Environmental monitoring survey of oil and gas fields in Region II, 2003

TL 2003/011 – Sediment survey, Region II, 2003

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Preface

This report presents the results of the third regional environmental monitoring survey of Region II in the Norwegian sector of the North Sea. The report describes the sampling and analytical methods used, as well as the natural distribution and variation in the measured environmental variables and the bottom fauna. The results from sampling in the vicinity of each field are presented in separate chapters. These results are summarized at the end of the report to give an overall picture of the condition of Region II in 2003.

The data on which this report is based are available on a separate CD-ROM.

UNIFOB AS, Seksjon for anvendt miljøforskning in Bergen carried out this survey in co-operation with AnalyCen AS in Moss.

The work was commissioned by Esso Exploration and Production Norway AS (Agreement Number 4500149607) on behalf of the operators in Region II.

Bergen, March 25, 2004
Seksjon for anvendt miljøforskning

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We would also like to thank the master and the crew onboard M/V *Highland Eagle*.

Table of content

1. Summary

Esso Exploration and Production Norway AS commissioned UNIFOB AS, Seksjon for anvendt miljøforskning in May 2003 to conduct the regional environmental monitoring survey in Region II in the Norwegian sector of the North Sea. All together, the survey comprised 16 fields. The region has previously been surveyed in 1997 and 2000.

M/V Highland Eagle left Bergen on May 20 with the representative for the oil companies and the sampling crew onboard. Sampling in Region II commenced at Varg on May 21 and ceased at Odin on June 2. The vessel returned to Bergen on June 5 after the completion of some additional sampling at Gullfaks. Samples were collected at 194 sampling sites, of which 22 sites were regional or fields specific reference sites which were used for describing the natural conditions.

The sediments in the region consisted mainly of fine sand with varying content of pelite (grain size less than 63 μm). The lowest pelite content was found in the southern and the northern part of the region, whereas sediments with higher pelite content were found in the central part. Tendencies toward increased pelite content in the sediments were found in 2003 as in 2000.

In general, the highest concentrations of the measured chemical compounds were found in the sediments from the immediate vicinity of the field centres. Faunal disturbances were also found in the immediate vicinity of some fields centres.

Estimated minimum area (km^2) of THC contamination in the sediments had increased at 7 fields, decreased at 6 fields, and remained at the same level as in 2000 at 2 fields. At one field the area was not estimated in 2003. The total area with THC contaminated sediments increased in Region II from 5.27 km^2 in 2000 to 8.87 km^2 in 2003 (Table 1.1).

Estimated minimum area (km^2) of Ba contamination in the sediments had decreased at 9 fields, increased at 6 fields, and remained at the same level as in 2000 at 1 field. Since 2000, the total area with barium contaminated sediments decreased from 19.09 km^2 to 14.32 km^2.

The area (km^2) contaminated with other metals in the sediments increased at 8 fields, and decreased at 4 fields and remained at the same level at 2 fields since 2000. At one field the area was not estimated in 2003. The increase was mainly caused by zinc. Since 2000 the total area contaminated with other metals increased from 2.10 km^2 to 6.50 km^2.

Faunal disturbance was found at 7 fields, whereas no faunal disturbance was found at the remaining 9 fields. The total area suffering faunal disturbance in the region was reduced from 1.21 km^2 to 0.29 km^2.

Roughly estimated the total area of Region II is 44 700 km^2. Approximately 23 000 km^2 are located to the west of the Norwegian trench, where also the surveyed fields are located. Based on these estimates approximately 0.04 % of the area west of the trench was contaminated by THC, 0.06 % was contaminated by Ba and 0.03 % was contaminated by other metals, whereas 0.001 % of the area had some faunal disturbance.

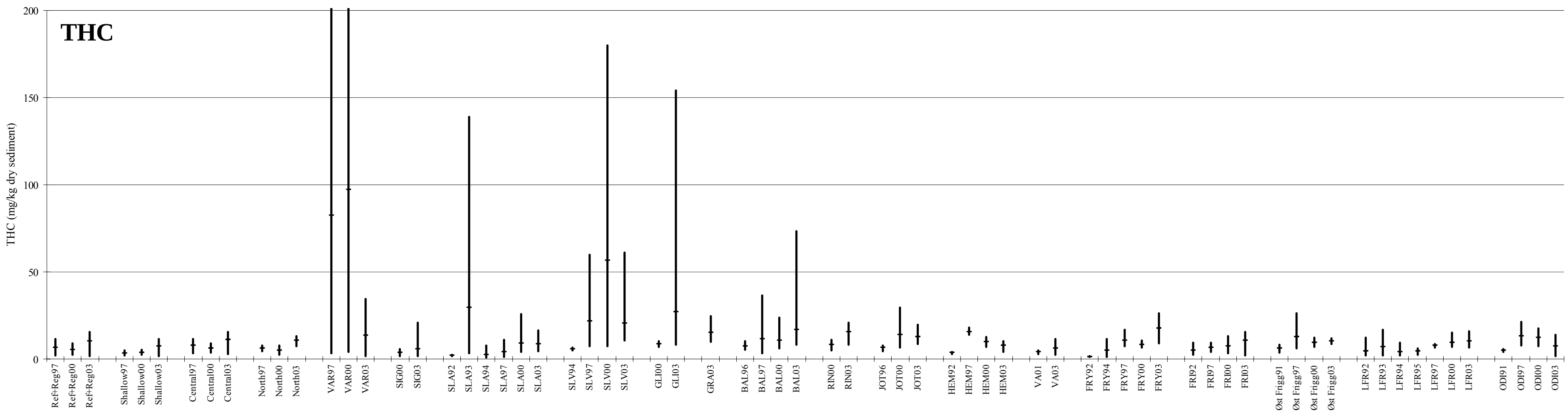


Figure 1.1. The average and range of THC at each field in Region II 2003 compared to previous surveys and the THC content at the regional and reference sites. Some values outside ordinate range.

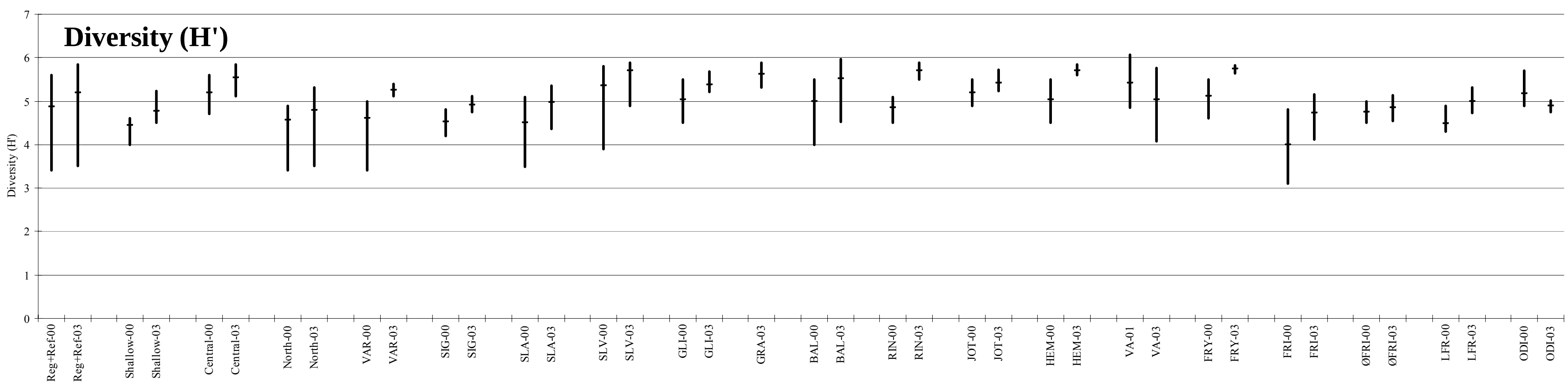


Figure 1.2. Average and range of diversity (H’) at the reference and regional sampling sites and at the petroleum fields in Region II in 2000 and 2003.

Table 1.1. Estimated minimum area (km²) of contaminated sediments and disturbed fauna in Region II 1997 – 2003. n.a. = not analyzed

Field	Year	THC	Ba	Other metals	Fauna
Varg	1997	1.18	0.10	0.00	0.00
Varg	2000	1.33	1.77	0.25	0.15
Varg	2003	0.07	0.20	0.20	0.05
Sigyn	1997	n.a.	n.a.	n.a.	n.a.
Sigyn	2000	0.00	0.00	0.00	0.00
Sigyn	2003	0.02	0.20	0.02	0.00
Sleipner Øst	1997	0.07	13.80	0.07	0.36
Sleipner Øst	2000	0.40	2.21	0.00	0.00
Sleipner Øst. Lok and Sla	2003	0.44	0.83	0.07	0.05
Sleipner Vest	1997	0.88	3.14	3.14	0.00
Sleipner Vest	2000	0.74	3.14	0.74	0.07
Sleipner Vest	2003	0.79	3.53	0.10	0.03
Glitne	1997	n.a.	n.a.	n.a.	n.a.
Glitne	2000	0.00	0.00	0.00	0.00
Glitne	2003	0.88	3.14	0.79	0.00
Hermod (Grane)	1997	0.18	0.37	0.00	0.00
Grane	2000	n.a.	n.a.	n.a.	n.a.
Grane	2003	0.10	0.98	0.05	0.00
Balder	1997	1.09	2.93	0.37	0.48
Balder	2000	0.54	4.21	0.15	0.37
Balder	2003	2.38	0.43	4.13	0.04
Ringhorne	1997	n.a.	n.a.	n.a.	n.a.
Ringhorne	2000	0.00	0.00	0.00	0.00
Ringhorne	2003	3.93	0.74	0.00	0.00
Jotun	1997	0.00	0.00	0.00	0.00
Jotun	2000	1.77	5.30	0.07	0.00
Jotun	2003	n.a	1.47	n.a	0.00
Heimdal	1997	0.25	0.25	0.25	0.11
Heimdal	2000	0.12	0.43	0.29	0.18
Heimdal	2003	0.00	0.08	0.15	0.05
Vale	1997	n.a.	n.a.	n.a.	n.a.
Vale	2000	n.a.	n.a.	n.a.	n.a.
Vale	2003	0.00	1.77	0.39	0.00
Frøy	1997	0.29	1.18	0.00	0.29
Frøy	2000	0.07	1.18	0.15	0.29
Frøy	2003	0.20	0.74	0.10	0.02
Frigg	1997	0.00	0.08	0.36	0.13
Frigg	2000	0.06	0.08	0.36	0.12
Frigg	2003	0.06	0.05	0.36	0.05
Øst Frigg	1997	0.11	0.33	0.00	0.07
Øst Frigg	2000	0.07	0.18	0.00	0.00
Øst Frigg	2003	0.00	0.02	0.02	0.00
Lille Frigg	1997	0.00	0.32	0.00	0.00
Lille Frigg	2000	0.15	0.59	0.07	0.00
Lille Frigg	2003	0.00	0.20	0.10	0.00
Odin	1997	0.02	0.01	0.02	0.02
Odin	2000	0.02	0.00	0.02	0.03
Odin	2003	0.00	0.00	0.03	0.00
Total area	1997	4.07	22.51	4.21	1.39
Total area	2000	5.27	19.09	2.10	1.21
Total area	2003	8.87	14.32	6.50	0.29

2 Introduction

In May 2003, Statoil ASA, Norsk Hydro Produksjon as, Esso Exploration and Production Norway AS, Total Exploration Norge AS and Pertra AS commissioned Seksjon for anvendt miljøforskning (SAM) to do the 2003 environmental monitoring survey of Region II in the Norwegian sector of the North Sea (Agreement Number 4500149607) (Figure 2.1). This is the third regional survey of Region II. The first took place in 1997 (Mannvik & al. 1998) and the second in 2000 (Mannvik & al. 2001). Prior to the regional surveys, smaller field specific surveys had been carried out.

The purpose of this survey was to assess the environmental conditions at regional sampling sites and at 18 different oil and gas fields situated within the region (Table 2.1), and compare the results from the 2003 survey with previous environmental surveys. A total of 189 field sites (including 13 reference sites) and 9 regional sites were sampled. Sediment samples were collected from each site for sediment description, and analysed for chemical content and bottom fauna.

Table 2.1. Brief summary of operators, fields, and number of sampling sites at each field surveyed in Region II in 2003.

Operator	Field	Number of sampling sites	Status of the field
Statoil	Glitne	11	Active
	Sleipner vest	10	Active
	Sleipner øst (SLE, SLA, Loke)	16	Active
Norsk Hydro	Vale	12	Active
	Grane	13	Under construction
	Heimdal	8	Active
ExxonMobil	Sigyn	14	Active
	Balder	29	Active
	Jotun	14	Active
	Ringhorne	14	Active
	Odin	6	Abandoned August 1994
Total	Frigg	9	Active
	Øst Frigg	5	Abandoned December 1997
	Lille-Frigg	8	Abandoned March 1999
	Frøy	8	Abandoned March 2001
	Skirne*		Baseline survey in 2002
Pertra	Varg	12	Active
	Regional sites	9	Reference

*A baseline survey was undertaken at the Skirne field in 2002. The drilling at the field comprise one well at Skirne and one well at the nearby Bygve. The wells were drilled from February to ultimo June 2003. Since the final decision on start up date for drilling and duration of drilling was not made when planning the regional survey of 2003 Skirne was not included in this survey. Skirne will be surveyed during 2006.

In addition to the sampling listed above 30 sites at Gullfaks were sampled during the same cruise. The results of that survey are given in a separate report.

Figure 2.1. Map showing the location of Region II in the Norwegian sector of the North Sea.

3 Methods

This monitoring survey was performed in accordance with *Forskrift om utføring av aktiviteter i petroleumsvirksomheten (Aktivitetsforskriften). Vedlegg 1 Krav til miljøovervåking av petroleumsvirksomheten på norsk kontinentalsokkel.*

3.1 Sampling cruise

The sampling cruise on board M/S *Highland Eagle* started in Bergen on May 20. Sampling commenced at the southernmost regional sampling site in Region II (RII-06) at 9:43 a.m. on May 21, and the last sample was collected at the northernmost regional sampling site (RII-01) at 22.11 p.m. on June 2. After sampling in Region II was finished the cruise continued to Gullfaks where samples from another 30 sites were collected. The results of these samples are reported separately. M/S *Highland Eagle* returned to Bergen on June 5.

The weather conditions were good during the whole cruise and there were no incidents hurting or damaging crew members, sample equipment, samples or the vessel. Some minor technical problems were solved during the cruise and did not cause delays.

3.2 Sampling area

The Norwegian continental shelf has been divided into regions in which environmental monitoring surveys are undertaken on a regular basis. Region II, which was last surveyed in 2000, is located approximately between 58° and 60° N in the North Sea. The water depth in the sampling area varies between 79 and 130 meters, and the sediments consist mainly of sand.

Offshore oil and gas production in Region II started in September 1977 at Frigg.

3.3 Sampling and sample treatment

Sampling took place at three different types of sampling sites, ordinary field sites, reference sites, and regional sites. Ordinary field sites were the most numerous. At each ordinary field site, 8 grab samples were taken. Five were used for biological analysis and 3 for chemical analysis (metals and oil hydrocarbons). Sediment that was used for chemical analysis was taken from the upper 0-1 cm of the sample. From field sites downstream and closest to the installation, additional sectioned samples were taken for chemical analysis from 1-3 and 3-6 cm depth of the sediment.

The second most common sampling sites were the field reference sites, which were the specific reference site for each surveyed field. From each of these sites, 15 grab samples were taken. Ten were used for biological analysis and 5 for chemical analysis. One of the samples for chemical analysis was sectioned as described above.

The regional sampling sites were fewest, and all were located outside the expected influence area of the oil and gas industry. The purpose of these sites was to describe the natural condition of the whole region. From each of these sites, 8 samples were taken. Five were used for biological analysis and 3 for chemical analysis.

The field sampling sites were spread out along two transects at a predefined distance from the installation. One transect extended upstream and downstream from the centre of the installation, and the other extended to the right and left at a right angel to the first transect at the centre of the installation.

Sediment samples were taken by a van Veen grab with adjustable weight and an opening of 0.1 m^2. The total volume of the grab was 23 litres. Due to softer sediments at Jotun a lighter (0.1 m^2) van Veen grab of 22 litres was used for sampling at this field.

On deck the volume of each sample was measured. Sediment was described, and colour was recorded, as well as anomalous odour and conspicuous taxonomic groups. Samples for biological analysis were sieved through sieves with 5 mm and 1 mm round holes. Material retained in the sieves was placed in 250-1000 ml plastic containers where formaline was added. Each sample was marked and stored in a designated 20 foot container on deck. Samples for chemical and geological analysis were taken through the hatches on top of the grab from the upper 0-1 cm of the sediment sample inside the grab. Each sample was put into Rilsan plastic bags which were marked and immediately frozen at ÷ 22° C. The samples were kept frozen until further analysis in the onshore laboratory. Samples for TOM and grain size analyses were taken from the upper 0-5 cm of the sediment and put in an additional plastic bag marked and frozen immediately.

Positioning of M/S *Highland Eagle* was done by the ship's crew and the surveyor according to site positions given by the operators. Global Positioning System (GPS) and Dynamic Positioning (DP) were used to keep the vessel at correct position with an accuracy of ± 1 m.

3.4 Sample analyses

Samples were described on deck when collected and further analyzed in the laboratory for grain size, TOM, oil hydrocarbons, heavy metals and bottom fauna.

3.4.1 Colour, grain size and TOM

The colour of the sediment was determined according to Munsell Soil Colour Chart when the sample arrived on deck.

A mixture consisting of sediment from the upper 0-5 cm of three separate grab samples was used for the grain size analysis at each sampling site. The grain size analysis was determined according to Buchanan (1984).

The amount of organic material (TOM) was determined as weight loss in a 2-3 gram dried sample (105° C for about 20 hours) after combustion at 550° C for 1 hour.

3.4.2 Chemical compound analyses

3.4.2.1 The principle of the oil hydrocarbons analysis

The petroleum hydrocarbon content was determined by GC/FID analysis of the extracts obtained as outlined in Intergovernmental Oceanographic Commission, Manuals & Guides no 11, UNESCO 1982.

The petroleum hydrocarbons were isolated from the sediment sample by saponification with methanolic potassium hydroxide for two hours, followed by extraction with pentane. The pentane phase is reduced using a Rotavapor, and is subsequently purified by solid phase extraction. The petroleum hydrocarbon components were eluted from the solid phase column with pentane followed by dichloromethane. The extract was reduced using a heating jacket and analyzed by Gas Chromatography with Flame Ionisation Detection (GC/FID). The analyses af PAHs and Decalines were performed by Gas Chromatography with Mass Selective Detection operating in the Single Ion Monitoring mode (GC/MS SIM).

Procedure

The sediment sample was homogenized by stirring and subsequently centrifuged at 2300 rpm for 5 minutes to remove additional water. The amount of dry matter in the centrifuged sample was determined by weighing a small part (about 10 g) of the sample before and after drying at 105°C for 16 hours.

Soxtec extraction

The saponification was carried out using a Soxtec System at 150°C, equipped with glass cups and cellulose thimbles. In order to reduce the background level of hydrocarbons in the blank samples, the empty cellulose thimbles were boiled for 1 hour in methanol prior to use.

About 20 g of the sample was placed in the cellulose thimble and boiled for 1 hour (in the “boiling position”) in 50 mL of a solution of potassium hydroxide in methanol (30 g/L). Before boiling, 1,0 mL of a mixture of internal standards is added to the extraction cups. The thimble was lifted to the “rinsing position” for 1 hour while the refluxing methanol extracted hydrocarbons from the sample. For every 20 samples, reference samples of HDF 200 (base oil in drilling fluid; for THC, olefins and decalines) and HS-4B (Harbour Marine Sediment Reference Material; for PAH and NPD) are extracted, purified and analysed according to this method for monitoring the accuracy of the method.

Pentane extraction

The methanol extract was collected in a Duran bottle. After cooling, 25 mL of pentane was added and the bottle was shaken for 10 minutes. The pentane phase was separated from the methanol phase and collected in a conical flask. Another 25 mL of pentane was added to the methanol, shaken, separated and added to the first pentane phase. The pentane was reduced to 1 mL using a Rotavapor with a water bath at 30°C.

Solid phase clean up

The final clean up was carried out using 200 mg florisil solid phase columns. The columns were conditioned prior to use. The sample was then added to the column, which was eluated with 2x2 mL pentane and 2 mL dichloromethane. The eluate was reduced to dryness using a heating jacket at 40°C. The residue was redissolved in 1 mL of dichloromethane and analyzed by GC/FID (THC and olefin) and GC/MS-SIM (PAH, NPD and decalines).

The quantification of the components

THC

The content of THC was quantified in the nC_{12}-nC_{35} boiling point range by using external and internal standards. The external standard was a solution of n-alkanes in dichloromethane (5 mg/L of each component, Restek # 57257). This external standard was also used to establish the retention time window. The internal standards (bromobenzene, *o*-terphenyl and squalane; all 5 mg/L) were added to the sample before boiling as well as to the external standard. The average THC value from blank samples was subtracted before the final quantification of the THC content of the sample. The conditions of the GC/FID system are shown in Table 3.1.

Prior to reporting the obtained results a method comparison was performed with an experienced laboratory. Here it was found, that the method used resulted in higher THC concentration. This was found to be a consequence of a divergence in the SPE extraction procedure. The SPE purification procedure used on the sediment samples lead to the eluting of high boiling phytosterol components. These phytosterols originate from natural occurring hydrocarbons and is not a petrogene component. This was verified by GC-MS analyses. Consequently, a number of experiments were performed in order to report results which can be compared with previuos reported results.

These experiments showed, that when the extracts were purified again, but this time only using pentane for the eluation og the SPE-columns, these high boiling Phytosterol components, had disappeared from the extract. Furthermore, it was found that similar results were obtained, when either performing a second SPE purification, or if the peaks resulting from the phytosterol components were subtracted from the calculations. Therefore, all the reported results have been subtracted the contribution from the high boiling Phytosterols.

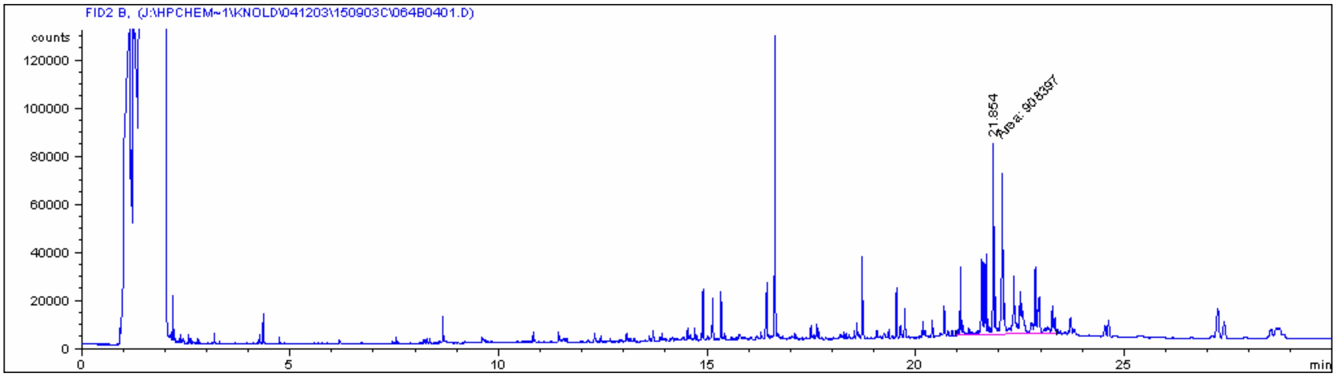


Figure 3.1. Chromatogram showing the subtracted phytosterol fraction of sediment sample.

Table 3.1. GC/FID conditions

GC system	Hewlett-Packard 5890 Series II Gas Chromatograph with split/splitless injector, Flame Ionisation Detector
Column	Agilent DB-5, length: 25 m, ID: 0,2 mm, film: 0,33 µm
Injector temperature	290°C
Detector temperature	300°C
Temperature program	35°C (3 min) - 15°C/min - 315°C (9,5 min)
Carrier gas	H_2, 1,4 mL/min
Injection	1 µL, splitless

Olefin

The olefins were identified using the "Novatec B" drilling fluid containing only C_{14} and C_{16} α-olefins. This fluid was analyzed by GC/FID to establish the retention times of the olefins. The samples as well as blank samples were analyzed by GC-FID and integrated in the established retention time windows. The quantification of the olefins were performed by subtracting the blank values and using a n-alkane solution as the external standard.

Decalines

The decaline components were analyzed by GC-MS SIM (single ion monitoring), and the molecular weight was used to choose the target ions (see Table 3.3). Details of the equipment used and the conditions prevailing during the analyses are compiled in Table 3.2.

Table 3.2. GC/MS conditions

GC system	Agilent Technologies 6890N Network GC System
MS	Agilent 5973 Network Mass Selective Detector
Column	Agilent DB-5ms, length: 30 m, ID: 0,25 mm, film: 0,25 µm
Injector temperature	300°C
Temperature program	80°C (2 min) - 25°C/min - 150°C (0 min) - 10°C/min - 250°C (o min) - 25°C/min – 300°C (5 min)
Carrier gas	He, 1,0 mL/min
Injection	1 µL, splitless, purge flow: 40 mL/min in 1 min

The decaline substances were quantified using a C5-decaline component (1,1,4,4,6-Pentamethyldecaline) obtained from Chiron (Chiron, 1394-15, Batch No. 2928). This C5-decaline standard was used for the quantification of all analysed decaline components, as it was not been possible to obtain representative C6 to C8-decaline standards. Hence, it was not possible to determine the response factors for the different decaline clusters. The integration of the decaline clusters were performed in retention time windows established from reference oils (among others the HDF 200).

For monitoring the performance of the analysis, a HDF control sample, which was though every step of the procedure, was analyzed for every 20 samples prepared. Furthermore, a solution of the HDF oil was analyzed.

The following Decaline clusters were analysed (Table 3.3);

Table 3.3. Analysed Dekaline clusters

Compound / cluster	**Target ion m/z**	**Corresponding internal standard**
C5-decaline	208	Squalane/ O-terphenyl
C6-decaline	222	Squalane/ O-terphenyl
C7-decaline	236	Squalane/ O-terphenyl
C8-decaline	250	Squalane/ O-terphenyl
O-terphenyl	230	
Squalane	183	

PAH and NPD

The PAHs/NPDs analysis was performed by GC/MS operating in the SIM (single ion monitoring) mode. The conditions of the GC/MS system are shown in Table 3.4.

Table 3.4. GC/MS conditions

GC system	Agilent Technologies 6890N Network GC System
MS	Agilent 5973 Network Mass Selective Detector
Column	Agilent DB-5ms, length: 30 m, ID: 0,25 mm, film: 0,25 μm
Injector temperature	300°C
Temperature program	60°C (2 min) - 12°C/min - 300°C (8 min)
Carrier gas	He, 1,0 mL/min
Injection	1 μL, splitless, purge flow: 40 mL/min in 1 min

The amounts of PAHs and NPDs were quantified using internal deuterium marked standards and calibration curves made from 3 levels of standards containing the 16 EPA PAHs and selected NPDs. The internal standards were added to the sample before boiling as well as to the external standard. The 16 standard EPA PAHs were obtained in PAH cocktail ampoules from Ehrensdorfer (20952500 PAH Mix 25) and Chemservice (PP-HC6JM). A NPD cocktail containing 1 compound representing each of the NPD clusters was obtained from Chiron (NPD Cocktail 3, S-4046). The NPD compounds in the cocktail were: Dibenzothiophene, 4-methyldibenzothiophene, 2,8-dimethyldibenzothiophene, 2,4,7-trimethyldibenzothiophene, naphthalene, 2-methylnaphthalene, 2,3-dimethylnaphthalene, 2,3,6-trimethylnaphtalene, phenanthrene, 2-methylphenanthrene, 1,6-dimethylphenanthrene and 1,2,8-trimethylphenanthrene. Table 1.6 shows target ion, qualifier ion, and the corresponding internal standard for each PAH compound and NPD cluster. Before the final quantification was carried out, the corresponding average concentration of blank samples was subtracted.

Table 3.5. Analyzed PAH compounds and NPD clusters

Compound / cluster	**Target ion m/z**	**Qualifier ion m/z**	**Corresponding internal standard**
Naphthalene	128	102	Naphthalene-d8
C1-naphthalene	142	141	Naphthalene-d8
C2-naphthalene	156	141	Acenaphthylene-d10
Acenaphthylene	152	151	Acenaphthylene-d10
Acenaphthene	153	154	Acenaphthylene-d10
C3-naphthalene	170	155	Acenaphthylene-d10
Flourene	166	165	Acenaphthylene-d10
Dibenzothiophene	139	168	Acenaphthylene-d10
Phenanthrene	178	176	Phenanthrene-d10
Anthracene	178	176	Phenanthrene-d10
C1-dibenzothiophene	198	-	Phenanthrene-d10
C1-phenanthrene	192	191	Phenanthrene-d10
C2-dibenzothiophene	212	-	Phenanthrene-d10
C2-phenanthrene	206	191	Phenanthrene-d10
Fluoranthene	202	101	Fluoranthene-d10
C3-dibenzothiophene	226	-	Fluoranthene-d10
Pyrene	202	101	Pyrene-d10
C3-phenanthrene/antracene	220	-	Pyrene-d10
Benzanthracene	228	114	Pyrene-d10
Chrysene/triphenylene	228	114	Pyrene-d10
Benz[bjk]fluoranthenes	252	250	Benz[a]pyrene-d12
Benz[a]pyrene	252	250	Benz[a]pyrene-d12
Indeno(1,2,3-cd)pyrene	276	274	Benz[a]pyrene-d12
Dibenzo[a,h]anthracene	278	-	Benz[a]pyrene-d12
Benzo(ghi)perylene	276	274	Benzo(ghi)perylene-d12
Internal standards			
Naphthalene-d8	136		
Acenaphthylene-d10	160		
Phenanthrene-d10	188		
Fluoranthene-d10	212		
Pyrene-d10	212		
Benz[a]pyrene-d12	264		
Benzo(ghi)perylene-d12	288		

Limit of detection

The limit of detection, DL, was determined from the standard deviation of at least 8 blank samples. The applied definition of the limit is recommended in the "VKI sag nr. 404444/910".

Formula 1. $$DL = t_{0,995}(f) \cdot s_{blank} \cdot \sqrt{1 + \frac{1}{n}}$$

$t_{0,995}$ t-distribution (Students t-test)
f degrees of freedom
s_{blank} standard deviation of blank level
n number of blank samples

Table 3.6 shows the limit of detection for THC, PAH compounds and NPD clusters.

Table 3.6. Limits of detection

Compound	DL [mg/kg TS]
THC	3,0
PAH/NPD	
Naphthalene	0,005
C1-naphthalene	0,003
Acenaphtylene	0,0005
C2-naphthalene	0,002
Acenaphthene	0,0005
C3-naphthalene	0,002
Fluorene	0,0005
Dibenzothiophene	0,001
Phenanthrene	0,0005
Anthracene	0,0005
C1-dibenzothiophene	0,001
C1-phenanthrene/anthracene	0,0005
C2-dibenzothiophene	0,0005
C2-phenanthrene/anthracene	0,001
Fluoranthene	0,0005
C3-dibenzothiophene	0,0005
Pyrene	0,0005
C3-phenanthrene/anthracene	0,0005
Benzanthracene	0,0005
Chrysene/triphenylene	0,0005
Benzo[bjk]fluoranthenes	0,0005
Benzo[a]pyrene	0,0005
Indeno(1,2,3-cd)pyrene	0,0005
Dibenzo[ah]anthracene	0,0005
Benzo[ghi]perylene	0,0005
Olefins	
Olefins	0,1
Decalines	
C5-Decaline	0,02
C6-Decaline	0,04
C7-Decaline	0,02
C8-Decaline	0,02

3.4.2.2 The principle of metal analysis

The metal content is determined by Inductively Coupled Plasma – Atomic Emission Spectrometry (ICP-AES) except mercury which determined by Cold Vapour Atomic Emission Spectrometry (CVAAS) after drying, sieving and digestion.

Procedure

The sediment samples were dried at 105°C or 40°C for samples for mercury determination. The sample was sieved through a 0.5 mm sieve. The fraction <0.5 mm was digested with nitric acid according to NS4770 modified by the use of microwave oven.

For total digestion, the sample was dried at 105°C. Then sieved through a 2 mm sieve. The fraction <2 mm was digested with fluoric acid/aqua regia according to Loring and Rantala (1992).

Digestion by nitric acid

Digestion was performed in a microwave oven. About 1 g of sample was weighed in to a Teflon vessel with 4 mL of nitric acid and 1 mL of hydrogen peroxide. The samples were then heated in the microwave oven. After cooling, the samples were filtered and diluted to 50 mL.

Digestion by fluoric acid/aqua regia

The digestion was performed in a microwave oven. About 0.2 g of sample was weighed in to a teflon vessel with 1 mL of aqua regia and 6 mL of fluoric acid was added. 2.8 g of H_3BO_3 was weighed in to a polypropylene tube and 20 mL H_2O was added. The content of the vessel was transferred to the polypropylene tube and shaken to complete the dissolution. The solution was then diluted to 50 mL with H_2O.

Metal analysis by ICP-AES

The metals, except mercury, were analysed by a Varian Liberty Series II ICP-AES. The analytical conditions are found in Table 3.7. For the samples digested by nitric acid, a glass concentric nebulizer and a cyclonic spray chamber were used. For the fluoric acid/aqua regia digestion, a Burgener T2002 nebulizer was used with the cyclone spray chamber.

Table 3.7. ICP-AES analytical conditions

Element	Wavelenght	Power (kW)	Peak tracking window (nm)	Background correction
Ba	233.527	1.2	0.040	Polynomial plotted background
Cd	228.802	1.2	0.015	Polynomial plotted background
Cr	267.716	1.2	0.040	Polynomial plotted background
Cu	324.754	1.2	0.040	Polynomial plotted background
Pb	220.353	1.2	0.027	Polynomial plotted background
Zn	213.856	1.2	0.027	Polynomial plotted background
Al	396.152	1.2	0.080	Polynomial plotted background
Li	670.784	1.2	0.080	Polynomial plotted background

Mercury analysis by CVAAS

Mercury was analyzed by a Cetac M6000-A mercury analyzer. The mercury in the solution was reduced by $SnCl_2$ to its elementary form Hg^0. Elementary mercury is volatile and was separated from the solution in a gas liquid separator by an argon carrier gas. The absorption at 254 nm was measured to determine the concentration of mercury.

Reference materials

PACS-2 Marine Sediment (National Research Council of Canada) and CRM015-050 metals on sediment (Resource Technology Corporation) were used as reference materials.

3.4.2.3 Limits of significant contamination (LSC)

Prior to estimation of the limits of significant contamination (LSC) it was necessary to investigate the entire data set for any sub-region within Region II. This was done by applying a PCA analysis on the data set from the chemical analysis. Any identified sub-region would then be the same for both THC and barium. For each sub-region, LSC was estimated both on the accumulated data from the period from 1996 to 2003 and on the data from 2003.

LSC values were calculated for following areas:

- the whole region (all reference and regional sites)
- any sub-regions (based on selected reference and regional sites)
- each field reference site

The decision on which part of the data set should be included in the final estimation of the LSC was based on an evaluation of all the different LSC values. See chapter 4 for more details concerning sub-subdivision of Region II.

LSC values were then calculated from the chosen data set by using a one-tailed student t-test at 95 % significant level according to the formula given in the "Aktivitetsforskrift". (See also NIVA-notat O-99218).

3.4.2.4 PCA, chemistry and geology

Based on the amount of pelite, sand, gravel, median Φ, TOM, Cu, Ba, Zn, Cr, Pb and THC at each sampling site, all sites within each field and nearby regional and field specific reference sites were compared by a PCA analysis. Log (x+1) transformation were used in the analyses.

3.4.3 Biological analyses

Prior to sorting and species identification, each sample was sieved and washed once more to remove formalin. Specimens were then sorted out under dissecting microscope, and each taxonomic group placed in a small bottle with ethanol. The specimens were then identified, mostly to species level, and enumerated and returned to the fixation fluid.

A complete species list is presented in the appendix. Only the bottom fauna (benthos) was used for further analyses which used:

- Total number of species
- Total number of specimens standardised to 0.5 m^2 of sea floor
- The ten most prevailing species at each site (species name, number of specimens and % of total number of specimens)
- Cumulative species / area graph, for reference sites only (10 samples)
- Species diversity stated as "Shannon Wiener index" on a $\log_2$ base (Shannon & Weaver 1963)
- Eveness as Pielous's "J" (Pielou 1966)
- Expected number of species among 100 specimens (ES_{100})
- Cluster analysis based on "Bray-Curtis dissimilarity index" (Bray & Curtis 1957), followed by "group average sorting" on 4^{th} root transformed data
- Ordination by "multidimensional scaling"

3.5 Linking biota to multivariate environmental patterns

A BIO-ENV procedure are used for matching biotic to environmental patterns (all combinations of the environmental variables pelite, sand, gravel, median Φ, TOM, Cu, Ba, Zn, Cr, Pb and THC). A weigthed spearman. correlation coefficient was used in the analysis.

3.6 Estimation of influenced area

The estimated area of contaminated sediments and disturbed fauna is based on the calculation of an asymmetric ellipse. The distance to contaminated/disturbed sites was used in the calculation of influenced sites. The radius varies from field to field and between transects within a field.

3.7 Quality control

Only samples where the grab was completely closed, and with open space between the sediment surface and the lid was accepted. In this way only complete and undisturbed sediment samples were collected for further processing.

All laboratories involved in the work are accredited and perform their analysis in accordance to the accreditation.

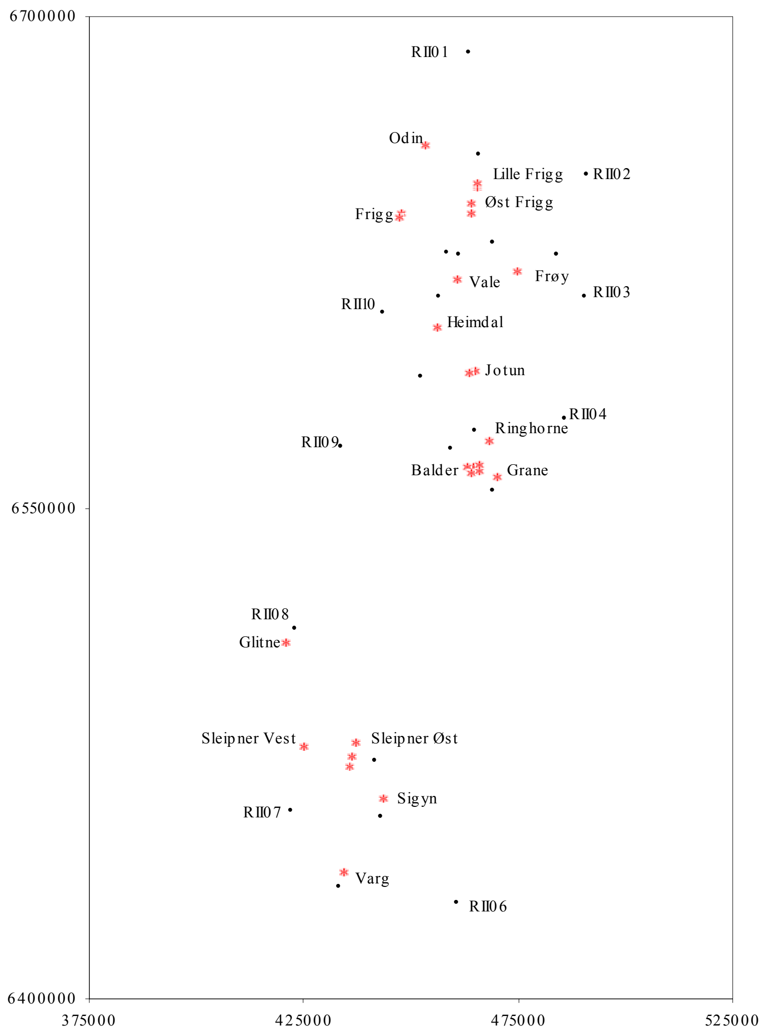
3.8 Storage of samples

Sediment samples analysed for chemical substances are stored at Analycen AS for 5 years from March 2004. Biological samples are stored at the Zoological Museum in Bergen, whereas selected specimens of high quality are included in the reference collection kept at Seksjon for anvendt miljøforskning in Bergen.

4 Regional and reference sites

4.1. Introduction

This survey comprises 9 regional and 13 field reference sites. The two regional sites RII-07 and RII-08 have a dual function as they are both regional sites and serve as reference sites for Glitne and Sleipner respectively. So far there have been two regional surveys in Region II, one in 1997 (Mannvik & al. 1998) and one in 2000 (Mannvik & al. 2001). They both concluded that all regional and reference sites where undisturbed and uncontaminated, and that variations found in the data were due to natural variations in the region. Figure 4.1 shows the distribution of the petroleum fields and the regional sampling sites in Region II.



Site	ED50 UTM Zone 31		Depth
	E	N	(m)
RII01	463281	6688937	115
RII02	490795	6651639	118
RII03	490702	6614517	119
RII04	485867	6577412	118
RII06	460684	6429120	77
RII07	421831	6457534	101
RII08	422936	6513198	111
RII09	433551	6568688	119
RII10	443670	6609362	122

Site	ED50 UTM Zone 31		Depth
	E	N	(m)
VAR14R	433187	6434316	85
SIG17R	443211	6455657	80
SLE41R	441623	6472715	81
GRA14R	469297	6554935	128
BAL27R	459203	6567845	126
RIN29R	465101	6573496	129
JOT30R	452182	6590203	127
HEM22R	456430	6614401	121
VA13R	461199	6627052	114
FRY18R	483795	6627075	118
FRI10R	458362	6627966	116
PSB13R	469290	6630899	116
LFR01R	465976	6657599	116

Figure 4.1. Map showing the internal distribution of petroleum fields and the regional sampling sites in Region II. Positioning according to UTM ED50 zone 31.

4.2. Results and discussion

4.2.1 Sediments characteristics

TOM, and the amount (%) of gravel, sand, pelite, median (Φ), mean (Φ), sorting, skewness and kurtosis in the sediment from the present survey is presented in Table 4.2. Additional information on colour and smell can be found in the Appendix. Pelite, sand and TOM are compared with data from 2000 in Figure 4.2.

The sediments in Region II are sandy, and classified from very fine sand to medium sand with median (Φ) values ranging from 1.76 (RII04) to 3.69 (PSB13R). The amount of pelite varied from 1.03 % (SLE41R) to 21.8 % (JOT30R), the sand varied from 78.1 % (JOT30R) to 98.9 % (SLE41R), and the TOM varied from 0.5 % (SLE41R) to 2.2 % (JOT30R). There was more pelite and TOM at the deeper sites in the central and northern part of Region II than at the shallower sites in the southern part of the region (Figure 4.1).

Compared to the 2000 survey, there were no major changes in the sediment characteristics (Figure 4.2).

Table 4.1. Total organic matter and sediment grain size at all regional and reference sites in 2003. For comparison averages, standard deviations, and max and min values for the regional and reference sites are included.

Site	TOM %	Gravel %	Sand %	Pelite %	Median (Φ)	Sorting	Skewness	Kurtosis
RII-01 $_{\text{03 (north)}}$	1.19	0.03	95.79	4.17	2.55	0.54	0.13	1.40
RII-02 $_{\text{03 (north)}}$	0.93	0.01	95.76	4.23	2.61	0.68	0.16	1.37
RII-03 $_{\text{03 (central)}}$	1.42	0.50	89.53	9.97	2.72	1.28	0.16	1.64
RII-04 $_{\text{03 (central)}}$	0.73	0.35	96.61	3.04	1.76	0.96	0.03	1.05
RII-06 $_{\text{03 (shallow)}}$	0.69	0.02	97.94	2.05	2.49	0.43	-0.07	1.11
RII-07/SLV$_{\text{03 (central)}}$	1.16	0.08	94.31	5.61	2.51	1.00	0.06	1.39
RII-08/GLI$_{\text{03 (central)}}$	1.92	0.02	87.42	12.56	2.67	1.15	0.44	2.03
RII-09 $_{\text{03 (central)}}$	1.55	0.00	90.40	9.60	2.68	0.93	0.51	2.08
RII-10 $_{\text{03 (central)}}$	1.89	2.19	82.46	15.35	2.99	1.28	0.22	1.67
VAR14R$_{\text{03 (shallow)}}$	0.90	0.02	96.60	3.38	2.48	0.61	0.01	1.55
SIG17R$_{\text{03 (shallow)}}$	0.57	0.00	97.10	2.90	2.51	0.49	0.09	1.33
SLE41R$_{\text{03 (shallow)}}$	0.51	0.04	98.93	1.03	2.47	0.45	-0.18	1.14
GRA14R$_{\text{03 (central)}}$	2.05	0.12	86.58	13.30	2.61	1.19	0.44	2.95
BAL27R$_{\text{03 (central)}}$	2.16	0.01	85.10	14.89	2.72	1.12	0.57	1.87
RIN29R$_{\text{03 (central)}}$	2.18	0.01	82.95	17.04	2.81	1.22	0.57	1.60
JOT30R$_{\text{03 (central)}}$	2.19	0.12	78.12	21.77	3.34	1.40	0.41	1.68
HEM22R$_{\text{03 (central)}}$	1.66	0.02	83.99	15.99	2.93	1.16	0.42	1.52
VA13R$_{\text{03 (north)}}$	0.68	0.03	97.12	2.85	2.45	0.67	-0.06	1.51
FRY18R$_{\text{03 (central)}}$	1.62	0.03	89.24	10.74	2.78	1.18	0.27	1.64
FRI10R$_{\text{03 (north)}}$	1.04	0.00	94.23	5.77	2.60	0.88	0.18	1.59
PSB13R$_{\text{03 (north)}}$	0.95	0.00	94.05	5.95	3.69	0.78	0.23	1.87
LFR01R$_{\text{03 (north)}}$	1.17	0.03	93.99	5.98	2.46	0.94	0.08	1.72
Average[1]	0.67	0.02	97.64	2.34	2.49	0.50	-0.04	1.28
Sd[1]	0.17	0.02	1.02	1.03	0.02	0.08	0.11	0.21
Min[1]	0.51	0.00	96.60	1.03	2.47	0.43	-0.18	1.11
Max[1]	0.90	0.04	98.93	3.38	2.51	0.61	0.09	1.55
Average[2]	1.71	0.29	87.23	12.49	2.71	1.16	0.34	1.76
Sd[2]	0.45	0.62	5.20	5.12	0.37	0.14	0.19	0.46
Min[2]	0.73	0.00	78.12	3.04	1.76	0.93	0.03	1.05
Max[2]	2.19	2.19	96.61	21.77	3.34	1.40	0.57	2.95
Average[3]	0.99	0.02	95.16	4.83	2.73	0.75	0.12	1.58
Sd[3]	0.19	0.02	1.27	1.28	0.48	0.15	0.10	0.19
Min[3]	0.68	0.00	93.99	2.85	2.45	0.54	-0.06	1.37
Max[3]	1.19	0.03	97.12	5.98	3.69	0.94	0.23	1.87
Average[4]	1.33	0.17	91.28	8.55	2.68	0.92	0.21	1.62
Sd[4]	0.56	0.47	6.01	5.87	0.37	0.30	0.22	0.40
Min[4]	0.51	0.00	78.12	1.03	1.76	0.43	-0.18	1.05
Max[4]	2.19	2.19	98.93	21.77	3.69	1.40	0.57	2.95

[1] Reg+Ref $_{\text{shallow 03}}$
[2] Reg+Ref $_{\text{central 03}}$
[3] Reg+Ref $_{\text{north 03}}$
[4] Reg+Ref $_{\text{RII 03}}$

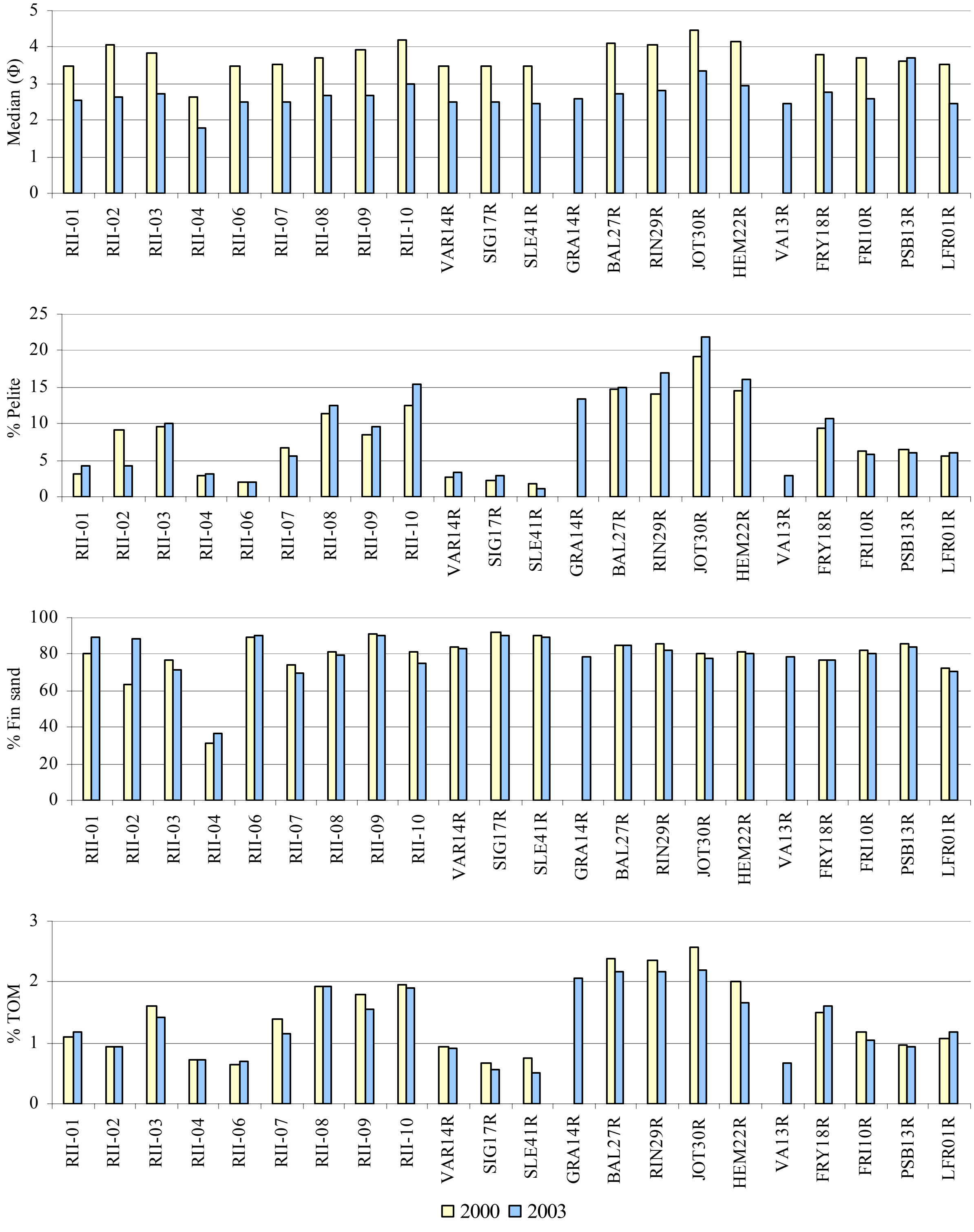


Figure 4.2. Sediment characteristics at regional and reference sites in 2000 and 2003. The fine sand is the relative amount of sand with grain size 63-250 μm.

As anticipated, there was a strong relationship between the amount of pelite and TOM in the sediments (Figure 4.3), since finer sediments with more pelite have a higher affinity for organic material and chemical compounds. There was also a relationship between water depth and the amount of pelite, and between TOM and water depth. This implies that the finer sediments from the deeper sites and fields have a higher natural capacity for containing chemical compounds than the coarser sediments from the shallower sites and fields.

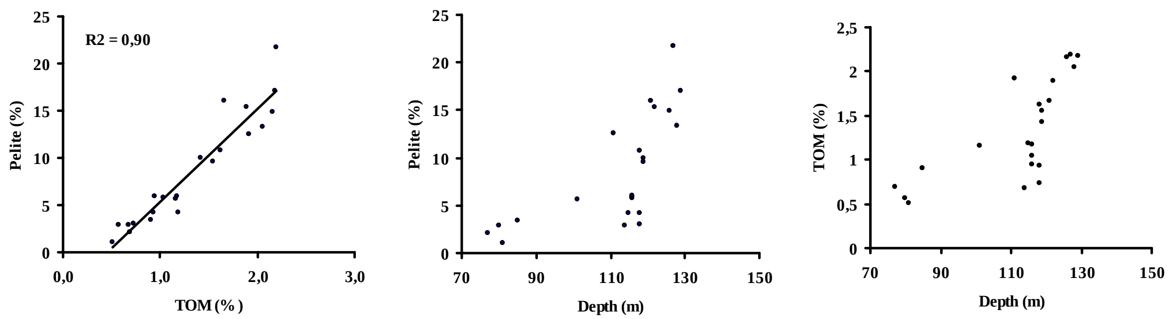


Figure 4.3. The relationship between pelite and TOM, pelite and water depth, and TOM and water depth at the regional and reference sampling sites in 2003.

4.2.2 Chemical compounds

4.2.2.1 LSC

Due to the sediment characteristics, it seamed logical to divide Region II into two sub-regions with one shallow part (77-85 m deep) including the regional site RII06 and the petroleum fields Varg, Sigyn and Sleipner Øst, and one deeper part (101-129 m) including the rest of the regional sites and the other petroleum fields. Mannvik & al. (2001) divided Region II into similar sub-regions in 2000. However, a separate PCA analysis of the chemical data set from 2003 and a PCA analysis on the merged chemical data set from 1997 to 2003 revealed that Region II can be divided into three sub-regions (Figure 4.4). The shallow sub-region in the south remains as before whereas the deeper part is further divided into a central part and a northern part.

The central part includes Sleipner Vest, Glitne, Grane, Balder, Ringhorne, Jotun, Heimdal and Frøy, plus the regional sites RII03, RII04, RII07, RII08 and RII10. The water depth in this part of Region II varies from 101 to 130 m. The northern part includes Vale, Frigg, Øst-Frigg, Lille-Frigg and Odin plus the regional sites RII01 and RII02. The water depth in the northern part varies from 100 to 120 m. The conditions at RII04 were somewhat special. According to the PCA analysis (Figure 4.4), RII04 belonged to the shallow southern sub-region, but as will be shown later, the species assemblage at RII04 was more similar to the fauna in the northern part of Region II. Based on the mixed “signals”, the water depth (118 m) and the proximity to the other fields and sites in the central part of Region II, it was decided to include RII04 in the central part of Region II.

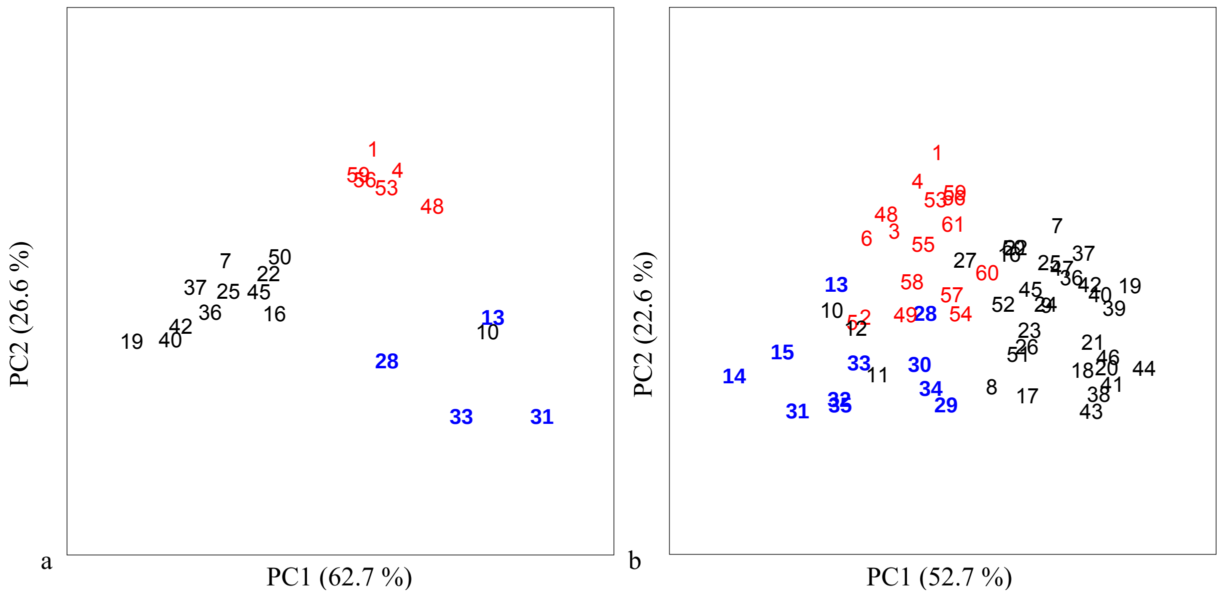


Figure 4.4. PCA plot based on the chemical data set (THC, Ba, Pb, Zn and Cu) from a) 2003 and b) the merged chemical data sets from 1997 to 2003. The data is from the regional and field specific reference sites in Region II. Sites from the shallow part of Region II are marked in blue, sites from the central part are marked in black, and sites from the northern part are marked in red. Codes are given in the table below. PC1 (x-axis) and PC2 (y-axis) account for 89.3 % (a) and 75.3 (b) % of the variation in the data.

1	RII01-03	11	RII04-00	21	RII08/GLI-97	**31**	**SIG17R-03**	41	RIN29R-00	51	FRY18R-00
2	RII01-00	12	RII04-97	22	RII09-03	**32**	**SIG17R-00**	42	JOT30R-03	52	FRY18R-97
3	RII01-97	**13**	**RII06-03**	23	RII09-00	**33**	**SLE41R-03**	43	JOT30R-00	53	FRI10R-03
4	RII02-03	**14**	**RII06-00**	24	RII09-97	**34**	**SLE41R-00**	44	JOT30R-96	54	FRI10R-00
5	RII02-00	**15**	**RII06-97**	25	RII10-03	**35**	**SLE41R-97**	45	HEM22R-03	55	FRI10R-97
6	RII02-97	16	RII07/SLV-03	26	RII10-00	36	GRA14R-03	46	HEM22R-00	56	PSB13R-03
7	RII03-03	17	RII07/SLV-00	27	RII10-97	37	BAL27R-03	47	HEM22R-97	57	PSB13R-00
8	RII03-00	18	RII07/SLV-97	**28**	**VAR14R-03**	38	BAL27R-00	48	VA13R-03	58	PSB13R-97
9	RII03-97	19	RII08/GLI-03	**29**	**VAR14R-00**	39	BAL27R-97	49	VA13R-01	59	LFR01R-03
10	RII04-03	20	RII08/GLI-00	**30**	**VAR14R-97**	40	RIN29R-03	50	FRY18R-03	60	LFR01R-00
										61	LFR01R-97

LSC (limits of significant contamination) values were calculated for the whole region which includes all regional sites and field specific reference sites with data from 1997 to 2003 ($LSC_{RII\ 97-03}$). LSC was also calculated for the three sub-regions within Region II ($LSC_{shallow\ 97-03}$, $LSC_{central\ 97-03}$ and $LSC_{north\ 97-03}$). Based on the data from 2003, LSC values were also calculated for each field's specific reference site. The results of the LSC calculations of hydrocarbons and metals are given in Table 4.2.

The sediments were coarser in the shallow part of the region than in the central and northern parts. Finer sediments have a higher affinity for chemical substances, like THC and metals, than coarser sediments. To compensate for this natural variation $LSC_{shallow\ 97-03}$, $LSC_{central\ 97-03}$ and $LSC_{north\ 97-03}$ will be used in their respective sub-regions.

Table 4.2. Limits of Significant Contamination (LSC) for Region II in 2003. All values in mg/kg dry sediment.

Site	THC	PAH	NPD	Decalins	Cu	Cr	Zn	Ba	Pb	Cd	Hg
Reg + Ref $_{shallow\ 97\text{-}03}$	9.1				1.0	10.0	9.1	32	6.9	0.03[1]	0.008
Reg + Ref $_{central\ 97\text{-}03}$	14.5				2.2	9.4	12.4	161	6.8	0.03[1]	0.012
Reg + Ref $_{north\ 97\text{-}03}$	13.3				1.4	5.9	7.4	76	3.8	0.03[1]	0.008
Reg + Ref $_{RII\ 97\text{-}03}$	13.3				2.0	9.4	11.1	136	6.6	0.03[1]	0.011
Reg + Ref $_{deep\ 97\text{-}03}$	13.9				2.1	9.1	11.6	143	6.5	0.03[1]	0.011
Reg + Ref $_{RII\ 97\text{-}00}$	9.8				2.0	9.6	8.9	146	7.0	0.03	0.008
Reg + Ref $_{shallow\ 97\text{-}00}$	6.6				1.2	10.2	8.1	38	7.4	0.008	0.006
Reg + Ref $_{shallow\ 03}$	14.0	0.032	0.013	0.196	0.6[1]	10.9	8.8	25	6.7	0.03[1]	0.012
Reg + Ref $_{central\ 03}$	18.1	0.117	0.028	0.390	2.0	9.2	11.9	124	5.3	0.03[1]	0.014
Reg + Ref $_{north\ 03}$	14.9	0.045	0.018	0.334	0.9	6.3	6.6	50	3.1	0.03[1]	0.010
Reg + Ref $_{RII\ 03}$	16.6	0.100	0.026	0.345	1.7	9.3	11.4	104	5.7	0.03[1]	0.013
Reg + Ref $_{deep\ 03}$	16.7	0.106	0.027	0.366	1.8	9.0	11.9	109	5.3	0.03[1]	0.013
VAR14R$_{03\ (shallow)}$	11.3	0.033	0.017	0.238	0.7	8.4	8.2	24	5.4	0.06	0.006
SIG17R$_{03\ (shallow)}$	3.0[1]	0.018	0.015	0.127	0.6[1]	8.4	6.2	10	5.4	0.03[1]	0.007
SLE41R$_{03\ (shallow)}$	9.8	0.014	0.013	0.138	0.6[1]	9.4	7.7	9	6.2	0.03[1]	0.008
RII07/SLV$_{03\ (central)}$	14.6	0.048	0.026	0.239	0.8	10.1	10.9	93	4.8	0.03[1]	0.009
RII08/GLI$_{03\ (central)}$	18.8	0.097	0.045	0.332	1.6	9.7	12.6	183	5.5	0.03[1]	0.015
GRA14R$_{03\ (central)}$	18.2	0.092	0.031	0.324	1.5	7.8	10.3	95	4.9	0.03[1]	0.030
BAL27R$_{03\ (central)}$	21.1	0.140	0.035	1.160	1.8	9.5	11.1	104	4.9	0.03	0.011
RIN29R$_{03\ (central)}$	16.9	0.142	0.037	0.346	2.4	9.3	14.1	107	6.3	0.03[1]	0.014
JOT30R$_{03\ (central)}$	21.5	0.148	0.035	0.329	1.9	8.4	11.7	77	5.0	0.03[1]	0.013
HEM22R$_{03\ (central)}$	15.7	0.079	0.020	0.409	1.9	8.3	10.7	118	4.6	0.05	0.009
VA13R$_{03\ (north)}$	9.2	0.029	0.012	0.146	0.7	4.5	6.7	26	3.0	0.03[1]	0.005
FRY18R$_{03\ (central)}$	13.4	0.073	0.022	0.622	1.3	7.0	9.0	94	3.6	0.03[1]	0.009
FRI10R$_{03\ (north)}$	17.1	0.043	0.019	0.179	0.7	5.7	6.1	58	3.4	0.03[1]	0.010
PSB13R$_{03\ (north)}$	19.5	0.036	0.029	0.793	0.8	5.4	6.8	79	3.2	0.03[1]	0.013
LFR01R$_{03\ (north)}$	14.7	0.040	0.016	0.054	0.9	8.9	7.7	58	3.2	0.03[1]	0.011

[1] LSC value = detection limit

4.2.2.2 Hydrocarbons

Summarised results of the analyses of hydrocarbon content in the sediments are given in Table 4.3. The complete data set including replicates is given in the Appendix. Comparison of the THC content in 2003 with previous surveys is presented in Figure 4.5.

Table 4.3. The content of oil hydrocarbons in sediments from regional and reference sites in 2003. All values in mg/kg dry sediment.

Site	THC		PAH(16)		NPD		Dekalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
RII-01 $_{03\ (north)}$	13.2	0.5	0.028	0.003	0.013	0.001	0.185	0.010
RII-02 $_{03\ (north)}$	9.4	1.0	0.016	0.003	0.012	0.001	0.135	0.000
RII-03 $_{03\ (central)}$	15.5	1.2	0.055	0.004	0.017	0.002	0.198	0.025
RII-04 $_{03\ (central)}$	<3.0	-	0.013	0.002	0.012	0.001	0.095	0.000
RII-06 $_{03\ (shallow)}$	7.3	0.3	0.016	0.002	0.012	0.001	0.132	0.006
RII-07/SLV $_{03\ (central)}$	13.8	0.6	0.039	0.004	0.020	0.003	0.191	0.021
RII-08/GLI $_{03\ (central)}$	14.2	3.7	0.066	0.013	0.027	0.008	0.224	0.046
RII-09 $_{03\ (central)}$	10.0	1.6	0.052	0.012	0.019	0.003	0.188	0.015
RII-10 $_{03\ (central)}$	10.2	3.0	0.068	0.019	0.019	0.003	0.192	0.031
VAR14R $_{03\ (shallow)}$	11.3	8.6	0.023	0.004	0.012	0.002	0.161	0.033
SIG17R $_{03\ (shallow)}$	<3.0	-	0.016	0.001	0.012	0.001	0.107	0.008
SLE41R $_{03\ (shallow)}$	5.1	2.0	0.007	0.003	0.011	0.001	0.103	0.015
GRA14R $_{03\ (central)}$	12.5	2.4	0.063	0.012	0.020	0.005	0.238	0.037
BAL27R $_{03\ (central)}$	15.2	2.5	0.094	0.020	0.025	0.005	0.461	0.299
RIN29R $_{03\ (central)}$	12.6	1.9	0.098	0.019	0.026	0.005	0.253	0.040
JOT30R $_{03\ (central)}$	12.0	4.1	0.102	0.020	0.025	0.005	0.238	0.039
HEM22R $_{03\ (central)}$	6.8	3.8	0.061	0.008	0.018	0.001	0.237	0.074
VA13R $_{03\ (north)}$	7.4	0.7	0.022	0.003	0.011	0.000	0.119	0.011
FRY18R $_{03\ (central)}$	9.5	1.7	0.095	0.107	0.017	0.002	0.265	0.153
FRI10R $_{03\ (north)}$	11.3	2.5	0.037	0.003	0.016	0.002	0.174	0.002
PSB13R $_{03\ (north)}$	11.3	3.5	0.031	0.002	0.016	0.006	0.287	0.217
LFR01R $_{03\ (north)}$	11.2	1.5	0.033	0.003	0.012	0.002	0.042	0.005
av. ± sd.[1]	6.3 ± 4.1		0.015 ± 0.006		0.012 ± 0.001		0.126 ± 0.027	
min – max[1]	<3.0- 11.3		0.007 - 0.023		0.011 - 0.012		0.103 - 0.161	
av. ± sd.[2]	11.2 ± 4.0		0.067 ± 0.027		0.020 ± 0.004		0.232 ± 0.085	
min – max[2]	<3.0-15.5		0.013-0.102		0.012-0.027		0.095-0.461	
av. ± sd.[3]	10.6 ± 2.0		0.028 ± 0.008		0.013 ± 0.002		0.157 ± 0.081	
min – max[3]	7.4-13.2		0.016-0.037		0.011-0.016		0.042-0.287	
av. ± sd.[4]	10.1 ± 3.9		0.047 ± 0.030		0.017 ± 0.005		0.192 ± 0.087	
min – max[4]	<3.0- 15.5		0.007 - 0.102		0.011 - 0.027		0.042 -0.461	

[1] Reg+Ref $_{shallow\ 03}$
[2] Reg+Ref $_{central\ 03}$
[3] Reg+Ref $_{north\ 03}$
[4] Reg+Ref $_{RII\ 03}$

THC was found in the range from <3.0 mg/kg at the reference site at Sigyn to 15.5 mg/kg at the regional site RII03. In the shallow part of the region, average THC content was 6.3 ± 4.1 mg/kg, whereas it was 11.1 ± 3.7 mg/kg in the central part and 10.6 ± 2.0 mg/kg in the northern part. The THC content in the sediments had increased since 2000 at most sites, except at the reference sites at Sigyn and Heimdal where it had decreased, and at the regional site RII04 where it was at the same level. The distribution of THC at the regional and reference sites is shown in Figure 4.7.

PAH was found in the range from 0.007 mg/kg at the reference site at Sleipner Øst to 0.1 mg/kg at the reference site at Jotun. In the shallow part of the region, average PAH content was 0.015 ± 0.006 mg/kg, whereas it was 0.067 ± 0.027 mg/kg in the central part and 0.028 ± 0.008 mg/kg in the northern part.

NPD was found in the range from 0.011 mg/kg at the reference sites at Sleipner Øst and Vale to 0.027 mg/kg at the regional site RII08. In the shallow part of the region, average NPD content was 0.012 ± 0.001 mg/kg, whereas it was 0.020 ± 0.004 mg/kg in the central part and 0.013 ± 0.002 mg/kg in the northern part.

Decalins were found in the range from 0.042 mg/kg at the reference site at Lille Frigg to 0.461 mg/kg at reference site at Balder. In the shallow part of the region, average content of decalins were 0.126 ± 0.027 mg/kg, whereas it was 0.232 ± 0.085 mg/kg in the central part and 0.157 ± 0.081 mg/kg in the northern part.

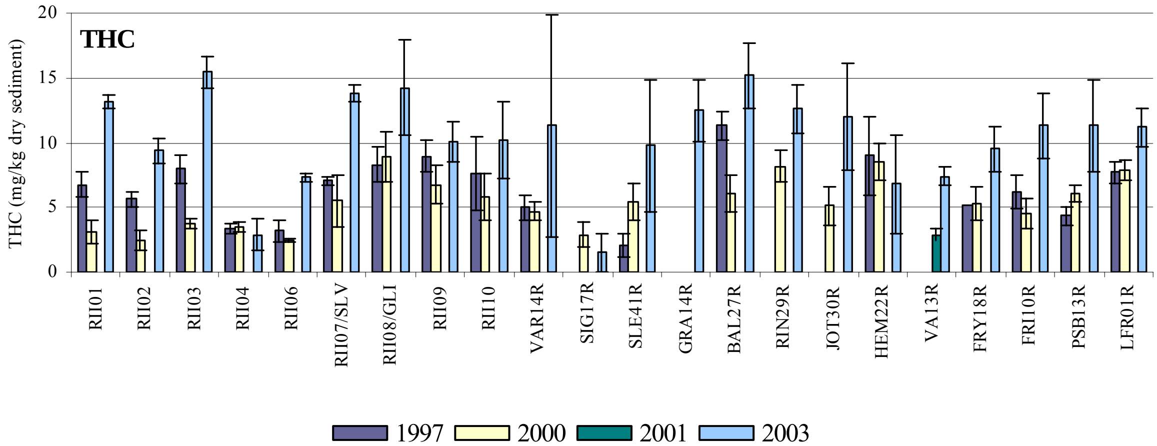


Figure 4.5. THC concentrations in sediments from regional and reference sites in 2003 and previous years.

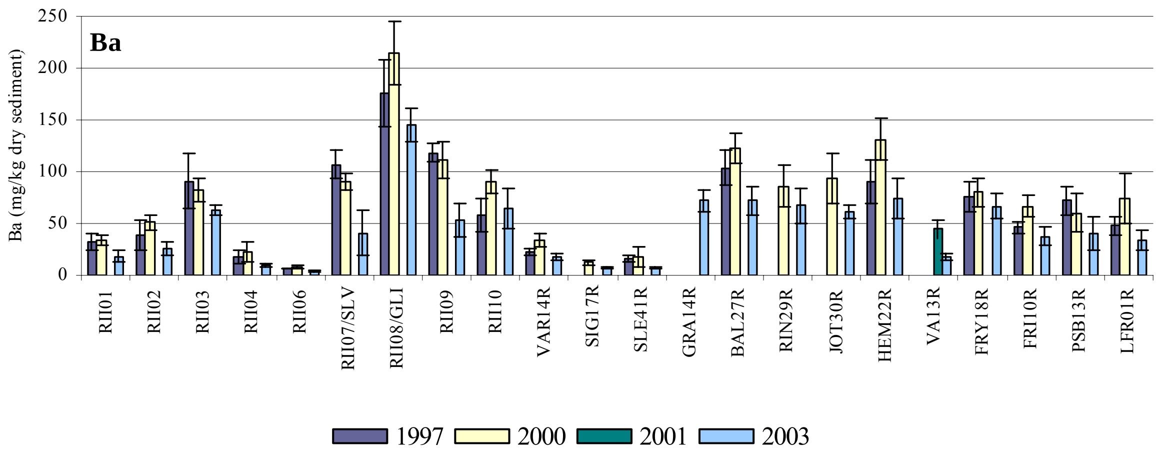


Figure 4.6. Barium concentrations in sediments from regional and reference sites in 2003 and previous years.

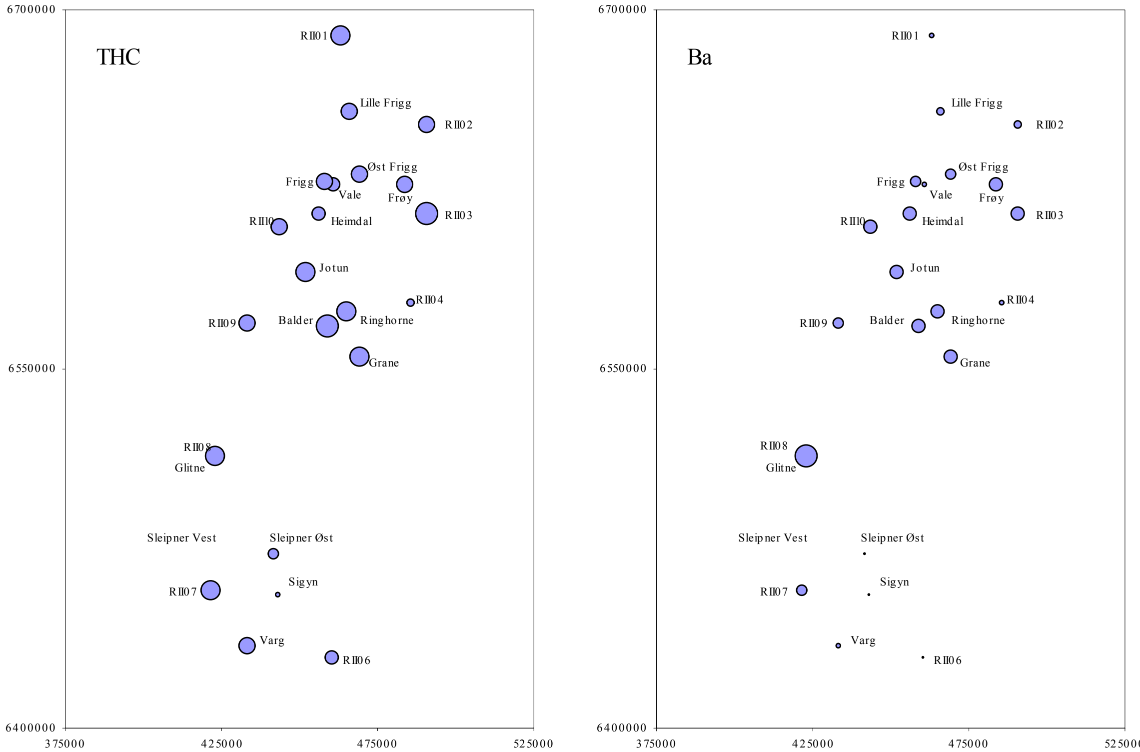


Figure 4.7. Distribution of THC and barium in sediments at the sampling sites at regional and reference sites in 2003. The sizes of the circles indicate the relative amount of THC and Ba.

4.2.2.3 Metals

Summarised results of the analyses of metals in the sediments are given in Table 4.4. The complete data set including replicates is given in the Appendix. Comparison of the barium content in 2003 with previous surveys is presented in Figure 4.6, whereas similar comparisons for the other metals are presented in Figure 4.8.

Barium was found in the range from 4 mg/kg at the regional site RII04 to 146 mg/kg at the regional site RII08. In the shallow part of the region, average barium content was 9 ± 6 mg/kg, whereas it was 66 ± 31 mg/kg in the central part and 29 ± 10 mg/kg in the northern part. At all sites, the barium content in the sediments had decreased since 2000. The distribution of barium at the regional and reference sites is shown in Figure 4.7.

Table 4.4 Content of metals in sediments from regional and reference sites in 2003. All values in mg/kg dry sediment.

Site	Cu		Cr		Zn		Ba		Pb		Cd		Hg	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
RII-01 $_{03\ (north)}$	0.8	0.1	5.4	0.2	6.3	0.1	18	5	2.1	0.0	<0.03	-	0.008	0.001
RII-02 $_{03\ (north)}$	<0.6	-	3.8	0.3	6.1	0.3	26	6	2.2	0.3	<0.03	-	0.008	0.004
RII-03 $_{03\ (central)}$	1.1	0.1	5.6	0.3	9.3	0.3	63	4	3.7	0.3	<0.03	-	0.010	0.000
RII-04 $_{03\ (central)}$	<0.6	-	4.9	0.1	6.8	0.2	10	2	3.6	0.3	<0.03	-	0.006	0.001
RII-06 $_{03\ (shallow)}$	<0.6	-	6.3	0.1	5.9	0.4	4	1	4.1	0.1	<0.03	-	0.004	0.001
RII-07/SLV$_{03\ (central)}$	0.6	0.1	8.5	0.7	9.6	0.6	41	22	4.4	0.2	<0.03	-	0.006	0.001
RII-08/GLI$_{03\ (central)}$	1.4	0.1	8.9	0.4	12.0	0.3	146	16	5.1	0.1	<0.03	-	0.011	0.002
RII-09 $_{03\ (central)}$	1.0	0.1	7.0	0.1	9.0	0.8	53	16	3.5	0.6	<0.03	-	0.010	0.002
RII-10 $_{03\ (central)}$	1.3	0.3	6.1	1.2	9.7	1.2	65	20	3.8	0.6	<0.03	-	0.012	0.001
VAR14R$_{03\ (shallow)}$	<0.6	-	7.6	0.3	7.4	0.4	18	3	5.2	0.1	<0.03	-	0.005	0.001
SIG-17R$_{03\ (shallow)}$	<0.6	-	7.9	0.2	5.8	0.2	8	1	4.9	0.2	<0.03	-	0.004	0.001
SLE41R$_{03\ (shallow)}$	<0.6	-	9.2	0.1	7.2	0.2	7	1	5.7	0.2	<0.03	-	0.005	0.001
GRA14R$_{03\ (central)}$	1.3	0.1	7.3	0.2	9.4	0.4	72	10	4.6	0.1	<0.03	-	0.014	0.007
BAL27R$_{03\ (central)}$	1.4	0.2	8.0	0.6	9.4	0.7	72	14	4.3	0.3	<0.03	-	0.009	0.001
RIN29R$_{03\ (central)}$	1.7	0.3	7.7	0.7	10.7	1.5	67	17	5.0	0.5	<0.03	-	0.010	0.002
JOT30R$_{03\ (central)}$	1.7	0.1	7.2	0.5	10.6	0.5	61	7	4.6	0.2	<0.03	-	0.011	0.001
HEM22R$_{03\ (central)}$	1.4	0.2	6.5	0.8	8.5	0.9	74	19	3.7	0.4	<0.03	-	0.007	0.001
VA13R$_{03\ (north)}$	<0.6	-	3.7	0.3	5.9	0.3	18	3	2.5	0.2	<0.03	-	0.004	0.000
FRY18R$_{03\ (central)}$	1.0	0.1	5.6	0.6	8.0	0.5	67	12	3.4	0.1	<0.03	-	0.008	0.001
FRI10R$_{03\ (north)}$	<0.6	-	4.5	0.5	5.5	0.3	37	9	2.8	0.3	<0.03	-	0.007	0.001
PSB13R$_{03\ (north)}$	0.7	0.1	4.4	0.4	5.6	0.5	41	16	2.7	0.2	<0.03	-	0.007	0.003
LFR01R$_{03\ (north)}$	0.8	0.1	5.6	1.4	6.0	0.7	34	10	2.5	0.3	<0.03	-	0.008	0.001
av. ± sd.[1]	<0.6		7.8 ± 1.2		6.6 ± 0.8		9 ± 6		5.0 ± 0.7		<0.03		0.004 ± 0.001	
min - max[1]	<0.6		6.3 - 9.2		5.8 - 7.4		4 - 18		4.1-5.7		<0.03		0.004-0.005	
av. ± sd.[2]	1.2 ± 0.4		6.9 ± 1.2		9.4 ± 1.3		66 ± 31		4.2 ± 0.6		<0.03		0.009 ± 0.003	
min - max[2]	<0.6-1.7		4.9-8.9		6.8-12.0		10-146		3.4-5.1		<0.03		0.006-0.014	
av. ± sd.[3]	<0.6		4.6 ± 0.8		5.9 ± 0.3		29 ± 10		2.5 ± 0.3		<0.03		0.007 ± 0.001	
min – max[3]	<0.6-0.8		3.7-5.6		5.5-6.3		18-41		2.1-2.8		<0.03		0.004 -0.014	
av. ± sd.[4]	0.8 ± 0.5		6.4 ± 1.6		7.9 ± 2.0		46 ± 33		3.8 ± 1.1		<0.03		0.008 ± 0.003	
min – max[4]	<0.6 - 1.7		3.7 - 9.2		5.5 - 12.0		4 - 146		2.1 - 5.7		<0.03		0.004 - 0.014	

[1] Reg+Ref $_{shallow\ 03}$
[2] Reg+Ref $_{central\ 03}$
[3] Reg+Ref $_{north\ 03}$
[4] Reg+Ref $_{RII\ 03}$

Copper concentrations ranged from 0.3 mg/kg at the regional sites RII04 and RII06 and at the field specific reference sites at Sigyn and Sleipner Øst to 17 mg/kg at the field specific reference sites at Ringhorne and Balder. In the shallow part of the region, average copper content was 0.3 ± 0.005 mg/kg, whereas it was 1.2 ± 0.4 mg/kg in the central part and 0.6 ± 0.1 mg/kg in the northern part. Generally, the copper content in the sediments was lower in 2003 than in 2000 (Figure 4.8).

Chromium concentrations ranged from 3.7 mg/kg at the field specific reference sites at Vale to 9.2 mg/kg at the field specific reference sites at Sleipner Øst. In the shallow part of the region, average chromium content was 7.8 ± 1.2 mg/kg, whereas it was 6.9 ± 1.2 mg/kg in the central part and 4.6 ± 0.8 mg/kg in the northern part. Chromium occurred at the same levels in 2000 and 2003 (Figure 4.8).

Zinc concentrations ranged from 5.5 mg/kg at the field specific reference sites at Frigg to 12.0 mg/kg at the regional site RII08. In the shallow part of the region, average zinc content was 6.6 ± 0.8 mg/kg, whereas it was 9.4 ± 1.3 mg/kg in the central part and 5.9 ± 0.3 mg/kg in the northern part. Generally, the zinc content in the sediments was higher in 2003 than in 2000 (Figure 4.8).

Lead concentrations ranged from 2.1 mg/kg at the regional site RII01 to 5.7 mg/kg at the field specific reference sites at Sleipner Øst. In the shallow part of the region, average lead content was 5.0 ± 0.7 mg/kg, whereas it was 4.2 ± 0.6 mg/kg in the central part and 2.5 ± 0.3 mg/kg in the northern part. Generally, the lead content in the sediments was lower in 2003 than in 2000 (Figure 4.8).

Cadmium occurred above the detection limit of 0.03 mg in one sample from RII09 (0.04 mg Cd/kg), one sample from VAR14R (0.05 mg Cd/kg) and in one sample from HEM22R (0.04 mg Cd/kg). All other samples from the upper layer of the sediments from the regional and field specific reference sites had cadmium content at or below the detection limit (Figure 4.8).

Mercury concentrations ranged from 0.004 mg/kg at RII06, SIG17R and VA13R to 0.014 mg/kg at GRA14R. In the shallow part of the region, average mercury content was 0.004 ± 0.001 mg/kg, whereas it was 0.009 ± 0.003 mg/kg in the central part and 0.007 ± 0.001 mg/kg in the northern part. Generally, the mercury content in the sediments was lower in 2003 than in 2000 (Figure 4.8).

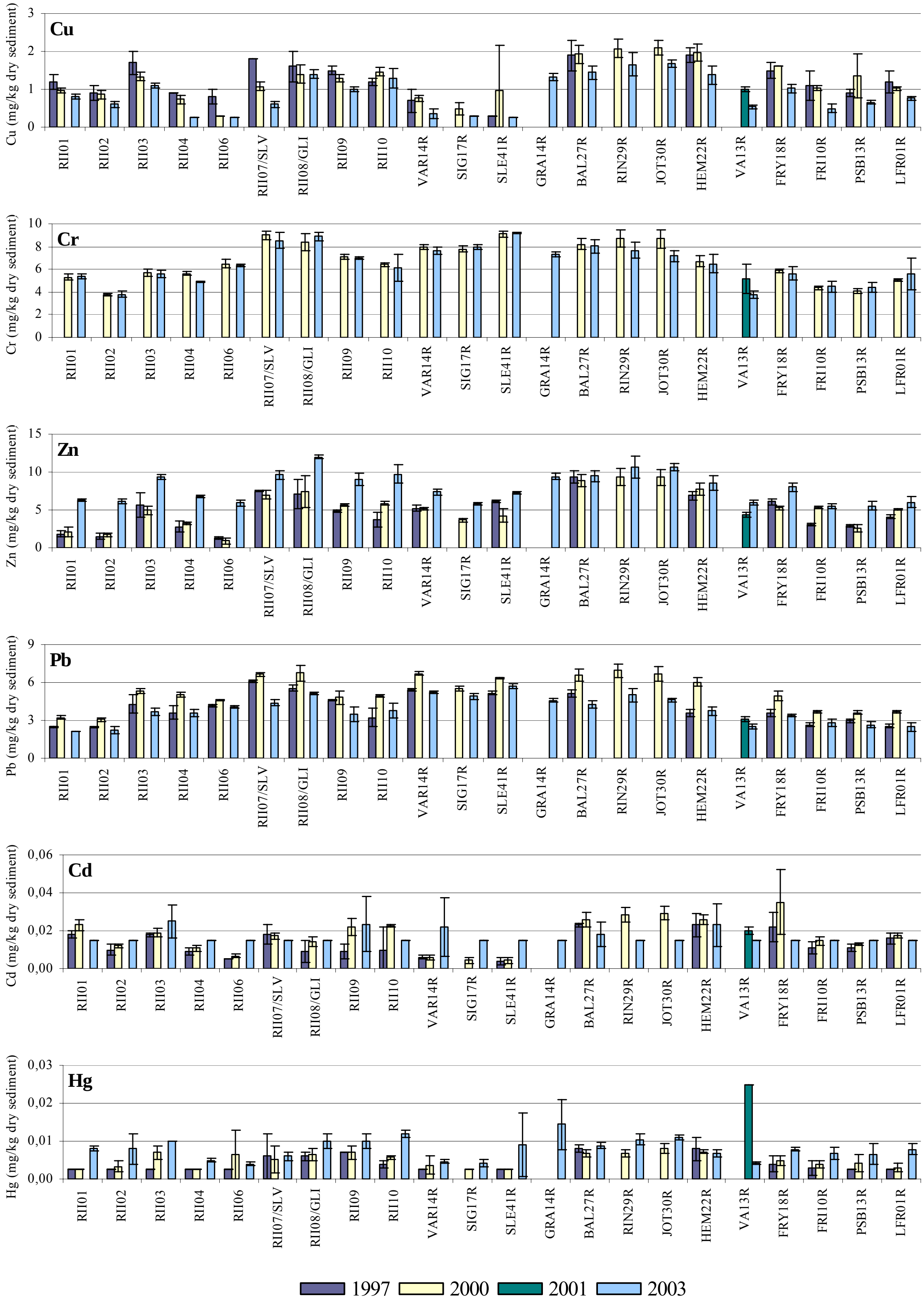


Figure 4.8. The content of metals in sediment from regional and reference sites in 2003 and previous years.

In addition to Ba, Cd, Cr, Cu, Pb and Zn, aluminium and lithium concentrations were measured in the samples from the regional sampling sites. Ba, Cd, Cr, Cu, Pb and Zn were digested by HF/Aqua regia in addition to the ordinary nitric acid digestion. Since HF/Aqua regia is a stronger digester than nitric acid, digestion by HF/Aqua regia dissolved more metals from the sediment samples (Table 4.5). For copper, 1.5 to 20 times higher content was found in samples digested by HF/Aqua regia. For chromium, 1.5 to 2.8 times higher content was found in the HF/Aqua regia digested samples. For zinc 1.0 to 1.4, for barium 1.4 to 36.5, and for lead 2.0 to 3.3 times higher content was found in the HF/Aqua regia digested samples.

The measured concentrations of aluminium and lithium were adjusted to compensate for natural sediment characteristics like grain size and organic content and these values are shown in the scatter plots in Figure 4.9. Anthropogenic supply of metals is assumed to result in outliers in the plots. This was not obvious in the current data set, and the sediments are considered to contain natural background levels of metals.

Table 4.5. Average concentration of selected metals from three replicate sediments samples from the regional sampling sites in Region II in 2003. NS4770 refers to digestion by nitric acid and Total refers to digestion by HF/aqua regia. All values in mg/kg, except Al which is in g/kg.

	Cu		Cr		Zn		Ba		Pb		Cd		Al	Li
Site	NS4770	Total	NS4770	Total	NS4770	Total	NS4770	Total	NS4770	Total	NS4770	Total	Total	Total
RII-01 $_{\text{03 (north)}}$	0.8	1.4	5.4	15.3	6.3	9.1	18	192	2.1	6.3	<0.03	<0.04	10.7	4.2
RII-02 $_{\text{03 (north)}}$	0.5	1.2	3.8	9.5	6.1	7.6	26	199	2.2	7.2	0.030	0.040	13.0	4.2
RII-03 $_{\text{03 (central)}}$	1.1	1.9	5.6	15.0	9.3	12.5	63	197	3.7	9.7	<0.03	0.040	8.1	5.4
RII-04 $_{\text{03 (central)}}$	<0.5	1.1	4.9	7.7	6.8	7.6	10	216	3.6	8.5	0.030	0.040	17.7	4.2
RII-06 $_{\text{03 (shallow)}}$	0.1	1.0	6.3	11.1	5.9	5.8	4	163	4.1	8.3	0.030	0.040	13.1	3.5
RII-07/SLV$_{\text{03 (central)}}$	0.5	1.6	8.6	14.4	9.7	12.4	48	189	4.4	10.9	<0.03	<0.04	12.6	5.8
RII-08/GLI$_{\text{03 (central)}}$	1.4	2.1	8.6	16.0	12.1	14.8	154	223	5.2	11.0	<0.03	<0.04	8.0	6.6
RII-09 $_{\text{03 (central)}}$	1.0	1.8	7.0	10.5	9.0	12.2	53	269	3.5	8.7	<0.03	0.018	15.7	6.4
RII-10 $_{\text{03 (central)}}$	1.3	2.0	6.1	16.4	9.7	12.3	65	215	3.8	8.4	0.030	0.040	8.2	5.9

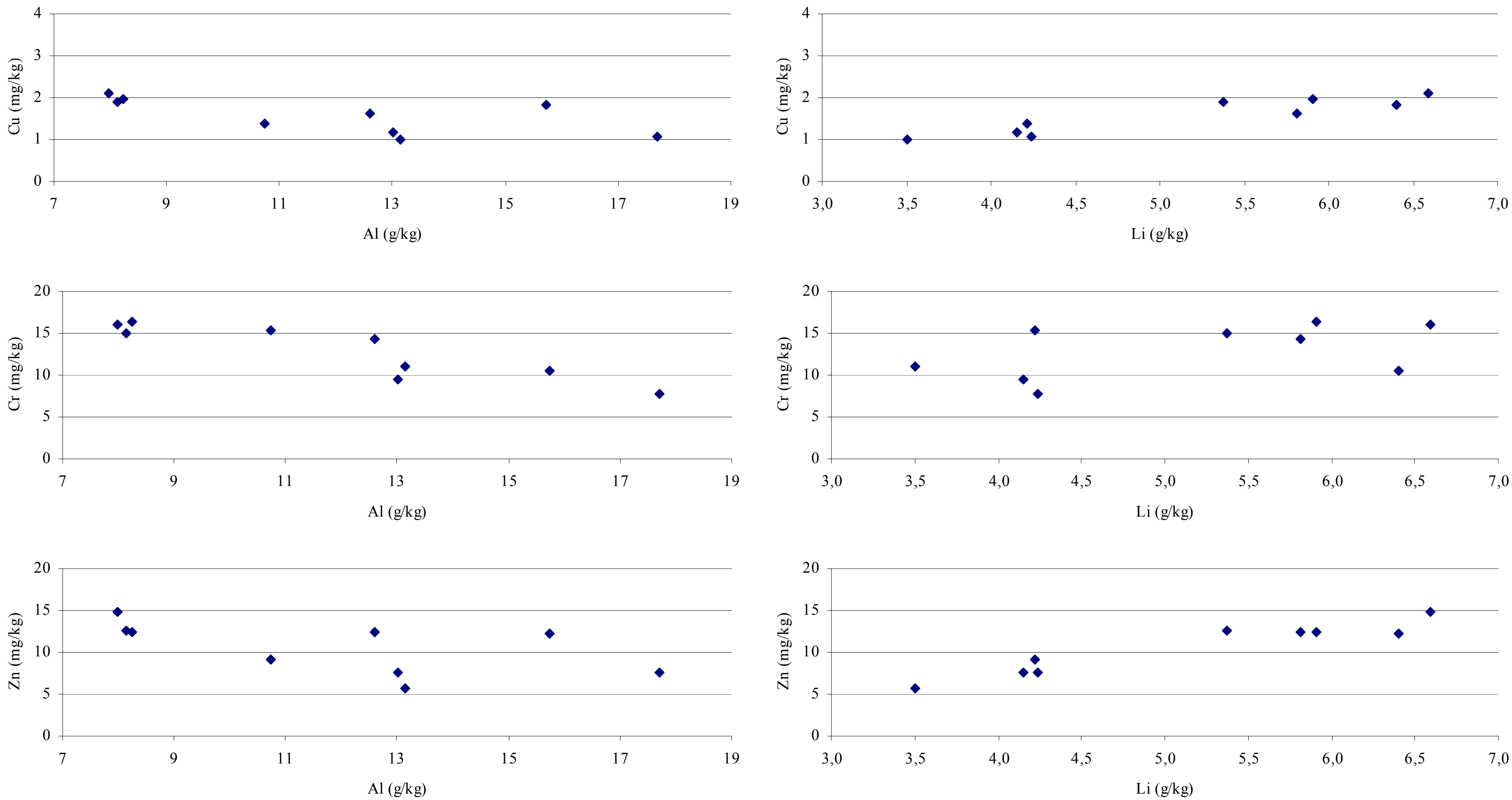


Figure 4.9. The concentration of metals determined by total digestion of the sediments plotted against aluminium and lithium at the regional sampling sites in 2003.

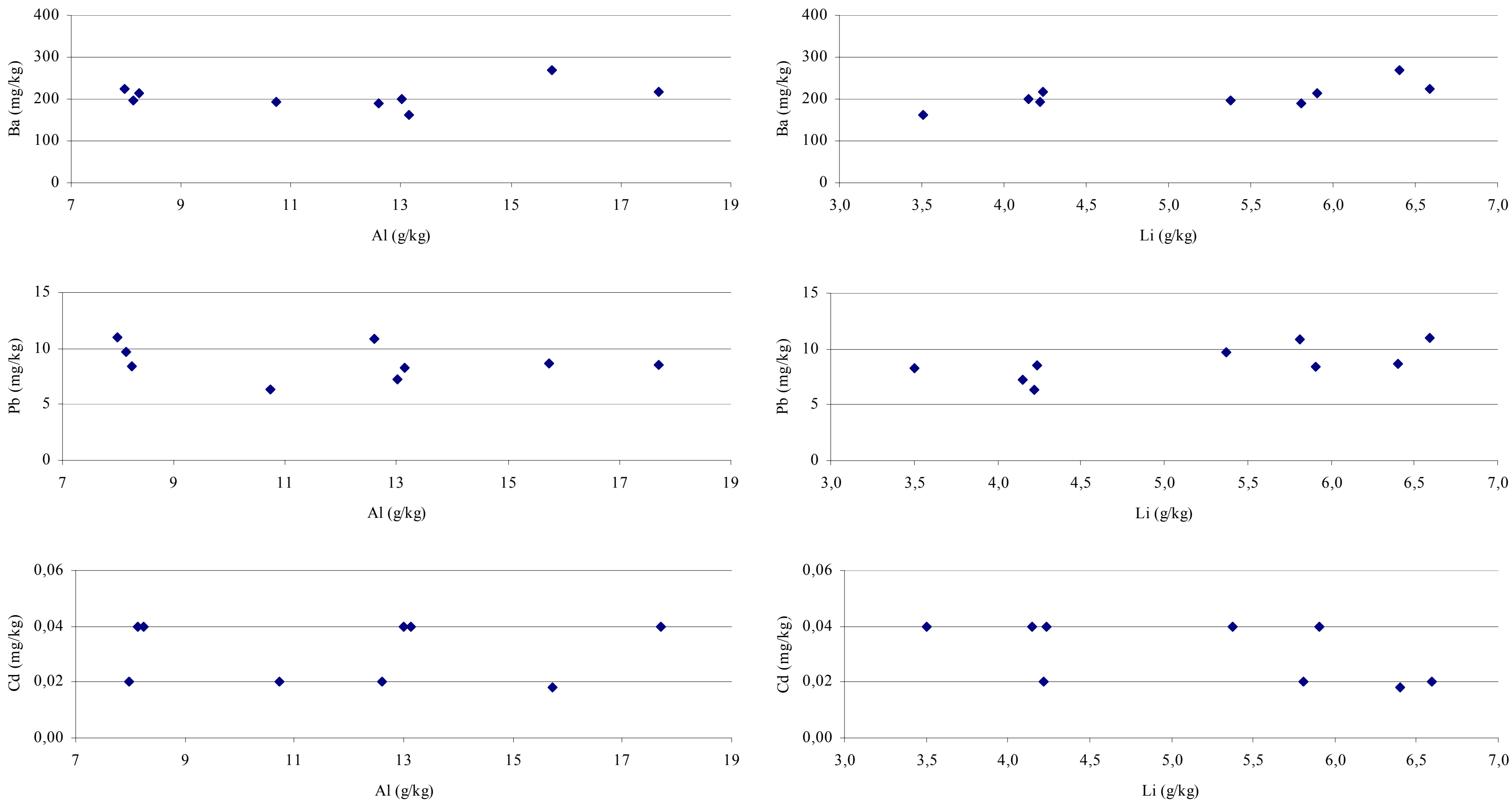


Figure 4.9. continue. The concentration of metals determined by total digestion of the sediments plotted against aluminium and lithium at the regional sampling sites in 2003.

4.2.3 Bottom fauna

A summary of the distribution of individuals and taxa within the main taxonomic groups is given in Table 4.6. A complete species list is available in the Appendix. Unidentified juveniles of the sea urchins Spatangoids (40279 individuals) and Echinoides (3234 individuals) are omitted from the data, as they occurred in extremely high numbers. In total, 27852 individuals within 375 taxa were collected at the regional and field specific reference sites. The fauna was numerically dominated by annelida with 56 % of the individuals and 45 % of the taxa (Table 4.6).

Among the sites in the shallow part (RII06, VAR14R, SIG17R and SLE41R), 2116 individuals within 133 taxa were collected. The fauna in this part of Region II was dominated by annelida with 41 % of the individuals and 47 % of the taxa.

Among the sites in the central part (RII03, RII04, RII07/SLV, RII08/GLI, RII09, GRA14R, BAL27R, RIN29R, JOT30R, HEM22R and FRY18R), 15495 individuals within 319 taxa were collected. The fauna in this part of Region II was dominated by annelida with 55 % of the individuals and 45 % of the taxa.

Among the sites in the northern part (RII01, RII02, VA13R, FRI10R, PSB13R and LFR01R), 10241 individuals within 226 taxa were collected. The fauna in this part of Region II was also dominated by annelida with 61 % of the individuals and 51 % of the taxa.

The differences between the shallow, central and northern parts of Region II were partly due to difference in the number of samples from each part of the region. However, when standardising the numbers of individuals and number of taxa to a mutual unit like average per 0.5 m^2, 243 ± 42 individuals and 53 ± 8 taxa were found in the shallow part, 774 ± 230 individuals and 113 ± 14 taxa were found in the central part and 919 ± 428 individuals and 95 ± 12 taxa were found in the northern part (Table 4.7). Fewer individuals and taxa were found in the shallow part of the region than in the deeper central and northern parts.

The relative distribution among the taxa in the different parts of Region II seams to be similar, although the relative distribution among the individuals' seams to change from a polycheate and echinodermata dominated fauna in the shallow part to a fauna more dominated by polychaeta and mollusca with fewer echinodermata in the central and northern parts (Table 4.6). It is assumed that this shift in the fauna assemblage is caused by natural factors.

Table 4.6. Distribution of individuals and taxa within the main taxonomic groups at regional and reference sites in Region II in 2003 (unidentified juveniles of Spatangoida and Echinoidea are not included).

Main taxonomic groups Reg + Ref $_{Shallow\ 03}$	**Number of individuals**	**%**	**Number of taxa**	**%**
Annelida	866	41	62	47
Arthropoda	256	12	26	20
Mollusca	188	9	23	17
Echidermata	610	29	11	8
Diverse groups	196	9	11	8
Total	2116	100	133	100

Main taxonomic groups Reg + Ref $_{Central\ 03}$	**Number of individuals**	**%**	**Number of taxa**	**%**
Annelida	8489	55	144	45
Arthropoda	1570	10	77	24
Mollusca	2710	17	65	20
Echidermata	1550	10	14	4
Diverse groups	1176	8	19	6
Total	15495	100	319	100

Main taxonomic groups Reg + Ref $_{North\ 03}$	**Number of individuals**	**%**	**Number of taxa**	**%**
Annelida	6258	61	115	51
Arthropoda	462	5	46	20
Mollusca	1148	11	40	18
Echidermata	1627	16	14	6
Diverse groups	746	7	11	5
Total	10241	100	226	100

Main taxonomic groups Reg + Ref $_{RII\ 03}$	**Number of individuals**	**%**	**Number of taxa**	**%**
Annelida	15613	56	170	45
Arthropoda	2288	8	91	24
Mollusca	4046	15	73	19
Echidermata	3787	14	20	5
Diverse groups	2118	8	21	6
Total	27852	100	375	100

The species/area curves for the regional and field specific reference sites indicate that five replicate samples give a representative impression of the bottom fauna at each sampling site (Figure 4.10). However, as more area is sampled, more taxa are collected, indicating that not even 10 replicate samples give the full species assemblage of the area. The species/area curves indicate that this is more so at sites in the deeper central and northern parts than in the shallow part of Region II.

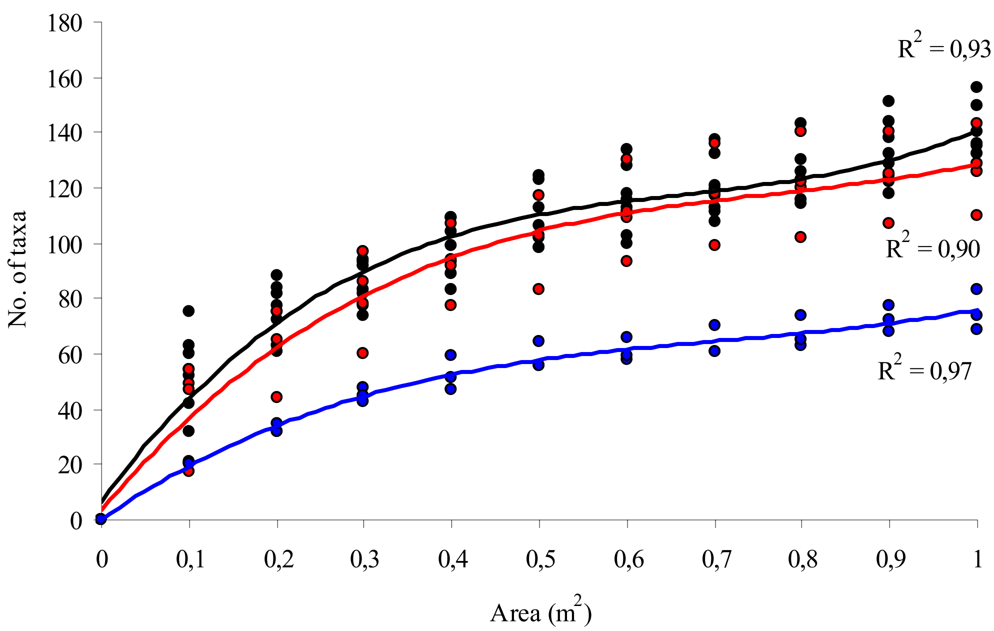


Figure 4.10. Species/area curves for the regional and field specific reference sites in Region II in 2003. Juveniles are removed from the data set as described in the chapter concerning the specific field. Blue circles = shallow sites, black circles = central sites, and red circles = north sites.

The distribution of individuals and taxa among the sampling sites are shown in Figure 4.10. Number of individuals and taxa at each site, and the calculated diversity indexes (H' and ES_{100}) are given in Table 4.7 and Figure 4.11. The number of individuals varied from 181 (SLE41R) to 1749 (RII02), and the number of taxa varied from 47 (RII06) to 141 (RII10). The Shannon-Wiener diversity index (H') varied from 3.51 (RII02) to 5.85 (RII03), whereas the ES_{100} index varied from 24.6 (RII02) to 47.9 (RII03). The evenness index J varied from 0.52 (RII02) to 0.88 (VAR14R). The high number of the polychaete *Owenia fusiformis* (865 individuals) at RII02 depressed the diversity and evenness at this site. The ranges of these parameters are considered natural and representative for Region II, and the number of taxa, diversity, and evenness also indicate good environmental conditions at all sites.

Table 4.7. Number of individuals, taxa and, selected community indices for each site (0.5 m^2) in Region II in 2003. Unidentified juveniles of Spatangoida, Echinoidea, the polychaeta *Owenia fusiformis,* and the brittle star *Amphiura filiformis* are not included in the data set from RII01-RII06 and RII09-RII10. For the other sites, juveniles are removed from the data set as described in the chapters concerning the specific field.

Site number	Number of individuals	Number of taxa	Diversity H'	Evenness J	H'-max	ES_{100}
RII-01 $_{03\ (north)}$	574	80	5.16	0.82	6.32	37.7
RII-02 $_{03\ (north)}$	1749	104	3.51	0.52	6.70	24.6
RII-03 $_{03\ (central)}$	1202	136	5.85	0.82	7.09	47.9
RII-04 $_{03\ (central)}$	580	116	5.52	0.81	6.86	44.4
RII-06 $_{03\ (shallow)}$	268	47	4.50	0.81	5.55	30.3
*RII-07/SLV$_{03\ (central)}$	488	94	5.12	0.79	6.55	41.3
*RII-08/GLI$_{03\ (central)}$	525	98	5.23	0.79	6.61	43.8
RII-09 $_{03\ (central)}$	692	109	5.61	0.83	6.77	44.7
RII-10 $_{03\ (central)}$	982	141	5.76	0.81	7.14	46.5
*VAR14R$_{03\ (shallow)}$	255	65	5.23	0.88	6.01	41.2
*SIG17R$_{03\ (shallow)}$	270	53	4.63	0.81	5.73	32.5
*SLE41R$_{03\ (shallow)}$	181	49	4.73	0.85	5.59	35.5
*GRA14R$_{03\ (central)}$	533	104	5.69	0.85	6.70	46.9
*BAL27R$_{03\ (central)}$	699	116	5.68	0.83	6.86	45.4
*RIN29R$_{03\ (central)}$	733	102	5.23	0.79	6.67	38.7
*JOT30R$_{03\ (central)}$	885	109	5.47	0.81	6.76	42.3
*HEM22R$_{03\ (central)}$	989	125	5.76	0.83	6.96	45.7
*VA13R$_{03\ (north)}$	643	82	4.81	0.76	6.35	33.0
*FRY18R$_{03\ (central)}$	986	113	5.66	0.83	6.82	44.8
*FRI10R$_{03\ (north)}$	932	109	4.89	0.73	6.77	36.2
*PSB13R$_{03\ (north)}$	870	97	5.02	0.76	6.59	35.9
*LFR01R$_{03\ (north)}$	750	102	5.31	0.80	6.67	39.6
Average±sd[1]	243 ± 42	53 ± 8	4.77±0-32	0.84±0.03	5.72±0.21	34.8±4.7
Min- Max[1]	181-270	47-65	4.50-5.23	0.81-0.88	5.55-6.01	30.3-41.2
Average±sd[2]	774 ± 230	113 ± 14	5.55±0.24	0.81±0.02	6.81±0.18	44.3±2.6
Min- Max[2]	488-1202	94-141	5.12-5.85	0.79-0.85	6.55-7.14	38.7-47.9
Average±sd[3]	919 ± 428	95 ± 12	4.78±0.65	0.73±0.11	6.57±0.19	34.5±5.3
Min- Max[3]	574-1749	80-109	3.51-5.31	0.52-0.82	6.32-6.77	24.6-39.6
Average±sd[4]	717 ± 358	98 ± 26	5.20±0.55	0.80±0.07	6.55±0.45	39.9±6.2
Min- Max[4]	181-1749	47-141	3.51-5.85	0.52-0.88	5.55-7.14	24.6-47.9

[1] Reg + Ref $_{shallow\ 03}$
[2] Reg + Ref $_{central03}$
[3] Reg + Ref $_{north03}$
[4] Reg + Ref $_{RII\ 03}$
*Average of sample 6-10 and 11-15

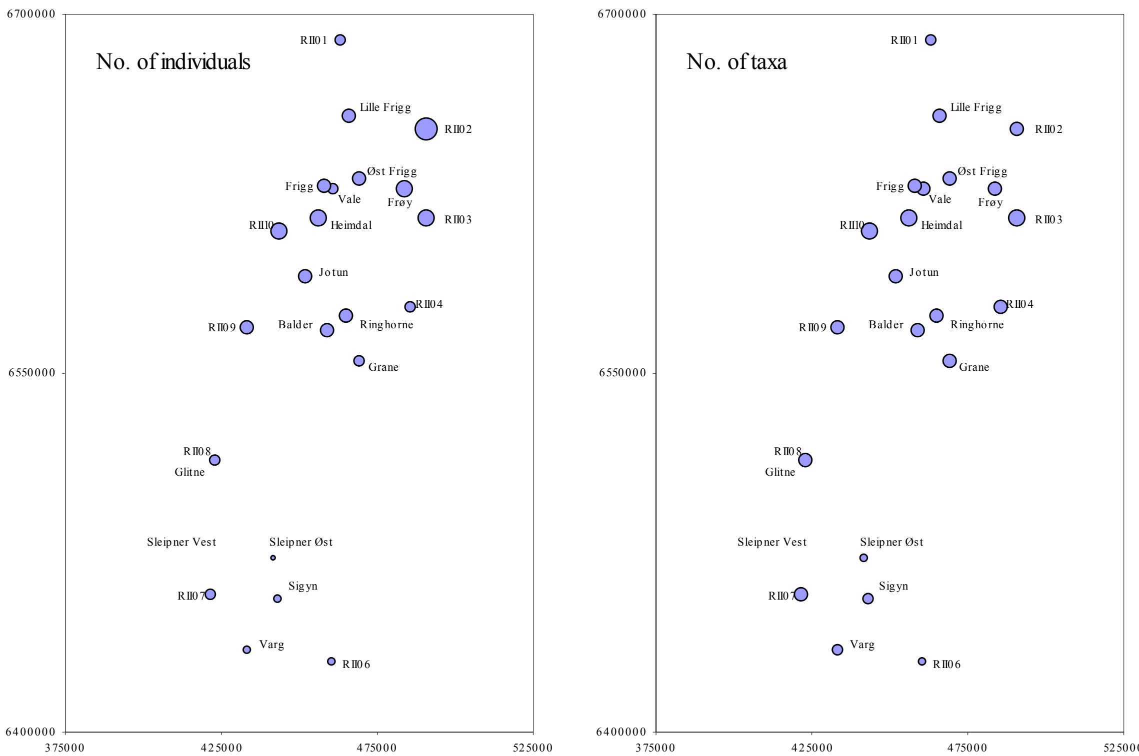


Figure 4.11. Distribution of bottom fauna (individuals and taxa) for the regional and field specific reference sites in 2003. The size of the circles indicates the relative number of individuals and taxa for each site (0.5 m^2). Values for the reference sites are average of sample 6-10 and 11-15. Unidentified juveniles of Spatangoida, Echinoidea, the polychaeta *Owenia fusiformis*, and the brittle star *Amphiura filiformis* are not included in the data set from RII01-RII06 and RII09-RII10. For the other sites, juveniles are removed from the data set as described in the chapter concerning the specific field.

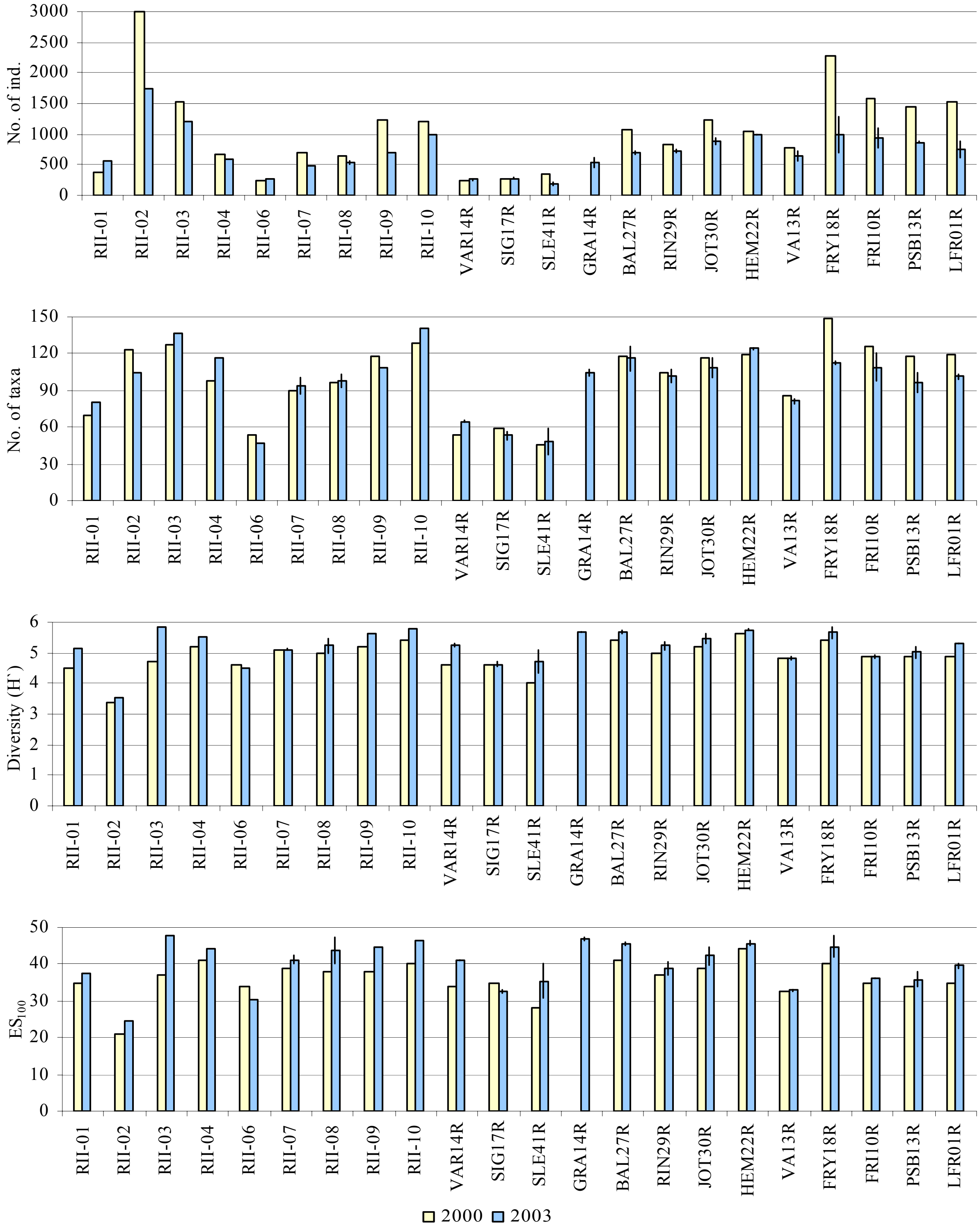


Figure 4.12. Number of individuals, number of taxa, and selected community indices for each site (0.5 m^2) in Region II in 2000 and 2003. Unidentified juveniles of Spatangoida, Echinoidea, the polychaeta *Owenia fusiformis*, and the brittle star *Amphiura filiformis* are not included in the data set from RII01-RII06 and RII09-RII10. For the other sites, juveniles are removed from the data set as described in the chapter concerning the specific field. Values for the reference sites are average ± SD of sample 6-10 and 11-15.

Distribution of taxa in, geometrical classes is presented in Figure 4.13. The smooth graphs indicate undisturbed bottom fauna, whereas the graph describing the fauna at RII06 might indicate some deviation in the fauna at this site compared to the other sites.

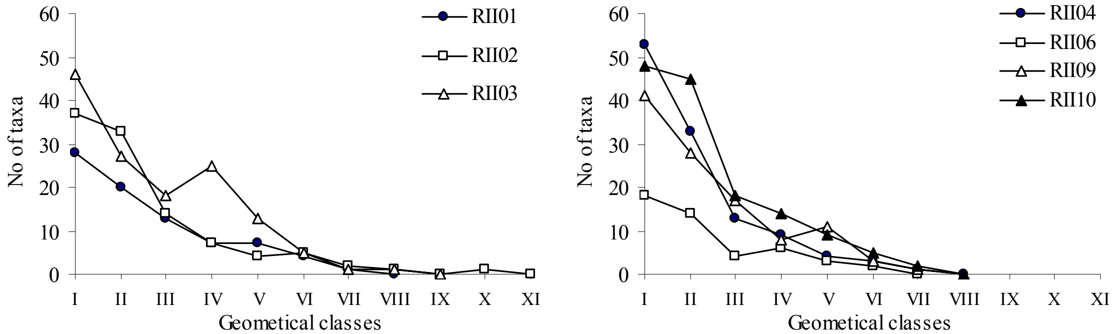


Figure 4.13. Distribution of taxa in geometrical classes for the sites at regional sites in 2003. Unidentified juveniles of Spatangoida, Echinoidea, the polychaeta *Owenia fusiformis*, and the brittle star *Amphiura filiformis* are not included in the data set from RII01-RII06 and RII09-RII10. For the other sites juveniles are removed from the data set as described in the chapter concerning the specific field.

The ten most numerous taxa are listed in Table 4.9 at the end of this chapter. The list comprises 48 taxa and 21407 individuals, which was 12.8 % of all (375) taxa and 76.8 % of all (27856) individuals. Different taxa dominated at different sites, indicating environmental variation within Region II.

Among the most abundant species occurring at all sites and in high numbers, were the polychetes *Ownia fusiformis, Myriochele occulata* and *Paramphinome jeffreysii*. The latter two were particularly abundant in the deeper parts, whereas the first one was somewhat more abundant in slightly coarser sediment. The polychaetes *Spiophanes krøyeri* and *Goniada maculate*, the brittle star *Amphiura filiformis*, and the phoronida *Phoronis* sp. were other abundant species occurring at all sites regional and field specific reference sites. The taxa assemblage indicates good environmental conditions at the other sites.

The results of the multivariate analyses are given in the dendrogramme (Figure 4.14) and the MDS plott (Figure 4.15).

The cluster analyses divided the data set into three groups. The first group comprise the sites from the southern shallow part, RII06, VAR14R, SIG17R and SLE41R. The second group comprise the sites from the northern part, RII01, RII02, LFR01R, PSB13R, FRI10R, VA13R and RII04, whereas the third group comprise the remaining sampling sites in the central part of Region II. The similarity between the samples from the southern part and the rest of the material was approximately 38 %. The similarity between the fauna from the northern and the central part on Region II was approximately 50 %. Similarity within the fauna from the shallow southern part was approximately 58 %, whereas it was approximately 55 % within the two other groups.

The results of the MDS analysis support the findings in the cluster analysis, and further indicate that the natural variation in water depth is an important factor for the observed faunal distribution within Region II. The stress test of the MDS analysis was 0.08, indicating a good fit of the data.

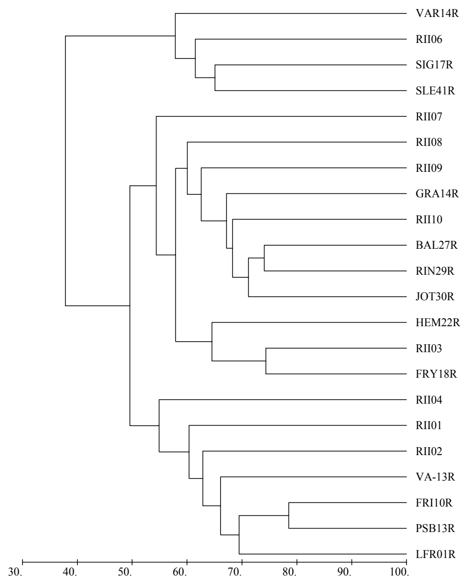


Figure 4.14. Dendrogram showing the similarity between fauna from regional and from reference sites in Region II in 2003. Unidentified juveniles of Spatangoida, Echinoidea, the polychaeta *Owenia fusiformis*, and the brittle star *Amphiura filiformis* are not included in the data set from RII01-RII06 and RII09-RII10. For the other sites, juveniles are removed from the data set as described in the chapter concerning the specific field.

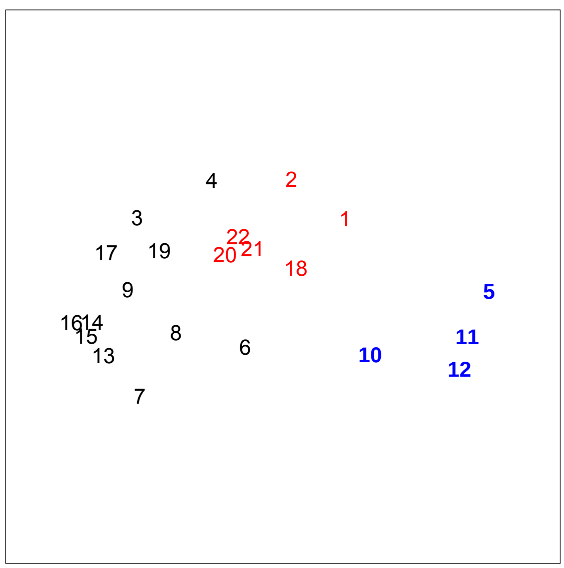


Figure 4.15. A 2-dimetional plott of the MDS analysis of the fauna data from regional and reference sites in Region II in 2003. Sites from the shallow part of Region II are marked in red. Stress = 0.08. Unidentified juveniles of Spatangoida, Echinoidea, juveniles of the polychaeta *Owenia fusiformis*, and the brittle star *Amphiura filiformis* are not included in the data set from RII01-RII06 and RII09-RII10. For the other sites juveniles are removed from the data set as described in the chapter concerning the specific field.

1	RII01	6	RII07	11	SIG17R	16	JOT30R	21	PSB13R
2	RII02	7	RII08	12	SLE41R	17	HEM22R	22	LFR01R
3	RII03	8	RII09	13	GRA14R	18	VA-13R		
4	RII04	9	RII10	14	BAL27R	19	FRY18R		
5	RII06	10	VAR14R	15	RIN29R	20	FRI10R		

Linking of biotic and environmental variables by BIOENV revealed that water depth at the sampling sites, TOM, barium and lead content in the sediments were correlated to the biota at $\rho_w = 0.89$ (Table 4.8). Natural conditions and factors which are associated with those factors are considered to be important for the faunal distribution among the regional and field specific sites in Region II.

Table 4.8. Combinations of the 11 environmental variables, taken *k* at a time, yielding the best matches of biotic and abiotic similarity matrices for each *k*, as measured by weighted Spearman rank correlation ρ_w. Bold type indicates overall best correlation. Calculated correlation coefficients (ρ_w) of all possible combinations of environmental variables and the fauna are given in the Appendix.

Number of variables (*k*)	Correlation coefficient (ρ_w)	Environmental variables										
1	0.694	Ba										
1	0.683	Depth										
1	0.624	Pelite										
1	0.606	TOM										
1	0.581	Cu										
1	0.389	Sand										
1	0.367	Zn										
1	0.306	Pb										
1	0.259	THC										
1	0.198	Cr										
1	-0.154	Gravel										
2	0.816	Depth	Ba									
3	0.876	Depth		Pb	Pelite							
4	**0.892**	**Depth**	**Ba**	**Pb**		**TOM**						
5	0.886	Depth	Ba	Pb	Pelite	TOM						
6	0.877	Depth	Ba	Pb	Pelite	TOM	Cr					
7	0.866	Depth	Ba	Pb	Pelite	TOM	Cr			Cu		
8	0.860	Depth	Ba	Pb	Pelite	TOM	Cr	THC	Sand			
9	0.852	Depth	Ba	Pb	Pelite	TOM	Cr	THC	Sand	Cu		
10	0.842	Depth	Ba	Pb	Pelite	TOM	Cr	THC	Sand	Cu	Zn	
11	0.727	Depth	Ba	Pb	Pelite	TOM	Cr	THC	Sand	Cu	Zn	Gravel

4.3 Summary and conclusions

The results from the regional and field specific reference sites are considered to indicate uncontaminated sediments and undisturbed bottom fauna, as well as describing the natural variation of the sea floor in the region in 2003.

As shown in previous surveys, the sediment in Region II varies from sandy in the shallow (77-85 m) waters in the south to fine sediments in the deeper (101-130 m) central and northern parts of the region. Compared to the survey in 2000, there were no major changes in the sediment characteristics such as grain size and TOM.

Among the regional and field specific reference sites, the total hydrocarbon content (THC) in the sediments varied from <3.0 to 15.5 mg/kg dry sediment. The barium content varied from 4 to 146 mg/kg. Copper, chromium, zinc, lead, cadmium and mercury were found respectively in the ranges 0.3-1.7, 3.7-9.2, 5.5-12.0, 2.1-5.7, <0.03-0.04 and 0.004-0.014 mg/kg dry sediment.

The THC content in the sediments had increased since 2000 at most sites, except at the reference sites at Sigyn and Heimdal were it had decreased, and at the regional site RII04 where it was at the same level.

In general, the content of barium, copper, lead and mercury were lower in 2003 than in 2000, whereas the zinc content was higher. Cadmium was generally below the limit of detection (0.03 mg/kg) in 2003.

A PCA analysis comparing the sampling sites on metal content and THC in the sediments, grouped the sites into three distinct groups. The first group comprised the sites from the shallow waters in the south (RII06, VAR14R, SIG17R, and SLE41R), whereas the second group comprised the sites in the central part of Region II (RII03, RII04, RII07/SLV, RII08/GLI, RII09, GRA14R, BAL27R, RIN29R, JOT30R, HEM22R and FRY18R) and the third group comprised the sites in the northern part of the region (RII01, RII02, VA13R, FRI10R, PSB13R and LFR01R). The sites in the central part generally had higher content of metals and THC than the sites in the shallow and northern parts. Based on this result, values for Least Significant Contamination (LSC) were calculated for the THC and metals for all three parts of Region II, as well as for the whole region and each field specific reference site.

The fauna samples contained 375 taxa and more than 27 000 individuals. The highest numbers of taxa and individuals were found in the central and northern parts of the region. The species diversity was high, but almost the same as in 2000. As in 2000, variation in the species assemblages was found among the sites. Most of the variation in the species data could be explained by the variation in water depth at the sampling sites and the TOM, barium and lead content in the sediments. In the shallow south, the brittle star *Amphiura filiformis*, the polychaeta *Scoloplos armiger* and the crustacean *Eudorellopsis deformis* were common species, whereas the polychaetes *Owenia fusiformis* and *Myriochele oculata*, and the brittle star *Amphiura filiformis* were common species in the northern part. The polychaetes *Myriochele oculata* and *Paramphinome jeffreysi*, the bivalves *Thyasira croluensis* and *Thyasira equalis* were more common in the deeper central part of the region.

Table 4.9. Number of individuals and relative abundance of the ten predominant taxa at regional and field specific reference sites in 2003. Unidentified juveniles of Spatangoida, Echinoidea, the polychaete *Owenia fusiformis*, and the brittle star *Amphiura filiformis* are not included in the data set from RII01-RII06 and RII09-RII10. For the other sites juveniles are removed from the data set as described in the chapter concerning the specific field. Sample size at RII sites is 0.5 m ², whereas sample size at the other sites is 1.0 m ².

RII01	No. of ind.	%	Cum %
Amphiura filiformis	74	12,9	12,9
Ophiura affinis	45	7,8	20,7
Chaetozone sp.	37	6,4	27,2
Thyasira flexuosa	35	6,1	33,3
Owenia fusiformis	33	5,7	39,0
Spiophanes bombyx	26	4,5	43,6
Myriochele oculata	26	4,5	48,1
Hippomedon denticulatus	20	3,5	51,6
Scoloplos armiger	18	3,1	54,7
Harpinia antennaria	17	3,0	57,7

RII02	No. of ind.	%	Cum %
Owenia fusiformis	865	49,5	49,5
Myriochele oculata	142	8,1	57,6
Phoronis sp.	86	4,9	62,5
Myriochele fragilis	83	4,7	67,2
Thyasira flexuosa	53	3,0	70,3
Ophiura affinis	48	2,7	73,0
Myriochele danielsseni	46	2,6	75,6
Chaetozone sp.	45	2,6	78,2
Amphiura filiformis	43	2,5	80,7
Spiophanes bombyx	27	1,5	82,2

RII03	No. of ind.	%	Cum %
Thyasira croulinensis	130	10,8	10,8
Myriochele oculata	100	8,3	19,1
Eclysippe vanelli	50	4,2	23,3
Spiophanes bombyx	48	4,0	27,3
Thyasira ferruginea	41	3,4	30,7
Laonice sarsi	39	3,2	33,9
Phoronis sp.	38	3,2	37,1
Diplocirrus glaucus	30	2,5	39,6
Urothoe elegans	28	2,3	41,9
Prionospio dubia	28	2,3	44,3

RII04	No. of ind.	%	Cum %
Spiophanes bombyx	68	11,7	11,7
Myriochele oculata	55	9,5	21,2
Myriochele fragilis	43	7,4	28,6
Lanice conchilega	38	6,6	35,2
Sabellidae indet.	26	4,5	39,7
Nothria conchylega	22	3,8	43,4
Phoronis sp.	21	3,6	47,1
Paramphinome jeffreysii	19	3,3	50,3
Owenia fusiformis	13	2,2	52,6
Ampelisca tenuicornis	12	2,1	54,7

RII06	No. of ind.	%	Cum %
Phoronis sp.	37	13,8	13,8
Scoloplos armiger	36	13,4	27,2
Magelona filiformis	24	9,0	36,2
Amphiura filiformis	20	7,5	43,7
Eudorellopsis deformis	20	7,5	51,1
Spiophanes bombyx	15	5,6	56,7
Cerianthus lloydii	11	4,1	60,8
Bathyporeia sp.	10	3,7	64,6
Goniada maculata	9	3,4	67,9
Spiophanes kroeyeri	8	3,0	70,9
Sthenelais limicola	8	3,0	73,9

RII07/SLV	No. of ind.	%	Cum %
Amphiura filiformis	231	23,7	23,7
Phoronis sp.	62	6,4	30,0
Spiophanes kroeyeri	44	4,5	34,5
Myriochele oculata	42	4,3	38,8
Scoloplos armiger	42	4,3	43,1
Ampelisca tenuicornis	35	3,6	46,7
NEMERTINI indet.	29	3,0	49,7
Goniada maculata	28	2,9	52,6
Ampharete falcata	25	2,6	55,1
Paramphinome jeffreysii	22	2,3	57,4

RII08/GLI	No. of ind.	%	Cum %
Myriochele oculata	252	24,0	24,0
Thyasira croulinensis	63	6,0	30,0
Paramphinome jeffreysii	42	4,0	34,0
Parvicardium minimum	42	4,0	38,0
Nephtys hystericis	38	3,6	41,7
Amphiura chiajei	27	2,6	44,2
Spiophanes kroeyeri	25	2,4	46,6
Eclysippe vanelli	23	2,2	48,8
Harpinia antennaria	23	2,2	51,0
Cerianthus lloydii	22	2,1	53,1

RII09	No. of ind.	%	Cum %
Myriochele oculata	81	11,7	11,7
Paramphinome jeffreysii	45	6,5	18,2
Spiophanes bombyx	41	5,9	24,1
Amphiura chiajei	39	5,6	29,8
Phoronis sp.	29	4,2	34,0
Harpinia antennaria	23	3,3	37,3
Urothoe elegans	21	3,0	40,3
Thyasira equalis	18	2,6	42,9
Thyasira croulinensis	17	2,5	45,4
Goniada maculata	17	2,5	47,8
Terebellides stroemi	17	2,5	50,3

RII10	No. of ind.	%	Cum %
Paramphinome jeffreysii	109	11,1	11,1
Amphiura chiajei	82	8,4	19,5
Lanice conchilega	55	5,6	25,1
Thyasira croulinensis	53	5,4	30,4
Laonice sarsi	44	4,5	34,9
Thyasira ferruginea	43	4,4	39,3
Myriochele oculata	35	3,6	42,9
Cerianthus lloydii	27	2,7	45,6
Urothoe elegans	20	2,0	47,7
Phoronis sp.	19	1,9	49,6

VAR14R	No. of ind.	%	Cum %
Spiophanes kroeyeri	46	9,0	9,0
Scoloplos armiger	45	8,8	17,8
Harpinia antennaria	34	6,7	24,5
Phoronis sp.	27	5,3	29,8
Amphiura filiformis	24	4,7	34,5
Spiophanes bombyx	23	4,5	39,0
Ophiura affinis	17	3,3	42,4
Owenia fusiformis	17	3,3	45,7
Sthenelais limicola	17	3,3	49,0
Goniada maculata	16	3,1	52,2
Eudorellopsis deformis	16	3,1	55,3

SIG17R	No. of ind.	%	Cum %
Mysella bidentata	56	10,4	10,4
Scoloplos armiger	50	9,3	19,7
Phoronis sp.	48	8,9	28,6
Eudorellopsis deformis	46	8,5	37,1
Magelona filiformis	41	7,6	44,7
Spiophanes kroeyeri	25	4,6	49,4
Bathyporeia sp.	22	4,1	53,4
Amphiura filiformis	21	3,9	57,3
Goniada maculata	21	3,9	61,2
Spiophanes bombyx	21	3,9	65,1

SLE41R	No. of ind.	%	Cum %
Amphiura filiformis	41	11,4	11,4
Scoloplos armiger	36	10,0	21,3
Bathyporeia sp.	32	8,9	30,2
Eudorellopsis deformis	27	7,5	37,7
Goniada maculata	25	6,9	44,6
Spiophanes bombyx	16	4,4	49,0
Owenia fusiformis	14	3,9	52,9
Phoronis sp.	14	3,9	56,8
Spiophanes kroeyeri	12	3,3	60,1
Sthenelais limicola	10	2,8	62,9

Table 4.9. continue. Number of individuals and relative abundance of the ten predominant taxa at regional and field specific reference sites in 2003. Unidentified juveniles of Spatangoida, Echinoidea, the polychaeta *Owenia fusiformis*, and the brittle star *Amphiura filiformis* are not included in the data set from RII01-RII06 and RII09-RII10. For the other sites juveniles are removed from the data set as described in the chapter concerning the specific field. Sample size at RII sites is 0.5 m ², whereas sample size at the other sites is 1.0 m ².

GRA14R	No. of ind.	%	Cum %
Paramphinome jeffreysii	108	10,1	10,1
Thyasira croulinensis	62	5,8	16,0
Thyasira equalis	60	5,6	21,6
Phoronis sp.	58	5,4	27,0
Myriochele oculata	56	5,3	32,3
Lanice conchilega	42	3,9	36,2
Spiophanes kroeyeri	33	3,1	39,3
Aporrhais spp.	32	3,0	42,3
Urothoe elegans	28	2,6	45,0
Sabellidae indet.	26	2,4	47,4
Harpinia antennaria	26	8,4	55,8

BAL27R	No. of ind.	%	Cum %
Paramphinome jeffreysii	123	8,8	8,8
Thyasira equalis	86	6,2	15,0
Thyasira croulinensis	77	5,5	20,5
Diplocirrus glaucus	67	4,8	25,3
Amphiura chiajei	67	4,8	30,1
Myriochele oculata	65	4,7	34,7
Sabellidae indet.	54	3,9	38,6
Natatolana borealis	54	3,9	42,4
Phoronis sp.	49	3,5	46,0
Laonice sarsi	36	2,6	48,5

RIN29R	No. of ind.	%	Cum %
Paramphinome jeffreysii	194	13,2	13,2
Lanice conchilega	103	7,0	20,3
Thyasira equalis	97	6,6	26,9
Diplocirrus glaucus	93	6,3	33,2
Thyasira croulinensis	87	5,9	39,2
Myriochele oculata	77	5,3	44,4
Natatolana borealis	63	4,3	48,7
Amphiura chiajei	62	4,2	52,9
Phoronis sp.	47	3,2	56,1
Sabellidae indet.	35	2,4	58,5

JOT30R	No. of ind.	%	Cum %
Lanice conchilega	189	10,7	10,7
Paramphinome jeffreysii	180	10,2	20,9
Thyasira croulinensis	120	6,8	27,6
Thyasira equalis	88	5,0	32,6
Laonice sarsi	76	4,3	36,9
Diplocirrus glaucus	67	3,8	40,7
Myriochele oculata	60	3,4	44,1
Amphiura chiajei	55	3,1	47,2
Prionospio cirrifera	45	2,5	49,7
Cerianthus lloydii	39	2,2	52,0
Aricidea catherinae	39	2,2	54,2

HEM22R	No. of ind.	%	Cum %
Paramphinome jeffreysii	185	9,4	9,4
Thyasira croulinensis	125	6,3	15,7
Spiophanes bombyx	108	5,5	21,1
Lumbrineridae indet.	83	4,2	25,3
Amphiura chiajei	82	4,1	29,5
Cerianthus lloydii	73	3,7	33,2
Phoronis sp.	70	3,5	36,7
Thyasira ferruginea	62	3,1	39,8
Myriochele oculata	56	2,8	42,7
Laonice sarsi	55	2,8	45,4

VA13R	No. of ind.	%	Cum %
Owenia fusiformis	175	13,6	13,6
Spiophanes bombyx	142	11,1	24,7
Ophiura affinis	124	9,6	34,3
Amphiura filiformis	104	8,1	42,4
Myriochele oculata	84	6,5	48,9
Phoronis sp.	56	4,4	53,3
Thyasira flexuosa	45	3,5	56,8
Montacuta substriata	43	3,3	60,2
Lanice conchilega	38	3,0	63,1
Goniada maculata	35	2,7	65,8

FRY18R	No. of ind.	%	Cum %
Myriochele oculata	227	11,5	11,5
Thyasira croulinensis	113	5,7	17,3
Phoronis sp.	111	5,6	22,9
Spiophanes bombyx	90	4,6	27,4
Thyasira ferruginea	78	4,0	31,4
Owenia fusiformis	76	3,9	35,3
Myriochele fragilis	69	3,5	38,8
Eclysippe vanelli	59	3,0	41,8
Paramphinome jeffreysii	49	2,5	44,2
Diplocirrus glaucus	49	2,5	46,7
Laonice sarsi	49	2,5	49,2

FRI10R	No. of ind.	%	Cum %
Owenia fusiformis	417	22,4	22,4
Spiophanes bombyx	193	10,4	32,7
Myriochele oculata	160	8,6	41,3
Amphiura filiformis	102	5,5	46,8
Thyasira flexuosa	95	5,1	51,9
Phoronis sp.	91	4,9	56,8
Chaetozone setosa	46	2,5	59,2
Lanice conchilega	38	2,0	61,3
Harpinia antennaria	36	1,9	63,2
Goniada maculata	34	1,8	65,0

LFR01R	No. of ind.	%	Cum %
Amphiura filiformis	200	13,3	13,3
Phoronis sp.	90	6,0	19,3
Thyasira flexuosa	86	5,7	25,1
Myriochele oculata	83	5,5	30,6
Cerianthus lloydii	79	5,3	35,9
Spiophanes bombyx	76	5,1	41,0
Mysella bidentata	68	4,5	45,5
Chaetozone setosa	54	3,6	49,1
Goniada maculata	49	3,3	52,4
Scoloplos armiger	44	2,9	55,3

PSB13R	No. of ind.	%	Cum %
Owenia fusiformis	217	12,5	12,5
Myriochele oculata	193	11,1	23,6
Amphiura filiformis	166	9,5	33,1
Phoronis sp.	120	6,9	40,0
Spiophanes bombyx	114	6,6	46,6
Thyasira flexuosa	97	5,6	52,2
Chaetozone sp.	87	5,0	57,2
Myriochele fragilis	45	2,6	59,7
Cylichna cylindracea	42	2,4	62,2
Harpinia antennaria	42	2,4	64,6

5 Varg

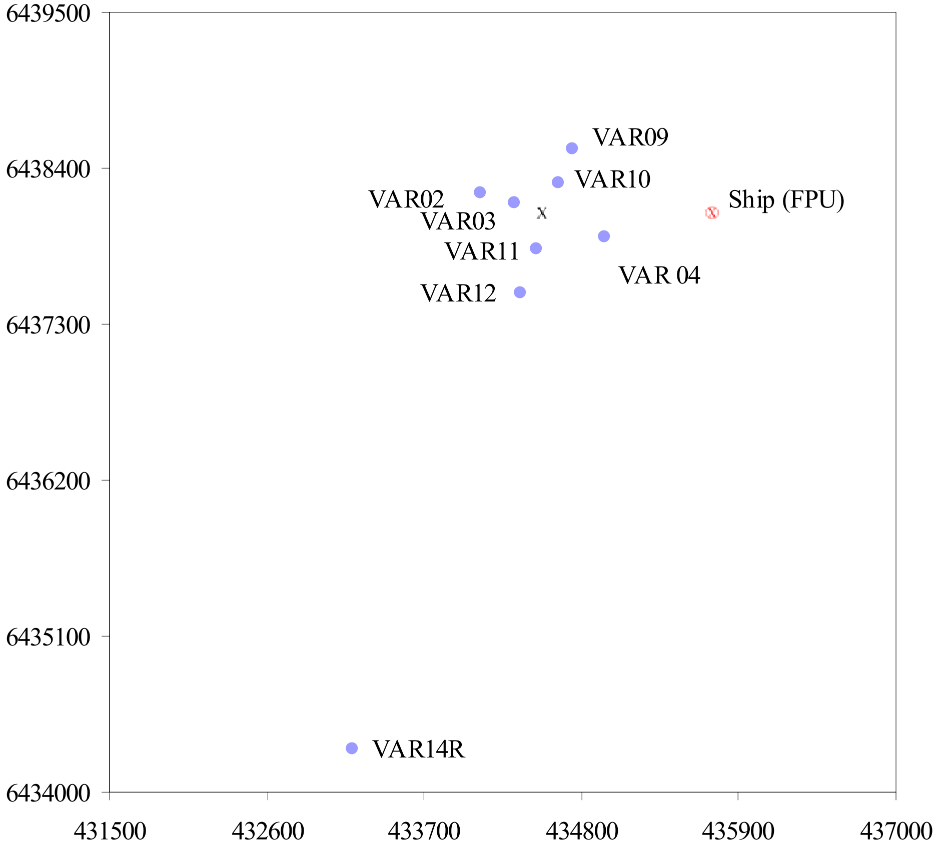
5.1. Introduction

The Varg field is situated in block 15/12. Production started at Varg in December 1998. A baseline survey was carried out in 1997 and was followed by an ordinary monitoring survey in 2000 (Mannvik & al. 2001). In the baseline survey no faunal disturbances were found. However, THC contamination extended out to 1000 m to the north east, and out to 500 m in the other directions. Elevated levels of barium were found out to 250 m to the north east and south west. During the monitoring survey in 2000, faunal disturbances and elevated levels of THC were found out to 250 m to the north east and south west. There has been no drilling or discharge at Varg since 1999, thus no sampling was undertaken at VAR07 in 2003 and samples from VAR01, VAR05, VAR08 and VAR13 would only be processed if contaminations from the activity are found in the proximity of the installation. Recent discharges at Varg are listed in Table 5.1, and sampling sites are shown in Figure 5.1

Table 5.1. Recent well drilling and discharges from operations and accidents at Varg. All values in tonnes except accidental discharges in 1998 and 1999 which are in cubic meters.

