43 %	Eudorellopsis deformis	29	43 %	Spiophanes bombyx	21	39 %
Goniada maculata	17	50 %	Scoloplos armiger	20	45 %	Spiophanes kroyeri	24	50 %	Scoloplos armiger	25	50 %	Scoloplos armiger	17	45 %
Phoronis sp.	13	54 %	Eudorellopsis deformis	18	51 %	Bathyporeia sp.	22	56 %	Goniada maculata	24	57 %	Spiophanes kroyeri	17	50 %
Mysella sp.	12	58 %	Mysella sp.	17	56 %	Scoloplos armiger	17	61 %	Spiophanes kroyeri	15	61 %	Paramphinome jeffreysii	16	55 %
Spiophanes kroyeri	12	62 %	Phoronis sp.	14	60 %	Mysella sp.	14	65 %	Phoronis sp.	12	64 %	Phoronis sp.	13	59 %
Bathyporeia sp.	10	66 %	Abra prismatica	12	64 %	Phoronis sp.	12	69 %	Abra prismatica	9	66 %	Bathyporeia sp.	10	62 %
Paramphinome jeffreysii	10	69 %	Paramphinome jeffreysii	11	67 %	Ophiuroidea indet. juv.	11	72 %	Mysella sp.	9	69 %	Abra prismatica	9	65 %
									Nephtys caeca	9	71 %	Mysella sp.	9	67 %
SIG06 (100°/ 500m)	No. ind	Acc. %	SIG07 (100°/ 1000m)	No. ind	Acc. %	SIG08 (100°/ 2000m)	No. ind	Acc. %	SIG09 (280°/ 2000m)	No. ind	Acc. %	SIG10 (280°/ 1000m)	No. ind	Acc. %
Amphiura filiformis	81	22 %	Amphiura filiformis	67	17 %	Amphiura filiformis	72	17 %	Amphiura filiformis	78	27 %	Amphiura filiformis	44	15 %
Mysella sp.	24	28 %	Spiophanes kroyeri	35	26 %	Spiophanes bombyx	38	25 %	Spiophanes bombyx	22	34 %	Mysella sp.	28	25 %
Spiophanes kroyeri	24	35 %	Eudorellopsis deformis	32	34 %	Phoronis sp.	32	33 %	Mysella sp.	17	40 %	Spiophanes kroyeri	24	34 %
Spiophanes bombyx	23	41 %	Spiophanes bombyx	25	40 %	Eudorellopsis deformis	25	38 %	Spiophanes kroyeri	16	45 %	Eudorellopsis deformis	23	42 %
Eudorellopsis deformis	22	47 %	Bathyporeia sp.	24	46 %	Goniada maculata	23	44 %	Eudorellopsis deformis	15	50 %	Spiophanes bombyx	21	49 %
Paramphinome jeffreysii	22	53 %	Goniada maculata	23	52 %	Spiophanes kroyeri	22	49 %	Phoronis sp.	13	55 %	Bathyporeia sp.	20	56 %
Goniada maculata	21	58 %	Phoronis sp.	22	57 %	Bathyporeia sp.	21	53 %	Goniada maculata	12	59 %	Goniada maculata	13	60 %
Nemertini indet.	13	62 %	Paramphinome jeffreysii	14	61 %	Magelona filiformis	19	58 %	Abra prismatica	11	63 %	Scoloplos armiger	13	65 %
Bathyporeia sp.	11	65 %	Nemertini indet.	11	63 %	Scoloplos armiger	18	62 %	Scoloplos armiger	11	66 %	Phoronis sp.	10	69 %
Scoloplos armiger	10	68 %	Scoloplos armiger	11	66 %	Ophiuroidea indet. juv.	14	65 %	Bathyporeia sp.	9	69 %	Abra prismatica	7	71 %
												Ophiuroidea indet. juv.	7	73 %
												Paramphinome jeffreysii	7	76 %

Continue Table 11-11

SIG11 (280°/ 500m)	No. ind	Acc. %	SIG12 (280°/ 250m)	No. ind	Acc. %	SIG13 (190°/ 250m)	No. ind	Acc. %	SIG14 (190°/ 500m)	No. ind	Acc. %	SIG15 (190°/ 1000m)	No. ind	Acc. %
Amphiura filiformis	52	23 %	Amphiura filiformis	71	22 %	Amphiura filiformis	76	23 %	Amphiura filiformis	59	18 %	Amphiura filiformis	57	17 %
Mysella sp.	19	31 %	Spiophanes bombyx	30	31 %	Mysella sp.	30	33 %	Goniada maculata	26	26 %	Eudorellopsis deformis	24	24 %
Spiophanes bombyx	19	39 %	Eudorellopsis deformis	29	40 %	Bathyporeia sp.	19	39 %	Spiophanes bombyx	25	34 %	Goniada maculata	22	31 %
Eudorellopsis deformis	16	46 %	Mysella sp.	24	47 %	Eudorellopsis deformis	16	44 %	Spiophanes kroyeri	22	41 %	Mysella sp.	21	37 %
Phoronis sp.	13	52 %	Bathyporeia sp.	18	52 %	Spiophanes kroyeri	16	48 %	Bathyporeia sp.	20	47 %	Spiophanes bombyx	17	42 %
Scoloplos armiger	12	57 %	Scoloplos armiger	17	58 %	Phoronis sp.	15	53 %	Eudorellopsis deformis	18	53 %	Paramphinome jeffreysii	16	47 %
Goniada maculata	11	62 %	Goniada maculata	14	62 %	Spiophanes bombyx	14	57 %	Phoronis sp.	14	57 %	Phoronis sp.	15	52 %
Ampelisca macrocephala	9	66 %	Spiophanes kroyeri	14	66 %	Goniada maculata	12	61 %	Ophiuroidea indet. juv.	13	61 %	Bathyporeia sp.	11	55 %
Paramphinome jeffreysii	9	70 %	Paramphinome jeffreysii	12	70 %	Nemertini indet.	12	65 %	Scoloplos armiger	11	65 %	Scoloplos armiger	11	58 %
Sthenelais limicola	6	73 %	Nemertini indet.	9	73 %	Paramphinome jeffreysii	9	68 %	Anobothrus gracilis	9	68 %	Spiophanes kroyeri	11	62 %

SIG16 (190°/ 2000m)	No. ind	Acc. %	SIG17R (190°/ 5000m)	No. ind	Acc. %
Amphiura filiformis	71	18 %	Amphiura filiformis	72	26 %
Bathyporeia sp.	30	26 %	Goniada maculata	16	32 %
Eudorellopsis deformis	29	33 %	Eudorellopsis deformis	15	37 %
Spiophanes bombyx	26	39 %	Scoloplos armiger	13	42 %
Phoronis sp.	25	46 %	Spiophanes bombyx	13	47 %
Spiophanes kroyeri	25	52 %	Mysella sp.	12	51 %
Goniada maculata	21	57 %	Bathyporeia sp.	11	55 %
Paramphinome jeffreysii	19	62 %	Phoronis sp.	11	59 %
Scoloplos armiger	15	66 %	Spiophanes kroyeri	8	62 %
Abra prismatica	10	69 %	Ophiuroidea indet. juv.	7	65 %
			Owenia fusiformis	7	67 %

Table 11-12: Station information for Sigyn field, 2000.

St. no.	Distance (m)	Direction (degr.)	Volume (litres)
SIG01	2000	10	27
SIG02	1000	10	32
SIG03	500	10	29
SIG04	250	10	29
SIG05	250	100	35
SIG06	500	100	36
SIG07	1000	100	37
SIG08	2000	100	36
SIG09	2000	280	33
SIG10	1000	280	37
SIG11	500	280	34
SIG12	250	280	35
SIG13	250	190	34
SIG14	500	190	36
SIG15	1000	190	38
SIG16	2000	190	39
SIG17R	5000	190	33 *

* The additional five grab samples taken gave 36 litres of sediment.

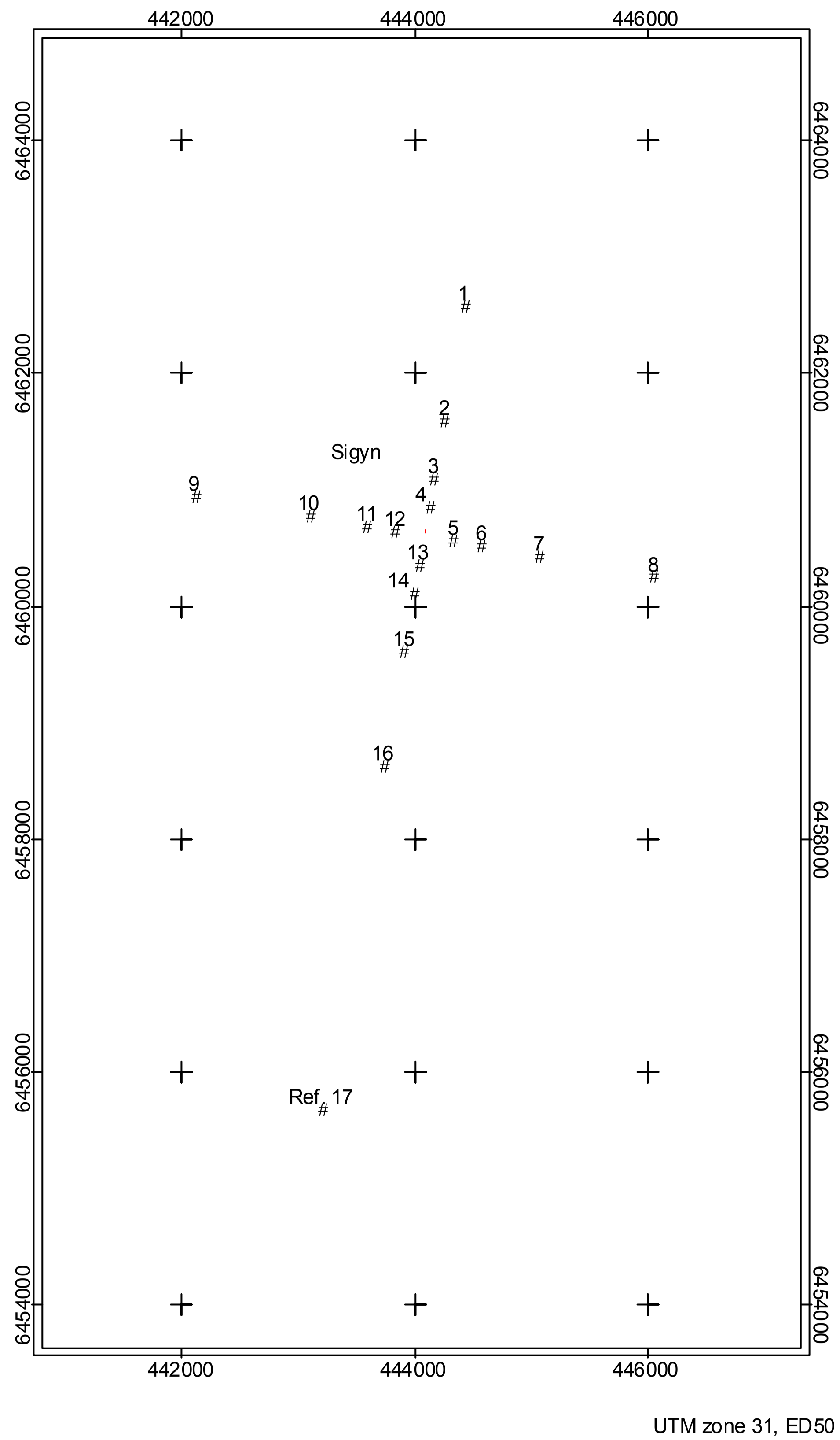

Figure 11-11: Map of sampling positions for Sigyn field, 2000

12 Balder field

12.1 Introduction

The Balder field is located in Block 25/11 of the Norwegian sector in the North Sea. Production drilling at the field started in May 1996, and was completed in December 1998. The production ship on the field, Balder FPU, is connected to four sub sea installations (A, B, C and D). During the previous surveys in 1996 and 1997, the same installations were named D, C, B and A, respectively. Data on recent drilling and discharges are given in Table 12-1.

At this field baseline and monitoring surveys have been carried out in 1996 (Jensen *et al*., 1997) and in 1997 (Mannvik *et al*., 1998). In 1997 the survey did show contamination of hydrocarbons plus olefins at the stations placed on the well templates C and A, while the 250-500 m stations on the same axis were contaminated with barium. Well template D had contamination of hydrocarbons out to 500 m and for barium extends out to 1000 m. From well template B the area contaminated with hydrocarbons and barium extended out to 500 m on the 198° axis and out to 1000 m on the 135° axis. In 1997 the fauna was found to be slightly disturbed at eight stations situated 250 – 500 m from the centres (stations 9, 16, 22, 33, 37, 42, 45 and 46).

Information on the sampling stations is shown in Figure 12-17 and Table 12-13, both on the foldout page at the end of this chapter (page 12-29).

Table 12-1: Summary of recent wells drilled and operational and accidental discharges at the Balder field, (all discharges in tonnes).

	1997	1998	1999	2000	Comments
No of wells drilled	4	3	0	0	
Barite	2059	1643	0	0	
Cuttings	2682	2797	0	0	
Base oil (with cuttings)**	70	0	0	0	** AncoTecB (Poly-α-olefins C14/C16)
Water-based drilling mud	3786	3187	0	0	
Cementing and other chemicals	16,13	1,55	0	0	
Completion chemicals	1791,59	46,73	0	0	
Oil in produced water	0	0	0	3,95*	*=21 ppm $\times$ 188223 Sm^3

12.2 Results and discussion

12.2.1 Physical characteristics

The median phi value and the amount (%) of pelite, fine sand and total organic material (TOM) in the sediment from the present and previous surveys are shown in Table 12-2 and Figure 12-1. 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 in the area are classified as fine sand with median values varying from 3.69 at station BAL12 to 4.15 at station BAL24. The amount of pelite in the sediment varies from 6.86 % (BAL39) to 14.08 % (BAL05), the fine sand from 82.9 (BAL12) to 92.5 % (BAL39) while the TOM varies between 1.72 % (BAL37) to 2.67 % (BAL04). The pelite content is higher at the reference station BAL27R than at the field stations.

The TOM value has decreased remarkably from the previous survey at stations BAL03, BAL04, BAL33 and BAL42, situated in the vicinity of template D and A. On the other hand the TOM has increased at the reference station.

Table 12-2: The median (phi) and amount of pelite, fine sand and TOM in the sediment from stations at the Balder field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	Distance (m)	Direction (degr.)	Median	Classification	Pelite	Fine sand	TOM
BAL03	250	54	3.87	Fine sand	12.60	86.6	2.17
BAL04	500	54	3.75	Fine sand	13.52	85.6	**2.67**
BAL05	1000	54	3.82	Fine sand	**14.08**	84.7	2.31
BAL09	250	135	3.83	Fine sand	13.96	84.4	2.44
BAL10	500	135	3.76	Fine sand	12.65	85.8	2.46
BAL11	1000	135	3.73	Fine sand	11.53	85.8	2.11
BAL12	2000	135	**3.69**	Fine sand	13.49	**82.9**	1.88
BAL16	250	198	3.71	Fine sand	11.15	88.0	1.82
BAL17	500	198	3.84	Fine sand	12.71	85.2	2.35
BAL18	1000	198	3.81	Fine sand	9.91	88.9	1.93
BAL22	250	270	3.90	Fine sand	13.40	85.9	1.91
BAL23	500	270	3.89	Fine sand	13.70	85.5	2.25
BAL24	1000	270	**4.15**	Silt	12.99	85.7	1.88
BAL28	250	135	3.65	Fine sand	8.42	90.6	2.10
BAL29	500	135	3.79	Fine sand	12.22	86.7	2.44
BAL30	1000	135	3.70	Fine sand	12.32	86.5	2.13
BAL31	2000	135	3.73	Fine sand	12.59	84.9	2.08
BAL33	250	315	3.73	Fine sand	11.86	87.0	2.10
BAL34	500	315	3.78	Fine sand	12.65	83.8	2.32
BAL35	1000	315	3.77	Fine sand	13.06	86.4	1.73
BAL37	250	135	3.71	Fine sand	10.78	88.0	**1.72**
BAL38	500	135	3.71	Fine sand	10.74	88.6	2.00
BAL39	1000	135	3.73	Fine sand	**6.86**	**92.5**	2.21
BAL42	250	180	3.79	Fine sand	12.33	86.9	1.94
BAL43	500	180	3.73	Fine sand	13.17	86.0	2.11
BAL44	1000	180	3.77	Fine sand	12.19	87.0	2.00
BAL46	500	315	3.96	Fine sand	12.67	86.6	1.96
BAL47	1000	315	3.89	Fine sand	14.02	85.0	2.21
BAL27R	10000	315	4.10	Silt	14.70	84.9	2.38
Average *			3.79		12.20	86.5	2.12
St. dev. *			0.10		1.66	2.0	0.23

* Excluding the reference station.

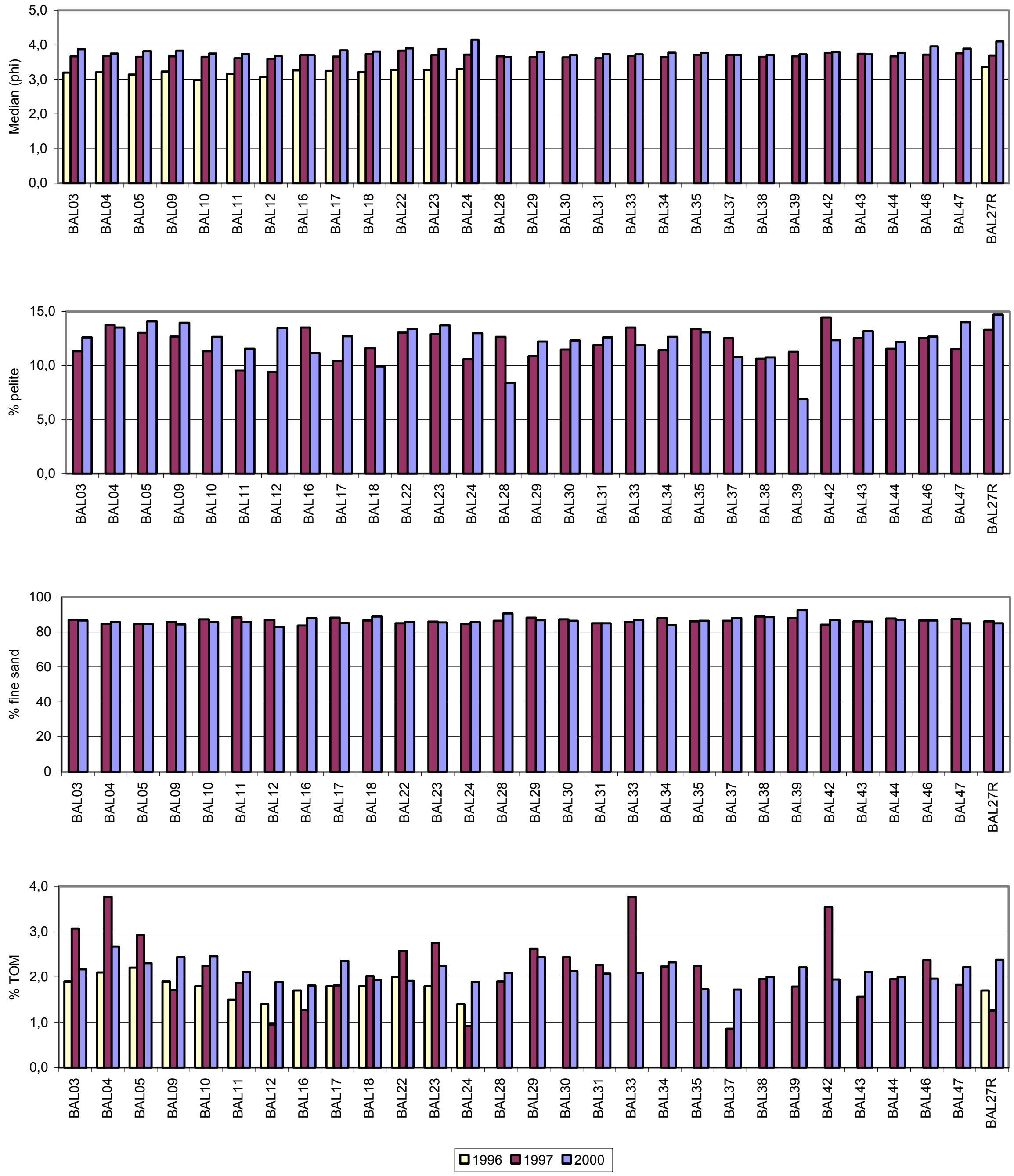

Figure 12-1: Sediment characteristics at the Balder field in 2000 and previous years.

12.2.2 Chemical characteristics

The calculated limits of significant contamination for selected hydrocarbons and metals in sediments from Region II ($LSC_{97\text{-}00\ RegII}$) are presented previously in the chapter that deals with the regional and reference stations. In addition to the regional limits, field-specific limits of significant contamination are calculated from the reference station ($LSC_{00\ BAL27R}$). Both sets of data are presented in Table 12-3. Balder has somewhat higher levels of metals than most of the other fields in Region II (see Regional and reference stations chapter). The limits of significant contamination based on sediments from the reference station are therefore correspondingly higher than the limits calculated for the whole region. Based on the analysis results of the Balder field, both LSC´s are used as a basis by which to assign areas contaminate with the chemical parameters. The sediments from Balder are, in addition to the standard parameters, analysed for olefins. Synthetic base oil as olefins, that are included in synthetic drilling mud, is not naturally present in uncontaminated sediments. If olefins are found in the sediments, the sediments are considered as contaminated.

The results of analyses of the hydrocarbons and components of synthetic base oil analyses are summarised in Table 12-4. Concentrations of selected compounds in vertical sediment sections are presented in Table 12-5. The full data set of replicate measurements and data from previous years are given in the Appendix. THC values and content of synthetic base oil from 2000 are compared with those from previous years in Figure 12-3 and Figure 12-4 respectively.

Table 12-3: Background levels and Limits of Significant Contamination for the Balder field, 2000. All values in mg/kg dry sediment.

	THC	NPD's	3-6 ring	Decalins	Cd	Hg	Cu	Zn	Ba	Cr	Pb
$LSC_{00\ BAL27R}$	9.3	0.056	0.155	0.046	0.035	0.009	2.5	10.7	155	9.3	7.7
$LSC_{97\text{-}00\ RegII}$	9.8	*	*	*	0.029	0.008	2.0	8.9	146	9.6	7.0

*) Regional stations not analysed for NPD's, 3-6 ring aromatics and decalins.

Table 12-4: Concentrations of hydrocarbons and synthetic base oil in sediments from the Balder field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between $LSC_{00\ BAL27R}$ and $LSC_{97\text{-}00\ RegII}$ light shaded. Olefin values at or above the limit of quantitation are dark shaded.

Station	THC		Olefins		NPD's		3-6 ring		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
BAL03	11.4	0.7	1.4	0.1	n.a.		n.a.		n.a.	
BAL04	9.5	1.1	<0.1	-	n.a.		n.a.		n.a.	
BAL05	7.0	0.5	<0.1	-	n.a.		n.a.		n.a.	
BAL09	23.6	9.8	32.3	13.7	0.133	0.054	0.156	0.037	0.411	0.258
BAL10	9.1	1.4	0.6	0.3	n.a.		n.a.		n.a.	
BAL11	9.1	1.1	0.2	0.0	n.a.		n.a.		n.a.	
BAL12	8.9	1.6	0.2	0.1	0.042	0.010	0.103	0.018	0.029	0.010
BAL16	9.4	0.4	<0.1	-	n.a.		n.a.		n.a.	
BAL17	8.1	1.5	<0.1	-	n.a.		n.a.		n.a.	
BAL18	7.2	0.1	<0.1	-	n.a.		n.a.		n.a.	
BAL22	6.5	0.2	<0.1	-	n.a.		n.a.		n.a.	
BAL23	8.9	2.5	<0.1	-	n.a.		n.a.		n.a.	
BAL24	8.1	1.6	<0.1	-	n.a.		n.a.		n.a.	
BAL28	9.8	5.3	2.8	0.9	0.040	0.015	0.122	0.030	0.037	0.001
BAL29	9.3	0.9	1.0	0.1	n.a.		n.a.		n.a.	
BAL30	8.9	2.5	0.5	0.9	n.a.		n.a.		n.a.	
BAL31	12.7	2.4	<0.1	-	0.037	0.003	0.126	0.012	0.062	0.008
BAL33	15.5	4.4	1.1	0.4	n.a.		n.a.		n.a.	
BAL34	15.5	8.3	<0.1	-	n.a.		n.a.		n.a.	
BAL35	6.0	2.1	<0.1	-	n.a.		n.a.		n.a.	
BAL37	15.2	2.8	12.6	3.7	n.a.		n.a.		n.a.	
BAL38	7.3	3.2	0.4	0.1	n.a.		n.a.		n.a.	
BAL39	6.5	2.6	<0.1	-	n.a.		n.a.		n.a.	
BAL42	19.1	16.6	7.2	6.1	n.a.		n.a.		n.a.	
BAL43	6.2	3.5	<0.1	-	n.a.		n.a.		n.a.	
BAL44	8.1	0.8	<0.1	-	n.a.		n.a.		n.a.	
BAL46	12.3	12.3	0.2	0.2	n.a.		n.a.		n.a.	
BAL47	13.5	7.1	<0.1	-	n.a.		n.a.		n.a.	
BAL27R	6.0	1.4	<0.1	-	0.032	0.010	0.122	0.014	0.023	0.010

n.a. Not analysed.

Table 12-5: Concentrations of hydrocarbons and synthetic base oil in vertical sections of the sediment samples from the Balder field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between $LSC_{00\ BAL27R}$ and $LSC_{97\text{-}00\ RegII}$ light shaded. Olefin values at or above the limit of quantitation are dark shaded.

Station	Layer (cm)	THC	Olefins	NPD's	3-6 ring	Decalins
BAL09	0-1	28.5	44.2	0.158	0.146	0.584
	1-3	20.8	36.6	0.203	0.124	0.876
	3-6	14.3	8.6	0.096	0.154	0.498
BAL12	0-1	9.9	0.3	0.044	0.083	0.030
	1-3	8.5	0.1	0.069	0.155	0.035
	3-6	7.9	<0.1	0.044	0.153	0.022
BAL28	0-1	5.1	2.0	0.026	0.092	0.037
	1-3	17.7	5.7	0.042	0.119	0.098
	3-6	17.8	6.4	0.057	0.143	0.206
BAL31	0-1	13.7	<0.1	0.033	0.113	0.055
	1-3	12.4	<0.1	0.040	0.146	0.067
	3-6	10.3	<0.1	0.036	0.143	0.062
BAL27R	0-1	6.3	<0.1	0.049	0.124	0.018
	1-3	9.3	<0.1	0.036	0.148	0.039
	3-6	10.2	<0.1	0.048	0.193	0.020

n.a. Not analysed.

The THC content range from values at the background level across Region II (5.9 ± 2.3 mg/kg) to 24 ± 10 mg/kg. In addition to THC, the sediments are analysed with regard to traces of the synthetic base oil Anco TecB, which consists of a mixture of poly-α–olefins (C14/C16). Olefins are not degenerated during the standard work-up procedure for hydrocarbons, and the gas chromatogram of sediment extracts containing Anco TecB show a characteristic profile (Figure 12-2). Anco TecB is quantified from the gas chromatograms by measuring the amounts of olefins against known quantities of a pure sample of the original base oil. The olefin values ranges from concentrations below the limit of quantitation (0.1 mg/kg) to 32 ± 14 mg/kg dry sediment. The highest concentrations of THC, NPD´s, 3-6 ring aromatics, decalins and olefins are found in sediments from BAL09. Hydrocarbons and olefins are contaminated down to 6 cm depth at this station (Table 12-5). Hydrocarbon values above the calculated LSC and olefin values at or above the limit of quantitation are shaded in Table 12-4 and Table 12-5.

From the fold out map at the end of this chapter, it can be seen that the Balder field consist of the well templates A, B, C and D. Generally, the THC content are somewhat uneven distributed along the different well template axes. Weak gradients of decreasing amounts of THC with increasing distance from the centre are only found along the D54^o- and the B198^o-axes. Compared to the $LSC_{97\text{-}00\ RegII}$ the area contaminated with THC extends out to 250 m on the A180^o-, B135^o-, C135^o and D54^o –axes, out to 500 m on the D315^o-axis and out to 1000 m on the A315^o-axis.

Gradients of decreasing amounts of olefins with increasing distance from the centre, are found in the main current direction (135^o-axis) from well templates B, C and D. The olefin content at the innermost stations on well template A, B, C and D, range from values below the limit of quantitation (0.1 mg/kg) to 32 mg/kg. Traces of olefins are found out to 250 m on the A180^o, D54^o- and D315^o-axes and out to 500 on the A315^o- and B135^o-axes, while traces of olefins are found out to 1000 and 2000 m on the D135^o- and C135^o-axes respectively

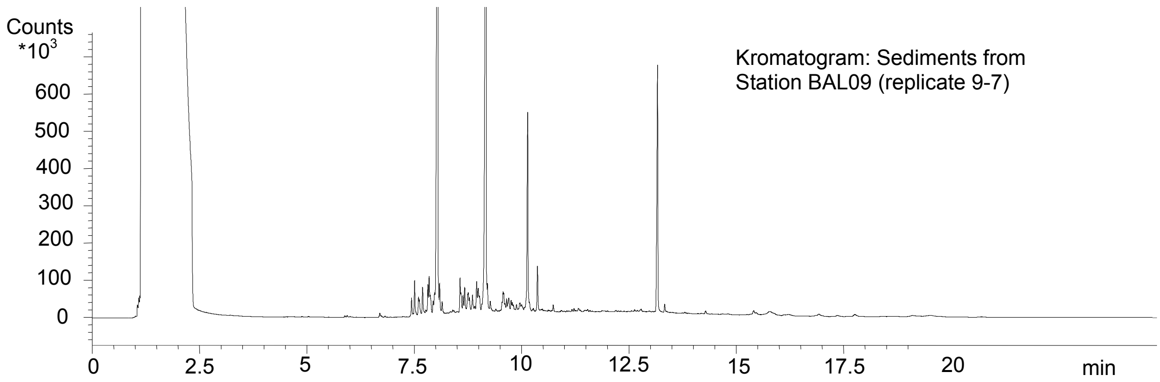

Figure 12-2: Gas chromatogram of a sediment extract from the Balder field, 2000.

The results of the metal analyses for the Balder field are summarised in Table 12-6. Concentrations of selected metals in the vertical sediment sections are presented in Table 12-7. The full data set of replicate measurements, including selected data from previous years, are given in the Appendix. Metal values from 2000 are compared with those from previous years in Figure 12-5 and Figure 12-6.

Table 12-6: Concentrations of selected metals in sediments from the Balder field, 2000. All values in mg/kg dry sediment. Values above $LSC_{00\ BAL27R}$ are dark shaded and values between $LSC_{00\ BAL27R}$ and $LSC_{97\text{-}00\ RegII}$ are light shaded.

Station	Cd		Hg		Cu		Zn		Ba		Cr		Pb	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
BAL03	0.021	0.003	n.a.		2.2	0.5	8.9	0.8	749	80	8.4	0.5	6.9	0.6
BAL04	0.023	0.004	n.a.		2.1	0.1	9.6	0.6	340	31	8.9	0.4	7.4	0.3
BAL05	0.027	0.004	n.a.		1.9	0.3	8.8	1.6	190	61	8.4	0.9	6.5	1.0
BAL09	0.029	0.007	0.008	0.002	2.7	1.4	9.0	2.6	1794	814	8.5	1.2	6.6	1.3
BAL10	0.031	0.012	n.a.		2.1	0.4	9.1	1.5	600	352	8.4	0.5	6.6	1.7
BAL11	0.019	0.002	n.a.		1.7	0.1	7.9	0.5	246	37	7.6	0.3	6.6	0.4
BAL12	0.019	0.001	0.007	0.001	1.5	0.1	7.2	0.4	170	22	7.2	0.2	6.2	0.1
BAL16	0.023	0.002	n.a.		1.6	0.2	7.7	0.9	232	30	7.8	0.5	6.0	0.4
BAL17	0.029	0.006	n.a.		1.7	0.3	8.4	1.5	147	17	7.9	0.5	5.9	0.9
BAL18	0.026	0.007	n.a.		1.7	0.2	8.2	0.6	119	24	7.8	0.6	6.0	0.7
BAL22	0.024	0.004	n.a.		1.5	0.2	7.1	1.3	118	41	7.3	0.6	5.2	0.7
BAL23	0.026	0.004	n.a.		1.9	0.1	8.0	0.6	122	14	7.7	0.5	5.9	0.2
BAL24	0.029	0.003	n.a.		2.4	1.2	7.9	1.5	96	14	7.0	0.5	5.7	0.7
BAL28	0.029	0.005	0.009	0.005	2.3	0.3	9.6	0.7	1495	354	8.0	0.3	6.5	0.3
BAL29	0.029	0.004	n.a.		2.0	0.2	9.0	0.7	415	78	7.9	0.3	7.0	0.8
BAL30	0.024	0.001	n.a.		1.9	0.2	8.5	1.2	243	77	7.7	0.6	6.9	1.0
BAL31	0.021	0.001	0.007	0.001	1.7	0.3	8.6	0.7	209	40	7.7	0.5	7.3	1.0
BAL33	0.022	0.004	n.a.		2.2	0.4	8.7	0.9	600	111	7.7	0.6	6.7	0.5
BAL34	0.025	0.006	n.a.		2.0	0.0	10.8	2.8	230	18	8.4	0.3	7.0	0.1
BAL35	0.021	0.001	n.a.		1.8	0.3	8.3	1.6	170	22	7.3	0.1	6.3	0.4
BAL37	0.025	0.003	n.a.		2.4	0.3	8.0	0.3	1959	376	7.8	0.4	6.8	0.3
BAL38	0.031	0.015	n.a.		1.7	0.2	7.8	0.6	432	138	7.5	0.3	6.7	0.5
BAL39	0.025	0.005	n.a.		1.9	0.1	8.7	0.5	268	19	7.9	0.2	7.3	0.4
BAL42	0.026	0.003	n.a.		1.9	0.1	8.3	0.2	426	98	7.9	0.2	6.7	0.2
BAL43	0.030	0.004	n.a.		1.9	0.1	9.2	0.5	196	27	8.2	0.2	6.7	0.1
BAL44	0.026	0.003	n.a.		1.7	0.3	7.9	1.4	131	36	7.5	0.6	6.2	0.5
BAL46	0.025	0.004	n.a.		1.5	0.1	7.2	0.9	130	14	7.0	0.5	5.8	0.4
BAL47	0.030	0.001	n.a.		1.8	0.5	8.5	2.2	142	49	7.9	1.0	6.4	1.0
BAL27R	0.026	0.004	0.007	0.001	1.9	0.2	8.9	0.8	123	14	8.2	0.5	6.5	0.5

n.a. Not analysed.

Table 12-7: Concentrations of selected metals in vertical sections of the sediment samples from the Balder field. All values in mg/kg dry sediment. Values above $LSC_{00\ BAL27R}$ are dark shaded and values between $LSC_{00\ BAL27R}$ and $LSC_{97\text{-}00\ RegII}$ are light shaded.

Station	Layer (cm)	Cd	Hg	Cu	Zn	Ba	Cr	Pb
BAL09	0-1	0.034	0.010	4.2	11.8	2674	9.8	8.0
	1-3	0.033	0.010	7.5	10.4	1743	9.0	8.6
	3-6	0.041	0.010	2.0	9.3	568	8.5	7.5
BAL12	0-1	0.019	0.007	1.6	7.2	158	7.4	6.2
	1-3	0.027	0.008	1.6	7.6	175	7.6	6.2
	3-6	0.062	0.007	1.8	8.6	130	8.2	6.6
BAL28	0-1	0.024	0.014	2.4	9.6	1573	8.2	6.8
	1-3	0.032	0.006	2.2	8.8	1688	7.8	6.6
	3-6	0.033	0.007	2.0	8.5	1021	7.5	7.1
BAL31	0-1	0.021	0.007	2.0	9.0	244	8.0	8.2
	1-3	0.032	0.008	2.2	10.6	232	8.8	8.6
	3-6	0.030	0.007	2.2	9.6	153	7.7	7.5
BAL27R	0-1	0.021	0.006	1.6	7.9	103	7.5	5.9
	1-3	0.031	0.007	1.6	8.0	100	7.8	6.2
	3-6	0.037	0.006	1.8	9.0	64	8.0	7.0

n.a. Not analysed.

The concentrations of barium range from 96 ± 14 to 1959 ± 376 mg/kg. The content of cadmium range from 0.019 ± 0.001 to 0.031 ± 0.015 mg/kg, copper from 1.5 ± 0.1 to 2.7 ± 0.4 mg/kg, lead from 5.2 ± 0.7 to 7.4 ± 0.3 mg/kg, zinc from 7.1 ± 1.3 to 10.8 ± 2.8 mg/kg and chromium from 7.0 ± 0.5 to 8.5 ± 1.2 mg/kg dry sediment. The high standard deviation connected to the mean barium concentration at BAL09 is due to one high replicate value: 1641, 1068 and 2674 mg/kg dry sediment. This replicate sediment sample also contains the highest concentrations of copper, zinc and chromium. It should be mentioned that the core sample from BAL09 is taken from this replicate, and in this core elevated metal contents are found down to 6 cm depth (Table 12-6). According to the calculated $LSC_{97\text{-}00\ RegII}$ elevated levels of copper, zinc and lead are found at several stations, but by using the $LSC_{00\ BAL27R}$ none of the stations are regarded as contaminated with lead, while stations BAL09 and BAL34 have slightly elevated levels of copper and zinc respectively (Table 12-6).

Gradients of decreasing amounts of barium with increasing distance from the centre are found along the well template A, B, C and D axes. The highest barium concentrations (1495-1959 mg/kg) are found at the 250 m stations in the main-current direction from well templates B, C and D (BAL37, BAL09 and BAL28). All stations located on the well templates C- and D-axes are regarded as contaminated with barium. For the well template B, the area contaminated with barium extends out to the outermost station in the main-current direction and out to 250 m on the B198^{o}-axis. At well template A, stations contaminated with barium are found out to 500 m on the A180^{o}-axis. The remaining of the selected metals are more uniform distributed over the Balder field and the content range from values below to values slightly above the corresponding levels at the field-specific reference station. The 250 m stations in the main current-direction from well templates D and C have elevated levels of copper and zinc.

The mercury concentrations in the five replicate sediment samples from the Balder reference station (BAL27R) range from 0.006 to 0.008 mg/kg dry sediment. In the core sample from BAL27R, mercury is uniform distributed down to 6 cm depth (Table 12-7). The highest mercury concentration (0.014 mg/kg) is found in one of the replicate sediment samples from BAL28. In addition, one of the three replicate sediment samples from BAL09 contains more mercury (0.010 mg/kg) than the reference station. In this replicate, the mercury content is 0.010 mg/kg down to 6 cm depth. Stations BAL09 and BAL28 have elevated levels of mercury. Compared to the 1997 results, the average content of mercury is unchanged at the stations investigated.

Comparison with previous survey(s)

In the present survey, the THC content at the Balder reference station (BAL27R) is 6.0 ± 1.4 mg/kg dry sediment. This value is comparable to the amount (6.9 ± 1.6 mg/kg) found in the 1996 baseline survey (Jensen *et al.,* 1997.) In the present survey, analysis of a sediment core from BAL27R show increasing amounts of THC with depth (Table 12-5) and the amount found in the 3-6 cm layer is comparable to the content (12 mg/kg) found in the two top layers in 1997 (Mannvik *et al.,* 1998). The amounts of NPD’s and 3-6 ring aromatics are almost unchanged since 1997 (1997 values: 0.039 ± 0.002, 0.127 ± 0.001 mg/kg respectively) while the amount of decalins has decreased from 0.125 ± 0.058 mg/kg to 0.023 ± 0.010 mg/kg. The sediments from the reference station contain almost the same level of cadmium, copper, barium and zinc as in the previous survey, while the content of lead has increased from 5.1 ± 0.3 to 6.5 ± 0.5 mg/kg dry sediment. Vertical sediment sections were not analysed for metals in 1997.

THC concentrations for 1997 are previously reported as the sum of mineral oil and olefins (Mannvik *et al.*, 1998.) The THC values for 1997 presented in the histogram in Figure 12-3 are the recalculated THC values found by substraction of olefin-concentrations (adjusted for response factor) from the THC values reported in 1997. It should be mentioned that it is difficult to distinguish between olefins and THC at stations with high amounts of olefins. By comparing the recalculated 1997 THC values with the 1997 LSC for Region II (7.6 mg/kg), the area contaminated with THC in 1997 extended out to 500 m on the A315°-, B198°-, C135°- and D54°-axes and out to 1000 m on the A180°- and B135°-axes.

By comparing this year’s THC values with the recalculated 1997 THC results, the THC content at the well templates A, B and C axes are almost unchanged or reduced. The largest reductions are seen at the 250 and 500 m stations on the A180°- and B135°-axis axes (BAL42, BAL43, BAL37 and BAL38) and at the 250 m station on the C135°-axis (BAL09) where the THC contents have decreased with 13-14 mg/kg. At the well template D315°-axis the THC content has increased (7-10 mg/kg) at the two innermost stations (BAL33 and BAL34), while the THC contents are almost unchanged or slightly reduced at the remaining stations on the well template D-axes.

In the 1997 survey, the innermost and outermost stations on the 135°-axis from well templates C (BAL09 and BAL12) and D (BAL28 and BAL31) were investigated for NPD´s, 3-6 ring aromatics and decalins. The amounts of NPD´s, 3-6 ring aromatics and decalins have clearly decreased at BAL09. In 1997, the concentrations of NPD´s, 3-6 ring aromatics and decalins at BAL09 were 0.435 ± 0.267, 0,259 ± 0.029 and 1.644 ± 0.996 mg/kg dry sediment respectively. In the present survey, the amounts of decalins found at BAL12 and BAL28 are one third and one halve the concentrations found in 1997, while the amounts of NPD´s and 3-6 ring aromatics are almost unchanged.

Compared to the 1997 olefin results, the contents of olefins have decreased at all stations (Figure 12-4). The largest decreases (365-465 mg/kg) are seen at the innermost stations on the well templates B and C axes (BAL09, BAL16 and BAL37). In addition, the olefin contents have decreased with 130-240 mg/kg at the innermost stations on the well templates A270°- and A180°-axes (BAL22 and BAL42) and at the two innermost stations on the D315°-axis (BAL33 and BAL34.)

Since 1997, the barium content has increased at the innermost stations on the B135°-, D135°- and D54°-axes and at the two innermost stations on the C135°-axis. The largest increase is seen at BAL09, where the amount of barium has increased with 1020 mg/kg dry sediment. Decreasing amounts of barium down the sediment core from BAL09 (Table 12-7) support this finding. At the remaining stations the amount of barium is unchanged or reduced. The largest reductions (1330–1820 mg/kg) in barium contents are seen at the innermost stations on the A180°-, A270°-, B198°- and D315°-axes. At these stations, reduced barium content is accompanied of reduced cadmium, copper, zinc and lead contents and the stations in question are regarded as uncontaminated with these metals in the present survey. At the remaining stations the content cadmium and lead are unchanged or only slightly increased, while the content of copper and zinc are unchanged or reduced (Figure 12-6.)

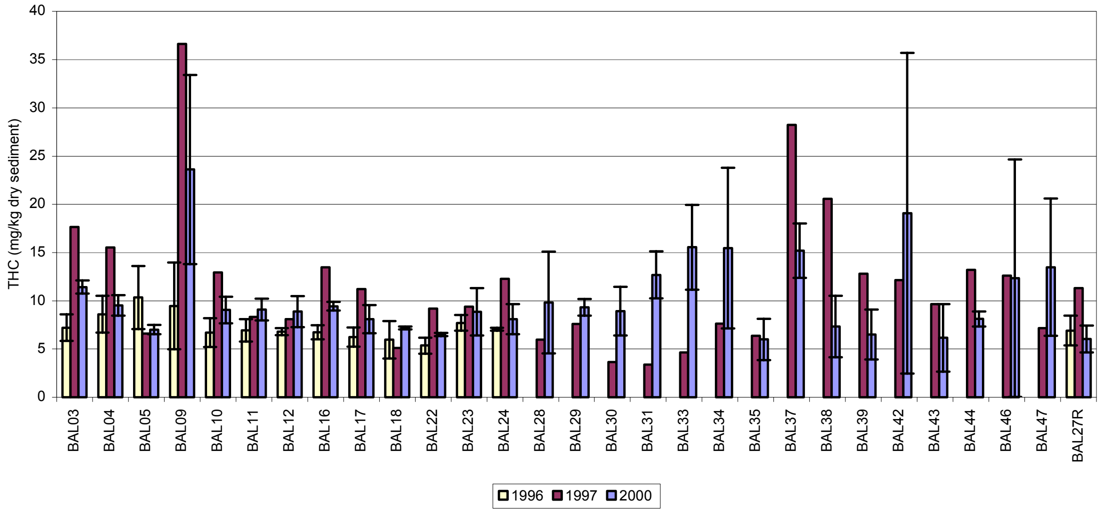

Figure 12-3: THC levels in sediment from the present (2000) and previous surveys, Balder field.

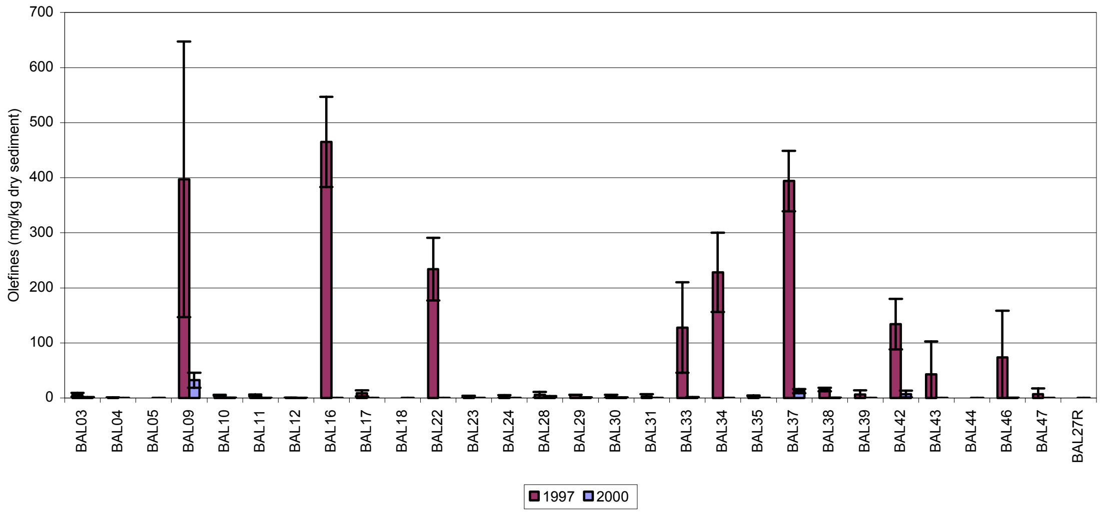

Figure 12-4: Synthetic base oil levels in sediments from the present (2000) and previous surveys, Balder field.

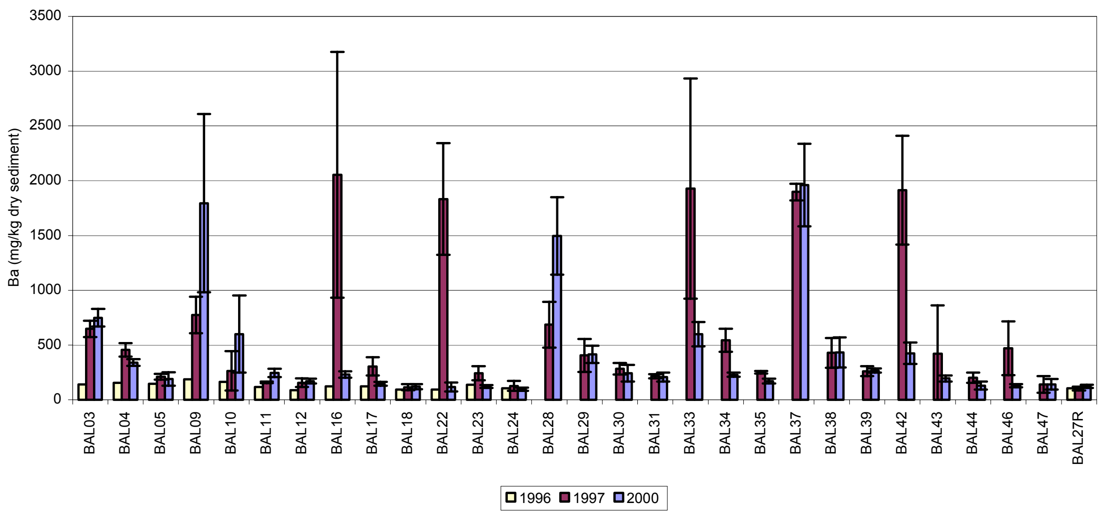

Figure 12-5: Barium levels in sediment from the present (2000) and previous survey, Balder field.

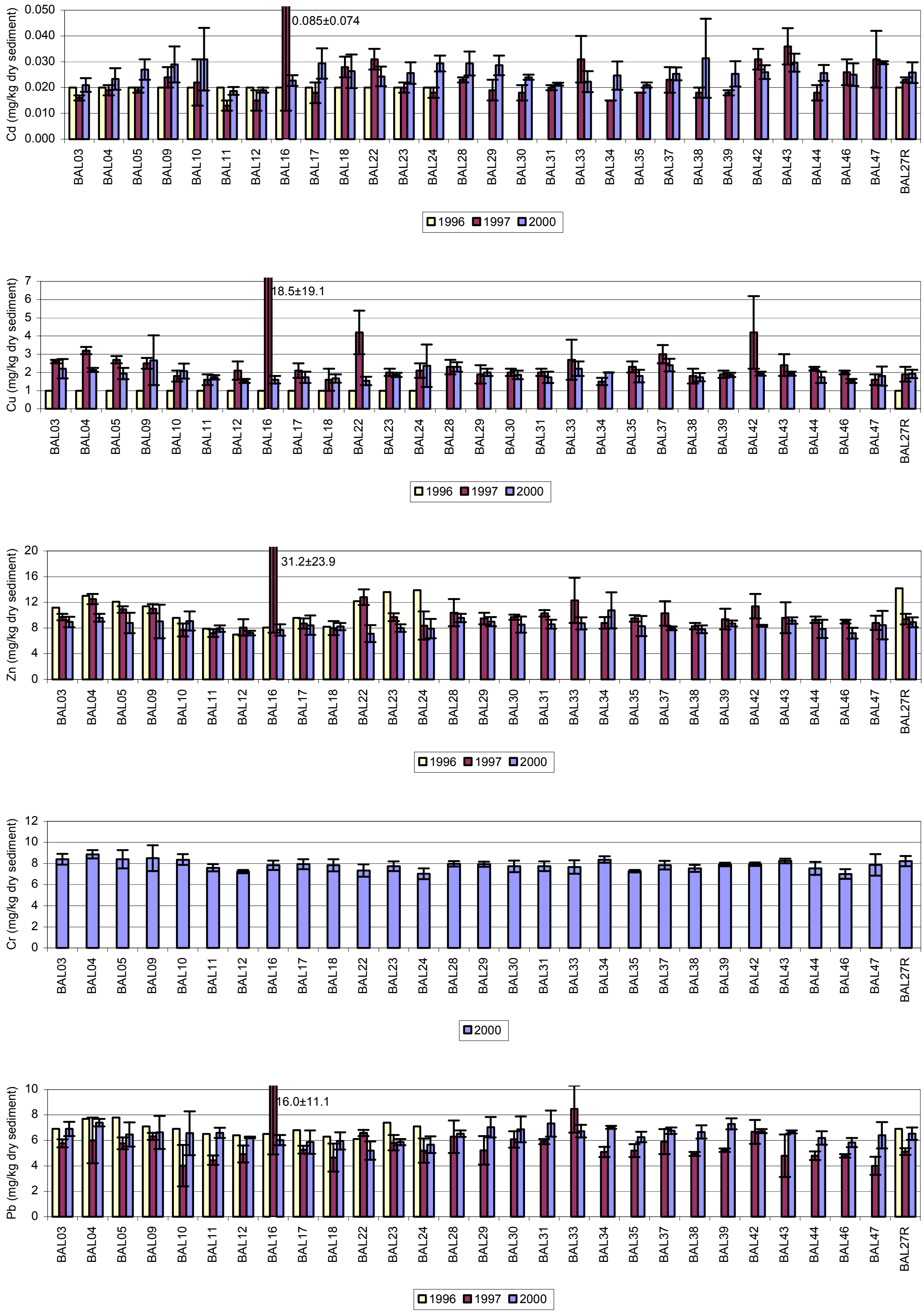

Figure 12-6: Levels of selected metals in sediments from the present (2000) and previous surveys, Balder field.

12.2.3 Biology

The distribution of individuals and taxa within the main taxonomic groups are given in Table 12-8. A total of 32129 individuals within 282 taxa were registered at the Balder field in the present survey (excluding juveniles). The polychaetes dominate the fauna with 53 % of the individuals and 52 % of the taxa recorded.

Table 12-8: Distribution of individuals and taxa within the main taxonomic groups at Balder, 2000 (excluding juveniles).

Main taxonomic groups	Individuals		Taxa	
	Number	%	Number	%
Polychaeta	16922	53	147	52
Mollusca	4964	15	53	19
Crustacea	3427	11	55	20
Echinodermata	1386	4	10	4
Diverse groups	5430	17	17	6
Total	32129	100	282	100

The species/area curve for the field reference station is shown in Figure 12-7. A total of 141 taxa are registered in the ten grab samples, of which 61 (43 %) are taken in the first sample and 118 (83 %) in the first five samples. The shape of the curve indicates that not all taxa in the area are present in the ten grab samples but the representativity of five samples is relatively good.

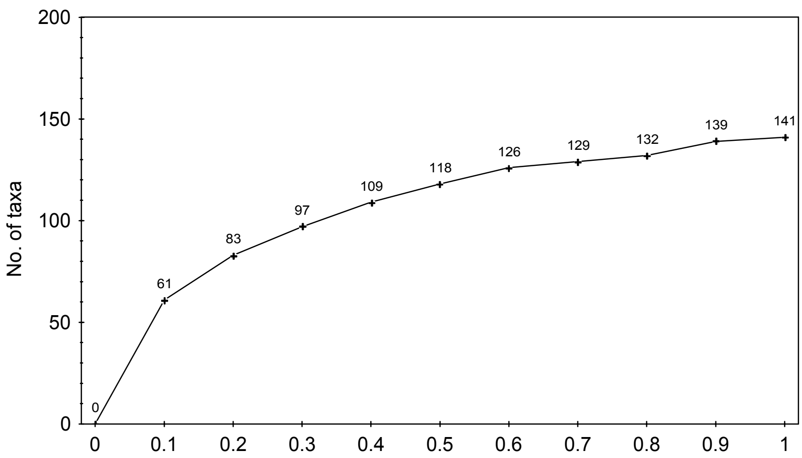

Figure 12-7: Species/area curve for the reference station at the Balder field (area in m^2).

The number of individuals and taxa at each station, together with selected community indices are presented in Table 12-9 and Figure 12-8. The number of individuals recorded at Balder varies from 696 (BAL04) to 1558 (BAL11). The number of taxa varies from 87 (BAL37) to 128 (BAL18), the diversity index H' from 4.0 to 5.5, the evenness index J between 0.62 and 0.81 and the ES_{100} between 25 and 44. The indices H', J and ES_{100} have highest and lowest values at station BAL04 and BAL37 respectively. The corresponding values at the reference station BAL27R are within the variation at the field stations.

The changes in the number of individuals and taxa at the stations have resulted in a general trend of lower diversity sin the previous survey in 1997.

Table 12-9: Number of individuals and taxa and selected community indices for each station (0.5 m²) at the Balder field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	No. ind.	No. taxa	H'	J	ES_{100}
BAL03	1321	121	5.1	0.74	37
BAL04	**696**	107	**5.5**	**0.81**	**44**
BAL05	896	107	5.1	0.75	38
BAL09	1541	123	4.9	0.71	35
BAL10	925	120	5.3	0.76	40
BAL11	**1558**	118	4.5	0.66	32
BAL12	1125	114	4.8	0.70	35
BAL16	1054	119	5.1	0.73	36
BAL17	922	114	5.3	0.77	40
BAL18	1296	**128**	5.1	0.74	37
BAL22	918	106	5.1	0.76	38
BAL23	1028	115	5.1	0.75	38
BAL24	991	125	5.2	0.75	40
BAL28	1265	103	4.7	0.71	31
BAL29	837	105	5.2	0.78	40
BAL30	1258	124	5.1	0.73	38
BAL31	1181	112	5.1	0.75	37
BAL33	1277	118	4.8	0.70	34
BAL34	1309	117	4.9	0.71	37
BAL35	1325	104	4.3	0.64	30
BAL37	1310	**87**	**4.0**	**0.62**	**25**
BAL38	967	113	5.1	0.74	37
BAL39	880	100	5.0	0.76	37
BAL42	1087	101	4.6	0.69	33
BAL43	935	111	5.3	0.78	40
BAL44	795	103	5.1	0.76	38
BAL46	1188	123	5.0	0.72	37
BAL47	1171	114	5.2	0.76	39
BAL27R	1073	118	5.4	0.78	41
Sum *	31056				
Average *	1109	113	5.0	0.73	37
St. dev. *	220	9	0.3	0.04	4

* Excluding the reference station.

Figure 12-8: Biological characteristics at the Balder field, 2000 and previous surveys.

The distribution of taxa in geometrical classes is shown in Figure 12-9. Seven stations have taxa in class 9 (256 – 511 individuals), 16 stations in class 8 (128 – 255 individuals) and the remaining stations in class 7. These results do not give any clear indication of faunal disturbance in the area.

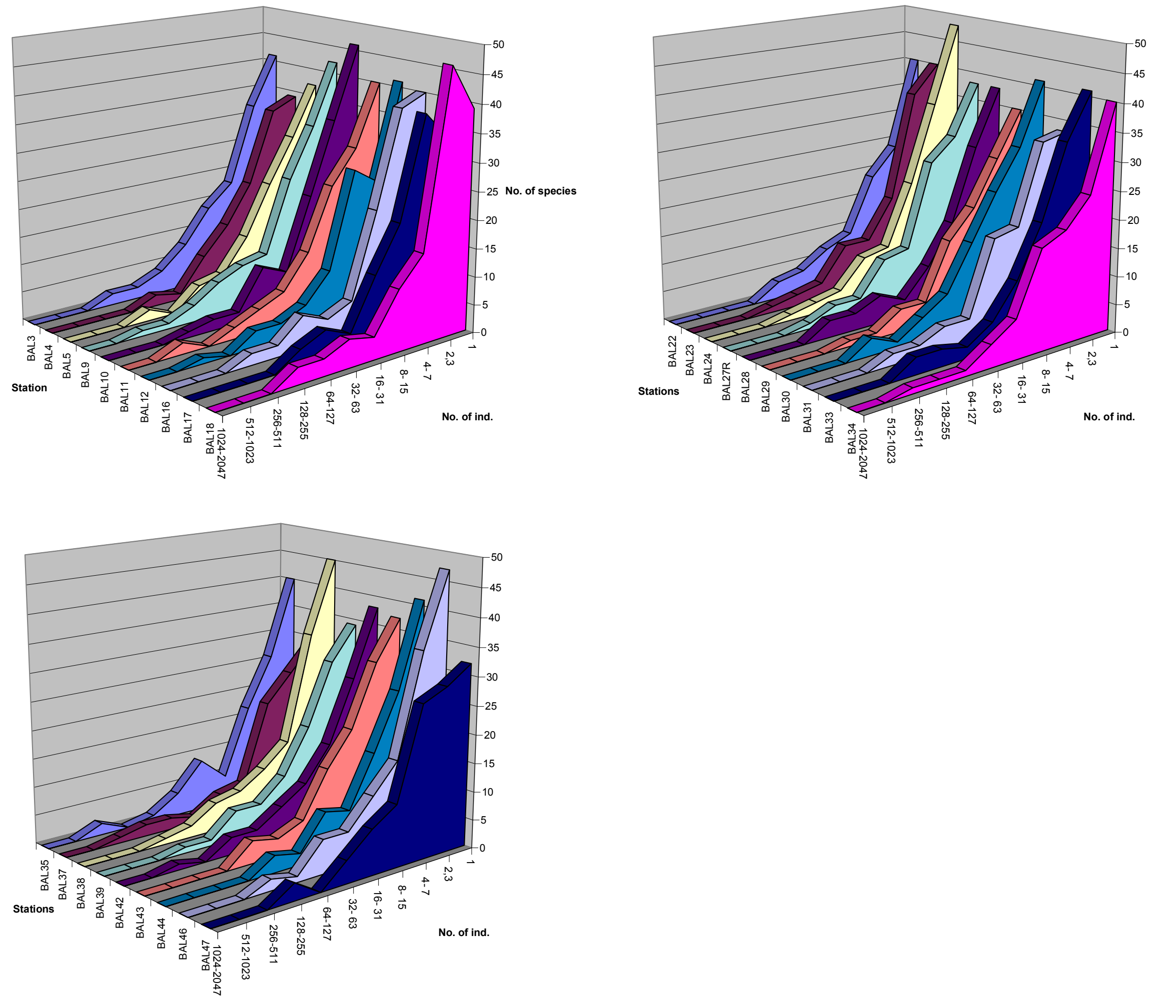

Figure 12-9: Distribution of taxa in geometrical classes at Balder, 2000.

The ten most dominant taxa at each station are shown in Table 12-12 at the end of this chapter. A total of 31 taxa, inclusive three juvenile groups, are among the ten most dominant taxa at one or more stations. These 31 taxa comprise 76 % of the total number of individuals and 11 % of the total number of taxa registered at the Balder field in the present survey.

The most dominant taxa among the adult forms are the phoronid *Phoronis* sp., the polychaetes *Spiophanes bombyx, Paramphinome jeffreysii, Galatowenia oculata, Diplocirrus glaucus, Lanice conchilega*, *Spiophanes kroyeri*, the cumacean *Eudorella emarginata* and the bivalve *Thyasira croulinensis.* The polychaeta *P. jeffreysii* and the phoronid *Phoronis* sp. are among the five most dominant taxa at all stations. The polychaetes *Chaetozone* sp. and *Pseudopolydora paucibranchiata* and the bivalve *Thyasira sarsi* and *T. flexuosa* are among the ten most dominants at six stations (station BAL03, BAL09, BAL28, BAL33, BAL37 and BAL42). These four species are known to be abundant in disturbed sediments and might indicate some faunal disturbance in the area.

The ten most abundant taxa at the stations comprise between 51% (station BAL04) and 81 % (station BAL37) of the total number of individuals registered at the respective stations. The corresponding value at the reference station BAL27R is 53 %.

Figure 12-10 shows the dendrogram from the cluster analysis for the field stations and regional and reference stations while Figure 12-11 shows the 2-D plot from the MDS analysis.

In the cluster analysis field station BAL37 is separated out at 43 % dissimilarity level, regional station RII03, RII09 and RII10 and reference stations at Heimdal and Frøy at 41 – 42 % level, while the remaining stations are separated into two main groups at 34 % dissimilarity level. One of these groups contains field stations BAL03, BAL09, BAL10, BAL28, BAL33 and BAL34. The other group contains the remaining field stations together with the reference stations at Balder, Ringhorne and Jotun. The correlation coefficient shows a good fit to the data (r = 0.81).

Due to the differences seen in the cluster analysis between the field stations and some of the regional and reference stations, the 2-D plot from the MDS analyses of field stations only is shown in Figure 12-11. The plots including all stations are given in the Appendix.

The MDS analyses separates BAL09, BAL28 and BAL37 from the main groups of field stations. The stress test shows a fair to poor fit to the data (0.33).

These analyses indicate a high degree of similarity between most of the field stations, with a few stations separated from the other.

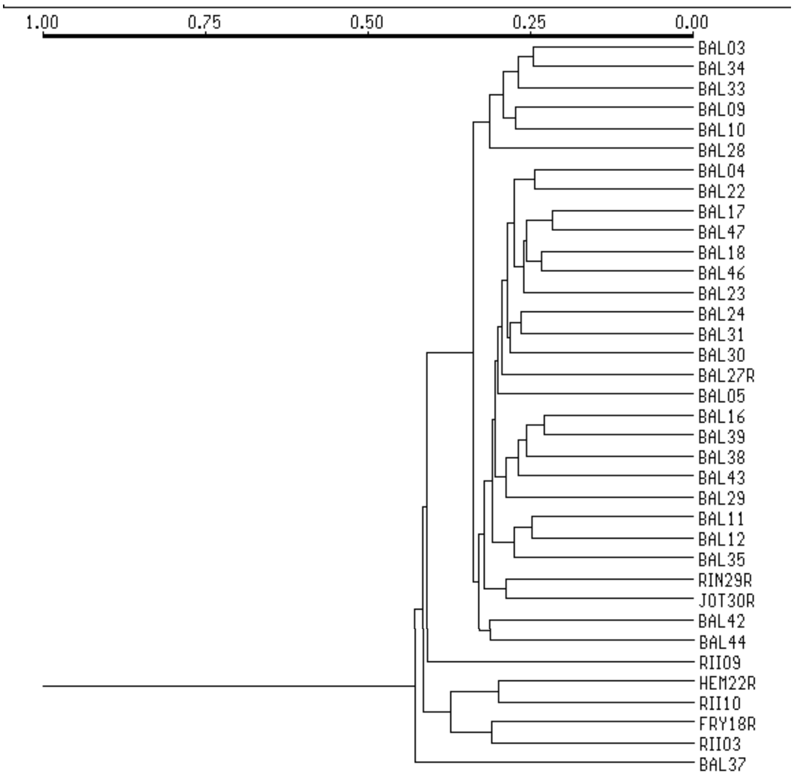

Figure 12-10: Cluster analysis of the Balder field stations and selected regional and reference stations in Region II, 2000.

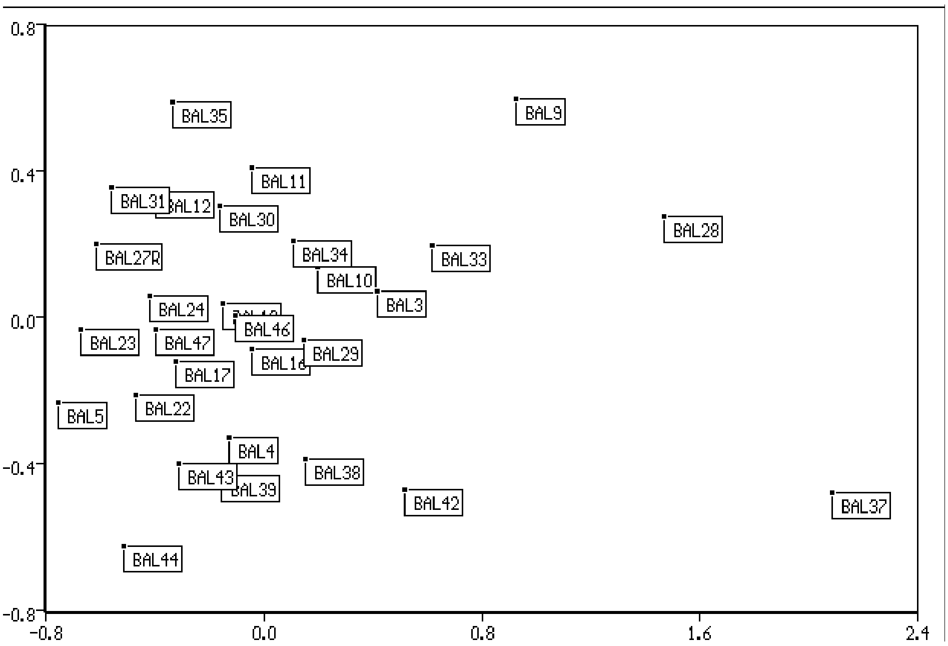

Figure 12-11: 2-D plot from the MDS analysis carried out on the station data form Balder field, 2000.

A Canonical Correspondence Analysis (CCA) of the data from the Balder field together with selected regional and reference stations was carried out to examine the association between the biological data and the measured environmental variables in these areas.

Through the forward selection procedure in CANOCO, six of ten variables gave the best fit and were significant. 38.3 % of the biological variance was explained by the first two axes of the ordination space which is constrained by these environmental variables.

Figure 12-12 shows a biplot from the analysis using cadmium (Cd), zinc (Zn), barium (Ba), pelite (Pel), fine sand (FS) and TOM as the constraining environmental variables while Figure 12-13 shows the taxa with highest contributions on the two axes.

The first axis shows a gradient from regional station RII03 on the positive end to field station BAL37 on the negative end and is negatively correlated with the amount of fine sand (- 0.78), zinc (- 0.75) and barium (- 0.66) in the sediments. The taxa with highest contribution on this axis are the polychaetes *Galathowenia oculata* (22.3 %), *Myriochele fragilis* (11.2 %), *Chaetozone* sp. (7.6 %), *Mugga wahrbergi* (5.3 %) and *Paramphinome jeffreysii* (4.9 %) and the bivalve *Thyasira sarsi* (5.8 %).

The second axis shows a gradient from field station BAL37 on the positive end to the Ringhorne reference station RIN29R on the negative end and is positively correlated with amount of barium in the sediments (+ 0.59). The taxa with highest contribution on this axis are the polychaete *Chaetozone* sp. (31.1 %) and the bivalve *Thyasira sarsi* (21.5 %). Both these taxa are known to be abundant in disturbed sediments.

These results indicate a gradient of faunal disturbance at stations from the upper left corner to undisturbed fauna at stations in the lower right corner of the plot. Stations BAL09, BAL28 and BAL37 all have high levels of barium and other chemical parameters in the sediments. The associated taxa are shown in Figure 12-13 where *Thyasira sarsi*, *Chaetozone* sp. and *Thyasira flexuosa* are located in the upper left corner.

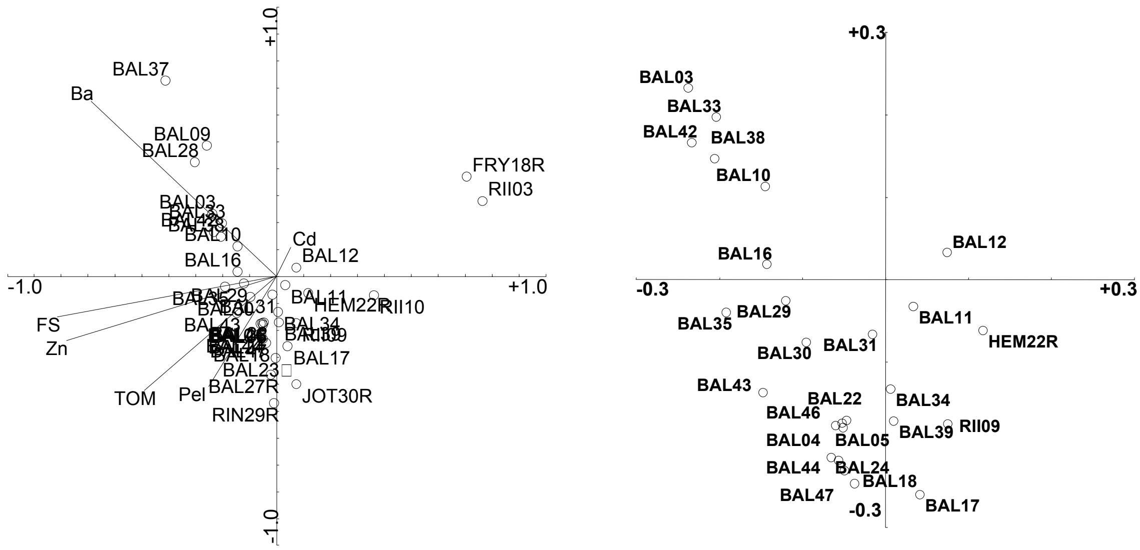

Figure 12-12: Biplot from the CCA analysis for the Balder field stations and selected regional and reference stations in Region II, 2000 (left), and details of the stations close to the centre of the plot (right).

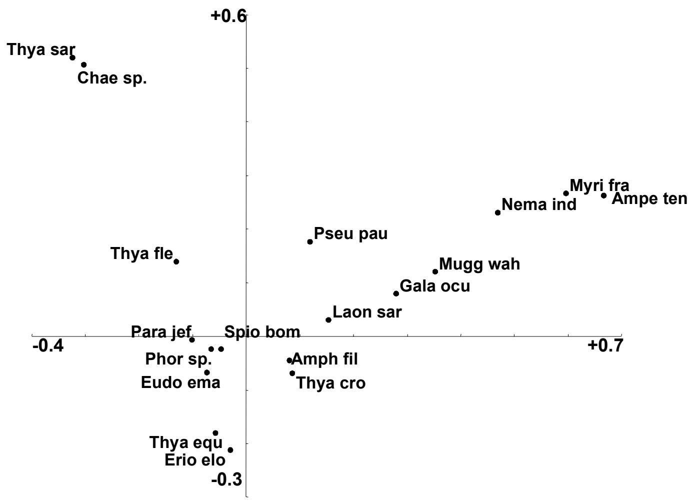

Figure 12-13: Taxa with high contribution on two axes from the CCA analysis for the Balder field stations and selected regional and reference stations in Region II, 2000.

A second CCA of the data from the Balder field including olefins among the environmental data was carried out. Through the forward selection procedure in CANOCO, two of eleven variables gave the best fit and were significant. 22.8 % of the biological variance was explained by the first two axes of the ordination space which is constrained by these environmental variables.

Figure 12-14 shows a biplot from the analysis using olefins (Ole) and cadmium (Cd) as the constraining environmental variables while Figure 12-15 shows the taxa with highest contributions on the two axes.

The first axis shows a gradient from station BAL09 on the positive end to stations BAL17, BAL24, BAL43 and BAL47 on the negative end and is positively correlated with the amount of olefins in the sediments (+ 0.76). Taxa with high contribution on this axis are the polychaete *Chaetozone* sp. (35.5 %) and the bivalve *Thyasira sarsi* (26.7 %). Both this taxa are known to be abundant in disturbed sediments. This axis, therefore, indicates a gradient of faunal disturbance from the positive to the negative end. Station BAL09 has the highest concentration of olefins in the sediment.

The second axis shows a gradient from station BAL11 on the positive end to station BAL38 on the negative end and is negatively correlated with the amount of cadmium in the sediments (+ 0.77). Taxa with high contribution on this axis are the polychaetes *Spiophanes bombyx* (22.1 %) and *Paramphinome jeffreysii* (5.2 %), the phoronid *Phoronis* sp. (6.8 %) and the bivalve *Thyasira equalis* (5.9 %). The amount of cadmium is low over the whole field and this axis, therefor, indicate a gradient of natural variation in the sediment structure.

The associated taxa are shown in Figure 12-15 where, among other, *Thyasira sarsi* and *Chaetozone* sp. are placed on the positive end of the first axis.

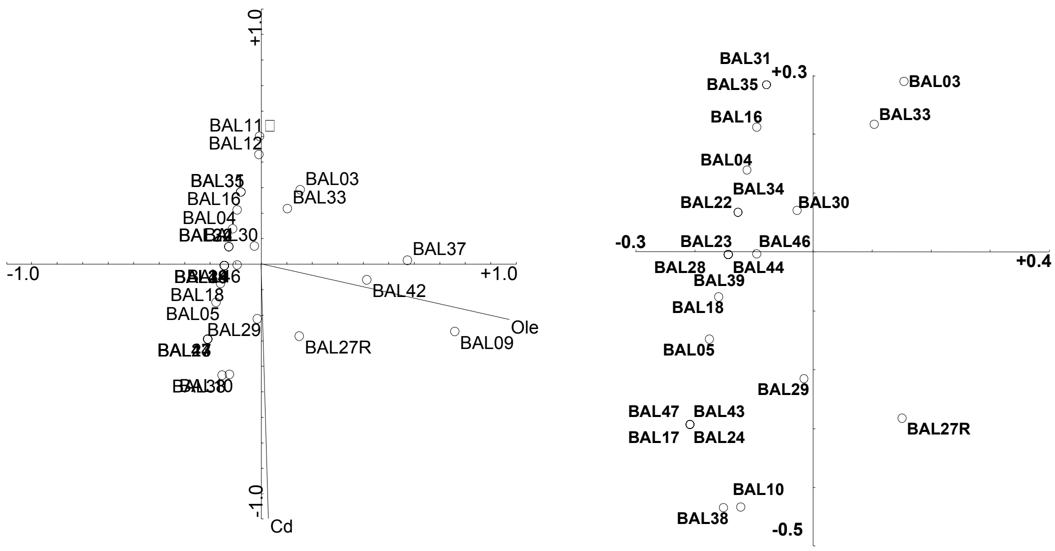

Figure 12-14: Biplot from the CCA analysis including olefins for the Balder field, 2000 (left), and details of the stations close to the centre of the plot (right).

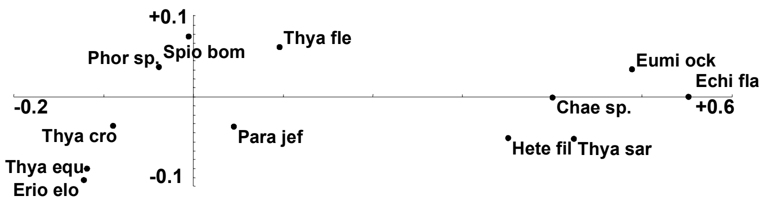

Figure 12-15: Taxa with high contribution on the two axes from the CCA analysis including olefins for the Balder field, 2000.