	1997	1998	1999	2000	2001	2002
No of wells drilled	1	4	5	0	0	0
Barite	n.a.	n.a.	174	0	0	0
Cuttings	1615	3510	2671	0	0	0
Oil-based drilling mud	-	[1)]	[1)]	0	0	0
Water-based drilling mud	1810	6726	7106	0	0	0
Cementing chemicals	160 [2)]	53	36	0	0	0
Completion chemicals	-	4	5	0	0	0
Oil in produced water	-	-	1	0.45305 [3)]	0	0
Accidental discharges	-	$0.250 m^3$ [3)]	$0.329 m^3$	0.0425 [4)]	0	0

n.a. = Not available
1) Used but shipped onshore, possible discharge of 4862 t mud/cuttings (OBM) in 1999
2) Estimated value
3) 1st quarter
4) Diesel discharge on sea surface



Site	ED50 UTM Zone 31		Distance (m) / direction (º)	Depth (m)
	E	N		
VAR-02	434090	6438231	500/290	87
VAR-03	434325	6438160	250/290	87
VAR-04	434959	6437919	500/110	83
VAR-09	434733	6438543	500/20	85
VAR-10	434640	6438300	250/20	85
VAR-11	434478	6437835	250/200	85
VAR-12	434367	6437523	500/200	86
VAR-14R	433187	6434316	4000/200	85

Figure 5.1. Map showing the internal distribution of sampling sites in Varg 2003. Positioning according to UTM ED50 zone 31. The field centre and ship (FPU) are marked with an X.

5.2. Results and discussion

5.2.1 Sediments characteristics

TOM, and the amount (%) of gravel, sand, pelite, median (Φ), sorting, skewness and kurtosis in the sediment from the present survey is presented in Table 5.2. Additional information on colour and smell can be found in the Appendix. Median (Φ), pelite, sand and TOM are compared with data from 2000 in Figure 5.2.

The sediments at Varg are classified as fine sand with median (Φ) values ranging from 2.11 (VAR04) to 2.40 (VAR02). The amount of pelite varied from 1.62 % (VAR04) to 3.15 % (VAR11), the sand varied from 96.82 % (VAR11) to 98.29 % (VAR04), and the TOM varied from 0.60 % (VAR04) to 0.75 % (VAR10). There was slightly more pelite and TOM at the reference site (VAR14R) than at the field sites.

Since 2000, there has been an overall increase in the pelite content and a decrease in TOM. The change in the median value between 2000 and 2003 is probably due to different methods of calculation.

Table 5.2. Total organic matter and sediment grain size at all sites at Varg in 2003. For comparison, averages, standard deviations, max and min values for the regional and reference sites are included.

Site	TOM %	Gravel %	Sand %	Pelite %	Median (Φ)	Sorting	Skewness	Kurtosis
VAR02	0.74	0.46	96.84	2.70	2.40	0.72	-0.09	1.38
VAR03	0.73	0.01	97.12	2.88	2.35	0.71	-0.08	1.19
VAR04	0.60	0.09	98.29	1.62	2.11	0.69	-0.02	0.82
VAR09	0.61	0.20	97.33	2.48	2.18	0.74	0.01	0.94
VAR10	0.75	0.03	96.86	3.11	2.27	0.74	-0.03	1.03
VAR11	0.72	0.03	96.82	3.15	2.31	0.75	-0.05	1.10
VAR12	0.69	0.01	97.44	2.55	2.29	0.72	-0.07	1.05
VAR14R	0.90	0.02	96.60	3.38	2.48	0.61	0.01	1.55
Average[1]	0.69	0.12	97.24	2.64	2.27	0.73	-0.05	1.07
SD[1]	0.06	0.17	0.53	0.52	0.10	0.02	0.03	0.18
Min[1]	0.60	0.01	96.82	1.62	2.11	0.69	-0.09	0.82
Max[1]	0.75	0.46	98.29	3.15	2.40	0.75	0.01	1.38
Average[2]	0.67	0.02	97.64	2.34	2.49	0.50	-0.04	1.28
SD[2]	0.17	0.02	1.02	1.03	0.02	0.08	0.11	0.21
Min[2]	0.51	0.00	96.60	1.03	2.47	0.43	-0.18	1.11
Max[2]	0.90	0.04	98.93	3.38	2.51	0.61	0.09	1.55

[1] Field sites, exclusive VAR14R
[2] Reg + Ref $_{\text{shallow 03}}$

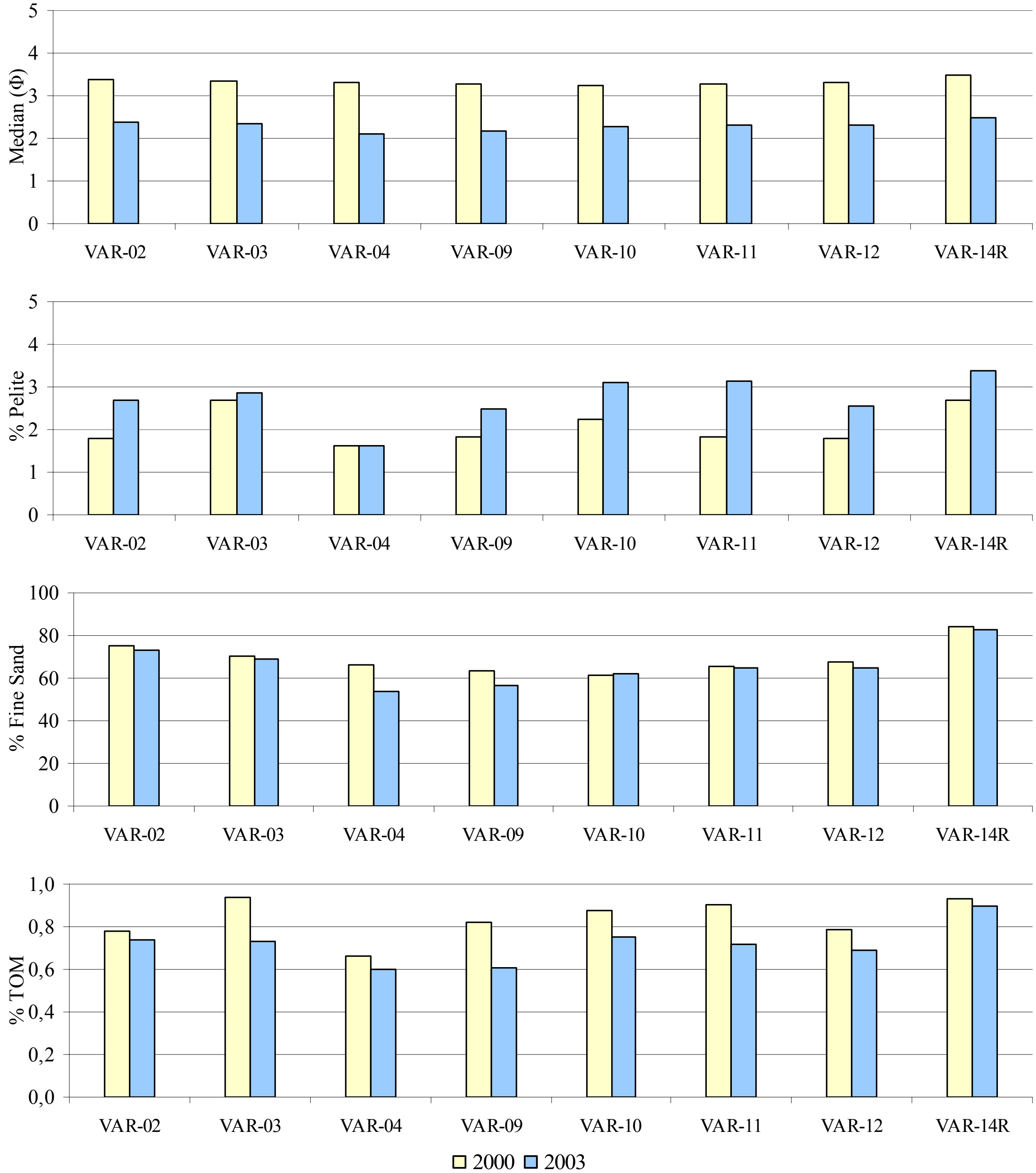


Figure 5.2. Sediment characteristics at Varg in 2000 and 2003. Fine sand is the relative amount of sand with grain size 63-250 µm.

5.2.2 Chemical compounds

5.2.2.1 LSC

The results of the LSC (limits of significant contamination) calculations of hydrocarbons and metals are presented in the chapter concerning the regional and reference sites. Both the $LSC_{shallow\ 97\text{-}03}$ and the field specific LSC value ($LSC_{VAR14R\ 03}$) are presented in Table 5.3. LSC in the text relates to $LSC_{shallow\ 97\text{-}03}$.

Table 5.3. Limits of Significant Contamination (LSC) for the Varg field in 2003, the shallow part of Region II based on data from 1997 to 2003 ($LSC_{shallow\ 97\text{-}03}$), and the whole of Region II based on data from 1997 to 2003 ($LSC_{regII\ 97\text{-}03}$). For comparison, LSC-values from 2000 are included. All values in mg/kg dry sediment.

	THC	PAH (16)	NPD's	Decalins	Cu	Cr	Zn	Ba	Pb	Cd	Hg
$LSC_{VAR14R\ 03}$	11.3	0.033	0.017	0.238	0.7	8.4	8.2	24	5.4	0.06	0.006
$LSC_{shallow\ 97\text{-}03}$	9.1	*	*	*	1.0	10.0	9.1	32	6.9	0.03[1]	0.008
$LSC_{regII\ 97\text{-}03}$	13.3	*	*	*	2.0	9.4	11.1	136	6.6	0.03[1]	0.011
$LSC_{VAR14R\ 00}$**	6.3	*	0.019	0.033	1.0	8.4	5.5	49	7.0	0.009	0.009
$LSC_{shallow\ 97\text{-}00}$**	6.6	*	*	*	1.2	10.2	8.1	38	7.4	0.008	0.006

* NPD's, PAH's and decalins are not analysed at regional sites in 1997 and 2000.
** Data from Mannvik & al. 2001
[1]LSC = detection limit

5.2.2.2 Hydrocarbons

Summarised results of the hydrocarbon analyses, along with the content of selected hydrocarbon compounds in the different layers (0-1, 1-3 and 3-6) are given in Table 5.4 and Table 5.5. The complete data set including replicates is given in the Appendix. Comparison of the THC content in 2003 with previous surveys is presented in Figure 5.3.

Table 5.4. The content of oil hydrocarbons in sediments from Varg in 2003. All values in mg/kg dry sediment. THC values above $LSC_{shallow\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{VAR14R\ 03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data for the regional and field reference sites in the shallow part of region II are included.

Site	THC		PAH		NPD		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
VAR02	4.8	0.5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
VAR03	7.3	10.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
VAR04	<3.0	-	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
VAR09	7.1	2.8	0.007	0.003	0.008	0.001	0.720	0.510
VAR10	25.8	12.0	0.013	0.003	0.024	0.009	3.717	2.436
VAR11	34.5	21.8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
VAR12	12.3	9.5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
VAR14R	8.6	2.2	0.023	0.004	0.012	0.002	0.161	0.033
av. ± sd.[1]	13.3 ± 12.2							
min – max[1]	<3.0 - 34.5							
av. ± sd.[2]	6.3 ± 4.1		0.015 ± 0.006		0.012 ± 0.001		0.126 ± 0.027	
min – max[2]	<3.0 - 11.3		0.007 - 0.023		0.011 - 0.012		0.103 - 0.161	

n.a. = not analysed.
[1] Field sites, exclusive VAR14R
[2] Reg + $Ref_{shallow\ 03}$

THC was found in the range from <3.0 (detection limit) to 34.5 mg/kg, and THC concentrations above LSC were found at VAR10, VAR11 and VAR12. Highest concentrations were found out to 250 m to the north and to the south. In general there was lower THC content in the sediments in 2003 than in 1997 and 2000.

At VAR10, hydrocarbon contamination was found down to 6 cm in the sediments, whereas contamination was found in the 1-3 cm layer at VAR09 and in the 1-6 cm layer at the reference site, VAR14R (Table 5.5).

Table 5.5. The content of oil hydrocarbons in vertical sections of sediment from 3 sampling sites at Varg in 2003. All values in mg/kg dry sediment. THC values above $LSC_{shallow\ 97\text{-}03}$ and PAH, NPD and decalins values above $LSC_{VAR14R\ 03}$ are dark shaded.

Site	Layer (cm)	THC	PAH	NPD	Decalins
VAR09	0-1	4.4	0.003	0.009	0.200
	1-3	16.0	0.079	0.027	3.960
	3-6	7.9	0.014	0.017	0.980
VAR10	0-1	13.0	0.012	0.017	1.030
	1-3	14.0	0.005	0.010	2.440
	3-6	18.0	0.019	0.020	2.970
VAR14R	0-1	4.8	0.025	0.010	0.190
	1-3	9.6	0.023	0.023	0.220
	3-6	11.0	0.033	0.013	0.185

5.2.2.3 Metals

Table 5.6 summarises the results of the metal analyses of the Varg field in 2003. Concentrations of selected metals in the different layers (0-1, 1-3 and 3-6) of sediment are given in Table 5.7, whereas the complete data set including replicates is given in the Appendix. A comparison of the metal contents in 2003 with the metal contents in previous surveys is presented in Figure 5.6.

Table 5.6 Content of metals in sediments from Varg in 2003. All values in mg/kg dry sediment. Values above $LSC_{shallow\ 97\text{-}03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data for the regional and field reference sites in the shallow part of region II are included.

Site	Cu		Cr		Zn		Ba		Pb		Cd		Hg	
	av.	sd.	av.	Sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
VAR02	<0.6	-	8.2	0.2	6.9	0.5	22	4	5.7	0.2	<0.03	-	n.a.	n.a.
VAR03	0.6	0.1	8.7	0.5	7.2	0.5	54	20	6.7	0.2	<0.03	-	n.a.	n.a.
VAR04	<0.6	-	8.1	0.2	7.2	0.2	21	3	7.1	0.1	<0.03	-	n.a.	n.a.
VAR09	0.6	0.2	9.1	0.4	8.3	0.3	88	13	7.4	0.5	<0.03	-	0.006	0.000
VAR10	0.8	0.2	9.1	0.3	9.8	1.0	229	10	7.2	0.5	<0.03	-	0.005	0.001
VAR11	0.8	0.1	9.0	0.6	8.7	1.0	208	36	6.6	0.4	<0.03	-	n.a.	n.a.
VAR12	<0.6	-	8.3	0.7	7.1	0.3	69	8	6.9	0.9	<0.03	-	n.a.	n.a.
VAR14R	<0.6	-	7.6	0.3	7.4	0.4	18	3	5.2	0.1	<0.03	-	0.005	0.001
av. ± sd.[1]	<0.6		8.6 ± 0.4		7.9 ± 1.1		98 ± 85		6.8 ± 0.6		<0.03			
min – max[1]	<0.6 - 0.8		8.1- 9.1		6.9 - 9.8		21 - 229		5.7 - 7.4		<0.03			
av. ± sd.[2]	<0.6		7.8 ± 1.2		6.6 ± 0.8		9 ± 6		5.0 ± 0.7		<0.03		0.004 ± 0.001	
min – max[2]	<0.6		6.3 - 9.2		5.8 - 7.4		5 - 18		4.1 - 5.7		<0.03		0.004 - 0.005	

n.a. = not analysed.
[1] Field sites, exclusive VAR14R
[2] Reg + $Ref_{shallow\ 03}$

Barium was found in a range from 21 mg/kg (VAR04) to 229 mg/kg (VAR10), lead from 5.7 mg/kg (VAR02) to 7.4 mg/kg (VAR09), cadmium was <0.03 mg/kg except in one sample where it was 0.05 mg/kg (VAR14R), copper from 0.6 mg/kg (VAR02, VAR04, VAR12 and VAR14R) to 0.8 mg/kg (VAR 10 and VAR11), chromium from 8.1 mg/kg (VAR04) to 9.1 mg/kg (VAR09 and VAR10), mercury from 0.005 mg/kg (VAR10 and VAR14R) to 0.006 mg/kg (VAR 09) and zinc from 6.9 mg/kg (VAR02) to 9.8 mg/kg (VAR09) (Table 5.6).

Sediments from VAR03, VAR09, VAR10, VAR11 and VAR12 had barium (54-229 mg/kg) content above LSC. Zinc was present above LSC at VAR10 (9.8 mg/kg). Lead was present above LSC at VAR04, VAR09 and VAR10.

Vertical sediment samples (0-1, 1-3 and 3-6 cm) from VAR09 and VAR10 had barium content above LSC in all depth intervals, and zinc occurred above LSC in the 3-6 cm interval at VAR10. Lead occurred above LSC in the 0-1 and 1-3 cm interval at VAR09 and VAR10 (Table 5.7). There was a relatively uniform distribution of the metals in the sectioned samples. In 2000 there was a more distinct decrease in the barium content with increasing sediment depth at VAR10.

Table 5.7. The content of metals in vertical sections of sediment from 3 sampling sites at Varg in 2003. All values in mg/kg dry sediment. Values above $LSC_{shallow\ 97\text{-}03}$ are dark shaded.

Site	Layer (cm)	Cu	Cr	Zn	Ba	Pb	Cd	Hg
VAR09	0-1	0.8	9.3	8.3	83	7.2	<0.03	0.006
	1-3	0.5	8.9	8.0	66	7.4	<0.03	0.007
	3-6	0.5	9.2	7.6	71	6.9	<0.03	0.006
VAR10	0-1	0.7	8.8	9.1	232	7.1	<0.03	0.004
	1-3	0.6	8.4	8.5	129	7.1	<0.03	0.004
	3-6	0.6	8.8	9.2	170	6.8	0.03	0.006
VAR14R	0-1	<0.5	7.6	7.3	16	5.2	<0.03	0.005
	1-3	0.6	7.8	7.5	19	5.6	<0.03	0.005
	3-6	0.5	7.8	8.0	25	5.6	<0.03	0.005

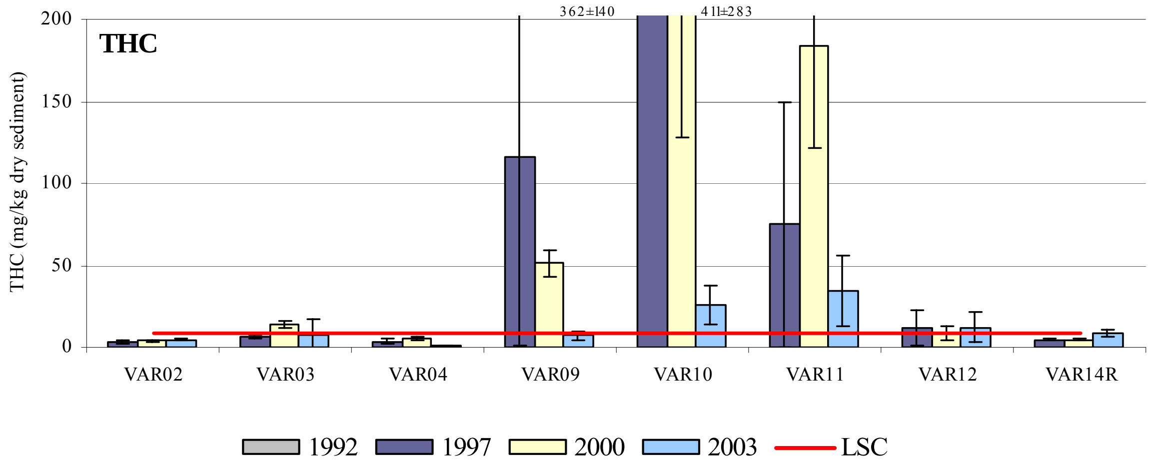


Figure 5.3. Average THC concentrations and standard deviations in sediments at Varg in 2003 and previous years. Red line is $LSC_{shallow\ 97\text{-}03}$.

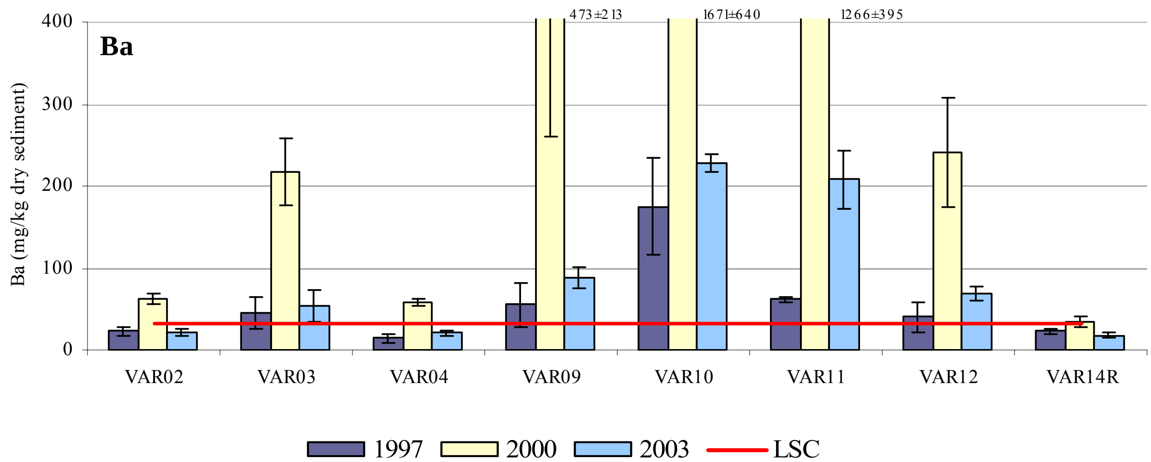


Figure 5.4. Average barium concentrations and standard deviations in sediments at Varg in 2003 and previous years. Red line is $LSC_{shallow\ 97\text{-}03}$.

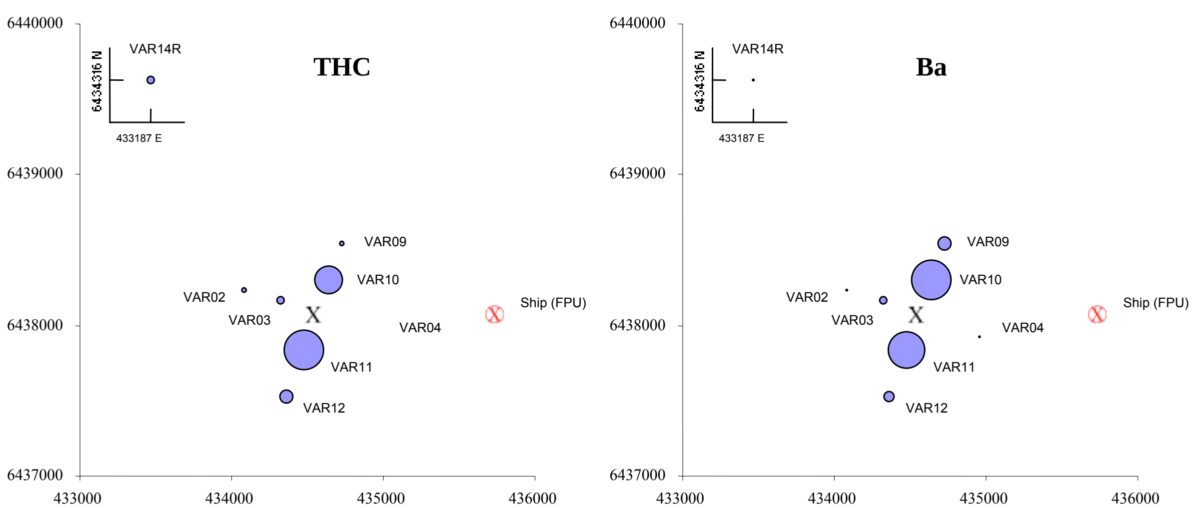


Figure 5.5. Distribution of THC and barium in sediments at Varg in 2003. The size of the circle indicates the amount of THC and Ba. The field centre and ship (FPU) are marked with an X.

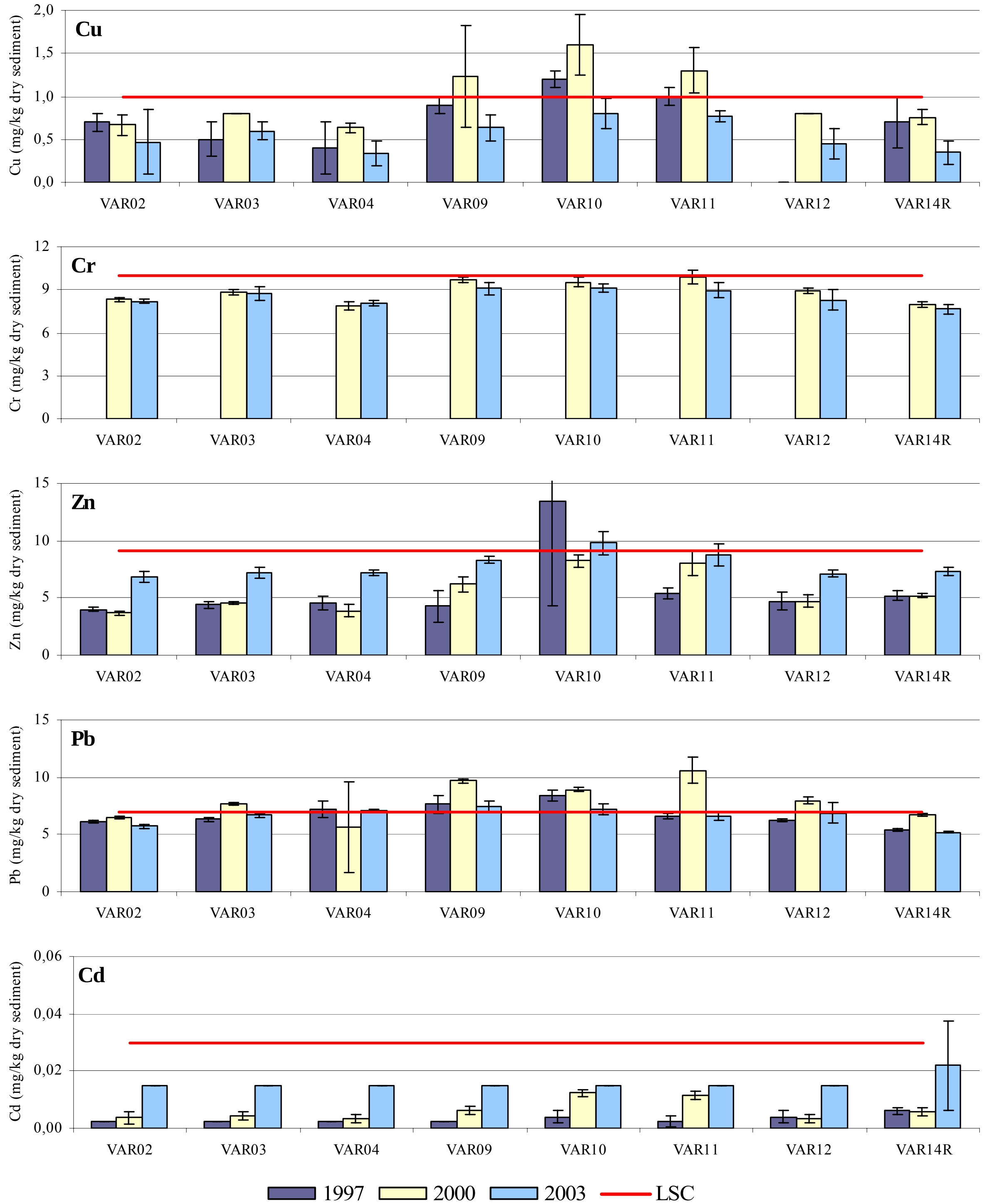
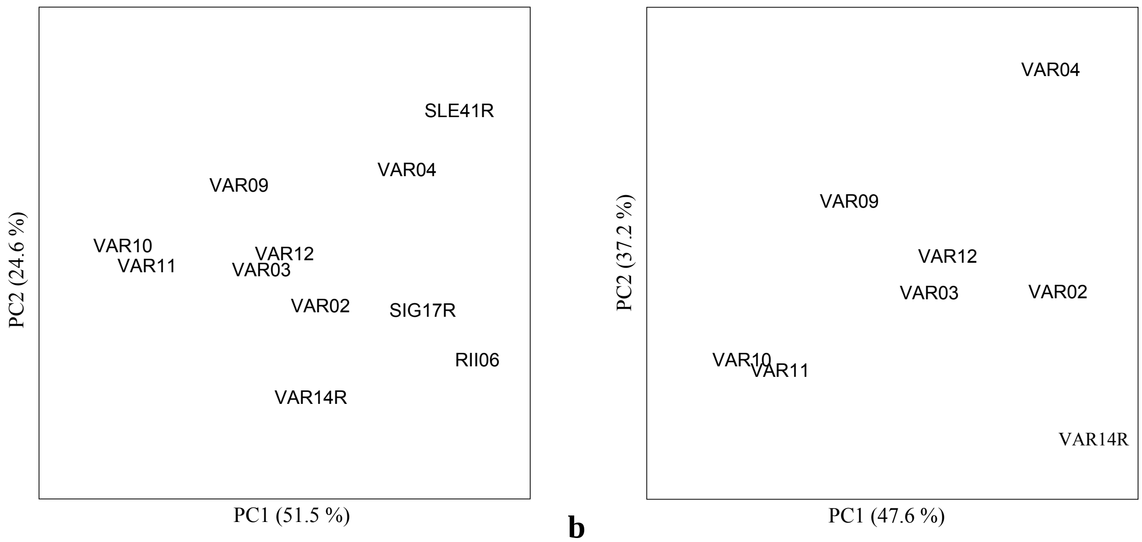


Figure 5.6. Average content and standard deviations of metals in sediment from Varg in 2003 and previous surveys. Red line is $LSC_{shallow\ 97\text{-}03}$. For cadmium, half of the detection limit has been used in the figure. Most samples had lower cadmium content than the detection limit (0.03 mg/kg).

The field sites at Varg were compared to nearby regional and field specific reference sites based on sediment characteristics (TOM and pelite) and chemical content in the sediments (Figure 5.7). VAR10 and VAR11 did not group together with the other sites, but were distinct due to the higher content of chemical compounds in the sediments.



a **b**

Figure 5.7. 2-D plot from the PCA analysis of environmental variables (% pelite, % sand, % gravel, median Φ, % TOM, Cu, Ba, Zn, Cr, Pb and THC) carried out on:
a) Varg field sites and the reference sites at Sigyn, Sleipner Øst and the regional site RII06. Explained variation in the data 76.1 %.
b) Varg field sites. Explained variation in the data 84.8 %.

5.2.3 Bottom fauna

A summary of the distribution of individuals and taxa within the main taxonomic groups is given in Table 5.8. A complete species list is available in the Appendix. Unidentified juveniles of the sea urchin Spatangoids (13605 individuals) and juveniles of the brittle star *Amphiura filiformis* (370 individuals) are omitted from the analyses, as they occurred in extremely high numbers. In total, 2302 individuals within 158 taxa were collected at Varg in 2003. The fauna was numerically dominated by annelida with 54 % of the individuals and 45 % of the taxa. A complete species list is available in the Appendix.

Table 5.8. Distribution of individuals and taxa within the main taxonomic groups at Varg in 2003 including data from VAR14R (unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis* are not included).

Main taxonomic groups	Number of individuals	%	Number of taxa	%
Annelida	1249	54	71	45
Arthropoda	253	11	33	21
Mollusca	168	7	32	20
Echidermata	262	11	12	8
Diverse groups	370	16	10	6
Total	2302	100	158	100

The species/area curve for VAR14R indicates that five replicate samples give a representative impression of the bottom fauna in the area (Figure 5.8). However, as more area is sampled, more taxa are collected, indicating that not even 10 replicate samples give the full species assemblage of the area.

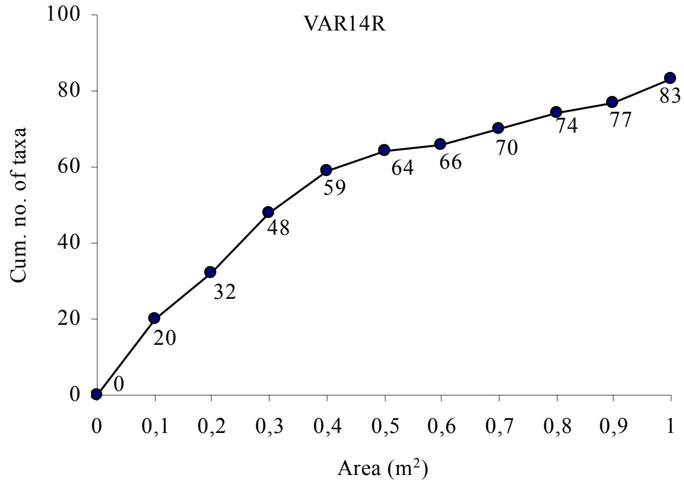


Figure 5.8. Species/area curve for the reference site at the Varg field. Unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis* are excluded.

The distribution of individuals and taxa are shown in Figure 5.9. Number of individuals and taxa at each site, and the calculated diversity indexes (H' and ES_{100}) are given in Table 5.9 and Figure 5.10. The number of individuals varied from 162 (VAR10) to 355 (VAR12), and the number of taxa varied from 52 (VAR10) to 72 (VAR12). The Shannon-Wiener diversity index (H') varied from 5.11 (VAR11) to 5.39 (VAR04), whereas the ES_{100} index varied from 39.4 (VAR11) to 43.3 (VAR04). The evenness index J varied from 0.86 (VAR03 and VAR12) to 0.92 (VAR10). The corresponding values at VAR14R are within the variation at the field sites. The number of taxa, diversity and evenness indicate good environmental conditions at all sites.

Table 5.9. Number of individuals, species/taxa, and selected community indices for each site (0.5 m^2) at the Varg field in 2003. Exclusive unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis*.

Site number	Number of individuals	Number of taxa	Diversity H'	Evenness J	H'-max	ES_{100}
VAR02	241	65	5.22	0.87	6.02	42.7
VAR03	285	70	5.29	0.86	6.13	41.0
VAR04	301	69	5.39	0.88	6.11	43.3
VAR09	242	60	5.15	0.87	5.91	39.7
VAR10	162	52	5.24	0.92	5.70	41.8
VAR11	206	56	5.11	0.88	5.81	39.4
VAR12	355	72	5.33	0.86	6.17	41.0
VAR14R (6-10)	238	64	5.19	0.87	6.00	41.2
VAR14R (11-15)	272	65	5.27	0.88	6.02	41.1
VAR14R (6-15)	510	83	5.37	0.84	6.38	41.0
Sum[1]	1792	137				
Average[1]	256	63	5.25	0.88	5.98	41.3
SD[1]	64	8	0.10	0.02	0.18	1.4
Min[1]	162	52	5.11	0.86	5.70	39.4
Max[1]	355	72	5.39	0.92	6.17	43.3
Average[2]	243	53	4.77	0.84	5.72	34.8
SD[2]	42	8	0.32	0.03	0.21	4.7
Min[2]	181	47	4.50	0.81	5.55	30.3
Max[2]	270	65	5.23	0.88	6.01	41.2

[1]Field sites, exclusive VAR14R
[2]Reg + Ref $_{shallow\ 03}$

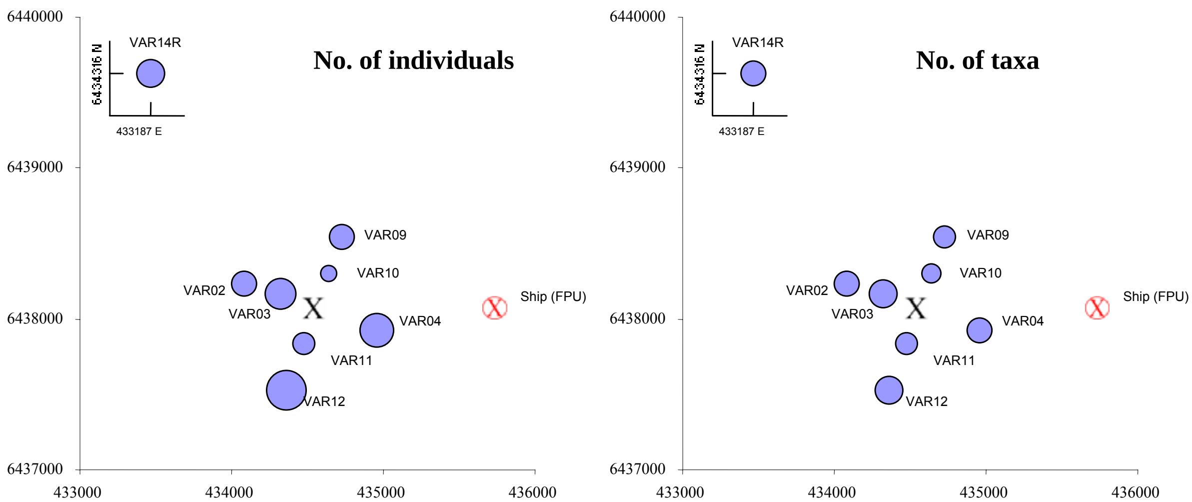


Figure 5.9. Distribution of bottom fauna (individuals and taxa) among the sampling sites in 2003. The size of the circle indicates the number of individuals or taxa, respectively. Unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis* are not included. Values for VAR14R are average of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2). The field centre and ship (FPU) are marked with an X.

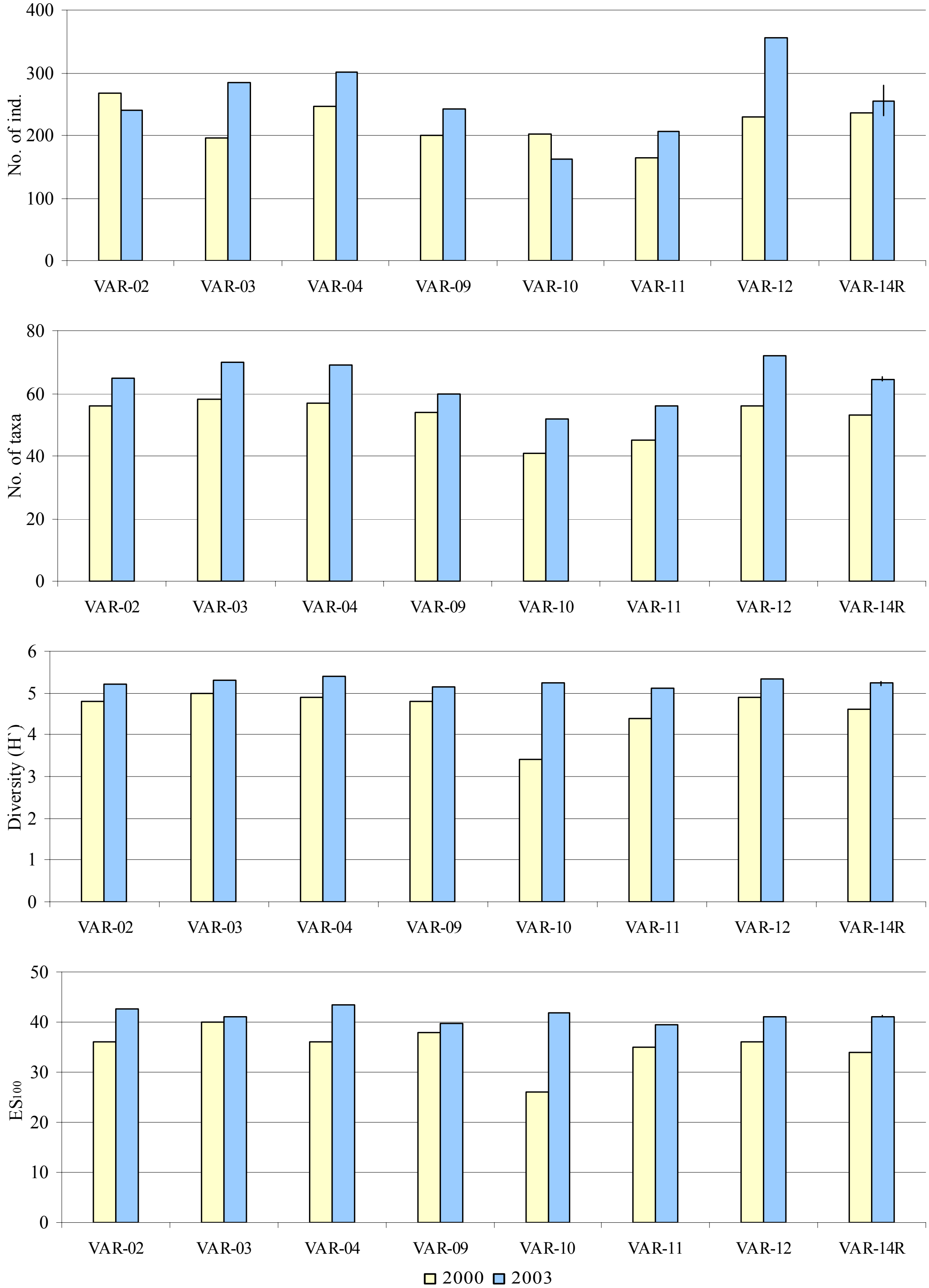


Figure 5.10. Number of individuals, taxa, and selected community indices for each site (0.5 m^2) at the Varg field for 2000 and 2003. (Exclusive unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis* in 2003). Values for VAR14R are average ± standard deviation of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2).

Distribution of taxa in geometrical classes is presented in Figure 5.11. Smooth graph are indicating undisturbed bottom fauna. However, the graph formed by the fauna at VAR11 indicates some disturbance.

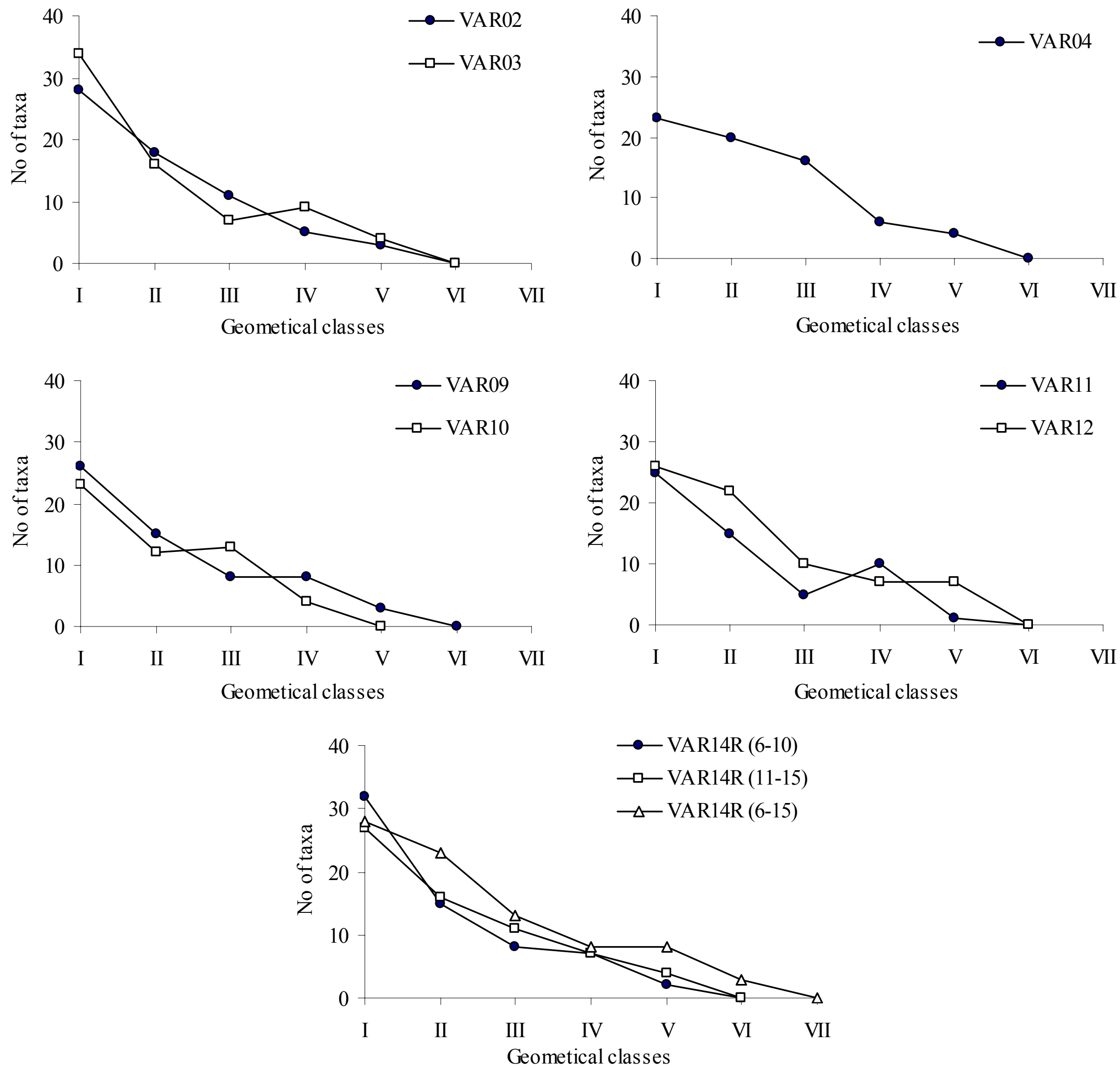


Figure 5.11. Distribution of taxa in geometrical classes for the sites at Varg in 2003. Unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis* are not included.

The ten most numerous taxa are listed in Table 5.12 at the end of this chapter. The list comprises 26 taxa and 2002 individuals, which was 16.5 % of all (158) taxa and 87 % of all (2302) individuals. Different taxa were dominating at different sites, indicating local environmental variation. The high numbers of the polychate *Chaetozone setosa* indicate some faunal disturbance at VAR11. The taxa assemblages indicate good environmental conditions at the other sites.

The results of the multivariate analyses are given in the dendrogramme (Figure 5.12 a and b) and the MDS plott (Figure 5.13 a and b).

In the cluster analysis, all sites at Varg are grouped together within 53 % similarity, indicating separation of sites based on the species assemblage (Figure 5.12b). The sites are grouped into three groups with slightly different species assemblage. The two sites at 250 m upstream (VAR11) and downstream (VAR10) comprise one group, while the other field sites (VAR02-VAR12) comprise the second group and the reference site VAR14R forms the third group.

The results of the MDS analysis support the findings in the cluster analysis, confirming the partitioning of sites into three groups. The stress test of the MDS analysis was 0.05, indicating a very good fit of the data.

At VAR10 and VAR11, fewer individuals and taxa were present than at the other sites. In addition, a slightly higher density of the polycaete *Chaetozone setosa*, and a few individuals of the polychaete *Capitella capitata* were found at these sites. At the same time, the polychaete *Scoloplos armiger*, which was abundant at the other sites, and the sea urchin *Echinocardium flavescens* were absent at VAR10 and VAR11. Small differences such as these cause the partitioning of sites into the three groups. The presence of the pollution tolerant species and the absence of the pollution intolerant species indicate that the fauna at VAR10 and VAR11 is slightly affected by the activity at Varg, whereas as the other surveyed sites are unaffected.

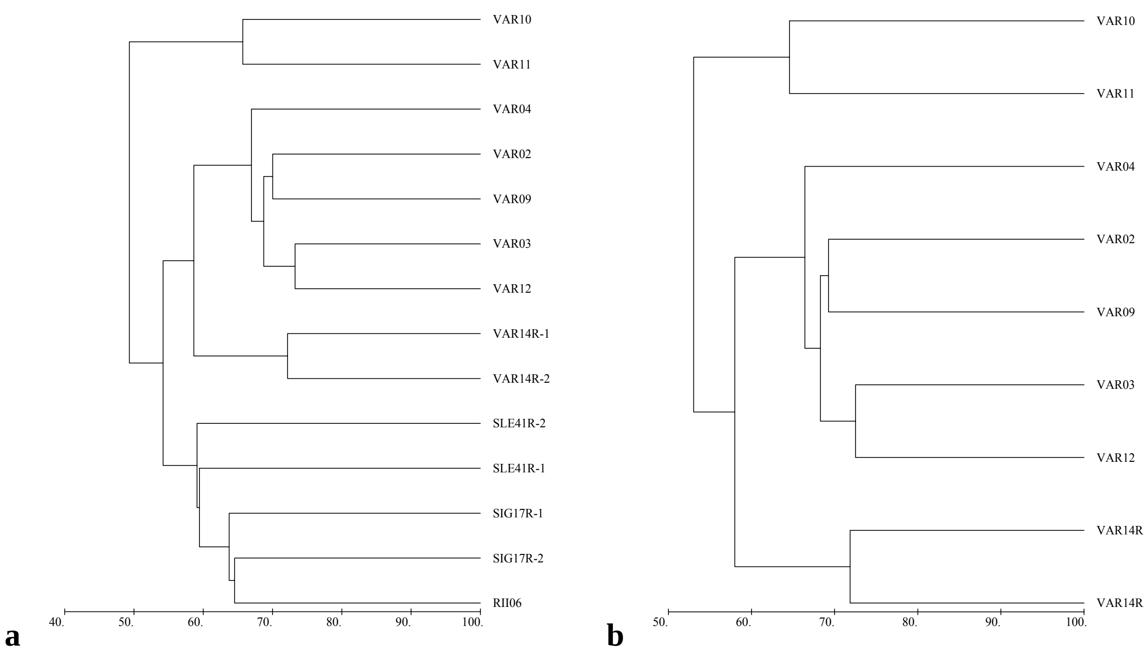
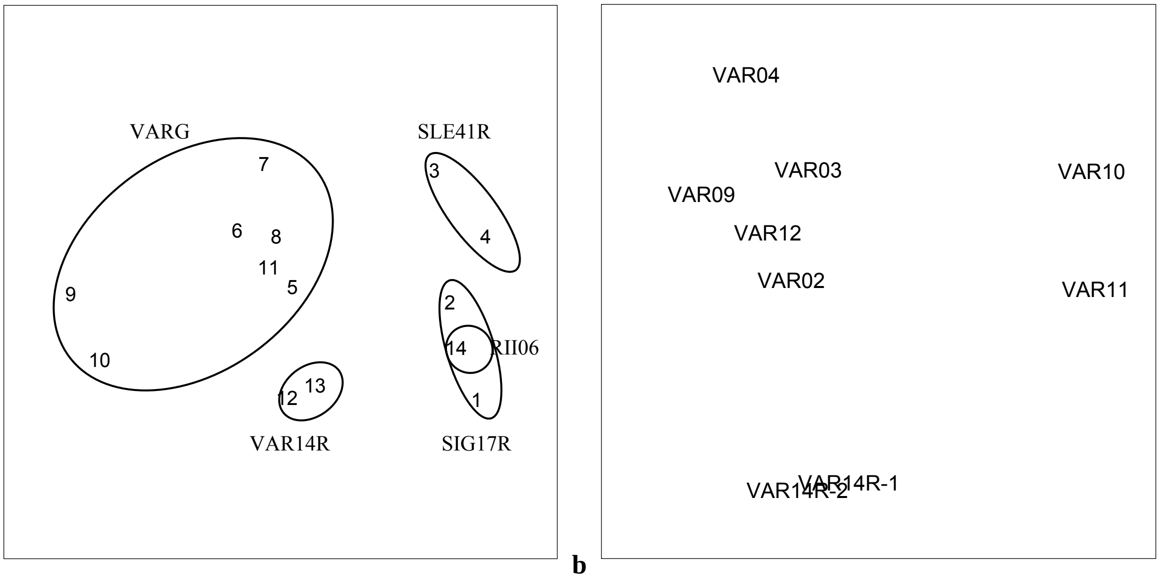


Figure 5.12. Dendrogram showing the similarity between fauna from sampling sites at:
a) Varg field compared to the reference site at Sigyn, Sleipner Øst and the regional site RII06. Unidentified juveniles of Spatangoida and Echinoidea are not included.
b) Varg field sites. Unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis* are not included.



a **b**

Figure 5.13. A 2-dimentional plott of the MDS analysis of the fauna data from:
a) All sampling sites at Varg, the reference site at Sigyn and Sleipner Øst and regional site RII06 in 2003. Stress = 0.09. Unidentified juveniles of Spatangoida and Echinoidea are not included. Numbers in the plot identify the sampling sites. See table below.
b) All sampling sites at Varg 2003. Stress = 0.05. Unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis* are not included.

1	SIG17R-1	6	VAR03	11	VAR12
2	SIG17R-2	7	VAR04	12	VAR14R-1
3	SLE41R-1	8	VAR09	13	VAR14R-2
4	SLE41R-2	9	VAR10	14	RII06
5	VAR02	10	VAR11		

Linking of biotic and environmental variables by BIOENV revealed that TOM, THC and copper were best correlated to the biota at $\rho_w = 0.71$ (Table 5.10). This indicates that there was an association between some environmental variables and the bottom fauna.

Table 5.10. Combinations of the 10 environmental variables, taken *k* at a time, yielding the best matches of biotic and abiotic similarity matrices for each *k*, as measured by weighted Spearman rank correlation ρ_w. Bold type indicates overall optimum. All possible combinations of variables and associated correlation to the biotic are given in the Appendix.

Number of Variables (*k*)	Correlation coefficient (ρ_w)	Environmental variables									
1	0.382	Zn									
1	0.370	THC									
1	0.346	Cu									
1	0.332	TOM									
1	0.288	Ba									
1	0.284	Pelite									
1	0.275	Cr									
1	0.247	Pb									
1	0.099	Sand									
1	-0.175	Gravel									
2	0.671	TOM	Zn								
3	**0.711**	**TOM**		**THC**	**Cu**						
4	0.708	TOM	Zn	THC		Pb					
5	0.698	TOM	Zn	THC	Cu	Pb					
6	0.685	TOM	Zn	THC	Cu		Ba	Pelite			
7	0.657	TOM	Zn	THC	Cu	Pb	Ba		Cr		
8	0.636	TOM	Zn	THC	Cu		Ba	Pelite	Cr	Sand	
9	0.609	TOM	Zn	THC	Cu	Pb	Ba	Pelite	Cr	Sand	
10	0.495	TOM	Zn	THC	Cu	Pb	Ba	Pelite	Cr	Sand	Gravel

5.2.4 Estimation of influenced area

The extension of contamination along sampling transects and the minimum area of contaminated sediments for THC, barium and other metals as well as for faunal disturbance (Figure 5.14 and Table 5.11). The contaminated area was smaller in 2003 than in 2000 for THC, barium, other metals, and faunal disturbance.

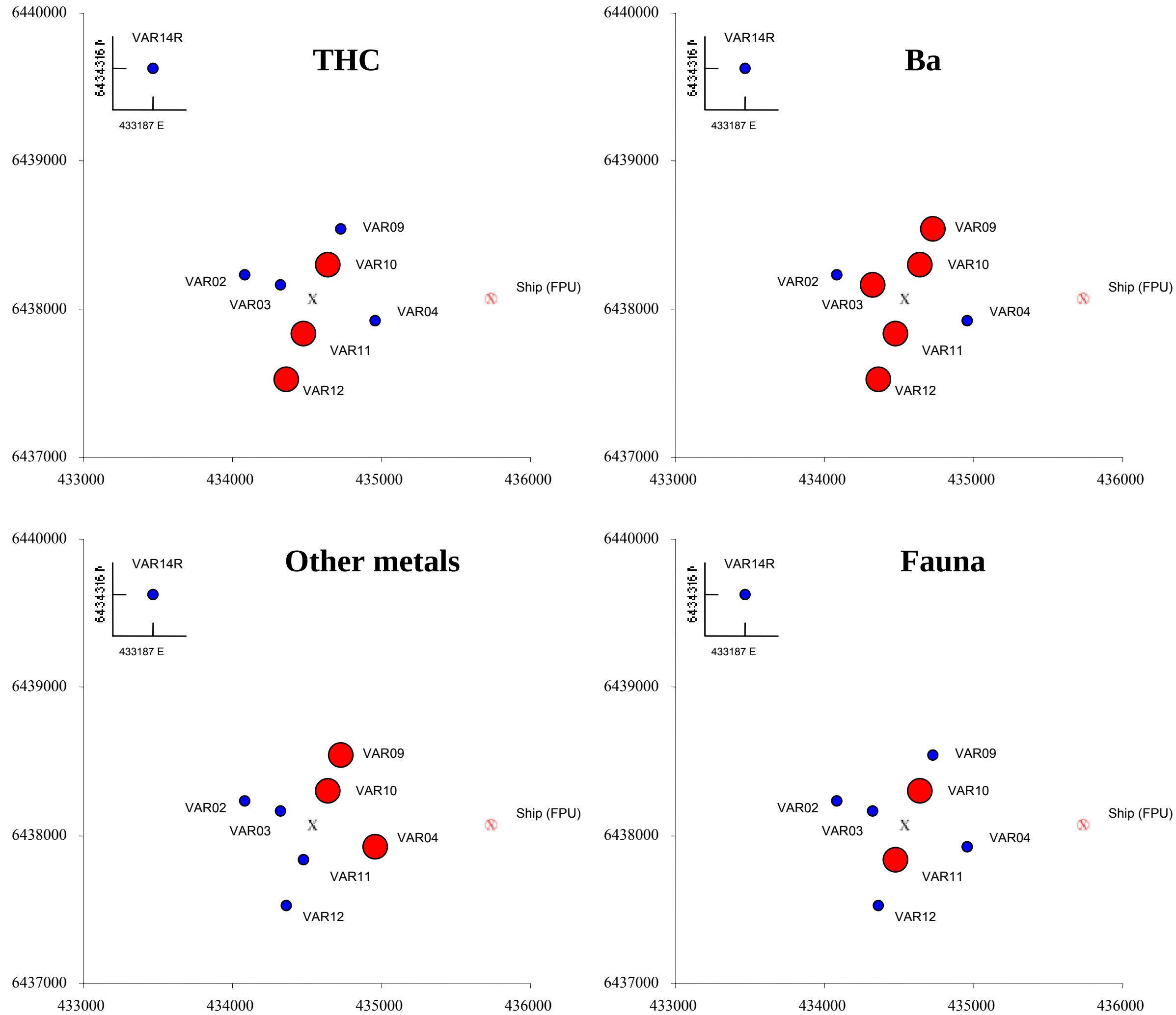


Figure 5.14. Faunal disturbance and chemical contamination of the sediments at Varg in 2003. The field centre and ship (FPU) are marked with an X. Uncontaminated sites and sites with no faunal disturbance are marked with small blue circles.

Table 5.11. Estimated distance of contamination and faunal disturbance from the installation, and estimated area of contamination and faunal disturbance around the field centre.

Varg	N m	E m	S m	W m	2003 km^2	2000 km^2	1997 km^2
THC	250	0	500	0	0.07	1.33	1.18
Ba	500	0	500	250	0.20	1.77	0.10
Other metals	500	500	0	0	0.20	0.25	0.00
Fauna	250	0	250	0	0.05	0.15	0.00

5.3 Summary and conclusions

There has been no drilling or discharges at Varg since 1999. The sediments are still characterized as fine sand, although there has been a slight increase in the pelite and decrease in TOM content since 2000. The amounts of THC, barium and most metals, except zinc, have decreased since 2000. More taxa and individuals were found in the bottom fauna in 2003 than in 2000, and the diversity of the fauna was high. Comparisons of fauna assemblage showed that the innermost (250 m distance) sampling sites to the north and to the south were slightly disturbed. The measured chemical compounds occurred in highest concentrations at the same two sites. The fauna assemblages were well correlated to the distribution of THC, copper and TOM, which show that the activity at Varg had some environmental influence in the immediate vicinity of the installation. The area of impact was smaller in 2003 than in 2000.

Table 5.12. Number of individuals and relative abundance for the ten predominant taxa at each site at the Varg field in 2003. Exclusive unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis*.

VAR02	No. of ind.	%	Cum %
Scoloplos armiger	29	12.0	12.0
Phoronis sp.	23	9.5	21.6
Spiophanes kroeyeri	16	6.6	28.2
Goniada maculata	14	5.8	34.0
Aricidea catherinae	12	5.0	39.0
Spiophanes bombyx	9	3.7	42.7
Amphiura chiajei	8	3.3	46.1
Ophiura affinis	8	3.3	49.4
Sthenelais limicola	6	2.5	51.9
Eudorellopsis deformis	6	2.5	54.4

VAR03	No. of ind.	%	Cum %
Phoronis sp.	23	8.1	8.1
Spiophanes kroeyeri	19	6.7	14.7
Spiophanes bombyx	16	5.6	20.4
Ophiura affinis	16	5.6	26.0
Scoloplos armiger	15	5.3	31.2
Amphiura chiajei	15	5.3	36.5
Cerianthus lloydii	14	4.9	41.4
Eudorellopsis deformis	13	4.6	46.0
Aricidea catherinae	10	3.5	49.5
Nemertini indet.	10	3.5	53.0
Pectinaria auricoma	10	3.5	56.5

VAR04	No. of ind.	%	Cum %
Aricidea catherinae	25	8.3	8.3
Spiophanes kroeyeri	23	7.6	15.9
Bathyporeia sp.	20	6.6	22.6
Aonides paucibranchiata	16	5.3	27.9
Phoronis sp.	15	5.0	32.9
Spiophanes bombyx	15	5.0	37.9
Cerianthus lloydii	11	3.7	41.5
Owenia fusiformis	11	3.7	45.2
Scoloplos armiger	8	2.7	47.8
Nephtys longosetosa	8	2.7	50.5

VAR09	No. of ind.	%	Cum %
Phoronis sp.	26	10.7	10.7
Spiophanes kroeyeri	19	7.9	18.6
Bathyporeia sp.	18	7.4	26.0
Aonides paucibranchiata	11	4.5	30.6
Travisia forbesii	10	4.1	34.7
Amphiura filiformis	10	4.1	38.8
Aricidea catherinae	9	3.7	42.6
Cerianthus lloydii	9	3.7	46.3
Scoloplos armiger	9	3.7	50.0
Amphiura chiajei	9	3.7	53.7

VAR10	No. of ind.	%	Cum %
Phoronis sp.	11	6.8	6.8
Nemertini indet.	9	5.6	12.3
Cerianthus lloydii	8	4.9	17.3
Chaetozone setosa	8	4.9	22.2
Bathyporeia sp.	7	4.3	26.5
Spiophanes bombyx	7	4.3	30.9
Ophiura affinis	7	4.3	35.2
Platyhelmintes indet.	7	4.3	39.5
Eudorellopsis deformis	6	3.7	43.2
Glycera alba	6	3.7	46.9
Virgularia mirabilis	6	3.7	50.6

VAR11	No. of ind.	%	Cum %
Chaetozone setosa	20	9.7	9.7
Nemertini indet.	14	6.8	16.5
Phoronis sp.	12	5.8	22.3
Cerianthus lloydii	12	5.8	28.2
Spiophanes bombyx	11	5.3	33.5
Paramphinome jeffreysii	10	4.9	38.3
Ophiura affinis	9	4.4	42.7
Eudorellopsis deformis	9	4.4	47.1
Glycera alba	8	3.9	51.0
Virgularia mirabilis	8	3.9	54.9
Amphiura chiajei	8	3.9	58.7

VAR12	No. of ind.	%	Cum %
Amphiura chiajei	26	7.3	7.3
Spiophanes kroeyeri	23	6.5	13.8
Scoloplos armiger	23	6.5	20.3
Phoronis sp.	22	6.2	26.5
Aricidea catherinae	20	5.6	32.1
Spiophanes bombyx	17	4.8	36.9
Travisia forbesii	17	4.8	41.7
Cerianthus lloydii	14	3.9	45.6
Amphiura filiformis	13	3.7	49.3
Goniada maculata	11	3.1	52.4
Ampharete lindstroemi	11	3.1	55.5

VAR14R	No. of ind.	%	Cum %
Spiophanes kroeyeri	46	9.0	9.0
Scoloplos armiger	45	8.8	17.8
Harpinia antennaria	34	6.7	24.5
Phoronis sp.	27	5.3	29.8
Amphiura filiformis	24	4.7	34.5
Spiophanes bombyx	23	4.5	39.0
Ophiura affinis	17	3.3	42.4
Owenia fusiformis	17	3.3	45.7
Sthenelais limicola	17	3.3	49.0
Goniada maculata	16	3.1	52.2
Eudorellopsis deformis	16	3.1	55.3

6 Sigyn

6.1. Introduction

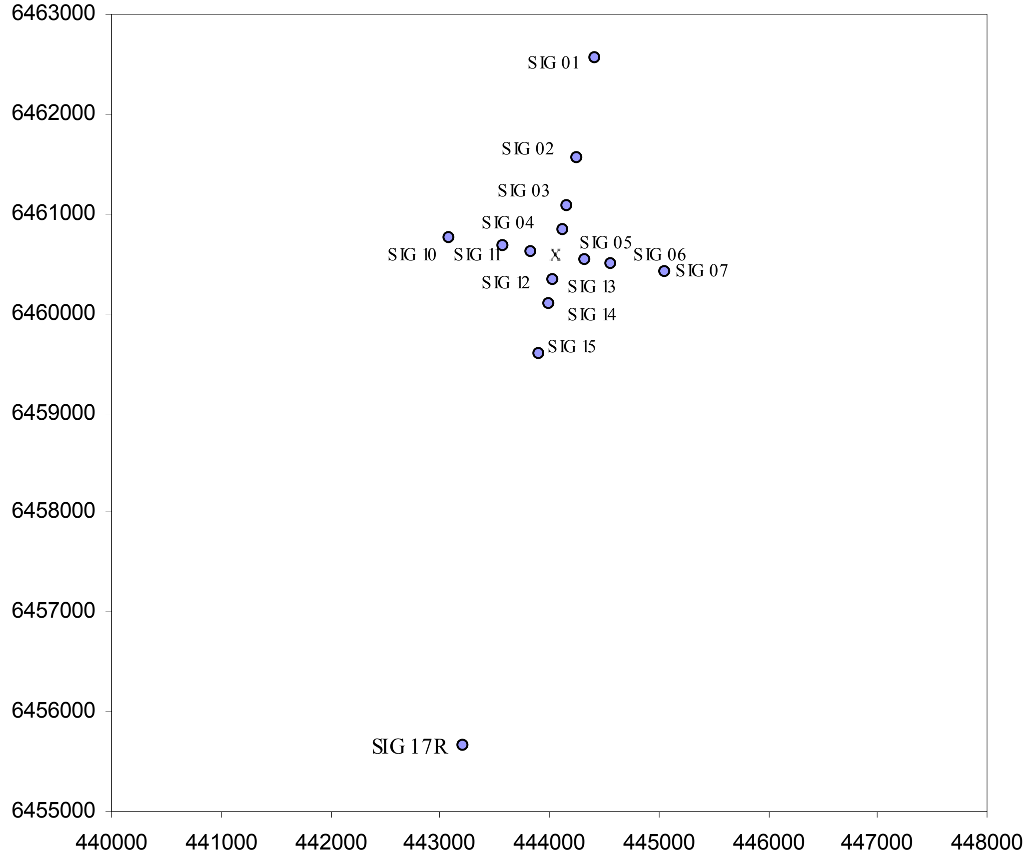
The Sigyn field is situated in block 16/7, and production started in 2003. A baseline survey undertaken in 2000 detected no faunal disturbance of elevated levels of THC or barium.

Three wells were drilled during 2002, but only water based mud was used and discharged. Recent discharges at Sigyn are listed in Table 6.1, and sampling sites are shown in Figure 6.1

Table 6.1. Recent well drilling and discharges from operations and accidents at Sigyn. Unless notified are all numbers in tonnes.

	1997	1998	1999	2000	2001	2002	Comments
No of wells drilled	2	0	0	0	-	3	
Barite	432	0	0	0	-	691	
Cuttings	500	0	0	0	-	1476	
Water-based drilling mud	1600	0	0	0	-	3252	
Cementing chemicals	26*	0	0	0	-	1.5	
Completion chemicals	-	-	-	-	-	304	
Oil in produced water	-	-	-	-	-	0	
Accidental discharges	-	-	-	-	-	0	

* Cementing and other chemicals
\- = no data



Site	ED50 UTM Zone 31 E	N	Distance (m) / direction (º)	Depth (m)
SIG-01	444426	6462551	2000/10	79
SIG-02	444253	6461566	1000/10	79
SIG-03	444166	6461073	500/10	79
SIG-04	444122	6460827	250/10	79
SIG-05	444325	6460538	250/100	79
SIG-06	444571	6460494	500/100	79
SIG-07	445064	6460407	1000/100	79
SIG-10	443094	6460755	1000/280	80
SIG-11	443587	6460668	500/280	79
SIG-12	443833	6460624	250/280	79
SIG-13	444036	6460335	250/190	79
SIG-14	443992	6460089	500/190	79
SIG-15	443905	6459596	1000/190	79
SIG-17R	443211	6455657	5000/190	80

Figure 6.1. Map showing the internal distribution of sampling sites at Sigyn in 2003. Positioning according to UTM ED50 zone 31. The field centre is marked with an X.

6.2. Results and discussion

6.2.1 Sediments characteristics

TOM, and the amount (%) of gravel, sand, pelite, median (Φ), sorting, skewness and kurtosis in the sediment from the present survey is presented in Table 6.2. Additional information on colour and smell can be found in the Appendix. Pelite, sand, median (Φ) and TOM are compared with data from 2000 in Figure 6.2.

The sediments at Sigyn are classified as fine sand with median (Φ) values ranging from 2.45 (SIG13) to 2.49 (SIG03, SIG04, SIG10 and SIG 15). The amount of pelite varied from 1.98 % (SIG13) to 3.41 % (SIG02), the sand varied from 96.1 % (SIG05) to 98.0 % (SIG13), and the TOM varied from 0.4 % (SIG03) to 0.8 % (SIG05). The sediments were relatively uniform in the sampling area and the reference site had similar sediment characteristic as the field sites. Compared to the 2000 survey the sediments had more pelite and less TOM in 2003 (Figure 6.2). The change in the median value between 2000 and 2003 are probably due to different methods of calculation.

Table 6.2. Total organic matter and sediment grain size at all sites at Sigyn in 2003. For comparison, average, standard deviation, and max and min values for the regional and reference sites are included.

	TOM %	Gravel %	Sand %	Pelite %	Median (Φ)	Sorting	Skewness	Kurtosis
SIG01	0.50	0.00	97.56	2.44	2.47	0.50	-0.06	1.33
SIG02	0.49	0.00	96.59	3.41	2.48	0.55	0.00	1.50
SIG03	0.41	0.06	97.74	2.20	2.49	0.50	-0.01	1.35
SIG04	0.42	0.00	97.77	2.23	2.49	0.54	-0.01	1.45
SIG05	0.79	1.07	96.14	2.79	2.46	0.56	-0.06	1.51
SIG06	0.53	0.01	97.99	2.01	2.46	0.51	-0.09	1.33
SIG07	0.49	0.00	97.66	2.34	2.47	0.54	-0.04	1.42
SIG10	0.47	0.01	97.76	2.23	2.49	0.54	-0.02	1.45
SIG11	0.45	0.14	97.61	2.25	2.48	0.51	-0.05	1.38
SIG12	0.54	0.96	96.45	2.59	2.46	0.59	-0.05	1.55
SIG13	0.43	0.01	98.01	1.98	2.45	0.50	-0.14	1.27
SIG14	0.52	0.33	97.13	2.54	2.47	0.56	-0.03	1.50
SIG15	0.48	0.00	97.15	2.85	2.49	0.55	-0.01	1.49
SIG17R	0.57	0.00	97.10	2.90	2.51	0.49	0.09	1.33
Average[1]	0.50	0.20	97.35	2.45	2.47	0.53	-0.04	1.42
SD[1]	0.10	0.37	0.61	0.39	0.01	0.03	0.04	0.09
Min[1]	0.41	0.00	96.14	1.98	2.45	0.50	-0.14	1.27
Max[1]	0.79	1.07	98.01	3.41	2.49	0.59	0.00	1.55
Average[2]	0.67	0.02	97.64	2.34	2.49	0.50	-0.04	1.28
SD[2]	0.17	0.02	1.02	1.03	0.02	0.08	0.11	0.21
Min[2]	0.51	0.00	96.60	1.03	2.47	0.43	-0.18	1.11
Max[2]	0.90	0.04	98.93	3.38	2.51	0.61	0.09	1.55

[1] Field sites, exclusive SIG17R
[2] Reg + Ref$_{\text{shallow 03}}$

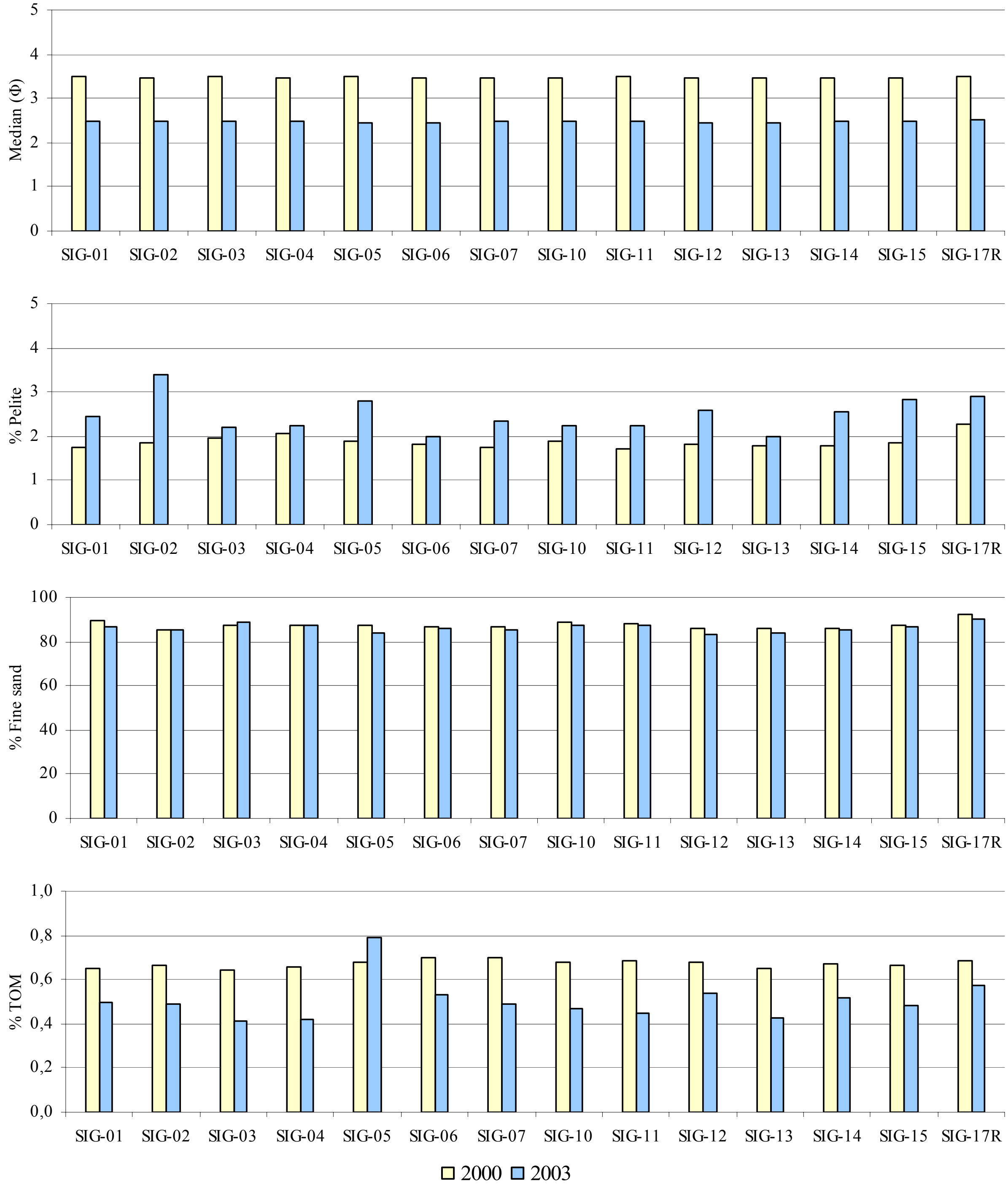


Figure 6.2. Sediment characteristics at Sigyn in 2000 and 2003. Fine sand is the relative amount of sand with grain size 63-250 µm.

6.2.2 Chemical compounds

6.2.2.1 LSC

The results of the LSC (limits of significant contamination) calculations of hydrocarbons and metals are presented in the chapter concerning the regional and reference sites. Both the $LSC_{shallow\ 97\text{-}03}$ and the field specific LSC value ($LSC_{SIG17R\ 03}$) are presented in Table 6.3. The field specific LSC value ($LSC_{SIG17R\ 03}$) is regarded as representative as the sediment characteristics at this site is within the variation found at all reference sites at in the shallow part of Region II. LSC in the text relates to $LSC_{shallow\ 97\text{-}03}$.

Table 6.3. Limits of Significant Contamination (LSC) for the Sigyn field in 2003, the shallow part of Region II based on data from 1997 to 2003 ($LSC_{shallow\ 97\text{-}03}$), and the whole of Region II based on data from 1997 to 2003 ($LSC_{regII\ 97\text{-}03}$). For comparison, LSC-values from 2000 are included. All values in mg/kg dry sediment.

	THC	PAH (16)	NPD's	Decalins	Cu	Cr	Zn	Ba	Pb	Cd[1]	Hg
$LSC_{SIG17R\ 03}$	3.0[1]	0.018	0.015	0.127	0.6[1]	8.4	6.2	10	5.4	0.03[1]	0.007
$LSC_{shallow\ 97\text{-}03}$	9.1	*	*	*	1.0	10.0	9.1	32	6.9	0.03[1]	0.008
$LSC_{regII\ 97\text{-}03}$	13.3	*	*	*	2.0	9.4	11.1	136	6.6	0.03[1]	0.011
$LSC_{SIG17R\ 00}$**	5.2	*	0.012	0.032	0.9	8.4	4.3	19	6.0	0.008	n.d.
$LSC_{shallow\ 97\text{-}00}$**	6.6	*	*	*	1.2	10.2	8.1	38	7.4	0.008	0.006

* NPD's, PAH's and decalins are not analysed at regional sites in 1997 and 2000.
** Data from Mannvik & al. 2001
n.d. = not detected
[1] LSC = detection limit

6.2.2.2 Hydrocarbons

Summarised results of the hydrocarbon analyses, along with the content of selected hydrocarbon compounds in the different layers (0-1, 1-3 and 3-6) are given in Table 6.4 and Table 6.5. The complete data set including replicates is given in the Appendix. Comparison of the THC content in 2003 with the 2000 survey is presented in Figure 6.3.

Table 6.4. The content of oil hydrocarbons in sediment from Sigyn in 2003. All values in mg/kg dry sediment. THC values above $LSC_{shallow\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{SIG17R\ 03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data for the regional and field reference sites in the shallow part of region II are included.

Site	THC		PAH(16)		NPD		Decalin	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
SIG01	5.2	3.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SIG02	3.7	0.3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SIG03	7.1	3.8	0.011	0.001	0.013	0.001	0.465	0.370
SIG04	7.0	5.5	0.014	0.003	0.015	0.004	1.480	1.288
SIG05	<3.0	1.8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SIG06	<3.0	0.0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SIG07	<3.0	1.4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SIG10	<3.0	1.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SIG11	5.3	3.4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SIG12	20.9	11.5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SIG13	5.3	1.7	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SIG14	4.7	2.8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SIG15	7.0	4.0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SIG17R	<3,0	-	0.016	0.001	0.012	0.001	0.107	0.008
av. ± sd.[1]	5.8 ± 5.0							
min – max[1]	<3.0-20.9							
av. ± sd.[2]	6.3 ± 4.1		0.015 ± 0.006		0.012 ± 0.001		0.126 ± 0.027	
min – max[2]	<3.0-11.3		0.007 - 0.023		0.011 - 0.012		0.103 - 0.161	

n.a. = not analysed.
[1] Field sites, exclusive SIG17R
[2] Reg + $Ref_{shallow\ 03}$

THC was found in the range from <3.0 (detection limit) to 20.9 mg/kg, and THC concentrations above LSC was found at SIG12, 250 m to the west of the field centre. In general there was low THC content in the sediments at most sites as in 2000, but the THC content had increased at the sites out to 500 m to the north, out to 1000 m to the south and 500 m to the west (Figure 6.3).

At SIG04, 250 m to the north THC and decalins were found above LSC in all depth intervals in the sediments down to 6 cm. PAH was found above LSC in the 1-3 cm interval and NPD was above LSC in the 0-1 cm interval. At SIG03, 500 m to the north only decalins were found above LSC in the vertical sediment profile down to 6 cm (Table 6.5). At the reference site PAH occurred in concentration above $LSC_{SIG17R\ 03}$ in the 1-3 and 3-6 cm interval.

Table 6.5. The content of oil hydrocarbons in vertical sections of sediment from 3 sampling sites at Sigyn in 2003. All values in mg/kg dry sediment. THC values above $LSC_{shallow\ 97\text{-}03}$ and PAH, NPD and decalins values above $LSC_{SIG17R\ 03}$ are dark shaded.

Site	Layer (cm)	THC	PAH(16)	NPD	Decalins
SIG03	0-1	4.1	0.012	0.012	0.215
	1-3	4.3	0.009	0.011	0.290
	3-6	5.8	0.018	0.012	0.165
SIG04	0-1	12.8	0.014	0.016	2.930
	1-3	22.9	0.166	0.014	5.560
	3-6	11.8	0.017	0.012	1.580
SIG17R	0-1	<3.0	0.017	0.012	0.105
	1-3	<3.0	0.019	0.013	0.105
	3-6	5.1	0.033	0.013	0.115

6.2.2.3 Metals

Table 6.6 summarises the results of the metal analyses of the Sigyn field in 2003. Concentrations of selected metals in the different layers (0-1, 1-3 and 3-6) of sediment are given in Table 6.7, whereas the complete data set including replicates is given in the Appendix. Comparisons of the metal contents in 2003 with the metal contents in 2000 are presented in Figure 6.6.

Table 6.6 Content of metals in sediments from Sigyn in 2003. All values in mg/kg dry sediment. Values above $LSC_{shallow\ 97\text{-}03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data for the regional and field reference sites in the shallow part of region II are included.

Site	Cu		Cr		Zn		Ba		Pb		Cd		Hg	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
SIG01	<0.6	-	9.2	0.2	5.9	0.3	8	0.3	5.2	0.6	<0.03	-	n.a.	n.a.
SIG02	<0.6	-	9.5	0.3	6.0	0.3	20	6.1	5.4	0.1	<0.03	-	n.a.	n.a.
SIG03	<0.6	-	10.3	0.7	6.3	0.5	43	23.8	5.2	0.1	<0.03	-	0.004	0.001
SIG04	<0.6	-	9.5	0.2	6.3	0.1	71	37.4	5.6	0.2	<0.03	-	0.005	0.003
SIG05	<0.6	-	9.5	1.1	6.0	0.6	10	3.8	5.4	0.7	<0.03		n.a.	n.a.
SIG06	<0.6	-	9.5	0.2	5.9	0.1	8	3.1	5.6	0.2	<0.03	-	n.a.	n.a.
SIG07	<0.6	-	9.4	0.5	6.1	0.3	8	2.2	5.5	0.6	<0.03	-	n.a.	n.a.
SIG10	<0.6	-	9.5	0.2	7.3	1.9	10	1.9	5.2	0.2	<0.03	-	n.a.	n.a.
SIG11	<0.6		9.6	0.2	6.1	0.2	43	5.8	5.4	0.3	<0.03	-	n.a.	n.a.
SIG12	<0.6	-	11.0	1.1	6.9	1.2	61	27.1	5.9	0.6	<0.03	-	n.a.	n.a.
SIG13	<0.6	-	9.9	0.4	6.2	0.2	14	1.7	5.9	0.3	<0.03	-	n.a.	n.a.
SIG14	<0.6	-	9.0	0.8	6.4	0.2	18	1.9	5.4	0.4	<0.03	-	n.a.	n.a.
SIG15	<0.6	-	9.7	0.3	6.2	0.2	8	0.3	5.7	0.7	<0.03	-	n.a.	n.a.
SIG17R	<0.6	-	7.9	0.2	5.8	0.2	8	1.2	4.9	0.2	<0.03	-	0.004	0.001
av. ± sd.[1]	<0.6		9.7 ± 0.5		6.3 ± 0.4		25 ± 22		5.5 ± 0.2		<0.03			
min – max[1]	<0.6		9.0 - 11.0		5.9 - 7.3		8 - 71		5.2 - 5.9		<0.03			
av. ± sd.[2]	<0.6		7.8±1.19		6.6±0.84		9±6		5.0±0.67		<0.03		0.004±0.001	
min – max[2]	<0.6		6.3-9.2		5.8-7.4		4 -18		4.1-5.7		<0.03		0.004-0.005	

n.a. = not analysed.
[1] Field sites, exclusive SIG17R
[2] Reg + $Ref_{shallow\ 03}$

Table 6.7. The content of metals in vertical sections of sediment from 3 sampling sites at Sigyn in 2003. All values in mg/kg dry sediment. Values above LSC $_{shallow\ 97\text{-}03}$ are dark shaded.

Site	Layer (cm)	Cu	Cr	Zn	Ba	Pb	Cd	Hg
SIG03	0-1	<0.6	9.8	6.1	29	5.2	<0.03	0.003
	1-3	<0.6	9.7	5.9	28	5.3	<0.03	0.003
	3-6	<0.6	10.6	6.3	29	5.3	<0.03	0.004
SIG04	0-1	<0.6	9.7	6.3	102	5.4	<0.03	0.009
	1-3	<0.6	10.6	6.4	32	5.8	<0.03	0.006
	3-6	<0.6	10.0	6.7	25	6.0	0.04	0.005
SIG17R	0-1	<0.6	7.8	6.1	9	5.2	<0.03	0.004
	1-3	<0.6	8.2	6.5	13	5.5	<0.03	0.005
	3-6	<0.6	8.3	6.6	17	5.5	<0.03	0.005

Barium was found in a range from 8 to 71 mg/kg, lead from 5.2 to 5.9 mg/kg, mercury from 0.004 to 0.005 mg/kg and zinc from 5.9 to 7.3 mg/kg (Table 6.6). Cadmium was below the limit of detection in all samples but one sample from SIG04 where it was 0.04 mg Cd/kg. Also copper was below the limit of detection in all samples except in one sample from SIG11 where it was 1.1 mg Cu/kg. Sediments from SIG03 and SIG12 had chromium content above LSC. Barium was present above LSC at SIG03, SIG04, SIG11 and SIG12 (Table 6.6).

Vertical sediment samples (0-1, 1-3 and 3-6 cm) from SIG04 had barium content above LSC in the 0-1 cm layer. Barium concentrations decreased with increasing depth in the sediments at SIG04, indicating recent entry of barium to the site. At the same site occurred cadmium above LSC in the 3-6 cm layer (Table 6.7)

Compared to the baseline survey of 2000 elevated barium content was found at SIG 02, SIG03, SIG04, SIG11 and SIG12. The higher barium content was found at the two nearest (250 and 500 m) sites to the north (downstream) of the installation and at the two nearest (250 and 500 m) sites to the west of the installation (Figure 6.3 and Figure 6.5). For the other metals there were only minor changes (Figure 6.6).

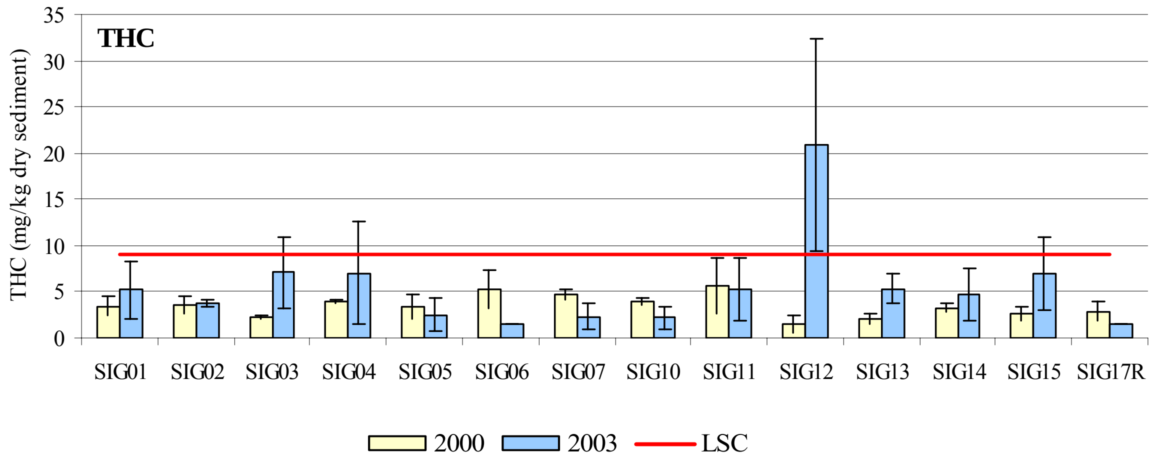


Figure 6.3. Average THC concentrations and standard deviations in sediments at Sigyn in 2000 and 2003. Red line is $LSC_{shallow\ 97\text{-}03}$.

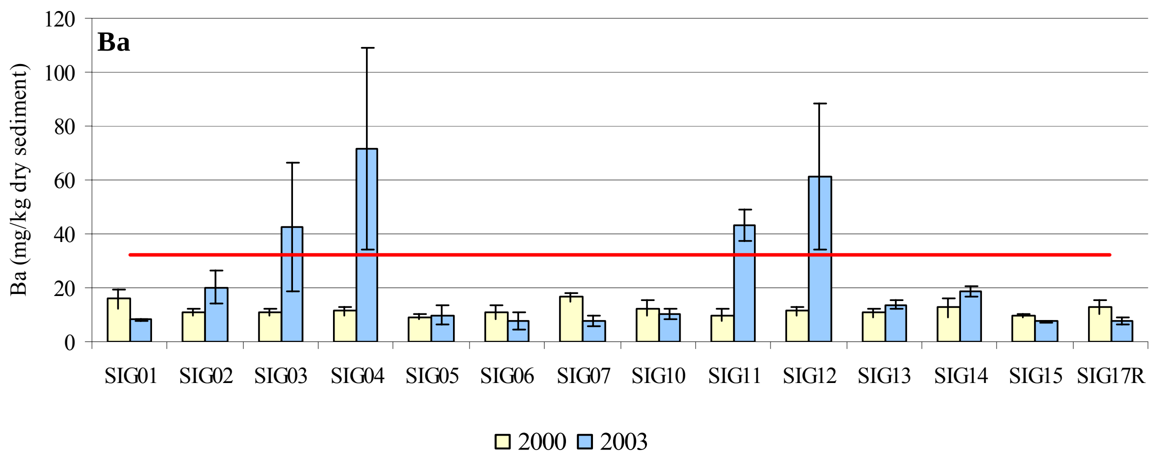


Figure 6.4. Average barium concentrations and standard deviations in sediments at Sigyn in 2000 and 2003. Red line is $LSC_{shallow\ 97\text{-}03}$.

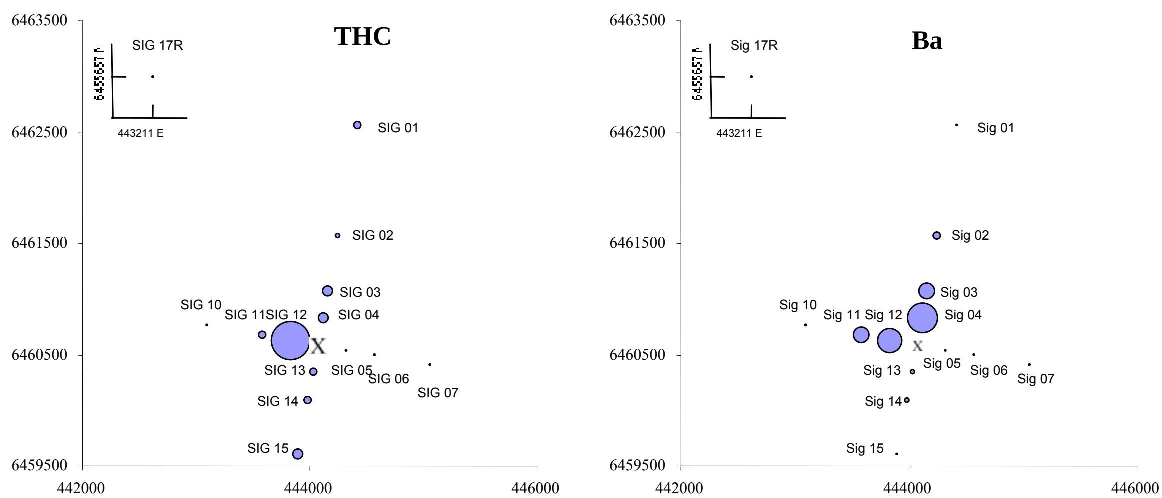


Figure 6.5. Distribution of THC and barium in sediments at the sampling sites at Sigyn in 2003. The size of the circle indicates the amount of THC and Ba. The field centre are marked with an X.

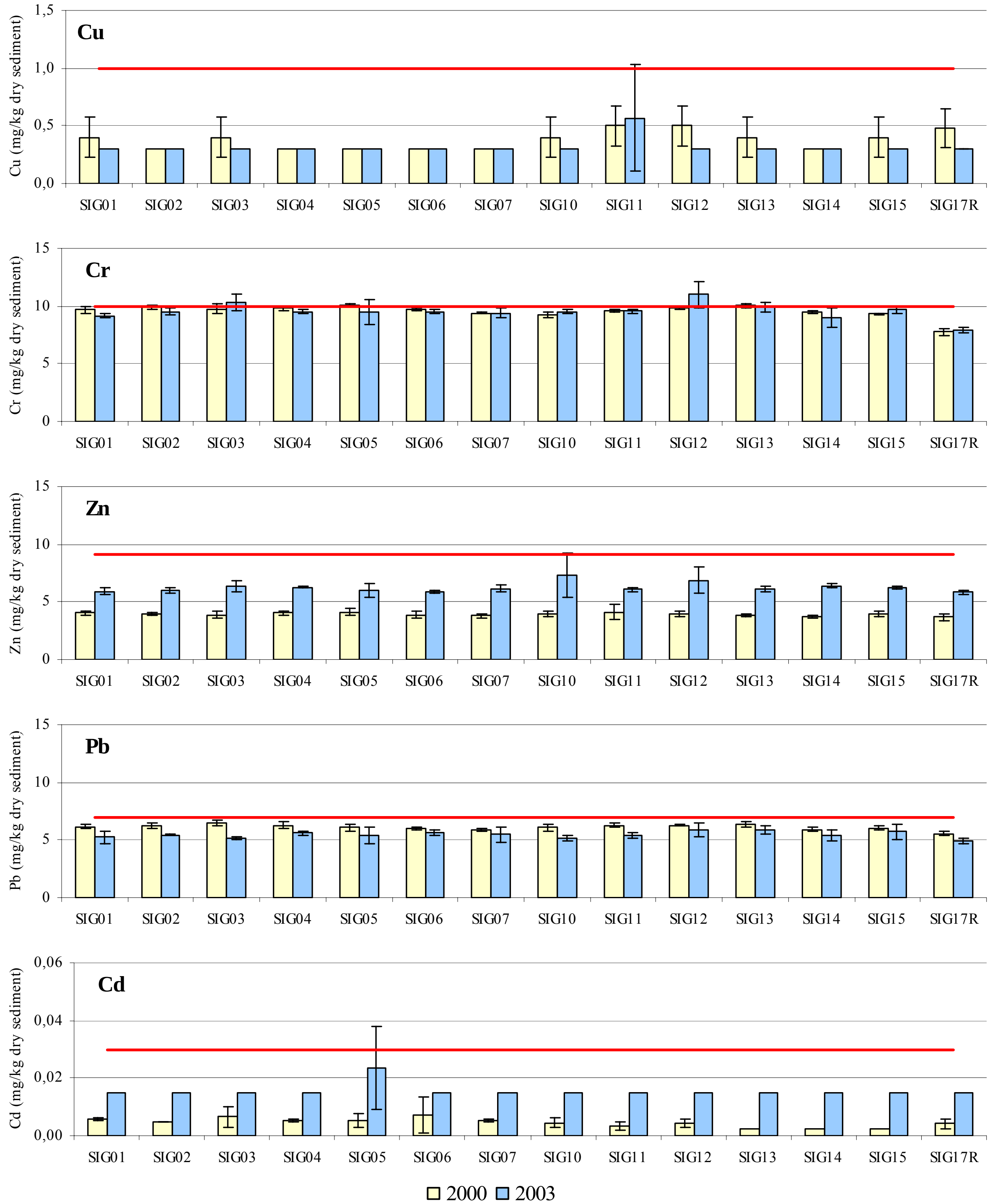


Figure 6.6. Average content and standard deviations of metals in sediment from Sigyn in 2003 and 2000. Red line is $LSC_{shallow\ 97\text{-}03}$. Cadmium was below the detection limit in most samples, thus the half value of the detection limit is used in the figure.

The field sites at Sigyn were compared to nearby regional and field specific reference sites based on sediment characteristics (TOM and pelite) and chemical content in the sediments (Figure 6.7). SIG12 (250 m to the west) did not group together with the other sites, but were distinct due to the higher content of chemical compounds in the sediments.

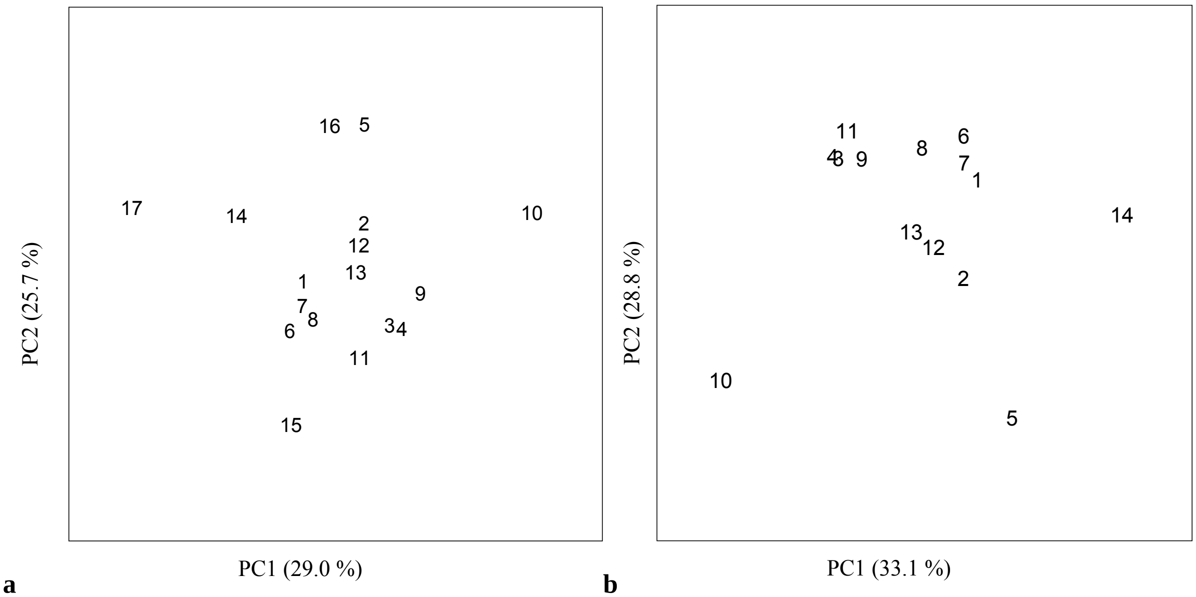


Figure 6.7. 2-D plot from the PCA analysis of environmental variables (% pelite, % sand, % gravel, median Φ, % TOM, Cu, Ba, Zn, Cr, Pb and THC) carried out on:
a) Sigyn field sites compared to the reference site at Sleipner Øst, Varg and the regional site RII06. Explained variation in the data 54.6 %.
b) Sigyn fiels sites. Explained variation in the data 61.9 %.
Numbers in the plot identify the sampling sites. See table below.

1	SIG01	7	SIG07	13	SIG15
2	SIG02	8	SIG10	14	SIG17R
3	SIG03	9	SIG11	15	SLE41R
4	SIG04	10	SIG12	16	VAR14R
5	SIG05	11	SIG13	17	RII06
6	SIG06	12	SIG14		

6.2.3 Bottom fauna

A summary of the distribution of individuals and taxa within the main taxonomic groups is given in Table 6.8. Unidentified juveniles of the sea urchin Spatangoids (44982 individuals) and juveniles of the brittle star *Ampiura filiformis* (1116 individuals) are omitted from the analyses, as they occurred in extremely high numbers. In total (exclusive omitted individuals), 4314 individuals within 170 taxa were collected at Sigyn in 2003. The fauna was numerically dominated by annelida with 53 % the individuals and 44 % of the taxa. A complete species list is available in the Appendix.

Table 6.8. Distribution of individuals and taxa within the main taxonomic groups at Sigyn in 2003 inclusive data from SIG17R (unidentified juveniles of Spatangoida and juvenile *Amphiura filiformis* are excluded).

Main taxonomic groups	Individuals		Taxa	
	Number	%	Number	%
Annelida	2300	53	74	44
Arthropoda	742	17	37	22
Mollusca	287	7	31	18
Echidermata	289	7	16	9
Diverse groups	696	16	12	7
Total	4314	100	170	100

The species/area curve for SIG17R indicates that five replicate samples give a representative impression of the bottom fauna in the area (Figure 6.8). However, as more area is sampled, more taxa are collected, indicating that not even 10 replicate samples give the full species assemblage of the area.

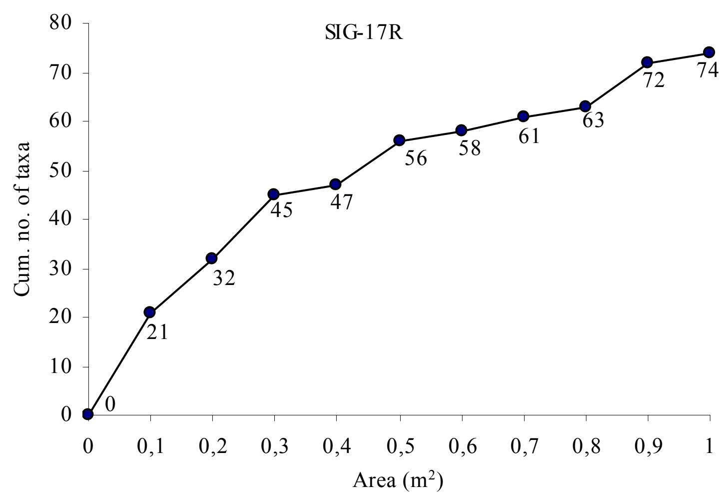


Figure 6.8. Species/area curve for the reference site at the Sigyn field. Unidentified juveniles of Spatangoida and juvenile *Amphiura filiformis* are not included.

The distribution of individuals and taxa are shown in Figure 6.9. Number of individuals and taxa at each site, and the calculated diversity indexes (H' and ES_{100}) are given in Table 6.9 and Figure 6.10. The number of individuals varied from 225 (SIG12) to 348 (SIG07), and the number of taxa varied from 51 (SIG01) to 67 (SIG10). The Shannon-Wiener diversity index (H') varied from 4.74 (SIG01) to 5.12 (SIG12), whereas the ES_{100} index varied from 31.5 (SIG01) to 38.3 (SIG12). The evenness index J varied from 0.82 (SIG10) to 0.89 (SIG12). The corresponding values at SIG17R are within or near the variation at the field sites. The number of taxa, diversity and evenness indicate good environmental conditions at all sites. The number of individuals and taxa and the corresponding diversity indexes are slightly better than in 2000 (Figure 6.10).

Table 6.9. Number of individuals, species/taxa, and selected community indices for each site (0.5 m^2) at the Sigyn field in 2003. Unidentified juveniles of Spatangoida and juvenile *Amphiura filiformis* are not included.

Site number	Number of Individuals	Number of Taxa	Diversity H'	Evenness J	H'-max	ES_{100}
SIG01	298	51	4.74	0.84	5.67	31.5
SIG02	325	59	4.97	0.84	5.88	35.0
SIG03	229	53	4.84	0.85	5.73	34.7
SIG04	291	52	4.97	0.87	5.70	34.6
SIG05	300	57	4.88	0.84	5.83	33.3
SIG06	340	58	4.87	0.83	5.86	34.4
SIG07	348	56	4.88	0.84	5.81	33.8
SIG10	260	67	4.97	0.82	6.07	38.2
SIG11	251	52	4.85	0.85	5.70	33.6
SIG12	225	53	5.12	0.89	5.73	38.3
SIG13	309	60	5.10	0.86	5.91	37.1
SIG14	325	62	4.92	0.83	5.95	35.0
SIG15	274	53	4.75	0.83	5.73	32.2
SIG17R (6-10)	279	55	4.56	0.79	5.78	32.8
SIG17R (11-15)	260	51	4.69	0.83	5.67	32.1
SIG17R (6-15)	539	73	4.88	0.79	6.19	33.3
Sum[1]	3775	159				
Average[1]	290	56	4.91	0.85	5.81	34.7
SD[1]	40	5	0.11	0.02	0.12	2.1
Min[1]	225	51	4.74	0.82	5.67	31.5
Max[1]	348	67	5.12	0.89	6.07	38.3
Average[2]	243	53	4.77	0.84	5.72	34.8
SD[2]	42	8	0.32	0.03	0.21	4.7
Min[2]	181	47	4.50	0.81	5.55	30.3
Max[2]	270	65	5.23	0.88	6.01	41.2

[1]Field sites, exclusive SIG17R
[2]Reg + ref $_{shallow\ 03}$

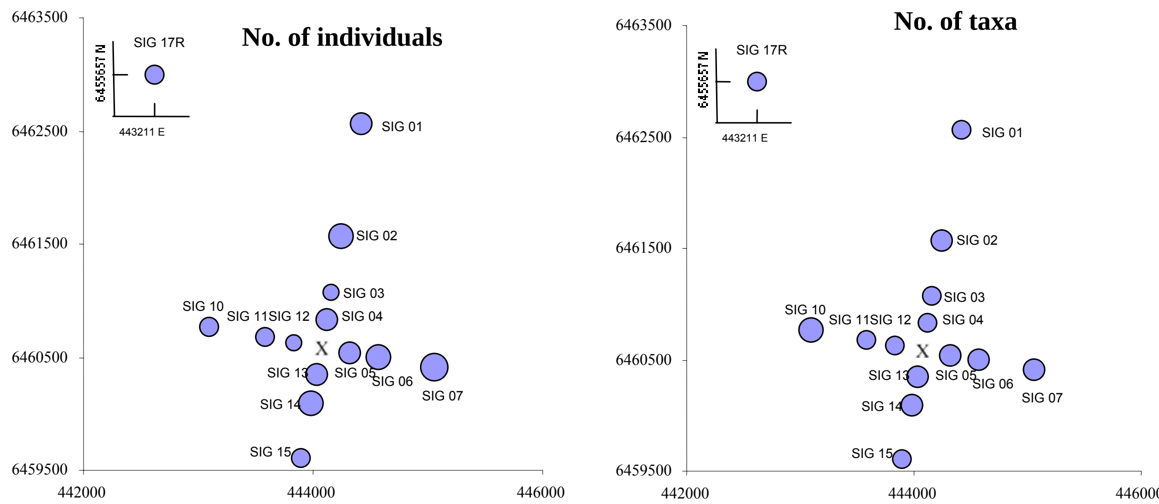


Figure 6.9. Distribution of bottom fauna (individuals and taxa) among the sampling sites in 2003. The size of the circle indicate the number of individuals and taxa. Unidentified juveniles of Spatangoida and juvenile *Amphiura filiformis* are not included. Values for SIG17R are average of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2). The field centre is marked with an X.

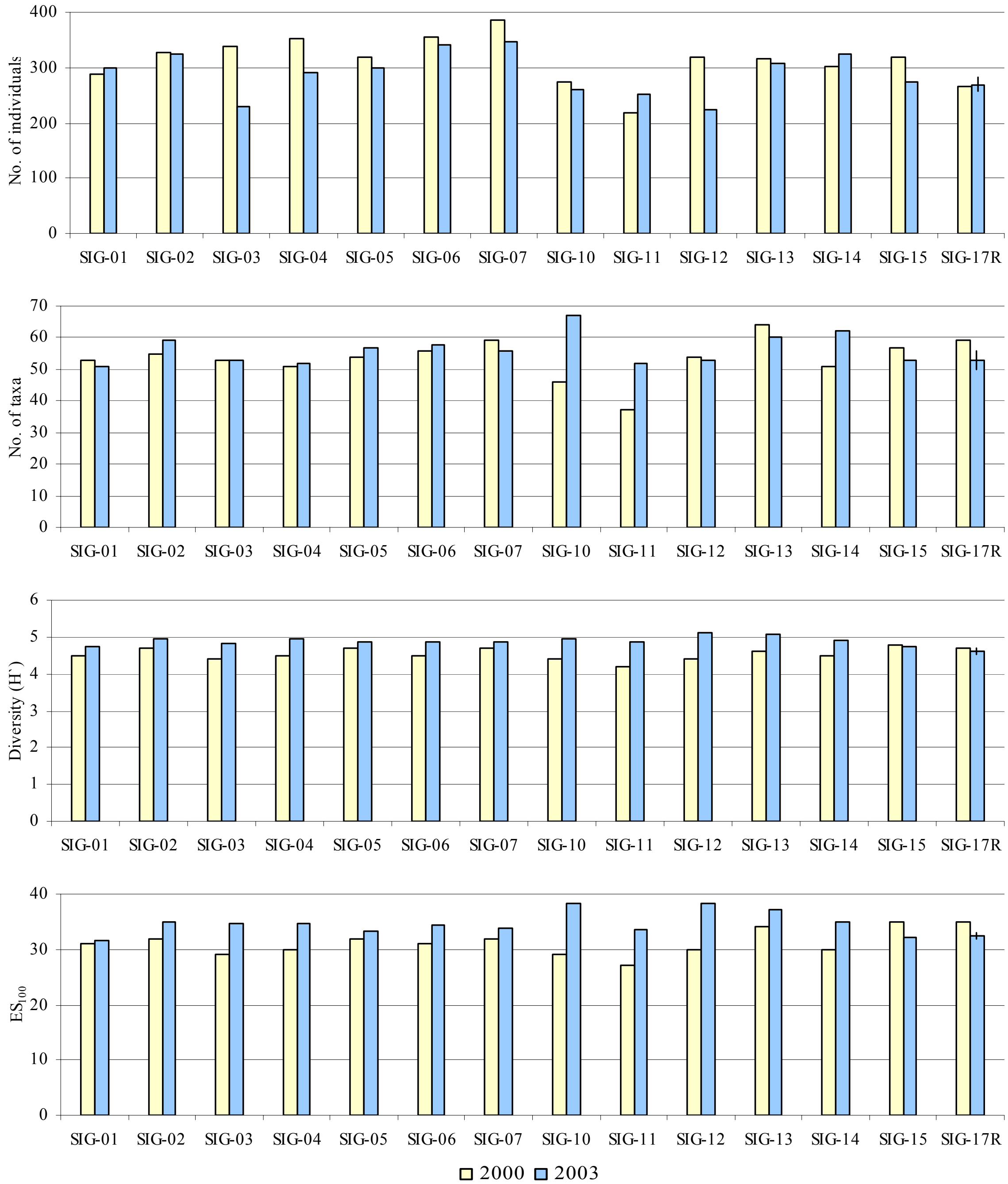


Figure 6.10. Number of individuals, taxa, and selected community indices for each site (0.5 m^2) at the Sigyn field in 2000 and 2003. Unidentified juveniles of Spatangoida and *Amphiura filiformis* are not included in 2003. Values for SIG17R are average ± standard deviation of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2).

Distribution of taxa in geometrical classes is presented in Figure 6.11. The smooth graphs are indicating undisturbed bottom fauna, and good environmental conditions at al sites.

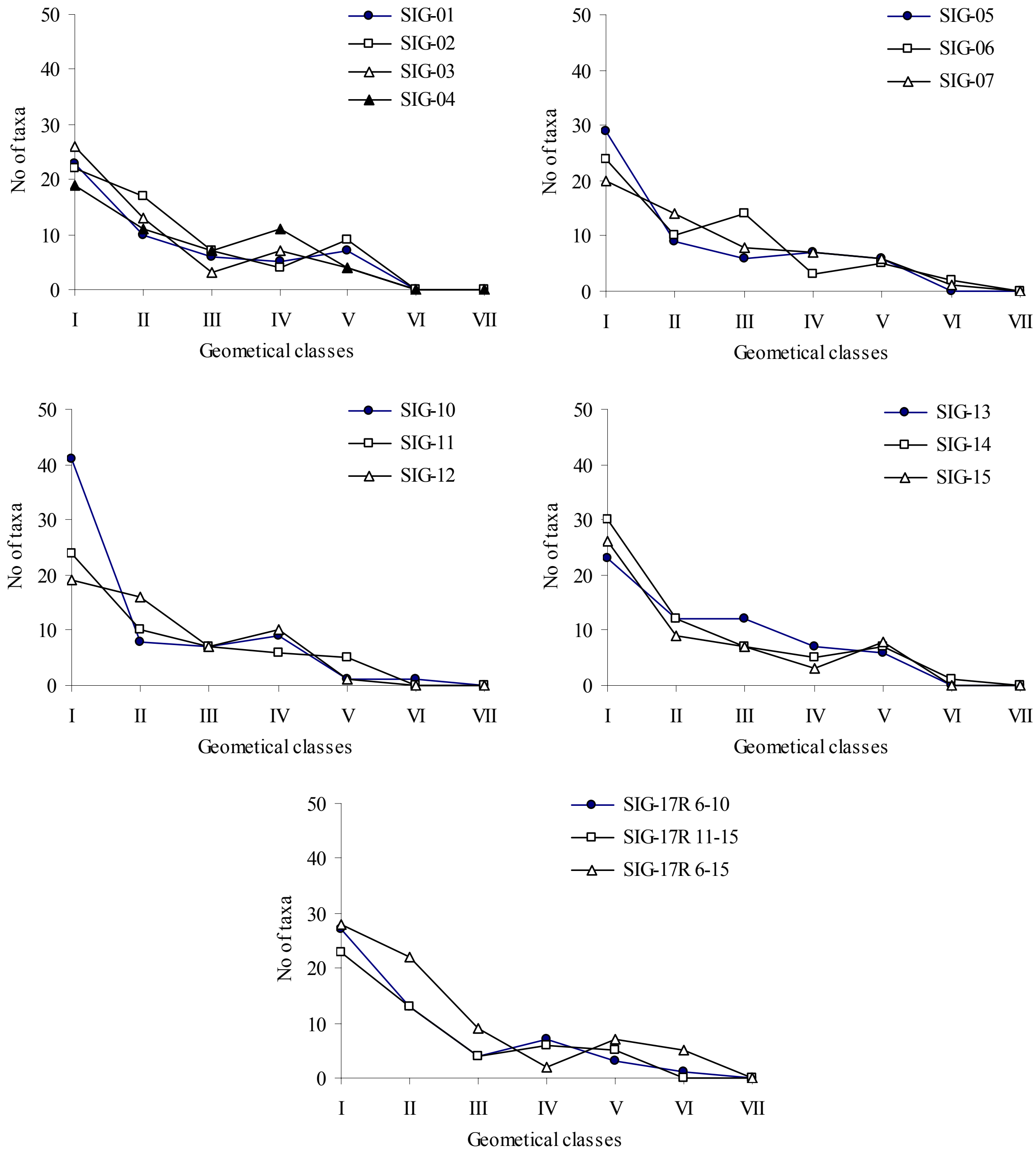


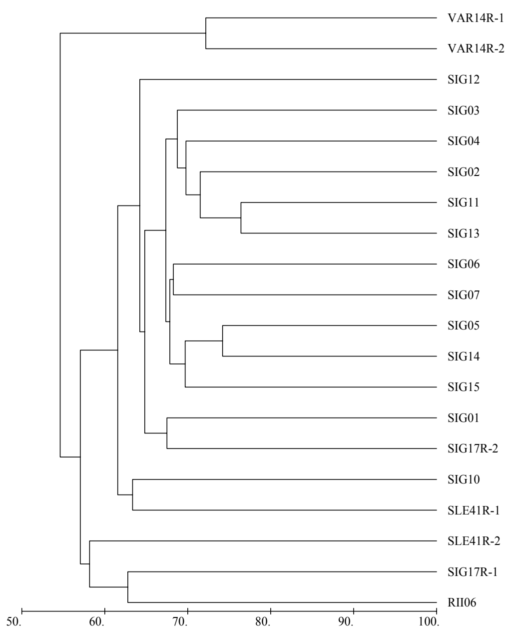
Figure 6.11. Distribution of taxa in geometrical classes for the sites at Sigyn in 2003. Exclusive unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis*.

The ten most numerous taxa are listed in Table 6.12 at the end of this chapter. The list comprise 18 taxa and 3229 individuals, which was 10.6 % of all (170) taxa and 74.8 % of all (4314) individuals. Among the more abundant species at all sites were the crustacean *Eudorella deformis* and *Bathyporeia* sp., the phoronoid *Phoronis* sp., the polychaetes *Goniada maculata*, *Owenia fusiformis* and *Spiophanes kryoeri* and the brittle star *Amphiura filiformis*. The numerical domination of few taxa indicates homogenous environmental condition at Sigyn in 2003 and the taxa assemblages indicate good environmental conditions at all sites.

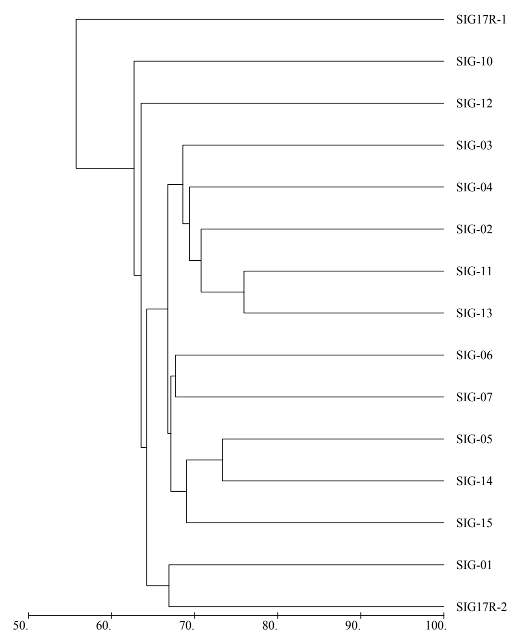
The results of the multivariate analyses are given in the dendrogramme (Figure 6.12) and the MDS plott (Figure 6.13).

In the cluster analysis, all sites except the first 5 samples from SIG17R, were grouped together within 62 % similarity, indicating relatively high similarity in the species assemblages within the field. The species assemblages at SIG11 and SIG13 were the most similar (75 %).

The results of the MDS analysis support the findings in the cluster analysis, confirming the similarity in species assemblage and further not grouping the fauna into groups indicating strong environmental gradients in the data. The stress test of the MDS analysis was 0.18, indicating a potential useful presentation of the data.



a



b

Figure 6.12. Dendrogram showing the similarity between fauna from sampling sites at:
a) Sigyn field compared to the reference site at Varg, Sleipner Øst and the regional site RII06. Unidentified juveniles of Spatangoida and Echinoidea are not included.
b) Sigyn field sites. Unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis* are not included.

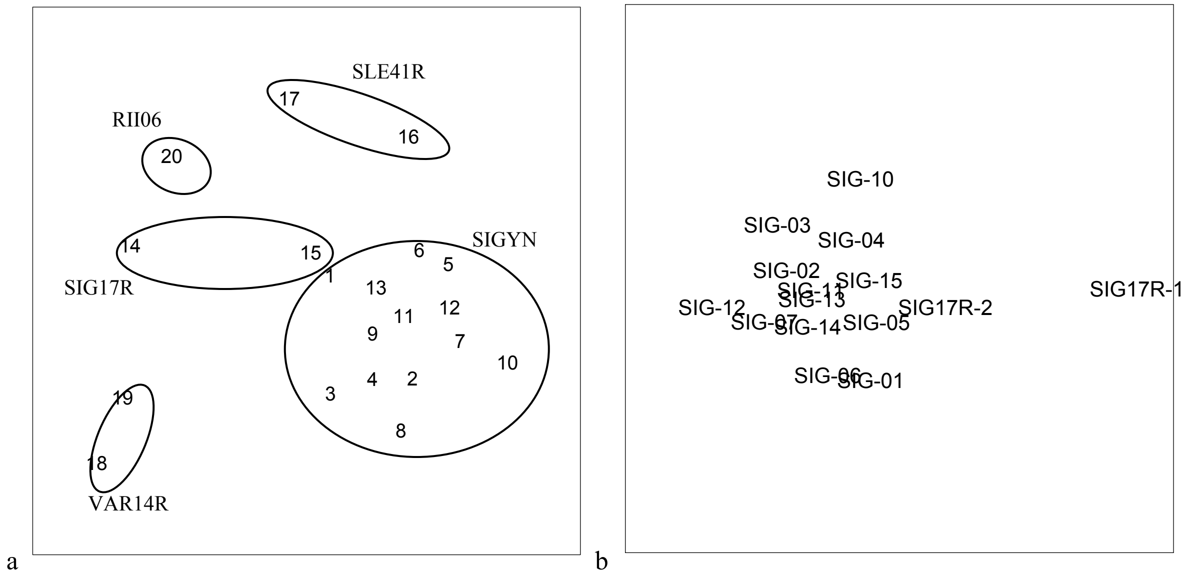


Figure 5.13. A 2-dimentional plott of the MDS analysis of the fauna data from:
a) All sampling sites at Sigyn, the reference site at Varg and Sleipner Øst and regional site RII06 in 2003. Stress = 0.17. Unidentified juveniles of Spatangoida and Echinoidea are not included. Numbers in the plot identify the sampling sites. See table below.
b) All sampling sites at Sigyn in 2003. Stress = 0.18. Unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis* are not included.

1	SIG01	6	SIG06	11	SIG13	16	SLE41R-1
2	SIG02	7	SIG07	12	SIG14	17	SLE41R-2
3	SIG03	8	SIG10	13	SIG15	18	VAR14R-1
4	SIG04	9	SIG11	14	SIG17R-1	19	VAR14R-2
5	SIG05	10	SIG12	15	SIG17R-2	20	RII06

Linking of biotic and environmental variables by BIOENV revealed that the distribution of chromium, zinc and THC were best correlated to the biota at $\rho_w = 0.5$ (Table 6.10). This indicates that there was an association between some environmental variables and the bottom fauna, although not a very strong one.

Table 6.10. Combinations of the 10 environmental variables, taken *k* at a time, yielding the best matches of biotic and abiotic similarity matrices for each *k*, as measured by weighted Spearman rank correlation ρ_w. Bold type indicates overall optimum. All possible combinations of variables and associated correlation to the biotic are given in the Appendix.

Number of variables (*k*)	Correlation coefficient (ρ_w)	Environmental variables									
1	0.279	Zn									
1	0.236	Ba									
1	0.218	Cr									
1	0.209	Pb									
1	0.178	Cu									
1	0.048	TOM									
1	-0.029	Sand									
1	-0.043	Pelite									
1	-0.128	THC									
1	-0.171	Gravel									
2	0.460	Cr	Zn								
3	**0.505**	**Cr**	**Zn**	**THC**							
4	0.504	Cr	Zn	THC	TOM						
5	0.498	Cr	Zn	THC	TOM	Pb					
6	0.490	Cr	Zn	THC		Pb	Ba	Gravel			
7	0.465	Cr	Zn	THC		Pb	Ba	Gravel	Sand		
8	0.426	Cr	Zn	THC	TOM	Pb	Ba	Gravel	Sand		
9	0.379	Cr	Zn	THC	TOM	Pb	Ba	Gravel	Sand	Pelite	
10	0.215	Cr	Zn	THC	TOM	Pb	Ba	Gravel	Sand	Pelite	Cu

6.2.4 Estimation of influenced area

The extension of contamination along sampling transects and the minimum area of contaminated sediments for THC, barium and other metals as well as for faunal disturbance are shown in Figure 6.14 and Table 6.11. Compared to the results from the baseline survey in 2000 the contaminated area has increased for THC, barium, and other metals (chromium). The influence area around Sigyn seams to be toward the northwest. No faunal disturbance was found in 2003.

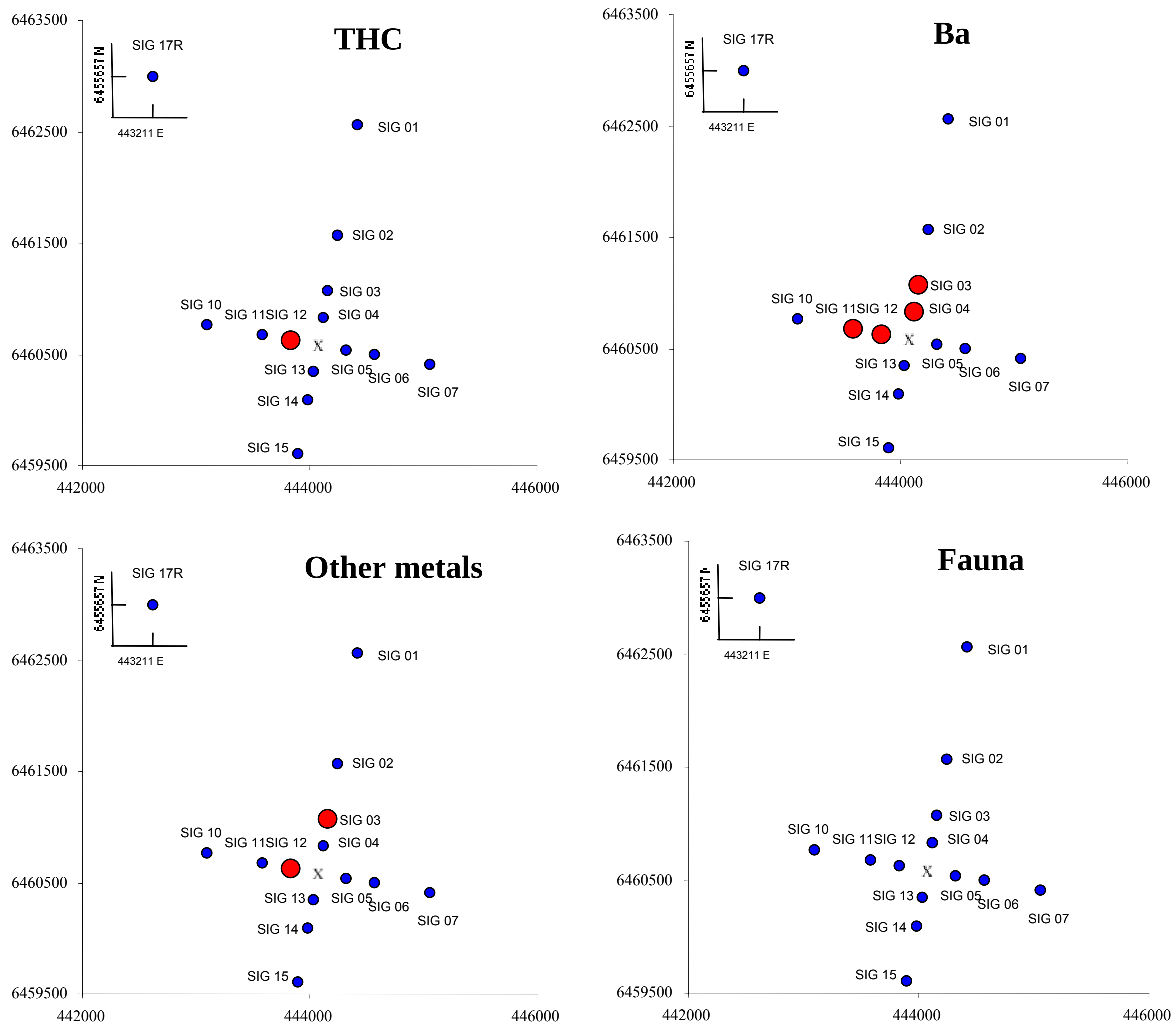


Figure 6.14. Faunal disturbance and chemical contamination of the sediments at Sigyn in 2003. The field centre is marked with an X. Uncontaminated sites and sites with no faunal disturbance are marked with small blue circles.

Table 6.11. Estimated distance of contamination and faunal disturbance from the installation, and estimated area of contamination and faunal disturbance around the field centre.

Sigyn	N M	E m	S m	W m	2003 km²	2000 km²
THC	0	0	0	250	0.02	0.00
Ba	500	0	0	500	0.20	0.00
Other metals	0	0	0	250	0.02	0.00
Fauna	0	0	0	0	0.00	0.00

6.3 Summary and conclusions

During 2002 three new wells were drilled at Sigyn. The sediments are still characterized as fine sand, although there has been a slight increase in the pelite and decrease in TOM content since 2000. The amounts of THC and barium had increased at the sampling sites toward the north and the west. The largest increase was found closest to the installation. The other metals were at the same level as in the baseline survey of 2000, except for chromium which occurred above LSC at two sites. Species diversity was at the same levels as in 2000 and the fauna was found to be homogenous at the sampling sites and there was no strong association between the distribution of fauna and chemical compounds at Sigyn. The activity at Sigyn has so far not lead to any faunal disturbance in the sampling area, although the area of contamination was larger in 2003 than in 2000.

Table 6.12. Number of individuals and abundance for the ten predominant taxa at each site at the Sigyn field in 2003. Unidentified juveniles of Spatangoida and juvenile *Amphiura filiformis* are not included.

SIG-01	No. of ind.	%	kum %
Mysella bidentata	29	9.7	9.7
Amphiura filiformis	27	9.1	18.8
Magelona filiformis	22	7.4	26.2
Scoloplos armiger	20	6.7	32.9
Bathyporeia sp.	19	6.4	39.3
Cerianthus lloydii	17	5.7	45.0
Goniada maculata	16	5.4	50.3
Owenia fusiformis	15	5.0	55.4
Eudorellopsis deformis	15	5.0	60.4
Phoronis sp.	15	5.0	65.4

SIG-02	No. of ind.	%	kum %
Amphiura filiformis	29	8.9	8.9
Bathyporeia sp.	28	8.6	17.5
Eudorellopsis deformis	22	6.8	24.3
Phoronis sp.	19	5.8	30.2
Spiophanes kroeyeri	19	5.8	36.0
Magelona filiformis	18	5.5	41.5
Goniada maculata	17	5.2	46.8
Owenia fusiformis	16	4.9	51.7
Spiophanes bombyx	16	4.9	56.6
Cerianthus lloydii	14	4.3	60.9

SIG-03	No. of ind.	%	kum %
Phoronis sp.	22	9.6	9.6
Bathyporeia sp.	19	8.3	17.9
Eudorellopsis deformis	17	7.4	25.3
Goniada maculata	17	7.4	32.8
Amphiura filiformis	15	6.6	39.3
Spiophanes kroeyeri	15	6.6	45.9
Magelona filiformis	13	5.7	51.5
Cerianthus lloydii	11	4.8	56.3
Scoloplos armiger	10	4.4	60.7
Owenia fusiformis	8	3.5	64.2
Aricidea catherinae	8	3.5	67.7

SIG-04	No. of ind.	%	kum %
Phoronis sp.	25	8.6	8.6
Spiophanes kroeyeri	24	8.2	16.8
Eudorellopsis deformis	20	6.9	23.7
Amphiura filiformis	18	6.2	29.9
Cerianthus lloydii	15	5.2	35.1
Bathyporeia sp.	14	4.8	39.9
Owenia fusiformis	13	4.5	44.3
Goniada maculata	12	4.1	48.5
Scoloplos armiger	12	4.1	52.6
Sthenelais limicola	12	4.1	56.7

SIG-05	No. of ind.	%	kum %
Scoloplos armiger	29	9.7	9.7
Bathyporeia sp.	23	7.7	17.3
Spiophanes kroeyeri	22	7.3	24.7
Phoronis sp.	20	6.7	31.3
Amphiura filiformis	19	6.3	37.7
Eudorellopsis deformis	18	6.0	43.7
Owenia fusiformis	15	5.0	48.7
Cerianthus lloydii	14	4.7	53.3
Goniada maculata	12	4.0	57.3
Spiophanes bombyx	12	4.0	61.3
Travisia forbesii	12	4.0	65.3

SIG-06	No. of ind.	%	kum %
Spiophanes kroeyeri	36	10.6	10.6
Phoronis sp.	35	10.3	20.9
Eudorellopsis deformis	25	7.4	28.2
Bathyporeia sp.	24	7.1	35.3
Cerianthus lloydii	24	7.1	42.4
Travisia forbesii	24	7.1	49.4
Owenia fusiformis	17	5.0	54.4
Amphiura filiformis	11	3.2	57.6
Goniada maculata	10	2.9	60.6
Spiophanes bombyx	9	2.6	63.2

SIG-07	No. of ind.	%	kum %
Scoloplos armiger	35	10.1	10.1
Phoronis sp.	30	8.6	18.7
Eudorellopsis deformis	27	7.8	26.4
Bathyporeia sp.	26	7.5	33.9
Travisia forbesii	21	6.0	39.9
Magelona filiformis	20	5.7	45.7
Spiophanes kroeyeri	18	5.2	50.9
Amphiura filiformis	14	4.0	54.9
Owenia fusiformis	13	3.7	58.6
Goniada maculata	12	3.4	62.1

SIG-10	No. of ind.	%	kum %
Mysella bidentata	44	16.9	16.9
Bathyporeia sp.	22	8.5	25.4
Scoloplos armiger	14	5.4	30.8
Phoronis sp.	13	5.0	35.8
Amphiura filiformis	12	4.6	40.4
Eudorellopsis deformis	12	4.6	45.0
Magelona filiformis	12	4.6	49.6
Goniada maculata	11	4.2	53.8
Spiophanes kroeyeri	10	3.8	57.7
Owenia fusiformis	10	3.8	61.5

Table 6.12 continue. Number of individuals and abundance for the ten predominant taxa at each site at the Sigyn field in 2003. Exclusive unidentified juveniles of Spatangoida and juvenile *Amphiura filiformis*.

SIG-11	No. of ind.	%	kum %
Phoronis sp.	22	8.8	8.8
Bathyporeia sp.	21	8.4	17.1
Goniada maculata	20	8.0	25.1
Spiophanes kroeyeri	17	6.8	31.9
Owenia fusiformis	16	6.4	38.2
Amphiura filiformis	13	5.2	43.4
Scoloplos armiger	13	5.2	48.6
Eudorellopsis deformis	13	5.2	53.8
Magelona filiformis	13	5.2	59.0
Cerianthus lloydii	10	4.0	62.9

SIG-12	No. of ind.	%	kum %
Bathyporeia sp.	19	8.4	8.4
Goniada maculata	14	6.2	14.7
Owenia fusiformis	13	5.8	20.4
Eudorellopsis deformis	13	5.8	26.2
Cerianthus lloydii	12	5.3	31.6
Amphiura filiformis	11	4.9	36.4
Spiophanes kroeyeri	10	4.4	40.9
Chaetozone sp.	10	4.4	45.3
Phoronis sp.	9	4.0	49.3
Pectinaria auricoma	9	4.0	53.3

SIG-13	No. of ind.	%	kum %
Cerianthus lloydii	23	7.4	7.4
Scoloplos armiger	21	6.8	14.2
Bathyporeia sp.	21	6.8	21.0
Owenia fusiformis	21	6.8	27.8
Spiophanes kroeyeri	20	6.5	34.3
Eudorellopsis deformis	19	6.1	40.5
Goniada maculata	14	4.5	45.0
Phoronis sp.	14	4.5	49.5
Travisia forbesii	11	3.6	53.1
Magelona filiformis	10	3.2	56.3
Spiophanes bombyx	10	3.2	59.5
Anobothrus gracilis	10	3.2	62.8

SIG-14	No. of ind.	%	kum %
Bathyporeia sp.	32	9.8	9.8
Spiophanes kroeyeri	30	9.2	19.1
Eudorellopsis deformis	25	7.7	26.8
Owenia fusiformis	22	6.8	33.5
Phoronis sp.	21	6.5	40.0
Travisia forbesii	19	5.8	45.8
Cerianthus lloydii	17	5.2	51.1
Scoloplos armiger	17	5.2	56.3
Goniada maculata	15	4.6	60.9
Magelona filiformis	11	3.4	64.3

SIG-15	No. of ind.	%	kum %
Bathyporeia sp.	24	8.8	8.8
Cerianthus lloydii	24	8.8	17.5
Scoloplos armiger	22	8.0	25.5
Goniada maculata	20	7.3	32.8
Magelona filiformis	19	6.9	39.8
Eudorellopsis deformis	18	6.6	46.4
Phoronis sp.	17	6.2	52.6
Spiophanes kroeyeri	16	5.8	58.4
Spiophanes bombyx	13	4.7	63.1
Owenia fusiformis	12	4.4	67.5

SIG-17R (6-15)	No. of ind.	%	kum %
Mysella bidentata	56	10.4	10.4
Scoloplos armiger	50	9.3	19.7
Phoronis sp.	48	8.9	28.6
Eudorellopsis deformis	46	8.5	37.1
Magelona filiformis	41	7.6	44.7
Spiophanes kroeyeri	25	4.6	49.4
Bathyporeia sp.	22	4.1	53.4
Amphiura filiformis	21	3.9	57.3
Goniada maculata	21	3.9	61.2
Spiophanes bombyx	21	3.9	65.1

7 Sleipner Øst

7.1. Introduction

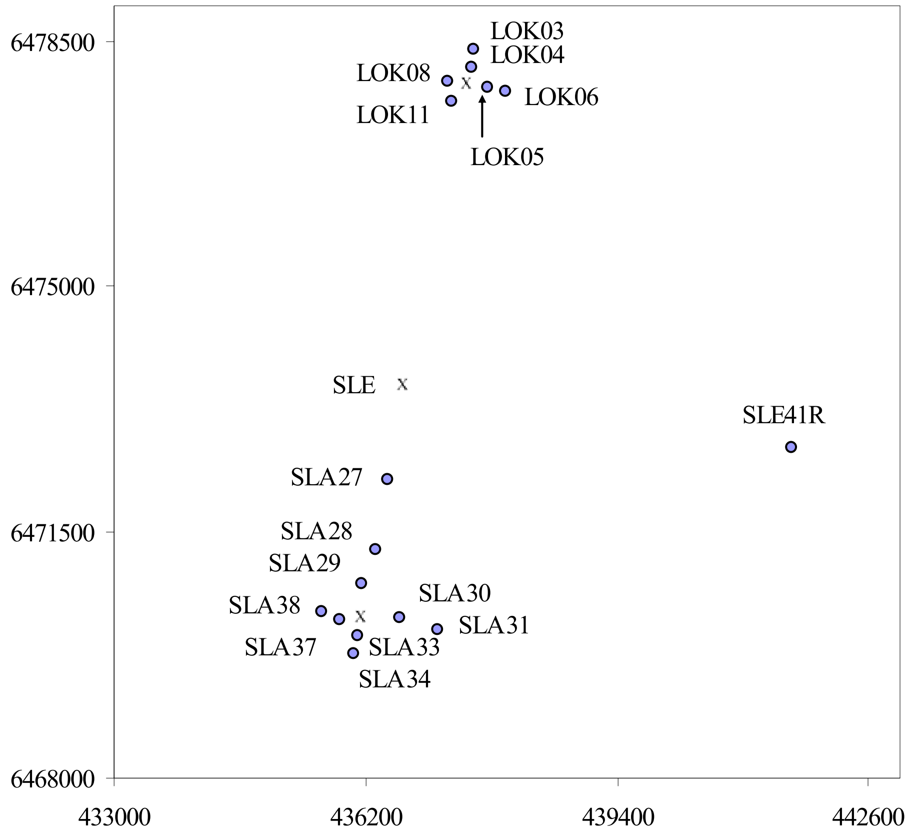
The Sleipner Øst field which is situated in block 15/9, includes the Sleipner A platform (SLA) and the two templates Loke and Sleipner Øst. Production at Sleipner Øst started in August 1993, and recent discharges at Sleipner A are listed in Table 7.1. The Sleipner Øst template was not included in the 2003 monitoring survey, due to no drilling activity at this template over the last years. At Loke the last drilling was in 1998, when 252 tonnes of water based drilling mud was discharged and 7 tonnes of olefin based mud was accidental discharged. The locations of sampling sites are shown in Figure 7.1. See Figure 7.16 at the end of this chapter for illustration of deviation in planned and real sampling.