On the basis of the results from the uni- and multivariate analyses, the stations at Balder are classified into three different faunal groups (see Table 12-10). Field station BAL37 is placed in group C (disturbed fauna), stations BAL03, BAL09, BAL28, BAL33 and BAL42 are placed in group B (slightly disturbed fauna) while the remaining stations are placed in group A (undisturbed fauna).

The stations in group B and C have relatively high abundance of the polychaete *Chaetozone* sp. and the bivalves *Thyasira sarsi* and *T. flexuosa* in some combinations. These taxa are known to be abundant in disturbed or organic enriched sediments. At station BAL37, *Chaetozone* sp. and *T. sarsi* are the two most dominant taxa and this station was separated from all other field stations in the multivariate analyses. The stations placed in group B has lower abundance of the taxa mentioned, but were separated from the remaining field stations in the multivariate analyses. In the cluster analysis, station BAL10 was grouped together with these stations, but the lack of the indicator taxa, and low levels of the measured chemical parameters, indicates that that station has undisturbed fauna. All group B and C stations are situated at 250 m distance from their respective centre and have relatively high levels of THC, olefins and barium, indicating that the faunal disturbance can be related to the petroleum activity at the templates.

In 1997 the classification of group B stations was based on relatively high abundance of the polychaete *Capitella capitata*. This indicator species is not recorded at any of the stations included in the present survey. On the other hand the indicator species recorded at disturbed stations in 2000 were absent or had very low individual numbers at the stations in 1997.

Compared with the previous survey the area of disturbed fauna has decreased around Template A, has decreased in area but increased in intensity around Template B, is similar around Template C and has increased in area around Template D.

Table 12-10: Classification into impact groups, distance to installation and biological statistics for the field stations at Balder field, 2000.

Station	Impact group	Dist. (m)	Statistics			No. of individuals							
			No. ind	No. taxa	H'	Psp	Sbo	Pje	Eem	Tcr	Tfl	Tsa	Csp
BAL03	B	250	1321	121	5,1	202	190	92	54	13	78	7	53
BAL04	A	500	696	107	5,5	93	24	83	42	28	8	0	8
BAL05	A	1000	896	107	5,1	128	21	153	50	61	3	0	1
BAL09	B	250	1541	123	4,9	111	136	314	44	7	1	92	90
BAL10	A	500	925	120	5,3	146	80	106	29	42	0	2	2
BAL11	A	1000	1558	118	4,5	349	340	98	40	31	2	0	0
BAL12	A	2000	1125	114	4,8	270	107	100	45	40	0	0	0
BAL16	A	250	1054	119	5,1	172	71	129	73	44	7	1	2
BAL17	A	500	922	114	5,3	78	123	107	57	43	0	0	0
BAL18	A	1000	1296	128	5,1	172	144	133	70	68	2	0	2
BAL22	A	250	918	106	5,1	119	50	109	78	54	0	0	4
BAL23	A	500	1028	115	5,1	166	104	112	58	32	1	0	0
BAL24	A	1000	991	125	5,2	112	154	112	48	28	0	0	1
BAL28	B	250	1265	103	4,7	203	144	150	59	2	64	79	80
BAL29	A	500	837	105	5,2	136	47	99	60	35	9	5	12
BAL30	A	1000	1258	124	5,1	128	229	156	44	42	0	0	4
BAL31	A	2000	1181	112	5,1	143	188	93	55	60	0	0	0
BAL33	B	250	1277	118	4,8	138	219	181	65	10	75	16	28
BAL34	A	500	1309	117	4,9	198	288	98	63	10	12	1	5
BAL35	A	1000	1325	104	4,3	272	364	74	51	42	1	1	0
BAL37	C	250	1310	87	4,0	80	164	124	28	0	0	207	356
BAL38	A	500	967	113	5,1	196	54	82	66	24	18	0	0
BAL39	A	1000	880	100	5,0	163	49	86	60	44	4	0	2
BAL42	B	250	1087	101	4,6	96	42	293	69	21	88	35	11
BAL43	A	500	935	111	5,3	95	48	102	70	55	12	6	4
BAL44	A	1000	795	103	5,1	117	31	91	66	54	3	0	3
BAL46	A	500	1188	123	5,0	224	92	144	51	33	3	2	9
BAL47	A	1000	1171	114	5,2	171	133	131	48	56	0	0	0
BAL27R	A	10000	1073	118	5,4	147	94	72	70	49	6	0	0
RII03	A	-	1523	127	4,7	0	54	0	0	96	0	0	0
RII09	A	-	1221	118	5,2	49	103	66	0	0	0	0	40
RII10	A	-	1200	128	5,4	44	106	58	37	102	0	0	0
FRY18R	A	-	2289	149	5.4	90	111	0	0	101	0	0	0
RIN29R	A	-	824	104	5,0	0	151	80	47	30	0	0	0
JOT30R	A	-	1221	117	5,2	49	191	157	65	46	0	0	0
HEM22R	A	-	1032	119	5.6	58	46	35	0	143	0	0	0

Psp = *Phoronis sp*, Sbo = *Spiophanes bombyx* Pje = *Paramphinome jeffreysii*, Eem = *Eudorella emarginata*, Tcr = *Thyasira crouliensis*, Tfl = *Thyasira flexuosa,* Tsa = *Thyasira sarsi*, Csp = *Chaetozone sp.*

12.3 Summary and conclusions

The sediment at the Balder field is classified as fine sand with relatively high amount of pelite (6.9 – 14.1 %) and TOM (1.7 – 2.7 %). The sediment structure is similar to that found on the neighbouring Ringhorne field. The TOM value has decreased remarkably from the previous survey at stations BAL03, BAL04, BAL33 and BAL42, situated in the vicinity of template D and A. On the other hand the TOM has increased at the reference station.

The highest concentrations of THC (24 ± 10 mg/kg), olefins (32 ± 14 mg/kg) and barium (1794 ± 814 mg/kg) are found in sediments from BAL09. Hydrocarbons, olefins and metals are contaminated at least down to 6 cm depth at this station.

The general picture of the Balder field is that the 250-500 m stations are contaminated with THC and olefins. The only exceptions are found for olefins in the main-current direction from well templates C and D, where traces of olefins are found out to 2000 and 1000 m respectively. The A270°- and B198°-axes are uncontaminated with THC and olefins. All stations located around well templates C and D are regarded as contaminated with barium. From well template B, the area contaminated with barium extends out to the outermost station in the main-current direction and out to 250 m on the B198°-axis. From well template A, stations contaminated with barium are found out to 500 m on the A180°-axis.

By comparing this year's THC values with the recalculated 1997 THC results, the THC content at the well templates A, B, C and D axes are almost unchanged or reduced. The only exceptions are found at the two innermost stations on the D315°-axis where the THC content has increased somewhat. Compared to the 1997 olefin results, the contents of olefins have decreased at all stations. The largest reductions in olefin content (365-465 mg/kg) are seen at the stations with the highest content of olefins in 1997. The barium content has increased at the innermost stations on the B135°-, D135°- and D54°-axes and the two innermost stations on the C135°-axis. At the remaining stations the amount of barium is unchanged or reduced.

A relatively high variation in the number of individuals and taxa are registered at the stations. However, the faunal compositions in undisturbed sediments are relatively similar to that found at the neighbouring Ringhorne field. The stations at Balder are classified into three different faunal groups: station BAL37 is placed in group C (disturbed fauna), stations BAL03, BAL09, BAL28, BAL33 and BAL42 are placed in group B (slightly disturbed fauna) while the remaining stations are placed in group A (undisturbed fauna).

The stations in group B and C have relatively high abundance of the polychaete *Chaetozone* sp. and the bivalves *Thyasira sarsi* and *T. flexuosa* in some combinations. These taxa are known to be abundant in disturbed or organic enriched sediments. At station BAL37, *Chaetozone* sp. and *T. sarsi* are the two most dominant taxa and this station was separated from all other field stations in the multivariate analyses. The stations placed in group B has lower abundance of the taxa mentioned, but were separated from the remaining field stations in the multivariate analyses. In the cluster analysis, station BAL10 was grouped together with these stations, but the lack of the indicator taxa, and low levels of the measured chemical parameters, indicates that that station has undisturbed fauna. All group B and C stations are situated at 250 m distance from their respective centre and have relatively high levels of THC, olefins and barium, indicating that the faunal disturbance can be related to the petroleum activity at the templates.

In 1997 the classification of group B stations was based on relatively high abundance of the polychaete *Capitella capitata*. This indicator species is not recorded at any of the stations included in the present survey. On the other hand the indicator species recorded at disturbed stations in 2000 were absent or had very low individual numbers at the stations in 1997.

Compared with the previous survey the area of disturbed fauna has decreased around Template A, has decreased in area but increased in intensity around Template B, is similar around Template C and has increased in area around Template D.

The calculated minimum area and spatial extent of contaminated sediments at the Balder field is shown in Table 12-11 and Figure 12-16.

Table 12-11: Distance along the transects and calculated minimum area of contaminated sediments the Balder field, 2000 and previous survey.

Template A	S	W	NW		Km^2 (2000)	Km^2 (1997)
Group B	250	125	125	125	0.07	0.22
Group C	0	0	0	0	0.00	0.00
THC	250	125	1000	125	0.25	0.29
Olefins	250	125	500	125	0.15	2.50
Ba	500	125	125	125	0.12	0.49
Other metals	0	0	0	0	0.00	0.15
Template B	SE	SW			Km^2 (2000)	Km^2 (1997)
Group B	250	125	125	125	0.07	0.11
Group C	250	125	125	125	0.07	0.00
THC	250	125	125	125	0.07	0.55
Olefins	500	125	125	125	0.12	6.88
Ba	1000	250	125	125	0.33	0.55
Other metals	0	0	0	0	0.00	0.07
Template C	SE				Km^2 (2000)	Km^2 (1997)
Group B	250	125	125	125	0.07	0.07
Group C	0	0	0	0	0.00	0.00
THC	250	125	125	125	0.07	0.12
Olefins	2000	125	125	125	0.42	0.42
Ba	2000	125	125	125	0.42	0.12
Other metals	250	125	125	125	0.07	0.00
Template D	NE	SE	NW		Km^2 (2000)	Km^2 (1997)
Group B	250	250	250	125	0.15	0.07
Group C	0	0	0	0	0.00	0.00
THC	250	125	500	125	0.15	0.12
Olefins	250	1000	250	125	0.44	4.17
Ba	1000	2000	1000	125	3.34	1.77
Other metals	125	250	125	125	0.07	0.15
Sum Balder					Km^2 (2000)	Km^2 (1997)
Group B					0.37	0.48
Group C					0.07	0.00
THC					0.54	1.09
Olefins					1.13	13.98
Ba					4.21	2.93
Other metals					0.15	0.37

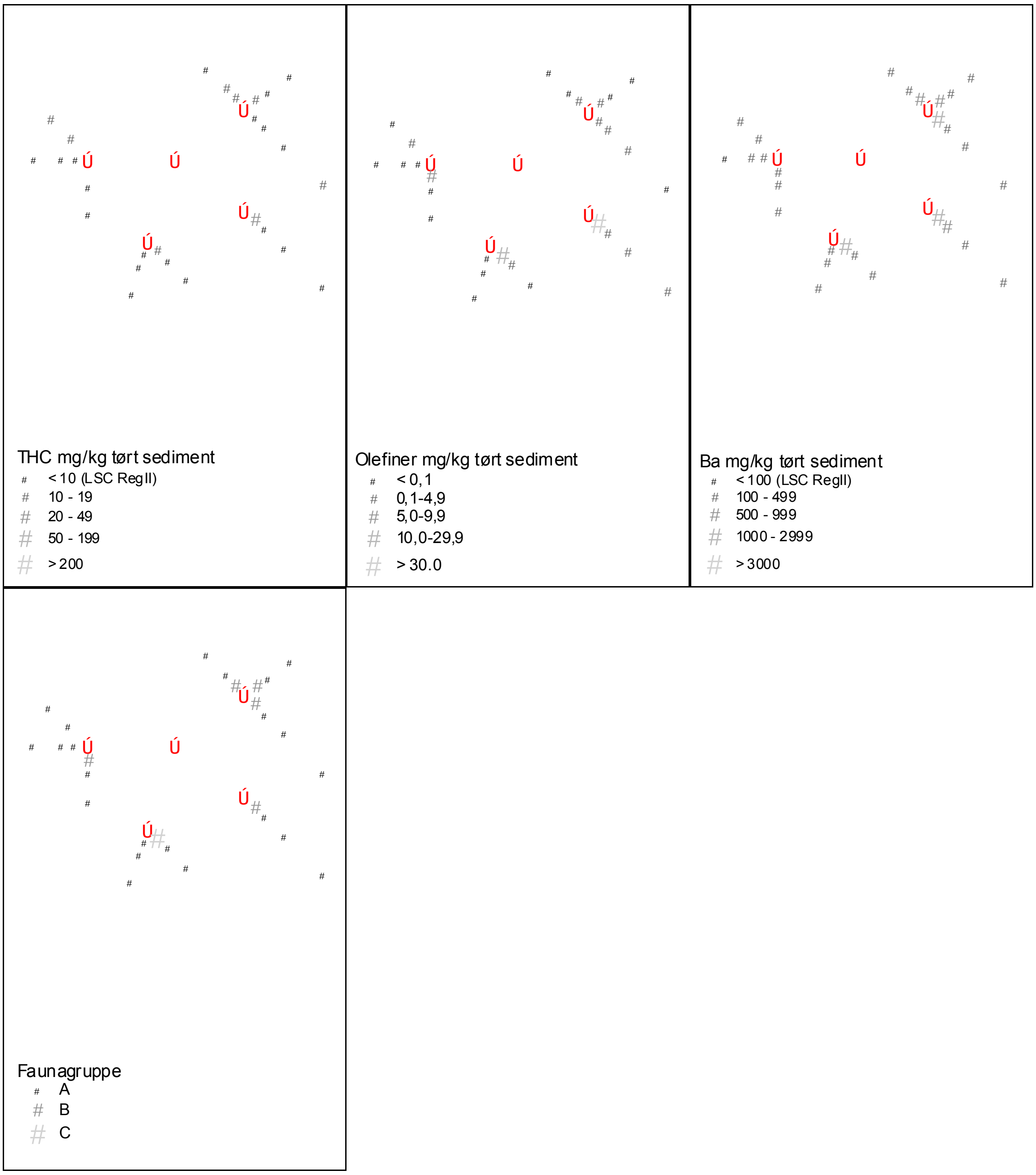

Figure 12-16: Distribution of disturbed fauna and the amounts of THC, olefin and barium at the Balder field, 2000.

Table 12-12: Number of individuals and the accumulative abundance for the ten most dominant taxa at each station at the Balder field, 2000.

BAL03 (54° / 250 m)	No. ind	Acc. %	BAL04 (54° / 500 m)	No. ind	Acc. %	BAL05 (54° / 1000 m)	No. ind	Acc. %	BAL09 (135° / 250 m)	No. ind	Acc. %	BAL10 (135° / 500 m)	No. ind	Acc. %
Phoronis sp.	202	15 %	Phoronis sp.	93	13 %	Paramphinome jeffreysii	153	16 %	Paramphinome jeffreysii	314	19 %	Phoronis sp.	146	14 %
Spiophanes bombyx	190	28 %	Paramphinome jeffreysii	83	24 %	Phoronis sp.	128	29 %	Spiophanes bombyx	136	27 %	Paramphinome jeffreysii	106	25 %
Paramphinome jeffreysii	92	35 %	Eudorella emarginata	42	30 %	Thyasira croulinensis	61	35 %	Phoronis sp.	111	34 %	Spiophanes bombyx	80	33 %
Thyasira flexuosa	78	41 %	Thyasira croulinensis	28	34 %	Eudorella emarginata	50	40 %	Thyasira sarsi	92	39 %	Diplocirrus glaucus	43	37 %
Galathowenia oculata	61	45 %	Galathowenia oculata	24	37 %	Natatolana borealis juv.	49	45 %	Chaetozone sp.	90	44 %	Natatolana borealis juv.	43	41 %
Eudorella emarginata	54	49 %	Spiophanes bombyx	24	40 %	Thyasira equalis	41	50 %	Pectinaria sp. juv.	68	49 %	Thyasira croulinensis	42	45 %
Chaetozone sp.	53	53 %	Spiophanes kroyeri	23	44 %	Philine sp.	39	54 %	Galathowenia oculata	60	52 %	Galathowenia oculata	30	48 %
Diplocirrus glaucus	39	56 %	Lanice conchilega	21	46 %	Spiophanes kroyeri	23	56 %	Pseudopolydora paucibranchiata	59	56 %	Eudorella emarginata	29	51 %
Spiophanes kroyeri	31	58 %	Diplocirrus glaucus	19	49 %	Spiophanes bombyx	21	58 %	Owenia fusiformis	56	59 %	Lanice conchilega	22	53 %
Thyasira obsoleta	29	60 %	Thyasira equalis	16	51 %	Amphiura chiajei	20	60 %	Pectinaria auricoma	50	62 %	Spiophanes kroyeri	22	55 %
						Galathowenia oculata	20	62 %						
BAL11 (135° / 1000 m)	No. ind	Acc. %	BAL12 (135° / 2000 m)	No. ind	Acc. %	BAL16 (198° / 250 m)	No. ind	Acc. %	BAL17 (198° / 500 m)	No. ind	Acc. %	BAL18 (198° / 1000m)	No. ind	Acc. %
Phoronis sp.	349	21 %	Phoronis sp.	270	23 %	Phoronis sp.	172	16 %	Spiophanes bombyx	123	13 %	Phoronis sp.	172	13 %
Spiophanes bombyx	340	42 %	Spiophanes bombyx	107	32 %	Paramphinome jeffreysii	129	27 %	Paramphinome jeffreysii	107	23 %	Spiophanes bombyx	144	23 %
Paramphinome jeffreysii	98	47 %	Paramphinome jeffreysii	100	41 %	Eudorella emarginata	73	34 %	Phoronis sp.	78	31 %	Paramphinome jeffreysii	133	33 %
Galathowenia oculata	86	53 %	Lanice conchilega	91	48 %	Spiophanes bombyx	71	40 %	Eudorella emarginata	57	37 %	Lanice conchilega	74	39 %
Pectinaria sp. juv.	67	57 %	Eudorella emarginata	45	52 %	Lanice conchilega	46	44 %	Thyasira croulinensis	43	42 %	Eudorella emarginata	70	44 %
Lanice conchilega	49	60 %	Galathowenia oculata	45	56 %	Thyasira croulinensis	44	48 %	Lanice conchilega	36	45 %	Thyasira croulinensis	68	49 %
Spiophanes kroyeri	44	62 %	Thyasira croulinensis	40	60 %	Diplocirrus glaucus	43	52 %	Diplocirrus glaucus	32	48 %	Eriopisa elongata	52	53 %
Diplocirrus glaucus	42	65 %	Diplocirrus glaucus	19	61 %	Thyasira equalis	38	56 %	Eriopisa elongata	32	52 %	Spiophanes kroyeri	41	56 %
Eudorella emarginata	40	67 %	Spiophanes kroyeri	19	63 %	Spiophanes kroyeri	35	59 %	Pectinaria sp. juv.	27	54 %	Diplocirrus glaucus	38	59 %
Thyasira croulinensis	31	69 %	Aporrhais sp.	18	64 %	Amphiura chiajei	32	62 %	Thyasira equalis	23	57 %	Galathowenia oculata	37	61 %
			Nemertini indet.	18	66 %									
			Pectinaria sp. juv.	18	67 %									

Table 12-12 continue

BAL22 (270° / 250 m)	No. ind	Acc. %	BAL23 (270° / 500 m)	No. ind	Acc. %	BAL24 (270° / 1000 m)	No. ind	Acc. %	BAL28 (135° / 250 m)	No. ind	Acc. %	BAL29 (135° / 500 m)	No. ind	Acc. %
Phoronis sp.	119	13 %	Phoronis sp.	166	15 %	Spiophanes bombyx	154	14 %	Phoronis sp.	203	15 %	Phoronis sp.	136	16 %
Paramphinome jeffreysii	109	24 %	Paramphinome jeffreysii	112	26 %	Paramphinome jeffreysii	112	24 %	Paramphinome jeffreysii	150	26 %	Paramphinome jeffreysii	99	27 %
Eudorella emarginata	78	32 %	Spiophanes bombyx	104	35 %	Phoronis sp.	112	35 %	Spiophanes bombyx	144	37 %	Eudorella emarginata	60	34 %
Thyasira croulinensis	54	38 %	Eudorella emarginata	58	41 %	Eudorella emarginata	48	39 %	Chaetozone sp.	80	43 %	Spiophanes bombyx	47	39 %
Spiophanes bombyx	50	43 %	Thyasira equalis	44	45 %	Pectinaria sp. juv.	36	43 %	Thyasira sarsi	79	49 %	Thyasira croulinensis	35	43 %
Eriopisa elongata	41	48 %	Thyasira croulinensis	32	48 %	Cerianthus lloydi juv.	35	46 %	Thyasira flexuosa	64	54 %	Diplocirrus glaucus	33	47 %
Thyasira equalis	38	52 %	Lanice conchilega	31	51 %	Eriopisa elongata	34	49 %	Eudorella emarginata	59	58 %	Galathowenia oculata	25	50 %
Diplocirrus glaucus	29	55 %	Spiophanes kroyeri	27	53 %	Harpinia antennaria	34	52 %	Galathowenia oculata	48	62 %	Spiophanes kroyeri	24	53 %
Spiophanes kroyeri	27	57 %	Diplocirrus glaucus	25	55 %	Thyasira croulinensis	28	55 %	Pseudopolydora paucibranchiata	35	64 %	Nemertini indet.	20	55 %
Aporrhais sp.	20	60 %	Galathowenia oculata	25	58 %	Lanice conchilega	27	57 %	Diplocirrus glaucus	34	67 %	Lanice conchilega	16	57 %
Harpinia antennaria	20	62 %												
BAL30 (135° / 1000 m)	No. ind	Acc. %	BAL31 (135° / 2000 m)	No. ind	Acc. %	BAL33 (315° / 250 m)	No. ind	Acc. %	BAL34 (315° / 500 m)	No. ind	Acc. %	BAL35(315° / 1000 m)	No. ind	Acc. %
Spiophanes bombyx	229	17 %	Spiophanes bombyx	188	15 %	Spiophanes bombyx	219	17 %	Spiophanes bombyx	288	20 %	Spiophanes bombyx	364	26 %
Paramphinome jeffreysii	156	29 %	Phoronis sp.	143	26 %	Paramphinome jeffreysii	181	30 %	Phoronis sp.	198	34 %	Phoronis sp.	272	45 %
Phoronis sp.	128	38 %	Paramphinome jeffreysii	93	33 %	Phoronis sp.	138	41 %	Paramphinome jeffreysii	98	41 %	Paramphinome jeffreysii	74	50 %
Galathowenia oculata	64	43 %	Pectinaria sp. juv.	81	39 %	Thyasira flexuosa	75	46 %	Pectinaria sp. juv.	72	46 %	Pectinaria sp. juv.	67	55 %
Pectinaria sp. juv.	52	47 %	Galathowenia oculata	73	45 %	Diplocirrus glaucus	66	51 %	Eudorella emarginata	63	51 %	Eudorella emarginata	51	58 %
Eudorella emarginata	44	50 %	Thyasira croulinensis	60	50 %	Eudorella emarginata	65	56 %	Galathowenia oculata	46	54 %	Galathowenia oculata	46	62 %
Spiophanes kroyeri	42	53 %	Eudorella emarginata	55	54 %	Galathowenia oculata	54	60 %	Diplocirrus glaucus	39	57 %	Thyasira croulinensis	42	65 %
Thyasira croulinensis	42	56 %	Lanice conchilega	50	58 %	Lanice conchilega	34	63 %	Spiophanes kroyeri	34	59 %	Amphiura filiformis	34	67 %
Lanice conchilega	34	59 %	Spiophanes kroyeri	40	61 %	Chaetozone sp.	28	65 %	Lanice conchilega	28	61 %	Harpinia antennaria	27	69 %
Nemertini indet.	23	60 %	Diplocirrus glaucus	27	63 %	Caudofoveata indet.	27	67 %	Nemertini indet.	28	63 %	Antalis sp.	26	71 %
Thyasira equalis	23	62 %				Nemertini indet.	24	69 %				Diplocirrus glaucus	26	73 %

Table 12-12 continue

BAL37 (135° / 250 m)	No. ind	Acc. %	BAL38 (135° / 500 m)	No. ind	Acc. %	BAL39 (135° / 1000 m)	No. ind	Acc. %	BAL42 (180° / 250 m)	No. ind	Acc. %	BAL43 (180° / 500 m)	No. ind	Acc. %
Chaetozone sp.	356	26 %	Phoronis sp.	196	20 %	Phoronis sp.	163	18 %	Paramphinome jeffreysii	293	26 %	Paramphinome jeffreysii	102	10 %
Thyasira sarsi	207	41 %	Paramphinome jeffreysii	82	28 %	Paramphinome jeffreysii	86	27 %	Phoronis sp.	96	35 %	Phoronis sp.	95	19 %
Spiophanes bombyx	164	53 %	Eudorella emarginata	66	34 %	Eudorella emarginata	60	34 %	Thyasira flexuosa	88	42 %	Thyasira equalis	78	27 %
Paramphinome jeffreysii	124	62 %	Spiophanes bombyx	54	40 %	Spiophanes bombyx	49	40 %	Eudorella emarginata	69	49 %	Eudorella emarginata	70	33 %
Phoronis sp.	80	68 %	Lanice conchilega	53	45 %	Thyasira croulinensis	44	44 %	Diplocirrus glaucus	47	53 %	Natatolana borealis juv.	55	39 %
Pectinaria sp. juv.	47	71 %	Diplocirrus glaucus	40	49 %	Diplocirrus glaucus	40	49 %	Spiophanes bombyx	42	57 %	Thyasira croulinensis	55	44 %
Lanice conchilega	43	74 %	Amphiura chiajei	33	52 %	Lanice conchilega	39	53 %	Thyasira sarsi	35	60 %	Spiophanes bombyx	48	49 %
Diplocirrus glaucus	31	76 %	Spiophanes kroyeri	32	55 %	Amphiura chiajei	27	56 %	Amphiura chiajei	27	62 %	Diplocirrus glaucus	32	52 %
Eudorella emarginata	28	78 %	Thyasira croulinensis	24	58 %	Thyasira equalis	25	59 %	Lanice conchilega	27	64 %	Spiophanes kroyeri	30	55 %
Echinocardium flavescens	18	80 %	Thyasira equalis	23	60 %	Aporrhais sp.	23	61 %	Spiophanes kroyeri	26	67 %	Amphiura chiajei	24	57 %
Heteromastus filiformis	18	81 %												

BAL44 (180° / 1000 m)	No. ind	Acc. %	BAL46 (315° / 500 m)	No. ind	Acc. %	BAL47 (315° / 1000 m)	No. ind	Acc. %	BAL27R (315° / 10000 m)	No. ind	Acc. %
Phoronis sp.	117	14 %	Phoronis sp.	224	18 %	Phoronis sp.	171	14 %	Phoronis sp.	147	13 %
Paramphinome jeffreysii	91	25 %	Paramphinome jeffreysii	144	29 %	Spiophanes bombyx	133	24 %	Spiophanes bombyx	94	21 %
Eudorella emarginata	66	33 %	Spiophanes bombyx	92	37 %	Paramphinome jeffreysii	131	35 %	Paramphinome jeffreysii	72	27 %
Thyasira croulinensis	54	39 %	Thyasira equalis	59	42 %	Thyasira croulinensis	56	39 %	Eudorella emarginata	70	33 %
Thyasira equalis	43	44 %	Diplocirrus glaucus	57	46 %	Thyasira equalis	52	43 %	Galathowenia oculata	59	39 %
Spiophanes bombyx	31	48 %	Eudorella emarginata	51	50 %	Eudorella emarginata	48	47 %	Thyasira croulinensis	49	43 %
Diplocirrus glaucus	29	52 %	Amphiura filiformis	35	53 %	Pectinaria sp. juv.	35	50 %	Thyasira equalis	38	46 %
Eriopisa elongata	27	55 %	Spiophanes kroyeri	35	56 %	Amphiura chiajei	32	52 %	Lanice conchilega	28	49 %
Amphiura chiajei	20	57 %	Thyasira croulinensis	33	58 %	Diplocirrus glaucus	30	55 %	Pectinaria sp. juv.	27	51 %
Lanice conchilega	19	60 %	Pectinaria sp. juv.	32	61 %	Galathowenia oculata	30	57 %	Eriopisa elongata	26	53 %

Table 12-13: Station information for Balder field, 2000.

St. no.	Well template	Distance (m)	Direction (degr.)	Volume (litres)
BAL03	D	250	54	32
BAL04	D	500	54	33
BAL05	D	1000	54	45
BAL09	C	250	135	54
BAL10	C	500	135	48
BAL11	C	1000	135	29
BAL12	C	2000	135	29
BAL16	B	250	198	50
BAL17	B	500	198	53
BAL18	B	1000	198	55
BAL22	A	250	270	43
BAL23	A	500	270	37
BAL24	A	1000	270	42
BAL28	D	250	135	33
BAL29	D	500	135	31
BAL30	D	1000	135	54
BAL31	D	2000	135	41
BAL33	D	250	315	42
BAL34	D	500	315	29
BAL35	D	1000	315	34
BAL37	B	250	135	37
BAL38	B	500	135	37
BAL39	B	1000	135	34
BAL42	A	250	180	49
BAL43	A	500	180	46
BAL44	A	1000	180	53
BAL46	A	500	315	34
BAL47	A	1000	315	41
BAL27R	C	10000	315	44 *

* The additional five grab samples taken gave 38 litres of sediment.

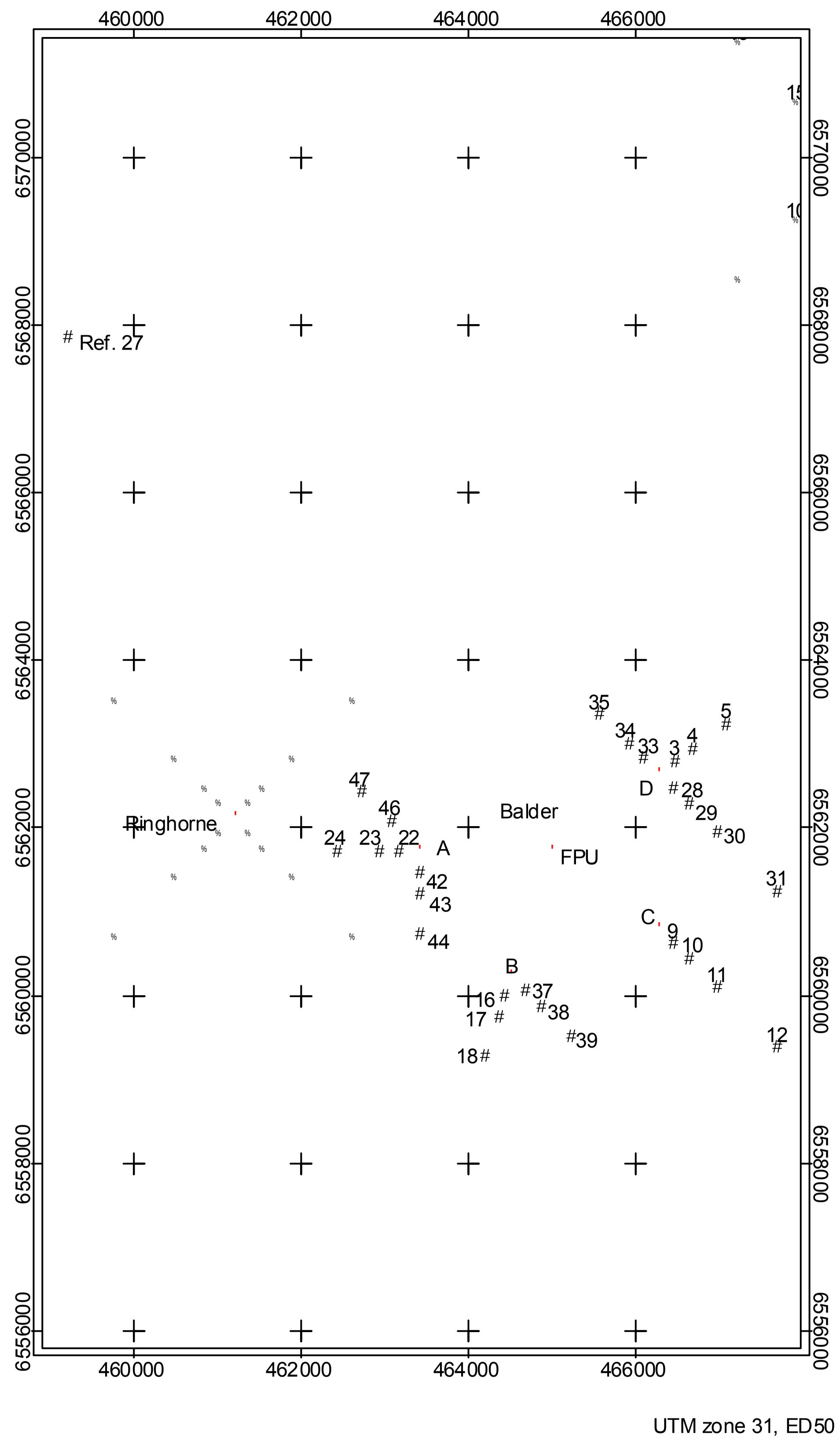

Figure 12-17: Map with sampling positions for Balder field, 2000

13 Jotun field

13.1 Introduction

The Jotun field is located in Block 25/7 and 25/8 in the middle part of Region II, situated north of the Ringhorne and Balder field. Since 1970 there has been drilled 9 exploration wells, all with water based drilling mud, in the Jotun field, - six wells were drilled after 1992. Production drilling started in March 1999.

The centre positions have been changed since the baseline survey carried out in 1996 (approximately 400 m NNW) and new transects and station positions are established around Jotun B. The reference station is at the same position as in 1996. There are two installations at the Jotun field, Jotun A (production ship) and Jotun B (well head platform). Data on recent drilling and discharges are given in Table 13-1.

In 1996, sediments at Jotun revealed low hydrocarbon levels that were comparable with levels found in earlier baseline studies of the area (Jensen *et al*. 1997). However, according to the North Sea Quality Status Report of 1993 these levels were a little elevated compared to the average hydrocarbon level of the North Sea. Also the levels of selected metals were in general low at Jotun in 1996, except from elevated barium levels in sediments at two stations in the periphery relative to Jotun B. The fauna was found to be undisturbed.

Information on the sampling stations is shown in Figure 13-13 and Table 13-13, both on the foldout page at the end of this chapter (page 13-21).

Table 13-1: Summary of recent wells drilled and operational and accidental discharges at the Jotun field (discharges in tonnes).

	1999	2000	Comments
No of wells drilled	5	5	
Barite	834	850	Barite in water based mud (WBM)
Cuttings	1694	1700	Cuttings with WBM
Water-based drilling mud	7463	7450	Only WBM discharge to sea
Cementing and other chemicals	8,26	8,25	Reinjected
Oil in produced water		25,1*	*= 31,2 ppm × 805960 Sm^3
Accidental discharges	0	30 litres	Oil based mud

13.2 Results and discussion

13.2.1 Physical characteristics

The median phi value and the amount (%) of pelite, fine sand and total organic material (TOM) in the sediment from the present and previous surveys shown in Table 13-2 and Figure 13-1. 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 in the Jotun field are classified as silt with median values varying from 4.23 (JOT08) to 4.45 (JOT09). The amount of pelite in the sediment varies from 17.6 % (JOT01) to 21.6 % (JOT15), the fine sand from 78.0 % (JOT15) to 81.1 % (JOT01) while the TOM varies from 2.1 % (JOT09) to 2.9 % (JOT10). The corresponding values at the reference station JOT30R are within the variation at the field stations.

The pelite and TOM values are somewhat higher than those found at the neighbouring Heimdal and Ringhorne fields. The TOM values are somewhat higher than those found in the baseline survey in 1996.

Table 13-2: The median (phi) and amount of pelite, fine sand and TOM in the sediment from stations at the Jotun field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	Distance (m)	Direction (degr.)	Median	Classification	Pelite	Fine sand	TOM
JOT01	2000	22.5	4.25	Silt	**17.57**	**81.05**	2.55
JOT02	1000	22.5	4.43	Silt	21.39	78.23	2.74
JOT03	500	22.5	4.41	Silt	20.44	79.25	2.57
JOT04	250	22.5	4.36	Silt	20.70	78.83	2.45
JOT05	250	135	4.31	Silt	19.27	80.19	2.31
JOT06	500	135	4.34	Silt	18.67	80.88	2.34
JOT07	1000	135	4.37	Silt	20.45	79.20	2.53
JOT08	2000	135	**4.23**	Silt	19.05	80.58	2.45
JOT09	2000	315	**4.45**	Silt	19.51	80.00	**2.12**
JOT10	1000	315	4.39	Silt	19.78	79.63	**2.91**
JOT11	500	315	4.39	Silt	20.10	79.53	2.35
JOT12	250	315	4.37	Silt	20.26	79.28	2.19
JOT13	250	225	4.41	Silt	19.96	79.61	2.44
JOT14	500	225	4.34	Silt	21.10	78.64	2.57
JOT15	1000	225	4.43	Silt	**21.55**	**78.03**	2.64
JOT16	2000	225	4.42	Silt	19.72	79.42	2.67
JOT30R	11330	267.3	4.47	Silt	19.29	80.26	2.57
Average *			4.37		19.97	79.52	2.49
St. dev. *			0.06		1.03	0.87	0.20

* Excluding the reference station.

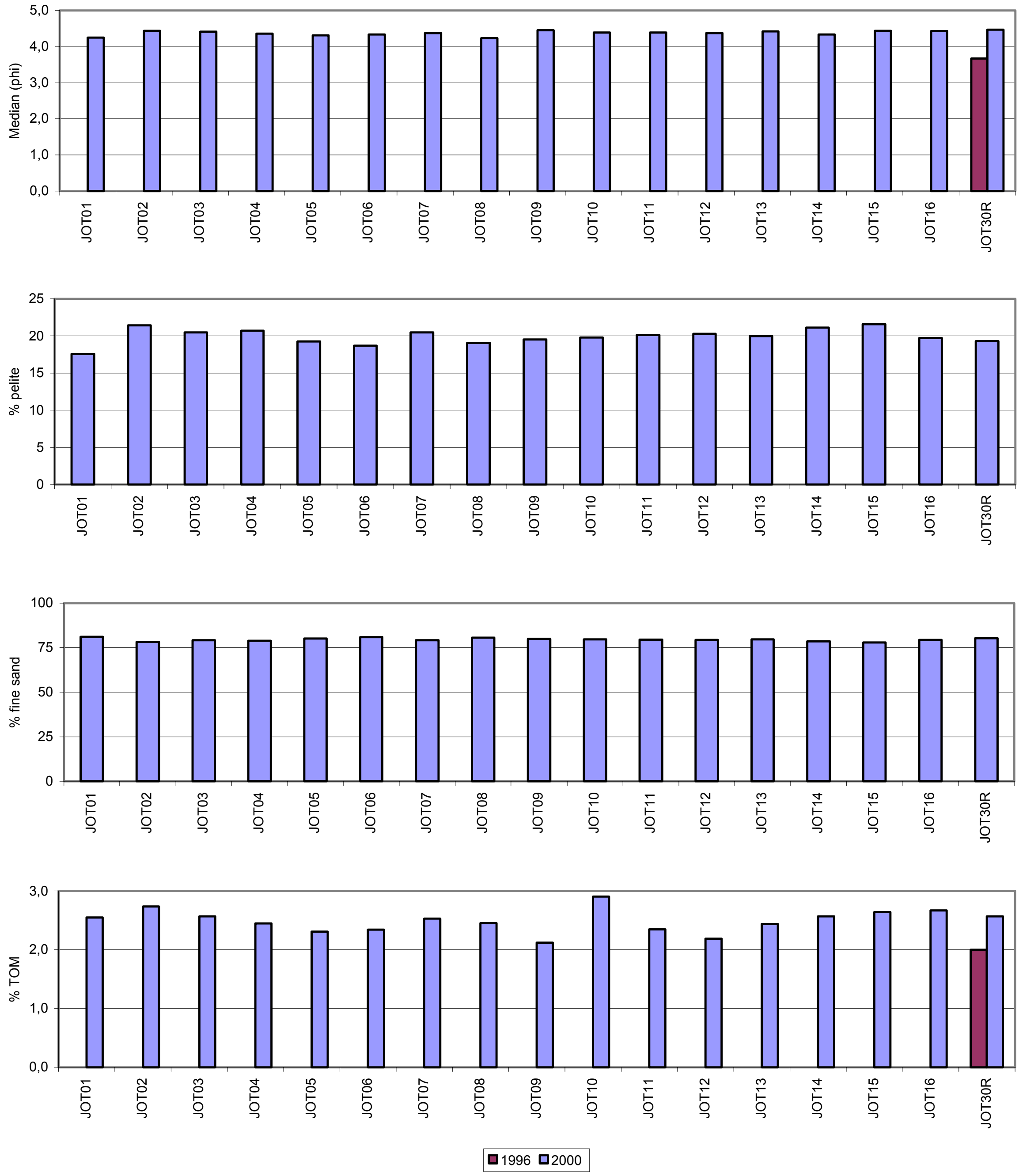

Figure 13-1: Sediment characteristics at the Jotun field, 2000 and previous surveys.

13.2.2 Chemical characteristics

The calculated limits of significant contamination for selected hydrocarbons and metals in sediments from Region II ($LSC_{97\text{-}00\ RegII}$) are presented previously in the chapter that deals with the regional and reference stations. In addition to the regional limits, field-specific limits of significant contamination are calculated from the field reference station ($LSC_{00\ JOT30R}$). Both sets of data are presented in Table 13-3. Jotun has somewhat higher levels of metals than most of the other fields in Region II (see Regional and reference stations chapter). The limits of significant contamination based on sediments from the reference station are therefore correspondingly higher than the limits calculated for the whole region. Based on the analysis results of the Jotun field, both LSC's are used as a basis by which to assign areas contaminated with the chemical parameters.

The results of analyses of hydrocarbons are summarised in Table 13-4. Concentrations of selected compounds in vertical sediment sections are presented in Table 13-5. The full data set of replicate measurements and date from previous years are given in the Appendix. THC values are compared with those from previous years in Figure 13-3.

Table 13-3: Background levels and Limits of Significant Contamination for the Jotun field, 2000. All values in mg/kg dry sediment.

	THC	NPD's	3-6 ring	Decalins	Cd	Hg	Cu	Zn	Ba	Cr	Pb
$LSC00_{JOT30R}$	8.6	0.040	0.128	0.108	0.038	0.011	2.6	11.8	149	10.5	8.1
$LSC_{97\text{-}00\ Region\ II}$	9.8	*	*	*	0.029	0.008	2.0	8.9	146	9.6	7.0

*) Regional stations not analysed for NPD's, 3-6 ring aromatics and decalins.

Table 13-4: Concentrations of hydrocarbons in sediments from the Jotun field, 2000. All values in mg/kg dry sediment. Values above LSC_{JOT30R} are dark shaded and values between $LSC_{97\text{-}00RegII}$ and LSC_{JOT30R} are light shaded.

Station	THC		NPD's		3-6 ring		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
JOT01	8.3	1.0	n.a.		n.a.		n.a.	
JOT02	9.3	2.5	n.a.		n.a.		n.a.	
JOT03	8.4	3.2	n.a.		n.a.		n.a.	
JOT04	12.7	4.4	n.a.		n.a.		n.a.	
JOT05	15.6	4.4	0.041	0.007	0.122	0.009	0.396	0.181
JOT06	8.8	3.2	n.a.		n.a.		n.a.	
JOT07	6.5	2.4	n.a.		n.a.		n.a.	
JOT08	6.8	2.2	0.044	0.004	0.136	0.007	0.049	0.022
JOT09	7.3	1.0	n.a.		n.a.		n.a.	
JOT10	7.0	0.4	n.a.		n.a.		n.a.	
JOT11	21.8	4.4	0.040	0.002	0.151	0.010	0.229	0.026
JOT12	25.3	1.2	0.039	0.002	0.136	0.008	0.374	0.058
JOT13	29.7	6.2	0.033	0.002	0.124	0.002	0.456	0.122
JOT14	15.5	1.3	n.a.		n.a.		n.a.	
JOT15	11.4	3.2	n.a.		n.a.		n.a.	
JOT16	13.5	2.9	n.a.		n.a.		n.a.	
JOT30R	5.1	1.5	0.031	0.004	0.094	0.015	0.084	0.010

n.a. Not analysed.

Table 13-5: Concentrations of hydrocarbons in vertical sections of sediment samples from the Jotun field, 2000. All values in mg/kg dry sediment. Values above LSC_{JOT30R} are dark shaded and values between $LSC_{97\text{-}00RegII}$ and LSC_{JOT30R} are light shaded.

Station	Layer (cm)	THC	NPD's	3-6 ring	Decalins
JOT05	0-1	12.6	0.036	0.128	0.305
	1-3	15.0	0.055	0.140	0.331
	3-6	8.1	0.049	0.180	0.049
JOT08	0-1	7.2	0.040	0.129	0.042
	1-3	8.9	0.058	0.152	0.077
	3-6	6.4	0.072	0.157	0.041
JOT30R	0-1	5.4	0.023	0.072	0.067
	1-3	7.2	0.031	0.096	0.071
	3-6	7.9	0.034	0.121	0.079

n.a. Not analysed.

In the present survey, THC values range from 6.5 ± 2.4 mg/kg dry sediment to 29.7 ± 6.2 mg/kg (Table 13-4). The highest concentrations, 29.7 ± 6.2 mg/kg dry sediment are found at JOT13. Elevated levels of THC are found in sediments at all stations along this transect. Contamination is also found in sediments at stations JOT11 and JOT12, while concentrations just above LSC are found at JOT04 and JOT05. Values of aromatics and decalins above LSC are found in sediments at stations JOT05, JOT08 and JOT11 to JOT13. These findings match the THC findings except at station JOT08 were THC levels below LSC are found. At JOT08 NPD and 3-6 ring aromatics concentrations are just above LSC.

Vertical sediment samples were collected at stations JOT05, JOT08, and JOT30R (Table 13-5). The 0-1 cm and 1-3 cm layers at station JOT05 have THC values just above LSC, with the highest concentration, 15.0 mg/kg, found in the 1-3 cm layer. At JOT08, the highest concentration is also found in the 1-3 cm layer, though it is below LSC. However, there are no distinct THC gradients with depth in the sediments at the three locations in question. Distribution of aromatics and decalins also roughly follows this pattern at station JOT05, with elevated levels of NPD's, 3-6 ring aromatics and decalins in the 1-3 cm layer. Minor increases downward in the sediments are found for aromatics and decalins at station JOT08. Elevated levels of NPD's and 3-6 ring aromatics occur in all layers on this station.

In general, hydrocarbon contents above LSC are found in sediments at eight of sixteen field stations at Jotun. The hydrocarbon levels at the contaminated stations range from 11.4 mg/kg to 29.7 mg/kg. Elevated levels of THC are found in sediments at all stations in direction 225° relative to the installation. Contamination is also found in sediments out to 500 m at 315°, while concentrations just above LSC are found 250 m at 22.5° and 250m at135° relative to the installation. Gas chromatograms of sediment extracts from all these locations indicate contamination with mineral oil (Figure 13-2). In the vertical sediment samples, highest hydrocarbon contents are found in the 1-3 cm layers at the stations sampled.

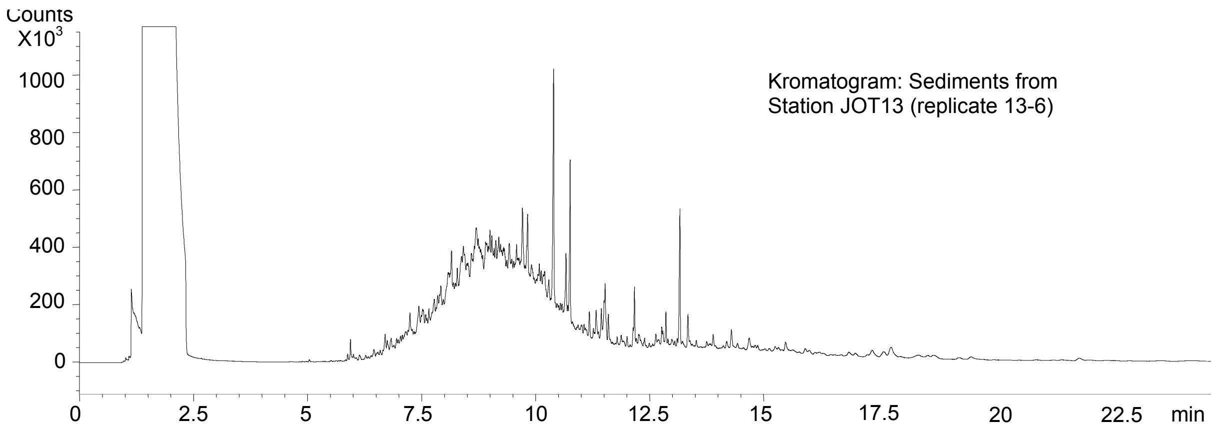

Figure 13-2: Gas chromatogram of a sediment extract from the Jotun field, 2000.

The results of metal analyses in sediments from the Jotun field are summarised in Table 13-6. Concentrations of selected metals in the vertical sediment sections are presented in Table 13-7. The full set of replicate measurements, including selected data from previous years is given in the Appendix. Metal values from 2000 are compared with those from previous years in Figure 13-4 and Figure 13-5.

Table 13-6: Concentrations of selected metals in sediments from the Jotun field, 2000. All values in mg/kg dry sediment. Values above LSC_{JOT30R} are dark shaded and values between $LSC_{97\text{-}00RegII}$ and LSC_{JOT30R} are light shaded.

	Cd		Hg		Cu		Zn		Ba		Cr		Pb	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
JOT01	0.026	0.001	n.a.		2.1	0.1	8.8	0.7	153	24	7.7	0.4	6.3	0.2
JOT02	0.041	0.012	n.a.		2.6	0.3	11.4	1.9	240	44	9.7	0.5	6.9	0.8
JOT03	0.042	0.019	n.a.		2.3	0.1	9.7	0.6	412	100	8.7	0.3	6.5	0.4
JOT04	0.030	0.002	n.a.		2.4	0.3	9.6	0.8	1019	495	8.6	0.5	6.5	0.3
JOT05	0.030	0.003	0.009	0.002	2.3	0.4	9.0	0.7	1350	480	8.1	0.4	6.0	0.5
JOT06	0.027	0.003	n.a.		2.3	0.1	9.4	0.5	373	46	8.6	0.1	6.5	0.3
JOT07	0.028	0.004	n.a.		2.2	0.4	9.8	1.4	395	285	8.7	0.8	6.8	1.0
JOT08	0.040	0.021	0.010	0.001	2.3	0.1	10.3	1.5	172	11	8.4	0.2	6.6	0.3
JOT09	0.035	0.013	n.a.		1.8	0.1	8.1	0.5	126	57	8.0	0.2	5.5	0.7
JOT10	0.030	0.003	n.a.		2.5	0.3	10.5	1.0	380	91	9.0	0.4	7.3	0.3
JOT11	0.032	0.003	n.a.		2.4	0.1	10.1	0.4	427	93	8.9	0.3	7.0	0.4
JOT12	0.030	0.000	n.a.		2.9	0.3	11.3	1.0	1976	261	8.8	0.4	7.5	0.2
JOT13	0.033	0.005	n.a.		2.4	0.2	9.9	0.2	680	458	8.6	0.4	6.9	0.3
JOT14	0.033	0.006	n.a.		2.3	0.6	10.3	2.0	352	268	9.2	1.2	7.2	1.0
JOT15	0.043	0.005	n.a.		2.4	0.4	10.3	2.3	118	52	9.4	1.0	7.1	2.0
JOT16	0.030	0.003	n.a.		2.3	0.1	10.2	0.5	159	25	9.1	0.3	6.8	0.2
JOT30R	0.029	0.004	0.008	0.001	2.1	0.2	9.3	1.1	93	24	8.7	0.8	6.7	0.6

n.a. Not analysed.

Table 13-7: Concentrations of selected metals in vertical sections of the sediment samples from the Jotun field. All values in mg/kg dry sediment. Values above LSC_{JOT30R} are dark shaded and values between $LSC_{97\text{-}00RegII}$ and LSC_{JOT30R} are light shaded.

Station	Layer (cm)	Cd	Hg	Cu	Zn	Ba	Cr	Pb
JOT05	0-1	0.027	0.009	2.2	9.2	1889	8.2	6.4
	1-3	0.035	0.009	2.4	9.7	699	8.9	7.1
	3-6	0.036	0.014	2.3	10.3	331	8.5	7.2
JOT08	0-1	0.027	0.009	2.3	10.0	181	8.5	6.7
	1-3	0.039	0.009	2.6	10.9	153	9.1	7.4
	3-6	0.031	0.009	2.4	10.9	135	9.1	7.6
JOT30R	0-1	0.028	0.007	2.0	8.7	83	8.1	6.6
	1-3	0.042	0.009	2.0	9.6	92	9.0	6.4
	3-6	0.044	0.013	2.5	11.0	110	9.5	7.5

n.a. Not analysed.

At Jotun, barium values range from 118 ± 52 mg/kg to 1976 ± 261 mg/kg dry sediment, cadmium from 0.026 ± 0.001 mg/kg to 0.043 ± 0.005 mg/kg, copper from1.8 ± 0.1 mg/kg to 2.9 ± 0.3 mg/kg, lead from 5.5 ± 0.7 mg/kg to 7.5 ± 0.2 mg/kg, zinc from 8.1 ± 0.5 mg/kg to 11.4 ± 1.9 mg/kg and chromium from 8.1 ± 0.4 to 9.7 ± 0.5 mg/kg (Table 13-6). Relatively high barium concentrations are found at all stations situated 250 m from the installation. The values range from 680 mg/kg to 1976 mg/kg, with the highest concentrations found in sediments from station JOT12. All 500 m stations also contain sediments with barium levels above LSC, ranging from 352 mg/kg to 427 mg/kg. Barium levels above LSC are also found in sediments at the 1000 m stations except JOT15. Background levels are found at this station and at stations 2000 m from the field centre. Among the other selected metals, four stations reveal cadmium values near LSC_{JOT30R}. However, at stations JOT02, JOT03 and JOT08 one of three replicates contain high concentration of cadmium, resulting in a high standard deviation. At JOT15 cadmium levels are just above LSC, 0.043 ± 0.005 mg/kg, and so are the copper concentrations at station JOT12 with 0.029 ± 0.003 mg/kg. None of the sediments can be described as contaminated by chromium or lead, all though chromium has values near LSC at JOT02. Mercury is measured in sediments from stations JOT05, JOT08 and JOT30R. Concentrations range from 0.008 to 0.010 mg/kg, all values being in the grey zone between the field specific and regional LSC.

Vertical sediment samples at stations JOT 05, JOT08 and JOT30R reveal the highest concentrations of barium in the top layer, decreasing downwards in the sediments (Table 13-7). Slight increases in cadmium, zinc, chromium and lead concentrations are found with increasing depth in the sediment. Also for mercury increases are seen downward in the sediments with contamination in the 3-6 cm layers at stations JOT05 and JOT30R.

In general, thirteen of sixteen field stations at Jotun contain barium concentrations above LSC. Most stations have cadmium, copper and zinc values above the regional LSC, though under the field-specific LSC. Lead concentrations over the regional LSC, but under the field-specific LSC are found in sediments at five stations. All mercury concentrations are also in level between regional and field-specific LSC.

<u>Comparison with previous survey(s)</u>

The centre position has been changed approximately 400 m NNW since the baseline survey in 1996, but position of the reference station remains unchanged. New transects and station positions were established in 2000. Virtually no changes in sediment levels of THC, barium, lead and copper are found, while concentrations of cadmium have increased from 0.021 ± 0.008 mg/kg to 0.029 ± 0.004 mg/kg dry sediment. Zinc concentrations have decreased from 15.4 ± 2.0 mg/kg to 9.3 ± 1.1 mg/kg.

The baseline survey of Jotun was performed in 1996. The area was described as generally low in hydrocarbons, although the natural background levels were described as higher than the average for the North Sea. A direct comparison between the baseline survey and this year's survey is impossible because of new sampling positions, but the tendencies in the field seem clear. In the present survey contamination with hydrocarbons is found in sediments at stations situated 250 m from the field centre, extending to 500 m/315° and 2000 m/225°. Chromatograms of sediment extracts from these stations indicate contamination by mineral oil. The field history includes discharges of 25.1 tons oil in produced water in addition to a minor accidental discharge of oil-based mud. This may explain the mineral oil profiles found in chromatograms. In addition, ten wells have been drilled at Jotun with discharges of 3394 tons of cuttings including 1684 tons of barite, 14913 tons of water based drilling mud and 16.51 tons of cementing-/other chemicals.

In the baseline survey only two stations in the periphery of the field centre revealed elevated sediment levels of barium. In 2000 only three stations have sediments with barium levels under LSC (Figure 13-4). Relatively high barium values are found in sediments at the stations situated 250 m from the field centre, the highest concentrations found in the 315° direction. Distribution patterns for the other selected metals seem to follow barium, but only a few stations reveal sediments with elevated levels of these metals (Figure 13-5).

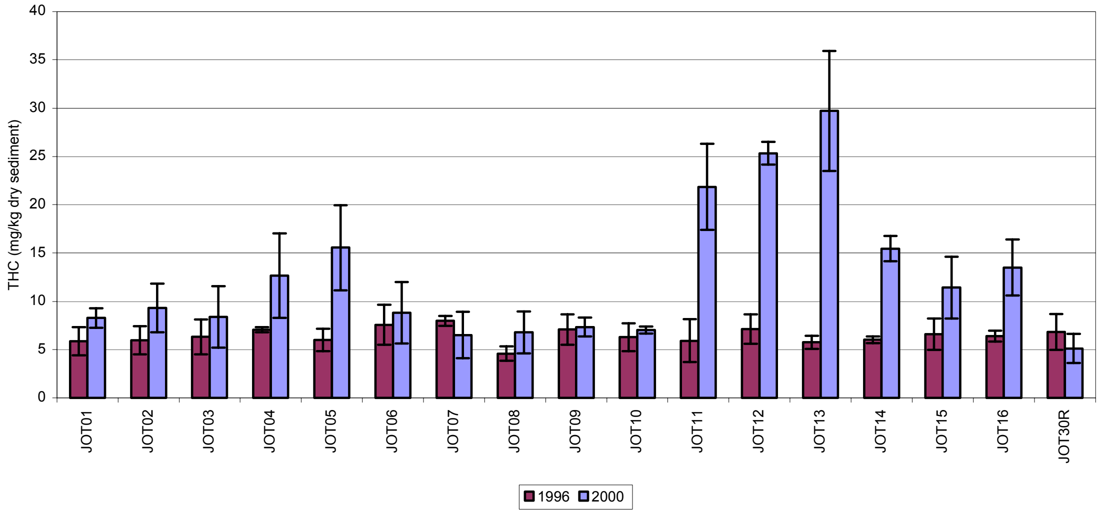

Figure 13-3: THC levels in sediment from the present (2000) and previous surveys, Jotun field.

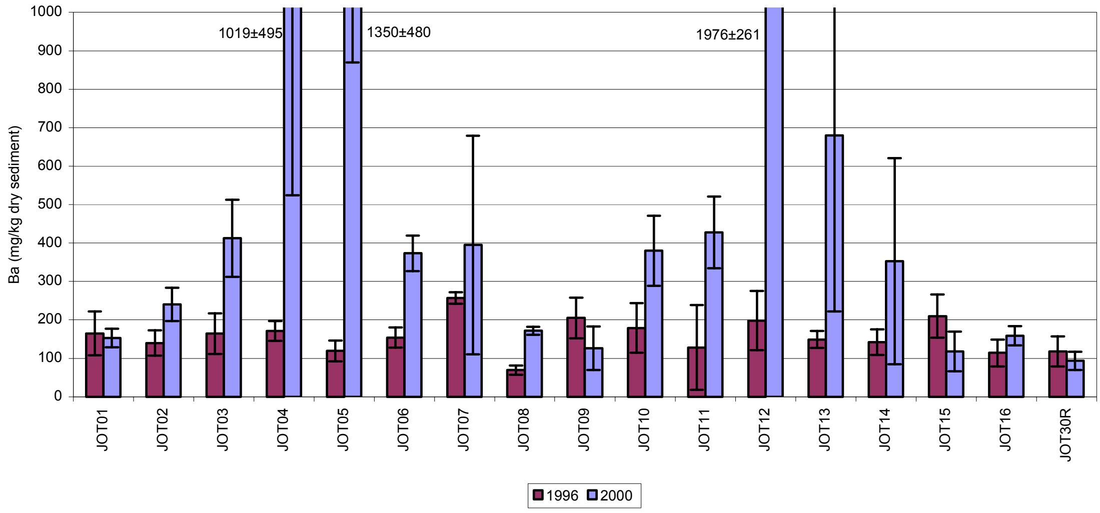

Figure 13-4: Barium levels in sediment from the present (2000) and previous surveys, Jotun field.

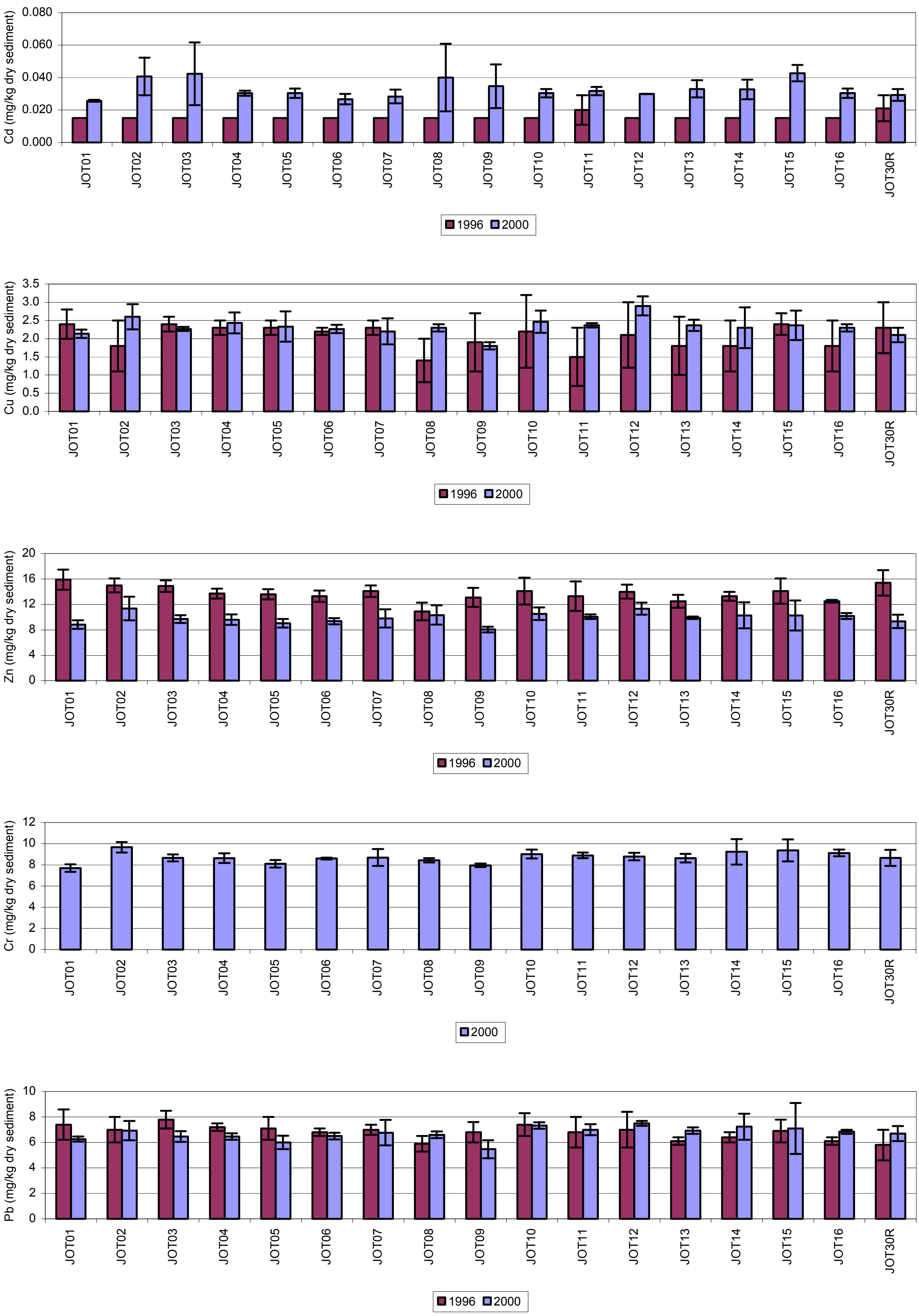

Figure 13-5: Levels of selected metals in sediments from the present (2000) and previous surveys, Jotun field.

13.2.3 Biology

The distribution of individuals and taxa within the main taxonomic groups are given in Table 13-8. A total of 12701 individuals within 234 taxa were registered at the Jotun field in the present survey (excluding juveniles). The polychaetes dominate the fauna with 58 % of the individuals and 54 % of the taxa recorded.

Table 13-8: Distribution of individuals and taxa within the main taxonomic groups at Jotun, 2000 (excluding juveniles).

Main taxonomic groups	Individuals		Taxa	
	Number	%	Number	%
Polychaeta	7326	58	127	54
Mollusca	2332	18	39	17
Crustacea	1298	10	44	19
Echinodermata	471	4	8	3
Diverse groups	1274	10	16	7
Total	12701	100	234	100

The species/area curve for the field reference station is shown in Figure 13-6. A total of 146 taxa are recorded in the ten grab samples, of which 57 (39 %) occur in the first sample and 117 (80 %) in the first five samples. The shape of the curve indicates that not all taxa in the area are present in the ten grab samples, but the representativity of five samples seems to be relatively good compared with the curves form other reference stations in the region.

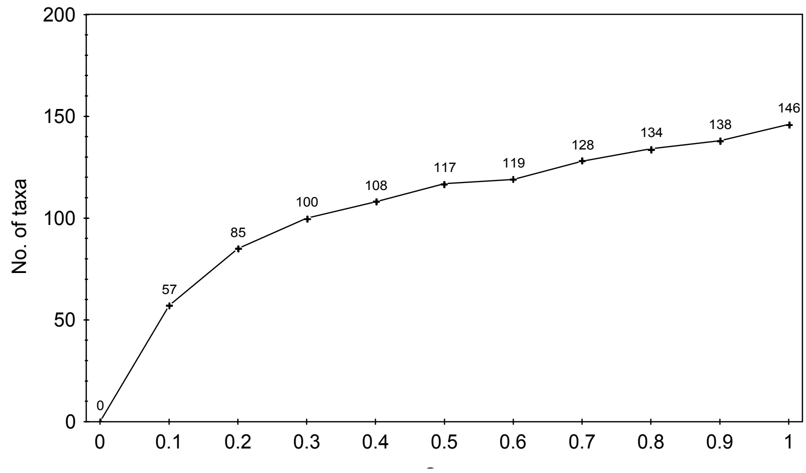

Figure 13-6: Species/area curve for the reference station at the Jotun field (area in m^2)

The number of individuals and taxa at each station, together with selected community indices is presented in Figure 13-7 and Table 13-9. The number of individuals recorded at Jotun varies from 535 (JOT06) to 1017 (JOT01). The number of taxa varies from 88 (JOT05) to 122 (JOT01), the diversity index H' between 4.9 and 5.5, the evenness index J between 0.75 and 0.82 and the ES_{100} between 37 and 44. The indices H', J and ES_{100} have highest and lowest values at station JOT09 and JOT03 respectively. The number of individuals is higher at the reference station JOT30R while the corresponding values for the other parameters are within the variation at the field stations.

The number of taxa at the reference station has increased since the previous survey in 1996 while the values for the other parameters are at similar levels in the two surveys.

Table 13-9: Number of individuals and taxa and selected community indices for each station (0.5 m^2) sampled at the Jotun field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	No. of ind.	No. of taxa	H'	J	ES100
JOT01	**1017**	**122**	5.3	0.76	41
JOT02	660	98	5.4	**0.82**	43
JOT03	702	90	**4.9**	**0.75**	**37**
JOT04	618	91	**4.9**	**0.75**	39
JOT05	595	**88**	5.2	0.80	40
JOT06	**535**	92	5.3	0.81	41
JOT07	595	89	5.0	0.77	38
JOT08	650	99	5.3	0.80	40
JOT09	848	109	**5.5**	**0.82**	**44**
JOT10	940	103	5.3	0.80	40
JOT11	620	95	5.2	0.79	39
JOT12	843	95	5.2	0.78	38
JOT13	750	105	5.5	**0.82**	43
JOT14	557	95	5.1	0.78	40
JOT15	719	94	5.3	0.80	40
JOT16	831	106	**5.5**	0.81	42
JOT30R	1221	117	5.2	0.76	39
Sum	11480				
Average *	718	98	5.2	0.79	40
St. dev. *	142	9	0.2	0.02	2

* Excluding the reference station.

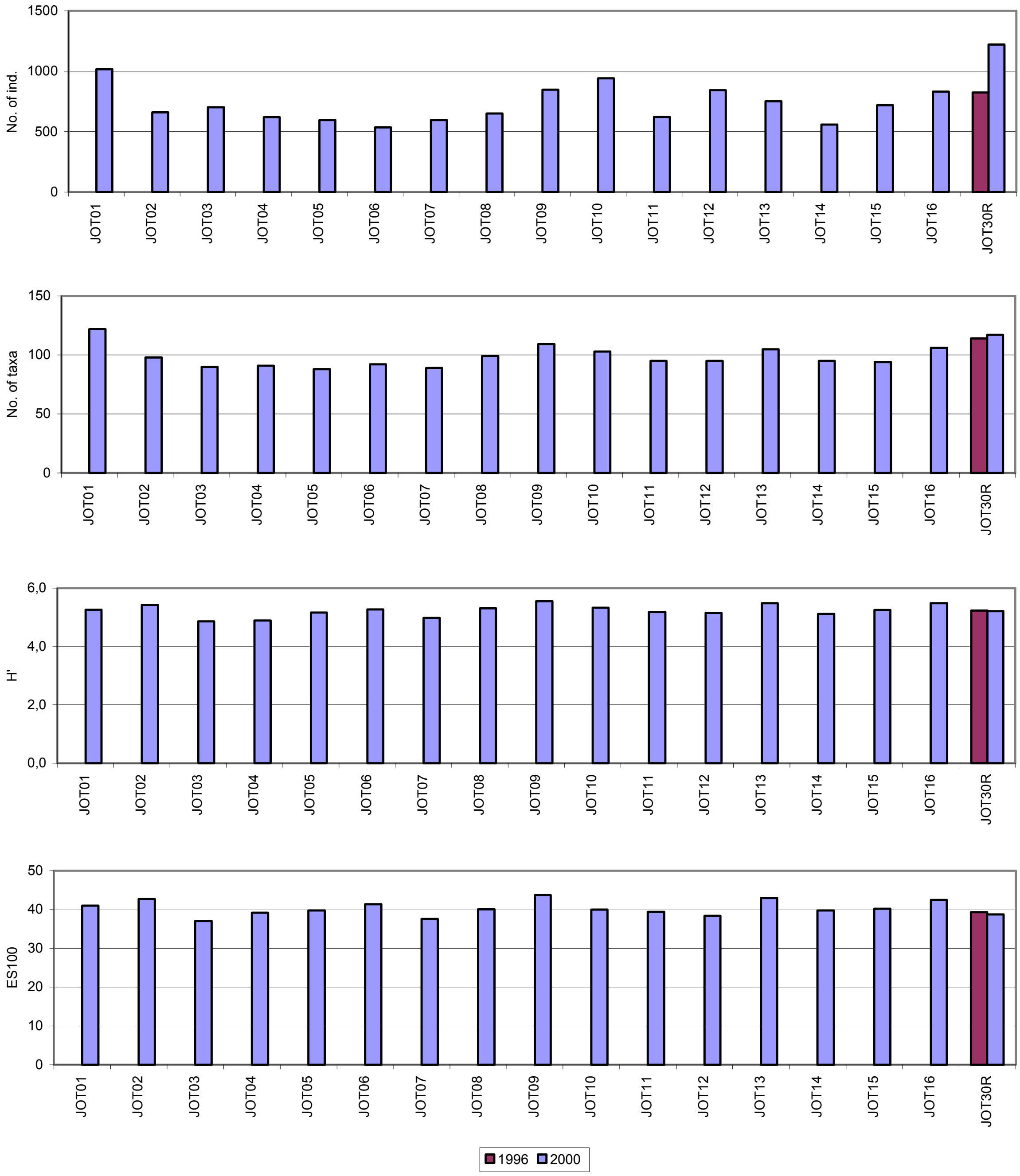

Figure 13-7: Biological characteristics at the Jotun, 2000 and previous survey.

The distribution of taxa in geometrical classes is shown in Figure 13-8. Seven stations have taxa in class 8 (128-255 individuals), while the rest of the stations, included the reference station, have taxa in class 7 (64-127 individuals). Occurrence of taxa in high classes might indicate faunal disturbance, which is not the case here.

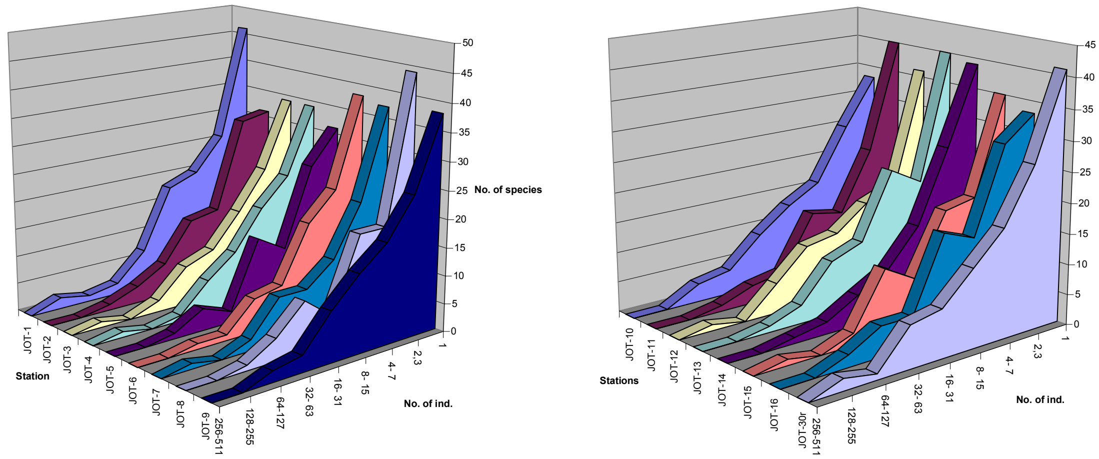

Figure 13-8: Distribution of taxa in geometrical classes at Jotun, 2000.

The ten most dominant taxa at each station are shown in Table 13-12 at the end of this chapter. A total of 23 taxa, inclusive three juvenile groups, are among the ten most dominant taxa at one or more stations. These 23 taxa comprise 58 % of the total number of individuals and 9 % of the total number of taxa registered at the Jotun field in the present survey.

The most dominant taxa among the adult forms are the polychaetes *Paramphinome jeffreysii, Spiophanes bombyx,* the bivalve *Thyasira croulinensis* and *Thyasira equalis,* the phoronid *Phoronis* sp and the cumacean *Eudorella emarginata.* The polychaeta *P. jeffreysii* is among the two most dominant taxa at all stations. The other taxa mentioned are among the ten most dominants at 13 or more stations. At station JOT05, the bivalve *Thyasira sarsi*, known to be abundant in disturbed sediments, occur among the most dominant taxa.

The ten most abundant taxa at the stations comprise between 51 % (station JOT09) and 66 % (station JOT05) of the total number of individuals registered at the respective stations. The corresponding value at the reference station JOT30R is 58 %.

The results indicate a uniform distribution of the fauna, although some minor signs of disturbance might be seen at station JOT05.

Figure 13-9 shows the dendrogram from the cluster analysis for the field stations and the regional and reference stations in Region II while Figure 13-10 shows the 2-D plot from the MDS analysis carried out on the field stations.

The cluster analysis separates out all regional and reference stations, with the exception of the reference stations at Jotun (JOT30R) and Ringhorne (RIN29R), at dissimilarity levels between 73 and 36 %. Further field station JOT08 is separated out at 32 % level while the remaining stations, including reference stations JOT30R and RIN29R, are separated into two main groups at approximately 30 % dissimilarity level. This result indicates a high degree of similarity in the distribution of the fauna at the field stations. The correlation coefficient shows a very good fit to the data (r = 0.93).

Due to the dissimilarity between the field stations and the regional and reference stations, the MDS plot shown in Figure 13-10 contains only field stations. The plot shows an evenly distribution of the stations in the plot, with station JOT08 somewhat isolated from the other stations. But the analyses indicate a high degree of similarity between the field stations. The stress test shows a poor fit to the data (0.44).

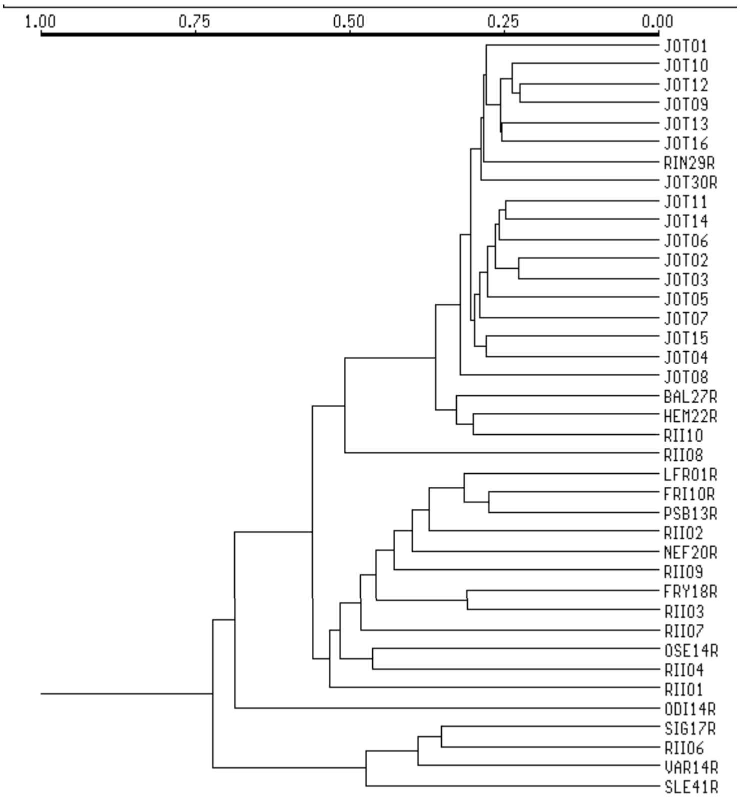

Figure 13-9: Cluster analysis of the Jotun field and the regional and reference stations in Region II, 2000.

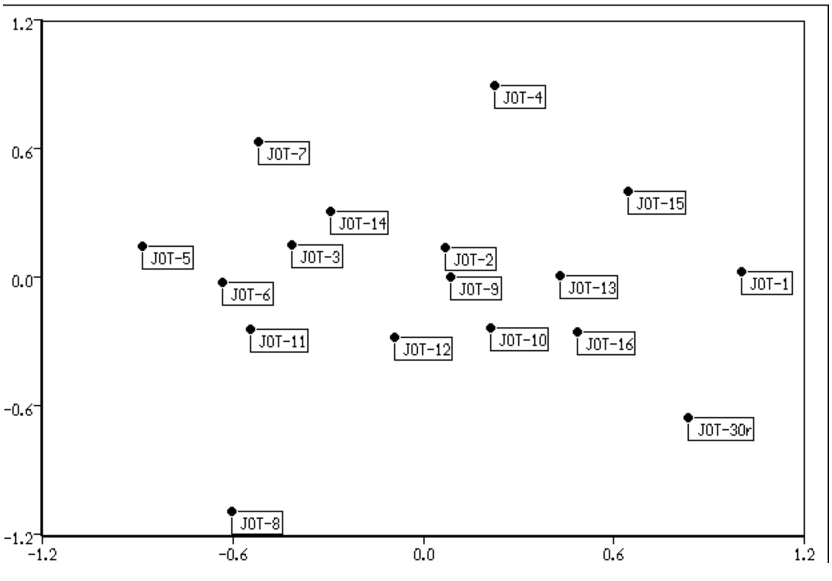

Figure 13-10: 2-D plot from the MDS analysis carried out on the station data form Jotun field, 2000.

A Canonical Correspondence Analysis (CCA) of the data from the field stations, including the field reference station, was carried out to examine the association between the biological data and the measured environmental variables in these areas. The analysis was carried out excluding the data from regional and reference stations due to the differences revealed in the cluster analysis for the whole region. CCA including some of the regional and reference stations is presented in the Appendix.

Through the forward selection procedure in CANOCO, two of ten variables gave the best fit and were significant. 19.1 % of the biological variance was explained by the first two axes of the ordination space which is constrained by these environmental variables.

Figure 13-11 shows a biplot from the analysis using cadmium (Cd) and barium Ba) as the constraining environmental variables together with a plot of the taxa with highest contribution on two axes. The first axis shows a gradient from field station JOT12 on the positive end to reference station JOT30R on the negative end and is positively correlated with the amount of cadmium in the sediments (+ 0.77). The taxa with the highest contribution on this axis are the polychaetes *Spiophanes bombyx* (29.4 %), *Paramphinome jeffreysii* (5.7 %) and *Galathowenia oculata* (4.4 %) and the bivalve *Thyasira equalis* (5.1 %). Other taxa, which contribute with more than 1 % on this axis, occur in low individual numbers at the stations.

The second axis shows a gradient from station JOT15 on the positive end to JOT12 on the negative end and is positively correlated with the amount of cadmium in the sediments (+ 0.85). The taxon with highest contribution on this axis is the amphiod *Eriopisa elongata* (6.7 %). Other taxa have low contribution or occur in low individual numbers at the stations.

These results might indicate some minor disturbance of the fauna at the stations situated in the lower right side of the plot (JOT04, JOT05 and JOT12). At these stations the highest amounts of barium in the sediments are found.

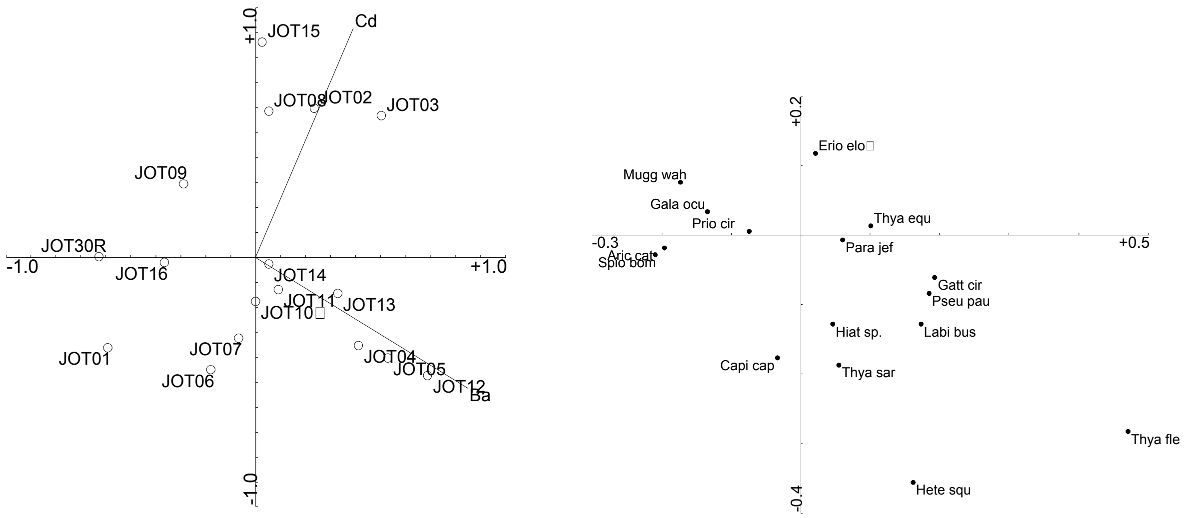

Figure 13-11: Biplot from the CCA analysis for the Jotun field stations, 2000 (left) and taxa with high contribution on two axes (right)

On the basis of the results from the uni- and multivariate analyses carried out on the data from the stations at Jotun, all stations are classified as group A station (undisturbed fauna, see Table 13-10). The multivariate analyses indicate a uniform distribution of the fauna over the field. Some of the stations (JOT01, JOT04, JOT05 and JOT12) have slightly higher abundance of some taxa, which are known to be abundant in disturbed sediments, than the other stations. At the same stations, elevated levels of THC and heavy metals are found. However, all stations are dominated by taxa that occur in undisturbed sediments, and are therefore considered as undisturbed.

Table 13-10: Classification into impact groups, distance to installation and biological statistics for the field stations at Jotun field, 2000.

Station	Impact group	Dist. (m)	Statistics			No. of individuals								
			No. ind	No. taxa	H'	Pje	Sbo	Tcr	Teq	Psp	Skr	Ppa	Tsa	Cca
JOT01	A	2000	1017	122	5,3	162	138	79	11	53	41	5	12	17
JOT02	A	1000	660	98	5,4	98	27	45	40	27	33	6	1	0
JOT03	A	500	702	90	4,9	183	15	41	55	24	23	6	3	0
JOT04	A	250	618	91	4,9	177	17	9	19	11	19	21	10	2
JOT05	A	250	595	88	5,2	109	10	45	36	32	12	12	12	0
JOT06	A	500	535	92	5,3	91	30	24	38	28	14	6	2	0
JOT07	A	1000	595	89	5,0	140	10	34	33	21	23	4	2	2
JOT08	A	2000	650	99	5,3	96	42	23	24	29	33	2	1	4
JOT09	A	2000	848	109	5,5	108	75	32	27	34	34	9	4	9
JOT10	A	1000	940	103	5,3	126	62	68	46	68	36	13	1	0
JOT11	A	500	620	95	5,2	104	15	55	43	39	20	11	2	3
JOT12	A	250	843	95	5,2	154	61	28	55	39	17	18	0	23
JOT13	A	250	750	105	5,5	107	25	46	50	38	22	21	2	0
JOT14	A	500	557	95	5,1	114	13	29	49	18	22	2	4	1
JOT15	A	1000	719	94	5,3	131	33	27	39	21	24	11	0	1
JOT16	A	2000	831	106	5,5	89	80	31	51	41	34	10	2	0
JOT30R	A	11330	1221	117	5,2	157	191	46	32	49	39	1	1	11
RII03	A	-	1523	127	4,7	1	54	96	0	20	50	35	0	1
RII09	A	-	1221	118	5,2	66	103	10	3	49	25	2	0	0
RII10	A	-	1200	128	5,4	58	106	102	5	44	33	6	1	0
FRY18R	A	-	2289	149	5.4	2	111	101	0	90	79	106	0	0
RIN29R	A	-	824	104	5,0	80	151	30	43	0	29	2	1	1
BAL27R	A	-	1073	118	5,4	72	94	49	38	147	23	6	0	0
HEM22R	A	-	1032	119	5.6	35	46	143	1	58	32	14	0	0

Pje = *Paramphinome jeffreysii*, Sbo = *Spiophanes bombyx*, Tcr = Thyasira crouliensis, Teq = Thyasira equalis, Eem = Eudorella emarginata, Skr = Spiophanes kroyeri, Afi = *Amphiura filiformis,* Ppa = Pseudopolydora pauchibranchiata, Tsa = Thyasira sarsi, Tfl = Thyasira flexuosa.

13.3 Summary and conclusions

The sediment at the field is classified as silt with a relatively high amount of pelite (17.6 – 21.6 %) and TOM (2.1 – 2.9 %). The pelite and TOM values are somewhat higher than those found at the neighbouring Heimdal and Ringhorne fields. The TOM values are somewhat higher than those found in the baseline survey in 1996.

In the present survey contamination with hydrocarbons is found in sediments at all stations situated 250 m from the field centre, extending to 500 m at 315° and 2000 m at 225°. In 1996 no hydrocarbon contamination was found in sediments at Jotun. Mineral oil profiles are seen in chromatograms of sediment extracts from the contaminated stations in 2000. The field history includes discharges of 25.1 tons oil in produced water in addition to a minor accidental discharge of oil-based mud. This may explain the mineral oil profiles found in chromatograms.

In the baseline survey only two stations in the periphery of the field centre revealed elevated sediment levels of barium. In 2000 only three stations have sediments with barium levels below limit of significant contamination. Relatively high values are found in sediments at all stations situated 250 m from the field centre, with the highest average concentration, 1976 mg/kg, found in the 315° direction. The area of elevated barium levels extends to 1000 m at 135°, 1000 m at 315°, 500 m at 225° and 500 m at 22.5°. Distribution patterns for the other selected metals seem to follow barium, though none of the concentrations exceed LSC. Most sediment concentrations of cadmium, copper and zinc are in the grey zone between the field-specific and regional LSC. Since 1999 ten wells have been drilled at Jotun. Spills of 3394 tons of cuttings, including 1684 tons of barite and 14913 tons of water-based drilling mud, have been discharged in the field. This likely explains the increases in sediment concentrations of selected metals.

There is a relatively high variation in the number of individuals (535 – 1017) and taxa (88 – 122) at the field stations, but the multivariate analyses indicate a uniform distribution of the fauna over the field. Some of the stations (JOT01, JOT04, JOT05 and JOT12) have slightly higher abundance of some taxa, which are known to be abundant in disturbed sediments, than the other stations. At the same stations, elevated levels of THC and heavy metals are found. However, all stations are dominated by taxa that occur in undisturbed sediments, and are therefore considered as undisturbed.

The calculated minimum area and spatial extent of contaminated sediments at the Jotun field is shown in Table 13-11 and Figure 13-12.

Table 13-11: Distance along the transects and calculated minimum area of contaminated sediments at the Jotun field, 2000 and previous survey.

Jotun	N/NE	E/SE	SW	NW	Km^2 (2000)	Km^2 (1996)
THC	250	500	2000	500	1.77	0
Ba	2000	2000	1000	250	5.30	0
Other metals	125	125	125	250	0.07	0

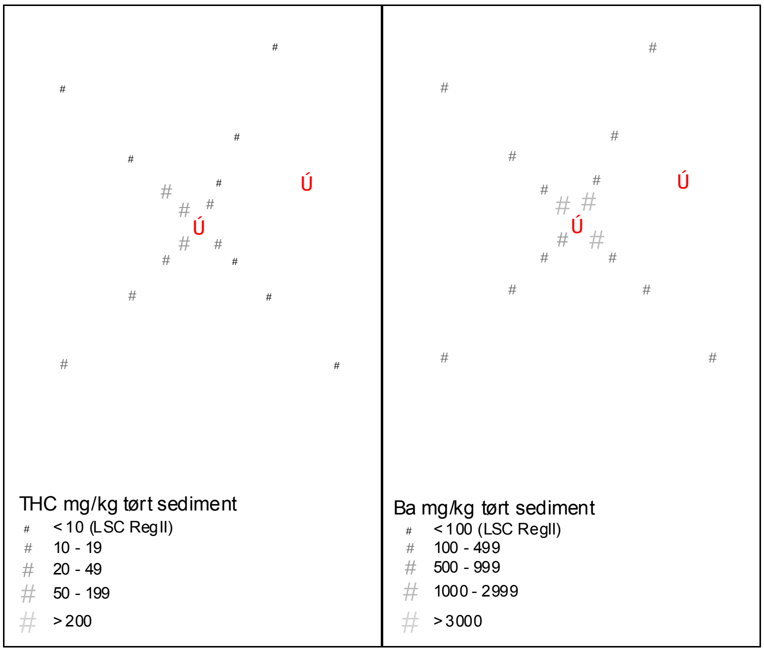

Figure 13-12: Distribution of the amounts of THC and barium in the sediments at the Jotun field, 2000.

Table 13-12: Number of individuals and the accumulative abundance for the ten predominant taxa at each station at the Jotun field, 2000.

JOT01 (22,5° / 2000 m)	No. ind	Acc. %	JOT02 (22,5° / 1000 m)	No. ind	Acc. %	JOT03 (22,5° / 500 m)	No. ind	Acc. %	JOT04 (22,5° / 250 m)	No. ind	Acc. %	JOT05 (135° / 250 m)	No. ind	Acc. %
Paramphinome jeffreysii	162	13 %	Paramphinome jeffreysii	98	13 %	Paramphinome jeffreysii	183	24 %	Paramphinome jeffreysii	177	22 %	Paramphinome jeffreysii	109	15 %
Pectinaria sp. juv.	159	26 %	Pectinaria sp. juv.	56	20 %	Thyasira equalis	55	31 %	Pectinaria sp. juv.	175	43 %	Pectinaria sp. juv.	70	25 %
Spiophanes bombyx	138	38 %	Thyasira croulinensis	45	26 %	Pectinaria sp. juv.	47	37 %	Eudorella emarginata	41	48 %	Thyasira croulinensis	45	32 %
Thyasira croulinensis	79	44 %	Thyasira equalis	40	32 %	Thyasira croulinensis	41	43 %	Lanice conchilega	31	52 %	Thyasira equalis	36	37 %
Phoronis sp.	53	49 %	Spiophanes kroyeri	33	36 %	Eudorella emarginata	30	47 %	Pseudopolydora paucibranchiata	21	55 %	Eudorella emarginata	34	42 %
Spiophanes kroyeri	41	52 %	Phoronis sp.	27	40 %	Eriopisa elongata	25	50 %	Diplocirrus glaucus	19	57 %	Phoronis sp.	32	46 %
Galathowenia oculata	30	54 %	Spiophanes bombyx	27	43 %	Phoronis sp.	24	53 %	Spiophanes kroyeri	19	59 %	Ophiuroidea indet. juv.	26	50 %
Nemertini indet.	25	56 %	Eudorella emarginata	21	46 %	Spiophanes kroyeri	23	56 %	Thyasira equalis	19	62 %	Diplocirrus glaucus	22	53 %
Lanice conchilega	23	58 %	Nemertini indet.	21	49 %	Nemertini indet.	19	58 %	Spiophanes bombyx	17	64 %	Lanice conchilega	22	56 %
Diplocirrus glaucus	20	60 %	Galathowenia oculata	20	52 %	Diplocirrus glaucus	16	61 %	Onchnesoma steenstrupi	13	65 %	Amphiura chiajei	12	58 %
						Lanice conchilega	16	63 %				Amphiura filiformis	12	59 %
												Caudofoveata indet.	12	61 %
												Pseudopolydora paucibranchiata	12	63 %
												Spiophanes kroyeri	12	65 %
												Thyasira sarsi	12	66 %

JOT06 (135° / 500 m)	No. ind	Acc. %	JOT07 (135° / 1000 m)	No. ind	Acc. %	JOT08 (135° / 2000 m)	No. ind	Acc. %	JOT09 (315° / 2000 m)	No. ind	Acc. %	JOT10 (315° / 1000 m)	No. ind	Acc. %
Pectinaria sp. juv.	108	16 %	Paramphinome jeffreysii	140	21 %	Paramphinome jeffreysii	96	13 %	Pectinaria sp. juv.	130	13 %	Paramphinome jeffreysii	126	11 %
Paramphinome jeffreysii	91	30 %	Pectinaria sp. juv.	60	30 %	Pectinaria sp. juv.	71	23 %	Paramphinome jeffreysii	108	23 %	Pectinaria sp. juv.	116	22 %
Thyasira equalis	38	36 %	Thyasira croulinensis	34	35 %	Spiophanes bombyx	42	28 %	Spiophanes bombyx	75	31 %	Phoronis sp.	68	28 %
Spiophanes bombyx	30	40 %	Thyasira equalis	33	40 %	Eriopisa elongata	34	33 %	Phoronis sp.	34	34 %	Thyasira croulinensis	68	34 %
Phoronis sp.	28	45 %	Eudorella emarginata	28	44 %	Eudorella emarginata	33	37 %	Spiophanes kroyeri	34	37 %	Spiophanes bombyx	62	40 %
Diplocirrus glaucus	26	49 %	Spiophanes kroyeri	23	47 %	Spiophanes kroyeri	33	42 %	Thyasira croulinensis	32	41 %	Thyasira equalis	46	44 %
Thyasira croulinensis	24	52 %	Nemertini indet.	22	51 %	Phoronis sp.	29	46 %	Prionospio cirrifera	29	43 %	Spiophanes kroyeri	36	48 %
Eudorella emarginata	22	56 %	Phoronis sp.	21	54 %	Lanice conchilega	26	49 %	Eudorella emarginata	28	46 %	Galathowenia oculata	35	51 %
Lanice conchilega	18	58 %	Amphiura chiajei	20	57 %	Thyasira equalis	24	53 %	Thyasira equalis	27	49 %	Eudorella emarginata	28	53 %
Nemertini indet.	15	61 %	Diplocirrus glaucus	19	60 %	Thyasira croulinensis	23	56 %	Diplocirrus glaucus	24	51 %	Prionospio cirrifera	26	56 %
Ophiuroidea indet. juv.	15	63 %	Eriopisa elongata	19	63 %									

Table 13-12 continue

JOT11	No. ind	Acc. %	JOT12	No. ind	Acc. %	JOT13	No. ind	Acc. %	JOT14	No. ind	Acc. %	JOT15	No. ind	Acc. %
Paramphinome jeffreysii	104	14%	Pectinaria sp. juv.	167	16%	Paramphinome jeffreysii	107	12%	Paramphinome jeffreysii	114	19%	Paramphinome jeffreysii	131	16%
Pectinaria sp. juv.	81	25%	Paramphinome jeffreysii	154	31%	Pectinaria sp. juv.	78	21%	Thyasira equalis	49	26%	Pectinaria sp. juv.	84	26%
Thyasira croulinensis	55	33%	Spiophanes bombyx	61	36%	Thyasira equalis	50	27%	Pectinaria sp. juv.	40	33%	Thyasira equalis	39	30%
Thyasira equalis	43	38%	Thyasira equalis	55	42%	Thyasira croulinensis	46	32%	Eudorella emarginata	32	38%	Spiophanes bombyx	33	34%
Phoronis sp.	39	44%	Phoronis sp.	39	45%	Phoronis sp.	38	37%	Thyasira croulinensis	29	43%	Eudorella emarginata	31	38%
Eudorella emarginata	28	47%	Eudorella emarginata	34	49%	Spiophanes bombyx	25	39%	Diplocirrus glaucus	25	47%	Diplocirrus glaucus	28	41%
Lanice conchilega	22	50%	Diplocirrus glaucus	32	52%	Eriopisa elongata	24	42%	Spiophanes kroyeri	22	50%	Lanice conchilega	28	44%
Ophiuroidea indet. juv.	20	53%	Thyasira croulinensis	28	54%	Galathowenia oculata	23	45%	Phoronis sp.	18	53%	Galathowenia oculata	27	48%
Spiophanes kroyeri	20	56%	Cerianthus lloydi juv.	26	57%	Lanice conchilega	23	47%	Lanice conchilega	17	56%	Thyasira croulinensis	27	51%
Nemertini indet.	17	58%	Nemertini indet.	24	59%	Abyssoninoe scopa aequilobata	22	50%	Eriopisa elongata	13	58%	Spiophanes kroyeri	24	54%
						Cerianthus lloydi juv.	22	52%	Spiophanes bombyx	13	60%			
						Eudorella emarginata	22	55%						
						Spiophanes kroyeri	22	58%						

JOT16	No. ind	Acc. %	JOT30R	No. ind	Acc. %
Pectinaria sp. juv.	93	10%	Spiophanes bombyx	191	14%
Paramphinome jeffreysii	89	19%	Paramphinome jeffreysii	157	25%
Spiophanes bombyx	80	28%	Pectinaria sp. juv.	146	35%
Thyasira equalis	51	33%	Eudorella emarginata	65	40%
Phoronis sp.	41	37%	Galathowenia oculata	55	43%
Galathowenia oculata	39	41%	Phoronis sp.	49	47%
Diplocirrus glaucus	35	45%	Thyasira croulinensis	46	50%
Spiophanes kroyeri	34	49%	Spiophanes kroyeri	39	53%
Thyasira croulinensis	31	52%	Abyssoninoe scopa aequilobata	38	56%
Eudorella emarginata	23	54%	Diplocirrus glaucus	36	58%

Table 13-13: Station information for Jotun field, 2000.

St. no.	Distance (m)	Direction (degr.)	Volume (litres)
JOT01	2000	22,5	70
JOT02	1000	22,5	84
JOT03	500	22,5	82
JOT04	250	22,5	82
JOT05	250	135	75
JOT06	500	135	80
JOT07	1000	135	77
JOT08	2000	135	79
JOT09	2000	315	86
JOT10	1000	315	74
JOT11	500	315	88
JOT12	250	315	86
JOT13	250	225	75
JOT14	500	225	95
JOT15	1000	225	75
JOT16	2000	225	74
JOT30R	11330	267,3	72 *

* The additional five grab samples taken gave 89 litres of sediment.

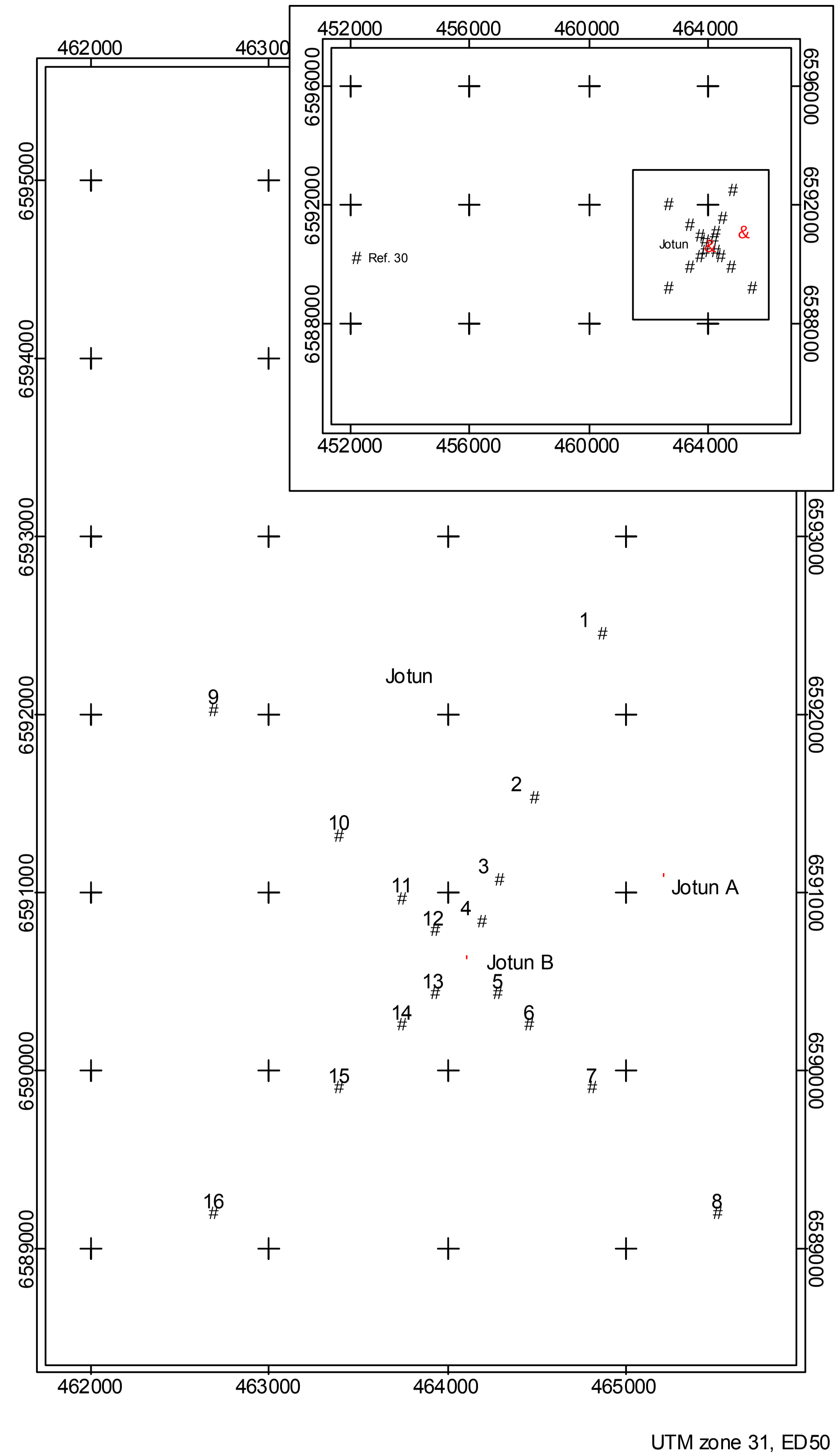

Figure 13-13: Map of sampling positions for Jotun field, 2000

14 Odin field

14.1 Introduction

The Odin field is located in Block 30-10 in the northern part of Region II, situated approximately 22 km north east of the Frigg area. Odin was a gas production platform. Drilling at Odin ended 18 years ago when only water based mud was used. Production of at the field ended in 1994 and the installation was removed in 1997. During this operation, physical disturbance of the sediments occurred. The present survey is the second survey after removal of the installation.

At this field monitoring surveys have been carried out in 1991 (Holte *et al.,* 1992) and 1997 (Mannvik *et al.,* 1998). In 1997 the monitoring survey was carried out only a few months after the installation was removed. Sediments at Odin were significantly contaminated by hydrocarbons at the 100 m stations on the 160°, 250° and 340°- axes. Cadmium, copper, zinc and lead contaminated sediments at the same stations, while only the 100 m station in the 340° direction had sediments with elevated barium levels. The fauna was found to be disturbed at the 100 m stations in the previous survey.

Information on the sampling stations is shown in Figure 14-13 and Table 14-12, both on the foldout page at the end of this chapter (page 14-19).

14.2 Results and discussion

14.2.1 Physical characteristics

The median phi value and the amount (%) of pelite, fine sand and total organic material (TOM) in the sediment from the present and previous surveys shown in Table 14-1 and Figure 14-1. 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 at the Odin field are classified as fine sand with median values varying from 3.28 (ODI06) to 3.50 (ODI12). The amount of pelite in the sediment varies from 1.99 % (ODI01) to 3.09 % (ODI02), the fine sand from 65.0 % (ODI06) to 88.7 % (ODI12) while the TOM varies from 0.68 % (ODI06) to 0.92 % (ODI07). The reference station ODI14R is significantly different from the field stations in sediment structure, with classification as medium sand, and the amount of fine sand is only 5.2 %.

The pelite content has increased at field station ODI02, while the TOM value has decreased at the field station ODI05 since 1997. The large differences seen at the reference station is believed to be a result of sampling at different positions in the two surveys. Apparently the position used in the present survey is wrong.

Table 14-1: The median (phi) and amount of pelite, fine sand and TOM in the sediment from stations at the Odin field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	Distance (m)	Direction (degr.)	Median	Classification	Pelite	Fine sand	TOM
ODI01	100	70	3.46	Fine sand	**1.99**	85.1	0.82
ODI02	500	70	3.45	Fine sand	**3.09**	81.5	0.76
ODI03	100	340	3.45	Fine sand	2.14	84.3	0.88
ODI04	500	340	3.39	Fine sand	2.59	75.3	0.78
ODI05	100	250	3.42	Fine sand	2.18	80.0	0.86
ODI06	500	250	**3.28**	Fine sand	2.41	**65.0**	0.68
ODI07	100	160	3.38	Fine sand	2.17	74.8	**0.92**
ODI08	500	160	3.45	Fine sand	2.31	84.1	0.72
ODI12	1000	160	**3.50**	Fine sand	2.94	**88.7**	**0.69**
ODI14R	10000	70	1.59	Medium sand	2.66	5.2	0.64
Average *			3.42		2.42	79.87	0.79
St. dev. *			0.06		0.38	7.18	0.09

* Excluding the reference station.

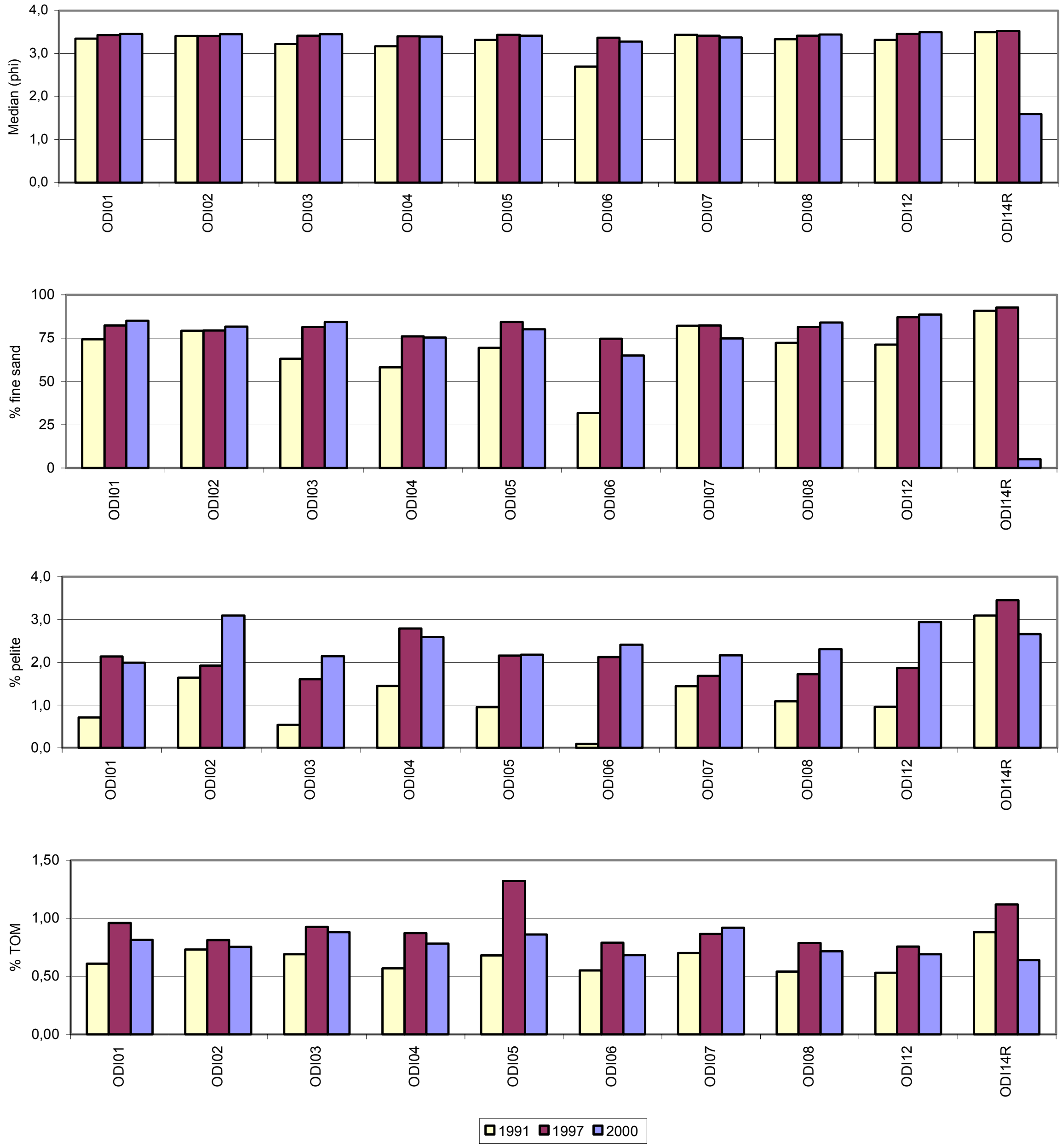

Figure 14-1: Sediment characteristics at the Odin field, 2000 and previous surveys.

14.2.2 Chemical characteristics

The calculated limits of significant contamination for selected hydrocarbons and metals in sediments from Region II ($LSC_{97\text{-}00\ RegII}$) are presented previously in the chapter that deals with the regional and reference stations. In addition to the regional limits, field-specific limits of significant contamination are calculated from the field reference station ($LSC_{00\ ODI14R}$). However, in the present survey 5.2% fine sand is found in sediments at the reference station, while the content in 1997 was 92.8%. The field stations at Odin have sediments with grain sizes comparable with the 1997 sediments. Results of analysis of sediments from the reference station are by that reason considered as non-comparable with former surveys. This is also the reason why LSC's calculated for aromatics and decalins at Nordøst Frigg, the neighbour field, are used in the description of contamination status of aromatics and decalins at Odin. The sets of data are presented in Table 14-2. Based on analysis results of the Odin field, the $LSC_{97\text{-}00\ RegII}$ is regarded as representative of the entire region and will therefore be used as further basis for discussion of the contamination status of this field. Those limits will hereafter simply be referred to as LSC.

The results of analyses of the hydrocarbons are summarised in Table 14-3. Concentrations of selected compounds in the vertical sediment sections are presented in Table 14-4. The full data set of replicate measurements and date from previous years are given in the Appendix. THC values from 2000 are compared with those from previous years in Figure 14-3.

Table 14-2: Background levels and Limits of Significant Contamination for the Odin field, 2000. All values in mg/kg dry sediment.

	THC	NPD's	3-6 ring	Decalins	Cd	Hg	Cu	Zn	Ba	Cr	Pb
$LSC_{00\ ODI14R}$	3.2	0.005	0.009	0.008	0.021	0.016	1.3	5.2	82	6.8	5.5
$LSC_{97\text{-}00\ Region\ II}$	9.8	*	*	*	0.029	0.008	2.0	8.9	146	9.6	7.0
$LSC_{00\ Nordøstfrigg}$		0.021	0.049	0.050							

*) Regional stations not analysed for NPD's, 3-6 ring aromatics and decalins.

Table 14-3: Concentrations of hydrocarbons in sediments from the Odin field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00RegII}$ are dark shaded.

Station	THC		NPD's		3-6 ring		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
ODI01	7.3	1.0	n.a.		n.a.		n.a.	
ODI02	2.9	0.4	n.a.		n.a.		n.a.	
ODI03	11.7	4.3	n.a.		n.a.		n.a.	
ODI04	5.5	1.2	n.a.		n.a.		n.a.	
ODI05	12.4	3.6	n.a.		n.a.		n.a.	
ODI06	4.0	1.1	n.a.		n.a.		n.a.	
ODI07	17.5	4.4	0.126	0.123	0.027	0.009	0.072	0.015
ODI08	4.3	0.6	n.a.		n.a.		n.a.	
ODI12	4.7	0.1	0.005	0.001	0.017	0.000	0.025	0.005
ODI14R	2.2	0.4	0.003	0.001	0.007	0.001	0.004	0.001

n.a. Not analysed.

Table 14-4: Concentrations of hydrocarbons in vertical sections of the sediment samples from the Odin field, 2000. All concentrations in mg/kg dry sediment. Values above $LSC_{97\text{-}00RegII}$ are dark shaded.

Station	Layer (cm)	THC	NPD's	3-6 ring	Decalins
ODI07	0-1	22.3	0.061	0.022	0.081
	1-3	12.4	0.032	0.020	0.055
	3-6	10.6	0.032	0.027	0.057
ODI12	0-1	4.7	0.004	0.017	0.030
	1-3	4.9	0.008	0.019	0.011
	3-6	5.1	0.008	0.025	0.011
ODI14R	0-1	1.9	0.004	0.008	0.005
	1-3	3.5	0.007	0.009	0.007
	3-6	0.8	0.008	0.018	0.005

n.a. Not analysed.

The THC values range from 2.9 ± 0.4 mg/kg to 17.5 ± 4.4 mg/kg dry sediment (Table 14-3). Stations ODI03, ODI05 and ODI07 reveal sediments with THC values above LSC. Concentrations ranging from 11.7 ± 4.3 mg/kg to 17.5 ± 4.4 mg/kg dry sediment are found here, standard deviations being relatively high. Sediments on the six remaining field stations all have THC values well beyond LSC of the region. Aromatics and decalins are measured in sediments at stations ODI07 and ODI12 (Table 14-3). At ODI07 sediments are contaminated by NPD's and decalins. NPD values of 0.126 ± 0.120 mg/kg are found here. However, high NPD values in replicate 7-7 give very high standard deviation, making this result rather uncertain (Table 14-2). Levels below LSC of aromatics and decalins are found in sediments at ODI12. Vertical core samples from ODI07 reveals the highest THC value in the top layer (22.3 mg/kg) and lower concentrations in the deeper layers (Table 14-4). All these values are above LSC. This is also the case for NPD's and decalins. At station ODI12 background levels of THC are found down to 6 cm in the sediment. Also here the concentrations of aromatics and decalins seem to match the THC concentrations.

In general low sediment concentrations of hydrocarbons are found at Odin. Stations situated 100 m from the field centre in directions 340°, 250°, and 160° reveal sediments with hydrocarbon contamination.

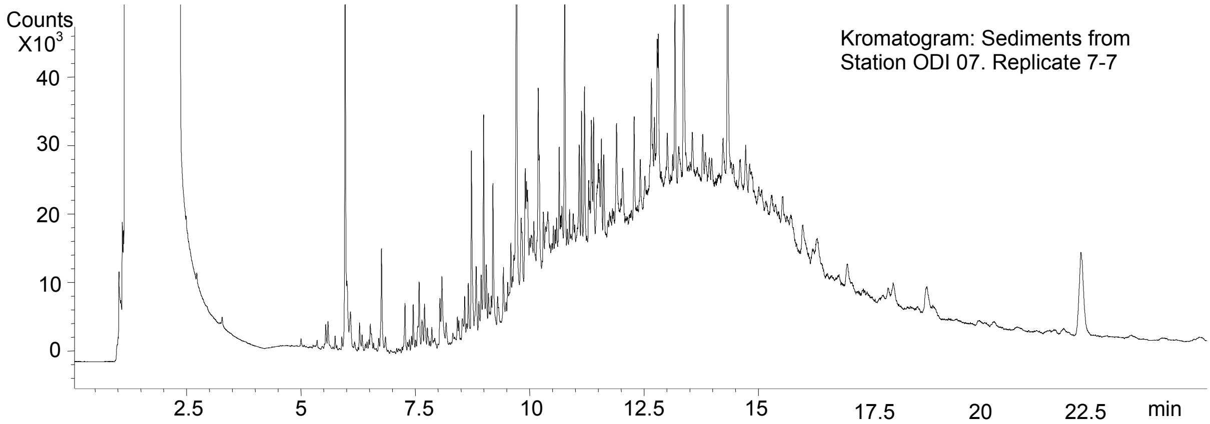

Figure 14-2: Gas chromatogram of a sediment extract from the Odin field, 2000.

The results of the metal analyses for the Odin field are summarised in Table 14-5. Concentrations of selected metals in the vertical sediment sections are presented in Table 14-6. The full set of replicate measurements, including selected data from previous years is given in the Appendix. Metal values from 2000 are compared with those from previous years in Figure 14-4 and Figure 14-5.

Table 14-5: Concentrations of selected metals in sediments from the Odin field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00RegII}$ are dark shaded.

	Cd		Hg		Cu		Zn		Ba		Cr		Pb	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
ODI01	0.013	0.004	n.a.		2.4	0.3	6.0	0.3	27	10	5.0	0.5	5.5	0.6
ODI02	0.013	0.001	n.a.		0.9	0.1	0.7	0.3	27	8	4.7	0.3	2.7	0.2
ODI03	0.018	0.003	n.a.		3.2	0.3	27.5	14.6	35	16	5.2	0.3	8.9	0.7
ODI04	0.010	0.002	n.a.		1.1	0.1	2.2	0.9	44	17	4.8	0.3	3.2	0.4
ODI05	0.018	0.002	n.a.		3.4	0.7	25.4	10.5	31	8	5.9	0.2	8.9	0.6
ODI06	0.012	0.007	n.a.		0.9	0.2	1.7	1.1	49	37	4.4	0.2	3.1	0.3
ODI07	0.018	0.001	0.004	0.002	3.9	0.5	21.7	4.3	28	3	5.8	0.7	9.0	0.9
ODI08	0.008	0.001	n.a.		0.8	0.0	<1.0	-	22	5	4.1	0.1	2.6	0.2
ODI12	0.007	0.001	<0.005	-	0.7	0.1	<1.0	-	19	3	4.1	0.3	3.2	0.4
ODI14R	0.015	0.003	0.005	0.005	0.9	0.2	3.6	0.7	51	13	5.7	0.5	4.8	0.3

n.a. Not analysed.

Table 14-6: Concentrations of selected metals in vertical sections of the sediment samples from the Odin field. All concentrations in mg/kg dry sediment. Values above $LSC_{97\text{-}00RegII}$ are dark shaded.

Station	Layer (cm)	Cd	Hg	Cu	Zn	Ba	Cr	Pb
ODI07	0-1	0.019	0.006	3.3	21.1	25	5.0	8.8
	1-3	0.022	<0.005	5.3	27.4	70	5.5	8.2
	3-6	0.021	<0.005	7.8	24.1	36	5.6	13.6
ODI12	0-1	0.008	<0.005	0.6	<1.0	16	3.9	2.9
	1-3	0.011	<0.005	0.8	1.0	54	4.5	3.5
	3-6	0.026	<0.005	1.0	1.8	162	4.9	3.9
ODI14R	0-1	0.017	0.013	0.8	2.9	40	5.0	4.6
	1-3	0.011	<0.005	0.8	3.6	59	5.5	4.3
	3-6	0.011	<0.005	1.0	4.0	105	5.5	4.6

n.a. Not analysed.

At Odin barium values range from 19 ± 3 mg/kg to 49 ± 37 mg/kg dry sediment, cadmium from 0.007 ± 0.001 mg/kg to 0.018 ± 0.003 mg/kg, copper from 0.7 ± 0.1 mg/kg to 3.9 ± 0.5 mg/kg, lead from 2.6 ± 0.2 mg/kg to 8.9 ± 0.7 mg/kg, zinc from 0.7 ± 0.3 mg/kg to 27.5 ± 14.6 mg/kg and chromium from 4.1 ± 0.3 to 5.9 ± 0.2 mg/kg (Table 14-2). Low concentrations of barium are found in sediments at all stations on Odin. This is also the case for cadmium and chromium. Stations ODI01, ODI03, ODI05 and ODI07, all situated 100 m from the field centre, are contaminated by copper, values raging from 2.4 to 3.9 mg/kg dry sediment. Station ODI03, ODI05 and ODI07 also have sediments with elevated levels of zinc (21.7 – 27.5 mg/kg) and lead (8.9 – 9.0 mg/kg). Mercury levels are low in sediments at both stations examined.

All layers examined in vertical core samples at station ODI07 reveal elevated levels of copper, zinc and lead. Slight increases in concentrations down in the sediment seem to be the overall picture. This is also valid for cadmium, barium and chromium, though none of these metals reveal concentrations above LSC. Also at station ODI12 virtually all concentrations are below LSC, increasing down in the sediments. In general very low sediment concentrations of barium are found at Odin. Background levels of the other metals are also found in sediments at all field stations except those situated 100 m from the field centre where elevated levels of copper is found and levels of zinc and lead above LSC are found at three of four stations. Chromium is at background levels and so is mercury. No distinct metal gradients with depth in the sediments are observed.

<u>Comparison with previous survey(s)</u>

Sediments at the reference station are, as previously mentioned, not directly comparable with those of 1997. Sediments with higher proportions of medium and coarse sand are expected to reveal lower amounts of hydrocarbons and changes in the levels of metals. Indeed, this is the case for the hydrocarbons. However, metals in sediments at the reference station do not seem to be very much affected. Slight increases in sediment barium and lead concentrations are found. The other selected metals seem to be at level or a bit lower than in 1997 (Figure 14-4, Figure 14-5).

In the 2000 survey sediments at stations situated 100 m in the 160°, 250° and 340° directions are contaminated by hydrocarbons, as they were in 1997 (Figure 14-3). In direction 250° a decrease has occurred, with a concomitant increase in the 160° direction. In sum the sediment concentrations of hydrocarbons in the Odin field are unchanged since the last survey. At Odin no discharges has taken place since 1994. By removing the platform in 1997 it was expected that sediment disturbance and release of old oil might be mixed into the upper layers of the sediments. No indications of such a release of oil are seen in 2000. At the innermost stations there may have been some stirring of the sediments, but chromatograms do not show clear profiles of degraded oil (Figure 14-2).

No barium values above LSC are found in surface sediments at Odin in 2000. Barium levels have gone down since 1997 and so have cadmium levels (Figure 14-4 and Figure 14-5). Copper is contaminating sediments at all 100 m stations and seems relatively unchanged regarding total levels.

Lead and zinc concentrations are also relatively unchanged and follow the pattern of THC regarding distribution. Mercury levels are unchanged.

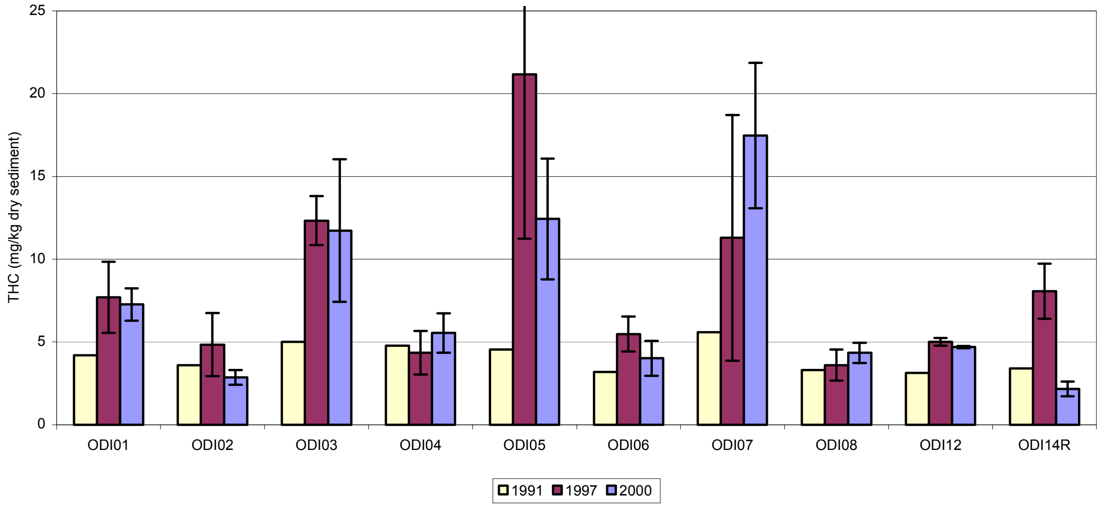

Figure 14-3: THC levels in sediment from the present (2000) and previous surveys, Odin field.

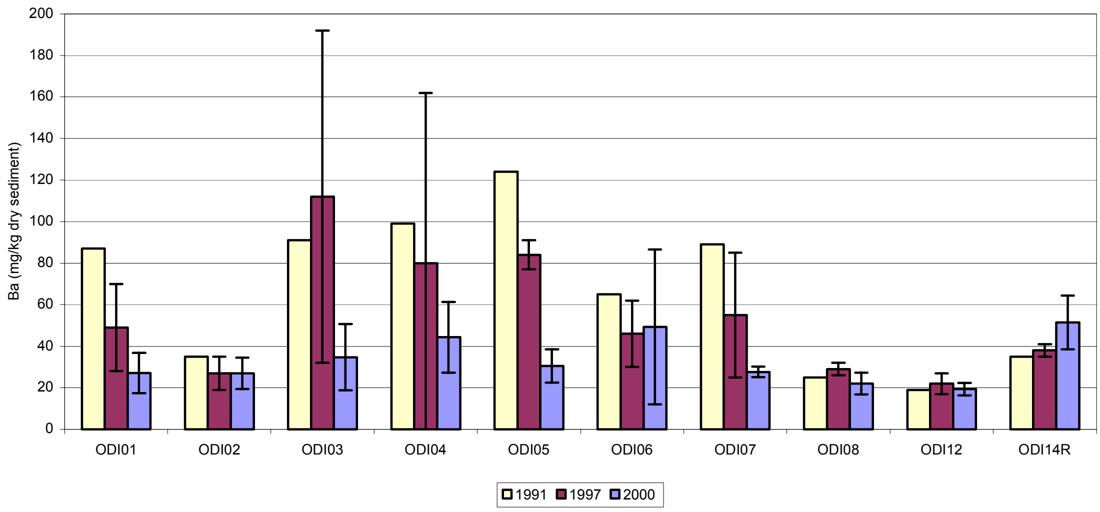

Figure 14-4: Barium levels in sediment from the present (2000) and previous survey, Odin field.

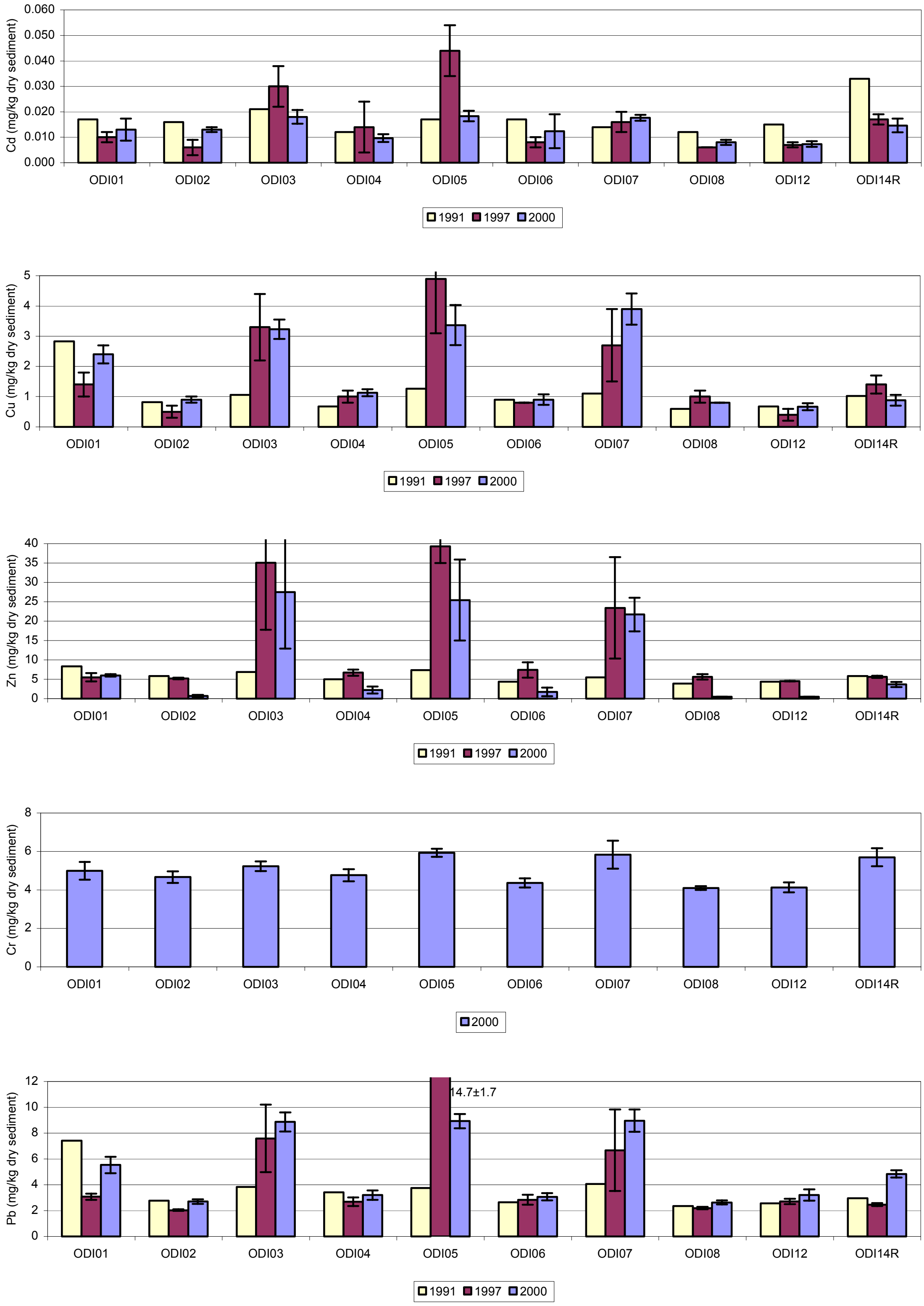

Figure 14-5: Levels of selected metals in sediments from the present (2000) and previous surveys, Odin field.

14.2.3 Biology

The distribution of individuals and taxa within the main taxonomic groups are given in Table 14-7. A total of 6797 individuals within 244 taxa were registered at the Odin field in the present survey (excluding juveniles). The polychaetes dominate the fauna with 48 % of the individuals and 50 % of the taxa recorded.

Table 14-7: Distribution of individuals and taxa within the main taxonomic groups at Odin, 2000 (excluding juveniles).

Main taxonomic groups	Individuals		Taxa	
	Number	%	Number	%
Polychaeta	3281	48	123	50
Mollusca	1030	15	42	17
Crustacea	759	11	46	19
Echinodermata	924	14	15	6
Diverse groups	803	12	18	7
Total	6797	100	244	100

The species/area curve for the field reference station is shown in Figure 14-6. A total of 136 taxa are recorded in the ten grab samples, of which 47 (34 %) occur in the first sample and 103 (75 %) in the first five samples. The shape of the curve indicates that not all taxa in the area are present in the ten grab samples, and the representativity of five samples seems to be relatively low compared with the curves form other reference stations in the region.

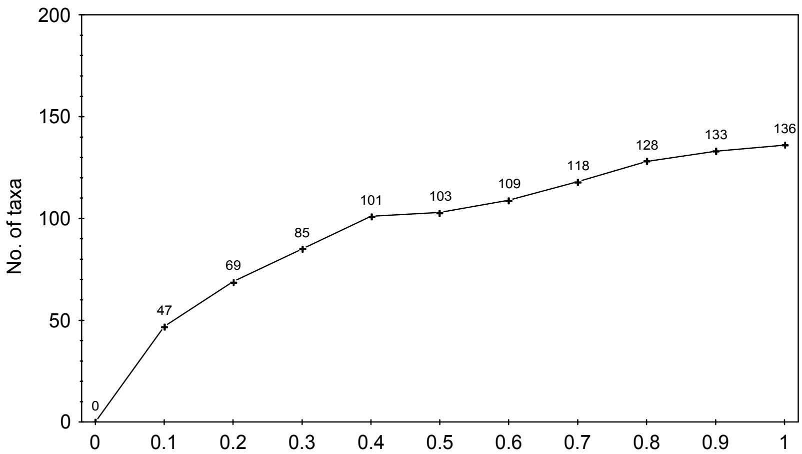

Figure 14-6: Species/area curve for the reference station at the Odin field (area in m^2).

The number of individuals and taxa at each station, together with selected community indices, is presented in Figure 14-7 and Table 14-8. The number of individuals recorded at Odin varies from 568 (ODI01) to 771 (ODI04). The number of taxa varies from 81 (ODI12) to 112 (ODI03), the diversity index H' between 4.7 and 5.7, the evenness index J between 0.73 and 0.83 and the ES_{100} between 34 and 45. The indices H', J and ES_{100} have highest and lowest values at station ODI04 and ODI03 respectively. The corresponding values at the reference station ODI14R are within the variation at the field stations.

There has been a decrease in the number of individuals at most of the stations with largest decrease at field stations ODI05, ODI06 and ODI07.

Table 14-8: Number of individuals and taxa and selected community indices for each station (0.5 m2) at the Odin field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	No. of ind	No. of taxa	H'	J	ES100
ODI01	**568**	84	5.0	0.78	36
ODI02	710	104	5.1	0.75	38
ODI03	694	**112**	**5.7**	**0.83**	**45**
ODI04	**771**	87	**4.7**	**0.73**	**34**
ODI05	705	95	4.9	0.74	36
ODI06	641	94	5.1	0.78	38
ODI07	704	102	5.1	0.77	39
ODI08	650	90	4.8	0.74	36
ODI12	658	**81**	4.8	0.75	36
ODI14R	696	103	5.4	0.81	44
Sum*	6101				
Average *	678	94	5.0	0.76	38
St. dev. *	57	10	0.3	0.03	3

* Excluding the reference station.

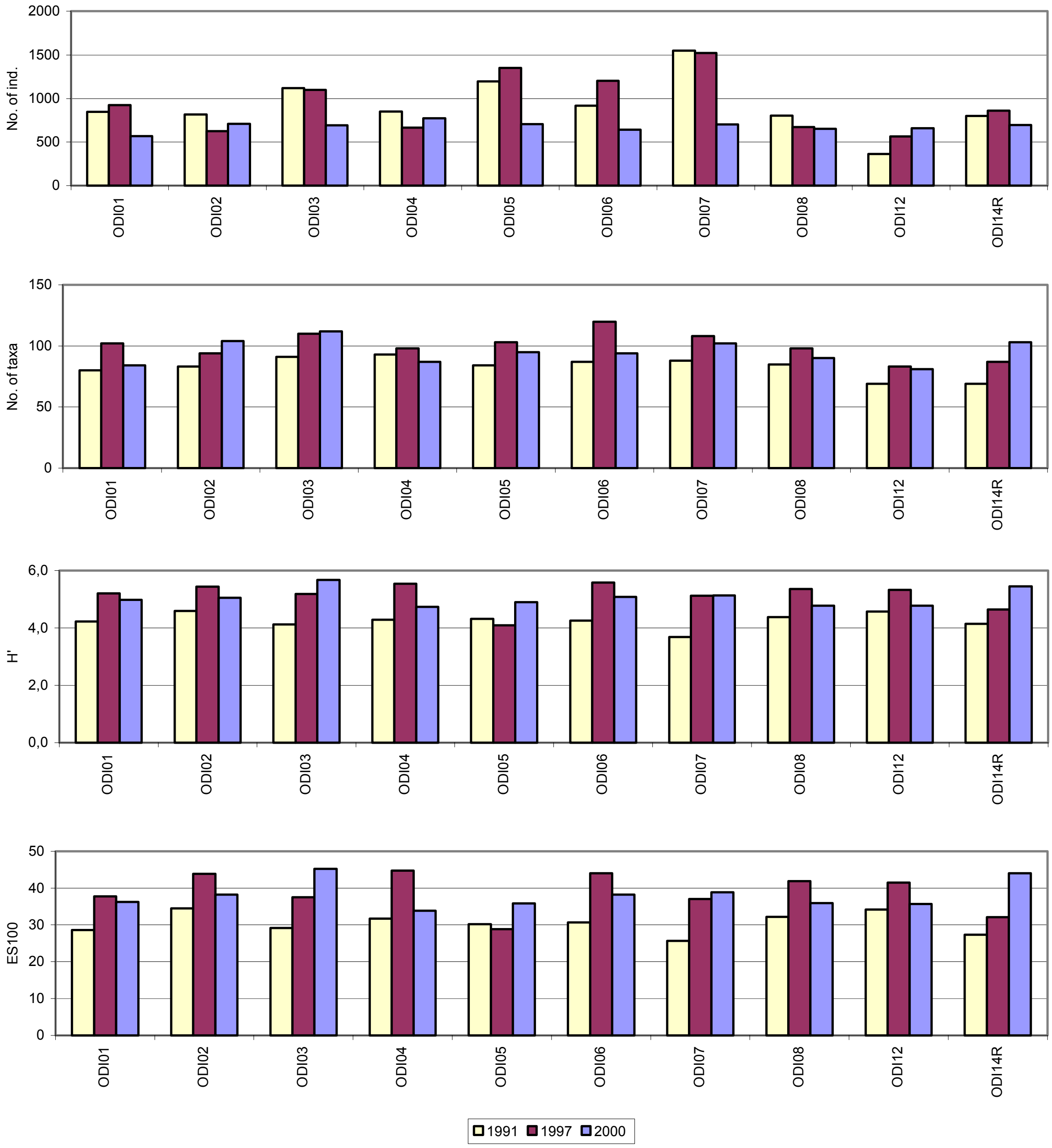

Figure 14-7: Biological characteristics at the Odin field, 2000 and previous surveys.

The distribution of taxa in geometrical classes is shown in Figure 14-8. One station (ODI04) has taxa in class 8 (128-255 individuals) while the rest of the stations, included the reference station, has taxa in class 7 (64-127 individuals) and lower. Occurrence of taxa in high classes might indicate faunal disturbance, which is not the case here.

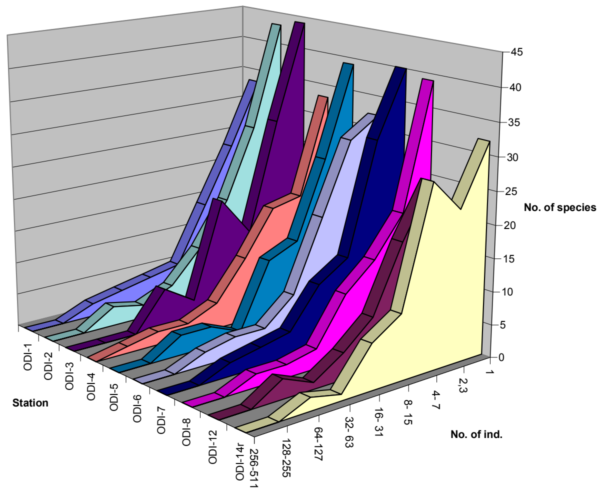

Figure 14-8: Distribution of taxa in geometrical classes from the stations at Odin, 2000.

The ten most dominant taxa at each station are shown in Table 14-11 at the end of this chapter. A total of 28 taxa, inclusive four juvenile groups, are among the ten most dominant taxa at one or more stations. These 28 taxa comprise 75 % of the total number of individuals and 11 % of the total number of taxa recorded at the Odin field in the present survey.

The most dominant taxa among the adult forms are the brittle star *Amphiura filiformis*, the polychaetes *Spiophanes bombyx, Galathowenia oculata*, *Spiophanes kroyeri*, the phoronid *Phoronis* sp., and the bivalve *Lucinoma borealis*. The brittle star *A. filiformis* and the polychaete *S. bombyx* are among the most dominant taxa at all but the reference station. At the reference station a complete different faunal composition is seen, probably as a result of the differences in the sediment structure.

The polychaetes *Ditrupa arietina* and *Chaetozone setosa* are among the ten most dominant taxa at stations ODI01 and ODI04, respectively, while the bivalve *Thyasira flexuosa* is among the ten most dominant at four stations (ODI01, ODI03, ODI05 and ODI07). These three species are known to increase in abundance in disturbed sediments, indicating that there might be some faunal disturbance at these stations.

The ten most abundant taxa at the stations comprise between 51 % (station ODI03) and 70 % (station ODI08) of the total number of individuals registered at the respective stations. The corresponding value at the reference station ODI14R is 60 %.

Figure 14-9 shows the dendrogram from the cluster analysis for the field stations and regional and reference stations in Region II while Figure 14-10 shows the 2-D plot from the MDS analysis for the field stations and selected regional and reference stations.

In the cluster analysis the Odin field stations are separated from all regional and reference stations at 85 % dissimilarity level. Within the field stations, station ODI03 is separated out at 44 % level while the remaining field stations are separated into two main groups at 37 % dissimilarity level, one group containing stations ODI01, ODI05 and ODI07. The correlation coefficient shows a very good fit to the data (r = 0.96).

In the MDS analyses, the selected regional and reference stations are separated from the field stations, where station ODI03 is isolated from the other field stations in the 2-D plot. The stress test shows a fair fit to the data (0.23).

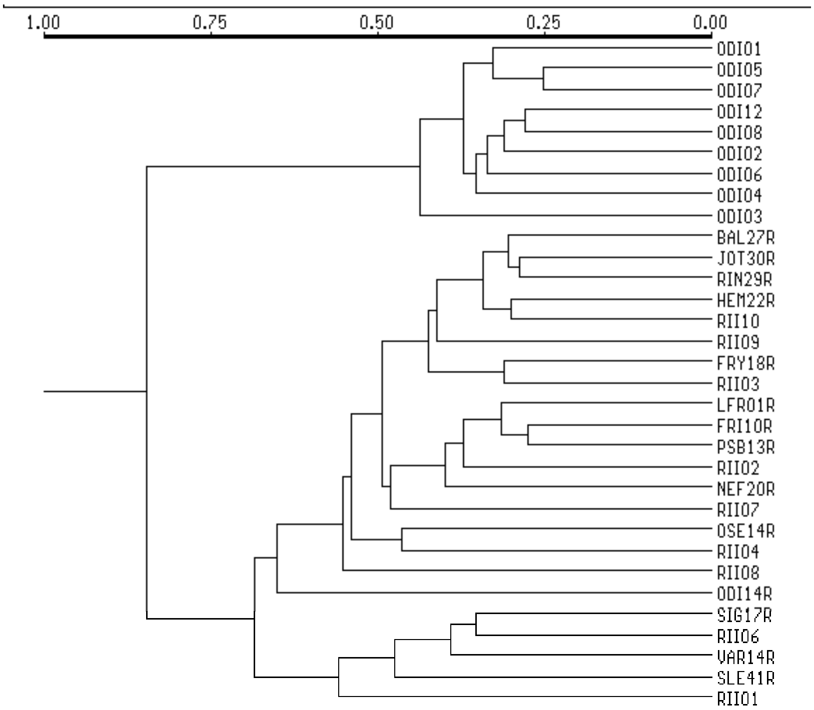

Figure 14-9: Cluster analysis of the Odin field and selected regional and reference stations in Region II, 2000.

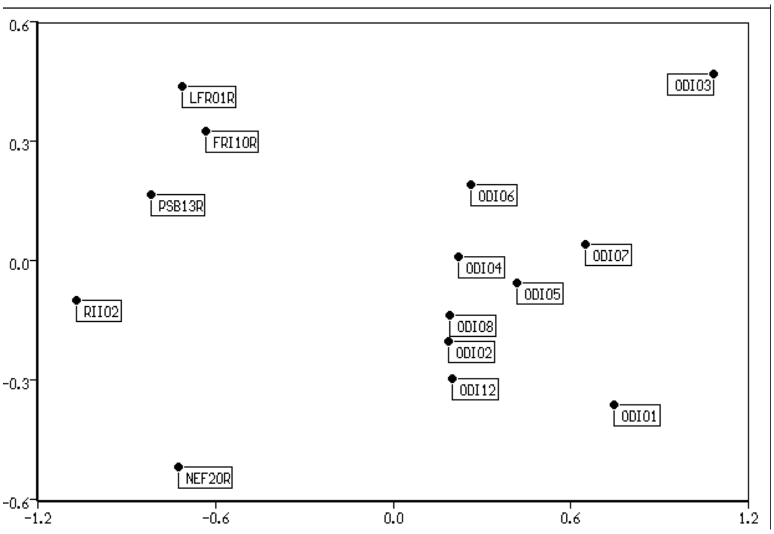

Figure 14-10: 2-D plot from the MDS analysis carried out on the station data from Odin field and selected regional and reference stations in Region II, 2000.

A Canonical Correspondence Analysis (CCA) of the data from the field stations together with selected regional reference stations was carried out to examine the association between the biological data and the measured environmental variables in these areas. The analysis was carried out excluding the data from the Odin reference station due to the differences revealed in the cluster analysis for the whole region.

Through the forward selection procedure in CANOCO, three of the ten variables gave the best fit and was significant. 45.2 % of the biological variance was explained by the first two axes of the ordination space which is constrained by these environmental variables.

Figure 14-11 shows a biplot from the analysis using copper, pelite and TOM as the constraining environmental variables, together wit a plot of the taxa with highest contribution on the two axes. The first axis shows a gradient from regional station RII02 on the positive end to field station ODI01 on the negative end and is correlated with the amount of pelite (+ 0.94) and copper (- 0.51) in the sediments. The taxa with the highest contribution on this axis are the ploychaetas *Owenia fusiformis* (27.8 %), *Myriochele danielsseni* (19.1 %), *M. fragilis* (7.4 %) and *Lucinoma borealis* (5.9 %). These taxa are known to be relatively abundant in undisturbed sediments.

The second axis shows a gradient from field station ODI07 at the positive end to station ODI08 at the negative end and is positively correlated with the amount of copper in the sediments (+ 0.78). The taxa with highest contribution on this axis are the polychaete *Lucinioma borealis* (32.8 %), the bivalve *Thyasira flexuosa* (6.3 %), the brittle star *Amphiura filiformis* (4.8 %) and the phoronid *Phoronis* sp. (4.2 %). Stations situated in the upper left part of the plot (ODI01, ODI03, ODI05 and ODI07) have highest levels of copper in the sediments.

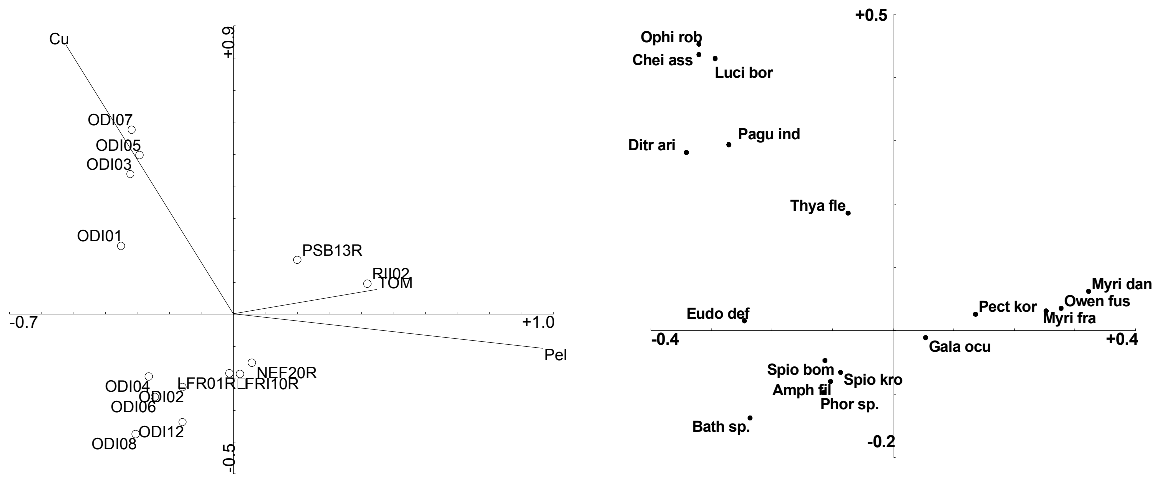

Figure 14-11: Biplot from the CCA analysis for the Odin field and selected regional and reference stations in Region II, 2000 (left) and taxa with high contribution on the two axis (right).

On the basis of the results from the uni- and multivariate analyses the stations at Odin are classified into two faunal groups (see Table 14-9). Stations ODI01, ODI03, ODI05 and ODI07 are classified as group B stations (slightly disturbed fauna) while the other field stations are placed in group A (undisturbed fauna). The stations in group B are situated at 100 m distance from the field centre. These four stations have relatively high abundance of the polychaetes *Ditrupa arietina* and *Chaetozone* sp. (including *C. setosa)* and the bivalves *Thyasira flexuosa* and *Lucinoma borealis*. At least three of these taxa are known to increase in abundance in disturbed sediments. In the multivariate analyses the same stations were separated from the other field stations.

In 1997, station ODI05 was placed in faunal group C (disturbed fauna) due to the high occurrence of the polychaete *Capitella capitata* (520 individuals). In the present survey only one individual is recorded at the Odin stations. This indicates that the intensity of faunal disturbance at the field has been reduced.

Table 14-9: Classification into impact groups, distance to installation and biological statistics for the field stations at Odin field, 2000.

Station	Impact group	Dist. (m)	Statistics			No. of individuals								
			No. ind	No. taxa	H'	Afi	Sbo	Psp	Goc	Skr	Dar	Lbo	Tfl	Csp
ODI01	B	100	568	84	5,0	69	72	45	26	26	33	41	26	1
ODI02	A	500	710	104	5,1	125	78	64	32	55	0	0	4	13
ODI03	B	100	694	112	5,7	48	44	18	36	26	1	43	50	14
ODI04	A	500	771	87	4,7	129	98	106	41	54	0	5	8	21
ODI05	B	100	705	95	4,9	62	89	37	97	19	3	88	34	4
ODI06	A	500	641	94	5,1	69	93	48	32	61	0	4	0	6
ODI07	B	100	704	102	5,1	39	81	24	54	26	5	114	42	15
ODI08	A	500	650	90	4,8	124	113	54	19	36	0	0	3	12
ODI12	A	1000	658	81	4,8	117	103	64	10	49	0	0	4	10
ODI14R	A	10000	696	103	5,4	1	5	5	112	14	0	2	0	0
RII02	A	-	2994	123	3.4	62	34	36	302	40	0	0	50	50
FRI10R	A	-	1598	128	4.9	146	216	160	256	45	0	5	30	1
NEF20R	A	-	1221	68	4.0	68	149	23	301	70	0	5	25	19
PSB13R	A	-	1459	121	4.9	132	121	37	223	65	0	4	29	25
LFR01R	A	-	1523	119	4.9	156	55	66	312	44	0	1	19	3

Afi = *Amphiura filiformis*, Sbo = *Spiophanes bombyx*, Psp = *Phoronis sp*., Goc = *Galatowenia oculata*, Skr = Spiophanes kroyeri, Lbo = *Lucinoma borealis*, Dar= *Ditrupa arietina,* Csp = *Chaetozone sp*, Tfl = *Thyasira flexuosa*.

14.3 Summary and conclusions

The sediments at the Odin field is classified as fine sand with a relatively small amount of pelite (2.0 – 3.1 %) and TOM (0.7 – 0.9 %). The pelite content has increased at field station ODI02, while the TOM value has decreased at the field station ODI05 since 1997. The large differences registered at the reference station in the present and previous survey is believed to be a result of sampling at different positions in the two surveys. Apparently the position used in the present survey is wrong.

In the 2000 survey sediments at stations situated 100 m in the 160°, 250° and 340° directions are contaminated by hydrocarbons, as they were in 1997. The maximum value is measured at the station situated at 100 m distance in the 160° direction, with 17.5 mg/kg dry sediment. In the 250° direction a decrease has occurred, with a concomitant increase in the 160° direction.

In sum the sediment concentrations of hydrocarbons in the Odin field are unchanged since the last survey. No discharge has taken place since 1997. By removing the platform in 1997 it was expected that sediment disturbance and release of old oil might be mixed into the upper layers of the sediments. No indications of such a release of oil are seen in 2000. At the innermost stations there may have been some stirring of the sediments, but chromatograms do not show clear profiles of degraded oil.

No barium values above limit of significant contamination are found in surface sediments at Odin in 2000. Barium levels have gone down since 1997 and so have cadmium levels. Copper is contaminating sediments at all 100 m stations and seems relatively unchanged regarding total levels. Lead and zinc concentrations are also relatively unchanged and follow the THC distribution pattern. Mercury levels are unchanged.

The number of individuals is relatively uniform over the field stations. A decrease in the number of individuals has occurred since 1997 with the largest decrease recorded at station ODI05, ODI06 and ODI07.

Stations ODI01, ODI03, ODI05 and ODI07 are classified as group B stations (slightly disturbed fauna) while the other field stations are placed in group A (undisturbed fauna). The stations in group B are situated at 100 m distance from the field centre. These four stations have relatively high abundance of the polychaetes *Ditrupa arietina* and *Chaetozone* sp. (including *C. setosa)* and the bivalves *Thyasira flexuosa* and *Lucinoma borealis*. At least three of these taxa are known to increase in abundance in disturbed sediments. In the multivariate analyses the same stations were separated from the other field stations.