Monitoring of the Sleipner Øst was undertaken in 1992 (Thorvaldsen & Jensen 1993), 1993 (Neverdal & Stokland 1994), 1997 (Mannvik & al. 1998) and 2000 (Mannvik & al. 2001).

In 2000 no faunal disturbances were found while elevated levels of THC, olefins and barium were detected around Sleipner A and Loke. The content of esters was very low or not detectable in the analysed samples. Since 2000 five wells have been drilled at Sleipner A and both water based and olefine based mud have been used.

Table 7.1. Recent drilling and discharges from operations and accidents at Sleipner A.

	2000	2001	2002	Comments
No of wells drilled	2	1	2	
Barite, tonnes	2068	488	670	
Cuttings, tonnes	4390	1613	2118	
Water-based drilling mud, m^3	3128	1929	1797	
Other drilling mud, m^3	321	241	150	
Cementing chemicals, tonnes	127	30	30	
Completion chemicals, tonnes	0	20	0	
Oil in water, tonnes	8.7	4.8	4.4	
Accidental discharges oil/oil based mud, m^3	6.9	1.9	5.6	



Site	ED50 UTM Zone 31		Distance (m) / direction (º)	Depth (m)
	E	N		
LOK-03	437590	6478367	500/10	87
LOK-04	437546	6478121	250/10	86
LOK-05	437749	6477832	250/100	86
LOK-06	437995	6477788	500/100	85
LOK-08	437257	6477918	250/280	87
LOK-11	437309	6477629	250/205	86
SLA-27	436497	6472241	2000/10	84
SLA-28	436323	6471256	1000/10	84
SLA-29	436166	6470763	500/7	83
SLA-30	436650	6470271	500/90	83
SLA-31	437134	6470097	1000/100	83
SLA-33	436106	6470025	250/190	83
SLA-34	436063	6469779	500/190	83
SLA-37	435873	6470264	250/275	84
SLA-38	435657	6470358	500/280	84
SLE-41R	441623	6472715	5000/100	81

Figure 7.1. Map showing the internal distribution of sampling sites in Sleipner Øst in2003. Positioning according to UTM ED50 zone 31. The field centre is marked with an X.

7.2. Results and discussion

7.2.1 Sediments characteristics

TOM, and the amount (%) of gravel, sand, pelite, median (Φ), sorting, skewness and kurtosis in the sediment from the present survey is presented in Table 7.2. Additional information on colour and smell can be found in the Appendix. Median (Φ), pelite, sand and TOM are compared with data from 2000 in Figure 7.2.

Table 7.2. Total organic matter (TOM) and sediment grain size at all sites at Sleipner Øst in 2003. For comparison, averages, standard deviations, max and min values for the regional and reference sites are included.

Site	TOM %	Gravel %	Sand %	Pelite %	Median (Φ)	Sorting	Skewness	Kurtosis
LOK-03	0.58	0.00	98.30	1.70	2.52	0.39	0.12	0.97
LOK-04	0.63	0.06	97.23	2.70	2.52	0.42	0.16	1.09
LOK-05	0.68	0.02	97.71	2.27	2.52	0.41	0.15	1.05
LOK-06	0.57	0.00	98.46	1.54	2.52	0.38	0.11	0.95
LOK-08	0.78	0.28	97.46	2.26	2.53	0.42	0.17	1.11
LOK-11	0.61	0.03	97.76	2.21	2.53	0.42	0.16	1.10
SLA-27	0.70	0.03	98.17	1.80	2.52	0.40	0.14	1.02
SLA-28	0.53	0.01	98.74	1.26	2.52	0.38	0.11	0.95
SLA-29	0.83	0.02	97.43	2.55	2.54	0.45	0.19	1.18
SLA-30	0.66	0.01	98.59	1.40	2.52	0.40	0.14	1.02
SLA-31	0.59	0.00	98.49	1.51	2.51	0.40	0.13	0.99
SLA-33	0.66	0.08	98.40	1.52	2.52	0.39	0.12	0.98
SLA-34	0.54	0.05	98.89	1.06	2.51	0.33	0.00	0.74
SLA-37	0.61	0.19	98.65	1.17	2.52	0.38	0.11	0.95
SLA-38	0.85	0.78	98.12	1.11	2.51	0.34	0.00	0.74
SLE-41R	0.51	0.04	98.93	1.03	2.47	0.45	-0.18	1.14
LOK								
Average[1]	0.64	0.06	97.82	2.12	2.52	0.41	0.15	1.04
SD[1]	0.08	0.11	0.47	0.42	0.01	0.02	0.02	0.07
Min[1]	0.57	0.00	97.23	1.54	2.52	0.38	0.11	0.95
Max[1]	0.78	0.28	98.46	2.70	2.53	0.42	0.17	1.11
SLA								
Average[1]	0.66	0.13	98.39	1.49	2.52	0.39	0.10	0.95
SD[1]	0.11	0.25	0.44	0.46	0.01	0.04	0.06	0.14
Min[1]	0.53	0.00	97.43	1.06	2.51	0.33	0.00	0.74
Max[1]	0.85	0.78	98.89	2.55	2.54	0.45	0.19	1.18
Average[2]	0.67	0.02	97.64	2.34	2.49	0.50	-0.04	1.28
SD[2]	0.17	0.02	1.02	1.03	0.02	0.08	0.11	0.21
Min[2]	0.51	0.00	96.60	1.03	2.47	0.43	-0.18	1.11
Max[2]	0.90	0.04	98.93	3.38	2.51	0.61	0.09	1.55

[1] Field sites, exclusive SLE41R
[2] Reg + $Ref_{shallow\ 03}$

The sediments at Sleipner Øst are classified as fine sand with median (Φ) values ranging from 2.51 (SLE31, SLE34 and SLE38) to 2.54 (SLE29). The amount of pelite varied from 1.06 % (SLE34) to 2.7 % (LOK04), the sand varied from 97.2 % (LOK04) to 98.9 % (SLE34), and the TOM varied from 0.53 % (SLA28) to 0.85 % (SLA38). The conditions at the reference site (SLE41R) were close to or within the variation found at the field sites. The sediments at Sleipner Øst were homogeneous in 2003 as in 2000.

Compared to the results of 2000 only minor differences were seen in slightly lower TOM and pelite content in 2003 (Figure 7.2). The change in the median value between 2000 and 2003 are probably due to different methods of calculation.

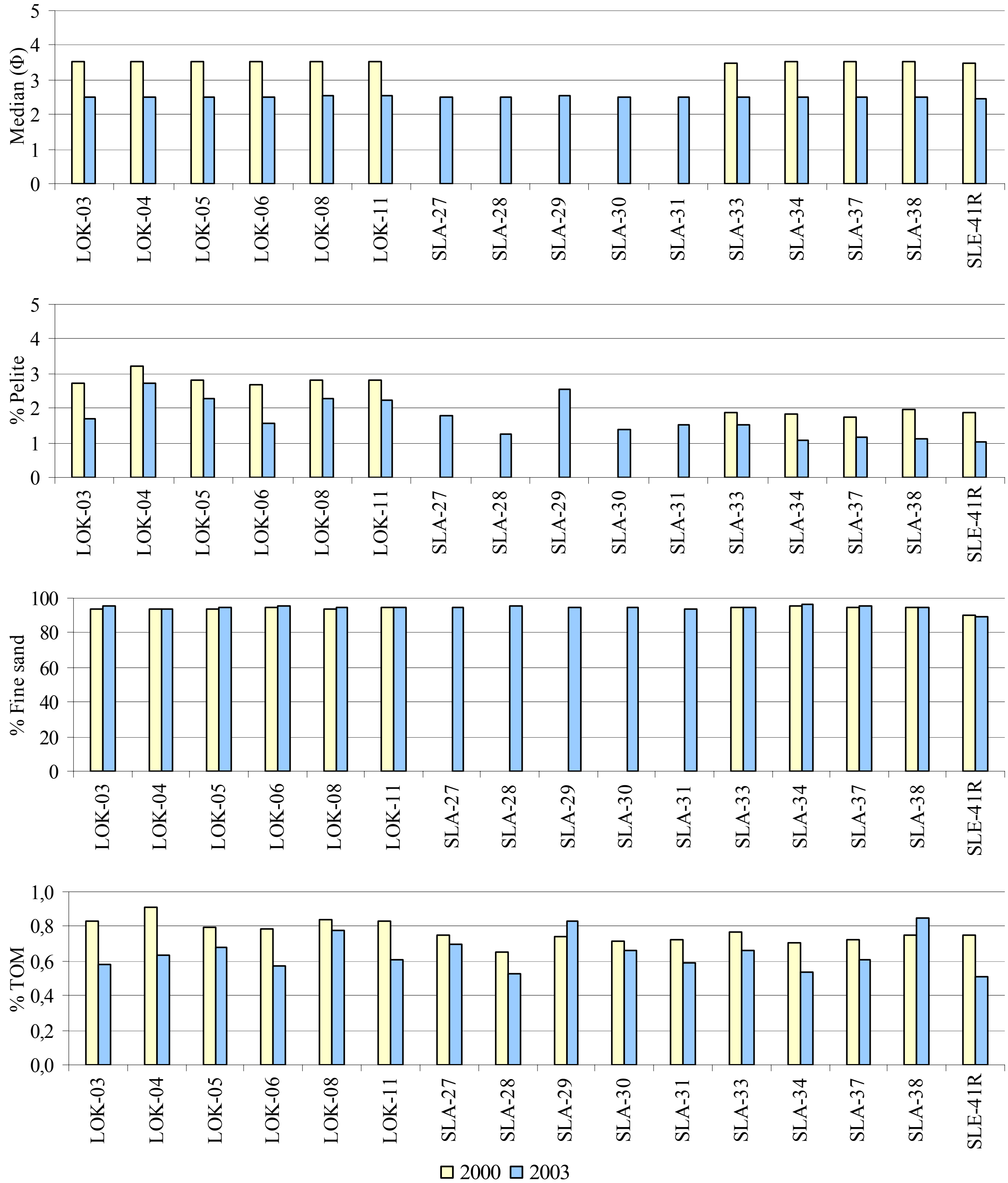


Figure 7.2. Sediment characteristics at Sleipner Øst in 2000 and 2003. Fine sand is the relative amount of sand with grain size 63-250 µm.

7.2.2 Chemical compounds

7.2.2.1 LSC

The results of the LSC (limits of significant contamination) calculations of hydrocarbons and metals are presented in the chapter concerning the regional and reference sites. Both the $LSC_{shallow\ 97-03}$ and the field specific LSC value are presented in Table 7.3. Fine sediments are more likely to have higher affinity for pollutants than coarse sediments. LSC in the text relates to $LSC_{shallow\ 97-03}$.

Table 7.3. Limits of Significant Contamination (LSC) for the Sleipner Øst field in 2003, the shallow part of Region II based on data from 1997 to 2003 ($LSC_{shallow\ 97-03}$) and the whole of Region II based on data from 1997 to 2003 ($LSC_{regII\ 97-03}$). For comparison, LSC-values from 2000 are included. All values in mg/kg dry sediment.

	THC	PAH (16)	NPD's	Decalins	Cu	Cr	Zn	Ba	Pb	Cd	Hg
$LSC_{SLE41R\ 03}$	9.8	0.014	0.013	0.138	0.6[1]	9.4	7.7	9	6.2	0.03[1]	0.008
$LSC_{shallow\ 97-03}$	9.1	*	*	*	1.0	10.0	9.1	32	6.9	0.03[1]	0.008
$LSC_{regII\ 97-03}$	13.3	*	*	*	2.0	9.4	11.1	136	6.6	0.03[1]	0.011
$LSC_{SLE41R\ 00}$ **	8.8	*	0.018	0.064	3.7	9.7	6.3	40	6.5	0.008	n.d.
$LSC_{shallow\ 97-00}$ **	6.6	*	*	*	1.2	10.2	8.1	38	7.4	0.008	0.006

n.d. = not detected
* NPD's, PAH's and decalins are not analysed at regional sites in 1997 and 2000
** Data from Mannvik & al. 2001
[1]LSC = detection limit

4.2.2.2 Hydrocarbons

Summarised results of the hydrocarbon analyses, along with the content of selected hydrocarbon compounds in the different layers (0-1, 1-3 and 3-6) are given in Table 7.4 and Table 7.5. The complete data set including replicates is given in the Appendix. Comparison of the olefin and THC content in 2003 with previous surveys is presented in Figure 7.3 and Figure 7.4.

Table 7.4. The content of oil hydrocarbons in sediments from Sleipner Øst in 2003. All values in mg/kg dry sediment. THC values above $LSC_{shallow\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{SLE41R\ 03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data for the regional and field reference sites in the shallow part of region II are included.

Site	THC		Olefins		PAH(16)		NPD		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
LOK03	8.8	1.2	n.a.	n.a.	0.048	0.062	0.030	0.032	0.240	0.148
LOK04	16.3	0.4	n.a.	n.a.	0.022	0.015	0.020	0.0005	0.840	0.106
LOK05	7.3	1.0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
LOK06	6.4	8.5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
LOK08	9.2	5.6	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
LOK11	4.3	4.9	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SLA27	7.3	1.1	0.07	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SLA28	4.2	2.3	0.10	0.06	0.007	0.001	0.027	0.027	0.120	0.043
SLA29	6.4	2.8	0.16	0.01	0.007	0.003	0.012	0.003	0.137	0.055
SLA30	4.2	0.6	0.06	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SLA31	4.0	2.5	0.06	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SLA33	6.5	1.0	0.26	0.08	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SLA34	4.3	2.6	0.10	0.06	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SLA37	5.2	0.8	0.06	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SLA38	4.5	0.4	0.06	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SLE41R	5.1	2.0	0.06	0.00	0.007	0.003	0.011	0.001	0.103	0.015
LOK										
av. ± sd.[1]	8.7 ± 4.1									
min – max[1]	4.3 - 16.3									
SLA										
av. ± sd.[1]	5.2 ± 1.2		0.10 ± 0.07							
min – max[1]	4.0 - 7.3		0.06 – 0.16							
av. ± sd.[2]	6.3±4.1				0.015±0.006		0.012±0.001		0.126±0.027	
min – max[2]	<3-11.3				0.007-0.023		0.011-0.012		0.103-0.161	

n.a. = not analysed.
[1] Field sites, exclusive SLA41R
[2] Reg + $Ref_{shallow\ 03}$

In general the THC content in the sediments at Loke and Sleipner A had deceased between 2000 and 2003.

At Loke, the THC content was above LSC at LOK04 and LOK08, 250 m to the north and west of the field centre. PAH, NPD and decalins were found in concentrations above $LSC_{SLE41R\ 03}$ at LOK04 and LOK03, 250 and 500 m to the north of the installation.

In the sectioned samples from LOK03 and LOK04, Decalins were found above $LSC_{03\ SLE41R}$ in all depth intervals. NPDs were found above $LSC_{SLE41R\ 03}$ in the 0-1 cm at LOK03 and in the 0-1 and 1-3 cm intervals at LOK04. THC was above LSC in the 3-6 cm interval at LOK03, and in the 0-1 and 1-3 cm intervals at LOK04. The vertical distributions of these substances were relative uniform, but the concentration was higher at LOK04, 250 m to the north of the installation than at LOK03, 500 m to the north of the installation.

At Sleipner A, average THC content was below LSC at all sampling sites. NPD was above $LSC_{SLE41R\ 03}$ at SLA28, 1000 m to the north of the installation. THC, NPD and decalins were above $LSC_{SLE41R\ 03}$ in the 0-1 and 1-3 cm layers at SLA29, 500 m to the north of the installation. NPD was above LSC in the 1-3 cm layer at SLE41R.

Olefins were measured in the range from 0.06 to 0.26 mg/kg in samples from Sleipner A, which was significant lower than in 2000 (Figure 7.3).

Table 7.5. The content of oil hydrocarbons in vertical sections of sediment from 5 sampling sites at Sleipner Øst in 2003. All values in mg/kg dry sediment. THC values above $LSC_{shallow\ 97\text{-}03}$ and PAH, NPD and decalins values above $LSC_{SLE41R\ 03}$ are dark shaded.

Site	Layer (cm)	THC	Olefins	PAH(16)	NPD	Decalins
LOK03	0-1	7.4		0.012	0.014	0.155
LOK03	1-3	9.3		0.012	0.011	0.410
LOK03	3-6	13.0		0.016	0.012	0.390
LOK04	0-1	16.0		0.039	0.020	0.760
LOK04	1-3	20.0		0.014	0.017	1.430
LOK04	3-6	7.2		0.012	0.013	0.420
SLA28	0-1	<3.0	0.06	0.007	0.011	0.095
SLA28	1-3	4.1	0.06	0.007	0.011	0.095
SLA28	3-6	<3.0	0.06	0.011	0.011	0.075
SLA29	0-1	9.6	0.16	0.010	0.015	0.200
SLA29	1-3	9.7	0.15	0.013	0.014	0.450
SLA29	3-6	5.0	0.06	0.014	0.011	0.135
SLE41R	0-1	<3.0	0.06	0.005	0.011	0.095
SLE41R	1-3	3.7	0.06	0.007	0.015	0.095
SLE41R	3-6	<3.0	0.06	0.005	0.011	0.055

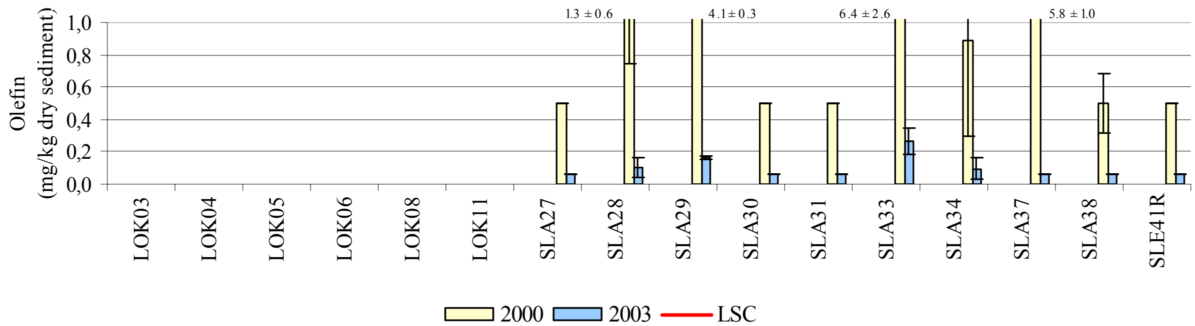


Figure 7.3. The content of olefins in sediments from Sleipner A in 2000 and 2003.

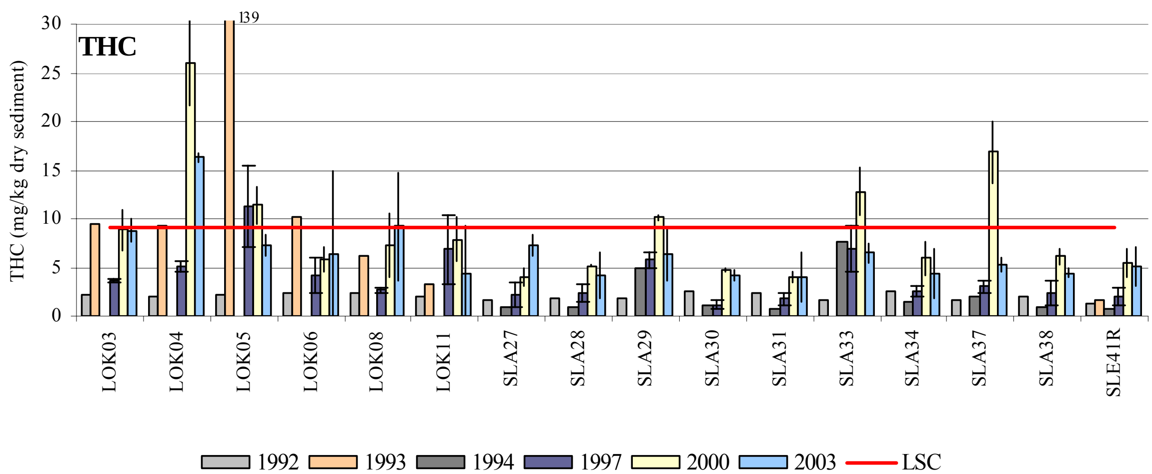


Figure 7.4. Average THC concentrations and standard deviations in sediments at Sleipner Øst in 2003 and previous years. Red line is $LSC_{shallow\ 97\text{-}03}$.

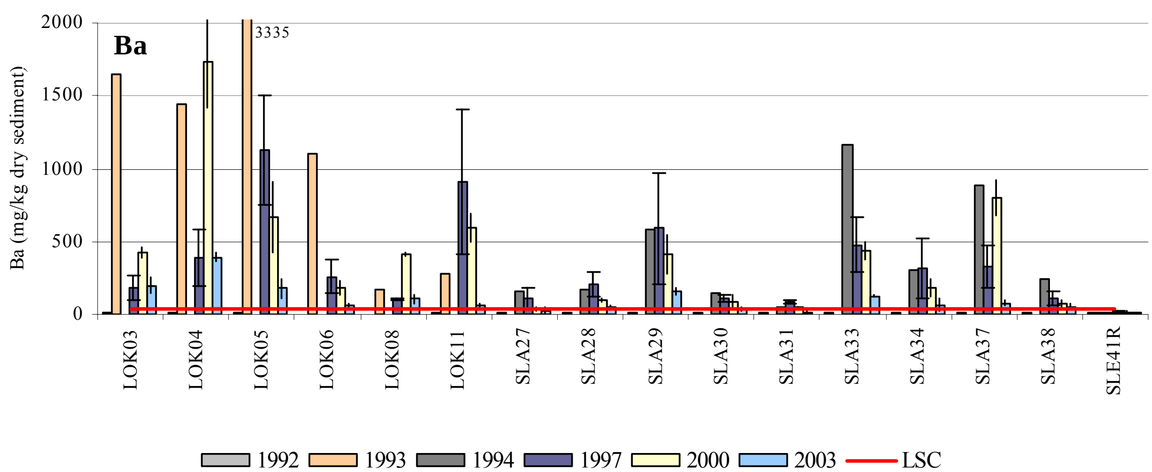


Figure 7.5. Average barium concentrations and standard deviations in sediments from Sleipner Øst in 2003 and previous years. Red line is $LSC_{shallow\ 97\text{-}03}$.

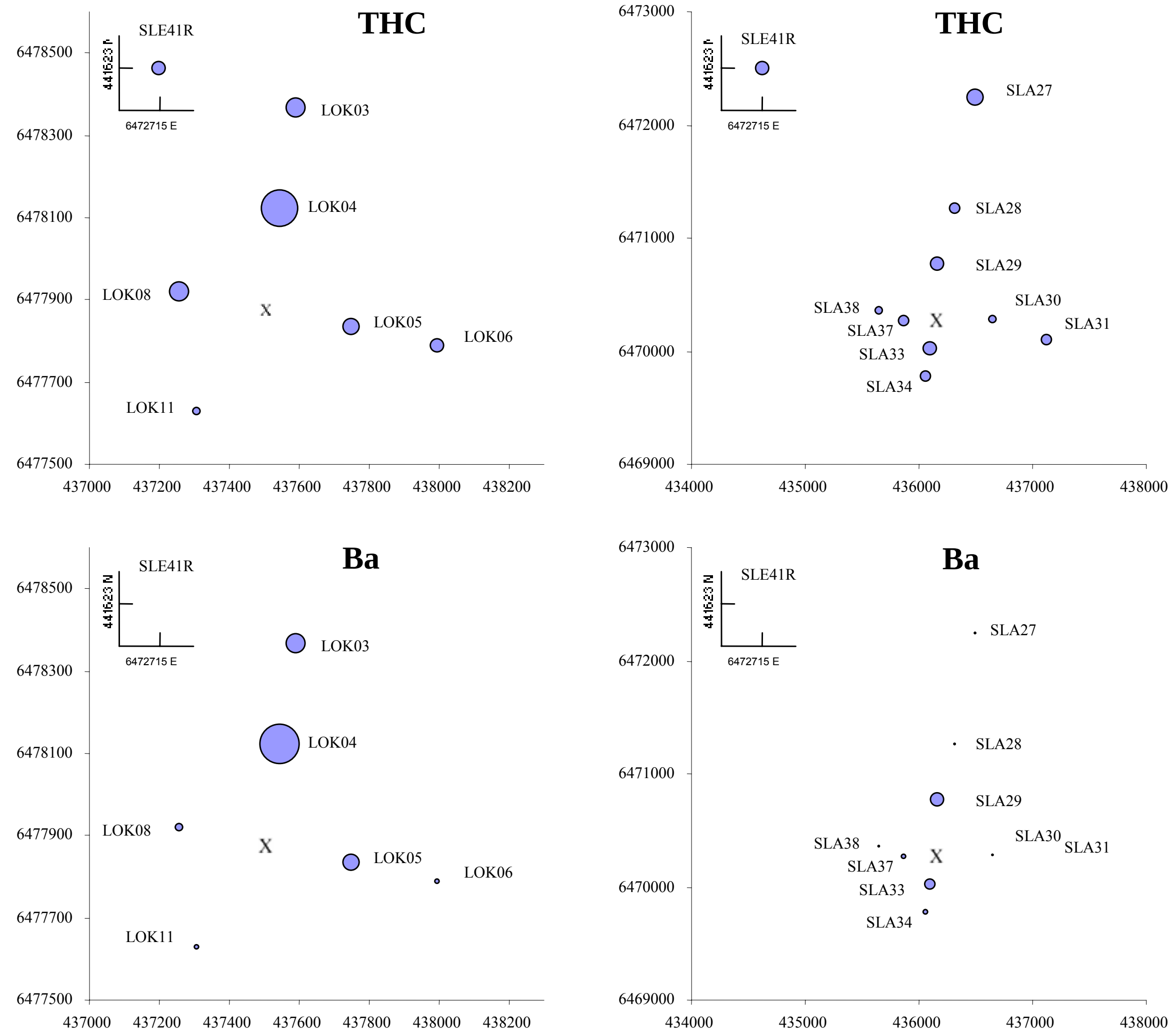


Figure 7.6. Distribution of THC and barium in sediments at the sampling sites at Sleipner Øst in 2003. The sizes of the circles are comparable and indicate the amount of THC and Ba. SLE41R is not visible in the figure due to low relative barium content (7 mg Ba/kg). The field centre is marked with an X.

7.2.2.3 Metals

Table 7.6 summarises the results of the metal analyses of the Sleipner Øst field in 2003. Concentrations of selected metals in the different layers (0-1, 1-3 and 3-6 cm) of sediment are given in Table 7.7, whereas the complete data set including replicates is given in the Appendix. Comparisons of the metal contents in 2003 with the metal contents in 1997 and in 2000 are presented in Figure 7.6.

Table 7.6 Content of metals in sediments from Sleipner Øst in 2003. All values in mg/kg dry sediment. Values above $LSC_{shallow\ 97\text{-}03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data and the regional and field reference sites are included.

Site	Cu		Cr		Zn		Ba		Pb		Cd		Hg	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
LOK03	<0.6	-	7.2	0.4	7.9	0.3	173	22	5.2	0.3	<0.03	-	0.006	0.000
LOK04	0.8	0.1	7.2	0.4	8.5	0.6	393	34	5.7	0.2	<0.03	-	0.006	0.001
LOK05	<0.6	-	7.0	0.2	6.9	0.7	178	64	5.0	0.1	<0.03	-	n.a.	n.a.
LOK06	<0.6	-	6.8	0.4	7.4	1.9	61	13	4.8	0.4	<0.03	-	n.a.	n.a.
LOK08	<0.6	-	6.3	0.4	5.9	0.5	103	32	4.8	0.1	<0.03	-	n.a.	n.a.
LOK11	<0.6	-	6.4	0.7	6.1	0.6	64	13	4.5	0.3	<0.03	-	n.a.	n.a.
SLA27	<0.6	-	8.3	0.4	6.8	0.7	28	23	4.8	0.1	<0.03	-	n.a.	n.a.
SLA28	<0.6	-	7.7	0.2	7.9	0.4	50	7	4.2	0.1	<0.03	-	0.004	0.001
SLA29	1.0	0.4	8.0	0.3	12.5	2.9	155	21	5.2	0.1	<0.03	-	0.006	0.001
SLA30	<0.6	-	7.5	0.6	7.9	0.6	37	10	4.6	0.2	<0.03	-	n.a.	n.a.
SLA31	<0.6	-	8.2	0.1	7.7	0.2	17	5	4.7	0.2	<0.03	-	n.a.	n.a.
SLA33	0.8	0.1	7.8	0.4	9.9	0.3	125	4	5.4	0.2	<0.03	-	n.a.	n.a.
SLA34	<0.6	-	7.2	0.6	8.0	0.7	62	42	4.5	0.3	<0.03	-	n.a.	n.a.
SLA37	<0.6	-	8.0	0.7	8.6	1.0	77	22	4.6	0.1	<0.03	-	n.a.	n.a.
SLA38	<0.6	-	7.9	0.4	7.9	0.3	54	18	4.8	0.2	<0.03	-	n.a.	n.a.
SLE41R	<0.6	-	9.2	0.1	7.2	0.2	7	1	5.7	0.2	<0.03	-	0.005	0.001
LOK														
av. ± sd.[1]	<0.6		6.8 ± 0.4		7.1 ± 1.0		162 ± 124		5.0 ± 0.4		<0.03			
min-max[1]	<0.6-0.8		6.3 - 7.2		5.9 - 8.5		61 - 393		4.5 - 5.7		<0.03			
SLA														
av. ± sd.[1]	<0.6		7.8 ± 0.3		8.6 ± 1.7		67 ± 46		4.7 ± 0.4		<0.03			
min-max[1]	<0.6 - 1.0		7.2 - 8.3		6.8 - 12.5		17 - 155		4.2 - 5.4		<0.03			
av. ± sd.[2]	<0.6		7.8 ± 1.0		4.8 ± 2.1		14 ± 9		5.3 ± 0.8		<0.03		0.004 ± 0.001	
min-max[2]	<0.6 - 1		6.3 - 9.2		0.9 - 7.4		5 - 34		4.1 - 6.7		<0.03		0.004 - 0.005	

n.a. = not analysed.
[1] Field sites, exclusive SLE41R
[2] Reg + $Ref_{shallow\ 03}$

Table 7.7. The content of metals in vertical sections of sediment from 5 sampling sites at Sleipner Øst in 2003. All values in mg/kg dry sediment. Values above $LSC_{shallow\ 97\text{-}03}$ are dark shaded.

Site	Layer (cm)	Cu	Cr	Zn	Ba	Pb	Cd	Hg
LOK03	0-1	0.6	7.6	8.2	183	5.6	<0.03	0.006
LOK03	1-3	0.6	7.7	8.4	260	5.4	<0.03	0.014
LOK03	3-6	0.4	6.5	7.1	125	4.8	<0.03	0.005
LOK04	0-1	0.8	7.7	8.3	422	5.9	<0.03	0.006
LOK04	1-3	1.1	7.5	8.9	551	6.7	<0.03	0.006
LOK04	3-6	0.7	7.5	8.4	279	5.7	<0.03	0.007
SLA28	0-1	<0.5	7.5	7.7	44	4.1	<0.03	0.005
SLA28	1-3	0.6	8.0	7.7	96	4.7	<0.03	0.004
SLA28	3-6	<0.5	8.1	8.7	140	4.8	<0.03	0.006
SLA29	0-1	0.7	7.8	15.8	140	5.1	<0.03	0.005
SLA29	1-3	1.0	8.7	12.6	246	5.3	<0.03	0.006
SLA29	3-6	0.8	9.0	13.2	234	5.6	<0.03	0.005
SLA41R	0-1	<0.5	9.2	7.2	6	5.5	<0.03	0.004
SLA41R	1-3	<0.5	9.2	7.3	8	5.9	<0.03	0.005
SLA41R	3-6	<0.5	9.8	7.5	12	6.3	<0.03	0.005

In general, the barium, lead and copper content in the sediments decreased between 2000 and 2003, whereas the zinc content increased.

Barium was found in a range from 17 to 393 mg/kg, lead from 4.2 to 5.7 mg/kg, cadmium was <0.03 mg/kg in all samples, chromium from 6.3 to 8.3 mg/kg, copper from <0.06 to 1.0 mg/kg, mercury from 0.004 to 0.006 mg/kg and zinc from 5.9 to 12.5 mg/kg (Table 7.6). Sediments from all sites except the reference site (SLE41R), and the northernmost and eastern sites at Sleipner A (SLA27 and SLA31) had barium content above LSC. Zinc occurred above LSC at SLA29, 500 m to the north and SLA33, 250 m to the south.

Vertical sediment samples (0-1, 1-3 and 3-6 cm) from LOK03 (500 m to the north), LOK04 (250 m to the north), SLA28 and SLA29 (500 and 1000m to the north) had barium content above LSC in all depth intervals (Table 7.7). Mercury was found above LSC in the 1-3 cm interval at LOK03, copper in the 1-3 cm layer at LOK04 and zinc in all depth intervals at SLA29.

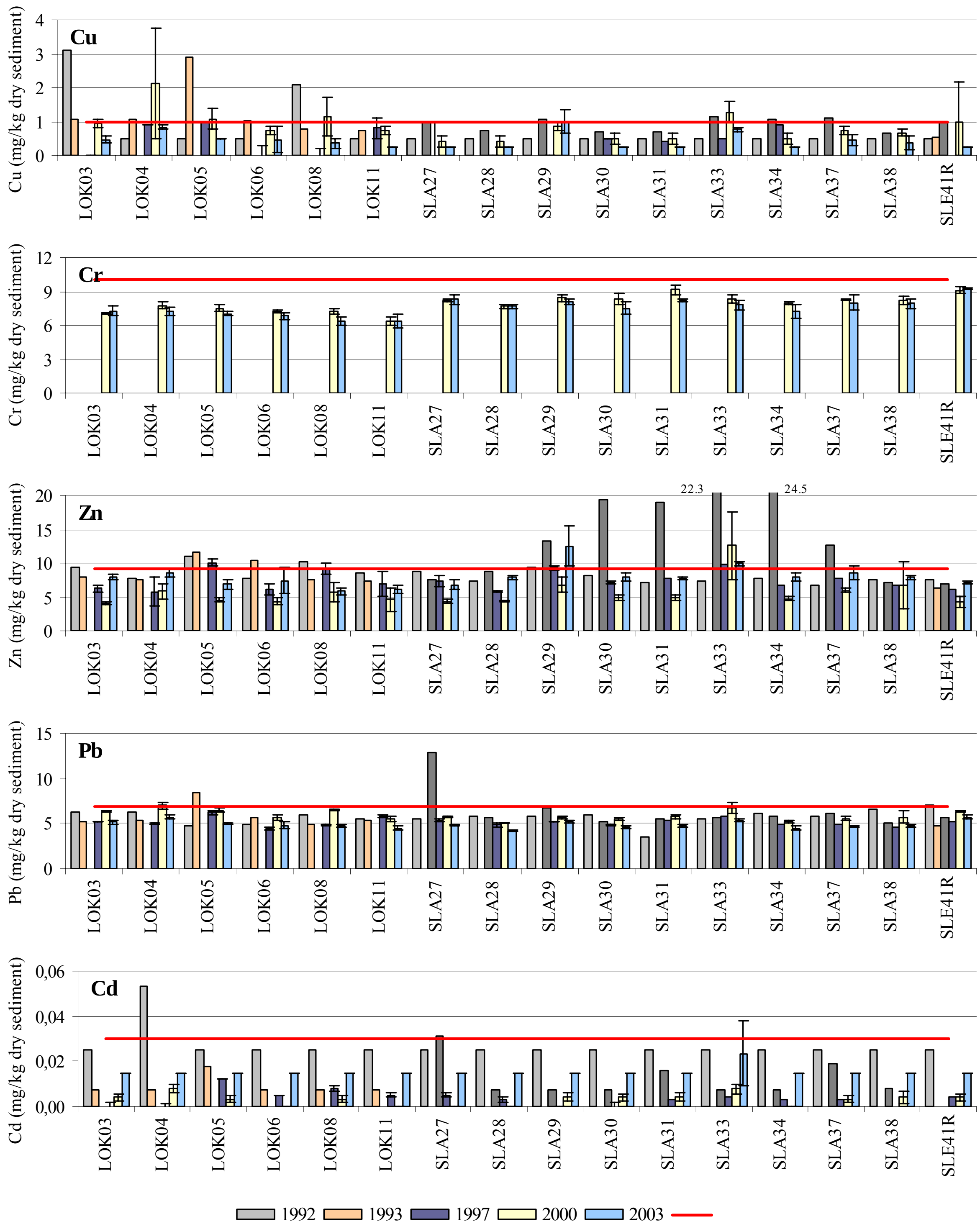
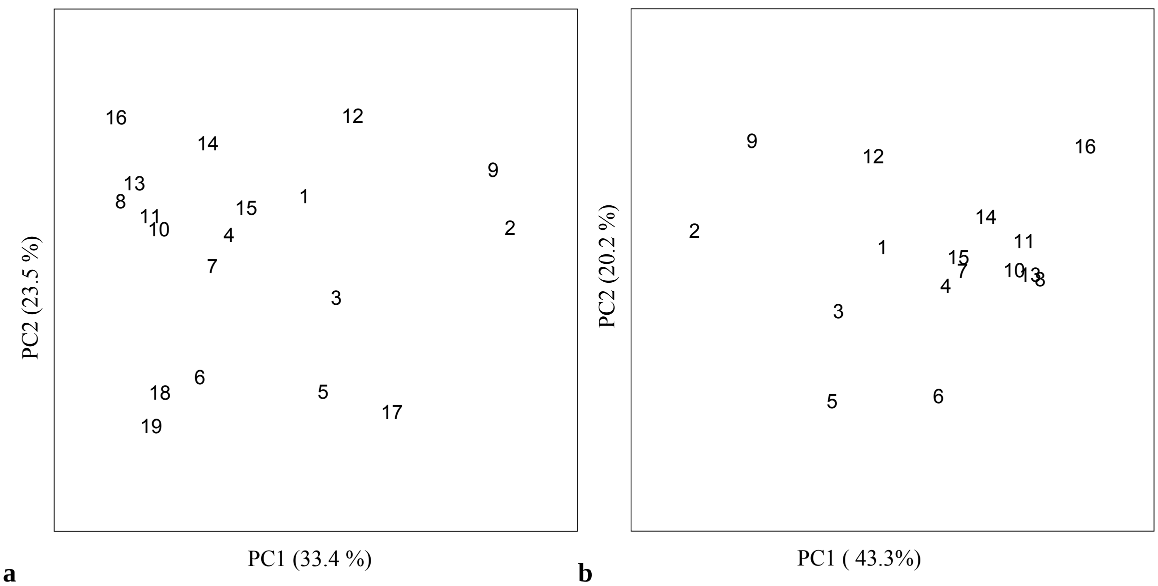


Figure 7.7. Average content and standard deviations of metals in sediment from Sleipner Øst in 2003 and previous surveys. Red line is $LSC_{shallow\ 97\text{-}03}$.

The field sites at Loke and Sleipner A were compared to nearby regional and field specific reference sites based on sediment characteristics (TOM and pelite) and chemical content in the sediments (Figure 7.8). LOK04 (250 m to the north of Loke) and SLA29 (500 m to the north of Sleipner A) did not group together with the other sites, but were distinct due to the higher content of chemical compounds in the sediments.



a **b**

Figure 7.8. 2-D plot from the PCA analysis of environmental variables (% pelite, % sand, % gravel, median Φ, % TOM, Cu, Ba, Zn, Cr, Pb and THC) carried out on the
a) Sleipner Øst field sites compared to the reference site at Varg, Sigyn and the regional site RII06. Explained variation in the data 56.9 %.
b) Sleipner Øst field sites. Explained variation in the data 63.5 %.
Numbers in the plot identify the sampling sites. See table below.

1	LOK03	6	LOK11	11	SLA31	16	SLE41R
2	LOK04	7	SLA27	12	SLA33	17	VAR14R
3	LOK05	8	SLA28	13	SLA34	18	SIG17R
4	LOK06	9	SLA29	14	SLA37	19	RII06
5	LOK08	10	SLA30	15	SLA38		

7.2.3 Bottom fauna

A summary of the distribution of individuals and taxa within the main taxonomic groups is given in Table 7.8. Unidentified juveniles of the sea urchin Spatangoids (37956 individuals) and the brittle star *Ophiura affinis* (1254 individuals) are omitted from the analyses, as they occurred in high numbers. In total, 4941 individuals within 180 taxa were collected at Sleipner Øst in 2003. The fauna was numerically dominated by annelida with 53 % the individuals and 40 % of the taxa. A complete species list is available in the Appendix.

Table 7.8. Distribution of individuals and taxa within the main taxonomic groups at Sleipner Øst in 2003 (unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis* are not included).

Main taxonomic groups	Number of individuals	%	Number of taxa	%
LOKE				
Annelida	1009	52	58	44
Arthropoda	209	11	25	19
Mollusca	132	7	28	21
Echidermata	232	12	11	8
Diverse groups	351	18	10	8
Total	1933	100	132	100
SLA				
Annelida	1429	54	62	43
Arthropoda	356	13	29	20
Mollusca	137	5	29	20
Echidermata	259	10	10	7
Diverse groups	466	18	14	10
Total	2647	100	144	100
SLEIPNER ØST (LOK, SLA and SLE41R)				
Annelida	2616	53	72	40
Arthropoda	638	13	40	22
Mollusca	295	6	40	22
Echidermata	545	11	12	7
Diverse groups	847	17	16	9
Total	4941	100	180	100

The species/area curve for SLE41R indicates that five replicate samples give a representative impression of the bottom fauna in the area (Figure 7.9). However, as more area is sampled, more taxa are collected, indicating that not even 10 replicate samples give the full species assemblage of the area.

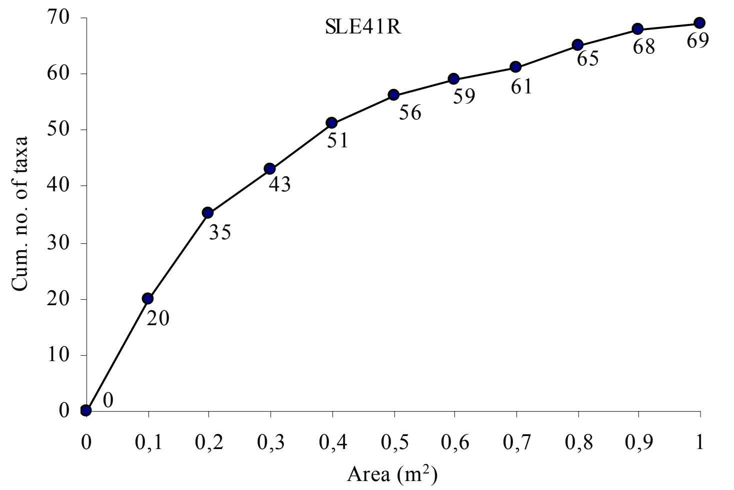


Figure 7.9. Species/area curve for the reference site at the Sleipner Øst field. Unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis* are not included.

The distribution of individuals and taxa are shown in Figure 7.10. Number of individuals and taxa at each site, and the calculated diversity indexes (H' and ES_{100}) are given in Table 7.9 and Figure 7.11. The number of individuals varied from 247 (SLA29) to 391 (LOK08), and the number of taxa varied from 45 (SLA33) to 70 (SLA28). The Shannon-Wiener diversity index (H') varied from 4.36 (SLA33) to 5.36 (SLA28), whereas the ES_{100} index varied from 29.4 (SLA33) to 42.1 (SLA28). The evenness index J varied from 0.79 (SLA33) to 0.87 (SLA28). The corresponding values at SLE41R were within the variation at the field sites. The number of taxa, diversity and evenness indicate good environmental conditions at all sites.

Compared to the results of 2000 there was higher species diversity at all sites except at SLA33 and SLA37. This was due to higher evenness among the taxa as seen as an increase in average evenness from 0.77 ± 0.05 in 2000 to 0.85 ± 0.02 in 2003. The minor decrease in the diversity at SLA33 and SLA37 was due to fewer taxa in 2003 than in 2000. High evenness is considered as an indicator of good environmental conditions.

Table 7.9. Number of individuals, species/taxa, and selected community indices for each site (0.5 m^2) at the Sleipner Øst field in 2003. Unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis* are not included.

Site number	Number of individuals	Number of taxa	Diversity H'	Evenness J	H'-max	ES_{100}
LOK03	296	56	4.90	0.84	5.81	35.0
LOK04	294	63	5.03	0.84	5.98	36.9
LOK05	356	59	4.88	0.83	5.88	34.5
LOK06	307	68	5.11	0.84	6.09	39.5
LOK08	391	67	5.21	0.86	6.07	38.9
LOK11	289	59	5.03	0.86	5.88	37.8
SLA27	273	60	4.98	0.84	5.91	37.6
SLA28	294	70	5.36	0.87	6.13	42.1
SLA29	247	49	4.86	0.86	5.61	34.8
SLA30	326	59	4.96	0.84	5.88	34.9
SLA31	262	52	4.84	0.85	5.70	33.8
SLA33	269	45	4.36	0.79	5.49	29.4
SLA34	297	58	5.03	0.86	5.86	35.8
SLA37	295	49	4.82	0.86	5.61	32.9
SLA38	384	65	5.13	0.85	6.02	36.7
SLE41R (6-10)	197	56	5.00	0.86	5.81	38.8
SLE41R (11-15)	164	41	4.46	0.83	5.36	32.1
SLE41R (6-15)	361	69	5.00	0.82	6.11	37.1
LOK						
Sum[1]	1933	132				
Average[1]	322	62	5.03	0.84	5.95	37.1
SD[1]	42	5	0.13	0.01	0.11	2.0
Min[1]	289	56	4.88	0.83	5.81	34.5
Max[1]	391	68	5.21	0.86	6.09	39.5
SLA						
Sum[1]	2647	145				
Average[1]	294	56	4.93	0.85	5.80	35.3
SD[1]	41	8	0.27	0.02	0.21	3.5
Min[1]	247	45	4.36	0.79	5.49	29.4
Max[1]	384	70	5.36	0.87	6.13	42.1
SLEIPNER ØST (LOK and SLA)						
Sum[1]	4580	175				
Average[1]	305	59	4.97	0.85	5.86	36.0
SD[1]	42	7	0.22	0.02	0.19	3.0
Min[1]	247	45	4.36	0.79	5.49	29.4
Max[1]	391	70	5.36	0.87	6.13	42.1
Average[2]	243	53	4.77	0.84	5.72	34.8
SD[2]	42	8	0.32	0.03	0.21	4.7
Min[2]	181	47	4.50	0.81	5.55	30.3
Max[2]	270	65	5.23	0.88	6.01	41.2

[1]Field sites, exclusive SLE41R
[2]Reg + Ref $_{\text{shallow 03}}$

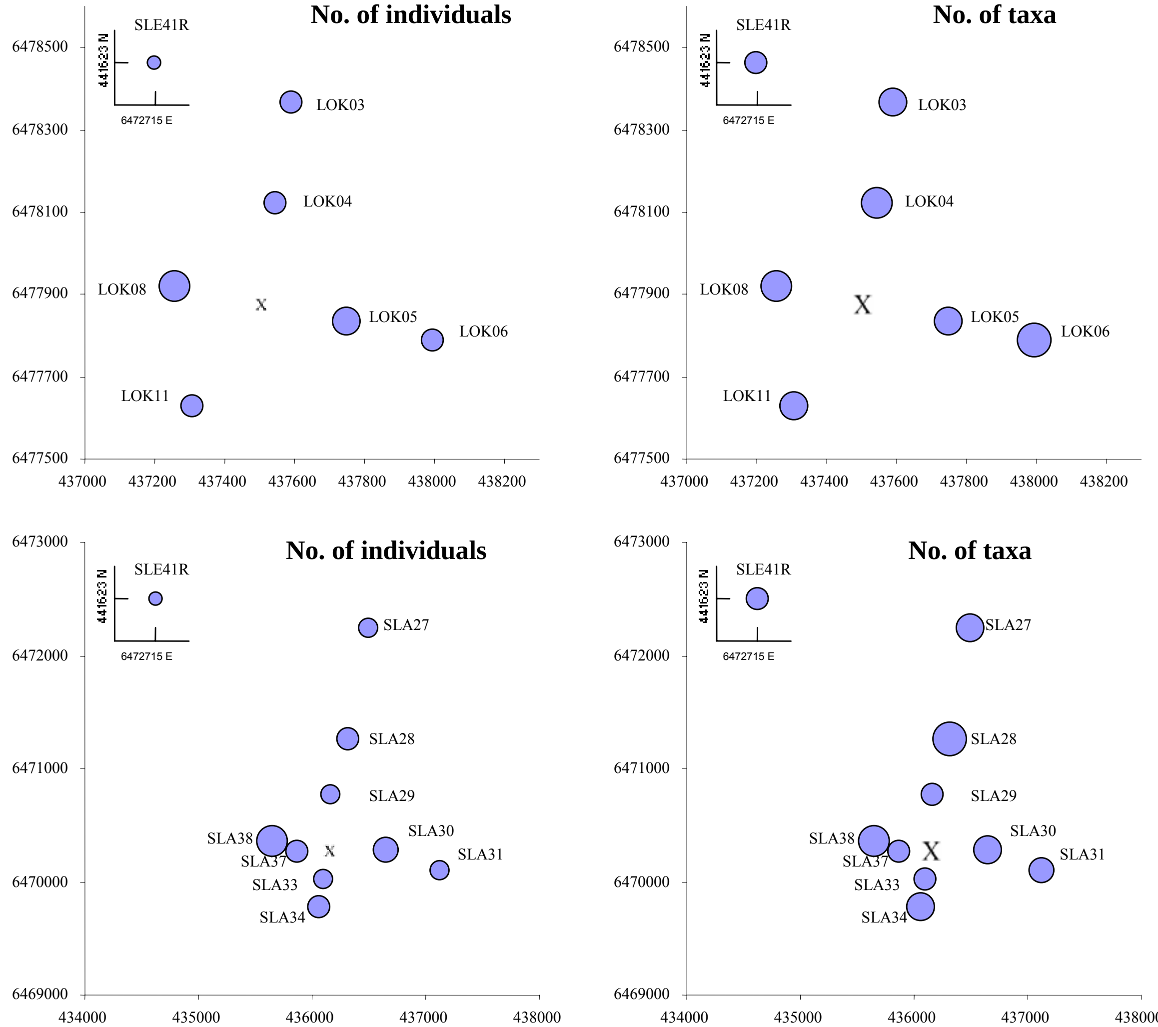


Figure 7.10. Distribution of bottom fauna (individuals and taxa, in relative numbers) among the sampling sites in 2003. The size of the circle indicates the number of individuals and taxa. Unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis* are not included. Values for SLE41R are average of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2). The field centre is marked with an X.

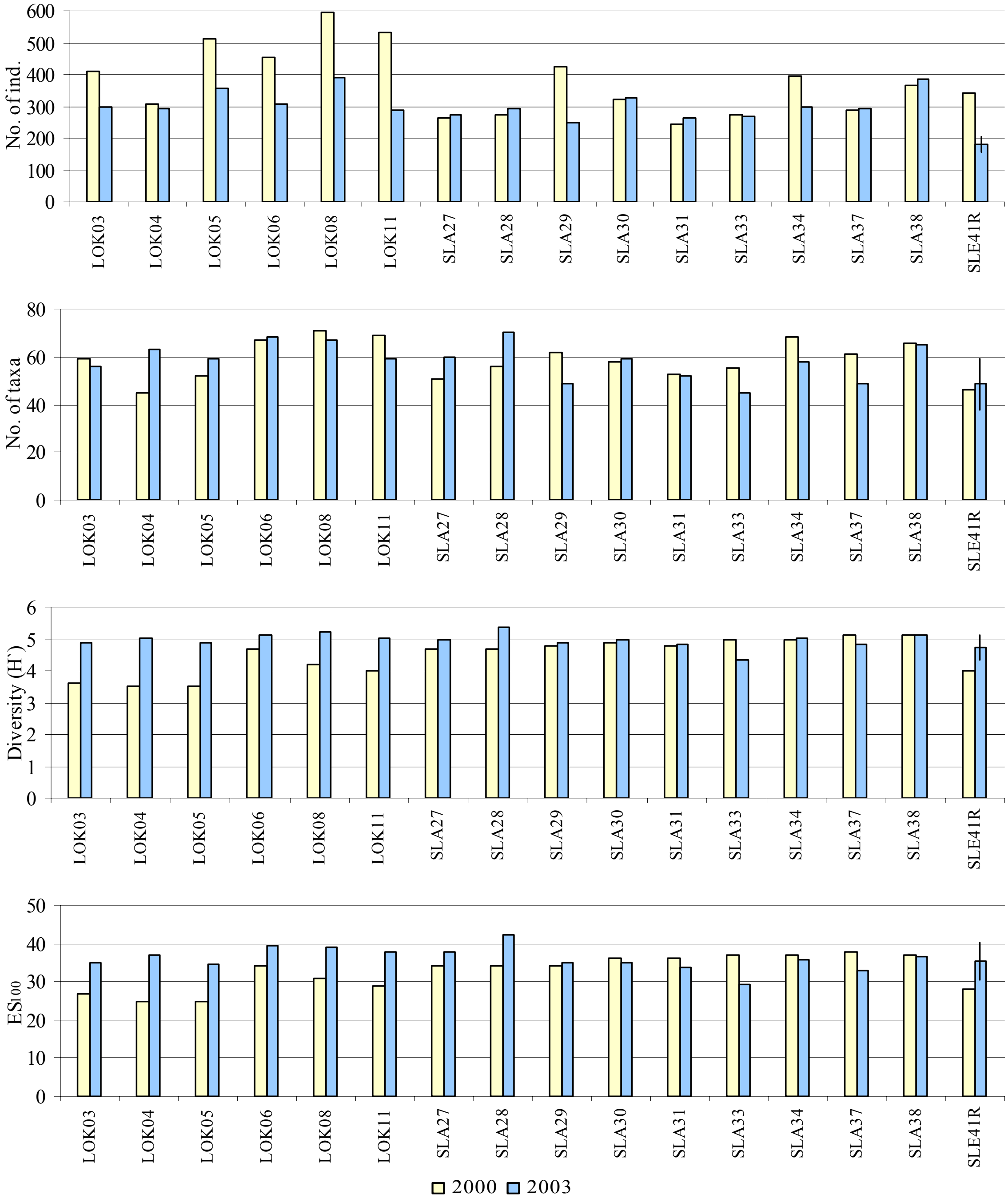


Figure 7.11. Number of individuals, taxa, and selected community indices for each site (0.5 m^2) at the Sleipner Øst field in 2000 and 2003. Unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis* are not included in 2003. Values for SLE41R in 2003 are average ± standard deviation of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2).

Distribution of taxa in geometrical classes is presented in Figure 7.12. The graphs are indicating undisturbed bottom fauna and good environmental conditions.

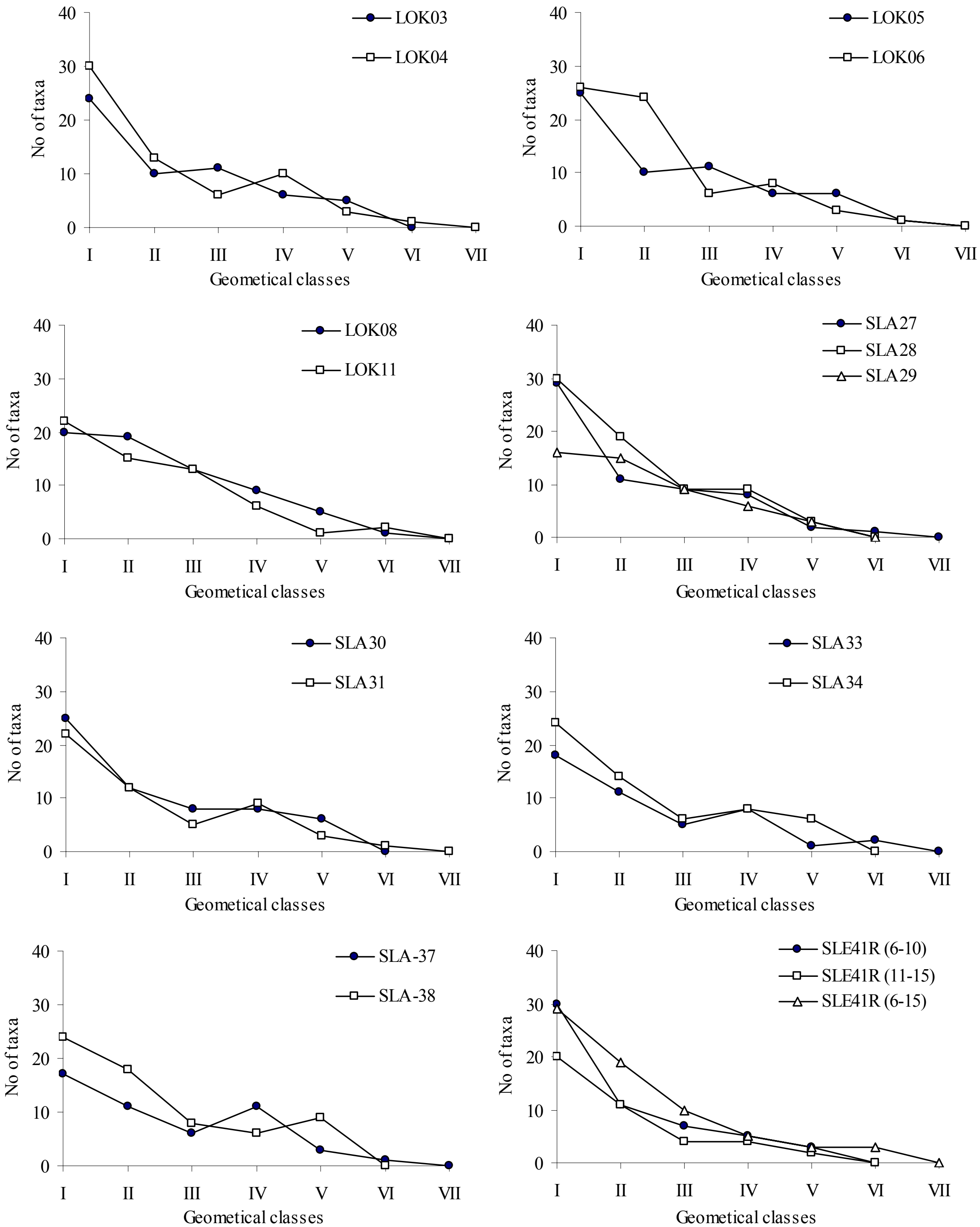


Figure 7.12. Distribution of taxa in geometrical classes for the sites at Sleipner Øst in 2003. Unidentified juveniles of Spatangoida juveniles of *Amphiura filiformis* are not included.

The ten most numerous taxa are listed in Table 7.12 at the end of this chapter. The list comprise 25 taxa and 4068 individuals, which was 13.9 % of all (180) taxa and 82.3 % of all (4941) individuals. The most widespread species were the phoronid *Phoronis* sp. and the crustacean *Eudorellopsis deformis,* which were present in high numbers at all sites, although the most abundant species were the anthozoa *Cerianthus lloydii* (present at 15 of 16 sites) and the brittle star *Amphiura filiformis* (present at 14 of 16 sites). Species known to occur in disturbed sediments, like the polychaete *Chaetozone setosa* (present at 14 of 16 sites) and *Ditrupa arietina* (present at 9 of 16 sites) were among the ten most abundant species at respectively 7 and 4 sites.

The results of the multivariate analyses are given in the dendrogramme (Figure 7.13) and the MDS plott (Figure 7.14).

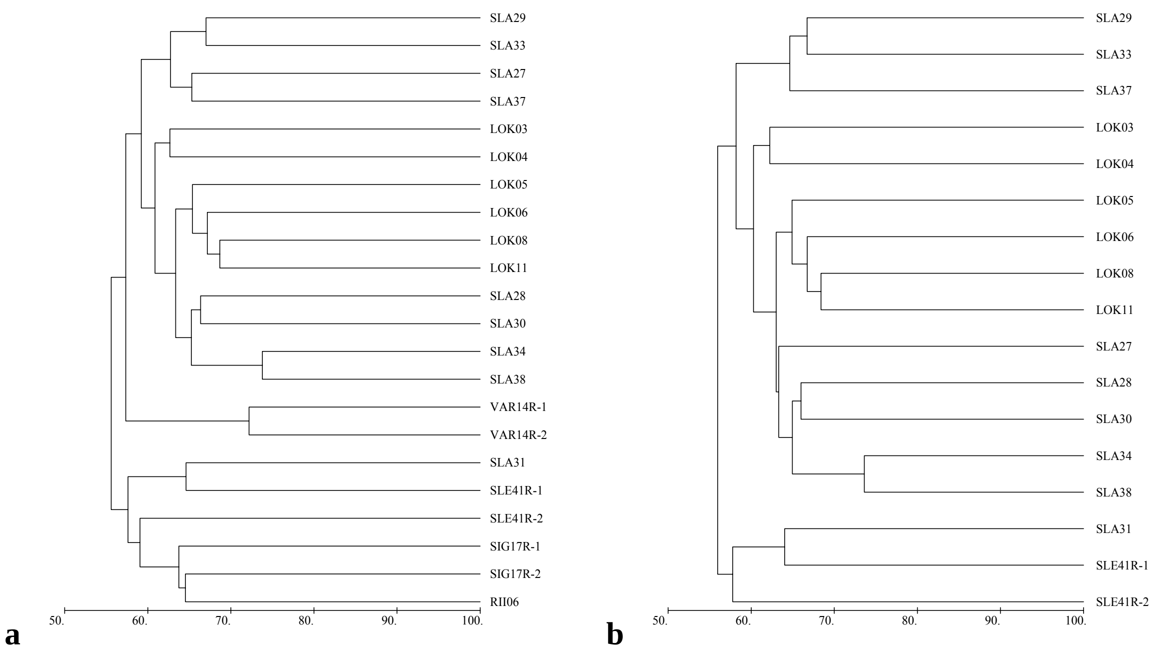


Figure 7.13. a) Dendrogram showing the similarity between fauna from sampling sites at:
a) Sleipner Øst field compared to the reference site at Sigyn, Varg and the regional site RII06 in 2003. Unidentified juveniles of Spatangoida and Echinoidea are not included.
b) Sleipner Øst field sites, 2003. Unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis* are not included.

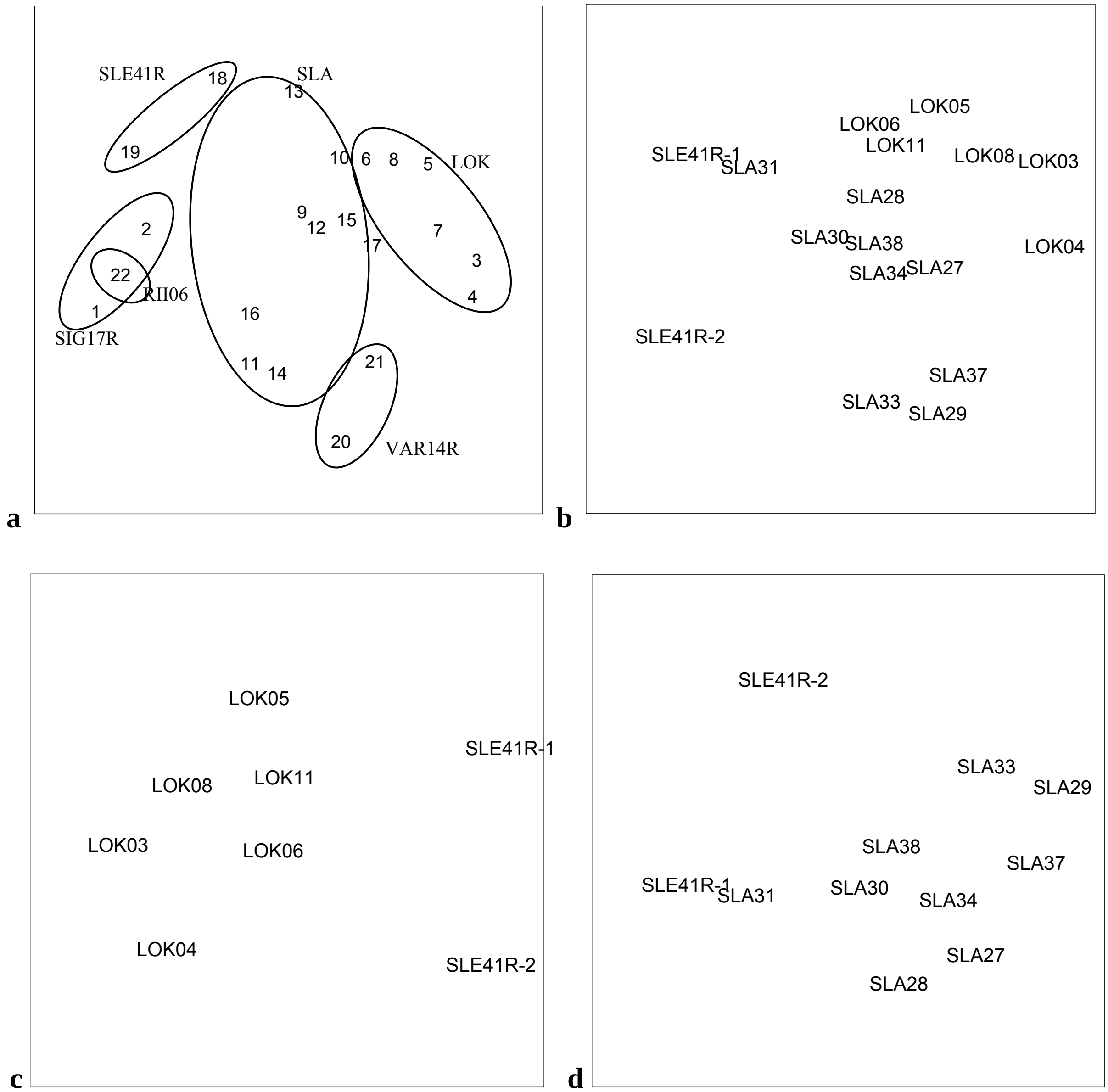


Figure 7.14. A 2-dimetional plott of the MDS analysis of the fauna data from:
a) The sampling sites at Sleipner Øst compared to the reference site at Sigyn, Varg and the regional site RII06 in 2003. Stress = 0.23. Unidentified juveniles of Spatangoida and Echinoidea are not included. Numbers in the plot identify the sampling sites. See table below.
b) The sampling sites at Sleipner Øst, 2003. Stress = 0.18.
c) LOK. Stress = 0.09.
d) SLA. Stress = 0.11.
b-d) Exclusive unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis*.

1	SIG17R-1	7	LOK08	13	SLA31	19	SLE41R-2
2	SIG17R-2	8	LOK11	14	SLA33	20	VAR14R-1
3	LOK03	9	SLA27	15	SLA34	21	VAR14R-2
4	LOK04	10	SLA28	16	SLA37	22	RII06
5	LOK05	11	SLA29	17	SLA38		
6	LOK06	12	SLA30	18	SLE41R-1		

In the cluster analysis, all sites are grouped together within approximately 56 % similarity, indicating relatively high similarity in the species assemblages within the field. The species assemblages at SLA34 and SLA38 were the most similar (74 %). The cluster analyses divide the sites into 5 subgroups. The reference site SLE41R and the easternmost site at Sleipner A (SLA31) comprise one group. The two sites north of Loke (LOK03 and LOK04) comprise the second group and the three sites nearest Sleipner A to the south (SLA33, 250 m), west (SLA37, 250 m) and north (SLA29, 500 m) comprise the third group. Finally the rest of the SLA sites comprise one group, while the rest of the LOK sites comprise the last group.

The results of the MDS analysis support the findings in the cluster analysis. Both the MDS plott and the cluster analysis are indicating differences among 2x5 samples from the reference site. This might indicate the magnitude of possible natural variation in the fauna assemblage. The stress test of the MDS analysis was 0.18, indicating a potential useful presentation of the data.

Two separate MDS analysis of the Loke and the Sleipner A data are shown in Figure 7.14. This gives two high resolution plots which illustrates the subgroups of sites within Loke and Sleipner A in a better way. The stress tests of these plotts are respectively 0.09 and 0.11 for Loke and Sleipner A, which indicates good ordination with no prospect of misleading interpretation of the plots.

Linking of biotic and environmental variables by BIOENV revealed that zinc, barium, lead and chromium were best correlated to the biota at $\rho_w = 0.51$ (Table 5.10). This indicates that there was some association between some environmental variables and the bottom fauna.

Table 7.10. Combinations of the 10 environmental variables, taken *k* at a time, yielding the best matches of biotic and abiotic similarity matrices for each *k*, as measured by weighted Spearman rank correlation ρ_w. Text in bold indicates overall optimum. All possible combinations of variables and associated correlation to the biotic are given in the Appendix.

Number of Variables (*k*)	Correlation coefficient (ρ_w)	Environmental variables									
1	0.418	Ba									
1	0.246	Cr									
1	0.171	Pb									
1	0.142	Cu									
1	0.103	Zn									
1	0.067	Pelite									
1	0.022	Sand									
1	-0.089	THC									
1	-0.147	TOM									
1	-0.201	Gravel									
2	0.487	Zn	Ba								
3	0.506	Zn	Ba	Pb							
4	**0.512**	**Zn**	**Ba**	**Pb**	**Cr**						
5	0.489	Zn	Ba	Pb	Cr	Cu					
6	0.468	Zn	Ba	Pb	Cr	Cu	Pelite				
7	0.443	Zn	Ba	Pb	Cr	Cu	Pelite	THC			
8	0.399	Zn	Ba	Pb	Cr	Cu	Pelite	THC	Sand		
9	0.344	Zn	Ba	Pb	Cr	Cu	Pelite	THC	Sand	TOM	
10	0.239	Zn	Ba	Pb	Cr	Cu	Pelite	THC	Sand	TOM	Gravel

7.2.4 Estimation of influenced area

The extension of contamination along sampling transects and the minimum area of contaminated sediments for THC, barium and other metals as well as for faunal disturbance are given in Figure 7.15 and Table 7.11. The area contaminated by THC decreased from 2000 to 2003 at Loke but increased at Sleipner A. The size of the barium contaminated area was unchanged at Loke, whereas it decreased at Sleipner A from 2000 to 2003. Since 2000 both the area contaminated by other metals and the area with disturbed fauna were unchanged at Loke, whereas a small increase was found at Sleipner A.

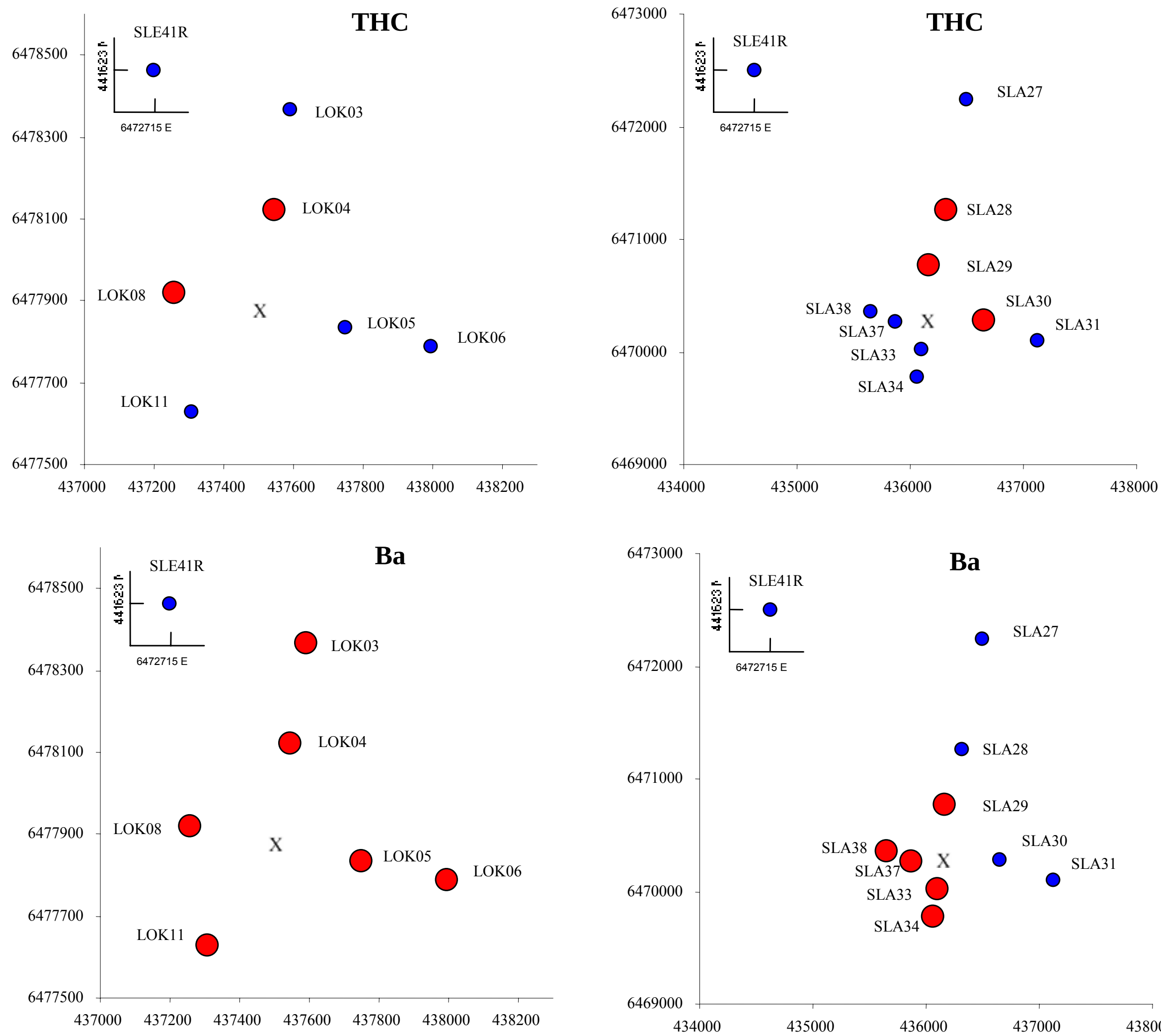


Figure 7.15. Faunal disturbance and chemical contamination of the sediments at Sleipner Øst in 2003. The field centre is marked with an X. Uncontaminated sites and sites with no faunal disturbance are marked with small blue circles.

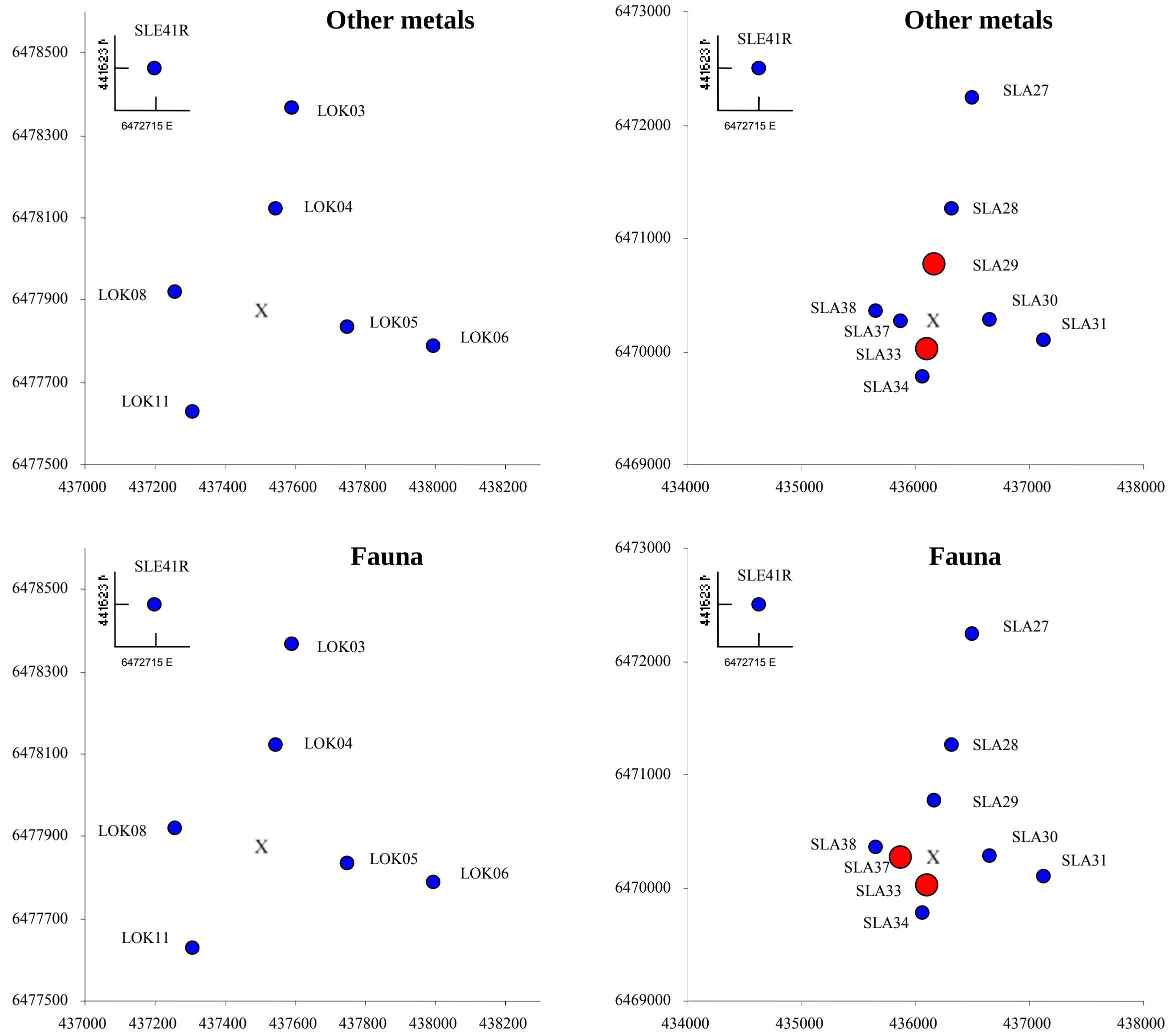


Figure 7.15.continue. Faunal disturbance and chemical contamination of the sediments at Sleipner Øst in 2003. The field centre is marked with an X. Uncontaminated sites and sites with no faunal disturbance are marked with small blue circles.

Table 7.11. Estimated distance from the installation to the borderline of contamination by THC and barium and distance from installation to disturbed bottom fauna. Area of contamination and disturbance is estimated as an asymmetric ellipse in 2000 and 2003.

Loke	N m	E m	S m	W m	2003 km²	2000 km²	1997 km²
THC	250	0	0	250	0.05	0.18	0.07
Ba	500	500	250	250	0.44	0.44	1.23
Other metals	0	0	0	0	0.00	0.00	0.07
Fauna	0	0	0	0	0.00	0.00	0.07

Sleipner A	N m	E m	S m	W m	2003 km²	2000 km²	1997 km²
THC	1000	500	0	0	0.39	0.22	0.00
Ba	500	0	500	500	0.39	1.77	12.57
Other metals	500	0	250	0	0.07	0.00	0.00
Fauna	0	0	250	250	0.05	0.00	0.29

LOK+SLA	N m	E m	S m	W m	2003 km²	2000 km²	1997 km²
THC					0.44	0.40	0.07
Ba					0.83	2.21	13.80
Other metals					0.07	0.00	0.07
Fauna					0.05	0.00	0.36

7.3 Summary and conclusions

Since the last survey at Sleipner Øst in 2000 five new wells have been drilled. The sediments are still characterized as fine sand, although there has been a slight decrease in the pelite and in TOM content since 2000 except at SLA29 and at SLA38, north of Sleipner A, where the TOM content increased. The amounts of olefins, barium, copper and lead in the sediments had decreased since 2000, whereas the zinc content had increased. The THC content had decreased or was approximately at the same level as in 2000. The species diversity was approximately the same in 2000 and 2003, except at SLA33 and SLA37, 250 m to the south and west of Sleipner A, where it decreased. The measured chemical compounds did not occur in particularly high concentrations at SLA33 and SLA37 although the distribution of fauna was best correlated to the distribution of zinc, barium, lead and chromium. Since 2000 there was a slight increase in total area of sediments contaminated by THC and other metals as well as in the total area with some faunal disturbance. The total area with barium contaminated sediments was smaller in 2003 than in 2000.

Table 7.12. Number of individuals and relative abundance for the ten predominant taxa at each site at the Sleipner Øst field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis*.

LOK-03	No. of ind.	%	Cum %
Amphiura filiformis	30	10,1	10,1
Myriochele oculata	26	8,8	18,9
Phoronis sp.	26	8,8	27,7
Spiophanes kroeyeri	24	8,1	35,8
Eudorellopsis deformis	19	6,4	42,2
Cerianthus lloydii	15	5,1	47,3
Chaetozone setosa	14	4,7	52,0
Goniada maculata	9	3,0	55,1
Owenia fusiformis	9	3,0	58,1
Scoloplos armiger	8	2,7	60,8
Spiophanes bombyx	8	2,7	63,5

LOK-04	No. of ind.	%	Cum %
Cerianthus lloydii	35	11,9	11,9
Chaetozone setosa	24	8,2	20,1
Eudorellopsis deformis	20	6,8	26,9
Amphiura filiformis	17	5,8	32,7
Spiophanes kroeyeri	15	5,1	37,8
Myriochele oculata	14	4,8	42,5
Scoloplos armiger	14	4,8	47,3
Nemertini indet.	12	4,1	51,4
Phoronis sp.	10	3,4	54,8
Goniada maculata	10	3,4	58,2

LOK-05	No. of ind.	%	Cum %
Spiophanes kroeyeri	42	11,8	11,8
Cerianthus lloydii	31	8,7	20,5
Amphiura filiformis	30	8,4	28,9
Phoronis sp.	29	8,1	37,1
Myriochele oculata	22	6,2	43,3
Scoloplos armiger	21	5,9	49,2
Spiophanes bombyx	16	4,5	53,7
Pectinaria auricoma	13	3,7	57,3
Eudorellopsis deformis	10	2,8	60,1
Caudofoveata indet.	9	2,5	62,6
Arctica islandica	9	2,5	65,2

LOK-06	No. of ind.	%	Cum %
Spiophanes kroeyeri	38	12,4	12,4
Phoronis sp.	28	9,1	21,5
Amphiura filiformis	26	8,5	30,0
Scoloplos armiger	17	5,5	35,5
Cerianthus lloydii	15	4,9	40,4
Eudorellopsis deformis	15	4,9	45,3
Goniada maculata	12	3,9	49,2
Sthenelais limicola	11	3,6	52,8
Spiophanes bombyx	9	2,9	55,7
Harpinia antennaria	9	2,9	58,6

LOK-08	No. of ind.	%	Cum %
Amphiura filiformis	35	9,0	9,0
Eudorellopsis deformis	29	7,4	16,4
Scoloplos armiger	26	6,6	23,0
Spiophanes kroeyeri	23	5,9	28,9
Spiophanes bombyx	23	5,9	34,8
Myriochele oculata	23	5,9	40,7
Chaetozone setosa	15	3,8	44,5
Cerianthus lloydii	14	3,6	48,1
Phoronis sp.	13	3,3	51,4
Goniada maculata	12	3,1	54,5

LOK-11	No. of ind.	%	Cum %
Amphiura filiformis	34	11,8	11,8
Spiophanes kroeyeri	32	11,1	22,8
Phoronis sp.	19	6,6	29,4
Scoloplos armiger	15	5,2	34,6
Cerianthus lloydii	14	4,8	39,4
Spiophanes bombyx	13	4,5	43,9
Eudorellopsis deformis	12	4,2	48,1
Myriochele oculata	10	3,5	51,6
Pectinaria auricoma	8	2,8	54,3
Bathyporeia sp.	7	2,4	56,7
Echinocardium flavescens	7	2,4	59,2
Harpinia antennaria	7	2,4	61,6

SLA-27	No. of ind.	%	Cum %
Amphiura filiformis	46	16,8	16,8
Scoloplos armiger	18	6,6	23,4
Eudorellopsis deformis	18	6,6	30,0
Phoronis sp.	14	5,1	35,2
Goniada maculata	13	4,8	39,9
Spiophanes kroeyeri	11	4,0	44,0
Owenia fusiformis	11	4,0	48,0
Mysella bidentata	9	3,3	51,3
Cerianthus lloydii	8	2,9	54,2
Spiophanes bombyx	8	2,9	57,1
Pectinaria auricoma	8	2,9	60,1

SLA-28	No. of ind.	%	Cum %
Amphiura filiformis	22	7,5	7,5
Cerianthus lloydii	21	7,1	14,6
Scoloplos armiger	19	6,5	21,1
Phoronis sp.	15	5,1	26,2
Myriochele oculata	15	5,1	31,3
Spiophanes bombyx	14	4,8	36,1
Bathyporeia sp.	13	4,4	40,5
Goniada maculata	12	4,1	44,6
Eudorellopsis deformis	11	3,7	48,3
Spiophanes kroeyeri	10	3,4	51,7

Table 7.12. continue. Number of individuals and relative abundance for the ten predominant taxa at each site at the Sleipner Øst field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis*.

SLA-29	No. of ind.	%	Cum %
Eudorellopsis deformis	27	10,9	10,9
Phoronis sp.	22	8,9	19,8
Chaetozone setosa	22	8,9	28,7
Cerianthus lloydii	15	6,1	34,8
Owenia fusiformis	14	5,7	40,5
Amphiura filiformis	13	5,3	45,7
Scoloplos armiger	13	5,3	51,0
Goniada maculata	12	4,9	55,9
Spiophanes bombyx	8	3,2	59,1
Ophiura affinis	7	2,8	61,9

SLA-30	No. of ind.	%	Cum %
Cerianthus lloydii	28	8,6	8,6
Amphiura filiformis	28	8,6	17,2
Owenia fusiformis	26	8,0	25,2
Eudorellopsis deformis	24	7,4	32,5
Harpinia antennaria	18	5,5	38,0
Phoronis sp.	17	5,2	43,3
Scoloplos armiger	14	4,3	47,5
Spiophanes kroeyeri	14	4,3	51,8
Pectinaria auricoma	14	4,3	56,1
Ditrupa arietina	13	4,0	60,1

SLA-31	No. of ind.	%	Cum %
Amphiura filiformis	32	12,2	12,2
Scoloplos armiger	18	6,9	19,1
Spiophanes kroeyeri	17	6,5	25,6
Phoronis sp.	16	6,1	31,7
Cerianthus lloydii	15	5,7	37,4
Goniada maculata	15	5,7	43,1
Bathyporeia elegans	15	5,7	48,9
Owenia fusiformis	14	5,3	54,2
Eudorellopsis deformis	11	4,2	58,4
Spiophanes bombyx	10	3,8	62,2
Montacuta ferruginosa	10	3,8	66,0

SLA-33	No. of ind.	%	Cum %
Ditrupa arietina	53	19,7	19,7
Chaetozone setosa	42	15,6	35,3
Cerianthus lloydii	18	6,7	42,0
Phoronis sp.	15	5,6	47,6
Glycera alba	14	5,2	52,8
Eudorellopsis deformis	12	4,5	57,2
Owenia fusiformis	10	3,7	61,0
Spiophanes bombyx	10	3,7	64,7
Pectinaria auricoma	9	3,3	68,0
Sthenelais limicola	9	3,3	71,4

SLA-34	No. of ind.	%	Cum %
Owenia fusiformis	26	8,8	8,8
Eudorellopsis deformis	21	7,1	15,8
Phoronis sp.	20	6,7	22,6
Cerianthus lloydii	18	6,1	28,6
Bathyporeia sp.	17	5,7	34,3
Chaetozone setosa	16	5,4	39,7
Amphiura filiformis	15	5,1	44,8
Myriochele oculata	14	4,7	49,5
Spiophanes kroeyeri	13	4,4	53,9
Pectinaria auricoma	10	3,4	57,2
Sthenelais limicola	10	3,4	60,6
Goniada maculata	10	3,4	64,0
Scoloplos armiger	10	3,4	67,3

SLA-37	No. of ind.	%	Cum %
Cerianthus lloydii	43	14,6	14,6
Ditrupa arietina	20	6,8	21,4
Phoronis sp.	18	6,1	27,5
Spiophanes bombyx	16	5,4	32,9
Chaetozone setosa	15	5,1	38,0
Myriochele oculata	14	4,7	42,7
Eudorellopsis deformis	13	4,4	47,1
Bathyporeia sp.	12	4,1	51,2
Nemertini indet.	12	4,1	55,3
Pectinaria auricoma	11	3,7	59,0

SLA-38	No. of ind.	%	Cum %
Amphiura filiformis	29	7,6	7,6
Spiophanes kroeyeri	25	6,5	14,1
Scoloplos armiger	25	6,5	20,6
Owenia fusiformis	24	6,3	26,8
Eudorellopsis deformis	23	6,0	32,8
Cerianthus lloydii	22	5,7	38,5
Ditrupa arietina	18	4,7	43,2
Phoronis sp.	17	4,4	47,7
Harpinia antennaria	16	4,2	51,8
Nemertini indet.	15	3,9	55,7

SLE41R	No. of ind.	%	Cum %
Amphiura filiformis	41	11,4	11,4
Scoloplos armiger	36	10,0	21,3
Bathyporeia sp.	32	8,9	30,2
Eudorellopsis deformis	27	7,5	37,7
Goniada maculata	25	6,9	44,6
Spiophanes bombyx	16	4,4	49,0
Owenia fusiformis	14	3,9	52,9
Phoronis sp.	14	3,9	56,8
Spiophanes kroeyeri	12	3,3	60,1
Sthenelais limicola	10	2,8	62,9

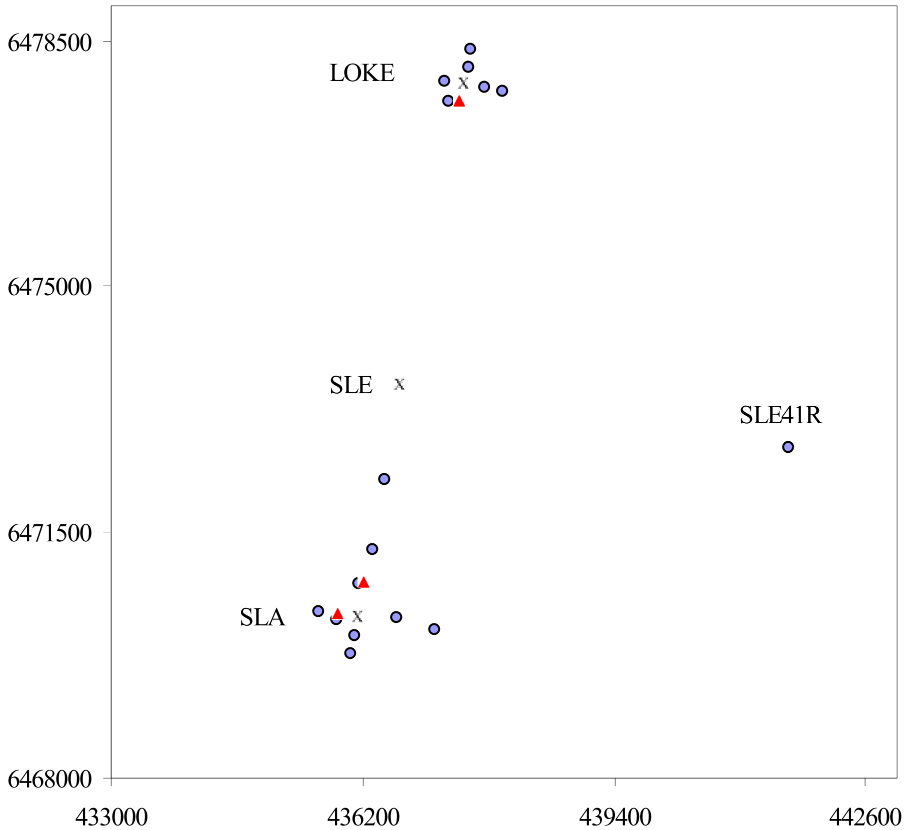


Figure 7.16. Illustration of deviations in planned and real sampling at Sleipner Øst. Location of sampling sites according to the programme, red triangle, and location of the sites where sampling were executed, blue circles.

8 Sleipner Vest

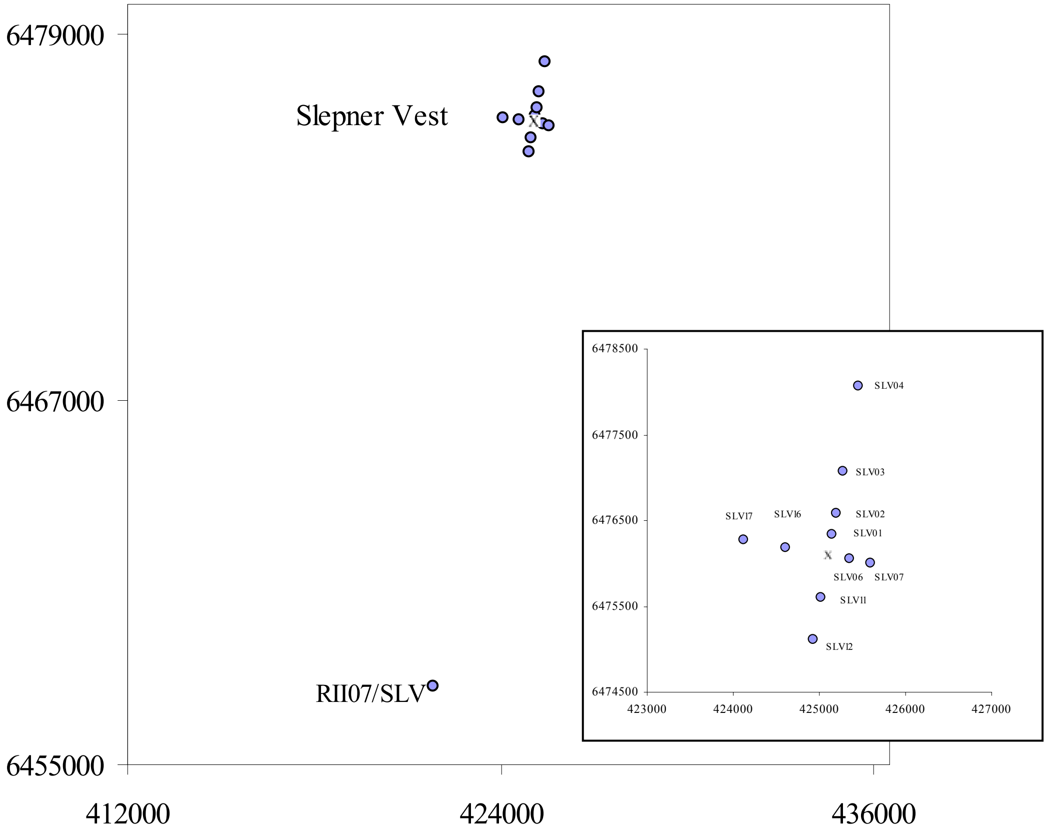
8.1. Introduction

The Sleipner Vest field is situated in block 15/6, west of the Sleipner Øst field. Production started at Sleipner Vest in August 1996. The baseline survey was carried out in 1994 (Gjøs & al. 1995) and monitoring surveys were carried out in 1997 (Mannvik & al. 1998) and 2000 (Mannvik & al. 2001). In 1997, the whole field was regarded as contaminated with barium, cadmium and zinc. THC contamination was significant out to 100 m to the north, out to 500 m to the west and south and 250 m to the east. However, the fauna was considered undisturbed and uniformly distributed over the field. In 2000, relatively high levels of THC were found out to 1000 m to the north and 250 m to the west, and faunal disturbances were found at the sampling site at 250 m to the north.

Recent drilling and discharges at Sleipner Vest are listed in Table 8.1, and sampling sites are shown in Figure 8.1. The Regional sampling site RII-07 is used as both a regional site and a reference site for Sleipner Vest.

Table 8.1. Recent well drilling and discharges from operations and accidents at Sleipner Vest.

	1997	1998	1999	2000	2001	2002	Comments
No of wells drilled	3	3	2	3	0	0	
Barite	2856	1148	302	579	0	0	
Cuttings	3429	2355	410	1968	0	0	
Water-based drilling mud	7889	5919	2058	3192	0	0	
Cementing chemicals	80	45	45	74	0	0	
Completion chemicals	0	714	0	0	0	0	
Oil in produced water	1	2	1.8	0.82	0	0	
Accidental discharges	9*	1.4	0	0.06	0	0	* Oil based mud



Site	ED50 UTM Zone 31		Distance (m) / direction (º)	Depth
	E	N		(m)
SLV-01	425143	6476347	255/10	109
SLV-02	425186	6476593	500/10	109
SLV-03	425273	6477086	1000/10	109
SLV-04	425446	6478071	2000/10	109
SLV-06	425345	6476058	250/100	108
SLV-07	425592	6476014	500/100	109
SLV-11	425012	6475609	500/190	109
SLV-012	424926	6475116	1000/190	109
SLV-016	424607	6476188	500/280	109
SLV-017	424114	6476275	1000/280	110
RII-07	421831	6457534	18781/188	101

Figure 8.1. Map showing the internal distribution of sampling sites in Sleipner Vest, 2003. Positioning according to UTM ED50 zone 31. The field centre is marked with an X.

8.2. Results and discussion

8.2.1 Sediments characteristics

TOM, and the amount (%) of gravel, sand, pelite, median (Φ), sorting, skewness and kurtosis in the sediment from the present survey is presented in Table 8.2. Additional information on colour and smell can be found in the Appendix. Median (Φ), pelite, sand and TOM are compared with data from 2000 in Figure 8.2.

The sediments at Sleipner Vest are classified as fine sand with median (Φ) values ranging from 2.77 (SLV16) to 3.15 (SLV01). The amount of pelite varied from 12.4 % (SLV03) to 24.8 % (SLV01), the sand varied from 74.1 % (SLV01) to 87.4 % (SLV03), and the TOM varied from 1.6 % (SLV03) to 2.5 % (SLV01). There was less pelite and more sand, and lower TOM at the reference site (RII07) than at the field sites. There were slightly more pelite and slightly less TOM at most sites in 2003 than in 2000. The largest difference was the reduction in TOM at SLV01 between 2000 and 2003 (Figure 8.2). The change in the median values between 2000 and 2003 are probably due to different methods of calculation.

Table 8.2. Total organic matter and sediment grain size at all sites at Sleipner Vest in 2003. For comparison, averages, standard deviations, and max and min values for the regional and reference sites are included.

Site	TOM %	Gravel %	Sand %	Pelite %	Median (Φ)	Sorting	Skewness	Kurtosis
SLV01	2.48	1.10	74.11	24.79	3.15	1.82	0.31	1.75
SLV02	2.09	0.02	84.80	15.18	3.07	1.12	0.32	1.54
SLV03	1.64	0.19	87.38	12.44	2.80	1.08	0.46	1.56
SLV04	1.85	0.08	84.75	15.17	2.95	1.13	0.39	1.52
SLV06	2.15	1.36	84.71	13.93	2.82	1.12	0.46	1.55
SLV07	1.83	0.42	86.04	13.55	2.78	1.10	0.50	1.62
SLV11	1.75	0.02	86.39	13.59	2.87	1.09	0.44	1.54
SLV12	1.91	0.40	83.72	15.88	3.05	1.13	0.34	1.54
SLV16	2.18	0.03	85.82	14.14	2.77	1.11	0.51	1.65
SLV17	1.71	0.28	85.06	14.66	2.96	1.12	0.38	1.52
RII07/SLV	1.16	0.08	94.31	5.61	2.51	1.00	0.06	1.39
Average[1]	1.96	0.39	84.28	15.33	2.92	1.18	0.41	1.58
SD[1]	0.26	0.47	3.72	3.47	0.13	0.22	0.07	0.07
Min[1]	1.64	0.02	74.11	12.44	2.77	1.08	0.31	1.52
Max[1]	2.48	1.36	87.38	24.79	3.15	1.82	0.51	1.75
Average[2]	1.71	0.29	87.23	12.49	2.71	1.16	0.34	1.76
SD[2]	0.45	0.62	5.20	5.12	0.37	0.14	0.19	0.46
Min[2]	0.73	0.00	78.12	3.04	1.76	0.93	0.03	1.05
Max[2]	2.19	2.19	96.61	21.77	3.34	1.40	0.57	2.95

[1] Field sites, exclusive RII07/SLV
[2] Reg + Ref $_{central\ 03}$

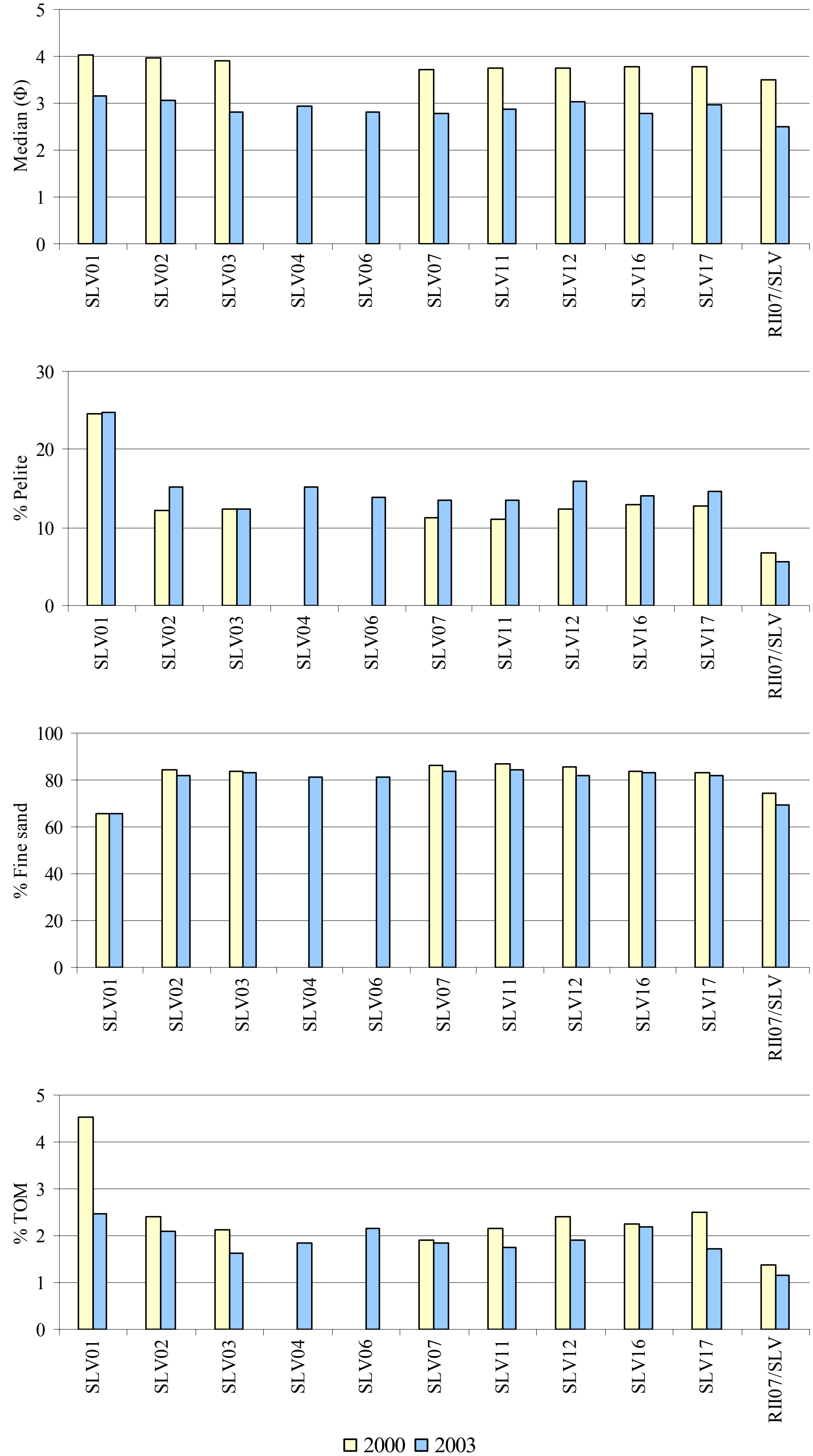


Figure 8.2. Sediment characteristics at Sleipner Vest in 2000 and 2003. Fine sand is the relative amount of sand with grain size 63-250 µm.

8.2.2 Chemical compounds

8.2.2.1 LSC

The results of the LSC (limits of significant contamination) calculations of hydrocarbons and metals are presented in the chapter concerning the regional and reference sites. Both the $LSC_{central\ 97\text{-}03}$ and the field specific LSC value ($LSC_{03\ RII07/SLV}$) are presented in Table 8.3. Fine sediments are more likely to have higher affinity for pollutants than coarse sediments. Thus further use of the field specific LSC value ($LSC_{RII07/SLV\ 03}$) is not reasonable as the sediment at the reference site was coarser (more sand) than the sediments at the field sites. LSC in the text relates to $LSC_{central\ 97\text{-}03}$.

Table 8.3. Limits of Significant Contamination (LSC) for the Sleipner Vest field in 2003, the central part of Region II based on data from 1997 to 2003 ($LSC_{central\ 97\text{-}03}$) and the whole of Region II based on data from 1997 to 2003 ($LSC_{regII\ 97\text{-}03}$). For comparison, LSC-values from 2000 are included. All values in mg/kg dry sediment.

	THC	PAH (16)	NPD's	Decalins	Cu	Cr	Zn	Ba	Pb	Cd	Hg
$LSC_{RII07/SLV\ 03}$	14.6	0.048	0.026	0.239	0.8	10.1	10.9	93	4.8	0.03[1]	0.009
$LSC_{central\ 97\text{-}03}$	14.5	*	*	*	2.2	9.4	12.4	161	6.8	0.03[1]	0.012
$LSC_{regII\ 97\text{-}03}$	13.3	*	*	*	2.0	9.4	11.1	136	6.6	0.03[1]	0.011
$LSC_{RII07/SLV\ 00}$ **	10.1	*	0.026	0.027	1.3	9.8	8.3	109	7.1	0.02	0.013
$LSC_{regII\ 97\text{-}00}$ **	9.8	*	*	*	2.0	9.6	8.9	146	7.0	0.03	0.008

* NPD's, PAH's and decalins are not analysed at regional sites in 1997 and 2000
** Data from Mannvik & al. 2001
[1] LSC = detection limit

8.2.2.2 Hydrocarbons

Summarised results of the hydrocarbon analyses, along with the content of selected hydrocarbon compounds in the different layers (0-1, 1-3 and 3-6) are given in Table 8.4 and Table 8.5. The complete data set including replicates is given in the Appendix. Comparison of the THC content in 2003 with previous surveys is presented in Figure 8.3.

THC was found in the range from 10.6 to 61.3 mg/kg, and THC concentrations above LSC were found at SLV01, SLV02, SLV03, SLV04, SLV06 and SLV07. Highest concentrations of THC were found at SLV01 at 255 m to the north. The THC content decreased with increasing distance to the field centre in all directions. Compared to the results of 2000 there was a general decrease in the THC content along the northern transects, whereas the THC content at the other transects was still low but slightly higher than before.

Hydrocarbon above LSC was found down to 6 cm in the sediments at both SLV01, 250 m to the north and SLV02, 500 m to the north. The sediments at SLV01 were more contaminated than sediments at SLV02 (Table 8.5).

Table 8.4. The content of oil hydrocarbons in sediments from Sleipner Vest in 2003. All values in mg/kg dry sediment. THC values above $LSC_{central\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{RII07/SLV\ 03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data for the regional and field reference sites in the central part of region II are included.

Site	THC		PAH(16)		NPD		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
SLV01	61.3	24.5	0.208	0.212	0.225	0.093	9.240	4.871
SLV02	22.4	4.1	0.068	0.015	0.036	0.010	1.590	1.180
SLV03	16.1	3.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SLV04	15.3	0.6	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SLV06	19.8	4.8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SLV07	18.6	1.3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SLV11	14.3	2.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SLV12	13.8	0.0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SLV16	13.6	1.4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SLV17	10.6	2.4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
RII-07/SLV	13.8	0.6	0.039	0.004	0.020	0.003	0.191	0.021
av. ± sd.[1]	20.6 ± 14.7							
min – max[1]	10.6 - 61.3							
av. ± sd.[2]	11.2±4.0		0.067±0.027		0.020±0.004		0.232±0.085	
min – max[2]	<3.0-15.5		0.013-0.102		0.012-0.027		0.095-0.461	

n.a. = not analysed.
[1] Field sites, exclusive RII07/SLV
[2] Reg + Ref $_{central\ 03}$

Table 8.5. The content of oil hydrocarbons in vertical sections of sediment from 3 sampling sites at Sleipner Vest in 2003. All values in mg/kg dry sediment. THC values above $LSC_{central\ 97\text{-}03}$ and PAH, NPD and decalins values above $LSC_{RII07/SLV\ 03}$ are dark shaded.

Site	Layer (cm)	THC	PAH(16)	NPD	Decalins
SLV01	0-1	48	0.085	0.150	7.64
	1-3	68	0.105	0.177	13.58
	3-6	84	0.082	0.174	18.83
SLV02	0-1	26	0.080	0.044	2.76
	1-3	52	0.071	0.060	8.89
	3-6	23	0.065	0.033	2.28
RII-07/SLV	0-1	13.4	0.038	0.023	0.195
	1-3	14.5	0.044	0.021	0.210
	3-6	10.3	0.044	0.018	0.180

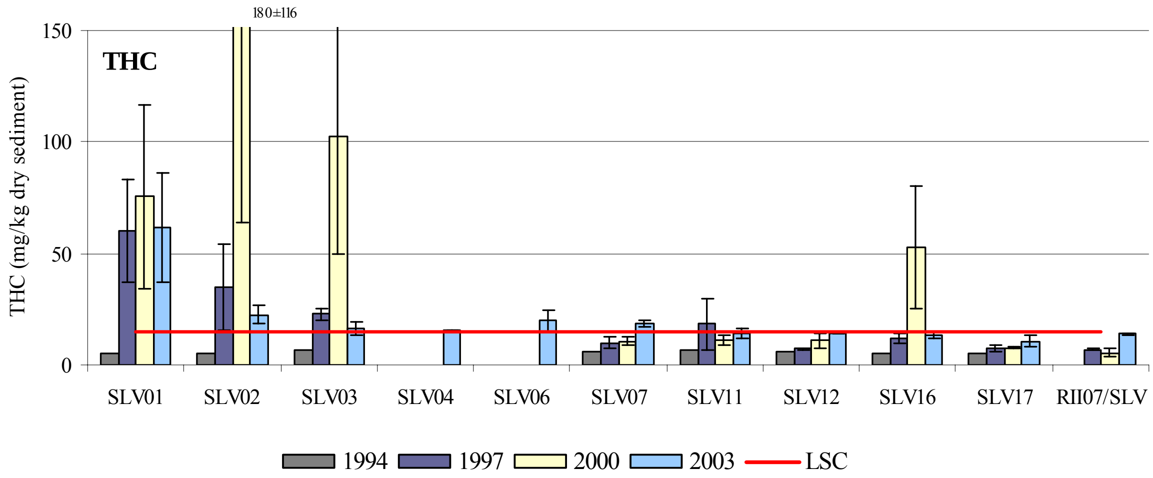


Figure 8.3. Average THC concentrations and standard deviations in sediments from Sleipner Vest in 2003 and previous years. Red line is $LSC_{central\ 97\text{-}03}$.

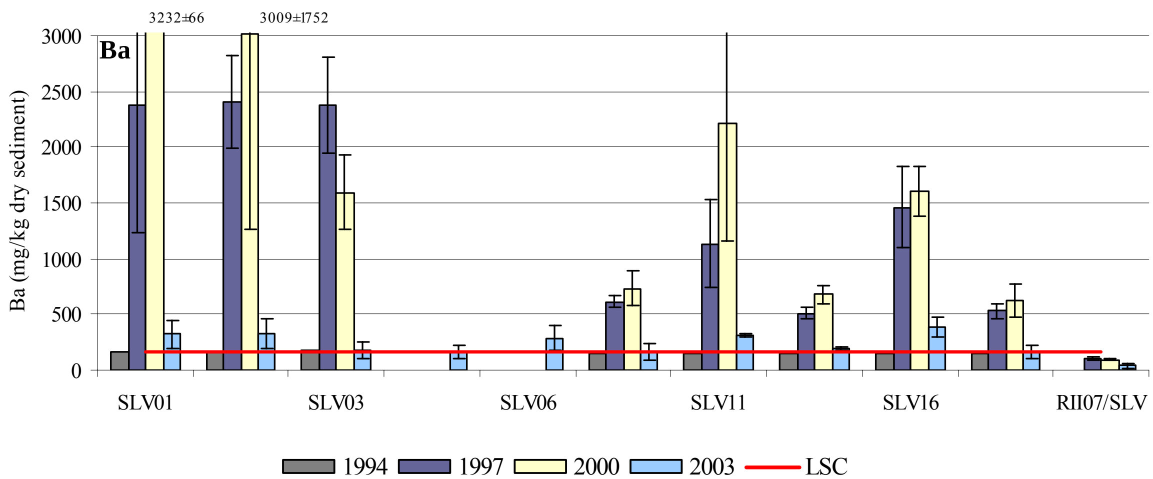


Figure 8.4. Average barium concentrations and standard deviations in sediments from Sleipner Vest in 2003 and previous years. Red line is $LSC_{central\ 97\text{-}03}$..

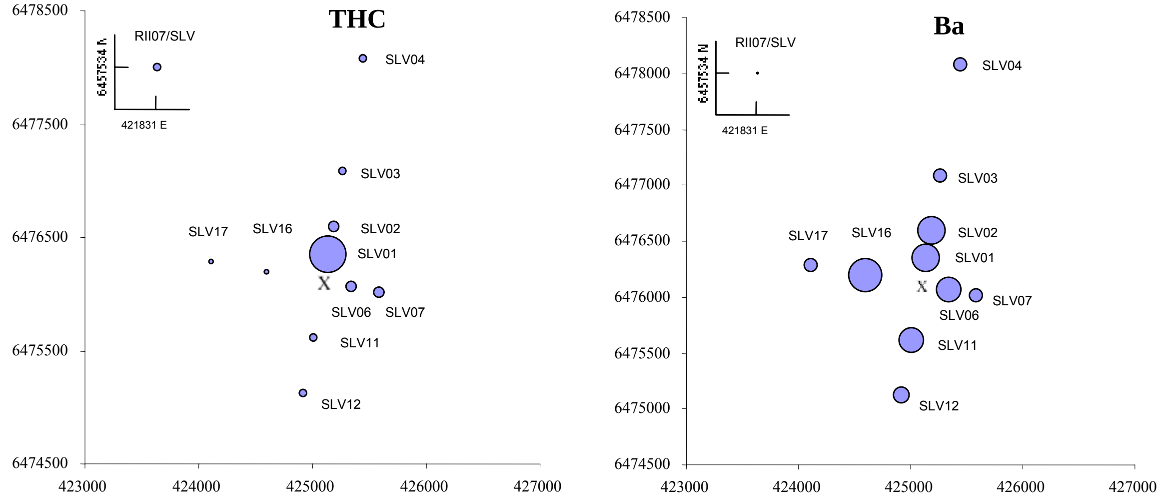


Figure 8.5. Distribution of THC and barium in sediments at the sampling sites at Sleipner Vest in 2003. The size of the circle indicate the amount of THC and Ba. The field centre is marked with an X.

8.2.2.3 Metals

Table 8.6 summarises the results of the metal analyses of the Sleipner Vest field in 2003. Concentrations of selected metals in the different layers (0-1, 1-3 and 3-6) of sediment are given in Table 8.7, whereas the complete data set including replicates is given in the Appendix. Comparisons of the metal contents in 2003 with the metal contents in 1997 and in 2000 are presented in Figure 8.6.

Table 8.6 Content of metals in sediments from Sleipner Vest in 2003. All values in mg/kg dry sediment. Values above $LSC_{central\ 97\text{-}03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data in the regional and field reference sites in the central part of the region II are included.

Site	Cu		Cr		Zn		Ba		Pb		Cd		Hg	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
SLV01	5.4	2.2	10.2	1.0	28.2	9.8	326	125	8.1	2.3	<0.03	-	0.012	0.002
SLV02	2.3	0.1	8.5	0.2	14.9	1.3	328	129	5.7	0.4	<0.03	-	0.009	0.000
SLV03	1.5	0.5	8.1	0.1	12.9	3.9	180	71	5.0	1.0	<0.03	-	n.a.	n.a.
SLV04	1.3	0.2	8.2	0.4	11.0	1.4	163	63	5.3	0.8	<0.03	-	n.a.	n.a.
SLV06	1.5	0.3	8.7	0.3	11.4	1.7	288	115	4.7	0.6	<0.03	-	n.a.	n.a.
SLV07	1.4	0.1	8.3	0.3	10.4	0.1	165	79	5.0	0.1	<0.03	-	n.a.	n.a.
SLV11	1.5	0.2	8.7	0.5	10.6	0.8	312	21	4.9	0.4	<0.03	-	n.a.	n.a.
SLV12	1.5	0.1	8.9	0.5	11.2	0.4	193	13	5.0	0.2	<0.03	-	n.a.	n.a.
SLV16	1.5	0.1	8.8	0.7	12.1	0.9	387	83	4.8	0.3	<0.03	-	n.a.	n.a.
SLV17	1.1	0.2	8.3	0.4	10.8	1.0	169	60	4.3	0.6	<0.03	-	n.a.	n.a.
RII07/SLV	<0.6	-	8.5	0.7	9.6	0.6	41	22	4.4	0.2	<0.03	-	0.006	0.001
av. ± sd.[1]	1.9 ± 1.3		8.7 ± 0.6		13.3 ± 5.4		25 ± 85		5.3 ± 1.1					
min – max[1]	1.1 - 5.4		8.1 - 10.2		10.4 - 28.2		163 - 387		4.3 - 8.1					
av. ± sd.[2]	1.2 ± 0.4		6.9 ± 1.2		9.4 ± 1.3		66 ± 31		4.2 ± 0.6		<0.03		0.009±0.003	
min – max[2]	<0.6-1.7		4.9-8.9		6.8-12.0		10-146		3.4-5.1		<0.03		0.006-0.014	

n.a. = not analysed.
[1] Field sites, exclusive RII07/SLV
[2] Reg + Ref $_{central\ 03}$

Table 8.7. The content of metals in vertical sections of sediment from 3 sampling sites at Sleipner Vest in 2003. All values in mg/kg dry sediment. Values above $LSC_{central\ 97\text{-}03}$ are dark shaded.

Site	Layer (cm)	Cu	Cr	Zn	Ba	Pb	Cd	Hg
SLV01	0-1	3.7	9.7	19.1	400	6.0	<0.03	0.011
	1-3	7.2	12.4	28.6	348	10	<0.03	0.014
	3-6	9.7	14.4	84.4	233	12	<0.03	0.020
SLV02	0-1	2.4	8.7	15.2	450	6.0	<0.03	0.009
	1-3	2.5	9.5	19.1	193	6.5	<0.03	0.008
	3-6	1.6	8.6	11.5	416	4.8	<0.03	0.010
RII07/SLV	0-1	0.5	7.6	8.9	28.0	4.5	<0.03	0.005
	1-3	0.7	8.8	10.2	47.8	5.1	<0.03	0.006
	3-6	0.7	9.0	12.0	64.5	5.1	<0.03	0.007

Barium was found in a range from 163 to 387 mg/kg, lead from 4.3 to 8.1 mg/kg, cadmium from <0.03 to 0.04 mg/kg, copper from 1.1 to 5.4 mg/kg, chromium from 8.1 to 10.2 mg/kg, mercury from 0.009 to 0.012 mg/kg and zinc from 10.4 to 28.2 mg/kg (Table 8.6). Sediments from all the field sites had barium (163-387 mg/kg) content above LSC. Also all the other metals, except cadmium and mercury, occurred above LSC at SLV01, 250 m north and downstream from the installation. In addition copper was present above LSC at SLV02, 500 m north of the installation and zinc was present above LSC at SLV02 and SLV03, out to 1000 m to the north. Cadmium was below LSC at all sites.

Vertical sediment samples (0-1, 1-3 and 3-6 cm) from SLV01 had barium, copper, chromium and zinc content above LSC in all depth intervals, and lead and mercury was found above LSC in the 1-3 and 3-6 cm interval. At SLV02 barium were present above LSC in all depth intervals. Whereas copper and zinc was above LSC in the 0-1 and 1-3 cm layers and chromium was above the LSC in the 1-3 cm layer.

All metals, but zinc, occurred in lower concentrations in 2003 than in 2000.

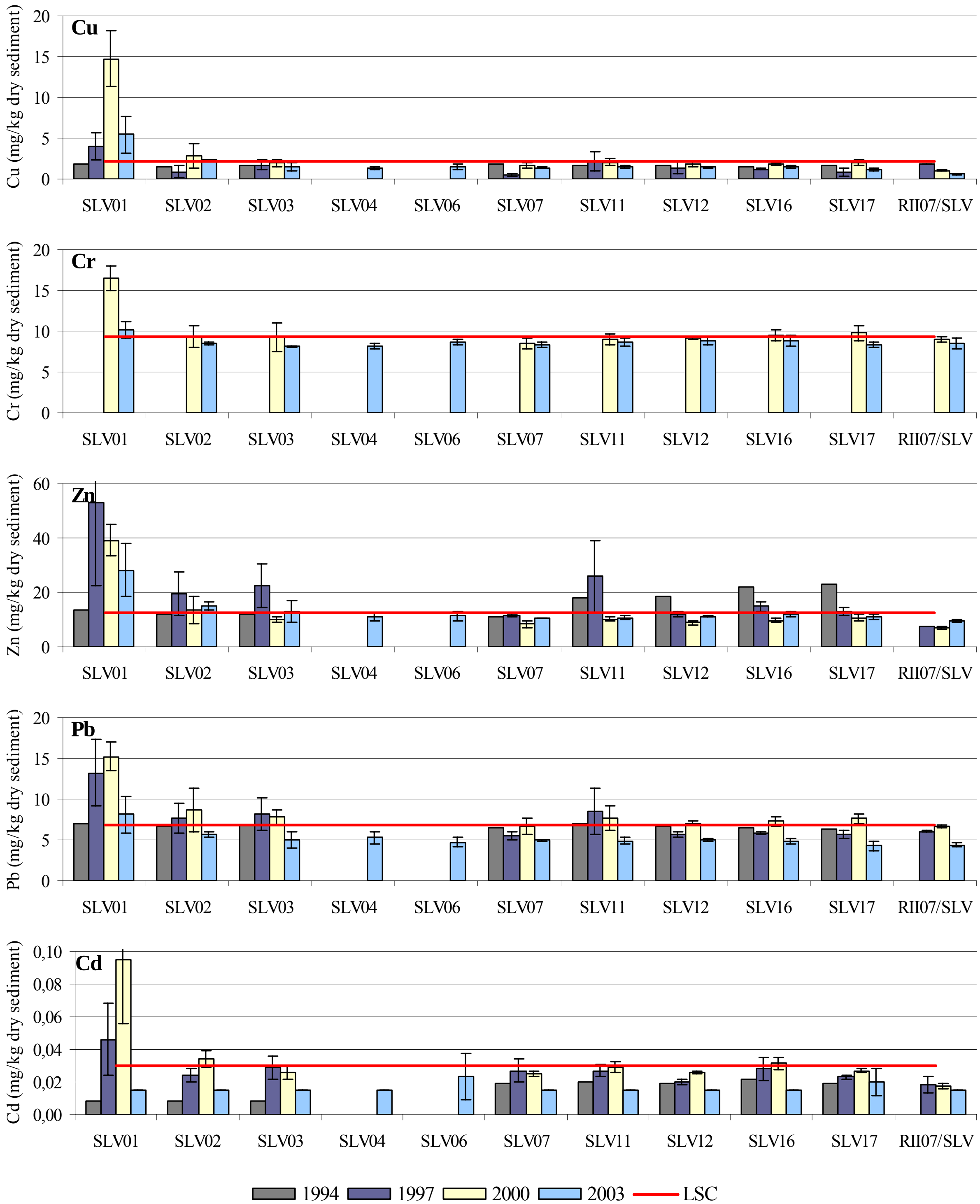


Figure 8.6. Average content and standard deviations of metals in sediment from Sleipner Vest in 2003 and previous surveys. Red line is $LSC_{central\ 97-03}$.

The field sites at Sleipner Vest were compared to nearby regional and field specific reference sites based on sediment characteristics (TOM and pelite) and chemical content in the sediments (Figure 8.7). SLV01 and RII07/SLV did not group together with the other sites, but were separated from the other sites. SLV01 was separate due to higher content of chemical compounds, whereas RII07/SLV was separated due to more sandy sediments with lower content of chemical compounds.

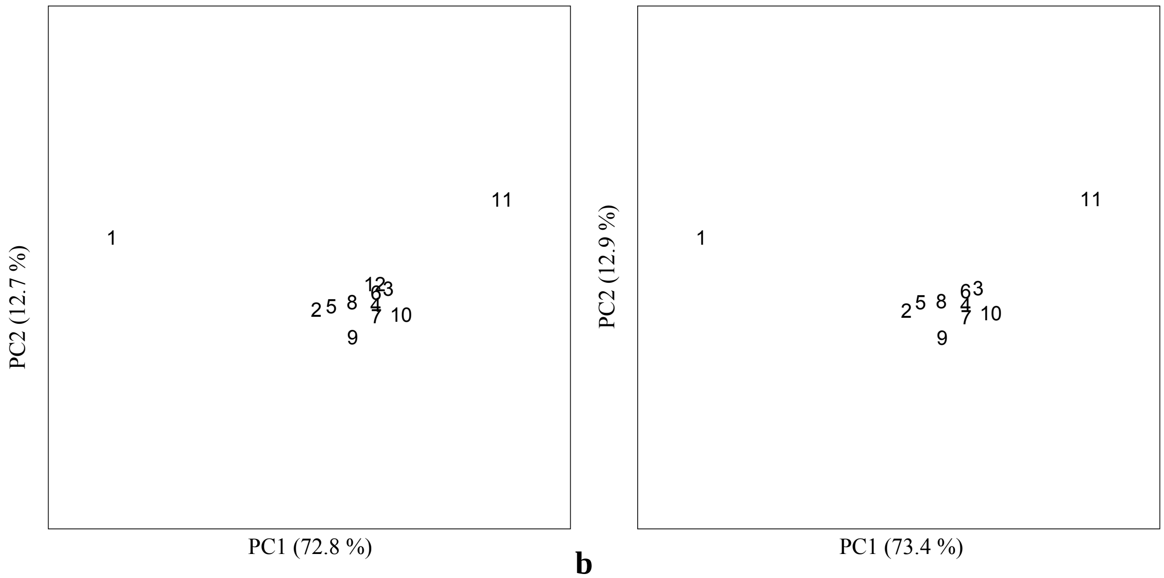


Figure 8.7. 2-D plot from the PCA analysis of environmental variables (% pelite, % sand, % gravel, median Φ, % TOM, Cu, Ba, Zn, Cr, Pb and THC) carried out on the:
a) Sleipner Vest field sites, the reference site at Sleipner Vest (RII07/SLV) and the regional site RII08. Explained variation in the data 85.5 %.
b) Sleipner Øst field sites. Explained variation in the data 86.3 %.
Numbers in the plot identify the sampling sites. See table below.

1	SLV01	5	SLV06	9	SLV16
2	SLV02	6	SLV07	10	SLV17
3	SLV03	7	SLV11	11	RII07/SLV
4	SLV04	8	SLV12	12	RII-08

8.2.3 Bottom fauna

A summary of the distribution of individuals and taxa within the main taxonomic groups is given in Table 8.8. Unidentified juveniles of the sea urchin Spatangoids (15413 individuals) are omitted from the analyses, as they occurred in extremely high numbers. In total, 7346 individuals within 256 taxa were collected at Sleipner Vest in 2003. The fauna was numerically dominated by annelida with 54 % the individuals and 43 % of the taxa. A complete species list is available in the Appendix.

Table 8.8. Distribution of individuals and taxa within the main taxonomic groups at Sleipner Vest in 2003 including data from the reference site (RII07/SLV) (unidentified juveniles of Spatangoida are not included).

Main taxonomic groups	Number of individuals	%	Number of taxa	%
Annelida	3982	54	109	43
Arthropoda	1248	17	66	26
Mollusca	854	12	47	18
Echidermata	716	10	15	6
Diverse groups	546	7	19	7
Total	7346	100	256	100

The species/area curve for RII07/SLV indicates that five replicate samples give a representative impression of the bottom fauna in the area (Figure 8.8). However, as more area is sampled, more taxa are collected, indicating that not even 10 replicate samples give the full species assemblage of the area.

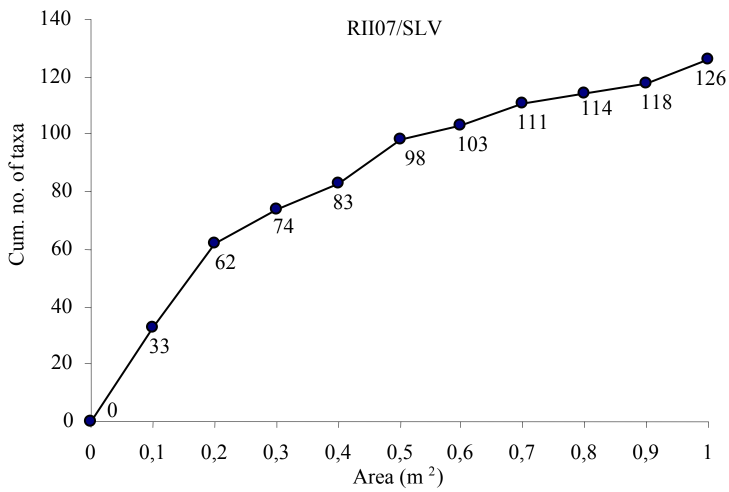


Figure 8.8. Species/area curve for the reference site at the Sleipner Vest field. Unidentified juveniles of Spatangoida are not included.

The distribution of individuals and taxa are shown in Figure 8.9. Number of individuals and taxa at each site, and the calculated diversity indexes (H' and ES_{100}) are given in Table 8.9 and Figure 8.10. The number of individuals varied from 465 (SLV01) to 829 (SLV07), and the number of taxa varied from 78 (SLV01) to 123 (SLV06). The Shannon-Wiener diversity index (H') varied from 4.90 (SLV01) to 5.89 (SLV16), whereas the ES_{100} index varied from 36.2 (SLV01) to 49.7 (SLV17). The evenness index J varied from 0.78 (SLV01) to 0.87 (SLV04, SLV16 and SLV17). The corresponding values at RII07/SLV are within or near the variation at the field sites, although most values are lower at the reference site than the average values for the field sites. The number of taxa, diversity and evenness indicate good environmental conditions at all sites.

Table 8.9. Number of individuals, species/taxa, and selected community indices for each site (0.5 m^2) at the Sleipner Vest field in 2003. Unidentified juveniles of Spatangoida are not included.

Site number	Number of individuals	Number of taxa	Diversity H'	Evenness J	H'-max	ES_{100}
SLV01	465	78	4.90	0.78	6.29	36.2
SLV02	716	101	5.60	0.84	6.66	44.5
SLV03	727	114	5.84	0.85	6.83	47.7
SLV04	629	106	5.83	0.87	6.73	47.7
SLV06	711	123	5.88	0.85	6.94	48.2
SLV07	829	109	5.83	0.86	6.77	47.3
SLV11	514	102	5.66	0.85	6.67	45.7
SLV12	608	107	5.78	0.86	6.74	47.0
SLV16	606	111	5.89	0.87	6.79	49.5
SLV17	564	106	5.85	0.87	6.73	49.7
RII07 (6-10)	489	98	5.13	0.78	6.61	42.0
RII07 (11-15)	488	89	5.10	0.79	6.48	40.5
RII07 (6-15)	976	126	5.25	0.75	6.98	41.6
Sum[1]	6369	231				
Average[1]	637	106	5.71	0.85	6.72	46.3
SD[1]	110	12	0.30	0.03	0.17	3.9
Min[1]	465	78	4.90	0.78	6.29	36.2
Max[1]	829	123	5.89	0.87	6.94	49.7
Average[2]	774	113	5.55	0.81	6.81	44.3
SD[2]	230	14	0.24	0.02	0.18	2.6
Min[2]	488	94	5.12	0.79	6.55	38.7
Max[2]	1202	141	5.85	0.85	7.14	47.9

[1]Field sites, exclusive RII07
[2]Reg + Ref $_{\text{central 03}}$

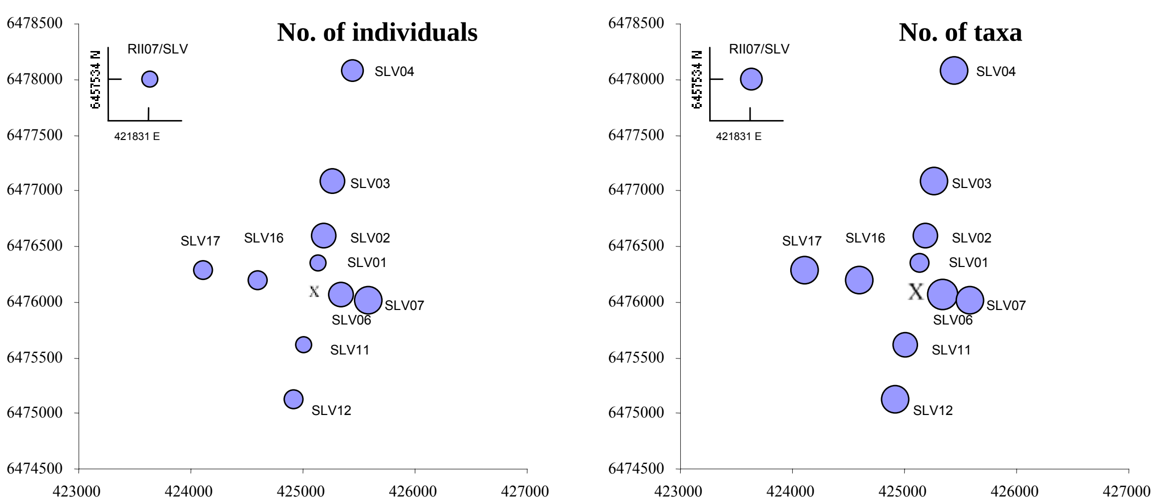


Figure 8.9. Distribution of bottom fauna (individuals and taxa) among the sampling sites in 2003. The size of the circle indicates the number of individuals and taxa. Unidentified juveniles of Spatangoida are not included. Values for RII-07 are average of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2). The field centre is marked with an X.

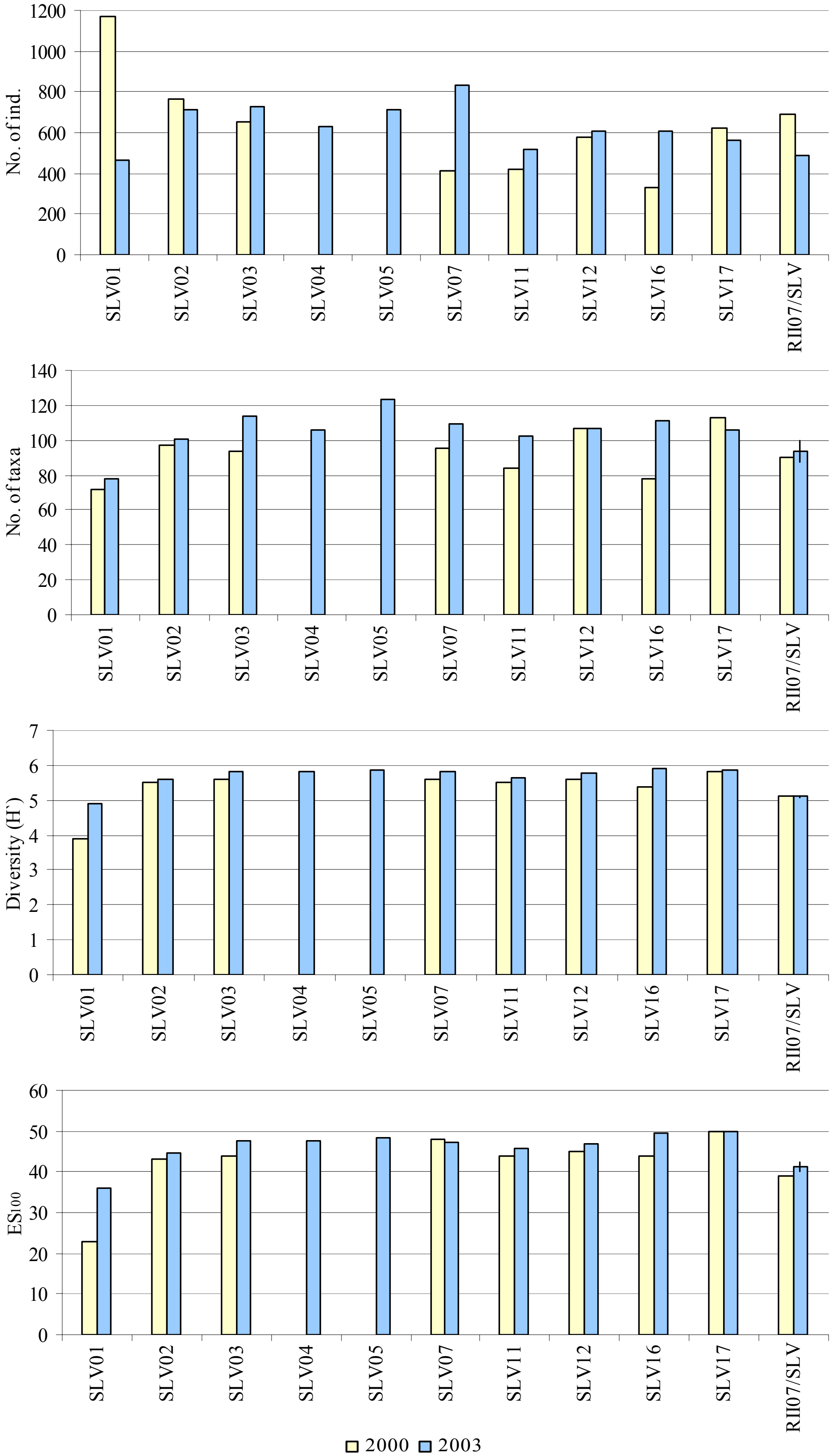


Figure 8.10. Number of individuals, taxa, and selected community indices for each site (0.5 m^2) at the Sleipner Vest field for 2000 and 2003. (Exclusive unidentified juveniles of Spatangoida in 2003). Values for RII07/SLV are average ± standard deviation of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2).

Distribution of taxa in geometrical classes is presented in Figure 8.11. The smooth graphs are representing undisturbed bottom fauna.