In 1997, station ODI05 was placed in faunal group C (disturbed fauna) due to the high occurrence of the polychaete *Capitella capitata* (520 individuals). In the present survey only one individual is recorded at the Odin stations. This indicates that the intensity of faunal disturbance at the field has been reduced, as a result of the close down and removing of the platform.

During the removal of the platform before and after the survey in 1997, physical disturbance of the sediments occurred. This might have had effects on the fauna in the previous survey.

The calculated minimum area and spatial extent of contaminated sediments and disturbed fauna at the Odin field is shown in Table 14-10 and Figure 14-12.

Table 14-10: Distance along the transects and calculated minimum area of contaminated sediments and disturbed fauna at the Odin field, 2000 and previous survey.

Odin	NE	SE	SW	NW	Km^2 (2000)	Km^2 (1997)
Group B	100	100	100	100	0.03	0.02
Group C	0	0	0	0	0	0.01
THC	50	100	100	100	0.02	0.02
Ba	0	0	0	0	0	0.01
Other metals	50	100	100	100	0.02	0.02

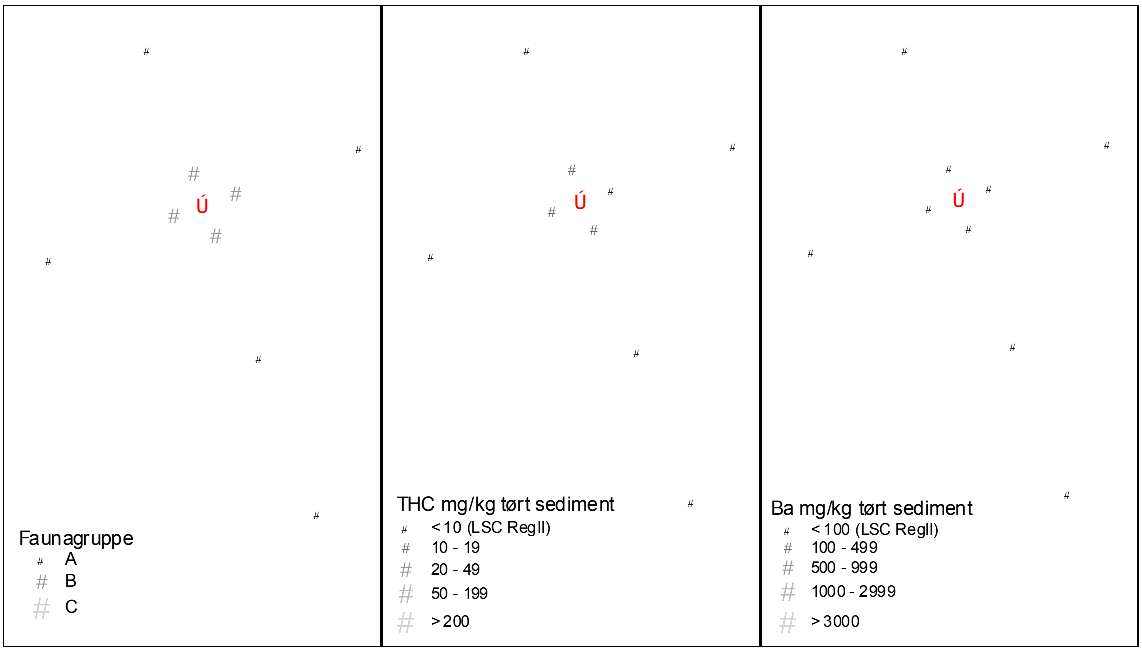

Figure 14-12: Distribution of disturbed fauna and the amounts of THC and barium in the sediments at the Odin field, 2000.

Table 14-11: Number of individuals and the accumulative abundance for the ten most dominant taxa at each station at the Odin field, 2000.

ODI01 (70° / 100 m)	No. ind	Acc. %	ODI02 (70° / 500 m)	No. ind	Acc. %	ODI03 (340° / 100 m)	No. ind	Acc. %	ODI04 (340° / 500 m)	No. ind	Acc. %	ODI05 (250° / 100 m)	No. ind	Acc. %
Ophiuroidea indet. juv.	81	11 %	Amphiura filiformis	125	13 %	Pectinaria sp. juv.	65	8 %	Pectinaria sp. juv.	130	13 %	Ophiuroidea indet. juv.	98	11 %
Spiophanes bombyx	72	21 %	Pectinaria sp. juv.	114	26 %	Ophiuroidea indet. juv.	61	15 %	Amphiura filiformis	129	25 %	Galathowenia oculata	97	21 %
Amphiura filiformis	69	30 %	Spiophanes bombyx	78	34 %	Thyasira flexuosa	50	21 %	Phoronis sp.	106	35 %	Spiophanes bombyx	89	31 %
Pectinaria sp. juv.	51	37 %	Phoronis sp.	64	41 %	Amphiura filiformis	48	26 %	Spiophanes bombyx	98	45 %	Lucinoma borealis	88	41 %
Phoronis sp.	45	43 %	Spiophanes kroyeri	55	47 %	Spiophanes bombyx	44	31 %	Ophiuroidea indet. juv.	64	51 %	Amphiura filiformis	62	48 %
Lucinoma borealis	41	49 %	Ophiuroidea indet. juv.	51	53 %	Lucinoma borealis	43	36 %	Spiophanes kroyeri	54	56 %	Pectinaria sp. juv.	55	54 %
Ditrupa arietina	33	53 %	Galathowenia oculata	32	56 %	Galathowenia oculata	36	40 %	Galathowenia oculata	41	60 %	Phoronis sp.	37	58 %
Galathowenia oculata	26	57 %	Owenia fusiformis juv.	24	59 %	Ophiura robusta	36	45 %	Owenia fusiformis juv.	38	64 %	Owenia fusiformis juv.	35	61 %
Spiophanes kroyeri	26	60 %	Cerianthus lloydi juv.	21	61 %	Spiophanes kroyeri	26	48 %	Abra prismatica	21	66 %	Thyasira flexuosa	34	65 %
Thyasira flexuosa	26	64 %	Eudorellopsis deformis	21	63 %	Paguridae indet.	24	51 %	Chaetozone setosa	21	68 %	Cerianthus lloydi juv.	20	67 %
ODI06 (250° / 500 m)	No. ind	Acc. %	ODI07 (160° / 100 m)	No. ind	Acc. %	ODI08 (160° / 500 m)	No. ind	Acc. %	ODI12 (160° / 1000 m)	No. ind	Acc. %	ODI14R (70° / 10000 m)	No. ind	Acc. %
Spiophanes bombyx	93	11 %	Lucinoma borealis	114	12 %	Pectinaria sp. juv.	144	16 %	Amphiura filiformis	117	13 %	Owenia fusiformis juv.	171	19 %
Pectinaria sp. juv.	70	19 %	Spiophanes bombyx	81	21 %	Amphiura filiformis	124	29 %	Pectinaria sp. juv.	108	24 %	Galathowenia oculata	112	31 %
Amphiura filiformis	69	27 %	Ophiuroidea indet. juv.	77	30 %	Spiophanes bombyx	113	42 %	Spiophanes bombyx	103	36 %	Poecilochaetus serpens	64	39 %
Owenia fusiformis juv.	64	35 %	Pectinaria sp. juv.	63	36 %	Ophiuroidea indet. juv.	64	49 %	Owenia fusiformis juv.	74	44 %	Spio sp.	34	42 %
Spiophanes kroyeri	61	42 %	Galathowenia oculata	54	42 %	Phoronis sp.	54	55 %	Ophiuroidea indet. juv.	66	51 %	Aonides paucibranchiata	31	46 %
Phoronis sp.	48	47 %	Owenia fusiformis juv.	42	47 %	Spiophanes kroyeri	36	59 %	Phoronis sp.	64	58 %	Pista sp.	31	49 %
Ophiuroidea indet. juv.	46	53 %	Thyasira flexuosa	42	51 %	Owenia fusiformis juv.	31	62 %	Spiophanes kroyeri	49	63 %	Nemertini indet.	27	52 %
Galathowenia oculata	32	56 %	Amphiura filiformis	39	56 %	Galathowenia oculata	19	64 %	Abra prismatica	21	65 %	Edwardsia sp.	21	55 %
Abra prismatica	27	60 %	Cerianthus lloydi juv.	26	58 %	Cerianthus lloydi juv.	17	66 %	Bathyporeia sp.	19	67 %	Aricidea cerrutii	18	57 %
Bathyporeia sp.	27	63 %	Spiophanes kroyeri	26	61 %	Bathyporeia sp.	16	68 %	Edwardsia sp.	19	69 %	Glycera lapidum	17	58 %
						Eudorellopsis deformis	16	70 %				Thracia villosiuscula	17	60 %

Table 14-12: Station information for Odin field, 2000.

St. no.	Distance (m)	Direction (degr.)	Volume (litres)
ODI01	100	70	41
ODI02	500	70	43
ODI03	100	340	36
ODI04	500	340	36
ODI05	100	250	38
ODI06	500	250	39
ODI07	100	160	35
ODI08	500	160	32
ODI12	1000	160	30
ODI14R	10000	70	52 *

* The additional five grab samples taken gave 58 litres of sediment.

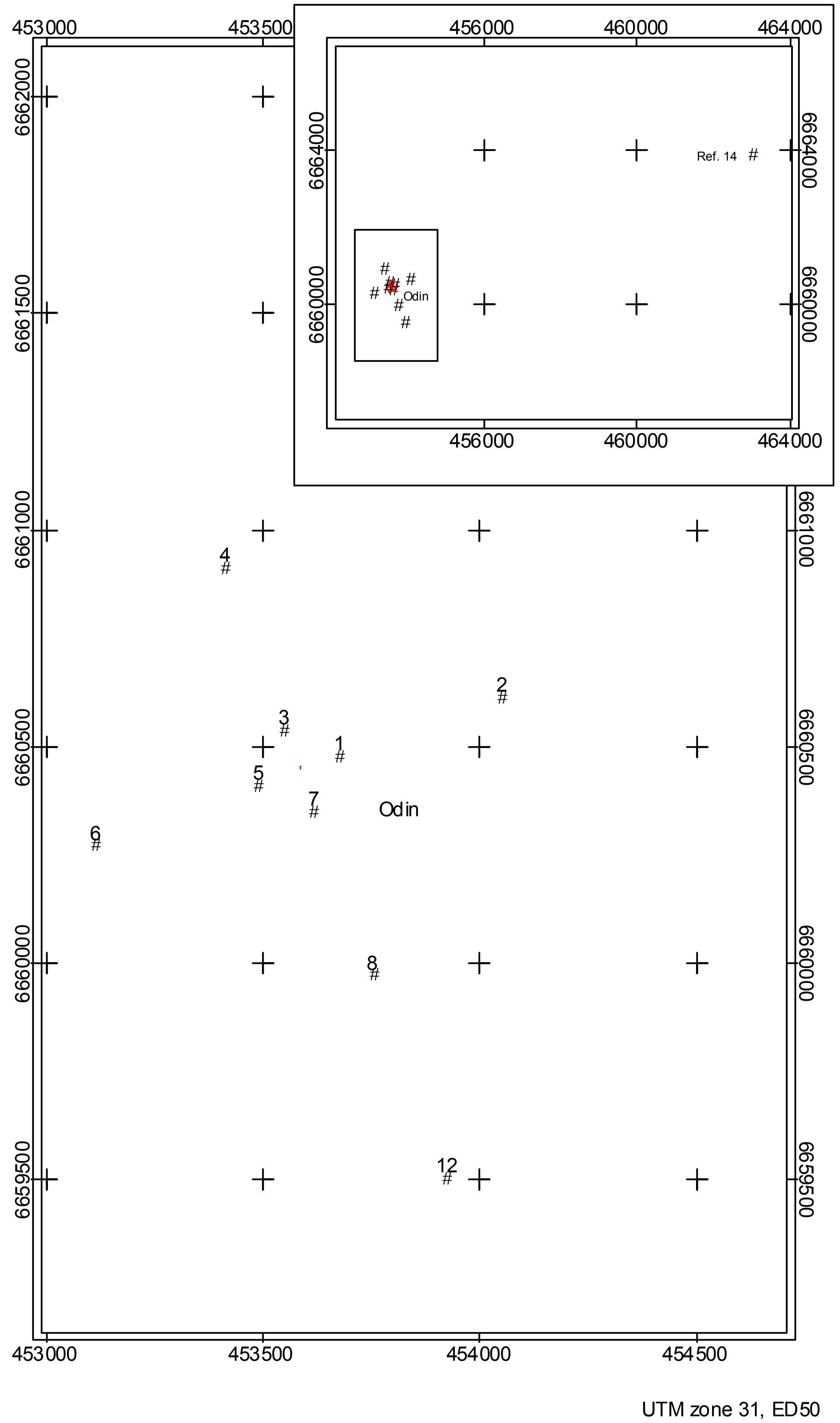

Figure 14-13: Map of sampling positions for Odin field, 2000.

15 Varg field

15.1 Introduction

The Varg field is located in block 15/12 in Region II. Production at the field started in 1998. Data on recent drilling and discharges are given in Table 15-1. Only water based mud and cuttings have been discharged during these operations.

In the baseline survey at the field in 1997 the fauna was found to be undisturbed while the area significantly contaminated with THC extended out to 1000 m/ 20o and out to 500 m 200o-, 245o- and 335o. Elevated levels of barium were found at the 250 m stations on the 20o– and 200o–axes. The 500 m stations on the 245o- and 335o-axes are excluded in the present survey.

Information on the sampling stations is shown in Figure 15-13 and Table 15-13, both on the foldout page at the end of this chapter (page 15-19).

Table 15-1: Summary of recent wells drilled and operational and accidental discharges at the Varg field (all discharges in tonnes).

	1997	1998	1999	2000	Comments
No of wells drilled	1	4	5	0	
Barite	*	*	174	0	* Not available
Cuttings	1615	3510	2671	0	
Oil-based drilling mud	-	*	*	0	* Used but shipped onshore, possible discharge of 4862 t mud/cuttings (OBM) in 1999
Water-based drilling mud	1810	6726	7106	0	
Cementing chemicals	160 *	53	36	0	* Estimated value.
Completion chemicals	-	4	5	0	
Oil in produced water	-	-	1	0.45305*	1st quarter
Accidental discharges	-	0.250m^3 *	0.329m^3	0.0425	* Diesel discharged on sea surface.

15.2 Results and discussion

15.2.1 Physical characteristics

The median phi value and the amount (%) of pelite, fine sand and total organic material (TOM) in the sediment from the present and previous surveys is shown in Table 15-2 and Figure 15-1. 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 sediment at the Varg field is classified as fine sand with median values from 3.39 (VAR02) to 2.67 (VAR01). The amount of pelite in the sediment varies from 1.34% (VAR05) to 2.68 % (VAR03), the fine sand from 25.33 % (VAR01) to 74.94 % (VAR02) while the TOM varies from 0.64 % (VAR05, VAR08) to 0.94 % (VAR03). The corresponding values at the reference station VAR14R are higher, with the exception of TOM, at the field stations.

Compared with the 1997 survey, there has been an increase in pelite at all stations, and the largest increase is at station VAR03, VAR04 and the reference station VAR14R. The largest increase of fine sand is seen at VAR04 and TOM at VAR03, VAR09 and VAR11, while these values are more or less similar between the surveys at the other stations.

Table 15-2: The median (phi) and amount (%) of pelite, fine sand and TOM in the sediment from stations at the Varg field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	Distance (m)	Direction (degr.)	Median	Classification	Pelite	Fine sand	TOM
VAR01	1000	290	**2.67**	Fine sand	1.41	**25.33**	0.71
VAR02	500	290	**3.39**	Fine sand	1.80	**74.94**	0.78
VAR03	250	290	3.35	Fine sand	**2.68**	70.61	**0.94**
VAR04	500	110	3.30	Fine sand	1.62	65.98	0.66
VAR05	1000	110	3.06	Fine sand	**1.34**	51.63	**0.64**
VAR07	2000	20	3.19	Fine sand	1.51	58.78	0.65
VAR08	1000	20	2.93	Fine sand	1.54	44.83	**0.64**
VAR09	500	20	3.26	Fine sand	1.81	63.33	0.82
VAR10	250	20	3.23	Fine sand	2.24	61.35	0.88
VAR11	250	200	3.29	Fine sand	1.83	65.29	0.91
VAR12	500	200	3.30	Fine sand	1.78	67.40	0.79
VAR13	1000	200	3.34	Fine sand	2.04	69.63	0.80
VAR14R	4000	200	3.48	Fine sand	2.70	84.05	0.93
Average *			3.19		1.80	59.9	0.77
St. dev. *			0.21		0.38	13.7	0.11

* Excluding the reference station.

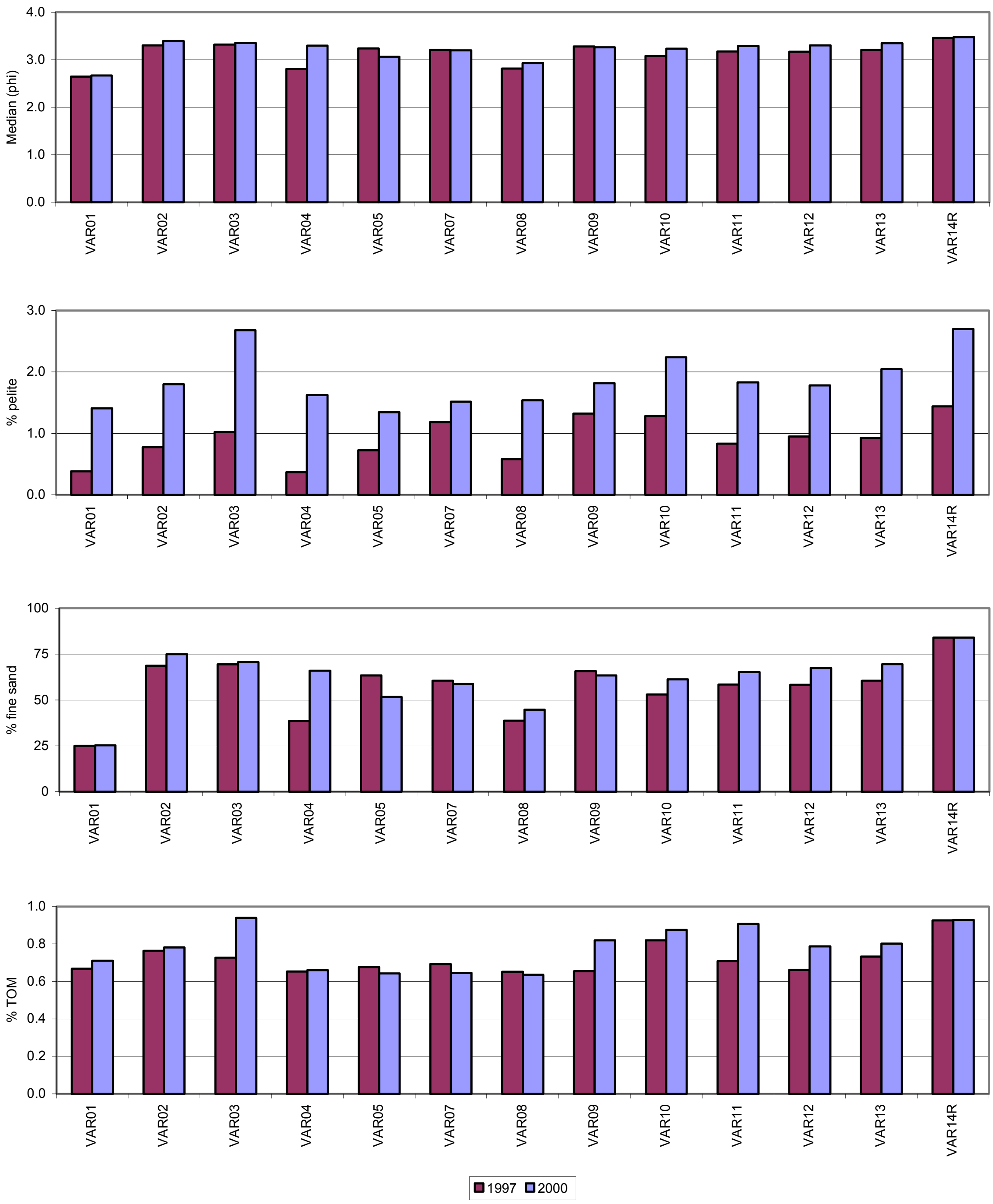

Figure 15-1: Sediment characteristics at the Varg field, 2000 and previous survey.

15.2.2 Chemical characteristics

The Varg field is located in the shallow area of Region II. The calculated limits of significant contamination for selected hydrocarbons and metals in sediments from the shallow area ($LSC_{97\text{-}00\ shallow\ RegII}$) are presented previously in the chapter that deals with the regional and reference stations. In addition to the sub-regional limits, field-specific limits of significant contamination are calculated from the reference station ($LSC_{00\ VAR14R}$). Both sets of data are presented in Table 15-3. Based on analysis results of the Varg field, the $LSC_{97\text{-}00\ shallow\ RegII}$ is regarded as representative and will therefore be used as further basis for discussion of the contamination status of this field. Those limits will hereafter simply be referred to as LSC.

The results of analyses of the hydrocarbons are summarised in Table 15-4. Concentrations of selected compounds in vertical sediment sections are presented in Table 15-5. The full data set of replicate measurements and data from previous years are given in the Appendix. THC values are compared with those from previous years in Figure 15-3.

Table 15-3: Background levels and Limits of Significant Contamination for the Varg field, 2000. All values in mg/kg dry sediment.

	THC	NPD's	3-6 ring	Decalins	Cd	Hg	Cu	Zn	Ba	Cr	Pb
$LSC_{00\ VAR14R}$	6.3	0.019	0.044	0.033	0.009	0.009	1.0	5.5	49	8.4	7.0
$LSC_{97\text{-}00\ shallow\ RegII}$	6.6	*	*	*	0.008	0.006	1.2	8.1	38	10.2	7.4

*) Regional stations not analysed for NPD's, 3-6 ring aromatics and decalins.

Table 15-4: Concentrations of hydrocarbons in sediments from the Varg field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ shallow\ RegII}$ are dark shaded.

Station	THC		NPD's		3-6 ring		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
VAR01	12.4	4.6	n.a.		n.a.		n.a.	
VAR02	3.9	0.6	n.a.		n.a.		n.a.	
VAR03	14.4	2.0	n.a.		n.a.		n.a.	
VAR04	5.1	1.0	n.a.		n.a.		n.a.	
VAR05	2.5	0.5	n.a.		n.a.		n.a.	
VAR07	2.8	0.0	0.005	0.000	0.017	0.002	0.033	0.011
VAR08	8.0	4.1	n.a.		n.a.		n.a.	
VAR09	51.2	8.0	0.017	0.002	0.022	0.001	0.135	0.123
VAR10	412	284	0.095	0.027	0.053	0.014	23.5	13.9
VAR11	184	63	0.040	0.011	0.028	0.004	0.418	0.264
VAR12	8.5	4.4	n.a.		n.a.		n.a.	
VAR13	4.1	0.4	n.a.		n.a.		n.a.	
VAR14R	4.7	0.7	0.013	0.002	0.036	0.003	0.028	0.002

n.a. Not analysed.

Table 15-5: Concentrations of hydrocarbons in vertical sections of the sediment samples from the Varg field, 2000. All concentrations in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ shallow\ RegII}$ are dark shaded.

Station	Layer (cm)	THC	NPD's	3-6 ring	Decalins
VAR07	0-1	2.8	0.005	0.015	0.045
	1-3	3.8	0.008	0.019	0.035
	3-6	2.4	0.007	0.018	0.025
VAR10	0-1	527	0.112	0.067	0.362
	1-3	175	0.044	0.025	0.430
	3-6	20.4	0.039	0.039	0.927
VAR14R	0-1	4.5	0.012	0.036	0.026
	1-3	5.4	0.019	0.041	0.031
	3-6	5.2	0.021	0.050	0.023

n.a. Not analysed.

The THC values range from values below the background level across the shallow sub region (3.7 mg/kg) to 412 ± 284 mg/kg dry sediment. The highest concentrations of THC, aromatics and decalins are found at VAR10. Hydrocarbons are contaminated down to 6 cm at this station. THC values above the calculated LSC are dark shaded in Table 15-4.

Along the 20°-, 110°- and 200°-axes gradients of decreasing amounts of THC with increasing distance from the installation are found. The stations contaminated with THC are VAR01, VAR03 and VAR08-VAR12. The gas chromatogram profile of the sediment extracts from contaminated stations show the presence of mineral oil (Figure 15-2.) At VAR10, petroleum related hydrocarbons are found down to 6 cm depth. According to data on recent drilling, oil-based mud was possible discharged in 1999.

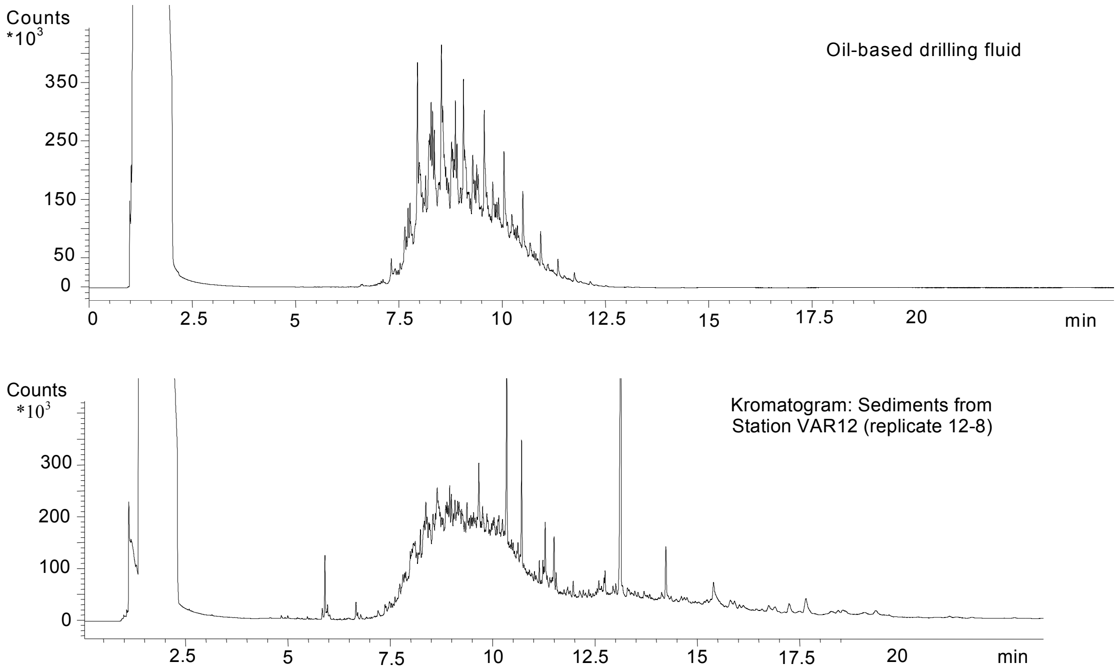

Figure 15-2: Gas chromatogram of an oil-based drilling fluid (upper) and a sediment extract from the Varg field (lower), 2000.

The results of the metal analyses are summarised in Table 15-6. Concentrations of selected metals in the vertical sediment sections are presented in Table 15-7. The full data set of replicate measurements, including selected data from previous years,are given in the Appendix. Metal values from 2000 are compared with those from previous years in Figure 15-4 and Figure 15-5.

Table 15-6: Concentrations of selected metals in sediments from the Varg field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ shallow\ RegII}$ are dark shaded and values between $LSC_{00\ VAR14R}$ and $LSC_{97\text{-}00\ shallow\ RegII}$ light shaded.

	Cd		Hg		Cu		Zn		Ba		Cr		Pb	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
VAR01	0.003	0.001	n.a.		0.4	0.2	3.1	0.4	65	12	6.6	0.6	6.6	0.4
VAR02	0.004	0.002	n.a.		0.7	0.1	3.7	0.2	63	7	8.3	0.2	6.5	0.2
VAR03	0.004	0.001	n.a.		0.8	0.0	4.6	0.2	217	41	8.8	0.2	7.7	0.1
VAR04	0.003	0.001	n.a.		0.6	0.1	3.9	0.5	57	5	7.9	0.3	5.7	4.0
VAR05	0.004	0.002	n.a.		0.7	0.1	4.7	0.6	24	13	9.2	0.7	8.1	0.3
VAR07	0.003	0.001	<0.005	-	0.6	0.1	4.3	0.4	39	17	8.9	0.1	7.5	0.6
VAR08	0.007	0.001	n.a.		0.8	0.4	5.9	0.6	106	42	9.9	0.1	10.5	0.5
VAR09	0.006	0.002	n.a.		1.2	0.6	6.2	0.7	473	213	9.7	0.2	9.7	0.2
VAR10	0.012	0.001	0.006	0.003	1.6	0.3	8.2	0.6	1671	640	9.5	0.3	8.9	0.2
VAR11	0.012	0.002	n.a.		1.3	0.3	8.0	1.0	1266	395	9.9	0.5	10.6	1.2
VAR12	0.003	0.001	n.a.		0.8	0.0	4.7	0.6	241	66	8.9	0.2	8.0	0.3
VAR13	0.007	0.005	n.a.		0.8	0.1	4.8	0.7	83	12	8.4	0.4	7.1	0.3
VAR14R	0.006	0.001	0.004	0.002	0.8	0.1	5.2	0.1	34	6	7.9	0.2	6.7	0.1

n.a. Not analysed.

Table 15-7: Concentrations of selected metals in vertical sections of the sediment samples from the Varg field. (All concentrations in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ shallow\ RegII}$ are dark shaded and values in grey zone light shaded.)

Station	Layer (cm)	Cd	Hg	Cu	Zn	Ba	Cr	Pb
VAR07	0-1	0.005	<0.005	0.6	4.0	24	9.0	7.2
	1-3	0.005	<0.005	0.8	4.3	136	9.3	7.5
	3-6	<0.005	<0.005	0.6	4.6	58	9.7	7.6
VAR10	0-1	0.013	<0.005	1.2	7.6	1151	9.4	8.8
	1-3	0.008	0.005	1.1	6.8	860	9.3	8.4
	3-6	0.007	<0.005	0.8	6.6	206	9.3	8.9
VAR14R	0-1	0.005	<0.005	0.6	5.2	24	8.1	6.5
	1-3	0.007	<0.005	0.8	5.1	61	7.9	6.5
	3-6	0.014	<0.005	0.8	5.4	171	7.8	7.0

n.a. Not analysed.

The content of barium, cadmium, lead, zinc, copper and chromium range from the corresponding background levels across the shallow sub region to 1671 ± 640, 0.012 ± 0.002, 11 ± 1.2, 8.2 ± 0.6, 1.6 ± 0.3 and 9.9 ± 0.5 mg/kg dry sediment respectively (Table 15-6). The highest contents of barium, cadmium, copper and zinc are found at VAR10 and VAR11, while the highest concentrations of chromium and lead are found in sediments from VAR08 and VAR11. The sectioned sediment samples analysed at VAR10 show decreasing amounts of barium with depth, while the remaining of the selected metals are more uniformly distributed down the sediment core. Metal concentrations above the calculated LSC are dark shaded in Table 15-6 and Table 15-7.

One of the five replicate sediment samples from the Varg reference station has mercury content (0.008 mg/kg) above the detection limit for mercury (0.005 mg/kg). Mercury is not detected in sediments from VAR07. At VAR10 the three replicate mercury concentrations are 0.006, 0.009 and < 0.005 mg/kg dry sediment.

Along the 20°-, 110°- and 200°-axes gradients of decreasing amounts of barium with increasing distance from the installation are found. Gradients of decreasing amounts of copper and zinc are seen at the 20°- axis and gradients of decreasing amounts of chromium and lead at the 200°- axis. The stations contaminated with barium are VAR01 – VAR03 and VAR08 - VAR13. The stations contaminated with lead are VAR03 and VAR05 - VAR12. In addition, elevated levels of chromium are found at the stations contaminated with lead.

<u>Comparison with previous survey(s)</u>

This year`s THC and metal contents at VAR14R are comparable to the amounts found in the 1997 baseline survey (Mannvik *et al.,* 1998.) Analysis of a sediment core from the reference station shows an almost uniform distribution of hydrocarbons and metals down to 6 cm depth. The only exceptions are found for NPD`s, 3-6 ring aromatics, cadmium and barium, of which the content increase slightly with increasing depth (Table 15-7.)

Compared to the 1997 results (Figure 15-3) the content of THC has increased at the three 250 m stations (VAR03, VAR10, and VAR11) and at the 1000 m station at the 290°-axis (VAR01). At the remaining stations the THC contents are almost unchanged or reduced since 1997. The content of barium has increased over the whole Varg field (Figure 15-4). The largest increases in THC and barium are found at VAR10 and VAR11, where the amounts have increased with 50 and 100 mg/kg (THC) and 1500 and 1200 mg/kg (barium) respectively. These findings are supported by the vertical distribution of THC and barium down the sediment core from VAR10 (Table 15-5 and Table 15-7.) At VAR03 and VAR01 the amount of THC have increased with 8-10 mg/kg since 1997. With the exceptions of increased levels of cadmium at VAR10 and VAR11 and increased amounts of lead and zinc at VAR11, the content of the remaining of the selected metals are almost unchanged (Figure 15-5.)

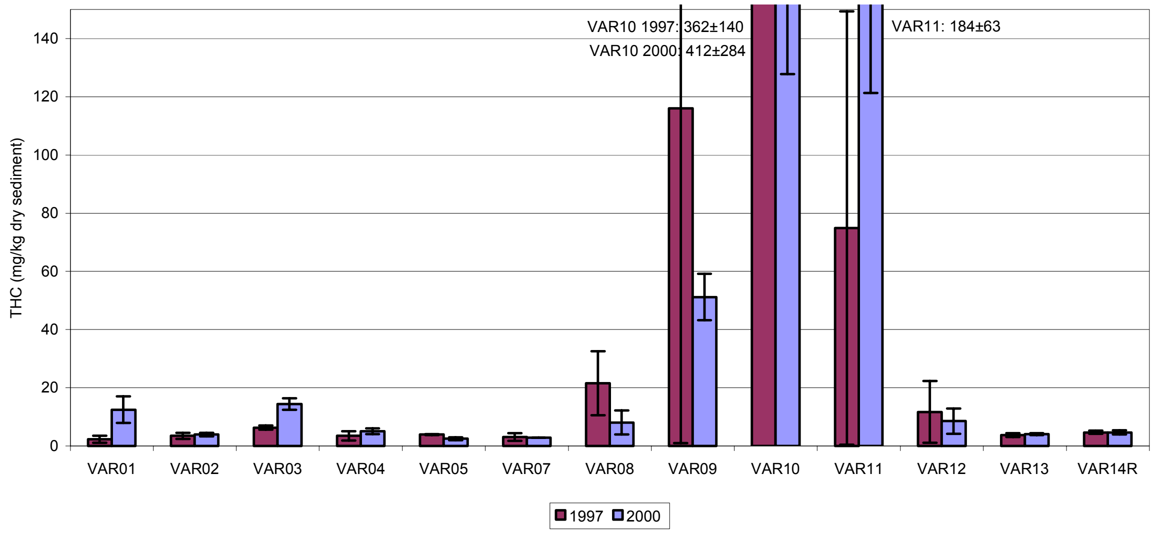

Figure 15-3: THC levels in sediment from the present (2000) and previous surveys, Varg field.

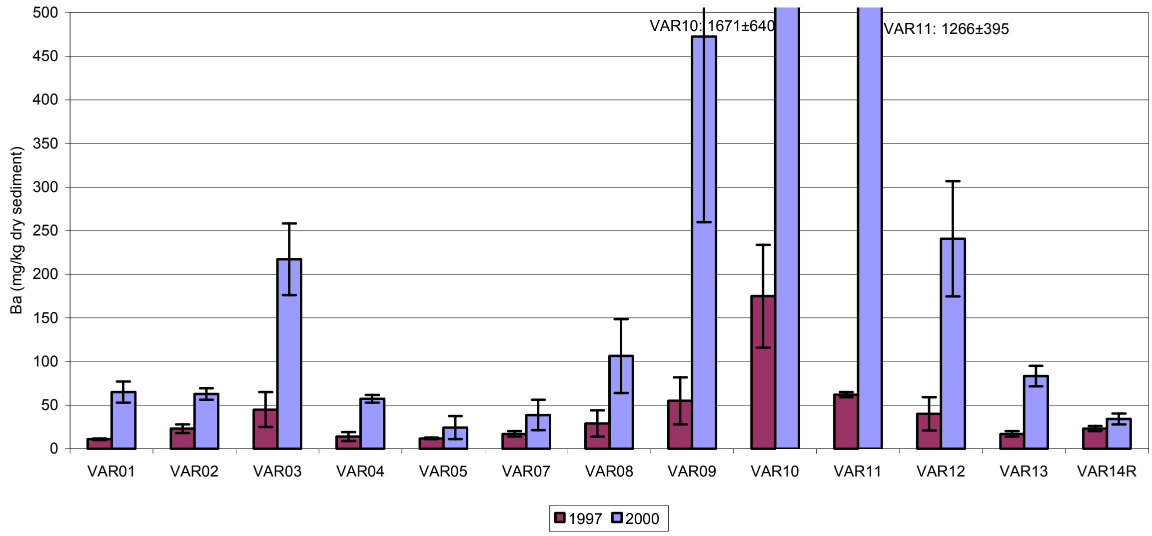

Figure 15-4: Barium levels in sediment from the present (2000) and previous survey, Varg field.

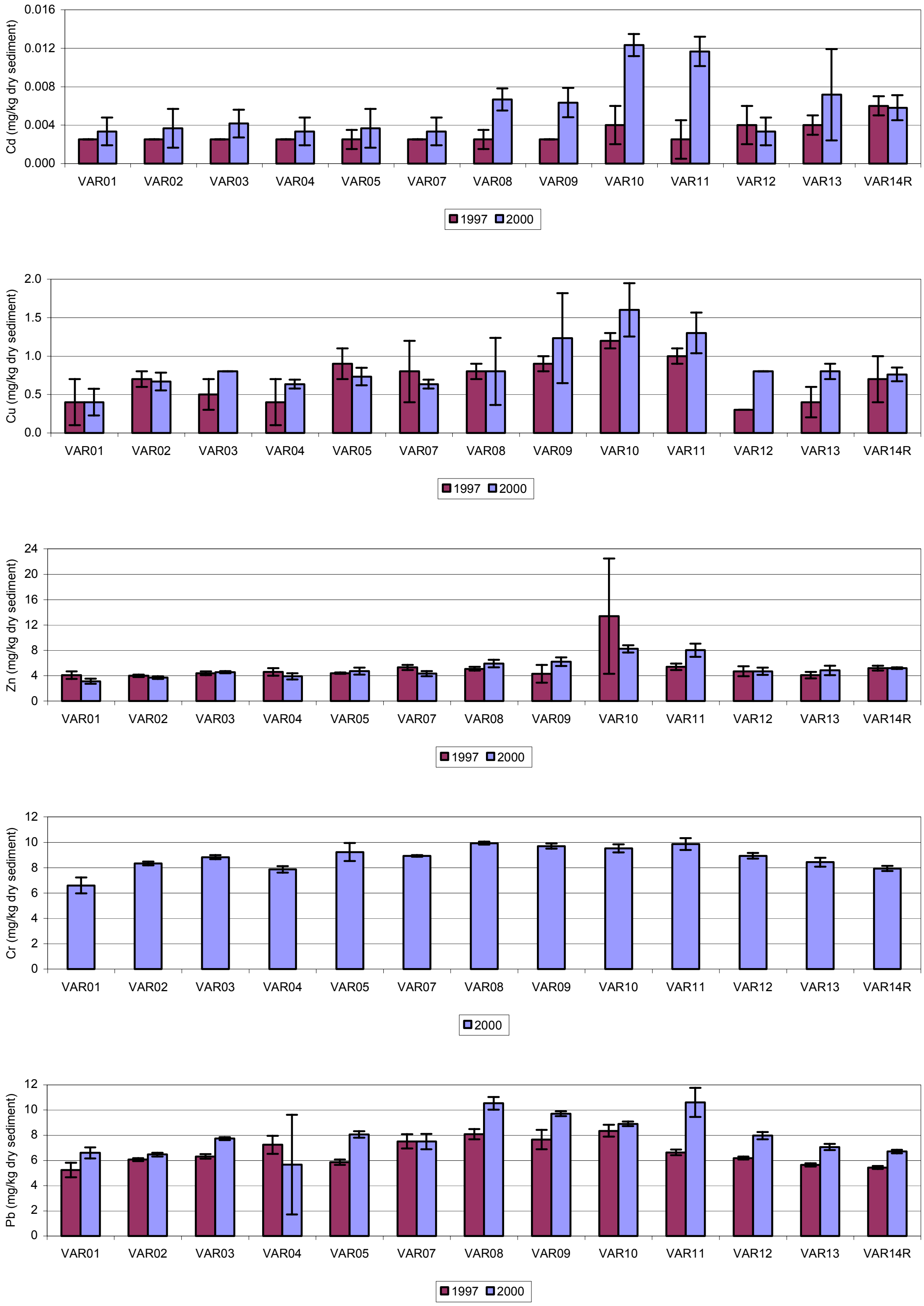

Figure 15-5: Levels of selected metals in sediments from the present (2000) and previous surveys, Varg field.

15.2.3 Biology

The distribution of individuals and taxa within the main taxonomic groups are given in Table 15-8. A total of 3350 individuals within 166 taxa were recorded at the Varg field in the present survey (excluding juveniles). The polychaetes dominate the fauna with 50 % of the individuals and 46 % of the taxa recorded.

Table 15-8: Distribution of individuals and taxa within the main taxonomic groups at Varg, 2000 (excluding juveniles).

Main taxonomic groups	Individuals		Taxa	
	Number	%	Number	%
Polychaeta	1685	50	77	46
Mollusca	526	16	40	24
Crustacea	351	10	27	16
Echinodermata	448	13	7	4
Diverse groups	340	10	15	9
Total	3350	100	166	100

The species/area curve for the field reference station is shown in Figure 15-6. A total of 84 taxa were recorded in the ten grab samples, of which 25 (30 %) occur in the first sample and 51 (60 %) occur in the first five samples. The shape of the curve indicates that not all taxa in the area are present in the ten grab samples and the representativity of five samples seems to be relatively low compared with the curves form other reference stations in the region.

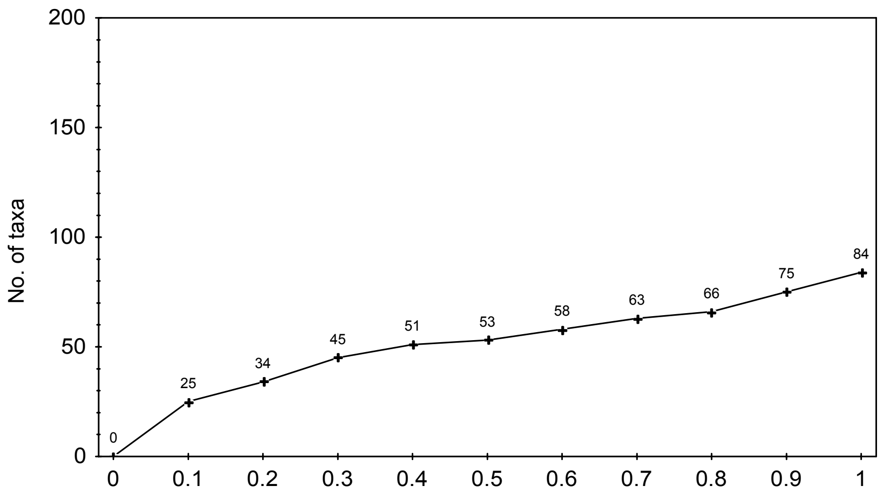

Figure 15-6: Species/area curve for the reference station at the Varg field, 2000 (area in m^2).

The number of individuals and taxa at each station, together with selected community indices is presented in Table 15-9 and Figure 15-7. The number of individuals recorded at Varg varies from 165 (VAR11) to 373 (VAR01). The number of taxa varies from 41 (VAR10) to 86 (VAR01), the diversity index H' from 3.4 (VAR10) to 5.7 (VAR01), the evenness index J from 0.63 (VAR10) to 0.88 (VAR01 and VAR08) and the ES_{100} from 26 (VAR10) to 46 (VAR01). The indices H', J and ES_{100} had higher average values than the reference station VAR14R.

The number of individuals and taxa has decreased at most of the stations since 1997 and, especially at station VAR10 situated 250 m north of the installation, this has resulted in a decrease in the diversity index.

Table 15-9: Number of individuals and taxa and selected community indices for each station (0.5 m^2) at the Varg field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	No. of ind.	No. of taxa	H'	J	ES_{100}
VAR01	**373**	**86**	**5.7**	**0.88**	**46**
VAR02	268	56	4.8	0.82	36
VAR03	196	58	5.0	0.85	40
VAR04	246	57	4.9	0.83	36
VAR05	332	63	4.6	0.78	35
VAR07	318	59	4.9	0.83	37
VAR08	250	68	5.3	**0.88**	43
VAR09	201	54	4.8	0.84	38
VAR10	202	**41**	**3.4**	**0.63**	**26**
VAR11	**165**	45	4.4	0.81	35
VAR12	230	56	4.9	0.85	36
VAR13	333	55	4.6	0.79	32
VAR14R	236	53	4.6	0.80	34
Sum *	3114				
Average *	260	58	4.8	0.82	37
St. dev. *	66	11	0.5	0.07	5

* Excluding the reference station.

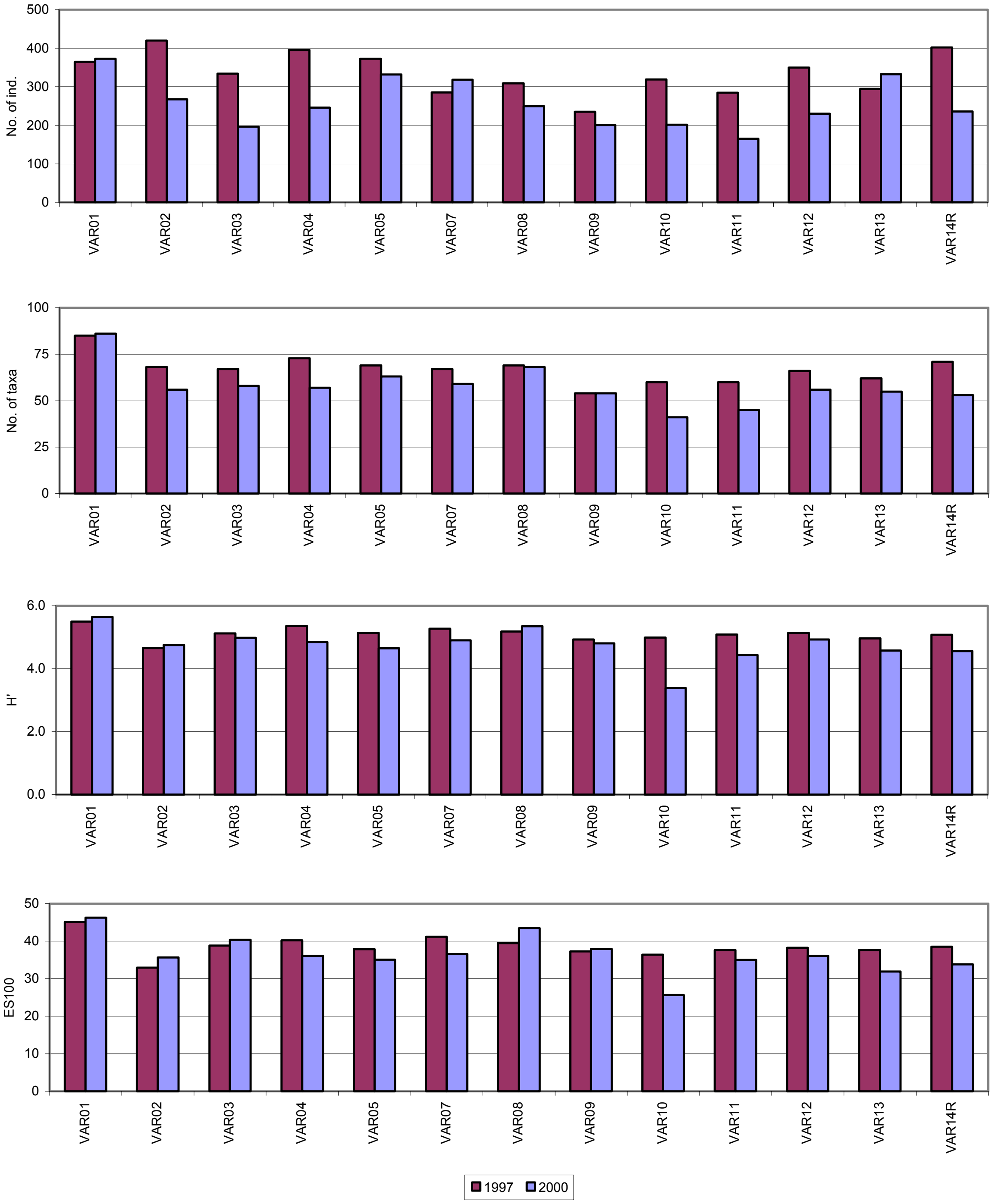

Figure 15-7: Biological characteristics at the Varg field, 2000 and previous survey.

The distribution of taxa in geometrical classes is shown in Figure 15-8. Three stations (VAR05, VAR10 and VAR13) have taxa in geometric class 7 64 – 127 individuals) while the rest of the stations have taxa in class 6 or lower (< 64 individuals). These results do not indicate any faunal disturbance at the stations.

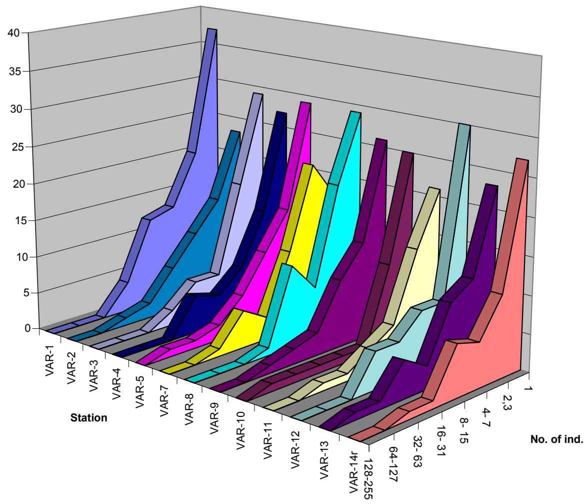

Figure 15-8: Distribution of taxa in geometrical classes from the stations at the Varg field, 2000.

The ten most dominant taxa at each station are shown in Table 15-12 at the end of this chapter. A total of 37 taxa (including four juvenile forms) are among the ten most dominant taxa at one or more stations. The brittle star *Amphiura filiformis*, known to be relatively abundant in undisturbed sediments, is the most dominant species at seven of the 13 stations, but do not occur among the ten most dominants at four stations (VAR03, VAR09, VAR10 and VAR11). The polychaetes *Paramphinome jeffreysii* and *Spiophanes bombyx* and the phoronid *Phoronis* sp. are among the ten most dominant taxa at 12, 11 and 10 stations, respectively. The polychaetes *Chaetozone setosa* and *Capitella capitata*, known to be relatively abundant in disturbed sediments, are among the most dominant taxa at two and one stations, respectively (VAR10 and VAR11). These results might indicate some faunal disturbance at at least two of the stations.

Figure 15-9 shows the dendrogram from the cluster analysis for the field stations and regional and reference stations while Figure 15-10 shows the 2-D plot from the MDS analysis.

The cluster analysis separates out field stations VAR09, VAR10 and VAR11 at 55 % dissimilarity level and further from each other between 47 and 49 % level. All regional and reference stations, including the reference station at Varg, are separated from the remaining field stations at 47 to 49 % dissimilarity level. Field station VAR01 are further separated out at 45 % level while the remaining field stations are separated from each other at dissimilarity level between 40 and 32 %. The correlation coefficient shows a good fit to the data (r = 0.81).

The MDS analyses supports the results from the cluster analysis with the separation of field station VAR01, VAR09, VAR10 and VAR11 and the regional and reference stations from the main groups of field stations in the middle of the 2-D plot. The stress test shows a fair fit to the data (0.22).

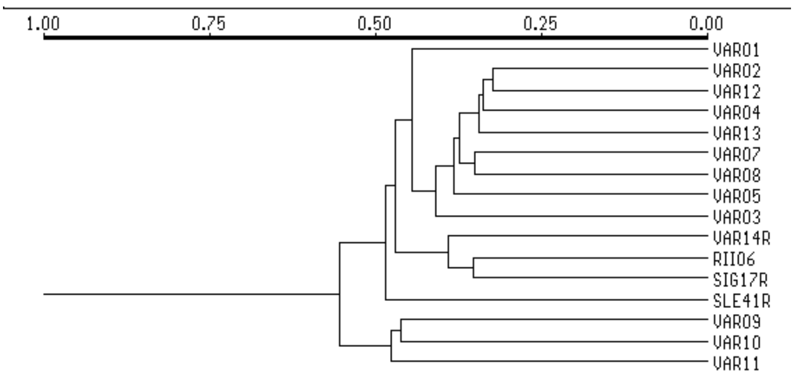

Figure 15-9: Cluster analysis of the Varg field stations and selected regional and reference stations in Region II, 2000.

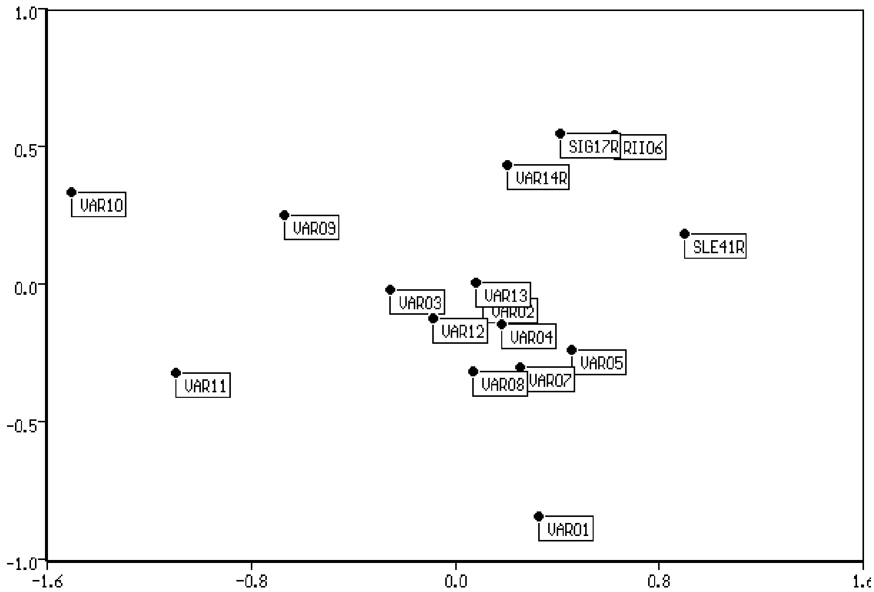

Figure 15-10: 2-D plot from the MDS analysis carried out on the Varg field stations and selected regional and reference stations in Region II, 2000.

A Canonical Correspondence Analysis (CCA) of the data from the Varg stations and selected regional and reference stations was carried out to examine the association between the biological data and the measured environmental variables in these areas.

Through the forward selection procedure in CANOCO, three of ten variables gave the best fit and are significant. 37.7 % of the biological variance was explained by the first two axes of the ordination space which is constrained by these environmental variables.

Figure 15-11 shows a biplot from the analysis using barium (Ba), THC and fine sand (FS) as the constraining environmental variables together with a plot of the taxa with highest contribution on two axes. The first axis shows a gradient from field station VAR10 at the positive end to regional station RII06 at the negative end and is positively correlated with the amount of THC (+ 0.93) and barium (+ 0.92) in the sediments. Taxa with high contribution on this axis are the polychaetes *Capitella capitata* (22.5 %), *Paramphinome jeffreysii* (19.4 %) and *Chaetozone setosa* (7.6 %), the brittle star *Amphiura filiformis* (10.3 %), the nemertin group Nemertini indet. (5.4 %) and the bivalve *Arctica islandica* (4.2 %). This axis clearly shows a faunal disturbance gradient with *C. capitata* and *C. setosa* associated with stations on the positive end of the axis and *A. filiformis* associated with stations on the negative end. Stations on the positive end have higher amount of both THC and barium in the sediments than those on the negative end.

The second axis shows a gradient from field station VAR01 on the positive end to the Sigyn reference station SIG17R on the negative end and is negatively correlated with the amount of fine sand in the sediments (- 0.97). Species with highest contribution on this axis are the polychaetes *Aricidea cerruti* (11.3 %) and *Nothria conchylega* ((8.5 %), the bivalve *Mysella* sp. (5.2 %) and the brittle star *Amphiura filiformis* (4.0 %). All this taxa are relatively abundant in undisturbed sediments. The second axis, therefore, shows a faunal gradient related to natural variations in the sediment structure. Stations on the negative end of this axis have higher amount of fine sand than those on the positive end.

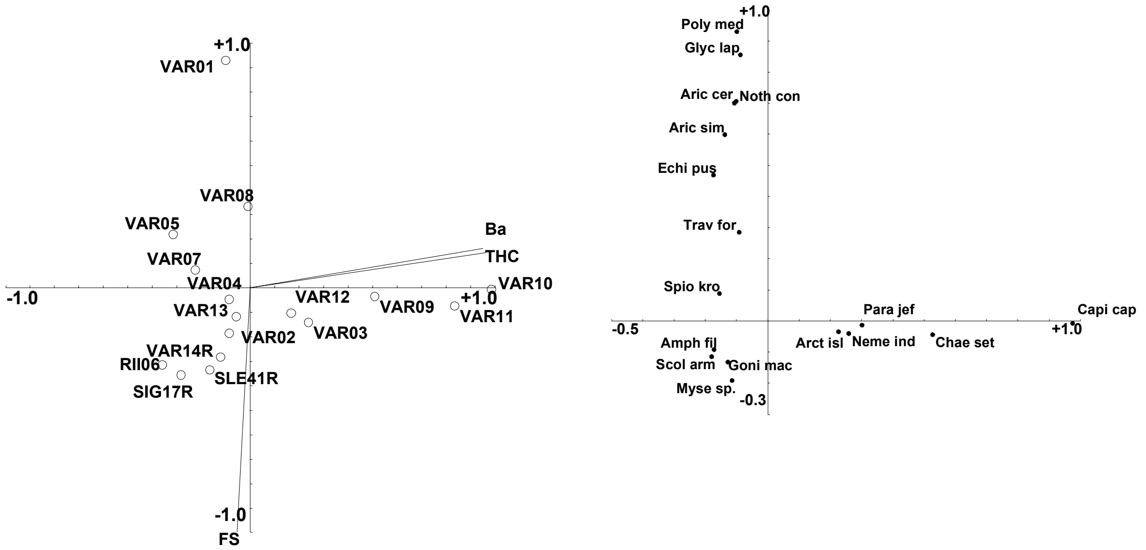

Figure 15-11: Biplot from the CCA analysis for the Varg field stations and selected regional and reference stations in Region II, 2000 (left) and the taxa with highest contribution on two axes (right).

On the basis of the results from the uni- and multivariate analyses, the stations at Varg are classified into two different faunal groups (see Table 15-10). Field stations VAR09, VAR10 and VAR11 are placed in group B (slightly disturbed fauna) while the remaining stations are placed in group A (undisturbed fauna). The stations in group B are separated from the other stations in the cluster and MDS analyses and all have relatively high abundance of Nemertini indet., *Chaetozone setosa* and *Capitella capitata* in some combinations. These taxa are known to increase in abundance in disturbed sediments. The same stations also have low abundance of *Spiophanes kroyeri* and *Amphiura filiformis*, which are known to avoid disturbed sediments. These two species also have low individual numbers at station VAR03, which might indicate some faunal disturbance. But at this station *C. setosa* and *C. capitata* do not occur in high numbers and is therefore placed in group A.

The stations in group B, which are situated at 250 m south west and 250 – 500 m north east of the centre, have high amounts of THC and barium in the sediments. The faunal disturbance can, therefore, be related to the petroleum activity at the field.

Table 15-10: Classification into impact groups, distance to installation and biological statistics for the field stations at Varg field, 2000.

Station	Impact group	Dist. (m)	Statistics			No. of individuals							
			No. ind	No. taxa	H'	Afi	Pje	Sbo	Skr	Psp	Nin	Csp	Cca
VAR01	A	1000	373	86	5.7	27	10	15	23	11	6	0	0
VAR02	A	500	268	56	4.8	55	21	14	15	17	9	3	0
VAR03	A	250	196	58	5.0	2	27	10	1	13	5	5	0
VAR04	A	500	246	57	4.9	28	20	28	20	16	6	1	0
VAR05	A	1000	332	63	4.6	77	15	28	34	5	5	0	0
VAR07	A	2000	318	59	4.9	51	18	13	24	7	0	0	0
VAR08	A	1000	250	68	5.3	9	27	15	15	8	8	5	0
VAR09	B	500	201	54	4.8	0	18	5	0	9	20	4	1
VAR10	B	250	202	41	3.4	0	78	0	0	2	19	14	39
VAR11	B	250	165	45	4.4	2	41	0	0	6	16	9	0
VAR12	A	500	230	56	4.9	19	18	20	5	8	9	2	0
VAR13	A	1000	333	55	4.6	64	42	16	21	16	6	5	0
VAR14R	A	4000	236	53	4.6	56	10	13	12	13	7	0	0
RII06	A	-	245	54	4,6	47	0	11	10	13	0	0	0
SIG17R	A	-	266	59	4,6	72	0	13	8	11	0	0	0
SLE41R	A	-	340	46	4,0	75	0	16	0	14	9	0	0

Afi = *Amphiura filiformis*, Pje = *Parampinome jeffreysii*, Sbo = *Spiophanes bombyx*, Skr = *Spiophanes kroyeri*, Psp = *Phoronis sp*, Nin = *Nemertini indet*., Csp. = *Chaetosone* sp. (incl. *C. setosa)*, Cca = *Capitella capitata.*

15.3 Summary and conclusions

The sediment at the Varg field is classified as fine sand with a relatively low amount of pelite (1.3 – 2.7 %) and TOM (0.6 – 0.9 %). The amount of pelite has increased at all stations, including the reference station, at Varg, while the TOM has increased most at stations VAR03 and VAR09, but the TOM levels are below 1 %.

The Varg field is located in shallow area south in Region II. As for the previous survey, the highest concentrations of THC (412 mg/kg) and barium (1671 mg/kg) are found at the innermost station in the main current direction from Varg (20°-axis). The area significantly contaminated with THC and barium reaches out to 1000 m on the 20°- and 290°-axes, while THC is contaminated out to 500 m and barium out to 1000 m on the 200°-axis. The gas chromatogram of sediment extracts from stations contaminated with THC show the presence of mineral oil. According to data on recent drilling, oil-based mud was possible discharged in 1999.

Compared to the 1997 results the THC levels have increased at the innermost stations on the 20°-, 200°- 290°- axes and at the outermost station on the 290°-axis. At the remaining stations the THC contents are almost unchanged or reduced. The barium content has increased over the whole Varg field. According to data on discharges, both barite and water-based drilling mud were discharged in 1999.

Since 1997 the area contaminated with THC is unchanged on the 20°- and 200°-axes, while the contaminated area has increased from 500 m to at least 1000 m along the 290°-axis. None of the stations on the 110°-axis are contaminated with THC in the present survey. The area contaminated with barium has increased from 250 m on the 20°- and 200°-axes to at least 1000 m on the 20°-, 200°- and 290°-axes.

The number of taxa and individuals are low at all stations at Varg, but at similar levels as the neighbouring Sigyn and Sleipner Øst. The number of both individuals and taxa has decreased at most of the stations since 1997 and, especially at station VAR10, this has resulted in a decrease of the diversity index.

The multivariate analyses separated stations VAR09, VAR10 and VAR11 from the other field stations. At these stations polychaete *Spiophanes kroyeri* and the brittle star *Amphiura filiformis*, which is relatively abundant in undisturbed sediments, is absent or occur in very low numbers. At the same stations the polychaetes *Chaetozone setosa* and *Capitella capitata* and the nemertin group Nemertini indet., known to be relatively abundant in disturbed sediments, are recorded in relatively high numbers. These stations are therefore classified as faunal group B (slightly disturbed fauna). Also at VAR03 *S. kroyeri* and *A filiformis* occur in low numbers, which might indicate some faunal disturbance. But at that station *C. setosa* and *C. capitata* did not occur in high numbers. This station was also grouped together with the main group of field stations in the multivariate analyses and is therefore classified as group A station (undisturbed fauna).

The stations in group B, which are situated at 250 m south west and 250 – 500 m north east of the centre, have high amounts of THC and barium in the sediments. The faunal disturbance can, therefore, be related to the petroleum activity at the field.

The calculated minimum area and spatial extent of contaminated sediments and disturbed fauna at the Varg field is shown in Table 15-11 and Figure 15-12.

Table 15-11: Distance along the transects and calculated minimum area of contaminated sediments and disturbed fauna at the Varg field, 2000 and previous survey.

Varg	N	E	S	W	Km^2 (2000)	Km^2 (1997)
Group B	500	125	250	125	0.15	0.00
THC	1000	125	500	1000	1.33	1.18
Ba	1000	125	1000	1000	1.77	0.10
Other metals	1000	125	250	125	0.25	0.00

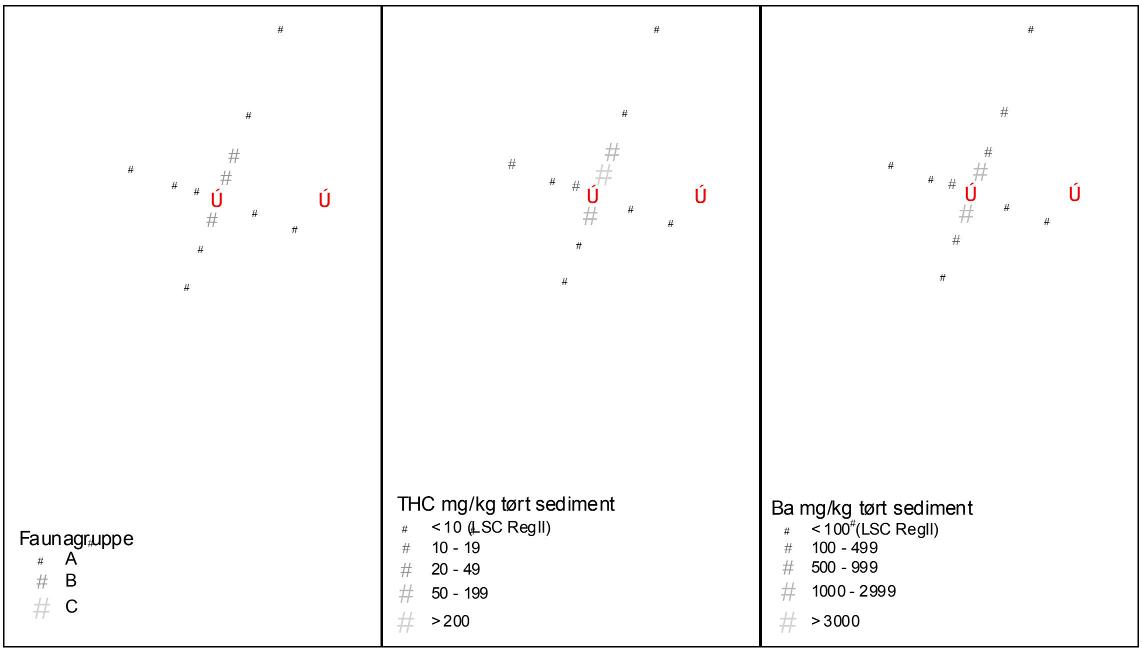

Figure 15-12: Distribution of disturbed fauna and the amounts of THC and barium in the sediments at the Varg field, 2000.

Table 15-12: Number of individuals and the accumulative abundance for the ten predominant taxa at each station at the Varg field, 2000.

VAR01 (290°/1000 m)	No. ind.	Acc. %	VAR02 (290°/500 m)	No. ind.	Acc. %	VAR03 (290°/250 m)	No. ind.	Acc. %	VAR04 (110°/500 m)	No. ind.	Acc. %	VAR05 (110°/1000 m)	No. ind.	Acc. %
Amphiura filiformis	27	6	Amphiura filiformis	55	19	Paramphinome jeffreysii	27	13	Amphiura filiformis	28	11	Amphiura filiformis	77	21
Spiophanes kroyeri	23	12	Paramphinome jeffreysii	21	27	Arctica islandica	22	23	Spiophanes bombyx	28	21	Spiophanes kroyeri	34	30
Aricidea cerrutii	21	17	Phoronis sp.	17	33	Phoronis sp.	13	29	Paramphinome jeffreysii	20	29	Spiophanes bombyx	28	38
Ophiuroidea indet. juv.	21	22	Spiophanes kroyeri	15	38	Eudorellopsis deformis	11	34	Spiophanes kroyeri	20	36	Mysella sp.	20	43
Nothria conchylega	17	26	Eudorellopsis deformis	14	43	Bathyporeia sp.	10	39	Phoronis sp.	16	42	Spiophanes sp. juv.	19	48
Spiophanes bombyx	15	30	Spiophanes bombyx	14	48	Spiophanes bombyx	10	44	Bathyporeia sp.	12	47	Paramphinome jeffreysii	15	52
Travisia forbesii	14	33	Abra prismatica	11	51	Goniada maculata	8	47	Mysella sp.	11	51	Bathyporeia sp.	12	56
Antalis sp.	12	36	Nemertini indet.	9	55	Nephtys longosetosa	6	50	Abra prismatica	9	54	Ophiuroidea indet. juv.	11	59
Pectinaria sp. juv.	12	39	Nephtys caeca	8	57	Ophiuroidea indet. juv.	6	53	Eudorellopsis deformis	8	57	Edwardsia sp.	8	61
Phoronis sp.	11	41	Arctica islandica	7	60	Spiophanes sp. juv.	6	56	Ophiuroidea indet. juv.	7	60	Goniada maculata	8	63
			Ophiuroidea indet. juv.	7	62							Nephtys longosetosa	8	65

VAR07 (20°/2000 m)	No. ind.	Acc. %	VAR08 (20°/1000 m)	No. ind.	Acc. %	VAR09 (20°/500 m)	No. ind.	Acc. %	VAR10 (20°/250 m)	No. ind.	Acc. %	VAR11 (200°/250 m)	No. ind.	Acc. %
Amphiura filiformis	51	14	Paramphinome jeffreysii	27	10	Arctica islandica	35	15	Paramphinome jeffreysii	78	38	Paramphinome jeffreysii	41	24
Scoloplos armiger	24	21	Spiophanes bombyx	15	15	Nemertini indet.	20	24	Capitella capitata	39	57	Nemertini indet.	16	33
Spiophanes kroyeri	24	28	Spiophanes kroyeri	15	21	Paramphinome jeffreysii	18	32	Nemertini indet.	19	66	Arctica islandica	13	41
Eudorellopsis deformis	19	33	Eudorellopsis deformis	14	26	Eudorellopsis deformis	13	38	Chaetozone setosa	14	73	Bathyporeia sp.	9	46
Travisia forbesii	19	38	Arctica islandica	10	30	Phoronis sp.	9	42	Mysella sp.	4	75	Chaetozone setosa	9	51
Paramphinome jeffreysii	18	44	Bathyporeia sp.	10	33	Bathyporeia sp.	8	46	Diplocirrus glaucus	3	76	Phoronis sp.	6	55
Arctica islandica	13	47	Abra prismatica	9	37	Nephtys sp. juv.	8	49	Ophiuroidea indet. juv.	3	78	Eudorellopsis deformis	5	58
Spiophanes bombyx	13	51	Amphiura filiformis	9	40	Ophiuroidea indet. juv.	8	53	Antalis sp.	2	79	Mysella sp.	4	60
Ophiuroidea indet. juv.	11	54	Aricidea catherinae	9	43	Spiophanes sp. juv.	6	55	Cnidaria indet.	2	80	Nephtys caeca	4	62
Spiophanes sp. juv.	10	57	Nemertini indet.	8	46	Aricidea catherinae	5	58	Glycera alba	2	81	Ophiura affinis	4	65
			Phoronis sp.	8	49	Mysella sp.	5	60	Nephtys hombergi	2	82	Ophiuroidea indet. juv.	4	67
			Travisia forbesii	8	52	Nephtys caeca	5	62	Nuculoma tenuis	2	83			
						Ophiura affinis	5	64	Ophiura affinis	2	83			
						Spiophanes bombyx	5	66	Phoronis sp.	2	84			
									Polinices pulchellus	2	85			
									Scalibregma inflatum	2	86			
									Timoclea ovata	2	87			

Table 15-12 cont.

VAR12 (200°/500 m)	No. ind.	Acc. %	VAR13 (200°/1000 m)	No. ind.	Acc. %	VAR14R (200°/4000 m)	No. ind.	Acc. %
Spiophanes bombyx	20	8	Amphiura filiformis	64	17	Amphiura filiformis	56	22
Amphiura filiformis	19	15	Paramphinome jeffreysii	42	29	Scoloplos armiger	17	29
Paramphinome jeffreysii	18	22	Spiophanes kroyeri	21	35	Eudorellopsis deformis	13	34
Bathyporeia sp.	17	28	Scoloplos armiger	19	40	Phoronis sp.	13	39
Eudorellopsis deformis	17	35	Abra prismatica	16	44	Spiophanes bombyx	13	44
Arctica islandica	15	41	Phoronis sp.	16	48	Goniada maculata	12	49
Spiophanes sp. juv.	14	46	Spiophanes bombyx	16	53	Spiophanes kroyeri	12	54
Abra prismatica	9	50	Spiophanes sp. juv.	16	57	Paramphinome jeffreysii	10	57
Nemertini indet.	9	53	Goniada maculata	14	61	Abra prismatica	8	61
Ophiuroidea indet. juv.	9	57	Arctica islandica	12	64	Nemertini indet.	7	63
Sthenelais limicola	9	60						

Table 15-13: Station information for Varg field, 2000.

St. no.	Distance (m)	Direction (degr.)	Volume (litres)
VAR01	1000	290	44
VAR02	500	290	32
VAR03	250	290	49
VAR04	500	110	39
VAR05	1000	110	41
VAR07	2000	20	28
VAR08	1000	20	29
VAR09	500	20	29
VAR10	250	20	40
VAR11	250	200	54
VAR12	500	200	40
VAR13	1000	200	34
VAR14R	4000	200	39 *

* The additional five grab samples taken gave 44 litres of sediment.

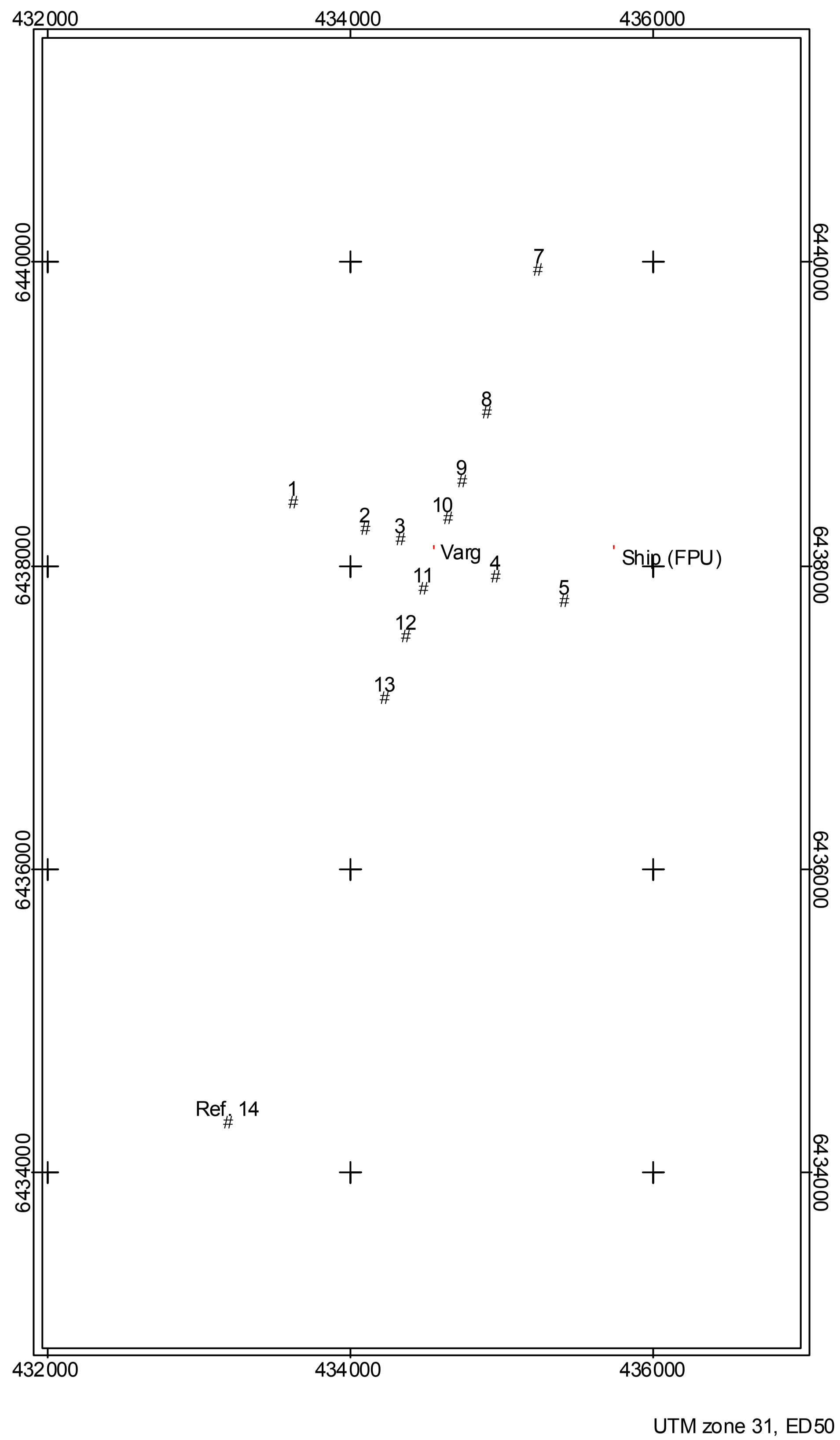

Figure 15-13: Map of sampling positions for Varg field, 2000.