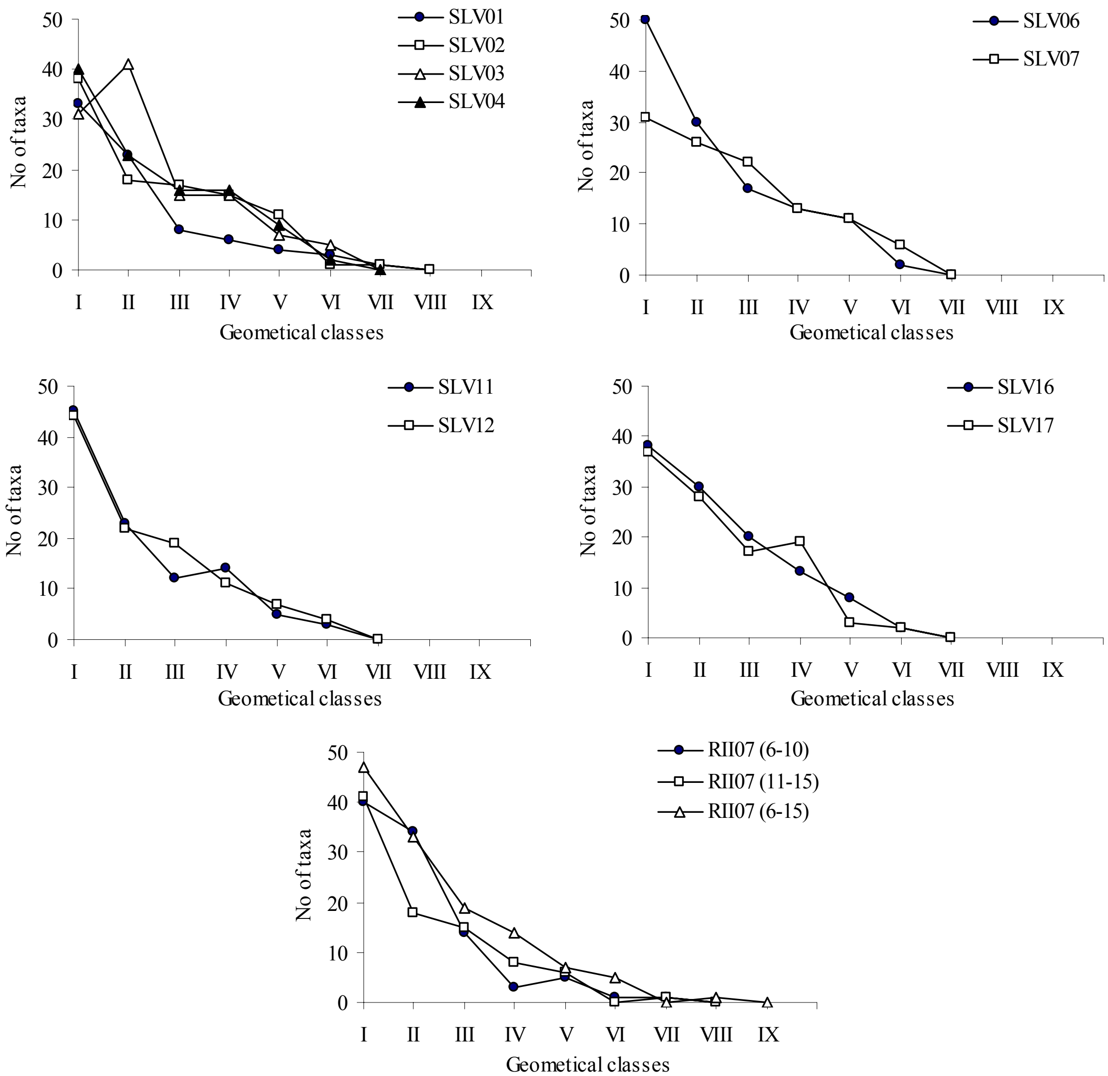


Figure 8.11. Distribution of taxa in geometrical classes for the sites at Sleipner Vest in 2003. Exclusive unidentified juveniles of Spatangoida.

The ten most numerous taxa are listed in Table 8.12 at the end of this chapter. The list comprise 35 taxa and 5164 individuals, which was 13.7 % of all (256) taxa and 70.3 % of all (7346) individuals. The crustacean *Ampelisca tenuicornis*, the polychates *Paramphinome jefferysii, Nephtys hystericis* and *Terebellides stroemi* and the brittle star *Amphiura filiformis* were the most abundant and widespread species at Sleipner Vest. At SLV01, 250 m north of and downstream from the installation, was the polychaete *Chaetozone setosa* most abundant. *Chaetozone setosa* occurred in low number at SLV02 (500 m to the north), SLV06 and SLV07 (250 m to the east and 500 m to the east) and SLV16 (500 m to the west). The taxa assemblages indicate good environmental conditions at most sites, but there were signs of some disturbance at SLV01.

The results of the multivariate analyses are given in the dendrogramme (Figure 8.12) and the MDS plott (Figure 8.13).

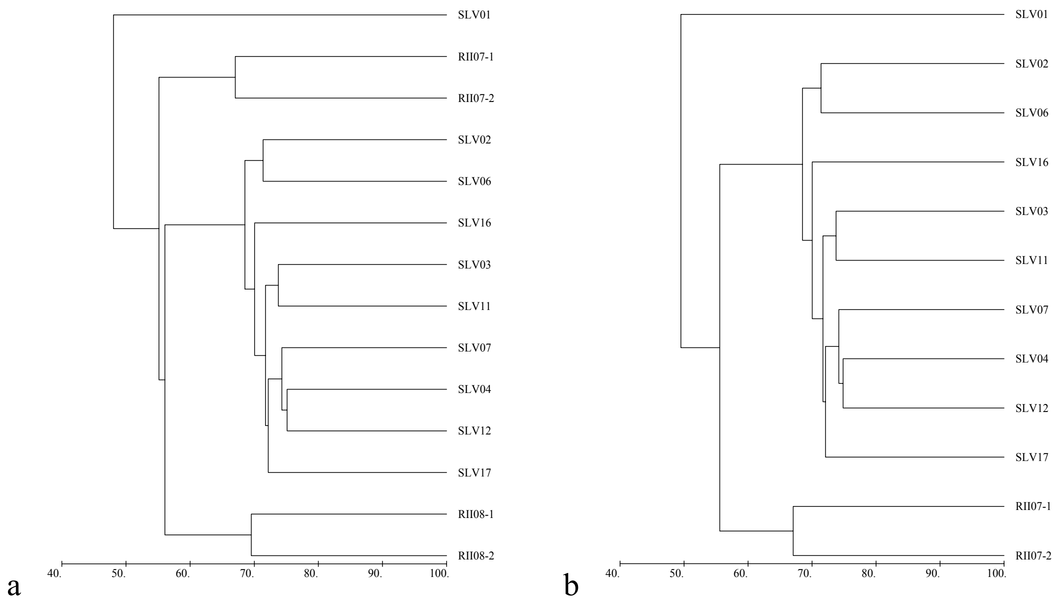


Figure 8.12. Dendrogram showing the similarity between fauna from sampling sites at:

a) Sleipner Vest field compared to the reference site at Glitne (RII08) in 2003. Unidentified juveniles of Spatangoida and Echinoidea are not included.
b) Sleipner Vest field sites in 2003. Unidentified juveniles of Spatangoida is not included.

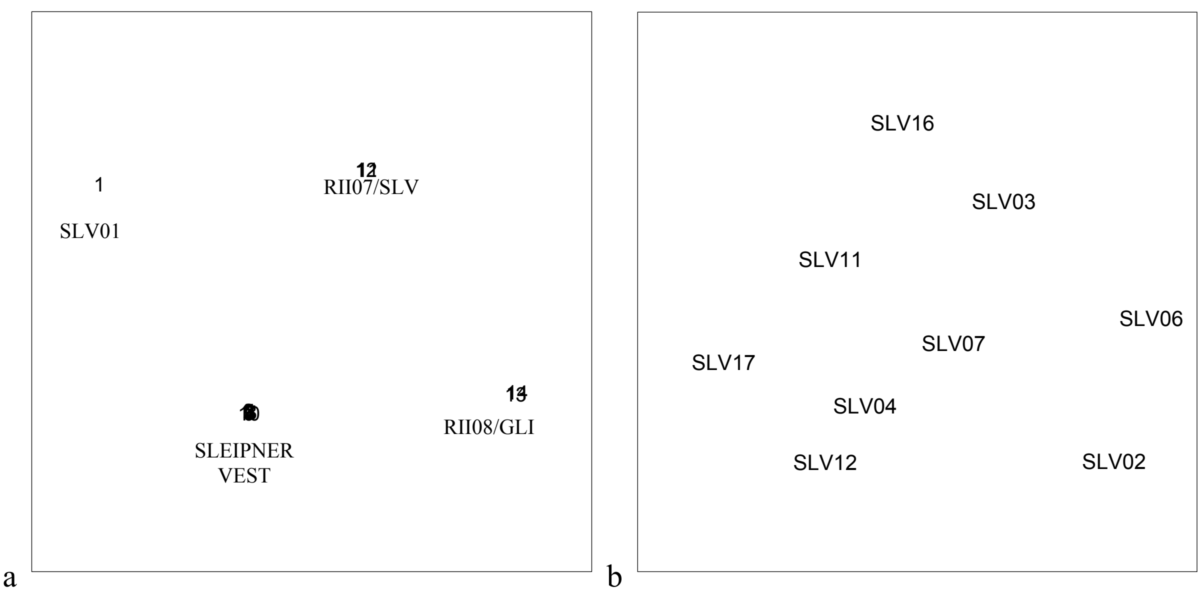


Figure 8.13. A 2-dimetional plott of the MDS analysis of the fauna data from:

a) Sleipner Vest field compared to the reference and regional site RII08 in 2003. Stress = 0.00. Exclusive unidentified juveniles of Spatangoida and Echinoidea.
b) Sleipner Vest field exclusive SLV01 and RII07/SLV. Stress = 0.13. Unidentified juveniles of Spatangoida is not included.

In the cluster analysis, all sites are grouped together within approximately 50 % similarity, indicating heterogeneity in the fauna assemblage at the field. In the analysis the fauna was grouped in three distinct groups. The fauna at SLV01 comprise one group and the fauna at RII07/SLV comprise the second group. The third group comprised the other field sites.

The results of the MDS analysis support the findings in the cluster analysis, confirming the difference in species assemblage at SLV01 and RII07/SLV and the rest of the sites. The stress test of the MDS analysis was 0.00, indicating an excellent fit of the data.

Linking of biotic and environmental variables by BIOENV revealed that TOM, THC, copper and sand content in the sediments were best correlated to the biota at $\rho_w = 0.86$ (Table 8.10). This indicates that there was a strong association between some environmental variables and the bottom fauna.

Table 8.10. Combinations of the 10 environmental variables, taken *k* at a time, yielding the best matches of biotic and abiotic similarity matrices for each *k*, as measured by weighted Spearman rank correlation ρ_w. Bold type indicates overall optimum. All possible combinations of variables and associated correlation to the biotic are given in the Appendix.

Number of variables (*k*)	Correlation coefficient (ρ_w)	Environmental variables									
1	0.675	TOM									
1	0.675	Cu									
1	0.604	Sand									
1	0.536	Zn									
1	0.522	Pelite									
1	0.449	Pb									
1	0.352	Ba									
1	0.235	THC									
1	0.117	Cr									
1	-0.003	Gravel									
2	0.835	TOM	THC								
3	0.848	TOM	THC	Cu							
4	**0.855**	**TOM**	**THC**	**Cu**	**Sand**						
5	0.842	TOM	THC	Cu	Sand	Ba					
6	0.841	TOM	THC	Cu	Sand	Ba	Zn				
7	0.835	TOM	THC	Cu	Sand	Ba	Zn	Pelite			
8	0.828	TOM	THC	Cu	Sand	Ba	Zn	Pelite	Gravel		
9	0.833	TOM	THC	Cu	Sand	Ba	Zn	Pelite	Gravel	Pb	
10	0.814	TOM	THC	Cu	Sand	Ba	Zn	Pelite	Gravel	Pb	Cr

8.2.4 Estimation of influenced area

The extension of contamination along sampling transects and the minimum area of contaminated sediments for THC, barium and other metals as well as for faunal disturbance is given in Figure 8.15 and Table 8.11. The contaminated area has increased compared to 2000 for THC and barium, whereas it the area contaminated by other metals has decreased. The area with faunal disturbance was also reduced from 2000 to 2003.

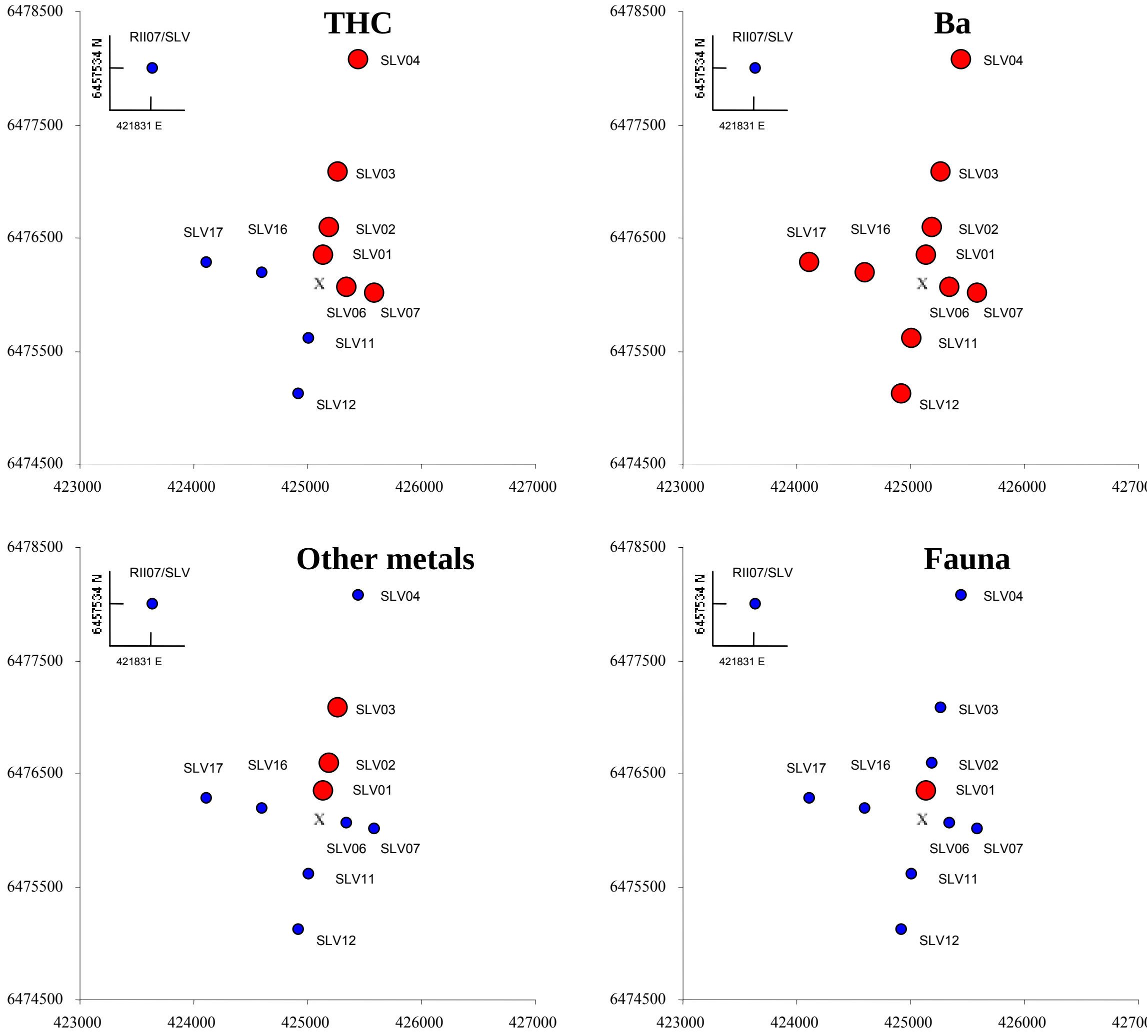


Figure 8.15. Faunal disturbance and chemical contamination of the sediments at Sleipner Vest in 2003. The field centre is marked with an X. Uncontaminated sites and sites with no faunal disturbance are marked with small blue circles.

Table 8.11. Estimated distance of contamination and faunal disturbance from the installation, and estimated area of contamination and faunal disturbance around the field centre.

Sleipner Vest	N m	E m	S m	W m	2003 km^2	2000 km^2	1997 km^2
THC	2000	500	0	0	0.79	0.74	0.88
Ba	2000	500	1000	1000	3.53	3.14	3.14
Other metals	1000	0	0	0	0.10	0.74	3.14
Fauna	255	0	0	0	0.03	0.07	0.00

8.3 Summary and conclusions

There has been no drilling or discharges at Sleipner Vest since 2000. The sediments are still characterized as fine sand, although there has been a slight increase in the pelite and decrease in TOM content since 2000. The amounts of THC, barium and metals in the sediments have decreased since 2000. More taxa were found in the bottom fauna in 2003 than in 2000, and the diversity of the fauna was high. Comparisons of fauna assemblage showed that the innermost (250 m distance) sampling site to the north was disturbed. The measured chemical compounds occurred in high concentrations at the same site. The fauna assemblage was well associated to the distribution of TOM, THC, copper and sand, which show that the activity at Sleipner Vest have some environmental influence in the immediate vicinity of the installation. The area contaminated by THC and barium was somewhat larger in 2003 than in 2000, whereas the area contaminated by other metals was somewhat smaller. The area with faunal disturbance was also somewhat smaller in 2003 than in 2000.

Table 8.12. Number of individuals and relative abundance for the ten predominant taxa at each site at the Sleipner Vest field in 2003. Exclusive unidentified juveniles of Spatangoida.

SLV01	No of ind.	%	Cum %
Chaetozone setosa	75	16.1	16.1
Nemertini indet.	57	12.3	28.4
Ampelisca tenuicornis	34	7.3	35.7
Diplocirrus glaucus	33	7.1	42.8
Myriochele oculata	30	6.5	49.2
Paramphinome jeffreysii	18	3.9	53.1
Parvicardium minimum	17	3.7	56.8
Cerianthus lloydii	16	3.4	60.2
Glycera alba	13	2.8	63.0
Lumbrineris scopa	8	1.7	64.7
Spiophanes kroeyeri	8	1.7	66.5
Ampharete lindstroemi	8	1.7	68.2
Astacilla arietina	8	1.7	69.9
Thyasira sarsii	8	1.7	71.6

SLV02	No of ind.	%	Cum %
Paramphinome jeffreysii	86	12.0	12.0
Terebellides stroemi	47	6.6	18.6
Nemertini indet.	30	4.2	22.8
Diplocirrus glaucus	28	3.9	26.7
Nephtys hystericis	26	3.6	30.3
Lumbrineris scopa	24	3.4	33.7
Thyasira croulinensis	23	3.2	36.9
Ampelisca tenuicornis	22	3.1	40.0
Amphiura filiformis	22	3.1	43.1
Spiophanes kroeyeri	19	2.7	45.7
Apistobranchus tenuis	19	2.7	48.4
Thyasira equalis	19	2.7	51.0

SLV03	No of ind.	%	Cum %
Terebellides stroemi	48	6.6	6.6
Paramphinome jeffreysii	47	6.5	13.1
Nephtys hystericis	39	5.4	18.4
Ampelisca tenuicornis	39	5.4	23.8
Nemertini indet.	32	4.4	28.2
Thyasira croulinensis	27	3.7	31.9
Amphiura filiformis	27	3.7	35.6
Apistobranchus tenuis	24	3.3	38.9
Spiophanes kroeyeri	22	3.0	42.0
Lumbrineris scopa	18	2.5	44.4
Polydora caeca	18	2.5	46.9

SLV04	No of ind.	%	Cum %
Nephtys hystericis	44	7.0	7.0
Terebellides stroemi	37	5.9	12.9
Ampelisca tenuicornis	29	4.6	17.5
Thyasira croulinensis	24	3.8	21.3
Harpinia antennaria	21	3.3	24.6
Lumbrineris scopa	20	3.2	27.8
Ampharete falcata	20	3.2	31.0
Amphiura filiformis	19	3.0	34.0
Paramphinome jeffreysii	18	2.9	36.9
Sabellidae indet.	17	2.7	39.6
Urothoe elegans	17	2.7	42.3

SLV06	No of ind.	%	Cum %
Paramphinome jeffreysii	61	8.6	8.6
Terebellides stroemi	44	6.2	14.8
Ampelisca tenuicornis	29	4.1	18.8
Apistobranchus tenuis	29	4.1	22.9
Nephtys hystericis	26	3.7	26.6
Sabellidae indet.	23	3.2	29.8
Laonice sarsi	23	3.2	33.1
Spiophanes kroeyeri	22	3.1	36.1
Goniada maculata	22	3.1	39.2
Amphiura filiformis	18	2.5	41.8
Nemertini indet.	18	2.5	44.3

SLV07	No of ind.	%	Cum %
Paramphinome jeffreysii	48	5.8	5.8
Nephtys hystericis	46	5.5	11.3
Terebellides stroemi	44	5.3	16.6
Amphiura filiformis	40	4.8	21.5
Cirratulus caudatus	40	4.8	26.3
Ampelisca tenuicornis	39	4.7	31.0
Anobothrus gracilis	22	2.7	33.7
Ampharete falcata	22	2.7	36.3
Spiophanes kroeyeri	21	2.5	38.8
Goniada maculata	19	2.3	41.1
Thyasira croulinensis	19	2.3	43.4

SLV11	No of ind.	%	Cum %
Ampelisca tenuicornis	45	8.8	8.8
Nephtys hystericis	33	6.4	15.2
Terebellides stroemi	32	6.2	21.4
Paramphinome jeffreysii	27	5.3	26.7
Amphiura filiformis	20	3.9	30.5
Urothoe elegans	20	3.9	34.4
Thyasira ferruginea	17	3.3	37.7
Thyasira equalis	16	3.1	40.9
Thyasira croulinensis	15	2.9	43.8
Goniada maculata	14	2.7	46.5

SLV12	No of ind.	%	Cum %
Nephtys hystericis	36	5.9	5.9
Paramphinome jeffreysii	36	5.9	11.8
Ampelisca tenuicornis	35	5.8	17.6
Amphiura filiformis	35	5.8	23.4
Terebellides stroemi	28	4.6	28.0
Spiophanes kroeyeri	22	3.6	31.6
Harpinia antennaria	21	3.5	35.0
Thyasira croulinensis	20	3.3	38.3
Sabellidae indet.	18	3.0	41.3
Anobothrus gracilis	17	2.8	44.1

SLV16	No of ind.	%	Cum %
Nephtys hystericis	52	8.6	8.6
Terebellides stroemi	38	6.3	14.9
Ampelisca tenuicornis	28	4.6	19.5
Paramphinome jeffreysii	27	4.5	23.9
Thyasira croulinensis	21	3.5	27.4
Thyasira equalis	21	3.5	30.9
Lumbrineris scopa	19	3.1	34.0
Amphiura filiformis	18	3.0	37.0
Sabellidae indet.	16	2.6	39.6
Eudorella emarginata	16	2.6	42.2

SLV17	No of ind.	%	Cum %
Nephtys hystericis	55	9.8	9.8
Ampelisca tenuicornis	39	6.9	16.7
Terebellides stroemi	29	5.1	21.8
Harpinia antennaria	20	3.5	25.4
Lumbrineris scopa	17	3.0	28.4
Thyasira croulinensis	15	2.7	31.0
Eudorella emarginata	15	2.7	33.7
Amphiura chiajei	15	2.7	36.3
Spiophanes kroeyeri	14	2.5	38.8
Sabellidae indet.	12	2.1	41.0
Ampelisca sp.	12	2.1	43.1

RII-07	No of ind.	%	Cum %
Amphiura filiformis	231	23.6	23.6
Phoronis sp.	62	6.3	30.0
Spiophanes kroeyeri	44	4.5	34.5
Myriochele oculata	42	4.3	38.8
Scoloplos armiger	42	4.3	43.1
Ampelisca tenuicornis	35	3.6	46.7
Nemertini indet.	29	3.0	49.6
Goniada maculata	28	2.9	52.5
Ampharete falcata	25	2.6	55.1
Paramphinome jeffreysii	22	2.3	57.3

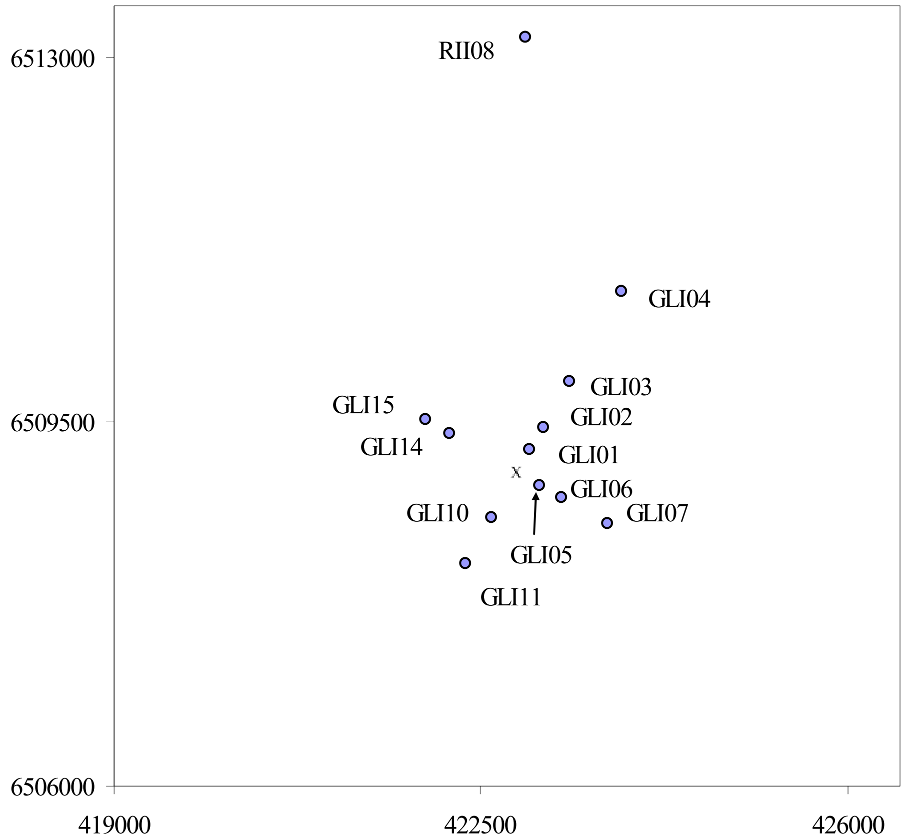
9 Glitne

9.1. Introduction

The Glitne field is situated in block 15/5. Production started at Glitne in August 2001. During the monitoring survey of Region II in 2000 a baseline survey of Glitne was undertaken. No faunal disturbances were detected and only low levels of THC were found. Recent discharges at Glitne are listed in Table 9.1, and sampling sites are shown in Figure 9.1. See Figure 9.16 at the end of this chapter for illustration of deviation in planned and real sampling. The regional site, RII08 was used as reference site for Glitne in 2003 as in 2000.

Table 9.1. Recent well drilling and discharges from operations and accidents at Glitne.

	2000	2001	2002
No of wells drilled	3	2	0
Barite, tonnes	631	419	0
Cuttings, tonnes	1864	1999	0
Water-based drilling mud, m^3	3513	2754	0
Cementing chemicals, tonnes	16.6	9.6	0
Completion chemicals, tonnes	687	566	0
Oil in produced water, tonnes of oil	0	0	5.2
Accidental discharges, m^3	0	0	0



Site	ED50 UTM Zone 31 E	N	Distance (m) / direction (º)	Depth (m)
GLI-01	422975	6509227	250/30	112
GLI-02	423100	6509443	500/30	112
GLI-03	423350	6509876	1000/30	112
GLI-04	423850	6510742	2000/30	111
GLI-05	423067	6508885	250/120	113
GLI-06	423283	6508760	500/120	114
GLI-07	423716	6508510	1000/120	114
GLI-10	422600	6508577	500/210	112
GLI-11	422350	6508144	1000/210	112
GLI-14	422200	6509385	750/300	112
GLI-15	421984	6509510	1000/300	111
RII08	422936	6513198	5261/19	111

Figure 9.1. Map showing the internal distribution of sampling sites in Glitne, 2003. Positioning according to UTM ED50 zone 31. The field centre is marked with an X.

9.2. Results and discussion

9.2.1 Sediments characteristics

TOM, and the amount (%) of gravel, sand, pelite, median (Φ), sorting, skewness and kurtosis in the sediment from the present survey are presented in Table 9.2. Additional information on colour and smell can be found in the Appendix. Median (Φ), pelite, sand and TOM are compared with data from 2000 in Figure 9.2.

The sediments at Glitne are classified as fine sand with median (Φ) values ranging from 2.59 (GLI14) to 2.89 (GLI07). The amount of pelite varied from 10 % (GLI15) to 16 % (GLI07), the sand varied from 83.8 % (GLI07) to 90 % (GLI15), and the TOM varied from 1.3 % (GLI01) to 2.1 % (GLI06). There was, as in 2000, slightly more sand at RII08 than at the field sites, whereas the pelite and TOM content were within the variation at the field sites. There was a tendency of slightly higher content of TOM at the field sites, except at GLI01, GLI14 and GLI15, in 2003 than in 2000. The change in the median values between 2000 and 2003 are probably due to different methods of calculation.

Table 9.2. Total organic matter and sediment grain size at all sites at Glitne in 2003. For comparison, averages, standard deviations, max and min values for the regional and reference sites are included.

Site	TOM %	Gravel %	Sand %	Pelite %	Median (Φ)	Sorting	Skewness	Kurtosis
GLI01	1.31	0.02	87.85	12.13	2.69	1.19	0.37	1.83
GLI02	1.69	0.34	89.40	10.25	2.76	1.13	0.31	1.64
GLI03	1.84	0.08	88.47	11.45	2.65	1.23	0.32	1.79
GLI04	1.70	0.03	88.52	11.45	2.71	1.20	0.33	1.73
GLI05	1.93	0.00	88.31	11.69	2.77	1.20	0.31	1.65
GLI06	2.08	0.01	87.34	12.65	2.88	1.23	0.25	1.60
GLI07	1.94	0.03	83.78	16.19	2.89	1.31	0.32	1.62
GLI10	1.91	0.01	87.87	12.12	2.74	1.30	0.24	1.54
GLI11	1.71	0.33	87.69	11.98	2.61	1.28	0.31	1.83
GLI14	1.70	0.01	88.77	11.22	2.59	1.19	0.36	2.18
GLI15	1.51	0.04	89.99	9.97	2.59	1.24	0.25	1.63
RII08	1.92	0.02	87.42	12.56	2.67	1.15	0.44	2.03
Average[1]	1.76	0.08	88.00	11.92	2.72	1.23	0.31	1.73
SD[1]	0.22	0.13	1.60	1.63	0.10	0.05	0.05	0.18
Min[1]	1.31	0.00	83.78	9.97	2.59	1.13	0.24	1.54
Max[1]	2.08	0.34	89.99	16.19	2.89	1.31	0.37	2.18
Average[2]	1.71	0.29	87.23	12.49	2.71	1.16	0.34	1.76
SD[2]	0.45	0.62	5.20	5.12	0.37	0.14	0.19	0.46
Min[2]	0.73	0.00	78.12	3.04	1.76	0.93	0.03	1.05
Max[2]	2.19	2.19	96.61	21.77	3.34	1.40	0.57	2.95

[1] Field sites, exclusive RII08
[2] Reg + Ref $_{\text{central 03}}$

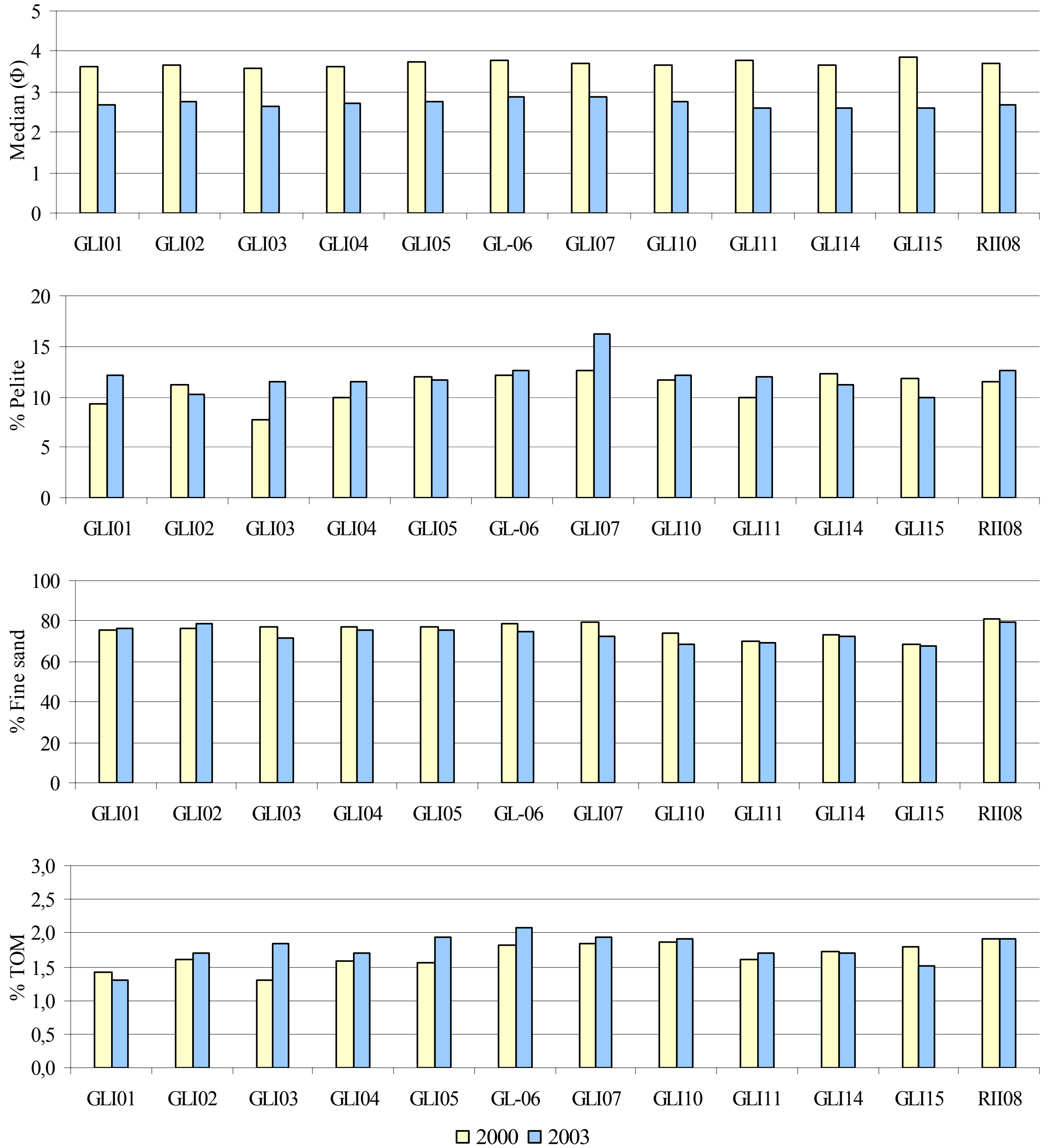


Figure 9.2. Sediment characteristics at Glitne in 2000 and 2003. Fine sand is the relative amount of sand with grain size 63-250 µm.

9.2.2 Chemical compounds

9.2.2.1 LSC

The results of the LSC (limits of significant contamination) calculations of hydrocarbons and metals are presented in the chapter concerning the regional and reference sites. Both the $LSC_{central\ 97\text{-}03}$ and the field specific LSC value ($LSC_{RII08/GLI\ 03}$) are presented in Table 9.3. Fine sediments are more likely to have higher affinity for pollutants than coarse sediments. LSC in the text relates to $LSC_{central\ 97\text{-}03}$.

Table 9.3. Limits of Significant Contamination (LSC) for the Glitne field in 2003, the central part of Region II based on data from 1997 to 2003 ($LSC_{central\ 97\text{-}03}$) and the whole of Region II based on data from 1997 to 2003 ($LSC_{regII\ 97\text{-}03}$). For comparison, LSC-values from 2000 are included. All values in mg/kg dry sediment.

	THC	PAH (16)	NPD's	Decalins	Cu	Cr	Zn	Ba	Pb	Cd	Hg
$LSC_{RII08/GLI\ 03}$	18.8	0.097	0.045	0.332	1.6	9.7	12.6	183	5.5	0.03[1]	0.015
$LSC_{central\ 97\text{-}03}$	14.5	*	*	*	2.2	9.4	12.4	161	6.8	0.03[1]	0.012
$LSC_{regII\ 97\text{-}03}$	13.3	*	*	*	2.0	9.4	11.1	136	6.6	0.03[1]	0.011
$LSC_{RII08/GLI\ 00}$**	13.5	*	0.033	0.026	2.0	10.2	12.2	286	8.2	0.02	0.010
$LSC_{regII\ 97\text{-}00}$**	9.8	*	*	*	2.0	9.6	8.9	146	7.0	0.03	0.008

* NPD's, PAH's and decalins are not analysed at regional sites in 1997 and 2000.
** Data from Mannvik & al. 2001
[1] LSC = detection limit

9.2.2.2 Hydrocarbons

Summarised results of the hydrocarbon analyses, along with the content of selected hydrocarbon compounds in the different layers (0-1, 1-3 and 3-6) are given in Table 9.4 and Table 9.5. The complete data set including replicates is given in the Appendix. Comparison of the THC content in 2003 with the previous survey is presented in Figure 9.3.

Table 9.4. The content of oil hydrocarbons in sediments from Glitne in 2003. All values in mg/kg dry sediment. THC values above $LSC_{central\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{RII08/GLI\ 03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data for the regional and field reference sites in the central part of region II are included.

Site	THC		PAH(16)		NPD		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
GLI01	154.5	62.8	0.060	0.006	0.090	0.068	51.20	23.769
GLI02	10.1	4.0	0.037	0.003	0.016	0.001	1.343	1.363
GLI03	17.7	3.9	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
GLI04	12.6	2.9	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
GLI05	10.3	1.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
GLI06	10.8	1.7	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
GLI07	13.7	4.3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
GLI10	36.5	31.0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
GLI11	8.3	4.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
GLI14	15.2	4.3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
GLI15	9.5	3.8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
RII08	14.2	3.7	0.066	0.013	0.027	0.008	0.224	0.046
av. ± sd.[1]	27.2 ± 43							
min – max[1]	8.3-154.5							
av. ± sd.[2]	11.2±4.0		0.067±0.027		0.020±0.004		0.232±0.085	
min – max[2]	<3.0-15.5		0.013-0.102		0.012-0.027		0.095-0.461	

n.a. = not analysed.
[1] Field sites, exclusive RII08
[2] Reg + $Ref_{central\ 03}$

THC was found in the range from 8.3 to 154.5 mg/kg, and THC concentrations above LSC were found at GLI01, GLI03, GLI10 and GLI14. Highest concentrations were found at GLI01, 250 m to the north of the field centre. Since the baseline survey in 2000 the THC content has increased at GLI01, 250 m to the north, and GLI10, 500 m to the west. At the other sites only minor changes in THC content between 2000 and 2003 were found, although a tendency of increased THC content was seen.

In vertical sediment samples from GLI01 THC was present above LSC in 1-3 and 3-6 cm layer. The THC concentration was highest (190 mg/kg) in the upper layer and lowest in the deepest layer (14 mg/kg). Decalins occurred above LSC in all layers, and the concentrations of decalins decreased with decreasing depth in the sediments. NPD occurred above LSC in the upper layer, 0-1 cm. At GLI02 (500 m to the north of the field centre) declins were present above LSC in all layers. The concentrations were decreasing with increasing depth in the sediments, indicating recent supply to the sediments. Also at the reference site RII08/GLI THC occurred above LSC in 0-1 and 3-6 cm layers, and PAH occurred above LSC in the 1-3 and 3-6 cm layers (Table 9.5).

Table 9.5. The content of oil hydrocarbons in vertical sections of sediment from 3 sampling sites at Glitne in 2003. All values in mg/kg dry sediment. THC values above $LSC_{central\ 97\text{-}03}$ and PAH, NPD and decalins values above $LSC_{RII08/GLI\ 03}$ are dark shaded.

Site	Layer (cm)	THC	PAH(16)	NPD	Decalins
GLI01	0-1	190.5	0.055	0.166	67.300
	1-3	91.8	0.057	0.040	28.100
	3-6	13.7	0.069	0.027	2.080
GLI02	0-1	14.0	0.040	0.015	2.880
	1-3	7.3	0.044	0.014	0.810
	3-6	6.4	0.060	0.021	0.630
RII08	0-1	14.6	0.075	0.028	0.235
	1-3	14.1	0.099	0.035	0.305
	3-6	19.3	0.108	0.033	0.265

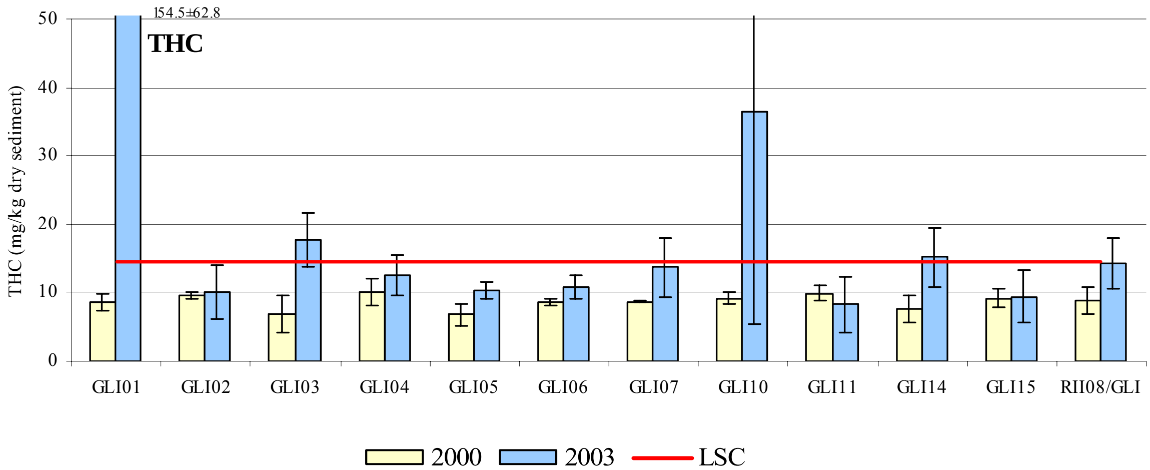


Figure 9.3. Average THC concentrations and standard deviations in sediments from Glitne in 2003 and previous years. Red line is $LSC_{central\ 97\text{-}03}$.

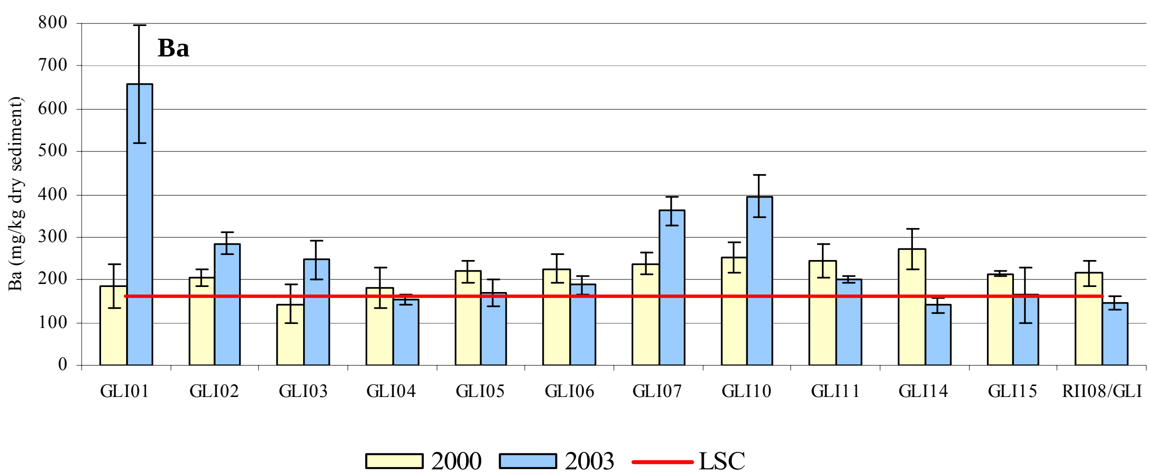


Figure 9.4. Average barium concentrations and standard deviations in sediments from Glitne in 2003 and previous years. Red line is $LSC_{central\ 97\text{-}03}$.

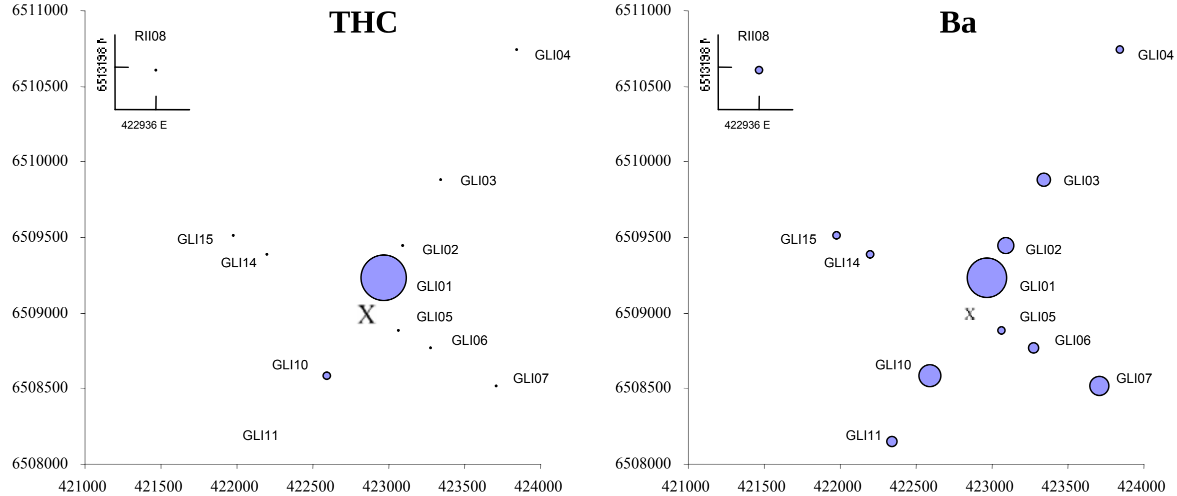


Figure 9.5. Distribution of THC and barium in sediments at the sampling sites at Glitne in 2003. The size of the circle indicate the amount of THC and Ba. The field centre is marked with an X.

9.2.2.3 Metals

Table 9.6 summarises the results of the metal analyses of the Glitne field in 2003. Concentrations of selected metals in the different layers (0-1, 1-3 and 3-6 cm) of sediment are given in Table 9.7, whereas the complete data set including replicates is given in the Appendix. Comparisons of the metal contents in 2003 with the metal contents in 2000 are presented in Figure 9.6.

Table 9.6 Content of metals in sediments from Glitne in 2003. All values in mg/kg dry sediment. Values above $LSC_{central\ 97\text{-}03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data in the regional and field reference sites in the central part of the region II are included.

Site	Cu		Cr		Zn		Ba		Pb		Cd		Hg	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
GLI01	1.8	0.3	8.6	0.8	15.3	3.1	658	137	6.4	0.5	<0.03	-	0.012	0.002
GLI02	1.5	0.4	8.3	0.2	13.3	5.4	285	26	5.3	0.2	<0.03	-	0.008	0.001
GLI03	1.1	0.2	8.2	0.7	12.2	3.1	246	44	5.1	0.5	<0.03	-	n.a.	n.a.
GLI04	1.0	0.2	8.5	0.1	22.3	11.5	155	12	5.3	0.2	<0.03	-	n.a.	n.a.
GLI05	0.9	0.2	7.8	0.7	18.2	1.2	169	32	4.9	0.5	<0.03	-	n.a.	n.a.
GLI06	1.2	0.1	9.2	0.3	18.4	5.2	188	22	5.4	0.2	<0.03	-	n.a.	n.a.
GLI07	1.1	0.2	8.6	0.8	17.4	2.9	361	33	5.0	0.4	<0.03	-	n.a.	n.a.
GLI10	1.5	0.3	8.7	0.8	11.3	1.3	396	49	5.9	0.6	<0.03	-	n.a.	n.a.
GLI11	1.2	0.1	8.4	0.6	10.2	0.1	200	8	5.0	0.4	<0.03	-	n.a.	n.a.
GLI14	0.8	0.1	7.9	0.3	16.2	5.7	141	18	5.0	0.1	<0.03	-	n.a.	n.a.
GLI15	1.8	0.5	8.6	0.7	19.3	4.2	164	65	5.1	0.9	<0.03	-	n.a.	n.a.
RII08	1.4	0.1	8.9	0.4	12.0	0.3	146	16	5.1	0.1	<0.03	-	0.011	0.002
av. ± sd.[1]	1.3 ± 0.3		8.4 ± 0.4		15.8 ± 3.7		269 ± 154		5.3 ± 0.5		<0.03			
min – max[1]	0.8 - 1.8		7.8 - 9.2		10.2 - 22.3		141 - 658		4.9 - 6.4		<0.03			
av. ± sd.[2]	1.2 ± 0.4		6.9 ± 1.2		9.4 ± 1.3		66 ± 31		4.2 ± 0.6		<0.03		0.009±0.003	
min – max[2]	<0.6-1.7		4.9-8.9		6.8-12.0		10-146		3.4-5.1		<0.03		0.006-0.014	

n.a. = not analysed.
[1] Field sites, exclusive RII08
[2] Reg + Ref $_{central\ 03}$

Table 9.7. The content of metals in vertical sections of sediment from 3 sampling sites at Glitne in 2003. All values in mg/kg dry sediment. Values above $LSC_{central\ 97\text{-}03}$ are dark shaded.

Site	Layer (cm)	Cu	Cr	Zn	Ba	Pb	Cd	Hg
GLI01	0-1	2.0	9.0	18.7	737	6.8	<0.03	0.010
	1-3	1.6	9.1	11.3	738	6.8	<0.03	0.010
	3-6	1.0	8.2	9.6	179	5.3	<0.03	0.008
GLI02	0-1	1.6	8.2	10.5	267	5.2	<0.03	0.009
	1-3	1.1	8.9	10.0	212	5.3	<0.03	0.007
	3-6	1.1	8.3	10.3	163	5.3	<0.03	0.009
RII08	0-1	1.3	8.8	12.4	156	5.0	<0.03	0.009
	1-3	1.2	8.8	11.8	134	5.0	<0.03	0.008
	3-6	1.1	8.1	11.0	122	5.0	<0.03	0.011

Barium was found in a range from 141 to 658 mg/kg, lead from 4.9 to 6.4 mg/kg, cadmium was <0.03 mg/kg at all sites, copper from 0.8 to 1.8 mg/kg, chromium from 7.8 to 9.2 mg/kg, mercury from 0.008 to 0.012 mg/kg and zinc from 10.2 to 22.3 mg/kg (Table 9.6). Sediments from all sites, except GLI04, GLI14 and the reference site RII08 had barium content above LSC. Zinc occurred above LSC at all sites, except at GLI03, GLI10 and GLI11. Copper, chromium, lead, cadmium and mercury were below LSC at all sites.

Vertical sediment samples (0-1, 1-3 and 3-6 cm) from GLI01 and GLI02 (250 and 500 m to the north and downstream from the installation) had barium content above LSC in all depth intervals. Highest barium content was found in the upper layers (0-1 and 1-3 cm), indicating recent supply of barium. Zinc was present above LSC in the upper layer (0-1 cm) at GLI01.

Between the baseline survey in 2000 and the monitoring survey in 2003 had the barium content in the sediments at GLI01, GLI02, GLI03, GLI07 and GLI10 increased, and so had the zinc content at all sites. The others metals were at the same levels or lower than in 2000.

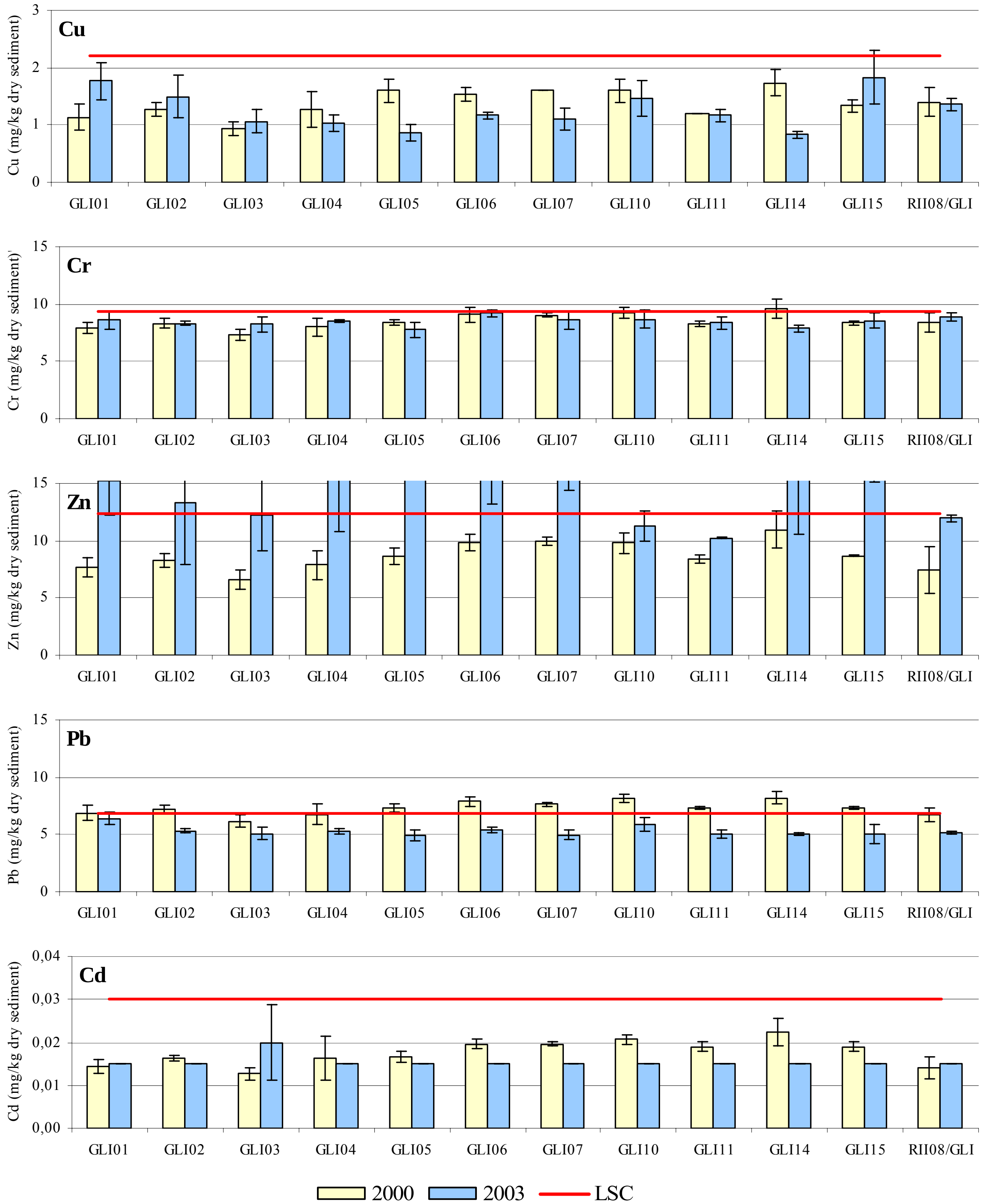


Figure 9.6. Average content and standard deviations of metals in sediment from Glitne in 2003 and previous surveys. Red line is $LSC_{central\ 97\text{-}03}$.

The field sites at Glitne were compared to nearby regional/reference sites (RII07/SLV and RII08/GLI) based on sediment characteristics (TOM and pelite) and chemical content in the sediments (Figure 9.7). GLI01, GLI07 and GLI10 did not group together with the other sites, but were separated from the other sites due to the higher content of chemical compounds in the sediments. RII07 was also clearly separated from the sites at Glitne.

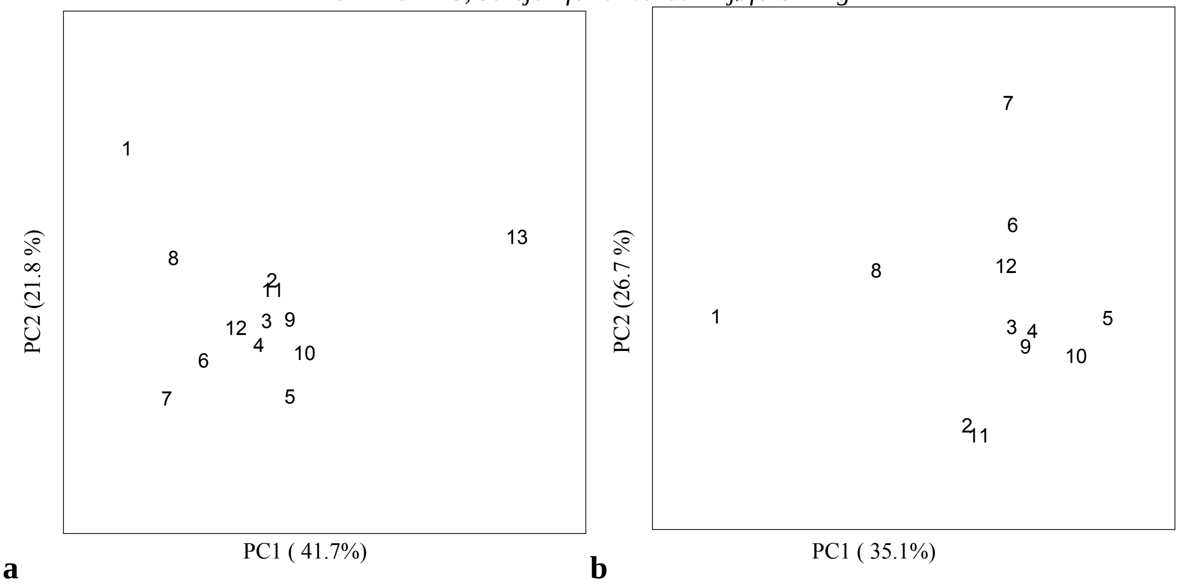


Figure 9.7. 2-D plot from the PCA analysis of environmental variables (% pelite, % sand, % gravel, median Φ, TOM, Cu, Ba, Zn, Cr, Pb and THC) carried out on the:

a) Glitne field sites compared to regional sites RII07/SLV and RII08/GLI. Explained variation in the data 63.6 %.
b) Glitne field sites in 2003. Explained variation in the data 61.8 %.

Numbers in the plot identify the sampling sites. See table below.

1	GLI01	6	GLI06	11	GLI15
2	GLI02	7	GLI07	12	RII08/GLI
3	GLI03	8	GLI10	13	RII07/SLV
4	GLI04	9	GLI11		
5	GLI05	10	GLI14		

9.2.3 Bottom fauna

A summary of the distribution of individuals and taxa within the main taxonomic groups is given in Table 9.8. Unidentified juveniles of the sea urchin Spatangoids (19300 individuals) and the brittle star *Amphiura filiformis* (316 individuals) are omitted from the analyses, as they occurred in extremely high numbers. In total, 8701 individuals within 241 taxa were collected at Glitne in 2003. The fauna was numerically dominated by annelida with 66 % the individuals and 47 % of the taxa. A complete species list is available in the Appendix.

Table 9.8. Distribution of individuals and taxa within the main taxonomic groups at Glitne in 2003 including data from RII08 (unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis* are not included).

Main taxonomic groups	Number of individuals	%	Number of taxa	%
Annelida	5754	66	113	47
Arthropoda	648	7	56	23
Mollusca	1039	12	46	19
Echidermata	650	7	10	4
Diverse groups	610	7	16	7
Total	8701	100	241	100

The species/area curve for RII08/GLI indicates that five replicate samples give a representative impression of the bottom fauna in the area (Figure 9.8). However, as more area is sampled, more taxa are collected, indicating that not even 10 replicate samples give the full species assemblage of the area.

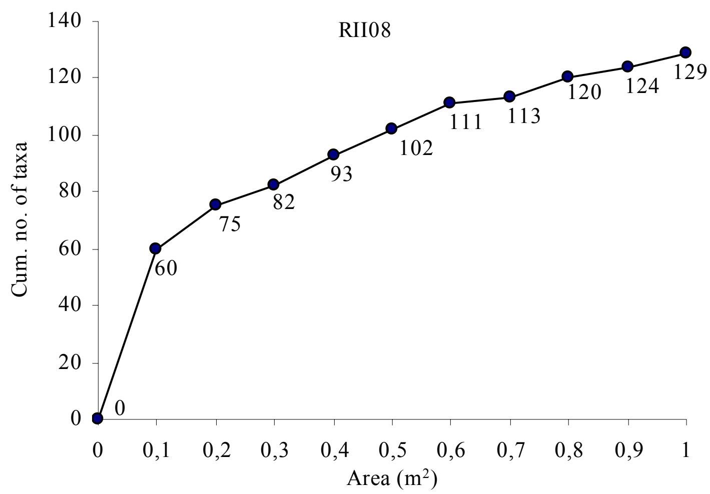


Figure 9.8. Species/area curve for the reference station at the Glitne field. Exclusive unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis*.

The distribution of individuals and taxa are shown in Figure 9.9. Number of individuals and taxa at each site, and the calculated diversity indexes (H' and ES_{100}) are given in Table 9.9 and Figure 9.10. The number of individuals varied from 480 (GLI15) to 887 (GLI11), and the number of taxa varied from 85 (GLI15) to 119 (GLI11). The Shannon-Wiener diversity index (H') varied from 5.21 (GLI07) to 5.68 (GLI05), whereas the ES_{100} index varied from 41.7 (GLI03) to 46.7 (GLI05). The evenness index J varied from 0.77 (GLI01 and GLI07) to 0.84 (GLI05). The corresponding values at RII08/GLI are within or near the variation at the field sites. The number of taxa, diversity and evenness indicate good environmental conditions at all sites as in 2000. At all sites except GLI02, GLI03 and GLI04 it were fewer individuals than in 2000. The number of taxa was approximately the same in 2000 and 2003, except at GLI15 where it was lower in 2003. Species diversity was higher at GLI01, GLI05, GLI06 GLI10 and GLI11 in 2003 than in 2000 and approximately equal in 2000 and 2003 at the other sites.

Table 9.9. Number of individuals, species/taxa and selected community indices for each station (0.5 m^2) at the Glitne field in 2003. Exclusive unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis*.

Site number	Number of individuals	Number of taxa	Diversity H'	Evenness J	H'-max	ES_{100}
GLI01	832	116	5.29	0.77	6.86	41.8
GLI02	689	105	5.39	0.80	6.71	42.4
GLI03	734	105	5.26	0.78	6.71	41.7
GLI04	534	94	5.39	0.82	6.55	43.8
GLI05	622	107	5.68	0.84	6.74	46.7
GLI06	671	112	5.42	0.80	6.81	44.7
GLI07	706	107	5.21	0.77	6.74	42.0
GLI10	858	116	5.55	0.81	6.86	44.1
GLI11	887	119	5.42	0.79	6.89	44.0
GLI14	639	104	5.33	0.80	6.70	43.3
GLI15	480	85	5.26	0.82	6.41	42.2
RII08 (6-10)	542	102	5.38	0.81	6.67	46.4
RII08 (11-15)	507	94	5.07	0.77	6.55	41.1
RII08 (6-15)	1049	129	5.36	0.76	7.01	44.0
Sum[1]	7652	232				
Average[1]	696	106	5.38	0.80	6.73	43.3
SD[1]	128	10	0.14	0.02	0.14	1.5
Min[1]	480	85	5.21	0.77	6.41	41.7
Max[1]	887	119	5.68	0.84	6.89	46.7
Average[2]	774	113	5.55	0.81	6.81	44.3
SD[2]	230	14	0.24	0.02	0.18	2.6
Min[2]	488	94	5.12	0.79	6.55	38.7
Max[2]	1202	141	5.85	0.85	7.14	47.9

[1]Field sites, exclusive RII08
[2]Reg + ref $_{\text{central 03}}$

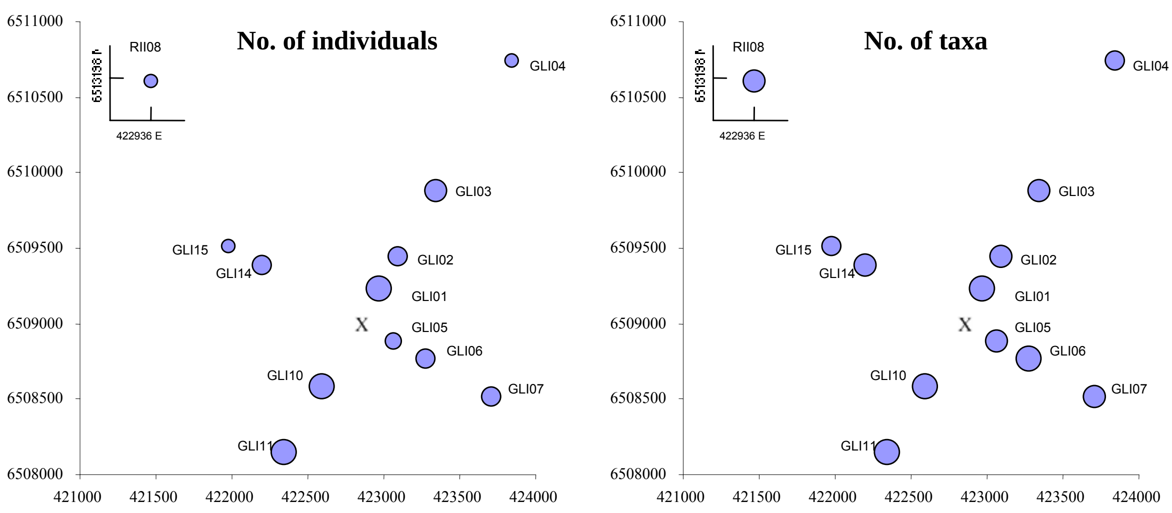


Figure 9.9. Distribution of bottom fauna (individuals and taxa) among the sampling sites in 2003. The size of the circle indicates the number of individuals and taxa. Exclusive unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis*. Values for RII08/GLI are average of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2). The field centre is marked with an X.

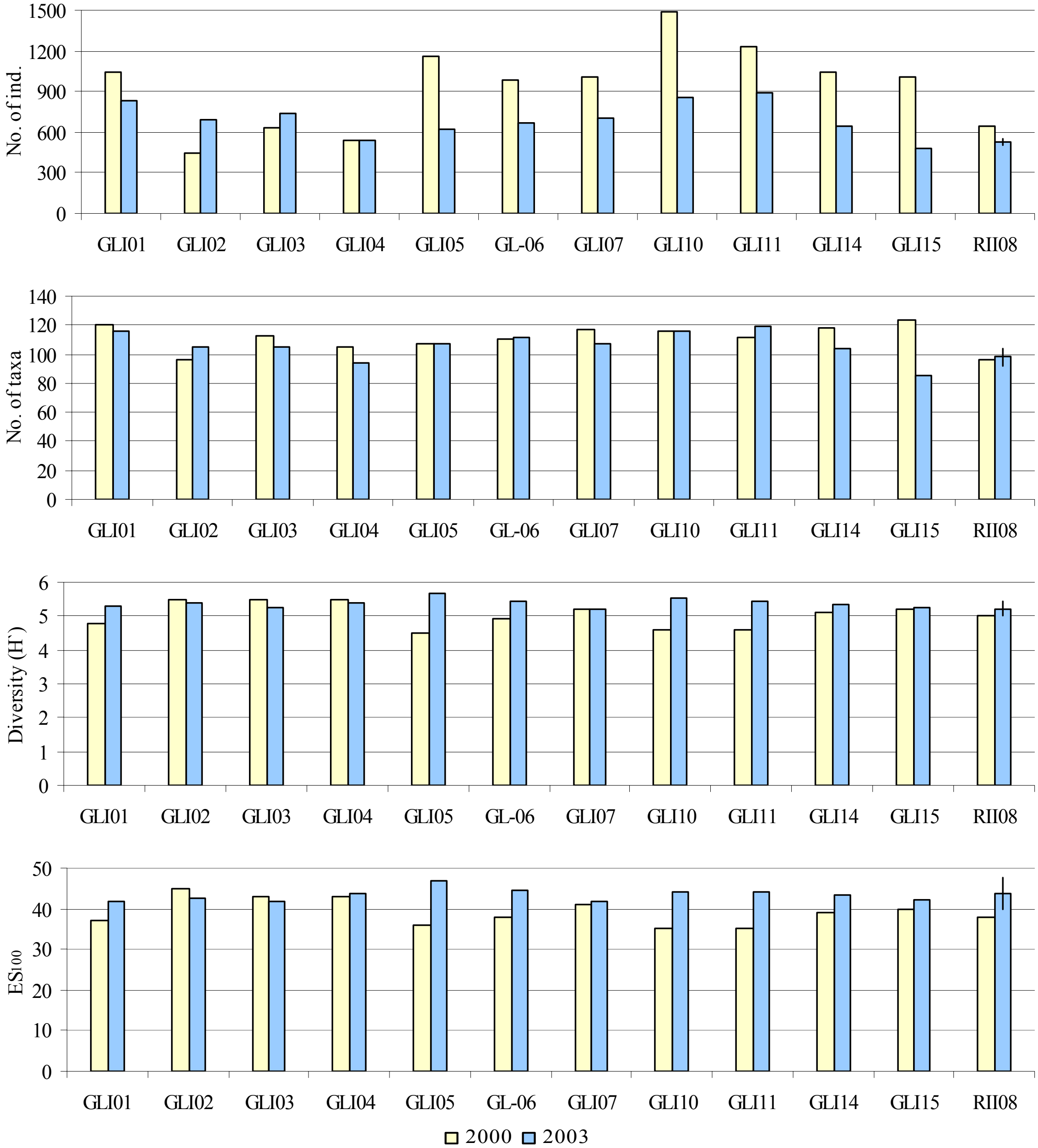


Figure 9.10. Number of individuals, taxa and selected community indices for each site (0.5 m^2) at the Glitne field for 2000 and 2003. (Exclusive unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis* in 2003). Values for RII08 are average ± standard deviation of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2)

Distribution of taxa in geometrical classes is presented in Figure 9.11. The smooth graphs are indicating undisturbed bottom fauna in 2003.

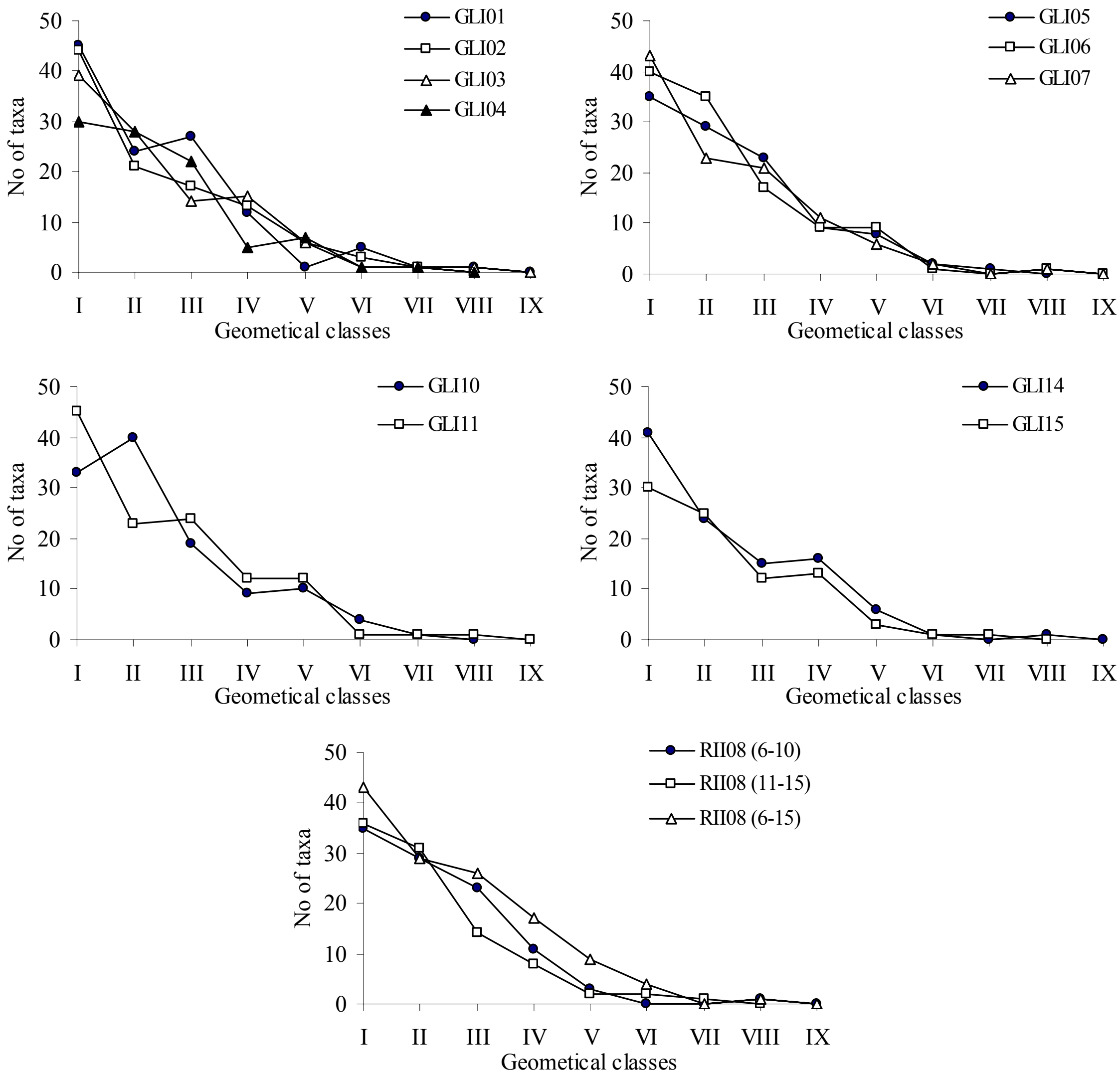


Figure 9.11. Distribution of taxa in geometrical classes for the sites at Glitne in 2003. Exclusive unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis*.

The ten most numerous taxa are listed in Table 9.12 at the end of this chapter. The list comprise 22 taxa and 6512 individuals, which was 9.1 % of all (241) taxa and 74.9 % of all (8701) individuals. The most abundant and widespread species were the polychetes *Myriochele oculata* and *Paramphinone jeffreysii* and the bivalve *Thyasira croulinensis*. The polycheate group *Sabellidae* indet. was also widespread but occurred only in low numbers (8) at the reference site RII08/GLI. *Paramphinome jeffreysii* and *Thyasira croulinensis* were also abundant and widespread in 2000.

The results of the multivariate analyses are given in the dendrogramme (Figure 9.12) and the MDS plott (Figure 9.13).

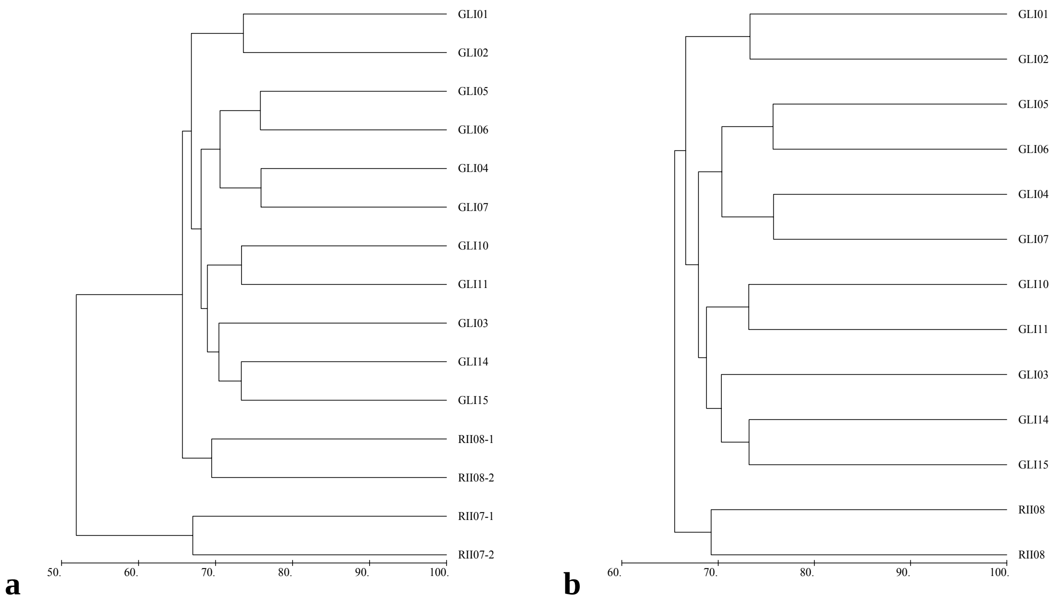


Figure 9.12. Dendrogram showing the similarity between fauna from

a) sampling sites at Glitne and reference site at Sleipner Vest in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.
b) sampling sites at Glitne in 2003. Exclusive unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis*.

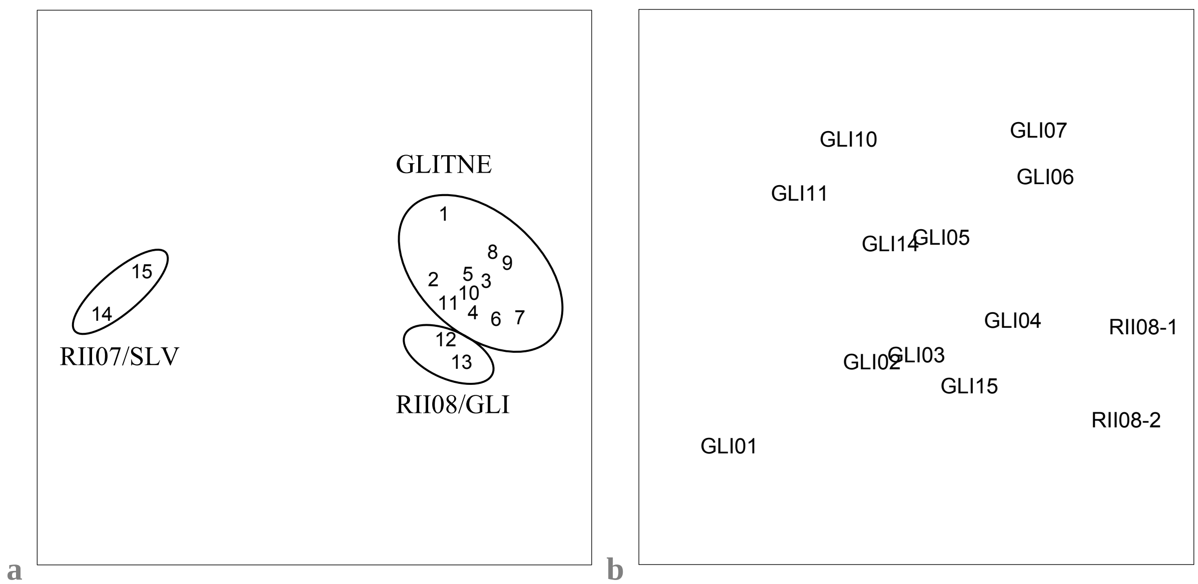


Figure 9.13. A 2-dimetional plott of the MDS analysis of the fauna data from:

a) Sampling sites at Giltne compared to the reference site at Sleipner Vest in 2003. Stress = 0.09. Exclusive unidentified juveniles of Spatangoida and Echinoidea. Codes in table below.
b) Sampling sites at Glitne in 2003. Stress = 0.16. Exclusive unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis*.

1	GLI01	6	GLI06	11	GLI15
2	GLI02	7	GLI07	12	RII08-1
3	GLI03	8	GLI10	13	RII08-2
4	GLI04	9	GLI11	14	RII07-1
5	GLI05	10	GLI14	15	RII07-2

In the cluster analysis, all sites are grouped together within 65 % similarity, indicating relatively high similarity in the species assemblages within the field. The fauna was not dividing the field into extremely distinct group of sites. However, the reference site had a slightly different fauna assemblage than the field sites and so had the GLI01, 250 m downstream the installation, too. The bivalve Thyasira sarsii was only found in samples from GLI01.

The results of the MDS analyses support the findings in the cluster analysis, confirming the similarity in species assemblage over the field but also that there are some minor differences in the species assemblage within the field. The stress test of the MDS analysis was 0.16, indicating a potential useful fit of the data.

Linking of biotic and environmental variables by BIOENV revealed that THC and sand were best correlated to the biota at $\rho_w = 0.30$ (Table 9.10). This indicates that there was only weak association between some environmental variables and the bottom fauna.

Table 9.10. Combinations of the 10 environmental variables, taken *k* at a time, yielding the best matches of biotic and abiotic similarity matrices for each *k*, as measured by weighted Spearman rank correlation ρ_w. Bold type indicates overall optimum. All possible combinations of variables and associated correlation to the biotic are given in the Appendix.

Number of variables (*k*)	Correlation coefficient (ρ_w)	Environmental variables									
1	0.219	THC									
1	0.210	Ba									
1	0.069	Pb									
1	0.043	TOM									
1	-0.042	Pelite									
1	-0.058	Zn									
1	-0.061	Sand									
1	-0.178	Cu									
1	-0.259	Gravel									
1	-0.277	Cr									
2	**0.303**	**THC**	**Sand**								
3	0.258	THC	Sand	Ba							
4	0.296			Ba	TOM	Pelite	Zn				
5	0.274	THC		Ba	TOM	Pelite	Zn				
6	0.280	THC	Sand	Ba	TOM	Pelite	Zn				
7	0.261	THC	Sand	Ba	TOM	Pelite	Zn	Gravel			
8	0.262	THC	Sand	Ba	TOM	Pelite	Zn	Gravel	Pb		
9	0.175	THC	Sand	Ba	TOM	Pelite	Zn	Gravel	Pb	Cr	
10	0.091	THC	Sand	Ba	TOM	Pelite	Zn	Gravel	Pb	Cr	Cu

9.2.4 Estimation of influenced area

The extension of contamination along sampling transects and the minimum area of contaminated sediments for THC, barium and other metals as well as for faunal disturbance are given in Figure 9.15 and Table 9.11. Since the baseline survey in 2000 five well were drilled. No contaminations were found in the baseline survey. In this monitoring survey contaminations by THC, barium and other metals were revealed at several sampling sites and thus the area influence by the activity at the field was large in 2003 than in 2000.

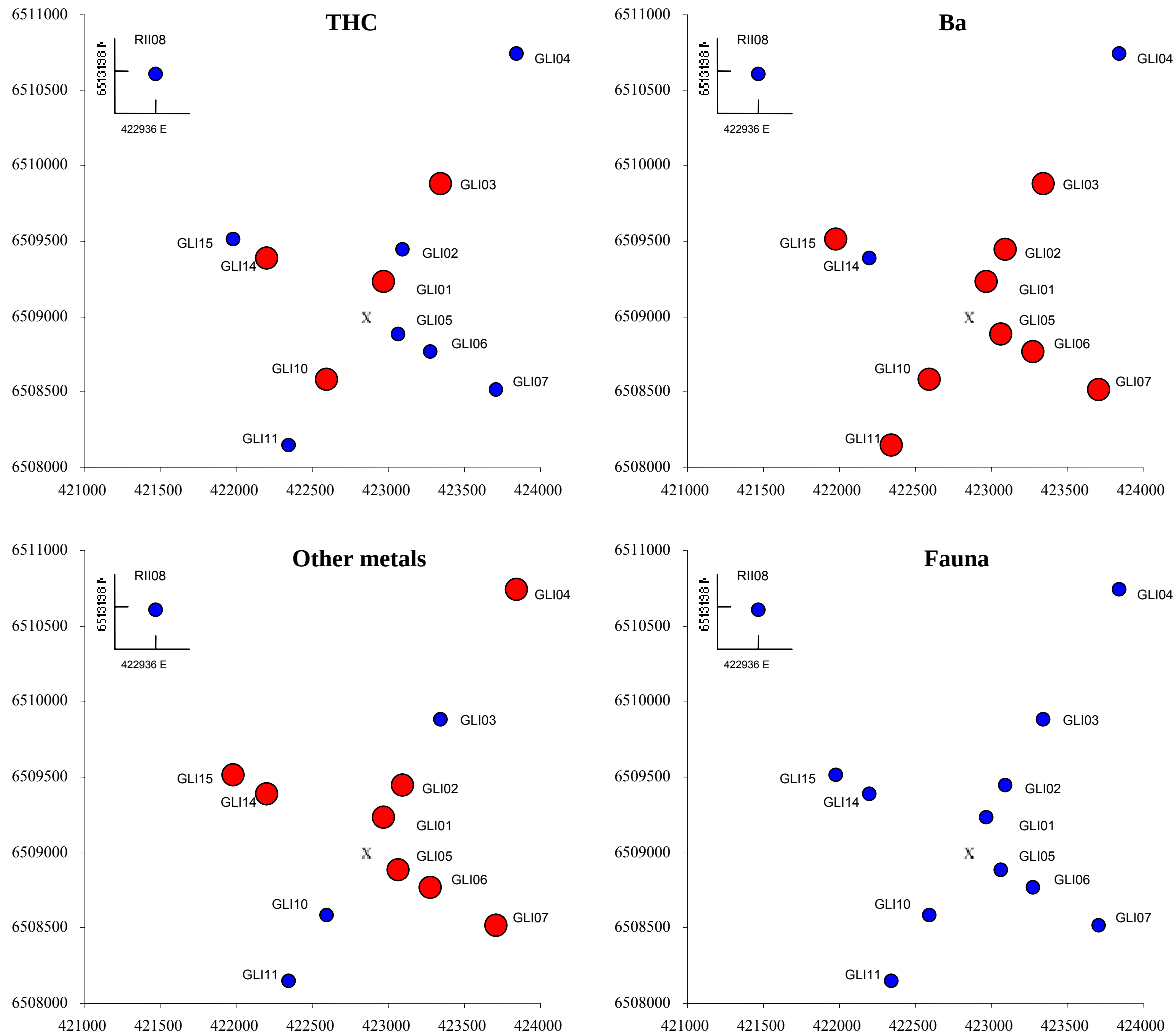


Figure 9.15. Faunal disturbance and chemical contamination of the sediments at Glitne in 2003. The field centre is marked with an X. Uncontaminated sites and sites with no faunal disturbance are marked with small blue circles.

Table 9.11. Estimated distance from the installation of contamination and faunal disturbance and estimated area of contamination and faunal disturbance around the field centre.

Glitne	N	E	S	W	2003	2000
	m	m	m	m	km^2	km^2
THC	1000	0	500	750	0.88	0.00
Ba	1000	1000	1000	1000	3.14	0.00
Other metals	500	1000	0	1000	0.79	0.00
Fauna	0	0	0	0	0	0.00

9.3 Summary and conclusions

In 2000 and 2001 respectively 3 and 2 wells were drilled at Glitne. The sediments are still characterized as fine sand as in 2000. Only minor changes in the sediment characteristics were found and they are most likely caused by natural variation. The amounts of THC in the sediments had increased at the sites 250 m to the north and 500 m to the west of the field centre since 2000. And the barium content in the sediments increased at all sites out to 1000 m to the north and at 500 m to the west. An increase of barium was also found at 1000 m to the east. The other metals were at the same levels as in 2000 except for zinc which showed a general tendency of somewhat higher concentrations. The species diversity was high as in 2000. Comparisons of fauna assemblage showed high homogeneity across the Glitne field and there were only weak association between the fauna and the measured environmental variables. Due to increased content of THC and barium the area of contamination was larger in 2003, although there was no faunal disturbance.

Table 9.12. Number of individuals and relative abundance for the ten predominant taxa at each site at the Glitne field in 2003. Exclusive unidentified juveniles of Spatangoida and juveniles of *Amphiura filiformis*.

GLI01	No. of ind.	%	Cum %
Myriochele oculata	134	16.1	16.1
Sabellidae indet.	111	13.3	29.4
Nemertini indet.	46	5.5	35.0
Pseudopolydora paucibranchiata	44	5.3	40.3
Paramphinome jeffreysii	39	4.7	45.0
Terebellides stroemi	34	4.1	49.0
Cerianthus lloydii	32	3.8	52.9
Nephtys hystericis	17	2.0	54.9
Lumbrineris scopa	15	1.8	56.7
Thyasira croulinensis	13	1.6	58.3

GLI02	No. of ind.	%	Cum %
Myriochele oculata	111	16.1	16.1
Sabellidae indet.	53	7.7	23.8
Paramphinome jeffreysii	47	6.8	30.6
Amphiura filiformis	32	4.6	35.3
Thyasira croulinensis	26	3.8	39.0
Pseudopolydora paucibranchiata	22	3.2	42.2
Terebellides stroemi	20	2.9	45.1
Spiophanes kroeyeri	20	2.9	48.0
Nemertini indet.	18	2.6	50.7
Nephtys hystericis	18	2.6	53.3

GLI03	No. of ind.	%	Cum %
Myriochele oculata	148	20.2	20.2
Sabellidae indet.	68	9.3	29.4
Pseudopolydora paucibranchiata	34	4.6	34.1
Thyasira croulinensis	30	4.1	38.1
Terebellides stroemi	25	3.4	41.6
Parvicardium minimum	25	3.4	45.0
Paramphinome jeffreysii	19	2.6	47.5
Spiophanes kroeyeri	18	2.5	50.0
Laonice sarsi	16	2.2	52.2
Nephtys hystericis	15	2.0	54.2
Amphiura chiajei	15	2.0	56.3

GLI04	No. of ind.	%	Cum %
Myriochele oculata	94	17.6	17.6
Sabellidae indet.	37	6.9	24.5
Thyasira croulinensis	29	5.4	30.0
Spiophanes kroeyeri	23	4.3	34.3
Amphiura chiajei	19	3.6	37.8
Nephtys hystericis	17	3.2	41.0
Cerianthus lloydii	17	3.2	44.2
Eclysippe vanelli	17	3.2	47.4
Paramphinome jeffreysii	16	3.0	50.4
Phoronis sp.	15	2.8	53.2

GLI05	No. of ind.	%	Cum %
Myriochele oculata	81	13.0	13.0
Paramphinome jeffreysii	35	5.6	18.6
Sabellidae indet.	33	5.3	24.0
Lumbrineris scopa	26	4.2	28.1
Amphiura filiformis	22	3.5	31.7
Thyasira croulinensis	20	3.2	34.9
Pseudopolydora paucibranchiata	20	3.2	38.1
Thyasira ferruginea	18	2.9	41.0
Amphiura chiajei	17	2.7	43.7
Nephtys hystericis	17	2.7	46.5

GLI06	No. of ind.	%	Cum %
Myriochele oculata	141	21.0	21.0
Thyasira croulinensis	42	6.3	27.3
Amphiura chiajei	27	4.0	31.3
Paramphinome jeffreysii	26	3.9	35.2
Nephtys hystericis	25	3.7	38.9
Lumbrineris scopa	20	3.0	41.9
Sabellidae indet.	17	2.5	44.4
Amphiura filiformis	17	2.5	46.9
Thyasira ferruginea	17	2.5	49.5
Spiophanes kroeyeri	16	2.4	51.9
Eclysippe vanelli	16	2.4	54.2

GLI07	No. of ind.	%	Cum %
Myriochele oculata	166	23.5	23.5
Thyasira croulinensis	45	6.4	29.9
Nephtys hystericis	32	4.5	34.4
Amphiura chiajei	29	4.1	38.5
Sabellidae indet.	28	4.0	42.5
Spiophanes kroeyeri	28	4.0	46.5
Paramphinome jeffreysii	20	2.8	49.3
Parvicardium minimum	19	2.7	52.0
Eclysippe vanelli	16	2.3	54.2
Lumbrineris scopa	15	2.1	56.4

GLI10	No. of ind.	%	Cum %
Myriochele oculata	123	14.3	14.3
Paramphinome jeffreysii	63	7.3	21.7
Sabellidae indet.	48	5.6	27.3
Thyasira croulinensis	42	4.9	32.2
Pseudopolydora paucibranchiata	36	4.2	36.4
Lumbrineris scopa	31	3.6	40.0
Spiophanes kroeyeri	27	3.1	43.1
Amphiura chiajei	25	2.9	46.0
Eclysippe vanelli	25	2.9	49.0
Laonice sarsi	25	2.9	51.9

GLI11	No. of ind.	%	Cum %
Myriochele oculata	176	19.8	19.8
Sabellidae indet.	73	8.2	28.1
Thyasira croulinensis	44	5.0	33.0
Spiophanes kroeyeri	30	3.4	36.4
Paramphinome jeffreysii	23	2.6	39.0
Amphiura chiajei	23	2.6	41.6
Eclysippe vanelli	21	2.4	44.0
Nephtys hystericis	21	2.4	46.3
Amphiura filiformis	21	2.4	48.7
Cerianthus lloydii	20	2.3	51.0

GLI14	No. of ind.	%	Cum %
Myriochele oculata	131	20.5	20.5
Sabellidae indet.	47	7.4	27.9
Eclysippe vanelli	27	4.2	32.1
Thyasira croulinensis	25	3.9	36.0
Paramphinome jeffreysii	25	3.9	39.9
Spiophanes kroeyeri	21	3.3	43.2
Lumbrineris scopa	19	3.0	46.2
Pseudopolydora paucibranchiata	16	2.5	48.7
Nemertini indet.	14	2.2	50.9
Ophiura affinis	14	2.2	53.1

GLI15	No. of ind.	%	Cum %
Myriochele oculata	89	18.5	18.5
Sabellidae indet.	40	8.3	26.9
Thyasira croulinensis	20	4.2	31.0
Myriochele fragilis	18	3.8	34.8
Eclysippe vanelli	17	3.5	38.3
Paramphinome jeffreysii	15	3.1	41.5
Cerianthus lloydii	15	3.1	44.6
Amphiura filiformis	15	3.1	47.7
Nephtys hystericis	13	2.7	50.4
Ampharete falcata	12	2.5	52.9

RII08	No. of ind.	%	Cum %
Myriochele oculata	252	24.0	24.0
Thyasira croulinensis	63	6.0	30.1
Paramphinome jeffreysii	42	4.0	34.1
Parvicardium minimum	42	4.0	38.1
Nephtys hystericis	38	3.6	41.7
Amphiura chiajei	27	2.6	44.3
Spiophanes kroeyeri	25	2.4	46.7
Eclysippe vanelli	23	2.2	48.9
Harpinia antennaria	23	2.2	51.0
Cerianthus lloydii	22	2.1	53.1

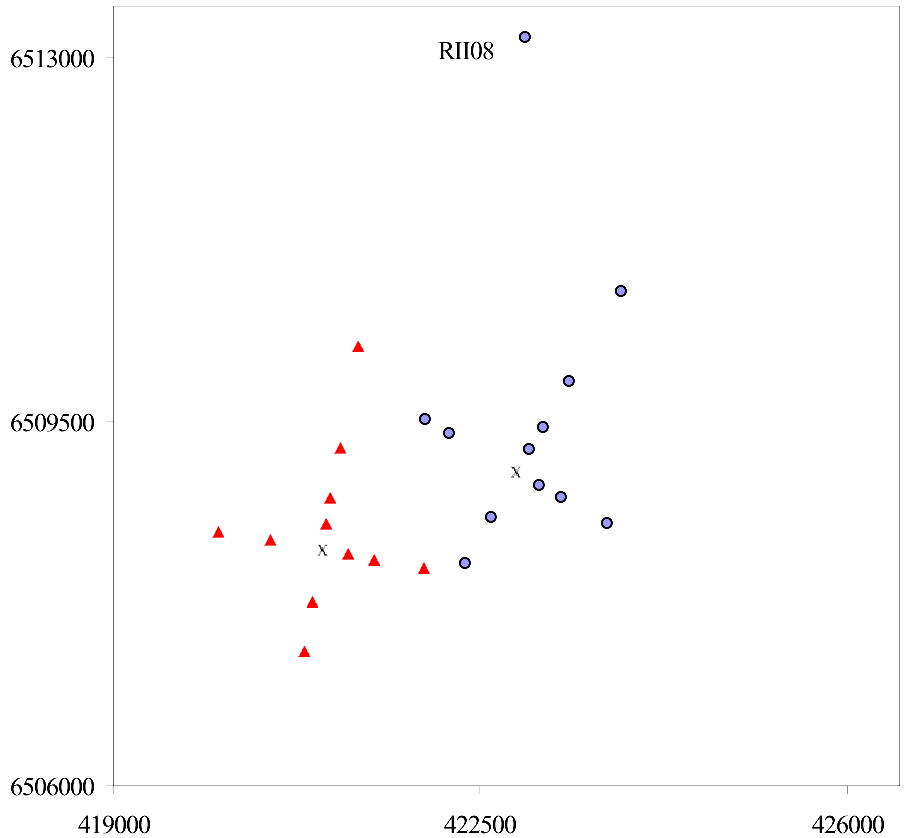


Figure 9.16. Illustration of deviations in planned and real sampling at Glitne. The field centre has been relocated since the baseline survey and the sampling sites have been relocated accordingly. Location of sampling sites according to the programme, red triangle, and location of the sites where sampling were executed, blue circles.

10 Grane

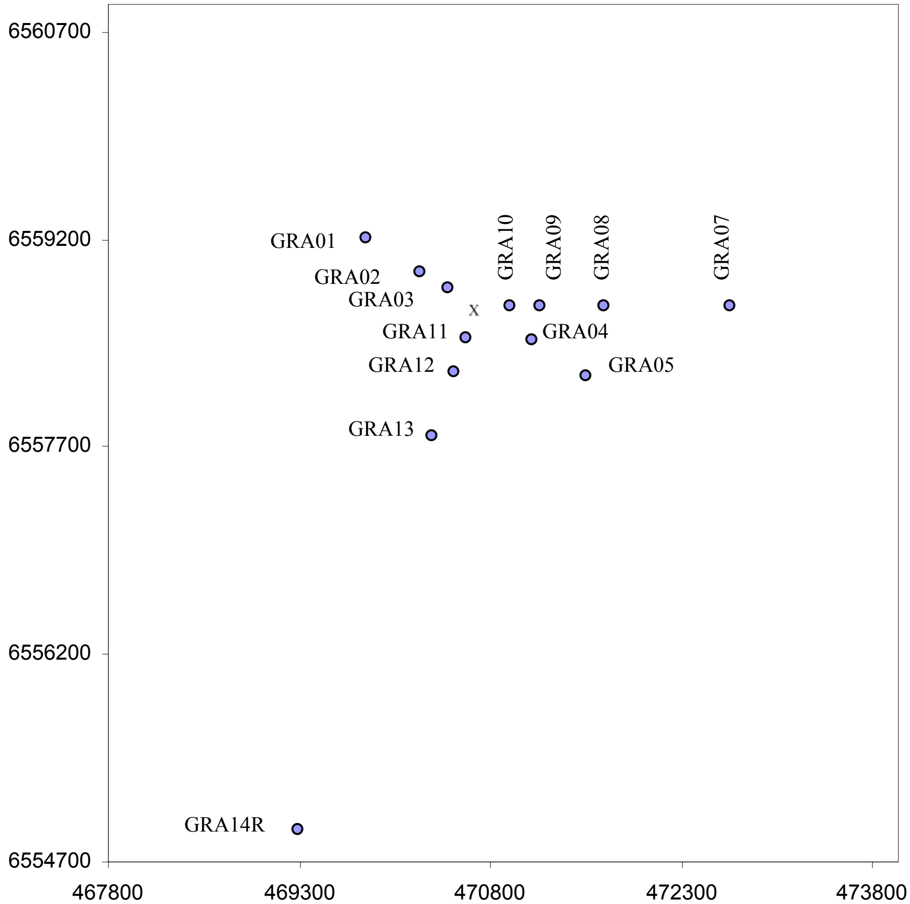
10.1. Introduction

The Grane field is situated in block 25/11. Production started during the fall of 2003, after the sampling was cruise was finished. Earlier Grane was called Hermod and a baseline survey was carried out at Hermod in 1997 (Mannvik & al. 1998). No faunal disturbance or elevated levels of THC were found during the baseline survey. Since the baseline survey the centre position of the field is moved approximately 250 m to the north and 1175 m to the east. Due to the relocation of the centre position the monitoring survey in 2003 did not cover the same sampling sites as in 1997 and no direct comparisons between the two surveys are undertaken. See Figure 10.16 at the end of this chapter for illustration of deviation in planned and real sampling. Recent discharges at Grane are listed in Table 10.1, and sampling sites are shown in Figure 10.1

Table 10.1. Recent well drilling and discharges (ton) from operations and accidents at Grane.

	2001	2002	2003 1. half year
No of wells drilled	4	10	1
Barite	546,4	1399,5	6,7
Cuttings	9685,3	16789,7	295,6
Water-based drilling mud	4774	n.a.	n.a.
Cementing chemicals	2	n.a.	n.a.
Completion chemicals	1	n.a.	n.a.
Accidental discharges	0	2	0

n.a. = Not available



Site	ED50 UTM Zone 31 E	ED50 UTM Zone 31 N	Distance (m) / direction (º)	Depth (m)
GRA-01	469823	6559216	1000/300	129
GRA-02	470256	6558966	500/300	128
GRA-03	470472	6558841	250/300	129
GRA-04	471122	6558466	500/120	128
GRA-05	471555	6558216	1000/120	128
GRA-07	472689	6558716	2000/90	123
GRA-08	471689	6558716	1000/90	126
GRA-09	471189	6558716	500/90	127
GRA-10	470959	6558716	270/90	128
GRA-11	470603	6558481	250/200	128
GRA-12	470518	6558246	500/200	128
GRA-13	470347	6557776	1000/200	129
GRA-14R	469297	6554935	4000/200	128

Figure 10.1. Map showing the internal distribution of sampling sites in Grane in 2003. Positioning according to UTM ED50 zone 31. The field centre is marked with an X.

10.2. Results and discussion

10.2.1 Sediments characteristics

TOM, and the amount (%) of gravel, sand, pelite, median (Φ), sorting, skewness and kurtosis in the sediment from the present survey is presented in Table 10.2. Additional information on colour and smell can be found in the Appendix.

The sediments at Grane are classified as fine sand with median (Φ) values ranging from 2.25 (GRA07) to 2.50 (GRA03). The amount of pelite varied from 9.1 % (GRA07) to 14.1 % (GRA10), the sand varied from 85.5 % (GRA10) to 90.8 % (GRA07), and the TOM varied from 1.5 % (GRA13) to 2.2 % (GRA09). There was slightly more pelite and less sand at the reference site (GRA14R) than at the field sites.

Table 10.2. Total organic matter and sediment grain size at all sites at Grane in 2003. For comparison averages, standard deviations, and max and min values for the regional and reference sites are included.

Site	TOM %	Gravel %	Sand %	Pelite %	Median (Φ)	Sorting	Skewness	Kurtosis
GRA01	2.10	0.25	88.03	11.72	2.48	1.33	0.18	2.75
GRA02	1.74	0.12	89.51	10.38	2.49	1.31	0.18	2.47
GRA03	1.81	0.04	87.97	11.99	2.50	1.48	0.17	1.86
GRA04	1.75	0.01	87.95	12.04	2.44	1.49	0.18	1.92
GRA05	1.78	0.28	90.20	9.52	2.40	1.38	0.09	1.90
GRA07	1.72	0.10	90.79	9.12	2.25	1.47	0.09	1.47
GRA08	1.92	0.07	87.04	12.89	2.38	1.55	0.19	1.84
GRA09	2.18	0.02	87.13	12.85	2.48	1.49	0.21	2.02
GRA10	1.97	0.35	85.52	14.14	2.46	1.60	0.18	2.20
GRA11	2.01	0.24	89.46	10.30	2.45	1.49	0.12	1.63
GRA12	1.53	0.23	89.69	10.08	2.44	1.40	0.13	2.00
GRA13	1.47	0.26	88.70	11.04	2.47	1.43	0.14	2.26
GRA14R	2.05	0.12	86.58	13.30	2.61	1.19	0.44	2.95
Average[1]	1.83	0.16	88.50	11.34	2.44	1.45	0.15	2.03
SD[1]	0.21	0.12	1.51	1.52	0.07	0.09	0.04	0.35
Min[1]	1.47	0.01	85.52	9.12	2.25	1.31	0.09	1.47
Max[1]	2.18	0.35	90.79	14.14	2.50	1.60	0.21	2.75
Average[2]	1.71	0.29	87.23	12.49	2.71	1.16	0.34	1.76
SD[2]	0.45	0.62	5.20	5.12	0.37	0.14	0.19	0.46
Min[2]	0.73	0.00	78.12	3.04	1.76	0.93	0.03	1.05
Max[2]	2.19	2.19	96.61	21.77	3.34	1.40	0.57	2.95

[1] Field sites, exclusive GRA14R
[2] Reg + Ref $_{\text{central 03}}$

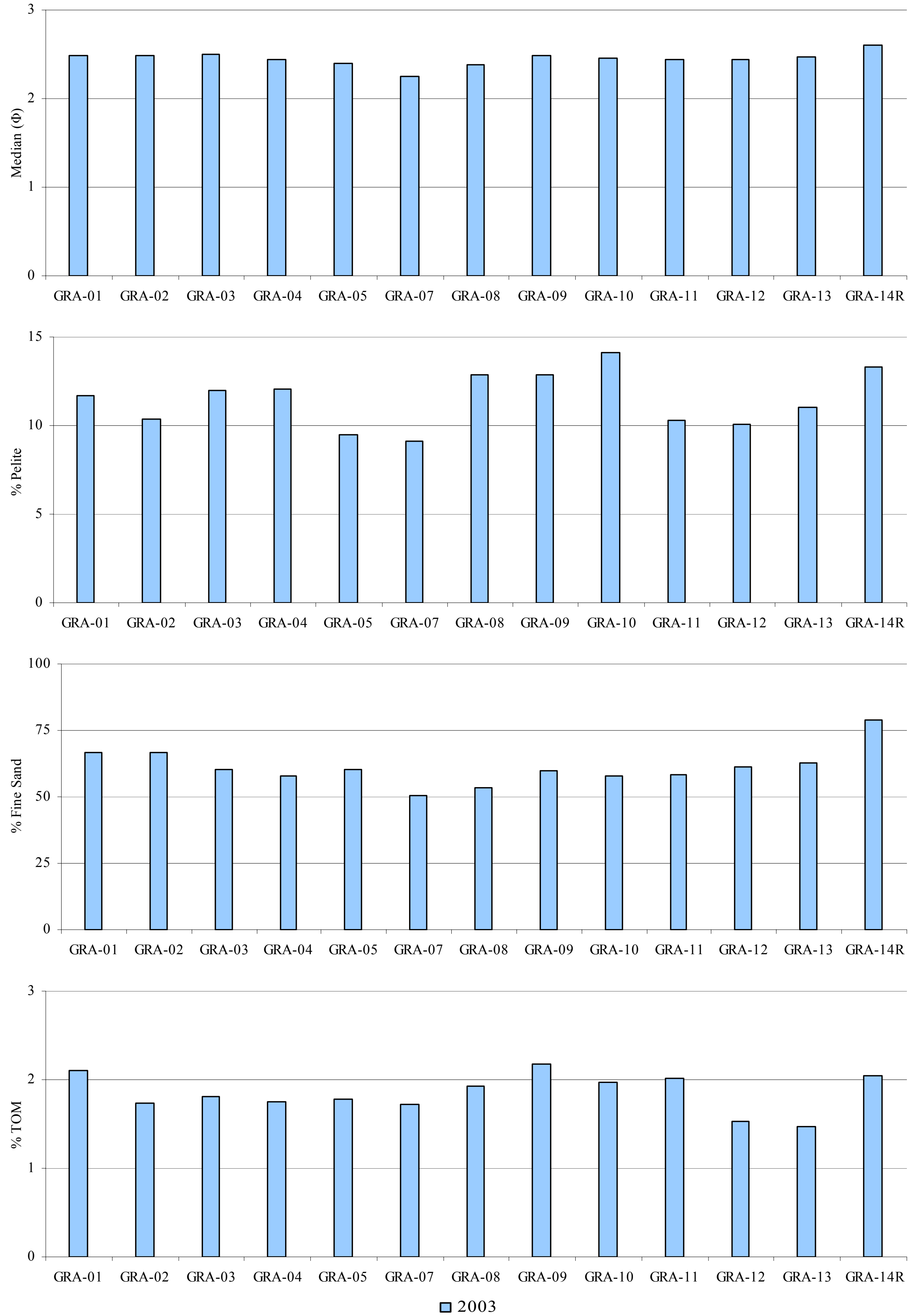


Figure 10.2. Sediment characteristics at Grane in 2003. Fine sand is the relative amount of sand with grain size 63-250 µm.

10.2.2 Chemical compounds

10.2.2.1 LSC

The results of the LSC (limits of significant contamination) calculations of hydrocarbons and metals are presented in the chapter concerning the regional and reference sites. Both the $LSC_{central\ 97\text{-}03}$ and the field specific LSC value ($LSC_{GRA14R\ 03}$) are presented in Table 10.3. LSC in the text relates to $LSC_{central\ 97\text{-}03}$.

Table 10.3. Limits of Significant Contamination (LSC) for the Grane field in 2003, and for the central part of Region II based on data from 1997 to 2003 ($LSC_{central\ 97\text{-}03}$) and the whole of Region II based on data from 1997 to 2003 ($LSC_{regII\ 97\text{-}03}$). For comparison, LSC-values from 2000 are included. All values in mg/kg dry sediment.

	THC	PAH (16)	NPD's	Decalins	Cu	Cr	Zn	Ba	Pb	Cd	Hg
$LSC_{GRA14R\ 03}$	18.2	0.092	0.031	0.324	1.5	7.8	10.3	95	4.9	0.03[1]	0.030
$LSC_{central\ 97\text{-}03}$	14.5	*	*	*	2.2	9.4	12.4	161	6.8	0.03[1]	0.012
$LSC_{regII\ 97\text{-}03}$	13.3	*	*	*	2.0	9.4	11.1	136	6.6	0.03[1]	0.011
$LSC_{regII\ 97\text{-}00}$ **	9.8	*	*	*	2.0	9.6	8.9	146	7.0	0.03	0.008

* NPD's, PAH's and decalins are not analysed at regional sites in 1997 and 2000
** Data from Mannvik & al. 2001
[1] LSC = detection limit

10.2.2.2 Hydrocarbons

Summarised results of the hydrocarbon analyses, along with the content of selected hydrocarbon compounds in the different layers (0-1, 1-3 and 3-6 cm) are given in Table 10.4 and Table 10.5. The complete data set including replicates is given in the Appendix.

Table 10.4. The content of oil hydrocarbons in sediments from Grane in 2003. All values in mg/kg dry sediment. THC values above $LSC_{central\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{GRA14R\ 03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data for the regional and field reference sites in the central part of region II are included.

Site	THC		PAH(16)		NPD		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
GRA01	13.7	8.7	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
GRA02	12.0	1.7	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
GRA03	15.3	4.5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
GRA04	13.6	3.4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
GRA05	14.5	1.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
GRA07	18.2	9.7	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
GRA08	15.9	2.4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
GRA09	10.9	0.8	0.215	0.046	0.075	0.018	0.215	0.026
GRA10	12.2	1.9	0.104	0.006	0.044	0.011	0.208	0.029
GRA11	21.0	2.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
GRA12	24.6	15.0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
GRA13	9.8	7.8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
GRA14R	12.5	2.4	0.063	0.012	0.020	0.005	0.238	0.037
av. ± sd.[1]	15.2±4.3							
min – max[1]	9.8-24.6							
av. ± sd.[2]	11.2±4.0		0.067±0.027		0.020±0.004		0.232±0.085	
min – max[2]	<3.0-15.5		0.013-0.102		0.012-0.027		0.095-0.461	

n.a. = not analysed.
[1] Field sites, exclusive GRA14R
[2] Reg + Ref $_{central\ 03}$

THC was found in the range from 9.8 to 24.6 mg/kg, and THC concentrations above LSC were found at GRA03, GRA07, GRA08, GRA11 and GRA12. Highest concentrations were found at GRA11 and GRA12 (21.0 and 24.6 mg/kg) at 250 and 500 m to the southwest of the field centre.

THC content above LSC was not found in the vertical samples of the sediments. PAH and NPD content were above LSC in the 0-1 cm layer at GRA10. PAH and NPD were above LSC in the 0-1 and 3-6 cm layers and decalins were above LSC in the 3-6 cm layer at GRA09, 500 m to the east of the field centre (Table 10.5).

Table 10.5. The content of oil hydrocarbons in vertical sections of sediment from 3 sampling sites at Grane in 2003. All values in mg/kg dry sediment. THC values above $LSC_{central\ 97\text{-}03}$ and PAH, NPD and decalins values above $LSC_{03\ GRA14R}$ are dark shaded.

Stasjon	Layer (cm)	THC	PAH(16)	NPD	Decalins
GRA09	0-1	10.7	0.202	0.071	0.205
	1-3	6.2	0.076	0.021	0.175
	3-6	14.5	0.153	0.032	0.415
GRA10	0-1	14.4	0.110	0.056	0.225
	1-3	8.2	0.073	0.023	0.280
	3-6	6.7	0.084	0.022	0.200
GRA14R	0-1	11.2	0.053	0.017	0.235
	1-3	8.3	0.038	0.017	0.175
	3-6	10.3	0.061	0.019	0.195

4.2.2.3 Metals

Table 10.6 summarises the results of the metal analyses of the Grane field in 2003. Concentrations of selected metals in the different layers (0-1, 1-3 and 3-6 cm) of sediment are given in Table 10.7, whereas the complete data set including replicates is given in the Appendix.

Table 10.6 Content of metals in sediments from Grane in 2003. All values in mg/kg dry sediment. Values above $LSC_{central\ 97\text{-}03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data in the regional and field reference sites in the central part of the region II are included.

Site	Cu		Cr		Zn		Ba		Pb		Cd		Hg	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
GRA01	1.3	0.2	7.2	0.5	9.7	1.1	168	55	4.7	0.7	<0.03	-	n.a.	n.a.
GRA02	1.3	0.1	6.6	0.2	8.9	0.2	197	33	4.3	0.3	<0.03	-	n.a.	n.a.
GRA03	1.6	0.2	6.9	1.0	10.8	2.3	358	118	4.2	1.0	<0.03	-	n.a.	n.a.
GRA04	1.6	0.1	7.3	0.3	9.9	1.0	401	10	5.2	0.5	<0.03	-	n.a.	n.a.
GRA05	1.5	0.4	7.2	1.2	9.5	2.2	173	104	4.9	0.9	<0.03	-	n.a.	n.a.
GRA07	1.2	0.1	6.8	0.7	9.9	2.1	99	8	4.5	0.1	<0.03	-	n.a.	n.a.
GRA08	1.4	0.3	6.7	0.9	9.6	1.1	169	33	5.0	0.6	<0.03	-	n.a.	n.a.
GRA09	1.6	0.2	7.9	0.4	10.6	0.8	329	109	4.9	0.2	<0.03	-	0.033	0.029
GRA10	2.9	0.5	9.6	1.7	13.4	1.7	589	3	5.5	0.5	<0.03	-	0.015	0.002
GRA11	1.8	0.4	7.2	0.5	9.8	0.8	325	117	4.3	0.3	<0.03	-	n.a.	n.a.
GRA12	1.2	0.2	6.8	0.7	9.0	1.7	114	13	3.9	0.7	<0.03	-	n.a.	n.a.
GRA13	1.1	0.1	6.1	0.4	7.9	0.2	118	8	4.3	0.2	<0.03	-	n.a.	n.a.
GRA14R	1.3	0.1	7.3	0.2	9.4	0.4	72	10	4.6	0.1	<0.03	-	0.014	0.007
av. ± sd.[1]	1.5 ± 0.5		7.2 ± 0.9		9.9 ± 1.3		253 ± 148		4.6 ± 0.5					
min – max[1]	1.1 - 2.9		6.1 - 9.6		7.9 - 13.4		99 - 589		3.9 - 5.5					
av. ± sd.[2]	1.2 ± 0.4		6.9 ± 1.2		9.4 ± 1.3		66 ± 31		4.2 ± 0.6		<0.03		0.009±0.003	
min – max[2]	<0.6-1.7		4.9-8.9		6.8-12.0		10-146		3.4-5.1		<0.03		0.006-0.014	

n.a. = not analysed.
[1] Exclusive GRA14R
[2] Reg + Ref $_{central\ 03}$

Table 10.7. The content of metals in vertical sections of sediment from 3 sampling sites at Grane in 2003. All values in mg/kg dry sediment. Values above $LSC_{central\ 97\text{-}03}$ are dark shaded.

Stasjon	Layer (cm)	Cu	Cr	Zn	Ba	Pb	Cd	Hg
GRA09	0-1	1.4	7.5	9.7	214	4.7	<0.03	0.020
	1-3	1.7	7.7	10.9	239	5.0	0.04	0.012
	3-6	1.4	7.4	10.5	112	5.0	0.04	0.012
GRA10	0-1	2.8	8.1	12.2	592	5.1	<0.03	0.013
	1-3	1.6	8.0	9.8	373	4.9	<0.03	0.012
	3-6	1.3	8.0	9.1	174	4.4	0.03	0.010
GRA14R	0-1	1.3	7.4	9.8	63	4.4	<0.03	0.011
	1-3	1.6	7.7	10.3	71	4.6	<0.03	0.050
	3-6	1.6	7.9	10.7	66	5.3	0.04	0.018

Barium was found in a range from 99 to 589 mg/kg, lead from 3.9 to 5.5 mg/kg, cadmium from <0.03 mg/kg, copper from 1.1 to 2.9 mg/kg, mercury from 0.015 to 0.033 mg/kg, zinc from 7.9 to 13.4 mg/kg and chromium from 6.1 to 9.6 mg/kg (Table 10.6). Sediments from GRA01, GRA02, GRA03, GRA04, GRA05, GRA08, GRA09, GRA10 and GRA11had barium (168-589 mg/kg) content above LSC. Copper, chromium, zinc and mercury occurred in concentration above LSC at GRA10. In addition mercury occurred in concentration above LSC at GRA09 and GRA14R. Both cadmium and lead occurred in concentrations below LSC at all sites.

Vertical sediment samples (0-1, 1-3 and 3-6 cm) from GRA09 (500 m to the east) and GRA10 (270 m to the east) had barium content above LSC in all depth intervals, except in the deepest (3-6 cm) interval at GRA09. Lowest concentrations of barium were detected in the deepest layers, which indicate recent supply of barium. At GRA09 also mercury occurred above LSC in the upper interval (0-1 cm), and cadmium occurred above LSC in the two deepest intervals (1-3 and 3-6 cm). At GRA10 occurred mercury and copper above LSC in the upper interval. At the reference site, GRA14R, occurred mercury above LSC in the 1-3 and 3-6 cm intervals and cadmium was found above LSC in the 3-6 cm interval (Table 10.7). Except for barium the metals had a relatively uniform vertical distribution in the sediments.

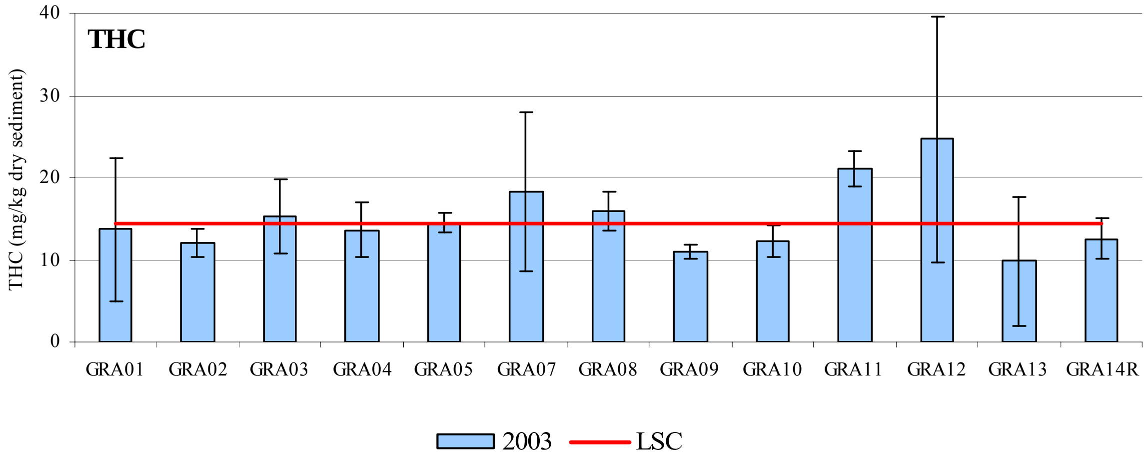


Figure 10.3. Average THC concentrations and standard deviations in sediments from Grane in 2003. Red line is LSC $_{central\ 97\text{-}03}$.

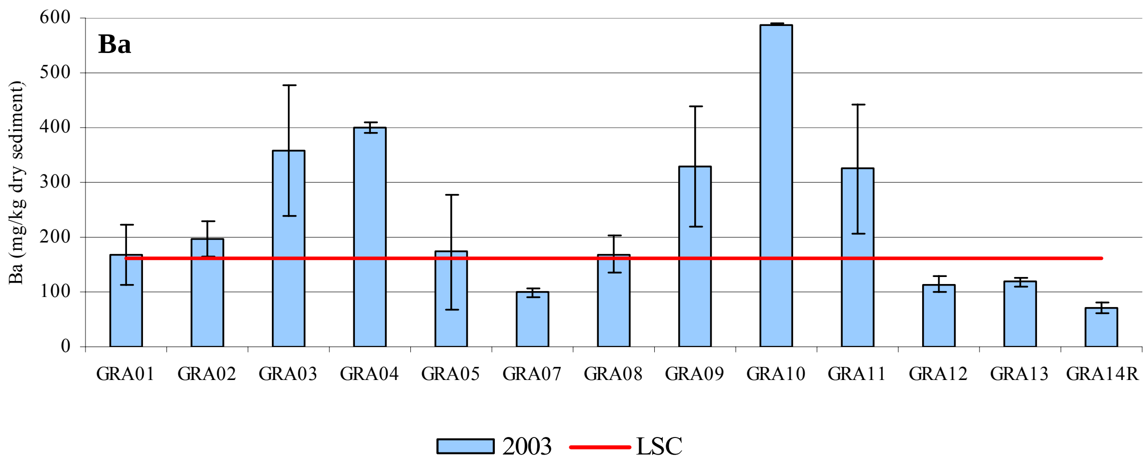


Figure 10.4. Average barium concentrations and standard deviation in sediments from Grane in 2003. Red line is LSC $_{central\ 97\text{-}03}$.

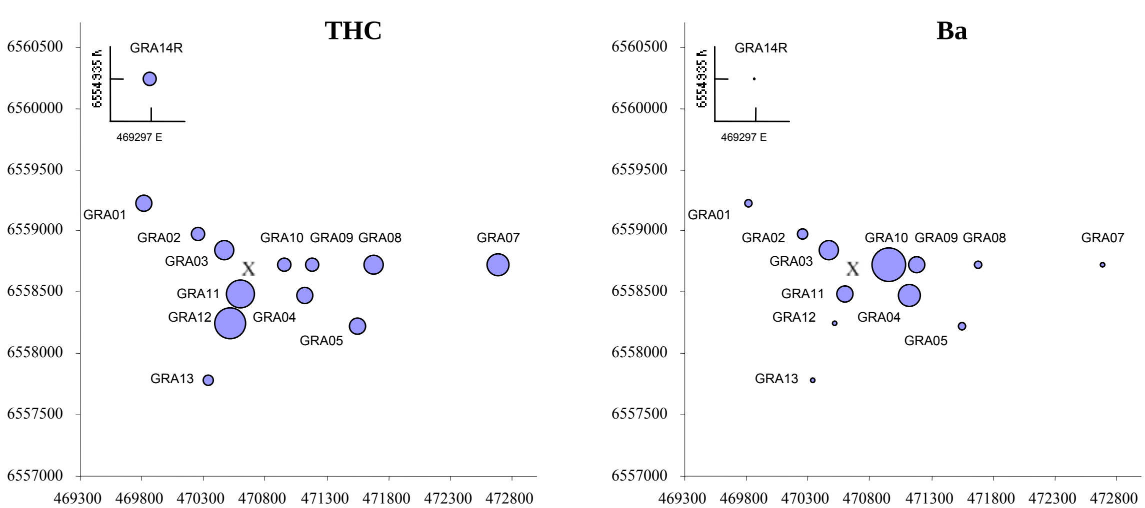


Figure 10.5. Distribution of THC and barium in sediments at the sampling sites at Grane in 2003. The size of the circle indicate the amount of THC and Ba. The field centre is marked with an X.

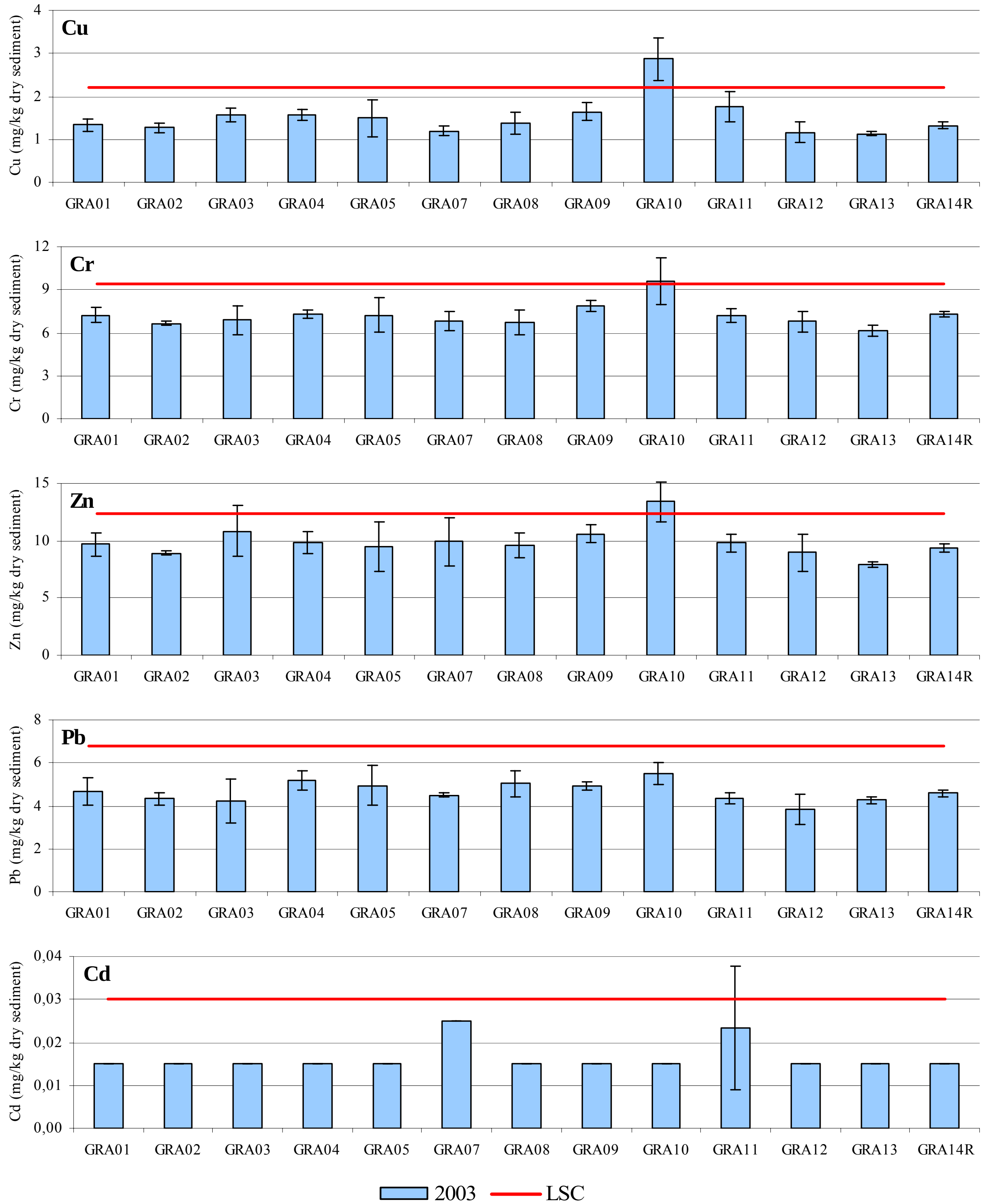


Figure 10.6. Average content and standard deviations of metals in sediment from Grane in 2003. Red line is LSC $_{\text{central 97-03}}$.

The field sites at Grane were compared to nearby regional and field specific reference sites (RII04, RII09, BAL27R, RIN29R and JOT30R) based on sediment characteristics (TOM and pelite) and chemical content in the sediments (Figure 10.7). GRA10, 270 m to east of the field centre, did not group together with the other sites, but was separated from the other sites due to higher content of chemical compounds in the sediments. Due to lower content of chemical compounds in the sediments RII04 was also clearly separated from the sites at Grane.

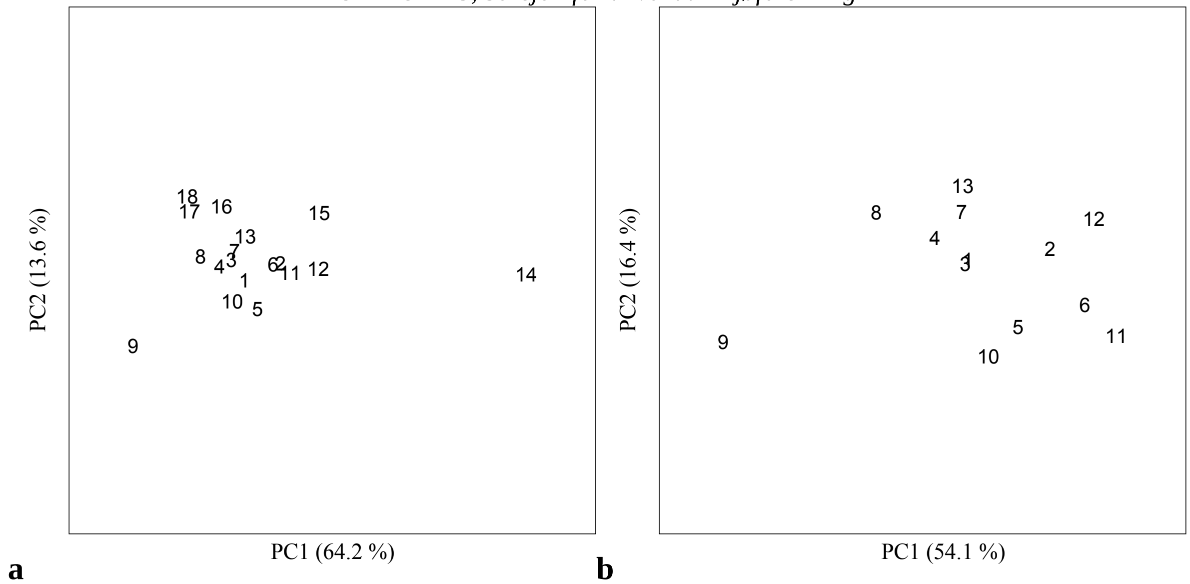


Figure 10.7. 2-D plot from the PCA analysis of environmental variables (% pelite, % sand, % gravel, median Φ, % TOM, Cu, Ba, Zn, Cr, Pb and THC carried out on the:

a) Grane field sites compared to reference site at Jotun, Ringhorne, Balder and regional sites RII04 and RII09. Explained variation in the data 77.8 %.
b) Grane field sites. Explained variation in the data 70.5 %.

Numbers in the plot identify the sampling sites. See table below.

1	GRA01	7	GRA08	13	GRA14R
2	GRA02	8	GRA09	14	RII04
3	GRA03	9	GRA10	15	RII09
4	GRA04	10	GRA11	16	BAL27R
5	GRA05	11	GRA12	17	RIN29R
6	GRA07	12	GRA13	18	JOT30R

10.2.3 Bottom fauna

A summary of the distribution of individuals and taxa within the main taxonomic groups are given in Table 10.8. Unidentified juveniles of the sea urchins Spatangoids (4786 individuals) and Echinoides (656 individuals) and juveniles of the brittle star *Amphiura chiajei* (450 individuals) are omitted from the analyses, as they occurred in extremely high numbers. In total, 6893 individuals within 259 taxa were collected at Grane in 2003. The fauna was numerically dominated by annelida with 57 % the individuals and 42 % of the taxa A complete species list is available in the Appendix.

Table 10.8. Distribution of individuals and taxa within the main taxonomic groups at Grane in 2003 including data from GRA14R (unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura chiajei* are not included).

Main taxonomic groups	Number of individuals	%	Number of taxa	%
Annelida	3925	57	110	42
Arthropoda	861	12	73	28
Mollusca	1292	19	46	18
Echidermata	343	5	14	5
Diverse groups	472	7	16	6
Total	6893	100	259	100

The species/area curve for GRA14R indicates that five replicate samples give a representative impression of the bottom fauna in the area (Figure 10.8). However, as more area is sampled, more taxa are collected, indicating that not even 10 replicate samples give the full species assemblage of the area.

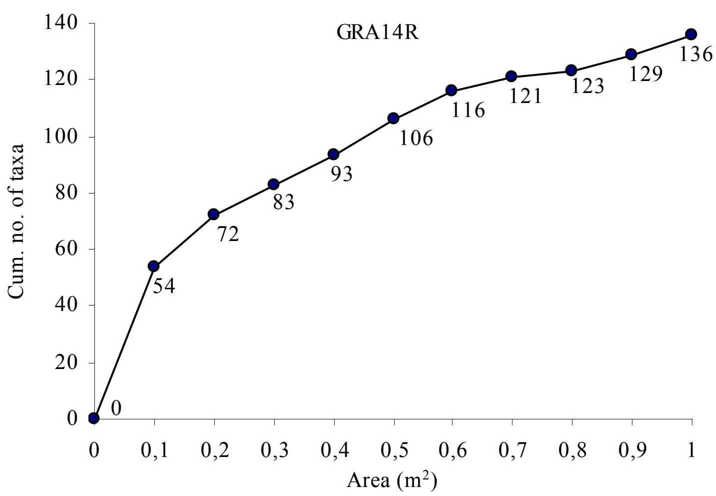


Figure 10.8. Species/area curve for the reference site at the Grane field. Unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura chiajei* are not included.

The distribution of individuals and taxa are shown in Figure 10.9. Number of individuals and taxa at each site, and the calculated diversity indexes (H' and ES_{100}) are given in Table 10.9 and Figure 10.10. The number of individuals varied from 310 (GRA12) to 744 (GRA07), and the number of taxa varied from 91 (GRA12) to 138 (GRA07). The Shannon-Wiener diversity index (H') varied from 5.31 (GRA12) to 5.89 (GRA07), whereas the ES_{100} index varied from 45.7 (GRA08) to 50.8 (GRA09). The evenness index J varied from 0.80 (GRA03) to 0.87 (GRA09). The corresponding values at GRA14R are within the variation at the field sites. The number of taxa, diversity and evenness indicate good environmental conditions at all sites.

Table 10.9. Number of individuals, species/taxa and selected community indices for each site (0.5 m^2) at the Grane field in 2003. Unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura chiajei* are not included.

Site number	Number of individuals	Number of taxa	Diversity H'	Evenness J	H'-max	ES_{100}
GRA01	573	117	5,64	0,82	6,87	48,0
GRA02	459	110	5,65	0,83	6,78	49,4
GRA03	600	122	5,54	0,80	6,93	47,0
GRA04	449	94	5,48	0,84	6,55	45,7
GRA05	420	97	5,59	0,85	6,60	47,2
GRA07	744	138	5,89	0,83	7,11	49,7
GRA08	487	105	5,55	0,83	6,71	45,7
GRA09	428	106	5,83	0,87	6,73	50,8
GRA10	503	110	5,62	0,83	6,78	48,0
GRA11	407	103	5,52	0,83	6,69	46,7
GRA12	310	91	5,31	0,82	6,51	46,4
GRA13	448	104	5,76	0,86	6,70	48,5
GRA14R	586	106	5,69	0,85	6,73	46,6
GRA14R	479	102	5,69	0,85	6,67	47,2
GRA14R	1065	136	5,83	0,82	7,09	47,3
Sum[1]	5828	251				
Average[1]	486	108	5,61	0,83	6,75	47,8
SD[1]	111	13	0,16	0,02	0,17	1,6
Min[1]	310	91	5,31	0,80	6,51	45,7
Max[1]	744	138	5,89	0,87	7,11	50,8
Average[2]	774	113	5.55	0.81	6.81	44.3
SD[2]	230	14	0.24	0.02	0.18	2.6
Min[2]	488	94	5.12	0.79	6.55	38.7
Max[2]	1202	141	5.85	0.85	7.14	47.9

[1]Field sites, exclusive GRA14R
[2]Reg + ref $_{\text{central 03}}$

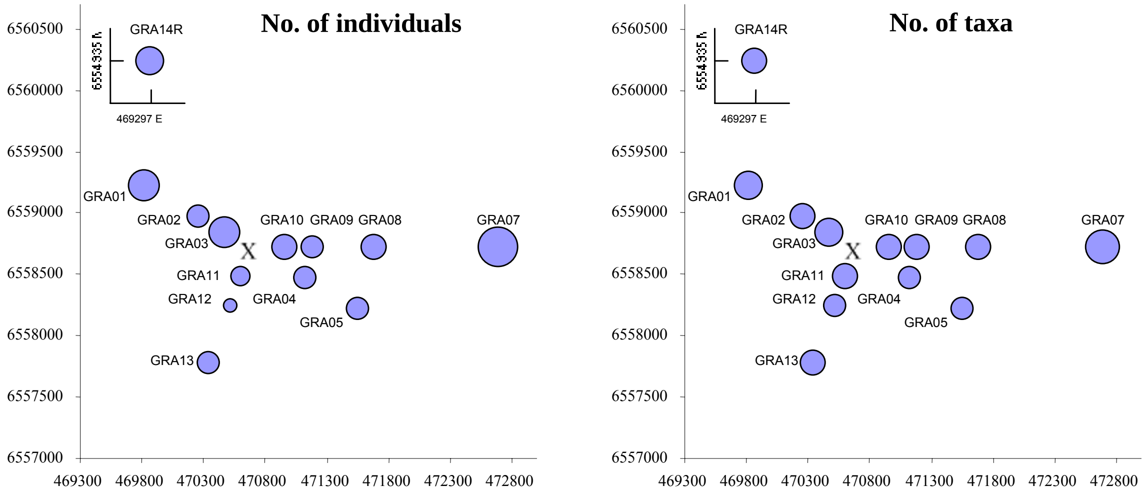


Figure 10.9. Distribution of bottom fauna (individuals and taxa) among the sampling sites in 2003. The size of the circle indicates the number of individuals and taxa. Unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura chiajei* are not included. Values for GRA14R are average of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2). The field centre is marked with an X.

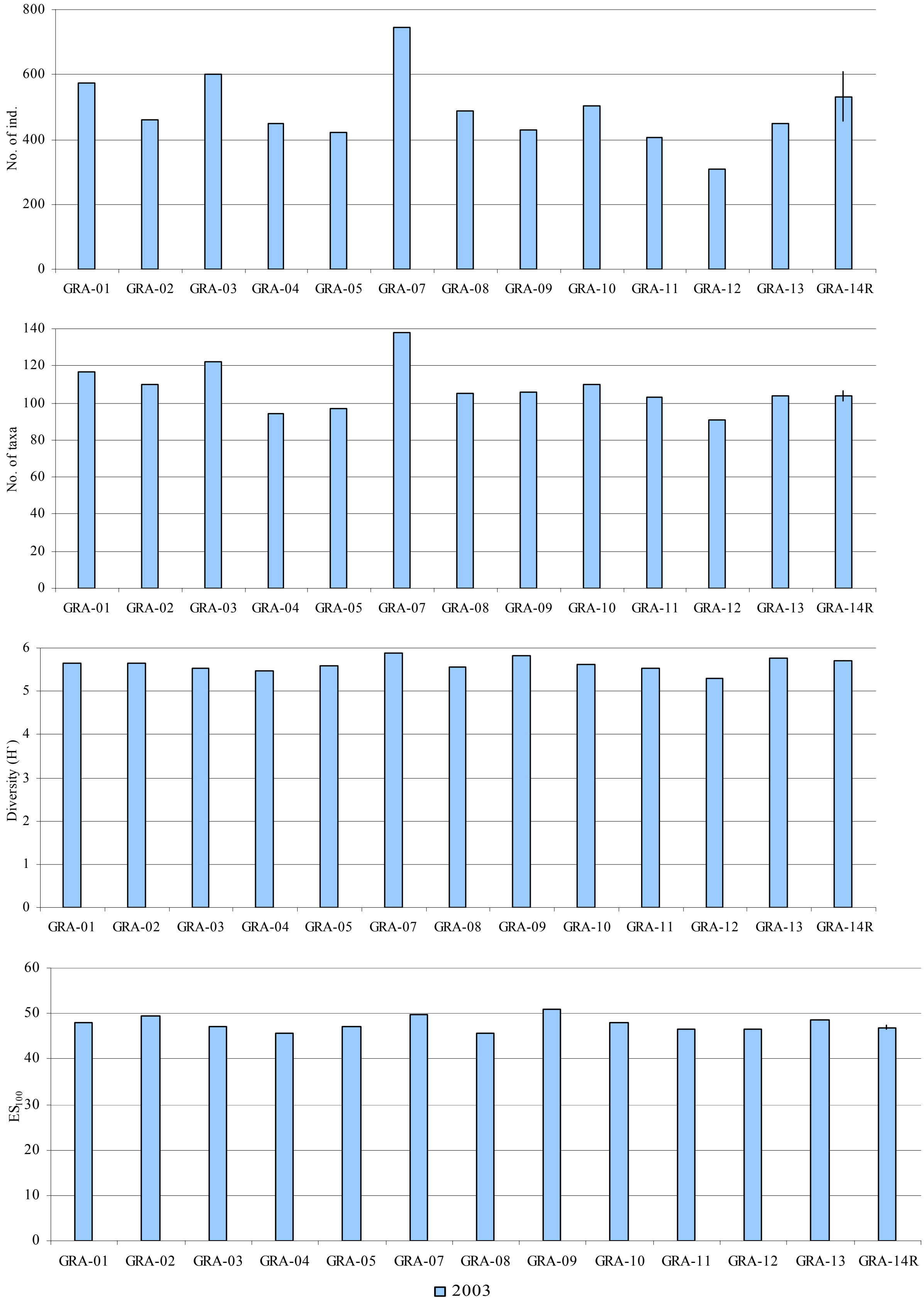


Figure 10.10. Number of individuals, taxa and selected community indices for each site (0.5 m^2) at the Grane field for 2003. (Unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura chiajei* are not included). Values for GRA14R are average ± standard deviation of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2).

Distribution of taxa in geometrical classes is presented in Figure 10.11. The smooth graphs representing are indicating undisturbed bottom fauna at all sites.