16 Heimdal field

16.1 Introduction

The Heimdal field is located in block 25/4 in Region II. Data on recent drilling and discharges are shown in Table 16-1.

In the monitoring survey at the field in 1997, sediments at all stations were contaminated by hydrocarbons. Barium, zinc, cadmium and copper values above LSC were found at all stations too. Elevated levels of lead were found at the 250 m stations in the 324° and 180° directions. The fauna was disturbed at the 250 m stations. Additional stations were therefor included in the present survey.

Information on the sampling stations is shown in Figure 16-12 and Table 16-14, both on the foldout page at the end of this chapter (page 16-19).

Table 16-1: Summary of recent wells drilled and operational and accidental discharges at the Heimdal field (all discharges in tonnes).

	1997	1998	1999	2000	Comments
Accidental discharges	0	0	0,06m^3	0	

16.2 Results and discussion

16.2.1 Physical characteristics

The median phi value and the amounts (%) of pelite, fine sand and total organic material (TOM) in the sediment from the present and previous surveys are shown in Table 16-2 and Figure 16-1. 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 at the Heimdal field are classified as fine sand and silt with median values RANGING from 3.71 (HEM15) to 4.21 (HEM18). The amount of pelite in the sediment varies from 7.9 % (HEM02) to 14.2 % (HEM18), the fine sand from 71.4 % (HEM15) to 84.2 % (HEM04) while the TOM varies from 1.31 % (HEM02) to 1.90 % (HEM18). The pelite and TOM values are higher at the reference station HEM22R than at the field stations.

There is a general trend of finer sediments at the stations compared with the results from 1997. The largest increase in the pelite content has occurred at three field stations (HEM03, HEM18 and HEM19) and the reference station HEM22R and the largest increase in TOM has occurred at station HEM18.

Table 16-2: The median (phi) and amount (%) of pelite, fine sand and TOM in the sediments from the stations at Heimdal, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	Distance (m)	Direction (degr.)	Median	Classification	Pelite	Fine sand	TOM
HEM01	1000	130	3.74	Fine sand	9.4	75.0	1.36
HEM02	500	115	3.76	Fine sand	**7.9**	78.4	**1.31**
HEM03	300	100	4.04	Silt	12.2	76.5	1.67
HEM04	250	315	4.08	Silt	10.7	**84.2**	1.71
HEM14	250	60	4.08	Silt	10.6	76.9	1.63
HEM15	500	60	**3.71**	Fine sand	8.6	**71.4**	1.36
HEM18	300	180	**4.21**	Silt	**14.3**	71.6	**1.90**
HEM19	500	180	4.10	Silt	10.6	76.3	1.49
HEM22R	10000	360	4.14	Silt	14.4	81.6	2.02
Average *			3.96		10.5	76.3	1.55
St. dev. *			0.19		2.0	4.1	0.21

* Excluding the reference station.

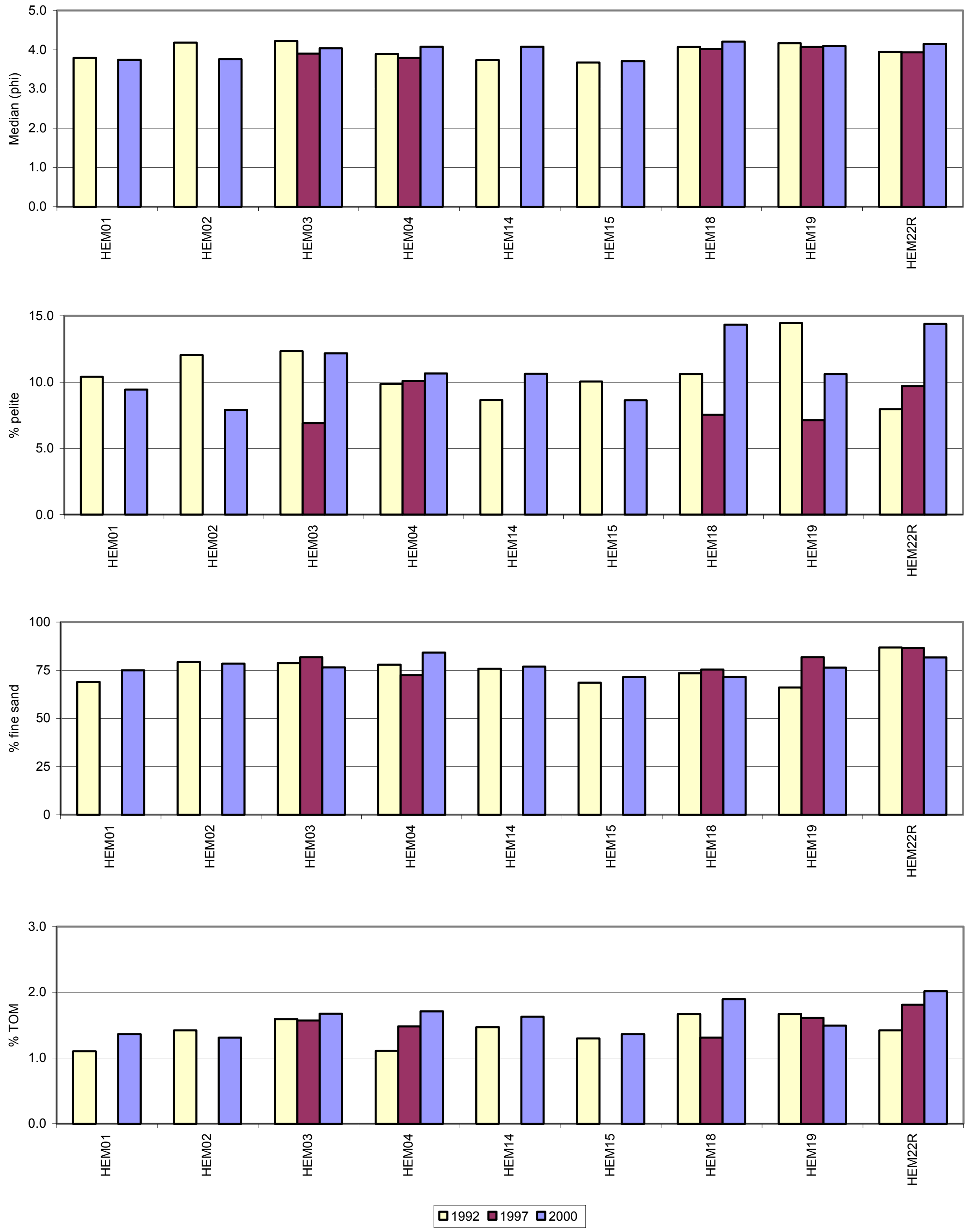

Figure 16-1: Sediment characteristics at the Heimdal field, 2000 and previous surveys.

16.2.2 Chemical characteristics

The calculated limits of significant contamination for selected hydrocarbons and metals in sediments from Region II ($LSC_{97\text{-}00\ RegII}$) are presented previously in the chapter that deals with the regional and reference stations. In addition to the regional limits, field-specific limits of significant contamination are calculated from the field reference station ($LSC_{00\ HEM22R}$). However, the proportion of pelite in these sediments is higher than general levels in the field and will therefor be disregarded in the further discussion. Both sets of data are presented in Table 16-3. Based on analysis results of the Heimdal field the $LSC_{97\text{-}00\ RegII}$ is regarded as representative of the entire region and will therefore be used as further basis for discussion of the contamination status of this field. Those limits will hereafter simply be referred to as LSC.

The results of analyses of hydrocarbons are summarised in Table 16-4. Concentrations of selected compounds in the vertical sediment sections are presented in Table 16-5. The full data set of replicate measurements and date from previous years are given in the Appendix. THC values are compared with those from previous years in Figure 16-3.

Table 16-3: Background levels and Limits of Significant Contamination for the Heimdal field, 2000. All values in mg/kg dry sediment.

	THC	NPD's	3-6 ring	Decalins	Cd	Hg	Cu	Zn	Ba	Cr	Pb
$LSC_{00\ HEM22R}$	11.9	0.074	0.207	0.187	0.031	0.008	2.5	9.5	178	7.9	6.9
$LSC_{97\text{-}00\ Region\ II}$	9.8	*	*	*	0.029	0.008	2.0	8.9	146	9.6	7.0

*) Regional stations not analysed for NPD's, 3-6 ring aromatics and decalins.

Table 16-4: Concentrations of hydrocarbons in sediments from the Heimdal field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between $LSC_{00HEM22R}$ and $LSC_{97\text{-}00\ RegII}$ light shaded.

Station	THC		NPD's		3-6 ring		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
HEM01	10.3	2.4	0.020	0.001	0.054	0.010	0.043	0.013
HEM02	6.8	1.8	n.a.		n.a.		n.a.	
HEM03	7.7	0.9	0.026	0.003	0.068	0.005	0.058	0.004
HEM04	10.8	4.1	n.a.		n.a.		n.a.	
HEM14	9.7	1.7	n.a.		n.a.		n.a.	
HEM15	8.1	1.0	n.a.		n.a.		n.a.	
HEM18	11.8	1.7	n.a.		n.a.		n.a.	
HEM19	12.9	2.1	n.a.		n.a.		n.a.	
HEM22R	8.5	1.4	0.037	0.016	0.104	0.044	0.055	0.057

n.a. Not analysed.

Table 16-5: Concentrations of hydrocarbons in vertical sections of the sediment samples from the Heimdal field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between $LSC_{00HEM22R}$ and $LSC_{97\text{-}00\ RegII}$ light shaded.

Station	Layer (cm)	THC	NPD's	3-6 ring	Decalins
HEM01	0-1	8.1	0.019	0.056	0.030
	1-3	7.9	0.025	0.069	0.034
	3-6	9.4	0.026	0.072	0.037
HEM03	0-1	8.2	0.027	0.067	0.062
	1-3	9.1	0.049	0.102	0.071
	3-6	10.9	0.047	0.098	0.079
HEM22R	0-1	6.5	0.065	0.182	0.154
	1-3	7.9	0.033	0.092	0.025
	3-6	7.1	0.030	0.099	0.023

n.a. Not analysed.

The THC values range from 6.8 ± 1.8 mg/kg to 12.9 ± 2.1 mg/kg dry sediment at Heimdal (Table 16-4). Contamination with THC is found at stations HEM18 and HEM19 with sediment concentrations of 11.8 ± 1.7 and 12.9 ± 2.1 mg/kg dry sediment. Also at HEM01 and HEM04 sediment concentrations just above LSC are found, with concentrations of 10.3 ± 2.4 mg/kg and 10.8 ± 4.1 mg/kg. However, taking standard deviation in consideration, THC values in sediments from these stations must be defined as borderline values. Gas chromatograms of sediment extracts do not indicate mineral oil at any of these locations (Figure 16-2). The concentrations of NPD's, 3-6 ring aromatics and decalins in sediments at HEM01 and HEM03 are below LSC of the field (Table 16-4).

Vertical core samples reveal no hydrocarbon concentrations above LSC in sediments at the three locations examined except in the 3-6 cm layer at station HEM03, where 10.9 mg/kg THC is found (Table 16-5). No distinct hydrocarbon concentration gradients with depth are seen in sediments at Heimdal.

In general, sediments out to 500 m in direction 180° are slightly contaminated by hydrocarbons. The other stations do not reveal sediments with concentrations above LSC.

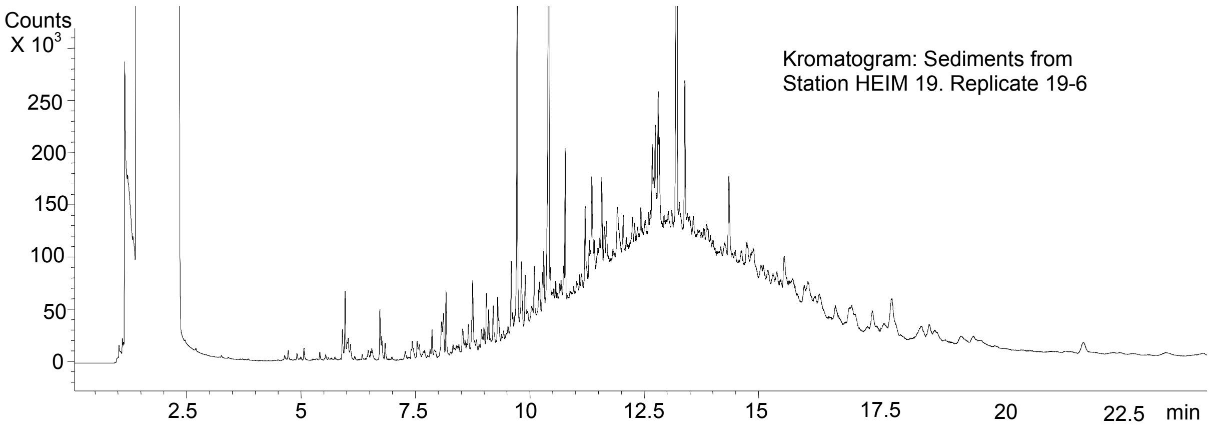

Figure 16-2: Gas chromatogram of a sediment extract from the Heimdal field, 2000.

The results of the metal analyses for the Heimdal field are summarised in Table 16-6. Concentrations of selected metals in the vertical sediment sections are presented in Table 16-7. The full set of replicate measurements, including selected data from previous years is given in the Appendix. Metal values from 2000 are compared with those from previous years in Figure 16-4 and Figure 16-5.

Table 16-6: Concentrations of selected metals in sediments from the Heimdal field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between $LSC_{00HEM22R}$ and $LSC_{97\text{-}00\ RegII}$ light shaded.

	Cd		Hg		Cu		Zn		Ba		Cr		Pb	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
HEM01	0.014	0.002	0.005	0.001	1.2	0.2	4.8	0.2	119	41	4.7	0.1	4.9	0.1
HEM02	0.018	0.003	n.a.		2.4	0.5	8.9	3.1	135	42	5.3	0.4	6.0	0.3
HEM03	0.026	0.004	0.005	0.002	2.1	0.9	8.1	1.8	492	131	5.9	0.2	6.1	0.8
HEM04	0.039	0.004	n.a.		6.1	0.8	47.2	1.2	889	98	7.2	0.7	14.4	0.7
HEM14	0.029	0.003	n.a.		3.8	0.5	17.9	1.4	921	226	6.7	0.5	8.9	0.8
HEM15	0.021	0.007	n.a.		1.6	0.2	7.9	2.2	151	11	4.9	0.1	5.6	0.5
HEM18	0.060	0.015	n.a.		10.3	1.9	57.4	7.6	1398	221	9.3	0.7	16.5	1.6
HEM19	0.030	0.002	n.a.		4.4	1.5	19.4	2.1	713	252	7.0	0.5	9.7	0.1
HEM22R	0.026	0.002	0.007	0.000	2.0	0.2	7.7	0.8	131	20	6.7	0.5	6.0	0.4

n.a. Not analysed.

Table 16-7: Concentrations of selected metals in vertical sections of the sediment samples from the Heimdal field. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are dark shaded and values between $LSC_{00HEM22R}$ and $LSC_{97\text{-}00\ RegII}$ light shaded.

Station	Layer (cm)	Cd	Hg	Cu	Zn	Ba	Cr	Pb
HEM01	0-1	0.013	0.005	1.0	4.6	106	4.6	4.8
	1-3	0.024	0.006	1.2	5.6	118	5.0	5.2
	3-6	0.028	0.007	1.6	6.4	144	5.8	6.6
HEM03	0-1	0.024	0.006	1.8	8.0	643	6.0	6.4
	1-3	0.028	0.007	1.8	7.6	530	6.0	5.8
	3-6	0.031	0.007	1.8	8.4	1020	6.4	6.8
HEM22R	0-1	0.027	0.008	2.0	8.0	128	6.8	6.4
	1-3	0.031	0.008	2.0	8.4	131	7.4	5.8
	3-6	0.032	0.007	1.8	7.4	124	6.8	6.0

n.a. Not analysed.

Barium values range from 119 ± 41 mg/kg to 1398 ± 221 mg/kg dry sediment, cadmium from 0.014 ± 0.002 mg/kg to 0.060 ± 0.015 mg/kg, copper from 1.2 ± 0.2 mg/kg to 10.3 ± 1.9 mg/kg, lead from 4.9 ± 0.1 mg/kg to 16.5 ± 1.6 mg/kg, zinc from 4.8 ± 0.2 mg/kg to 57.4 ± 7.6 mg/kg and chromium from 4.7 ± 0.1 to 9.3 ± 0.7 mg/kg (Table 16-6). Stations HEM03, HEM04, HEM14, HEM8 and HEM19 have sediments with barium levels above LSC. Concentrations ranging from 492 mg/kg to 1398 mg/kg are found at these localities. At the same stations, minus HEM03, elevated levels of copper (4.4 mg/kg to 10.3 mg/kg), zinc (19.4 mg/kg to 47.2 mg/kg) and lead (8.9 mg/kg to 16.5 mg/kg) are found. In addition the sediments at HEM04 and HEM18 reveal cadmium levels above LSC with 0.039 mg/kg and 0.060 mg/kg respectively. None of the sediment samples at Heimdal are contaminated by mercury.

Vertical sediment samples reveal elevated levels of barium in the top layer at station HEM03, increasing with depth (Table 16-7). Elevated levels of cadmium are found in the 3-6 cm layer at HEM03. No values above LSC for any of the other selected metals are found in the vertical core samples. Minor increases in concentrations with depth are found in core samples for all the selected metals.

In general, elevated levels of barium are found in sediments at the innermost stations and out to 500 m on the 180°-axis relative to the field centre. Contamination by copper and zinc and lead are found in sediments at the same stations, except the one situated 300 m in the 100° direction. Cadmium contaminates sediments 250m in directions 180° and 315°. Minor increases in sediment metal concentrations with depth are found.

<u>Comparison with previous survey(s)</u>

This year's THC concentrations at the reference station were comparable to the concentrations found in 1997 (Figure 16-3). Sediments at the reference station also contained the same low levels of barium, cadmium, copper, and zinc (Figure 16-4 and Figure 16-5). However, lead concentrations have increased from 3.6 ± 0.3 mg/kg to 6.0 ± 0.4 mg/kg.

The hydrocarbon levels are lower in sediments at Heimdal in this survey than they were in 1997 (Figure 16-3). According to field history an acute spill of 0.06 m^3 oil in 1999 is the only discharge at the Heimdal field the last four years. In this survey sediments out to 500 m in the 180° direction are contaminated by hydrocarbons. Borderline values are found in sediments at the positions mentioned under. In 1997 contamination were found out to 500 m in the 180° direction, 250 m in the 324° direction and 300 m in the 150° direction.

Compared to the 1997 survey barium concentrations have increased in sediments at Heimdal in 2000 (Figure 16-4). At the stations situated 300 m at 100°, 250 m at 315° and out to 500 m at 180° elevated barium levels are found, with 60- to 185% increases of the concentrations. Contamination and increased levels of zinc, lead and copper are also found in sediments from these stations minus the one situated 300 m in the 100° direction (Figure 16-5). Cadmium is increasing and contaminates sediments 250m in the180° direction and 300 m in the 315° direction. Mercury levels are unchanged. Minor increases in sediment metal concentrations with depth are found.

Like the Frigg and Frøy fields, history at Heimdal does not reveal any discharges that can explain the rise in sediment metal concentration since 1997. Also at Heimdal the proportion of pelite in sediments at both the reference and the field stations has increased with 3 to 5%. However, lead is the only metal that reveals increased sediment levels at the reference station.

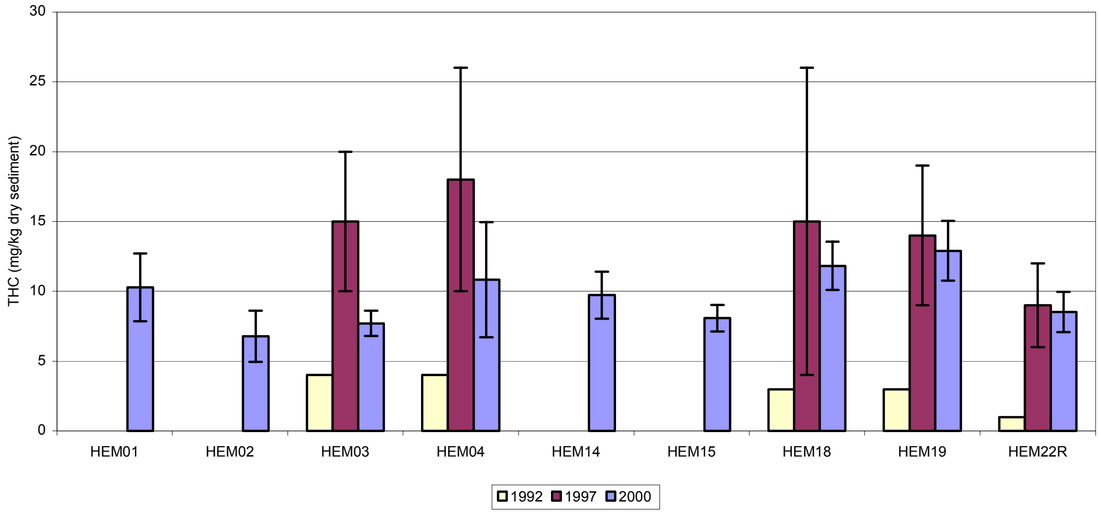

Figure 16-3: THC levels in sediment from the present (2000) and previous surveys, Heimdal field.

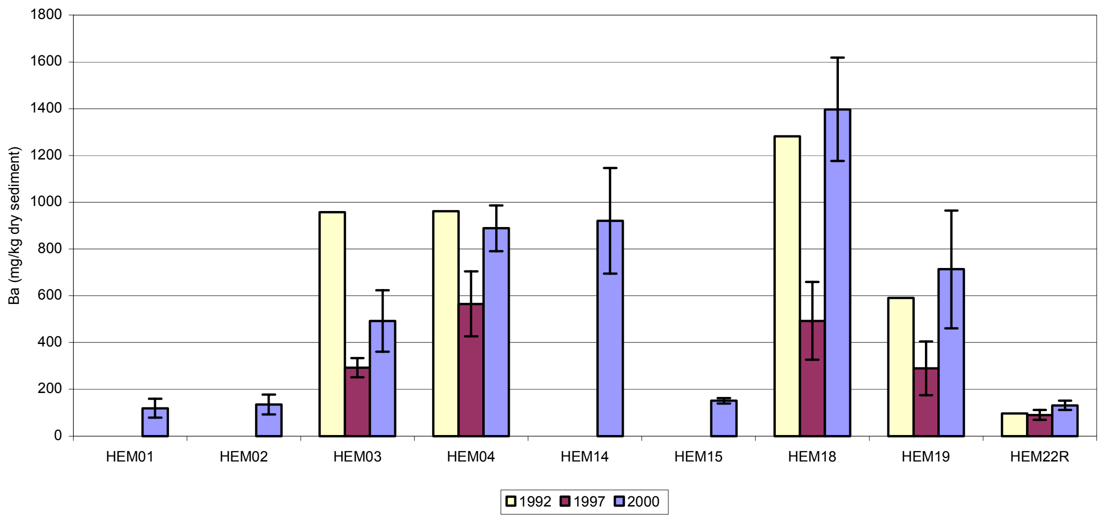

Figure 16-4: Barium levels in sediment from the present (2000) and previous survey, Heimdal field.

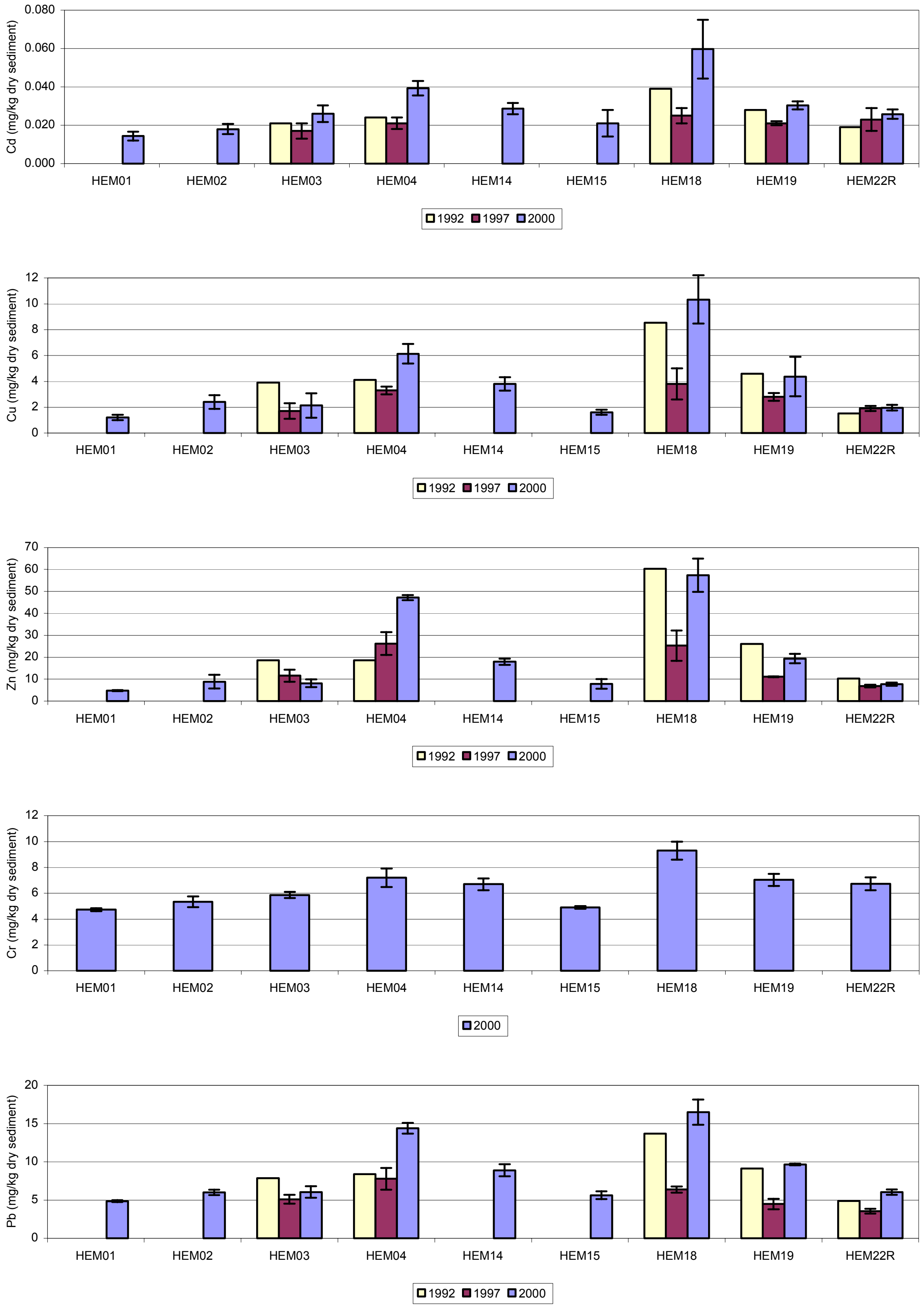

Figure 16-5: Levels of selected metals in sediments from the present (2000) and previous surveys, Heimdal field.

16.2.3 Biology

The distribution of individuals and taxa within the main taxonomic groups are given in Table 16-8. A total of 11086 individuals within 238 taxa were recorded at the Heimdal field in the present survey (excluding juveniles). The polychaetes dominate the fauna with 66 % of the individuals and 50 % of the taxa recorded.

Table 16-8: Distribution of individuals and taxa within the main taxonomic groups at Heimdal, 2000 (excluding juveniles).

Main taxonomic groups	Individuals		Taxa	
	Number	%	Number	%
Polychaeta	7267	66	118	50
Mollusca	1745	16	44	18
Crustacea	524	5	53	22
Echinodermata	452	4	10	4
Diverse groups	1098	10	13	5
Total	11086	100	238	100

The species/area curve for the field reference station is shown in Figure 16-6. A total of 150 taxa are recorded in the ten grab samples, of which 56 (37 %) occur in the first sample and 119 (79 %) occur in the first five samples. The shape of the curve indicates that most of the taxa in the area are present in the ten grab samples and the representativity of five samples seems to be relatively good

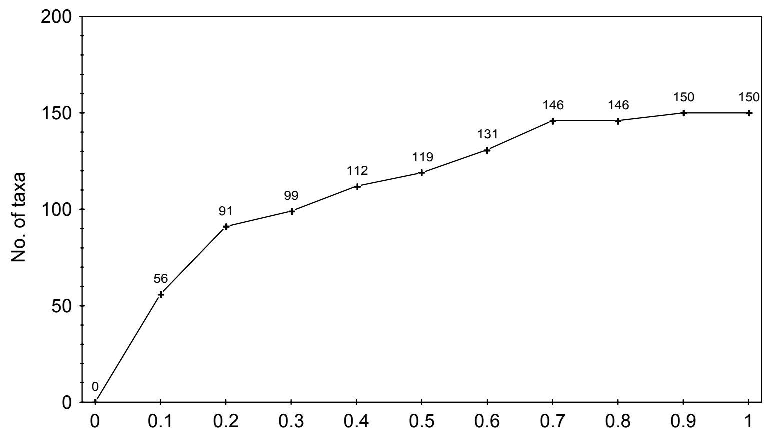

Figure 16-6: Species/area curve for the reference station at the Heimdal field (area in m^2).

The number of individuals and taxa at each station, together with selected community indices are presented in Table 16-9. The number of individuals recorded at Heimdal varies from 715 (HEM19) to 1607 (HEM01). The number of taxa varies from 87 (HEM15) to 129 (HEM04), the diversity index H' between 4.3 (HEM01, HEM15) to 5.5 (HEM18), the evenness index J from 0.61 (HEM01) to 0.79 (HEM18) and the ES_{100} from 32 (HEM01, HEM15) to 42 (HEM18). The corresponding values at the reference station HEM22R are within the variation at the field stations.

The number of taxa and individuals has decreased at most of the stations since the previous survey. This has resulted in a drop of the diversity index.

Table 16-9: Number of individuals and taxa and selected community indices for each station (0.5 m^2) at the Heimdal field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	No. of ind.	No. of taxa	H'	J	ES_{100}
HEM01	**1607**	121	**4.3**	**0.61**	**32**
HEM02	1145	115	4.5	0.65	33
HEM03	1529	126	4.8	0.69	36
HEM04	1398	**129**	5.3	0.75	40
HEM14	1435	108	4.8	0.70	34
HEM15	854	**87**	**4.3**	0.66	**32**
HEM18	1371	126	**5.5**	**0.79**	**42**
HEM19	**715**	105	5.1	0.76	39
HEM22R	1032	119	5.6	0.81	44
Sum *	10054				
Average *	1257	115	4.8	0.70	36
St. dev. *	323	14	0.5	0.06	4

* Excluding the reference station.

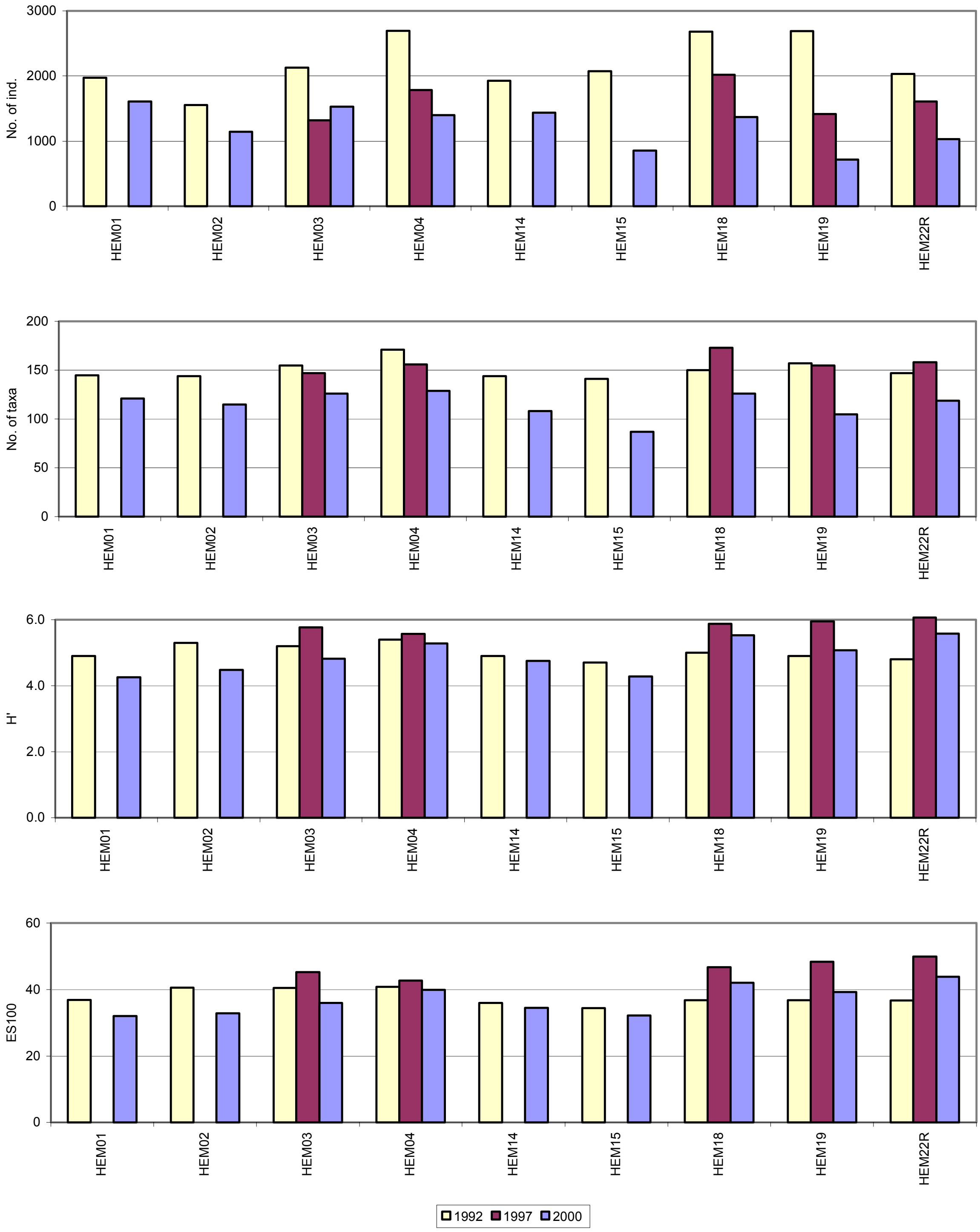

Table 16-10: Biological characteristics at the Heimdal field, 2000 and previous surveys.

The distribution of taxa in geometrical classes is shown in Figure 16-7. Station HEM01 has taxa in class 10 (512 – 1023 individuals), four stations have taxa in class 9 (356 – 511 individuals) while the remaining stations have taxa in class 8 or lower (< 256 individuals). The occurrence of taxa in high classes might indicate disturbed fauna.

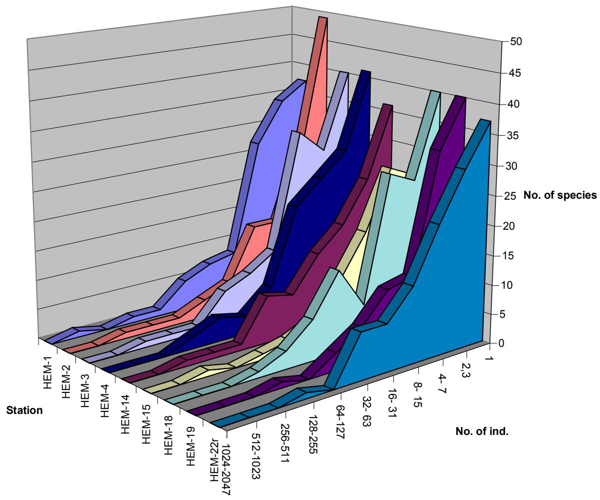

Figure 16-7: Distribution of taxa in geometrical classes for the stations at Heimdal, 2000.

The ten most dominant taxa at each station are shown in Table 16-13 at the end of this chapter. A total of 22 taxa, including three juvenile groups, are among the ten most dominant taxa at one or more stations. These 22 taxa comprise 75 % of the total number of individuals and 9 % of the total number of taxa registered at the Heimdal field in the present survey.

The polychaete *Spiophanes bombyx* is the most dominant taxa at all but the reference station HEM22R. Other dominant taxa are the polychaete *Galathowenia oculata*, the phoronid *Phoronis* sp. and the bivalve *Thyasira croulinensis*. The polychaete Chaetozone sp. and the bivalve Thyasira flexuosa are among the most dominant taxa at five and four stations, respectively. These two taxa are known to be abundant in disturbed sediments, which might indicate some faunal disturbance at the field.

The ten most abundant taxa at the stations comprise between 48 % (station HEM18) and 71 % (station HEM01) of the total number of individuals registered at the respective station. The corresponding value at the reference station HEM22R is 48 %.

Figure 16-8 shows the dendrogram from the cluster analysis for the Heimdal field stations and the regional and reference stations in Region II while Figure 16-9 shows the 2-D plot from the MDS analysis from the field stations and selected regional and reference stations.

In the cluster analysis all regional and reference stations, including the field reference station HEM22R, are separated from the field stations at dissimilarity level between 70 and 38 %. The field stations are further separated into pair of groups at dissimilarity levels between 35 and 36 %. The Product Moment correlation coefficient used to test the goodness of fit of the analytical outcome to the Bray-Curtis data matrices showed a very good fit to the data (r = 0.93).

The 2-D MDS plot supports the results from the cluster analysis of the station data in separating the field stations from the regional and reference stations with station HEM19 and HEM15 farthest away. The stress test shows a fair to poor fit to the data (0.33).

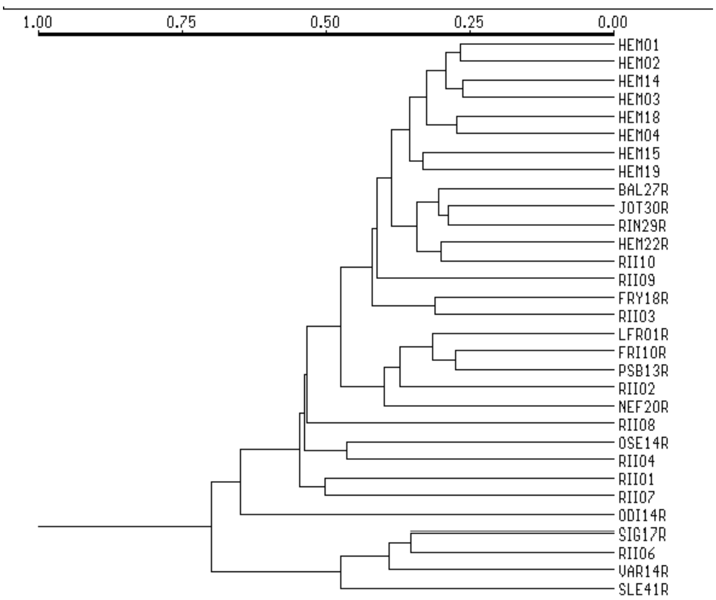

Figure 16-8: Cluster analysis of the Heimdal field stations and the regional and reference stations in Region II, 2000.

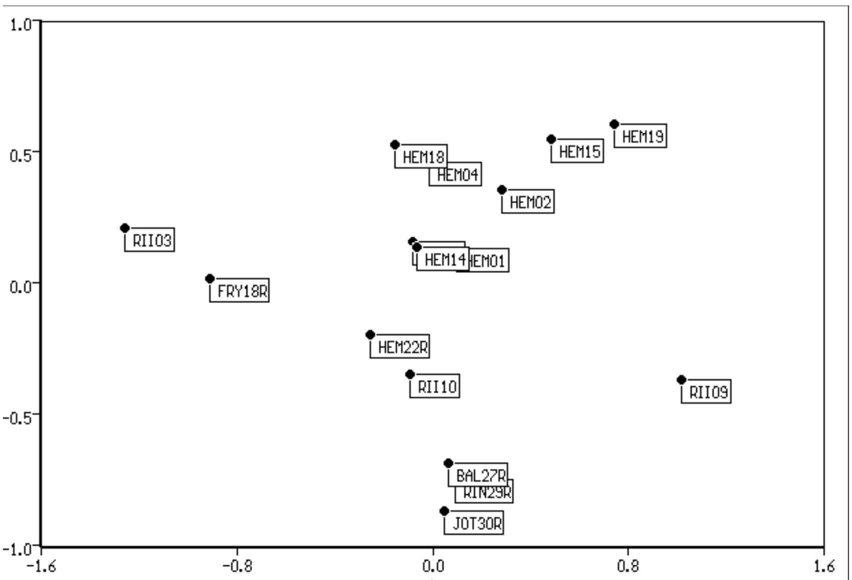

Figure 16-9: 2-D plot from the MDS analysis carried out on the Heimdal field stations and selected regional and reference stations in Region II, 2000.

A Canonical Correspondence Analysis (CCA) of the data from the Heimdal field stations and selected regional and reference stations was carried out to examine the association between the biological data and the measured environmental variables in these areas. The analysis was carried out excluding the data from other regional and reference stations due to the differences revealed in the cluster analysis for the whole region.

Through the forward selection procedure in CANOCO, four of ten variables gave the best fit and were significant. 33.6 % of the biological variance was explained by the first two axes of the ordination space which is constrained by these environmental variables.

Figure 16-10 shows a biplot from the analysis using cadmium (Cd), chromium (Cr), THC and pelite (Pel) as the constraining environmental variables. The first axis shows a gradient from the Frøy reference station FRY18R on the positive end to the Ringhorne reference station RIN29R on the negative end and is negatively correlated with the amount of pelite (-0.61) and chromium (- 0.58) in the sediments. The taxa with the highest contribution on this axis are the polychaetes *Paramphinome jeffreysii* (10.6 %), *Galathowenia oculata* (9.1 %) and *Myriochele fragilis* (7.1 %), the cumacean *Eudorella emarginata* (7.9 %) and the bivalve *Thyasira equalis* (6.9 %).

The second axis shows a gradient from the Jotun reference station JOT30R on the positive end to field station HEM19 at the negative end and is negatively correlated with the amount of THC in the sediments. The taxa with highest contribution on this axis are the polychaetes *Spiophanes bombyx* (15.4 %), *Chaetozone* sp. (15.4 %) and *Galathowenia oculata* (7.1 %) and the bivalve *Thyasira flexuosa* (5.5 %). *Chaetozone* sp. and *T. flexuosa*, known to increase in abundance in disturbed sediments, are associated with the stations located on the negative end of this axis, indicating a disturbance gradient from the negative to the positive end of the second axis.

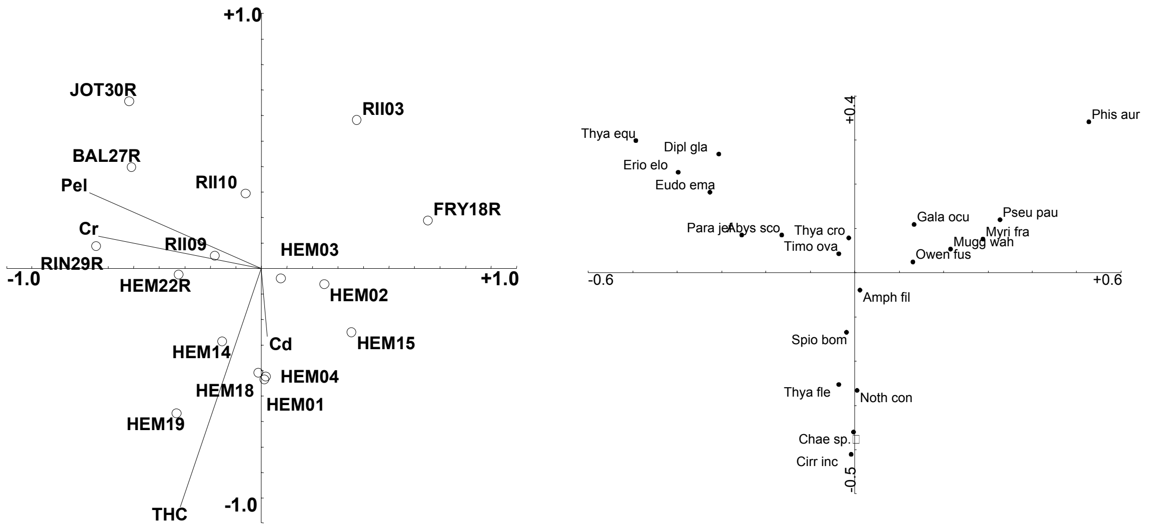

Figure 16-10: Biplot from the CCA analysis for the Heimdal field stations and selected regional and reference stations in Region II, 2000 (left) and taxa with high contribution on two axes (right).

On the basis of the results from the uni- and multivariate analyses the stations at Heimdal field are classified into two faunal groups (see Table 16-11). Stations HEM04, HEM18 and HEM19 are placed in group B (slightly disturbed fauna) while the remaining field stations are placed in group A (undisturbed fauna). The stations in group B have relatively high abundance of the polychaete *Chaetozone* sp and the bivalve *Thyasira flexuosa*, both known to increase in individual numbers in disturbed sediments.

In the previous survey in 1997, station HEM03 was classified as group C station (disturbed fauna) due to a relative high abundance of the polychaete Capitella capitata. This species is scarcely registered at the field in the present survey. The intensity in faunal disturbance, therefore, has decreased since 1997.

Table 16-11: Classification into impact groups, distance to installation and biological statistics for the field stations at Heimdal field, 2000.

Station.	Impact group	Dist. (m)	Statistics			No. of individuals								
			No. ind	No. taxa	H'	Sbo	Goc	Psp	Tcr	Skr	Afi	Tfl	Csp	Cin
HEM01	A	1000	1607	121	4.3	632	153	96	12	47	20	6	21	0
HEM02	A	500	1145	115	4.5	344	122	136	5	32	20	31	26	0
HEM03	A	300	1529	126	4.8	393	198	60	111	49	23	10	20	0
HEM04	B	250	1398	129	5.3	206	73	70	34	30	47	77	179	2
HEM14	A	250	1435	108	4.8	334	213	55	82	38	33	20	36	0
HEM15	A	500	854	87	4.3	299	12	108	40	14	38	8	20	0
HEM18	B	300	1371	126	5.5	157	108	90	51	31	24	46	92	17
HEM19	B	500	715	105	5.1	155	23	45	8	6	22	56	59	0
HEM22R	A	10000	1032	119	5.6	46	61	58	143	32	41	15	0	0
RII03	A	-	1523	127	4,7	54	520	0	96	50	0	0	0	0
RII09	A	-	1221	118	5,2	103	176	49	0	0	115	40	0	0
RII10	A	-	1200	128	5,4	106	142	44	102	0	0	0	0	0
FRY18R	A	-	2289	149	5.4	111	400	90	101	0	0	0	0	0
RIN29R	A	-	1073	118	5,4	151	49	0	30	29	0	0	0	0
BAL27R	A	-	1073	118	5,4	94	59	147	49	0	0	0	0	0
JOT30R	A	-	1221	117	5,2	191	55	49	46	39	0	0	0	0

Sbo = *Spiophanes bombyx,* Goc = *Galatowenia oculata,* Psp = *Phoronis* sp, Tcr = *Thyasira crouliensis*, Skr = *Spiophanes kroyeri,* Afi = *Amphiura filiformis*, Tfl = *Thyasira flexuosa*, Csp = *Chaetozone sp* (incl. *C. setosa*), Cin = *Cirratulus incertus.*

16.3 Summary and conclusions

The sediments at the Heimdal field are classified as fine sand and silt with a relatively high amount of pelite in the sediment (8 – 14 %). The pelite content has its largest increase since 1997 at field station HEM03 and HEM18 and at the reference station HEM22R. It is also registered a relatively high increase in the TOM at field station HEM18 (from 1.3 to 1.9 %) since the previous survey.

In this survey sediments out to 500 m in the 180° direction have elevated levels of total hydrocarbons. The highest concentration of total hydrocarbons in the field was found in sediments from the station situated 500 m at 180° with 12.9 mg/kg dry sediment. In addition to the position mentioned above contamination were found out to 500 m at 180°, 250 m at 324° and 300 m at 150° in 1997. In 2000 borderline values are found in sediments from these stations. Gas Chromatograms of sediment extracts from Heimdal do not reveal mineral oil profiles. This is in accordance with field history that includes an acute spill of 0.06 m^3 oil in 1999. This is the only discharge in the Heimdal field the last four years. In sum the hydrocarbon levels are lower in sediments at Heimdal in this survey than they were in 1997.

Elevated levels of barium are found at the stations situated 300 m at 100°, 250 m at 315° and out to 500 m at 180°, with 60- to 185% increase in sediment concentrations compared to the situation in 1997. Contamination and increased levels of zinc, lead and copper are also found in sediments from these stations minus the one situated 300 m in the 100° direction. Cadmium is increasing and contaminates sediments 250m at 180° and 300 m at 315°. Mercury levels are unchanged. Minor increases in sediment metal concentrations with depth are found.

Like the Frigg and Frøy fields, history at Heimdal does not reveal any discharges that can explain the rise in sediment metal concentration since 1997. At Heimdal, like the fields mentioned above, higher proportions of pelite are found in sediments in 2000 than in 1997. However, the increases are not dramatic and metal levels at the reference station are relatively unaffected.

The number of individuals and taxa has decreased at most of the stations since the previous surveys. On the basis of the results from the uni- and multivariate analyses the stations at Heimdal field are classified into two faunal groups. Stations HEM04, HEM18 and HEM19 are placed in group B (slightly disturbed fauna) while the remaining field stations are placed in group A (undisturbed fauna). The stations in group B have relatively high abundance of the polychaete *Chaetozone* sp and the bivalve *Thyasira flexuosa*, both known to increase in individual numbers in disturbed sediments.

In the previous survey in 1997, station HEM03 was classified as group C station (disturbed fauna) due to a relative high abundance of the polychaete Capitella capitata. This species is scarcely registered at the field in the present survey. The intensity in faunal disturbance, therefore, has decreased since 1997.

The calculated minimum area and spatial extent of contaminated sediments and disturbed fauna at the Heimdal field is shown in Table 16-12 and Figure 16-11.

Table 16-12: Distance along the transects and calculated minimum area of contaminated sediments and disturbed fauna at the Heimdal field, 2000 and previous survey.

Heimdal	NE	SE	S	NW	Km^2 (2000)	Km^2 (1997)
Group B	125	125	500	250	0.18	0.11
Group C	0	0	0	0	0	0.07
THC	125	125	500	125	0.12	0.25
Ba	500	300	500	250	0.43	0.25
Other metals	500	125	500	250	0.29	0.25

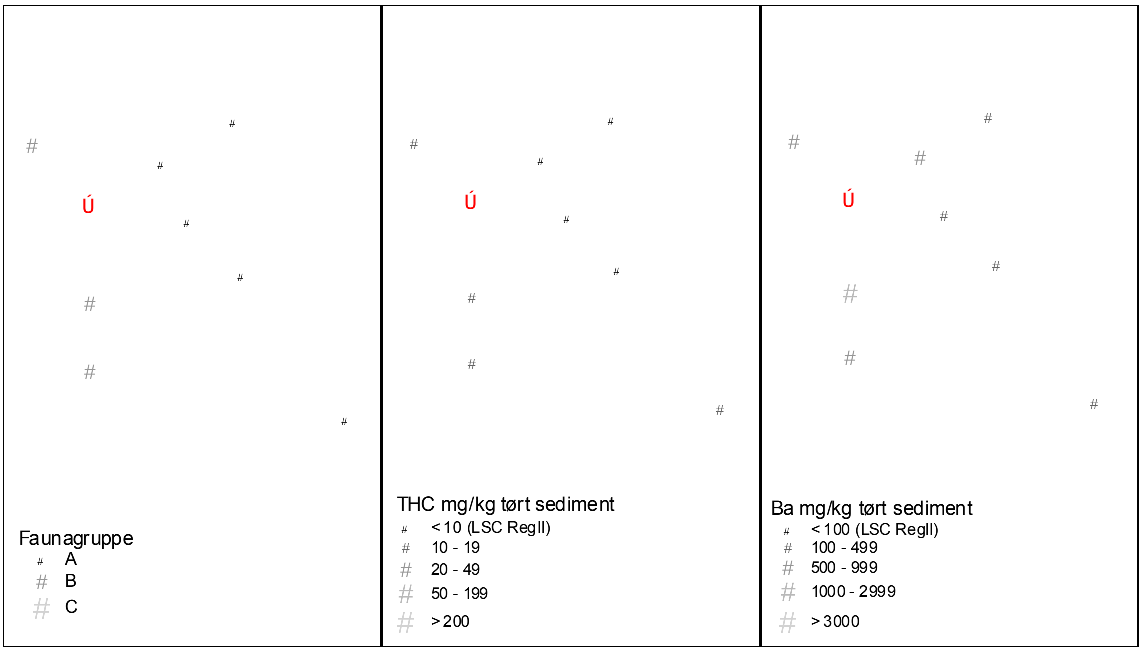

Figure 16-11: Distribution of disturbed fauna and the amounts of THC and barium in the sediments at the Heimdal field, 2000.

Table 16-13: Number of individuals and the accumulative abundance for the ten predominant taxa at each station at the Heimdal field, 2000.

HEM01 (130°/1000 m)	No. ind.	Acc. %	HEM02 (115°/500 m)	No. ind.	Acc. %	HEM03 (100°/300 m)	No. ind.	Acc. %	HEM04 (315°/250 m)	No. ind.	Acc. %	HEM14 (60°/250 m)	No. ind.	Acc. %
Spiophanes bombyx	632	35	Spiophanes bombyx	344	27	Spiophanes bombyx	393	22	Spiophanes bombyx	206	14	Spiophanes bombyx	334	21
Galathowenia oculata	153	44	Phoronis sp.	136	38	Galathowenia oculata	198	33	Chaetozone sp.	179	25	Galathowenia oculata	213	35
Pectinaria sp. juv.	136	51	Galathowenia oculata	122	47	Pectinaria sp. juv.	165	43	Paramphinome jeffreysii	78	30	Thyasira croulinensis	82	40
Phoronis sp.	96	57	Pectinaria sp. juv.	67	53	Thyasira croulinensis	111	49	Thyasira flexuosa	77	36	Pectinaria sp. juv.	76	45
Spiophanes kroyeri	47	59	Timoclea ovata	43	56	Phoronis sp.	60	52	Galathowenia oculata	73	40	Myriochele fragilis	58	48
Timoclea ovata	47	62	Lanice conchilega	37	59	Thyasira ferruginea	52	55	Phoronis sp.	70	45	Phoronis sp.	55	52
Mugga wahrbergi	43	64	Spiophanes kroyeri	32	61	Spiophanes kroyeri	49	58	Ophiuroidea indet. juv.	49	48	Thyasira ferruginea	48	55
Nemertini indet.	43	67	Ophiuroidea indet. juv.	31	64	Lanice conchilega	47	61	Amphiura filiformis	47	51	Ophiuroidea indet. juv.	42	58
Prionospio cirrifera	35	69	Thyasira flexuosa	31	66	Myriochele fragilis	44	63	Pectinaria sp. juv.	43	54	Paramphinome jeffreysii	42	60
Paramphinome jeffreysii	31	71	Chaetozone sp.	26	68	Ophiuroidea indet. juv.	43	66	Thyasira croulinensis	34	56	Lanice conchilega	38	63
												Spiophanes kroyeri	38	65

HEM15 (60°/500 m)	No. ind.	Acc. %	HEM18 (180°/300 m)	No. ind.	Acc. %	HEM19 (180°/500 m)	No. ind.	Acc. %	HEM22R (360°/10000 m)	No. ind.	Acc. %
Spiophanes bombyx	299	32	Spiophanes bombyx	157	10	Spiophanes bombyx	155	19	Thyasira croulinensis	143	13
Phoronis sp.	108	44	Galathowenia oculata	108	17	Chaetozone sp.	59	27	Galathowenia oculata	61	18
Thyasira croulinensis	40	48	Chaetozone sp.	92	23	Thyasira flexuosa	56	34	Phoronis sp.	58	24
Amphiura filiformis	38	52	Phoronis sp.	90	29	Phoronis sp.	45	40	Ophiuroidea indet. juv.	48	28
Lanice conchilega	31	56	Ophiuroidea indet. juv.	66	33	Pectinaria sp. juv.	39	44	Spiophanes bombyx	46	32
Pectinaria sp. juv.	29	59	Cerianthus lloydi juv.	51	36	Galathowenia oculata	23	47	Amphiura filiformis	41	36
Ophiuroidea indet. juv.	26	62	Thyasira croulinensis	51	40	Amphiura filiformis	22	50	Timoclea ovata	38	39
Thyasira ferruginea	23	64	Thyasira flexuosa	46	43	Eudorella emarginata	22	53	Laonice sarsi	36	42
Chaetozone sp.	20	66	Nothria conchylega	45	45	Cerianthus lloydi juv.	20	55	Paramphinome jeffreysii	35	46
Paramphinome jeffreysii	18	68	Paramphinome jeffreysii	45	48	Ophiuroidea indet. juv.	20	58	Spiophanes kroyeri	32	48

Table 16-14: Station information for Heimdal field, 2000.

St. no.	Distance (m)	Direction (degr.)	Volume (litres)
HEM01	1000	130	28
HEM02	500	115	31
HEM03	300	100	35
HEM04	250	315	35
HEM14	250	60	33
HEM15	500	60	30
HEM18	300	180	44
HEM19	500	180	31
HEM22R	10000	360	38 *

* The additional five grab samples taken gave 30 litres of sediment.

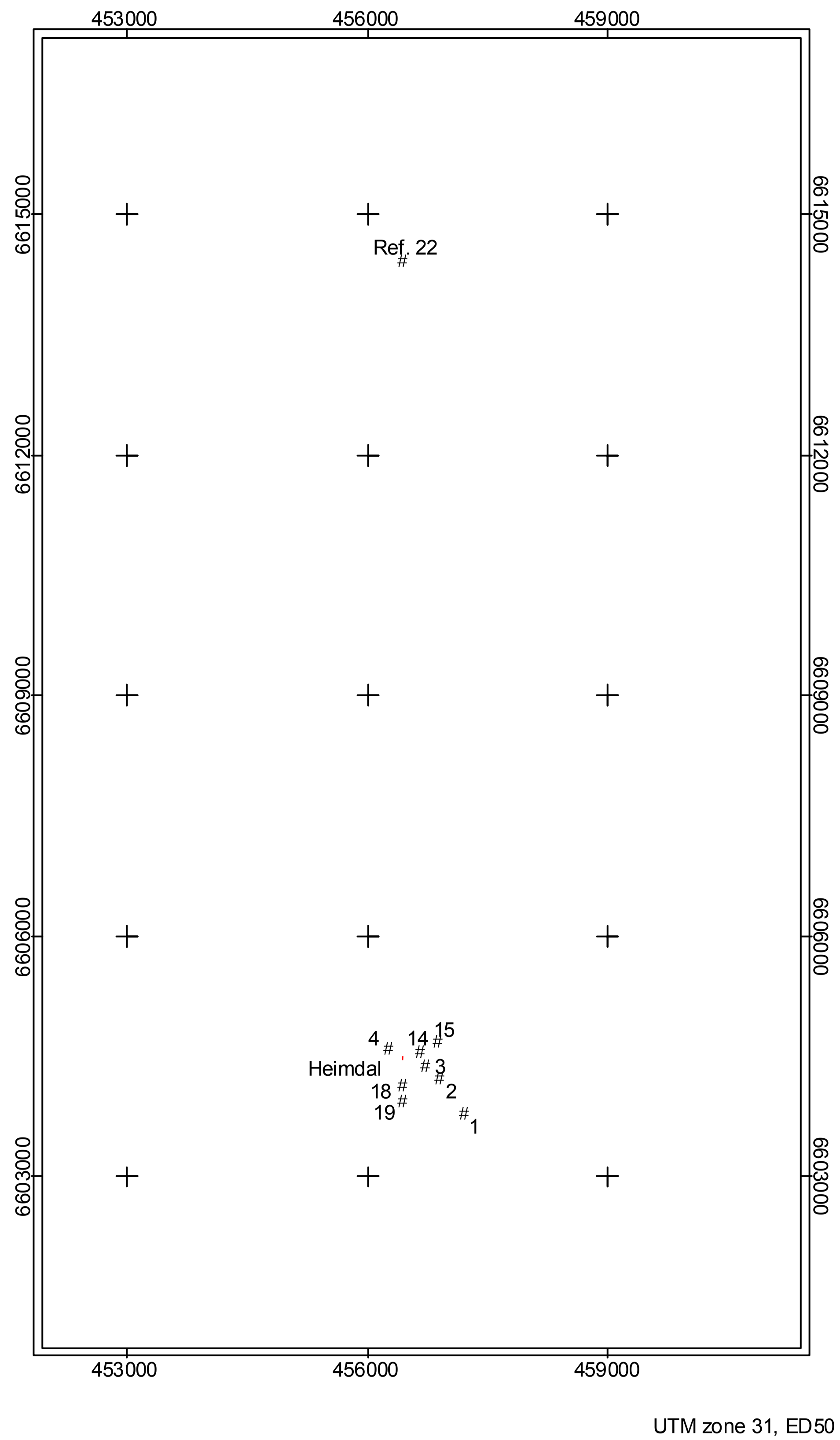

Figure 16-12: Map of sampling positions for Heimdal field, 2000.

17 Glitne field

17.1 Introduction

The Glitne field is located in Block 15-5 in the southern part of Region II, situated north of the Sleipner Vest field. There has been no activity on the field yet.

This survey is the baseline survey for the Glitne field. The sampling plan in 2000 does not include a separate reference station for the field. Instead, the regional station RII08 was used as the reference station. Information on the sampling stations is shown in Figure 17-12 and Table 17-11, both on the foldout page at the end of this chapter (page 17-19).

17.2 Results and discussion

17.2.1 Physical characteristics

The median phi value and the amount (%) of pelite, fine sand and total organic material (TOM) in the sediment from the present and previous surveys shown in Table 17-1 and Figure 17-1. 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 in the area are classified as fine sand with median values varying from 3.52 (GLI12) to 3.90 (GLI13). The amount of pelite in the sediment varies from 7.8 % (GLI03) to 13.1 % (GLI13), the fine sand from 68.7 % (GLI15) to 80.3 % (GLI08) while the TOM varies from 1.30 % (GLI03) to 2.08 % (GLI16). The values of pelite and TOM at the reference station RII08 are within the variations at the field stations, while the fine sand is higher at the reference station.

Table 17-1: The median (phi) and amount of pelite, fine sand and TOM in the sediment from stations at the Glitne field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	Distance (m)	Direction (degr.)	Median	Classification	Pelite	Fine sand	TOM
GLI01	250	10	3.61	Fine sand	9.2	75.5	1.41
GLI02	500	10	3.65	Fine sand	11.2	76.4	1.60
GLI03	1000	10	3.57	Fine sand	**7.8**	76.9	**1.30**
GLI04	2000	10	3.62	Fine sand	9.9	77.2	1.59
GLI05	250	100	3.73	Fine sand	12.0	77.4	1.55
GLI06	500	100	3.76	Fine sand	12.1	78.4	1.81
GLI07	1000	100	3.71	Fine sand	12.7	79.3	1.85
GLI08	2000	100	3.73	Fine sand	13.2	**80.3**	1.99
GLI09	250	280	3.79	Fine sand	8.1	75.2	1.56
GLI10	500	280	3.68	Fine sand	11.7	74.4	1.86
GLI11	1000	280	3.79	Fine sand	9.9	70.0	1.61
GLI12	2000	280	**3.52**	Fine sand	8.7	69.2	1.50
GLI13	250	190	**3.90**	Fine sand	**13.1**	71.8	1.54
GLI14	500	190	3.66	Fine sand	12.3	73.2	1.74
GLI15	1000	190	3.84	Fine sand	11.8	**68.7**	1.81
GLI16	2000	190	3.67	Fine sand	12.3	74.1	**2.08**
RII08	5261	19	3.68	Fine sand	11.45	80.9	1.92
Average *			3.70		11.00	74.9	1.67
St. dev. *			0.10		1.8	3.5	0.21

*Excluding the regional station

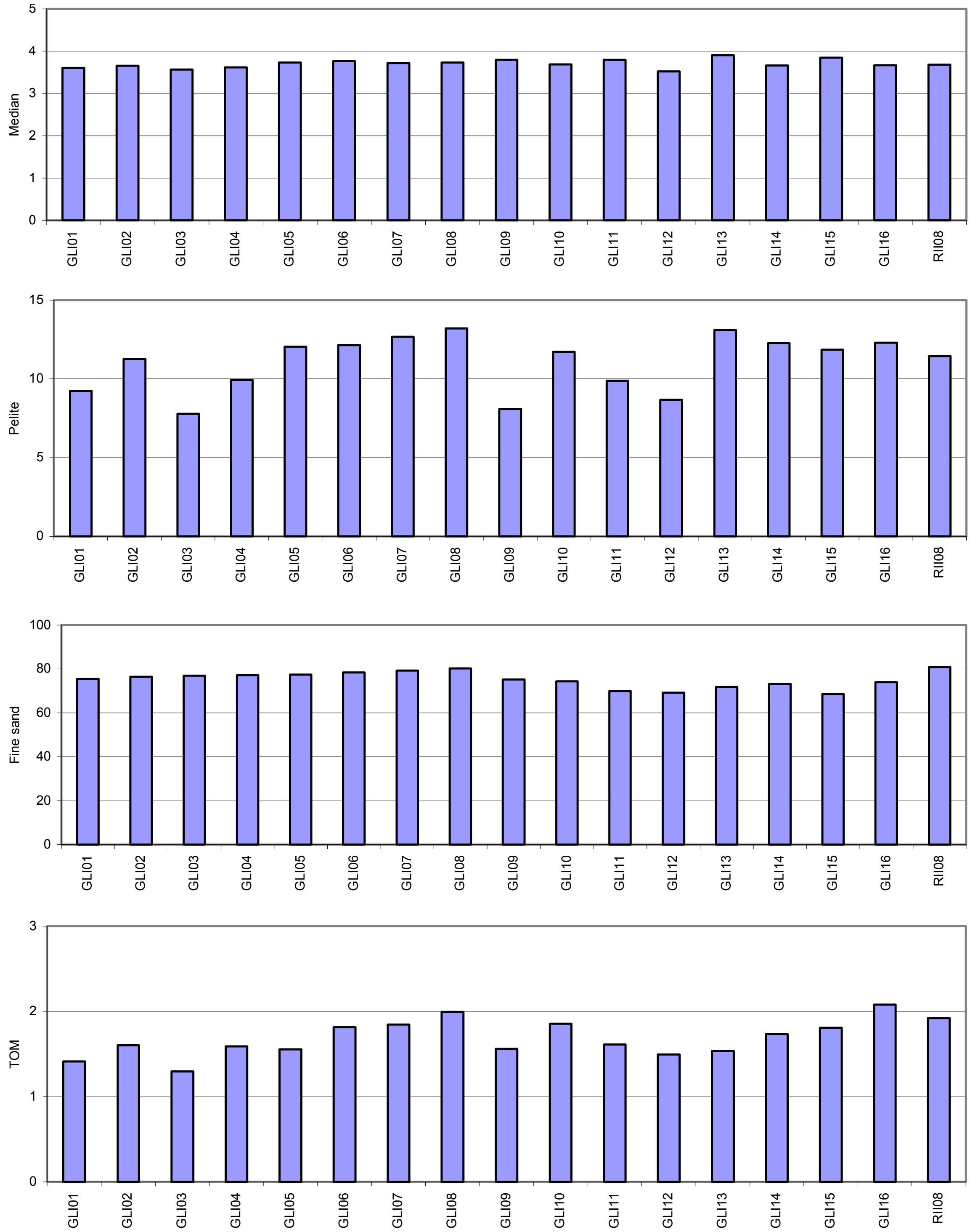

Figure 17-1: Sediment characteristics at the Glitne field, 2000.

17.2.2 Chemical characteristics

The calculated limits of significant contamination for selected hydrocarbons and metals in sediments from Region II ($LSC_{97\text{-}00\ RegII}$) are presented previously in the chapter that deals with the regional and reference stations. In addition to the Regional limits, field-specific limits of significant contamination are calculated from the reference station ($LSC_{00\ RII08/GLI}$). Both sets of data are presented in Table 17-2. Generally, Glitne has somewhat higher levels of THC and metals than most of the other fields in Region II (see Regional and reference stations). The limits of significant contamination based on sediments from the reference station are therefore correspondingly higher than the limits calculated for the whole region. Based on the analysis results of the Glitne field, both LSCs are used as a basis by which to assign areas contaminate with the chemical parameters.The results of analyses of the hydrocarbons are summarised in Table 17-3. Concentrations of the selected compounds in the vertical sediment sections are presented in Table 17-4. The full data set of replicate measurements is given in the Appendix. THC values from 2000 are presented as histogram in Figure 17-3.

Table 17-2: Background levels and Limits of Significant Contamination for the Glitne field, 2000. All values in mg/kg dry sediment.

	THC	NPD's	3-6 ring	Decalins	Cd	Hg	Cu	Zn	Ba	Cr	Pb
$LSC_{00\ RII08/GLI}$	13.5	0.033	0.079	0.026	0.020	0.010	2.0	12.2	286	10.2	8.2
$LSC_{97\text{-}00\ RegII}$	9.8	*	*	*	0.029	0.008	2.0	8.9	146	9.6	7.0

*) Regional stations not analysed for NPD's, 3-6 ring aromatics and decalins.

Table 17-3: Concentrations of hydrocarbons in sediments from the Glitne field, 2000. All values in mg/kg dry sediment Values above $LSC_{00\ RII08/GLI}$ are dark shaded and values between $LSC_{00\ RII08/GLI}$ and $LSC_{97\text{-}00\ RegII}$ are light shaded.

Station	THC		NPD's		3-6 ring		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
GLI01	8.6	1.1	0.024	0.003	0.052	0.005	0.027	0.005
GLI02	9.6	0.4	n.a.		n.a.		n.a.	
GLI03	6.9	2.8	n.a.		n.a.		n.a.	
GLI04	10.0	2.0	0.028	0.004	0.062	0.007	0.041	0.008
GLI05	6.8	1.7	n.a.		n.a.		n.a.	
GLI06	8.6	0.5	n.a.		n.a.		n.a.	
GLI07	8.7	0.2	n.a.		n.a.		n.a.	
GLI08	8.4	1.8	n.a.		n.a.		n.a.	
GLI09	9.6	2.4	n.a.		n.a.		n.a.	
GLI10	9.1	0.9	n.a.		n.a.		n.a.	
GLI11	9.9	1.1	n.a.		n.a.		n.a.	
GLI12	7.0	0.7	n.a.		n.a.		n.a.	
GLI13	9.7	0.2	n.a.		n.a.		n.a.	
GLI14	7.6	2.0	n.a.		n.a.		n.a.	
GLI15	9.2	1.4	n.a.		n.a.		n.a.	
GLI16	7.5	1.7	n.a.		n.a.		n.a.	
RII08/GLI	8.9	2.0	0.024	0.004	0.057	0.009	0.014	0.005
Mean*	8.6	1.7	-		-		-	

n.a. Not analysed.
* Excl. reference station.

Table 17-4: Concentrations of hydrocarbons in vertical sections of the sediment samples from the Glitne field, 2000. All concentrations in mg/kg dry sediment. Values above $LSC_{00\ RII08/GLI}$ are dark shaded and values between $LSC_{00\ RII08/GLI}$ and $LSC_{97\text{-}00\ RegII}$ are light shaded.

Station	Layer (cm)	THC	NPD's	3-6 ring	Decalins
GLI01	0-1	7.3	0.020	0.049	0.022
	1-3	8.8	0.048	0.125	0.026
	3-6	8.1	0.048	0.137	0.033
GLI04	0-1	12.3	0.028	0.066	0.035
	1-3	13.3	0.042	0.096	0.061
	3-6	7.4	0.044	0.116	0.078
RII08/GLI	0-1	8.1	0.027	0.065	0.012
	1-3	11.3	0.049	0.113	0.046
	3-6	9.1	0.048	0.159	0.036

n.a. Not analysed.

The THC values range from 6.8 ± 1.7 to 10.0 ± 2.0 mg/kg dry sediment (Table 17-3). According to the calculated $LSC_{97-00\ RegII}$ elevated level of THC are found at one station, GLI04. This station has elevated THC down to 3 cm depth (Table 17-4.) The gas chromatogram profiles of the sediment extracts from GLI04 does not indicate the presence of mineral oil, nor olefins (Figure 17-2,) which are not degenerated during the standard work-up procedure for hydrocarbons and are visible in the gas chromatograms of sediment extracts by a characteristic profile. According to the data on drilling or discharges there has been no activity at this field. By using the calculated $LSC_{00\ RII08/GLI}$ GLI04 is regarded as uncontaminated with THC. In the sectioned sediment samples, the highest contents of aromatics are found in the 1-3 and 3-6 cm layers, but the levels are comparable to the amounts found down in the core from the reference station.

The hydrocarbons are very evenly distributed over the Glitne field. The THC levels vary from values below to values barely above the level at the field-specific reference station. The sediments contain 7–10 mg/kg THC, which is comparable to the amounts (5–11 mg/kg) generally found at the Ringhorne field, situated north east of Glitne, and in uncontaminated sediments at the Sleipner Vest field, located south of Glitne. The sediments at the Glitne field are regarded as uncontaminated with hydrocarbons.

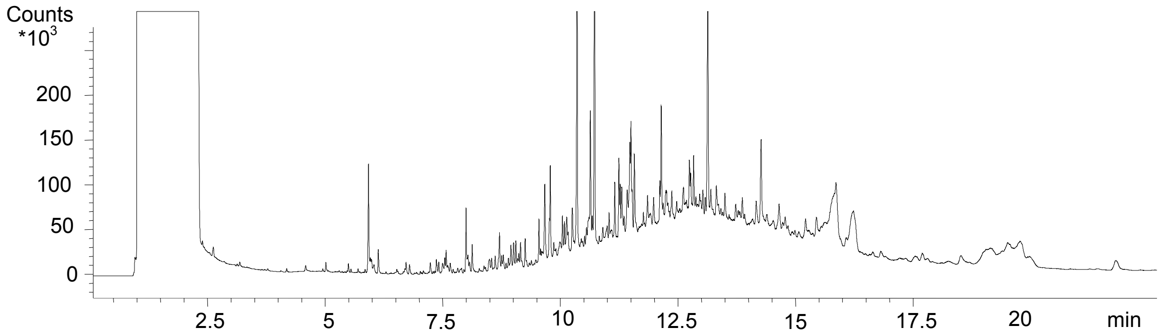

Figure 17-2: Gas chromatogram of a sediment extract from the GLI04, 2000.

The results of the metal analyses for the Glitne field are summarised in Table 17-5. Concentrations of selected metals in the vertical sediment sections are presented in Table 17-6. The full data set of replicate measurements is given in the Appendix. Metal values from 2000 are presented as histograms in Figure 17-4 and Figure 17-5.

Table 17-5: Concentrations of selected metals in sediments from the Glitne field, 2000. All values in mg/kg dry sediment. Values between $LSC_{00\ RII08/GLI}$ and $LSC_{97\text{-}00\ RegII}$ are shaded.

	Cd		Hg		Cu		Zn		Ba		Cr		Pb	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
GLI01	0.014	0.002	0.006	0.002	1.1	0.2	7.7	0.8	185	52	7.9	0.5	6.9	0.6
GLI02	0.016	0.001	n.a.		1.3	0.1	8.3	0.6	206	19	8.3	0.4	7.2	0.3
GLI03	0.013	0.002	n.a.		0.9	0.1	6.6	0.8	144	44	7.3	0.5	6.2	0.6
GLI04	0.016	0.005	0.006	0.001	1.3	0.3	7.9	1.3	183	47	8.0	0.8	6.8	0.9
GLI05	0.017	0.001	n.a.		1.6	0.2	8.7	0.7	220	26	8.4	0.3	7.3	0.3
GLI06	0.020	0.001	n.a.		1.5	0.1	9.8	0.7	226	34	9.1	0.6	7.9	0.5
GLI07	0.020	0.001	n.a.		1.6	0.0	10.0	0.4	238	26	9.0	0.2	7.6	0.2
GLI08	0.020	0.003	n.a.		1.5	0.2	9.5	1.5	228	35	8.8	0.7	7.5	0.4
GLI09	0.016	0.002	n.a.		1.1	0.3	7.5	1.2	187	57	7.9	0.7	6.8	0.6
GLI10	0.021	0.001	n.a.		1.6	0.2	9.8	0.9	253	36	9.3	0.5	8.2	0.3
GLI11	0.019	0.001	n.a.		1.2	0.0	8.4	0.3	244	39	8.3	0.2	7.3	0.1
GLI12	0.016	0.003	n.a.		1.1	0.1	8.0	0.2	189	5	8.5	0.1	6.9	0.1
GLI13	0.018	0.003	n.a.		1.3	0.3	8.8	1.5	235	10	8.7	0.9	7.4	1.0
GLI14	0.022	0.003	n.a.		1.7	0.2	11.0	1.6	272	47	9.6	0.9	8.2	0.5
GLI15	0.019	0.001	n.a.		1.3	0.1	8.7	0.1	215	8	8.4	0.2	7.3	0.1
GLI16	0.020	0.001	n.a.		1.5	0.1	9.4	0.1	219	6	8.6	0.2	7.4	0.3
RII08/GLI	0.014	0.003	0.006	0.002	1.4	0.2	7.4	2.1	215	30	8.4	0.8	6.7	0.6
Mean*	0.018	0.003	0.006	0.001	1.4	0.3	8.7	1.3	215	42	8.5	0.7	7.3	0.7

n.a. Not analysed.
* Excl. reference station.

Table 17-6: Concentrations of selected metals in vertical sections of the sediment samples from the Glitne field. All concentrations in mg/kg dry sediment. Values above $LSC_{00\ RII08/GLI}$ are dark shaded and values between $LSC_{00\ RII08/GLI}$ and $LSC_{97\text{-}00\ RegII}$ are light shaded.

Station	Layer (cm)	Cd	Hg	Cu	Zn	Ba	Cr	Pb
GLI01	0-1	0.014	0.008	1.0	7.8	175	8.0	6.6
	1-3	0.016	0.005	1.0	7.3	141	8.1	6.6
	3-6	0.024	0.008	1.4	9.3	186	8.9	7.3
GLI04	0-1	0.015	0.006	1.2	7.5	161	7.7	6.5
	1-3	0.023	0.005	1.2	8.3	197	8.1	7.1
	3-6	0.027	0.006	1.4	8.5	123	8.3	7.0
RII08/GLI	0-1	0.018	0.009	1.8	10.3	255	9.7	7.8
	1-3	0.020	0.008	1.4	8.8	209	8.8	7.4
	3-6	0.024	0.008	1.6	8.9	157	8.9	6.9

n.a. Not analysed.

The concentrations of barium range from 144 ± 44 to 272 ± 47 mg/kg, cadmium from 0.013 ± 0.002 to 0.022 ± 0.003 mg/kg and copper from 0.9 ± 0.1 to 1.7 ± 0.2 mg/kg. The content of lead range from 6.2 ± 0.6 to 8.2 ± 0.5 mg/kg, zinc from 6.6 ± 0.8 to 11.0 ± 1.6 mg/kg and chromium from 7.3 ± 0.5 to 9.6 ± 0.9 mg/kg dry sediment. According to the calculated $LSC_{97\text{-}00\ RegII}$ elevated levels of zinc, barium and lead are found at several stations (Table 17-5 and Table 17-6), but by using the $LSC_{00\ RII08/GLI}$ none of these stations are contaminated with zinc, barium and lead.

The metals are very evenly distributed over the Glitne field. The metal concentrations vary from values below to values barely above the levels at the field-specific reference station. The sediments at Glitne are regarded as uncontaminated with metals. The amounts of selected metals that are found across Glitne are comparable to the concentrations found in uncontaminated sediments at Sleipner Vest. The only exception is barium, of which the average amount across Glitne (215 mg/kg) is more than twice the concentration (90 mg/kg) found at the Sleipner Vest reference station. The Glitne field is located south west of the Ringhorne field. Generally, the sediments from the Glitne field contains 40-50% less cadmium and copper and twice as much barium as the sediments form the Ringhorne field stations. The concentrations of the remaining of the selected metals are only slightly above the corresponding concentrations found across Ringhorne.

In the 2000 baseline survey of the Glitne field, the THC content at the field-specific reference station (RII08/GLI) is 8.9 ± 2.0 mg/kg dry sediment *i.e.* somewhat higher than the amount found across the Region II (5.9 ± 2.3 mg/kg). The content of NPD´s, 3-6 ring aromatics and decalins are comparable to the corresponding values found at the Sleipner Vest reference station (see Sleipner Vest survey.) The concentrations of cadmium and copper at RII08/GLI are comparable to the corresponding values across Region II (see Regional and reference stations). The barium concentration is three times higher than the content (69 ± 45 mg/kg) across Region II, while the concentrations of zinc, chromium and led are approximately 30-50 % higher than the corresponding concentrations across Region II.

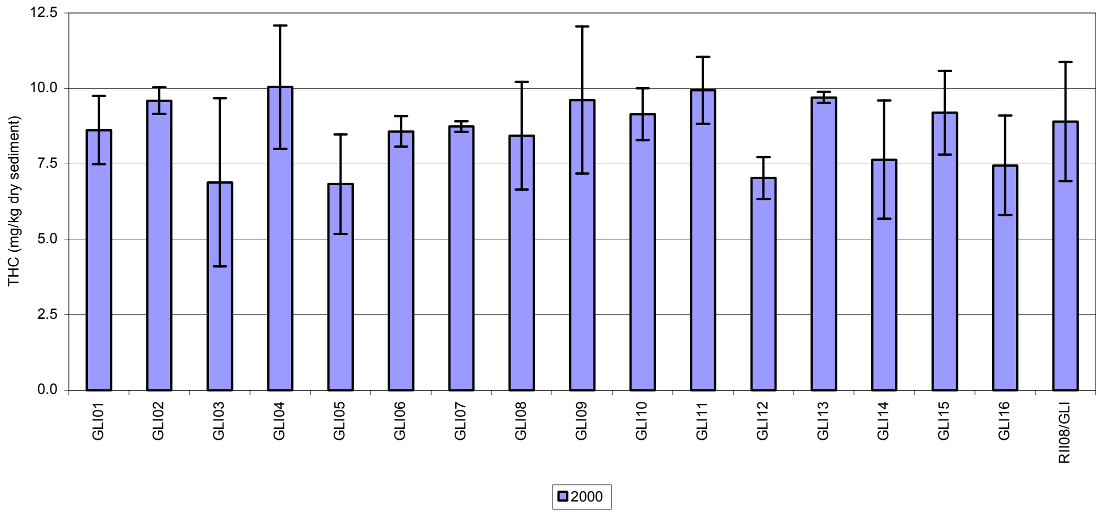

Figure 17-3: THC levels in sediment from the present (2000) survey, Glitne field.

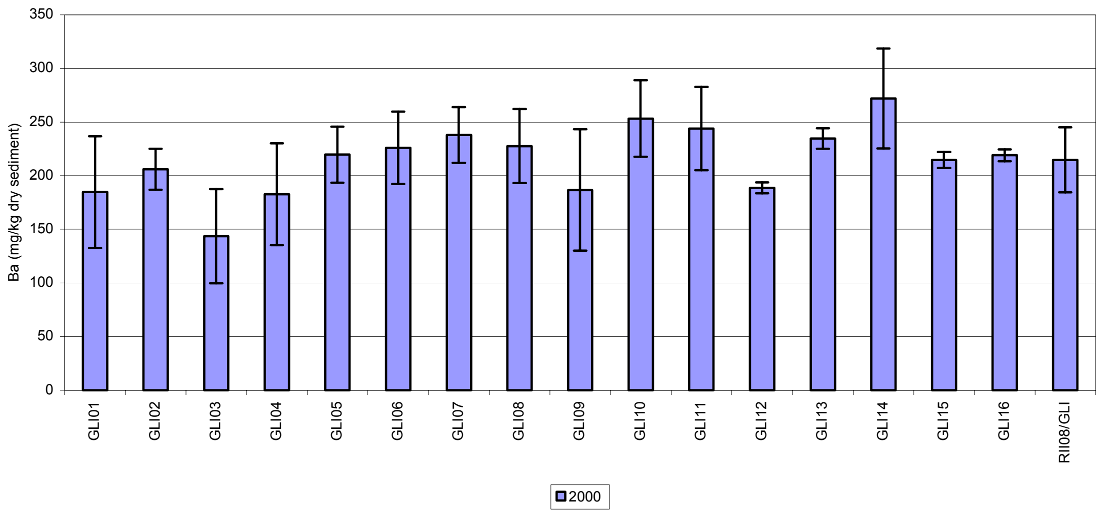

Figure 17-4: Barium levels in sediment from the present (2000) survey, Glitne field.

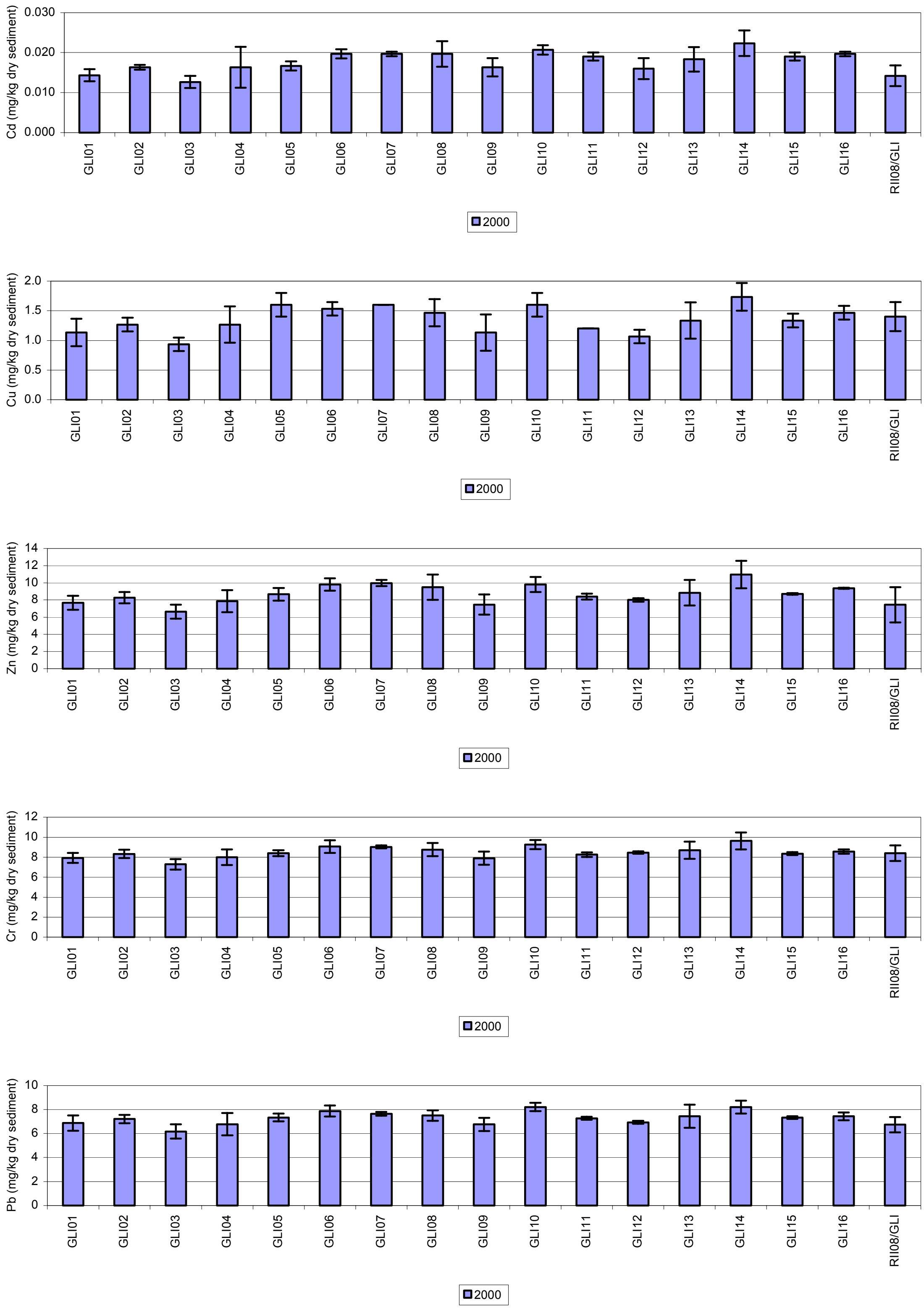

Figure 17-5: Levels of selected metals in sediments from the present (2000) survey, Glitne field.

17.2.3 Biology

The distribution of individuals and taxa within the main taxonomic groups are given in Table 17-7. A total of 16610 individuals within 272 taxa are recorded at the Glitne field in the present survey (excluding juveniles). The polychaetes dominate the fauna with 79 % of the individuals and 52 % of the taxa recorded.

Table 17-7: Distribution of individuals and taxa within the main taxonomic groups at Glitne, 2000 (excluding juveniles).

Main taxonomic groups	Individuals		Taxa	
	Number	%	Number	%
Polychaeta	13091	79	142	52
Mollusca	1588	10	59	22
Crustacea	497	3	47	17
Echinodermata	679	4	8	3
Diverse groups	755	5	16	6
Total	16610	100	272	100

The species/area curve for the reference station at Glitne (regional station RII08) is shown in Figure 17-6. A total of 132 taxa are recorded in the ten grab samples, of which 44 (33 %) occur in the first sample and 96 (73 %) in the first five samples. The shape of the curve indicates that not all taxa in the area are present in the ten grab samples, and the representativity of five samples seems to be relatively low compared with the curve form other reference stations in the region.

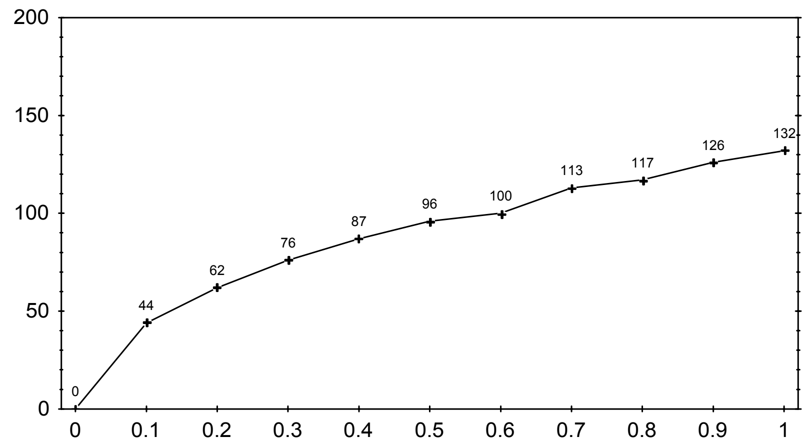

Figure 17-6: Species/area curve for the reference station at Glitne (regional station RII08) (area in m^2).

The number of individuals and taxa at each station, together with selected community indices is presented in Table 17-8 and Figure 17-7.

The number of individuals recorded at Glitne varies from 431 (GLI02) to 1508 (GLI16). The number of taxa varies from 89 (GLI08) to 132 (GLI16), the diversity index H' from 4.5 (GLI05) to 5.7 (GLI12), the evenness index J from 0.67 (GLI05 and GLI11) to 0.84 (GLI02) and the ES_{100} from 25 (GLI10 and GLI11) to 45 (GLI02 and GLI12). The corresponding values at the reference station RII08 are within the variation at the field stations.

Table 17-8: Number of individuals and taxa and selected community indices for each station (0.5 m²) at the Glitne field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	No. ind	No. taxa	H'	J	ES_{100}
GLI01	1045	120	4.8	0.70	37
GLI02	**448**	96	5.5	**0.84**	**45**
GLI03	638	113	5.5	0.80	43
GLI04	538	105	5.5	0.81	43
GLI05	1164	107	**4.5**	**0.67**	36
GLI06	985	111	4.9	0.72	38
GLI07	1010	117	5.2	0.76	41
GLI08	631	**89**	4.9	0.76	38
GLI09	1302	111	4.9	0.72	37
GLI10	1484	116	4.6	0.68	**35**
GLI11	1227	112	4.6	**0.67**	**35**
GLI12	951	124	**5.7**	0.81	**45**
GLI13	982	104	5.0	0.75	37
GLI14	1040	118	5.1	0.75	39
GLI15	1010	124	5.2	0.75	40
GLI16	**1508**	**132**	4.9	0.69	38
RII08	647	96	5.0	0.76	38
Sum*	15963				
Average*	998	112	5.0	0.74	39
St. dev.*	311	11	0.4	0.05	3

*Excluding the reference station.

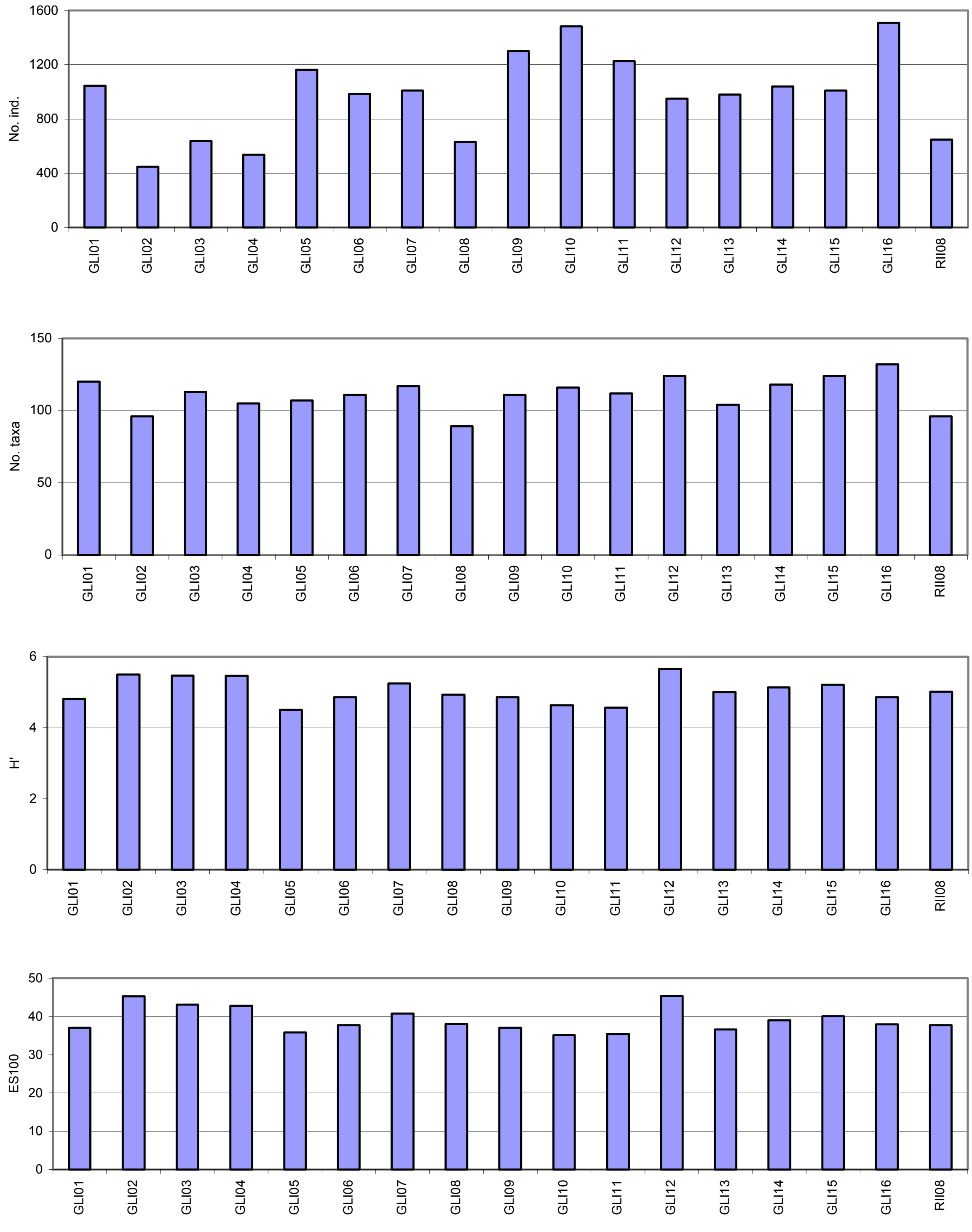

Figure 17-7: Biological characteristics at the stations at Glitne, 2000.

The distribution of taxa in geometrical classes is shown in Figure 17-8. Seven stations have taxa in class 9 (511 – 1023 individuals), seven stations have taxa in class 8 (256 – 511 individuals) while the remaining stations have taxa in class 7 or lower (< 256 individuals). The presence of taxa in high classes might indicate faunal disturbance. This is not the case in the present results.

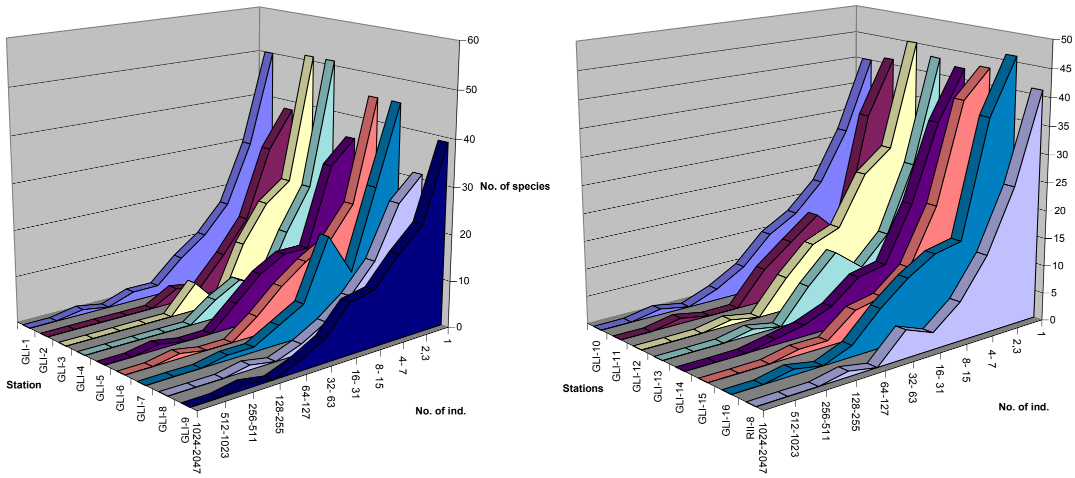

Figure 17-8: Distribution of taxa in geometrical classes from the station at Glitne, 2000.

The ten most dominant taxa at each station are shown in Table 17-10 at the end of this chapter. A total of 28 taxa, inclusive one juvenile group, are among the ten most dominant taxa at one or more stations. These 28 taxa comprise 77 % of the total number of individuals and 10 % of the total number of taxa registered at the Glitne field in the present survey.

The most dominant taxa among the adult forms are the polychaetes *Galatowenia oculata, Paramphinome jeffreysii, Nothria Conchylega, Spiophanes kroyeri, Jasmineira candela*, the bivalve *Thyasira croulinensis* and the brittle star *Amphiura filiformis*. All these species are among the most dominant taxa at all or most of the stations, indicating a uniform distribution of the fauna in the surveyed area.

The ten most abundant taxa at the stations comprise between 47 % (station GLI12) and 65 % (station GLI11) of the total number of individuals registered at the respective stations. The corresponding value at the regional station RII08 is 63 %.

Figure 17-9 shows the dendrogram from the cluster analysis for the field stations and regional and reference stations while Figure 17-10 shows the 2-D plot from the MDS analysis.

The cluster analysis separates the reference station RII08 from the field stations at 38 % dissimilarity level, field station GLI03 at 36 %, stations GLI02 and GLI08 at 35 %, GLI04 at 33 and the remaining stations are separated from each other at dissimilarity levels between 30 and 20 %. The correlation coefficient shows a good fit to the data (r = 0.86).

The MDS analyses support the result from the cluster analysis and separate the reference station RII08 and the field stations GLI02, GLI03, GLI04 and GLI08 from the main group of stations in the middle of the 2-D plot. The stress test shows a fair to poor fit to the data (0.33).

The results indicate a high degree of similarity in faunal composition between the stations included.

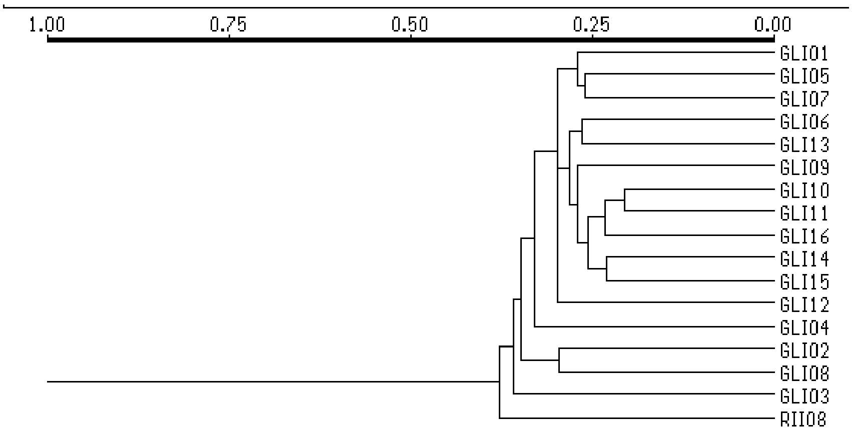

Figure 17-9: Cluster analysis of the Glitne field stations, 2000.

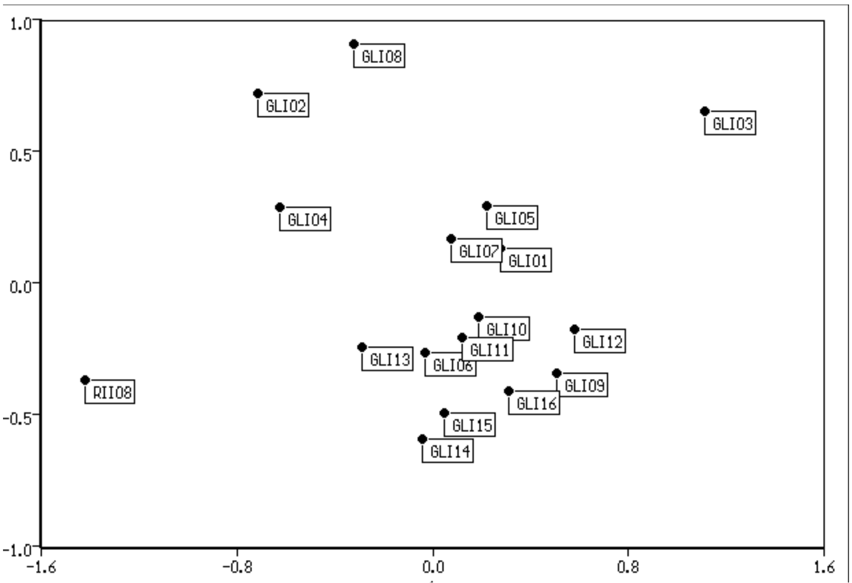

Figure 17-10: 2-D plot from the MDS analysis carried out on the station data from the Glitne field, 2000.

A Canonical Correspondence Analysis (CCA) of the data from the field and reference station was carried out to examine the association between the biological data and the measured environmental variables in these areas.

Through the forward selection procedure in CANOCO, two of ten variables gave the best fit and are significant. 20.5 % of the biological variance was explained by the first two axes of the ordination space which is constrained by these environmental variables.

Figure 17-11 shows a biplot from the analysis using cadmium (Cd) and barium (Ba) as the constraining environmental variables together with a plot of the taxa with the highest contribution on the two axes. The first axis shows a gradient from reference station RII08 at the positive end to field station GLI14 at the negative end and is negatively correlated with the amount of cadmium (- 0.84) and barium (- 0.67) in the sediment. Taxa with highest contribution on this axis are the polychaetes *Galathowenia oculata* (8.4 %), *Paramphinome jeffreysii* (7.8 %), *Streblosoma intestinalis* (3.7 %) and *Euclymene affinis* (3.6 %) and the brittle star *Amphiura filiformis* (2.3 %).

The second axis shows a gradient from field station GLI03 on the positive end to the reference station RII=8 on the negative end and is negatively correlated with the amount of barium in the sediments (-0.57). Taxa with the highest contribution on this axis are the polychaetes *Paramphinome jeffreysii* (4.7 %), *Myriochele fragilis* (3.1 %) and *Galathowenia oculata* (2.6 %).

The amounts of all measured chemical parameters are low and the correlations between the faunal distribution and cadmium and barium are believed to be a result of the natural variation in sediment structure in the surveyed area. None of the species known to be abundant in disturbed sediments appears in high individual numbers at the stations.

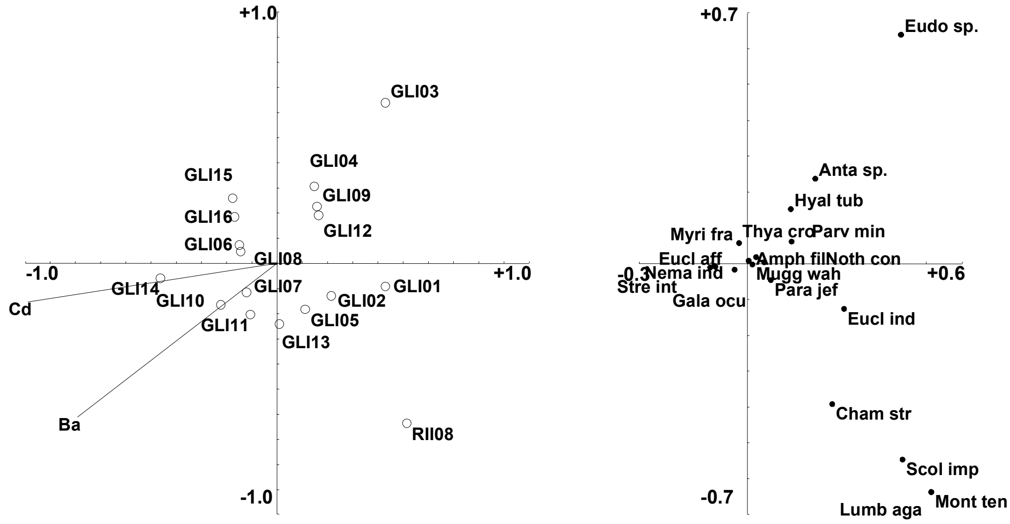

Figure 17-11: Biplot from the CCA analysis for the Glitne field, 2000 (left) and taxa with high contribution on two axes (right).

On the basis of the results from the uni- and multivariate analyses all stations are classified as group A stations (undisturbed fauna, see Table 17-9). The biological analyses indicate a uniform distribution of undisturbed fauna at the Glitne field. The correlations between the amount of cadmium and barium in the sediments and the faunal distribution are believed to be a result of natural variation in the sediment structure over the field. All measured chemical parameters are low and only taxa, which are abundant in undisturbed sediments, are recorded among the dominant taxa.

Table 17-9: Classification into impact groups, distance to installation and biological statistics for the field stations at Glitne field, 2000.

Station	Impact group	Dist. (m)	Statistics			No. of individuals								
			No. ind	No. taxa	H'	Goc	Pje	Nco	Tcr	Skr	Afi	Jca	Mfr	Lsa
GLI01	A	250	1045	120	4,8	308	79	76	45	26	44	22	31	7
GLI02	A	500	448	96	5,5	52	37	7	26	14	39	13	4	7
GLI03	A	1000	638	113	5,5	52	61	49	37	45	51	11	12	8
GLI04	A	2000	538	105	5,5	43	50	32	50	25	22	17	3	17
GLI05	A	250	1164	107	4,5	438	58	13	34	54	32	19	27	15
GLI06	A	500	985	111	4,9	292	43	63	36	34	30	26	17	30
GLI07	A	1000	1010	117	5,2	215	61	66	39	42	32	28	10	19
GLI08	A	2000	631	89	4,9	154	44	17	41	31	31	23	3	11
GLI09	A	250	1302	111	4,9	374	74	70	58	42	33	43	42	26
GLI10	A	500	1484	116	4,6	491	73	109	40	56	48	40	38	31
GLI11	A	1000	1227	112	4,6	440	61	37	49	36	38	39	27	26
GLI12	A	2000	951	124	5,7	129	38	56	42	52	23	29	35	13
GLI13	A	250	982	104	5,0	215	59	62	52	42	36	39	21	19
GLI14	A	500	1040	118	5,1	223	77	74	50	42	34	42	19	24
GLI15	A	1000	1010	124	5,2	211	53	85	51	41	24	35	49	18
GLI16	A	2000	1508	132	4,9	477	64	41	32	54	44	58	78	27
RII08	A	5261	647	96	5,0	36	132	0	32	42	35	8	2	25

Goc = *Galatowenia oculata*, Pje = *Paramphinome jeffreysii*, Nco = *Nothria conchylega*, Tcr = *Thyasira crouliensis*, Skr = *Spiophanes kroyeri*, Afi = *Amphiura filiformis,* Jca = *Jasmineira candela*, Mfr = *Myriochele fragilis,* Lsa = *Laonice sarsi.*

17.3 Summary and conclusions

The sediments at Glitne are classified as fine sand with relatively high amounts of pelite (7.8 – 13.1 %) and TOM (1.3 – 2.1 %). These levels are comparable to that found at the fields situated north east (i.e. Ringhorne) and south (Sleipner Vest) of Glitne. At the reference station, which is the regional station RII08, the pelite and TOM levels are within the variation found at the field station.

The THC and metals are very evenly distributed over the Glitne field. The concentrations of THC, cadmium, copper and chromium vary from values below to values barely above the corresponding background levels across the region. The levels of lead and zinc are slightly higher than the corresponding background levels found at most of the fields in Region II, but the levels don't exceed the amounts found at the field-specific reference station. The sediments at the Glitne field are regarded as uncontaminated with THC and metals.

The average THC and metal contents across the Glitne field are comparable to the amounts found in uncontaminated sediments at the Sleipner Vest field, south of Glitne. The only exception is barium, of which the average amount across Glitne (215 mg/kg) is more than twice the concentration (90 mg/kg) found at the Sleipner Vest reference station. The Ringhorne field is located north east of the Glitne field. The average THC content across the Glitne field is comparable to the amounts found across Ringhorne, but the sediments from Glitne contain more than twice as much barium and 40-50 % less cadmium and copper than the sediments form the Ringhorne field. The concentrations of the remaining of the selected metals are only slightly above the corresponding concentrations found across Ringhorne.

There is a great variation in the number of individuals (448 – 1508) and taxa (89 – 132) between the stations at the field. However, the biological analyses indicate a uniform distribution of undisturbed fauna at the Glitne field. The correlations between the amount of cadmium and barium in the sediments and the faunal distribution are believed to be a result of natural variation in the sediment structure over the field. All measured chemical parameters are low and only taxa, which are abundant in undisturbed sediments, are recorded among the dominant taxa. It is concluded that the fauna is undisturbed at all stations at the field.

Table 17-10: Number of individuals and accumulative abundance for the ten most dominant taxa at each station at the Glitne field, 2000.

GLI01 (10° / 250 m)	No. ind	Acc. %	GLI02 (10° / 500 m)	No. ind	Acc. %	GLI03 (10° / 1000 m)	No. ind	Acc. %	GLI04 (10° / 2000 m)	No. ind	Acc. %	GLI05 (100° / 250 m)	No. ind	Acc. %
Galathowenia oculata	308	28 %	Galathowenia oculata	52	11 %	Paramphinome jeffreysii	61	9 %	Paramphinome jeffreysii	50	9 %	Galathowenia oculata	438	36 %
Paramphinome jeffreysii	79	35 %	Amphiura filiformis	39	19 %	Galathowenia oculata	52	17 %	Thyasira croulinensis	50	18 %	Paramphinome jeffreysii	58	41 %
Nothria conchylega	76	42 %	Paramphinome jeffreysii	37	27 %	Amphiura filiformis	51	25 %	Galathowenia oculata	43	26 %	Spiophanes kroyeri	54	46 %
Thyasira croulinensis	45	46 %	Thyasira croulinensis	26	33 %	Nothria conchylega	49	32 %	Nothria conchylega	32	31 %	Mugga wahrbergi	37	49 %
Amphiura filiformis	44	50 %	Polydora coeca	19	37 %	Spiophanes kroyeri	45	39 %	Spiophanes kroyeri	25	36 %	Thyasira croulinensis	34	52 %
Myriochele fragilis	31	53 %	Spiophanes kroyeri	14	40 %	Thyasira croulinensis	37	44 %	Polydora coeca	23	40 %	Amphiura filiformis	32	54 %
Spiophanes kroyeri	26	55 %	Jasmineira candela	13	43 %	Anobothrus gracilis	15	46 %	Amphiura filiformis	22	44 %	Myriochele fragilis	27	56 %
Aphelochaeta sp.	23	57 %	Pectinaria auricoma	12	45 %	Notomastus latericeus	14	48 %	Jasmineira candela	17	47 %	Ophiuroidea indet. juv.	25	59 %
Ophiuroidea indet. juv.	23	59 %	Ophiuroidea indet. juv.	11	48 %	Terebellides stroemi	14	51 %	Laonice sarsi	17	50 %	Polydora coeca	23	60 %
Jasmineira candela	22	61 %	Parvicardium minimum	11	50 %	Phoronis sp.	13	52 %	Nemertini indet.	16	53 %	Pseudopolydora paucibranchiata	21	62 %
			Phoronis sp.	11	52 %				Phoronis sp.	16	56 %			
GLI06 (100° / 500 m)	**No. ind**	**Acc. %**	**GLI07 (100° / 1000 m)**	**No. ind**	**Acc. %**	**GLI08 (100° / 2000 m)**	**No. ind**	**Acc. %**	**GLI09 (280° / 250 m)**	**No. ind**	**Acc. %**	**GLI10 (280° / 500 m)**	**No. ind**	**Acc. %**
Galathowenia oculata	292	29 %	Galathowenia oculata	215	21 %	Galathowenia oculata	154	23 %	Galathowenia oculata	374	28 %	Galathowenia oculata	491	32 %
Nothria conchylega	63	35 %	Nothria conchylega	66	27 %	Paramphinome jeffreysii	44	30 %	Paramphinome jeffreysii	74	33 %	Nothria conchylega	109	39 %
Paramphinome jeffreysii	43	40 %	Paramphinome jeffreysii	61	33 %	Thyasira croulinensis	41	36 %	Nothria conchylega	70	39 %	Paramphinome jeffreysii	73	44 %
Thyasira croulinensis	36	43 %	Spiophanes kroyeri	42	37 %	Amphiura filiformis	31	41 %	Thyasira croulinensis	58	43 %	Spiophanes kroyeri	56	48 %
Spiophanes kroyeri	34	47 %	Thyasira croulinensis	39	40 %	Spiophanes kroyeri	31	46 %	Jasmineira candela	43	46 %	Amphiura filiformis	48	51 %
Amphiura filiformis	30	50 %	Amphiura filiformis	32	44 %	Jasmineira candela	23	49 %	Myriochele fragilis	42	49 %	Jasmineira candela	40	54 %
Laonice sarsi	30	52 %	Euclymene affinis	30	46 %	Polydora coeca	20	52 %	Spiophanes kroyeri	42	52 %	Thyasira croulinensis	40	56 %
Jasmineira candela	26	55 %	Streblosoma intestinale	30	49 %	Nothria conchylega	17	55 %	Amphiura filiformis	33	55 %	Myriochele fragilis	38	59 %
Polydora coeca	22	57 %	Jasmineira candela	28	52 %	Nephtys hystricis	15	57 %	Mugga wahrbergi	29	57 %	Laonice sarsi	31	61 %
Aphelochaeta sp.	21	59 %	Nematoda indet.	25	54 %	Aphelochaeta sp.	14	59 %	Eclysippe vanelli	27	59 %	Mugga wahrbergi	29	63 %

Continue Table 17-10

GLI11 (280° / 1000 m)	No. ind	Acc. %	GLI12 (280° / 2000 m)	No. ind	Acc. %	GLI13 (190° / 250 m)	No. ind	Acc. %	GLI14 (190° / 500 m)	No. ind	Acc. %	GLI15 (190° / 1000 m)	No.ind	Acc. %
Galathowenia oculata	440	35 %	Galathowenia oculata	129	13 %	Galathowenia oculata	215	21 %	Galathowenia oculata	223	21 %	Galathowenia oculata	211	20 %
Paramphinome jeffreysii	61	40 %	Nothria conchylega	56	19 %	Nothria conchylega	62	28 %	Paramphinome jeffreysii	77	28 %	Nothria conchylega	85	29 %
Thyasira croulinensis	49	44 %	Spiophanes kroyeri	52	24 %	Paramphinome jeffreysii	59	33 %	Nothria conchylega	74	35 %	Paramphinome jeffreysii	53	34 %
Jasmineira candela	39	47 %	Thyasira croulinensis	42	29 %	Thyasira croulinensis	52	39 %	Thyasira croulinensis	50	40 %	Thyasira croulinensis	51	39 %
Amphiura filiformis	38	50 %	Paramphinome jeffreysii	38	33 %	Spiophanes kroyeri	42	43 %	Jasmineira candela	42	44 %	Myriochele fragilis	49	44 %
Nothria conchylega	37	53 %	Myriochele fragilis	35	36 %	Jasmineira candela	39	47 %	Spiophanes kroyeri	42	48 %	Spiophanes kroyeri	41	48 %
Spiophanes kroyeri	36	56 %	Pseudopolydora paucibranchiata	34	40 %	Amphiura filiformis	36	50 %	Amphiura filiformis	34	51 %	Jasmineira candela	35	51 %
Eclysippe vanelli	27	59 %	Jasmineira candela	29	43 %	Euclymene affinis	31	53 %	Euclymene affinis	30	54 %	Streblosoma intestinale	31	54 %
Myriochele fragilis	27	61 %	Amphiura filiformis	23	45 %	Streblosoma intestinale	26	56 %	Nematoda indet.	25	57 %	Euclymene affinis	26	56 %
Laonice sarsi	26	63 %	Owenia fusiformis	22	47 %	Aphelochaeta sp.	23	58 %	Laonice sarsi	24	59 %	Amphiura filiformis	24	59 %
Terebellides stroemi	26	65 %												

GLI16 (190° / 2000 m)	No. ind	Acc. %	RII08 (58°45.00' / 01°40.00')	No. ind.	Acc.
Galathowenia oculata	477	31 %	Paramphinome jeffreysii	132	19 %
Myriochele fragilis	78	36 %	Nothria hyperborea	50	27 %
Paramphinome jeffreysii	64	40 %	Spiophanes kroyeri	42	33 %
Jasmineira candela	58	44 %	Galathowenia oculata	36	38 %
Spiophanes kroyeri	54	48 %	Amphiura filiformis	35	43 %
Amphiura filiformis	44	51 %	Thyasira croulinensis	32	48 %
Nothria conchylega	41	53 %	Ophiuroidea indet. juv.	31	52 %
Euclymene affinis	36	56 %	Polydora coeca	26	56 %
Nematoda indet.	35	58 %	Laonice sarsi	25	60 %
Thyasira croulinensis	32	60 %	Terebellides stroemi	20	63 %

Table 17-11: Station information for Glitne field, 2000.

St. no.	Distance (m)	Direction (degr.)	Volume (litres)
GLI01	250	10	30
GLI02	500	10	29
GLI03	1000	10	25
GLI04	2000	10	25
GLI05	250	100	30
GLI06	500	100	35
GLI07	1000	100	35
GLI08	2000	100	37
GLI09	250	280	29
GLI10	500	280	28
GLI11	1000	280	26
GLI12	2000	280	27
GLI13	250	190	33
GLI14	500	190	37
GLI15	1000	190	41
GLI16	2000	190	34
RII08	5261	19	25 *

* The additional five grab samples taken gave 25 litres of sediment.

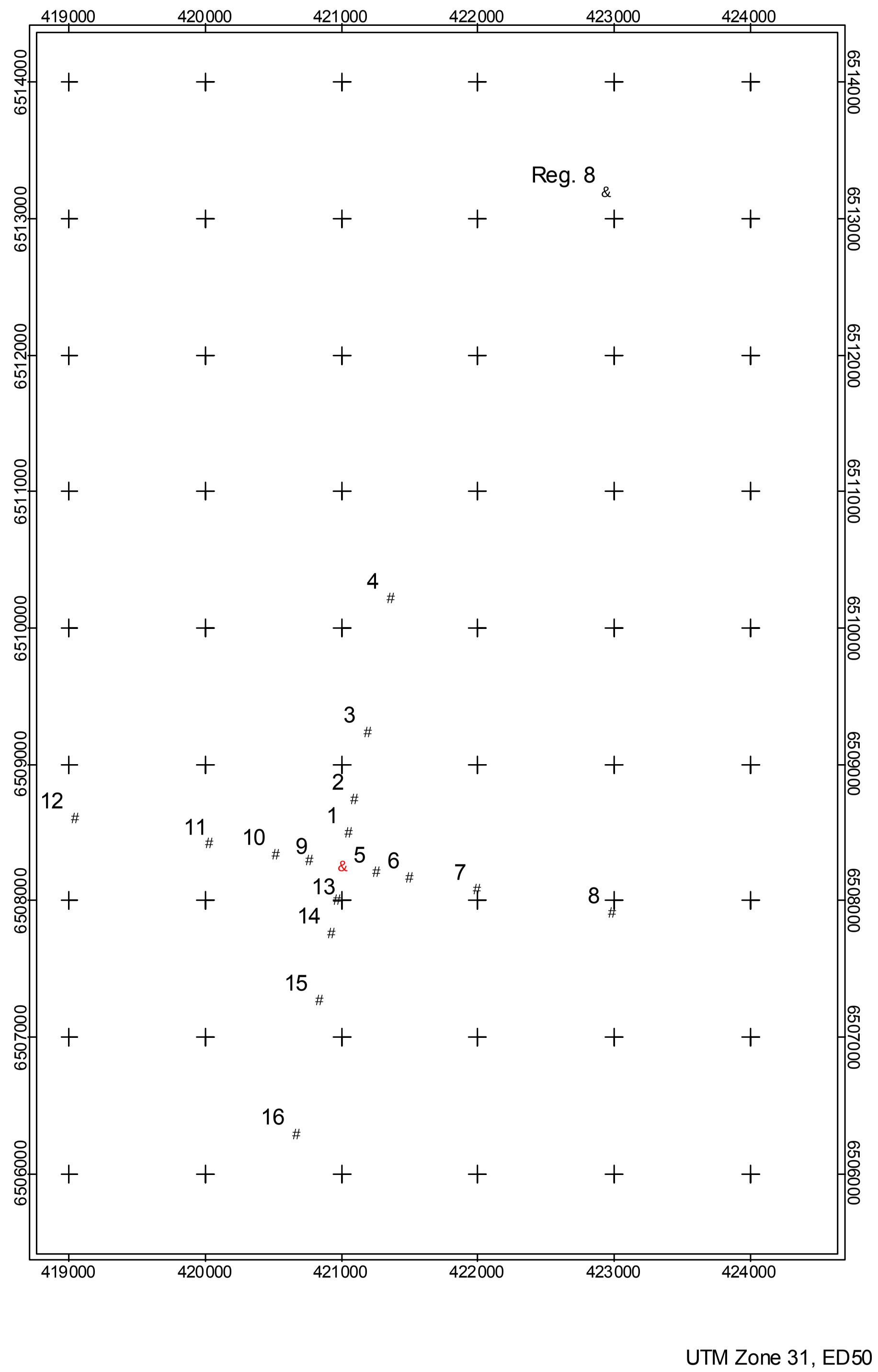

Figure 17-12: Map of sampling positions for Glitne field, 2000.

18 Sleipner Vest field

18.1 Introduction

The Sleipner Vest field is located in Block 15/6 in the southern part of Region II, situated west of the Sleipner Øst. Production at the field started in 1996. Data on recent drilling and discharges are given in Table 18-1.

At this field baseline and monitoring surveys have been carried out in 1994 (Gjøs *et al*. 1995) and 1997 (Mannvik *et al*. 1998). In 1997 the area significantly contaminated with THC extended out to 1000 m/10o, 500 m/190oand 280o and 250 m/100o. The whole field was regarded as contaminated with barium, cadmium and zinc. The fauna was found to be undisturbed with a uniform distribution over the field.

The sampling plan in 2000 does not include a separate reference station for the Sleipner Vest field. Instead, the Regional station RII07 is used as the reference station. Information on the sampling stations is shown in Figure 18-13 and Table 18-13, both on the foldout page at the end of this chapter (page 18-19).

Table 18-1: Summary of recent wells drilled and operational and accidental discharges at the Sleipner Vest field (all discharges in tonnes).

	1997	1998	1999	2000	Comments
No of wells drilled	3	3	2	1	
Barite	2856	1148	302	330	
Cuttings	3429	2355	410	881	
Water-based drilling mud	7889	5919	2058	2064	
Cementing chemicals	80	45	45	7	
Completion chemicals	0	714	0	0	
Oil in produced water	1	2	1.8	0.82	
Accidental discharges	9 *	1.4	0	0.05	* Oil based mud

18.2 Results and discussion

18.2.1 Physical characteristics

The median phi value and the amount (%) of pelite, fine sand and total organic matter (TOM) in the sediment from the present and previous surveys are shown in Table 18-2 and Figure 18-1. 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 in the area are classified as fine sand with median values varying from 3.73 (SLV07 and SLV08) to 4.03 (SLV01). The amount of pelite in the sediment varies from 11.1 % (SLV07 and SLV08) to 24.6 % (SLV01), the fine sand from 65.5 % (SLV01) to 87.1 % (SLV08) while the TOM varies from 1.91 % (SLV07) to 4.52 % (SLV01). The sediment is coarser at the RII07 where the pelite content is 6.8 % and the TOM is 1.26 %. At the field stations the pelite and TOM values are highest at the 250 m station north of field centre.

The amount of pelite and TOM has increased remarkably at station SLV01 since the previous survey. At the other stations the increase is much smaller.

Table 18-2: The median (phi) and amount of pelite, fine sand and TOM in the sediment from stations at the Sleipner Vest field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	Distance (m)	Direction (degr.)	Median	Classification	Pelite	Fine sand	TOM
SLV01	250	10	**4.03**	Silt	**24.6**	**65.5**	**4.52**
SLV02	500	10	3.98	Fine sand	12.1	84.4	2.41
SLV03	1000	10	3.91	Fine sand	12.3	83.8	2.13
SLV07	500	100	**3.73**	Fine sand	11.3	86.0	**1.91**
SLV08	1000	100	**3.73**	Fine sand	**11.1**	**87.1**	2.13
SLV11	500	190	3.75	Fine sand	**11.1**	86.6	2.15
SLV12	1000	190	3.76	Fine sand	12.4	85.6	2.41
SLV16	500	280	3.77	Fine sand	12.9	83.5	2.26
SLV17	1000	280	3.78	Fine sand	12.8	83.4	2.51
RII07	18000	190	3.53	Fine sand	6.8	74.3	1.26
Average *			3.82		13.4	82.9	2.49
St. dev. *			0.11		4.3	6.7	0.78

*Excluding the reference station.

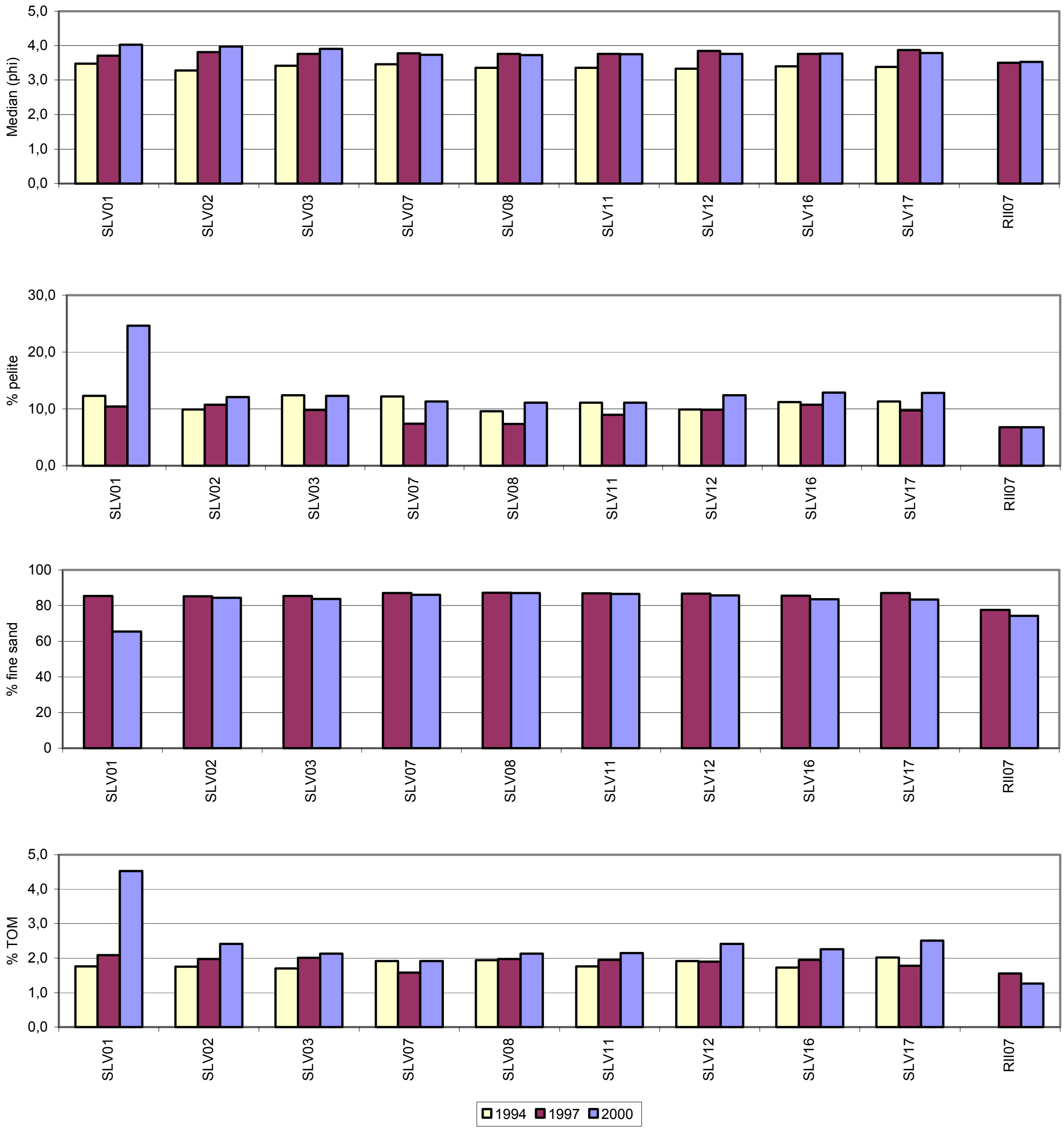

Figure 18-1: Sediment characteristics at the Sleipner Vest field, 2000 and previous surveys.

18.2.2 Chemical characteristics

The calculated limits of significant contamination for selected hydrocarbons and metals in sediments from Region II ($LSC_{97\text{-}00\ RegII}$) are presented previously in the chapter that deals with the regional and reference stations. In addition to the regional limits, field-specific limits of significant contamination are calculated from the reference station ($LSC_{00\ REG07/SLV}$) results. Both sets of data are presented in Table 18-3. Based on analysis results of the Sleipner Vest field, the $LSC_{97\text{-}00\ RegII}$ is regarded as representative of this area and will therefore be used as further basis for discussion of the contamination status of this field. Those limits will hereafter simply be referred to as LSC.The results of analyses of the hydrocarbons are summarised in Table 18-4. Concentrations of selected compounds in the vertical sediment sections are presented in Table 18-5. The full data set of replicate measurements and data from previous years are given in the Appendix. THC values from 2000 are compared with those from previous years in Figure 18-3.

Table 18-3: Background levels and Limits of Significant Contamination for the Sleipner Vest field, 2000. All values in mg/kg dry sediment.

	THC	NPD's	3-6 ring	Decalins	Cd	Hg	Cu	Zn	Ba	Cr	Pb
$LSC_{00\ RII07/SLV}$	10.1	0.026	0.076	0.027	0.021	0.013	1.3	8.3	109	9.8	7.1
$LSC_{97\text{-}00\ RegII}$	9.8	*	*	*	0.029	0.008	2.0	8.9	146	9.6	7.0

*) Regional stations not analysed for NPD's, 3-6 ring aromatics and decalins.

Table 18-4: Concentrations of hydrocarbons in sediments from the Sleipner Vest field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are shaded.

Station	THC		NPD's		3-6 ring		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
SLV01	75.5	41.5	1.277	0.494	0.207	0.032	0.528	0.234
SLV02	180	116	n.a.		n.a.		n.a.	
SLV03	102	53	0.075	0.006	0.114	0.033	0.280	0.185
SLV07	10.7	1.6	n.a.		n.a.		n.a.	
SLV08	7.5	1.8	n.a.		n.a.		n.a.	
SLV11	11.3	2.0	n.a.		n.a.		n.a.	
SLV12	10.8	3.2	n.a.		n.a.		n.a.	
SLV16	52.7	27.1	0.057	0.014	0.089	0.013	1.135	0.720
SLV17	7.6	0.4	n.a.		n.a.		n.a.	
RII07/SLV	5.5	2.0	0.019	0.003	0.052	0.010	0.011	0.007

n.a. Not analysed.

Table 18-5: Concentrations of hydrocarbons in vertical sections of the sediment samples from the Sleipner Vest field, 2000. All concentrations in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are shaded.

Station	Layer (cm)	THC	NPD's	3-6 ring	Decalins
SLV01	0-1	37.7	0.921	0.177	0.561
	1-3	41.1	0.156	0.145	0.086
	3-6	15.0	0.074	0.139	0.688
SLV03	0-1	62.4	0.080	0.149	0.097
	1-3	25.2	0.123	0.142	0.754
	3-6	22.0	0.066	0.110	0.455
RII07/SLV	0-1	5.5	0.021	0.069	0.015
	1-3	11.1	0.032	0.076	0.043
	3-6	8.2	0.031	0.099	0.036

n.a. Not analysed.

The THC values range from 7.5 ± 1.8 to 180 ± 116 mg/kg dry sediment. THC values above the calculated LSC are dark shaded in Table 18-4. Stations SLV07 and SLV12 are considered to be in the grey zone of contamination, while station SLV11 is regarded as contaminated because the gas chromatogram profile of the sediment extracts shows the presence of mineral oil.

The highest concentrations of THC are found in the main current direction (10^{o}-axis). Along this axis THC concentrations above 100 mg/kg are found out to 1000 m. Stations contaminated with THC are SLV01, SLV02, SLV03, SLV11 and SLV16. The hydrocarbon extracts from these stations contains mineral oil. The sectioned sediment samples (Table 18-5) reveal that THC, NPD´s, 3-6 ring aromatics and decalins are contaminated down to at least 6 cm sediment depth at SLV01 and SLV03. The gas chromatogram profile of sediment extracts from the core samples shows the presence of petroleum related hydrocarbons down to 6 cm depth. According to data on recent drilling, oil based mud is reported accidentally discharged during the first quarter of 2000.

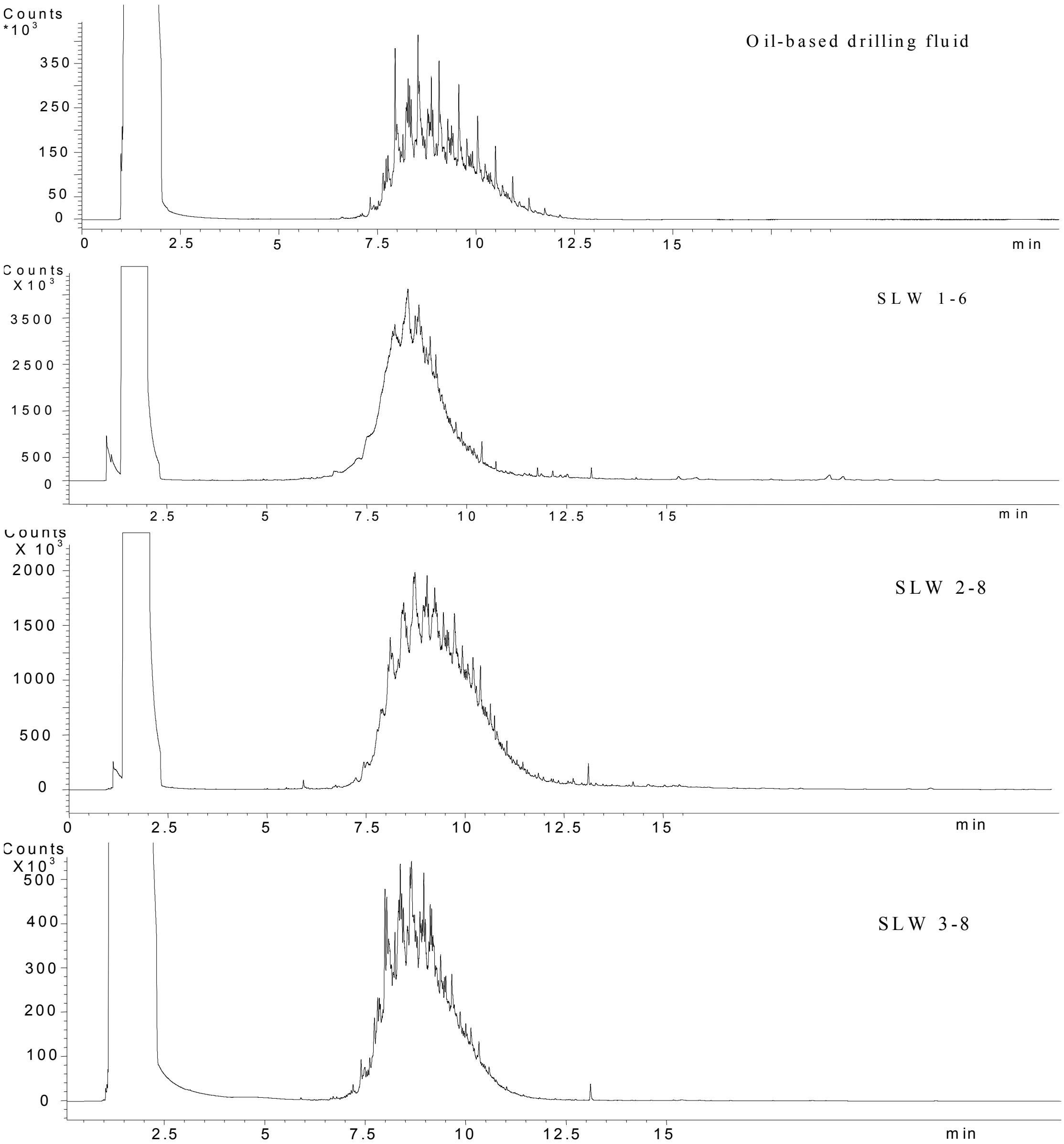

Figure 18-2: Gas chromatogram of an oil-based drilling fluid (upper) and sediment extracts from the Sleipner Vest field (three lower), 2000.

The results of the metal analyses for the Sleipner Vest field are summarised in Table 18-6. Concentrations of selected metals in the vertical sediment sections are presented in Table 18-7. The full data set of replicate measurements, including selected data from previous years, are given in the Appendix. Metal values from 2000 are compared with those from previous years in Figure 18-4 and Figure 18-5.

Table 18-6: Concentrations of selected metals in sediments from the Sleipner Vest field, 2000. All values in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are shaded.

	Cd		Hg		Cu		Zn		Ba		Cr		Pb	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
SLV01	0.095	0.039	0.019	0.004	14.7	3.4	39.2	5.9	3232	66	16.5	1.5	15.2	1.8
SLV02	0.034	0.005	n.a.		2.8	1.5	13.4	5.0	3009	1752	9.3	1.4	8.7	2.6
SLV03	0.026	0.004	0.006	0.003	1.9	0.5	9.9	1.0	1593	335	9.3	1.8	7.8	0.9
SLV07	0.025	0.002	n.a.		1.6	0.3	8.4	1.2	733	161	8.5	0.6	6.7	1.0
SLV08	0.026	0.003	n.a.		1.5	0.2	8.7	1.2	251	125	8.8	0.7	6.8	0.8
SLV11	0.029	0.003	n.a.		2.1	0.5	10.2	0.7	2208	1054	9.0	0.7	7.6	1.5
SLV12	0.026	0.001	n.a.		1.8	0.3	8.8	0.7	676	78	9.2	0.2	7.1	0.2
SLV16	0.031	0.004	n.a.		1.8	0.2	9.7	0.6	1607	225	9.5	0.7	7.3	0.6
SLV17	0.027	0.001	n.a.		2.0	0.3	10.7	1.1	624	153	9.8	0.9	7.6	0.6
RII07/SLV	0.017	0.002	0.005	0.003	1.1	0.1	7.0	0.6	90	8	9.0	0.3	6.6	0.2

n.a. Not analysed.

Table 18-7: Concentrations of selected metals in vertical sections of the sediment samples from the Sleipner Vest field. All concentrations in mg/kg dry sediment. Values above $LSC_{97\text{-}00\ RegII}$ are shaded .

Station	Layer (cm)	Cd	Hg	Cu	Zn	Ba	Cr	Pb
SLV01	0-1	0.070	0.015	18.5	35.9	3289	16.3	15.2
	1-3	0.058	0.017	7.6	26.0	3315	12.2	11.2
	3-6	0.038	0.009	3.4	14.2	2115	9.8	8.6
SLV03	0-1	0.030	0.007	2.2	11.0	1467	9.4	8.4
	1-3	0.029	0.008	2.0	11.7	1760	8.9	8.9
	3-6	0.032	0.008	1.8	10.1	517	9.6	8.0
RII07/SLV	0-1	0.016	<0.005	1.0	7.5	87	9.3	6.7
	1-3	0.016	0.006	1.1	7.0	134	8.9	6.8
	3-6	0.024	0.006	1.0	7.4	135	9.1	6.9

n.a. Not analysed.

The concentrations of barium range from 251 ± 125 to 3232 ± 66 mg/kg, cadmium from 0.025 ± 0.002 to 0.095 ± 0.039 mg/kg and copper from 1.6 ± 0.3 to 14.7 ± 3.4 mg/kg. The content of lead range from 6.7 ± 1.0 to 15.2 ± 1.8 mg/kg, zinc from 8.4 ± 1.2 to 39.2 ± 5.9 mg/kg and chromium from 8.5 ± 0.6 to 16.5 ± 1.5 mg/kg dry sediment (Table 18-6.) Station SLV01 has considerable higher concentrations of selected metals than the remaining stations. The sectioned sediment samples from SLV01 shows that metals are contaminated down to 6 cm depth. Metal concentrations above the calculated LSC are dark shaded in Table 18-6 and Table 18-7.

One of the five replicate sediment samples from RII07/SLV has a mercury content (0.011 mg/kg) above the detection limit (0.005 mg/kg.) The mercury content at SLV03 is at the background level, while the content at SLV01 nearly four times higher the background level across Region II (0.005 ± 0.001 mg/kg).

In the main current direction (10^o-axis), gradients of decreasing content of metals with increasing distance from the centre are found for all the selected metals. Along the 100^o-, 190^o- and 280^o-axes the highest concentrations of barium and cadmium are found at the innermost stations. The remaining metals are more even distributed along these axes. All stations are regarded as contaminated with barium, wile stations SLV01, SLV02, SLV03, SLV11 and SLV16 are deemed contaminated with the remaining metals.

<u>Comparison with previous survey(s)</u>

This year's THC content (5.5 ± 2.0 mg/kg) at the Sleipner Vest reference station (RII07/SLV) is slightly below the value (7.1 ± 0.3 mg/kg) found in 1997 (Mannvik *et al.,* 1998.) Analysis of a sediment core from RII07/SLV reveals that the 1-3 and 3-6 cm layers contains slightly more hydrocarbons than the top layer. The content of metals is almost unchanged since 1997.

Compared to the 1997 results (Figure 18-3) the THC levels have increased at stations SLV01, SLV02 and SLV03 (main current direction) and at SLV16. The largest increases in THC content are found in the main current direction. At the remaining stations the THC content is almost unchanged since 1997. The barium content has increased over the whole Sleipner Vest field. The only exceptions are found at SLV03 and SLV08 where the contents are lower than in 1997 (Figure 18-4). Increased amount of cadmium, lead and copper are found at SLV01 and SLV02. The content of zinc has clearly decreased over the whole field.

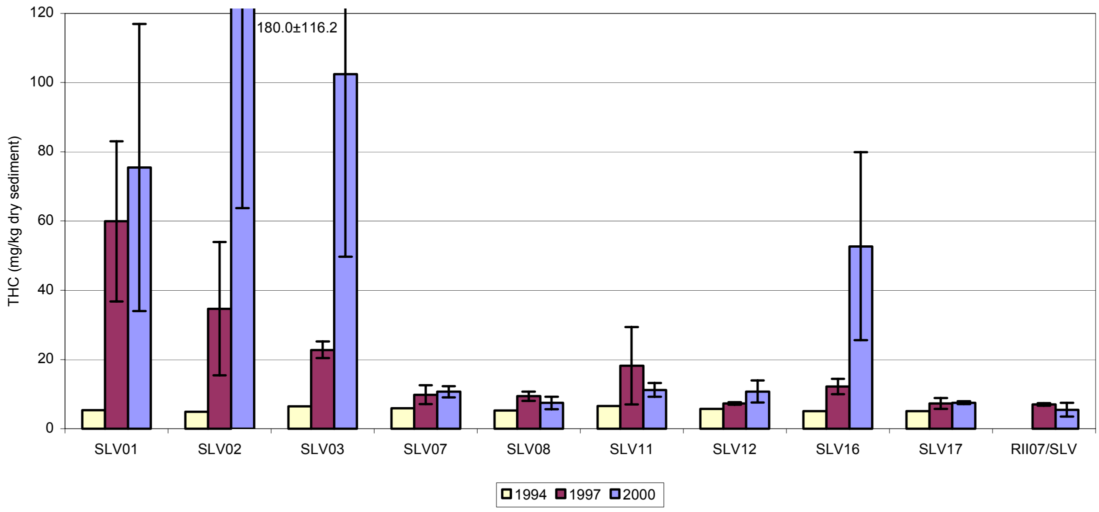

Figure 18-3: THC levels in sediment from the present (2000) and previous surveys, Sleipner Vest field.

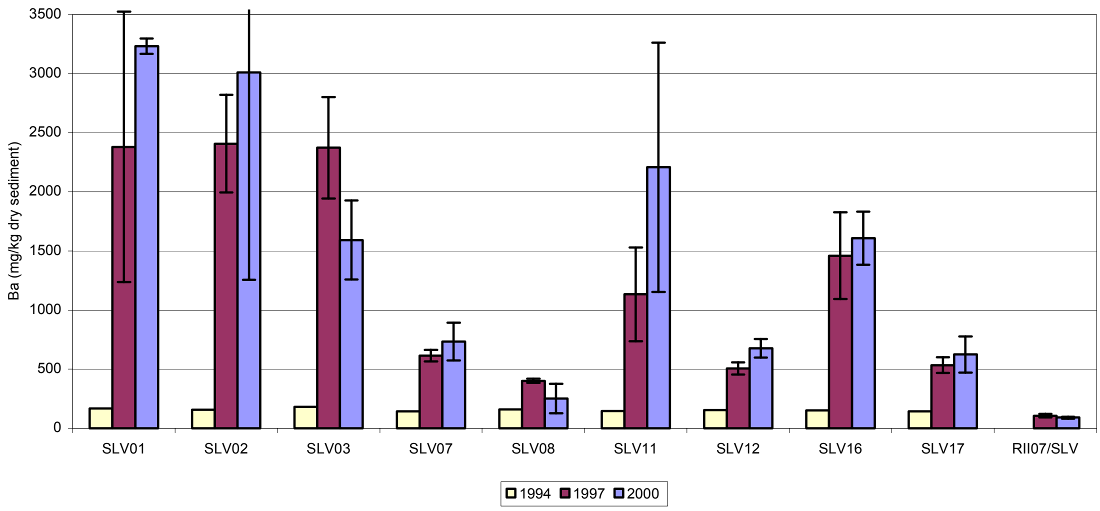

Figure 18-4: Barium levels in sediment from the present (2000) and previous survey, Sleipner Vest field.

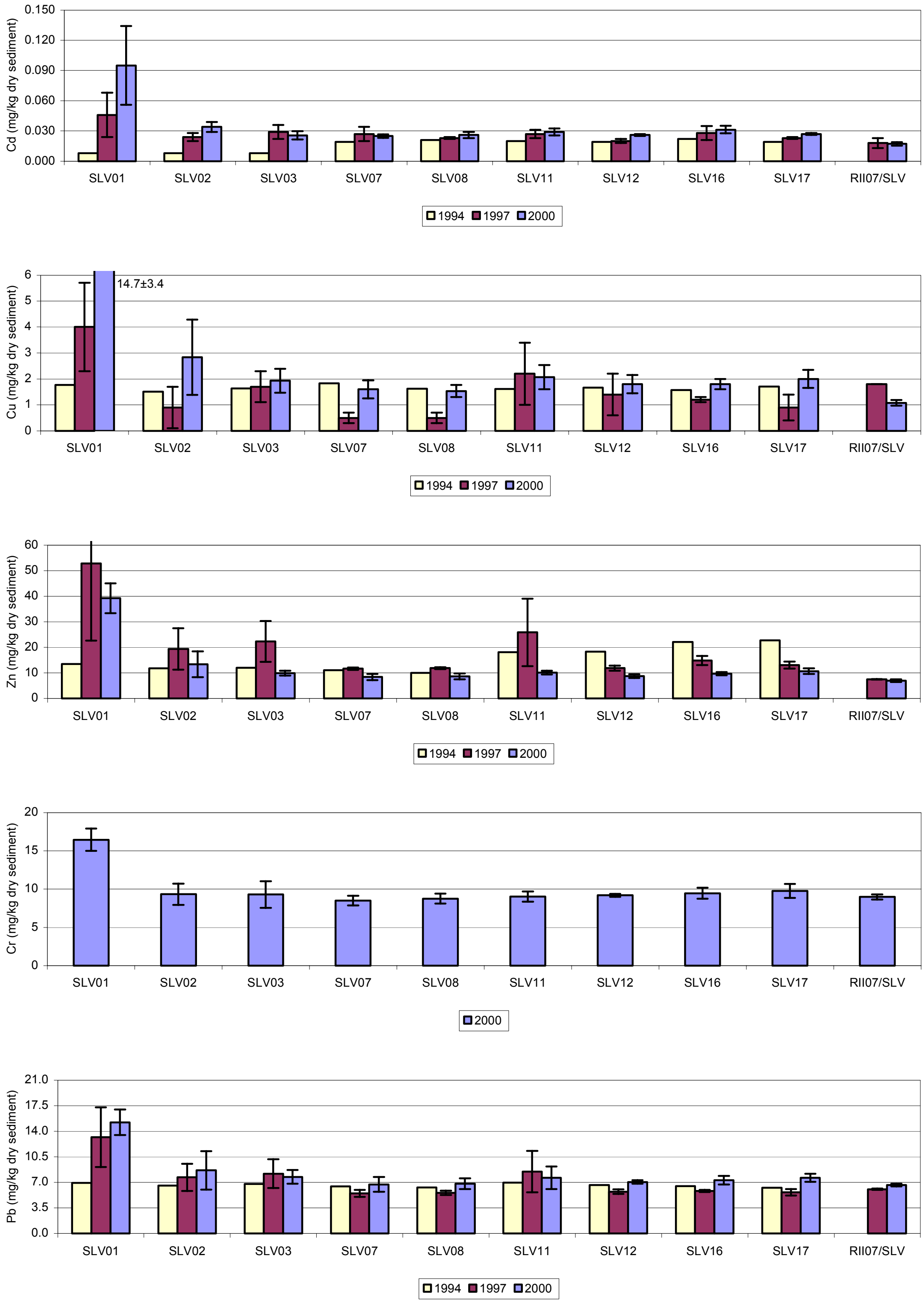

Figure 18-5: Levels of selected metals in sediments from the present (2000) and previous surveys, Sleipner Vest field.

18.2.3 Biology

The distribution of individuals and taxa within the main taxonomic groups are given in Table 18-8. A total of 6136 individuals within 216 taxa were registered at the Sleipner Vest field in the present survey (excluding juveniles). The polychaetes dominate the fauna with 65 % of the individuals and 52 % of the taxa recorded.

Table 18-8: Distribution of individuals and taxa within the main taxonomic groups at Sleipner Vest, 2000 (excluding juveniles).

Main taxonomic groups	Individuals		Taxa	
	Number	%	Number	%
Polychaeta	4012	65	112	52
Mollusca	828	13	42	19
Crustacea	335	5	37	17
Echinodermata	470	8	8	4
Diverse groups	491	8	17	8
Total	6136	100	216	100

The species/area curve for the reference station RII07 is shown in Figure 18-6. A total of 116 taxa are registered in the ten grab samples, of which 45 (38 %) occur in the first sample and 90 (77 %) in the first five samples. The shape of the curve indicates that not all taxa in the area are present in the ten grab samples and the representativity of five samples seems to be relatively low compared with the curves form other reference stations in the region.

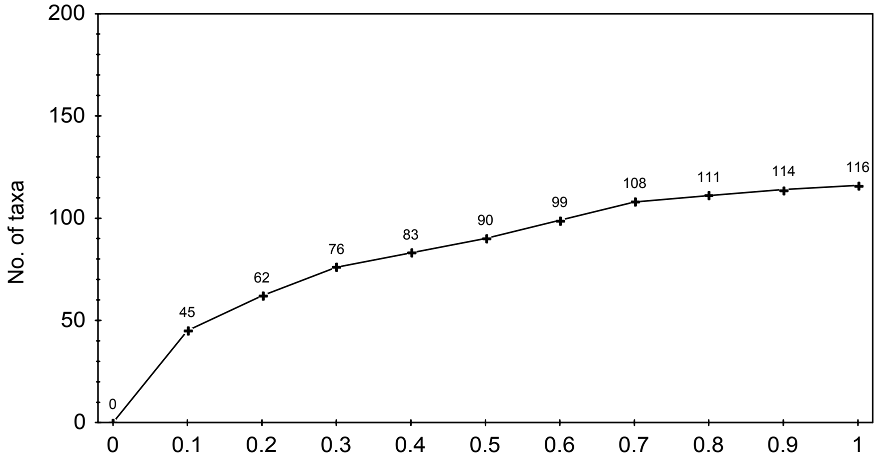

Figure 18-6: Species/area curve for the RII07 the Sleipner Vest field (area in m^2).