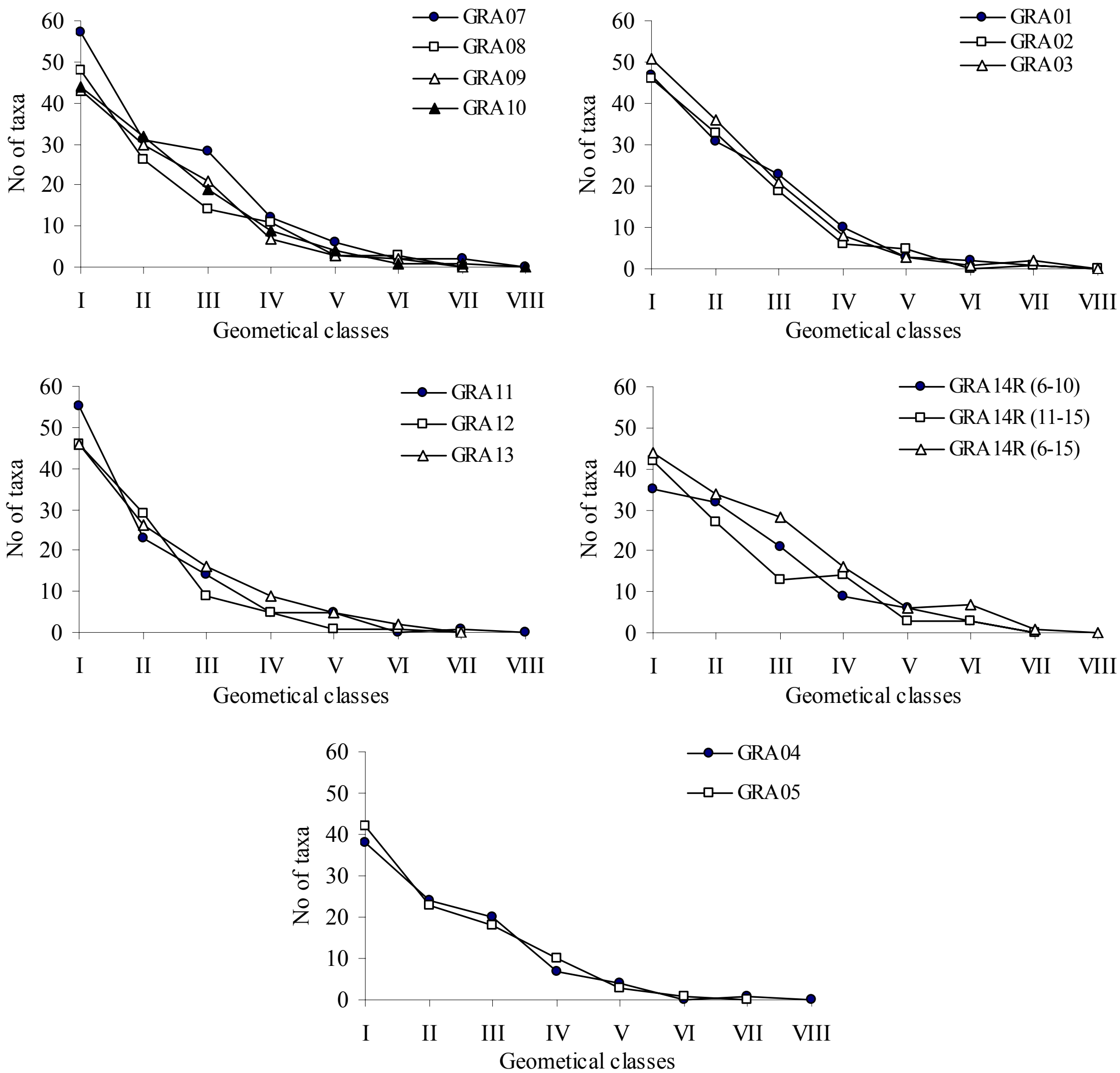


Figure 10.11. Distribution of taxa in geometrical classes for the sites at Grane in 2003. Unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura chiajei* are not included.

The ten most numerous taxa are listed in Table 10.12 at the end of this chapter. The list comprise 34 taxa and 5444 individuals, which was 13.1 % of all (259) taxa and 79 % of all (6893) individuals. The polycaete *Paramphinome jeffreysii* and the bivalve *Thyasira croulinensis* were abundant and widespread at all sites, and they were present among the ten most numerous taxa at all sites. The polycetes *Myriochele oculata, Sabellidae* indet. and *Lanice conchilega* together with the phronoid *Phoronis* sp. were also widespread and abundant at Grane in 2003. Several of these species were among the most abundant found in the baseline survey at Hermod in 1997.

The results of the multivariate analyses are given in the dendrogramme (Figure 10.12) and the MDS plott (Figure 10.13).

In the cluster analysis, all sites are grouped together within approximately 60 % similarity, indicating relatively high similarity in the species assemblages within the field. There were no clear grouping of sites based on species assemblage.

The results of the MDS analysis support the findings in the cluster analysis, confirming the similarity in species assemblage across the field. The lack of grouping of sites based on the species assemblage show that there were no faunal effects at Grane in 2003. The stress test of the MDS analysis was 0.16, indicating a potential good fit of the data

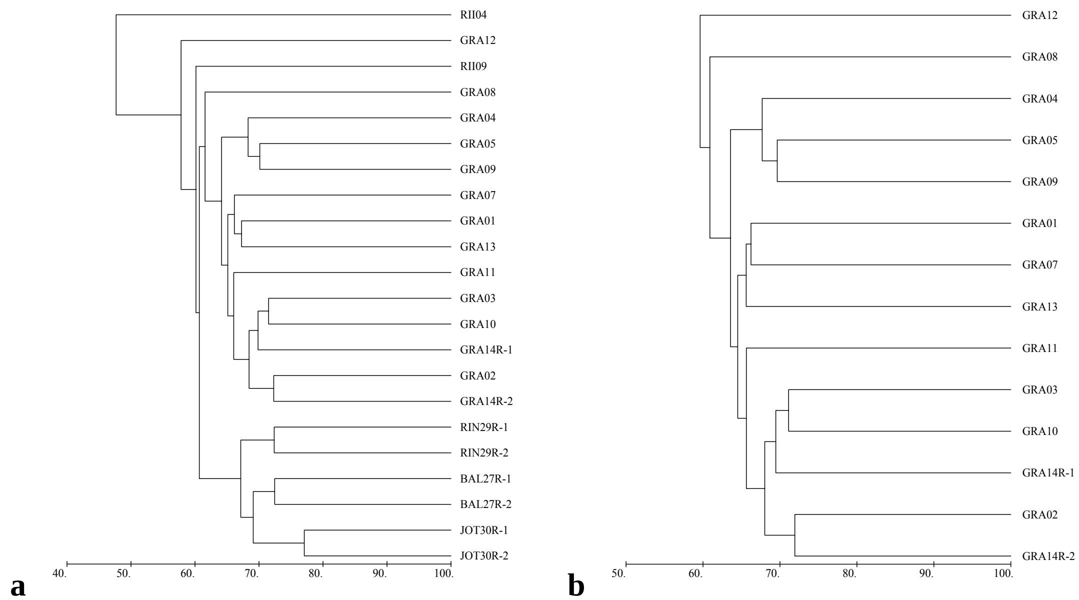
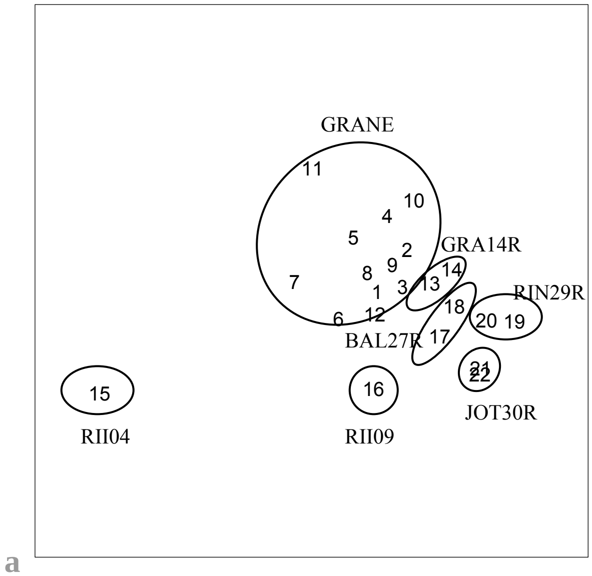


Figure 10.12. Dendrogram showing the similarity between fauna from sampling sites at:

a) Sampling sites at Grane and some regional sites (RII04 and RII09) and reference sites (BAL27R, RIN29R and JOT30R) in 2003. Unidentified juveniles of Spatangoida and Echinoidea are not included.
b) Sampling sites at Grane in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura chiajei*.



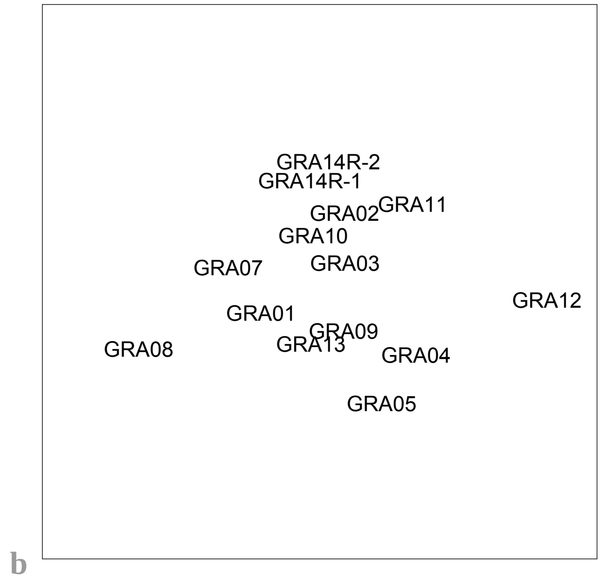


Figure 10.13. A 2-dimetional plott of the MDS analysis of the fauna data from:

a) Sampling sites at Grane and some regional sites (RII04 and RII09) and reference sites (BAL27R, RIN29R and JOT30R) in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea. Stress = 0.16. Codes in the table below.

b) Sampling sites at Grane in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura chiajei*. Stress = 0.16.

1	GRA01	7	GRA08	13	GRA14R-1	19	RIN29R-1
2	GRA02	8	GRA09	14	GRA14R-2	20	RIN29R-2
3	GRA03	9	GRA10	15	RII04	21	JOT30R-1
4	GRA04	10	GRA11	16	RII09	22	JOT30R-2
5	GRA05	11	GRA12	17	BAL27R-1		
6	GRA07	12	GRA13	18	BAL27R-2		

Linking of biotic and environmental variables by BIOENV revealed that THC was best correlated to the biota at $\rho_w = 0.23$ (Table 10.10). This indicates that there was only a weak correlation of the bottom fauna and THC.

Table 10.10. Combinations of the 10 environmental variables, taken *k* at a time, yielding the best matches of biotic and abiotic similarity matrices for each *k*, as measured by weighted Spearman rank correlation ρ_w. Bold type indicates overall optimum. All possible combinations of variables and associated correlation to the biotic are given in the Appendix.

Number of variables (*k*)	Correlation coefficient (ρ_w)	Environmental variables									
1	**0.230**	**THC**									
1	0.151	Pb									
1	0.019	Pelite									
1	0.002	TOM									
1	-0.019	Sand									
1	-0.161	Gravel									
1	-0.168	Cu									
1	-0.191	Ba									
1	-0.344	Cr									
1	-0.424	Zn									
2	0.127	THC	Pelite								
3	0.113	THC	Pelite	Pb							
4	0.093	THC	Pelite	Pb	Sand						
5	0.081	THC	Pelite	Pb	Sand	TOM					
6	0.043	THC	Pelite	Pb	Sand	TOM	Ba				
7	0.005	THC	Pelite	Pb	Sand	TOM	Ba	Cu			
8	-0.037	THC	Pelite	Pb	Sand	TOM	Ba	Cu	Cr		
9	-0.076	THC	Pelite	Pb	Sand	TOM	Ba	Cu	Cr	Gravel	
10	-0.113	THC	Pelite	Pb	Sand	TOM	Ba	Cu	Cr	Gravel	Zn

10.2.4 Estimation of influenced area

The extension of contamination along sampling transects and the minimum area of contaminated sediments for THC, barium and other metals as well as for faunal disturbance are given in Figure 10.15 and Table 10.11. Since this was the first survey of these sampling sites at Grane no comparison with former surveys are made.

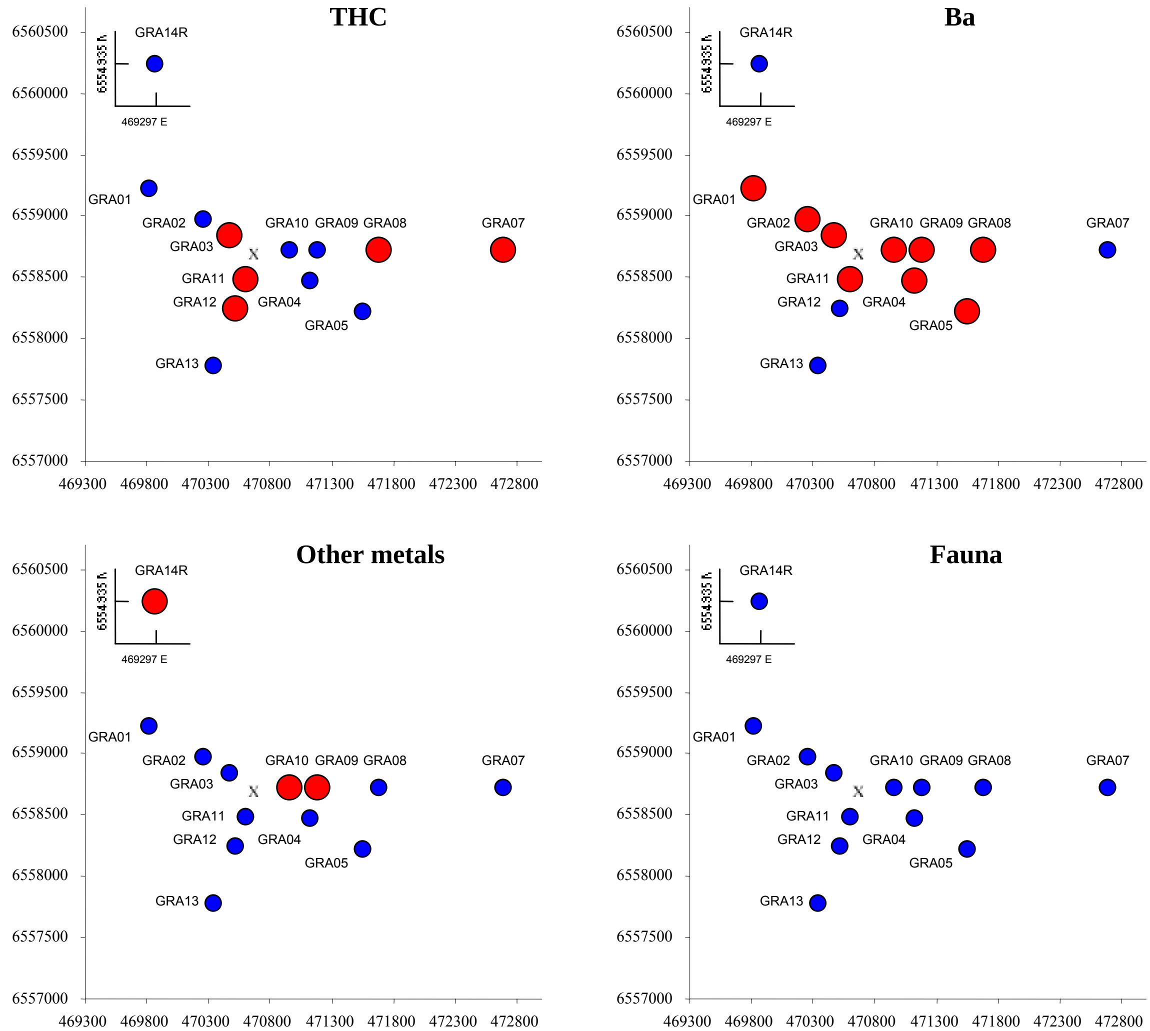


Figure 10.15. Faunal disturbance and chemical contamination of the sediments at Grane in 2003. The field centre are marked with an X. Uncontaminated sites and sites with no faunal disturbance are marked with small blue circles.

Table 10.11. Estimated distance of contamination and faunal disturbance from the installation, and estimated area of contamination and faunal disturbance around the field centre.

Grane	E m	SE m	SW m	NW m	2003 km^2
THC	0	0	500	250	0.10
Ba	1000	1000	250	1000	0.98
Other metals	500	0	0	0	0.05
Fauna	0	0	0	0	0

10.3 Summary and conclusions

During 2001 two wells were drilled at Grane. The sediments at Grane are characterized as fine sand. THC was relatively evenly distributed in the sediment, although the THC content was above LSC at 6 out of 12 field sites and the highest THC concentrations were found in sediment to the west of the field centre. The distribution of barium in the sediments was uneven with the highest content in the sediments in the immediate vicinity of the field centre. The vertical distribution of barium in the sediments indicates recent supply of barium to the sea floor. The other metals occurred in low and even concentrations at all sites except at 270 m to the east of the field centre where slightly higher levels were found. Fauna diversity was high and the correlation between the distribution of measured chemical compounds and the fauna was weak, showing that there were no signs of faunal disturbance at Grane in 2003.

Table 10.12. Number of individuals and relative abundance for the ten predominant taxa at each site at the Grane field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura chiajei*.

GRA-01	No. of ind.	%	Cum %
Sabellidae indet.	84	14,7	14,7
Paramphinome jeffreysii	62	10,8	25,5
Myriochele oculata	33	5,8	31,2
Thyasira croulinensis	24	4,2	35,4
Phoronis sp.	18	3,1	38,6
Nemertini indet.	16	2,8	41,4
Lumbrineris scopa	13	2,3	43,6
Urothoe elegans	12	2,1	45,7
Mugga wahrbergi	10	1,7	47,5
Lanice conchilega	10	1,7	49,2
Asteroidea indet.	10	1,7	51,0
Ascidiacea indet.	10	1,7	52,7

GRA-02	No. of ind.	%	Cum %
Paramphinome jeffreysii	84	18,3	18,3
Phoronis sp.	20	4,4	22,7
Sabellidae indet.	19	4,1	26,8
Thyasira croulinensis	19	4,1	30,9
Thyasira equalis	19	4,1	35,1
Thyasira ferruginea	16	3,5	38,6
Myriochele oculata	14	3,1	41,6
Caudofoveata indet.	11	2,4	44,0
Lanice conchilega	10	2,2	46,2
Hemilamprops roseus	10	2,2	48,4

GRA-03	No. of ind.	%	Cum %
Sabellidae indet.	93	15,5	15,5
Paramphinome jeffreysii	83	13,8	29,3
Myriochele oculata	32	5,3	34,7
Thyasira croulinensis	19	3,2	37,8
Phoronis sp.	18	3,0	40,8
Caudofoveata indet.	16	2,7	43,5
Thyasira equalis	15	2,5	46,0
Amphiura chiajei	13	2,2	48,2
Lanice conchilega	12	2,0	50,2
Parvicardium minimum	12	2,0	52,2

GRA-04	No. of ind.	%	Cum %
Paramphinome jeffreysii	77	17,1	17,1
Myriochele oculata	29	6,5	23,6
Sabellidae indet.	19	4,2	27,8
Thyasira ferruginea	16	3,6	31,4
Laonice sarsi	16	3,6	35,0
Thyasira croulinensis	15	3,3	38,3
Lanice conchilega	15	3,3	41,6
Phoronis sp.	14	3,1	44,8
Nemertini indet.	14	3,1	47,9
Spiophanes kroeyeri	13	2,9	50,8

GRA-05	No. of ind.	%	Cum %
Paramphinome jeffreysii	63	15,0	15,0
Myriochele oculata	27	6,4	21,4
Laonice sarsi	22	5,2	26,7
Sabellidae indet.	16	3,8	30,5
Thyasira croulinensis	15	3,6	34,0
Phoronis sp.	14	3,3	37,4
Lanice conchilega	12	2,9	40,2
Thyasira ferruginea	10	2,4	42,6
Spiophanes kroeyeri	10	2,4	45,0
Lumbrineridae indet.	10	2,4	47,4
Owenia fusiformis	10	2,4	49,8

GRA-07	No. of ind.	%	Cum %
Myriochele oculata	68	9,1	9,1
Sabellidae indet.	65	8,7	17,9
Paramphinome jeffreysii	59	7,9	25,8
Owenia fusiformis	36	4,8	30,6
Thyasira croulinensis	30	4,0	34,7
Myriochele fragilis	23	3,1	37,8
Aporrhais spp.	21	2,8	40,6
Laonice sarsi	19	2,6	43,1
Phoronis sp.	19	2,6	45,7
Spiophanes kroeyeri	16	2,2	47,8

GRA-08	No. of ind.	%	Cum %
Paramphinome jeffreysii	54	11,1	11,1
Myriochele oculata	52	10,7	21,8
Thyasira croulinensis	36	7,4	29,2
Myriochele fragilis	25	5,1	34,3
Phoronis sp.	16	3,3	37,6
Nothria conchylega	16	3,3	40,9
Lanice conchilega	12	2,5	43,3
Labidoplax buskii	12	2,5	45,8
Aporrhais spp.	11	2,3	48,0
Thyasira ferruginea	11	2,3	50,3
Nemertini indet.	11	2,3	52,6

GRA-09	No. of ind.	%	Cum %
Paramphinome jeffreysii	46	10,7	10,7
Myriochele oculata	34	7,9	18,7
Sabellidae indet.	18	4,2	22,9
Thyasira croulinensis	17	4,0	26,9
Lanice conchilega	17	4,0	30,8
Thyasira ferruginea	13	3,0	33,9
Lumbrineridae indet.	12	2,8	36,7
Nemertini indet.	11	2,6	39,3
Haliella stenostoma	11	2,6	41,8
Mugga wahrbergi	10	2,3	44,2

Table 10.12. continue. Number of individuals and relative abundance for the ten predominant taxa at each site at the Grane field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura chiajei*.

GRA-10	No. of ind.	%	Cum %
Paramphinome jeffreysii	71	14,1	14,1
Myriochele oculata	56	11,1	25,2
Thyasira croulinensis	25	5,0	30,2
Thyasira ferruginea	19	3,8	34,0
Sabellidae indet.	16	3,2	37,2
Phoronis sp.	16	3,2	40,4
Lanice conchilega	15	3,0	43,3
Spiophanes kroeyeri	11	2,2	45,5
Myriochele fragilis	11	2,2	47,7
Nemertini indet.	9	1,8	49,5
Lumbrineris scopa	9	1,8	51,3
Thyasira equalis	9	1,8	53,1

GRA-11	No. of ind.	%	Cum %
Paramphinome jeffreysii	67	16,5	16,5
Myriochele oculata	27	6,6	23,1
Thyasira croulinensis	23	5,7	28,7
Phoronis sp.	18	4,4	33,2
Sabellidae indet.	17	4,2	37,3
Lanice conchilega	16	3,9	41,3
Spiophanes kroeyeri	12	2,9	44,2
Eriopisa elongata	10	2,5	46,7
Nemertini indet.	9	2,2	48,9
Harpinia antennaria	9	2,2	51,1

GRA-12	No. of ind.	%	Cum %
Paramphinome jeffreysii	61	19,7	19,7
Laonice sarsi	31	10,0	29,7
Sabellidae indet.	15	4,8	34,5
Spiophanes bombyx	13	4,2	38,7
Ampharete falcata	13	4,2	42,9
Pectinaria auricoma	9	2,9	45,8
Ophiura affinis	8	2,6	48,4
Lanice conchilega	7	2,3	50,6
Harpinia antennaria	7	2,3	52,9
Thyasira croulinensis	6	1,9	54,8
Mugga wahrbergi	6	1,9	56,8

GRA-13	No. of ind.	%	Cum %
Paramphinome jeffreysii	38	8,5	8,5
Myriochele oculata	32	7,1	15,6
Phoronis sp.	30	6,7	22,3
Sabellidae indet.	22	4,9	27,2
Thyasira croulinensis	17	3,8	31,0
Spiophanes kroeyeri	17	3,8	34,8
Lanice conchilega	16	3,6	38,4
Laonice sarsi	14	3,1	41,5
Owenia fusiformis	12	2,7	44,2
Tanaidacea indet.	11	2,5	46,7

GRA-14R	No. of ind.	%	Cum %
Paramphinome jeffreysii	108	10,1	10,1
Thyasira croulinensis	62	5,8	16,0
Thyasira equalis	60	5,6	21,6
Phoronis sp.	58	5,4	27,0
Myriochele oculata	56	5,3	32,3
Lanice conchilega	42	3,9	36,2
Spiophanes kroeyeri	33	3,1	39,3
Aporrhais spp.	32	3,0	42,3
Urothoe elegans	28	2,6	45,0
Sabellidae indet.	26	2,4	47,4
Harpinia antennaria	26	8,4	55,8

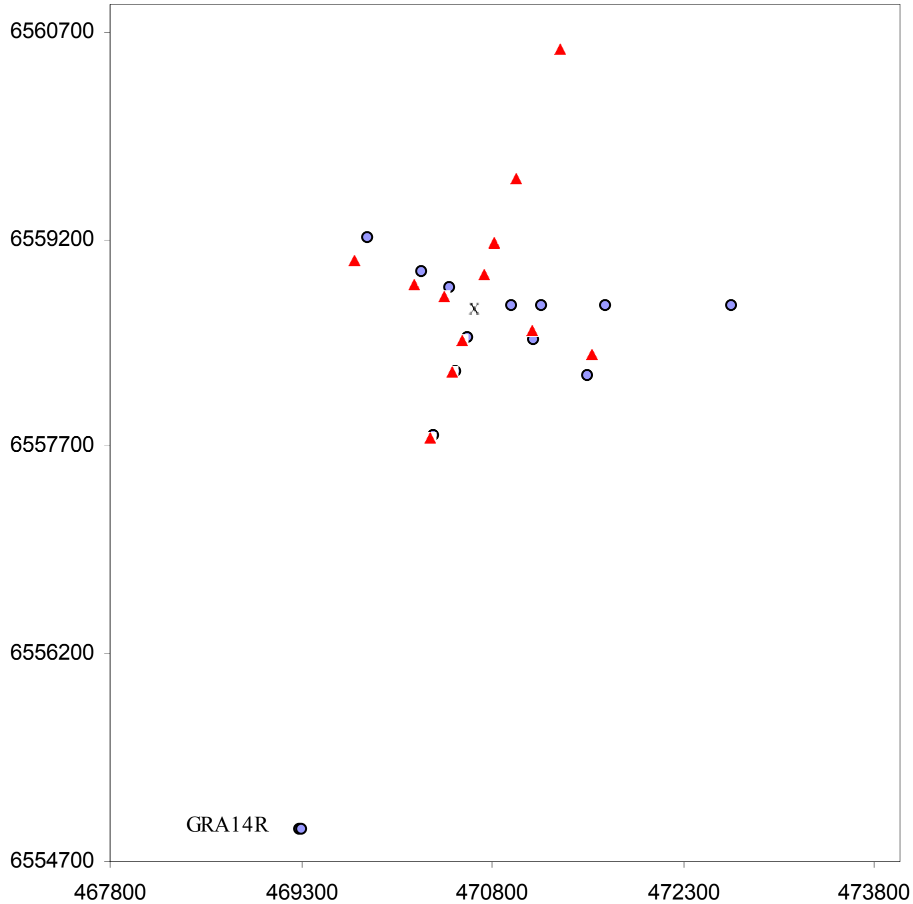


Figure 10.16. Illustration of deviations in planned and real sampling at Grane. Location of sampling sites according to the programme, red triangle, and location of the sites where sampling were executed, blue circles.

11 Balder

11.1. Introduction

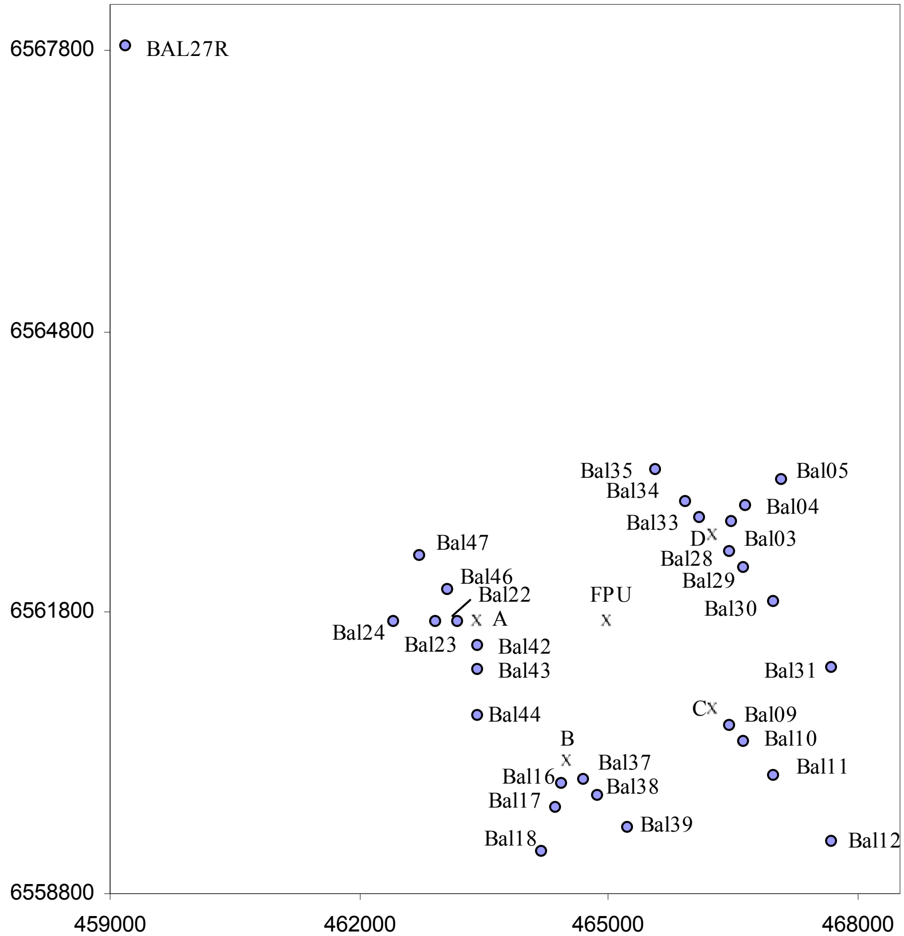
The Balder field is situated in block 25/11, and consist of one production ship (Balder FPU) and four sub sea templates (A, B, C and D). Drilling of production wells started in May 1996 and production started at in October 1999. Recent drilling and discharge history is listed in Table 11.1 and the locations of the sampling sites are shown in Figure 11.1.

An environmental baseline survey undertaken at Balder in 1997 revealed contamination by THC, olefins and barium in the immediate vicinity of template A and B. Contamination by THC and barium occurred also in the vicinity of template C and D. And the fauna was slightly disturbed out to 250 and 500 m distance from each template. The monitoring survey in 2000 revealed elevated levels of barium and olefins at many sampling sites and faunal disturbances were found at most of the sampling sites located at 250 m distance to the templates.

Table 11.1. Recent well drilling and discharges from operations and accidents at Balder. All numbers in tonnes except for accidental discharges which are in cubic metres. Drilling in 2001 from a floating rig at 25/11 B-18, 25/11 A-06, 25/11 A-04 and 25/11 C-03.

	1997	1998	1999	2000	2001	2002
No of wells drilled	4	3	0	0	4[4]	0
Barite	2059	1643	0	0	490	0
Cuttings	2682	2797	0	0	2533[3]	0
Base oil (with cuttings)	70[1]	0	0	0	0	0
Ester based drilling mud	0	0	0	0	221	0
Water-based drilling mud	3786	3187	0	0	615	0
Cementing and other chemicals	16.13	1.55	0	0	39	0
Completion chemicals	1791.6	46.73	0	0	0	0
Oil in produced water	0	0	0	4[2]	8	20
Accidental discharges, oil	-	-	-	0.07	0	0
Accidental discharges, chemicals	-	-	-	-	6.64	0

[1] Anco TecB (Poly-α-olefins C14/C16
[2] 21 ppm x 188223 Sm^3
[3] 2285 tonnes was cuttings with synthetic drilling mud
[4] 1 production well, 1 plugging and 2 side track



Site	ED50 UTM Zone 31		Distance (m) /direction (º)	Depth
	E	N		(m)
BAL-03	466476	6562773	250/54	129
BAL-04	466650	6562947	478/47	129
BAL-05	467083	6563214	1000/54	128
BAL-09	466451	6560597	250/135	127
BAL-10	466628	6560420	500/135	128
BAL-11	466981	6560067	1000/135	128
BAL-12	467688	6559360	2000/135	128
BAL-16	464436	6559964	250/198	127
BAL-17	464359	6559726	500/198	126
BAL-18	464204	6559251	1000/198	125
BAL-22	463175	6561700	250/270	127
BAL-23	462925	6561700	500/270	127
BAL-24	462425	6561700	1000/270	127
BAL-27R	459203	6567845	10000/315	126

Site	ED50 UTM Zone 31		Distance (m) /direction (º)	Depth
	E	N		(m)
BAL-28	466451	6562449	250/135	129
BAL-29	466628	6562272	500/135	129
BAL-30	466981	6561919	1000/135	128
BAL-31	467688	6561212	2000/135	129
BAL-33	466097	6562803	250/315	129
BAL-34	465920	6562980	500/315	129
BAL-35	465567	6563333	1000/315	129
BAL-37	464690	6560025	250/135	127
BAL-38	464867	6559848	500/135	127
BAL-39	465220	6559495	1000/135	127
BAL-42	463425	6561450	250/180	127
BAL-43	463425	6561200	500/180	126
BAL-44	463425	6560700	1000/180	126
BAL-46	463071	6562054	500/315	127
BAL-47	462718	6562407	1000/315	127

Figure 11.1. Map showing the internal distribution of sampling sites in Balder, 2003. Positioning according to UTM ED50 zone 31. The template centres is marked with an X.

11.2. Results and discussion

11.2.1 Sediments characteristics

TOM, the amount (%) of gravel, sand and pelite, median (Φ), sorting, skewness and kurtosis in the sediment from the present survey are presented in Table 11.2. Additional information on colour and smell can be found in the Appendix. Median (Φ), pelite, sand and TOM are compared with data from 2000 in Figure 11.2.

The sediments at Balder are classified as fine sand with median (Φ) values ranging from 2.61 (BAL12 and BAL31) to 2.76 (BAL29 and BAL47). The amount of pelite varied from 10.9 % (BAL31) to 23.9 % (BAL29), the sand varied from 76.0 % (BAL29) to 89.0 % (BAL31), and the TOM varied from 1.6 % (BAL42) to 2.9 % (BAL05). The conditions at the reference site (BAL27R) were within the variation at the field sites.

Compared to the results of 2000 there were more pelite in the sediments in 2003.

Table 11.2. Total organic matter and sediment grain size at all sites at Balder in 2003. For comparison, averages, standard deviations, max and min values for the regional and reference sites are included.

Site	TOM %	Gravel %	Sand %	Pelite %	Median (Φ)	Sorting	Skewness	Kurtosis
BAL03	2.59	1.08	84.32	14.61	2.65	1.11	0.59	2.76
BAL04	2.16	0.10	82.13	17.77	2.73	1.27	0.63	1.75
BAL05	2.85	0.80	78.28	20.92	2.69	1.44	0.69	1.79
BAL09	1.91	0.03	86.61	13.36	2.68	1.07	0.56	2.30
BAL10	1.72	0.00	82.36	17.64	2.70	1.27	0.64	1.98
BAL11	1.84	0.03	87.51	12.46	2.63	1.01	0.55	2.77
BAL12	1.65	0.03	86.87	13.10	2.61	1.03	0.56	2.78
BAL16	1.84	0.09	87.93	11.98	2.66	1.02	0.55	2.56
BAL17	1.78	0.03	86.15	13.82	2.63	1.06	0.58	2.85
BAL18	2.17	0.06	87.06	12.88	2.65	1.05	0.56	2.69
BAL22	1.73	0.00	87.86	12.14	2.65	1.02	0.55	2.66
BAL23	1.87	0.01	86.01	13.98	2.68	1.09	0.57	2.30
BAL24	2.05	0.87	84.87	14.26	2.66	1.10	0.58	2.58
BAL28	2.28	0.38	87.78	11.84	2.65	1.01	0.55	2.62
BAL29	2.02	0.06	76.01	23.93	2.76	1.55	0.69	1.37
BAL30	2.55	0.03	86.19	13.78	2.65	1.08	0.58	2.75
BAL31	1.83	0.02	89.04	10.94	2.61	0.95	0.51	2.61
BAL33	2.26	0.44	85.59	13.97	2.69	1.10	0.56	2.06
BAL34	2.06	0.00	85.65	14.35	2.66	1.10	0.59	2.79
BAL35	1.81	0.07	85.43	14.50	2.72	1.11	0.56	1.90
BAL37	2.17	0.00	86.45	13.55	2.70	1.08	0.56	2.00
BAL38	2.24	0.04	87.48	12.48	2.65	1.03	0.56	2.70
BAL39	2.22	0.31	87.60	12.10	2.64	1.01	0.55	2.69
BAL42	1.59	0.06	88.51	11.44	2.64	0.98	0.54	2.66
BAL43	2.05	0.03	85.29	14.68	2.72	1.11	0.56	1.89
BAL44	1.95	0.09	85.95	13.96	2.67	1.09	0.58	2.63
BAL46	2.00	0.22	85.69	14.09	2.67	1.09	0.58	2.39
BAL47	2.10	0.06	84.27	15.67	2.76	1.14	0.55	1.69
BAL27R	2.16	0.01	85.10	14.89	2.72	1.12	0.57	1.87
Average[1]	2.05	0.18	85.53	14.29	2.67	1.11	0.58	2.38
SD[1]	0.29	0.29	2.89	2.82	0.04	0.13	0.04	0.42
Min[1]	1.59	0.00	76.01	10.94	2.61	0.95	0.51	1.37
Max[1]	2.85	1.08	89.04	23.93	2.76	1.55	0.69	2.85
Average[2]	1.71	0.29	87.23	12.49	2.71	1.16	0.34	1.76
SD[2]	0.45	0.62	5.20	5.12	0.37	0.14	0.19	0.46
Min[2]	0.73	0.00	78.12	3.04	1.76	0.93	0.03	1.05
Max[2]	2.19	2.19	96.61	21.77	3.34	1.40	0.57	2.95

[1] Field sites, exclusive BAL27R
[2] Reg + Ref $_{\text{central 03}}$

Figure 11.2. Sediment characteristics at Balder in 2000 and 2003. Fine sand is the relative amount of sand with grain size 63-250 μm.

11.2.2 Chemical compounds

11.2.2.1 LSC

The results of the LSC (limits of significant contamination) calculations of hydrocarbons and metals are presented in the chapter concerning the regional and reference sites. Both the $LSC_{central\ 97-03}$ and the field specific LSC value ($LSC_{BAL27R\ 03}$) are presented in Table 11.3. Fine sediments, like those at Balder, are more likely to have higher affinity for pollutants than coarse sediments. LSC in the text relates to $LSC_{central\ 97-03}$.

Table 11.3. Limits of Significant Contamination (LSC) for the Balder field in 2003, and for the central part of Region II based on data from 1997 to 2003 ($LSC_{central\ 97-03}$) and the whole of Region II based on data from 1997 to 2003 ($LSC_{regII\ 97-03}$). For comparison, LSC-values from 2000 are included. All values in mg/kg dry sediment.

	THC	PAH (16)	NPD's	Decalins	Cu	Cr	Zn	Ba	Pb	Cd	Hg
$LSC_{BAL27R\ 03}$	21.1	0.140	0.035	1.160	1.8	9.5	11.1	104	4.9	0.03	0.011
$LSC_{central\ 97-03}$	14.5	*	*	*	2.2	9.4	12.4	161	6.8	0.03[1]	0.012
$LSC_{RII\ 97-03}$	13.3	*	*	*	2.0	9.4	11.1	136	6.6	0.03[1]	0.011
$LSC_{BAL27R\ 00}$	9.3	*	0.056	0.046	2.5	9.3	10.7	155	7.7	0.035	0.009
$LSC_{RII\ 97-00}$**	9.8	*	*	*	2.0	9.6	8.9	146	7.0	0.03	0.008

* NPD's, PAH's and decalins are not analysed at regional sites in 1997 and 2000
** Data from Mannvik & al. 2001
[1] LSC = detection limit

11.2.2.2 Hydrocarbons

Summarised results of the hydrocarbon analyses, along with the content of selected hydrocarbon compounds in the different layers (0-1, 1-3 and 3-6 cm) are given in Table 11.4 and Table 11.5. The complete data set including replicates is given in the Appendix. Comparison of the THC content in 2003 with previous surveys is presented in Figure 11.4.

THC was found in the range from 8.1 to 73.4 mg/kg, and THC concentrations above LSC were found at BAL09, BAL16, BAL17, BAL18, BAL22, BAL23, BAL37, BAL39, BAL42, BAL43, BAL44, BAL47 and BAL27R. Highest concentrations were found at 250 m to the south of template A (BAL42). Since 2000 there has been an increase in the THC content in the sediments around template A and B whereas the THC content was at the same level or had decreased around templates C and D. The increase in THC content was most evident toward south at template A, and most evident toward southeast and southwest at template B.

The field specific LSC-value ($LSC_{BAL27R\ 03}$) for THC was 21.1 mg/kg. If this value had been used instead of 14.5 mg/kg only BAL42, 250 m to the south of template A, and BAL16 250 m to the southwest and BAL37 250 to the southeast of template B would have ended up with THC content above LSC.

Sectioned samples were collected downstream of each template at 250 m and 500 m distance. At template A, THC, NPD and decalins occurred above LSC in all depth intervals (0-1, 1-3 and 3-6 cm) in the sediment at 250 m distance (BAL42). PAH occurred above LSC in the 3-6 cm interval. At 500 m distance (BAL43), THC occurred above LSC in all depth intervals too, but at lower concentrations than at 250 m distance. NPD and decalins were found above LSC in the 1-3 cm layer.

At template B, THC and NPD occurred above LSC down to 6 cm depth in the sediments at 250 m distance (BAL37) and decalins were present above LSC in 1-3 and 3-6 cm layers. At the 500 m distance NPD occurred above LSC in all depth intervals and THC were present above LSC in the 1-3 cm interval. The sampling site at 500 m (BAL38) had lower concentration than at 250 m distance (BAL37).

At template C, THC occurred above LSC in the 0-1 and 1-3 cm layers and NPD occurred above LSC in the 1-3 cm layer at 250 m distance (BAL09). None of the sectioned samples contained hydrocarbons above LSC at 500 m distance (BAL10).

At template D, THC and NPD occurred above LSC in the 1-3 cm layer at 250 m distance (BAL28). At 500 m distance none of the samples had hydrocarbon content above LSC (BAL29) (Table 11.5).

At the reference site (BAL27R), THC occurred above LSC in all depth intervals.

The content of olefins was measured in sediment samples form all sites. Olefins was found in the range from <0.13 to 21.3 mg/kg. Highest concentrations of olefins (21.3 mg/kg) were found at 250 m to the south of template A, The second highest concentrations (10.1 mg/kg) were found at 250 to the southeast of template B and the third highest concentrations (3.3 mg/kg) were found 250 m to the southeast of template C. At template D the highest (0.74 mg/kg) concentrations were found 250 m to the southeast. At all templates concentrations of olefins were decreasing with increasing distance to the template. Since 2000 the content of olefins has decreased at most sites except BAL42, 250 m to the south of template A (Figure 11.3).

Table 11.4. The content of oil hydrocarbons in sediments from Balder in 2003. All values in mg/kg dry sediment. THC values above $LSC_{central\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{BAL27R\ 03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data for the regional and field reference sites in the central part of region II are included.

Site	THC		PAH(16)		NPD		Decalins		Olefins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
BAL03	9.2	2.7							0.26	0.01
BAL04	8.2	0.8							<0.13	
BAL05	13.6	2.1							<0.13	
BAL09	18.4	1.9	0.066	0.005	0.028	0.002	0.430	0.020	3.30	0.66
BAL10	13.7	2.6	0.081	0.022	0.028	0.004	0.243	0.032	0.48	0.08
BAL11	12.8	0.7							<0.13	
BAL12	11.7	1.4							<0.13	
BAL16	21.9	3.4							1.67	0.59
BAL17	17.9	0.6							0.19	0.02
BAL18	16.7	4.4							0.17	0.10
BAL22	16.8	2.1							1.45	1.18
BAL23	14.6	3.7							0.30	0.23
BAL24	11.4	2.3							<0.13	
BAL28	11.2	3.4	0.067	0.016	0.024	0.004	0.262	0.074	0.74	0.25
BAL29	8.3	3.9	0.037	0.024	0.020	0.005	0.175	0.036	<0.13	
BAL30	14.1	1.5							<0.13	
BAL31	14.0	3.7							<0.13	
BAL33	8.3	0.5							0.34	0.05
BAL34	8.1	1.5							0.14	0.06
BAL35	10.2	3.0							<0.13	
BAL37	36.6	3.9	0.108	0.021	0.060	0.017	2.393	2.518	10.1	1.55
BAL38	14.5	1.9	0.095	0.025	0.042	0.009	0.368	0.056	0.48	0.15
BAL39	16.9	4.8							<0.13	
BAL42	73.4	19.2	0.109	0.013	0.048	0.007	2.813	1.666	21.3	5.13
BAL43	19.7	4.3	0.108	0.021	0.030	0.007	0.523	0.328	1.11	0.70
BAL44	17.1	0.8							0.26	0.05
BAL46	11.4	2.2							0.38	0.24
BAL47	16.3	4.3							<0.13	
BAL27R	15.2	2.5	0.094	0.020	0.025	0.005	0.461	0.299	<0.13	
av. ± sd.[1]	16.7 ± 12.5		0.084 ± 0.026		0.035 ± 0.014		0.901 ± 1.062		1.55 ± 4.34	
min – max[1]	8.1 - 73.4		0.037 - 0.109		0.020 - 0.060		0.175 - 2.813		<0.13 – 21.33	
av. ± sd.[2]	11.2±4.0		0.067±0.027		0.020±0.004		0.232±0.085			
min – max[2]	<3.0-15.5		0.013-0.102		0.012-0.027		0.095-0.461			

[1] Field sites, exclusive BAL27R
[2] Reg + Ref $_{central\ 03}$

Table 11.5. The content of oil hydrocarbons in vertical sections of sediment from 3 sampling sites at Balder in 2003. All values in mg/kg dry sediment. THC values above $LSC_{central\ 97\text{-}03}$ and PAH, NPD and decalins values above $LSC_{BAL27R\ 03}$ are dark shaded.

Site	Template	Distance (m)	Layer (cm)	THC	PAH(16)	NPD	Decalins
BAL09	C	250	0-1	17.4	0.064	0.027	0.410
			1-3	22.2	0.096	0.043	0.820
			3-6	13.8	0.076	0.025	0.500
BAL10	C	500	0-1	13.3	0.076	0.025	0.225
			1-3	12.3	0.064	0.022	0.230
			3-6	12.7	0.099	0.025	0.325
BAL28	D	250	0-1	11.0	0.060	0.024	0.235
			1-3	17.3	0.076	0.041	0.520
			3-6	13.9	0.083	0.029	0.600
BAL29	D	500	0-1	12.9	0.057	0.025	0.205
			1-3	9.1	0.042	0.020	0.175
			3-6	10.6	0.020	0.033	0.275
BAL37	B	250	0-1	36.5	0.132	0.078	0.980
			1-3	35.8	0.122	0.074	1.310
			3-6	30.1	0.124	0.066	2.000
BAL38	B	500	0-1	14.4	0.107	0.041	0.305
			1-3	17.7	0.105	0.040	0.530
			3-6	11.7	0.102	0.044	0.970
BAL42	A	250	0-1	67.1	0.116	0.048	1.710
			1-3	51.8	0.091	0.156	4.270
			3-6	41.7	0.489	0.067	3.950
BAL43	A	500	0-1	21.4	0.119	0.033	0.900
			1-3	27.0	0.130	0.049	1.240
			3-6	17.4	0.115	0.030	0.265
BAL27R			0-1	18.9	0.125	0.031	0.305
			1-3	14.6	0.078	0.019	0.205
			3-6	14.6	0.086	0.024	0.405

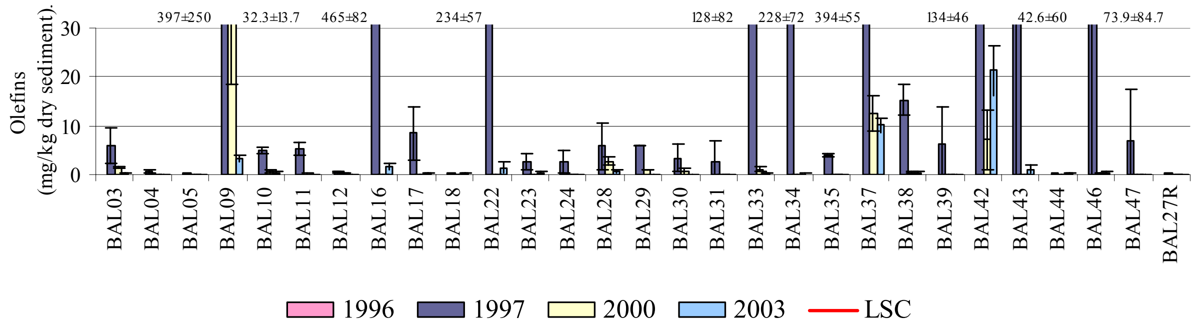


Figure 11.3. Average concentrations of olefins in the sediments in 2003, and in previous surveys.

11.2.2.3 Metals

Table 11.6 summarises the results of the metal analyses of the Balder field in 2003. Concentrations of selected metals in the different layers (0-1, 1-3 and 3-6) of sediment are given in Table 11.7, whereas the complete data set including replicates is given in the Appendix. Distribution of barium in the top layer of the sediments across the field is shown in Figure 11.6. Comparisons of the metal contents in 2003 with the metal contents with previous surveys are presented in Figure 11.7.

Barium was found in a range from 42 to 624 mg/kg, lead from 3.3 to 5.8 mg/kg, cadmium from <0.03 to 0.04 mg/kg, copper from 1.2 to 2.5 mg/kg, mercury from 0.007 to 0.015 mg/kg, chromium from 6.8 to 9.0 mg/kg and zinc from 10.4 to 62.0 mg/kg (Table 11.6). Sediments from BAL03, BAL04, BAL09, BAL10, BAL16, BAL22, BAL28, BAL33, BAL37, BAL38, BAL42 and BAL43 had barium (173-624 mg/kg) content above LSC. Zinc occurred above LSC at all field sites except BAL05, BAL16, BAL33, BAL34 and BAL35. Four of these sites were located northwest and northeast of template D and one site was located to the south west of template B. Copper was present above LSC at BAL37 and BAL42, both sites are located 250 m downstream template B and template A respectively. Cadmium was present above LSC at BAL05 and BAL29. Mercury was above LSC at BAL42. Chrome and lead were below LSC at all sites.

Vertical sediment samples (0-1, 1-3 and 3-6 cm) were collected downstream of each template at 250 m and 500 m distance. Barium occurred above LSC in all depth intervals at most field sites except at 500 m downstream of template D (BAL29) and in the 3-6 cm layer at 500 m downstream of template A (BAL43). The barium content decreased with increasing depth in the sediments at template A and B, indicating recent supply of barium to the sediments. At template C and D there was a more uniform distribution of barium in the sediments.

At template C zinc occurred above LSC down to 6 cm depth in the sediments both a 250 (BAL09) and 500 m (BAL10) distance to the template. At template A zinc occurred above LSC in the 0-1 and 3-6 cm layer at 500 m distance (BAL43). At template B zinc occurred above LSC in the 0-1 cm layer at 250 m distance (BAL37) and in the 3-6 cm layer at 500 m distance (BAL38). At template D zinc occurred above LSC in the 0-1 and 1-3 cm layer at 250 m (BAL28) and in the 0-1 cm layer at 500 m (BAL29).

Copper occurred above LSC in the 0-1 cm layer at 250 m distance at template A (BAL42) and B (BAL37), and in the 1-3 cm layer at 250 m (BAL28) at template D. Cadmium occurred above LSC in the 1-3 cm layer at 500 m distance to template A (BAL43), in the 1-3 cm layer at 250 m distance at template B (BAL37) and in the 1-3 and 3-6 cm layers at 500 m distance at template D (BAL29). Cadmium was also present above LSC in the 1-3 cm layer at the reference site BAL27R. Mercury occurred above LSC at 250 and 500 m distance to template C (BAL09 and BAL10) in respectively 1-3 and 0-1 cm layers. Also at 250 m distance to template A (BAL42) and D (BAL28) did mercury occur above LSC in the 1-3 cm layer. Chromium and lead did not occurred above LSC in any vertical sample.

There was a general decrease in the barium content in the sediments at Balder between 2000 and 2003, except at 250 and 500 m distance to the south of template A (BAL42 and BAL43), where the barium content increased. Also cadmium, lead and copper showed a general decrease in concentration from 2000 to 2003. Chromium occurred at same level in 2003 as in 2000, whereas there was an increase in the zinc content.

Table 11.6 Content of metals in sediments from Balder in 2003. All values in mg/kg dry sediment. Values above $LSC_{central\ 97\text{-}03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data in the regional and field reference sites in the central part of the region II are included.

Site	Cu		Cr		Zn		Ba		Pb		Cd		Hg	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
BAL03	1.8	0.2	7.8	0.7	13.9	4.2	277	50	4.6	0.4	<0.03	-	n.a.	n.a.
BAL04	1.9	0.3	8.5	0.7	14.5	7.1	180	55	5.0	0.6	<0.03	-	n.a.	n.a.
BAL05	1.7	0.3	8.8	1.3	10.4	1.3	131	48	4.7	0.8	0.04	-	n.a.	n.a.
BAL09	1.8	0.4	7.6	0.6	13.8	3.8	240	94	4.7	0.5	<0.03	-	0.010	0.001
BAL10	1.8	0.1	7.8	0.3	15.0	3.9	174	71	4.7	0.9	<0.03	-	0.011	0.003
BAL11	1.5	0.1	7.7	0.3	16.0	5.6	135	41	4.7	0.1	<0.03	-	n.a.	n.a.
BAL12	1.3	0.2	6.8	0.3	15.1	4.3	109	41	4.2	0.5	<0.03	-	n.a.	n.a.
BAL16	1.4	0.3	7.4	0.5	12.3	5.8	206	12	3.9	0.6	<0.03	-	n.a.	n.a.
BAL17	1.5	0.1	7.5	0.7	15.6	6.1	112	32	4.6	0.6	<0.03	-	n.a.	n.a.
BAL18	1.4	0.0	7.2	0.2	14.8	5.1	87	9	4.5	0.3	<0.03	-	n.a.	n.a.
BAL22	1.4	0.3	6.8	0.7	15.7	6.3	173	53	4.2	0.4	<0.03	-	n.a.	n.a.
BAL23	1.6	0.1	7.8	0.1	16.4	5.6	110	7	4.5	0.1	<0.03	-	n.a.	n.a.
BAL24	1.2	0.1	7.1	0.3	14.7	5.5	55	21	3.6	0.4	<0.03	-	n.a.	n.a.
BAL28	2.0	0.1	8.1	0.5	14.9	4.7	310	144	5.3	0.3	<0.03	-	0.011	0.001
BAL29	1.8	0.6	8.5	1.5	14.4	4.4	42	26	3.3	0.2	0.04	-	0.007	0.001
BAL30	1.6	0.2	7.6	0.4	13.0	5.1	122	29	4.8	0.6	<0.03	-	n.a.	n.a.
BAL31	1.4	0.2	7.5	0.6	15.4	6.1	112	24	4.6	0.2	<0.03	-	n.a.	n.a.
BAL33	1.5	0.2	7.7	0.5	9.3	0.6	199	46	4.4	0.5	<0.03	-	n.a.	n.a.
BAL34	1.8	0.4	8.1	1.0	10.5	1.7	155	43	4.8	0.8	<0.03	-	n.a.	n.a.
BAL35	1.6	0.3	8.1	1.1	10.7	0.4	101	25	4.5	0.3	<0.03	-	n.a.	n.a.
BAL37	2.4	0.2	9.0	0.2	15.7	4.8	497	41	5.8	0.3	<0.03	-	0.012	0.003
BAL38	1.7	0.1	8.2	0.3	22.3	9.6	264	82	4.7	0.2	<0.03	-	0.011	0.001
BAL39	1.6	0.2	7.8	0.4	20.3	3.1	133	35	4.5	0.6	<0.03	-	n.a.	n.a.
BAL42	2.5	0.1	8.2	0.4	17.2	4.6	624	74	5.6	0.5	<0.03	-	0.015	0.006
BAL43	2.0	0.3	8.5	0.4	12.7	0.3	307	68	4.9	0.7	<0.03	-	0.011	0.002
BAL44	1.4	0.2	7.4	0.9	15.1	6.2	116	31	4.3	0.6	<0.03	-	n.a.	n.a.
BAL46	1.6	0.2	7.8	0.5	15.6	4.7	128	30	4.3	0.4	<0.03	-	n.a.	n.a.
BAL47	1.4	0.1	6.9	0.4	15.0	5.2	92	24	4.0	0.4	<0.03	-	n.a.	n.a.
BAL27R	1.4	0.2	8.0	0.6	9.4	0.7	72	14	4.3	0.3	<0.03	-	0.009	0.001
av. ± sd.[1]	1.7 ± 0.3		7.8 ± 0.6		14.6 ± 2.7		185 ± 128		4.6 ± 0.5		<0.03		0.011 ± 0.002	
min-max[1]	1.2 - 2.5		6.8 - 9.0		9.3 - 22.3		42 - 624		3.3 - 5.8		<0.03-0.04		0.007 - 0.015	
av. ± sd.[2]	1.2 ± 0.4		6.9 ± 1.2		9.4 ± 1.3		66 ± 31		4.2 ± 0.6		<0.03		0.009±0.003	
min-max[2]	<0.6-1.7		4.9-8.9		6.8-12.0		10-146		3.4-5.1		<0.03		0.006-0.014	

n.a. = not analysed.
[1] Field sites, exclusive BAL27R
[2] Reg + Ref $_{central\ 03}$

Table 11.7. The content of metals in vertical sections of sediment from 3 sampling sites at Balder in 2003. All values in mg/kg dry sediment. Values above $LSC_{central\ 97\text{-}03}$ are dark shaded.

Site	Template	Layer (cm)	Cu	Cr	Zn	Ba	Pb	Cd	Hg
BAL09	C	0-1	1.5	6.9	17.9	347	4.2	<0.03	0.009
		1-3	1.3	6.8	20.0	314	4.0	0.03	0.014
		3-6	1.6	7.7	19.1	420	5.4	<0.03	0.010
BAL10	C	0-1	1.9	8.0	14.3	175	5.5	<0.03	0.014
		1-3	1.9	8.3	20.3	336	5.4	<0.03	0.012
		3-6	1.8	8.1	20.8	286	5.9	<0.03	0.011
BAL28	D	0-1	1.9	8.4	20.2	429	5.1	<0.03	0.011
		1-3	2.3	8.6	21.7	519	5.7	<0.03	0.013
		3-6	1.6	7.7	11.7	372	5.3	<0.03	0.008
BAL29	D	0-1	1.3	7.3	18.9	40.5	3.3	0.03	0.008
		1-3	1.1	7.2	9.4	10.7	3.0	0.04	0.007
		3-6	1.3	7.9	8.9	7	2.1	0.07	0.005
BAL37	B	0-1	2.5	9.1	12.5	511	6.1	<0.03	0.010
		1-3	1.8	7.8	11.0	447	5.3	0.05	0.010
		3-6	1.8	7.7	10.6	231	5.1	<0.03	0.009
BAL38	B	0-1	1.6	8.3	11.2	237	4.8	<0.03	0.011
		1-3	1.5	7.9	10.8	203	5.0	0.03	0.010
		3-6	1.6	8.1	20.0	190	4.8	<0.03	0.010
BAL42	A	0-1	2.6	8.2	11.9	580	5.1	<0.03	0.012
		1-3	1.5	6.9	10.7	519	4.0	<0.03	0.017
		3-6	1.7	7.3	9.7	187	4.3	<0.03	0.009
BAL43	A	0-1	2.2	8.5	13.0	338	5.5	<0.03	0.011
		1-3	1.7	8.3	12.3	272	4.5	0.06	0.011
		3-6	1.6	7.7	20.2	95.9	5.0	<0.03	0.010
BAL27R		0-1	1.5	8.5	9.8	81.3	4.3	0.03	0.009
		1-3	1.6	8.5	10.0	91.1	4.6	0.04	0.009
		3-6	1.8	8.6	10.6	104	4.8	<0.03	0.010

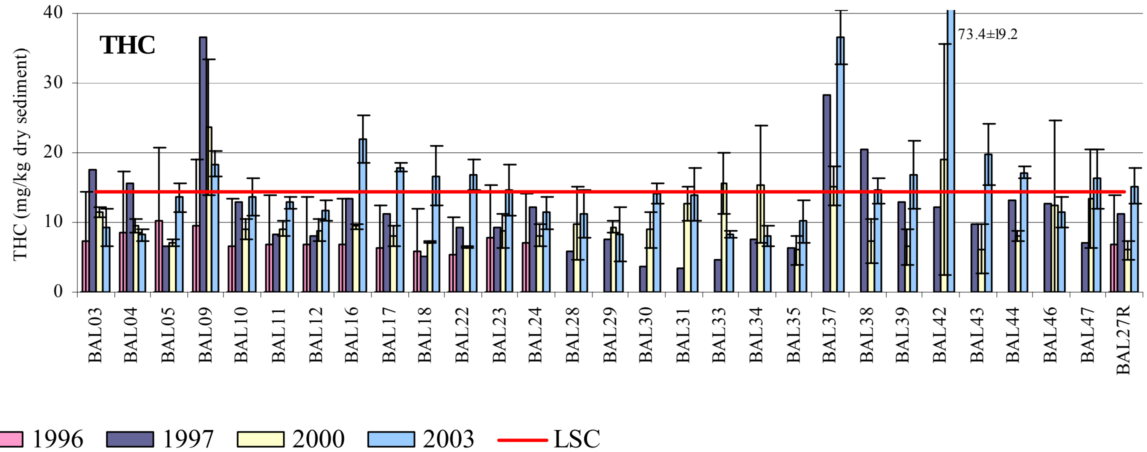


Figure 11.4. Average THC concentrations and standard deviations in sediments from Balder in 2003 and previous years. Red line is $LSC_{central\ 97\text{-}03}$.

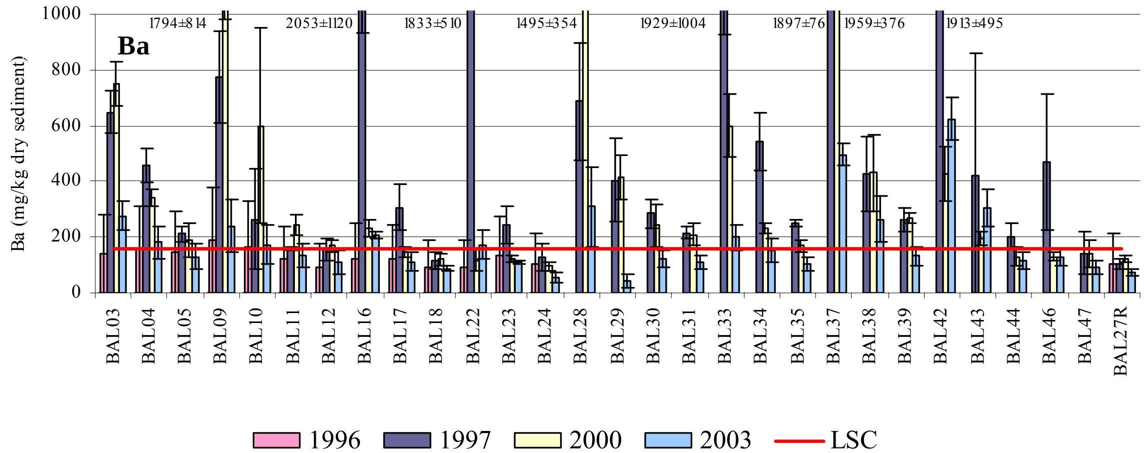


Figure 11.5. Average barium concentrations and standard deviations in sediments from Balder in 2003 and previous years. Red line is $LSC_{central\ 97\text{-}03}$.

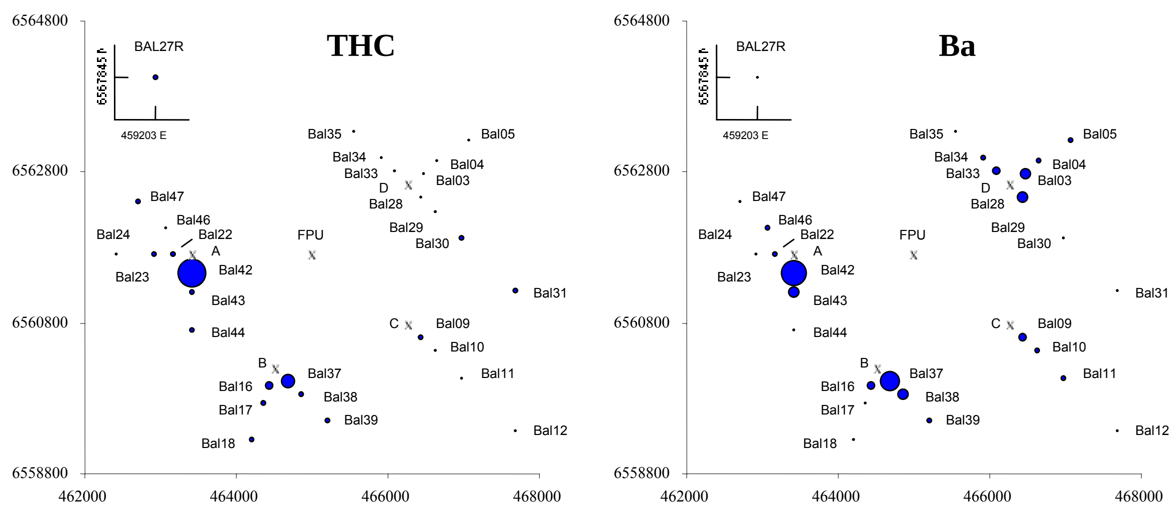


Figure 11.6. Distribution of THC and barium in sediments at the sampling sites at Balder in 2003. The sizes of the circles indicate the amount of THC and Ba. The templates centres and ship (FPU) are marked with an X.

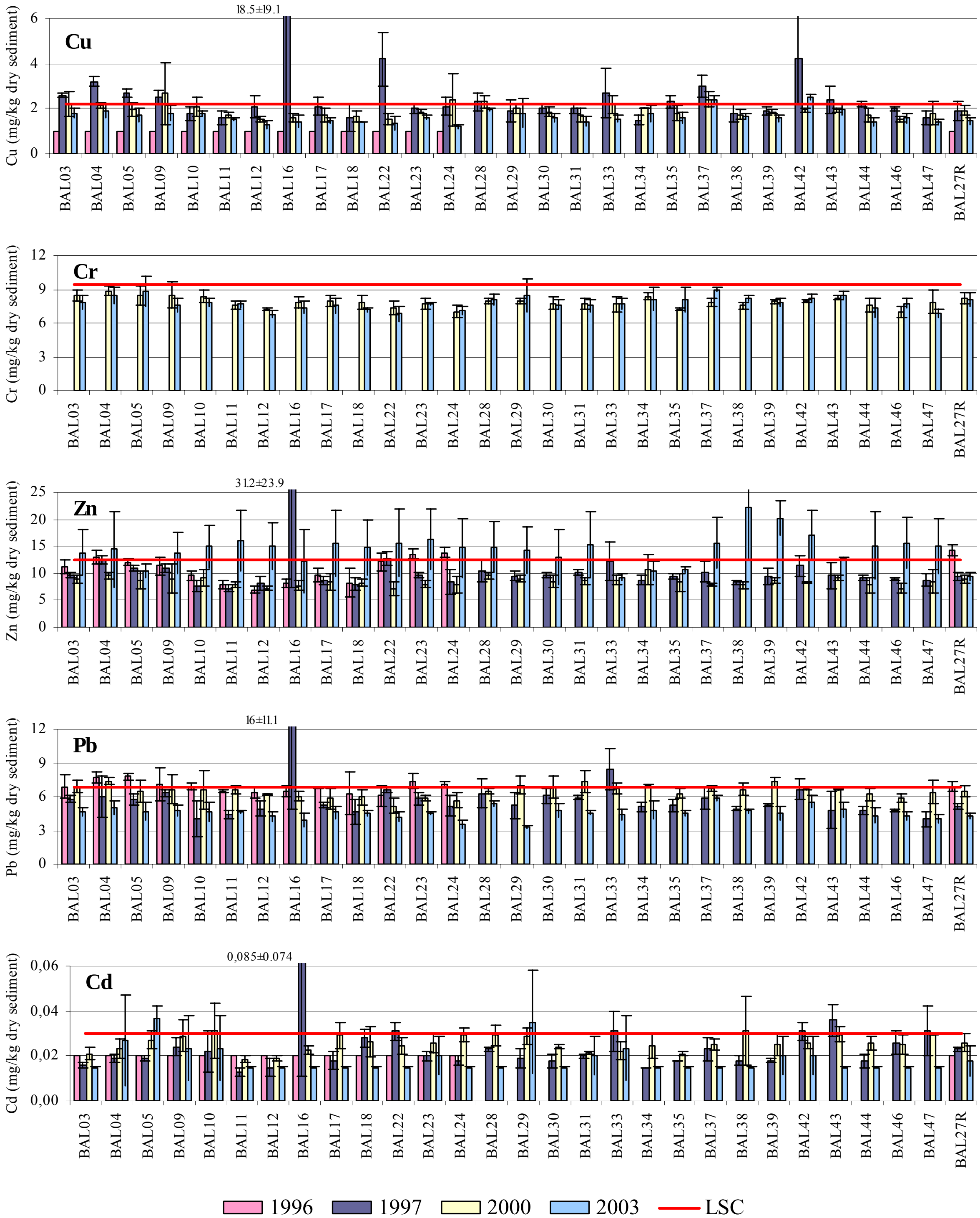


Figure 11.7. Average content and standard deviations of metals in sediment from Balder in 2003 and previous surveys. Red line is $LSC_{central\ 97\text{-}03}$.

The field sites at Balder were compared to nearby regional (RII04 and RII09) and field specific reference sites (GRA14, RIN29R and JOT30R) based on sediment characteristics (TOM and pelite) and chemical content in the sediments (Figure 11.8). Most of the field sampling sites and the reference site (BAL27R) formed one group, whereas BAL37 and BAL42 did separate from the other sites due to higher levels of copper, barium and lead, and BAL05 and BAL29 did separate from the other sites partly due to higher pelite content in the sediments.

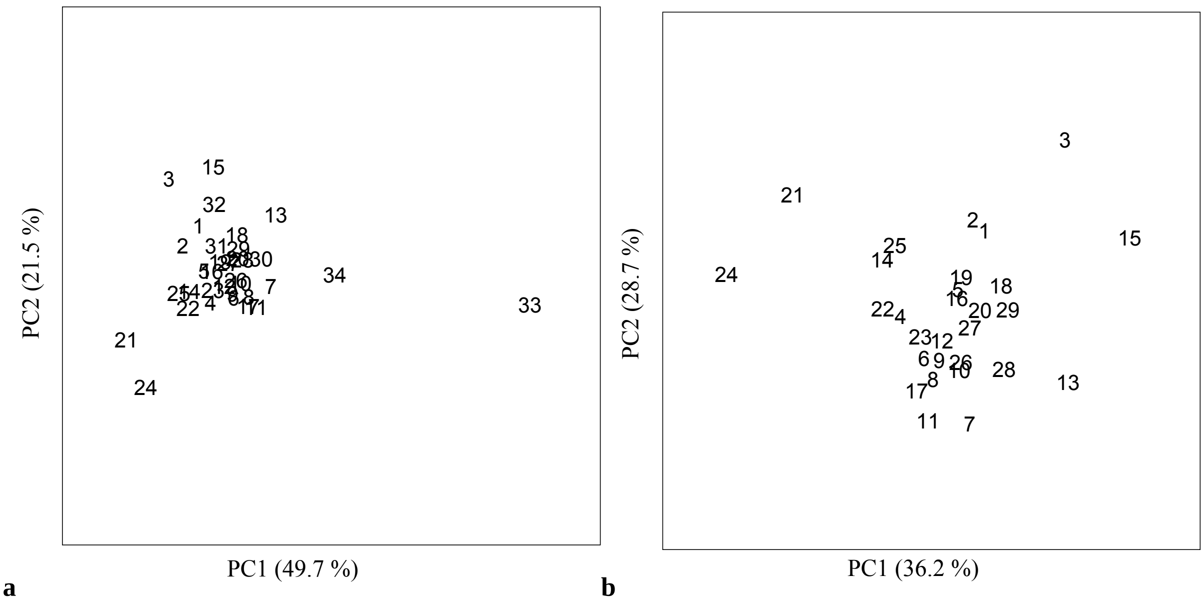


Figure 11.8. 2-D plot from the PCA analysis of environmental variables (% pelite, % sand, % gravel, median Φ, % TOM, Cu, Ba, Zn, Cr, Pb and THC) carried out on:

c) Balder field sites compared to the reference site at Grane, Ringhorne, Jotun and the regional sites RII04 and RII09. Explained variation in the data 71.2 %.
d) Balder fiels sites. Explained variation in the data 64.9 %.
Numbers in the plot identify the sampling sites. See table below.

1	BAL03	10	BAL18	19	BAL34	28	BAL47
2	BAL04	11	BAL22	20	BAL35	29	BAL27R
3	BAL05	12	BAL23	21	BAL37	30	GRA14R
4	BAL09	13	BAL24	22	BAL38	31	RIN29R
5	BAL10	14	BAL28	23	BAL39	32	JOT30R
6	BAL11	15	BAL29	24	BAL42	33	RII-04
7	BAL12	16	BAL30	25	BAL43	34	RII-09
8	BAL16	17	BAL31	26	BAL44		
9	BAL17	18	BAL33	27	BAL46		

11.2.3 Bottom fauna

A summary of the distribution of individuals and taxa within the main taxonomic groups is given in Table 11.8. Unidentified juveniles of the sea urchins Spatangoids (19474 individuals) and Echinoides (2781 individuals) are omitted from the analyses, as they occurred in extremely high numbers. In total, 21119 individuals within 273 taxa were collected at Balder in 2003. The fauna was numerically dominated by annelida with 50 % the individuals and 44 % of the taxa. A complete species list is available in the Appendix.

Table 11.8. Distribution of individuals and taxa within the main taxonomic groups at Balder in 2003 including data from BAL27R (unidentified juveniles of Spatangoida and Echinoidea are not included).

Main taxonomic groups	Number of individuals	%	Number of taxa	%
Annelida	10558	50	119	44
Arthropoda	2018	10	71	26
Mollusca	5228	25	49	18
Echidermata	1980	9	16	6
Diverse groups	1335	6	18	7
Total	21119	100	273	100

The species/area curve for BAL27R indicates that five replicate samples give a representative impression of the bottom fauna in the area (Figure 11.9). However, as more area is sampled, more taxa are collected, indicating that not even 10 replicate samples give the full species assemblage of the area.

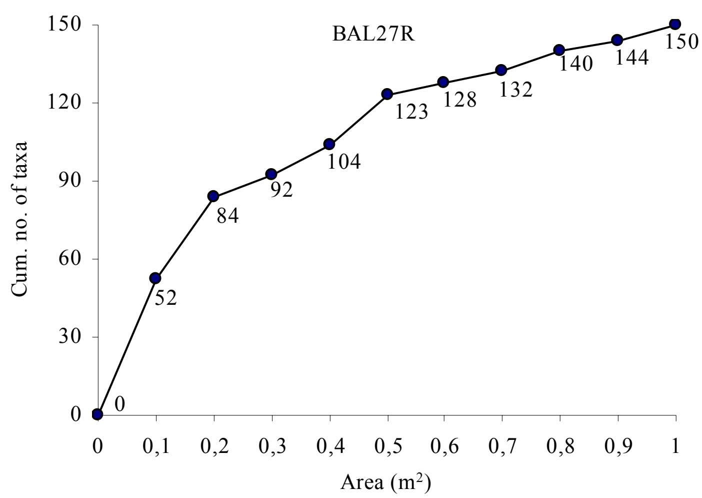


Figure 11.9. Species/area curve for the reference station at the Balder field. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

The distribution of individuals and taxa are shown in Figure 11.10. Number of individuals and taxa at each site, and the calculated diversity indexes (H' and ES_{100}) are given in Table 11.9 and Figure 11.11. The number of individuals varied from 466 (BAL11) to 1109 (BAL09), and the number of taxa varied from 95 (BAL42) to 124 (BAL43). The Shannon-Wiener diversity index (H') varied from 4.52 (BAL42) to 5.96 (BAL34), whereas the ES_{100} index varied from 30.5 (BAL42) to 51.0 (BAL34). The evenness index J varied from 0.69 (BAL42) to 0.87 (BAL34). The corresponding values at BAL27R are within or near the variation at the field sites. The number of taxa, diversity and evenness indicate good environmental conditions at all sites although BAL42 had relative low species diversity and evenness compared to the regional and field specific reference sites in the central part of Region II.

Table 11.9. Number of individuals, species/taxa and selected community indices for each station (0.5 m^2) at the Balder field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

Site number	Number of individuals	Number of taxa	Diversity H'	Evenness J	H'-max	ES_{100}
BAL03	601	111	5.73	0.84	6.79	46.3
BAL04	540	102	5.70	0.85	6.67	46.6
BAL05	651	99	5.45	0.82	6.63	42.7
BAL09	1109	113	4.96	0.73	6.82	36.9
BAL10	733	117	5.43	0.79	6.87	42.9
BAL11	466	105	5.69	0.85	6.71	47.4
BAL12	606	106	5.69	0.85	6.73	46.3
BAL16	722	102	5.37	0.81	6.67	41.2
BAL17	744	123	5.50	0.79	6.94	44.5
BAL18	599	107	5.41	0.80	6.74	43.8
BAL22	745	112	5.56	0.82	6.81	44.1
BAL23	658	97	5.45	0.83	6.60	43.0
BAL24	674	110	5.56	0.82	6.78	44.6
BAL28	715	116	5.67	0.83	6.86	44.9
BAL29	652	113	5.83	0.85	6.82	47.7
BAL30	751	117	5.76	0.84	6.87	47.1
BAL31	557	104	5.71	0.85	6.70	47.3
BAL33	632	110	5.74	0.85	6.78	46.9
BAL34	595	115	5.96	0.87	6.85	51.0
BAL35	722	99	5.63	0.85	6.63	44.9
BAL37	908	100	5.11	0.77	6.64	36.9
BAL38	574	109	5.81	0.86	6.77	48.2
BAL39	757	109	5.68	0.84	6.77	46.6
BAL42	1077	95	4.52	0.69	6.57	30.5
BAL43	945	124	5.44	0.78	6.95	42.7
BAL44	688	101	5.27	0.79	6.66	40.8
BAL46	609	100	5.54	0.83	6.64	44.7
BAL47	692	110	5.42	0.80	6.78	42.4
BAL27R	714	123	5.71	0.82	6.94	45.7
BAL27R	683	109	5.65	0.84	6.77	45.1
BAL27R	1397	150	5.82	0.80	7.23	45.9
Sum[1]	19722	268				
Average[1]	704	108	5.52	0.82	6.75	44.0
SD[1]	149	8	0.29	0.04	0.10	4.1
Min[1]	466	95	4.52	0.69	6.57	30.5
Max[1]	1109	124	5.96	0.87	6.95	51.0
Average[2]	774	113	5.55	0.81	6.81	44.3
SD[2]	230	14	0.24	0.02	0.18	2.6
Min[2]	488	94	5.12	0.79	6.55	38.7
Max[2]	1202	141	5.85	0.85	7.14	47.9

[1]Field sites, exclusive BAL27R
[2]Reg + Ref $_{central\ 03}$

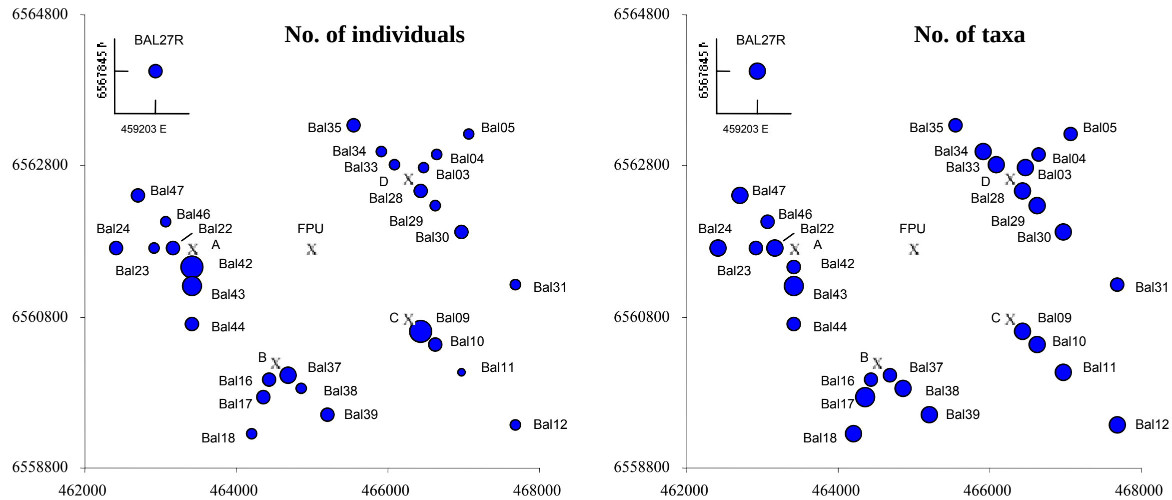


Figure 11.10. Distribution of bottom fauna (individuals and taxa) among the sampling sites in 2003. The size of the circle indicates the number of individuals and taxa. Exclusive unidentified juveniles of Spatangoida and Echinoidae. Values for BAL27R are average of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2). The templates centres and ship (FPU) are marked with an X.

Figure 11.11. Number of individuals, taxa and selected community indices for each site (0.5 m^2) at the Balder field for 2000 and 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea in 2003. Values for BAL27R are average ± standard deviation of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2).

Distribution of taxa in geometrical classes is presented in Figure 11.12. The smooth graphs indicate undisturbed bottom fauna.

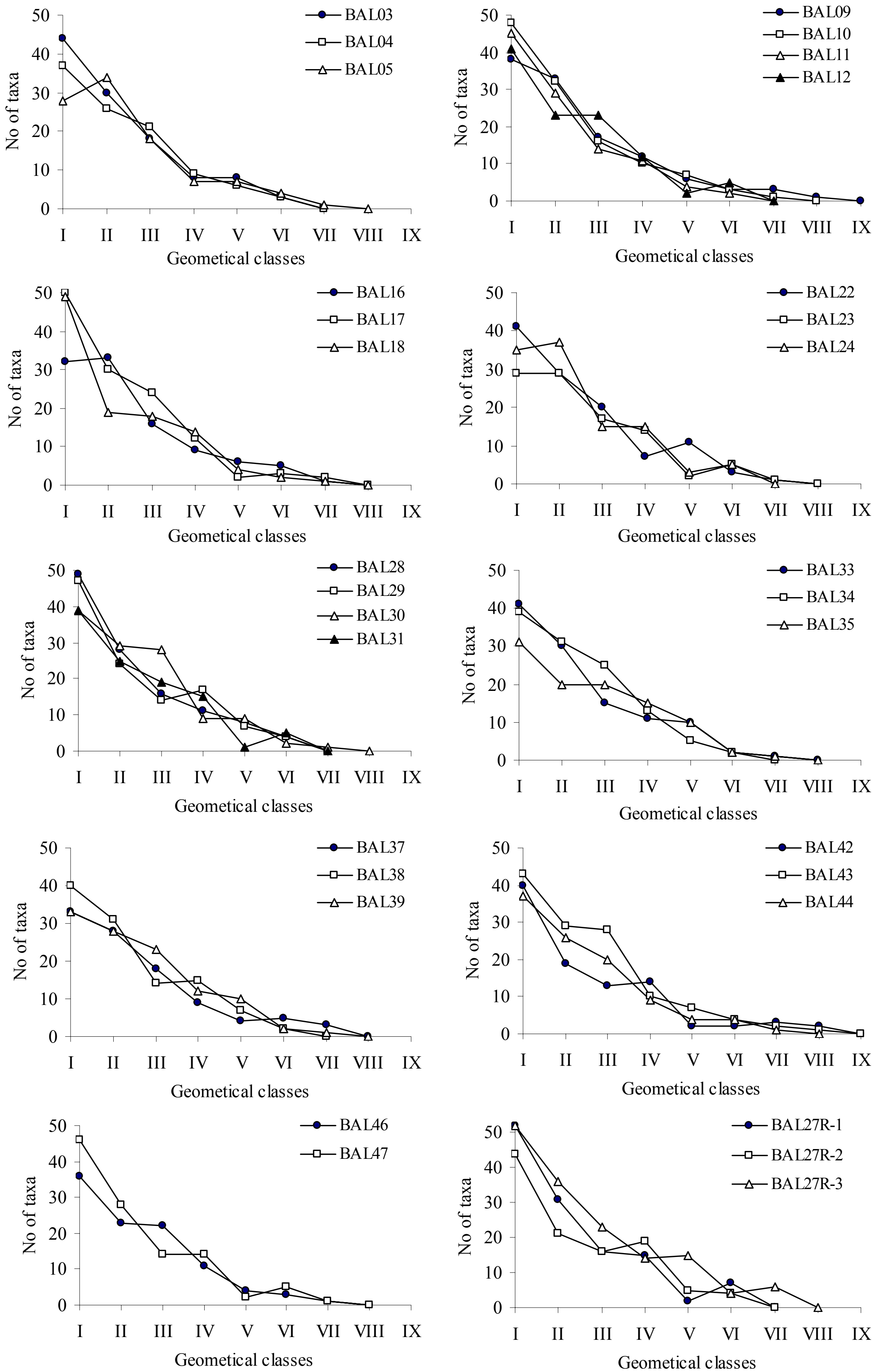


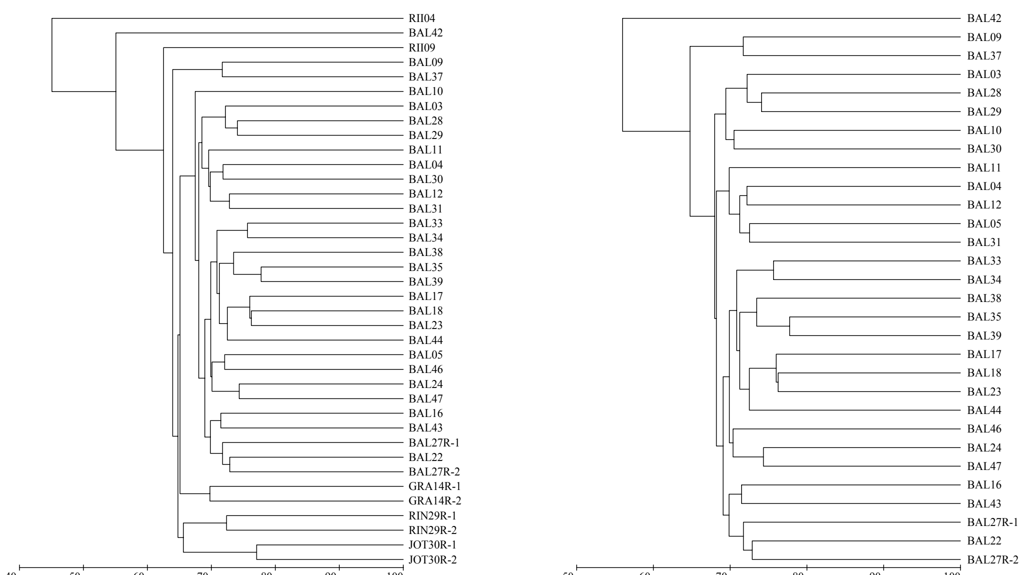
Figure 11.12. Distribution of taxa in geometrical classes at Balder in 2003. Unidentified juveniles of Spatangoida and Echinoidea are not included.

The ten most numerous taxa are listed in Table 11.12 at the end of this chapter. The list comprise 35 taxa and 15696 individuals, which was 12.8 % of all (273) taxa and 74.3 % of all (21119) individuals. The most widespread and abundant species was the polychaete *Paramphinome jeffreysii* which occurred as the most numerous species at 22 of 29 sites. The bivalves *Thyasira sarsii* and *Thyasira flexuosa* which are known to occur in disturbed environments were most abundant at BAL09 250 m to the south east of template C. These bivalves occurred in relatively high numbers at BAL37 and BAL42 too. Both sites were located 250 m downstream of template B and A respectively. The bivalves *Thyasira croulinensis* and *Thyasira ferruginea* known to occur in undisturbed sediment were not present at BAL37 and BAL42, and they occurred only in low numbers at BAL09. Both species were present at all the other sampling sites at Balder.

The results of the multivariate analyses are given in the dendrogramme (Figure 11.13) and the MDS plott (Figure 11.14).

The cluster analysis groups the sites into three groups. The first group consisted of BAL42 which had approximately 56 % similarity with the rest of the sites at Balder. The second group comprise BAL37 and BAL09, which are both located 250 m downstream of template B and C respectively. The third group comprise the rest of the sites which group within approximately 69 % similarity. The reference site belonged to this group.

The results of the MDS analysis support the findings in the cluster analysis although BAL09 did not form a separate group together with BAL37. The stress test of the MDS analysis was 0.19, indicating a potential useful presentation of the data.



a b

Figure 11.13. Dendrogram showing the similarity between fauna from sampling sites at:

a) Balder field compared to reference sites (RIN29R, GRA14R and JOT30R) and regional sites (RII04 and RII09).
b) Balder field in 2003.

Exclusive unidentified juveniles of Spatangoida and Echinoidea.

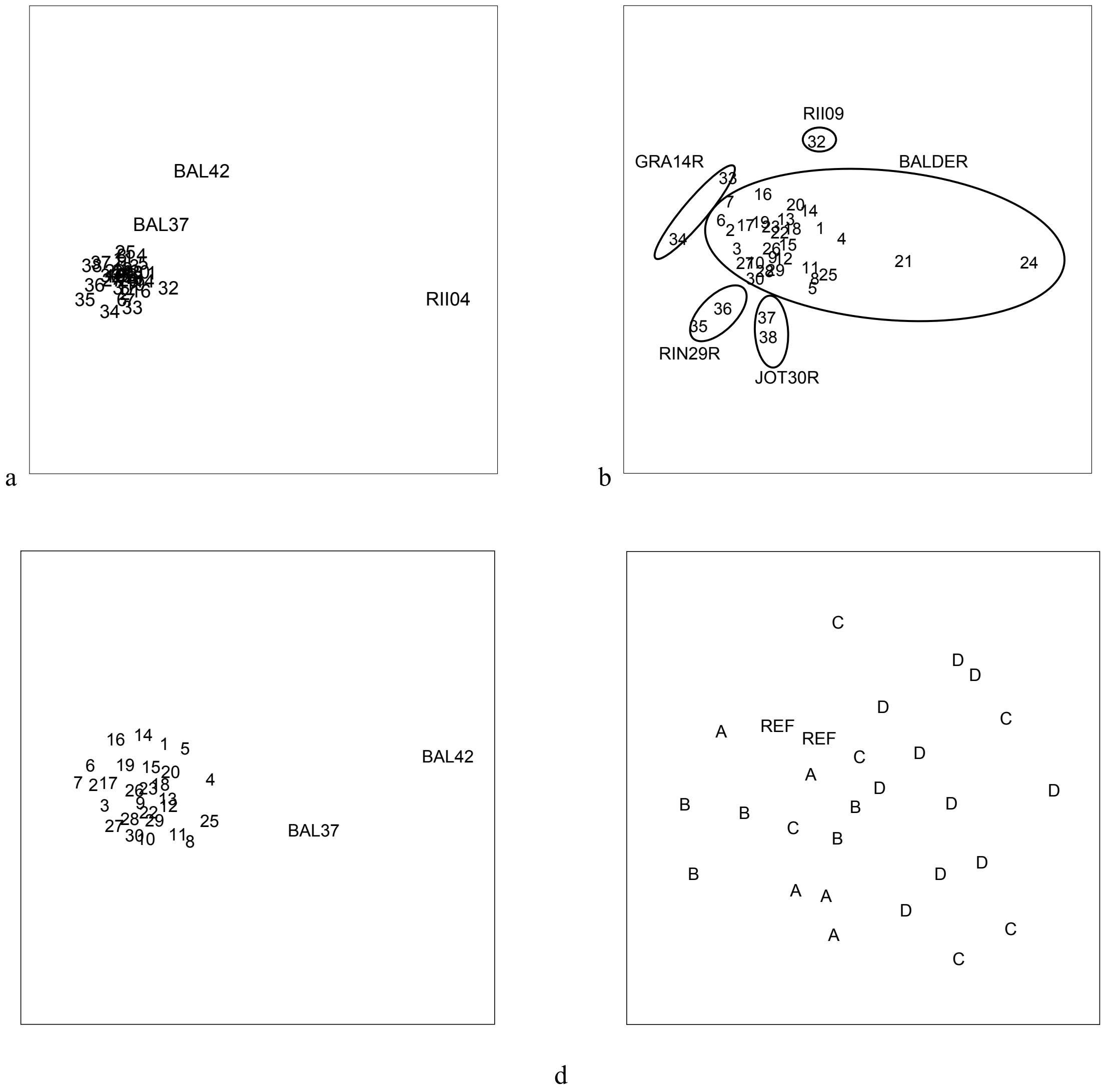


Figure 11.14. A 2-dimetional plott of the MDS analysis of the fauna data from:

a) Balder field compared to reference sites (RIN29R, GRA14R and JOT30R) and regional sites (RII04 and RII09). Stress = 0.14.
b) Same as a) exclusive RII04. Stress = 0.21.
c) Balder field in 2003. Stress = 0.19.
d) Balder field exclusive BAL37 and BAL42. Stress = 0.26. Letters refer to template A, B, C and D.

Exclusive unidentified juveniles of Spatangoida and Echinoidea.
Numbers in the plot identify the sampling sites. See table below.

1	BAL03	11	BAL22	21	BAL37	31	RII04
2	BAL04	12	BAL23	22	BAL38	32	RII09
3	BAL05	13	BAL24	23	BAL39	33	GRA14R-1
4	BAL09	14	BAL28	24	BAL42	34	GRA14R-2
5	BAL10	15	BAL29	25	BAL43	35	RIN29R-1
6	BAL11	16	BAL30	26	BAL44	36	RIN29R-2
7	BAL12	17	BAL31	27	BAL46	37	JOT30R-1
8	BAL16	18	BAL33	28	BAL47	38	JOT30R-2
9	BAL17	19	BAL34	29	BAL27R-1		
10	BAL18	20	BAL35	30	BAL27R-2		

Linking of biotic and environmental variables by BIOENV revealed that THC, copper and TOM were correlated to the biota at $\rho_w = 0.32$ (Table 11.10). The linking between the environmental variables and the fauna was relatively weak.

Table 11.10. Combinations of the 10 environmental variables, taken *k* at a time, yielding the best matches of biotic and abiotic similarity matrices for each *k*, as measured by weighted Spearman rank correlation ρ_w. Bold type indicates overall optimum. All possible combinations of variables and associated correlation to the biotic are given in the Appendix.

Number of variables (*k*)	Correlation coefficient (ρ_w)	Environmental variables									
1	0.280	Cu									
1	0.247	THC									
1	0.167	Ba									
1	0.118	Pb									
1	0.035	TOM									
1	-0.023	Cr									
1	-0.046	Pelite									
1	-0.055	Sand									
1	-0.182	Gravel									
1	-0.192	Zn									
2	0.308	THC	Cu								
3	**0.317**	**THC**	**Cu**	**TOM**							
4	0.286	THC	Cu	TOM	Ba						
5	0.275	THC	Cu	TOM	Ba	Cr					
6	0.266	THC	Cu	TOM	Ba		Pelite	Pb			
7	0.257	THC	Cu	TOM	Ba	Cr	Pelite	Pb			
8	0.244	THC	Cu	TOM	Ba	Cr	Pelite	Pb	Sand		
9	0.203	THC	Cu	TOM	Ba	Cr	Pelite	Pb	Sand	Gravel	
10	0.139	THC	Cu	TOM	Ba	Cr	Pelite	Pb	Sand	Gravel	Zn

11.2.4 Estimation of influenced area

The extension of contamination along sampling transects and the minimum area of contaminated sediments for THC, barium and other metals as well as for faunal disturbance are shown in Figure 11.15 and Table 11.11. Since 2000 the area contaminated by THC had increased at template A and template B, whereas it had decreased at template C and template D. The total area contaminated by THC was larger in 2003 (2.38 km²) than in 2000 (0.54 km²). The area contaminated by barium had decreased at all templates and the size of the total area contaminated by barium was reduced from 4.21 km² to 0.43 km². Also the area where faunal disturbance had been observed was reduced at all templates. The total area of faunal disturbance was reduced from 0.37 km² to 0.04 km². The area contaminated by other metals, in this case zinc, had increased at all templates, and the total size of the area had increased from 0.15 km² to 4.13 km².

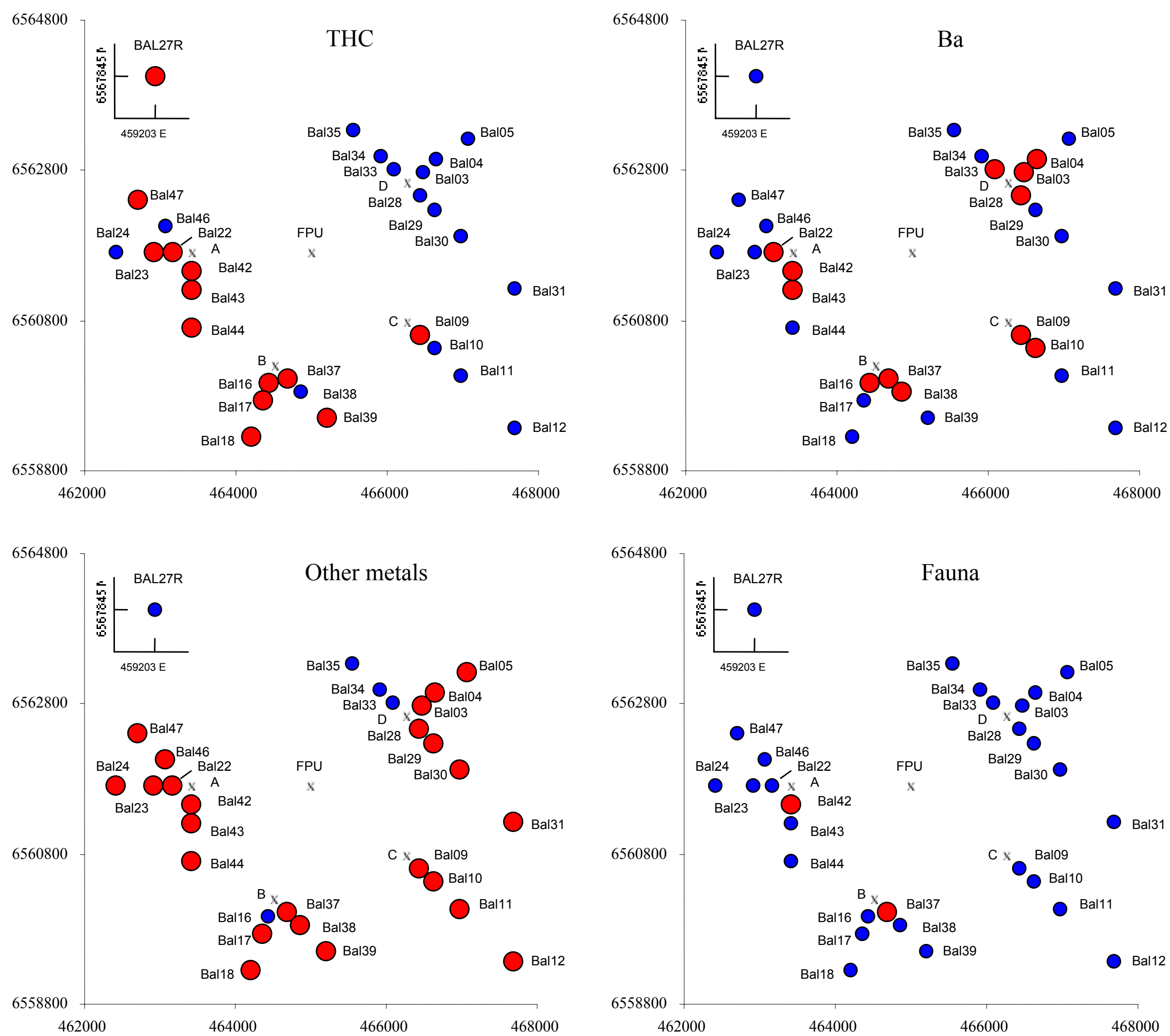


Figure 11.15. Faunal disturbance and chemical contamination of the sediments at Balder in 2003. The templates centres and ship (FPU) are marked with a X. Uncontaminated sites and sites with no faunal disturbance are marked with small blue circles.

Table 11.11. Estimated distance of contamination and faunal disturbance from the installation, and estimated area of contamination and faunal disturbance around the field centre.

Balder A	NW m	E m	S M	W m	2003 km^2	2000 km^2	1997 km^2
THC	1000	0	1000	500	0.79	0.25	0.29
Ba	0	0	500	250	0.10	0.12	0.49
Other metals	1000	0	1000	1000	1.57	0.00	0.15
Fauna	0	0	250	0	0.02	0.07	0.22

Balder B	N m	SE m	SW M	W m	2003 km^2	2000 km^2	1997 km^2
THC	0	1000	1000	0	1.57	0.07	0.55
Ba	0	500	250	0	0.10	0.33	0.55
Other metals	0	1000	1000	0	0.79	0.00	0.07
Fauna	0	0	250	0	0.02	0.07	0.11

Balder C	NE m	SE m	SW m	NW m	2003 km^2	2000 km^2	1997 km^2
THC	0	250	0	0	0.02	0.07	0.12
Ba	0	500	0	0	0.05	0.42	0.12
Other metals	0	2000	0	0	0.20	0.07	0.00
Fauna	0	0	0	0	0	0.07	0.07

Balder D	NE m	SE m	S m	NW m	2003 km^2	2000 km^2	1997 km^2
THC	0	0	0	0	0.00	0.15	0.12
Ba	478	250	0	250	0.19	3.34	1.77
Other metals	1000	2000	0	0	1.57	0.07	0.15
Fauna	0	0	0	0	0	0.15	0.07

Balder SUM	N m	E m	S m	W m	2003 km^2	2000 km^2	1997 km^2
THC					2.38	0.54	1.09
Ba					0.43	4.21	2.93
Other metals					4.13	0.15	0.37
Fauna					0.04	0.37	0.48

11.3 Summary and conclusions

The Balder field consists of four templates (A, B, C and D) and one production vessel. Since the monitoring survey at Balder in 2000 four new wells have been drilled at the field. In addition to this three wells were drilled from Balder to the nearby Ringhorne. The sediments are still characterized as fine sand, although there has been a slight increase in the pelite content since 2000. The amounts of THC had increased in the vicinity of template A and B and contamination by THC was revealed at several sites at these templates. A decrease in THC content was found in the vicinity of template C and D, and contamination by THC was only found at 250 m distance to the southeast of template C. At each template olefins occurred in highest concentrations at the innermost sampling site to the south or southeast. The highest concentrations of olefins were found at 250 m distance to the south of template A. At this site the content of olefins was higher in 2003 than in 2000. The barium content in the sediments was in general lower in 2003 than in 2000 although contamination was found in the immediate vicinity of all templates. Due to an increase in the zinc content in the sediments contamination by zinc was found at most sampling sites except the sites to the northwest of template D and at the reference site. The species diversity was in general higher in 2003 than in 2000 although fewer individuals of the bottom fauna were included in the analysis. There was high similarity in the bottom fauna across the field except at 250 m to the south at template A and 250 m to the southeast at template B where some faunal disturbance was found. In total the area where faunal disturbance were located was smaller in 2003 than in 2000.

Table 11.12. Number of individuals and relative abundance for the ten predominant taxa at each site at the Balder field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

BAL03	No. of ind.	%	Cum %
Thyasira equalis	44	7.3	7.3
Phoronis sp.	44	7.3	14.6
Sabellidae indet.	35	5.8	20.5
Paramphinome jeffreysii	30	5.0	25.5
Myriochele oculata	28	4.7	30.1
Harpinia antennaria	26	4.3	34.4
Amphiura chiajei	25	4.2	38.6
Diplocirrus glaucus	20	3.3	41.9
Laonice sarsi	19	3.2	45.1
Spiophanes kroeyeri	19	3.2	48.3

BAL04	No. of ind.	%	Cum %
Paramphinome jeffreysii	46	8.5	8.5
Thyasira equalis	34	6.3	14.8
Thyasira croulinensis	32	5.9	20.7
Amphiura chiajei	26	4.8	25.6
Diplocirrus glaucus	26	4.8	30.4
Sabellidae indet.	22	4.1	34.4
Phoronis sp.	21	3.9	38.3
Myriochele oculata	21	3.9	42.2
Spiophanes kroeyeri	18	3.3	45.6
Asteroidea indet.	14	2.6	48.1

BAL05	No. of ind.	%	Cum %
Paramphinome jeffreysii	70	10.8	10.8
Thyasira croulinensis	54	8.3	19.0
Thyasira equalis	53	8.1	27.2
Myriochele oculata	41	6.3	33.5
Diplocirrus glaucus	34	5.2	38.7
Amphiura chiajei	27	4.1	42.9
Phoronis sp.	19	2.9	45.8
Spiophanes kroeyeri	18	2.8	48.5
Lanice conchilega	18	2.8	51.3
Arctica islandica	17	2.6	53.9

BAL09	No. of ind.	%	Cum %
Diplocirrus glaucus	249	22.5	22.5
Thyasira sarsii	107	9.6	32.1
Paramphinome jeffreysii	86	7.8	39.9
Thyasira flexuosa	69	6.2	46.1
Thyasira equalis	49	4.4	50.5
Spiophanes bombyx	36	3.2	53.7
Terebellides stroemi	33	3.0	56.7
Amphiura chiajei	30	2.7	59.4
Myriochele oculata	28	2.5	61.9
Phoronis sp.	23	2.1	64.0

BAL10	No. of ind.	%	Cum %
Paramphinome jeffreysii	125	17.1	17.1
Amphiura chiajei	50	6.8	23.9
Diplocirrus glaucus	42	5.7	29.6
Thyasira equalis	37	5.0	34.7
Thyasira croulinensis	30	4.1	38.7
Laonice sarsi	29	4.0	42.7
Nemertini indet.	27	3.7	46.4
Sabellidae indet.	22	3.0	49.4
Phoronis sp.	20	2.7	52.1
Spiophanes kroeyeri	20	2.7	54.8

BAL11	No. of ind.	%	Cum %
Paramphinome jeffreysii	40	8.6	8.6
Amphiura chiajei	39	8.4	17.0
Thyasira croulinensis	31	6.7	23.6
Phoronis sp.	25	5.4	29.0
Diplocirrus glaucus	22	4.7	33.7
Thyasira equalis	21	4.5	38.2
Aporrhais spp.	13	2.8	41.0
Thyasira ferruginea	13	2.8	43.8
Myriochele oculata	12	2.6	46.4
Lanice conchilega	11	2.4	48.7

BAL12	No. of ind.	%	Cum %
Paramphinome jeffreysii	49	8.1	8.1
Phoronis sp.	46	7.6	15.7
Myriochele oculata	35	5.8	21.5
Amphiura chiajei	32	5.3	26.7
Lanice conchilega	32	5.3	32.0
Thyasira croulinensis	29	4.8	36.8
Thyasira equalis	24	4.0	40.8
Diplocirrus glaucus	15	2.5	43.2
Sabellidae indet.	15	2.5	45.7
Spiophanes kroeyeri	14	2.3	48.0

BAL16	No. of ind.	%	Cum %
Paramphinome jeffreysii	91	12.6	12.6
Diplocirrus glaucus	56	7.8	20.4
Thyasira equalis	50	6.9	27.3
Amphiura chiajei	48	6.6	33.9
Myriochele oculata	39	5.4	39.3
Thyasira sarsii	33	4.6	43.9
Thyasira croulinensis	27	3.7	47.6
Caudofoveata indet.	23	3.2	50.8
Laonice sarsi	20	2.8	53.6
Phoronis sp.	19	2.6	56.2

Table 11.12 continue. Number of individuals and relative abundance for the ten predominant taxa at each site at the Balder field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

BAL17	No. of ind.	%	Cum %
Paramphinome jeffreysii	107	14.4	14.4
Thyasira equalis	76	10.2	24.6
Thyasira croulinensis	53	7.1	31.7
Amphiura chiajei	45	6.0	37.8
Diplocirrus glaucus	35	4.7	42.5
Myriochele oculata	29	3.9	46.4
Laonice sarsi	16	2.2	48.5
Nemertini indet.	15	2.0	50.5
Aricidea catherinae	15	2.0	52.6
Caudofoveata indet.	14	1.9	54.4

BAL18	No. of ind.	%	Cum %
Paramphinome jeffreysii	98	16.4	16.4
Thyasira equalis	50	8.3	24.7
Thyasira croulinensis	48	8.0	32.7
Amphiura chiajei	26	4.3	37.1
Diplocirrus glaucus	21	3.5	40.6
Caudofoveata indet.	16	2.7	43.2
Phoronis sp.	16	2.7	45.9
Eriopisa elongata	14	2.3	48.2
Thyasira ferruginea	14	2.3	50.6
Myriochele oculata	12	2.0	52.6
Nemertini indet.	12	2.0	54.6
Aricidea catherinae	12	2.0	56.6

BAL22	No. of ind.	%	Cum %
Paramphinome jeffreysii	102	13.7	13.7
Diplocirrus glaucus	47	6.3	20.0
Thyasira equalis	41	5.5	25.5
Amphiura chiajei	36	4.8	30.3
Thyasira croulinensis	29	3.9	34.2
Sabellidae indet.	29	3.9	38.1
Myriochele oculata	27	3.6	41.7
Caudofoveata indet.	23	3.1	44.8
Nemertini indet.	19	2.6	47.4
Aricidea catherinae	19	2.6	49.9
Urothoe elegans	19	2.6	52.5
Prionospio cirrifera	19	2.6	55.0

BAL23	No. of ind.	%	Cum %
Paramphinome jeffreysii	66	10.0	10.0
Diplocirrus glaucus	60	9.1	19.1
Thyasira croulinensis	46	7.0	26.1
Thyasira equalis	42	6.4	32.5
Amphiura chiajei	42	6.4	38.9
Myriochele oculata	33	5.0	43.9
Sabellidae indet.	19	2.9	46.8
Caudofoveata indet.	16	2.4	49.2
Laonice sarsi	15	2.3	51.5
Nemertini indet.	14	2.1	53.6

BAL24	No. of ind.	%	Cum %
Thyasira equalis	63	9.3	9.3
Amphiura chiajei	61	9.1	18.4
Thyasira croulinensis	49	7.3	25.7
Diplocirrus glaucus	47	7.0	32.6
Paramphinome jeffreysii	46	6.8	39.5
Phoronis sp.	20	3.0	42.4
Caudofoveata indet.	19	2.8	45.3
Eriopisa elongata	18	2.7	47.9
Myriochele oculata	15	2.2	50.1
Asteroidea indet.	14	2.1	52.2

BAL28	No. of ind.	%	Cum %
Myriochele oculata	58	8.1	8.1
Paramphinome jeffreysii	56	7.8	15.9
Thyasira equalis	42	5.9	21.8
Phoronis sp.	38	5.3	27.1
Diplocirrus glaucus	31	4.3	31.5
Thyasira sarsii	30	4.2	35.7
Amphiura chiajei	28	3.9	39.6
Lanice conchilega	25	3.5	43.1
Laonice sarsi	23	3.2	46.3
Thyasira flexuosa	23	3.2	49.5

Table 11.12 continue. Number of individuals and relative abundance for the ten predominant taxa at each site at the Balder field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

BAL29	No. of ind.	%	Cum %
Myriochele oculata	43	6.6	6.6
Paramphinome jeffreysii	42	6.4	13.0
Thyasira croulinensis	35	5.4	18.4
Thyasira equalis	33	5.1	23.5
Amphiura chiajei	29	4.4	27.9
Phoronis sp.	24	3.7	31.6
Diplocirrus glaucus	21	3.2	34.8
Arctica islandica	19	2.9	37.7
Aporrhais spp.	18	2.8	40.5
Lanice conchilega	17	2.6	43.1
Nemertini indet.	17	2.6	45.7

BAL30	No. of ind.	%	Cum %
Paramphinome jeffreysii	69	9.2	9.2
Myriochele oculata	63	8.4	17.6
Amphiura chiajei	43	5.7	23.3
Phoronis sp.	30	4.0	27.3
Laonice sarsi	30	4.0	31.3
Thyasira equalis	27	3.6	34.9
Thyasira croulinensis	25	3.3	38.2
Sabellidae indet.	25	3.3	41.5
Diplocirrus glaucus	24	3.2	44.7
Nemertini indet.	20	2.7	47.4

BAL31	No. of ind.	%	Cum %
Paramphinome jeffreysii	43	7.7	7.7
Amphiura chiajei	40	7.2	14.9
Myriochele oculata	39	7.0	21.9
Thyasira equalis	36	6.5	28.4
Thyasira croulinensis	34	6.1	34.5
Nemertini indet.	16	2.9	37.3
Diplocirrus glaucus	14	2.5	39.9
Aporrhais spp.	13	2.3	42.2
Sabellidae indet.	12	2.2	44.3
Ampharete falcata	12	2.2	46.5

BAL33	No. of ind.	%	Cum %
Paramphinome jeffreysii	67	10.6	10.6
Amphiura chiajei	36	5.7	16.3
Myriochele oculata	35	5.5	21.8
Asteroidea indet.	25	4.0	25.8
Diplocirrus glaucus	22	3.5	29.3
Aporrhais spp.	21	3.3	32.6
Spiophanes kroeyeri	19	3.0	35.6
Harpinia antennaria	19	3.0	38.6
Thyasira equalis	18	2.8	41.5
Phoronis sp.	18	2.8	44.3
Laonice sarsi	18	2.8	47.2

BAL34	No. of ind.	%	Cum %
Myriochele oculata	46	7.7	7.7
Paramphinome jeffreysii	43	7.2	15.0
Laonice sarsi	28	4.7	19.7
Amphiura chiajei	24	4.0	23.7
Nemertini indet.	18	3.0	26.7
Diplocirrus glaucus	16	2.7	29.4
Harpinia antennaria	16	2.7	32.1
Aporrhais spp.	15	2.5	34.6
Spiophanes kroeyeri	15	2.5	37.1
Phoronis sp.	15	2.5	39.7
Sabellidae indet.	15	2.5	42.2
Lanice conchilega	15	2.5	44.7

BAL35	No. of ind.	%	Cum %
Paramphinome jeffreysii	80	11.1	11.1
Myriochele oculata	40	5.5	16.6
Amphiura chiajei	39	5.4	22.0
Thyasira croulinensis	31	4.3	26.3
Laonice sarsi	26	3.6	29.9
Diplocirrus glaucus	26	3.6	33.5
Phoronis sp.	25	3.5	37.0
Urothoe elegans	23	3.2	40.2
Lanice conchilega	22	3.0	43.2
Aporrhais spp.	20	2.8	46.0
Sabellidae indet.	20	2.8	48.8

BAL37	No. of ind.	%	Cum %
Thyasira sarsii	110	12.1	12.1
Thyasira flexuosa	97	10.7	22.8
Diplocirrus glaucus	80	8.8	31.6
Paramphinome jeffreysii	56	6.2	37.8
Natatolana borealis	54	5.9	43.7
Spiophanes bombyx	52	5.7	49.4
Myriochele oculata	36	4.0	53.4
Thyasira equalis	36	4.0	57.4
Terebellides stroemi	31	3.4	60.8
Laonice sarsi	20	2.2	63.0

BAL38	No. of ind.	%	Cum %
Paramphinome jeffreysii	52	9.1	9.1
Amphiura chiajei	35	6.1	15.2
Thyasira equalis	29	5.1	20.2
Phoronis sp.	26	4.5	24.7
Myriochele oculata	22	3.8	28.6
Diplocirrus glaucus	20	3.5	32.1
Harpinia antennaria	20	3.5	35.5
Lumbrineris scopa	16	2.8	38.3
Thyasira croulinensis	16	2.8	41.1
Aricidea catherinae	13	2.3	43.4
Lanice conchilega	13	2.3	45.6

Table 11.12 continue. Number of individuals and relative abundance for the ten predominant taxa at each site at the Balder field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

BAL39	No. of ind.	%	Cum %
Paramphinome jeffreysii	108	14.3	14.3
Thyasira equalis	40	5.3	19.6
Laonice sarsi	36	4.8	24.3
Aporrhais spp.	27	3.6	27.9
Aricidea catherinae	26	3.4	31.3
Thyasira croulinensis	25	3.3	34.6
Amphiura chiajei	23	3.0	37.6
Myriochele oculata	23	3.0	40.7
Diplocirrus glaucus	22	2.9	43.6
Phoronis sp.	20	2.6	46.2

BAL42	No. of ind.	%	Cum %
Paramphinome jeffreysii	201	18.7	18.7
Thyasira sarsii	178	16.5	35.2
Spiophanes bombyx	100	9.3	44.5
Brissopsis lyrifera	86	8.0	52.5
Thyasira flexuosa	66	6.1	58.6
Chaetozone sp.	57	5.3	63.9
Diplocirrus glaucus	45	4.2	68.1
Cerianthus lloydii	20	1.9	69.9
Nemertini indet.	19	1.8	71.7
Glycera lapidum	15	1.4	73.1

BAL43	No. of ind.	%	Cum %
Paramphinome jeffreysii	145	15.3	15.3
Diplocirrus glaucus	80	8.5	23.8
Thyasira equalis	80	8.5	32.3
Amphiura chiajei	44	4.7	36.9
Terebellides stroemi	39	4.1	41.1
Thyasira croulinensis	36	3.8	44.9
Myriochele oculata	33	3.5	48.4
Aricidea catherinae	26	2.8	51.1
Caudofoveata indet.	24	2.5	53.7
Labidoplax buskii	20	2.1	55.8

BAL44	No. of ind.	%	Cum %
Paramphinome jeffreysii	111	16.1	16.1
Thyasira equalis	60	8.7	24.9
Amphiura chiajei	50	7.3	32.1
Thyasira croulinensis	36	5.2	37.4
Diplocirrus glaucus	35	5.1	42.4
Sabellidae indet.	29	4.2	46.7
Myriochele oculata	26	3.8	50.4
Aricidea catherinae	19	2.8	53.2
Nemertini indet.	16	2.3	55.5
Phoronis sp.	15	2.2	57.7

BAL46	No. of ind.	%	Cum %
Paramphinome jeffreysii	79	13.0	13.0
Thyasira croulinensis	41	6.7	19.7
Thyasira equalis	40	6.6	26.3
Diplocirrus glaucus	32	5.3	31.5
Amphiura chiajei	31	5.1	36.6
Caudofoveata indet.	20	3.3	39.9
Phoronis sp.	18	3.0	42.9
Myriochele oculata	17	2.8	45.6
Sabellidae indet.	13	2.1	47.8
Lumbrineris scopa	13	2.1	49.9
Urothoe elegans	13	2.1	52.1

BAL47	No. of ind.	%	Cum %
Paramphinome jeffreysii	91	13.2	13.2
Thyasira equalis	53	7.7	20.8
Amphiura chiajei	51	7.4	28.2
Thyasira croulinensis	49	7.1	35.3
Diplocirrus glaucus	32	4.6	39.9
Myriochele oculata	32	4.6	44.5
Caudofoveata indet.	24	3.5	48.0
Sabellidae indet.	22	3.2	51.2
Asteroidea indet.	14	2.0	53.2
Amphiura filiformis	13	1.9	55.1
Lanice conchilega	13	1.9	56.9

BAL27R	No. of ind.	%	Cum %
Paramphinome jeffreysii	123	8.8	8.8
Thyasira equalis	86	6.2	15.0
Thyasira croulinensis	77	5.5	20.5
Amphiura chiajei	67	4.8	25.3
Diplocirrus glaucus	67	4.8	30.1
Myriochele oculata	65	4.7	34.7
Sabellidae indet.	54	3.9	38.6
Natatolana borealis	54	3.9	42.4
Phoronis sp.	49	3.5	46.0
Laonice sarsi	36	2.6	48.5

12 Ringhorne

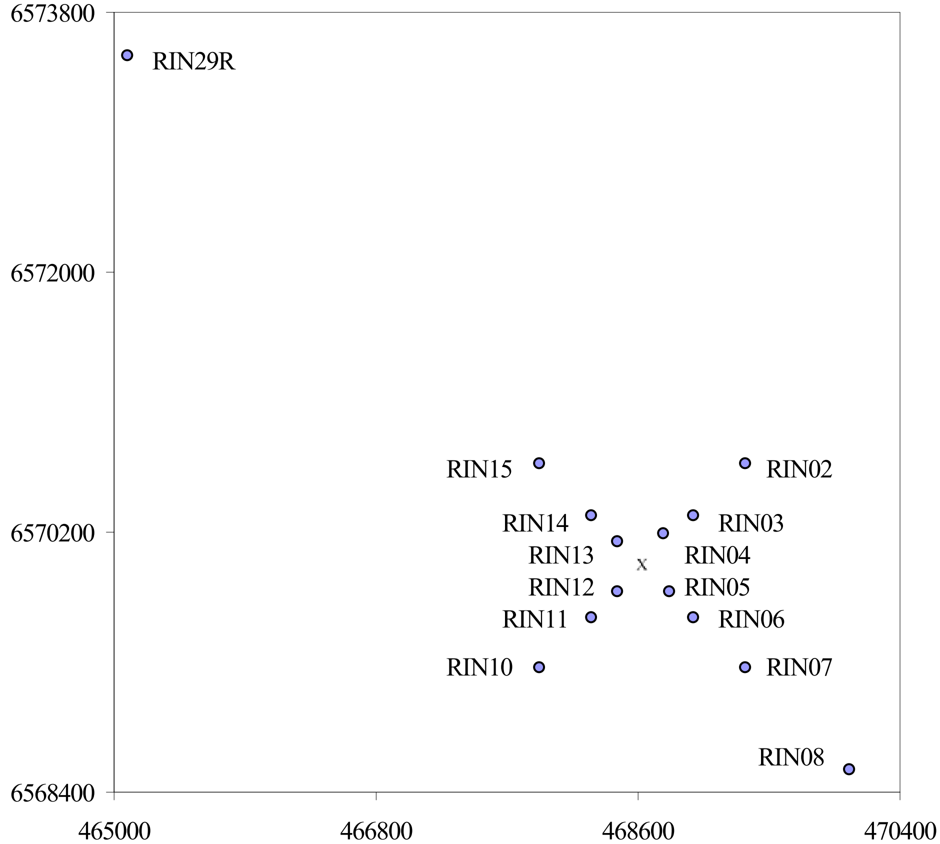
12.1. Introduction

The Ringhorne field is situated in block 25/10. Production at Ringhorne started during the spring of 2003. A baseline survey was undertaken at Ringhorne during the monitoring survey in region II in 2000. No faunal disturbances or elevated levels of barium or THC were found in 2000. Recent discharges at Ringhorne are listed in Table 12.1, and sampling sites are shown in Figure 12.1

Table 12.1. Recent well drilling and discharges from operations and accidents at Ringhorne.

	1997	1998	1999	2000	2001	2002
No of wells drilled	1	0	2	0	3*	1**
Barite, tonnes	216	0	61	0	725	155
Cuttings, tonnes	250	0	340	0	540[1]	160
Water-based drilling mud, tonnes	800	0	767	0	2682	1667
Ester -based drilling mud, tonnes	0	0	0	0	251	0
Cementing chemicals, tonnes	13	0	18.9	0	39.5	45
Completion chemicals, tonnes	-	-	-	0	0	18
Accidental discharges, chemicals, m^3	-	-	-	0	0.01	1
Accidental discharges, oil, m^3	-	-	-	0	0	0.06

* Drilling from a movable rig at the wells 25/11-C-03 CH/DH, 25/11-A-19H/AH and 25/11-A-20 H/AH
** Drilling from the Ringhorne installation
[1] 3.1 tonnes was synthetic



Site	ED50 UTM Zone 31 E	ED50 UTM Zone 31 N	Distance (m) / direction (º)	Depth (m)
RIN-02	469343	6570667	1000/45	129
RIN-03	468990	6570314	500/45	129
RIN-04	468776	6570180	258/30.4	129
RIN-05	468813	6569783	250/135	129
RIN-06	468990	6569606	500/135	129
RIN-07	469343	6569253	1000/135	129
RIN-08	470050	6568546	2000/135	129
RIN-10	467929	6569253	1000/225	129
RIN-11	468282	6569606	500/225	129
RIN-12	468459	6569783	250/225	129
RIN-13	468459	6570137	250/315	130
RIN-14	468282	6570314	500/315	130
RIN-15	467929	6570667	1000/315	130
RIN-29R	465101	6573496	5000/315	129

Figure 12.1. Map showing the internal distribution of sampling sites in Ringhorne in 2003. Positioning according to UTM ED50 zone 31. The field centre is marked with an X.

12.2. Results and discussion

12.2.1 Sediments characteristics

TOM, and the amount (%) of gravel, sand, pelite, median (Φ), sorting, skewness and kurtosis in the sediment from the present survey is presented in Table 12.2. Additional information on colour and smell can be found in the Appendix. Median (Φ), pelite, sand and TOM are compared with data from 2000 in Figure 12.2.

The sediments at Ringhorne are classified as fine sand with median (Φ) values ranging from 2.63 (RIN02, RIN04, RIN05 and RIN13) to 2.71 (RIN12 and RIN14). The amount of pelite varied from 12.5 % (RIN13) to 17.5 % (RIN03), the sand varied from 82.5 % (RIN03) to 87.5 % (RIN13), and the TOM varied from 1.6 % (RIN02) to 2.8 % (RIN03). The condtions at the reference site RIN29R were within the variation found at the field sites. Compared to the baseline survey of 2000, it were slightly more pelite and less sand at all sites in 2003, and the TOM content was somewhat higher at RIN03, RIN04, RIN08 and RIN10 in 2003. The change in the median value between 2000 and 2003 are probably due to different methods of calculation.

The sediments at the reference site RIN29R was finer, contained more pelite, than average of the reference sites in the central part of region II (Table 12.2).

Table 12.2. Total organic matter and sediment grain size at all sites at Ringhorne in 2003. For comparison averages, standard deviations, max and min values for the regional and reference sites are included.

Site	TOM %	Gravel %	Sand %	Pelite %	Median (Φ)	Sorting	Skewness	Kurtosis
RIN02	1.58	0.01	86.78	13.20	2.63	1.03	0.57	2.86
RIN03	2.79	0.00	82.50	17.50	2.69	1.26	0.65	2.13
RIN04	2.04	0.05	87.18	12.77	2.63	1.02	0.56	2.79
RIN05	2.22	0.06	86.98	12.96	2.63	1.02	0.56	2.83
RIN06	1.92	0.00	86.28	13.72	2.65	1.07	0.58	2.80
RIN07	1.80	0.01	85.19	14.80	2.67	1.11	0.59	2.73
RIN08	2.10	0.05	85.92	14.03	2.65	1.10	0.57	2.59
RIN10	2.41	0.00	84.22	15.78	2.70	1.15	0.59	2.07
RIN11	2.18	0.11	85.75	14.15	2.64	1.08	0.59	2.85
RIN12	2.10	0.01	85.82	14.17	2.71	1.10	0.56	1.96
RIN13	1.70	0.03	87.50	12.47	2.63	1.01	0.56	2.77
RIN14	2.31	0.01	83.91	16.08	2.71	1.16	0.59	1.96
RIN15	1.96	0.02	83.72	16.26	2.70	1.17	0.60	2.03
RIN29R	2.18	0.01	82.95	17.04	2.81	1.22	0.57	1.60
Average[1]	2.09	0.03	85.52	14.45	2.66	1.10	0.58	2.49
SD[1]	0.32	0.03	1.53	1.54	0.03	0.07	0.02	0.39
Min[1]	1.58	0.00	82.50	12.47	2.63	1.01	0.56	1.96
Max[1]	2.79	0.11	87.50	17.50	2.71	1.26	0.65	2.86
Average[2]	1.71	0.29	87.23	12.49	2.71	1.16	0.34	1.76
SD[2]	0.45	0.62	5.20	5.12	0.37	0.14	0.19	0.46
Min[2]	0.73	0.00	78.12	3.04	1.76	0.93	0.03	1.05
Max[2]	2.19	2.19	96.61	21.77	3.34	1.40	0.57	2.95

[1] Field sites, exclusive RIN29R
[2] Reg + Ref $_{\text{central 03}}$

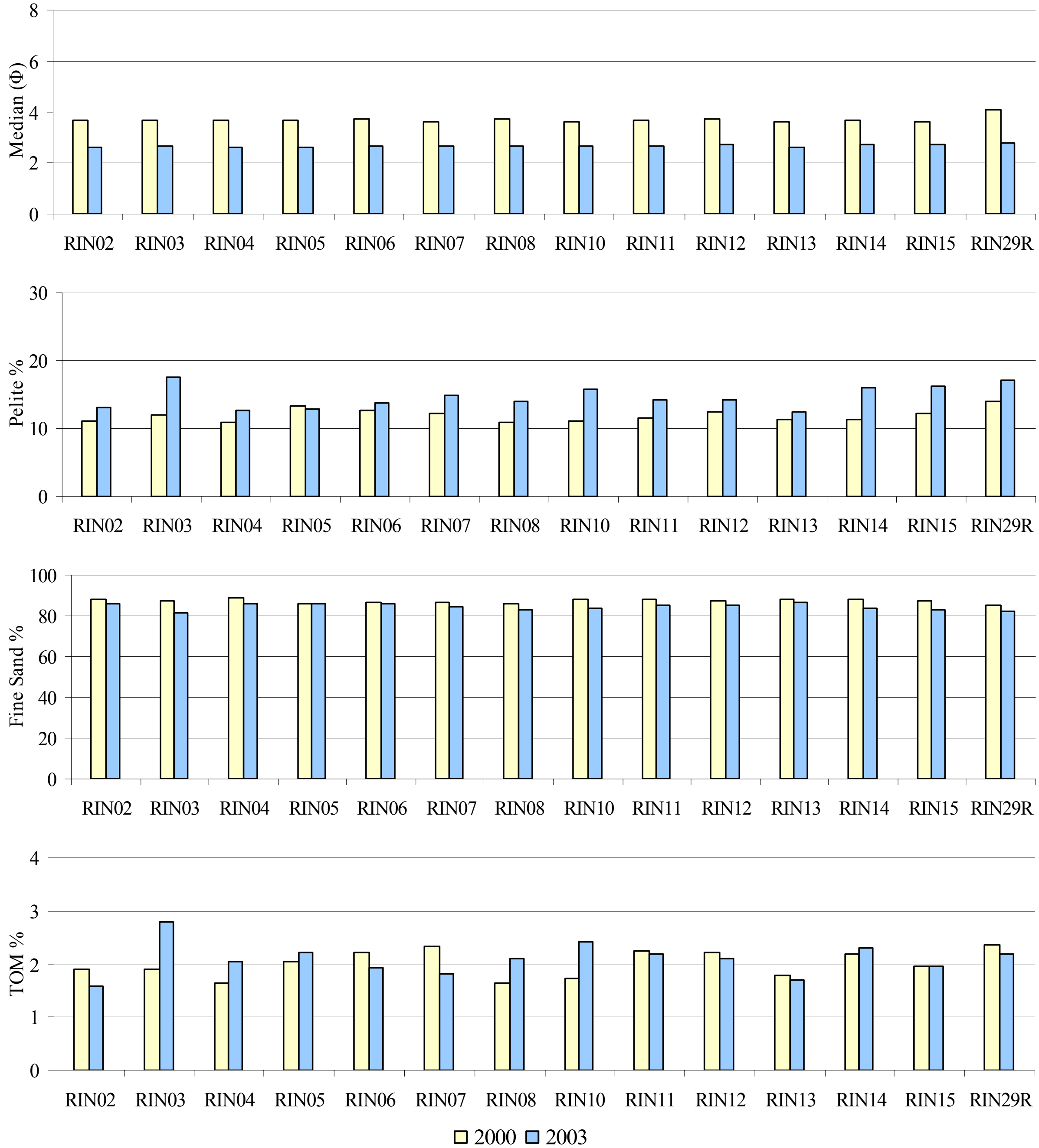


Figure 12.2. Sediment characteristics at Ringhorne in 2000 and 2003. Fine sand is the relative amount of sand with grain size 63-250 µm.

12.2.2 Chemical compounds

12.2.2.1 LSC

The results of the LSC (limits of significant contamination) calculations of hydrocarbons and metals are presented in the chapter concerning the regional and reference sites. Both the $LSC_{central\ 97\text{-}03}$ and the field specific LSC value are presented in Table 12.3. Fine sediments are more likely to have higher affinity for pollutants than coarse sediments. Thus the field specific LSC value ($LSC_{RIN29R\ 03}$) should perhaps be disregarded due to slightly higher content of fine sediments at the reference site compared to the other reference sites in the central part of region II. LSC in the text relates to $LSC_{central\ 97\text{-}03}$.

Table 12.3. Limits of Significant Contamination (LSC) for the Ringhorne field in 2003, and for the central part of Region II based on data from 1997 to 2003 ($LSC_{central\ 97\text{-}03}$) and the whole of Region II based on data from 1997 to 2003 ($LSC_{regII\ 97\text{-}03}$). For comparison, LSC-values from 2000 are included. All values in mg/kg dry sediment.

	THC	PAH (16)	NPD's	Decalins	Cu	Cr	Zn	Ba	Pb	Cd	Hg
$LSC_{RIN29R\ 03}$	16.9	0.142	0.037	0.346	2.4	9.3	14.1	107	6.3	0.03[1]	0.014
$LSC_{central\ 97\text{-}03}$	14.5	*	*	*	2.2	9.4	12.4	161	6.8	0.03[1]	0.012
$LSC_{regII\ 97\text{-}03}$	13.3	*	*	*	2.0	9.4	11.1	136	6.6	0.03[1]	0.011
$LSC_{RIN29R\ 00}$**	11.0	*	0.075	0.163	2.6	10.4	12.0	134	8.1	0.038	0.009
$LSC_{regII\ 97\text{-}00}$**	9.8	*	*	*	2.0	9.6	8.9	146	7.0	0.03	0.008

* NPD's, PAH's and decalins are not analysed at regional sites in 1997 and 2000
** Data from Mannvik & al. 2001
[1] LSC = detection limit

12.2.2.2 Hydrocarbons

Summarised results of the hydrocarbon analyses, along with the content of selected hydrocarbon compounds in the different layers (0-1, 1-3 and 3-6) are given in Table 12.4 and Table 12.5. The complete data set including replicates is given in the Appendix. Comparison of the THC content in 2003 with previous surveys is presented in Figure 12.3.

Table 12.4. The content of oil hydrocarbons in sediments from Ringhorne in 2003. All values in mg/kg dry sediment. THC values above $LSC_{central\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{RIN29R\ 03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data for the regional and field reference sites in the central part of region II are included.

Site	THC		PAH(16)		NPD		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
RIN02	14.6	4.7	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
RIN03	12.2	5.3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
RIN04	18.8	10.4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
RIN05	17.0	3.9	0.073	0.019	0.018	0.006	0.490	0.085
RIN06	13.7	0.4	0.096	0.017	0.025	0.003	0.273	0.048
RIN07	14.8	2.8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
RIN08	16.8	7.7	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
RIN10	14.7	4.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
RIN11	18.3	5.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
RIN12	16.4	5.9	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
RIN13	20.9	5.6	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
RIN14	16.1	9.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
RIN15	8.3	1.4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
RIN29R	12.6	1.9	0.098	0.019	0.026	0.005	0.253	0.040
av. ± sd.*	15.6 ± 3.2							
min – max*	8.3 - 20.9							
av. ± sd.**	11.2±4.0		0.067±0.027		0.020±0.004		0.232±0.085	
min – max**	<3.0-15.5		0.013-0.102		0.012-0.027		0.095-0.461	

n.a. = not analysed.
[1] Field sites, exclusive RIN29R
[2] Reg + Ref $_{central\ 03}$

THC was found in the range from 8.3 to 20.9 mg/kg, and THC concentrations above LSC were found at RIN02, RIN04, RIN05, RIN07, RIN08, RIN10, RIN11, RIN12, RIN13 and RIN14. Highest concentrations were found out to 250 m to the northwest (RIN13) and northeast (RIN04). In general there was higher THC content in the sediments in 2003 than in 2000.

At RIN05, 250 m downstream and to the southeast of the field centre, THC contamination was found down in the upper 0-1 and 1-3 cm layers. The 0-1 cm layer was also contaminated by decalins. At the reference site, RIN29R, contamination by THC was found in the 0-1 cm layer (Table 12.5).

Table 12.5. The content of oil hydrocarbons in vertical sections of sediment from 3 sampling sites at Ringhorne in 2003. All values in mg/kg dry sediment. THC values above $LSC_{central\ 97-03}$ and PAH, NPD and decalin values above $LSC_{RIN29R\ 03}$ are dark shaded.

Site	Layer (cm)	THC	PAH(16)	NPD	Decalins
RIN05	0-1	17.4	0.052	0.012	0.500
	1-3	16.2	0.105	0.031	0.240
	3-6	12.7	0.126	0.022	0.230
RIN06	0-1	13.3	0.090	0.024	0.275
	1-3	10.6	0.080	0.030	0.195
	3-6	10.8	0.104	0.022	0.195
RIN29R	0-1	14.8	0.118	0.028	0.285
	1-3	7.6	0.093	0.046	0.185
	3-6	10.2	0.106	0.023	0.215

12.2.2.3 Metals

Table 12.6 summarises the results of the metal analyses of the Ringhorne field in 2003. Concentrations of selected metals in the different layers (0-1, 1-3 and 3-6) of sediment are given in Table 12.7, whereas the complete data set including replicates is given in the Appendix. A comparison of the contents of metals in 2003 with the contents metals in 2000 is presented in Figure 12.6.

Table 12.6 Content of metals in sediments from Ringhorne in 2003. All values in mg/kg dry sediment. Values above $LSC_{central\ 97\text{-}03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data in the regional and field reference sites in the central part of the region II are included.

Site	Cu		Cr		Zn		Ba		Pb		Cd		Hg	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
RIN02	1.8	0.1	8.5	0.3	12.1	0.5	219	18	5.6	0.2	<0.03	-	n.a.	n.a.
RIN03	1.8	0.3	8.2	0.7	12.5	1.8	315	96	5.1	0.8	<0.03	-	n.a.	n.a.
RIN04	1.8	0.3	7.2	1.2	11.2	1.9	387	115	4.2	1.2	<0.03	-	n.a.	n.a.
RIN05	1.7	0.3	7.7	0.5	11.1	2.1	231	16	4.3	0.7	<0.03	-	0.010	0.001
RIN06	1.6	0.4	7.7	1.1	10.0	1.7	99	41	4.7	0.7	<0.03	-	0.011	0.001
RIN07	1.9	0.3	7.8	0.3	11.1	1.8	98	8	4.7	0.3	<0.03	-	n.a.	n.a.
RIN08	1.7	0.1	7.6	0.3	10.4	0.5	87	15	5.3	0.2	<0.03	-	n.a.	n.a.
RIN10	1.9	0.4	8.3	1.1	11.1	1.7	84	18	4.6	0.3	<0.03	-	n.a.	n.a.
RIN11	1.7	0.1	7.8	0.4	10.5	0.5	83	24	4.4	0.2	<0.03	-	n.a.	n.a.
RIN12	2.0	0.4	8.2	1.0	11.4	1.9	337	87	4.8	0.8	<0.03	-	n.a.	n.a.
RIN13	2.0	0.4	7.9	1.2	12.2	1.0	299	172	4.9	0.9	<0.03	-	n.a.	n.a.
RIN14	2.1	0.3	9.2	1.0	12.7	1.3	201	41	5.2	0.6	<0.03	-	n.a.	n.a.
RIN15	1.8	0.3	8.3	0.8	11.5	1.5	110	34	5.1	0.8	<0.03	-	n.a.	n.a.
RIN29R	1.7	0.3	7.7	0.7	10.7	1.5	67	17	5.0	0.5	<0.03	-	0.010	0.002
av. ± sd.[1]	1.8 ± 0.1		8.0 ± 0.5		11.4 ± 0.8		196 ± 110		4.8 ± 0.4		<0.03			
min-max[1]	1.6 - 2.1		7.2 - 9.2		10.0 - 12.7		83 - 387		4.2 - 5.6		<0.03			
av. ± sd.[2]	1.2 ± 0.4		6.9 ± 1.2		9.4 ± 1.3		66 ± 31		4.2 ± 0.6		<0.03		0.009±0.003	
min-max[2]	<0.6-1.7		4.9-8.9		6.8-12.0		10-146		3.4-5.1		<0.03		0.006-0.014	

n.a. = not analysed.
[1] Field sites, exclusive RIN29R
[2] Reg + $Ref_{central\ 03}$

Barium was found in a range from 83 to 387 mg/kg, lead from 4.2 to 5.6 mg/kg, copper from 1.6 to 2.1 mg/kg, mercury from 0.010 to 0.011 mg/kg, chromium from 7.2 to 9.2 and zinc from 10 to 12.7 mg/kg. Cadmium was below the detection limit (<0.03 mg/kg) at all sites (Table 12.6). Sediments from RIN02, RIN03, RIN04, RIN05, RIN12, RIN13 and RIN14 had barium (201-387 mg/kg) content above LSC. Zinc was found above LSC at RIN03 and RIN14. Copper, chromium, lead, cadmium and mercury were below LSC at all sites.

Compared to the baseline survey of 2000 the barium content had increased at RIN02, RIN03, RIN04, RIN05, RIN12, RIN13 and RIN14. The barium content was approximately the same at the other sites (Figure 12.3). There was also an overall increase in the zinc content and a decrease in the lead content whereas the other metals were almost at the same level in both 2000 and 2003 (Figure 12.6).