The number of individuals and taxa at each station, together with selected community indices is presented in Figure 18-7 and Table 18-9. The number of individuals recorded at Sleipner Vest varies from 327 (SLV16) to1173 (SLV01). The number of taxa varies from 72 (SLV01) to 113 (SLV17), the diversity index H' between 3.9 (SLV01) to 5.8 (SLV17), the evenness index J between 0.64 (SLV01) to 0.86 (SLV07, SLV11 and SLV17) and the ES_{100} between 23 (SLV01) to 50 (SLV17). The corresponding values at the reference station RII07 are within the variation recorded at the field stations.

The number of individuals and taxa has decreased at all stations since the previous survey in 1997. The diversity has increased at most stations in the same period with the exception of station SLV01 where a decrease has occurred.

Table 18-9: Number of individuals and taxa and selected community indices for each station (0.5 m^2) at the Sleipner Vest field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	No. of ind	No. of taxa	H'	J	ES_{100}
SLV01	**1173**	**72**	**3.9**	**0.64**	**23**
SLV02	764	97	5.5	0.83	43
SLV03	653	94	5.6	0.85	44
SLV07	411	95	5.6	**0.86**	48
SLV08	489	95	5.2	0.79	44
SLV11	423	84	5.5	**0.86**	44
SLV12	580	107	5.6	0.83	45
SLV16	**327**	78	5.4	0.85	44
SLV17	624	**113**	**5.8**	**0.86**	**50**
RII07	692	90	5.1	0.78	39
Sum*	4271				
Average*	534	95	5.5	0.84	45
St. dev*	146	11	0.2	0.02	2

* Excluding the reference station.

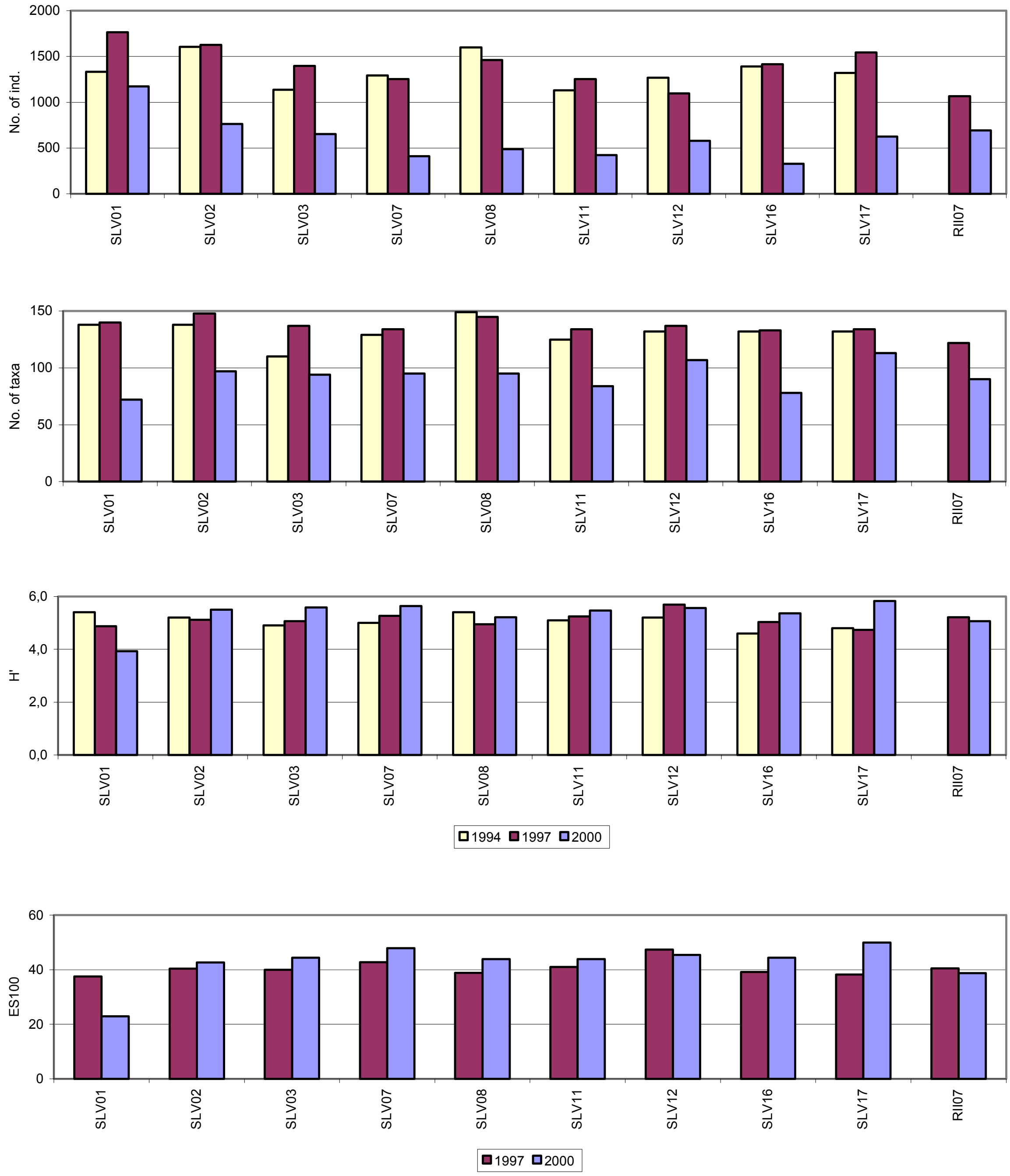

Figure 18-7: Biological characteristics at the stations at Sleipner Vest, 2000 and previous surveys.

The distribution of taxa in geometrical classes is shown in Figure 18-8. One station (SLV01) has taxa in class 8 (128 – 255 individuals) while the rest of the stations have taxa in class 7 or lower (< 128 individuals). Occurrence of taxa in high classes might indicate faunal disturbance. This is not seen in the result form this analysis.

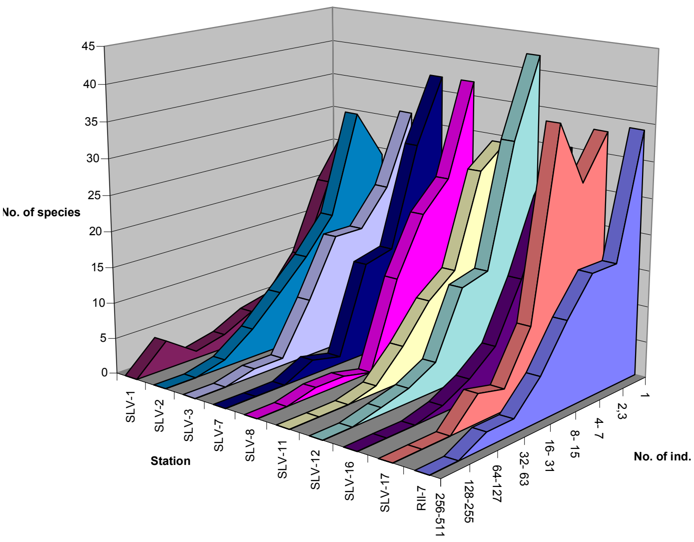

Figure 18-8: Distribution of taxa in geometrical classes at each station at Sleipner Vest, 2000.

The ten most dominant taxa at each station are shown in Table 18-12 at the end of this chapter. A total of 33 taxa, inclusive four juvenile groups, are among the ten most dominant taxa at one or more stations. These 33 taxa comprise 73 % of the total number of individuals and 15 % of the total number of taxa recorded at the Sleipner Vest field in the present survey.

The most dominant taxa among the adult forms are the polychaetes *Paramphinome jeffreysii*, *Galathowenia oculata*, *Spiophanes bombyx*, *Chaetozone setosa, Ampharete falcata,* the brittle star *Amphiura filiformis* and the nemertini group Nemertini indet. The polychaeta *P. jeffreysii* is among the five most dominant taxa at all stations. The brittle star *A. filiformis* and the polychaeta *G. oculata* are among the five most dominant species at six and four stations respectively. The brittle star *A. filiformis* is not among the ten most dominant taxa at stations SLV01, SLV02 and SLV16, where *C. setosa* is among the five most dominants. These results might indicate some faunal disturbance.

The ten most abundant taxa at the stations comprise between 43 % (station SLV07) and 81 % (station SLV01) of the total number of individuals registered at the respective stations. The corresponding value at the reference station RII07 is 58 %.

Figure 18-9 shows the dendrogram from the cluster analysis for the field stations and regional and reference stations while Figure 18-10 shows the 2-D plot from the MDS analysis.

In the cluster analysis, the field station SLV01 is separated from the other stations at 52 % dissimilarity level while the reference station RII07 is separated out at 45 % level. Further, stations SLV11 and SLV16 are separated out at 35 % while stations SLV02 and SLV03 are separated out dissimilarity level just below 35 %. The remaining field stations are further separated from each other at dissimilarity level between 35 and 27 %. The correlation coefficient shows a very good fit to the data (r =0.95).

The MDS analyses supports the cluster analysis with station SLV01 and the reference station RII07 isolated from the main group of stations in the lower left corner of the 2-D plot. The stress test shows a good fit to the data (0.13).

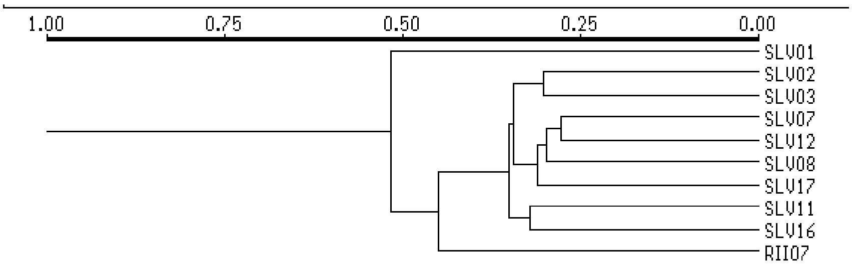

Figure 18-9: Cluster analysis of the Sleipner Vest field and reference stations, 2000.

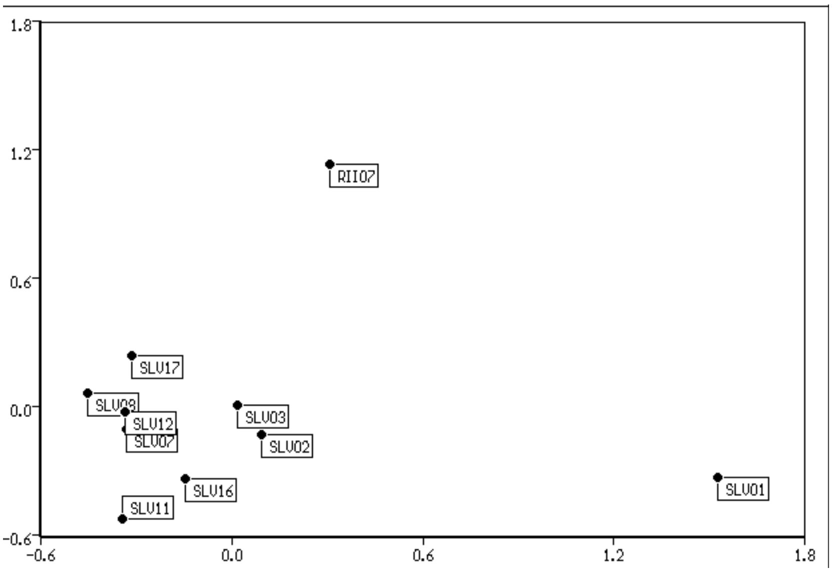

Figure 18-10: 2-D plot from the MDS analysis carried out on the Sleipner Vest field and reference stations, 2000.

A Canonical Correspondence Analysis (CCA) of the data from the Sleipner Vest field and reference stations was carried out to examine the association between the biological data and the measured environmental variables in these areas.

Through the forward selection procedure in CANOCO, three of ten variables gave the best fit and are significant. 53.7 % of the biological variance was explained by the first two axes of the ordination space which is constrained by these environmental variables.

Figure 18-11 shows a biplot from the analysis using barium (Ba), pelite (Pel) and fine sand (FS) as the constraining environmental variables together with a plot of the taxa with the highest contribution on two axes. The first axis shows a gradient from field station SLV01 at the positive end to station SLV08 on the negative end and is correlated with the amount of fine sand (- 0.86), pelite (+ 0.87) and barium (+ 0.67) in the sediments. Taxa with highest contribution on this axis are the polychaetes *Chaetozone setosa* (23.9 %) and *Diplocirrus glaucus* (4.6 %), the nemertini group Nemertini indet. (11.5 %), the brittle star *Amphiura filiformis* (9.5 %) and the bivalve *Thyasira sarsi* (5.6 %).

The second axis shows a gradient from reference station RII07 on the positive end to field station SLV02 at the negative end and is negative correlated with the amount of barium (- 0.71) and fine sand (- 0.50) in the sediments. Taxa with highest contribution on this axis are the polychaete *Galathowenia oculata* (9.3 %), the brittle star *Amphiura filiformis* (8.7 %) and the bivalve *Thyasira equalis* (3.8 %).

The taxa, which are known to increase in abundance (i.e. *Chaetozone setosa*, *Thyasira sarsi* and Nemertini indet.), are associated with station SLV01 located on the positive end on the first axis in the CCA plot.

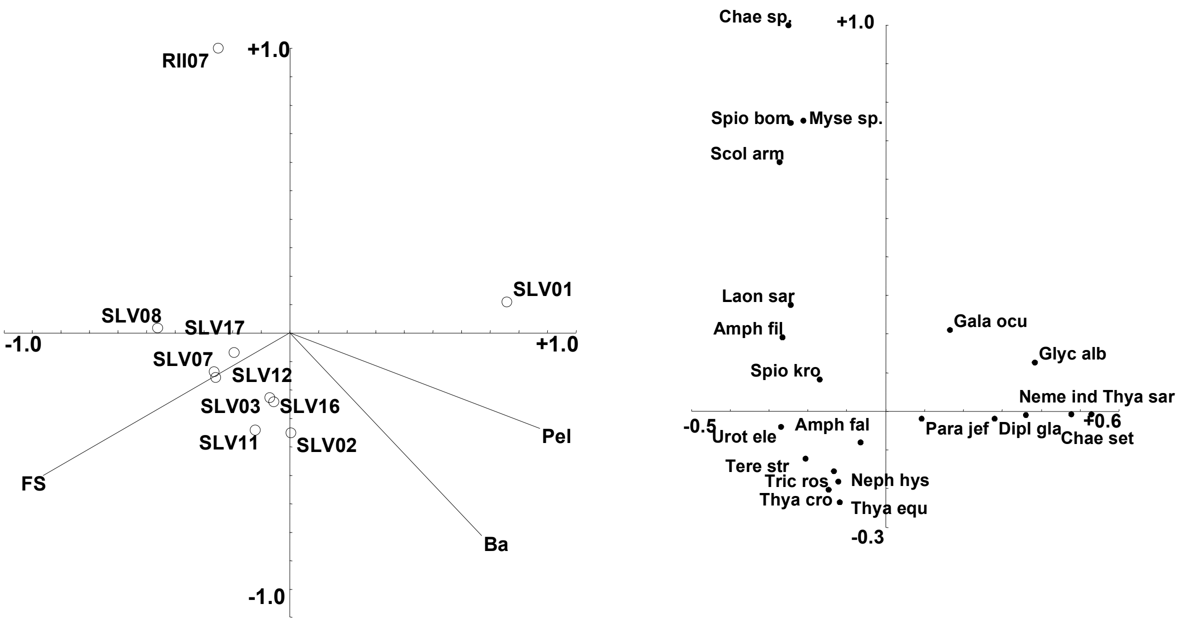

Figure 18-11: Biplot from the CCA analysis for the Sleipner Vest field and reference stations, 2000 (left) and plot of taxa with high contribution on two axes (right).

On the basis of the results from the uni- and multivariate analyses the stations at Sleipner Vest is classified in two faunal groups in the present survey. Station SLV01 is placed in group B (slightly disturbed fauna) while the other stations are placed in group A (undisturbed fauna). Station SLV01 has relatively high abundance of the polychaetes *Paramphinome jeffreysii*, *Diplocirrus glaucus* and *Chaetozone* sp. and the bivalve *Thyasira sarsi*, many of which are known to increase in individual numbers in disturbed sediments. The same station has low abundance of the brittle star *Amphiura filiformis* and the polychaete *Spiophanes kroyeri,* which decrease in numbers in disturbed sediments. This station was separated from all other field stations in the multivariate analyses and has relatively high levels of THC and highest levels of all measured heavy metals in the sediments compared with the other field stations.

Both the numbers of taxa and individuals has decreased remarkably at all stations on Sleipner Vest since 1997. Among the dominant taxa, the polychaetes *Galathowenia oculata* and *Paramphinome jeffreysii*, has decreased from several hundred individuals per stations to less than 100 individuals. Also other dominant taxa are recorded with lower individual number in the present survey.

In the previous survey in 1997 the fauna was found to be undisturbed at all stations. The faunal disturbance seen in the present survey, therefore, is related to the petroleum activity at the field installation in the last three years.

Table 18-10: Classification into impact groups, distance to installation and biological statistics for the field stations at Sleipner Vest field, 2000.

Station	Impact group	Dist. (m)	Statistics			No. of individuals								
			No. ind	No. taxa	H'	Afi	Goc	Skr	Nin	Pje	Dgl	Ppa	Csp	Tsa
SLV01	B	250	1173	72	3,9	1	135	1	150	230	88	7	218	44
SLV02	A	500	764	97	5,5	10	41	28	29	88	15	24	33	10
SLV03	A	1000	653	94	5,6	50	25	12	27	67	5	10	27	1
SLV07	A	500	411	95	5,6	33	2	9	10	56	9	2	10	1
SLV08	A	1000	489	95	5,2	107	5	10	4	58	8	0	6	0
SLV11	A	500	423	84	5,5	15	7	14	17	52	20	4	9	0
SLV12	A	1000	580	107	5,6	47	11	19	9	77	11	2	4	0
SLV16	A	500	327	78	5,4	2	4	8	7	49	11	3	17	6
SLV17	A	1000	624	113	5,8	39	50	11	12	60	10	4	1	0
RII07	A		692	90	5,1	113	92	36	8	58	6	11	19	0

Afi = *Amphiura filiformis,* Goc = *Galatowenia oculata*, Skr = *Spiophanes kroyeri*, Nin = Nemertini indet., Pje = *Paramphinome jeffreysii*, Dgl = *Diplocirrus glaucus*, Ppa = *Pseudopolydora pauchibranchiata*, Csp = *Chaetozone* sp. (incl. *C. setosa*), Tsa = *Thyasira sarsi*.

18.3 Summary and conclusions

The sediments at Sleipner Vest are classified as fine sand with a relatively high amount of pelite (11 - 25 %) and TOM (1.9 – 4.5 %). There is a general trend of increase in the amount of pelite and TOM at the stations at Sleipner Vest sin the previous survey in 1997. At station SLV01 the level of both parameters has increased remarkably, the pelite from 10 to 25 % and the TOM from 2 to 4.5 %. This station is situated 250 m north of the field centre and it is believed that the increase is a result of discharges from the installation.

The highest concentrations of THC (80-180 mg/kg) and barium (1593-3232 mg/kg) are found in the main current direction from the installation (10^{o}-axis). The area significantly contaminated with THC extends out to 1000 m on the 10^{o}-axis and out to 500 m on the 190^{o}- and 280^{o}-axes. The profile of mineral oil is visible in the gas chromatograms of hydrocarbon extracts from contaminated stations. According to data on recent drilling, oil based mud was accidentally discharged during the first quarter of 2000. The whole are investigated are significantly contaminated with barium. The remaining of the selected metals are contaminated out to 1000 m at the 10^{o}-axis and out to 500 m on the 190^{o}- and 280^{o}-axes. In 1997, the same stations as this year were regarded as significant contaminated with THC while the whole field was deemed contaminated with barium, cadmium and zinc.

Compared to the 1997 results the THC levels have increased at all stations in the main current direction and at the innermost station on the 280^{o}-axis. At the remaining stations the THC content is almost unchanged since 1997. The barium content has increased over the whole Sleipner Vest field. The only exceptions are found at the outermost station in the main current direction and at the outermost station on the 100^{o}-axis, where the contents have decreased since 1997. Increased amount of cadmium, lead and copper are found at the two innermost stations in the main current direction, while the content of zinc has clearly decreased over the whole field.

Both the numbers of taxa and individuals has decreased remarkably at all stations on Sleipner Vest since 1997. Among the dominant taxa, the polychaetes *Galathowenia oculata* and *Paramphinome jeffreysii*, has decreased from several hundred individuals per stations to less than 100 individuals. Also other dominant taxa are recorded with lower individual number in the present survey.

The multivariate analyses indicates that, with the exception of SLV01, the fauna has a relatively uniform distribution over the field in the present survey. Station SLV01 was separated from the other stations in the cluster, MDS and CCA analyses. At this station, taxa that are relatively abundant in disturbed sediments (i.e. the polychaete *Chaetozone setosa* and the bivalve *Thyasira sarsi*), dominate while taxa that are typically reduced in individual number in disturbed sediments (i.e. the brittle star *Amphiura filiformis* and the polychaete *Spiophanes kroyeri*), occur in very low numbers. This station is, therefore, classified as a group B station (slightly disturbed fauna) while the rest of the stations are classified as group A stations (undisturbed fauna). At the same time relatively high levels of THC and highest levels of all heavy metals in the sediments are registered at station SLV01.

In the previous survey in 1997 the fauna was found to be undisturbed at all stations. Therefore it is concluded that the faunal disturbance seen at station SLV01 in the present survey, is related to the petroleum activity at the field installation in the last three years.

The calculated minimum area and spatial extent of contaminated sediments and disturbed fauna at the Sleipner Vest field is shown in Table 18-11 and Figure 18-12.

Table 18-11: Distance along the transects and calculated minimum area of contaminated sediments and disturbed fauna at the Sleipner Vest field, 2000 and previous survey.

Sleipner Vest	N	E	S	W	Km^2 (2000)	Km^2 (1997)
Group B	250	125	125	125	0.07	0.00
THC	1000	125	500	500	0.74	0.88
Ba	1000	1000	1000	1000	3.14	3.14
Other metals	1000	125	500	500	0.74	3.14

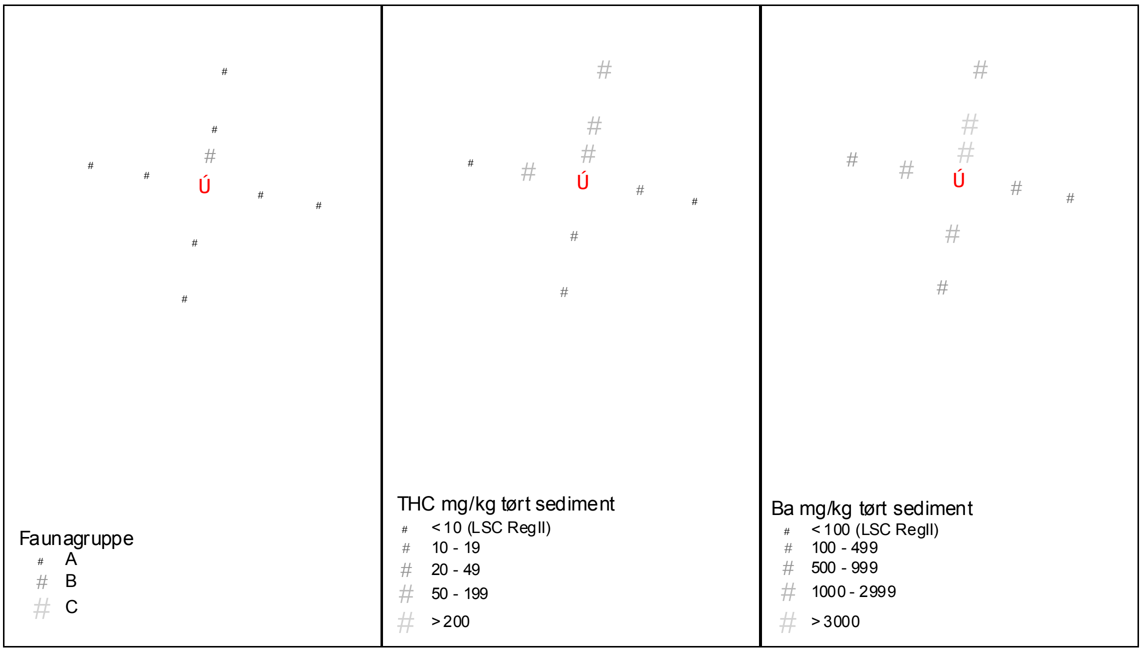

Figure 18-12: Distribution of disturbed fauna and the amounts of THC and barium in the sediments at the Sleipner Vest field, 2000.

Table 18-12: Number of individuals and the accumulative abundance for the ten most dominant taxa at each station at the Sleipner Vest field, 2000.

SLV01 (10°/ 250 m)	No. ind	Acc. %	SLV02 (10°/ 500 m)	No. ind	Acc. %	SLV03 (10°/ 1000 m)	No. ind	Acc. %	SLV07 (100°/ 500 m)	No. ind	Acc. %	SLV08 (10°/ 1000 m)	No. ind	Acc. %
Paramphinome jeffreysii	230	18 %	Paramphinome jeffreysii	88	11 %	Paramphinome jeffreysii	67	10 %	Paramphinome jeffreysii	56	13 %	Amphiura filiformis	107	21 %
Chaetozone setosa	218	36 %	Ampharete falcata	60	18 %	Amphiura filiformis	50	17 %	Amphiura filiformis	33	21 %	Paramphinome jeffreysii	58	32 %
Nemertini indet.	150	47 %	Galathowenia oculata	41	23 %	Ampharete falcata	31	22 %	Thyasira croulinensis	16	24 %	Eudorella emarginata	15	35 %
Galathowenia oculata	135	58 %	Chaetozone setosa	33	27 %	Chaetozone setosa	27	26 %	Polydora coeca	14	27 %	Urothoe elegans	15	38 %
Diplocirrus glaucus	88	65 %	Parvicardium minimum	33	31 %	Nemertini indet.	27	30 %	Terebellides stroemi	14	31 %	Terebellides stroemi	13	40 %
Natatolana borealis juv.	69	71 %	Nemertini indet.	29	35 %	Galathowenia oculata	25	34 %	Ampharete falcata	12	33 %	Phaxas pellucidus	12	43 %
Thyasira sarsi	44	74 %	Spiophanes kroyeri	28	38 %	Nephtys hystricis	24	37 %	Asteroidea indet. juv.	12	36 %	Thyasira equalis	12	45 %
Glycera alba	43	77 %	Thyasira equalis	27	41 %	Thyasira croulinensis	20	40 %	Chaetozone setosa	10	38 %	Thyasira croulinensis	11	47 %
Parvicardium minimum	25	79 %	Trichobranchus roseus	25	44 %	Mugga wahrbergi	18	43 %	Laonice sarsi	10	41 %	Pectinaria sp. juv.	10	49 %
Cirratulus caudatus	23	81 %	Pseudopolydora paucibranchiata	24	47 %	Trichobranchus roseus	18	45 %	Nemertini indet.	10	43 %	Spiophanes kroyeri	10	51 %
SLV11 (190°/ 500 m)	No. ind	Acc. %	SLV12 (190°/ 1000 m)	No. ind	Acc. %	SLV16 (280°/ 500 m)	No. ind	Acc. %	SLV17 (280°/ 1000 m)	No. ind	Acc. %	RII07 (58°15.00'/01°40.00')	No. ind	Acc. %
Paramphinome jeffreysii	52	11 %	Paramphinome jeffreysii	77	12 %	Paramphinome jeffreysii	49	14 %	Paramphinome jeffreysii	60	9 %	Amphiura filiformis	113	16 %
Thyasira equalis	26	17 %	Amphiura filiformis	47	20 %	Thyasira croulinensis	25	22 %	Galathowenia oculata	50	17 %	Galathowenia oculata	92	29 %
Asteroidea indet. juv.	24	22 %	Ampharete falcata	42	27 %	Thyasira equalis	19	27 %	Ampharete falcata	41	23 %	Paramphinome jeffreysii	58	37 %
Terebellides stroemi	23	27 %	Eudorella emarginata	23	30 %	Chaetozone setosa	17	32 %	Amphiura filiformis	39	29 %	Spiophanes kroyeri	36	42 %
Diplocirrus glaucus	20	32 %	Terebellides stroemi	23	34 %	Trichobranchus roseus	13	36 %	Nephtys hystricis	27	33 %	Laonice sarsi	22	45 %
Eudorella emarginata	17	35 %	Asteroidea indet. juv.	21	37 %	Diplocirrus glaucus	11	39 %	Polydora coeca	19	36 %	Ampharete falcata	19	48 %
Nemertini indet.	17	39 %	Spiophanes kroyeri	19	40 %	Polydora coeca	10	42 %	Thyasira croulinensis	17	39 %	Chaetozone sp.	19	51 %
Amphiura filiformis	15	42 %	Anobothrus gracilis	16	43 %	Eudorella emarginata	9	45 %	Terebellides stroemi	13	41 %	Phoronis sp.	18	53 %
Thyasira croulinensis	15	46 %	Urothoe elegans	15	45 %	Abyssoninoe scopa aequilobata	8	47 %	Nemertini indet.	12	43 %	Anobothrus gracilis	16	55 %
Spiophanes kroyeri	14	49 %	Ophiuroidea indet. juv.	14	48 %	Spiophanes kroyeri	8	50 %	Spiophanes kroyeri	11	44 %	Pectinaria auricoma	16	58 %

Table 18-13: Station information for Sleipner Vest field, 2000.

St. no.	Distance (m)	Direction (degr.)	Volume (litres)
SLV01	250	10	64
SLV02	500	10	49
SLV03	1000	10	58
SLV07	500	100	60
SLV08	1000	100	44
SLV11	500	190	44
SLV12	1000	190	40
SLV16	500	280	45
SLV17	1000	280	44
RII07	18000	190	43 *

* The additional five grab samples taken gave 34 litres of sediment.

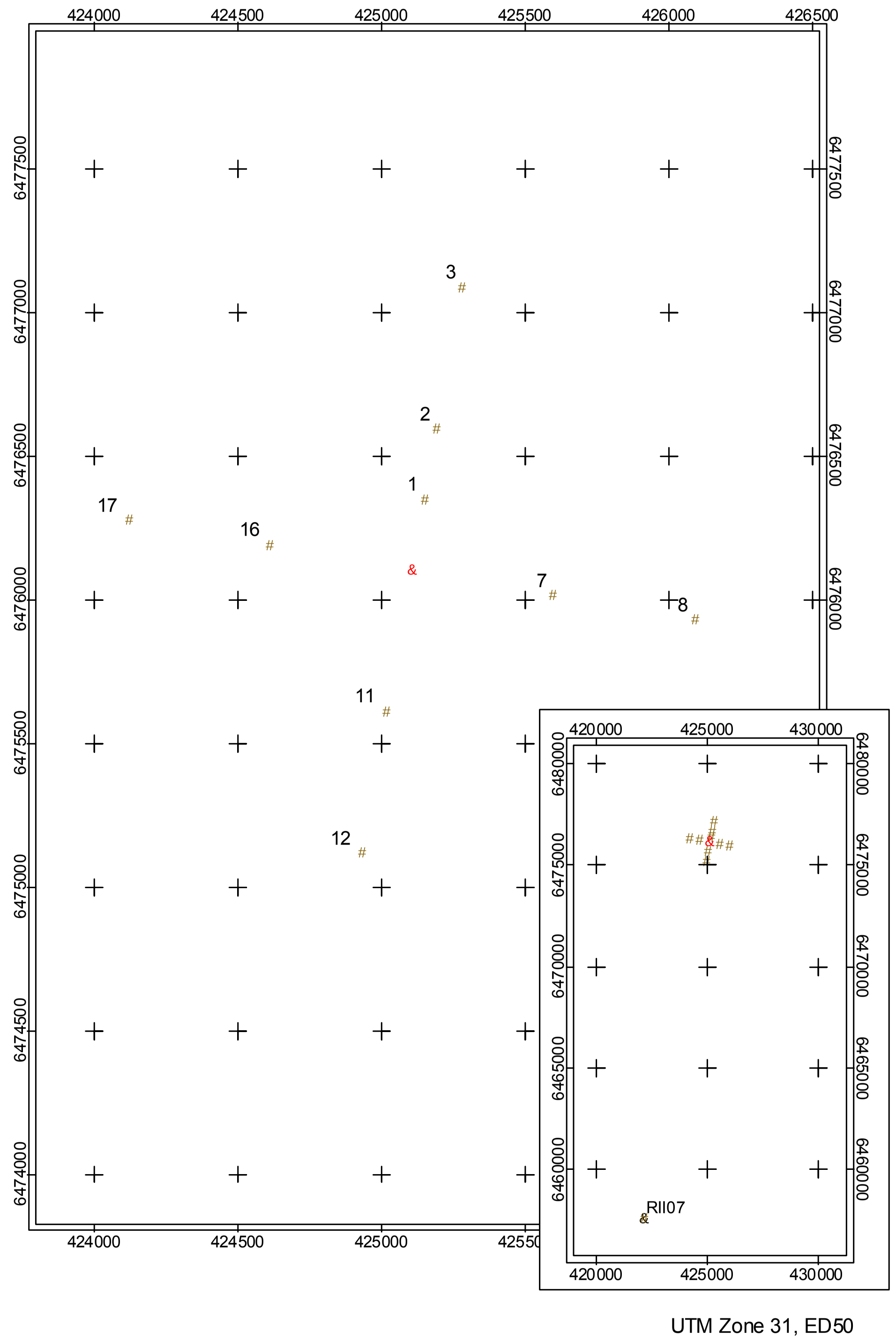

Figure 18-13: Map of sampling positions for Sleipner Vest field, 2000.

19 Sleipner Øst field

19.1 Introduction

The Sleipner Øst field includes the SLA platform and the two templates Loke and SLE. The field is located in Block 15/8 in the Norwegian sector of the North Sea, situated north of the Varg field in the southern part of Region II. Production at the field started in 1993. Data on recent drilling and discharges are given in Table 19-1. There have been no discharges from SLE since the previous survey. An accidental discharge of olefin based mud (7 tonnes) occurred at Loke in 1998 while 10 tonnes of diesel condensate was released at SLA the same year.

At this field baseline and monitoring surveys have been carried out in 1992 (Thorvaldsen & Jensen, 1993), 1993 (Neverdal & Stokland, 1994) and in 1997 (Mannvik *et al.* 1998). Compared with data from 1992 and 1993, the survey in 1997 revealed that the levels of hydrocarbons and selected metals were almost unchanged or reduced, with exception of station SLE24 where the THC, cadmium, lead, zinc, and copper levels had increased. At LOK5 the THC and barium concentrations had been reduced.

The number of individuals and species in 1997 were higher than those recorded in the 1993 survey and more comparable with data from 1992. The condition in the sediment had improved since 1993. In 1997 only LOK5 were characterised as slightly disturbed (Group B). One station at Sleipner Øst and three stations at Sleipner A (SLE24 and SLA 29, SLA33 and SLA 37) had changed from undisturbed in 1993 to slightly disturbed (Group B) in 1997. All Group B stations were at 250-500 m distance from their respective centre.

Information on the sampling stations is shown in Figure 19-14 and Table 19-13, both on the foldout page at the end of this chapter (page 19-25).

Table 19-1: Summary of recent wells drilled and operational and accidental discharges at the Sleipner Øst field (all discharges in tonnes).

	Year	SLA	Loke	Comments
No of wells drilled	1998	0	1	
	1999	0	0	
	2000	1	0	
Barite	2000	239	0	
Cuttings	2000	955	0	
Synthetic drilling mud	2000	120	0	
Water-based drilling mud	1998	0	252	
	1999	0	0	
	2000	593	0	
Cementing chemicals	2000	48	0	
Oil in produced water	1997	2 *	0	Occur at SLE
	1998	1 *	0	Occur at SLE
	1999	0.4 *	0	Occur at SLE
	2000	0.17 *	0	Occur at SLE
Accidental discharges	1997	2.4	0	
	1998	10 [1]	7 [2]	[1] Diesel condensate; [2] Olefin based mud
	1999	2.3	0	
	2000	1	0	

19.2 Results and discussion

19.2.1 Physical characteristics

The median phi value and the amount (%) of pelite, fine sand and total organic material (TOM) in the sediment from the present and previous surveys shown in Table 19-2 and Figure 19-1. 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 in the Sleipner Øst field are classified as fine sand with median values around 3.50 at all stations. The amount of pelite in the sediment varies from 1.73% (SLA28) to 3.2 % (LOK04), the fine sand from 93.5 % (SLA31) to 95.4 % (SLA34) while the TOM varies from 0.70 % (SLA34) to 0.92 % (SLE21). The corresponding values at the reference station SLE41R are at similar levels. This indicates that the sediment structure at the field is relatively uniform.

The amount of pelite has increased at all Loke stations and some of the Sleipner Øst stations since the previous survey in 1997. At station SLE24 a considerably decrease in the TOM is registered. Otherwise the sediment is relatively similar between the two surveys.

The change in the median value from 1992 to 1997 is believed to be a result of different ways of calculating that value.

Table 19-2: The median (phi) and amount of pelite, fine sand and TOM in the sediment from stations at the Sleipner Øst field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	Distance (m)	Direction (degr.)	Median	Classification	Pelite	Fine sand	TOM
LOK03	500	10	3.51	Fine sand	2.71	94.1	0.83
LOK04	250	10	3.52	Fine sand	**3.20**	93.6	0.91
LOK05	250	100	3.51	Fine sand	2.80	94.1	0.80
LOK06	500	100	3.52	Fine sand	2.70	94.3	0.78
LOK08	250	280	3.51	Fine sand	2.79	93.9	0.84
LOK11	250	190	3.52	Fine sand	2.83	94.3	0.83
SLE16	500	10	3.51	Fine sand	2.49	94.6	0.84
SLE17	250	10	3.52	Fine sand	2.41	94.9	0.78
SLE18	250	100	3.51	Fine sand	2.35	94.7	0.75
SLE21	250	280	3.52	Fine sand	2.42	95.1	**0.92**
SLE24	250	190	3.52	Fine sand	2.76	94.5	0.77
SLA27	2000	10	3.51	Fine sand	2.02	94.3	0.75
SLA28	1000	10	3.50	Fine sand	**1.73**	94.5	0.65
SLA29	500	10	3.51	Fine sand	2.00	94.6	0.74
SLA30	500	90	3.51	Fine sand	1.93	94.9	0.71
SLA31	1000	100	3.51	Fine sand	2.19	**93.5**	0.72
SLA33	250	190	3.50	Fine sand	1.86	94.2	0.77
SLA34	500	190	3.51	Fine sand	1.85	**95.4**	**0.70**
SLA37	250	280	3.51	Fine sand	1.74	95.1	0.72
SLA38	500	280	3.51	Fine sand	1.95	94.2	0.75
SLE41R	5000	100	3.48	Fine sand	1.88	90.3	0.75
Average*			3.51		2.34	94.4	0.78
St. dev.*			0.01		0.44	0.5	0.07

*Excluding the reference station.

Figure 19-1: Sediment characteristics at the Sleipner Øst field, 2000 and previous surveys.

19.2.2 Chemical characteristics

The Sleipner Øst field is located in the shallow area of Region II. The calculated limits of significant contamination for selected hydrocarbons and metals in sediments from the shallow area ($LSC_{97\text{-}00\ shallow\ RegII}$) are presented previously in the chapter that deals with the regional and reference stations. In addition to the sub-regional limits, field-specific limits of significant contamination are calculated from the reference station ($LSC_{00\ SIG17R}$). Both sets of data are presented in Table 19-3. Based on analysis results of the Sleipner Øst field, the $LSC_{97\text{-}00\ shallow\ RegII}$ is regarded as representative of this area and will therefore be used as further basis for discussion of the contamination status of this field. Those limits will hereafter simply be referred to as LSC. The sediments from Loke and SLA are, in addition to the standard parameters, analysed for olefins and traces of Petrofree ester. Synthetic base oils as esters and olefins that are included in synthetic drilling muds, are not naturally present in uncontaminated sediments. If these compounds are found in the sediments, the sediments are considered as contaminated.The results of analyses of the hydrocarbons and components of synthetic base oil analyses are summarised in Table 19-4. Concentrations of selected compounds in the vertical sediment sections are presented in Table 19-5. The full data set of replicate measurements and date from previous years are given in the Appendix. THC values from 2000 are compared with those from previous years in Figure 19-4.

Table 19-3: Background levels and Limits of Significant Contamination for the Sleipner Øst field, 2000. All values in mg/kg dry sediment.

	THC	NPD's	3-6 ring	Decalins	Cd	Hg	Cu	Zn	Ba	Cr	Pb
$LSC_{00\ SLE41R}$	8.8	0.018	0.038	0.064	0.008	n.d.	3.7	6.3	40	9.7	6.5
$LSC_{97\text{-}00\ shallow\ RegII}$	6.6	*	*	*	0.008	0.006	1.2	8.1	38	10.2	7.4

*) Regional stations not analysed for NPD's, 3-6 ring aromatics and decalins.

n.d. Not detected at the reference station.

The THC values at the Sleipner Øst field range from background level across the shallow sub region (3.7 mg/kg) to 26 ± 4 mg/kg dry sediment. The content of olefins comprise between values below the limit of quantitation (0.1 mg/kg) to 41 ± 4 mg/kg. The highest contents of THC and olefins are found in sediments from LOK04. Olefins, which are not degenerated during the standard work-up procedure for hydrocarbons are visible in the gas chromatograms of sediment extracts by a characteristic profile. The olefins were quantified from the gas chromatograms by measuring the amounts of olefins against an appropriate external standard. It should be mentioned that it is difficult to distinguish between olefins and THC at stations with high amounts of olefins. By comparing the gas chromatogram profile of the sediment extracts with the profile of different olefin mixtures, the profiles of the sediment extracts seems to correspond with poly-α-olefins with chain length C14 and C16 (Figure 19-2). According to the information about type and amount of operational discharges, spills of 120 tonnes synthetic drilling mud occurred at SLA in year 2000. At Loke, 7 tonnes olefin based mud was accidentally discharged in 1998. Hydrocarbon values above the calculated LSC and olefin values at or above the limit of quantitation are shaded in Table 19-4.

The sediments from Loke and SLA are analysed with regard to traces of the synthetic base oil Petrofree ester. Petrofree ester, which is degenerated during the standard work-up procedure for hydrocarbons, is extracted from the sediment using Soxhlet-extraction. The Petrofree ester consists of five homologous fatty acid esters which is identified in the gas chromatograms of sediment extracts by a characteristic profile. In the gas chromatograms, the two dominating ester compounds are 2-ethylhexyl dodecanoate and 2-ethylhexyl tetradecanoate (Figure 19-3). Petrofree ester is quantified from the gas chromatograms by measuring the amount of Petrofree against known amounts of a pure sample of the original base oil as external standard. The content of Petrofree comprises range from values below the limit of quantitation (0.1 mg/kg) to 2 ± 1 mg/kg dry sediment at LOK05. According to the information about the type and amount of operational discharges Petrofree ester was used in the time period 1994-1996. Ester values at or above the limit of quantitation are shaded in Table 19-4.

Table 19-4: Concentrations of hydrocarbons and synthetic base oils in sediments from the Sleipner Øst field, 2000. All values in mg/kg dry sediment. Hydrocarbon values above $LSC_{97\text{-}00\ shallow\ RegII}$ are dark shaded and values in grey zone light shaded. Olefin and ester values at or above the limit of quantitation are dark shaded.

Station	THC		Olefins		Ester		NPD's		3-6 ring		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
LOK03	8.9	2.1	6.1	5.5	<0.1	-	n.a.		n.a.		n.a.	
LOK04	26.0	4.4	40.9	4.2	0.6	0.3	0.067	0.002	0.058	0.014	1.019	0.130
LOK05	11.4	1.9	21.9	12.1	2.0	0.9	n.a.		n.a.		n.a.	
LOK06	5.8	1.3	0.7	1.2	0.3	0.3	n.a.		n.a.		n.a.	
LOK08	7.3	3.2	2.1	3.6	0.1	0.1	n.a.		n.a.		n.a.	
LOK11	7.9	2.3	<0.1	-	0.2	0.1	n.a.		n.a.		n.a.	
SLE16	5.0	1.2	n.a.		n.a.		n.a.		n.a.		n.a.	
SLE17	3.9	1.3	n.a.		n.a.		0.030	0.013	0.052	0.026	0.011	0.006
SLE18	3.7	0.4	n.a.		n.a.		n.a.		n.a.		n.a.	
SLE21	4.0	0.6	n.a.		n.a.		n.a.		n.a.		n.a.	
SLE24	3.8	0.9	n.a.		n.a.		n.a.		n.a.		n.a.	
SLA27	4.0	0.9	<0.1	-	n.a.		n.a.		n.a.		n.a.	
SLA28	5.1	0.1	1.3	0.6	n.a.		0.008	0.002	0.017	0.001	0.030	0.003
SLA29	10.1	0.3	4.1	0.3	<0.1	-	0.052	0.067	0.085	0.110	0.111	0.014
SLA30	4.8	0.2	<0.1	-	<0.1	-	n.a.		n.a.		n.a.	
SLA31	4.0	0.5	<0.1	-	<0.1	-	n.a.		n.a.		n.a.	
SLA33	12.8	2.4	6.4	2.6	0.1	0.0	n.a.		n.a.		n.a.	
SLA34	5.9	1.7	0.9	0.6	<0.1	-	n.a.		n.a.		n.a.	
SLA37	16.9	3.2	5.8	1.0	<0.1	-	n.a.		n.a.		n.a.	
SLA38	6.1	0.8	0.5	0.2	<0.1	-	n.a.		n.a.		n.a.	
SLE41R	5.4	1.4	<0.1	-	<0.1	-	0.008	0.004	0.020	0.007	0.027	0.016

n.a. Not analysed.

Table 19-5: Concentrations of hydrocarbons and synthetic base oil in vertical sections of the sediment samples from the Sleipner Øst field, 2000. All concentrations in mg/kg dry sediment. Hydrocarbon values above $LSC_{97\text{-}00\ shallow\ RegII}$ are dark shaded and values in grey zone light shaded. Olefin and ester values at or above the limit of quantitation are dark shaded.

Station	Layer (cm)	THC	Olefins	Ester	NPD's	3-6 ring	Decalins
LOK04	0-1	21.9	36.3	1.0	0.066	0.050	0.952
	1-3	73.7	347	1.7	0.219	0.073	0.183
	3-6	9.4	<0.1	0.3	0.032	0.041	0.140
SLE17	0-1	3.1	n.a.	n.a.	0.045	0.069	0.004
	1-3	5.6	n.a.	n.a.	0.080	0.046	0.032
	3-6	5.8	n.a.	n.a.	0.145	0.230	0.021
SLA28	0-1	5.2	1.1	n.a.	0.009	0.016	0.029
	1-3	2.7	0.6	n.a.	0.010	0.017	0.024
	3-6	6.0	<0.1	n.a.	0.018	0.025	0.029
SLA29	0-1	10.4	3.7	<0.1	0.013	0.021	0.126
	1-3	7.3	1.8	<0.1	0.018	0.028	0.094
	3-6	7.4	<0.1	<0.1	0.029	0.042	0.068
SLE41R	0-1	4.5	<0.1	<0.1	0.006	0.019	0.014
	1-3	4.4	<0.1	<0.1	0.007	0.020	0.024
	3-6	4.7	<0.1	<0.1	0.009	0.026	0.022

n.a. Not analysed.

In general, low THC concentrations (4-5 mg/kg) are found in the sediments around SLE. The core sample from SLE17 has THC content at or only slightly above the background level down to 6 cm depth. Gradients of decreasing THC and olefin contents with increasing distance from the centre are found on the Loke 10°- and 100 °–axes and on the SLA 10 ° -, 190 ° – and 280°- axes. The highest contents of THC and olefins are found at LOK04. In addition, LOK03 and SLA29, SLA33 and SLA37 separate out with THC and olefin contents at 9-17 mg/kg and 4-6 mg/kg respectively.

In the present survey at Sleipner Øst, the highest concentrations of THC (74 mg/kg), NPD´s (0.219 mg/kg) and olefins (347 mg/kg) are found in the 1-3 cm layer of the sediment core from LOK04. The content of THC and olefins in the 0-1 cm layer at the same station are 22 and 36 mg/kg respectively. The lower concentrations of THC and olefins in the 0-1 cm layer, might be a result of deposition of fresh drilling mud on the seabed or degeneration of THC and olefins in the top layer.

SLE is uncontaminated with THC and olefins. At Loke THC is contaminated out to 250 m on the 100^{o}-axis and out to 500 m on the 10^{o}-axis, but the THC content at the 500 m is only barely above the LSC. Olefins are contaminated out to 500 m/ 10^{o} and 100^{o} and out to 250 m/ 190^{o}. At SLA THC is contaminated out to 250 m on the 190^{o} and 280^{o}- axes. In addition, THC content slightly above the calculated LSC is found at the 500 m station on the 10^{o}–axis. Olefins are contaminated out to 1000 m/ 10^{o} and 500 m/ 190 ^{o} and 280^{o} at SLA. Traces of Petrofree are found at all the Loke stations except LOK03. At SLA, the only station with detectable amounts of Petrofree is SLA33.

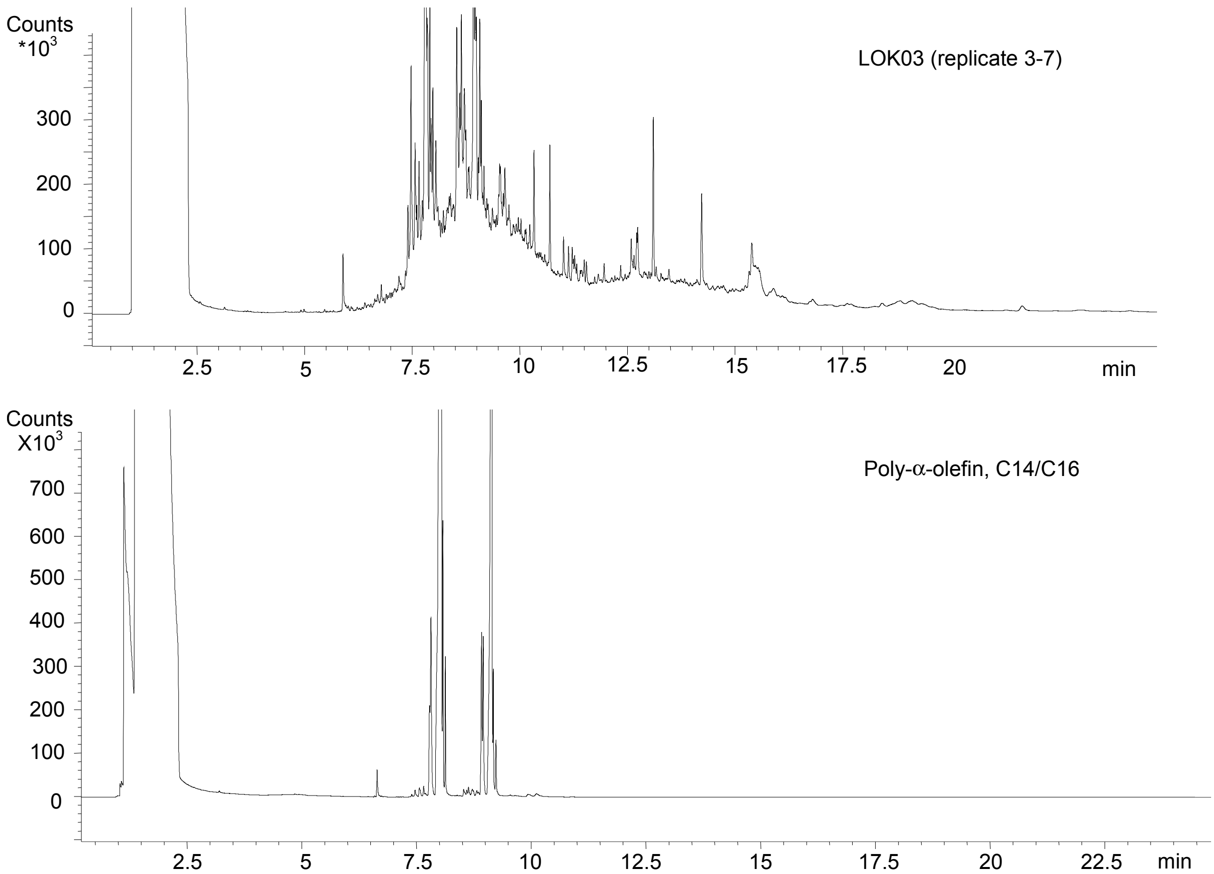

Figure 19-2: Gas chromatogram of C14/C16 poly-a-olefin based base oil (lower) and sediment extract from Loke (upper), 2000.

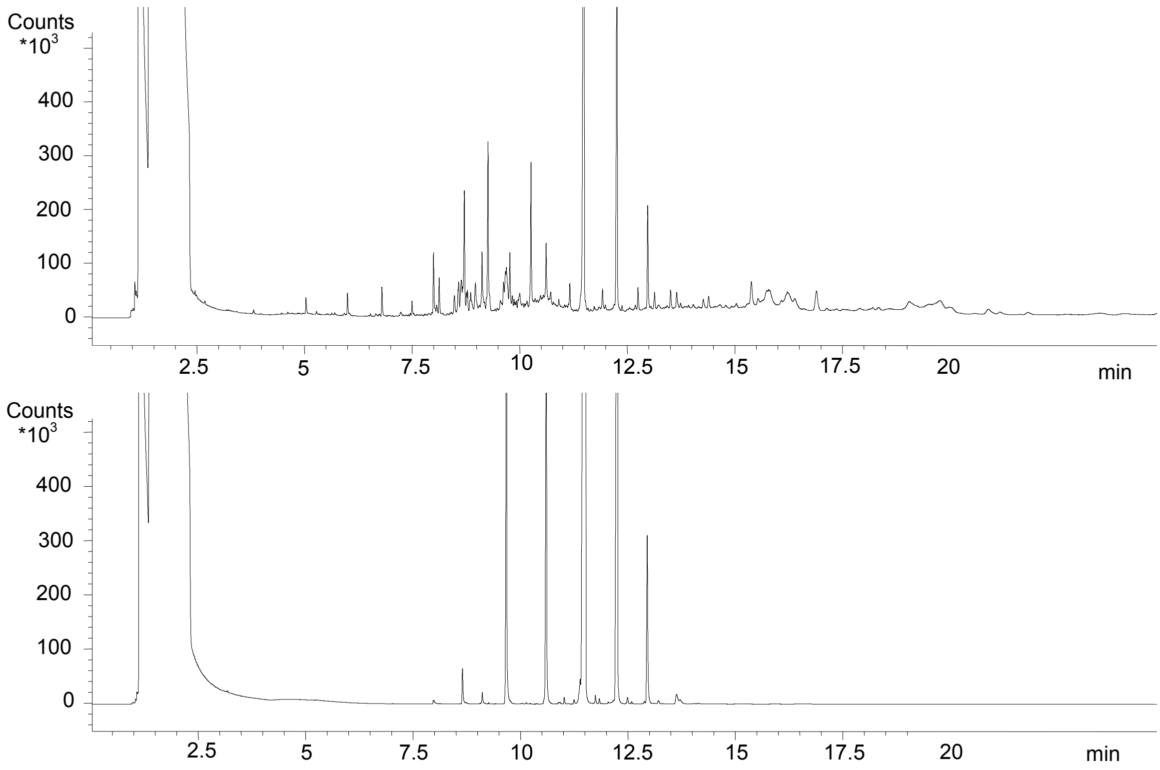

Figure 19-3: Gas chromatogram of Petrofree base oil (lower) and sediment extract from Loke (upper), 2000.

The results of the metal analyses for the Sleipner Øst field are summarised in Table 19-6. Concentrations of selected metals in the vertical sediment sections are presented in Table 19-7. The full data sets of replicate measurements, including selected data from previous years are given in the Appendix. Metal values from 2000 are compared with those from previous years in Figure 19-5 and Figure 19-6.

Table 19-6: Concentrations of selected metals in sediments from the Sleipner Øst field, 2000. All values in mg/kg dry sediment. Values above LSC_{97-00} shallow RegII are dark shaded and values in grey zone light shaded.

	Cd		Hg		Cu		Zn		Ba		Cr		Pb	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
LOK03	0.004	0.001	n.a.		0.9	0.1	4.0	0.2	422	38	7.0	0.1	6.3	0.1
LOK04	0.008	0.002	<0.005	-	2.1	1.6	5.9	1.1	1735	316	7.8	0.4	7.0	0.4
LOK05	0.003	0.001	n.a.		1.1	0.3	4.5	0.3	666	246	7.5	0.3	6.5	0.3
LOK06	<0.005	-	n.a.		0.7	0.1	4.4	0.6	184	48	7.3	0.1	5.7	0.3
LOK08	0.003	0.001	n.a.		1.1	0.6	5.8	1.4	415	11	7.2	0.2	6.5	0.1
LOK11	<0.005	-	n.a.		0.7	0.1	4.6	1.8	594	94	6.4	0.3	5.5	0.3
SLE16	0.010	0.008	n.a.		0.9	0.1	4.8	0.2	63	11	8.2	0.0	5.8	0.2
SLE17	0.004	0.001	<0.005	-	0.7	0.1	4.5	0.1	79	16	7.8	0.2	5.6	0.3
SLE18	0.003	0.001	n.a.		0.8	0.2	4.4	0.4	92	23	7.9	0.1	5.9	0.1
SLE21	0.003	0.001	n.a.		0.7	0.1	4.5	0.2	43	19	8.0	0.3	5.5	0.4
SLE24	0.004	0.001	n.a.		0.9	0.1	4.9	0.1	103	26	8.0	0.1	5.9	0.2
SLA27	<0.005	-	n.a.		0.4	0.2	4.4	0.3	40	13	8.2	0.2	5.8	0.1
SLA28	<0.005	-	<0.005	-	0.4	0.2	4.3	0.1	98	16	7.7	0.2	5.0	0.0
SLA29	0.005	0.002	<0.005	-	0.9	0.1	6.8	1.1	408	132	8.4	0.3	5.7	0.1
SLA30	0.004	0.001	n.a.		0.5	0.2	4.9	0.4	90	41	8.3	0.5	5.5	0.1
SLA31	0.005	0.002	n.a.		0.5	0.2	5.0	0.4	50	2	9.1	0.5	5.8	0.3
SLA33	0.008	0.002	n.a.		1.3	0.3	12.6	4.9	435	66	8.3	0.4	6.7	0.6
SLA34	<0.005	-	n.a.		0.5	0.2	4.8	0.4	179	62	8.0	0.1	5.2	0.2
SLA37	0.003	0.001	n.a.		0.7	0.1	5.9	0.3	802	125	8.2	0.1	5.6	0.3
SLA38	0.004	0.003	n.a.		0.7	0.1	6.8	3.5	74	29	8.2	0.4	5.7	0.7
SLE41R	0.004	0.002	<0.005	-	1.0	1.2	4.3	0.9	18	9	9.1	0.3	6.3	0.1

n.a. Not analysed.

Table 19-7: Concentrations of selected metals in vertical sections of the sediment samples from the Sleipner Øst field. All concentrations in mg/kg dry sediment. Values above LSC_{97-00} shallow RegII are dark shaded and values in grey zone light shaded.

Station	Layer (cm)	Cd	Hg	Cu	Zn	Ba	Cr	Pb
LOK04	0-1	0.007	<0.005	1.4	6.7	1596	8.1	6.9
	1-3	0.011	<0.005	1.6	6.1	1456	8.6	7.0
	3-6	0.011	<0.005	0.8	4.7	255	7.7	6.1
SLE17	0-1	0.005	<0.005	0.6	4.6	74	7.8	5.2
	1-3	0.009	<0.005	0.8	4.9	274	8.1	5.9
	3-6	0.008	<0.005	0.8	5.1	753	7.9	6.3
SLA28	0-1	<0.005	<0.005	<0.6	4.2	100	7.6	5.0
	1-3	<0.005	<0.005	0.6	4.4	169	8.0	5.4
	3-6	0.008	<0.005	0.8	6.2	206	8.4	5.8
SLA29	0-1	<0.005	<0.005	1.0	8.0	282	8.8	5.8
	1-3	0.009	<0.005	0.8	7.1	727	8.1	6.1
	3-6	0.012	<0.005	0.8	8.6	835	8.4	6.0
SLE41R	0-1	0.005	<0.005	<0.6	3.8	13	9.2	6.4
	1-3	0.007	<0.005	<0.6	3.6	30	9.0	6.6
	3-6	0.014	<0.005	0.6	4.0	83	9.6	7.0

n.a. Not analysed.

The content of barium, cadmium, lead, zinc, copper and chromium range from values below or barely above the corresponding background levels across the shallow sub region to 1735 ± 316, 0.010 ± 0.008, 7.0 ± 0.4, 12.6 ± 4.9, 2.1 ± 1.6 and 9.1 ± 0.5 mg/kg dry sediment respectively. The highest concentrations of barium, copper, and lead are found at the station with the highest amount of THC and olefins (LOK04). In addition LOK03, LOK05, LOK08, LOK11 and SLA29, SLA33 and SLA37 separate out with barium content at 400-800 mg/kg. At SLA28 and SLA29 the content of barium increase with increasing depth. Metal concentrations above the calculated LSC are shaded in Table 19-6 and Table 19-7.

Mercury is not detected in any of the sediment samples from the field stations, nor in the sediments from the field-specific reference station.

At SLE the barium content ranges from 40-103 mg/kg. The barium content increased down the sediment core from SLE17 and the 3-6 cm layer contains 10 times more barium than the 0-1 cm layer. Along the four axes at SLA gradients of decreasing barium content with increasing distance from the centres are found. At Loke the highest concentrations of barium are found at the innermost stations. All stations at Sleipner Øst, except SLE21 and SLA 27, are contaminated with barium. With the exception of copper at LOK04 and zinc at SLA33, the remaining of the selected metals are very evenly distributed over the field.

<u>Comparison with previous survey(s)</u>

This year's THC, NPD´s, 3-6 ring aromatics, decalins and metal contents at SLE41R are comparable to the amounts found in 1997 (Mannvik *et al.,* 1998). Analyses of a sediment core from the reference station reveal a uniform distribution of hydrocarbons down to 6 cm depth (Table 19-5), while the content of barium and cadmium increased with increasing depth (Table 19-7). Vertical sediment sections were not analysed for metals in 1997.

Compared to the 1997 results (Figure 19-4) the THC level at most of the Sleipner Øst stations are unchanged or only slightly increased (3-4 mg/kg), while the content of barium is unchanged or reduced. The only exceptions to the overall trend are found for LOK03, LOK04, LOK08 and SLA37 where both THC and barium have increased and for SLE24 where both THC and barium have decreased considerable since 1997. The largest increases in THC and barium contents are found at LOK04, where the contents have increased with 21 mg/kg (THC) and 1350 mg/kg (barium). At SLA37, the THC content has increases with 14 mg/kg and barium with 475 mg/kg. At LOK03 and LOK08 the THC contents have increased with 5 mg/kg of and barium with 250-300 mg/kg. The contents of the remaining of the selected metals are almost unchanged compared to 1997. The only exception is found for SLA24 where the content of cadmium, copper and zinc are only half the 1997 values.

As for the previous survey, the highest concentration of Petrofree ester is found at LOK05, but the amount has decreased from 13 ± 14 mg/kg in 1997 to 2 ± 0.9 mg/kg in 2000. The amounts of Petrofree are considerable reduced since the previous survey, but at Loke traces of Petrofree are found at the same stations as in 1997. Ester is only detected at one station at SLA (SLA33), while traces of Petrofree was found all six SLA stations investigated for ester in 1997.

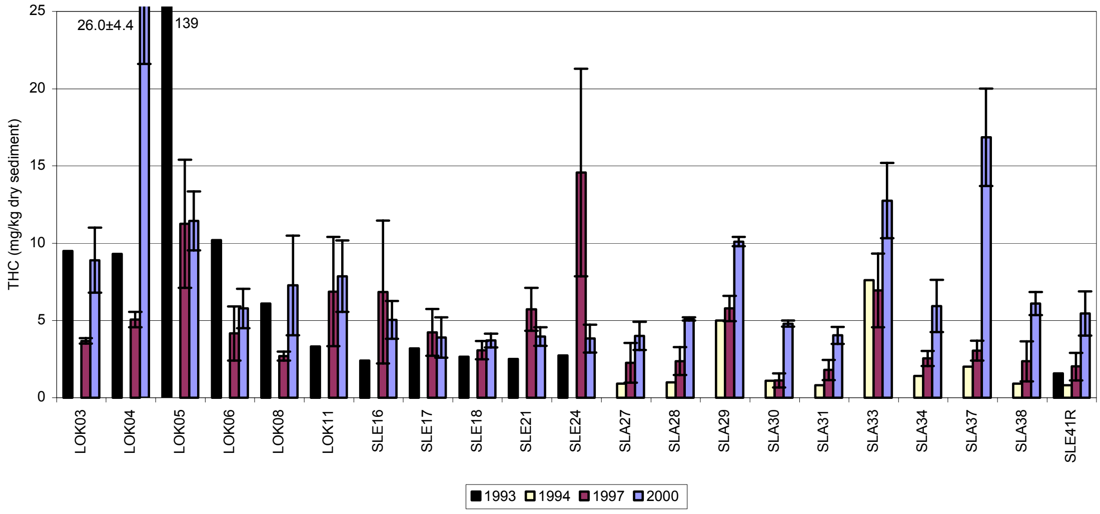

Figure 19-4: THC levels in sediment from the present (2000) and previous surveys, Sleipner Øst field.

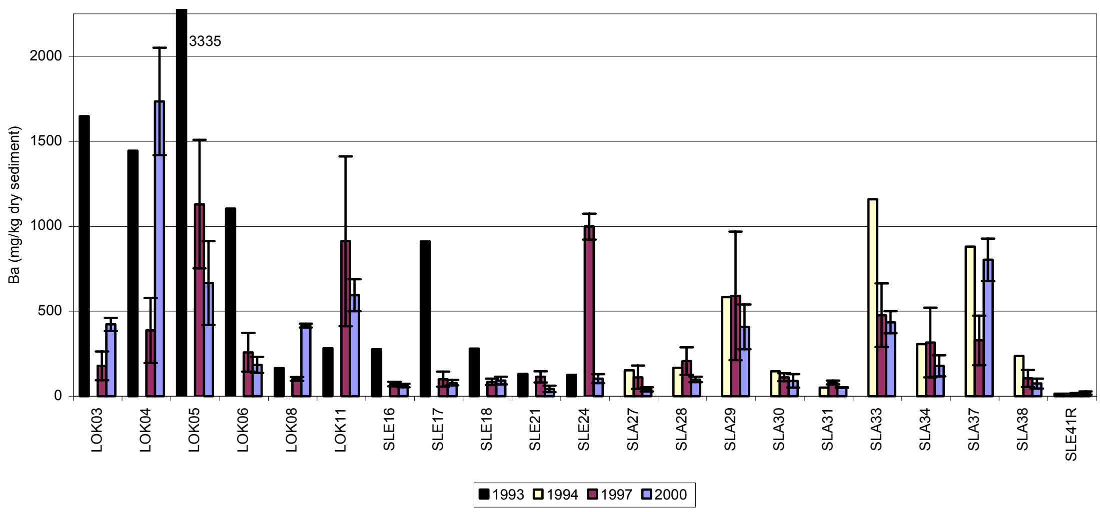

Figure 19-5: Barium levels in sediment from the present (2000) and previous survey, Sleipner Øst field.

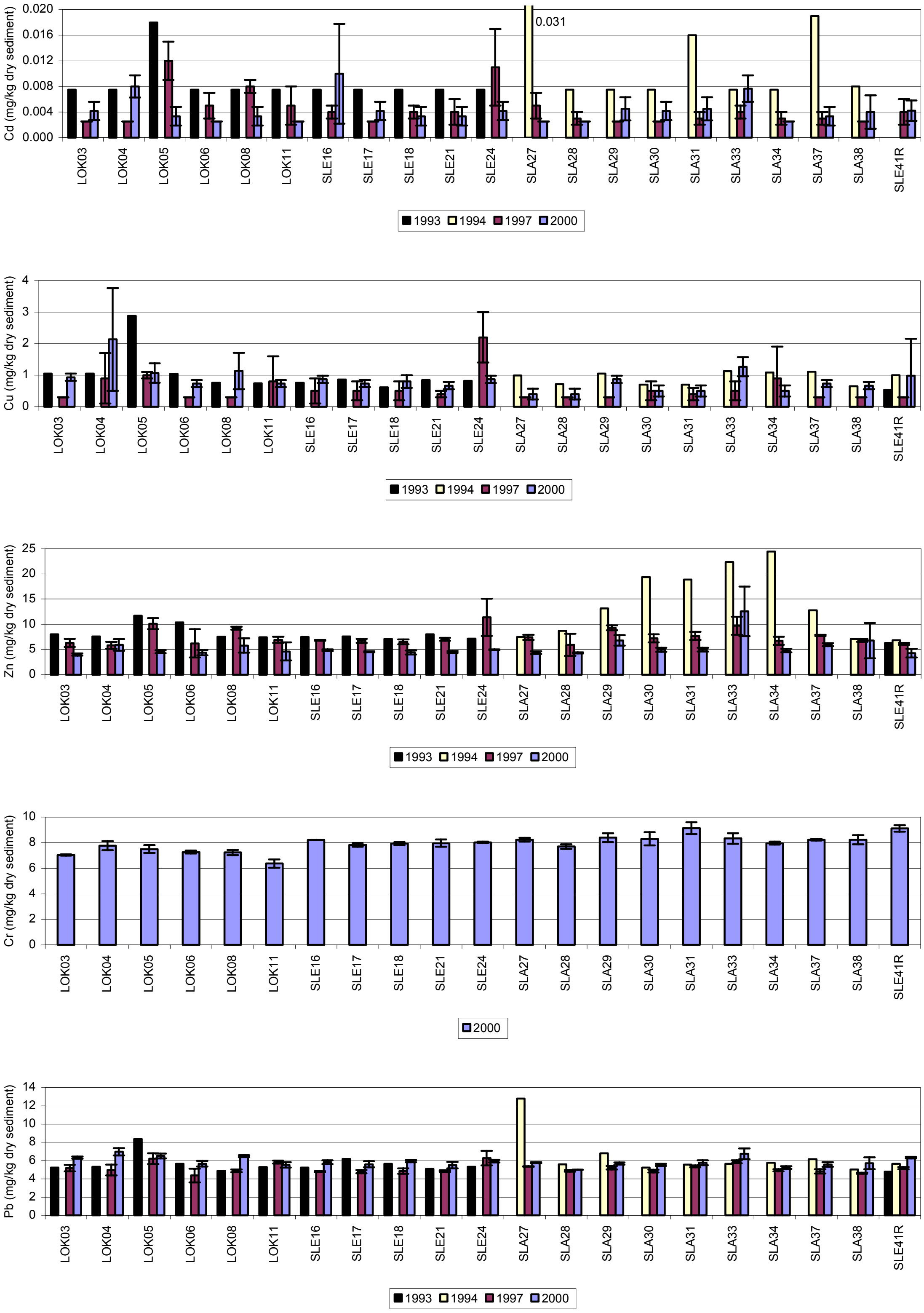

Figure 19-6: Levels of selected metals in sediments from the present (2000) and previous surveys, Sleipner Øst field.

19.2.3 Biology

The distribution of individuals and taxa within the main taxonomic groups are given in Table 19-8. A total of 7691 individuals within 193 taxa are recorded at the Sleipner Øst field in the present survey (excluding juveniles). The polychaetes dominate the fauna with 36 % of the individuals and 47 % of the taxa recorded.

Table 19-8: Distribution of individuals and taxa within the main taxonomic groups at Sleipner Øst, 2000 (excluding juveniles).

Main taxonomic groups	Individuals		Taxa	
	Number	%	Number	%
Polychaeta	2762	36	90	47
Mollusca	864	11	39	20
Crustacea	820	11	36	19
Echinodermata	1158	15	9	5
Diverse groups	2087	27	19	10
Total	7691	100	193	100

The species/area curve for the reference station SLE41R is shown in Figure 19-7. Only eight replicates are included in the curve. A total of 66 taxa are registered in the eight grab samples, of which 21 occur in the first sample and 50 in the first five samples. The shape of the curve indicates that not all of the taxa in the area are present in the eight grab samples.

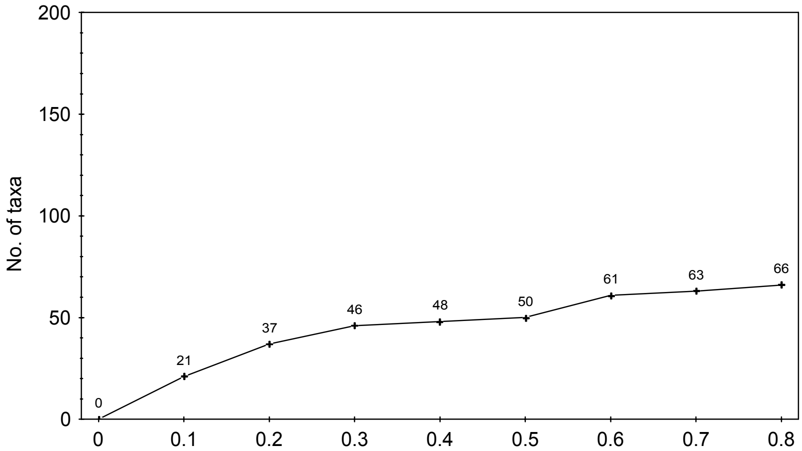

Figure 19-7: Species/area curve for the reference station at the Sleipner Øst field (area in m^2).

The number of individuals and taxa at each station, together with selected community indices is presented in Table 19-9 and Figure 19-8. The number of individuals registered at Sleipner Øst varies from 245 (SLA31) to 530 (LOK11), the number of taxa from 45 (LOK04) to 71 (LOK08), the diversity index H' from 3.5 (LOK04 and LOK05), to 5.1 (SLA37 and SLA38), the evenness index J from 0.61 (LOK03 and LOK05) to 0.86 (SLA33 and SLA37) and the ES_{100} between 25 (LOK04 and LOK05) to 38 (SLE18 and SLA37). The corresponding values at the reference station SLE41R are within the variation found at the field stations. The number of taxa and individuals are relatively low at the stations, but at comparable levels as that recorded on the neighbouring Sigyn and Varg fields.

There has been a relatively large decrease in number of individuals and taxa at some of the stations at Sleipner Øst (SLE24) and Sleipner A (SLA28, SLA29, SLA33 and SLA37) while the largest decrease in the diversity is seen at the stations at Loke (LOK03, LOK04 and LOK05). A reduction in individual numbers, taxa and diversity is also registered at the reference station SLE41R

Table 19-9: Number of individuals and taxa and selected community indices for each station (0.5 m^2) at the Sleipner Øst field, 2000 (minimum and maximum values for each parameter are indicated with bold text).

Station	No. of ind	No. of taxa	H'	J	ES100
LOK03	411	59	3.6	**0.61**	27
LOK04	307	**45**	**3.5**	0.64	**25**
LOK05	512	52	**3.5**	**0.61**	**25**
LOK06	453	67	4.7	0.77	34
LOK08	593	**71**	4.2	0.68	31
LOK11	**530**	69	4.0	0.65	29
SLE16	265	62	4.8	0.80	37
SLE17	355	54	4.5	0.78	32
SLE18	320	66	4.9	0.80	**38**
SLE21	347	62	4.8	0.81	36
SLE24	414	63	4.6	0.77	34
SLA27	264	51	4.7	0.82	34
SLA28	275	56	4.7	0.81	34
SLA29	422	62	4.8	0.80	34
SLA30	320	58	4.9	0.84	36
SLA31	**245**	53	4.8	0.83	36
SLA33	271	55	5.0	**0.86**	37
SLA34	396	68	5.0	0.82	37
SLA37	287	61	**5.1**	**0.86**	**38**
SLA38	364	66	**5.1**	0.84	37
SLE41R	340	46	4.0	0.73	28
Sum*	7351				
Average*	368	60	4.5	0.77	34
St. dev.*	98	7	0.5	0.08	4

*Excluding the reference station.

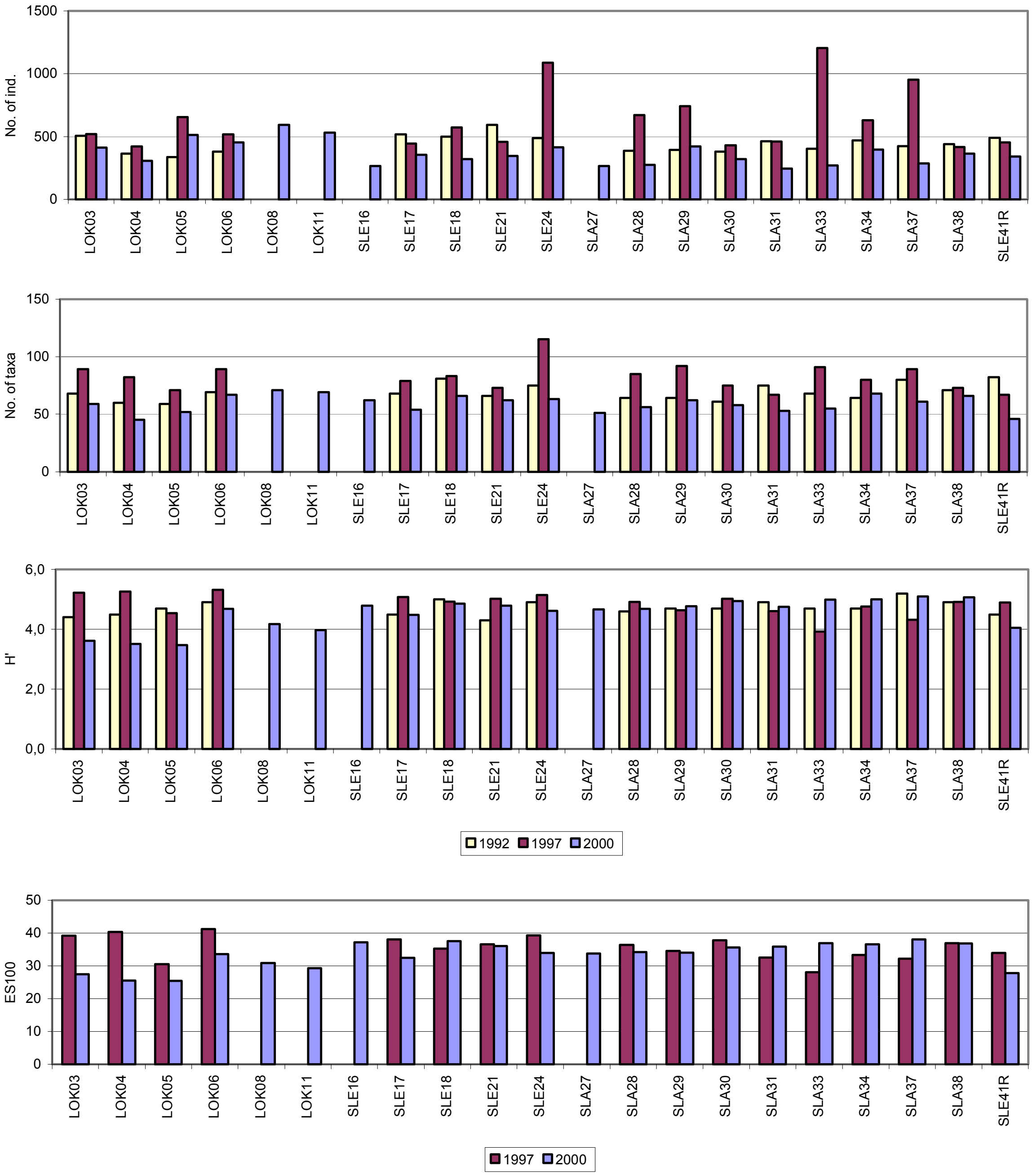

Figure 19-8: Biological characteristics at the stations at Sleipner Øst, 2000 and previous surveys.

The distribution of taxa in geometrical classes at the stations is shown in Figure 19-9. Five stations at Loke have taxa in geometric class 8 (128 – 255 individuals) while the rest of the stations have taxa in class 7 or lower (<128 individuals). Occurrence of taxa in high classes might indicate some faunal disturbance, which is not seen among the stations at Sleipner Øst.

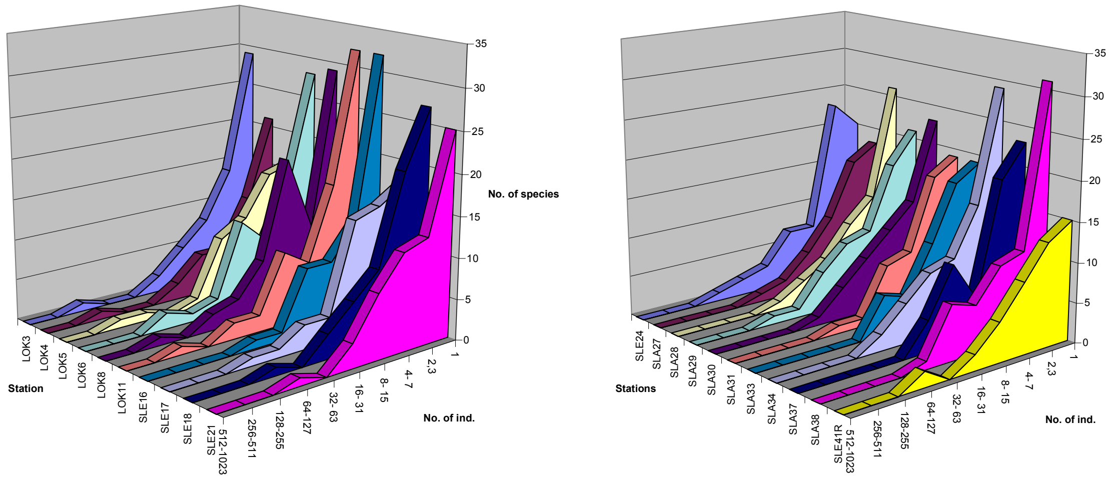

Figure 19-9: Distribution of taxa in geometrical classes from the stations at Sleipner Øst, 2000.

The ten most dominant taxa at each station are shown in Table 19-12 at the end of this chapter. A total of 35 taxa, inclusive three juvenile groups, are among the ten most dominant taxa at one or more stations. These 35 taxa comprise 85 % of the total number of individuals and 17 % of the total number of taxa registered at the Sleipner Øst field in the present survey.

The most dominant taxa among the adult forms are the brittle star *Amphiura filiformis*, the tunicata *Eugyra arenosa*, the cumacean *Eudorellopsis deformis*, the phoronid *Phoronis* sp. and the bivalve *Mysella* sp. Other dominant taxa are the polychaetes *Spiophanes bombyx, Spiophanes* kroyeri and *Chaetozone* sp. and the nemertini group Nemertini indet. The brittle star *A. filiformis* is the only species which is represented among the ten most dominants at all stations, and only at two of these (LOK04 and SLA37) is it not represented among the five most dominated species.

The polychaetes *S. kroyeri* and *S. bombyx* are among the five most dominant taxa at nine and eight stations, respectively, while *Chaetozone sp.* is among the five most dominant taxa at five stations. The tunicata *E. arenosa* and the cumacean *E. deformis* are represented among the five most dominant species at ten and fourteen stations, respectively.

The ten most abundant taxa at the stations comprise between 53 % (station SLA37) and 80 % (station LOK04) of the total number of individuals registered at the respective stations. The corresponding value at the reference station SLE41R is 72 %.

Figure 19-10 shows the dendrogram from the cluster analysis for the field stations and regional and reference stations while Figure 19-11 shows the 2-D plot from the MDS analysis.

In the cluster analysis, station LOK04 is separated out at approximately 50 % dissimilarity level, the regional and reference stations (including the field reference station SLE41R) at approximately 45 % while the rest of the field stations are separated into two main groups at 40 % dissimilarity level. In one of these groups, containing five stations at Loke, the stations are separated from each other at dissimilarity levels between 37 and 31 %. In the other group, containing a mixture of stations from Sleipner A and Sleipner Øst, the stations are further separated into bigger or smaller groups at dissimilarity levels between 37 and 27 %. The correlation coefficient shows a poor to good fit to the data (r = 0.79).

The MDS analyses support the results from the cluster analysis and separate the regional and reference stations and the Loke station LOK04 from the main group of stations in the middle part of the 2-D plot. Within this main group the Loke and most of the Sleipner A stations comprise two minor groups. The stress test shows a poor fit to the data.

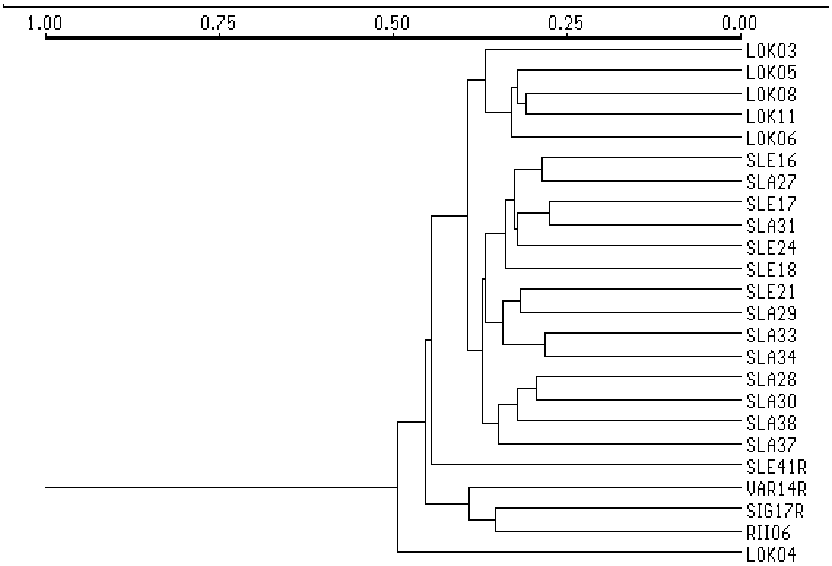

Figure 19-10: Cluster analysis of the Sleipner Øst field stations and selected regional and reference stations in Region II, 2000.

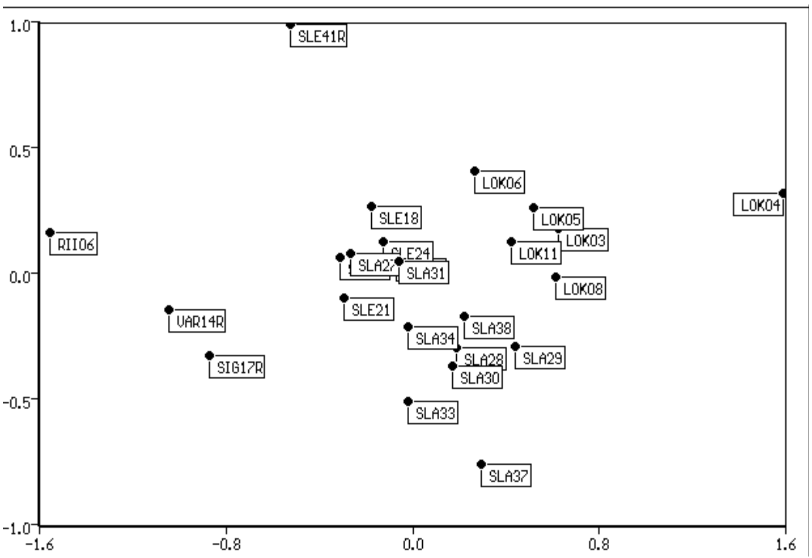

Figure 19-11: 2-D plot from the MDS analysis carried out on the Sleipner Øst field stations and selected regional and reference stations in Region II, 2000.

A Canonical Correspondence Analysis (CCA) of the data from the Sleipner Øst field and selected regional and reference stations was carried out to examine the association between the biological data and the measured environmental variables in these areas.

Through the forward selection procedure in CANOCO, three of ten variables gave the best fit and are significant. 28.0 % of the biological variance was explained by the first two axes of the ordination space which is constrained by these environmental variables.

Figure 19-12 shows a biplot from the analysis using zinc (Zn), THC and pelite (Pel) as the constraining environmental variables together with a plot showing the taxa with highest contribution on the two axes. The first axis shows a gradient from field station LOK04 at the positive end to field station SLA28 and regional station RII06 at the negative end and is positively correlated with the amount of THC (+ 0.71) and pelite (+ 0.66) in the sediments. The taxa with highest contribution on this axis are the tunicate *Eugyra arenosa* (60.3 %), the brittle star *Amphiura filiformis* (4.4 %), the bivalve *Mysella* sp. (3.3 %) and the cumacean *Eudorellopsis deformis* (2.4 %).

The second axis shows a gradient from field station SLA33 at the positive end to regional station RII06 at the negative end and is correlated with the amount of zinc (+ 0.72), THC (+0.55) and pelite (-0.52 in the sediments. Taxa with high contribution on this axis are the polychaetes *Chaetozone* sp. (9.8 %), *Ditrupa arietina* (8.3 %) and *Spiophanes bombyx* (4.1 %), the brittle star *Amphiura filiformis* (7.3 %) and the nemertini group Nemertini indet. (5.2 %).

The tunicate *Eugyra arenosa* is mostly associated with stations on the positive end of the first axis (i. e. the Loke stations) while the polychaetes *Chaetozone* sp and *Ditrupa arietina* and the nemertins Nemertini indet. are mostly associated with stations on the positive end of second axis (i.e. some of the stations at SLA). These taxa are known to be relatively abundant in disturbed sediments. Both axes are positively correlated with the amount of THC in the sediments and the result, therefore, indicates a faunal disturbance gradient along the axes.

The contribution from the polychaete *Glycera alba*, which is shown in the upper part of the plot, is not significant because it is represented with few individuals at the stations.

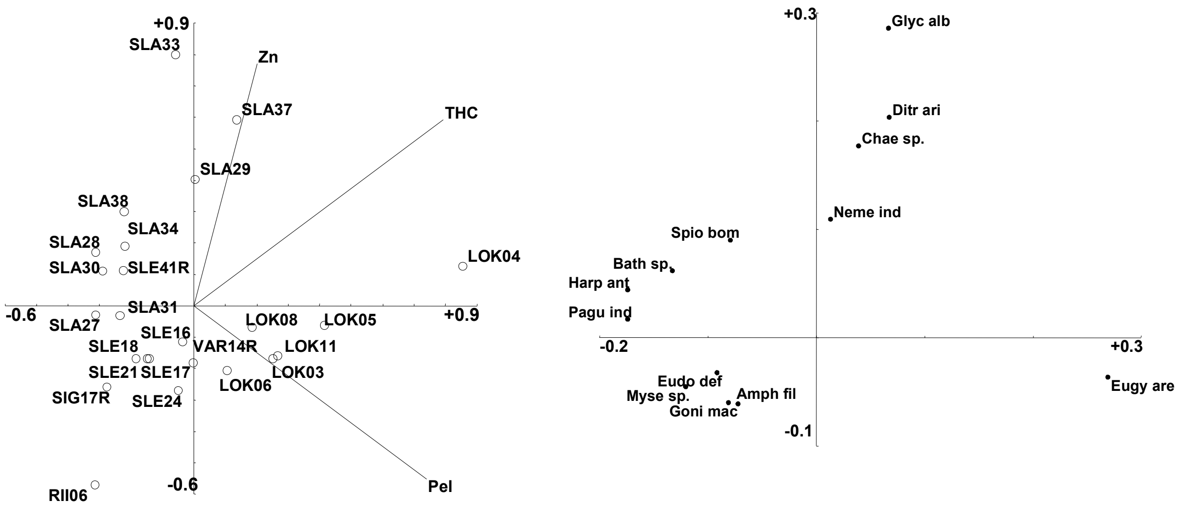

Figure 19-12: Biplot from the CCA analysis for the Sleipner Øst field stations and selected regional and reference stations in Region II, 2000 (left) and taxa with highest contribution on two axes in the CCA (right).

A second CCA of the data from the Sleipner Øst field including olefins among the environmental data was carried out to examine the association between the biological data and the measured environmental variables in these areas. The analysis was carried out excluding the data from the SLE stations and the regional and reference stations, where olefins were not analysed.

The analysis shows no significant correlations between the faunal distribution and the amount of olefins in the sediments and, therefore, does not bring new information to the results. The analysis is presented in the Appendix.

On the basis of the results from the uni- and multivariate analyses, the stations at the Sleipner Øst field are classified as group A stations (undisturbed fauna, see Table 19-10). Taxa, which are known to be abundant in disturbed sediments (i.e. *Chaetozone* sp., *Ditrupa arietina* and Nemertinin indet.) are present at all field stations, but not in large numbers. The filter feeding tunicate *Eugyra arenosa* occur in relatively high individual numbers at the Loke stations, but it is not known if this is a result of faunal disturbance. They were present at the stations in the previous survey in 1997, but then at similar abundance as seen at the SLA and SLE stations in 2000. The Loke stations are separated from the SLA and SLE stations in the multivariate analyses apparently as a result of the occurrence of *E. arenosa*.

In 1997, five stations were classified as group B stations, partly due to relatively high abundance of *Chaetozone setosa* at those stations. The faunal disturbance, therefore, seems to have decreased at the field.

Table 19-10: Classification into impact groups, distance to installation and biological statistics for the field stations at Sleipner Øst field, 2000.

Station	Impact group	Dist. (m)	Statistics			No. of individuals								
			No. ind	No. taxa	H'	Ear	Afi	Psp	Msp	Skr	Sbo	Nin	Dar	Csp
LOK03	A	500	411	59	3,6	191	31	27	11	14	7	14	4	4
LOK04	A	250	307	45	3,5	141	9	8	0	0	6	14	12	17
LOK05	A	250	512	52	3,5	237	64	27	1	15	8	13	6	4
LOK06	A	500	453	67	4,7	86	65	34	25	23	13	7	9	7
LOK08	A	250	593	71	4,2	214	56	40	6	13	4	19	14	23
LOK11	A	250	530	69	4,0	205	60	36	16	14	12	12	8	9
SLE16	A	500	265	62	4,8	4	59	14	9	8	14	9	0	3
SLE17	A	250	355	54	4,5	4	77	15	53	23	13	6	0	6
SLE18	A	250	320	66	4,9	7	69	17	3	22	15	13	0	9
SLE21	A	250	347	62	4,8	9	78	21	5	13	11	5	0	8
SLE24	A	250	414	63	4,6	3	102	21	33	18	10	14	0	5
SLA27	A	2000	264	51	4,7	15	55	14	3	20	12	7	0	3
SLA28	A	1000	275	56	4,7	26	49	14	0	15	8	6	1	10
SLA29	A	500	422	62	4,8	76	47	11	7	8	12	25	0	22
SLA30	A	500	320	58	4,9	5	32	9	9	23	26	7	5	13
SLA31	A	1000	245	53	4,8	3	49	14	2	11	11	15	6	1
SLA33	A	250	271	55	5,0	2	24	6	1	6	23	24	18	23
SLA34	A	500	396	68	5,0	13	56	7	36	17	18	13	31	17
SLA37	A	250	287	61	5,1	8	10	5	0	21	30	24	14	18
SLA38	A	500	364	66	5,1	27	40	8	17	16	31	17	6	7
SLE41R	A	5000	340	46	4,0	0	75	14	83	7	16	9	0	0
RII06	A	-	245	54	4,6	0	47	13	14	10	11	7	0	0
SIG17R	A	-	266	59	4,6	1	72	11	12	8	13	4	0	1
VAR14R	A	-	236	53	4,6	1	56	13	1	12	13	7	0	0

Ear = *Eugyra arenosa*, Afi = *Amphiura filiformis*, Psp = *Phoronis* sp., Msp = *Mysella* sp., Skr = *Spiophanes kroyeri,* Sbo = *Spiophanes bombyx*, Nin = Nemertini indet., Dar = *Ditrupa arietina*, Csp. = *Chaetosone* sp.

19.3 Summary and conclusions

The sediments at the Sleipner Øst field is classified as fine sand with relatively low amounts of pelite (1.7 – 3.2 %) and TOM (0.7 – 0.9 %). The pelite content has increased at all Loke and most of the SLE stations. A large decrease of the TOM is registered at SLE24.

Sleipner Øst is located in shallow area south in Region II. This year the highest amounts of THC (26 mg/kg), olefins (41 mg/kg) and barium (1735 mg/kg) are found at LOK04. Hydrocarbons and barium are contaminated down to 6 cm depth at this station, while olefins are contaminated down to 3 cm.

The general picture of Loke is that THC, olefins and barium are contaminated out to 500 m on the 10^o- and 100^o-axes, while olefins and barium are contaminated out to 250 m on the 190^o and 280^o-axes. At Loke, traces of Petrofree ester are found at the 250 m stations, in addition to the 500 m station on the 100°-axis. At SLA THC is contaminated at the innermost stations at the 10°-, 190°- and 280°-axes, while olefins and barium are contaminated out to 500 m on the 190°- and 280°-axes and out to 1000 m on the 10°-axis. In addition, elevated levels of barium are found out to 1000 m on the SLA 100°-axis and at all stations on the SLE 10°-, 100°- and 190°-axes. In 1997, LOK05 and SLE24 were regarded as contaminated with THC, while all the stations investigated were deemed contaminated with barium.

Compared to the results in the 1997 survey, the THC level at most of the Sleipner Øst stations are unchanged or only slightly increased, while the contents of barium are unchanged or reduced. The only exceptions are found for LOK03, LOK04, LOK08 and SLA37 where the contents of both THC and barium have increased and for SLE24 where the contents of THC and barium have decreased, since 1997. The content of Petrofree in sediments has clearly decreased since 1997, but trace of Petrofree is still present at the Loke-stations.

The area contaminated with THC is still reaching out to 250 m on the Loke 100°-axis, while the contaminated area has reached the 500 m stations on the Loke and SLA 10°-axes and the 250 m stations on the SLA 190°- and 280°-axes. The 250 m station on the SLE 190°-axis is regarded as uncontaminated with THC in the present survey. The whole Sleipner Øst, with the exception of SLE21 and SLA27, are still contaminated with barium.

The number of taxa and individuals are relatively low at the stations, but at comparable levels as that recorded on the neighbouring Sigyn and Varg fields. The number of individuals has decreased at most of the stations since 1997, the largest decrease found at SLE24, SLA33 and SLA37. The number of taxa as well has decreased at most of the stations, the largest decrease is seen at SLE24. On the basis of the results from the uni- and multivariate analyses the stations at the Sleipner Øst field are classified as group A stations (undisturbed fauna,). Taxa, which are known to be abundant in disturbed sediments (i.e. *Chaetozone* sp., *Ditrupa arietina* and Nemertinin indet.) are present at all field stations, but not in large numbers. The filter feeding tunicate *Eugyra arenosa* occur in relatively high individual numbers at the Loke stations, but it is not known if this is a result of faunal disturbance. They were present at the stations in the previous survey in 1997, but then at similar abundance as seen at the SLA and SLE stations.

In 1997, five stations were classified as group B stations, partly due to relatively high abundance of *Chaetozone setosa* at those stations. The faunal disturbance seems to have decreased at the field.

The calculated minimum area and spatial extent of contaminated sediments and disturbed fauna at the Sleipner Øst field is shown in Table 19-11 and Figure 19-13. The areas contaminated with barium for 2000 and 1997 cannot be compared because the number of stations included in the two surveys are different and because levels of barium do not reach the background value even at the outermost stations.

Table 19-11: Distance along the transects and calculated minimum area of contaminated sediments and disturbed fauna at the Sleipner Øst field, 2000 and previous survey.

Loke	N	E	S	W	Km^2 (2000)	Km^2 (1997)
Group B	0	0	0	0	0.00	0.07
THC	500	250	125	125	0.18	0.07
Ester	250	500	250	250	0.29	0.44
Olefin	500	500	125	250	0.37	n.a.
Ba	500	500	250	250	0.44	1.23
Other metals	0	0	0	0	0.00	0.07
SLA	N	E	S	W	Km^2 (2000)	Km^2 (1997)
Group B	0	0	0	0	0.00	0.29
THC	500	125	250	250	0.22	0.00
Ester	125	125	250	125	0.07	0.79
Olefin	1000	125	500	500	0.74	n.a.
Ba	1000	1000	500	500	1.77	12.57
Other metals	0	0	0	0	0.00	0.00
SLE	N	E	S	W	Km^2 (2000)	Km^2 (1997)
Group B	0	0	0	0	0.00	0.07
THC	0	0	0	0	0.00	0.07
Ba	500	250	250	125	0.22	0.29
Other metals	0	0	0	0	0.00	0.07
Sum Sleipner Øst					Km^2 (2000)	Km^2 (1997)
Group B					0.00	0.44
THC					0.40	0.15
Ester					0.37	1.23
Olefin					1.10	0.00
Ba					2.43	14.09
Other metals					0.00	0.15

n.a.) Not analysed.

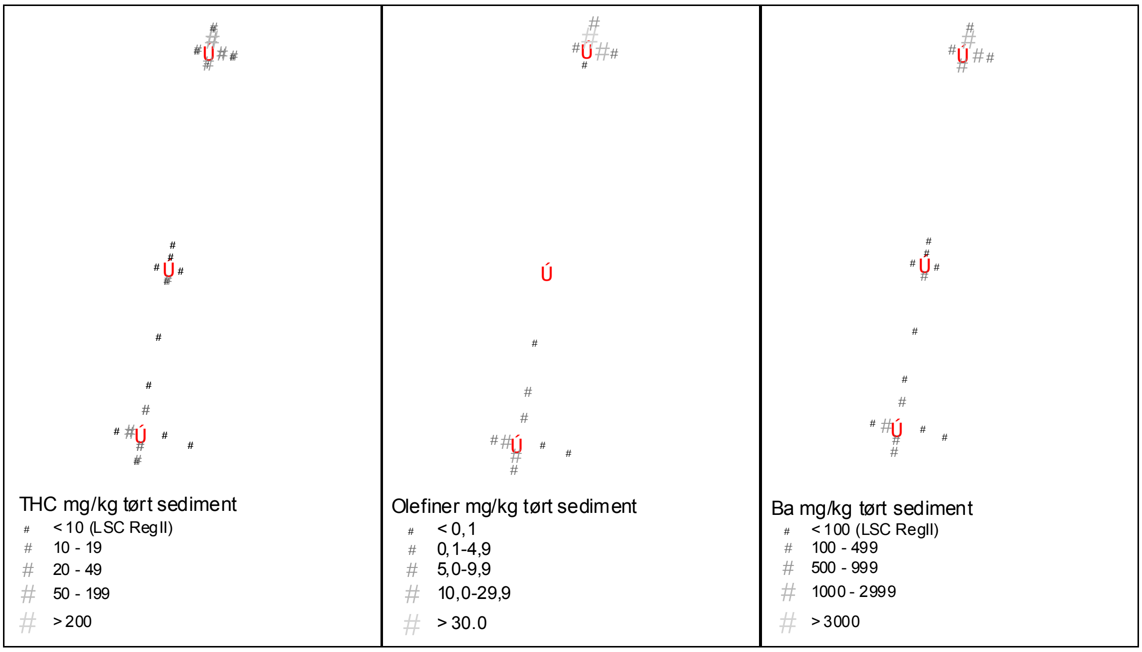

Figure 19-13: Distribution of faunal groups and amounts of THC, olefin and barium at the Sleipner Øst Field, 2000.

Table 19-12: Number of individuals and the accumulative abundance for the ten most dominant taxa at each station at the Sleipner Øst field, 2000.

LOK03 (10° / 500 m)	No. ind	Acc. %	LOK04 (10° / 250 m)	No. ind	Acc. %	LOK05 (100° / 250 m)	No. ind	Acc. %	LOK06 (100° / 500 m)	No. ind	Acc. %	LOK08 (280° / 250 m)	No. ind	Acc. %
Eugyra arenosa	191	45 %	Eugyra arenosa	141	44 %	Eugyra arenosa	237	45 %	Eugyra arenosa	86	18 %	Eugyra arenosa	214	35 %
Amphiura filiformis	31	52 %	Paramphinome jeffreysii	22	51 %	Amphiura filiformis	64	57 %	Amphiura filiformis	65	32 %	Amphiura filiformis	56	45 %
Phoronis sp.	27	58 %	Chaetozone sp.	17	57 %	Phoronis sp.	27	62 %	Phoronis sp.	34	39 %	Phoronis sp.	40	51 %
Nemertini indet.	14	62 %	Nemertini indet.	14	61 %	Spiophanes kroyeri	15	65 %	Mysella sp.	25	44 %	Eudorellopsis deformis	26	56 %
Spiophanes kroyeri	14	65 %	Caudofoveata indet.	13	65 %	Eudorellopsis deformis	13	67 %	Spiophanes kroyeri	23	49 %	Chaetozone sp.	23	59 %
Paramphinome jeffreysii	13	68 %	Ditrupa arietina	12	69 %	Nemertini indet.	13	70 %	Eudorellopsis deformis	15	52 %	Nemertini indet.	19	62 %
Mysella sp.	11	70 %	Amphiura filiformis	9	72 %	Goniada maculata	12	72 %	Spiophanes bombyx	13	55 %	Ditrupa arietina	14	65 %
Eudorellopsis deformis	10	73 %	Phoronis sp.	8	74 %	Anobothrus gracilis	10	74 %	Galathowenia oculata	12	58 %	Galathowenia oculata	14	67 %
Spiophanes bombyx	7	74 %	Ophiuroidea indet. juv.	7	77 %	Galathowenia oculata	8	75 %	Ophiuroidea indet. juv.	12	60 %	Spiophanes kroyeri	13	69 %
Goniada maculata	5	76 %	Platyhelminthes indet.	6	79 %	Paramphinome jeffreysii	8	77 %	Anobothrus gracilis	10	62 %	Nephtys cirrosa	11	71 %
Ophiuroidea indet. juv.	5	77 %	Spiophanes bombyx	6	80 %	Spiophanes bombyx	8	78 %	Goniada maculata	10	64 %			
Owenia fusiformis	5	78 %							Nephtys longosetosa	10	66 %			
									Sthenelais limicola	10	69 %			

LOK11 (190° / 250 m)	No. ind	Acc. %	SLE16 (10° / 500 m)	No. ind	Acc. %	SLE17 (10° / 250 m)	No. ind	Acc. %	SLE18 (100° / 250 m)	No. ind	Acc. %	SLE21 (280° / 250 m)	No. ind	Acc. %
Eugyra arenosa	205	37 %	Amphiura filiformis	59	21 %	Amphiura filiformis	77	20 %	Amphiura filiformis	69	21 %	Amphiura filiformis	78	21 %
Amphiura filiformis	60	48 %	Eudorellopsis deformis	23	29 %	Mysella sp.	53	34 %	Eudorellopsis deformis	26	28 %	Eudorellopsis deformis	28	29 %
Phoronis sp.	36	54 %	Phoronis sp.	14	34 %	Eudorellopsis deformis	23	40 %	Spiophanes kroyeri	22	35 %	Phoronis sp.	21	34 %
Eudorellopsis deformis	21	58 %	Spiophanes bombyx	14	39 %	Spiophanes kroyeri	23	46 %	Phoronis sp.	17	40 %	Harpinia antennaria	16	39 %
Mysella sp.	16	61 %	Goniada maculata	11	43 %	Goniada maculata	16	51 %	Spiophanes bombyx	15	45 %	Paramphinome jeffreysii	14	43 %
Spiophanes kroyeri	14	64 %	Ophiuroidea indet. juv.	10	47 %	Phoronis sp.	15	55 %	Nemertini indet.	13	49 %	Goniada maculata	13	46 %
Nemertini indet.	12	66 %	Paramphinome jeffreysii	10	50 %	Ophiuroidea indet. juv.	13	58 %	Cirratulus caudatus	10	51 %	Spiophanes kroyeri	13	50 %
Spiophanes bombyx	12	68 %	Montacuta ferruginosa	9	53 %	Spiophanes bombyx	13	61 %	Sthenelais limicola	10	54 %	Ophiuroidea indet. juv.	11	53 %
Ophiuroidea indet. juv.	10	70 %	Mysella sp.	9	57 %	Harpinia antennaria	8	64 %	Chaetozone sp.	9	57 %	Spiophanes bombyx	11	56 %
Chaetozone sp.	9	71 %	Nemertini indet.	9	60 %	Anobothrus gracilis	6	65 %	Scoloplos armiger	9	60 %	Eugyra arenosa	9	58 %
Pectinaria auricoma	9	73 %				Bathyporeia sp.	6	67 %				Owenia fusiformis	9	60 %
						Chaetozone sp.	6	68 %						
						Nemertini indet.	6	70 %						
						Nephtys longosetosa	6	72 %						
						Scoloplos armiger	6	73 %						
						Sthenelais limicola	6	75 %						

SLE24 (190° / 250 m)	No. ind	Acc. %	SLA27 (10° / 2000 m)	No. ind	Acc. %	SLA28 (10° / 1000 m)	No. ind	Acc. %	SLA29 (10° / 500 m)	No. ind	Acc. %	SLA30 (90° / 500 m)	No. ind	Acc. %
Amphiura filiformis	102	23 %	Amphiura filiformis	55	20 %	Amphiura filiformis	49	16 %	Eugyra arenosa	76	17 %	Amphiura filiformis	32	9 %
Eudorellopsis deformis	36	32 %	Spiophanes kroyeri	20	27 %	Eudorellopsis deformis	29	26 %	Amphiura filiformis	47	28 %	Eudorellopsis deformis	30	18 %
Mysella sp.	33	39 %	Eudorellopsis deformis	17	33 %	Eugyra arenosa	26	35 %	Paramphinome jeffreysii	29	34 %	Paguridae indet.	26	26 %
Phoronis sp.	21	44 %	Eugyra arenosa	15	39 %	Bathyporeia sp.	16	40 %	Nemertini indet.	25	40 %	Spiophanes bombyx	26	34 %
Goniada maculata	19	48 %	Phoronis sp.	14	44 %	Spiophanes kroyeri	15	45 %	Chaetozone sp.	22	45 %	Spiophanes kroyeri	23	41 %
Spiophanes kroyeri	18	52 %	Hippomedon denticulatus	12	48 %	Phoronis sp.	14	50 %	Eudorellopsis deformis	18	49 %	Chaetozone sp.	13	44 %
Nemertini indet.	14	56 %	Spiophanes bombyx	12	53 %	Spiophanes sp. juv.	11	54 %	Scoloplos armiger	16	52 %	Montacuta ferruginosa	13	48 %
Nephtys cirrosa	13	59 %	Goniada maculata	11	57 %	Chaetozone sp.	10	57 %	Ophiuroidea indet. juv.	13	55 %	Goniada maculata	9	51 %
Magelona sp.	10	61 %	Antalis sp.	7	59 %	Goniada maculata	10	60 %	Spiophanes bombyx	12	58 %	Mysella sp.	9	54 %
Paramphinome jeffreysii	10	63 %	Nemertini indet.	7	62 %	Ophiuroidea indet. juv.	10	64 %	Caudofoveata indet.	11	60 %	Ophiuroidea indet. juv.	9	56 %
Spiophanes bombyx	10	65 %	Paramphinome jeffreysii	7	64 %				Goniada maculata	11	63 %	Phoronis sp.	9	59 %
			Scoloplos armiger	7	67 %				Phoronis sp.	11	65 %			
									Sthenelais limicola	11	68 %			

Continue Table 19-12

SLA31 (100° / 1000 m)	No. ind	Acc. %	SLA33 (190° / 250 m)	No. ind	Acc. %	SLA34 (190° / 500 m)	No. ind	Acc. %	SLA37 (280° / 250 m)	No. ind	Acc. %	SLA38 (280° / 500 m)	No. ind	Acc. %
Amphiura filiformis	49	19 %	Amphiura filiformis	24	8 %	Amphiura filiformis	56	13 %	Spiophanes bombyx	30	10 %	Amphiura filiformis	40	11 %
Eudorellopsis deformis	21	27 %	Nemertini indet.	24	17 %	Mysella sp.	36	22 %	Nemertini indet.	24	18 %	Spiophanes bombyx	31	19 %
Nemertini indet.	15	33 %	Chaetozone sp.	23	25 %	Ditrupa arietina	31	29 %	Spiophanes kroyeri	21	25 %	Eugyra arenosa	27	26 %
Phoronis sp.	14	38 %	Spiophanes bombyx	23	33 %	Eudorellopsis deformis	23	35 %	Chaetozone sp.	18	30 %	Harpinia antennaria	21	31 %
Goniada maculata	11	43 %	Ditrupa arietina	18	39 %	Spiophanes bombyx	18	39 %	Ditrupa arietina	14	35 %	Eudorellopsis deformis	20	37 %
Spiophanes bombyx	11	47 %	Cerianthus lloydi	11	43 %	Chaetozone sp.	17	43 %	Goniada maculata	13	39 %	Mysella sp.	17	41 %
Spiophanes kroyeri	11	51 %	Paramphinome jeffreysii	10	46 %	Spiophanes kroyeri	17	47 %	Glycera alba	12	43 %	Nemertini indet.	17	46 %
Nephtys longosetosa	10	55 %	Eudorellopsis deformis	9	49 %	Harpinia antennaria	14	51 %	Bathyporeia sp.	11	47 %	Spiophanes kroyeri	16	50 %
Bathyporeia sp.	8	58 %	Cerianthus lloydi juv.	8	52 %	Eugyra arenosa	13	54 %	Amphiura filiformis	10	50 %	Paramphinome jeffreysii	13	53 %
Ophiuroidea indet. juv.	8	61 %	Nephtys cirrosa	8	55 %	Nemertini indet.	13	57 %	Spiophanes sp. juv.	10	53 %	Pectinaria auricoma	11	56 %

SLE41R (100° / 5000 m)	No. ind	Acc. %
Mysella sp.	83	23 %
Amphiura filiformis	75	44 %
Bathyporeia sp.	16	48 %
Spiophanes bombyx	16	52 %
Phoronis sp.	14	56 %
Eudorellopsis deformis	13	60 %
Goniada maculata	12	63 %
Ophiuroidea indet. juv.	12	67 %
Nephtys longosetosa	10	69 %
Nemertini indet.	9	72 %

Table 19-13: Station information for Sleipner Øst field, 2000.

St. no.	Distance (m)	Direction (degr.)	Volume (litres)
LOK03	500	10	30
LOK04	250	10	32
LOK05	250	100	32
LOK06	500	100	32
LOK08	250	280	30
LOK11	250	190	34
SLE16	500	10	33
SLE17	250	10	33
SLE18	250	100	31
SLE21	250	280	43
SLE24	250	190	33
SLA27	2000	10	30
SLA28	1000	10	31
SLA29	500	10	31
SLA30	500	90	31
SLA31	1000	100	30
SLA33	250	190	30
SLA34	500	190	29
SLA37	250	280	36
SLA38	500	280	32
SLE41R	5000	100	28 *

* The additional three grab samples taken gave 16 litres of sediment.

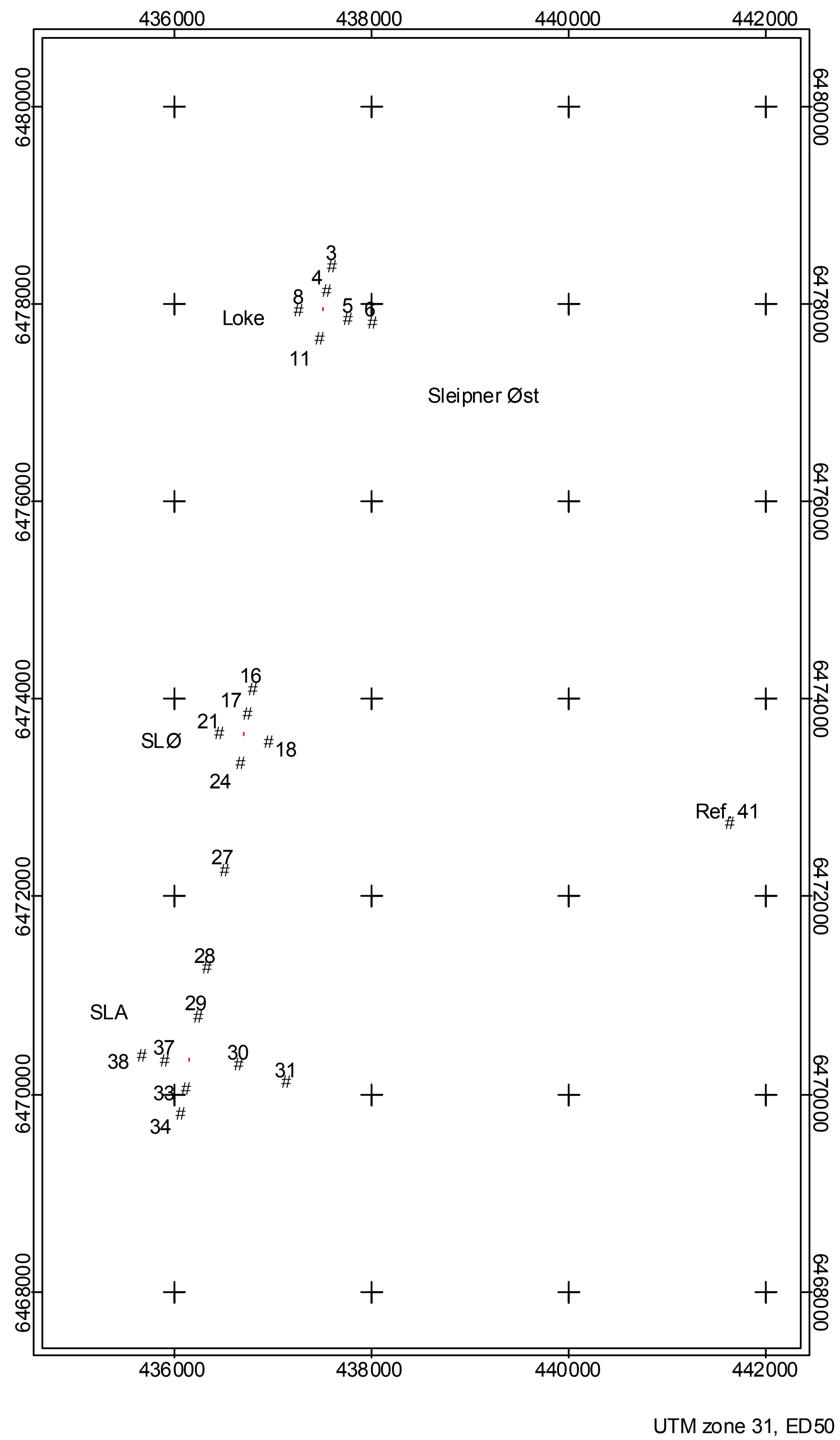

Figure 19-14: Map of sampling positions for Sleipner Øst field, 2000.

20 Status for Region II

20.1 Physical characteristics

The range and average value for median (phi) and the amount of pelite, fine sand and TOM at the fields (excluding the reference stations) in Region II in the present survey are shown in Figure 20-1.

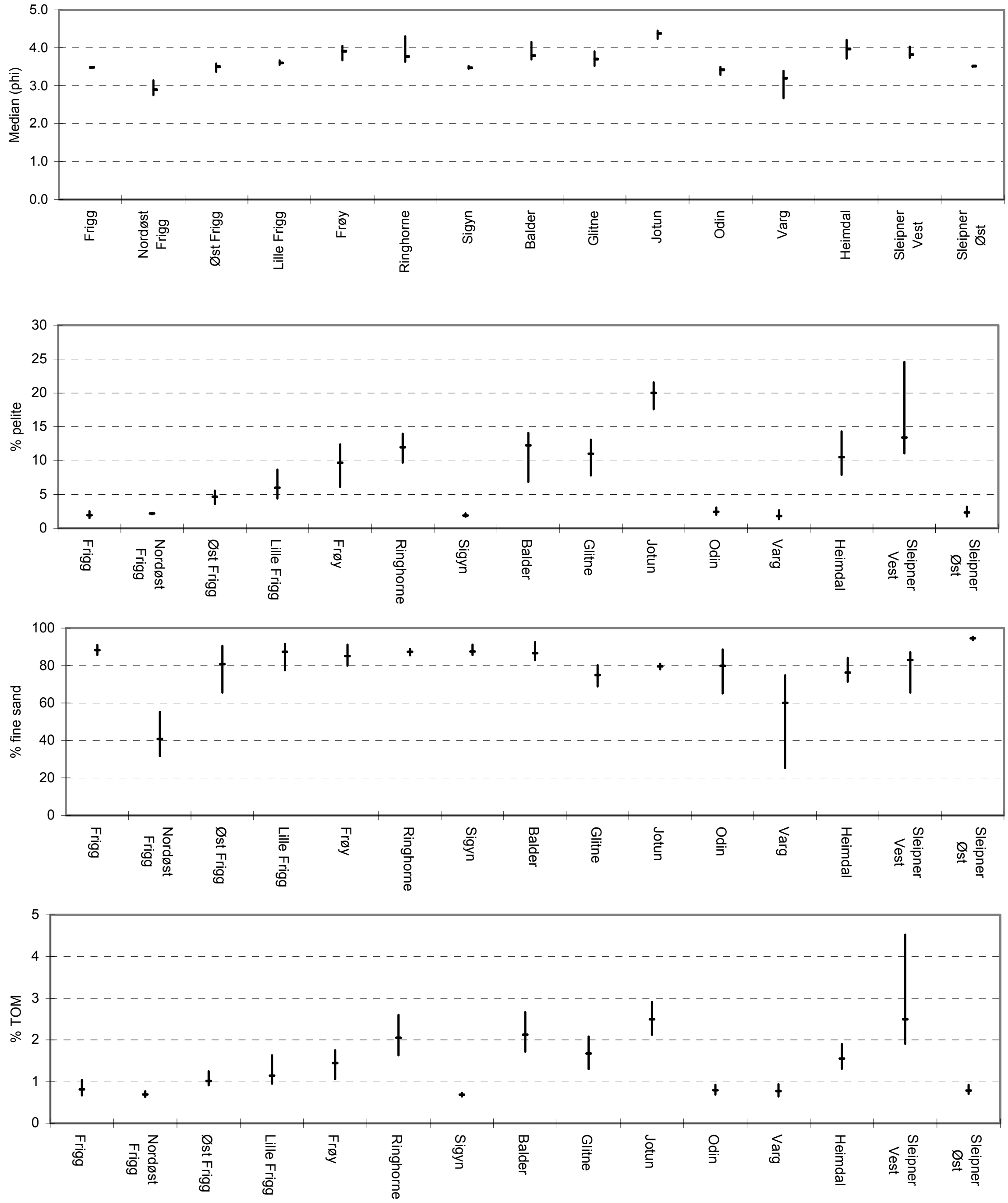

Figure 20-1: The range and average value for the median (phi), pelite, fine sand and TOM at the fields in Region II, 2000 (excluding the reference stations).

The figure shows the great variation in the sediment structure that is found in the region. The sediments at Frigg, Nordøst Frigg, Sigyn, Odin, Varg and Sleipner Øst all have relatively low amounts of pelite (< 5 %) and TOM (< 1 %) while the highest values are found at Jotun (> 15 and 2 %, respectively). The average value of fine sand is, for most of the field, around 80 % or higher, with the exceptions of Nordøst Frigg and Varg where the average is 40 and 60 %, respectively.

The relatively wide range and low average values of the pelite and TOM content at Sleipner Vest is caused by one station (station SLV01 located 250 m north of the centre) having high values compared to the other field stations. At this station the amount of pelite and TOM has increased remarkably since 1997, indicating input to the sediment through discharges from the platform.

There is a general trend of finer sediments in the present survey compared to the survey carried out in 1997.

20.2 Chemical characteristics

Different natural background levels of chemical parameters in different areas reflect variations in sediment characteristics across Region II. In general, the highest amounts of THC and metals are found at the regional/ reference stations with high contents of pelite and TOM. These stations are located in the central part of the region. The lowest amounts of THC, metals, pelite and TOM are found in shallow area south in the region (Sleipner Øst, Varg and Sigyn area). Multivariate analyses of the background material clarified the need for a sub-division into a shallow sub-region to take in account naturally lower levels of THC and metals in this area.

Region II consists of new and old fields. The oldest fields included in the present survey are Frigg, Nordøst Frigg, Heimdal and Øst Frigg where production started in 1977, 1983, 1985 and 1988, respectively. There has been no drilling activity at these fields since the previous survey in 1997. At Øst Frigg the wells were permanently plugged in 1999. Spills of barite occurred accidentally during this operation. The Odin platform was removed partially in 1994 and 1997. The year 2000 baseline programme includes the Sigyn, Ringhorne and Glitne fields. Drilling at the remaining fields started during the 1990´s and at these fields, drilling is still carried out. The only exceptions are Frøy and Lille Frigg, with no drilling activity in recent years. At Lille Frigg spills of barite and hydraulic oil occurred accidentally during the permanent plugging of the wells in June 2000.

With regard to the different field histories, different environmental influences in different areas of Region II are expected. A graphic presentation of the ranges in sediment contents of olefins and selected metals, except barium, are given in Figure 20-3 and Figure 20-4. Each column extends from the lowest and highest measured value over the field stations. The mean content of a parameter across the field is also marked. Because of the variation in the sediment structure, the number of stations and the station distance from the field centre, the average contents of THC and metals across fields cannot be directly compared. Maximum, minimum and average THC and barium values recorded in 2000 are compared with those from previous years in Figure 20-2.

In the present survey, the highest amount of THC (412 mg/kg dry sediment) is found in sediments from the 250 m station in the main current direction (20^{o}-axis) from Varg. The THC content at the 250 m station in the opposite direction (200^{o}-axis) is 184 mg/kg dry sediment. Despite high concentrations of THC at the 250 m stations at Varg, the level of THC decreases appreciably with increasing distance from the field centre and reaches background levels at the outermost stations. In the main current direction from Sleipner Vest (10^{o}-axis), sediment THC concentrations at 100 mg/kg are found out to 1000 m. Two of the fields, Jotun and Sleipner Øst, have maximum THC concentrations between 20 and 30 mg/kg on at least one of the innermost stations. The sediment extracts from stations contaminated with TCH at Jotun, Varg and Sleipner Vest show the presence of mineral oil. According to data on recent drilling accidental discharges of oil-based mud have been reported at these fields, however the discharge at Jotun is only minor. The THC content at the fields included in the year 2000 baseline programme ranges from 2-6 mg/kg at Sigyn in the shallow sub-region, to 7-10 mg/kg at Glitne and 6-13 mg/kg dry sediment at Ringhorne. Glitne and Ringhorne are located in the central part of the region where naturally higher background levels of THC and metals are found. The maximum THC contents at the remaining of the fields comprise between 10 to 20 mg/kg. The largest area contaminated with THC is found at Jotun, where the sediments are contaminated with THC out to 2000 m south west, 500 m north west and east/south east and 250 m north/north east of the installation

The highest amounts of barium are found at the innermost stations north to north east of Lille Frigg (3942 mg/kg) and Sleipner Vest (3232 mg/kg). Maximum barium concentrations from 1400 to 2000 mg/kg are found on at least one of the innermost stations at Frøy, Balder, Jotun, Varg, Heimdal and Sleipner Øst. The barium content at fields included in the 2000 baseline programme range from 9-23 mg/kg at Sigyn in shallow area, to 65-142 mg/kg at Ringhorne and 144-272 mg/kg at Glitne, both in the central part of the region. In addition, low barium contents are found in sediments from Frigg, Nordøst Frigg and Øst Frigg (20-300 mg/kg). The largest area contaminated with barium is found at Jotun, where sediments are contaminated with barium out to 2000 m north/north east and east/south east, 1000 m south west and 250 m north west of the installation.

The highest sediment concentrations of cadmium (0.095 mg/kg), copper (14.7 mg/kg) and chromium (16.5 mg/kg) are found at the 250 m station in the main-current direction from Sleipner Vest (10^o-axis). The highest sediment values of zinc (133 mg/kg) and lead (31 mg/kg) are found at the 200 m station on the 350^o-axis of Frigg TCP2.

Different types of synthetic drilling muds based on esters and olefins have been reported used and discharged at some fields in Region II. Olefin-based drilling muds have been used and discharged prior to 1997 at Balder and Frøy. In the present survey, sediments from these two fields are analysed for traces of olefins. At Frøy, olefins have almost disappeared from the sediments, but traces are still present at the innermost stations (0.3-3 mg/kg dry sediment). The general picture of Balder is that the 250-500 m stations contain olefins (0.1-32 mg/kg). Traces of olefins are still detected (0.2 mg/kg) at the outermost station (2000 m) in the main current direction from well template C. One explanation for the differences in olefin content at Balder and Frøy might be that discharges at Balder (1996: 300 tonnes, 1997: 70 tonnes) are more recent than at Frøy (1995: 400 tonnes, 1996: 100 tonnes). At Sleipner Øst, Petrofree ester was discharged during the time period from 1994 to 1996. The amount of Petrofree ester has decreased considerably since 1997, but traces (0.1-2 mg/kg) are still present at the Loke stations. Because of reported discharges of olefins at Loke and SLA, sediments from the seabed around these locations were analysed for traces of poly-α-olefins. The highest amounts of olefins, 41 and 22 mg/kg dry sediment, are found at the 250 m stations on the Loke 10^o- and 100^o-axes. At the remaining station, the olefin content range from values below 0.001 mg/kg to 6 mg/kg.

Comparison with previous survey(s) in Region II

By comparing the maximum, minimum and average THC contents over the same field stations in the present and previous survey (Figure 20-2), it can be concluded that the THC levels are almost unchanged or reduced at fields with no drilling activity in recent years (Frigg, Nordøst Frigg, Øst Frigg, Heimdal, Odin and Frøy). At these fields, the changes in barium contents are less obvious. At Nordøst Frigg and Odin, the contents of barium in sediments are almost unchanged or reduced compared to the 1997 results. Increased maximum and average barium contents are found at the Frigg, Frøy and Heimdal fields, even though there have been reports of discharges that can explain these increases. There has been no drilling activity at Øst Frigg and Lille Frigg in recent years, but accidentally spills of occurred during the permanent plugging of the wells. At Lille Frigg, the maximum amount of THC has increased from 9 to 15 mg/kg dry sediment and the maximum amount of barium has increased from 1232 to 3942 mg/kg respectively. Generally, increased contents of THC and barium at the innermost stations north east of C1, C2 and C3 might be explained by the accidentally discharges of 0.5 tonnes hydraulic oil and 140 tonnes barite during the permanent plugging of the wells immediately before the year 2000 survey. At Øst Frigg lower maximum, minimum and average THC and barium concentrations are found in the present survey, despite reported discharges of 81 tonnes barite and 804 tonnes water-based drilling mud during the permanent plugging of the wells in 1999.

At the Balder field, the maximum concentration of THC has decreased from 37 to 24 mg/kg, while the average THC content is unchanged compared to 1997. The area contaminated with THC has switched from south and south east of well templates A, B and C, to north west of well-templates A and D. The average content of barium has decreased slightly across the Balder field, however increased barium concentrations are found at the innermost stations in the main-current direction from well templates B, C and D. According to the data on discharges, barite was discharged at Balder in 1998.

The maximum and average content of THC and barium have increased at the Varg, Sleipner Vest and Jotun fields. At Varg, the area contaminated with THC is unchanged north east and south west of the centre, while the affected area has increased north west and decreased south east of the centre. The area contaminated with barium has increased from 250 m north east and south east of the installation in 1997 to at least 1000 m north west, north east and south west of the installation in year 2000. At Sleipner Vest, the areas contaminated with barium and THC are unchanged, the only exception is found at the 100^o-axis with no contamination of THC this year. At Jotun, the centre position has been moved approximately 400 m north to north west since the baseline survey in 1996. The content of THC was described as generally low in 1996, while elevated levels of barium were found at two stations in the periphery of the field centre. Direct comparison of THC and barium levels is not possible, but generally the amounts of THC and barium have increased in the area.

At Sleipner Øst, the maximum concentrations of THC has increased from 15 to 26 mg/kg and barium from 1130 to 1735 mg/kg, while the minimum and average contents are almost unchanged since the previous survey in 1997. The area contaminated with THC is still reaching out to 250 m on the Loke 100^o-axis, while the contaminated area has reached the 500 m stations on the Loke and SLA 10^o-axes and the 250 m stations on the SLA 190^o- and 280^o-axes. The 250 m station on the SLE 190^o-axis is regarded as uncontaminated with THC in the present survey. The Sleipner Øst stations regarded as contaminated with barium in the present survey were also deemed contaminated in 1997.

The calculated minimum area and total area of contamination with chemical parameters in the present and previous surveys in Region II is shown in Table 20-2 and Table 20-3. The total area contaminated with THC in Region II has increased from 4.15 km^2 in the previous survey to 5.27 km^2 in the present survey, while the total area contaminated synthetic base-oils has decreased from 15.67 km^2 in 1997 to 2.89 km^2 in year 2000. The total area contaminated with other metals is unchanged since 1997. The total areas contaminated with barium in year 2000 (17.87 km^2) and year 1997 (22.81 km^2) can not be compared because the number of stations included in the different field surveys might be different and because the levels of contaminants do not always reach background values even at the outermost stations. These circumstances are clearly reflected by the areas contaminated with barium at Sleipner Øst. In the 1997 survey, elevated levels of barium were generally found out to 1000 and 2000 m at the Loke and SLA axes, while only stations out to 500 and 1000 m at most of these axes are included in the present survey.

The THC level at one of the innermost station at Frigg has increased with 3 mg/kg dry sediment since 1997 and the THC level has just exceeded the LSC in the present survey. However the result is increased area contaminated with THC since 1997.

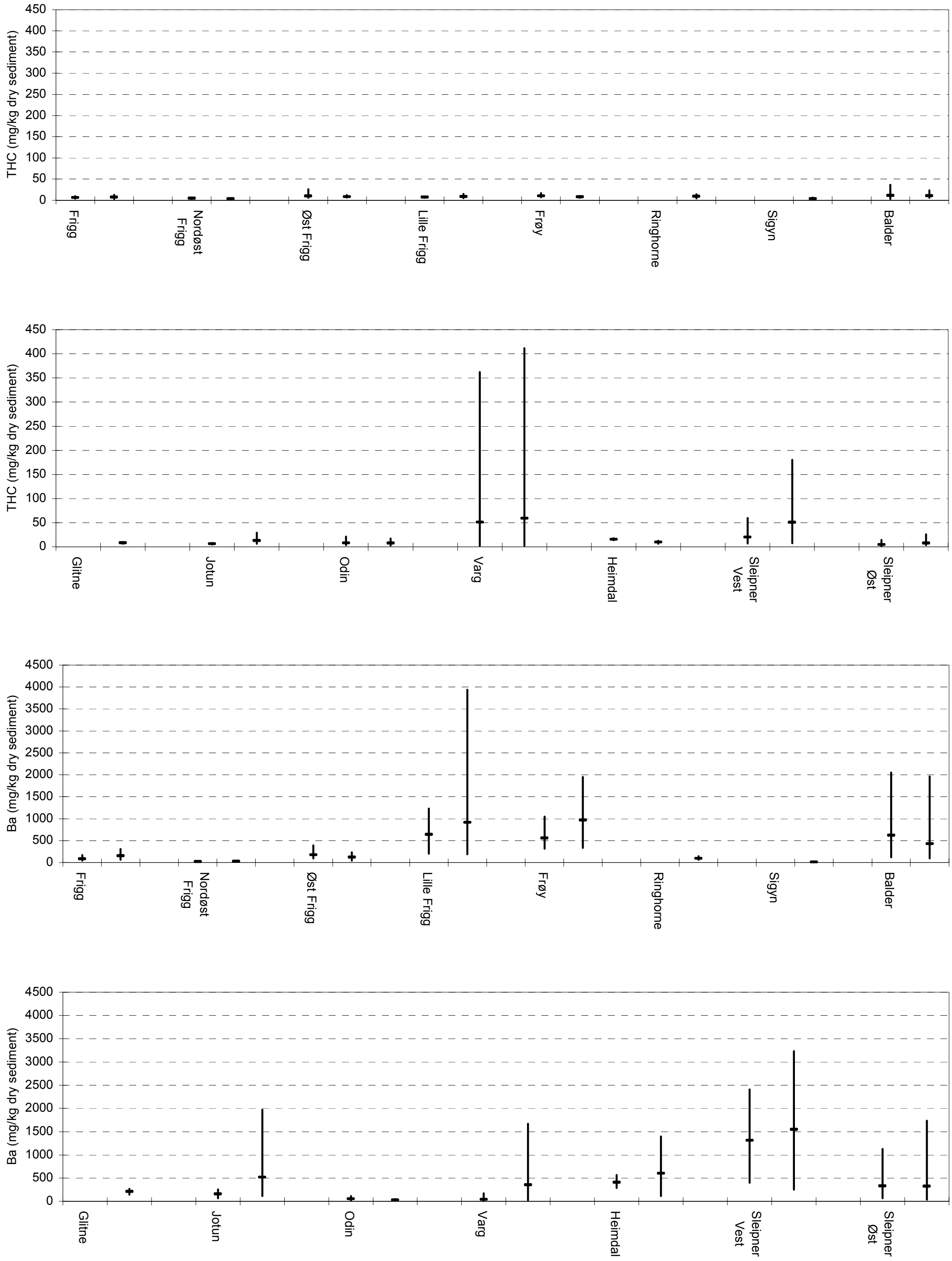

Figure 20-2: Range and average content of THC and barium in sediment at each field in the previous (left) and present (right) surveys, in Region II.

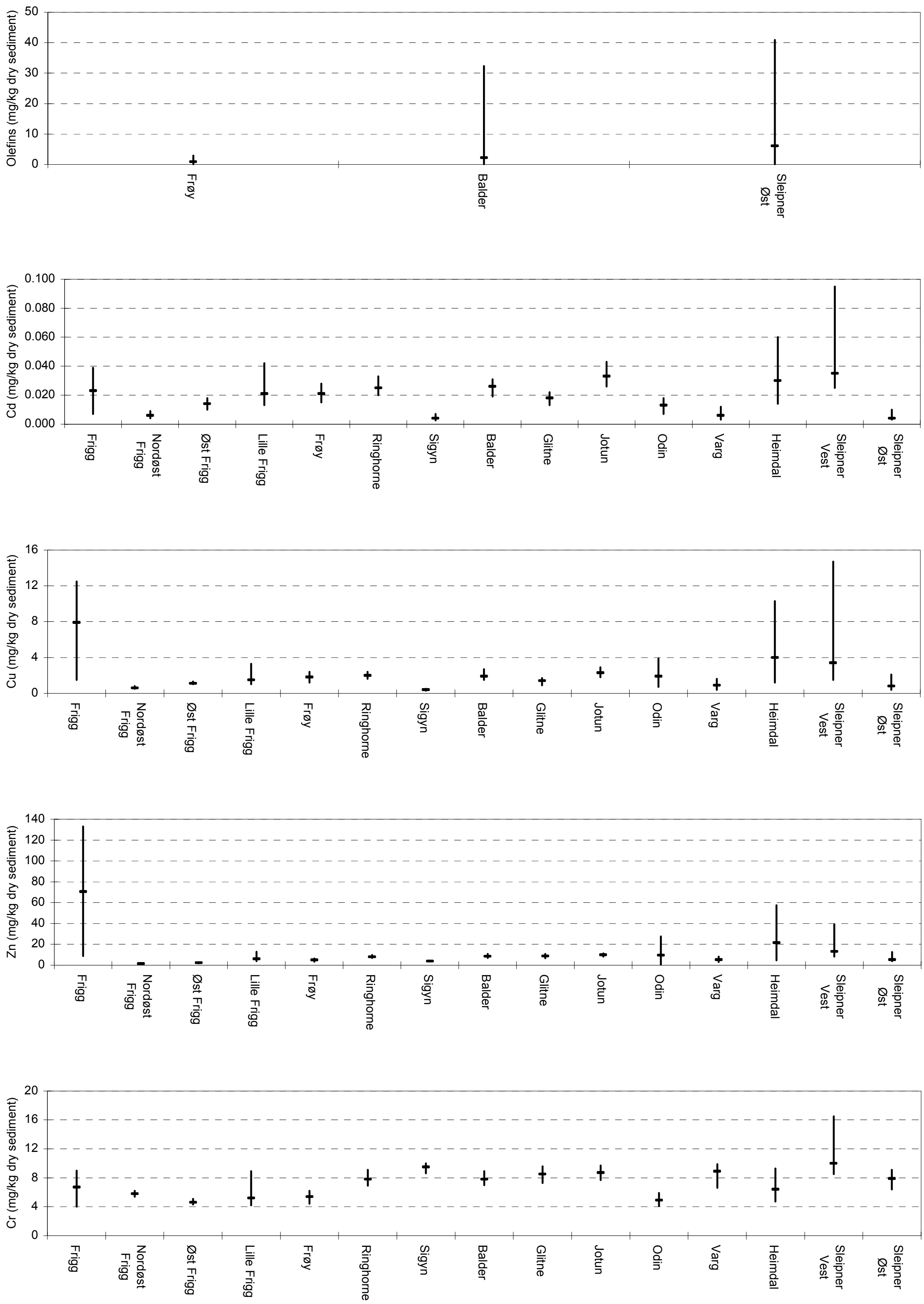

Figure 20-3: Range and average content of olefins, cadmium, copper, zinc and chromium in sediment at the fields in Region II, 2000.

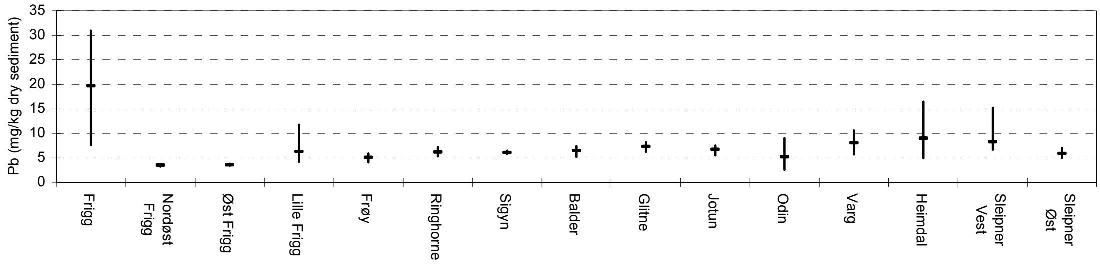

Figure 20-4: Range and average content of lead in sediments at the fields in Region II, 2000.

20.3 Biological characteristics

The distribution of individuals and taxa within the main taxonomic groups in Region II are given in Table 20-1. A total of 200672 individuals within 588 taxa are recorded at the stations in the present survey (excluding juveniles). Polychaete worms dominate the fauna, comprising 62 % of the individuals and 51 % of the taxa recorded.

Table 20-1: Distribution of individuals and taxa within the main taxonomic groups in Region II, 2000 (excluding juveniles).

Main taxonomic groups	Individuals		Taxa	
	Number	%	Number	%
Polychaeta	125046	62	300	51
Mollusca	25971	13	118	20
Crustacea	17284	9	116	20
Echinodermata	13747	7	26	4
Diverse groups	18624	9	28	5
Total	200672	100	588	100

The range and average value for the number of individuals and taxa and the diversity index H' at the fields (excluding the reference stations) in Region II in the present survey are shown in Figure 20-5. The number of individuals and taxa are lowest at the fields in the shallower, southern part of the region (Sigyn, Varg and Sleipner Øst). This is considered to be caused by natural variations in the sediment structure across the region.

The high number of individuals that are recorded at the Frigg, Frøy and Lille Frigg fields is caused by high abundance of a few taxa. Some of these taxa are abundant in undisturbed sediments while other are abundant in disturbed sediments. This is also the case at other fields in the region, but here the number of individuals for single taxa is lower.

The diversity index H' is above 4 at most of the fields. Values below 4 are found at Frigg, Varg and Sleipner Øst. Some of these stations are classified as having undisturbed fauna, dominated by a few taxa which are abundant in undisturbed sediments. Others are dominated by taxa that are abundant in disturbed sediments and, are thereby classified as having disturbed fauna to some degree.

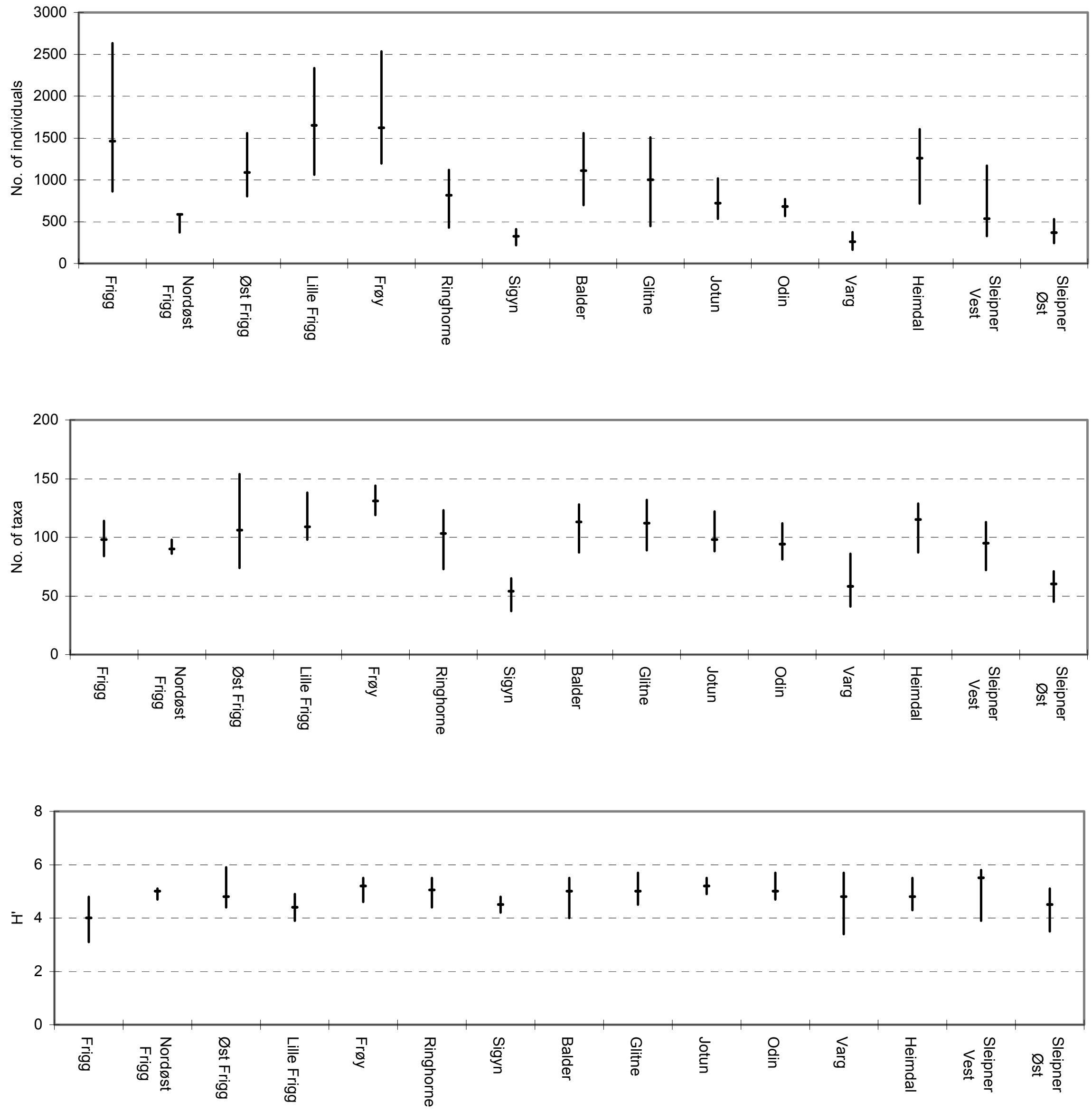

Figure 20-5: The range and average values for the number of individuals and taxa and the diversity index H' at the fields in Region II, 2000 (excluding the reference stations).

Through the evaluation of the results from the different analyses carried out on the data from each field, the fauna at each station is classified into groups according to disturbance levels. Eight of the fields in the region are found to have only undisturbed fauna (group A) at the surveyed stations. These are the three fields where baseline surveys are carried out in the present survey (Ringhorne, Sigyn and Glitne), together with the Jotun, Lille Frigg, Øst Frigg, Nordøst Frigg and Sleipner Øst fields.

Undisturbed and slightly disturbed fauna (group B) are found at four of the fields. At Odin, the 100 m stations at all transects are classified as having slightly disturbed fauna, at Varg the fauna is slightly disturbed out to 500 m north east and 250 m south west, at Heimdal out to 500 m south and 250 m north west and at Sleipner Vest out to 250 m north of the centre.

At the remaining three fields, three categories of faunal groups are detected; undisturbed, slightly disturbed and disturbed fauna (group C). At the Frigg field, the fauna are disturbed out to 330 m south east and 250 m south west of the TP1 installation and slightly disturbed out to 200 m north of the TP2 installation. At the Frøy field the fauna is disturbed out to 250 m north west and slightly disturbed out to 500 m south west and 250 south east and north east from the field centre. At Balder, the fauna is disturbed at the station 250 m south east of Template B and slightly disturbed at the stations 250 m south of Template A and C and at all three stations 250 m from Template D. The largest area of faunal disturbance are found at this field in the present survey.

The calculated minimum area of faunal disturbance in the present and previous survey in Region II is shown in Table 20-2 and Table 20-3. The total area of slightly disturbed fauna (group B) in Region II has decreased from 1.72 km^2 in the 1997 survey to 1.21 km^2 in the present survey while the area of disturbed fauna (group C) has increased from 0.18 km^2 in 1997 to 0.24 km^2 in 2000. This means that the total area of disturbed fauna has decreased while the intensity has increased during these years. But it should be mentioned that the group C fauna only is found at three of the fifteen fields and that the total area of disturbed fauna is relatively small.

Comparisons of single fields show that the area of faunal disturbance has decreased while the intensity has increased at the Frigg and Balder fields. At Varg and Sleipner Vest no faunal disturbance was detected in the previous survey, while slightly disturbed fauna is seen at these fields in the present survey. At Heimdal the area of faunal disturbance has increased while the intensity has decreased. At Øst Frigg, Lille Frigg and Sleipner Øst, where faunal disturbance was detected in 1997, the fauna is now found to be undisturbed. At Jotun and Nordøst Frigg the fauna was found to be undisturbed in both surveys.

Table 20-2: Calculated minimum area (km^2) of disturbed fauna and contaminated sediments in Region II, 2000.

Field	Faunal group B	Faunal group C	THC	Olefins/ ester	Ba	Other metals
Frigg	0.12	0.10	0.06	n.a.	0.08	0.36
Nordøst Frigg	0	0	0	n.a.	0	0
Øst Frigg	0	0	0.07	n.a.	0.18	0
Lille Frigg	0	0	0.15	n.a.	0.59	0.07
Frøy	0.29	0.07	0.07	0.29/n.a.	1.18	0.15
Ringhorne	0	0	0	n.a.	0	0
Sigyn	0	0	0	n.a.	0	0
Balder	0.37	0.07	0.54	1.13/n.a.	4.21	0.15
Glitne	0	0	0	n.a.	0	0
Jotun	0	0	1.77	n.a.	5.30	0.07
Odin	0.03	0	0.02	n.a.	0	0.02
Varg	0.15	0	1.33	n.a.	1.77	0.25
Heimdal	0.18	0	0.12	n.a.	0.43	0.29
Sleipner Vest	0.07	0	0.74	n.a.	3.14	0.74
Sleipner Øst	0	0	0.40	1.10/0.37	2.43	0
Total area 2000	1.21	0.24	5.27	2.89	17.87	2.11

n.a. = not analysed.

Table 20-3: Calculated area (km²) of disturbed fauna and contaminated sediments in Region II, 1997.

Field	Faunal group B	Faunal group C	THC	Olefins/ ester	Ba	Other metals
Frigg	0.13	0	0	n.a.	0.08	0.36
Nordøst Frigg	0	0	0	n.a.	0	0
Øst Frigg	0.07	0	0.11	n.a.	0.33	0
Lille Frigg	0.18	0	0	n.a.	0.32	0
Frøy	0.29	0.10	0.29	0.44/n.a.	1.18	0
Balder	0.48	0	1.09	14.0/n.a.	2.93	0.37
Jotun	0	0	0	n.a.	0	0
Odin	0.02	0.01	0.02	n.a.	0.01	0.02
Varg	0	0	1.18	n.a.	0.10	0
Grane (Hermod)	0	0	0.18	n.a.	0.37	0
Heimdal	0.11	0.07	0.25	n.a.	0.25	0.25
Sleipner Vest	0	0	0.88	n.a.	3.14	3.14
Sleipner Øst	0.44	0	0.15	n.a./1.23	14.1	0.15
Total area 1997	1.72	0.18	4.15	15.67	22.81	2.11

n.a. = not analysed.

The range of some physical, chemical and biological parameters at the regional and reference stations and the field stations in Region II in 2000 and the previous surveys are shown in Table 20-4. There are more stations included in the present than the previous survey. The general trend of decrease in both number of taxa and number of individuals between 1997 and 2000 is shown in the Table.

Table 20-4: Range of values of physical, chemical and biological parameters in Region II, 1997 and 2000.

Parameters	Background range *		Range of field stations	
	1997	2000	1997	2000
Total number of stations	23	22	168	217
Depth	71 – 123	71 – 123	78 – 126	78 – 126
Average grain size (Md)	1.6 – 3.9	1.6 – 4.5	2.3 – 4.1	2.7 – 4.5
Lead (mg/kg)	2.4 – 6.1	3.1 – 6.9	2.0 – 26.3	3.2 – 31.0
Cadmium (mg/kg)	0.003 – 0.023	0.004 – 0.035	0.005 – 0.085	0.003 – 0.095
Barium (mg/kg)	6 – 176	8 – 215	11 – 2480	9 – 3942
THC (mg/kg)	2.0 – 11.3	2.2 – 8.9	1.1 – 418	1.6 – 412
Diversity H’	3.2 – 6.1	3.4 – 5.6	3.9 – 5.9	3.1 – 5.9
Number of taxa per station	67 – 158	46 – 149	54 – 173	37 – 154
Number of individuals per station	402 - 2744	236 - 2994	235 - 3748	165 - 2635

* Based on data from the regional and reference station in the region.

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22 List of abbreviations

AAS	Atomic Absorption Spectrometry
Al	Aluminum
Ba	Barium
BV	Blind values
CCA	Canonical correspondence analysis
Cd	Cadmium
Cu	Copper
CVAAS	Cold vapour atomic absorption spectrometry
d	Sediment particle size (ϕ)
DL	Detection limit
EI/SIM	Electronic Ionosation/Single Ion Monitoring
ES_{100}	Expected number of species in a 100 specimen sample
Fe	Iron
GC/FID	Gas chromatography with flame ionization detector
GC/MS	Gas chromatography with mass selective detector
H'	Shannon-Wiener diversity
HC	Hydrocarbon
He	Helium
Hg	Mercury
ICP-AES	Inductive coupled plasma atomic emission spectrometry
J	Pielou's measure of evenness
$K\phi$	Sediment kurtosis
LOD	Limit of detection
LOQ	Limit of quantification
LSC	Limit of significant contamination
$Md\phi$	Median particle size
MDS	Multidimensional scaling
M_2	Mean particle diameter (graphic mean)
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
psi	Pressure unit (pounds per square inch)
Pb	Lead
SD	Standard deviation
$Sk\phi$	Sediment skewness
SFT	Statens Forurensningstilsyn (Norwegian State Pollution Control Authority)
$St\phi$	Sediment sorting index
THC	Total Hydrocarbon Content
TOM	Total Organic Material
UPGMA	Unweighted Pair Group Method Aritmethric Average
Zn	Zinc

23 List of Figures

24 List of Tables