Table 12.7. The content of metals in vertical sections of sediment from 3 sampling sites at Ringhorne in 2003. All values in mg/kg dry sediment. Values above $LSC_{central\ 97\text{-}03}$ are dark shaded.

Site	Layer (cm)	Cu	Cr	Zn	Ba	Pb	Cd	Hg
RIN05	0-1	1.3	7.1	8.9	231	3.6	<0.03	0.009
	1-3	1.5	7.1	10.1	80	4.7	<0.03	0.010
	3-6	1.2	6.9	8.6	46	4.5	<0.03	0.008
RIN06	0-1	1.4	6.7	8.8	61	4.0	<0.03	0.010
	1-3	1.5	7.6	9.6	55	5.0	<0.03	0.010
	3-6	1.4	7.3	9.1	38	4.1	<0.03	0.009
RIN29R	0-1	2.2	8.7	13.2	94	5.9	<0.03	0.013
	1-3	1.8	8.3	11.5	80	5.5	<0.03	0.011
	3-6	2.0	7.9	12.5	80	5.9	<0.03	0.012

Vertical sediment samples (0-1, 1-3 and 3-6 cm) from RIN05 had barium content above LSC in the upper depth interval (0-1 cm) and decreasing barium content with increasing depth in the sediment. This indicates recent supply of barium at RIN05. At the reference site RIN29R, mercury and zinc were found in low concentration although above LSC in the 0-1 and 3-6 cm layers (Zn) and 0-1 cm layer (Hg). The situation at RIN29R might be due to finer sediment at the reference site than at the other sites at Ringhorne and the other reference sites in the central part of region II.

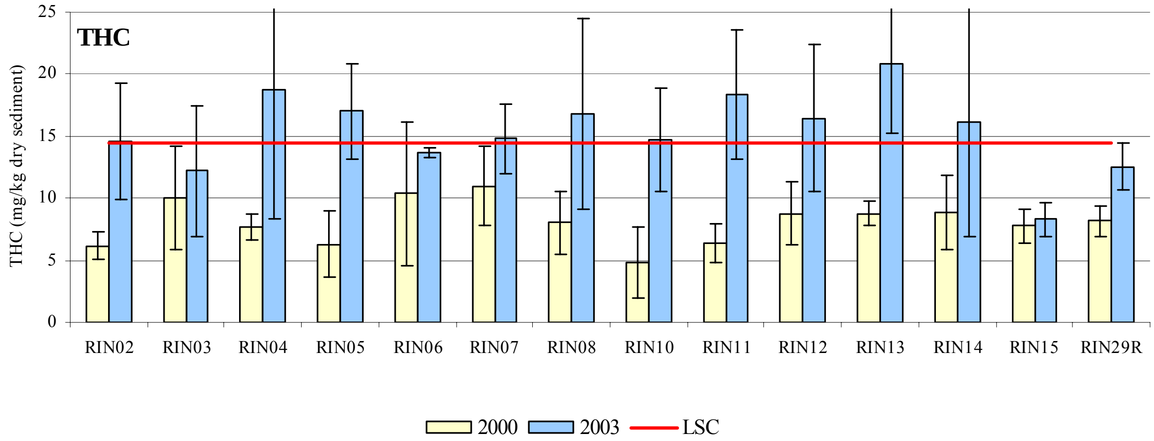


Figure 12.3. Average THC concentrations and standard deviations in sediments from Ringhorne in 2003 and previous years. Red line is $LSC_{central\ 97\text{-}03}$.

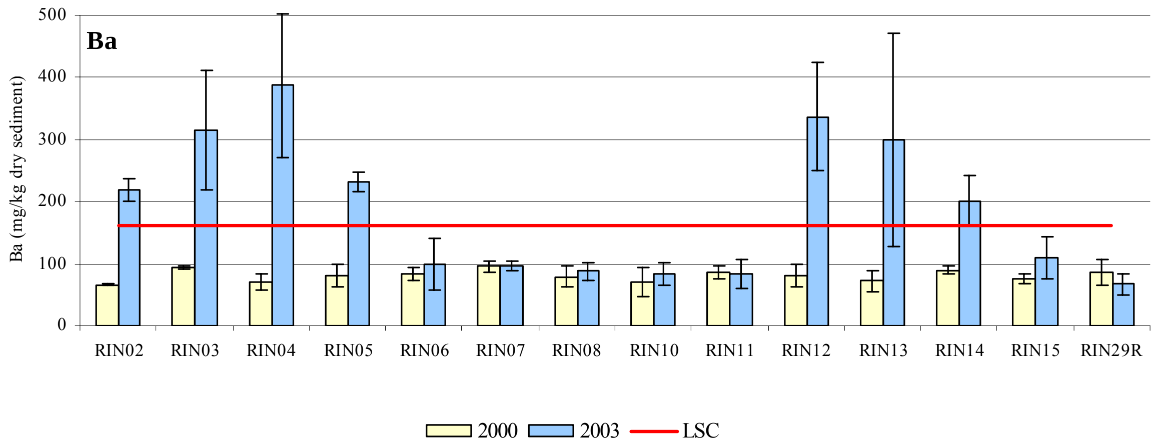


Figure 12.4. Average barium concentrations and standard deviations in sediments from Ringhorne in 2003 and previous years. Red line is $LSC_{central\ 97\text{-}03}$.

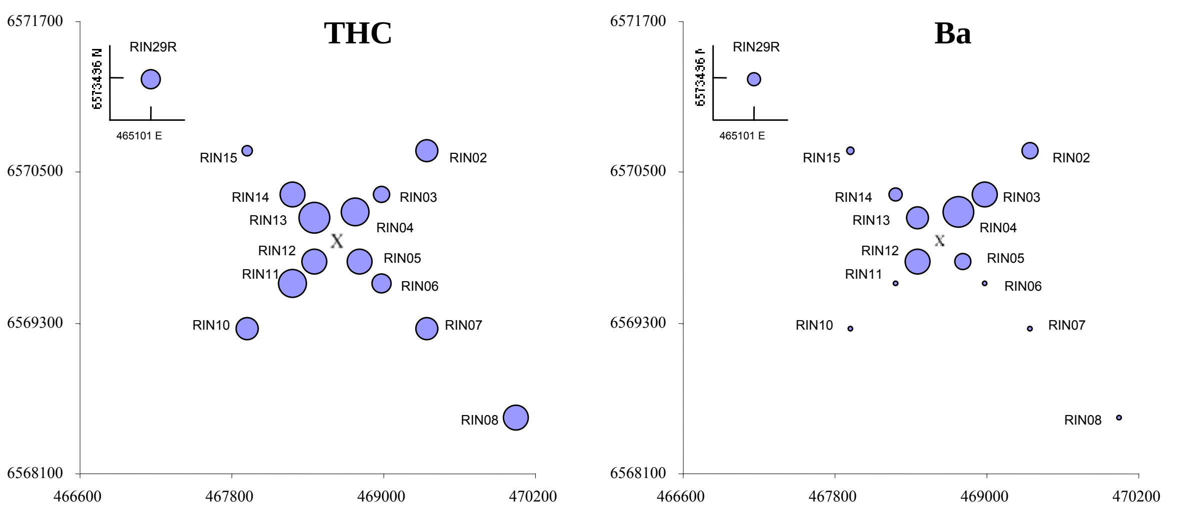


Figure 12.5. Distribution of THC and barium in sediments at the sampling sites at Ringhorne in 2003. The size of the circles indicates the amount of THC and Ba. The field centre is marked with an X.

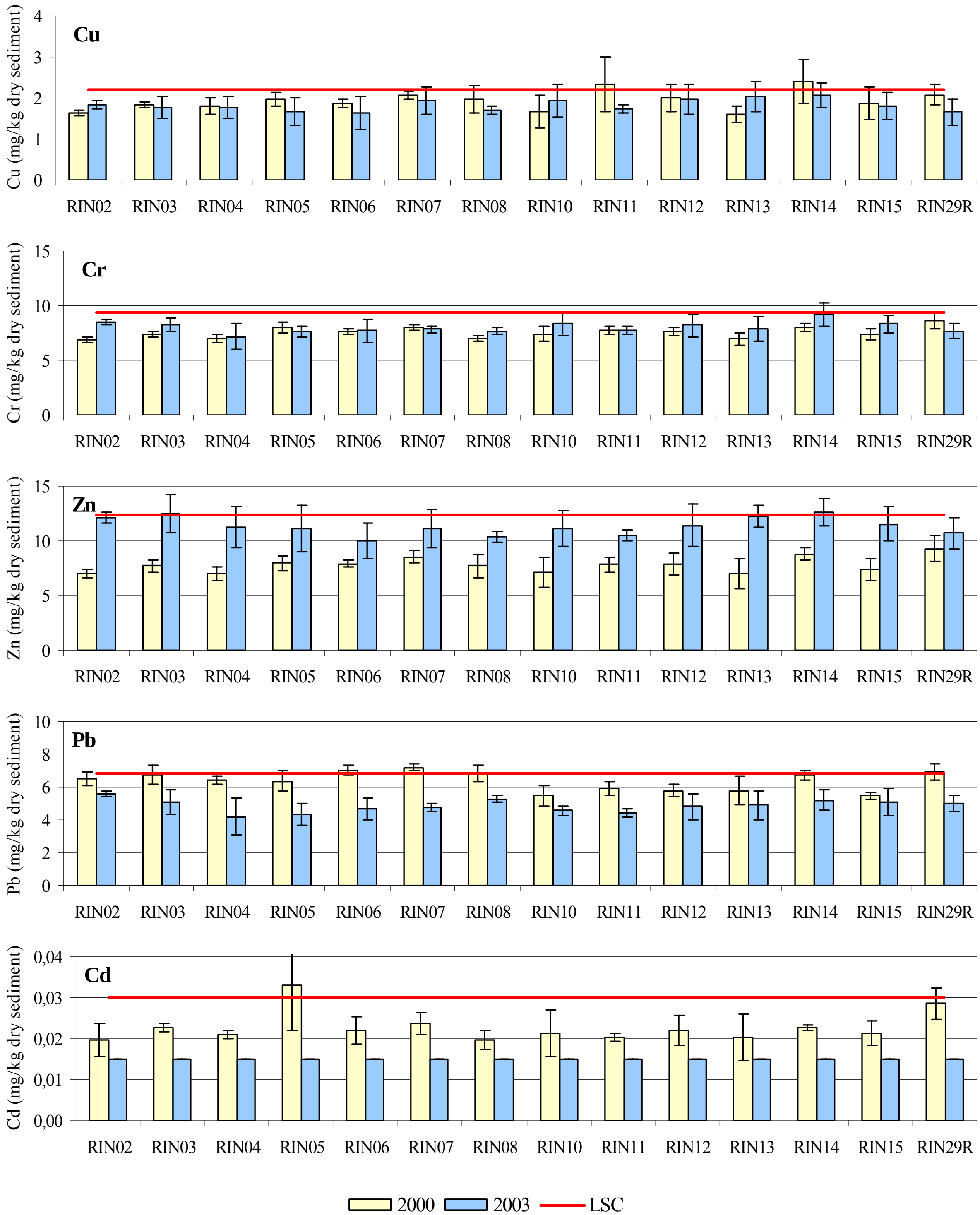


Figure 12.6. Average content and standard deviations of metals in sediment from Ringhorne in 2003 and previous surveys. Red line is $LSC_{central\ 97\text{-}03}$.

The field sites at Ringhorne were compared to nearby regional sites (RII04, RII09, GRA14R, BAL27R and JOT30R) based on sediment characteristics (TOM and pelite) and chemical content in the sediments (Figure 12.7). Sampling sites at Ringhorne grouped particularly well with the reference sites at the nearby Grane and Balder fields, whereas RII04 did not group at all with the other sites. This indicates that RII04 had different sediment characteristics and different chemical compound compositions compared to the other sites. The conditions at RII04 are supposed to describe some of the natural variation within region II. There were no strong environmental gradients at Ringhorne field sites.

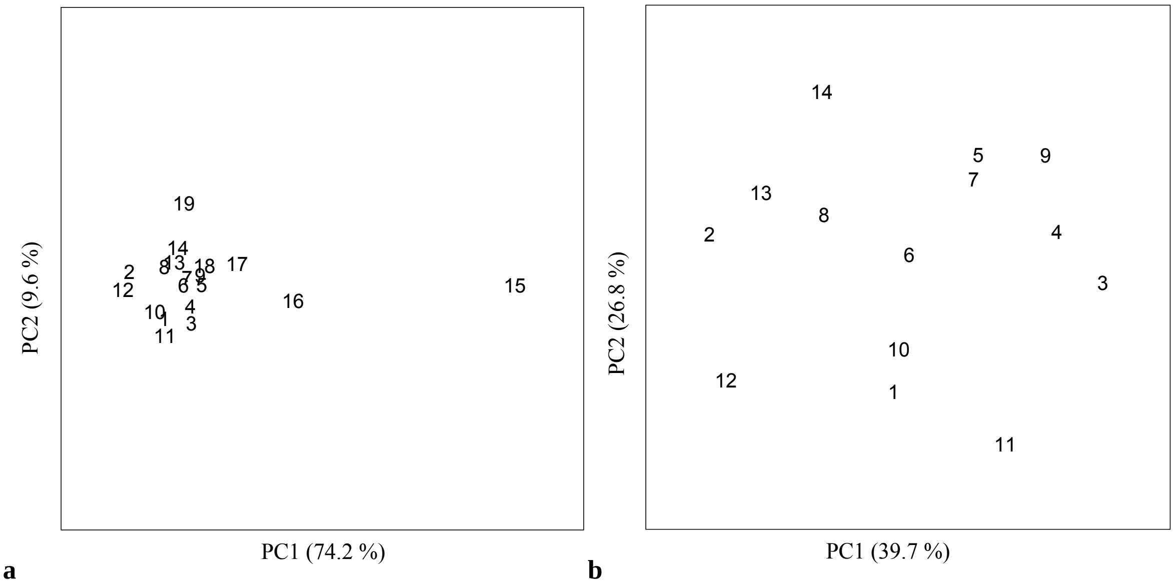


Figure 12.7. 2-D plot from the PCA analysis of environmental variables (% pelite, % sand, % gravel, median Φ, % TOM, Cu, Ba, Zn, Cr, Pb and THC carried out on:

a) Ringhorne field sites compared to the references sites at Grane, Balder and Jotun and the regional site RII04 an RII09. Explained variation in the data 83.8 %.
b) Ringhorne field sites in 2003. Explained variation in the data 66.5 %.
Numbers in the plot identify the sampling sites. See table below.

1	RIN02	6	RIN07	11	RIN13	16	RII09
2	RIN03	7	RIN08	12	RIN14	17	GRA14R
3	RIN04	8	RIN10	13	RIN15	18	BAL27R
4	RIN05	9	RIN11	14	RIN29R	19	JOT30R
5	RIN06	10	RIN12	15	RII04		

12.2.3 Bottom fauna

A summary of the distribution of individuals and taxa within the main taxonomic groups is given in Table 12.8. Unidentified juveniles of the sea urchins Spatangoids (9284 individuals) and Echinoides (1144 individuals) are omitted from the analyses, as they occurred in extremely high numbers. In total, 10304 individuals within 249 taxa were collected at Ringhorne in 2003. The fauna was numerically dominated by annelida with 49 % the individuals and 46 % of the taxa. A complete species list is available in the Appendix.

Table 12.8. Distribution of individuals and taxa within the main taxonomic groups at Ringhorne in 2003 including data from RIN29R (unidentified juveniles of Spatangoida and Echinoidea are not included).

Main taxonomic groups	Number of individuals	%	Number of taxa	%
Annelida	5028	49	114	46
Arthropoda	1400	14	57	23
Mollusca	2031	20	49	20
Echidermata	874	8	11	4
Diverse groups	971	9	18	7
Total	10304	100	249	100

The species/area curve for RIN29R indicates that five replicate samples give a representative impression of the bottom fauna in the area (Figure 12.8). However, as more area is sampled, more taxa are collected, indicating that not even 10 replicate samples give the full species assemblage of the area.

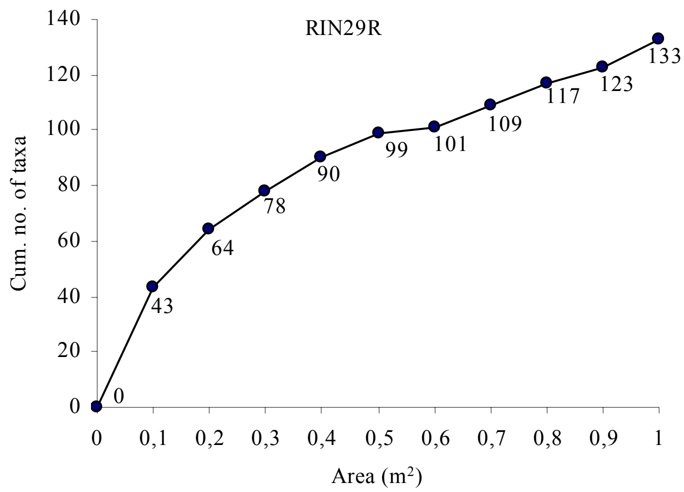


Figure 12.8. Species/area curve for the reference site at the Ringhorne field. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

The distribution of individuals and taxa are shown in Figure 12.9. Number of individuals and taxa at each site, and the calculated diversity indexes (H' and ES_{100}) are given in Table 12.9 and Figure 12.10. The number of individuals varied from 530 (RIN14) to 804 (RIN08), and the number of taxa varied from 104 (RIN10, RIN12 and RIN13) to 123 (RIN03). The Shannon-Wiener diversity index (H') varied from 5.49 (RIN04) to 5.89 (RIN03), whereas the ES_{100} index varied from 42.6 (RIN04) to 50.0 (RIN03). The evenness index J varied from 0.80 (RIN08) to 0.86 (RIN02). The corresponding values at RIN29R are within or near the variation at the field sites. The number of taxa, diversity and evenness indicate good environmental conditions at all sites.

Table 12.9. Number of individuals, species/taxa and selected community indices for each site (0.5 m^2) at the Ringhorne field in 2003. Unidentified juveniles of Spatangoida and Echinoidea are not included.

Site number	Number of individuals	Number of taxa	Diversity H'	Evenness J	H'-max	ES_{100}
RIN02	693	113	5.87	0.86	6.82	49.0
RIN03	621	123	5.89	0.85	6.94	50.0
RIN04	787	109	5.49	0.81	6.77	42.6
RIN05	729	119	5.85	0.85	6.89	48.3
RIN06	768	116	5.68	0.83	6.86	46.1
RIN07	737	120	5.81	0.84	6.91	48.3
RIN08	804	121	5.56	0.80	6.92	42.9
RIN10	541	104	5.67	0.85	6.70	46.6
RIN11	700	109	5.70	0.84	6.77	45.8
RIN12	578	104	5.64	0.84	6.70	45.7
RIN13	604	104	5.54	0.83	6.70	44.2
RIN14	530	111	5.69	0.84	6.79	47.8
RIN15	746	116	5.82	0.85	6.86	47.8
RIN29R (6-10)	716	98	5.14	0.78	6.61	37.4
RIN29R (11-15)	750	106	5.32	0.79	6.73	40.0
RIN29R (6-15)	1466	132	5.35	0.76	7.04	39.2
Sum[1]	8838	238				
Average[1]	680	113	5.71	0.84	6.82	46.5
SD[1]	94	7	0.13	0.02	0.09	2.3
Min[1]	530	104	5.49	0.80	6.70	42.6
Max[1]	804	123	5.89	0.86	6.94	50.0
Average[2]	774	113	5.55	0.81	6.81	44.3
SD[2]	230	14	0.24	0.02	0.18	2.6
Min[2]	488	94	5.12	0.79	6.55	38.7
Max[2]	1202	141	5.85	0.85	7.14	47.9

[1]Field sites, exclusive RIN29R
[2]Reg + Ref $_{\text{central 03}}$

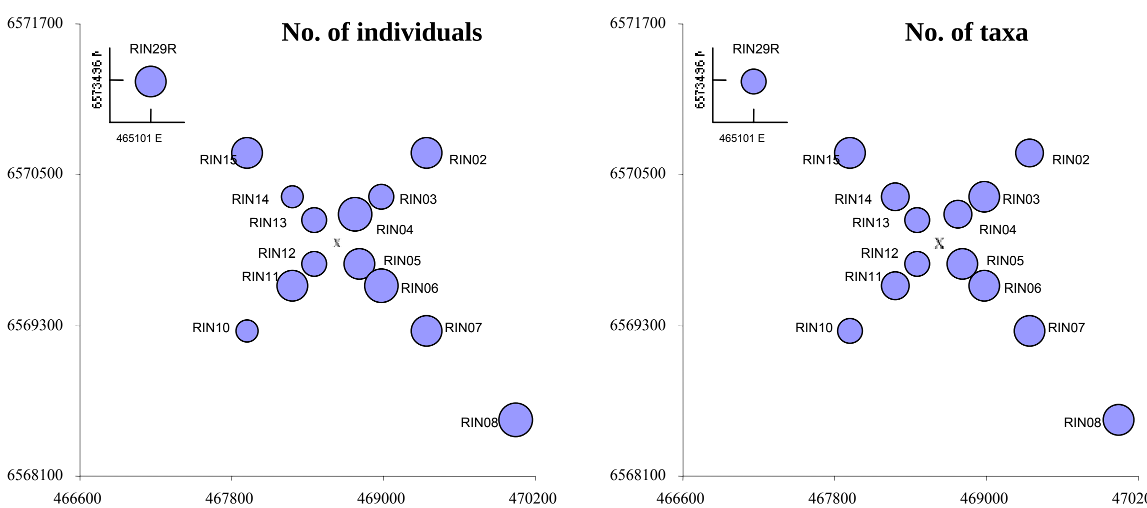


Figure 12.9. Distribution of bottom fauna (individuals and taxa) among the sampling sites in 2003. The size of the circle indicates the number of individuals and taxa. Exclusive unidentified juveniles of Spatangoida and Echinoidae. Values for RIN29R are average of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2). The field centre is marked with an X.

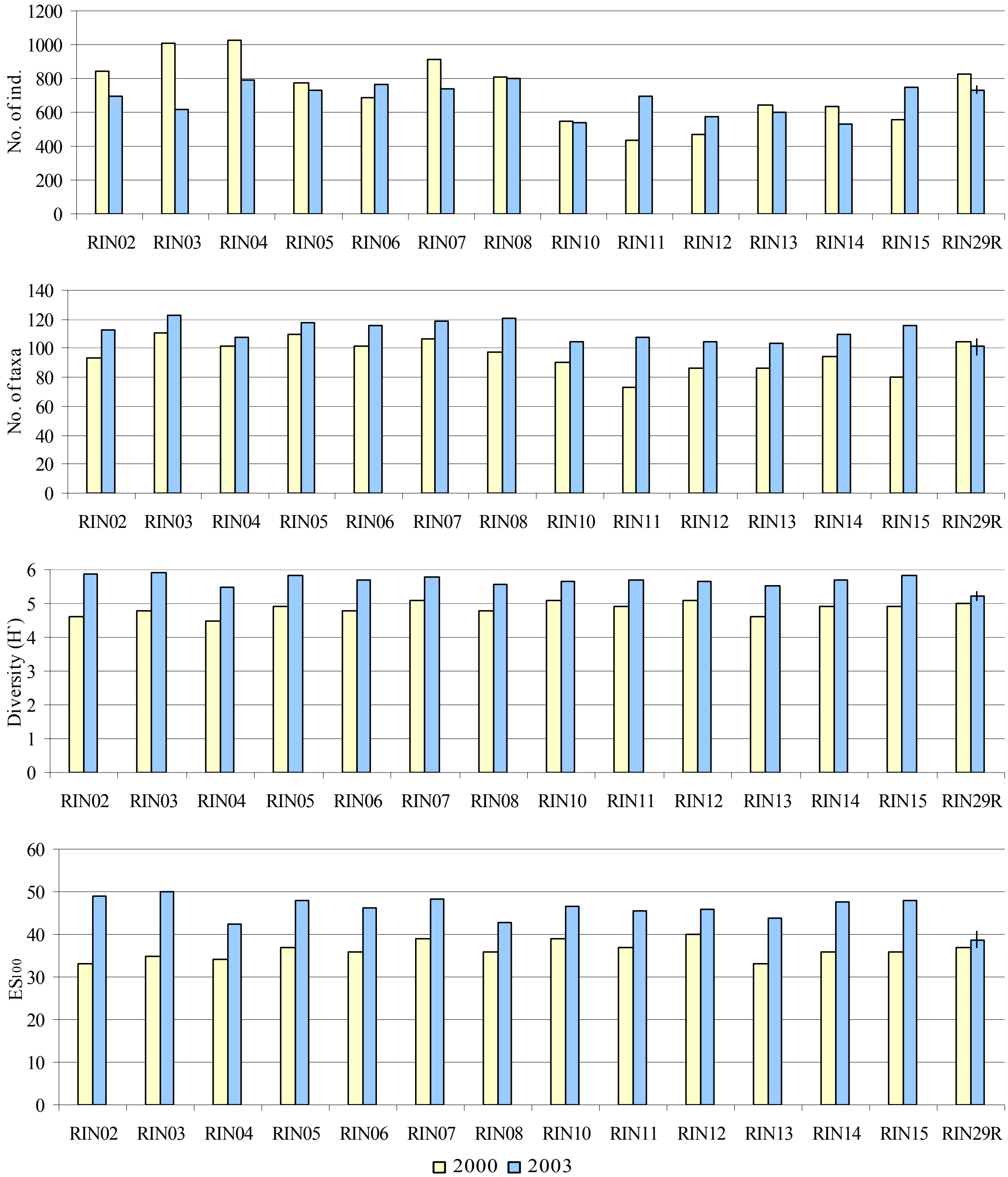


Figure 12.10. Number of individuals, taxa and selected community indices for each site (0.5 m^2) at the Ringhorne field for 2000 and 2003. (Unidentified juveniles of Spatangoida and Echinoidea are not included in 2003). Values for RIN29R are average ± standard deviation of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2).

Distribution of taxa in geometrical classes is presented in Figure 12.11. The smooth graphs are representing undisturbed bottom fauna.

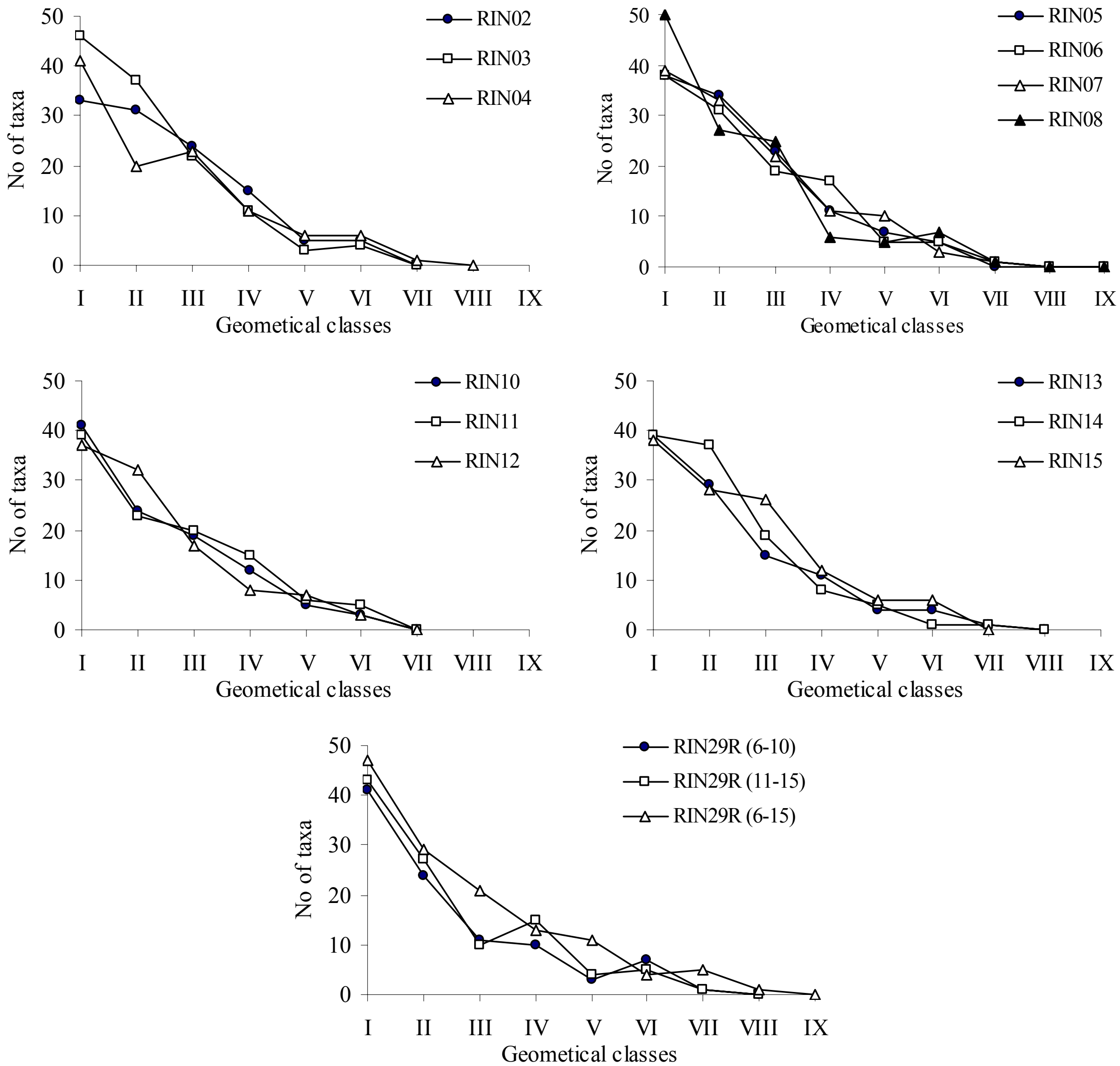


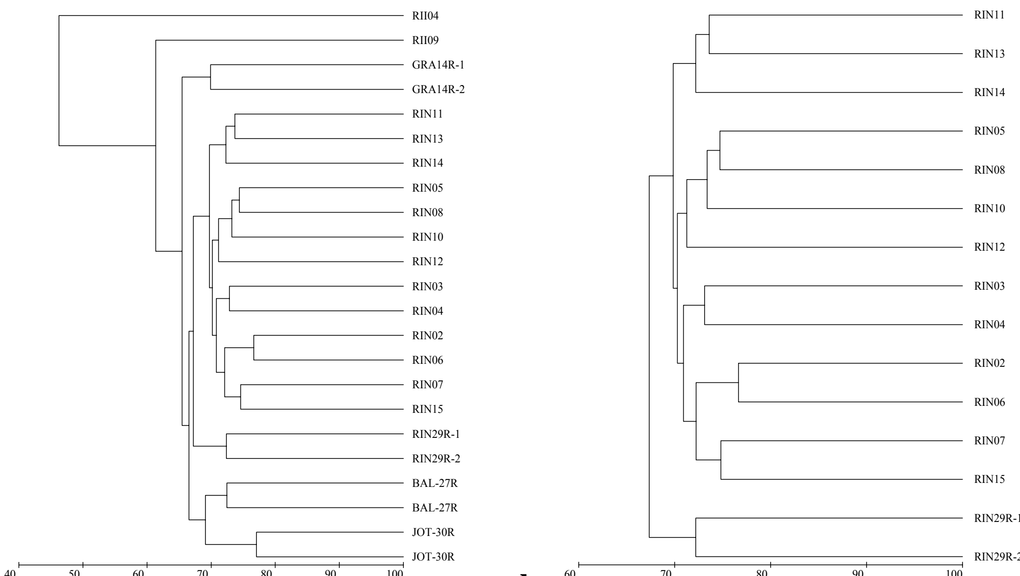
Figure 12.11. Distribution of taxa in geometrical classes for the sites at Ringhorne in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

The ten most numerous taxa are listed in Table 12.12 at the end of this chapter. The list comprise 23 taxa and 7771 individuals, which was 9.3 % of all (248) taxa and 75.4 % of all (10304) individuals. The most abundant and widespread species were the polychetes *Paramphinome jeffreysii, Lanice conchilega* and *Myriochele oculata* and the bivalve *Thyasira croulinensis*. The phoronide *Phoronis* sp. was also abundant although not present among the ten most numerous taxa at RIN07. *Paramphinome jeffreysii, Lanice conchilega* and *Thyasira croulinensis* were among the most abundant species in 2000 too. The occurrence and abundance of these species in 2003 indicate homogeneity and stability in the bottom fauna in space and time.

The results of the multivariate analyses are given in the dendrogramme (Figure 12.12) and the MDS plott (Figure 12.13).

In the cluster analysis, all sites are grouped together within approximately 67 % similarity, and within the field specific sites the similarity in fauna assemblage was approximately 70 %. The high similarity is supported by the distribution of the ten most numerous taxa, and indicate even environmental conditions for the fauna all over the field.

The results of the MDS analysis support the findings in the cluster analysis, confirming the similarity in species assemblage within the field and that there were no strong environmental gradients at Ringhorne in 2003. The stress test of the MDS analysis was 0.21, indicating a potential useful fit of the data.



a **b**

Figure 12.12. Dendrogram showing the similarity between fauna from sampling sites at:
a) Sampling sites at Ringhorne and some regional sites (RII04 and RII09) and reference sites (GRA14R, BAL27R and JOT30R) in 2003.
b) Sampling sites at Ringhorne in 2003.
Exclusive unidentified juveniles of Spatangoida and Echinoidea.

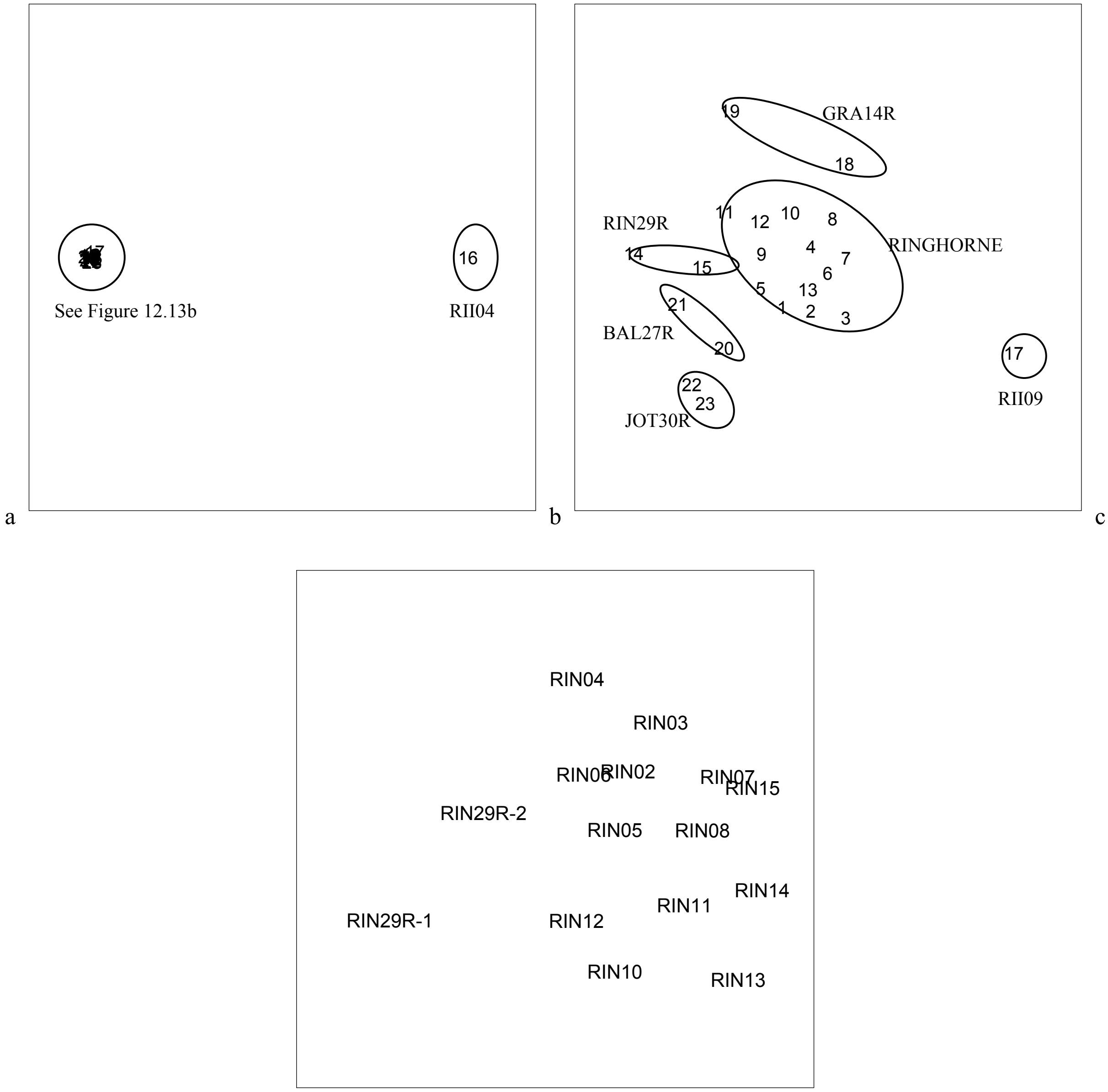


Figure 12.13. A 2-dimetional plott of the MDS analysis of the fauna data from:

a) Sampling sites at Ringhorne compared to some regional sites (RII04 and RII09) and reference sites (GRA14R, BAL27R and JOT30R) in 2003. Stress = 0.01.
b) Sampling sites at Ringhorne, regional site RII09 and reference sites (GRA14R, BAL27R and JOT30R) in 2003. Stress = 0.21.
c) Sampling sites at Ringhorne in 2003. Stress = 0.21.

Exclusive unidentified juveniles of Spatangoida and Echinoidea.
Numbers in the plot identify the sampling sites. See table below.

1	RIN02	6	RIN07	11	RIN13	16	RII04	21	BAL27R-2
2	RIN03	7	RIN08	12	RIN14	17	RII09	22	JOT30R-1
3	RIN04	8	RIN10	13	RIN15	18	GRA14R-1	23	JOT30R-2
4	RIN05	9	RIN11	14	RIN29R-1	19	GRA14R-2		
5	RIN06	10	RIN12	15	RIN29R-2	20	BAL27R-1		

Linking of biotic and environmental variables by BIOENV revealed that copper and barium were best correlated to the biota at $\rho_w = 0.19$ (Table 12.10). This indicates that there was only a weak association between some environmental variables and the bottom fauna.

Table 12.10. Combinations of the 10 environmental variables, taken *k* at a time, yielding the best matches of biotic and abiotic similarity matrices for each *k*, as measured by weighted Spearman rank correlation ρ_w. Bold type indicates overall optimum. All possible combinations of variables and associated correlation to the biotic are given in the Appendix.

Number of variables (*k*)	Correlation coefficient (ρ_w)	Environmental variables									
1	0.136	Ba									
1	0.135	Cu									
1	0.062	THC									
1	0.036	Sand									
1	0.018	Pelite									
1	-0.064	Zn									
1	-0.070	Cr									
1	-0.223	Pb									
1	-0.224	TOM									
1	-0.244	Gravel									
2	**0.190**	**Cu**	**Ba**								
3	0.175	Cu	Ba	Sand							
4	0.143	Cu	Ba	Sand	THC						
5	0.132	Cu	Ba	Sand	THC	Pelite					
6	0.125	Cu	Ba	Sand	THC	Pelite	Cr				
7	0.089	Cu	Ba	Sand	THC	Pelite	Cr	Zn			
8	0.063	Cu	Ba	Sand	THC	Pelite	Cr	Zn	TOM		
9	0.007	Cu	Ba	Sand	THC	Pelite	Cr	Zn	TOM	Pb	
10	-0.091	Cu	Ba	Sand	THC	Pelite	Cr	Zn	TOM	Pb	Gravel

12.2.4 Estimation of influenced area

The extension of contamination along sampling transects and the minimum area of contaminated sediments for THC, barium and other metals as well as for faunal disturbance are shown in Figure 12.15 and Table 12.11. The contaminated area was larger in 2003 than in 2000 for THC and barium, whereas faunal disturbance was not found in 2003.

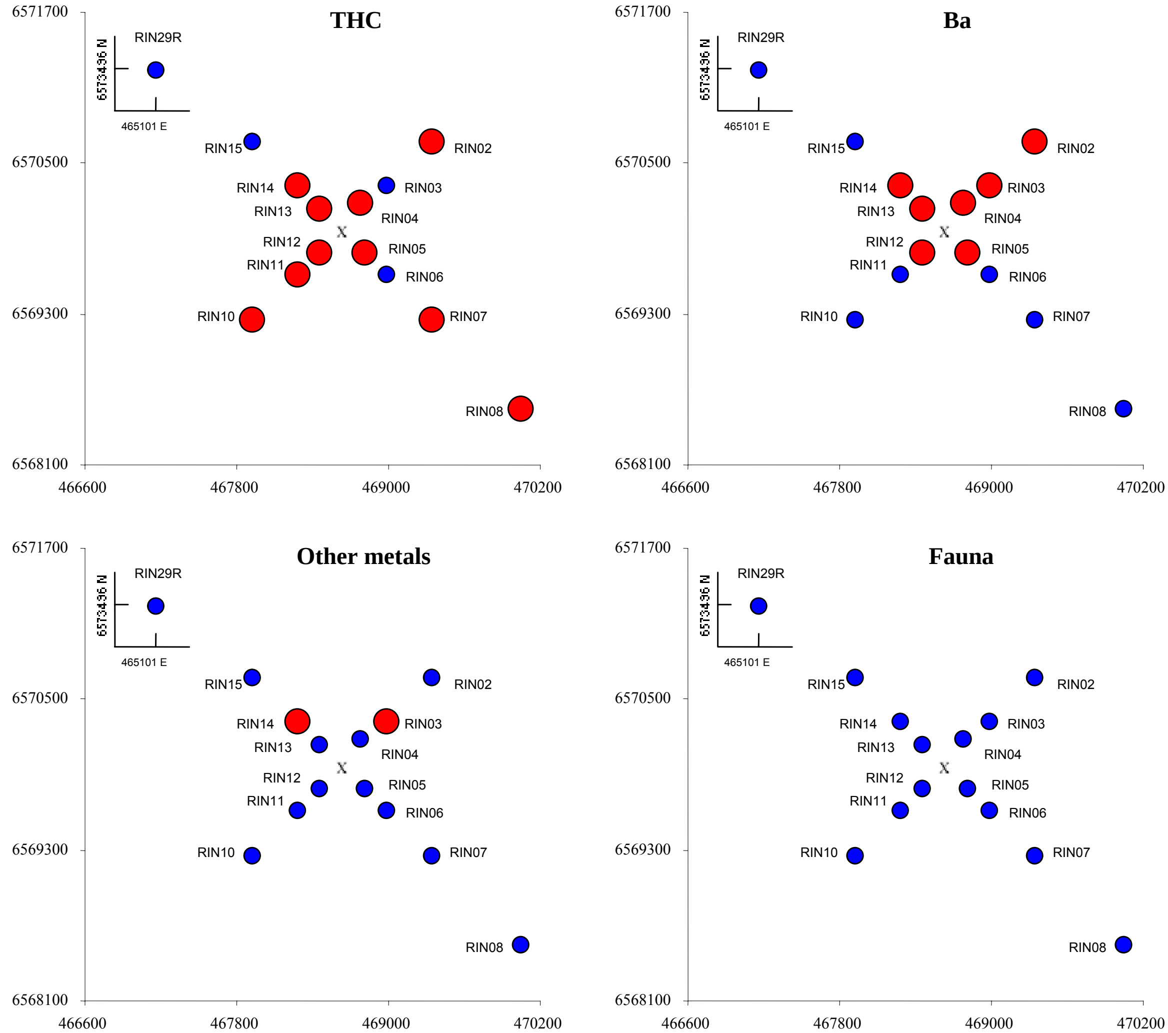


Figure 12.15. Faunal disturbance and chemical contamination of the sediments at Ringhorne in 2003. Uncontaminated sites and sites with no faunal disturbance are marked with small blue circles.

Table 12.11. Estimated distance of contamination and faunal disturbance from the installation, and estimated area of contamination and faunal disturbance around the field centre.

Ringhorne	NE m	SE m	SW m	NW m	2003 km^2	2000 km^2
THC	1000	2000	1000	500	3.93	0.00
Ba	1000	250	250	500	0.74	0.00
Other metals	0	0	0	0	0.00	0.00
Fauna	0	0	0	0	0.00	0.00

12.3 Summary and conclusions

During 2001 and 2002 respectively 3 and 2 wells were drilled at Ringhorne. The first environmental survey of the field was in 2000 when a baseline survey was accomplished. The sediments are still characterized as fine sand, although there has been a slight increase in the pelite content since 2000. The amounts of THC in the sediments have increased since 2000. Also the barium content in the sediments have increased since 2000, particularly toward the northeast and northwest, but also in the immediate vicinity of the fields centre to southeast and southwest too. Other metals occurred approximately at the same level in 2003 as in 2000. Species diversity remains high at Ringhorne and no fauna effects were found in 2003. Due to the drilling activity and discharges at Ringhorne the area of THC and barium contaminated sediments were larger in 2003 than in 2000.

Table 12.12. Number of individuals and relative abundance for the ten predominant taxa at each site at the Ringhorne field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

RIN02	No. of ind.	%	Cum %
Sabellidae indet.	48	6.9	6.9
Paramphinome jeffreysii	46	6.6	13.6
Phoronis sp.	41	5.9	19.5
Thyasira croulinensis	35	5.1	24.5
Myriochele oculata	34	4.9	29.4
Asteroidea indet.	27	3.9	33.3
Lanice conchilega	24	3.5	36.8
Urothoe elegans	22	3.2	40.0
Thyasira equalis	18	2.6	42.6
Thyasira obsoleta	16	2.3	44.9

RIN03	No. of ind.	%	Cum %
Paramphinome jeffreysii	54	8.7	8.7
Myriochele oculata	43	6.9	15.6
Phoronis sp.	41	6.6	22.2
Lanice conchilega	34	5.5	27.7
Thyasira croulinensis	28	4.5	32.2
Laonice sarsi	25	4.0	36.2
Amphiura chiajei	19	3.1	39.3
Asteroidea indet.	13	2.1	41.4
Urothoe elegans	13	2.1	43.5
Scolelepis korsuni	13	2.1	45.6

RIN04	No. of ind.	%	Cum %
Paramphinome jeffreysii	90	11.4	11.4
Phoronis sp.	58	7.4	18.8
Myriochele oculata	49	6.2	25.0
Thyasira croulinensis	45	5.7	30.7
Sabellidae indet.	42	5.3	36.1
Lanice conchilega	34	4.3	40.4
Amphiura chiajei	34	4.3	44.7
Aporrhais spp.	27	3.4	48.2
Nemertini indet.	20	2.5	50.7
Lumbrineris scopa	20	2.5	53.2

RIN05	No. of ind.	%	Cum %
Paramphinome jeffreysii	54	7.4	7.4
Phoronis sp.	46	6.3	13.7
Myriochele oculata	45	6.2	19.9
Lanice conchilega	38	5.2	25.1
Thyasira croulinensis	37	5.1	30.2
Aporrhais spp.	26	3.6	33.7
Thyasira equalis	24	3.3	37.0
Urothoe elegans	22	3.0	40.1
Amphiura chiajei	20	2.7	42.8
Diplocirrus glaucus	18	2.5	45.3

RIN06	No. of ind.	%	Cum %
Paramphinome jeffreysii	90	11.7	11.7
Phoronis sp.	51	6.6	18.4
Thyasira croulinensis	47	6.1	24.5
Sabellidae indet.	44	5.7	30.2
Myriochele oculata	34	4.4	34.6
Lanice conchilega	33	4.3	38.9
Amphiura chiajei	28	3.6	42.6
Aporrhais spp.	20	2.6	45.2
Asteroidea indet.	19	2.5	47.7
Thyasira equalis	16	2.1	49.7
Laonice sarsi	16	2.1	51.8

RIN07	No. of ind.	%	Cum %
Paramphinome jeffreysii	80	10.9	10.9
Sabellidae indet.	60	8.1	19.0
Thyasira croulinensis	33	4.5	23.5
Lanice conchilega	32	4.3	27.8
Myriochele oculata	28	3.8	31.6
Urothoe elegans	25	3.4	35.0
Laonice sarsi	24	3.3	38.3
Amphiura chiajei	20	2.7	41.0
Prionospio cirrifera	19	2.6	43.6
Thyasira equalis	17	2.3	45.9

RIN08	No. of ind.	%	Cum %
Sabellidae indet.	69	8.6	8.6
Lanice conchilega	61	7.6	16.2
Phoronis sp.	53	6.6	22.8
Paramphinome jeffreysii	50	6.2	29.0
Myriochele oculata	43	5.3	34.3
Asteroidea indet.	43	5.3	39.7
Thyasira croulinensis	35	4.4	44.0
Aporrhais spp.	33	4.1	48.1
Urothoe elegans	29	3.6	51.7
Tanaidacea indet.	25	3.1	54.9

RIN10	No. of ind.	%	Cum %
Paramphinome jeffreysii	47	8.7	8.7
Lanice conchilega	45	8.3	17.0
Phoronis sp.	42	7.8	24.8
Myriochele oculata	25	4.6	29.4
Thyasira equalis	19	3.5	32.9
Thyasira croulinensis	18	3.3	36.2
Urothoe elegans	18	3.3	39.6
Diplocirrus glaucus	18	3.3	42.9
Laonice sarsi	13	2.4	45.3
Amphiura chiajei	12	2.2	47.5
Spiophanes kroeyeri	12	2.2	49.7
Arctica islandica	12	2.2	51.9

Table 12.12. continue. Number of individuals and relative abundance for the ten predominant taxa at each site at the Ringhorne field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

RIN11	No. of ind.	%	Cum %
Paramphinome jeffreysii	48	6.9	6.9
Phoronis sp.	48	6.9	13.7
Thyasira croulinensis	47	6.7	20.4
Myriochele oculata	42	6.0	26.4
Sabellidae indet.	34	4.9	31.3
Thyasira equalis	31	4.4	35.7
Laonice sarsi	26	3.7	39.4
Amphiura chiajei	21	3.0	42.4
Urothoe elegans	20	2.9	45.3
Lanice conchilega	18	2.6	47.9
Nemertini indet.	18	2.6	50.4

RIN12	No. of ind.	%	Cum %
Paramphinome jeffreysii	60	10.4	10.4
Phoronis sp.	40	6.9	17.3
Thyasira croulinensis	35	6.1	23.4
Urothoe elegans	29	5.0	28.4
Amphiura chiajei	25	4.3	32.7
Lanice conchilega	23	4.0	36.7
Thyasira equalis	21	3.6	40.3
Myriochele oculata	19	3.3	43.6
Diplocirrus glaucus	17	2.9	46.5
Spiophanes kroeyeri	16	2.8	49.3

RIN13	No. of ind.	%	Cum %
Paramphinome jeffreysii	64	10.6	10.6
Phoronis sp.	43	7.1	17.7
Myriochele oculata	43	7.1	24.8
Lanice conchilega	36	6.0	30.8
Sabellidae indet.	32	5.3	36.1
Amphiura chiajei	26	4.3	40.4
Thyasira equalis	23	3.8	44.2
Thyasira croulinensis	22	3.6	47.8
Aporrhais spp.	14	2.3	50.2
Diplocirrus glaucus	13	2.2	52.3
Tryphosella sp.	13	2.2	54.5

RIN14	No. of ind.	%	Cum %
Paramphinome jeffreysii	65	12.3	12.3
Lanice conchilega	32	6.0	18.3
Phoronis sp.	31	5.8	24.2
Myriochele oculata	31	5.8	30.0
Sabellidae indet.	31	5.8	35.8
Thyasira croulinensis	22	4.2	40.0
Thyasira equalis	20	3.8	43.8
Amphiura chiajei	13	2.5	46.2
Diplocirrus glaucus	12	2.3	48.5
Urothoe elegans	10	1.9	50.4

RIN15	No. of ind.	%	Cum %
Paramphinome jeffreysii	53	7.1	7.1
Sabellidae indet.	51	6.8	13.9
Lanice conchilega	46	6.2	20.1
Myriochele oculata	43	5.8	25.9
Thyasira croulinensis	33	4.4	30.3
Amphiura chiajei	33	4.4	34.7
Phoronis sp.	27	3.6	38.3
Thyasira equalis	22	2.9	41.3
Spiophanes kroeyeri	20	2.7	44.0
Diplocirrus glaucus	17	2.3	46.2
Urothoe elegans	17	2.3	48.5

RIN29R	No. of ind.	%	Cum %
Paramphinome jeffreysii	194	13.2	13.2
Lanice conchilega	103	7.0	20.3
Thyasira equalis	97	6.6	26.9
Diplocirrus glaucus	93	6.3	33.2
Thyasira croulinensis	87	5.9	39.2
Myriochele oculata	77	5.3	44.4
Natatolana borealis	63	4.3	48.7
Amphiura chiajei	62	4.2	52.9
Phoronis sp.	47	3.2	56.1
Sabellidae indet.	35	2.4	58.5

13 Jotun

13.1. Introduction

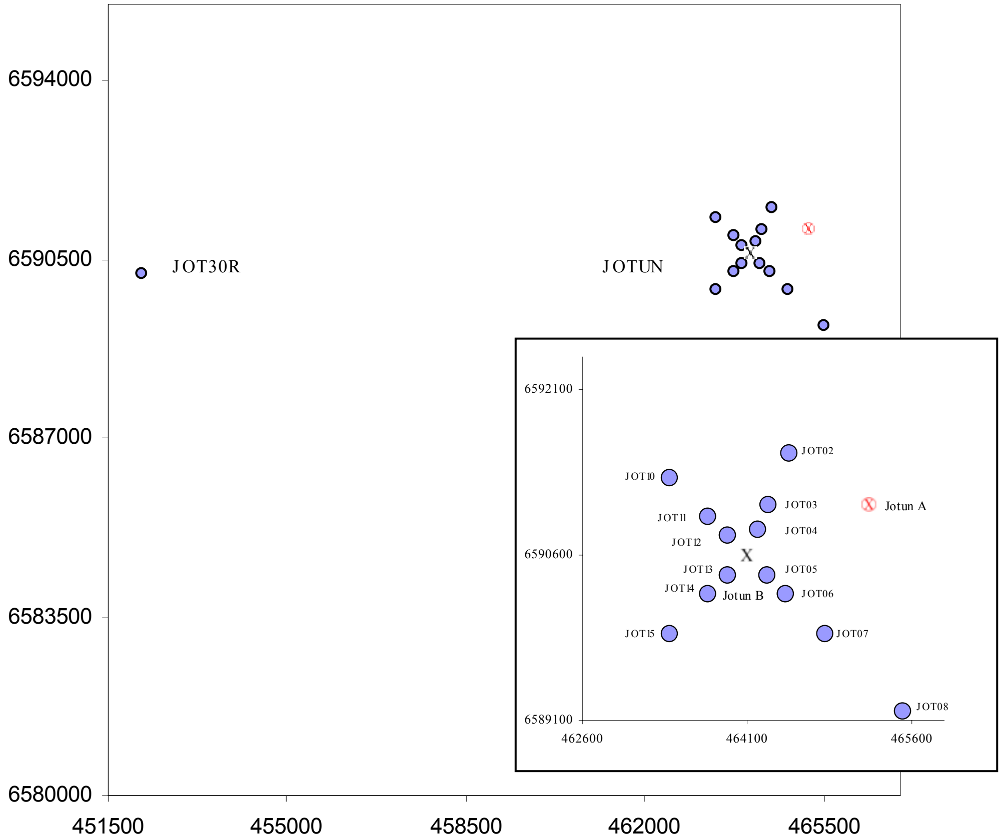
The Jotun field is situated in block 25/7 and 25/8. Jotun consist of two units Jotun A (production ship) and Jotun B (well head platform). Production at Jotun started in October 1999. A baseline survey accomplished in 1997 revealed no contamination of hydrocarbons or metals. Elevated levels of THC and barium were detected close to the field centre in 2000, but no faunal disturbanses were seen.

Between the baseline survey in 1997 and the monitoring survey in 2000 the field centre was relocated approximately 400 m to north northwest. Thus the sampling sites in 1996 and 2000 were not the same, although they were labelled with similar codes. In this report the codes are the same as in previous surveys and the positions of the sites are the same as in 2000.

Production drilling started in March 1999, whereas the first exploration drilling took place in 1970. During drilling only water based mud has been used. Recent discharges at Jotun are listed in Table 13.1, and sampling sites are shown in Figure 13.1. Drilling is executed from the platform (Jotun B).

Table 13.1. Recent well drilling and discharges at Jotun.

	1999	2000	2001	2002	Comments
No of wells drilled	5	10	3	3	One well empty, 17½”
Barite, tonnes	834	76	9	77	
Cuttings, tonnes	1694	3092	366	874	
Water-based drilling mud, tonnes	7463	11874	1315	2881	
Cementing chemicals, tonnes	8.26	44	3	67	
Completion chemicals, tonnes	0	0	0	1.1	
Oil in produced water, tonnes	-	25	75	54	
Accidental discharges, chemicals, m^3	0	0.04	0.23	3.27	
Accidental discharges, oil, m^3	0	1.66	0	0.1	



Site	ED50 UTM Zone 31 E	ED50 UTM Zone 31 N	Distance (m) / direction (°)	Depth (m)
JOT-02	464483	6591524	1000/22.5	129
JOT-03	464291	6591062	500/22.5	128
JOT-04	464196	6590831	250/22.5	128
JOT-05	464277	6590423	250/135	128
JOT-06	464454	6590246	500/135	128
JOT-07	464807	6589893	1000/135	129
JOT-08	465514	6589186	2000/135	129
JOT-10	463393	6591307	1000/315	129
JOT-11	463746	6590954	500/315	128
JOT-12	463923	6590777	250/315	129
JOT-13	463923	6590423	250/225	129
JOT-14	463746	6590246	500/225	129
JOT-15	463393	6589893	1000/225	128
JOT-30R	452182	6590203	11330/267.3	127

Figure 13.1. Map showing the internal distribution of sampling sites in Jotun in 2003. Positioning according to UTM ED50 zone 31. The field centre (Jotun B) and the ship (Jotun A) are marked with an X.

13.2. Results and discussion

13.2.1 Sediments characteristics

TOM, and the amount (%) of gravel, sand, pelite, median (Φ), sorting, skewness and kurtosis in the sediment from the present survey is presented in Table 13.2. Additional information on colour and smell can be found in the Appendix. Median (Φ), pelite, sand and TOM are compared with data from 2000 in Figure 13.2.

The sediments at Jotun are classified as fine sand with median (Φ) values ranging from 3.07 (JOT14) to 3.51 (JOT02 and JOT08). The amount of pelite varied from 21.45 % (JOT05) to 25.21 % (JOT15), the sand varied from 74.79 % (JOT15) to 78.53 % (JOT12), and the TOM varied from 2.12 % (JOT12) to 2.72 % (JOT07). The conditions at the reference site JOT30R were within the variation found at the field specific sampling sites. Compared to 2000 there was slightly more pelite in the sediments in 2003.

Table 13.2. Total organic matter and sediment grain size at all sites at Jotun in 2003. For comparison, averages, standard deviations, max and min values for the regional and reference sites are included.

Site	TOM %	Grevel %	Sand %	Pelite %	Median (Φ)	Sorting	Skewness	Kurtosis
JOT02	2.53	0.02	75.44	24.54	3.51	1.42	0.44	2.18
JOT03	2.62	0.00	75.06	24.94	3.38	1.51	0.44	1.64
JOT04	2.59	0.00	78.06	21.94	3.44	1.37	0.39	1.99
JOT05	2.37	0.08	78.46	21.45	3.17	1.42	0.48	1.53
JOT06	2.71	0.00	77.36	22.64	3.34	1.44	0.43	1.66
JOT07	2.72	0.01	76.61	23.38	3.14	1.49	0.52	1.48
JOT08	2.59	0.00	77.11	22.89	3.51	1.35	0.43	2.28
JOT10	2.68	0.00	76.53	23.47	3.42	1.45	0.42	1.79
JOT11	2.36	0.00	77.39	22.61	3.25	1.45	0.46	1.56
JOT12	2.12	0.00	78.53	21.47	3.13	1.42	0.50	1.52
JOT13	2.36	0.01	76.57	23.42	3.48	1.41	0.42	2.09
JOT14	2.57	0.18	77.03	22.79	3.07	1.48	0.55	1.47
JOT15	2.38	0.00	74.79	25.21	3.37	1.52	0.45	1.57
JOT30R	2.19	0.12	78.12	21.77	3.34	1.40	0.41	1.68
Average[1]	2.51	0.02	76.84	23.13	3.32	1.44	0.46	1.75
SD[1]	0.18	0.05	1.20	1.21	0.16	0.05	0.04	0.29
Min[1]	2.12	0.00	74.79	21.45	3.07	1.35	0.39	1.47
Max[1]	2.72	0.18	78.53	25.21	3.51	1.52	0.55	2.28
Average[2]	1.71	0.29	87.23	12.49	2.71	1.16	0.34	1.76
SD[2]	0.45	0.62	5.20	5.12	0.37	0.14	0.19	0.46
Min[2]	0.73	0.00	78.12	3.04	1.76	0.93	0.03	1.05
Max[2]	2.19	2.19	96.61	21.77	3.34	1.40	0.57	2.95

[1] Field sites, exclusive JOT30R
[2] Reg + Ref $_{\text{central 03}}$

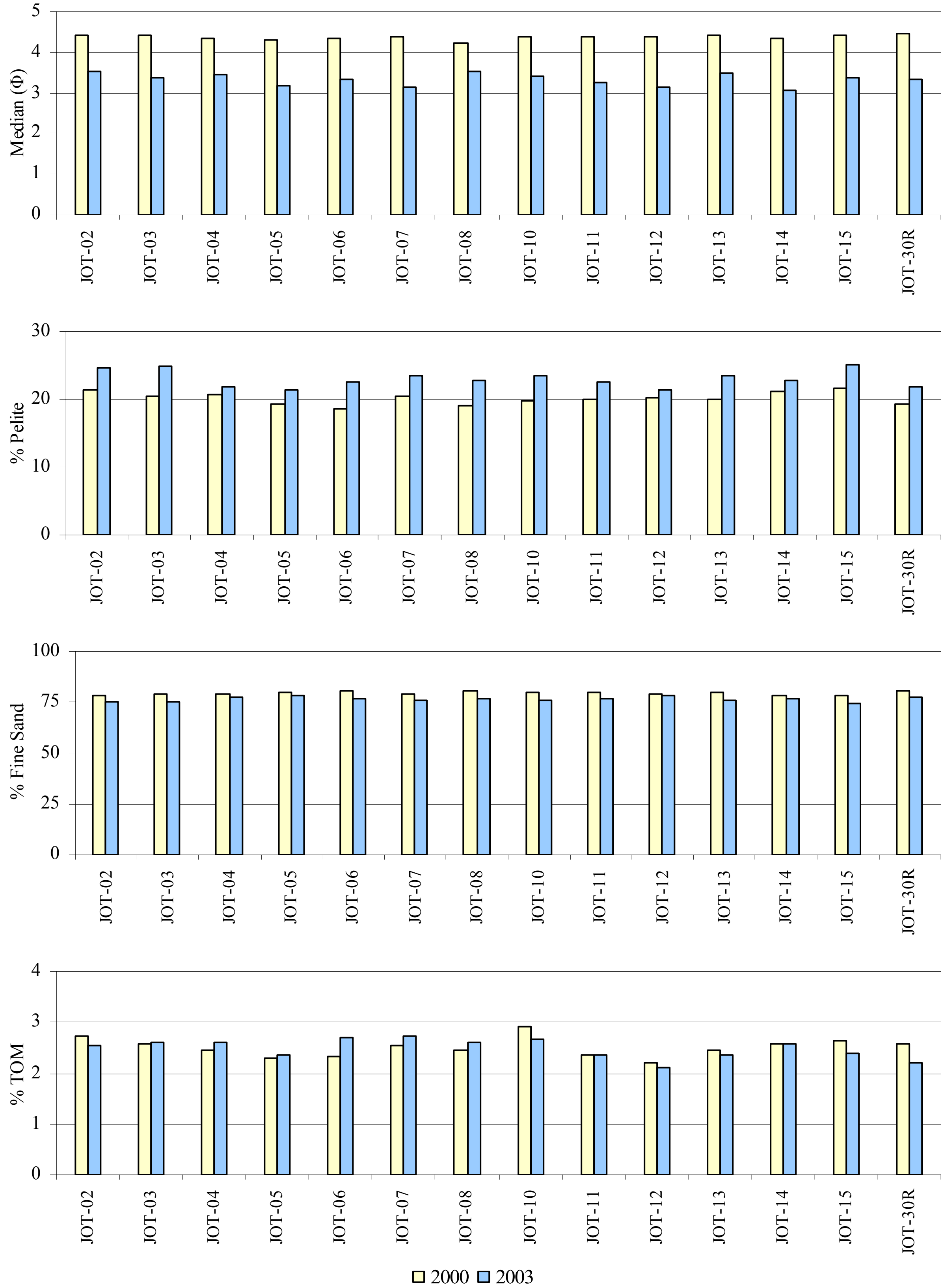


Figure 13.2. Sediment characteristics at Jotun in 2000 and 2003. Fine sand is the relative amount of sand with grain size 63-250 µm.

13.2.2 Chemical compounds

13.2.2.1 LSC

The results of the LSC (limits of significant contamination) calculations of hydrocarbons and metals are presented in the chapter concerning the regional and reference sites. Both the $LSC_{central\ 97-03}$ and the field specific LSC value ($LSC_{JOT30R\ 03}$) are presented in Table 13.3. LSC in the text relates to $LSC_{central\ 97-03}$.

Table 13.3. Limits of Significant Contamination (LSC) for the Jotun field in 2003, and for the central of Region II based on data from 1997 to 2003 ($LSC_{central\ 97-03}$) and the whole of Region II based on data from 1997 to 2003 ($LSC_{regII\ 97-03}$). For comparison, LSC-values from 2000 are included. All values in mg/kg dry sediment.

	THC	PAH (16)	NPD's	Decalins	Cu	Cr	Zn	Ba	Pb	Cd	Hg
$LSC_{JOT30R\ 03}$	21.5	0.148	0.035	0.329	1.9	8.4	11.7	77	5.0	0.03[1]	0.013
$LSC_{central\ 97-03}$	14.5	*	*	*	2.2	9.4	12.4	161	6.8	0.03[1]	0.012
$LSC_{regII\ 97-03}$	13.3	*	*	*	2.0	9.4	11.1	136	6.6	0.03[1]	0.011
$LSC_{JOT30R\ 00}$**	8.6	*	0.040	0.108	2.6	10.5	11.8	149	8.1	0.038	0.011
$LSC_{regII\ 97-00}$**	9.8	*	*	*	2.0	9.6	8.9	146	7.0	0.03	0.008

* NPD's, PAH's and decalins are not analysed at regional sites in 1997 and 2000
** Data from Mannvik & al. 2001
[1] LSC = detection limit

13.2.2.2 Hydrocarbons

Summarised results of the hydrocarbon analyses, along with the content of selected hydrocarbon compounds in the different layers (0-1, 1-3 and 3-6) are given in Table 13.4 and Table 13.5. The complete data set including replicates is given in the Appendix. Comparison of the THC content in 2003 with previous surveys is presented in Figure 13.3.

THC was found in the range from 8.4 to 19.5 mg/kg, and THC concentrations above LSC occurred at JOT02, JOT07 and JOT11. The distribution of THC was relatively uniform (12.6 ± 3.1 mg/kg) across the field sampling sites. Highest concentrations were found at JOT02, 1000 m to the north of the well head platform, while the lowest concentrations were seen at JOT14, 500 m to the southwest of the well head platform. Since 2000 the THC content in the sediments has decreased at the innermost sampling sites to the well head platform, and along the south-western and north-western transects, except at the JOT10 1000 m to the northwest. Whereas the THC content has increased along the north-eastern and south-eastern transects, which are closer to the ship Jotun A as well as downstream from the well head platform.

In the vertical samples from JOT05 and JOT06 decalins occurred above LSC in all depth intervals down to 6 cm and PAH occurred above LSC in the 3-6 cm interval. At the field specific reference site, JOT30R, THC occurred above LSC in the 1-3 cm interval and NPD occurred above LSC in the 3-6 cm interval. The vertical distributions of the compounds were relatively uniform.

Table 13.4. The content of oil hydrocarbons in sediments from Jotun in 2003. All values in mg/kg dry sediment. THC values above $LSC_{central\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{JOT30R\ 03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data for the regional and field reference sites in the central part of region II are included.

Site	THC		PAH(16)		NPD		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
JOT02	19.5	2.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
JOT03	13.1	2.8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
JOT04	9.4	5.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
JOT05	13.0	6.5	0,131	0,033	0,029	0,004	1,807	1,298
JOT06	12.2	6.7	0,113	0,019	0,028	0,002	0,528	0,144
JOT07	15.9	3.6	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
JOT08	14.5	1.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
JOT10	11.4	0.5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
JOT11	15.1	2.8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
JOT12	11.6	2.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
JOT13	10.2	1.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
JOT14	8.4	3.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
JOT15	10.0	2.0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
JOT30R	12.0	4.1	0,102	0,020	0,025	0,005	0,238	0,039
av. ± sd.[1]	12.6 ± 3.1							
min - max[1]	8.4-19.5							
av. ± sd.[2]	11.2±4.0		0.067±0.027		0.020±0.004		0.232±0.085	
min - max[2]	<3.0-15.5		0.013-0.102		0.012-0.027		0.095-0.461	

n.a. = not analysed.
[1] Field sites, exclusive JOT30R
[2] Reg + Ref $_{central\ 03}$

Table 13.5. The content of oil hydrocarbons in vertical sections of sediment from 3 sampling sites at Jotun in 2003. All values in mg/kg dry sediment. THC values above $LSC_{central\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{JOT30R\ 03}$ are dark shaded.

Site	Layer (cm)	THC	PAH(16)	NPD	Decalins
JOT05	0-1	8.8	0.136	0.031	1.310
	1-3	6.5	0.121	0.030	1.010
	3-6	<3.0	0.161	0.030	0.650
JOT06	0-1	4.4	0.134	0.030	0.480
	1-3	7.5	0.129	0.031	0.490
	3-6	4.5	0.160	0.029	0.470
JOT30R	0-1	10,6	0.079	0.020	0.200
	1-3	14,7	0.106	0.028	0.210
	3-6	14,0	0.135	0.036	0.235

13.2.2.3 Metals

Table 13.6 summarises the results of the metal analyses of the Jotun field in 2003. Concentrations of selected metals in the different layers (0-1, 1-3 and 3-6) of sediment are given in Table 13.7, whereas the complete data set including replicates is given in the Appendix. Comparisons of the metal contents in 2003 with the metal contents in 1997 and in 2000 are presented in Figure 13.6.

Barium was found in a range from 104 to 439 mg/kg, lead from 4.0 to 5.5 mg/kg, cadmium <0.03, copper from 1.6 to 2.2 mg/kg and zinc from 10.4 to 12.9 mg/kg. Mercury occurred at 0.009 mg/kg (Table 13.6). Sediments from JOT02, JOT03, JOT04, JOT05, JOT07, JOT11, JOT12 and JOT13 had barium content above LSC. Zinc was present above LSC at JOT02, JOT04, JOT07 and JOT11. Chromium occurred above LSC at JOT02 and JOT07. Copper, lead, cadmium and mercury were below LSC at all sites.

Compared to previous surveys the barium content in 2003 was at similar level as in 1997 and lower than in 2000. Also the other metals, except zinc, occurred in lower concentrations in 2003 than in 2000.

Vertical sediment samples (0-1, 1-3 and 3-6 cm) were taken from JOT05, JOT06 and JOT30R. The only metal occurring above LSC was barium at JOT05 where it was above LSC in all depth intervals. In 2000 all metals except chromium occurred in elevated levels in some of the depth intervals at the same sampling sites.

Table 13.6 Content of metals in sediments from Jotun in 2003. All values in mg/kg dry sediment. Values above $LSC_{central\ 97-03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data in the regional and field reference sites in the central part of the region II are included.

Site	Cu		Cr		Zn		Ba		Pb		Cd		Hg	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
JOT02	2.2	0.2	9.5	0.2	12.5	0.6	189	11	5.2	0.3	<0.03	-	n.a.	n.a.
JOT03	1.9	0.1	8.3	0.9	11.5	0.5	227	41	4.6	0.3	<0.03	-	n.a.	n.a.
JOT04	2.0	0.2	9.2	0.9	12.9	0.6	412	40	4.7	1.0	<0.03	-	n.a.	n.a.
JOT05	1.6	0.4	7.4	0.6	11.0	0.5	192	18	4.0	0.8	<0.03	-	0.009	0.001
JOT06	1.7	0.1	8.4	0.8	10.4	0.7	143	67	4.3	0.6	<0.03	-	0.009	0.002
JOT07	2.2	0.1	10.0	0.3	12.9	0.3	163	11	5.5	0.0	<0.03	-	n.a.	n.a.
JOT08	2.0	0.1	9.2	0.8	12.4	0.2	121	19	5.3	0.2	<0.03	-	n.a.	n.a.
JOT10	1.9	0.2	8.6	0.5	11.7	0.9	147	22	4.8	0.5	<0.03	-	n.a.	n.a.
JOT11	2.1	0.2	9.0	0.2	12.5	0.5	280	41	5.2	0.3	<0.03	-	n.a.	n.a.
JOT12	1.8	0.1	7.7	0.7	10.9	0.4	439	54	4.6	0.0	<0.03	-	n.a.	n.a.
JOT13	1.7	0.1	8.1	0.4	10.8	0.8	268	35	4.5	0.3	<0.03	-	n.a.	n.a.
JOT14	1.8	0.1	8.2	0.1	11.0	0.4	143	21	4.5	0.4	<0.03	-	n.a.	n.a.
JOT15	2.0	0.2	8.8	0.5	12.1	0.5	104	12	5.1	0.3	<0.03	-	n.a.	n.a.
JOT30R	1.7	0.1	7.2	0.5	10.6	0.5	61	7	4.6	0.2	<0.03	-	0.011	0.001
av. ± sd.[1]	1.9 ± 0.2		8.6 ± 0.7		11.7 ± 0.9		218 ± 107		4.8 ± 0.4		<0.03			
min - max[1]	1.6 - 2.2		7.4 - 10.0		10.4 - 12.9		104 - 439		4.0 - 5.5		<0.03			
av. ± sd.[2]	1.2 ± 0.4		6.9 ± 1.2		9.4 ± 1.3		66 ± 31		4.2 ± 0.6		<0.03		0.009±0.003	
min - max[2]	<0.6-1.7		4.9-8.9		6.8-12.0		10-146		3.4-5.1		<0.03		0.006-0.014	

n.a. = not analysed.
[1] Field sites, exclusive JOT30R
[2] Reg + ref $_{central\ 03}$

Table 13.7. The content of metals in vertical sections of sediment from 3 sampling sites at Jotun in 2003. All values in mg/kg dry sediment. Values above $LSC_{central\ 97-03}$ are dark shaded.

Site	Layer (cm)	Cu	Cr	Zn	Ba	Pb	Cd	Hg
JOT05	0-1	2.0	7.7	11.5	187	4.7	<0.03	0.010
	1-3	1.7	8.5	11.2	375	4.8	<0.03	0.010
	3-6	1.8	7.8	11.2	182	4.8	<0.03	0.010
JOT06	0-1	1.6	8.1	9.7	89.9	3.6	<0.03	0.007
	1-3	2.0	8.4	11.0	111	4.5	<0.03	0.012
	3-6	1.6	7.1	10.4	101	4.9	<0.03	0.009
JOT30R	0-1	1.6	6.7	10.0	56.1	4.3	<0.03	0.011
	1-3	1.5	7.1	9.9	63.2	4.4	<0.03	0.010
	3-6	1.7	7.9	10.4	65.4	4.6	<0.03	0.010

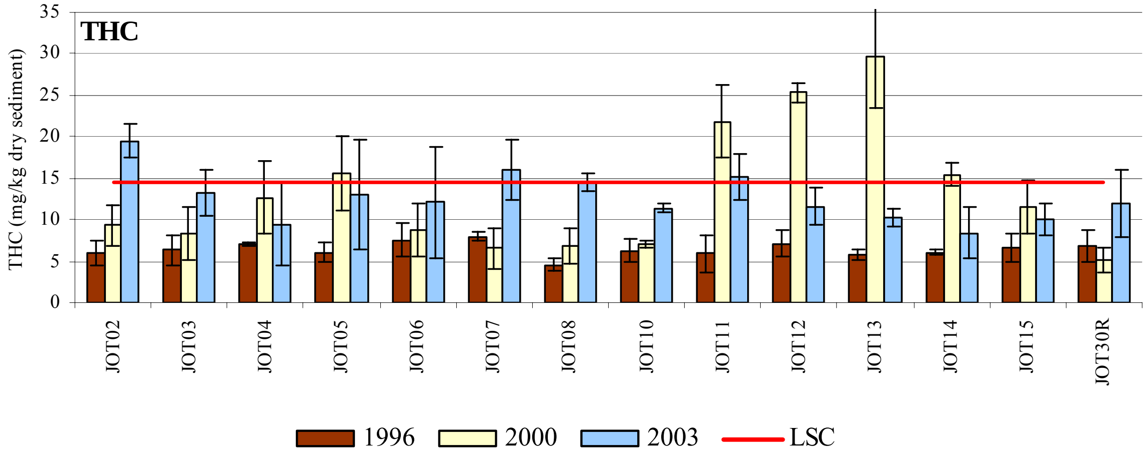


Figure 13.3. Average THC concentrations and standard deviations in sediments from Jotun in 2003 and previous years. Red line is $LSC_{central\ 97\text{-}03}$.

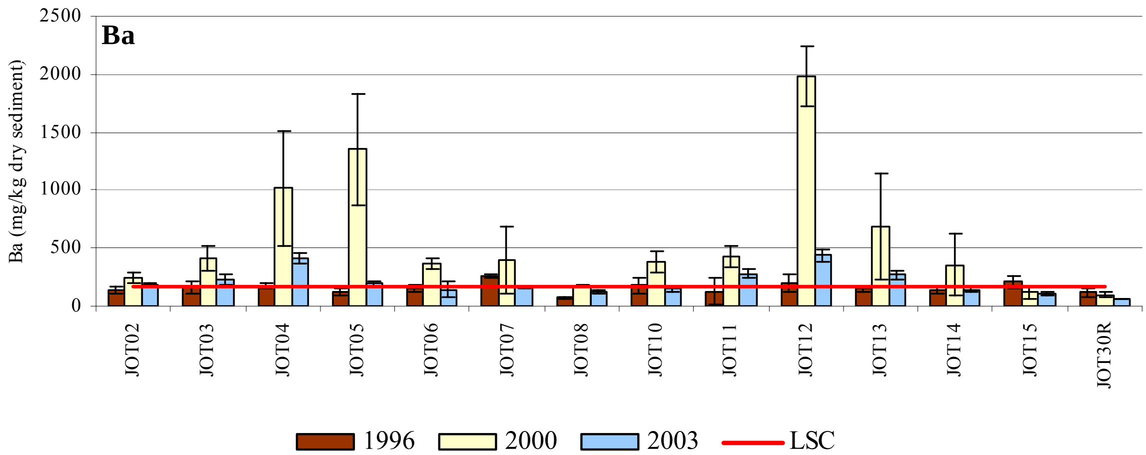


Figure 13.4. Average barium concentrations and standard deviations in sediments from Jotun in 2003 and previous years. Red line is $LSC_{central\ 97\text{-}03}$.

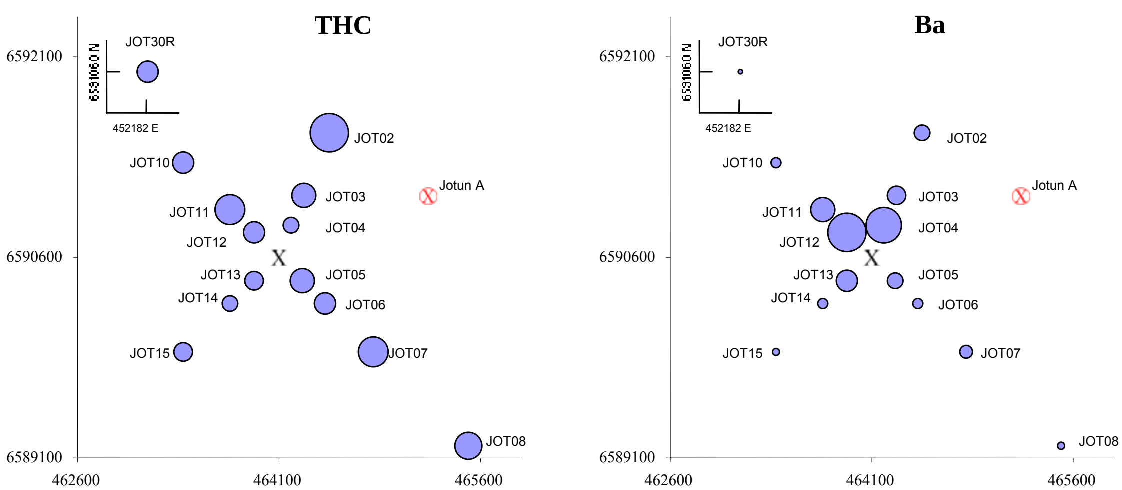


Figure 13.5. Distribution of THC and barium in sediments at the sampling sites at Jotun in 2003. The size of the circle indicate the amount of THC and Ba. The field centre and the ship (Jotun A) are marked with an X.

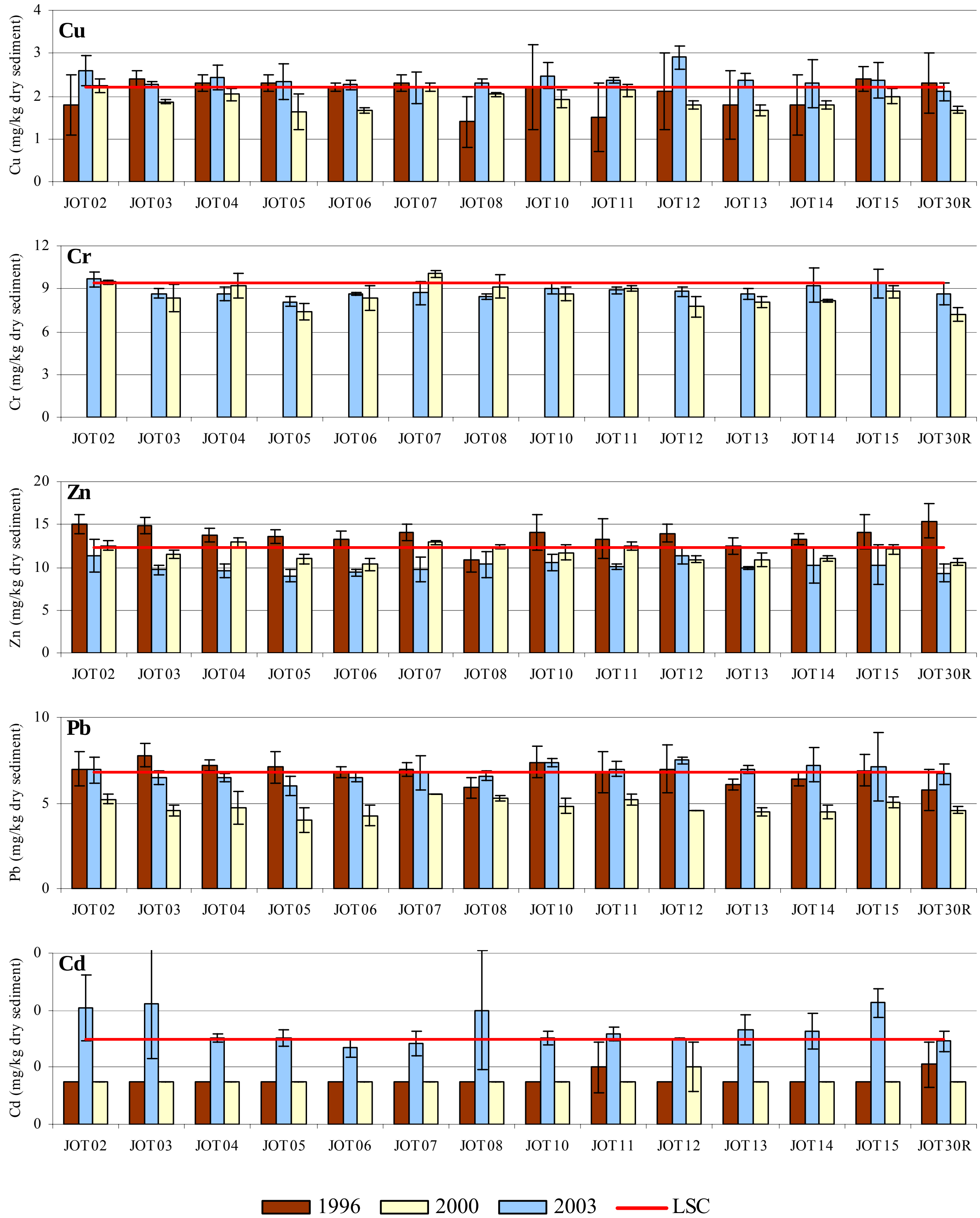


Figure 13.6. Average content and standard deviations of metals in sediment from Jotun in 2003 and previous surveys. Red line is $LSC_{central\ 97\text{-}03}$.

The field sites at Jotun were compared to nearby regional and field specific reference sites based on sediment characteristics (TOM and pelite) and chemical content in the sediments (Figure 13.7). The sampling sites at Jotun did not group together with the other sites. This indicates differences in the sediment characteristics and chemical content at the field specific sites compared to the other sites. Within the field specific sampling sites there was no clear grouping of sampling sites. This indicates a homogenous distribution of the measured compounds across the field.

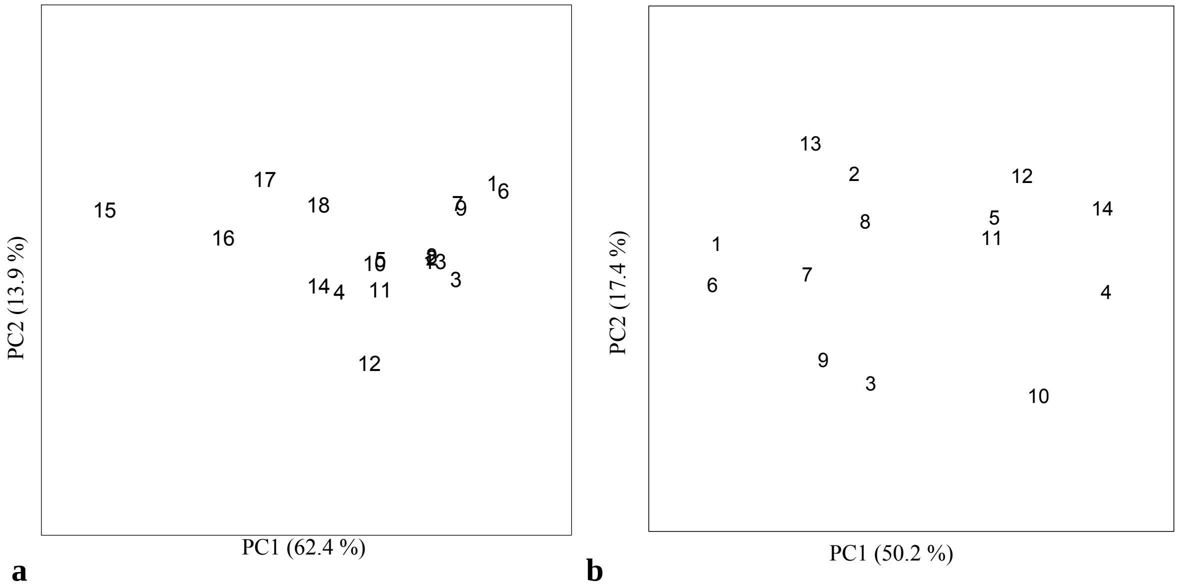


Figure 13.7. 2-D plot from the PCA analysis of environmental variables (% pelite, % sand, % gravel, median Φ, TOM, Cu, Ba, Zn, Cr, Pb and THC) carried out on the:

c) Jotun field sites compared to the reference sites at Grane, Balder and Ringhorn and the reference site RII09. Explained variation in the data 73.3 %.
d) Jotun field sites. Explained variation in the data 67.6 %.
Numbers in the plot identify the sampling sites. See table below.

1	JOT02	6	JOT07	11	JOT13	16	GRA14R
2	JOT03	7	JOT08	12	JOT14	17	BAL27R
3	JOT04	8	JOT10	13	JOT15	18	RIN29R
4	JOT05	9	JOT11	14	JOT30R		
5	JOT06	10	JOT12	15	RII09		

13.2.3 Bottom fauna

A summary of the distribution of individuals and taxa within the main taxonomic groups is given in Table 13.8. Unidentified juveniles of the sea urchins Spatangoids (4108 individuals) and Echinoides (16940 individuals) are omitted from the analyses, as they occurred in extremely high numbers. In total, 14293 individuals within 251 taxa were collected at Jotun in 2003. The fauna was numerically dominated by annelida with 58 % the individuals and 48 % of the taxa. A complete species list is available in the Appendix.

Table 13.8. Distribution of individuals and taxa within the main taxonomic groups at Jotun in 2003 including data from JOT30R (unidentified juveniles of Spatangoida and Echinoidea are not included).

Main taxonomic groups	Number of individuals	%	Number of taxa	%
Annelida	8281	58	119	48
Arthropoda	1209	8	57	23
Mollusca	2665	19	47	19
Echidermata	1275	9	10	4
Diverse groups	863	6	17	7
Total	14293	100	250	100

The species/area curve for JOT30R indicates that five replicate samples give a representative impression of the bottom fauna in the area (Figure 13.8). However, as more area is sampled, more taxa are collected, indicating that not even 10 replicate samples give the full species assemblage of the area.

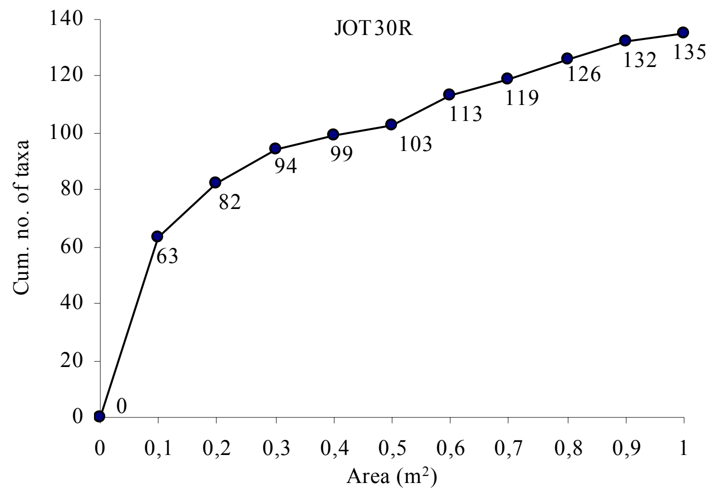


Figure 13.8. Species/area curve for the reference station at the Jotun field. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

The distribution of individuals and taxa are shown in Figure 13.9. Number of individuals and taxa at each site, and the calculated diversity indexes (H' and ES_{100}) are given in Table 13.9 and Figure 13.10. The number of individuals varied from 794 (JOT14) to 1144 (JOT05), and the number of taxa varied from 105 (JOT06) to 136 (JOT04). The Shannon-Wiener diversity index (H') varied from 5.23 (JOT06 and JOT15) to 5.73 (JOT04), whereas the ES_{100} index varied from 38.5 (JOT06) to 45.9 (JOT04). The evenness index J varied from 0.77 (JOT10 and JOT15) to 0.81 (JOT04 and JOT05). The corresponding values at JOT30R are within or near the variation at the field sites. The number of taxa, diversity and evenness indicate good environmental conditions at all sites.

Table 13.9. Number of individuals, species/taxa and selected community indices for each station (0.5 m^2) at the Jotun field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

Site number	Number of individuals	Number of taxa	Diversity H'	Evenness J	H'-max	ES_{100}
JOT02	904	115	5.41	0.79	6.85	41.1
JOT03	1086	122	5.54	0.80	6.93	42.9
JOT04	959	136	5.73	0.81	7.09	45.9
JOT05	1144	123	5.60	0.81	6.94	44.1
JOT06	976	105	5.23	0.78	6.71	38.5
JOT07	988	110	5.39	0.79	6.78	41.1
JOT08	921	118	5.39	0.78	6.88	41.5
JOT10	829	111	5.25	0.77	6.79	39.9
JOT11	916	115	5.42	0.79	6.85	40.8
JOT12	1092	124	5.54	0.80	6.95	43.1
JOT13	1006	110	5.45	0.80	6.78	41.8
JOT14	794	106	5.37	0.80	6.73	40.5
JOT15	908	111	5.23	0.77	6.79	39.6
JOT30R	850	103	5.37	0.80	6.69	40.5
JOT30R	920	114	5.57	0.81	6.83	44.0
JOT30R	1770	135	5.55	0.78	7.08	42.5
Sum[1]	12523	239				
Average[1]	963	116	5.43	0.79	6.85	41.61
SD[1]	102	9	0.15	0.01	0.10	1.99
Min[1]	794	105	5.23	0.77	6.71	38.52
Max[1]	1144	136	5.73	0.81	7.09	45.89
Average[2]	774	113	5.55	0.81	6.81	44.3
SD[2]	230	14	0.24	0.02	0.18	2.6
Min[2]	488	94	5.12	0.79	6.55	38.7
Max[2]	1202	141	5.85	0.85	7.14	47.9

[1]Field sites, exclusive JOT30R
[2]Reg + Ref $_{\text{central 03}}$

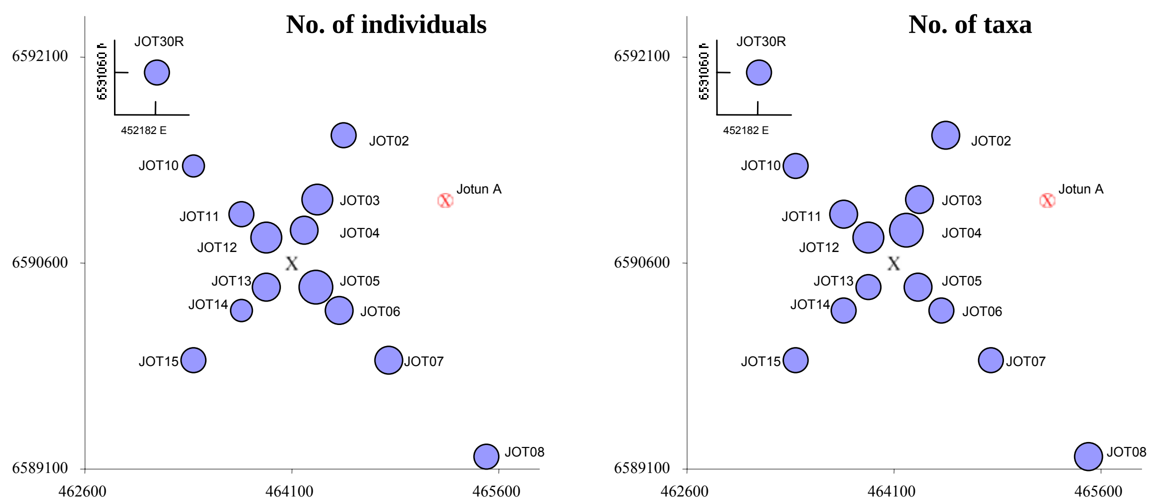


Figure 13.9. Distribution of bottom fauna (individuals and taxa) among the sampling sites in 2003. The size of the circle indicates the number of individuals and taxa. Exclusive unidentified juveniles of Spatangoida and Echinoidae. Values for JOT30R are average of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2). The field centre and the ship (Jotun A) are marked with an X.

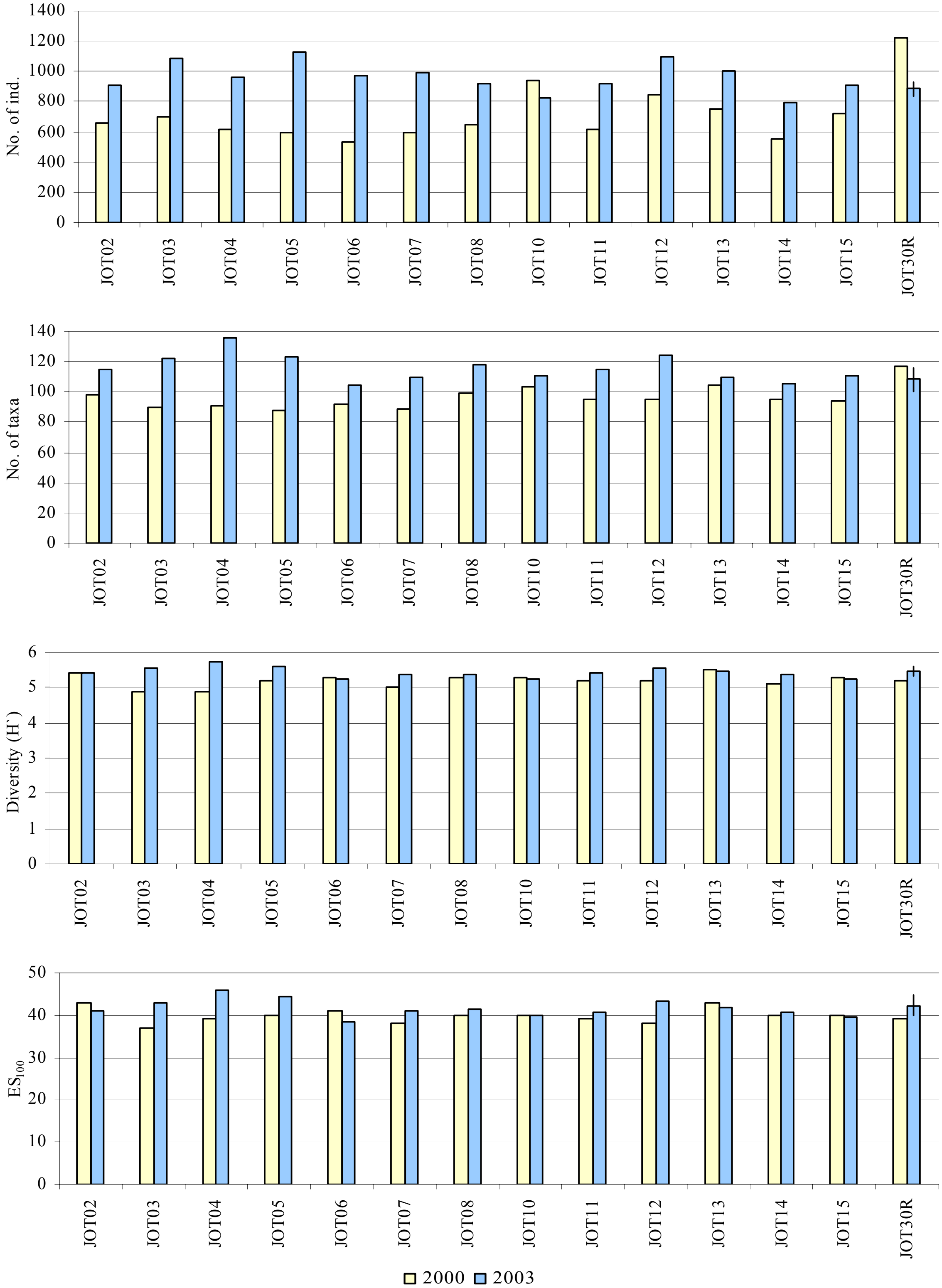


Figure 13.10. Number of individuals, taxa and selected community indices for each site (0.5 m^2) at the Jotun field for 2000 and 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea in 2003. Values for JOT30R are average ± standard deviation of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2).

Distribution of taxa in geometrical classes is presented in Figure 13.11. The smooth graphs representing the sampling sites at Jotun are examples of undisturbed bottom fauna.

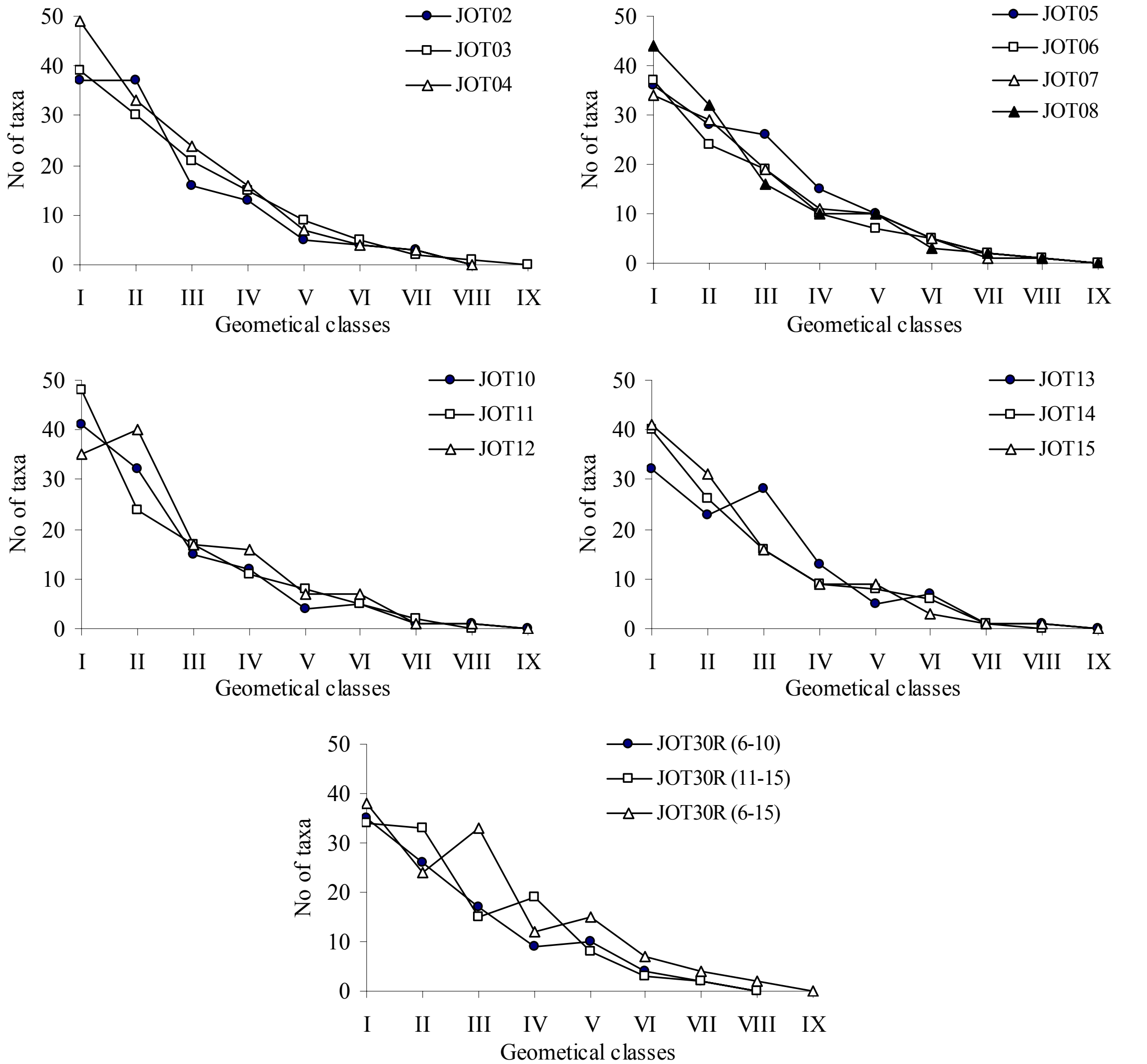


Figure 13.11. Distribution of taxa in geometrical classes for the sites at Jotun in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

The ten most numerous taxa are listed in Table 13.12 at the end of this chapter. The list comprise 17 taxa and 9240 individuals, which was 6.8 % of all (251) taxa and 64.6 % of all (14293) individuals. The polychaete *Paramphinome jefreysii* was most abundant at all sites except the reference site (JOT30R) where the polychaete *Lanice conchilega* was most abundant. Two other polychaetes *Diplocirrus glaucus* and *Laonice sarsii* and the two bivalves *Thyasira equalis* and *Thyasira croulinensis* were among the most numerous taxa at all sites. Although species indicating faunal disturbance like the bivalves *Thyasira flexuosa* and *Thyasira sarsii* occurred at several sampling sites the overall impression of the fauna was an undisturbed one.

The results of the multivariate analyses are given in the dendrogramme (Figure 13.12) and the MDS plott (Figure 13.13).

In the cluster analysis, all sites are grouped together within 71 % similarity, indicating high similarity in the species assemblages within the field and no clear grouping of sampling sites based on the species assemblage. This indicates homogenous conditions across the sampling area.

The results of the MDS analysis support the findings in the cluster analysis, confirming the similarity in species assemblage and the homogenous conditions across the sampling area. The stress test of the MDS analysis was 0.20, indicating a potential useful presentation of the data.

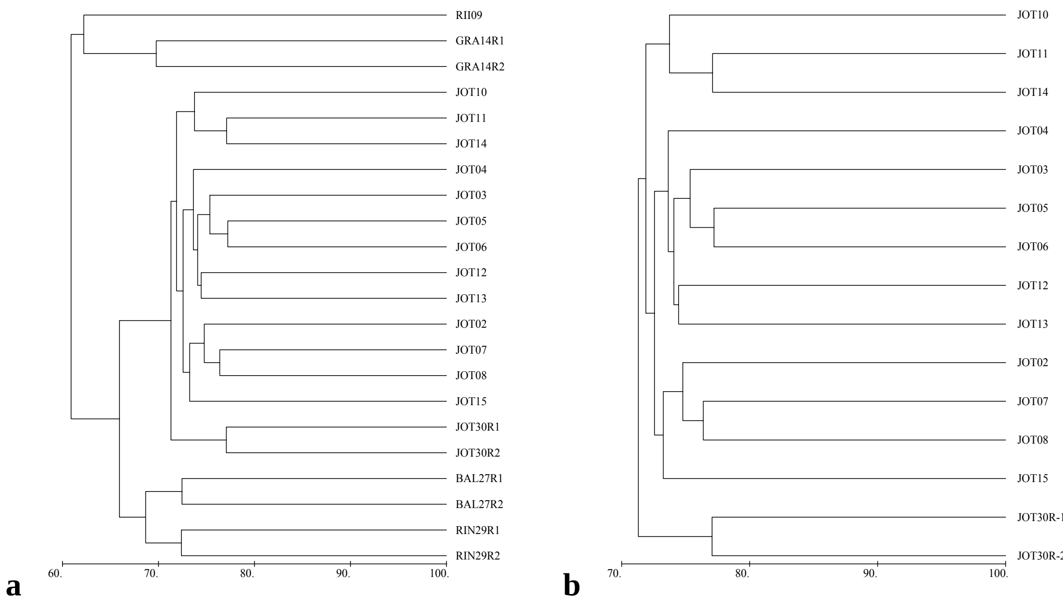


Figure 13.12. Dendrogram showing the similarity between fauna from sampling sites at:
a) Jotun field, regional site (RII09) and reference sites (GRA14R, BAL27R and RIN29R).
b) Jotun field in 2003.
Exclusive unidentified juveniles of Spatangoida and Echinoidea.

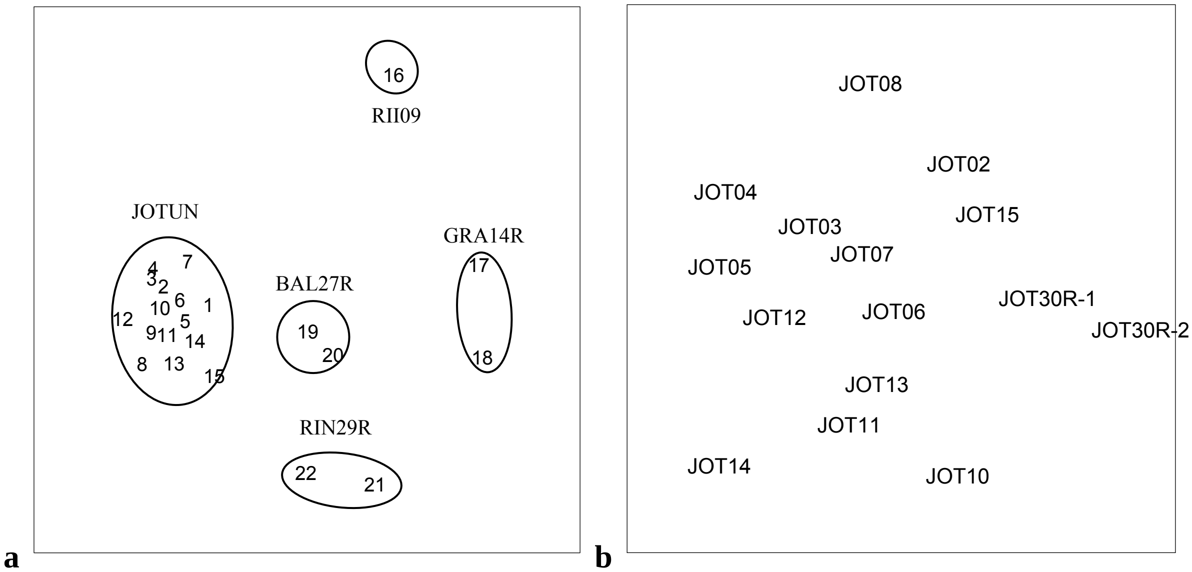


Figure 13.13. A 2-dimetional plott of the MDS analysis of the fauna data from:
a) Jotun field compared to regional site (RII09) and reference sites (GRA14R, BAL27R and RIN29R). Stress = 0.12. Numbers in the plot identify the sampling sites. See table below.
b) Jotun field in 2003. Stress = 0.20.
Exclusive unidentified juveniles of Spatangoida and Echinoidea.

1	JOT02	6	JOT07	11	JOT13	16	RII09	21	RIN29R1
2	JOT03	7	JOT08	12	JOT14	17	GRA14R1	22	RIN29R2
3	JOT04	8	JOT10	13	JOT15	18	GRA14R2		
4	JOT05	9	JOT11	14	JOT30R1	19	BAL27R1		
5	JOT06	10	JOT12	15	JOT30R2	20	BAL27R2		

Linking of biotic and environmental variables by BIOENV revealed that the content of barium, gravel and THC in the sediments, was correlated to the biota at $\rho_w = 0.28$ (Table 13.10). This indicates no strong association between the fauna and the measured environmental variables within the Jotun field.

Table 13.10. Combinations of the 10 environmental variables, taken *k* at a time, yielding the best matches of biotic and abiotic similarity matrices for each *k*, as measured by weighted Spearman rank correlation ρ_w. Bold type indicates overall optimum. All possible combinations of variables and associated correlation to the biotic are given in the Appendix.

Number of variables (*k*)	Correlation coefficient (ρ_w)	Environmental variables									
1	0.178	Ba									
1	0.158	Gravel									
1	-0.045	THC									
1	-0.057	Cr									
1	-0.057	Zn									
1	-0.067	Pelite									
1	-0.070	Cu									
1	-0.080	TOM									
1	-0.097	Sand									
1	-0.151	Pb									
2	0.270	Ba	Gravel								
3	**0.275**	**Ba**	**Gravel**	**THC**							
4	0.243	Ba	Gravel	THC	Pelite						
5	0.207	Ba	Gravel	THC	Pelite	Sand					
6	0.175	Ba	Gravel	THC	Pelite	Sand	Cr				
7	0.141	Ba	Gravel	THC	Pelite	Sand	Cr	Zn			
8	0.115	Ba	Gravel	THC	Pelite	Sand	Cr	Zn	Pb		
9	0.086	Ba	Gravel	THC	Pelite	Sand	Cr	Zn	Pb	TOM	
10	0.056	Ba	Gravel	THC	Pelite	Sand	Cr	Zn	Pb	TOM	Cu

13.2.4 Estimation of influenced area

The extension of contamination along sampling transects and the minimum area of contaminated sediments for barium, as well as for faunal disturbance is given in Figure 13.14 and Table 13.11. The contaminated area was smaller in 2003 than in 2000 for barium and no faunal disturbance were found in 2003. Due to the diffuse distribution pattern of THC and metal, except barium, no area of contamination of these compounds were estimated.

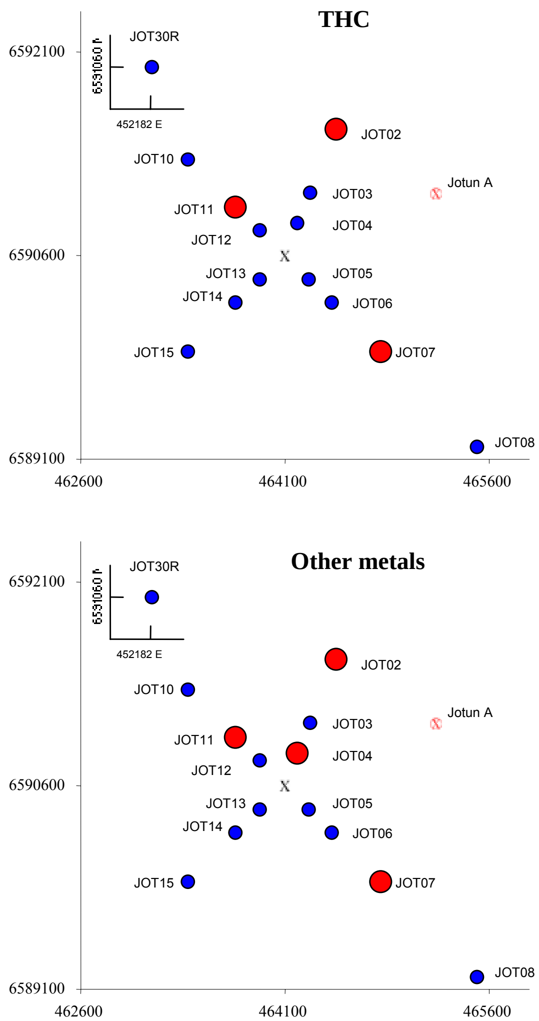


Figure 13.14. Faunal disturbance and chemical contamination of the sediments at Jotun in 2003. The field centre and the ship (Jotun A) are marked with an X. Uncontaminated sites and sites with no faunal disturbance are marked with small blue circles.

Table 13.11. Estimated distance of contamination and faunal disturbance from the installation, and estimated area of contamination and faunal disturbance around the field centre.

Jotun	NE m	SE m	SW m	NW m	2003 km^2	2000 km^2	1996 km^2
THC	n.e.	n.e.	0	n.e.	n.e.	1.77	0.00
Ba	1000	1000	250	500	1.47	5.30	0.00
Other metals	n.e.	n.e.	0	n.e.	n.e.	0.07	0.00
Fauna	0	0	0	0	0.00	0.00	0.00

n.e. = not estimated.

13.3 Summary and conclusions

At least 16 wells have been drilled at Jotun since the last environmental survey at the field. The sediments are still characterized as fine sand, although there has been a slight increase in the pelite content since 2000. The amount of THC has decreased at the sites where it occurred in the highest concentrations in 2000 and increased at the other sites. Thus the distribution of THC across the field was more even in 2003 than in 2000 and contamination of THC was only seen at 3 sites of which none where close to the field centre. The concentration of barium and other metals except zinc have decreased since 2000. The area of barium contamination was smaller in 2003 than in 2000. More taxa and individuals were found in the bottom fauna in 2003 than in 2000, and the diversity of the fauna remained high. Comparisons of fauna assemblage showed an even distribution of the fauna and no faunal disturbance. The distribution of fauna and environmental variables were not well correlated indicating no linking between fauna and the measured environmental variables.

Table 13.12. Number of individuals and relative abundance for the ten predominant taxa at each site at the Jotun field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

JOT02	No. of ind.	%	Cum %
Paramphinome jeffreysii	102	11,3	11,3
Thyasira equalis	73	8,1	19,4
Lanice conchilega	65	7,2	26,5
Thyasira croulinensis	58	6,4	33,0
Amphiura chiajei	55	6,1	39,0
Laonice sarsi	48	5,3	44,4
Diplocirrus glaucus	48	5,3	49,7
Lumbrineridae indet.	26	2,9	52,5
Myriochele oculata	25	2,8	55,3
Lumbrineris scopa	22	2,4	57,7

JOT03	No. of ind.	%	Cum %
Paramphinome jeffreysii	137	12,6	12,6
Thyasira equalis	70	6,4	19,1
Amphiura chiajei	64	5,9	25,0
Lanice conchilega	63	5,8	30,8
Thyasira croulinensis	54	5,0	35,7
Laonice sarsi	50	4,6	40,3
Diplocirrus glaucus	50	4,6	44,9
Myriochele oculata	32	2,9	47,9
Lumbrineris scopa	31	2,9	50,7
Cerianthus lloydii	29	2,7	53,4

JOT04	No. of ind.	%	Cum %
Paramphinome jeffreysii	95	9,9	9,9
Thyasira equalis	67	7,0	16,9
Lanice conchilega	66	6,9	23,8
Laonice sarsi	56	5,8	29,6
Diplocirrus glaucus	52	5,4	35,0
Amphiura chiajei	50	5,2	40,3
Cerianthus lloydii	32	3,3	43,6
Thyasira croulinensis	26	2,7	46,3
Myriochele oculata	23	2,4	48,7
Lumbrineris scopa	21	2,2	50,9

JOT05	No. of ind.	%	Cum %
Paramphinome jeffreysii	150	13,1	13,1
Thyasira equalis	68	5,9	19,1
Thyasira croulinensis	64	5,6	24,7
Laonice sarsi	62	5,4	30,1
Lanice conchilega	62	5,4	35,5
Diplocirrus glaucus	55	4,8	40,3
Asteroidea indet.	40	3,5	43,8
Amphiura chiajei	39	3,4	47,2
Cerianthus lloydii	22	1,9	49,1
Myriochele oculata	22	1,9	51,0
Prionospio cirrifera	22	1,9	53,0
Pseudopolydora paucibranchiata	22	1,9	54,9

JOT06	No. of ind.	%	Cum %
Paramphinome jeffreysii	149	15,3	15,3
Thyasira equalis	79	8,1	23,4
Lanice conchilega	68	7,0	30,3
Diplocirrus glaucus	49	5,0	35,3
Thyasira croulinensis	48	4,9	40,3
Amphiura chiajei	42	4,3	44,6
Laonice sarsi	41	4,2	48,8
Asteroidea indet.	38	3,9	52,7
Sabellidae indet.	31	3,2	55,8
Myriochele oculata	25	2,6	58,4

JOT07	No. of ind.	%	Cum %
Paramphinome jeffreysii	151	15,3	15,3
Thyasira equalis	71	7,2	22,5
Lanice conchilega	59	6,0	28,4
Amphiura chiajei	46	4,7	33,1
Thyasira croulinensis	42	4,3	37,3
Diplocirrus glaucus	39	3,9	41,3
Laonice sarsi	37	3,7	45,0
Lumbrineridae indet.	29	2,9	48,0
Sabellidae indet.	26	2,6	50,6
Lumbrineris scopa	26	2,6	53,2

JOT08	No. of ind.	%	Cum %
Paramphinome jeffreysii	146	15,9	15,9
Thyasira equalis	70	7,6	23,5
Lanice conchilega	67	7,3	30,7
Amphiura chiajei	43	4,7	35,4
Thyasira croulinensis	39	4,2	39,6
Diplocirrus glaucus	33	3,6	43,2
Laonice sarsi	30	3,3	46,5
Cerianthus lloydii	24	2,6	49,1
Lumbrineris scopa	23	2,5	51,6
Spiophanes bombyx	23	2,5	54,1

JOT10	No. of ind.	%	Cum %
Paramphinome jeffreysii	137	16,5	16,5
Thyasira equalis	83	10,0	26,5
Thyasira croulinensis	52	6,3	32,8
Diplocirrus glaucus	44	5,3	38,1
Laonice sarsi	42	5,1	43,2
Amphiura chiajei	32	3,9	47,0
Prionospio cirrifera	32	3,9	50,9
Lanice conchilega	23	2,8	53,7
Spiophanes bombyx	23	2,8	56,5
Cerianthus lloydii	21	2,5	59,0

Table 13.12. Number of individuals and relative abundance for the ten predominant taxa at each site at the Jotun field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

JOT11	No. of ind.	%	Cum %
Paramphinome jeffreysii	112	12,2	12,2
Thyasira equalis	66	7,2	19,4
Diplocirrus glaucus	52	5,7	25,1
Lanice conchilega	52	5,7	30,8
Laonice sarsi	51	5,6	36,4
Thyasira croulinensis	50	5,5	41,8
Amphiura chiajei	40	4,4	46,2
Aricidea catherinae	31	3,4	49,6
Spiophanes bombyx	28	3,1	52,6
Lumbrineris scopa	26	2,8	55,5

JOT12	No. of ind.	%	Cum %
Paramphinome jeffreysii	158	14,5	14,5
Lanice conchilega	70	6,4	20,9
Thyasira equalis	58	5,3	26,2
Laonice sarsi	56	5,1	31,3
Diplocirrus glaucus	50	4,6	35,9
Thyasira croulinensis	47	4,3	40,2
Myriochele oculata	38	3,5	43,7
Prionospio cirrifera	35	3,2	46,9
Amphiura chiajei	32	2,9	49,8
Aricidea catherinae	30	2,7	52,6

JOT13	No. of ind.	%	Cum %
Paramphinome jeffreysii	134	13,3	13,3
Lanice conchilega	70	7,0	20,3
Thyasira equalis	60	6,0	26,2
Diplocirrus glaucus	55	5,5	31,7
Thyasira croulinensis	51	5,1	36,8
Amphiura chiajei	40	4,0	40,8
Laonice sarsi	38	3,8	44,5
Spiophanes bombyx	33	3,3	47,8
Lumbrineris scopa	32	3,2	51,0
Prionospio cirrifera	30	3,0	54,0

JOT14	No. of ind.	%	Cum %
Paramphinome jeffreysii	114	14,4	14,4
Lanice conchilega	55	6,9	21,3
Amphiura chiajei	39	4,9	26,2
Thyasira croulinensis	38	4,8	31,0
Thyasira equalis	37	4,7	35,6
Diplocirrus glaucus	34	4,3	39,9
Lumbrineris scopa	32	4,0	44,0
Laonice sarsi	29	3,7	47,6
Prionospio cirrifera	28	3,5	51,1
Myriochele oculata	27	3,4	54,5

JOT15	No. of ind.	%	Cum %
Paramphinome jeffreysii	161	17,7	17,7
Thyasira equalis	83	9,1	26,9
Lanice conchilega	61	6,7	33,6
Thyasira croulinensis	44	4,8	38,4
Laonice sarsi	38	4,2	42,6
Amphiura chiajei	31	3,4	46,0
Diplocirrus glaucus	29	3,2	49,2
Asteroidea indet.	29	3,2	52,4
Myriochele oculata	27	3,0	55,4
Aricidea catherinae	22	2,4	57,8

JOT30R	No. of ind.	%	Cum %
Lanice conchilega	189	10,7	10,7
Paramphinome jeffreysii	180	10,2	20,8
Thyasira croulinensis	121	6,8	27,7
Thyasira equalis	88	5,0	32,7
Laonice sarsi	76	4,3	36,9
Diplocirrus glaucus	67	3,8	40,7
Myriochele oculata	60	3,4	44,1
Amphiura chiajei	55	3,1	47,2
Prionospio cirrifera	45	2,5	49,8
Aricidea catherinae	39	2,2	52,0
Cerianthus lloydii	39	2,2	54,2

14 Heimdal

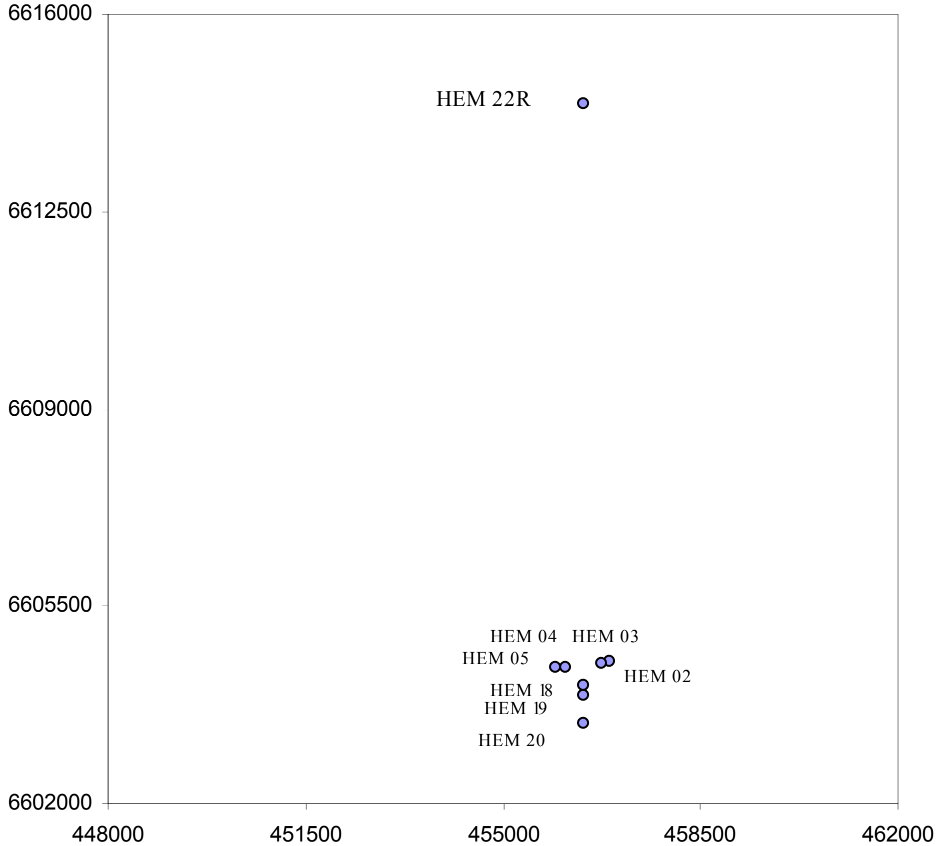
14.1. Introduction

The Heimdal field is situated in block 25/4. Production started at Heimdal in December 1985. The field was surveyed in the regional surveys of both 1997 and 2000. In 1997, all sampling sites were contaminated by THC, barium, zinc, cadmium and copper, and elevated levels of lead were found at sites 250 m from the installation in two directions. The bottom fauna was also disturbed at these sites. In 2000, slight THC, barium, copper, zinc and lead contamination of the sediments and disturbance of the fauna were detected out to 500 m to the south (HEM18 and HEM19), and 250 m to the north west (HEM04). Due to operations related to the production, only HEM18, HEM19 and HEM22R are precisely located at the same positions as in previous surveys. Recent discharges at Heimdal are listed in Table 14.1, and sampling sites are shown in Figure 14.1. See Figure 14.16 at the end of this chapter for illustration of deviation in planned and real sampling.

Table 14.1. Recent well drilling and discharges (m^3) from operations and accidents at Heimdal.

	1999	2000	2001	2002	2003 1. half year	Comments
No of wells drilled	n.a	0	0	0	0	
Barite	n.a	n.a	n.a	n.a	n.a	
Cuttings	n.a	n.a	n.a	n.a	n.a	
Water-based drilling mud	n.a	n.a	n.a	n.a	n.a	
Cementing chemicals	n.a	n.a	n.a	n.a	n.a	
Completion chemicals	n.a	n.a	n.a	n.a	n.a	
Oil in produced water	n.a	n.a	n.a	n.a	n.a	
Accidental discharges	0.06	n.a	n.a	n.a	n.a.	

n.a. = Not available



Site	ED50 UTM Zone 31 E	N	Distance (m) / direction (º)	Depth (m)
HEM-02	456913	6604531	500/75	120
HEM-03	456749	6604487	330/75	120
HEM-04	456110	6604401	320/270	122
HEM-05	455930	6604401	500/270	121
HEM-18	456430	6604101	300/180	123
HEM-19	456430	6603901	500/180	123
HEM-20	456430	6603401	1000/180	123
HEM-22R	456430	6614401	10000/360	121

Figure 14.1. Map showing the internal distribution of sampling sites in Heimdal, 2003. Positioning according to UTM ED50 zone 31.

14.2. Results and discussion

14.2.1 Sediments characteristics

TOM, and the amount (%) of gravel, sand, pelite, median (Φ), sorting, skewness and kurtosis in the sediment from the present survey are presented in Table 14.2. Additional information on colour and smell can be found in the Appendix. Median (Φ), pelite, sand and TOM are compared with data from 2000 in Figure 14.2.

The sediments at Heimdal are classified as fine sand and silt with median (Φ) values ranging from 2.78 (HEM05) to 3.17 (HEM20). The amount of pelite varied from 12 % (HEM02) to 15.9 % (HEM20), the sand varied from 84.1 % (HEM20) to 87.9 % (HEM02), and the TOM varied from 1.3 % (HEM03) to 1.8 % (HEM04). There was more pelite at the reference site (HEM22R) than at the field sites.

Table 14.2. Total organic matter and sediment grain size at all sites at Heimdal in 2003. For comparison averages, standard deviations, max and min values for the regional and reference sites are included.

Sites	TOM %	Gravel %	Sand %	Pelite %	Median (Φ)	Sorting	Skewness	Kurtosis
HEM02	1.51	0.09	87.91	11.99	2.87	1.20	0.26	1.58
HEM03	1.33	0.11	86.95	12.94	2.92	1.24	0.22	1.56
HEM04	1.83	0.03	84.68	15.29	2.84	1.21	0.40	1.61
HEM05	1.50	0.03	87.66	12.30	2.78	1.07	0.47	1.58
HEM18	1.77	0.16	86.38	13.45	3.08	1.33	0.05	1.46
HEM19	1.38	0.03	86.32	13.65	3.07	1.26	0.12	1.55
HEM20	1.68	0.02	84.07	15.91	3.17	1.27	0.12	1.64
HEM22R	1.66	0.02	83.99	15.99	2.93	1.16	0.42	1.52
Average[1]	1.57	0.07	86.28	13.65	2.96	1.22	0.24	1.57
SD[1]	0.19	0.05	1.44	1.46	0.15	0.08	0.15	0.05
Min[1]	1.33	0.02	84.07	11.99	2.78	1.07	0.05	1.46
Max[1]	1.83	0.16	87.91	15.91	3.17	1.33	0.47	1.64
Average[2]	1.71	0.29	87.23	12.49	2.71	1.16	0.34	1.76
SD[2]	0.45	0.62	5.20	5.12	0.37	0.14	0.19	0.46
Min[2]	0.73	0.00	78.12	3.04	1.76	0.93	0.03	1.05
Max[2]	2.19	2.19	96.61	21.77	3.34	1.40	0.57	2.95

[1] Field sites, exclusive HEM22R
[2] Reg + Ref $_{\text{central 03}}$

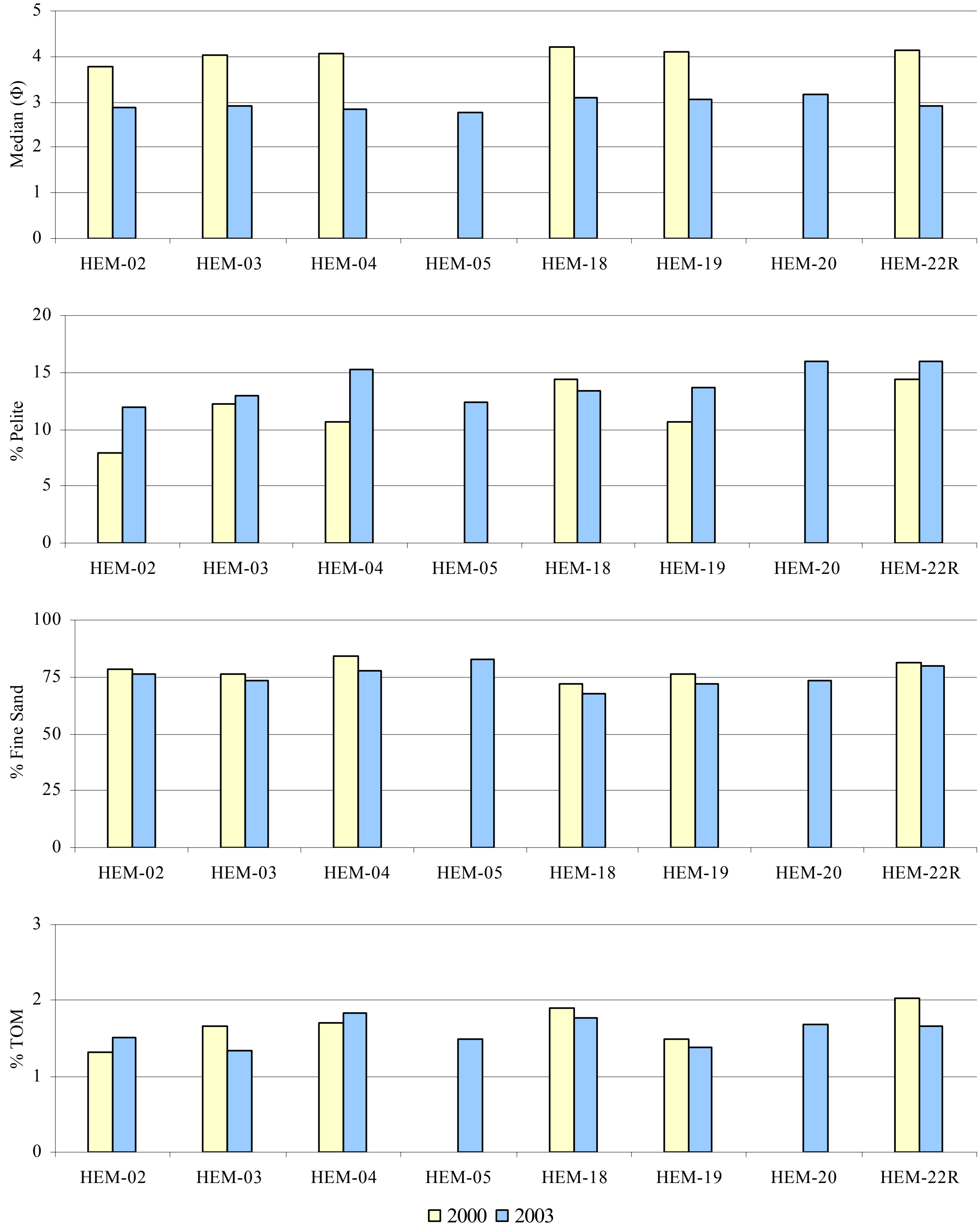


Figure 14.2. Sediment characteristics at Heimdal in 2000 and 2003. Fine sand is the relative amount of sand with grain size 63-250 µm.

14.2.2 Chemical compounds

14.2.2.1 LSC

The results of the LSC (limits of significant contamination) calculations of hydrocarbons and metals are presented in the chapter concerning the regional and reference sites. Both the $LSC_{central\ 97\text{-}03}$ and the field specific LSC value ($LSC_{HEM22R\ 03}$) are presented in Table 14.3. Fine sediments are more likely to have higher affinity for pollutants than coarse sediments. Thus the field specific LSC value should perhaps be disregarded due to slightly higher content of fine sediments at the reference site compared to the field sites. LSC in the text relates to $LSC_{central\ 97\text{-}03}$.

Table 14.3. Limits of Significant Contamination (LSC) for the Heimdal field in 2003, and for the central part of Region II based on data from 1997 to 2003 ($LSC_{central\ 97\text{-}03}$) and the whole of Region II based on data from 1997 to 2003 ($LSC_{regII\ 97\text{-}03}$). For comparison, LSC-values from 2000 are included. All values in mg/kg dry sediment.

	THC	PAH (16)	NPD's	Decalins	Cu	Cr	Zn	Ba	Pb	Cd	Hg
$LSC_{03\ HEM22R}$	15.7	0.079	0.020	0.409	1.9	8.3	10.7	118	4.6	0.05	0.009
$LSC_{central\ 97\text{-}03}$	14.5	*	*	*	2.2	9.4	12.4	161	6.8	0.03[1]	0.012
$LSC_{regII\ 97\text{-}03}$	13.3	*	*	*	2.0	9.4	11.1	136	6.6	0.03[1]	0.011
$LSC_{00\ HEM22R}$**	11.9	*	0.07	0.187	2.5	7.9	9.5	178	6.9	0.03	0.008
$LSC_{regII\ 97\text{-}00}$**	9.8	*	*	*	2.0	9.6	8.9	146	7.0	0.03	0.008

* NPD's, PAH's and decalins are not analysed at regional sites in 1997 and 2000
** Data from Mannvik & al. 2001
[1] LSC = detection limit

14.2.2.2 Hydrocarbons

Summarised results of the hydrocarbon analyses, along with the content of selected hydrocarbon compounds in the different layers (0-1, 1-3 and 3-6) are given in Table 14.4 and Table 14.5. The complete data set including replicates is given in the Appendix. Comparison of the THC content in 2003 with previous surveys is presented in Figure 14.3.

THC was found in the range from 4.2 to 10.1 mg/kg, and THC concentrations above LSC were not found in sediments from at any sampling site. Highest THC concentrations were found at HEM04 at 270 m to the west of the field centre. In general there was lower THC content in the sediments in 2003 than in 2000.

Vertical sediment samples (0-1, 1-3 and 3-6 cm) were contaminated by NPD in all layers both at HEM18 (250 m to the south) and at HEM19 (500 m to the south). In the same samples PAH contamination was found in the 0-1 and 1-3 cm layers at HEM18 and in the 1-3 and 3-6 cm layers at HEM19, whereas only the 0-1 cm layer at HEM18 was contaminated by decalins. There was a tendency of increasing concentrations of oil hydrocarbons with increasing depth in the sediment at HEM18, whereas the hydrocarbons in the sediments at HEM19 had a more uniform distribution. No vertical sediment samples were contaminated by THC.

Table 14.4. The content of oil hydrocarbons in sediments from Heimdal in 2003. All values in mg/kg dry sediment. THC values above $LSC_{central\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{HEM22R\ 03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data for the regional and field reference sites in the central part of region II are included.

Site	THC		PAH(16)		NPD		Dekalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
HEM02	4.2	2.7	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
HEM03	8.1	2.9	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
HEM04	10.1	2.7	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
HEM05	9.8	7.0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
HEM18	9.9	3.1	0.105	0.046	0.106	0.128	0.353	0.145
HEM19	8.5	1.7	0.067	0.008	0.023	0.004	0.513	0.508
HEM20	4.4	0.4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
HEM22R	6.8	3.8	0.061	0.008	0.018	0.001	0.237	0.074
av. ± sd.[1]	7.8 ± 2.5							
min – max[1]	4.2 - 10.1							
av. ± sd.[2]	11.2±4.0		0.067±0.027		0.020±0.004		0.232±0.085	
min – max[2]	<3.0-15.5		0.013-0.102		0.012-0.027		0.095-0.461	

n.a. = not analysed.
[1] Field sites, exclusive HEM22R
[2] Reg + Ref $_{central\ 03}$

Table 14.5. The content of oil hydrocarbons in vertical sections of sediment from 3 sampling sites at Heimdal May 2003. All values in mg/kg dry sediment. THC values above $LSC_{central\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{HEM22R\ 03}$ are dark shaded.

Site	Layer (cm)	THC	PAH(16)	NPD	Decalins
HEM18	0-1	13.4	0.152	0.253	0.520
HEM18	1-3	6.5	0.083	0.037	0.320
HEM18	3-6	5.8	0.074	0.034	0.270
HEM19	0-1	9.5	0.076	0.027	0.205
HEM19	1-3	7.7	0.088	0.026	0.360
HEM19	3-6	3.6	0.095	0.026	0.185
HEM22R	0-1	<3.0	0.061	0.018	0.155
HEM22R	1-3	4.1	0.057	0.018	0.235
HEM22R	3-6	<3.0	0.061	0.018	0.145

14.2.2.3 Metals

Table 14.6 summarises the results of the metal analyses of the Heimdal field in 2003. Concentrations of selected metals in the different layers (0-1, 1-3 and 3-6) of sediment are given in Table 14.7, whereas the complete data set including replicates is given in the Appendix. Comparisons of the metal contents in 2003 with the metal contents in 1997 and in 2000 are presented in Figure 14.6.

Table 14.6 Content of metals in sediments from Heimdal in 2003. All values in mg/kg dry sediment. Values above $LSC_{central\ 97\text{-}03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data in the regional and field reference sites in the central part of the region II are included.

Site	Cu		Cr		Zn		Ba		Pb		Cd		Hg	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
HEM02	1.2	0.1	5.4	0.3	9.2	1.5	91	4	3.8	0.4	<0.03	-	n.a.	n.a.
HEM03	2.4	0.2	5.8	0.4	10.2	0.9	108	30	4.4	0.4	<0.03	0.009	n.a.	n.a.
HEM04	2.2	0.3	6.6	0.6	13.1	0.6	231	54	5.6	0.4	<0.03	-	n.a.	n.a.
HEM05	1.5	0.2	5.7	0.6	9.1	0.7	131	17	4.4	0.3	<0.03	0.020	n.a.	n.a.
HEM18	8.8	1.7	8.2	0.1	42.3	8.1	315	55	11.2	1.6	0.04	0.023	0.008	0.001
HEM19	1.9	0.5	6.2	0.5	12.4	2.3	149	5	3.8	0.5	<0.03	-	0.006	0.001
HEM20	1.4	0.3	5.6	0.7	10.1	1.8	102	21	3.8	0.5	<0.03	-	n.a.	n.a.
HEM22R	1.4	0.2	6.5	0.8	8.5	0.9	74	19	3.7	0.4	<0.03	0.012	0.007	0.001
av. ± sd.[1]	2.8 ± 2.7		6.5 ± 1.0		15.2 ± 12.0		161 ± 83		5.3 ± 2.7		<0.03			
min - max[1]	1.2 - 8.8		5.4 - 8.2		9.1 - 42.3		91 - 315		3.8 - 11.2		<0.03 – 0.04			
av. ± sd.[2]	1.2 ± 0.4		6.9 ± 1.2		9.4 ± 1.3		66 ± 31		4.2 ± 0.6		<0.03		0.009±0.003	
min - max[2]	<0.6-1.7		4.9-8.9		6.8-12.0		10-146		3.4-5.1		<0.03		0.006-0.014	

n.a. = not analysed.
[1] Field sites, exclusive HEM22R
[2] Reg + Ref $_{central\ 03}$

Table 14.7. The content of metals in vertical sections of sediment from 3 sampling sites at Heimdal in May 2003. All values in mg/kg dry sediment. Values above $LSC_{central\ 97\text{-}03}$ are dark shaded.

Site	Layer (cm)	Cu	Cr	Zn	Ba	Pb	Cd	Hg
HEM18	0-1	8.8	8.2	37.8	289	10.1	0.04	0.007
HEM18	1-3	7.2	7.4	47.2	336	9.2	<0.03	0.007
HEM18	3-6	6.4	7.8	45.3	353	10.2	0.06	0.008
HEM19	0-1	1.9	6.1	13.3	152	4.0	<0.03	0.006
HEM19	1-3	1.8	6.4	11.8	170	4.0	<0.03	0.006
HEM19	3-6	1.9	7.2	17.6	186	4.7	<0.03	0.007
HEM22R	0-1	1.3	6.1	8.3	73	3.8	<0.03	0.007
HEM22R	1-3	1.5	6.4	9.1	87	3.9	0.04	0.008
HEM22R	3-6	1.5	6.9	8.9	93	4.4	0.03	0.007

Barium was found in a range from 91 to 315 mg/kg, lead from 3.8 to 11.2 mg/kg, cadmium from <0.03 to 0.04 mg/kg, copper from 1.2 to 8.8 mg/kg, mercury from 0.006 to 0.008 mg/kg, chromium from 5.4 to 8.2 mg/kg and zinc from 9.1 to 42.3 mg/kg (Table 14.6). Sediments from HEM04 and HEM18 had barium and zinc content above LSC. Copper was present above LSC at HEM03 and HEM18, and lead and cadmium were present above LSC at HEM18. Chrome and mercury were below LSC at all sites.

Compared to previous surveys the levels of metals were lower or at the same levels as before (Figure 14.6).

Vertical sediment samples (0-1, 1-3 and 3-6 cm) from HEM18 had barium, lead, copper and zinc content above LSC in all depth intervals, and cadmium was found above LSC in the 0-1 and 3-6 cm intervals. At HEM19 barium was present above LSC in 1-3 and 3-6 cm intervals and zinc in the 0-1 and 3-6 cm intervals. Cadmium was above LSC in the 1-3 cm interval at the reference site, HEM22R. The latter might be du to finer sediment at the reference site than at the other sites.

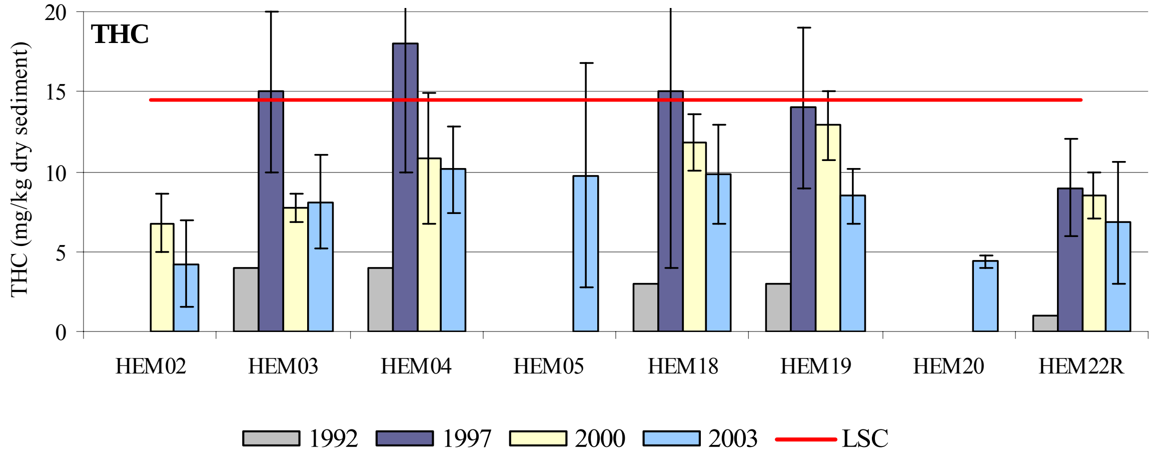


Figure 14.3. Average THC concentrations and standard deviations in sediments from Heimdal in 2003 and previous years. Red line is $LSC_{central\ 97\text{-}03}$.

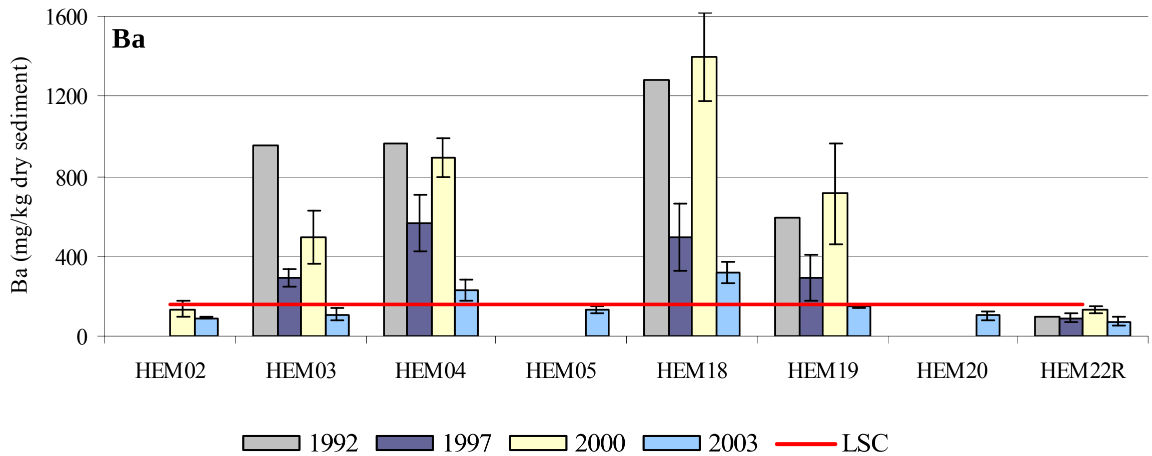


Figure 14.4. Average barium concentrations and standard deviations in sediments from Heimdal in 2003 and previous years. Red line is $LSC_{central\ 97\text{-}03}$.

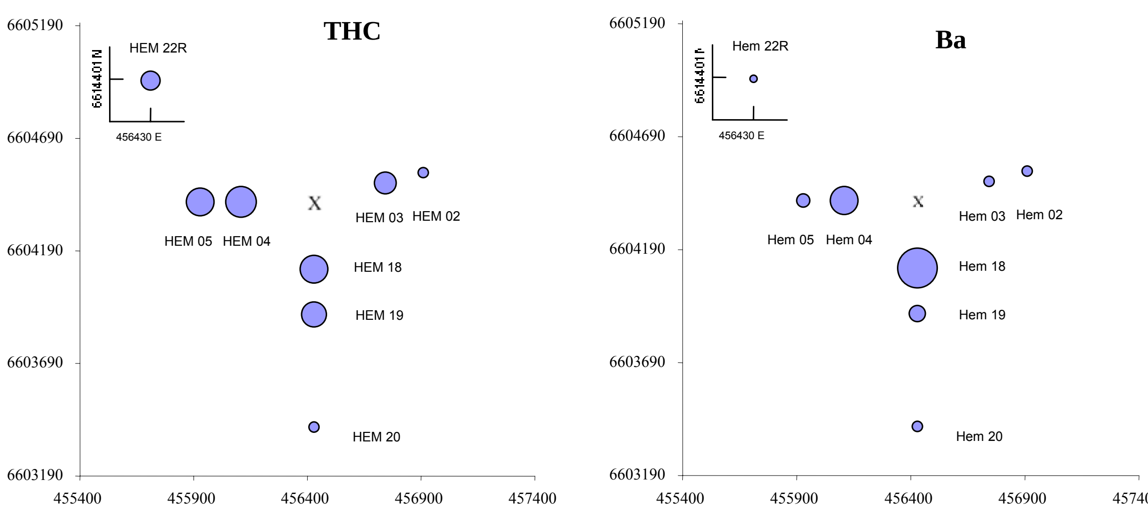


Figure 14.5. Distribution of THC and barium in sediments at the sampling sites at Heimdal in 2003. The size of the circle indicates the amount of THC and Ba. The field centre is marked with an X.

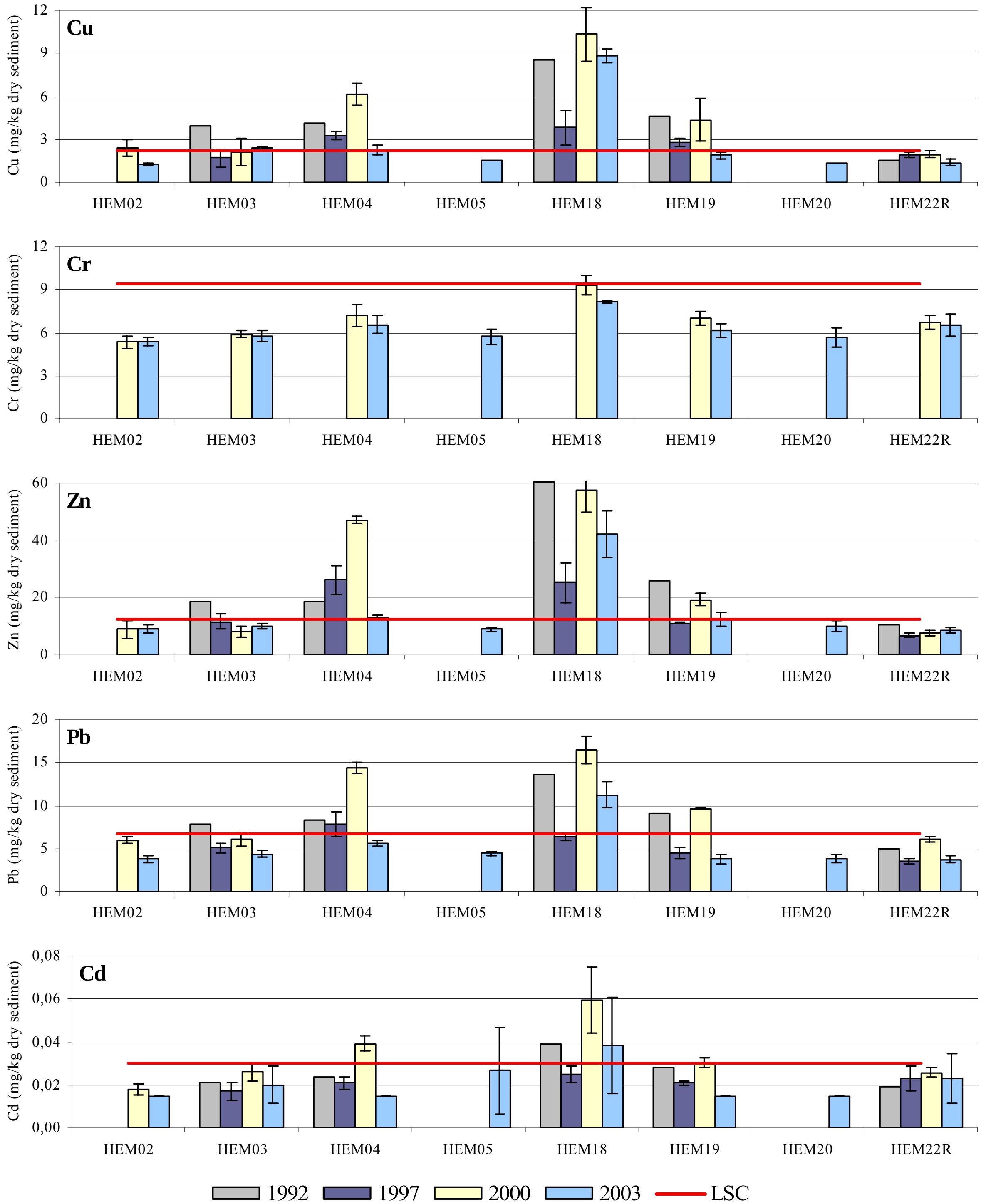


Figure 14.6. Average content and standard deviations of metals in sediment from Heimdal in 2003 and previous surveys. Red line is $LSC_{central\ 97\text{-}03}$.

The field sites at Heimdal were compared to nearby regional sites (RII03, RII10, VA14R and FRY18R) based on sediment characteristics (TOM and pelite) and chemical content in the sediments (Figure 14.7). Most of the sampling sites at Heimdal grouped particularly well, indicating homogeneity within the field sampling sites. However, HEM18 and partly HEM04 did not group with the other sites. This was due to higher content of chemical compounds in the sediments at these sites than at the other sites.

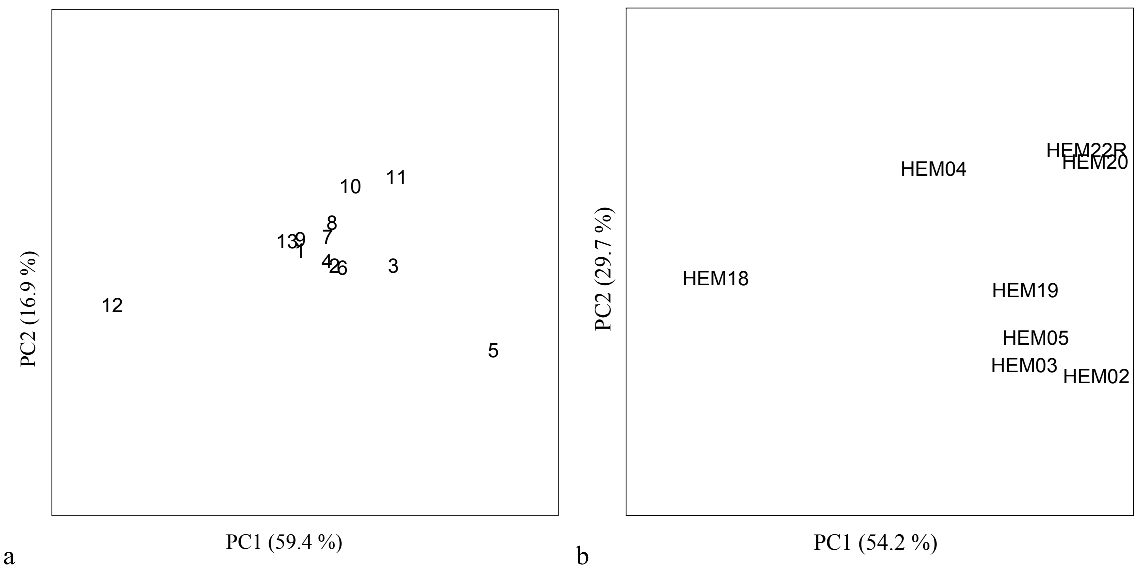


Figure 14.7. 2-D plot from the PCA analysis of environmental variables (% pelite, % sand, % gravel, median Φ, TOM, Cu, Ba, Zn, Cr, Pb and THC) carried out on:

a) Heimdal field stations compared to the reference site at Jotun, Vale and Frøy and regional site RII03 and RII10. Explained variation in the data 76.3 %. Numbers in the plot identify the sampling sites. See table below.
b) Heimdal field stations. Explained variation in the data 83.9 %

1	HEM02	5	HEM18	9	RII03
2	HEM03	6	HEM19	10	RII10
3	HEM04	7	HEM20	11	JOT30R
4	HEM05	8	HEM22R	12	VA13R
				13	FRY18R

14.2.3 Bottom fauna

A summary of the distribution of individuals and taxa within the main taxonomic groups is given in Table 14.8. Unidentified juveniles of the sea urchins Spatangoids (17452 individuals) and Echinoides (2834 individuals) are omitted from the analyses, as they occurred in extremely high numbers. In total, 10674 individuals within 271 taxa were collected at Heimdal in 2003. The fauna was numerically dominated by annelida with 53 % the individuals and 49 % of the taxa. A complete species list is available in the Appendix.

Table 14.8. Distribution of individuals and taxa within the main taxonomic groups at Heimdal in May 2003 including data from HEM22R (unidentified juveniles of Spatangoida and Echinoidea are not included).

Main taxonomic groups	**Number of individuals**	**%**	**Number of taxa**	**%**
Annelida	5686	53	134	49
Arthropoda	973	9	58	21
Mollusca	1729	16	50	18
Echidermata	943	9	16	6
Diverse groups	1343	13	13	5
Total	10674	100	271	100

The species/area curve for HEM22R indicates that five replicate samples give a representative impression of the bottom fauna in the area (Figure 14.8). However, as more area is sampled, more taxa are collected, indicating that not even 10 replicate samples give the full species assemblage of the area.

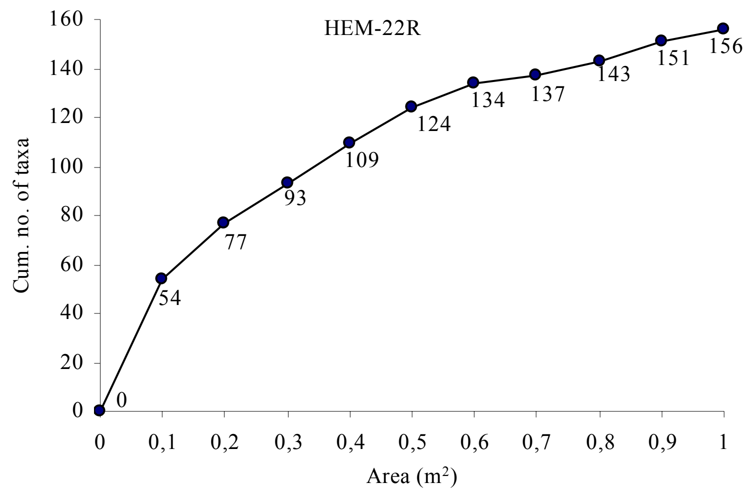


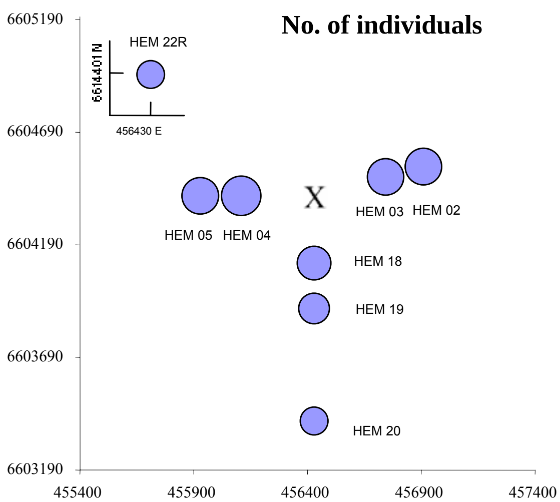
Figure 14.8. Species/area curve for the reference station at the Heimdal field. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

The distribution of individuals and taxa are shown in Figure 14.9. Number of individuals and taxa at each site, and the calculated diversity indexes (H' and ES_{100}) are given in Table 14.9 and Figure 14.10. The number of individuals varied from 1067 (HEM20) to 1398 (HEM04), and the number of taxa varied from 121 (HEM20) to 146 (HEM05). The Shannon-Wiener diversity index (H') varied from 5.59 (HEM18) to 5.85 (HEM05), whereas the ES_{100} index varied from 42.95 (HEM02) to 46.50 (HEM03). The evenness index J varied from 0.78 (HEM02) to 0.82 (HEM03 and HEN20). The corresponding values at HEM22R are within or near the variation at the field sites. The number of taxa, diversity and evenness indicate good environmental conditions at all sites.

Table 14.9. Number of individuals, species/taxa and selected community indices for each station (0.5 m^2) at the Heimdal field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

Site number	Number of individuals	Number of taxa	Diversity H'	Evenness J	H'-max	ES_{100}
HEM02	1279	146	5.63	0.78	7.19	43.0
HEM03	1270	141	5.83	0.82	7.14	46.5
HEM04	1398	142	5.69	0.80	7.15	44.3
HEM05	1281	146	5.85	0.81	7.19	46.0
HEM18	1258	122	5.59	0.81	6.93	43.2
HEM19	1143	127	5.65	0.81	6.99	44.5
HEM20	1067	121	5.69	0.82	6.92	44.9
HEM22R (6-10)	990	124	5.73	0.82	6.95	45.1
HEM22R (11-15)	988	125	5.78	0.83	6.97	46.2
HEM22R (6-15)	1978	156	5.84	0.80	7.29	45.9
Sum[1]	8696	260				
Average[1]	1242	135	5.70	0.81	7.07	44.6
SD[1]	107	11	0.10	0.01	0.12	1.3
Min[1]	1067	121	5.59	0.78	6.92	43.0
Max[1]	1398	146	5.85	0.82	7.19	46.5
Average[2]	774	113	5.55	0.81	6.81	44.3
SD[2]	230	14	0.24	0.02	0.18	2.6
Min[2]	488	94	5.12	0.79	6.55	38.7
Max[2]	1202	141	5.85	0.85	7.14	47.9

[1]Field sites, exclusive HEM22R
[2]Reg + Ref $_{central\ 03}$



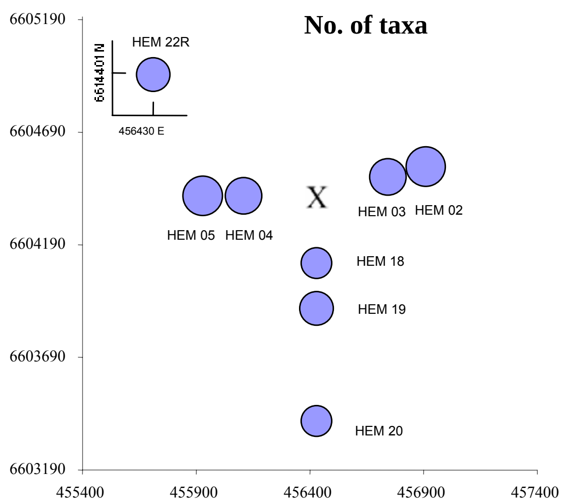


Figure 14.9. Distribution of bottom fauna (individuals and taxa) among the sampling sites in 2003. The size of the circle indicates the number of individuals and taxa. Exclusive unidentified juveniles of Spatangoida and Echinoidae. Values for HEM22R are average of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2). The field centre is marked with an X.

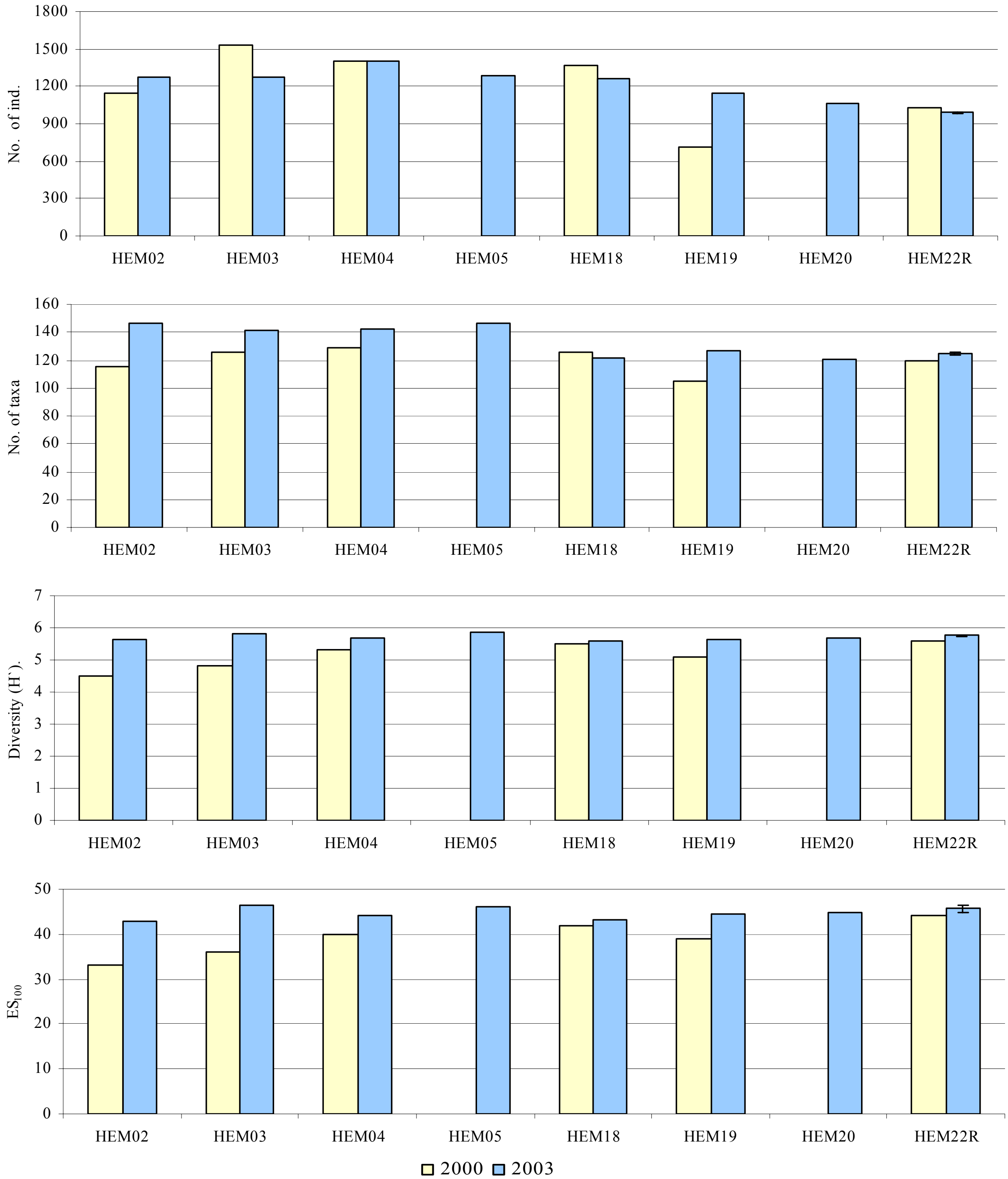


Figure 14.10. Number of individuals, taxa and selected community indices for each site (0.5 m^2) at the Heimdal field for 2000 and 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea in 2003. Values for HEM22R are average ± standard deviation of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2).

Distribution of taxa in geometrical classes is presented in Figure 14.11. The smooth graphs representing HEM22R and HEM20 are textbook examples of undisturbed bottom fauna, whereas the other graphs also indicate undisturbed bottom fauna.

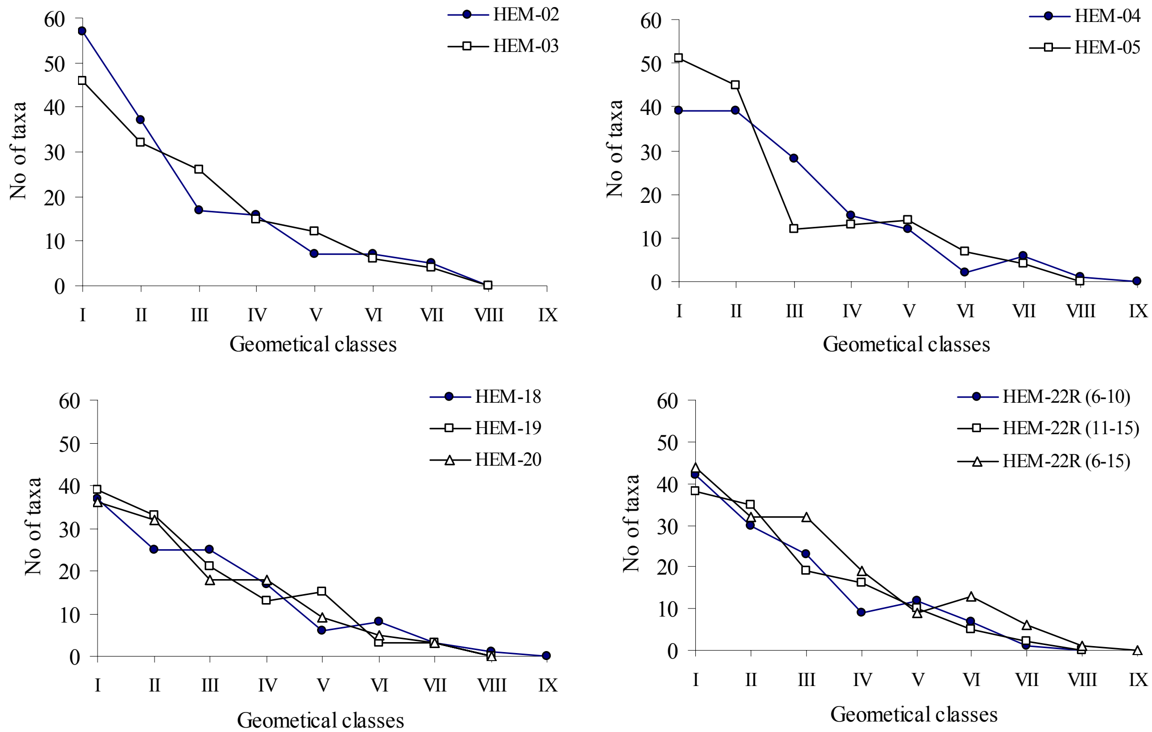


Figure 14.11. Distribution of taxa in geometrical classes for the sites at Heimdal in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

The ten most numerous taxa are listed in Table 14.12 at the end of this chapter. The list comprise 22 taxa and 6743 individuals, which was 8.1 % of all (271) taxa and 63.2 % of all (10674) individuals. Different taxa where dominating at different sites, indicating local environmental variation. The high numbers of the polychaete *Chaetozone setosa* at HEM18 indicate some negative disturbance. However, the presence of other species like the brittle stars *Amphiura filiformis* and *Amphiura chiajei*, are mitigating this impression. The taxa assemblage indicates good environmental conditions at the other sites.

The results of the multivariate analyses are given in the dendrogramme (Figure 14.12) and the MDS plott (Figure 14.13).

In the cluster analysis, all sites are grouped together within 63 % similarity, indicating relatively high similarity in the species assemblages within the field. The species assemblages at HEM22R and HEM20 were the most similar (73 %), whereas those at HEM18 and HEM19 were somewhat different from those at the other sites.

The results of the MDS analysis support the findings in the cluster analysis, confirming the similarity in species assemblage at HEM22R and HEM20, and that HEM18 and HEM19 are different from the other sites. HEM02, HEM03, HEM04 and HEM05 are shown comprise a middle group. The stress test of the MDS analysis was 0.11, indicating a good fit of the data.

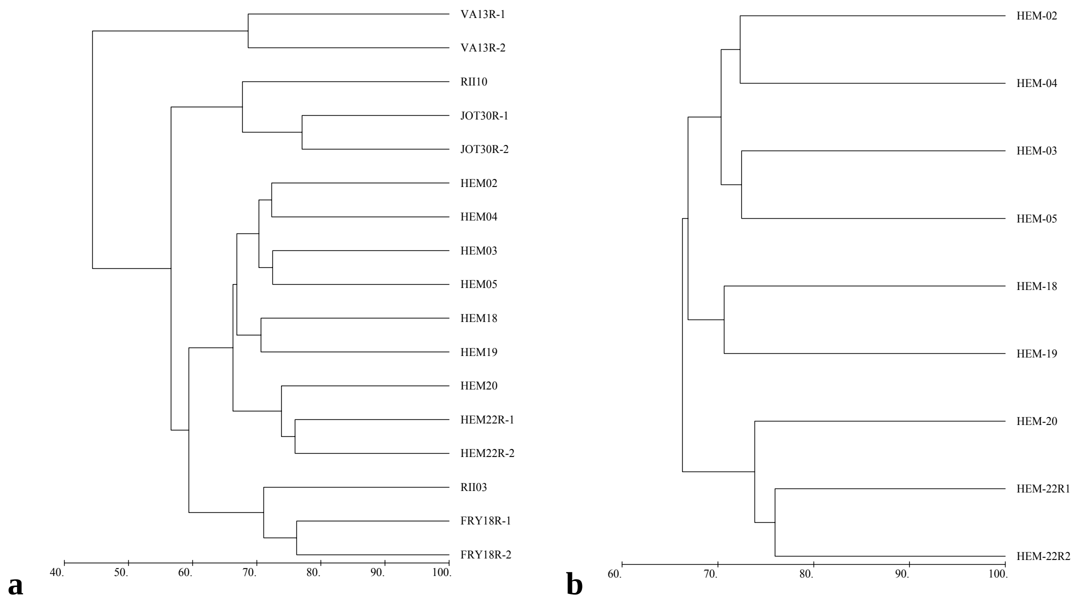


Figure 14.12. Dendrogram showing the similarity between fauna from sampling sites at:

a) Sampling sites at Heimdal compared to some regional sites (RII03 and RII10) and reference sites (JOT30R, VA13R and FRY18R) in 2003.

b) Sampling sites at Heimdal in 2003.

Exclusive unidentified juveniles of Spatangoida and Echinoidea.

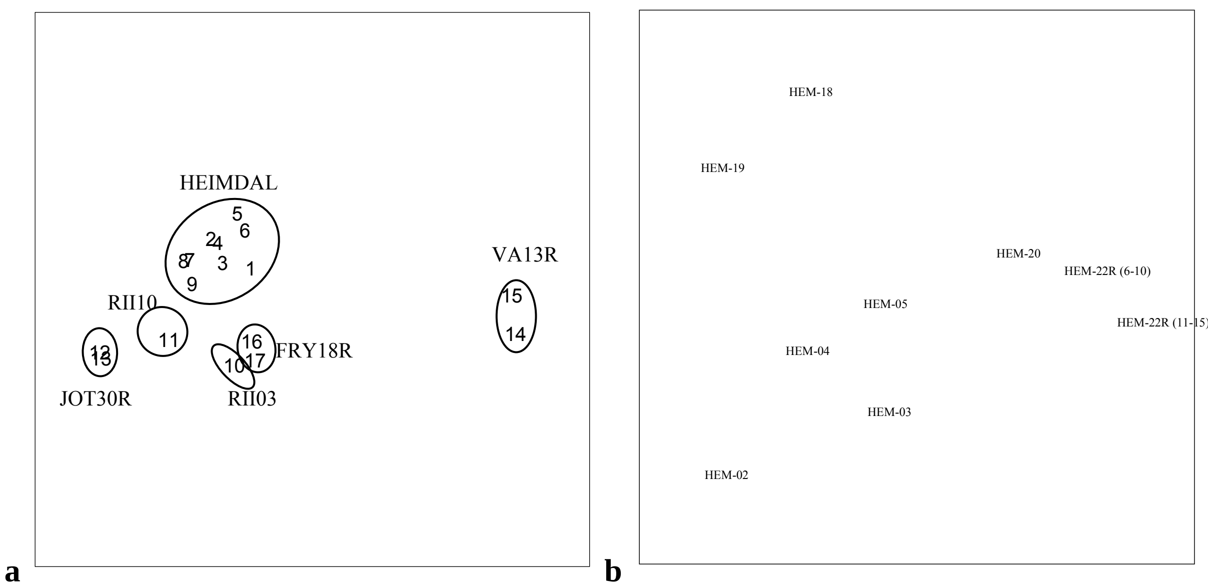


Figure 14.13. A 2-dimetional plott of the MDS analysis of the fauna data from:

a) Sampling sites at Heimdal and some regional sites (RII03 and RII10) and reference sites (JOT30R, VA13R and FRY18R) in 2003. Stress = 0.07. Numbers in the plot identify the sampling sites. See table below.

b) Sampling sites at Heimdal in 2003. Stress = 0.10.

Exclusive unidentified juveniles of Spatangoida and Echinoidea.

1	HEM02	4	HEM05	7	HEM20	10	RII03	13	JOT30R-2	16	FRY18R-1
2	HEM03	5	HEM18	8	HEM22R-1	11	RII10	14	VA13R-1	17	FRY18R-2
3	HEM04	6	HEM19	9	HEM22R-2	12	JOT30R-1	15	VA13R-2		

Linking of biotic and environmental variables by BIOENV revealed that the sand and barium content in the sediments were best correlated to the biota at $\rho_w = 0.53$ (Table 14.10). This indicates that there was an association between some environmental variables and the bottom fauna, and that they to some extend have a mutual distribution.

Table 14.10. Combinations of the 10 environmental variables, taken *k* at a time, yielding the best matches of biotic and abiotic similarity matrices for each *k*, as measured by weighted Spearman rank correlation ρ_w. Bold type indicates overall optimum. All possible combinations of variables and associated correlation to the biotic are given in the Appendix.

Number of variables (*k*)	Correlation coefficient (ρ_w)	Environmental variables									
1	0.412	Pelitt									
1	0.411	Sand									
1	0.368	Gravel									
1	0.262	Cu									
1	0.196	Ba									
1	0.176	Zn									
1	0.148	Cr									
1	0.074	Pb									
1	-0.024	TOM									
1	-0.201	THC									
2	**0.531**	**Ba**	**Sand**								
3	0.525	Ba	Sand	Pelite							
4	0.517	Ba	Sand	Pelite	Gravel						
5	0.499	Ba	Sand	Pelite	Gravel	Zn					
6	0.487	Ba	Sand	Pelite	Gravel		Cu	Cr			
7	0.487	Ba	Sand	Pelite	Gravel	Zn	Cu	Cr			
8	0.470	Ba	Sand	Pelite	Gravel	Zn	Cu	Cr	Pb		
9	0.404	Ba	Sand	Pelite	Gravel	Zn	Cu	Cr	Pb	THC	
10	0.336	Ba	Sand	Pelite	Gravel	Zn	Cu	Cr	Pb	THC	TOM

14.2.4 Estimation of influenced area

The extension of contamination along sampling transects and the minimum area of contaminated sediments for THC, barium and other metals as well as for faunal disturbance is given in Figure 14.15 and Table 14.11. The area contaminated by THC, barium and other metals was smaller in 2003 than in 2000. The area with faunal disturbance was also reduced in 2003 compared to 2000.

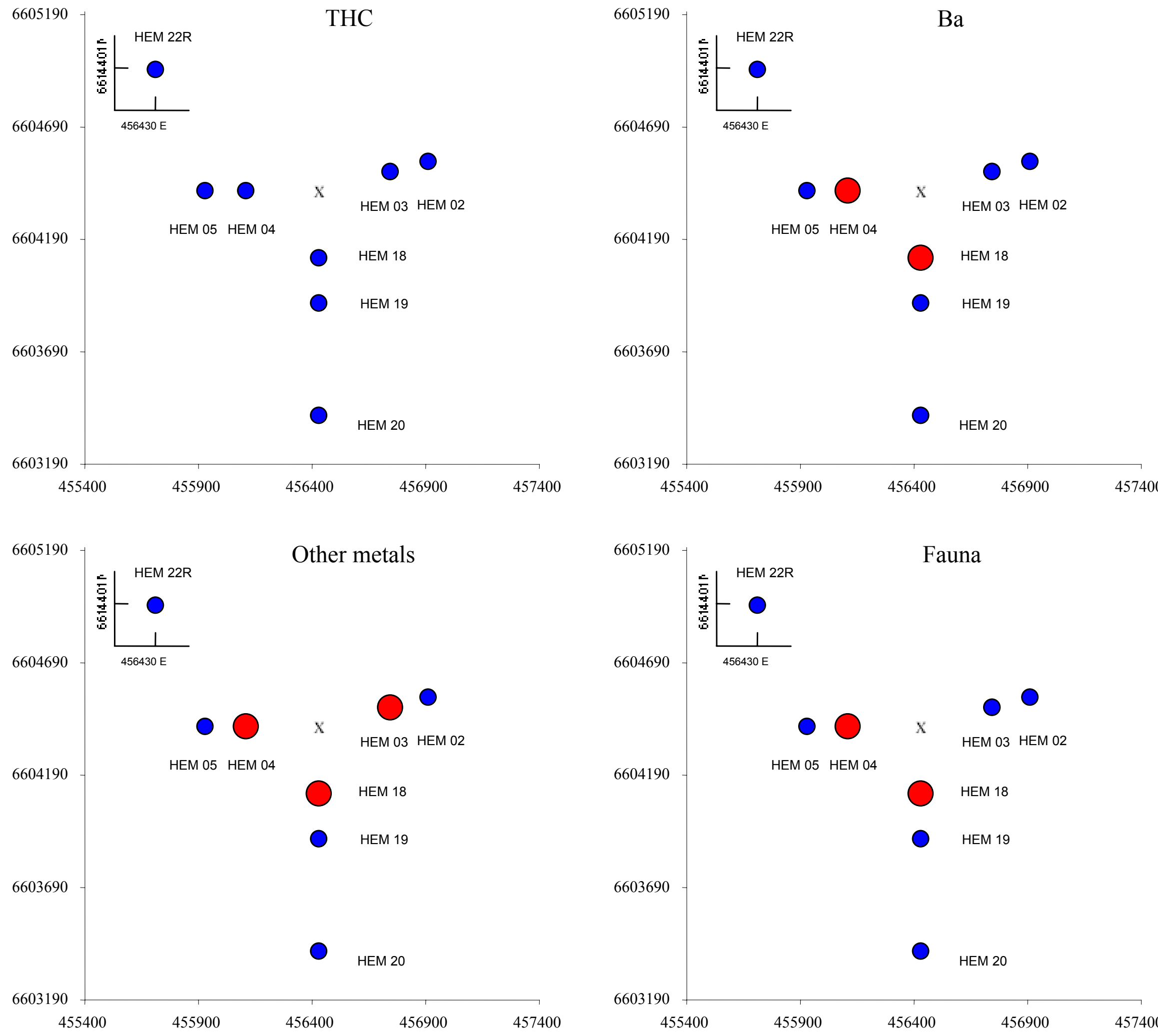


Figure 14.15. Faunal disturbance and chemical contamination of the sediments at Varg in 2003. The field centre are marked with a X. Uncontaminated sites and sites with no faunal disturbance are marked with small blue circles.

Table 14.11. Estimated distance of contamination and faunal disturbance from the installation, and estimated area of contamination and faunal disturbance around the field centre.

Heimdal	N m	E m	S m	W m	2003 km²	2000 km²	1997 km²
THC	-	0	0	0	0.00	0.12	0.25
Ba	-	0	300	320	0.08	0.43	0.25
Other metals	-	330	300	320	0.15	0.29	0.25
Fauna	-	0	500	0	0.05	0.18	0.11

14.3 Summary and conclusions

Since the last survey at Heimdal only one well is drilled. The sediments are still characterized as fine sand, although there has been a slight increase in the pelite content since 2000. The THC content in the sediments was low and generally lower in 2003 than in 2000. THC contamination was not detected in 2003, although elevated levels of PAH, NPDs and decalins were found in samples taken 300 and 500 m to the south (downstream) of the field centre. Also the levels of metals in the sediments were lower in 2003 than in 2000. The sharpest decrease was seen at sites were metals previously occurred in the highest concentrations. Despite this, sediments were still contaminated by barium out to 500 m to the south and out to 270 m to the west, and contamination by other metals were found out to 300 m to the south, and for copper also out to 330 m to the east and 270 m to the west. Species diversity was slightly higher in 2003 than in 2000. Some faunal disturbances were found out to 500 m to the south. The area of contaminated sediments and faunal disturbance was reduced in 2003 compared to the situation in 2000.

Table 14.12. Number of individuals and relative abundance for the ten predominant taxa at each site at the Heimdal field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

HEM-02	No of ind.	%	Cum %
Montacuta substriata	117	9.1	9.1
Cerianthus lloydii	95	7.4	16.6
Lanice conchilega	82	6.4	23.0
Myriochele oculata	78	6.1	29.1
Paramphinome jeffreysii	64	5.0	34.1
Phoronis sp.	55	4.3	38.4
Spiophanes bombyx	52	4.1	42.5
Thyasira croulinensis	52	4.1	46.5
Owenia fusiformis	42	3.3	49.8
Laonice sarsi	36	2.8	52.6
Amphiura filiformis	36	2.8	55.4

HEM-03	No of ind.	%	Cum %
Myriochele oculata	101	8.0	8.0
Cerianthus lloydii	86	6.8	14.7
Phoronis sp.	71	5.6	20.3
Paramphinome jeffreysii	69	5.4	25.7
Spiophanes bombyx	61	4.8	30.6
Thyasira croulinensis	61	4.8	35.4
Lanice conchilega	43	3.4	38.7
Thyasira ferruginea	38	3.0	41.7
Sabellidae indet.	37	2.9	44.6
Laonice sarsi	32	2.5	47.2

HEM-04	No of ind.	%	Cum %
Paramphinome jeffreysii	128	9.2	9.2
Thyasira croulinensis	91	6.5	15.7
Spiophanes bombyx	87	6.2	21.9
Myriochele oculata	86	6.2	28.0
Cerianthus lloydii	83	5.9	34.0
Phoronis sp.	72	5.2	39.1
Thyasira ferruginea	71	5.1	44.2
Laonice sarsi	48	3.4	47.6
Amphiura chiajei	48	3.4	51.1
Prionospio cirrifera	30	2.1	53.2

HEM-05	No of ind.	%	Cum %
Phoronis sp.	83	6.5	6.5
Paramphinome jeffreysii	80	6.2	12.7
Spiophanes bombyx	74	5.8	18.5
Myriochele oculata	64	5.0	23.5
Thyasira flexuosa	62	4.8	28.3
Lanice conchilega	51	4.0	32.3
Thyasira croulinensis	43	3.4	35.7
Laonice sarsi	42	3.3	39.0
Chaetozone setosa	38	3.0	41.9
Cerianthus lloydii	36	2.8	44.7
Thyasira ferruginea	36	2.8	47.5

HEM-18	No of ind.	%	Cum %
Chaetozone setosa	128	10.2	10.2
Cerianthus lloydii	97	7.7	17.9
Spiophanes bombyx	78	6.2	24.1
Phoronis sp.	77	6.1	30.2
Paramphinome jeffreysii	57	4.5	34.7
Eudorella truncatula	45	3.6	38.3
Laonice sarsi	41	3.3	41.6
Glycera lapidum	41	3.3	44.8
Thyasira flexuosa	36	2.9	47.7
Amphiura chiajei	36	2.9	50.6

HEM-19	No of ind.	%	Cum %
Cerianthus lloydii	112	9.8	9.8
Thyasira flexuosa	98	8.6	18.4
Spiophanes bombyx	82	7.2	25.5
Paramphinome jeffreysii	58	5.1	30.6
Phoronis sp.	56	4.9	35.5
Owenia fusiformis	39	3.4	38.9
Harpinia antennaria	30	2.6	41.6
Amphiura filiformis	29	2.5	44.1
Myriochele oculata	28	2.4	46.5
Chaetozone setosa	27	2.4	48.9
Ophiura affinis	27	2.4	51.3

HEM-20	No of ind.	%	Cum %
Paramphinome jeffreysii	92	8.6	8.6
Laonice sarsi	78	7.3	15.9
Amphiura chiajei	76	7.1	23.1
Spiophanes bombyx	51	4.8	27.8
Cerianthus lloydii	50	4.7	32.5
Thyasira croulinensis	47	4.4	36.9
Myriochele oculata	38	3.6	40.5
Thyasira ferruginea	34	3.2	43.7
Lumbrineridae indet.	28	2.6	46.3
Lanice conchilega	25	2.3	48.6
Prionospio cirrifera	25	2.3	51.0

HEM-22R	No of ind.	%	Cum %
Paramphinome jeffreysii	185	9.4	9.4
Thyasira croulinensis	125	6.3	15.7
Spiophanes bombyx	108	5.5	21.1
Lumbrineridae indet.	83	4.2	25.3
Amphiura chiajei	82	4.1	29.5
Cerianthus lloydii	73	3.7	33.2
Phoronis sp.	70	3.5	36.7
Thyasira ferruginea	62	3.1	39.8
Myriochele oculata	56	2.8	42.7
Laonice sarsi	55	2.8	45.4

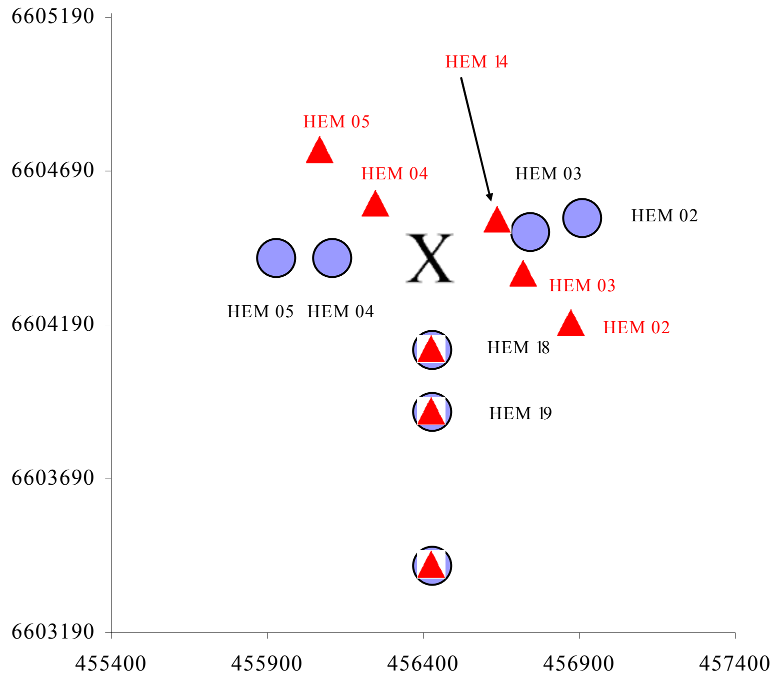


Figure 14.16. Illustration of deviations in planned and real sampling at Heimdal. Location of sampling sites according to the programme, red triangle, and location of the sites where sampling were executed, blue circles.

15 Vale

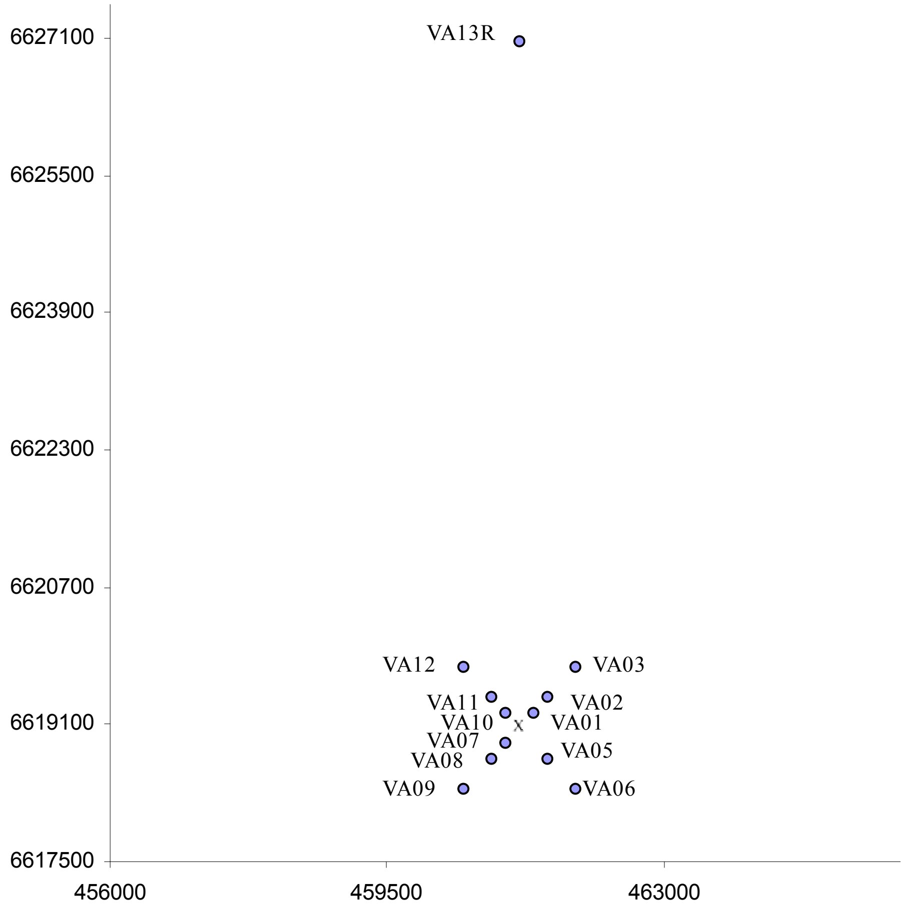
15.1. Introduction

The Vale field is situated in block 25/4. Production started at Vale in May 2002. A baseline survey accomplished in 2001 revealed no faunal disturbanses or elevated levels of hydrocarbons in the sediments. One well was drilled during 2001 and only water based drilling mud was used during the operation. Recent well drilling and discharges at Vale are listed in Table 15.1, and sampling sites are shown in Figure 15.1. Compared to the baseline survey of 2001 the sampling sites are relocated 45°. Thus the sites are not the same as in 2001 although they are labelled with similar codes. See Figure 15.15 at the end of this chapter for illustration of deviation in planned and real sampling.

Table 15.1. Recent well drilling and discharges (ton) from operations and accidents at Vale.

	2001	2002	2003 1. half year
No of wells drilled	1	1[1)]	n.a.
Barite	977,5	51521[1)]	n.a.
Cuttings	387,6	n.a.	n.a.
Water-based drilling mud	2038	n.a.	n.a.
Cementing chemicals	1	n.a.	n.a.
Accidental discharges	0.07	0.03	n.a.

[1)] Completion
n.a. = Not available



Site	ED50 UTM Zone 31		Distance (m) / direction (°)	Depth (m)
	E	N		
VA-01	461376	6619229	250/45	117
VA-02	461553	6619406	500/45	115
VA-03	461906	6619759	1000/45	114
VA-05	461553	6618698	500/135	115
VA-06	461906	6618345	1000/135	115
VA-07	461022	6618875	250/225	117
VA-08	460845	6618698	500/225	118
VA-09	460492	6618345	1000/225	118
VA-10	461022	6619229	250/315	116
VA-11	460845	6619406	500/315	118
VA-12	460492	6619759	1000/315	120
VA-13R	461199	6627052	8000/0	114

Figure 15.1. Map showing the internal distribution of sampling sites in Vale, 2003. Positioning according to UTM ED50 zone 31. The field centre is marked with an X.

15.2. Results and discussion

15.2.1 Sediments characteristics

TOM, the amount (%) of gravel, sand and pelite, median (Φ), sorting, skewness and kurtosis in the sediment from the present survey is presented in Table 15.2. Additional information on colour and smell can be found in the Appendix. Median (Φ), pelite, sand and TOM are compared with data from 2001 in Figure 15.2.

The sediments at Vale are classified as fine sand with median (Φ) values ranging from 2.54 (VA05) to 2.82 (VA12). The amount of pelite varied from 4.9 % (VA03) to 11.2 % (VA07), the sand varied from 88.6 % (VA07) to 95.1 % (VA03), and the TOM varied from 0.9 % (VA10) to 1.5 % (VA09). There was less pelite at the reference site (VA13R) than at the field sites.

Table 15.2. Total organic matter and sediment grain size at all sites at Vale in 2003. For comparison, averages, standard deviations, max and min values for the regional and reference sites are included.

Site	TOM %	Gravel %	Sand %	Pelite %	Median (Φ)	Sorting	Skewness	Kurtosis
VA01	1.13	0.02	92.74	7.24	2.57	0.90	0.30	2.14
VA02	1.08	0.37	91.79	7.84	2.58	0.91	0.33	2.34
VA03	0.98	0.06	95.09	4.85	2.56	0.60	0.13	1.46
VA05	1.27	0.02	92.41	7.57	2.54	0.98	0.28	2.12
VA06	1.17	0.01	93.09	6.91	2.61	0.84	0.36	1.96
VA07	1.28	0.21	88.60	11.19	2.65	1.13	0.40	2.09
VA08	1.36	0.26	89.78	9.96	2.72	1.04	0.41	1.68
VA09	1.53	0.09	89.52	10.39	2.73	1.05	0.42	1.66
VA10	0.91	0.00	94.28	5.72	2.61	0.72	0.30	1.61
VA11	1.02	0.31	90.48	9.22	2.69	1.00	0.42	1.74
VA12	1.17	0.06	89.38	10.56	2.82	1.02	0.42	1.48
VA13R	0.68	0.03	97.12	2.85	2.45	0.67	-0.06	1.51
Average[1]	1.17	0.13	91.56	8.31	2.64	0.93	0.34	1.84
SD[1]	0.18	0.13	2.15	2.09	0.09	0.16	0.09	0.30
Min[1]	0.91	0.00	88.60	4.85	2.54	0.60	0.13	1.46
Max[1]	1.53	0.37	95.09	11.19	2.82	1.13	0.42	2.34
Average[2]	0.99	0.02	95.16	4.83	2.73	0.75	0.12	1.58
SD[2]	0.19	0.02	1.27	1.28	0.48	0.15	0.10	0.19
Min[2]	0.68	0.00	93.99	2.85	2.45	0.54	-0.06	1.37
Max[2]	1.19	0.03	97.12	5.98	3.69	0.94	0.23	1.87

[1] Field sites, exclusive VA13R
[2] Reg + Ref $_{\text{north 03}}$

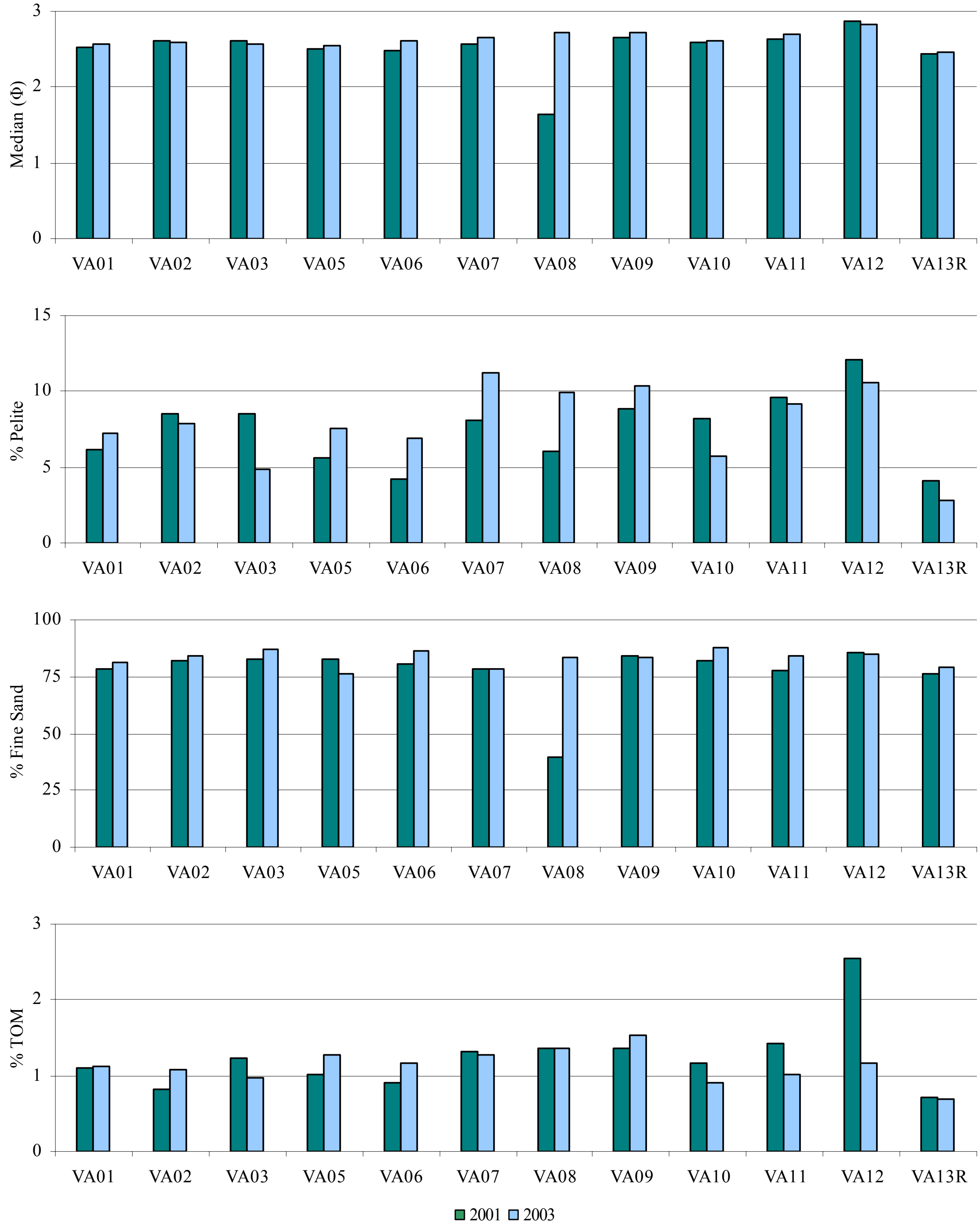


Figure 15.2. Sediment characteristics at Vale in 2001 and 2003. Fine sand is the relative amount of sand with grain size 63-250 µm.

15.2.2 Chemical compounds

15.2.2.1 LSC

The results of the LSC (limits of significant contamination) calculations of hydrocarbons and metals are presented in the chapter concerning the regional and reference sites. Both the $LSC_{north\ 97\text{-}03}$ and the field specific LSC value ($LSC_{VA13R\ 03}$) are presented in Table 15.3. LSC in the text relates to $LSC_{north\ 97\text{-}03}$.

Table 15.3. Limits of Significant Contamination (LSC) for the Vale field in 2003, and for the north part of Region II based on data from 1997 to 2003 ($LSC_{north\ 97\text{-}03}$) and the whole of Region II based on data from 1997 to 2003 ($LSC_{regII\ 97\text{-}03}$). For comparison, LSC-values from 2001 are included. All values in mg/kg dry sediment.

	THC	PAH (16)	NPD's	Decalins	Cu	Cr	Zn	Ba	Pb	Cd	Hg
$LSC_{VA13R\ 03}$	9.2	0.029	0.012	0.146	0.7	4.5	6.7	26	3.0	0.03[1]	0.005
$LSC_{north\ 97\text{-}03}$	13.3	*	*	*	1.4	5.9	7.4	76	3.8	0.03[1]	0.008
$LSC_{regII\ 97\text{-}03}$	13.3	*	*	*	2.0	9.4	11.1	136	6.6	0.03[1]	0.011
$LSC_{VA13R\ 01}$**	4.8	0.060	0.016	n.a.	1.2	10.1	5.4	78	3.7	0.02	n.a.
$LSC_{regII\ 97\text{-}00}$***	9.8	*	*	*	2.0	9.6	8.9	146	7.0	0.03	0.008

NPD's, PAH's and decalins are not analysed at regional sites in 1997 and 2000
** Data from Botnen & al. 2002
*** Data from Mannvik & al. 2001
n.a. = not analysed

15.2.2.2 Hydrocarbons

Summarised results of the hydrocarbon analyses, along with the content of selected hydrocarbon compounds in the different layers (0-1, 1-3 and 3-6) are given in Table 15.4 and Table 15.5. The complete data set including replicates is given in the Appendix. Comparison of the THC content in 2003 with previous survey in 2001 is presented in Figure 15.3.

THC was found in the range from 2.3 to 11.5 mg/kg, and no sample contained THC above LSC. Highest THC concentrations were found from the field centre and out to 500 m along the south-western sampling transect. In general the sediments around Vale had a tendency of slightly higher THC content in 2003 than in 2001.

Average content of PAH, NPD and decalins were above $LSC_{VA13R\ 03}$ at VA07 and VA08.

Vertical sediment samples (0-1, 1-3 and 3-6 cm) from VA07 and VA08 had PAH and NPD content above LSC in all depth intervals. At VA08 also decalins occurred above LSC in all depth intervals, whereas decalins occurred above LSC in the 1-3 and 3-6 cm intervals at VA07. At the reference site PAH and NPD occurred above LSC in the 3-6 cm interval. All vertical sediment samples had THC below LSC. All vertical sediment samples had THC below LSC. The vertical distributions of the hydrocarbons were relatively uniform.

Table 15.4. The content of oil hydrocarbons in sediments from Vale in 2003. All values in mg/kg dry sediment. THC values above $LSC_{north\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{VA13R\ 03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data for the regional and field reference sites in the north part of region II are included.

Site	THC		PAH(16)		NPD		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
VA01	<3.0	-	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
VA02	3.1	2.7	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
VA03	10.1	4.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
VA05	<3.0	-	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
VA06	<3.0	-	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
VA07	10.0	5.7	0.044	0.015	0.017	0.005	0.517	0.578
VA08	11.5	2.1	0.041	0.004	0.014	0.001	0.250	0.068
VA09	3.6	3.7	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
VA10	5.2	0.9	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
VA11	6.4	2.0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
VA12	9.5	0.4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
VA13R	7.4	0.7	0.022	0.003	0.011	0.000	0.119	0.011
av. ± sd.[1]	6.1 ± 3.5							
min – max[1]	<3.0 - 11.5							
av. ± sd.[2]	10.6 ± 2.0		0.028 ± 0.008		0.013 ± 0.002		0.157 ± 0.081	
min – max[2]	7.4-13.2		0.016-0.037		0.011-0.016		0.042-0.287	

n.a. = not analysed.
[1] Field sites, exclusive VA13R
[2] Reg + Ref $_{north\ 03}$

Table 15.5. The content of oil hydrocarbons in vertical sections of sediment from 3 sampling sites at Vale in 2003. All values in mg/kg dry sediment. THC values above $LSC_{north\ 97\text{-}03}$ and PAH, NPD and decalins values above $LSC_{VA13R\ 03}$ are dark shaded.

Site	Layer (cm)	THC	PAH(16)	NPD	Decalins
VA07	0-1	5,1	0.034	0.013	0.070
	1-3	10.5	0.059	0.018	0.590
	3-6	6,8	0.089	0.017	0.400
VA08	0-1	11.5	0.045	0.015	0.245
	1-3	9,5	0.054	0.016	0.420
	3-6	12.4	0.101	0.017	0.210
VA13R	0-1	7,2	0.021	0.011	0.115
	1-3	8,0	0.024	0.012	0.125
	3-6	8,5	0.041	0.013	0.145

15.2.2.3 Metals

Table 15.6 summarises the results of the metal analyses of the Vale field in 2003. Concentrations of selected metals in the different layers (0-1, 1-3 and 3-6 cm) of sediment are given in Table 15.7, whereas the complete data set including replicates is given in the Appendix. Comparisons of the metal contents in 2003 with the metal contents in 2001 are presented in Figure 15.6.

Table 15.6 Content of metals in sediments from Vale in 2003. All values in mg/kg dry sediment. Metal values above $LSC_{north\ 97\text{-}03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data in the regional and field reference sites in the north part of the region II are included.

Site	Cu		Cr		Zn		Ba		Pb		Cd		Hg	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
VA01	0.8	0.2	4.1	0.3	5.8	0.2	89	25	3.1	0.2	<0.03	-	n.a.	n.a.
VA02	1.1	0.2	4.2	0.1	8.4	2.1	90	27	3.9	0.8	<0.03	-	n.a.	n.a.
VA03	0.7	0.1	4.3	0.3	5.3	0.3	40	6	2.8	0.1	<0.03	-	n.a.	n.a.
VA05	1.0	0.1	5.2	0.3	8.0	0.2	84	8	3.5	0.1	<0.03	-	n.a.	n.a.
VA06	0.7	0.1	4.8	0.3	6.6	0.9	48	5	2.9	0.2	<0.03	-	n.a.	n.a.
VA07	1.9	0.3	5.5	0.4	8.6	0.6	559	141	4.9	0.9	<0.03	-	0.009	0.001
VA08	1.0	0.1	5.3	0.1	8.0	0.3	179	31	3.2	0.3	<0.03	-	0.010	0.004
VA09	1.1	0.2	4.8	0.4	6.5	0.7	86	23	3.2	0.5	<0.03	-	n.a.	n.a.
VA10	0.7	0.2	5.0	0.4	6.5	0.4	271	28	3.6	0.4	<0.03	-	n.a.	n.a.
VA11	0.9	0.1	4.9	0.6	7.2	0.3	135	10	3.0	0.3	<0.03	-	n.a.	n.a.
VA12	1.1	0.1	5.3	0.3	8.2	0.1	97	22	3.3	0.2	<0.03	-	n.a.	n.a.
VA13R	<0.6	-	3.7	0.3	5.9	0.3	18	3	2.5	0.2	<0.03	-	0.004	0.000
av. ± sd.[1]	1.0 ± 0.3		4.8 ± 0.5		7.2 ± 1.1		153 ± 150		3.4 ± 0.6		<0.03			
min - max[1]	0.7 - 1.9		4.1 - 5.5		5.3 - 8.6		40 - 559		2.8 - 4.9		<0.03			
av. ± sd.[2]	<0.6		4.6 ± 0.8		5.9 ± 0.3		29 ± 10		2.5 ± 0.3		<0.03		0.007 ± 0.001	
min - max[2]	<0.6-0.8		3.7-5.6		5.5-6.3		18-41		2.1-2.8		<0.03		0.004 -0.014	

n.a. = not analysed.
[1] Field sites, exclusive VA13R
[2] Reg + Ref $_{north\ 03}$

Table 15.7. The content of metals in vertical sections of sediment from 3 sampling sites at Vale in 2003. All values in mg/kg dry sediment. THC values above $LSC_{north\ 97\text{-}03}$ are dark shaded.

Site	Layer (cm)	Cu	Cr	Zn	Ba	Pb	Cd	Hg
VA07	0-1	1.7	5.1	8.0	418	4.3	<0.03	0.008
	1-3	1.4	4.9	7.8	346	3.5	<0.03	0.007
	3-6	1.3	5.3	8.8	193	3.6	<0.03	0.009
VA08	0-1	0.9	5.3	7.7	151	2.8	<0.03	0.007
	1-3	1.1	5.3	8.7	139	3.1	<0.03	0.007
	3-6	1.1	5.6	8.7	99.4	3.4	<0.03	0.017
VA13R	0-1	0.5	3.3	5.6	15.1	2.6	<0.03	0.004
	1-3	0.6	4.4	6.8	35.5	2.6	<0.03	0.010
	3-6	0.7	4.1	6.4	28.7	2.7	<0.03	0.007

Barium was found in a range from 40 to 559 mg/kg, lead from 2.8 to 4.9 mg/kg, copper from 1.2 to 8.8 mg/kg, mercury from 0.009 to 0.010 mg/kg, chromium from 4.1 to 5.5 and zinc from 5.3 to 8.6 mg/kg. Cadmium was below the detection limit (0.03 mg/kg) at all sampling sites (Table 15.6). All sampling sites except VA03, VA06 and VA13R had barium content above LSC. Zinc was above LSC at VA02, VA05, VA07, VA08 and VA12, lead above LSC at VA02 and VA07, copper at VA07 and mercury at VA07 and VA08. Chromium and cadmium occurred in concentrations below LSC. No samples from Vale contained barium above LSC in 2001.

Vertical sediment samples (0-1, 1-3 and 3-6 cm) from VA07 and VA08 had barium and zinc content above LSC in all depth intervals. The barium content decreased with increasing sediment depth, indicating recent supply of barium to the sediments. At VA07 copper and lead occurred above LSC in the 0-1 cm layer and mercury in the 3-6 cm layer. Mercury was above LSC at VA08 in the 3-6 cm layer and at VA13R in the 1-3 cm interval.

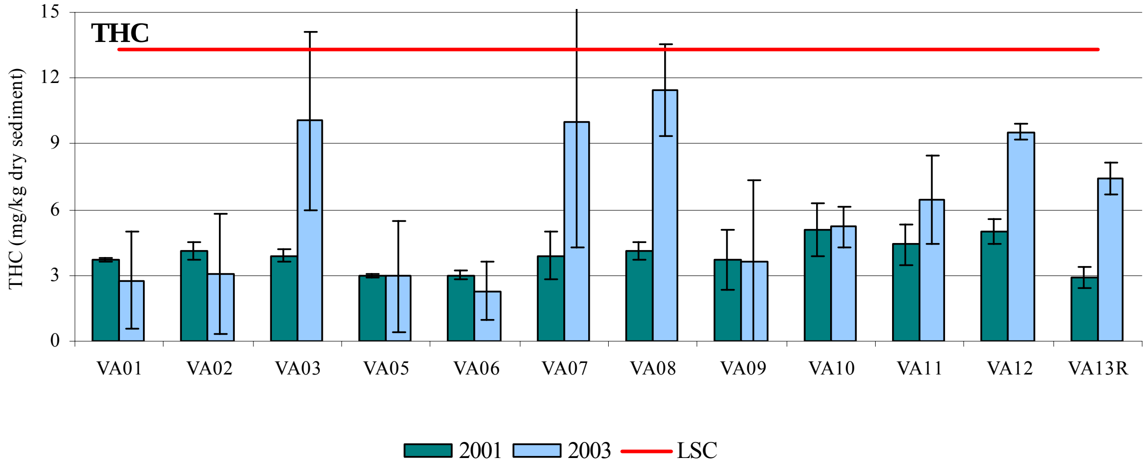


Figure 15.3. Average THC concentrations and standard deviations in sediments from Vale in 2003 and previous years. Red line is $LSC_{north\ 97\text{-}03}$.

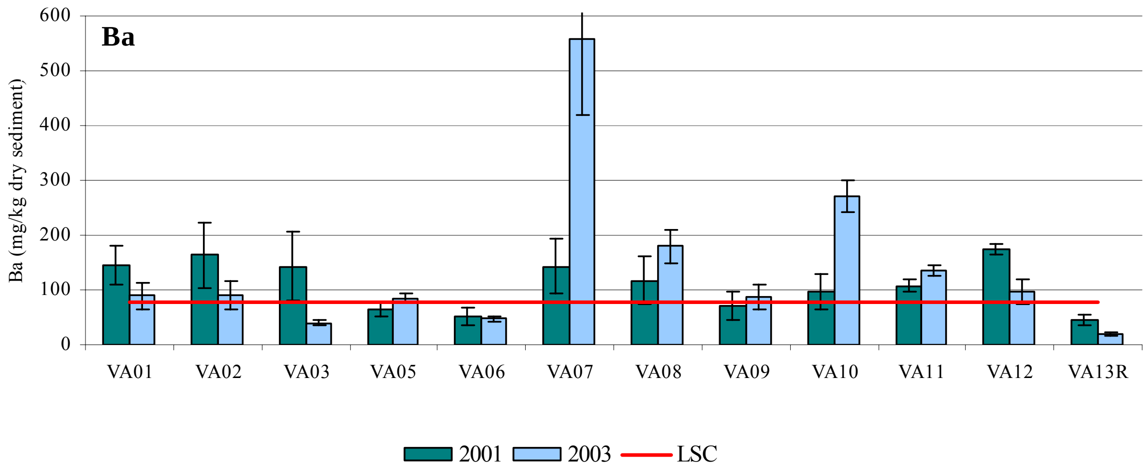


Figure 15.4. Average barium concentrations and standard deviations in sediments from Vale in 2003 and previous years. Red line is Red line is $LSC_{north\ 97\text{-}03}$.

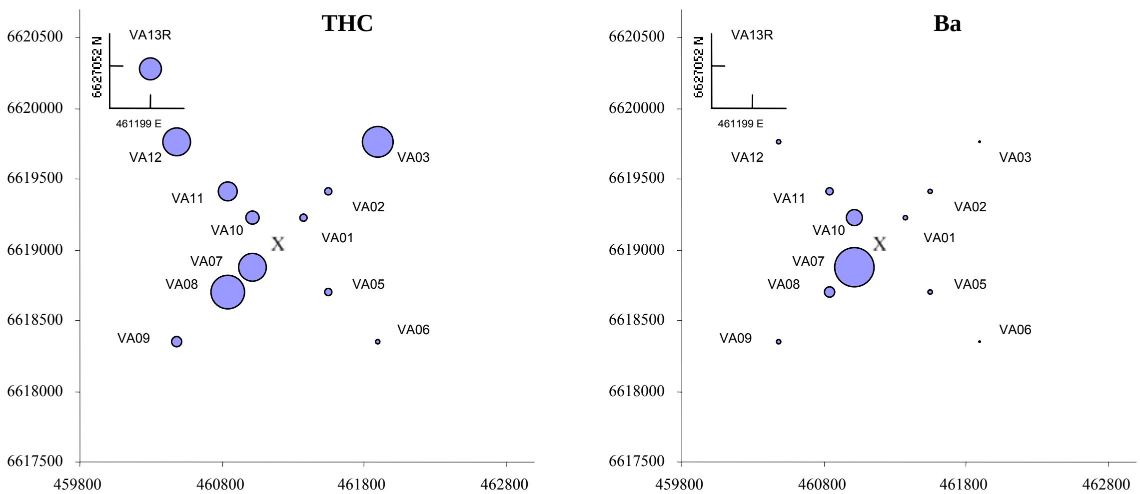


Figure 15.5. Distribution of THC and barium in sediments at the sampling sites at Vale in 2003. The size of the circle indicate the amount of THC and Ba. The field centre is marked with an X.

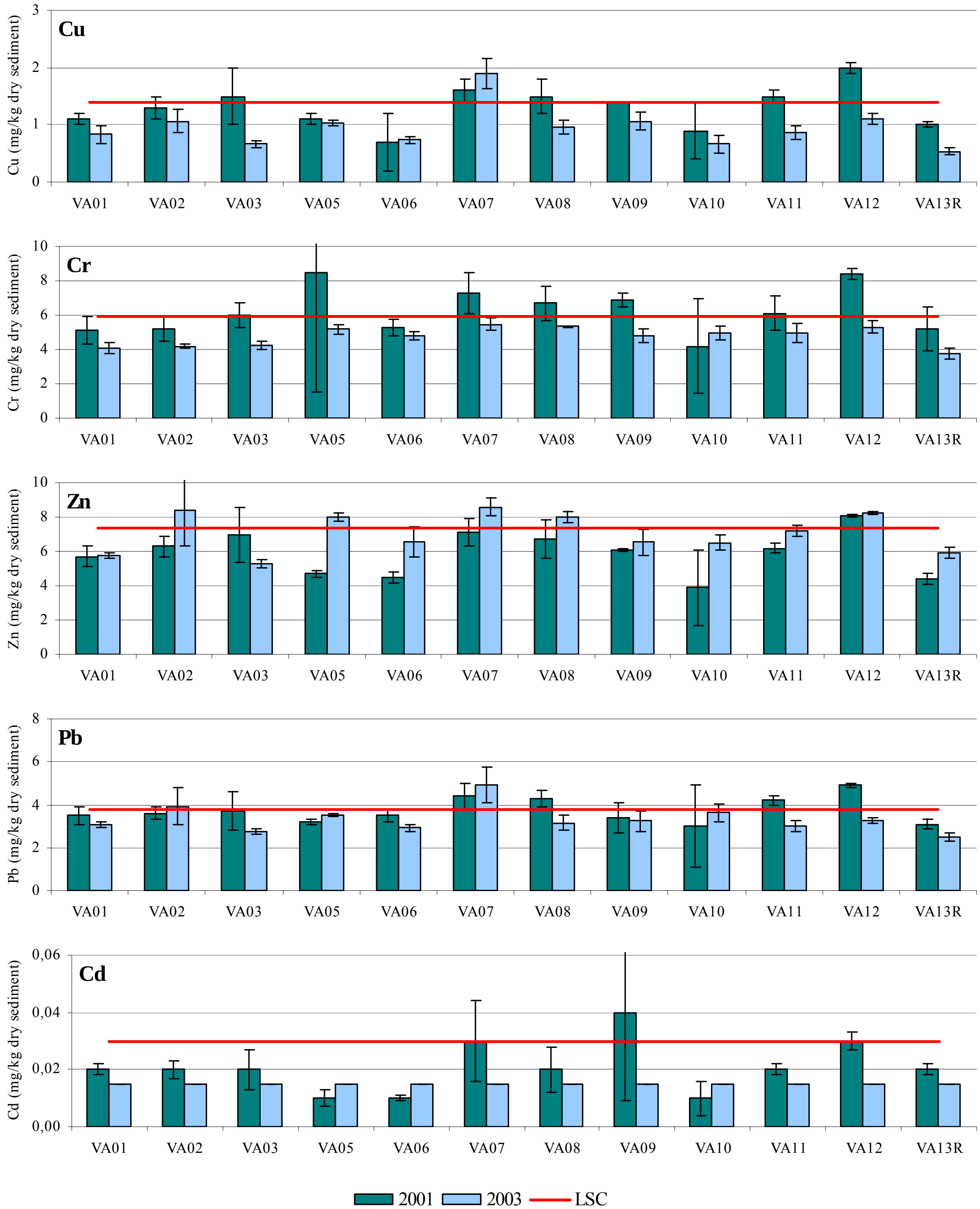


Figure 15.6. Average content and standard deviations of metals in sediment from Vale in 2003 and previous surveys. Red line is Red line is $LSC_{north\ 97\text{-}03}$.

The field sites at Vale were compared to nearby regional sites and field specific reference sites (FRI10R, PSB13R, LFR01R, RII01 and RII02) based on sediment characteristics (TOM and pelite) and chemical content in the sediments (Figure 14.7). Most of the sampling sites at Vale grouped particularly well, indicating homogeneity within the field sampling sites. However, VA07 did not group with the other sites. This was due to higher content of chemical compounds in the sediments at this site than at the other sites. It is also clear that the field specific reference site VA13R was somewhat different from the other sites at Vale.

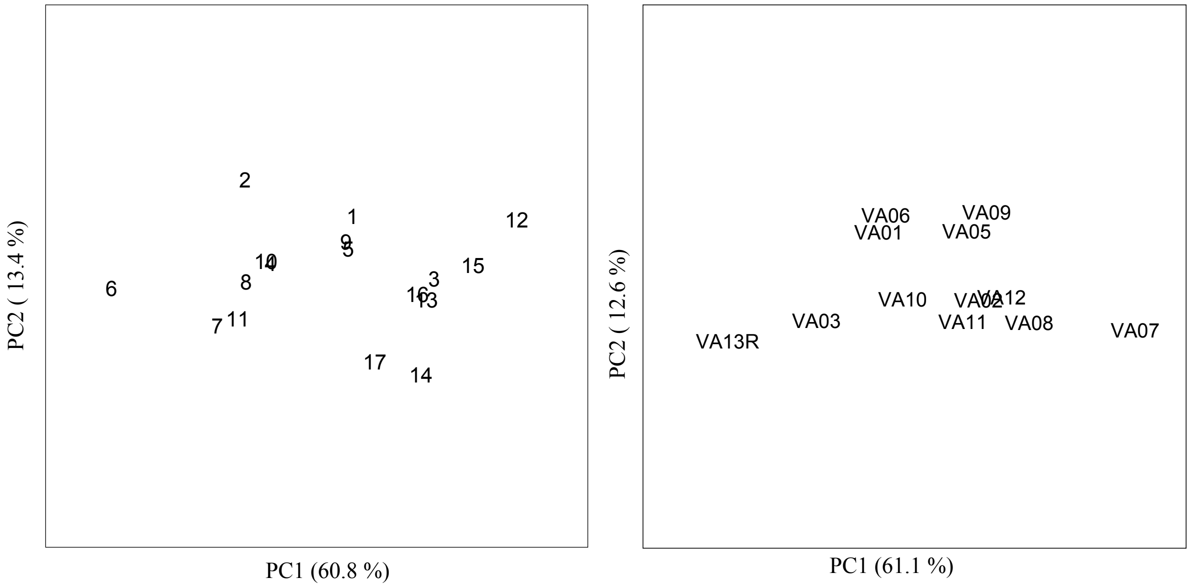


Figure 15.7. 2-D plot from the PCA analysis of environmental variables (% pelite, % sand, % gravel, median Φ, TOM, Cu, Ba, Zn, Cr, Pb and THC) carried out on:

a) Vale field sites compared to the reference sites at Frigg, Øst Frigg, Lille Frigg, Frøy and the regional sites RII01 an RII02. Explained variation in the data 74.2 %.
b) Vale field sites. Explained variation in the data 73.7 %.

Numbers in the plot identify the sampling sites. See table below.

1	VA01	5	VA06	9	VA10	13	FRI10R
2	VA02	6	VA07	10	VA11	14	RII01
3	VA03	7	VA08	11	VA12	15	RII02
4	VA05	8	VA09	12	VA13R	16	PSB13R
						17	LFR01R

15.2.3 Bottom fauna

A summary of the distribution of individuals and taxa within the main taxonomic groups are given in Table 15.8. Unidentified juveniles of the sea urchins Spatangoids (14349 individuals) and Echinoides (544 individuals) are omitted from the analyses, as they occurred in extremely high numbers. In total, 13812 individuals within 248 taxa were collected at Vale in 2003. The fauna was numerically dominated by annelida with 68 % the individuals and 48 % of the taxa. A complete species list is available in the Appendix.

Table 15.8. Distribution of individuals and taxa within the main taxonomic groups at Vale in 2003 including data from VA13R (unidentified juveniles of Spatangonida and Echinoidea are not included).

Main taxonomic groups	Number of individuals	%	Number of taxa	%
Annelida	9351	68	118	48
Arthropoda	624	5	52	21
Mollusca	1541	11	50	20
Echidermata	1282	9	13	5
Diverse groups	1014	7	15	6
Total	13812	100	248	100

The species/area curve for VA13R indicates that five replicate samples give a representative impression of the bottom fauna in the area (Figure 15.8). However, as more area is sampled, more taxa are collected, indicating that not even 10 replicate samples give the full species assemblage of the area.

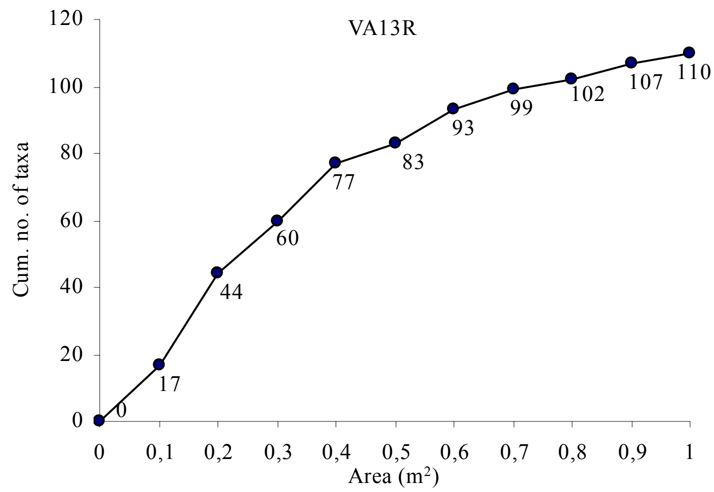


Figure 15.8. Species/area curve for the reference site at the Vale field. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

The distribution of individuals and taxa are shown in Figure 15.9. Number of individuals and taxa at each site, and the calculated diversity indexes (H' and ES_{100}) are given in Table 15.9 and Figure 15.10. The number of individuals varied from 927 (VA10) to 1314 (VA01), and the number of taxa varied from 89 (VA10) to 128 (VA11). The Shannon-Wiener diversity index (H') varied from 4.07 (VA10) to 5.76 (VA07), whereas the ES_{100} index varied from 31.4 (VA10) to 47.1 (VA07). The evenness index J varied from 0.63 (VA10) to 0.83 (VA07). The corresponding values at VA13R are within or near the variation at the field sites except for number of individuals and number of taxa which were lower at the reference site. The number of taxa, diversity and evenness indicate good environmental conditions at all sites.

Table 15.9. Number of individuals, taxa, and selected community indices for each site (0.5 m^2) at the Vale field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

Site number	Number of individuals	Number of taxa	Diversity H'	Evenness J	H'-max	ES_{100}
VA01	1314	112	4.56	0.67	6.81	34.7
VA02	1262	117	4.74	0.69	6.87	35.6
VA03	1051	105	4.66	0.69	6.71	34.1
VA05	1195	126	5.05	0.72	6.98	40.0
VA06	1135	114	4.63	0.68	6.83	34.7
VA07	1084	122	5.76	0.83	6.93	47.1
VA08	1203	116	5.13	0.75	6.86	39.6
VA09	1021	118	5.66	0.82	6.88	44.4
VA10	927	89	4.07	0.63	6.48	31.4
VA11	1116	128	5.69	0.81	7.00	45.2
VA12	1219	124	5.37	0.77	6.95	40.6
VA13R (6-10)	693	83	4.84	0.76	6.38	33.1
VA13R (11-15)	592	80	4.78	0.76	6.32	32.8
VA13R (6-15)	1285	110	4.92	0.73	6.78	33.5
Sum[1]	12527	235				
Average[1]	1139	116	5.03	0.73	6.85	38.9
SD[1]	114	11	0.55	0.07	0.15	5.2
Min[1]	927	89	4.07	0.63	6.48	31.4
Max[1]	1314	128	5.76	0.83	7.00	47.1
Average[2]	919	95	4.78	0.73	6.57	34.5
SD[2]	428	12	0.65	0.11	0.19	5.3
Min[2]	574	80	3.51	0.52	6.32	24.6
Max[2]	1749	109	5.31	0.82	6.77	39.6

[1]Vale field, exclusive VA13R
[2]Reg + Ref $_{north\ 03}$

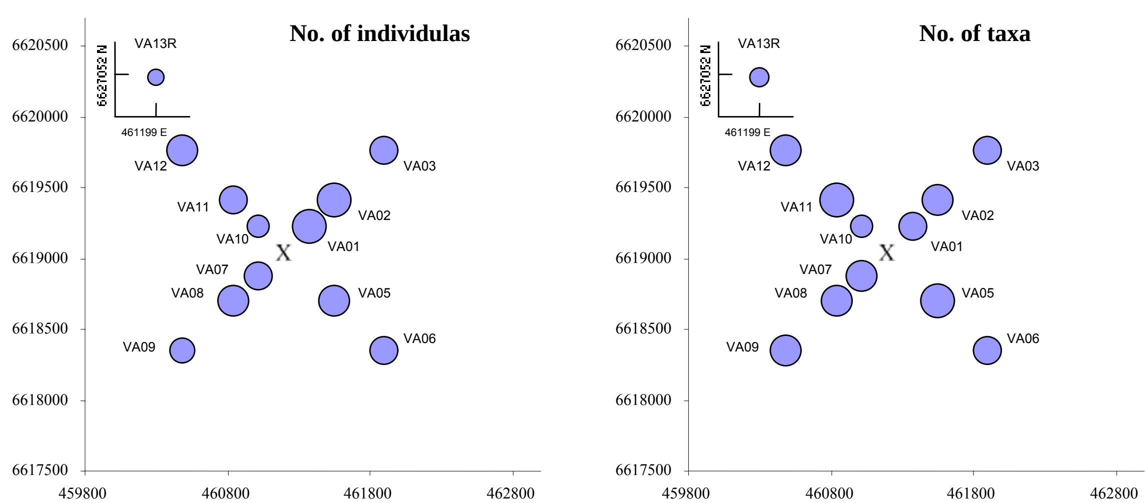


Figure 15.9. Distribution of bottom fauna (individuals and taxa) among the sampling sites in 2003. The size of the circles indicates the number of individuals and taxa. Exclusive unidentified juveniles of Spatangoida and Echinoidae. Values for VA13R are average of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2). The field centre is marked with an X.

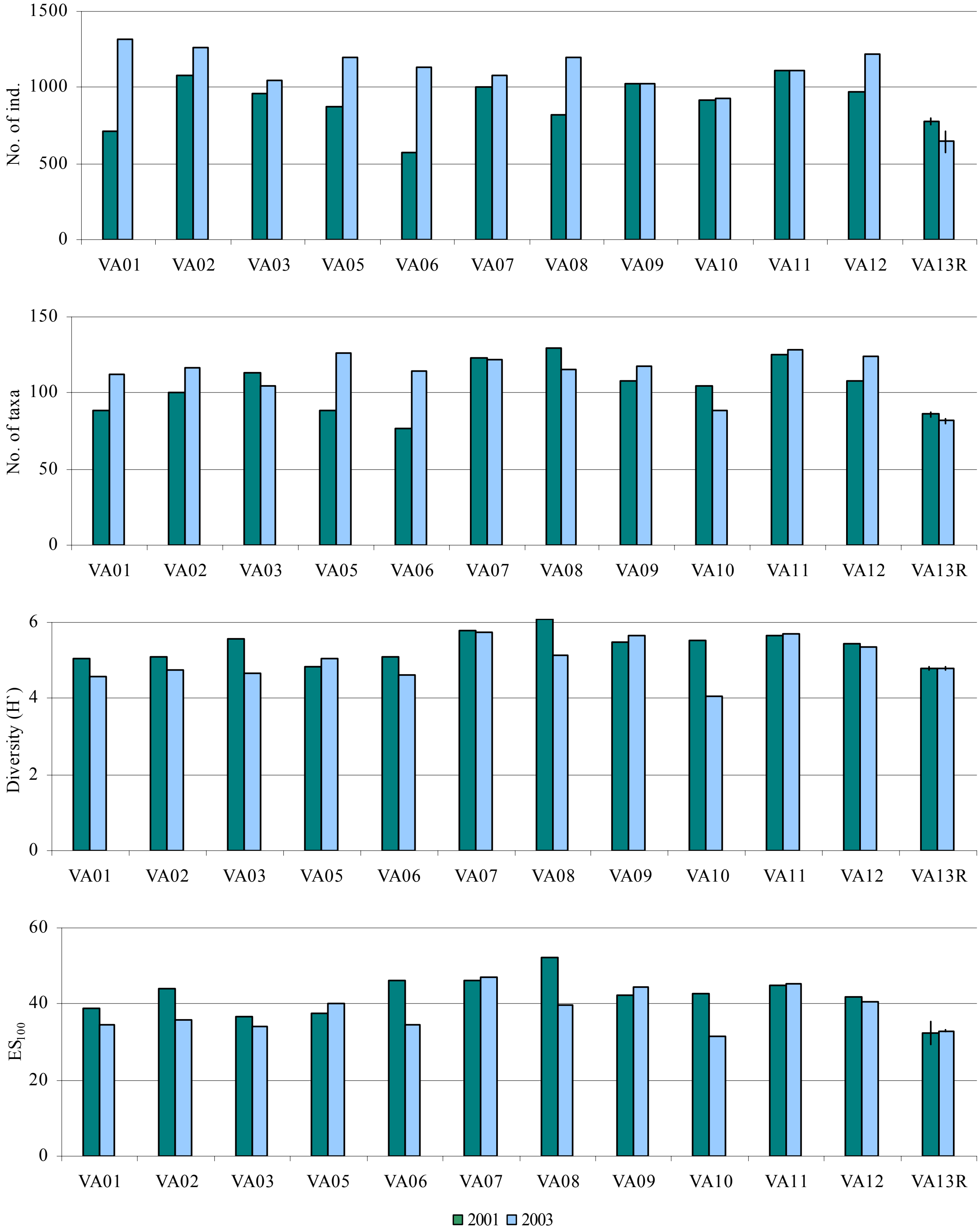


Figure 15.10. Number of individuals, taxa and selected community indices for each site (0.5 m^2) at the Vale field for 2001 and 2003. (Exclusive unidentified juveniles of Spatangoida and Echinoidea in 2003). Values for VA13R are average ± standard deviation of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2).

Distribution of taxa in geometrical classes is presented in Figure 15.11. The smooth graphs are indicating undisturbed bottom fauna.

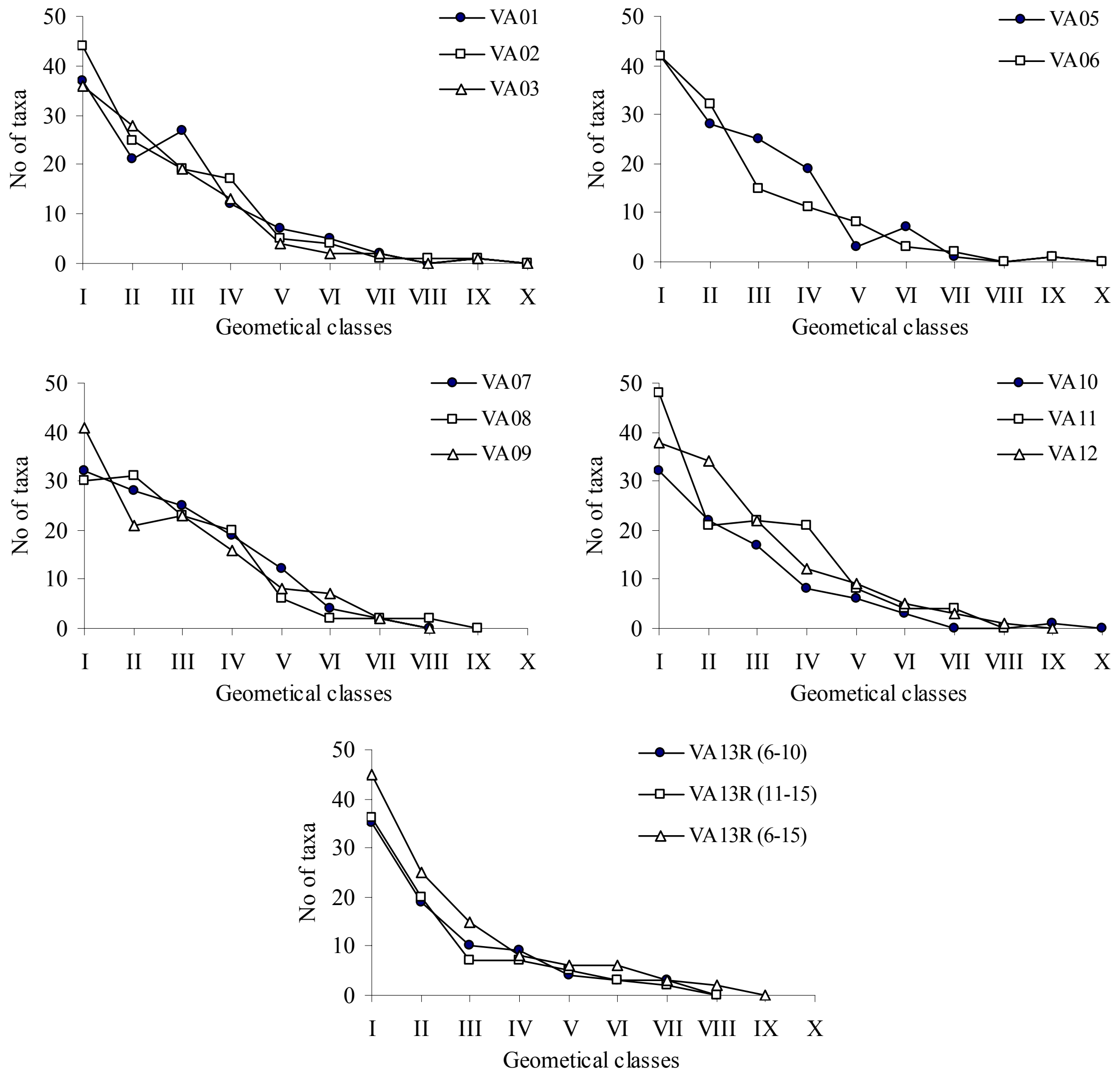


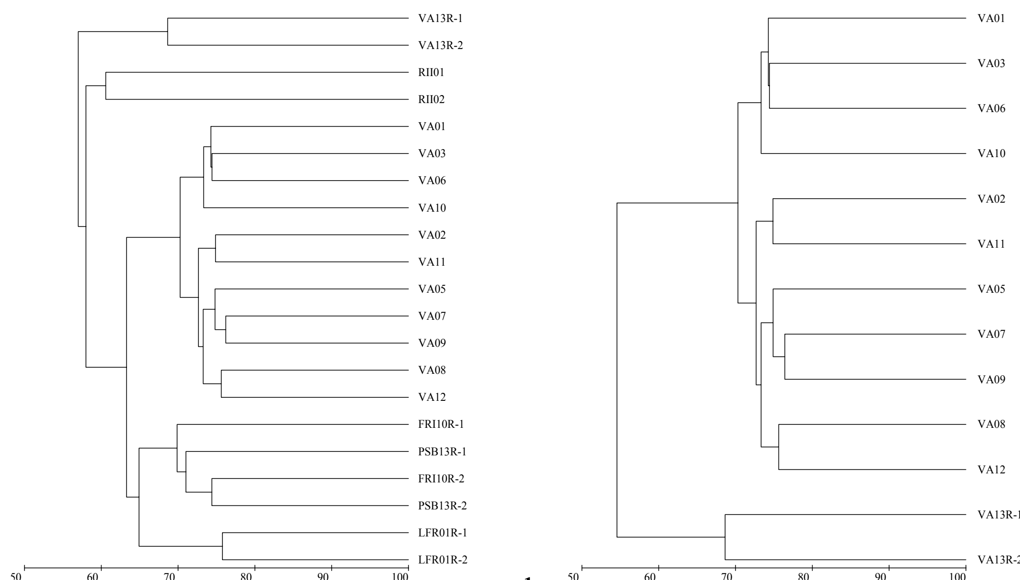
Figure 15.11. Distribution of taxa in geometrical classes for the sites at Vale in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

The ten most numerous taxa are listed in Table 15.12 at the end of this chapter. The list comprise 23 taxa and 9879 individuals, which was 9.3 % of all (248) taxa and 71.5 % of all (13812) individuals. The polychaete *Owenia fusiformis* was the most abundant species at all sites except at VA07 (250 m to the southwest) and VA09 (1000 m to the southwest) where the polychaete *Paramphinone jeffreysii* was most abundant. The polychaete *Capitella capitata* which are known to occur in high numbers in disturbed bottom fauna occurred among the most abundant species at VA07 and VA11 (500 m to the northwest). The species was also present in the fauna at VA01 (250 m to the northeast) and at VA08 (500 m to the southwest). Despite the presence of *Capitella capitata* the cohabiting fauna indicated good environmental conditions and no faunal disturbances at these sites. The taxa assemblages indicated good environmental conditions at the other sites too.

The results of the multivariate analyses are given in the dendrogramme (Figure 15.12) and the MDS plott (Figure 15.13).

In the cluster analysis, all sites are grouped together within approximately 70 % similarity, indicating high homogeneity in the species assemblages within the field. The similarity in the species assemblage at the field specific sampling sites and the reference site was about 55 %. The absence of the bivalves *Thyasira ferruginea* and *Thyasira pygmaea* and the polychaetes *Diplocirrus glaucus, Prionospio cirrifera* and *Prionospio dubia* and the presence of the polychaete *Chateozone setosa* at the reference site explain some of the measured difference among the field specific sites and the reference site.

The results of the MDS analysis support the findings in the cluster analysis, confirming the homogeneity in species assemblage within the field specific sampling sites and the difference between the field specific sites and the reference site. The stress test of the MDS analysis was 0.12, indicating a good fit of the data.



a b

Figure 15.12. Dendrogram showing the similarity between fauna from sampling sites at:

a) Vale field sites compared to the reference sites FRI01R, LFR01R and PSB13R, and the regionale sites RII01 and RII02 in 2003.
b) Vale field sites in 2003.

Exclusive unidentified juveniles of Spatangoida and Echinoidea.

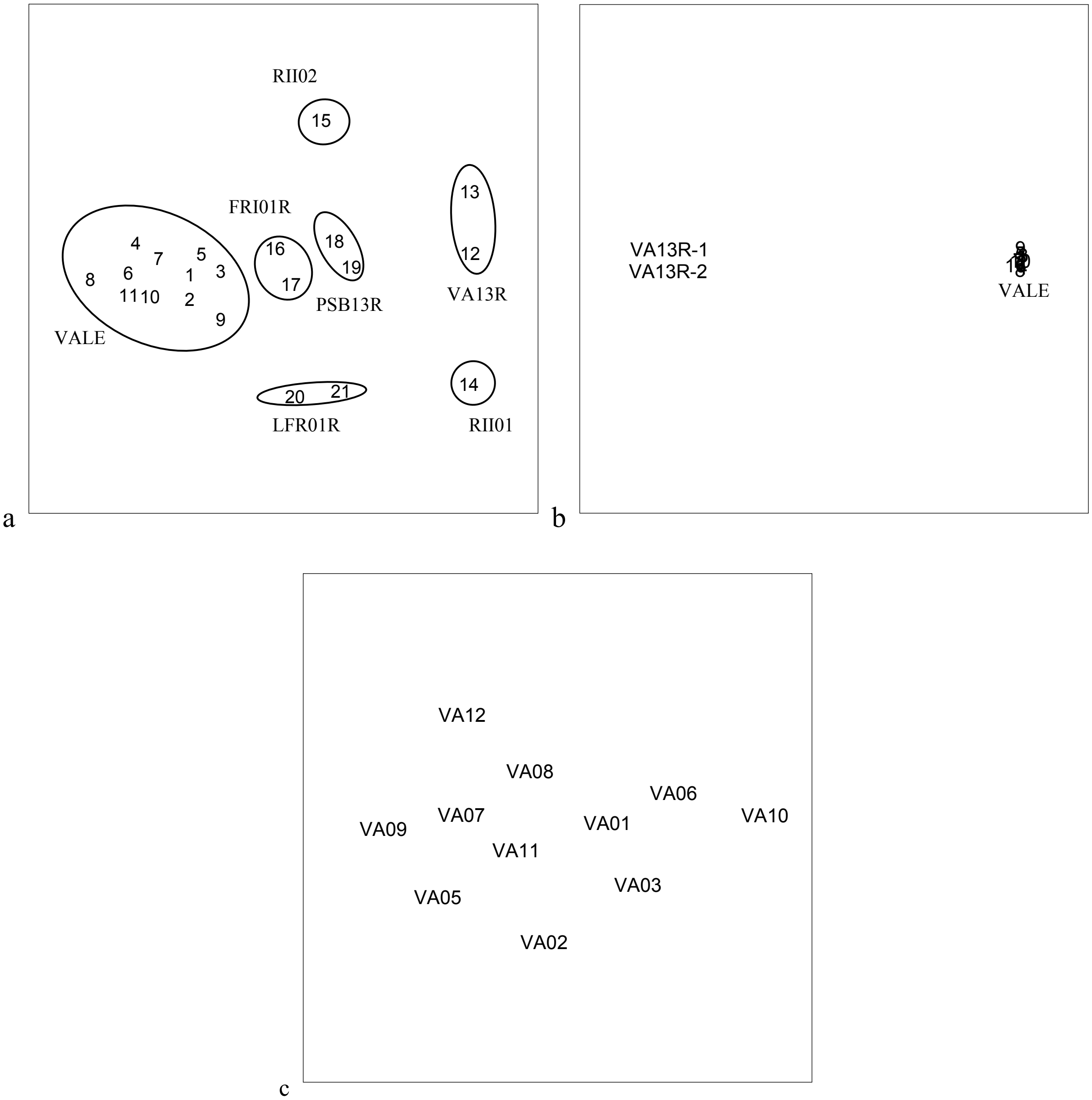


Figure 15.13. A 2-dimetional plott of the MDS analysis of the fauna data from:

a) Vale field compared to reference sites (FRI01R, LFR01R and PSB13R) and regional sites (RII01 and RII02) in 2003. Stress = 0.12.
b) Vale field in 2003. Stress = 0.01.
c) Vale field exclusive the reference site VA13R. Stress = 0.12.

Exclusive unidentified juveniles of Spatangoida and Echinoidea.
Numbers in the plot identify the sampling sites. See table below.

1	VA01	7	VA08	13	VA13R-2	19	PSB13R-2
2	VA02	8	VA09	14	RII01	20	LFR01R-1
3	VA03	9	VA10	15	RII02	21	LFR01R-2
4	VA05	10	VA11	16	FRI10R-1		
5	VA06	11	VA12	17	FRI10R-2		
6	VA07	12	VA13R-1	18	PSB13R-1		

Linking of biotic and environmental variables by BIOENV revealed that pelite, a natural variable of the sediments, was best correlated to the biota at $\rho_w = 0.6$ (Table 15.10).

Table 15.10. Combinations of the 10 environmental variables, taken *k* at a time, yielding the best matches of biotic and abiotic similarity matrices for each *k*, as measured by weighted Spearman rank correlation ρ_w. Bold type indicates overall optimum. All possible combinations of variables and associated correlation to the biotic are given in the Appendix.

Number of variables (*k*)	Correlation coefficient (ρ_w)	Environmental variables									
1	**0.602**	**Pelite**									
1	0.506	Sand									
1	0.486	TOM									
1	0.248	Cr									
1	0.220	Cu									
1	0.215	Ba									
1	0.136	Pb									
1	0.015	Zn									
1	-0.147	THC									
1	-0.229	Gravel									
2	0.582	TOM	Pelite								
3	0.596	TOM	Pelite	Sand							
4	0.587	TOM	Pelite	Sand	Cr						
5	0.597	TOM	Pelite	Sand	Cr	Gravel					
6	0.550	TOM	Pelite	Sand	Cr	Gravel	Ba				
7	0.530	TOM	Pelite	Sand	Cr	Gravel	Ba	Zn			
8	0.479	TOM	Pelite	Sand	Cr	Gravel	Ba	Zn	THC		
9	0.395	TOM	Pelite	Sand	Cr	Gravel	Ba	Zn	THC	Cu	
10	0.319	TOM	Pelite	Sand	Cr	Gravel	Ba	Zn	THC	Cu	Pb

15.2.4 Estimation of influenced area

The extension of contamination along sampling transects and the minimum area of contaminated sediments for THC, barium and other metals as well as for faunal disturbance is given in Figure 15.14 and Table 15.11. The previous survey at Vale was a baseline survey in 2001. No contaminated sediments or disturbed fauna were detected in 2001, whereas contamination by barium and other metals were found in 2003.

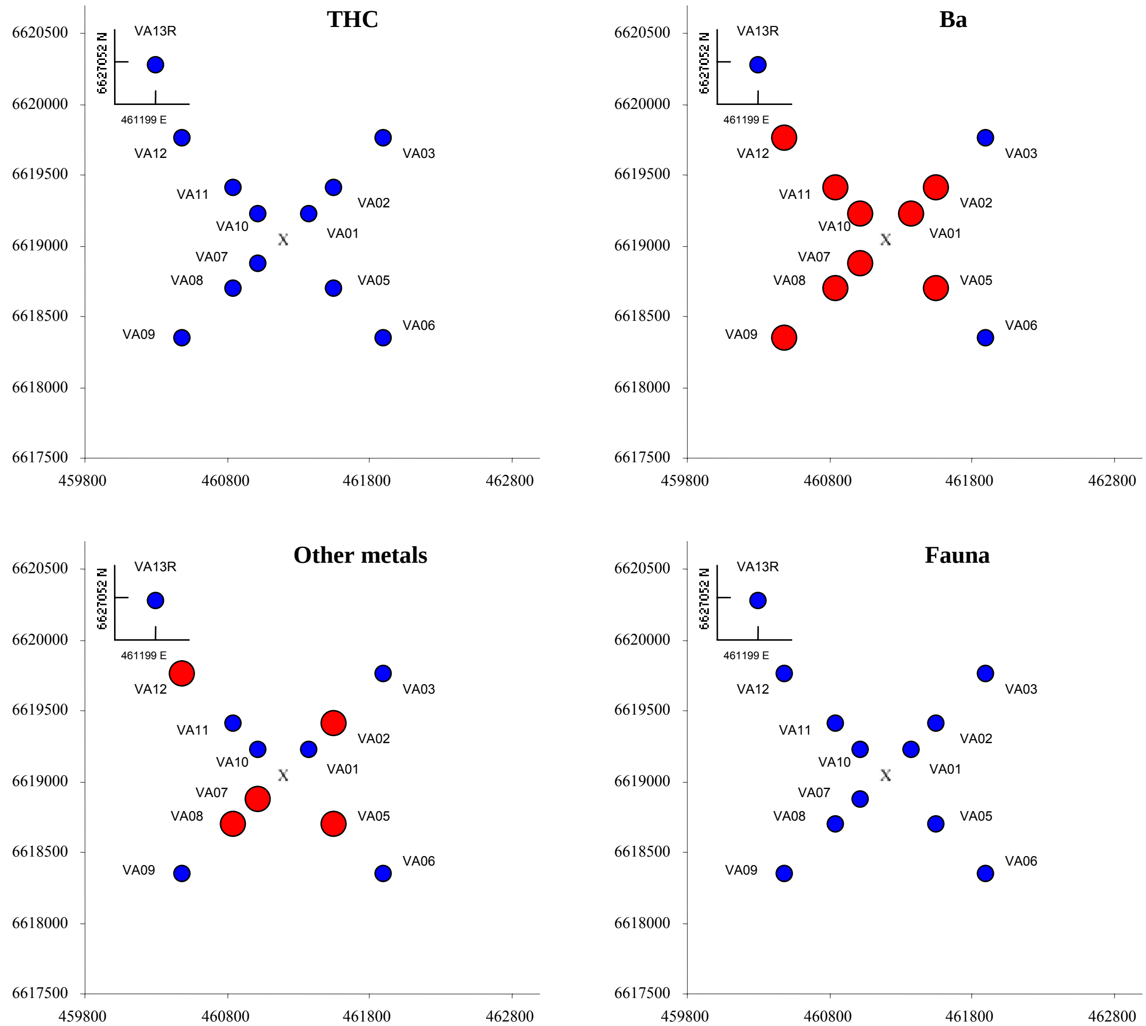


Figure 15.14. Faunal disturbance and chemical contamination of the sediments at Vale in 2003. Uncontaminated sites and sites with no faunal disturbance are marked with small blue circles. The field centre is marked with an X.

Table 15.11. Estimated distance of contamination and faunal disturbance from the installation, and estimated area of contamination and faunal disturbance around the field centre.

Vale	NE m	SE m	SW m	NW m	2003 km^2	2001 km^2
THC	0	0	0	0	0.00	0.00
Ba	500	500	1000	1000	1.77	0.00
Other metals	500	500	500	0	0.39	0.00
Fauna	0	0	0	0	0.00	0.00

15.3 Summary and conclusions

Since the baseline survey at Vale in 2001 one well has been drilled at the field. The sampling sites were relocated in 2003 and the results of this survey can not be directly compared site by site. The sediments at Vale are still characterized as fine sand. The amount of THC in the sediments was higher in 2003 than in 2001 although THC contamination was not revealed. Contamination by barium was found at most sites except the two sites at 1000 m to the northeast and southeast. None of the other metals occurred in particularly high concentrations although contamination by zinc was revealed at several sites and contamination by copper and lead were revealed 250 m to the southwest of the field centre. Faunal disturbance was not revealed at Vale in 2003.

Table 15.12. Number of individuals and relative abundance for the ten predominant taxa at each site at the Vale field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

VA01	No of ind.	%	Cum %
Owenia fusiformis	452	34,4	34,4
Ophiura affinis	82	6,2	40,6
Spiophanes bombyx	66	5,0	45,7
Myriochele oculata	62	4,7	50,4
Amphiura filiformis	57	4,3	54,7
Paramphinome jeffreysii	47	3,6	58,3
Phoronis sp.	45	3,4	61,7
Cerianthus lloydii	37	2,8	64,5
Nemertini indet.	22	1,7	66,2
Aricidea suecica	19	1,4	67,7

VA02	No of ind.	%	Cum %
Owenia fusiformis	351	27,8	27,8
Spiophanes bombyx	134	10,6	38,4
Myriochele oculata	98	7,8	46,2
Paramphinome jeffreysii	53	4,2	50,4
Thyasira ferruginea	49	3,9	54,3
Phoronis sp.	46	3,6	57,9
Amphiura filiformis	41	3,2	61,2
Cerianthus lloydii	24	1,9	63,1
Nemertini indet.	23	1,8	64,9
Thyasira croulinensis	23	1,8	66,7

VA03	No of ind.	%	Cum %
Owenia fusiformis	281	26,7	26,7
Myriochele oculata	122	11,6	38,3
Spiophanes bombyx	75	7,1	45,5
Amphiura filiformis	63	6,0	51,5
Ophiura affinis	52	4,9	56,4
Paramphinome jeffreysii	31	2,9	59,4
Phoronis sp.	30	2,9	62,2
Myriochele fragilis	30	2,9	65,1
Cerianthus lloydii	23	2,2	67,3
Lanice conchilega	15	1,4	68,7
Chaetozone sp.	15	1,4	70,1
Aonides paucibranchiata	15	1,4	71,6

VA05	No of ind.	%	Cum %
Owenia fusiformis	325	27,2	27,2
Myriochele oculata	97	8,1	35,3
Paramphinome jeffreysii	59	4,9	40,3
Phoronis sp.	43	3,6	43,8
Spiophanes bombyx	38	3,2	47,0
Ophiura affinis	35	2,9	50,0
Myriochele fragilis	35	2,9	52,9
Thyasira croulinensis	35	2,9	55,8
Amphiura filiformis	32	2,7	58,5
Cerianthus lloydii	24	2,0	60,5

VA06	No of ind.	%	Cum %
Owenia fusiformis	355	31,3	31,3
Spiophanes bombyx	94	8,3	39,6
Myriochele oculata	79	7,0	46,5
Amphiura filiformis	55	4,8	51,4
Phoronis sp.	42	3,7	55,1
Cerianthus lloydii	40	3,5	58,6
Paramphinome jeffreysii	31	2,7	61,3
Thyasira croulinensis	23	2,0	63,3
Lanice conchilega	23	2,0	65,4
Thyasira flexuosa	20	1,8	67,1

VA07	No of ind.	%	Cum %
Paramphinome jeffreysii	124	11,4	11,4
Spiophanes bombyx	94	8,7	20,1
Capitella capitata	50	4,6	24,7
Myriochele oculata	48	4,4	29,2
Ophiura affinis	42	3,9	33,0
Thyasira croulinensis	36	3,3	36,3
Owenia fusiformis	25	2,3	38,7
Phoronis sp.	25	2,3	41,0
Cerianthus lloydii	25	2,3	43,3
Diplocirrus glaucus	24	2,2	45,5

VA08	No of ind.	%	Cum %
Owenia fusiformis	213	17,7	17,7
Spiophanes bombyx	174	14,5	32,2
Paramphinome jeffreysii	87	7,2	39,4
Myriochele oculata	66	5,5	44,9
Phoronis sp.	50	4,2	49,0
Amphiura filiformis	40	3,3	52,4
Thyasira croulinensis	28	2,3	54,7
Thyasira ferruginea	22	1,8	56,5
Goniada maculata	22	1,8	58,4
Lanice conchilega	22	1,8	60,2

VA09	No of ind.	%	Cum %
Paramphinome jeffreysii	100	9,8	9,8
Myriochele oculata	79	7,7	17,5
Thyasira croulinensis	55	5,4	22,9
Phoronis sp.	44	4,3	27,2
Spiophanes bombyx	43	4,2	31,4
Lanice conchilega	40	3,9	35,4
Owenia fusiformis	36	3,5	38,9
Laonice sarsi	36	3,5	42,4
Amphiura filiformis	34	3,3	45,7
Thyasira ferruginea	31	3,0	48,8

Table 15.12 continue. Number of individuals and relative abundance for the ten predominant taxa at each site at the Vale field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.

VA10	No of ind.	%	Cum %
Owenia fusiformis	397	42,8	42,8
Spiophanes bombyx	54	5,8	48,7
Amphiura filiformis	46	5,0	53,6
Myriochele oculata	37	4,0	57,6
Chaetozone sp.	31	3,3	60,9
Thyasira flexuosa	24	2,6	63,5
Phoronis sp.	22	2,4	65,9
Goniada maculata	19	2,0	68,0
Paramphinome jeffreysii	17	1,8	69,8
Harpinia antennaria	17	1,8	71,6

VA11	No of ind.	%	Cum %
Owenia fusiformis	118	10,6	10,6
Spiophanes bombyx	69	6,2	16,8
Capitella capitata	67	6,0	22,8
Paramphinome jeffreysii	65	5,8	28,6
Phoronis sp.	55	4,9	33,5
Myriochele oculata	49	4,4	37,9
Amphiura filiformis	47	4,2	42,1
Thyasira croulinensis	36	3,2	45,3
Thyasira flexuosa	28	2,5	47,8
Cerianthus lloydii	23	2,1	49,9
Ophiura affinis	23	2,1	52,0

VA12	No of ind.	%	Cum %
Owenia fusiformis	160	13,1	13,1
Paramphinome jeffreysii	116	9,5	22,6
Spiophanes bombyx	103	8,4	31,1
Amphiura filiformis	83	6,8	37,9
Myriochele oculata	51	4,2	42,1
Thyasira ferruginea	45	3,7	45,8
Thyasira croulinensis	40	3,3	49,1
Phoronis sp.	37	3,0	52,1
Laonice sarsi	32	2,6	54,7
Thyasira flexuosa	29	2,4	57,1

VA13R	No of ind.	%	Cum %
Owenia fusiformis	175	13,6	13,6
Spiophanes bombyx	142	11,1	24,7
Ophiura affinis	124	9,6	34,3
Amphiura filiformis	104	8,1	42,4
Myriochele oculata	84	6,5	48,9
Phoronis sp.	56	4,4	53,3
Thyasira flexuosa	45	3,5	56,8
Montacuta substriata	43	3,3	60,2
Lanice conchilega	38	3,0	63,1
Goniada maculata	35	2,7	65,8

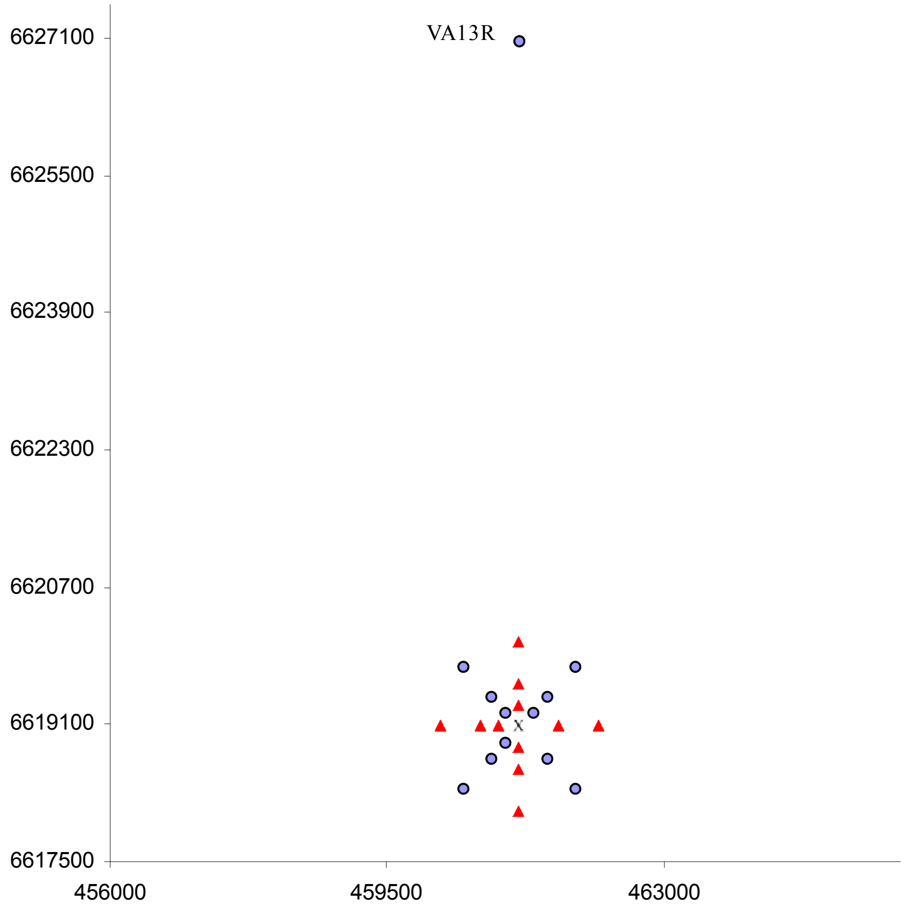


Figure 15.15. Illustration of deviations in planned and real sampling at Vale. Location of sampling sites according to the programme, red triangle, and location of the sites where sampling were executed, blue circles.

16 Frøy

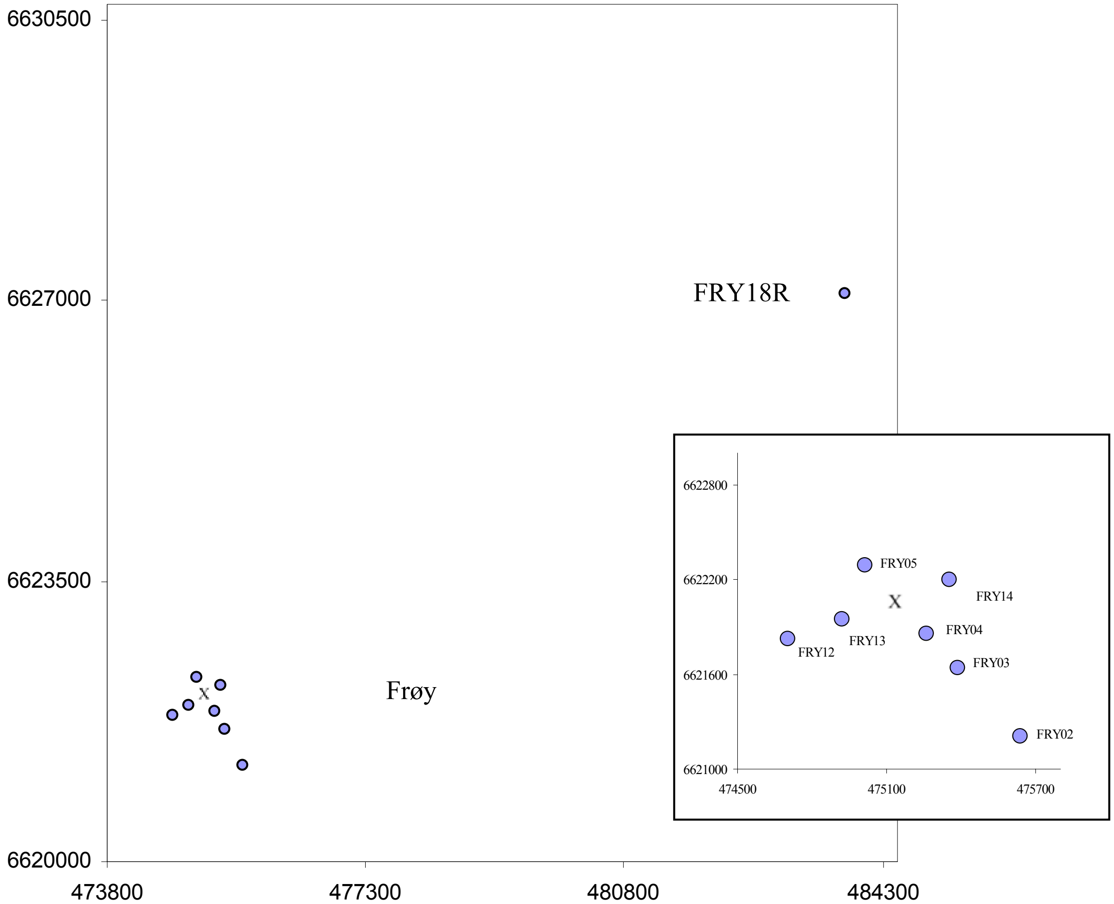
16.1. Introduction

The Frøy field is situated in block 25/2 and 25/5. Production started at Frøy in 1995 and ceased in 2001, when the wells were permanently plugged and abandoned. The jacket was removed in 2002. This is the first post production monitoring survey of the field. In the monitoring survey in 2000, faunal disturbances were found out to 500 m to the south west and out to 250 in the other directions. Elevated levels of THC and olefins were found at sampling sites nearest to the installation. There has been no drilling activity at Frøy since 1997 and the only discharge during the last years was 1180 tonnes of water based drilling mud in connection with the plugging of the wells in 2001 (Table 16.1). The sampling sites used in 2003 are shown in Figure 16.1

Table 16.1. Recent well drilling and discharges from operations and accidents at Frøy.

	1997	1998	1999	2000	2001	2002
No of wells drilled	0	0	0	0	0	0
Water-based drilling mud, tonnes	0	0	0	0	1180*	0
Accidental discharges, tonnes	1.4	0.09	0.4	0.1	0.1	0

98 % was “green” chemicals and water. 20 tonnes were chemicals classified as in the “yellow”.



Site	ED50 UTM Zone 31 E	ED50 UTM Zone 31 N	Distance (m) / direction (º)	Depth (m)
FRY-02	475635	6621209	1000/150	120
FRY-03	475385	6621642	500/150	121
FRY-04	475260	6621859	250/150	121
FRY-05	475010	6622292	250/330	121
FRY-12	474702	6621825	500/240	120
FRY-13	474918	6621950	250/240	121
FRY-14	475352	6622200	250/60	122
FRY-18R	483795	6627075	1000/60	118

Figure 16.1. Map showing the internal distribution of sampling sites in Frøy, 2003. Positioning according to UTM ED50 zone 31. The field centre is marked with an X.

16.2. Results and discussion

16.2.1 Sediments characteristics

TOM, and the amount (%) of gravel, sand, pelite, median (Φ), sorting, skewness and kurtosis in the sediment from the present survey is presented in Table 16.2. Additional information on colour and smell can be found in the Appendix. Median (Φ), pelite, sand and TOM are compared with data from 2000 in Figure 16.2.

The sediments at Frøy are classified as fine sand with median (Φ) values ranging from 2.78 (FRY12) to 3.01 (FRY04). The amount of pelite varied from 11.3 % (FRY03) to 14.5 % (FRY14), the sand varied from 85.4 % (FRY14) to 88.7 % (FRY03), and the TOM varied from 0.4 % (FRY03) to 1.9 % (FRY13). The condition at the reference site was similar to the field specific sites. Since the last survey in 2000 the sediments have become slightly finer, as seen as an increase in the pelite content. The change in the median value between 2000 and 2003 are probably due to different methods of calculations.

Table 16.2. Total organic matter and sediment grain size at all sites at Frøy in 2003. For comparison averages, standard deviations, max and min values for the regional and reference sites are included.

Site	TOM %	Gravel %	Sand %	Pelite %	Median (Φ)	Sorting	Skewness	Kurtosis
FRY02	1.32	0.13	87.26	12.61	2.81	1.22	0.30	1.66
FRY03	0.39	0.00	88.69	11.31	2.79	1.14	0.33	1.63
FRY04	1.77	0.11	85.97	13.93	3.01	1.11	0.33	1.51
FRY05	1.52	0.31	87.76	11.93	2.90	1.14	0.30	1.60
FRY12	1.48	0.46	87.91	11.64	2.78	1.05	0.47	1.58
FRY13	1.92	0.09	85.60	14.31	2.94	1.10	0.40	1.53
FRY14	1.83	0.07	85.44	14.50	2.99	1.12	0.36	1.52
FRY18R	1.62	0.03	89.24	10.74	2.78	1.18	0.27	1.64
Average[1]	1.46	0.17	86.95	12.89	2.89	1.13	0.36	1.58
SD[1]	0.52	0.16	1.28	1.34	0.10	0.05	0.06	0.06
Min[1]	0.39	0.00	85.44	11.31	2.78	1.05	0.30	1.51
Max[1]	1.92	0.46	88.69	14.50	3.01	1.22	0.47	1.66
Average[2]	1.71	0.29	87.23	12.49	2.71	1.16	0.34	1.76
SD[2]	0.45	0.62	5.20	5.12	0.37	0.14	0.19	0.46
Min[2]	0.73	0.00	78.12	3.04	1.76	0.93	0.03	1.05
Max[2]	2.19	2.19	96.61	21.77	3.34	1.40	0.57	2.95

[1] Field sites, exclusive FRY18R
[2] Reg + Ref $_{central\ 03}$

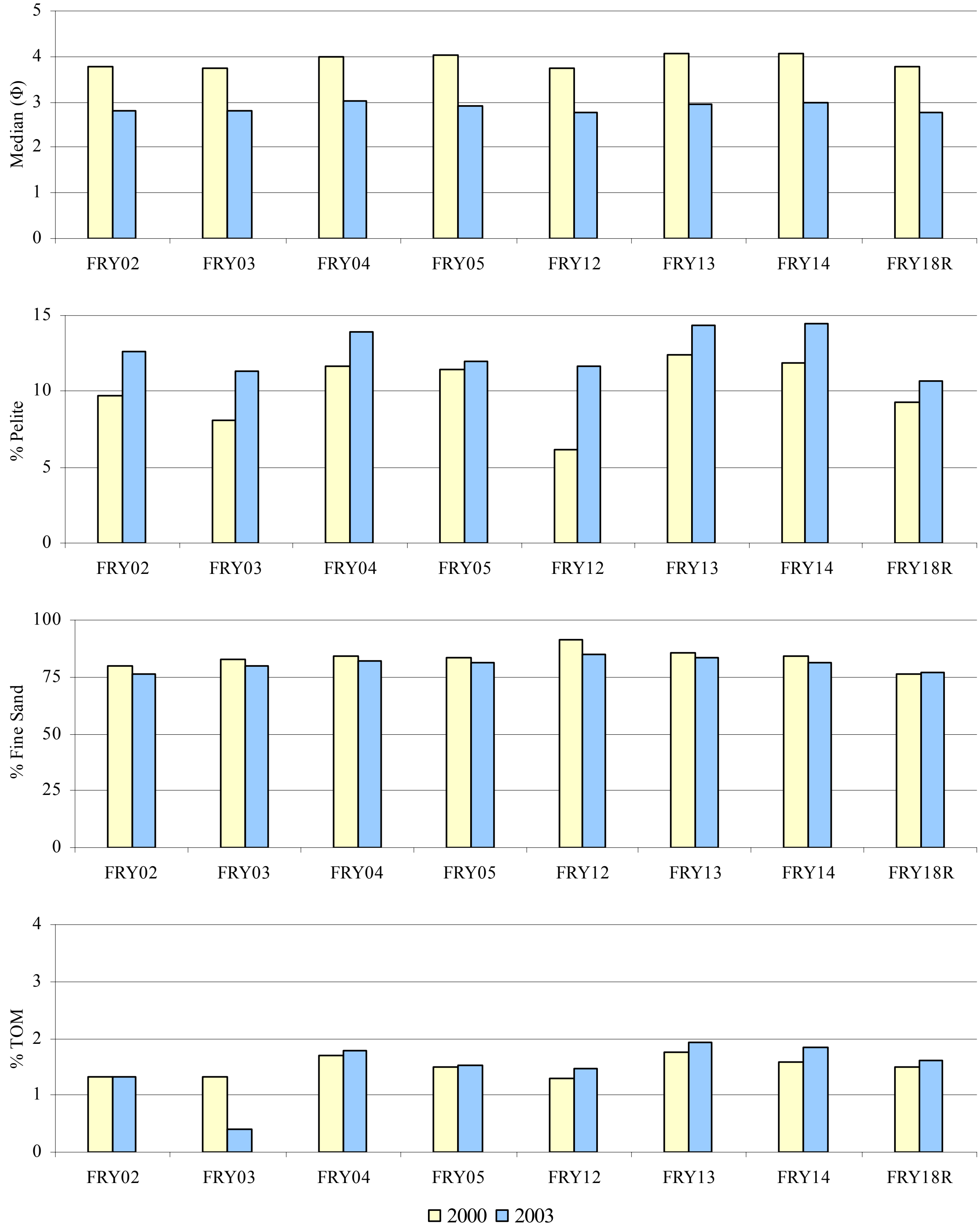


Figure 16.2. Sediment characteristics at Frøy in 2000 and 2003. Fine sand is the relative amount of sand with grain size 63-250 µm.

16.2.2 Chemical compounds

16.2.2.1 LSC

The results of the LSC (limits of significant contamination) calculations of hydrocarbons and metals are presented in the chapter concerning the regional and reference sites. Both the $LSC_{central\ 97\text{-}03}$ and the field specific LSC value ($LSC_{FRY18R\ 03}$) are presented in Table 16.3. Fine sediments are more likely to have higher affinity for pollutants than coarse sediments. LSC in the text relates to $LSC_{central\ 97\text{-}03}$.

Table 16.3. Limits of Significant Contamination (LSC) for the Frøy field in 2003, and for the central part of Region II based on data from 1997 to 2003 ($LSC_{central\ 97\text{-}03}$) and the whole of Region II based on data from 1997 to 2003 ($LSC_{regII\ 97\text{-}03}$). For comparison, LSC-values from 2000 are included. All values in mg/kg dry sediment.

	THC	PAH (16)	NPD's	Decalins	Cu	Cr	Zn	Ba	Pb	Cd[1]	Hg
$LSC_{FRY18R\ 03}$	13.4	0.073	0.022	0.622	1.3	7.0	9.0	94	3.6	0.03[1]	0.009
$LSC_{central\ 97\text{-}03}$	14.5	*	*	*	2.2	9.4	12.4	161	6.8	0.03[1]	0.012
$LSC_{regII\ 97\text{-}03}$	13.3	*	*	*	2.0	9.4	11.1	136	6.6	0.03[1]	0.011
$LSC_{FRY18R\ 00}$**	8.3	*	0.024	0.084	1.6	6.3	5.6	111	5.8	0.075	0.008
$LSC_{regII\ 97\text{-}00}$**	9.8	*	*	*	2.0	9.6	8.9	146	7.0	0.029	0.008

* NPD's, PAH's and decalins are not analysed at regional sites in 1997 and 2000
** Data from Mannvik & al. 2001
[1] LSC = detection limit

16.2.2.2 Hydrocarbons

Summarised results of the hydrocarbon analyses, along with the content of selected hydrocarbon compounds in the different layers (0-1, 1-3 and 3-6) are given in Table 16.4 and Table 16.5. The complete data set including replicates is given in the Appendix. Comparison of the THC content in 2003 with previous surveys is presented in Figure 16.4.

THC was found in the range from 9.0 to 26.1 mg/kg, and THC concentrations above LSC occurred at FRY04, FRY05, FRY12 and FRY13. Highest concentrations were found at FRY13, 250 m to the southeast of the field centre. In general there was higher THC content at most sites in 2003 than in 2000. The increase was particularly evident at 250 m distance to the southeast, southwest and northwest. In the surface layer of the sediments PAH and NPDs occurred above LSC at FRY04, 250 m to the southeast.

Vertical sediments samples taken at FRY04, 250 m downstream from the field centre, occurred THC and NPD above LSC in all layers (0-1, 1-3 and 3-6 cm) in the sediment. Decalins occurred above LSC in the 0-1 and 3-6 cm layers and PAH occurred above LSC in the 0-1 cm layer. The content of THC, PAH and NPD decreased with increasing depth in the sediments. Vertical sediments samples taken at FRY03, 500 m downstream from the field centre, revealed that NPD occurred above LSC in the 0-1 and 1-3 cm layers (Table 16.5).

Table 16.4. The content of oil hydrocarbons in sediments from Frøy in 2003. All values in mg/kg dry sediment. THC values above $LSC_{central\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{FRY18R\ 03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data for the regional and field reference sites in the central part of region II are included.

Site	THC		Olefins		PAH(16)		NPD		Dekalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
FRY02	9.0	0.9	0.07	0.00						
FRY03	10.9	4.0	0.10	0.07	0.035	0.014	0.020	0.006	0.263	0.080
FRY04	20.3	5.4	0.88	0.19	0.240	0.256	0.270	0.203	0.477	0.168
FRY05	25.2	1.5	0.87	0.20	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
FRY12	17.4	2.6	0.07	0.00	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
FRY13	26.1	1.0	0.75	0.16	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
FRY14	13.2	1.9	0.09	0.04	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
FRY18R	9.5	1.7	0.07	0.00	0.042	0.014	0.017	0.002	0.265	0.153
av. ± sd.[1]	17.4 ± 6.8		0.40±0.41							
min – max[1]	9.0 - 26.1		0.07-0.88							
av. ± sd.[2]	11.2±4.0				0.067±0.027		0.020±0.004		0.232±0.085	
min – max[2]	<3.0-15.5				0.013-0.102		0.012-0.027		0.095-0.461	

n.a. = not analysed.
[1] Field sites, exclusive FRY18R
[2] Reg + $Ref_{central\ 03}$

Table 16.5. The content of oil hydrocarbons in vertical sections of sediment from 3 sampling sites at Frøy in 2003. All values in mg/kg dry sediment. THC values above $LSC_{central\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{FRY18R\ 03}$ are dark shaded.

Site	Layer (cm)	THC	Olefins	PAH(16)	NPD	Decalins
FRY03	0-1	13.5	0.07	0.051	0.026	0.285
	1-3	8.7	0.07	0.038	0.023	0.190
	3-6	6.7	0.07	0.041	0.022	0.155
FRY04	0-1	21.5	0.60	0.104	0.193	0.670
	1-3	15.4	0.54	0.048	0.124	0.420
	3-6	17.6	0.73	0.046	0.118	0.660
FRY18R	0-1	10.6	0.07	0.047	0.018	0.235
	1-3	11.1	0.07	0.064	0.020	0.215
	3-6	6.8	0.07	0.058	0.015	0.175

Olefins were found in the range from 0.07 to 0.88 mg/kg. The highest content was found in sediments at 250 m to the southeast (FRY04) and 250 m to the northwest (FRY05) of the field centre. The olefin content of the sediments was lower in 2003 than in 1997 and 2000 (Figure 16.3).

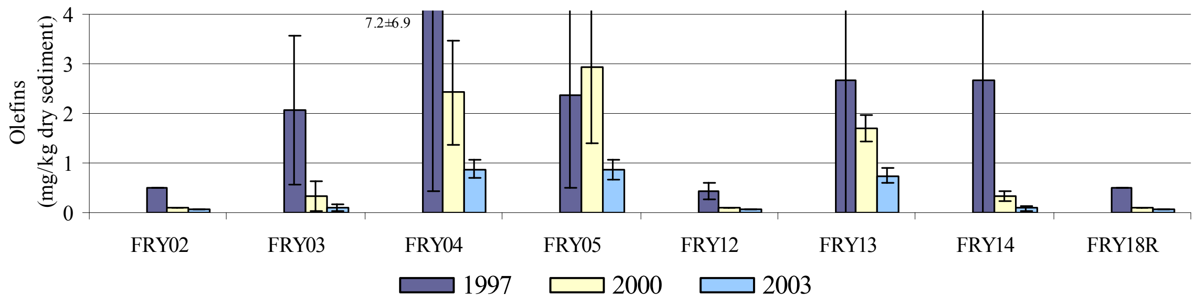


Figure 16.3. Average content and standard deviations of olefins in the sediments at the sampling sites at Frøy in 1997, 2000 and 2003.

16.2.2.3 Metals

Table 16.6 summarises the results of the metal analyses of the Frøy field in 2003. Concentrations of selected metals in the different layers (0-1, 1-3 and 3-6) of sediment are given in Table 16.7, whereas the complete data set including replicates is given in the Appendix. Comparisons of the metal contents in 2003 with the metal contents in 1997 and in 2000 are presented in Figure 16.7.

Table 16.6 Content of metals in sediments from Frøy in 2003. All values in mg/kg dry sediment. Values above $LSC_{central\ 97\text{-}03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data in the regional and field reference sites in the central part of the region II are included.

Site	Cu		Cr		Zn		Ba		Pb		Cd		Hg	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
FRY02	1.0	0.1	5.4	0.3	7.5	0.5	169	47	3.5	0.4	<0.03	-	n.a.	n.a.
FRY03	1.1	0.2	5.1	0.6	7.5	0.7	217	69	3.3	0.2	<0.03	-	0.008	0.001
FRY04	2.7	0.5	7.3	0.2	11.0	1.0	554	25	4.6	0.4	0.04	-	0.010	0.001
FRY05	2.5	0.4	7.0	0.6	11.4	1.6	532	103	4.6	0.5	<0.03	-	n.a.	n.a.
FRY12	1.1	0.2	5.6	0.5	7.6	0.7	204	58	3.1	0.5	<0.03	-	n.a.	n.a.
FRY13	2.3	0.2	6.8	0.6	9.9	0.4	442	33	4.1	0.3	<0.03	-	n.a.	n.a.
FRY14	1.4	0.2	6.5	1.0	8.6	0.3	300	33	3.7	0.3	<0.03	-	n.a.	n.a.
FRY18R	1.0	0.1	5.6	0.6	8.0	0.5	67	12	3.4	0.1	<0.03	-	0.008	0.001
av. ± sd.[1]	1.7 ± 0.8		6.3 ± 0.9		9.1 ± 1.7		346 ± 162		3.9 ± 0.6		<0.03			
min – max[1]	1.0 - 2.7		5.1 - 7.3		7.5 - 11.4		169 - 554		3.1 - 4.6		<0.03-0.04			
av. ± sd.[2]	1.2 ± 0.4		6.9 ± 1.2		9.4 ± 1.3		66 ± 31		4.2 ± 0.6		<0.03		0.009±0.003	
min – max[2]	<0.6-1.7		4.9-8.9		6.8-12.0		10-146		3.4-5.1		<0.03		0.006-0.014	

n.a. = not analysed.
[1] Field sites, exclusive FRY18R
[2] Reg + ref $_{central\ 03}$

Table 16.7. The content of metals in vertical sections of sediment from 3 sampling sites at Frøy in 2003. All values in mg/kg dry sediment. Values above $LSC_{central\ 97\text{-}03}$ are dark shaded.

Site	Layer (cm)	Cu	Cr	Zn	Ba	Pb	Cd	Hg
FRY03	0-1	1.2	5.5	7.5	212	3.3	<0.03	0.009
	1-3	1.2	4.9	7.6	128	3.4	<0.03	0.006
	3-6	1.3	6.2	9.3	305	3.9	<0.03	0.009
FRY04	0-1	2.7	7.2	11.9	578	5.0	0.03	0.010
	1-3	3.7	7.5	11.9	456	4.9	0.03	0.009
	3-6	2.3	7.4	11.9	611	5.6	0.03	0.011
FRY18R	0-1	1.2	6.3	8.2	81.2	3.5	<0.03	0.008
	1-3	1.2	6.1	8.1	81.9	3.3	<0.03	0.009
	3-6	1.0	5.4	7.8	68.3	3.7	<0.03	0.008

Barium was found in a range from 169 to 554 mg/kg, lead from 3.1 to 4.6 mg/kg, cadmium from <0.03 to 0.04 mg/kg, copper from 1.0 to 2.7 mg/kg, mercury from 0.008 to 0.010 mg/kg, chromium from 5.1 to 7.3 mg/kg and zinc from 7.5 to 11.4 mg/kg (Table 16.6). Sediments from all the field specific sampling sites had barium (169-554 mg/kg) content above LSC. Copper (2.3-2.7 mg/kg) was present above LSC at FRY04, FRY05 and FRY13, and cadmium (0.04 mg/kg) occurred above LSC at FRY04.

Vertical sediment samples (0-1, 1-3 and 3-6 cm) from FRY04 had barium and copper content above LSC in all depth intervals. At FRY03 barium occurred above LSC in the 0-1 and 3-6 cm intervals.

Since 2000 the content of barium and lead has decreased. The copper content has decreased at most sites except at FRY04 and FRY05, and the zinc content has increased at all sites.

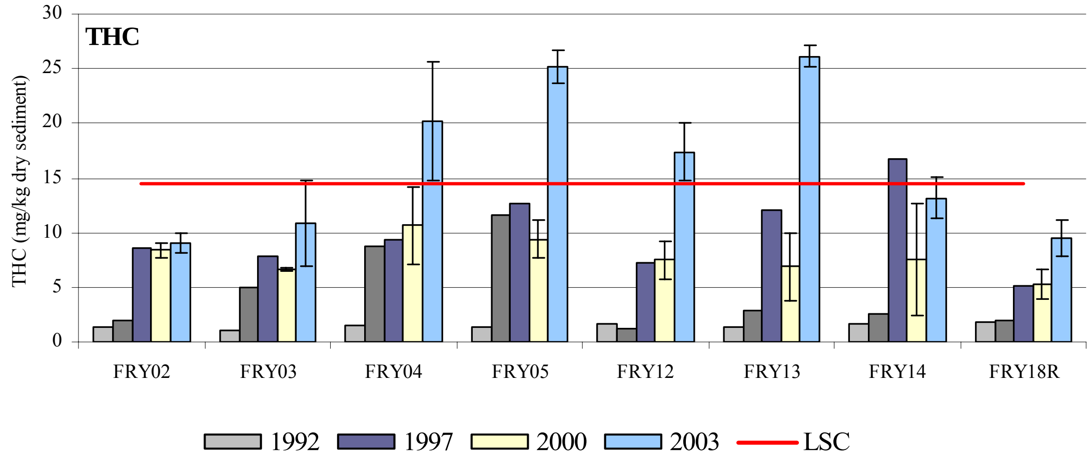


Figure 16.4. Average THC concentrations and standard deviations in sediments from Frøy in 2003 and previous years. Red line is $LSC_{central\ 97\text{-}03}$.

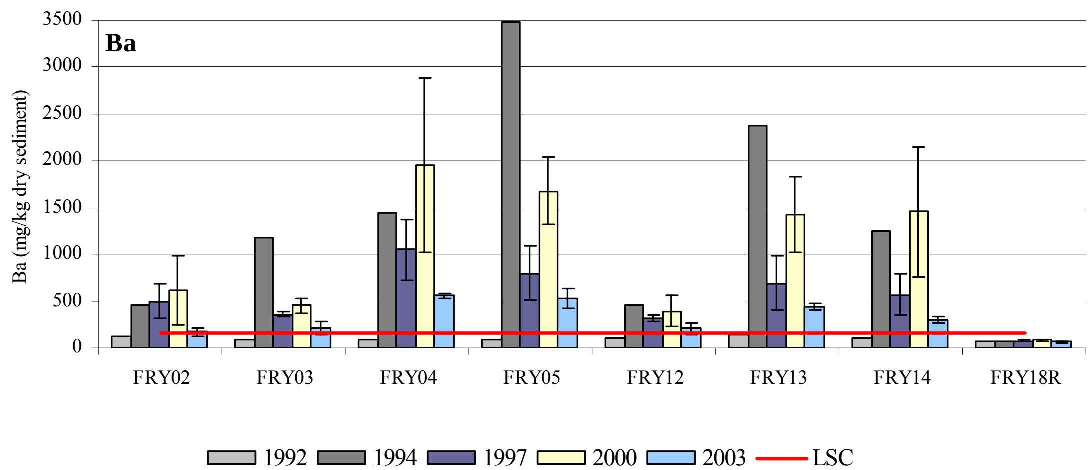


Figure 16.5. Average barium concentrations and standard deviations in sediments from Frøy in 2003 and previous years. Red line is $LSC_{central\ 97\text{-}03}$.

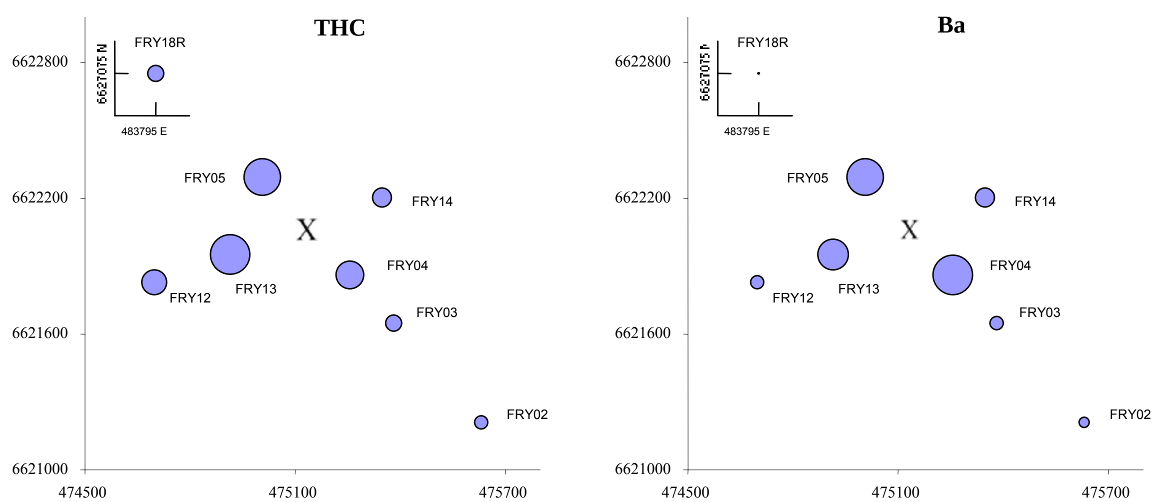


Figure 16.6. Distribution of THC and barium in sediments at the sampling sites at Frøy in 2003. The size of the circle indicate the amount of THC and Ba. The field centre is marked with an X.

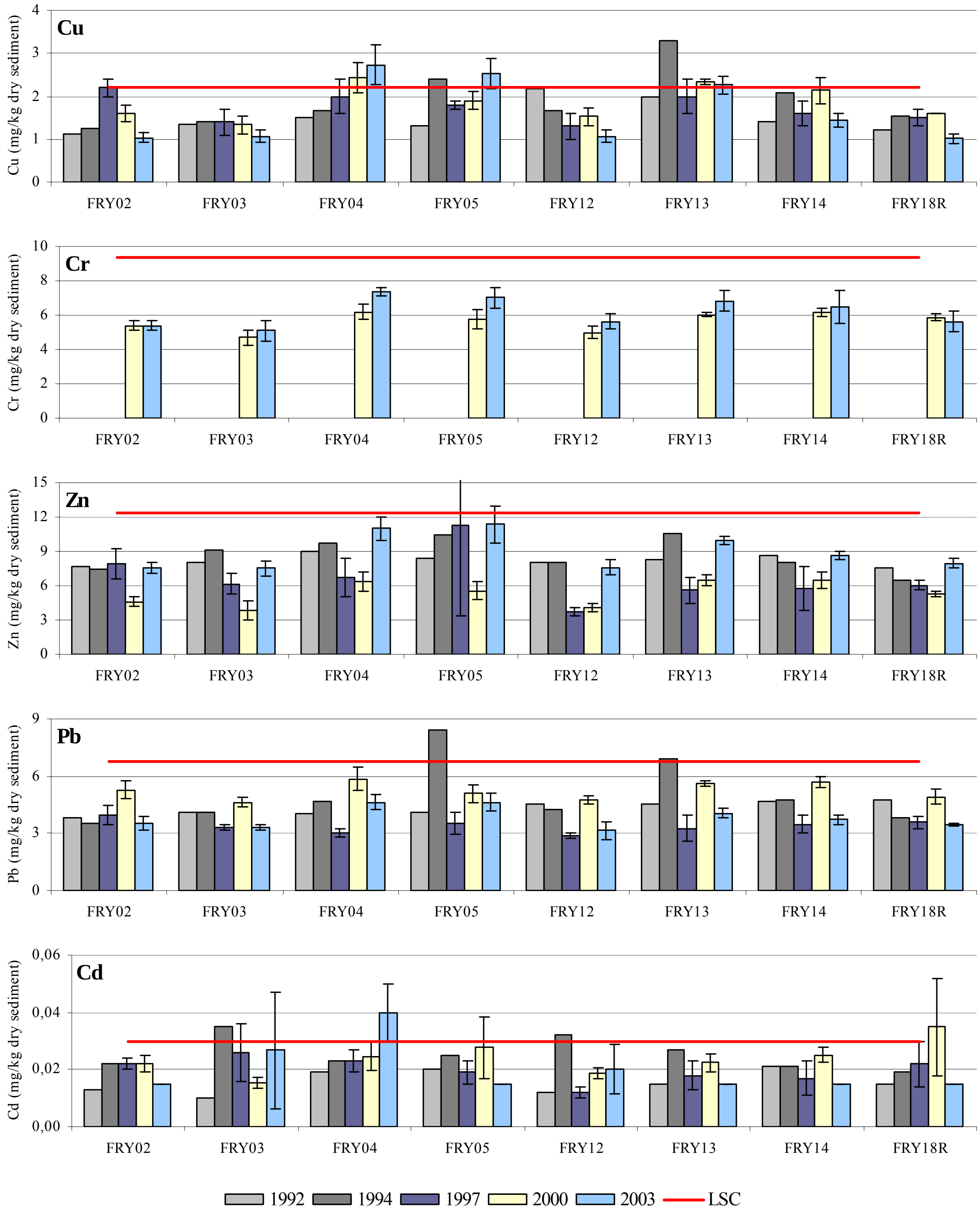


Figure 16.7. Average content and standard deviations of metals in sediment from Frøy in 2003 and previous surveys. Red line is $LSC_{central\ 97\text{-}03}$.

The field sites at Frøy were compared to nearby regional (RII03 and RII10) and field specific reference sites (JOT30R, HEM22R and VA13R) based on sediment characteristics (TOM and pelite) and chemical content in the sediments (Figure 16.8). FRY04 and FRY13 and partly FRY05, all at 250 m distance to the field centre, comprise a separate group due to higher content of chemical compounds in the sediments.

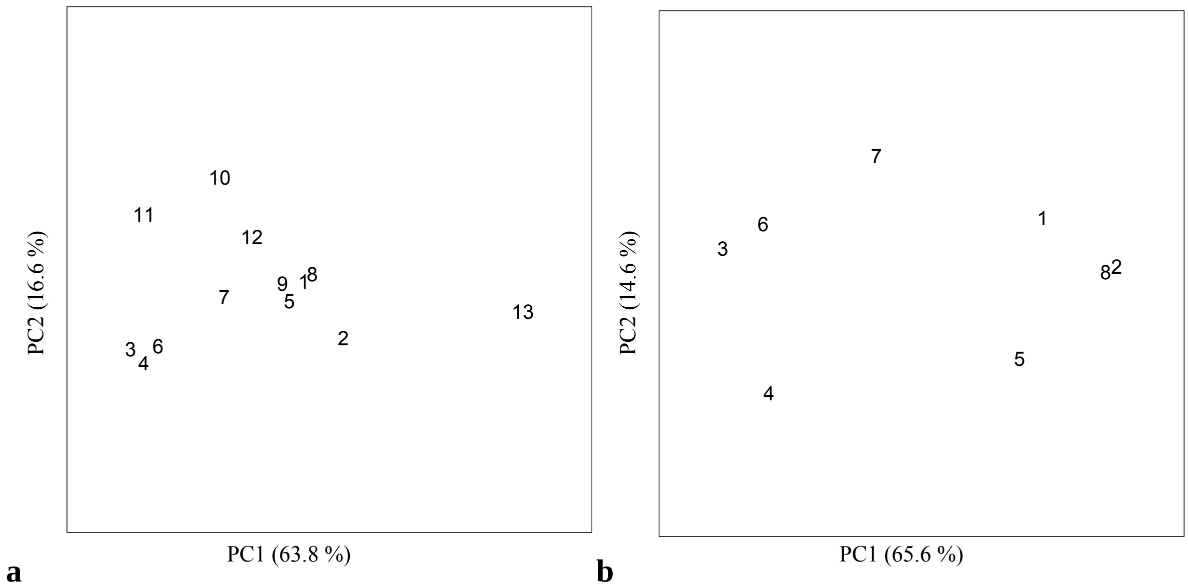


Figure 16.8. 2-D plot from the PCA analysis of environmental variables (% pelite, % sand, % gravel, median Φ, % TOM, Cu, Ba, Zn, Cr, Pb and THC) carried out on:
a) Frøy field sites compared to the reference sites at Jotun, Heimdal and Vale and the regional sites RII03 and RII10. Explained variation in the data 80.5 %.
b) Frøy fields sites. Explained variation in the data 80.1 %.
Numbers in the plot identify the sampling sites. See table below.

1	FRY02	6	FRY13	11	JOT30R
2	FRY03	7	FRY14	12	HEM22R
3	FRY04	8	FRY18R	13	VA13R
4	FRY05	9	RII-03		
5	FRY12	10	RII-10		

16.1.2.3 Bottom fauna

A summary of the distribution of individuals and taxa within the main taxonomic groups are given in Table 16.8. Unidentified juveniles of the sea urchins Spatangoids (6981 individuals) and Echinoides (640 individuals), and juveniles of the brittle stars *Amphiura filiformis* (576 individuals) and *Ophiura affinis* (338 individuals) are omitted from the analyses, as they occurred in high numbers. In total, 9862 individuals within 233 taxa were collected at Frøy in 2003. The fauna was numerically dominated by annelida with 66 % the individuals and 47 % of the taxa.

Table 16.8. Distribution of individuals and taxa within the main taxonomic groups at Frøy in 2003 including data from FRY18R (unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis* and *Ophiura affinis* are not included).

Main taxonomic groups	Number of individuals	%	Number of taxa	%
Annelida	6480	66	110	47
Arthropoda	531	5	46	20
Mollusca	1511	15	47	20
Echidermata	526	5	14	6
Diverse groups	814	8	16	7
Total	9862	100	233	100

The species/area curve for FRY18R indicates that five replicate samples give a representative impression of the bottom fauna in the area (Figure 16.9). However, as more area is sampled, more taxa are collected, indicating that not even 10 replicate samples give the full species assemblage of the area.

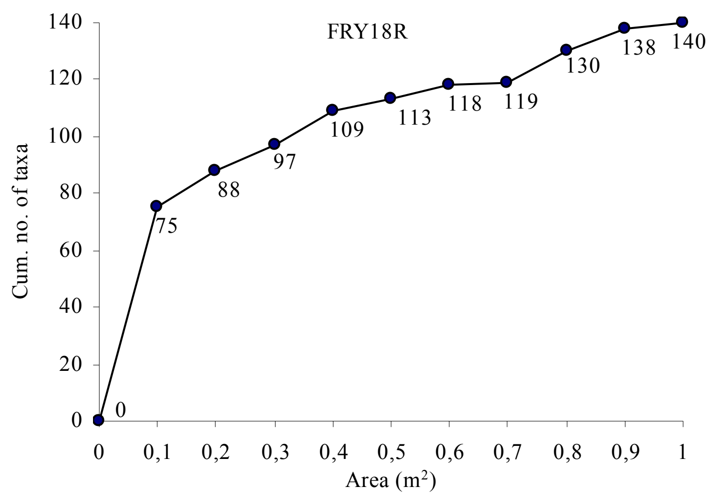


Figure 16.9. Species/area curve for the reference station at the Frøy field. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis* and *Ophiura affinis*.

The distribution of individuals and taxa are shown in Figure 16.10. Number of individuals and taxa at each site, and the calculated diversity indexes (H' and ES_{100}) are given in Table 16.9 and Figure 16.11. The number of individuals varied from 884 (FRY12) to 1549 (FRY05), and the number of taxa varied from 113 (FRY03) to 139 (FRY14). The Shannon-Wiener diversity index (H') varied from 5.63 (FRY05) to 5.82 (FRY14), whereas the ES_{100} index varied from 43.0 (FRY05) to 47.5 (FRY12). The evenness index J varied from 0.80 (FRY05) to 0.85 (FRY03). The corresponding values at FRY18R are within or near the variation at the field sites. The number of taxa, diversity and evenness indicate good environmental conditions at all sites.

Compared to the results from 2000 there were fewer individuals and slightly fewer taxa in 2003. Despite this the species diversity and evenness increased between 2000 and 2003.

Table 16.9. Number of individuals, species/taxa and selected community indices for each site (0.5 m^2) at the Frøy field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis* and *Ophiura affinis*.

Site number	Number of individuals	Number of Taxa	Diversity H'	Evenness J	H'-max	ES_{100}
FRY 02	913	124	5.72	0.82	6.95	45.9
FRY 03	926	113	5.77	0.85	6.82	46.5
FRY 04	1276	133	5.70	0.81	7.06	46.2
FRY 05	1549	133	5.63	0.80	7.06	43.0
FRY 12	884	117	5.80	0.84	6.87	47.5
FRY 13	1023	124	5.69	0.82	6.95	46.7
FRY 14	1320	139	5.82	0.82	7.12	46.8
FRY 18R (6-10)	1191	113	5.52	0.81	6.82	42.7
FRY 18R (11-15)	780	112	5.80	0.85	6.81	46.8
FRY 18R (6-15)	1971	140	5.73	0.80	7.13	44.8
Sum[1]	7891	225				
Average[1]	1127	126	5.73	0.82	6.98	46.1
SD[1]	256	9	0.07	0.02	0.11	1.5
Min[1]	884	113	5.63	0.80	6.82	43.0
Max[1]	1549	139	5.82	0.85	7.12	47.5
Average[2]	774	113	5.55	0.81	6.81	44.3
SD[2]	230	14	0.24	0.02	0.18	2.6
Min[2]	488	94	5.12	0.79	6.55	38.7
Max[2]	1202	141	5.85	0.85	7.14	47.9

[1]Field sites, exclusive FRY18R
[2]Reg + Ref $_{central\ 03}$

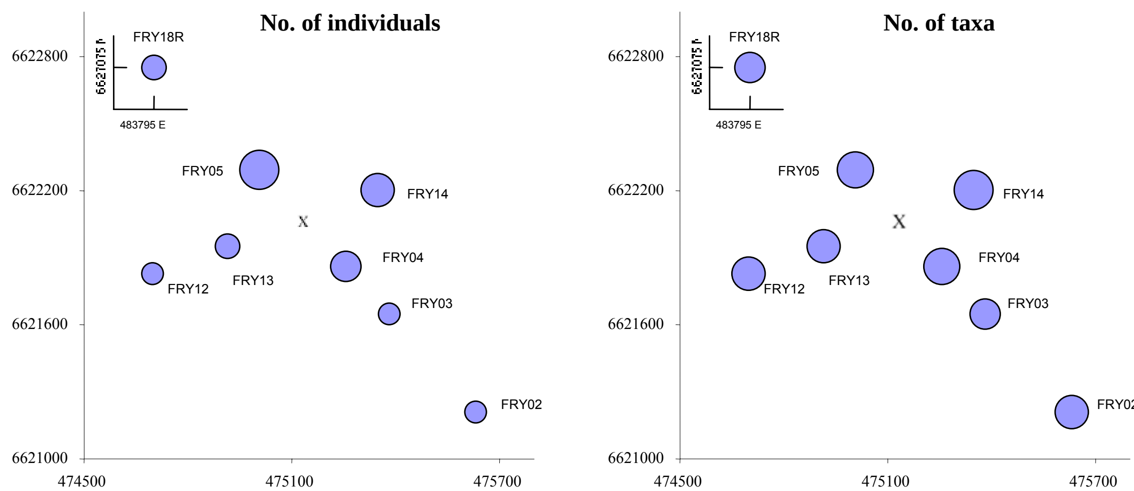


Figure 16.10. Distribution of bottom fauna (individuals and taxa) among the sampling sites in 2003. The size of the circle indicates the number of individuals and taxa. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis* and *Ophiura affinis*. Values for FRY18R are average of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2). The field centre is marked with an X.

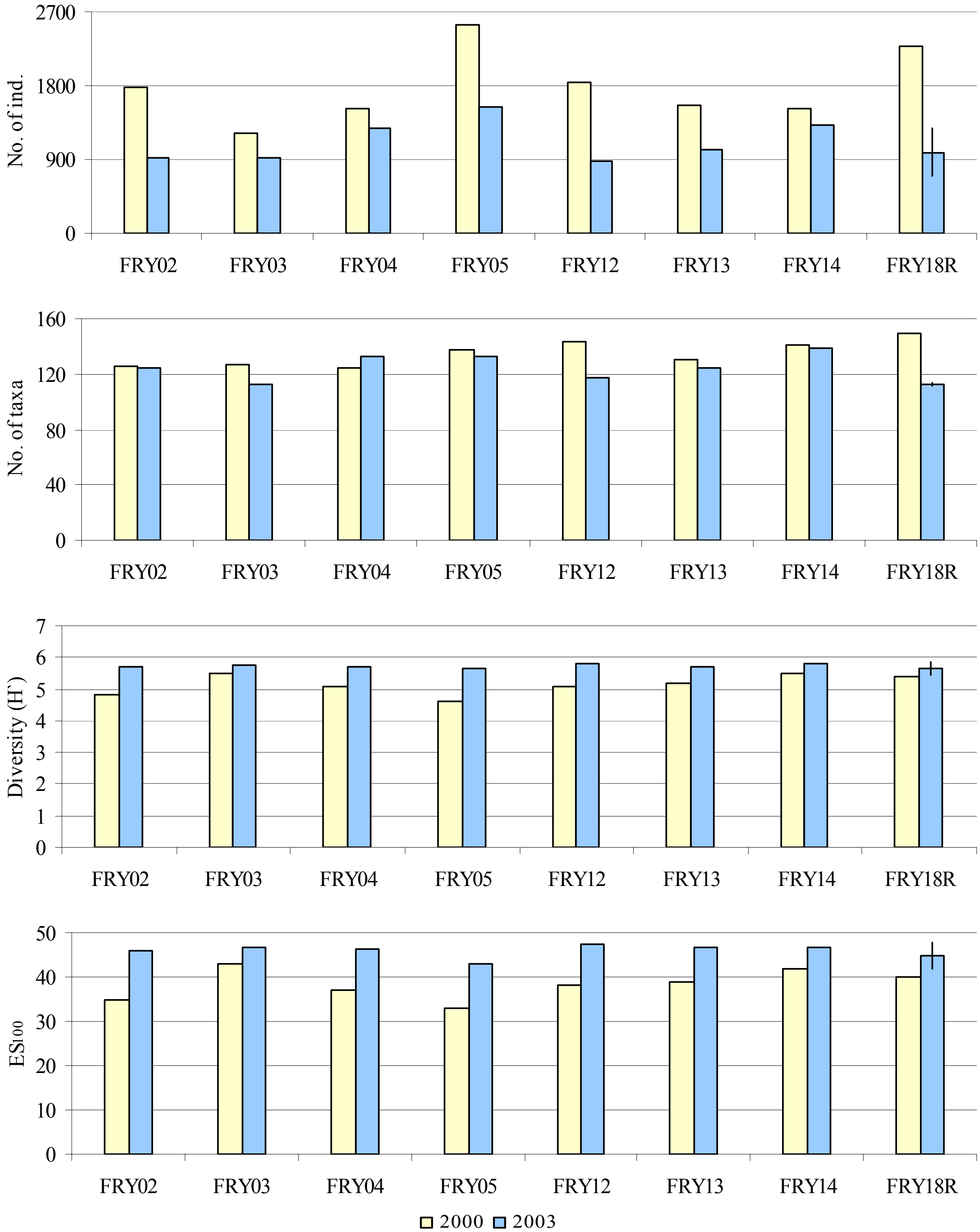


Figure 16.11. Number of individuals, taxa and selected community indices for each site (0.5 m^2) at the Frøy field for 2000 and 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis* and *Ophiura affinis*. Values for FRY18R are average ± standard deviation of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2).

Distribution of taxa in geometrical classes is presented in Figure 16.12. The smooth graphs are indicating undisturbed bottom fauna.

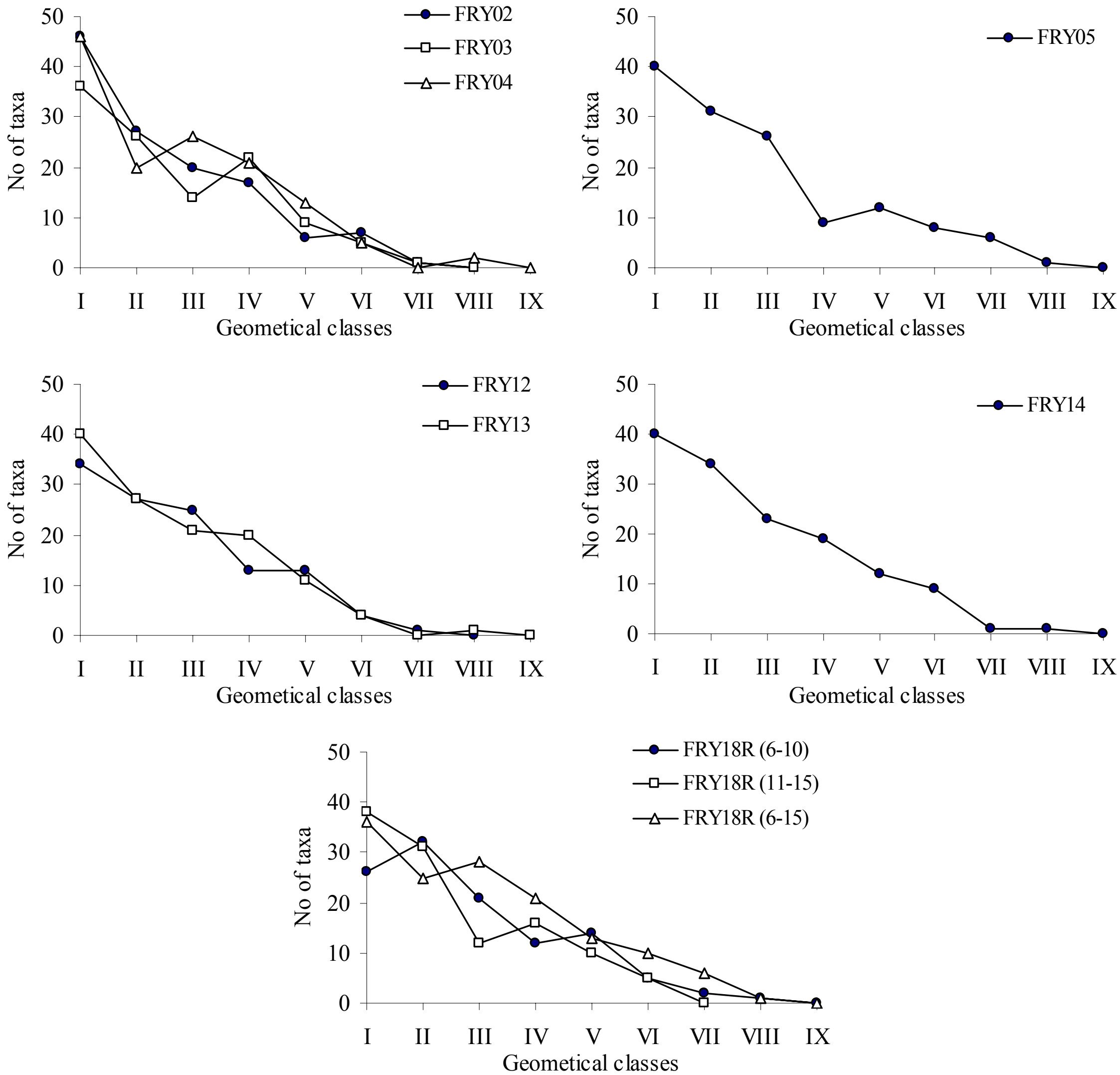


Figure 16.12. Distribution of taxa in geometrical classes for the sites at Frøy in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis* and *Ophiura affinis*.

The ten most numerous taxa are listed in Table 16.12 at the end of this chapter. The list comprise 26 taxa and 6560 individuals, which was 11.2 % of all (233) taxa and 66.5 % of all (9862) individuals. The most abundant species were the polycaetes *Myriochele oculata, Paramphinome jeffreysii, Laonice sarsi* and *Spiophanes bombyx* and the phoronid *Phoronis* sp. The polychaetes *Capitella capitata* and *Chetozone* sp. were abundant at FRY05, which is located 250 m to the northwest of the installation. The taxa assemblage indicates good environmental conditions at all sites, although the occurrence of *Capitalla capitata* might indicate some faunal disturbance at FRY05.

The results of the multivariate analyses are given in the dendrogramme (Figure 16.13) and the MDS plott (Figure 16.14).

In the cluster analysis, all sites are grouped together within approximately 70 % similarity, indicating high similarity in the species assemblages within the field.

The results of the MDS analysis support the findings in the cluster analysis, confirming the similarity in species assemblage within the field and confirming that there were no well pronounced faunal gradients at Frøy in 2003. The stress test of the MDS analysis was 0.12, indicating a good fit of the data.

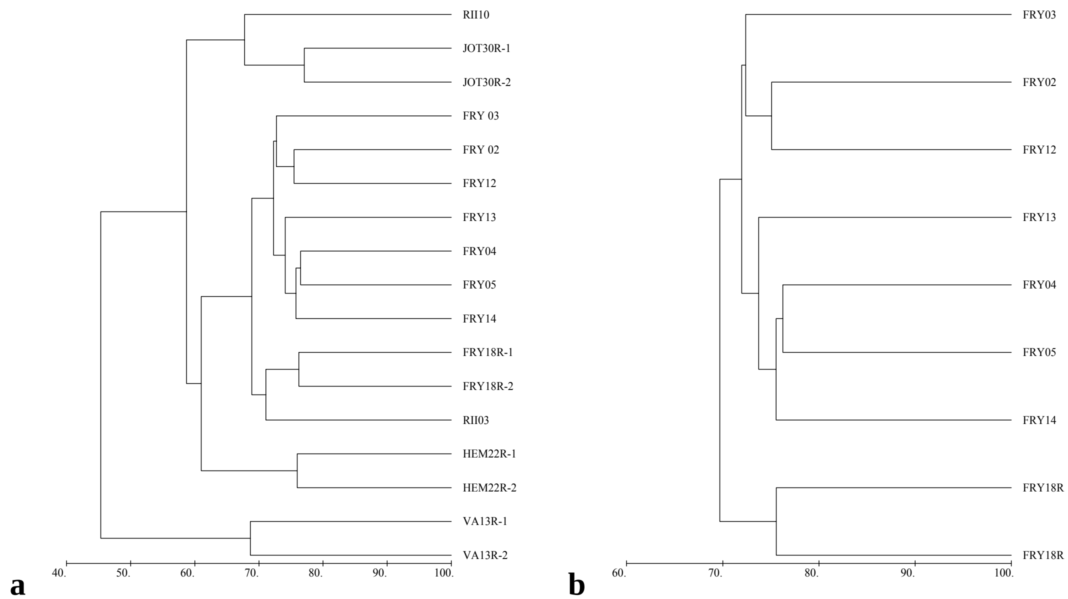
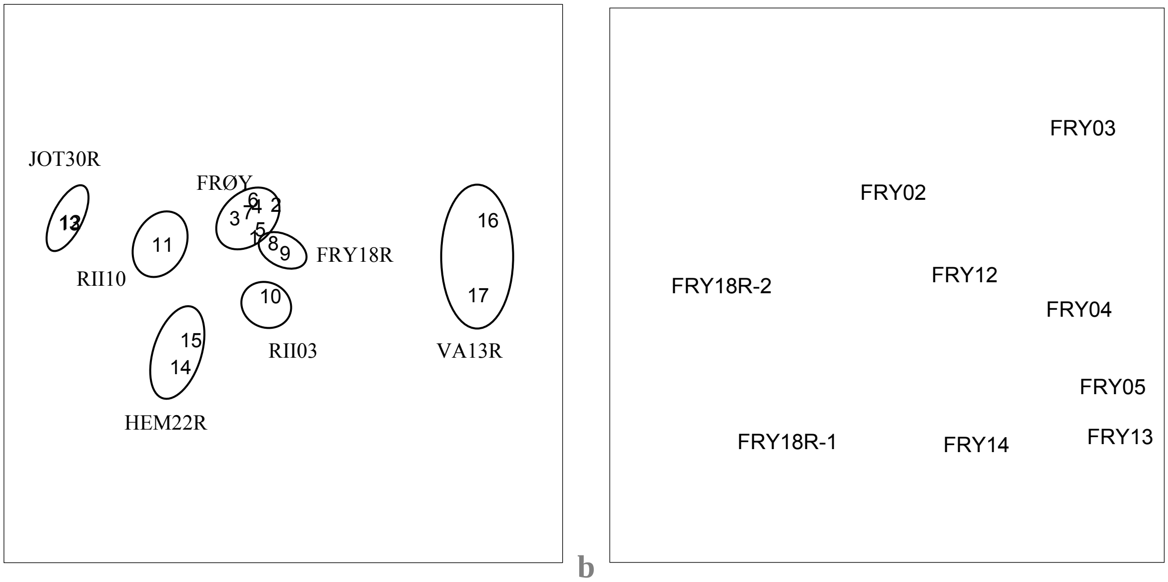


Figure 16.13. Dendrogram showing the similarity between fauna from sampling sites at:

a) Frøy field, regional sites (RII03 and RII10) and reference sites (JOT30R, HEM22R and VA13R) in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.
b) Frøy field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis* and *Ophiura affinis*.



a b

Figure 16.14. A 2-dimetional plott of the MDS analysis of the fauna data from:

a) Frøy field compared to some regional sites (RII03 and RII10) and reference sites (JOT30R, HEM22R and VA13R) in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea. Stress = 0.06. Codes in table below.
b) Frøy field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis* and *Ophiura affinis*. Stress = 0.12.

1	FRY 02	4	FRY05	7	FRY14	10	RII03	14	HEM22R-1
2	FRY 03	5	FRY12	8	FRY18R-1	11	RII10	15	HEM22R-2
3	FRY04	6	FRY13	9	FRY18R-2	12	JOT30R-1	16	VA13R-1
						13	JOT30R-2	17	VA13R-2

Linking of biotic and environmental variables by BIOENV revealed that barium and TOM, best correlated to the biota at $\rho_w = 0.67$ (Table 5.10). This indicates that there was an association between some environmental variables and the bottom fauna.

Table 16.10. Combinations of the 10 environmental variables, taken *k* at a time, yielding the best matches of biotic and abiotic similarity matrices for each *k*, as measured by weighted Spearman rank correlation ρ_w. Bold type indicates overall optimum. All possible combinations of variables and associated correlation to the biotic are given in the Appendix.

Number of variables (*k*)	Correlation coefficient (ρ_w)	Environmental variables									
1	0.630	Ba									
1	0.254	Cr									
1	0.251	THC									
1	0.132	Sand									
1	0.118	Pelite									
1	0.099	Cu									
1	0.070	Zn									
1	0.050	TOM									
1	-0.028	Pb									
1	-0.172	Gravel									
2	**0.673**	Ba	TOM								
3	0.671	Ba	TOM	THC							
4	0.667	Ba	TOM	THC	Pelite						
5	0.600	Ba	TOM	THC		Sand	Cr				
6	0.560	Ba	TOM	THC	Pelite	Sand	Cr				
7	0.504	Ba	TOM	THC	Pelite	Sand	Cr	Cu			
8	0.448	Ba	TOM	THC	Pelite	Sand	Cr	Cu	Gravel		
9	0.400	Ba	TOM	THC	Pelite	Sand	Cr	Cu	Gravel	Zn	
10	0.355	Ba	TOM	THC	Pelite	Sand	Cr	Cu	Gravel	Zn	Pb

16.2.4 Estimation of influenced area

The extension of contamination along sampling transects and the minimum area of contaminated sediments for THC, barium and other metals as well as for faunal disturbance is given in Figure 16.15 and Table 16.11. The contaminated area was smaller in 2003 than in 2000 for barium and other metals. The area with faunal disturbance was also reduced in 2003 compared to 2000. Whereas the area contaminated by THC had increased.

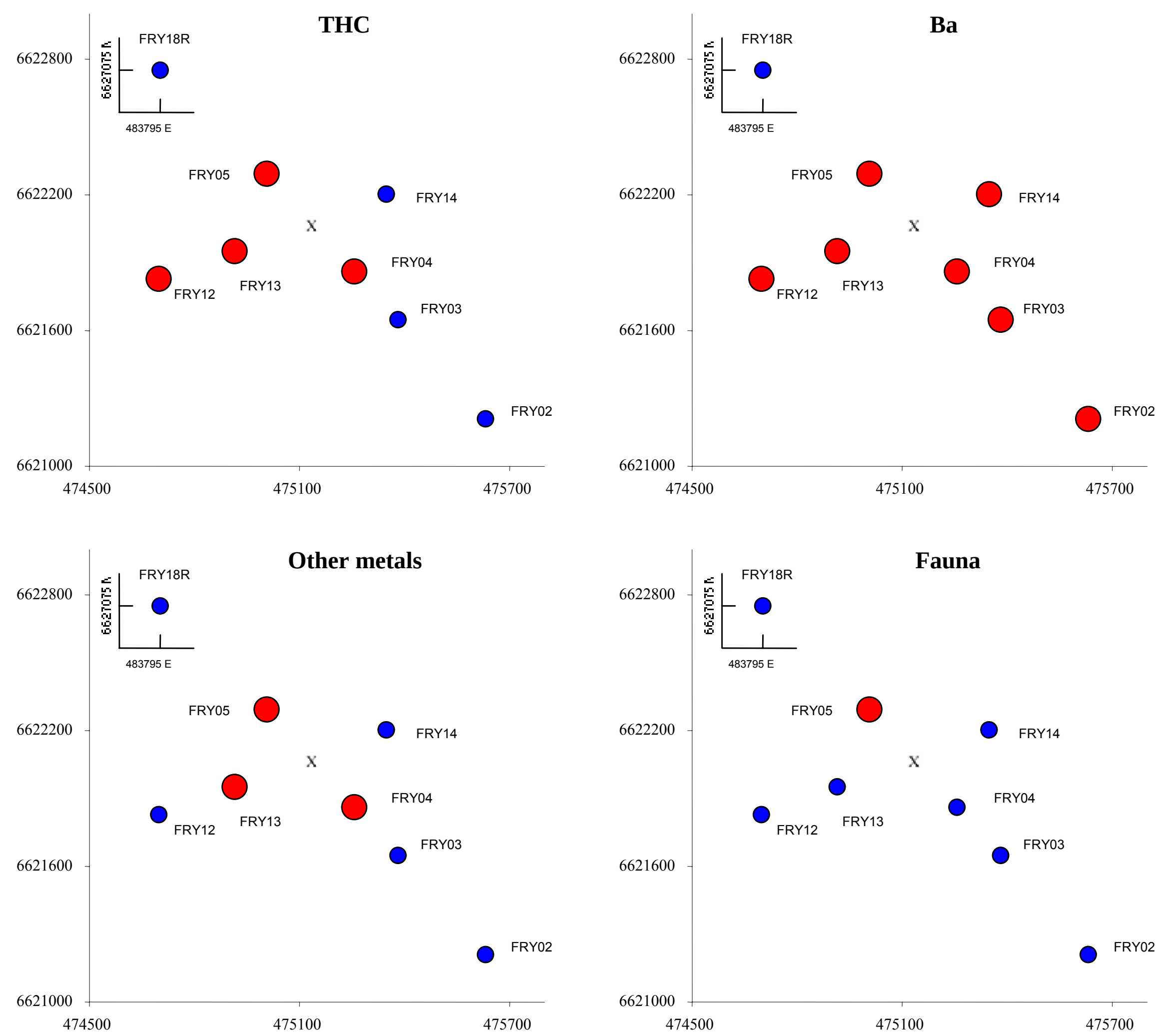


Figure 16.15. Faunal disturbance and chemical contamination of the sediments at Frøy in 2003. The field centre is marked with a X. Uncontaminated sites and sites with no faunal disturbance are marked with small blue circles.

Table 16.11. Estimated distance of contamination and faunal disturbance from the installation, and estimated area of contamination and faunal disturbance around the field centre.

Frøy	NE (m)	SE (m)	SW (m)	NW (m)	2003 (km^2)	2000 (km^2)	1997 (km^2)
THC	0	250	500	250	0.20	0.07	0.29
Ba	250	1000	500	250	0.74	1.18	1.18
Other metals	0	250	250	250	0.10	0.15	0.00
Fauna	0	0	0	250	0.02	0.29	0.29

16.3 Summary and conclusions

Since the previous survey at Frøy in 2000 the wells were plugged and abandoned in 2001 and the jacket removed in 2002. The sediments are still characterized as fine sand, although there has been a slight increase in the pelite content since 2000. The amount of THC in the sediments has increased since 2000 perhaps due to redistribution of sediments in conjunction with the removal of the jacket, whereas the amounts of olefins, barium and lead have decreased. Highest concentrations of the chemical compounds were found at 250 m distance to the field center to the southeast, southwest and northwest. Fewer individuals and slightly fewer taxa were found among the bottom fauna in 2003 than in 2000. Despite this the diversity of the fauna has increased, indicating improved environmental conditions, although the fauna assemblage showed that the innermost (250 m distance) sampling sites to the northwest were slightly disturbed. The measured chemical compounds occurred in high concentrations at the same site and the fauna assemblage were well associated to the distribution of barium and TOM, which show that Frøy still have some environmental disturbance in the immediate vicinity of the field centre, although the area of disturbance was smaller in 2003 than in 2000.

Table 16.12. Number of individuals and relative abundance for the ten predominant taxa at each station at the Frøy field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis* and *Ophiura affinis*.

FRY02	No. of ind.	%	Cum %
Myriochele oculata	96	10.5	10.5
Spiophanes bombyx	56	6.1	16.6
Paramphinome jeffreysii	54	5.9	22.6
Thyasira croulinensis	43	4.7	27.3
Phoronis sp.	43	4.7	32.0
Laonice sarsi	42	4.6	36.6
Amphiura filiformis	34	3.7	40.3
Thyasira ferruginea	33	3.6	43.9
Thyasira obsoleta	20	2.2	46.1
Amphiura chiajei	19	2.1	48.2

FRY03	No. of ind.	%	Cum %
Myriochele oculata	82	8.9	8.9
Phoronis sp.	58	6.3	15.1
Laonice sarsi	49	5.3	20.4
Paramphinome jeffreysii	46	5.0	25.4
Owenia fusiformis	40	4.3	29.7
Amphiura filiformis	36	3.9	33.6
Spiophanes bombyx	28	3.0	36.6
Chaetozone sp.	24	2.6	39.2
Sabellidae indet.	22	2.4	41.6
Cerianthus lloydii	21	2.3	43.8
Eclysippe vanelli	21	2.3	46.1

FRY04	No. of ind.	%	Cum %
Paramphinome jeffreysii	147	11.5	11.5
Myriochele oculata	140	11.0	22.5
Laonice sarsi	62	4.9	27.4
Thyasira flexuosa	60	4.7	32.1
Phoronis sp.	46	3.6	35.7
Prionospio cirrifera	38	3.0	38.6
Pseudopolydora paucibranchiata	33	2.6	41.2
Eclysippe vanelli	30	2.4	43.6
Spiophanes kroeyeri	26	2.0	45.6
Caudofoveata indet.	26	2.0	47.6

FRY05	No. of ind.	%	Cum %
Myriochele oculata	143	9.2	9.2
Capitella capitata	109	7.0	16.3
Chaetozone sp.	102	6.6	22.9
Phoronis sp.	80	5.2	28.0
Owenia fusiformis	70	4.5	32.5
Paramphinome jeffreysii	66	4.3	36.8
Thyasira flexuosa	65	4.2	41.0
Laonice sarsi	45	2.9	43.9
Spiophanes bombyx	44	2.8	46.7
Pectinaria auricoma	40	2.6	49.3

FRY12	No. of ind.	%	Cum %
Myriochele oculata	96	10.9	10.9
Laonice sarsi	49	5.5	16.4
Paramphinome jeffreysii	46	5.2	21.6
Spiophanes bombyx	40	4.5	26.1
Phoronis sp.	37	4.2	30.3
Owenia fusiformis	26	2.9	33.3
Eclysippe vanelli	26	2.9	36.2
Amphiura filiformis	25	2.8	39.0
Prionospio cirrifera	24	2.7	41.7
Chaetozone sp.	20	2.3	44.0
Thyasira croulinensis	20	2.3	46.3
Urothoe elegans	20	2.3	48.5

FRY13	No. of ind.	%	Cum %
Myriochele oculata	163	15.9	15.9
Paramphinome jeffreysii	49	4.8	20.7
Chaetozone sp.	47	4.6	25.3
Laonice sarsi	42	4.1	29.4
Eclysippe vanelli	33	3.2	32.6
Spiophanes bombyx	28	2.7	35.4
Thyasira flexuosa	27	2.6	38.0
Lucinoma borealis	26	2.5	40.6
Owenia fusiformis	25	2.4	43.0
Diplocirrus glaucus	25	2.4	45.5

FRY14	No. of ind.	%	Cum %
Myriochele oculata	152	11.5	11.5
Paramphinome jeffreysii	85	6.4	18.0
Phoronis sp.	59	4.5	22.4
Diplocirrus glaucus	48	3.6	26.1
Laonice sarsi	45	3.4	29.5
Spiophanes bombyx	45	3.4	32.9
Amphiura filiformis	43	3.3	36.1
Chaetozone sp.	40	3.0	39.2
Thyasira croulinensis	38	2.9	42.0
Prionospio cirrifera	34	2.6	44.6
Amphiura chiajei	34	2.6	47.2

FRY18R	No. of ind.	%	Cum %
Myriochele oculata	227	11.5	11.5
Thyasira croulinensis	113	5.7	17.3
Phoronis sp.	111	5.6	22.9
Spiophanes bombyx	90	4.6	27.4
Thyasira ferruginea	78	4.0	31.4
Owenia fusiformis	76	3.9	35.3
Myriochele fragilis	69	3.5	38.8
Eclysippe vanelli	59	3.0	41.8
Paramphinome jeffreysii	49	2.5	44.2
Diplocirrus glaucus	49	2.5	46.7
Laonice sarsi	49	2.5	49.2

17 Frigg

17.1. Introduction

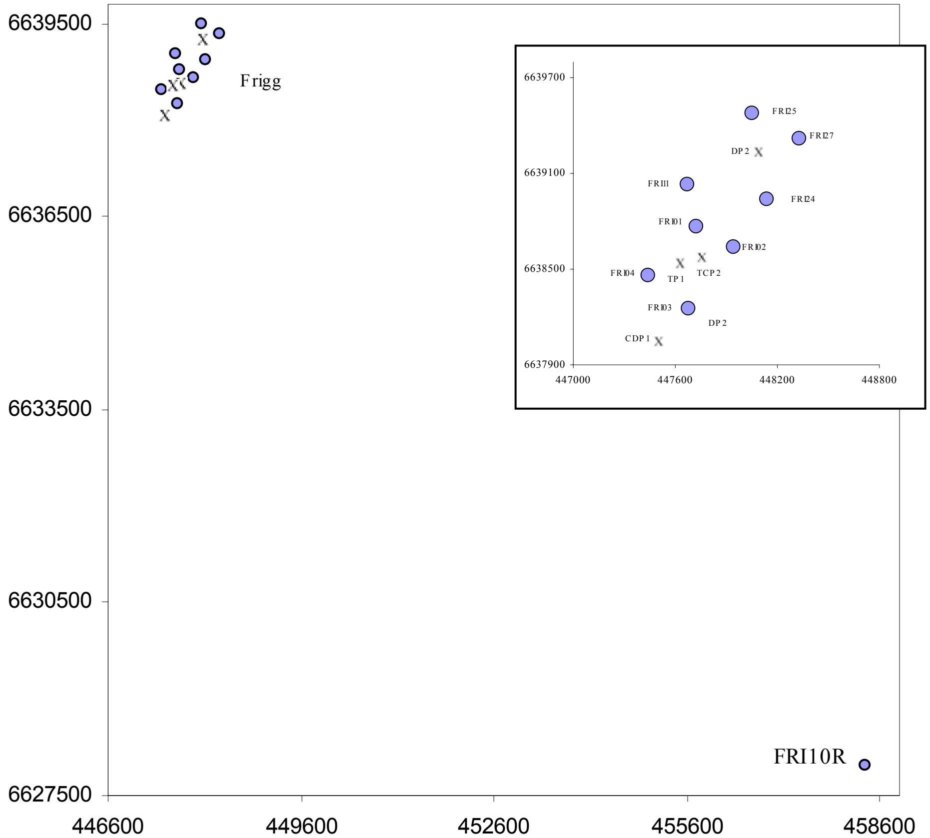
The Frigg field is situated in block 25/1. Production started at Frigg in September 1977 and cessation is planned on July 1, 2004. Permanent plugging and abandonment of 14 wells were accomplished during the period from March to June 2004. Recent discharges at Frigg are listed in Table 17.1, and sampling sites are shown in Figure 17.1.

The field was surveyed in the regional surveys of both 1997 and 2000. In 1997, none of the sediment samples were evaluated as significantly contaminated by hydrocarbons. Contamination by barium, cadmium, zinc, lead and copper were found in sediments at a sampling site at 200 m to the north of TCP2, and contamination by barium, zinc, lead and copper were found in sediments at a sampling site 200 m to the east of TCP2. Contamination by lead, zinc and copper were found at all sites, except one sampling site situated 330 m to the east of DP2. Minor signs of faunal disturbance were found at the sampling sites closest to TCP2 and TP1. Faunal disturbances were detected at the same sites in the 2000 survey too. Due to this the same sites were re-sampled in 2003.

Table 17.1. Recent discharges from operations and accidental releases at Frigg, all numbers in tonnes. In conjunction with the permanent plugging and abandonment of 14 wells (March 21 to June 4, 2004) 10.7 tonnes of chemicals were discharged from Frigg DP2.

	1997	1998	1999	2000	2001	2002	2003
Oil in produced water*	42.5	36.0	13.5	2.5	0	0	0
Chemicals**	0	0	0	20	18.1	8.3	17.0
Accidental discharges	25.7	18.3	1.0	0.7	0.02	7.2[1]	0.32

*Produced water discharges stopped in 2000. Produced water is now injected into the reservoir.
** 80-90 % of chemical discharges are in the green and yellow category
[1] Accidental release of glycol, a yellow category chemical



Site	ED50 UTM Zone 31 E	N	Distance (m) / direction (º)	Depth (m)
FRI-01	447719	6638770	200/350	104
FRI-02	447942	6638641	200/70	103
FRI-03	447674	6638253	330/194	100
FRI-04	447440	6638466	200/249	104
FRI-11	447668	6639031	500/350	106
FRI-24	448135	6638942	250/170	101
FRI-25	448049	6639480	250/350	100
FRI-27	448327	6639324	250/70	102
FRI-10R	458362	6627966	14686/135.4	116

Figure 17.1. Map showing the internal distribution of sampling sites in Frigg, 2003. Positioning according to UTM ED50 zone 31. The field centres is marked with an X.

17.2. Results and discussion

17.2.1 Sediments characteristics

TOM, the amount (%) of gravel, sand and pelite, median (Φ), sorting, skewness and kurtosis in the sediment from the present survey is presented in Table 17.2. Additional information on colour and smell can be found in the Appendix. Median (Φ), pelite, sand and TOM are compared with data from 2000 in Figure 17.2.

The sediments at Frigg are classified as fine sand with median (Φ) values ranging from 2.42 (FRI25) to 2.50 (FRI02). The amount of pelite varied from 1.83 % (FRI02) to 2.55 % (FRI24), the sand varied from 96.3 % (FRI04) to 98.2 % (FRI02), and the TOM varied from 0.54 % (FRI02) to 0.86 % (FRI04). There were more pelite and TOM at the reference site (FRI10R) than at the field sites. There were no major differences between 2000 and 2003. The change in the median value between 2000 and 2003 are probably due to different ways of calculation of the value.

Samples from three sampling sites, FRI01, FRI03 and FRI04, contained lots of shells of dead tusk (Scaphopoda) and some shell fragments of blue mussels (Mytilidae).

Table 17.2. Total organic matter and sediment grain size at all sites at Frigg in 2003. For comparison averages, standard deviations, max and min values for the regional and reference sites are included.

Site	TOM %	Gravel %	Sand %	Pelite %	Median (Φ)	Sorting	Skewness	Kurtosis
FRI01	0.65	0.12	97.74	2.14	2.47	0.48	-0.12	1.25
FRI02	0.54	0.01	98.16	1.83	2.50	0.46	0.00	1.21
FRI03	0.61	0.10	97.94	1.97	2.48	0.50	-0.07	1.32
FRI04	0.86	1.15	96.31	2.53	2.49	0.47	-0.04	1.28
FRI11	0.74	0.06	97.41	2.53	2.47	0.54	-0.03	1.43
FRI24	0.61	0.07	97.38	2.55	2.46	0.52	-0.06	1.36
FRI25	0.69	0.36	97.44	2.20	2.42	0.62	-0.17	1.41
FRI27	0.59	0.23	97.81	1.96	2.49	0.46	-0.04	1.22
FRI10R	1.04	0.00	94.23	5.77	2.60	0.88	0.18	1.59
Average[1]	0.66	0.26	97.52	2.21	2.47	0.50	-0.07	1.31
SD[1]	0.10	0.38	0.56	0.29	0.02	0.05	0.05	0.08
Min[1]	0.54	0.01	96.31	1.83	2.42	0.46	-0.17	1.21
Max[1]	0.86	1.15	98.16	2.55	2.50	0.62	0.00	1.43
Average[2]	0.99	0.02	95.16	4.83	2.73	0.75	0.12	1.58
SD[2]	0.19	0.02	1.27	1.28	0.48	0.15	0.10	0.19
Min[2]	0.68	0.00	93.99	2.85	2.45	0.54	-0.06	1.37
Max[2]	1.19	0.03	97.12	5.98	3.69	0.94	0.23	1.87

[1] Field sites, exclusive VA13R
[2] Reg + Ref $_{north\ 03}$

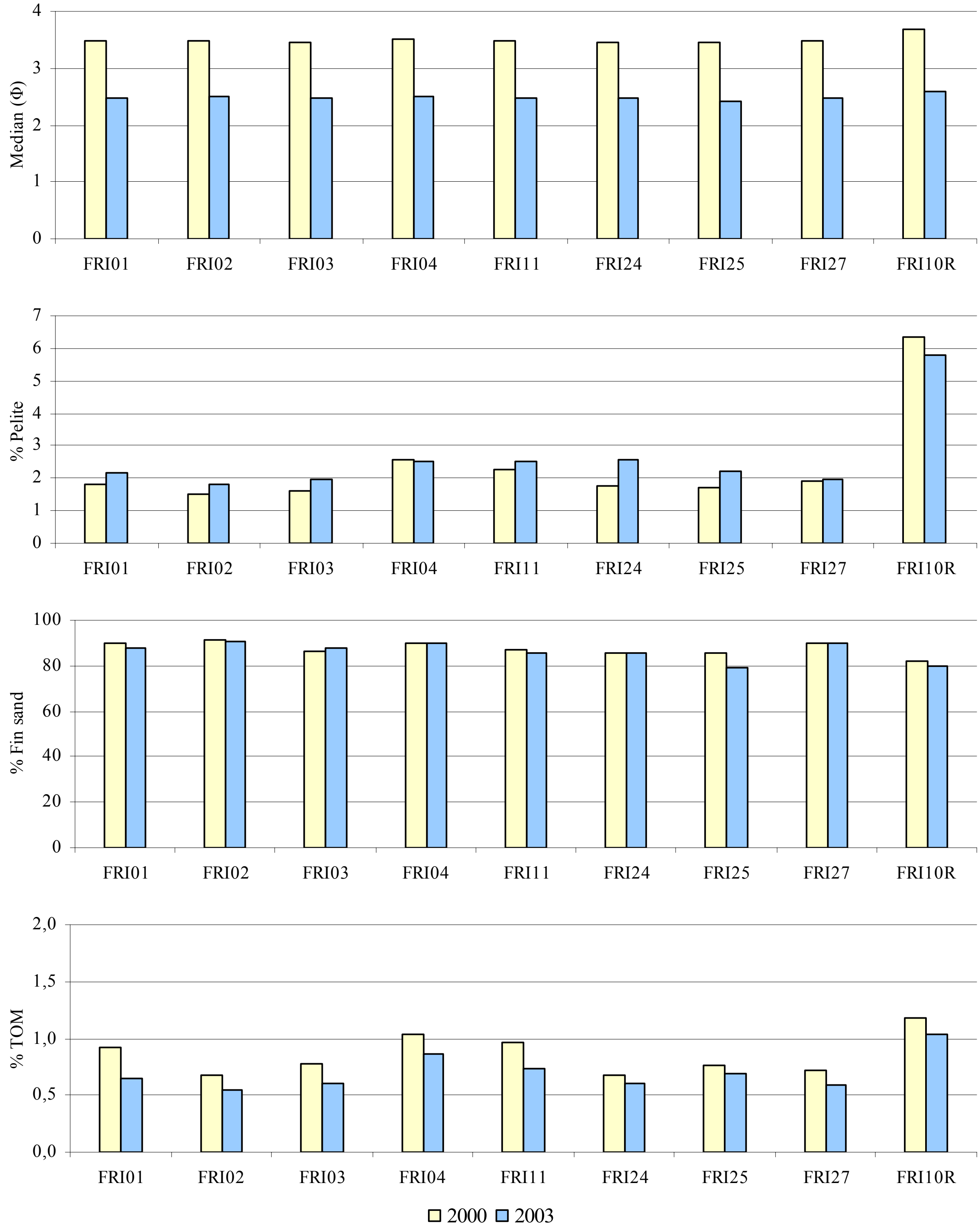


Figure 17.2. Sediment characteristics at Frigg in 2000 and 2003. Fine sand is the relative amount of sand with grain size 63-250 µm.

17.2.2 Chemical compounds

17.2.2.1 LSC

The results of the LSC (limits of significant contamination) calculations of hydrocarbons and metals are presented in the chapter concerning the regional and reference sites. Both the $LSC_{north\ 97\text{-}03}$ and the field specific LSC value ($LSC_{FRI10R\ 03}$) are presented in Table 17.3. Fine sediments are more likely to have higher affinity for pollutants than coarse sediments. Thus the field specific LSC value should perhaps be disregarded due to slightly higher content of fine sediments at the reference site compared to the field sites. LSC in the text relates to $LSC_{north\ 97\text{-}03}$.

Table 17.3. Limits of Significant Contamination (LSC) for the Frigg field in 2003, and for the north part of Region II based on data from 1997 to 2003 ($LSC_{north\ 97\text{-}03}$) and the whole of Region II based on data from 1997 to 2003 ($LSC_{regII\ 97\text{-}03}$). For comparison, LSC-values from 2000 are included. All values in mg/kg dry sediment.

	THC	PAH (16)	NPD's	Decalins	Cu	Cr	Zn	Ba	Pb	Cd	Hg
$LSC_{FRI10R\ 03}$	17.1	0.043	0.019	0.179	0.7	5.7	6.1	58	3.4	0.03[1]	0.010
$LSC_{north\ 97\text{-}03}$	13.3	*	*	*	1.4	5.9	7.4	76	3.8	0.03[1]	0.008
$LSC_{regII\ 97\text{-}03}$	13.3	*	*	*	2.0	9.4	11.1	136	6.6	0.03[1]	0.011
$LSC_{FRI10R\ 00}$**	7.3	*	0.018	0.062	1.2	4.8	5.7	91	4.0	0.02	0.007
$LSC_{regII\ 97\text{-}00}$**	9.8	*	*	*	2.0	9.6	8.9	146	7.0	0.03	0.008

*NPD's, PAH's and decalins are not analysed at regional sites in 1997 and 2000
** Data from Mannvik & al. 2001
n.a. not analysed
[1] LSC = detection limit

17.2.2.2 Hydrocarbons

Summarised results of the hydrocarbon analyses, along with the content of selected hydrocarbon compounds in the different layers (0-1, 1-3 and 3-6 cm) are given in Table 17.4 and Table 17.5. The complete data set including replicates is given in the Appendix. Comparison of the THC content in 2003 with previous surveys is presented in Figure 17.3.

Table 17.4. The content of oil hydrocarbons in sediments from Frigg in 2003. All values in mg/kg dry sediment. THC values above $LSC_{north\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{FRI10R\ 03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data for the regional and field reference sites in the north part of region II are included.

Site	THC		PAH(16)		NPD		Dekalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
FRI01	8.8	8.4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
FRI02	<3.0	0.9	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
FRI03	12.2	3.6	0.119	0.097	0.073	0.052	0.312	0.163
FRI04	8.0	11.3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
FRI11	15.3	6.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
FRI24	15.7	2.4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
FRI25	12.5	9.6	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
FRI27	9.8	2.0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
FRI10R	11.3	2.5	0.037	0.003	0.016	0.002	0.174	0.002
av. ± sd.[1]	10.6 ± 4.5							
min – max[1]	<3.0 - 15.7							
av. ± sd.[2]	10.6 ± 2.0		0.028 ± 0.008		0.013 ± 0.002		0.157 ± 0.081	
min – max[2]	7.4-13.2		0.016-0.037		0.011-0.016		0.042-0.287	

n.a. = not analysed.
[1] Field sites, exclusive FRI10R
[2] Reg + $Ref_{north\ 03}$

THC was found in the range from <3.0 (detection limit) to 15.7 mg/kg, and THC concentrations above LSC was found at FRI11, 500 m to the north of TCP2, and at FRI24, 250 m to the south of DP2. The average PAH, NPD and decalin content was above $LSC_{FRI10R\ 03}$ at FRI03.

At FRI03, NPD occurred above LSC in all layers (0-1, 1-3 and 3-6 cm) and PAH occurred above LSC in the upper 0-1 cm layer. At the reference site THC occurred above LSC in the 0-1 cm layer, whereas PAH and decalins were present above LSC in lower 3-6 cm layer (Table 17.5)

Compared to previous surveys the THC content had increased at FRI03, FRI11, FRI24, FRI27 and FRI10R. Despite the increase the THC level remain low in the area (Figure 17.3).

Table 17.5. The content of oil hydrocarbons in vertical sections of sediment from 3 sampling sites at Frigg in 2003. All values in mg/kg dry sediment. THC values above $LSC_{north\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{FRI10R\ 03}$ are dark shaded.

Site	Layer (cm)	THC	PAH(16)	NPD	Dekalins
FRI03	0-1	8.4	0.228	0.059	0.145
	1-3	10.2	0.023	0.031	0.175
	3-6	7.0	0.012	0.027	0.145
FRI10R	0-1	14.4	0.035	0.018	0.175
	1-3	12.0	0.038	0.016	0.165
	3-6	8.2	0.050	0.018	0.240

17.2.2.3 Metals

Table 17.6 summarises the results of the metal analyses of the Frigg field in 2003. Concentrations of selected metals in the different layers (0-1, 1-3 and 3-6) of sediment are given in Table 17.7, whereas the complete data set including replicates is given in the Appendix. Comparisons of the metal contents in 2003 with previous surveys are presented in Figure 17.6.

Table 17.6 Content of metals in sediments from Frigg in 2003. All values in mg/kg dry sediment. Metal values above $LSC_{north\ 97\text{-}03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data in the regional and field reference sites in the north part of the region II are included.

Site	Cu		Cr		Zn		Ba		Pb		Cd		Hg	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
FRI01	17.0	3.5	9.8	1.4	230.3	58.1	72	28	43.7	6.2	0.05	0.026	n.a.	n.a.
FRI02	3.2	0.4	5.3	0.3	33.8	3.5	28	4	12.0	0.4	<0.03	-	n.a.	n.a.
FRI03	11.1	0.4	8.1	0.7	128.0	14.7	35	13	28.8	1.8	<0.03	-	0.014	0.002
FRI04	7.0	1.2	6.7	0.5	67.3	19.3	31	1	16.4	1.0	<0.03	-	n.a.	n.a.
FRI11	5.3	1.5	5.4	0.6	36.7	3.8	42	12	13.1	1.6	<0.03	-	n.a.	n.a.
FRI24	4.8	1.4	5.1	1.0	25.4	3.6	102	60	13.9	3.4	<0.03	-	n.a.	n.a.
FRI25	6.2	2.0	6.5	0.8	51.5	10.4	103	23	18.9	3.2	<0.03	-	n.a.	n.a.
FRI27	0.9	0.1	4.4	0.2	7.6	0.9	33	15	4.9	0.6	<0.03	-	n.a.	n.a.
FRI10R	0.5	0.1	4.5	0.5	5.5	0.3	37	9	2.8	0.3	<0.03	-	0.007	0.001
av. ± sd.[1]	6.9 ± 5.0		6.4 ± 1.8		72.6 ± 73.4		56 ± 32		19.0 ± 12.1		<0.03			
min - max[1]	0.9 - 17.0		4.4 - 9.8		7.6 - 230.3		28 - 103		4.9 - 43.7		<0.03-0.05			
av. ± sd.[2]	<0.6		4.6 ± 0.8		5.9 ± 0.3		29 ± 10		2.5 ± 0.3		<0.03		0.007 ± 0.001	
min - max[2]	<0.6-0.8		3.7-5.6		5.5-6.3		18-41		2.1-2.8		<0.03		0.004 -0.014	

n.a. = not analysed.
[1] Field sites, exclusive VA13R
[2] Reg + Ref $_{north\ 03}$

Table 17.7. The content of metals in vertical sections of sediment from 3 sampling sites at Frigg in 2003. All values in mg/kg dry sediment. Metal values above $LSC_{north\ 97\text{-}03}$ are dark shaded.

Site	Layer (cm)	Cu	Cr	Zn	Ba	Pb	Cd	Hg
FRI03	0-1	10.9	8.1	141	22.0	30.7	<0.03	0.015
	1-3	14.7	9.6	167	42.6	40.9	0.05	0.032
	3-6	17.9	11.0	268	79.0	38.2	0.05	0.024
FRI10R	0-1	0.6	4.4	5.8	51.5	3.2	<0.03	0.007
	1-3	0.6	4.3	5.6	45.8	2.8	<0.03	0.006
	3-6	0.7	4.7	8.4	102	2.9	<0.03	0.007

Barium was found in a range from 28 to 103 mg/kg, lead from 4.9 to 43.7 mg/kg, cadmium from <0.03 to 0.05 mg/kg, copper from 0.9 to 17 mg/kg, mercury occurred at 0.014 mg/kg, chromium from 4.4 to 9.8 mg/kg and zinc from 9.1 to 42.3 mg/kg (Table 17.6). Zinc and lead occurred in concentration above LSC at all sampling sites, except the reference site. Copper was above LSC at all sites except at FRI27, 250 m to the north east of DP2, and the reference site FRI10R. Chromium occurred in concentrations above LSC at FRI01, FRI03, FRI04 and FRI25, and barium at FRI24 and FRI25. At FRI01, 200 m to the north of TCP2, also cadmium occurred above LSC. Mercury was present above LSC at FRI03, 330 m south of TCP2.

Vertical sediment samples (0-1, 1-3 and 3-6 cm) from FRI03, 330 m south of TCP2, had copper, chromium, zinc, lead and mercury content above LSC in all depth intervals, and cadmium were found above LSC in the 1-3 cm and 3-6 cm intervals. Barium had content above LSC in the 3-6 cm interval. There was a tendency of increasing concentrations of metals with increasing sediment depth at FRI03, whereas the metals, except barium, had a more uniform vertical distribution in the sediments at the reference site. This indicates former supply of these metals to the sampling area.

At the reference site FRI10R, zinc and barium were above LSC in the 3-6 cm interval.

Compared to the results in 2000 there was a tendency of reduced content of metals or content of metals at the same level at all sites, except at FRI01 where the content of metals have increased (Figure 17.4 and Figure 17.6).

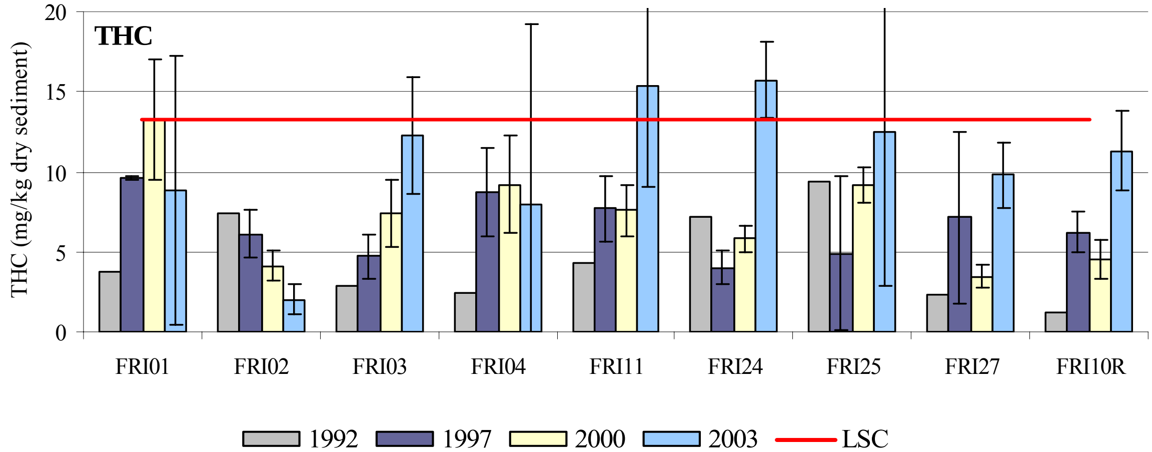


Figure 17.3. Average THC concentrations and standard deviations in sediments from Frigg in 2003 and previous years. Red line is $LSC_{north\ 97\text{-}03}$.

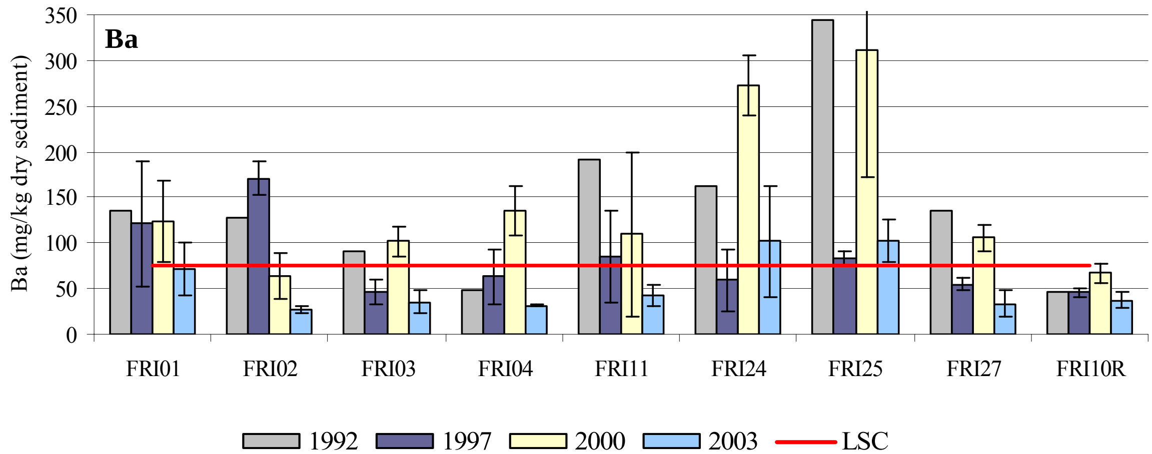


Figure 17.4. Average barium concentrations and standard deviations in sediments from Frigg in 2003 and previous years. Red line is $LSC_{north\ 97\text{-}03}$.

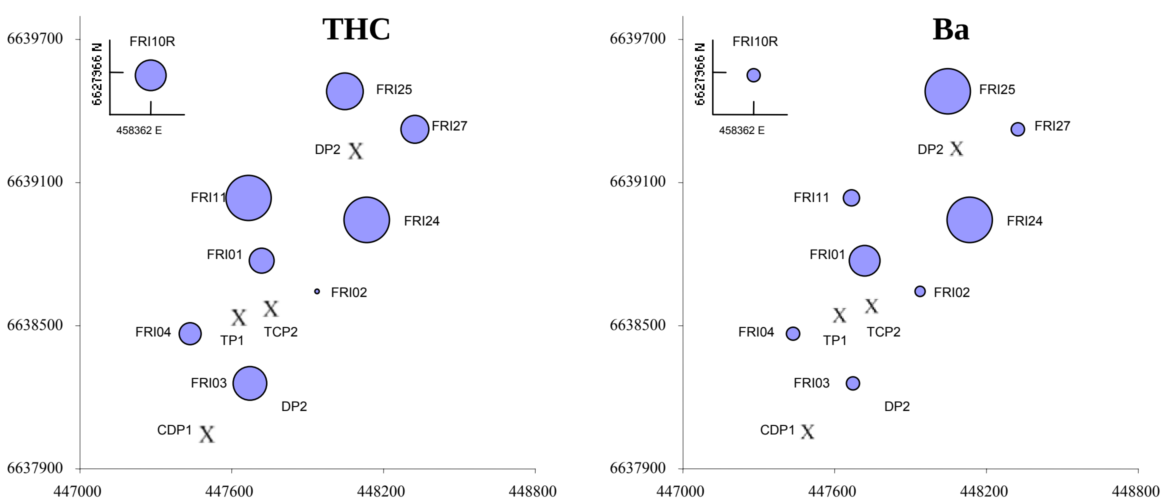


Figure 17.5. Distribution of THC and barium in sediments at the sampling sites at Frigg in 2003. The size of the circle indicate the amount of THC and Ba. The field centres is marked with an X.

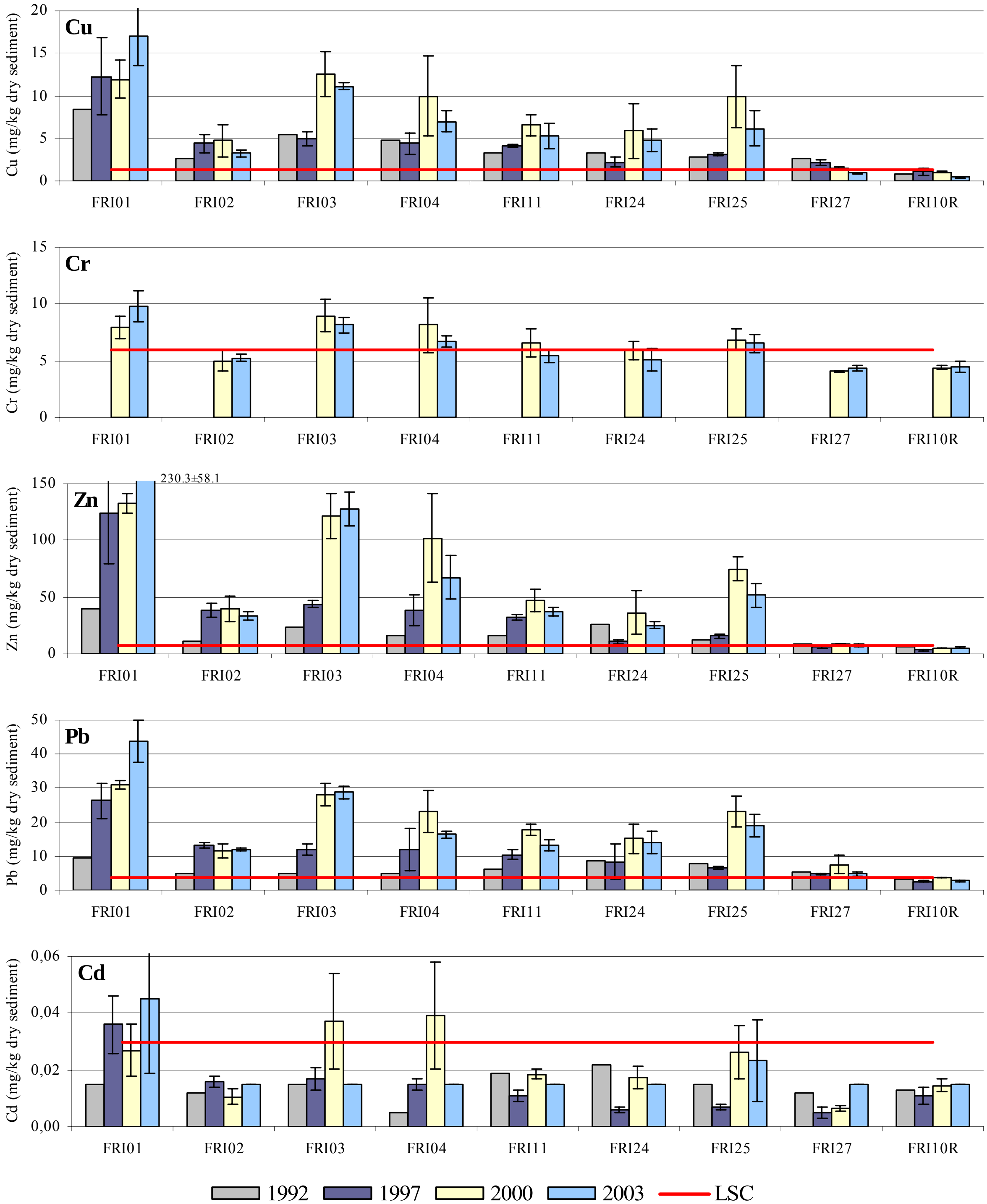
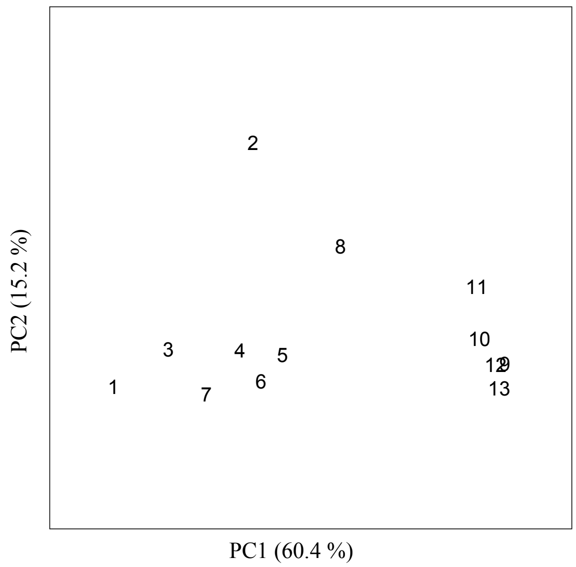
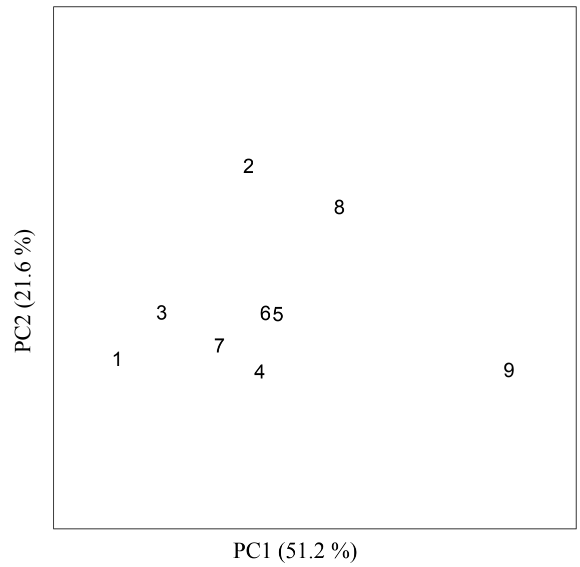


Figure 17.6. Average content and standard deviations of metals in sediment from Frigg in 2003 and previous surveys. Red line is $LSC_{north\ 97-03}$.

The field sites at Frigg were compared to nearby regional (RII01 and RII02) and field specific reference sites (PSB13R and LFR01R) based on sediment characteristics (TOM and pelite) and chemical content in the sediments (Figure 17.7). FRI02, 200 m to northeast of TCP2 and FRI27, 250 m to the north east of DP2, did not group together with the other sites, but was separated from the other sites due to generally lower content of chemical compounds in the sediments. The reference site FRI10R was grouped with the other reference sites.



a



b

Figure 17.7. 2-D plot from the PCA analysis of environmental variables (% pelite, % sand, % gravel, median Φ, %TOM, Cu, Ba, Zn, Cr, Pb and THC) carried out on:

c) Frigg field sites compared to the reference site at Øst Frigg and Lille Frigg and the regional sites RII01 and RII02. Explained variation in the data 75.6 %.
d) Frigg field sites. Explained variation in the data 72.8 %.

Numbers in the plot identify the sampling sites. See table below.

1	FRI-01	6	FRI-24	11	RII-02
2	FRI-02	7	FRI-25	12	PSB13R
3	FRI-03	8	FRI-27	13	LFR01R
4	FRI-04	9	FRI-10R		
5	FRI-11	10	RII-01		

17.2.3 Bottom fauna

A summary of the distribution of individuals and taxa within the main taxonomic groups are given in Table 17.8. Unidentified juveniles of the sea urchins Spatangoids (22723 individuals) and Echinoides (852 individuals), juveniles of the brittle stars *Ophiura affinis* (852 individuals) and *Ampihura filiformis* (406 individuals), juveniles of the anthozoan *Cerianthus lloydii* (556 individuals) and juveniles of the polychaete *Owenia fusiformis* (795 individuals) are omitted from the analyses, as they occurred in extremely high numbers. In total, 8471 individuals within 233 taxa were collected at Frigg in 2003. The fauna was numerically dominated by annelida with 73 % the individuals and 46 % of the taxa. A complete species list is available in the Appendix.

Table 17.8. Distribution of individuals and taxa within the main taxonomic groups at Frigg in 2003 including data from FRI10R (unidentified juveniles of Spatangonida and Echinoidea and juveniles of *Cerianthus loydii, Owenia fusiformis*, *Ophiura affinis* and *Amphiura filiformis* are not included).

Main taxonomic groups	Number of individuals	%	Number of taxa	%
Annelida	6198	73	107	46
Arthropoda	598	7	44	19
Mollusca	794	9	46	20
Echidermata	284	3	18	8
Diverse groups	597	7	18	8
Total	8471	100	233	100

The species/area curve for FRI10R indicates that five replicate samples give a representative impression of the bottom fauna in the area (Figure 17.8). However, as more area is sampled, more taxa are collected, indicating that not even 10 replicate samples give the full species assemblage of the area.

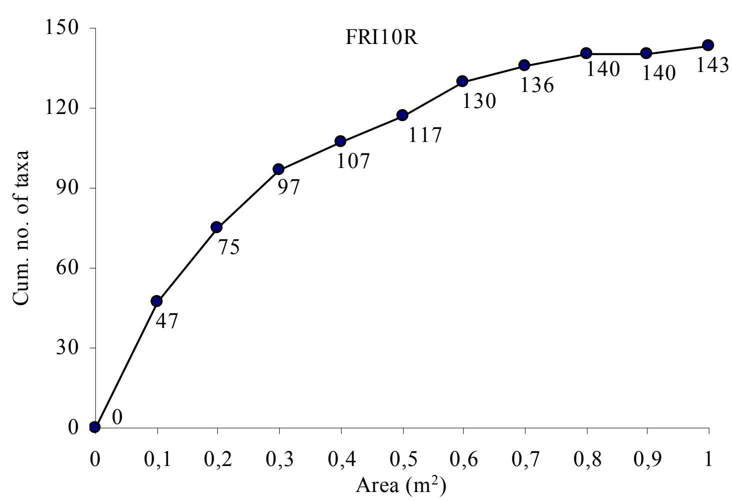


Figure 17.8. Species/area curve for the reference station at the Heimdal field. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Cerianthus loydii, Owenia fusiformis*, *Ophiura affinis* and *Amphiura filiformis.*

The distribution of individuals and taxa are shown in Figure 17.9. Number of individuals and taxa at each site, and the calculated diversity indexes (H' and ES_{100}) are given in Table 17.9 and Figure 17.10. The number of individuals varied from 632 (FRI25) to 1025 (FRI04), and the number of taxa varied from 72 (FRI03) to 105 (FRI04). The Shannon-Wiener diversity index (H') varied from 4.12 (FRI03) to 5.15 (FRI25), whereas the ES_{100} index varied from 30.3 (FRI01) to 41.5 (FRI25). The evenness index J varied from 0.67 (FRI) to 0.77 (FRI24 and FRI25). The corresponding values at FRI10R are within or near the variation at the field sites. The number of taxa, diversity and eveness indicate good environmental conditions at all sites.

Table 17.9. Number of individuals, species/taxa and selected community indices for each station (0.5 m^2) at the Frigg field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Cerianthus llodydii, Owenia fusiformis*, *Ophiura affinis* and *Amphiura filiformis.*

Site number	Number of individuals	Number of taxa	Diversity H'	Evenness J	H'-max	ES_{100}
FRI01	1013	89	4.36	0.67	6.48	30.3
FRI02	819	99	4.72	0.71	6.63	35.4
FRI03	745	72	4.12	0.67	6.17	30.5
FRI04	1025	105	4.89	0.73	6.71	35.7
FRI11	884	96	4.64	0.70	6.58	33.3
FRI24	722	85	4.92	0.77	6.41	36.9
FRI25	632	100	5.15	0.77	6.64	41.5
FRI27	767	102	4.98	0.75	6.67	38.4
FRI10R (6-10)	1045	117	4.86	0.71	6.87	36.2
FRI10R (11-15)	819	101	4.92	0.74	6.66	36.1
FRI10R (6-15)	1864	143	4.97	0.69	7.16	36.4
Sum[1]	6607	195				
Average[1]	826	94	4.72	0.72	6.54	35.3
SD[1]	140	11	0.34	0.04	0.18	3.8
Min[1]	632	72	4.12	0.67	6.17	30.3
Max[1]	1025	105	5.15	0.77	6.71	41.5
Average[2]	919	95	4.78	0.73	6.57	34.5
SD[2]	428	12	0.65	0.11	0.19	5.3
Min[2]	574	80	3.51	0.52	6.32	24.6
Max[2]	1749	109	5.31	0.82	6.77	39.6

[1]Frigg field, exclusive FRI10R
[2]Reg + Ref $_{\text{north 03}}$

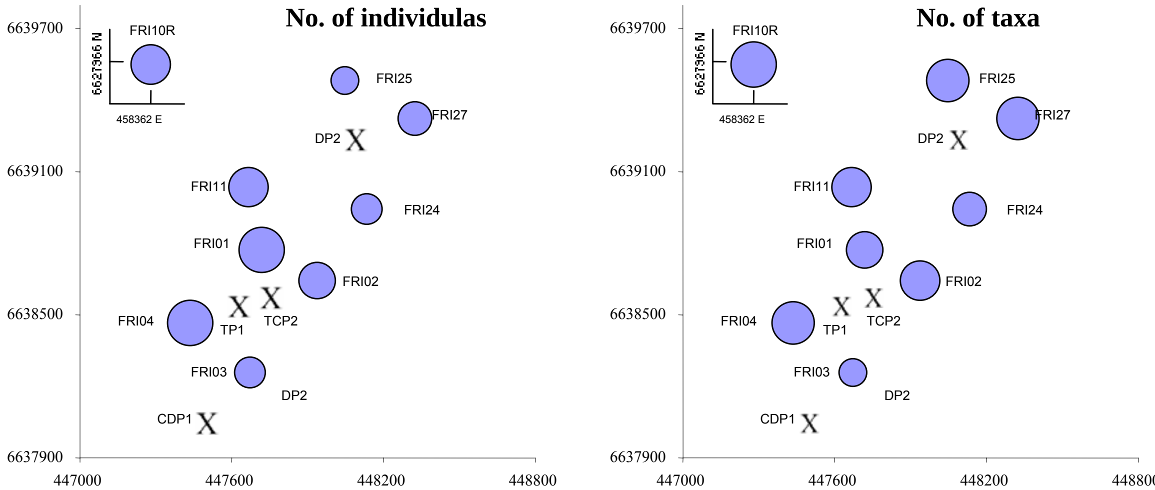


Figure 17.9. Distribution of bottom fauna (individuals and taxa) among the sampling sites in 2003. The size of the circle indicates the number of individuals and taxa. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Cerianthus loydii, Owenia fusiformis*, *Ophiura affinis* and *Amphiura filiformis.* Values for FRI10R are average of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2). The field centre is marked with an X.

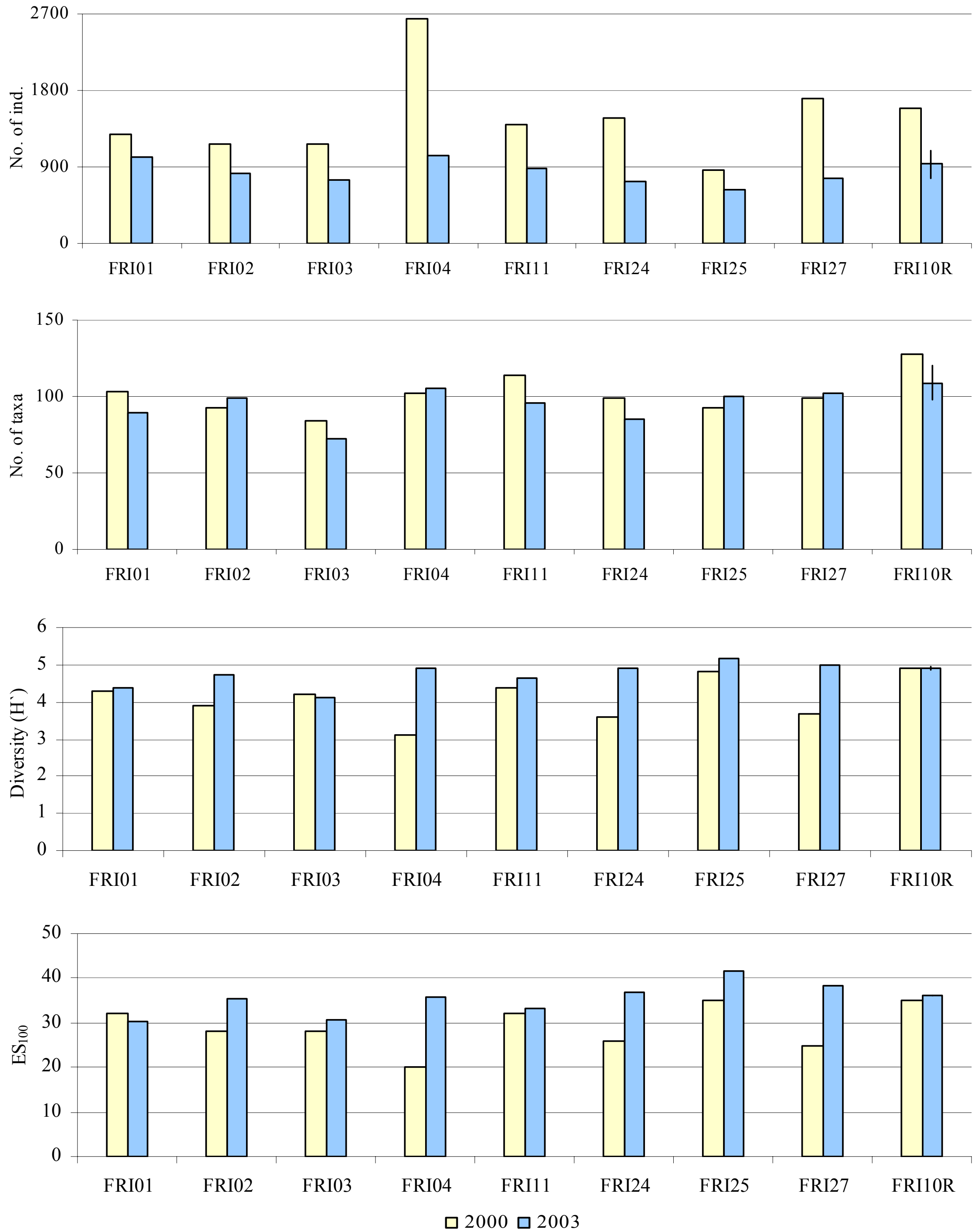


Figure 17.10. Number of individuals, taxa and selected community indices for each site (0.5 m^2) at the Frigg field for 2000 and 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Cerianthus lloydii, Owenia fusiformis*, *Ophiura affinis* and *Amphiura filiformis* in 2003). Values for FRI10R are average ± standard deviation of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2).

Distribution of taxa in geometrical classes is presented in Figure 17.11. The smooth graphs are indicating undisturbed bottom fauna.

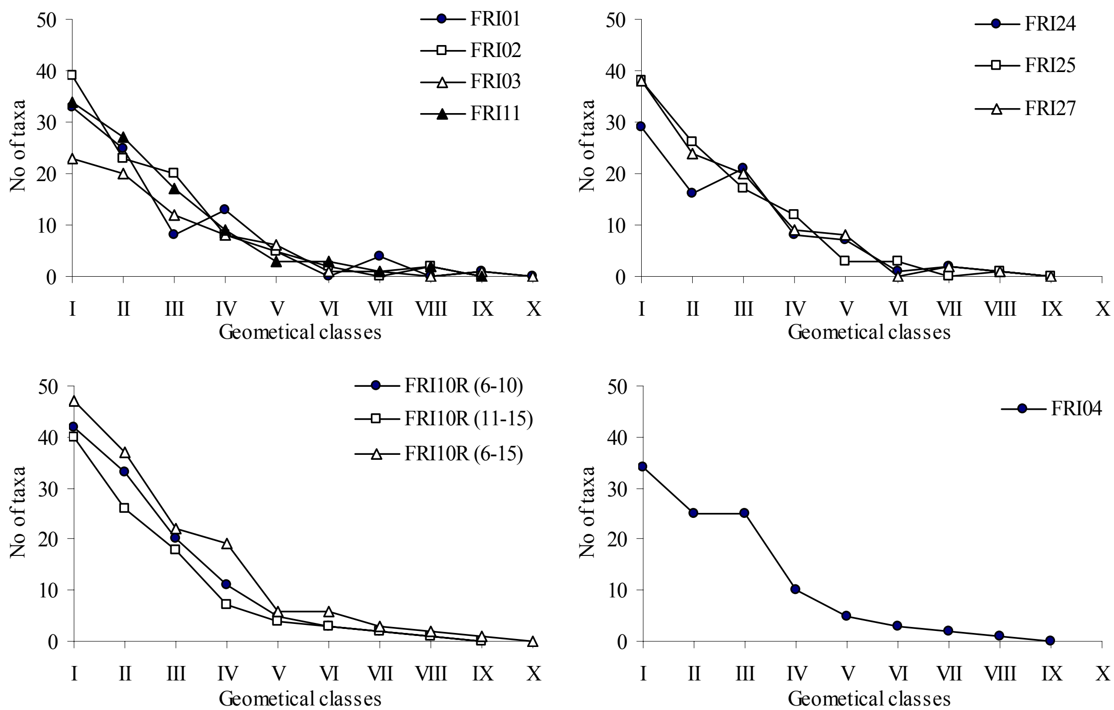


Figure 17.11. Distribution of taxa in geometrical classes for the sites at Frigg in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Cerianthus lloydii, Owenia fusiformis*, *Ophiura affinis* and *Amphiura filiformis.*

The ten most numerous taxa are listed in Table 17.12 at the end of this chapter. The list comprise 29 taxa and 6614 individuals, which was 12.4 % of all (233) taxa and 78.1 % of all (8471) individuals. The polychetes *Spiophanes bombyx* and *Owenia fusiformis* were the most abundant species at all sites except FRI03, FRI04 and FRI11. The polychaete *Ditrupa arietina* was among the most abundant species at FRI01, FRI03 and FRI04. Only a couple of individuals of *Ditrupa arietina* were found at FRI02 and FRI25. The brittle star *Amphiura filiformis* was abundant at FRI10R, but occurred only in low numbers at the other sites, except at FRI01 and FRI03 where it was not present at all. This might indicate some faunal disturbance at FRI01 and FRI03. *Spiophanses bombyx* was among the most abundant species in 2000 too.

The results of the multivariate analyses are given in the dendrogramme (Figure 17.12) and the MDS plott (Figure 17.13).

In the cluster analysis, all sites are grouped together within approximately 55 % similarity. The sites are grouped into 3 distinct groups by the cluster analysis. The most distinct group comprise the reference site, FRI10R, whereas the field sites were grouped into two separate sub-groups of sites. The smallest group comprise FRI01, FRI03 and FRI04, which are all located in the immediate vicinity of TCP2 (FRI01 and FRI03) and TP1. The largest group of sites comprise the rest of the field specific sites.

The results of the MDS analysis support the main findings in the cluster analysis, confirming the grouping of sites into 3 distinct groups, but also showing that FRI04 was not as well connected to FRI01 and FRI03 as indicated in the cluster analysis. The results indicate that the fauna did respond to an environmental gradient at Frigg. The stress test of the MDS analysis was 0.05, indicating an excellent fit of the data.

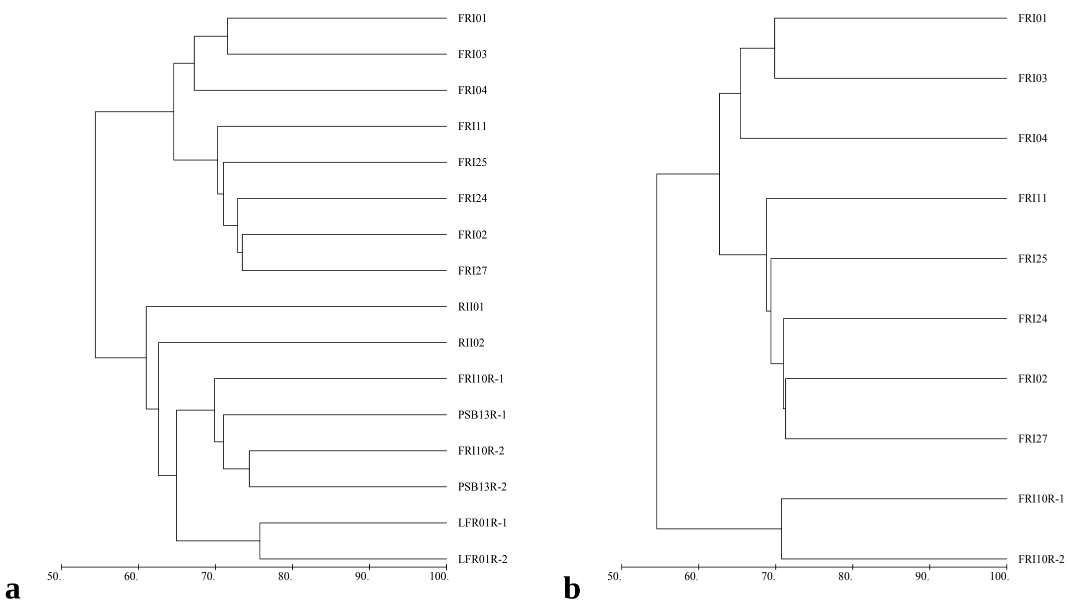


Figure 17.12. Dendrogram showing the similarity between fauna from sampling sites at:

a) Frigg field, regional sites (RII01 and RII02) and reference sites (PSB13R and LFR01R) in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.
b) Frigg field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Cerianthus loydii*, *Owenia fusiformis*, *Ophiura affinis* and *Amphiura filiformis.*

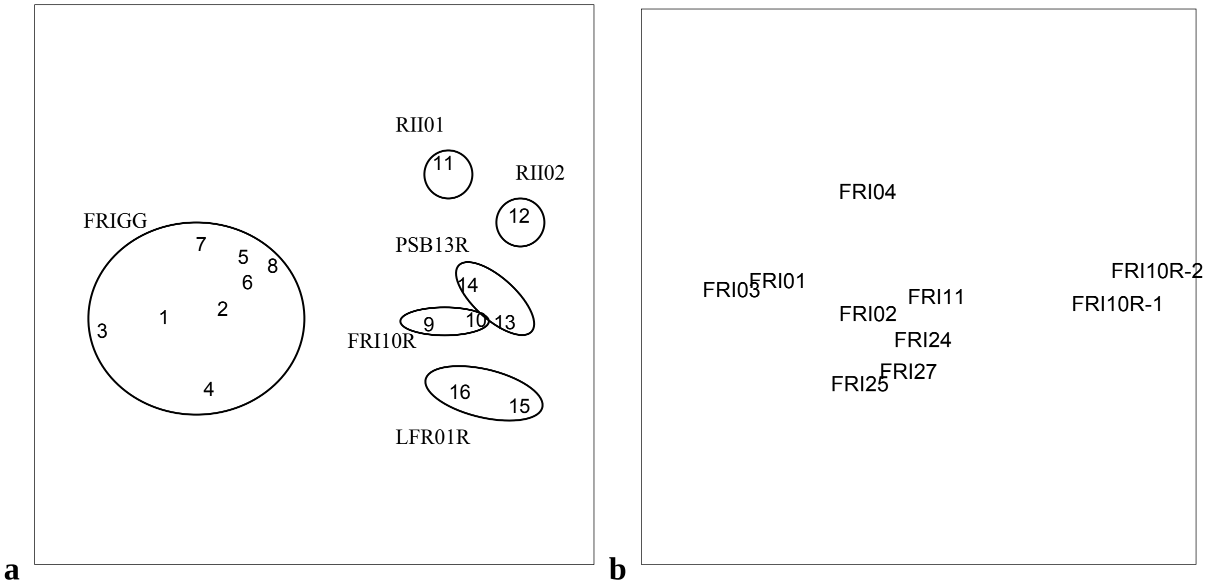


Figure 17.13. A 2-dimetional plott of the MDS analysis of the fauna data from:

a) Frigg field, regional sites (RII01 and RII02) and reference sites (PSB13R and LFR01R) in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea. Stress = 0.09. Codes in table below.

b) Frigg field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Cerianthus loydii, Owenia fusiformis*, *Ophiura affinis* and *Amphiura filiformis.* Stress = 0.05.

1	FRI01	6	FRI24	11	RII01
2	FRI02	7	FRI25	12	RII02
3	FRI03	8	FRI27	13	PSB13R-1
4	FRI04	9	FRI10R-1	14	PSB13R-2
5	FRI11	10	FRI10R-2	15	LFR01R-1
				16	LFR01R-2

Linking of biotic and environmental variables by BIOENV revealed that chromium, TOM and pelite, a natural variable of the sediments, were correlated to the biota at $\rho_w = 0.81$ (Table 17.10).

Table 17.10. Combinations of the 10 environmental variables, taken *k* at a time, yielding the best matches of biotic and abiotic similarity matrices for each *k*, as measured by weighted Spearman rank correlation ρ_w. Bold type indicates overall optimum. All possible combinations of variables and associated correlation to the biotic are given in the Appendix.

Number of Variables (*k*)	Correlation coefficient (ρ_w)	Environmental variables									
1	0.633	Sand									
1	0.536	TOM									
1	0.533	Pb									
1	0.527	Pelite									
1	0.458	Zn									
1	0.439	Cu									
1	0.224	Cr									
1	0.011	Gravel									
1	-0.264	Ba									
1	-0.319	THC									
2	0.759	Cr	Sand								
3	**0.814**	**Cr**		**TOM**	**Pelite**						
4	0.802	Cr	Sand	TOM	Pelite						
5	0.808	Cr	Sand	TOM	Pelite	Gravel					
6	0.788	Cr	Sand	TOM	Pelite	Gravel	Zn				
7	0.773	Cr	Sand	TOM	Pelite	Gravel	Zn	Pb			
8	0.749	Cr	Sand	TOM	Pelite	Gravel	Zn	Pb	Cu		
9	0.712	Cr	Sand	TOM	Pelite	Gravel	Zn	Pb	Cu	Ba	
10	0.581	Cr	Sand	TOM	Pelite	Gravel	Zn	Pb	Cu	Ba	THC

17.2.4 Estimation of influenced area

The extension of contamination along sampling transects and the minimum area of contaminated sediments for THC, barium and other metals as well as for faunal disturbance is given in Figure 17.14 and Table 17.11. The total area contaminated by THC and other metals was the same in 2003 as in 2000, whereas there was a slight decrease in the total area contaminated by barium between 2000 and 2003. The total area with faunal disturbance was reduced in 2003 compared to the situation in 1997 and 2000.

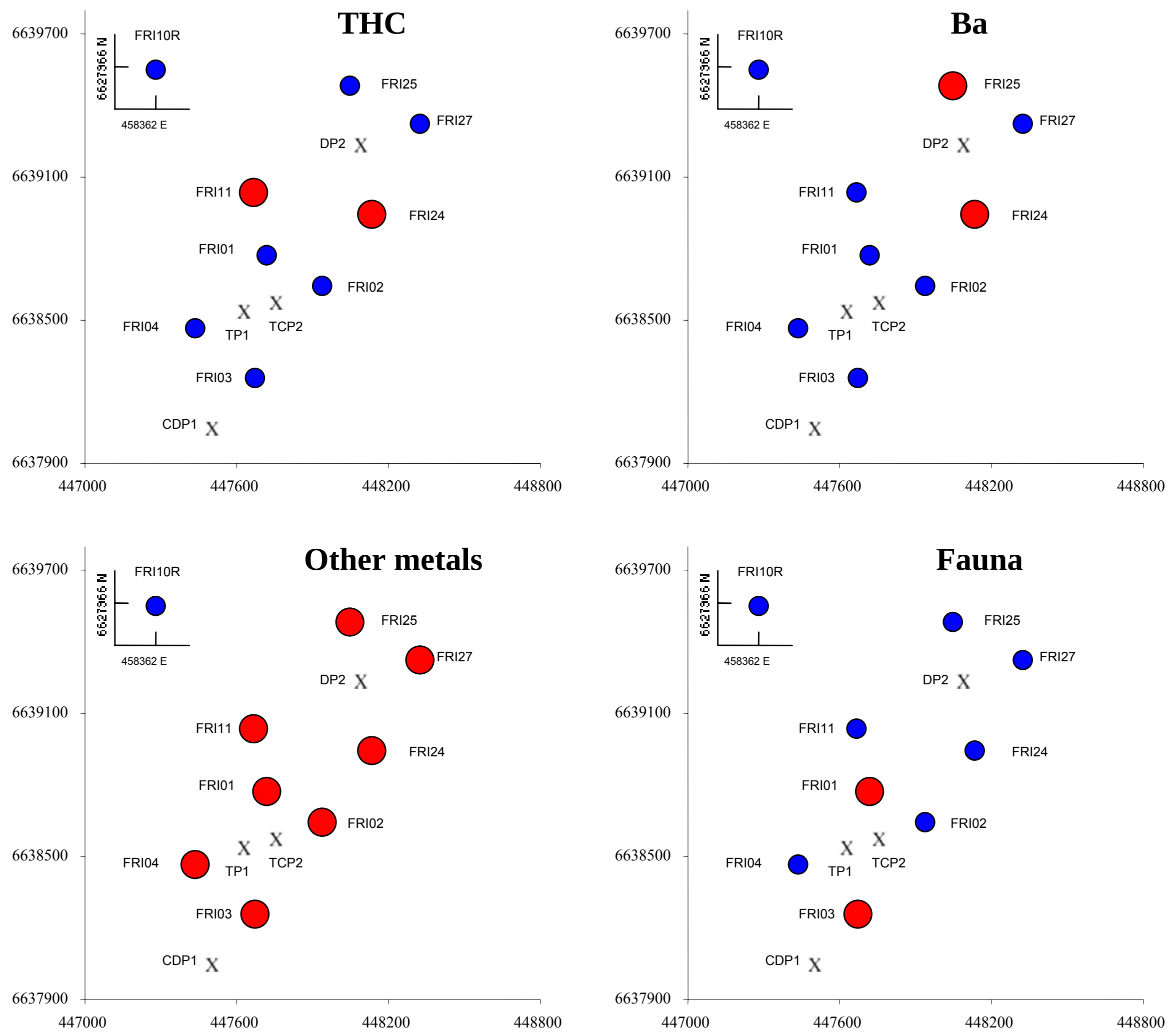


Figure 17.14. Faunal disturbance and chemical contamination of the sediments at Frigg in 2003. Uncontaminated sites and sites with no faunal disturbance are marked with small blue circles. The field centre are marked with a X.

Table 17.11. Estimated distance of contamination and faunal disturbance from the installation, and estimated area of contamination and faunal disturbance around the field centre.

Frigg TCP2+TP1	N m	E m	S m	W m	2003 km^2	2000 km^2	1997 km^2
THC	0	0	0	0	0.00	0.06	0.00
Ba	0	0	0	0	0.00	0.00	0.08
Other metals	500	200	330	200	0.26	0.26	0.26
Fauna	200	0	330	0	0.05	0.12	0.13

Frigg DP2	N m	E m	S m	W m	2003 km^2	2000 km^2	1997 km^2
THC	0	0	250	300	0.06	0.00	0.00
Ba	250	0	250	0	0.05	0.08	0.00
Other metals	250	250	250	0	0.10	0.10	0.10
Fauna	0	0	0	0	0.00	0.00	0.00

Sum Frigg	N m	E m	S m	W m	2003 km^2	2000 km^2	1997 km^2
THC					0.06	0.06	0.00
Ba					0.05	0.08	0.08
Other metals					0.36	0.36	0.36
Fauna					0.05	0.12	0.13

17.3 Summary and conclusions

The only drilling operation at Frigg over the last 6 years was during the permanently plugging and abandonment of 14 wells in the period from March to June 2004, just before the monitoring survey was conducted. The plugging operation was planned as a zero discharge and only minor amounts of water soluble chemicals were discharged. The sediments are still characterized as fine sand. The amounts of THC in the sediments were generally low despite an increase in the THC level at five sampling sites since 2000. The barium content had decreased at all sites since 2000, and the content of other metals decreased as well except at one site (FRI01) located 200 m to the north of TCP2 were the content other metals seams to increase. Despite a generally decrease of metals in the sediments all sampling sites were contaminated by metals, except the reference site. The fauna was correlated to some of the measured environmental variables (chromium, TOM and pelite), but no faunal disturbances were revealed. The total area contaminated by THC and other metals was the same in 2000 and 2003, whereas the area contaminated by barium was reduced. The area with faunal disturbances was also reduced in 2003 compared to the situation in 2000.

Table 17.12. Number of individuals and relative abundance for the ten predominant taxa at each site at the Frigg field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Cerianthus lloydii*, *Owenia fusiformis*, *Ophiura affinis* and *Amphiura filiformis.*

FRI01	No. of ind.	%	Cum %
Spiophanes bombyx	296	29.2	29.2
Owenia fusiformis	94	9.3	38.5
Ditrupa arietina	93	9.2	47.7
Chaetozone sp.	74	7.3	55.0
Myriochele oculata	67	6.6	61.6
Edwardsia sp.	30	3.0	64.6
Glycera lapidum	25	2.5	67.0
Nemertini indet.	21	2.1	69.1
Spio sp.	20	2.0	71.1
Chaetozone setosa	18	1.8	72.9

FRI02	No. of ind.	%	Cum %
Owenia fusiformis	182	22.2	22.2
Spiophanes bombyx	141	17.2	39.4
Myriochele oculata	62	7.6	47.0
Chaetozone sp.	36	4.4	51.4
Phoronis sp.	26	3.2	54.6
Eudorellopsis deformis	25	3.1	57.6
Edwardsia sp.	23	2.8	60.4
Chaetozone setosa	19	2.3	62.8
Hippomedon denticulatus	16	2.0	64.7
Glycera lapidum	14	1.7	66.4

FRI03	No. of ind.	%	Cum %
Spiophanes bombyx	286	38.4	38.4
Ditrupa arietina	65	8.7	47.1
Owenia fusiformis	39	5.2	52.3
Cirratulus cirratus	27	3.6	56.0
Chaetozone sp.	25	3.4	59.3
Siphonocetes kroyeranus	23	3.1	62.4
Phoronis sp.	20	2.7	65.1
Nemertini indet.	19	2.6	67.7
Chaetozone setosa	18	2.4	70.1
Spio sp.	15	2.0	72.1

FRI04	No. of ind.	%	Cum %
Spiophanes bombyx	208	20.3	20.3
Myriochele oculata	115	11.2	31.5
Thyasira flexuosa	94	9.2	40.7
Chaetozone sp.	60	5.9	46.5
Chaetozone setosa	60	5.9	52.4
Ditrupa arietina	42	4.1	56.5
Owenia fusiformis	26	2.5	59.0
Cirratulus caudatus	26	2.5	61.6
Spiophanes kroeyeri	24	2.3	63.9
Cirratulus cirratus	22	2.1	66.0

FRI11	No. of ind.	%	Cum %
Owenia fusiformis	158	17.9	17.9
Myriochele oculata	155	17.5	35.4
Spiophanes bombyx	114	12.9	48.3
Chaetozone sp.	44	5.0	53.3
Chaetozone setosa	36	4.1	57.4
Edwardsia sp.	34	3.8	61.2
Phoronis sp.	30	3.4	64.6
Scoloplos armiger	17	1.9	66.5
Harmothoe glabra	16	1.8	68.3
Eudorellopsis deformis	14	1.6	69.9

FRI24	No. of ind.	%	Cum %
Spiophanes bombyx	139	19.3	19.3
Owenia fusiformis	79	10.9	30.2
Myriochele oculata	73	10.1	40.3
Montacuta substriata	32	4.4	44.7
Phoronis sp.	29	4.0	48.8
Chaetozone sp.	24	3.3	52.1
Paramphinome jeffreysii	21	2.9	55.0
Chaetozone setosa	20	2.8	57.8
Eudorellopsis deformis	17	2.4	60.1
Glycera lapidum	16	2.2	62.3
Lucinoma borealis	16	2.2	64.5

FRI25	No. of ind.	%	Cum %
Spiophanes bombyx	144	22.8	22.8
Owenia fusiformis	54	8.5	31.3
Chaetozone sp.	38	6.0	37.3
Myriochele oculata	32	5.1	42.4
Glycera lapidum	21	3.3	45.7
Chaetozone setosa	17	2.7	48.4
Lucinoma borealis	16	2.5	50.9
Lanice conchilega	14	2.2	53.2
Scoloplos armiger	12	1.9	55.1
Phoronis sp.	11	1.7	56.8
Spiophanes kroeyeri	11	1.7	58.5
Pariambus typicus	11	1.7	60.3

FRI27	No. of ind.	%	Cum %
Owenia fusiformis	136	17.7	17.7
Spiophanes bombyx	115	15.0	32.7
Myriochele oculata	83	10.8	43.5
Chaetozone sp.	28	3.7	47.2
Goniada maculata	23	3.0	50.2
Chaetozone setosa	20	2.6	52.8
Paramphinome jeffreysii	20	2.6	55.4
Phoronis sp.	17	2.2	57.6
Eudorellopsis deformis	17	2.2	59.8
Dentalium entalis	17	2.2	62.1

FRI10R	No. of ind.	%	Cum %
Owenia fusiformis	417	22.4	22.4
Spiophanes bombyx	193	10.4	32.7
Myriochele oculata	160	8.6	41.3
Amphiura filiformis	102	5.5	46.8
Thyasira flexuosa	95	5.1	51.9
Phoronis sp.	91	4.9	56.8
Chaetozone setosa	46	2.5	59.2
Lanice conchilega	38	2.0	61.3
Harpinia antennaria	36	1.9	63.2
Goniada maculata	34	1.8	65.0

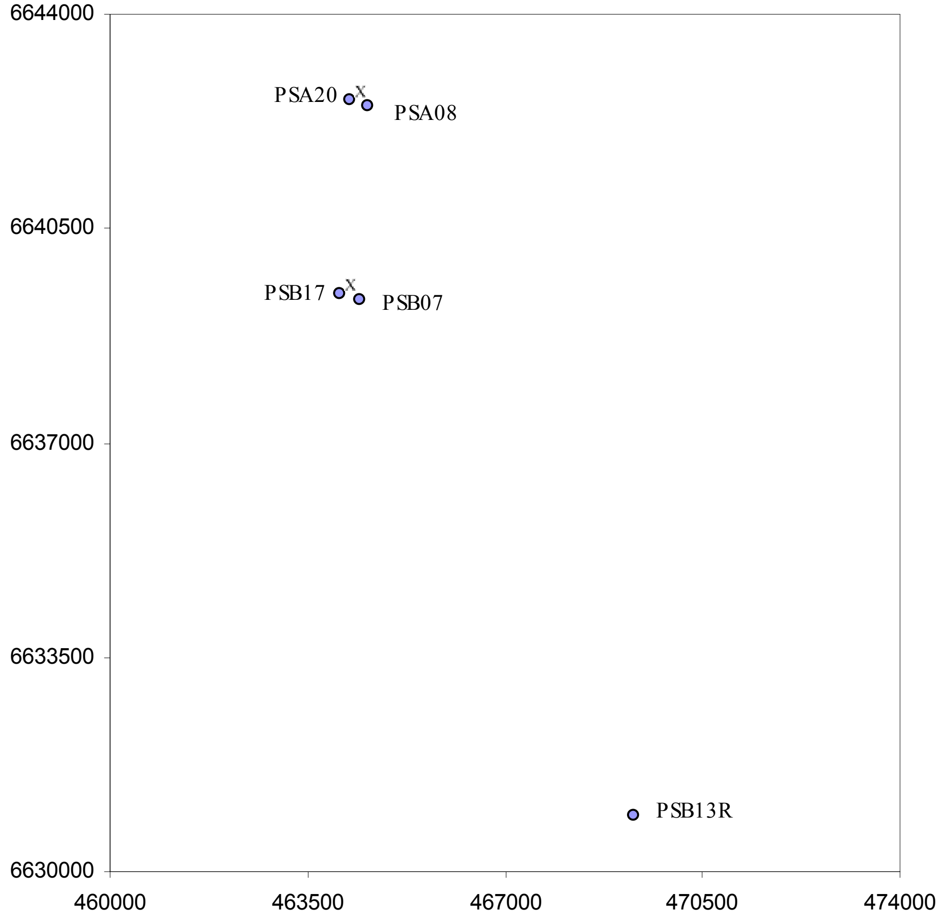
18 Øst Frigg

18.1. Introduction

The Øst Frigg field is situated in block 25/4 and 25/2. Production started at Øst Frigg in 1988 and ceased in December 1997. The wells were permanently plugged and abandoned in 1999 and the sub-sea structures were removed in 2002. This survey is the last mandatory survey after production shut down. The field was surveyed during the regional monitoring surveys of both 1997 and 2000, and a separate survey of the cutting piles was undertaken in 2000. No faunal disturbances were found, and only low levels of THC were detected at some of the sampling sites at 250 m distance in the monitoring survey in 2000, whereas the survey of the cuttings deposits showed that they were partly covered by natural sediments. Thus only the sites at 250 m to the south east and the south west of PSA and PSB were monitored in 2003. Recent discharges at Øst Frigg are listed in Table 18.1, and sampling sites are shown in Figure 18.1

Table 18.1. Recent discharges from operations and accidents at Øst Frigg (all number in tonnes).

	1997	1998	1999	2000	2001	2002
Barite	0	0	81	0	0	0
Water-based drilling mud	0	0	804	0	0	0
Cementing chemicals	0	0	310	0	0	0



Site	ED50 UTM Zone 31		Distance (m) / direction (º)	Depth
	E	N		(m)
PSA-08	464587	6642511	250/150	115
PSA-20	464245	6642602	250/240	113
PSB-07	464415	6639343	250/150	114
PSB-17	464074	6639434	250/240	113
PSB-13R	469290	6630899	10000/150	116

Figure 18.1. Map showing the internal distribution of sampling sites in Øst Frigg, 2003. Positioning according to UTM ED50 zone 31. The field centre is marked with an X.

18.2. Results and discussion

18.2.1 Sediments characteristics

TOM, the amount (%) of gravel, sand and pelite, median (Φ), sorting, skewness and kurtosis in the sediment from the present survey is presented in Table 18.2. Additional information on colour and smell can be found in the Appendix. Median (Φ), pelite, sand and TOM are compared with data from 2000 in Figure 18.2.

The sediments at Øst Frigg are classified as fine sand with median (Φ) values ranging from 3.29 (PSB07) to 3.51 (PSA20). The amount of pelite varied from 4.2 % (PSB07) to 5.1 % (PSA20), the sand varied from 94.9 % (PSA20) to 95.8 % (PSB07), and the TOM varied from 0.7 % (PSB07) to 1.2 % (PSA08). There was slightly more pelite at the reference site (PSB13R) than at the field sites. There were no significant difference between 2000 and 2003.

Table 18.2. Total organic matter and sediment grain size at all sites at Øst Frigg in 2003. For comparison averages, standard deviations, max and min values for the regional and reference sites are included.

Site	TOM %	Gravel %	Sand %	Pelite %	Median (Φ)	Sorting	Skewness	Kurtosis
PSA08	1.15	0.00	95.36	4.64	3.49	0.76	-0.05	1.44
PSA20	0.80	0.00	94.90	5.10	3.51	0.66	0.05	1.68
PSB07	0.74	0.01	95.83	4.16	3.29	0.61	0.05	1.57
PSB17	0.90	0.02	95.07	4.91	3.51	0.53	0.18	1.36
PSB13R	0.95	0.00	94.05	5.95	3.69	0.78	0.23	1.87
Average[1]	0.90	0.01	95.29	4.70	3.45	0.64	0.06	1.51
SD[1]	0.18	0.01	0.41	0.41	0.11	0.10	0.09	0.14
Min[1]	0.74	0.00	94.90	4.16	3.29	0.53	-0.05	1.36
Max[1]	1.15	0.02	95.83	5.10	3.51	0.76	0.18	1.68
Average[2]	0.99	0.02	95.16	4.83	2.73	0.75	0.12	1.58
SD[2]	0.19	0.02	1.27	1.28	0.48	0.15	0.10	0.19
Min[2]	0.68	0.00	93.99	2.85	2.45	0.54	-0.06	1.37
Max[2]	1.19	0.03	97.12	5.98	3.69	0.94	0.23	1.87

[1] Field sites, exclusive PSB13R
[2] Reg + Ref $_{north\ 03}$

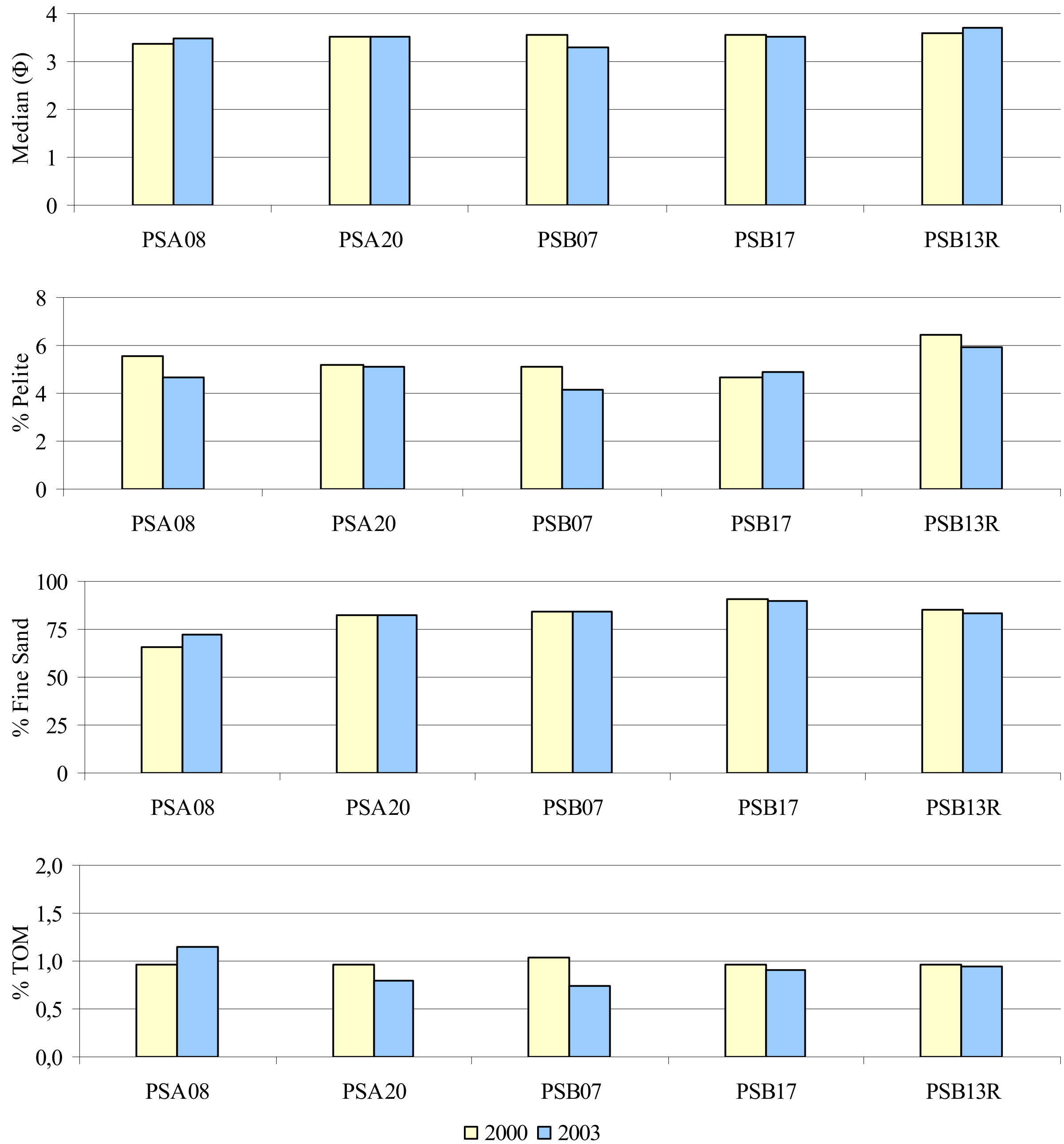


Figure 18.2. Sediment characteristics at Øst Frigg in 2000 and 2003. Fine sand is the relative amount of sand with grain size 63-250 µm.

18.2.2 Chemical compounds

18.2.2.1 LSC

The results of the LSC (limits of significant contamination) calculations of hydrocarbons and metals are presented in the chapter concerning the regional and reference sites. Both the $LSC_{north\ 97\text{-}03}$ and the field specific LSC value ($LSC_{PSB13R\ 03}$) are presented in Table 18.3. LSC in the text relates to $LSC_{north\ 97\text{-}03}$.

Table 18.3. Limits of Significant Contamination (LSC) for the Øst Frigg field in 2003, and for the deep part of Region II based on data from 1997 to 2003 ($LSC_{north\ 97\text{-}03}$) and the whole of Region II based on data from 1997 to 2003 ($LSC_{regII\ 97\text{-}03}$). For comparison, LSC-values from 2000 are included. All values in mg/kg dry sediment.

	THC	PAH (16)	NPD's	Decalins	Cu	Cr	Zn	Ba	Pb	Cd	Hg
$LSC_{PSB13R\ 03}$	19.5	0.036	0.029	0.793	0.8	5.4	6.8	79	3.2	0.03[1]	0.013
$LSC_{north\ 97\text{-}03}$	13.3	*	*	*	1.4	5.9	7.4	76	3.8	0.03[1]	0.008
$LSC_{regII\ 97\text{-}03}$	13.3	*	*	*	2.0	9.4	11.1	136	6.6	0.03[1]	0.011
$LSC_{PSB13R\ 00}$*	7.6	*	0.015	0.064	2.7	4.5	3.7	103	3.9	0.015	0.009
$LSC_{regII\ 97\text{-}00}$**	9.8	*	*	*	2.0	9.6	8.9	146	7.0	0.03	0.008

* NPD's, PAH's and decalins are not analysed at regional sites in 1997 and 2000
** Data from Mannvik & al. 2001
[1] LSC = detection limit

18.2.2.2 Hydrocarbons

Summarised results of the hydrocarbon analyses, along with the content of selected hydrocarbon compounds in the different layers (0-1, 1-3 and 3-6) are given in Table 18.4 and Table 18.5. The complete data set including replicates is given in the Appendix. Comparison of the THC content in 2003 with previous surveys is presented in Figure 18.3.

THC was found in the range from 8.6 to 11.8 mg/kg and occurrence above LSC was not found. Highest concentrations were found at PSB07 which was situated 250 m to the southeast of the southern field centre.

Compared to previous surveys the THC content was about the same levels, although an increase in the THC content at the reference site PSB13R is seen.

In the vertical sediment samples from the 3-6 cm layer only PAH was found above LSC at PSA08 and PSB07 (Table 18.5).

Table 18.4. The content of oil hydrocarbons in sediments from Øst Frigg in 2003. All values in mg/kg dry sediment. THC values above $LSC_{north\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{PSB13R\ 03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data for the regional and field reference sites in the north part of region II are included.

Site	THC		PAH(16)		NPD		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
PSA08	10.6	1.5	0.033	0.003	0.023	0.001	0.162	0.035
PSA20	8.6	3.8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
PSB07	11.8	0.7	0.022	0.004	0.015	0.003	0.207	0.062
PSB17	9.9	4.8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
PSB13R	11.3	3.5	0.031	0.002	0.016	0.006	0.287	0.217
av. ± sd.[1]	10.2 ± 1.3							
min – max[1]	8.6 - 11.8							
av. ± sd.[2]	10.6 ± 2.0		0.028 ± 0.008		0.013 ± 0.002		0.157 ± 0.081	
min – max[2]	7.4-13.2		0.016-0.037		0.011-0.016		0.042-0.287	

n.a. = not analysed.
[1] Field sites, exclusive PSB13R
[2] Reg + Ref $_{north\ 03}$

Table 18.5. The content of oil hydrocarbons in vertical sections of sediment from 3 sampling sites at Øst Frigg in 2003. All values in mg/kg dry sediment. THC values above $LSC_{north\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{PSB13R\ 03}$ are dark shaded.

Site	Layer (cm)	THC	PAH(16)	NPD	Decalins
PSA08	0-1	8.9	0.035	0.024	0.165
	1-3	12.2	0.036	0.023	0.205
	3-6	10.6	0.051	0.028	0.180
PSB07	0-1	11.1	0.026	0.015	0.245
	1-3	10.1	0.022	0.015	0.305
	3-6	13.1	0.038	0.023	0.290
PSB13R	0-1	9.0	0.028	0.008	0.175
	1-3	9.8	0.034	0.015	0.185
	3-6	13.1	0.006	0.019	0.165

18.2.2.3 Metals

Table 18.6 summarises the results of the metal analyses of the Øst Frigg field in 2003. Concentrations of selected metals in the different layers (0-1, 1-3 and 3-6) of sediment are given in Table 18.7, whereas the complete data set including replicates is given in the Appendix. Comparisons of the metal contents in 2003 with the metal contents in previous surveys are presented in Figure 18.6.

Table 18.6 Content of metals in sediments from Øst Frigg in 2003. All values in mg/kg dry sediment. Metal values above $LSC_{north\ 97\text{-}03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data in the regional and field reference sites in the north part of the region II are included.

Site	Cu		Cr		Zn		Ba		Pb		Cd		Hg	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
PSA08	0.6	0.1	5.6	0.3	5.4	0.2	73	9	2.8	0.1	<0.03	-	0.005	0.000
PSA20	<0.6	-	4.9	0.4	5.3	0.3	77	27	2.8	0.2	<0.03	-	n.a.	n.a.
PSB07	<0.6	-	4.6	0.5	4.9	0.6	63	34	2.7	0.1	<0.03	-	0.011	0.007
PSB17	<0.6	-	4.5	0.2	5.1	0.6	45	14	2.6	0.1	<0.03	-	n.a.	n.a.
PSB13R	0.7	0.1	4.4	0.4	5.6	0.5	41	16	2.7	0.2	<0.03	-	0.007	0.003
av. ± sd.[1]	<0.6		4.9 ± 0.5		5.2 ± 0.2		64 ± 14		2.7 ± 0.1		<0.03			
min-max[1]	<0.6 - 0.7		4.5 -5.6		4.9 - 5.4		45 - 77		2.6 - 2.8		<0.03			
av. ± sd.[2]	<0.6		4.6 ± 0.8		5.9 ± 0.3		29 ± 10		2.5 ± 0.3		<0.03		0.007 ± 0.001	
min-max[2]	<0.6-0.8		3.7-5.6		5.5-6.3		18-41		2.1-2.8		<0.03		0.004 -0.014	

n.a. = not analysed.
[1] Field sites, exclusive PSB13R
[2] Reg + ref $_{north\ 03}$

Table 18.7. The content of metals in vertical sections of sediment from 3 sampling sites at Øst Frigg in 2003. All values in mg/kg dry sediment. Metal values above $LSC_{north\ 97\text{-}03}$ are dark shaded.

Site	Layer (cm)	Cu	Cr	Zn	Ba	Pb	Cd	Hg
PSA08	0-1	0.7	5.6	5.4	79.6	2.7	<0.03	0.005
	1-3	0.8	5.9	6.0	73.7	3.3	<0.03	0.005
	3-6	0.9	5.7	6.7	186	3.4	<0.03	0.006
PSB07	0-1	0.7	5.1	5.5	101	2.8	<0.03	0.018
	1-3	0.7	4.8	5.3	79.3	2.7	<0.03	0.005
	3-6	0.6	4.6	5.3	60	2.6	<0.03	0.005
PSB13R	0-1	0.6	4.0	5.0	25.2	2.4	<0.03	0.005
	1-3	0.8	4.4	6.2	96.3	2.8	<0.03	0.014
	3-6	0.9	4.9	6.9	134	3.3	<0.03	0.016

Barium was found in a range from 45 to 77 mg/kg, lead from 2.6 to 2.8 mg/kg, cadmium was <0.03 mg/kg, copper from 0.4 to 0.6 mg/kg, mercury from 0.005 to 0.011 mg/kg, chromium from 4.5 to 5.6 mg/kg and zinc from 4.9 to 5.4 mg/kg (Table 18.6). Barium and mercury occurred above LSC at PSA20 and PSB07 respectively.

Compared to the previous surveys there was a decrease in the barium and copper content in the sediments and an increase in the zinc content, whereas the other metals were at the same levels as earlier.

Vertical sediment samples (0-1, 1-3 and 3-6 cm) from PSA08 had barium content above LSC in the 0-1 and 3-6 cm layer. At PSB07, barium was found above LSC in the 0-1 and 1-3 cm layer and mercury was found above LSC in the 0-1 cm layer. In the 1-3 and 3-6 cm layers at the reference site PSB13R, barium and mercury were found above LSC.

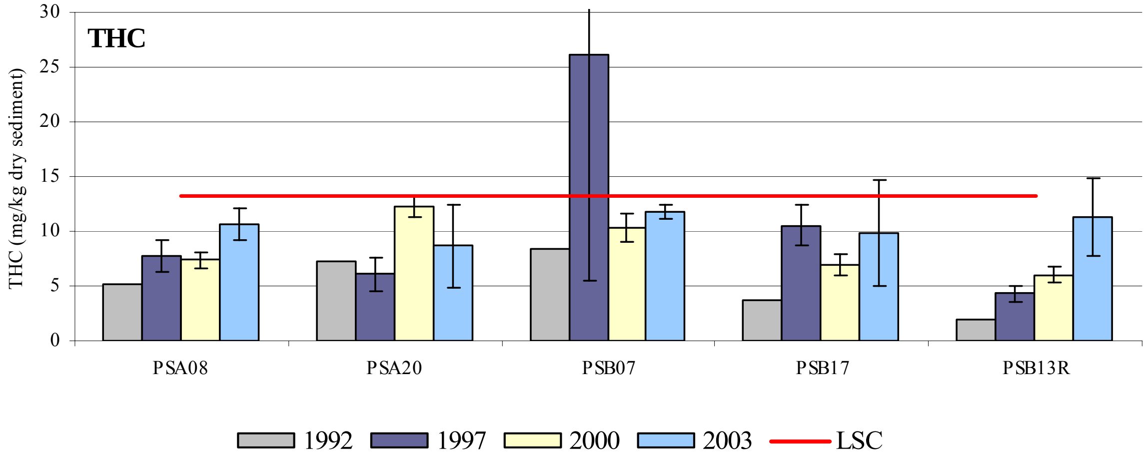


Figure 18.3. Average THC concentrations and standard deviations in sediments from Øst Frigg in 2003 and previous years. Red line is $LSC_{north\ 97-03}$.

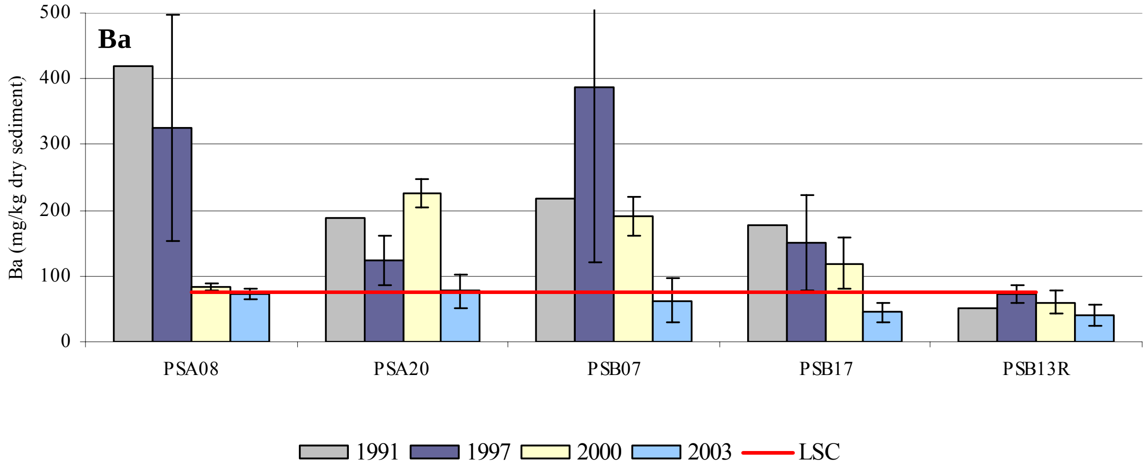


Figure 18.4. Average barium concentrations and standard deviations in sediments from Øst Frigg in 2003 and previous years. Red line is $LSC_{north\ 97-03}$.

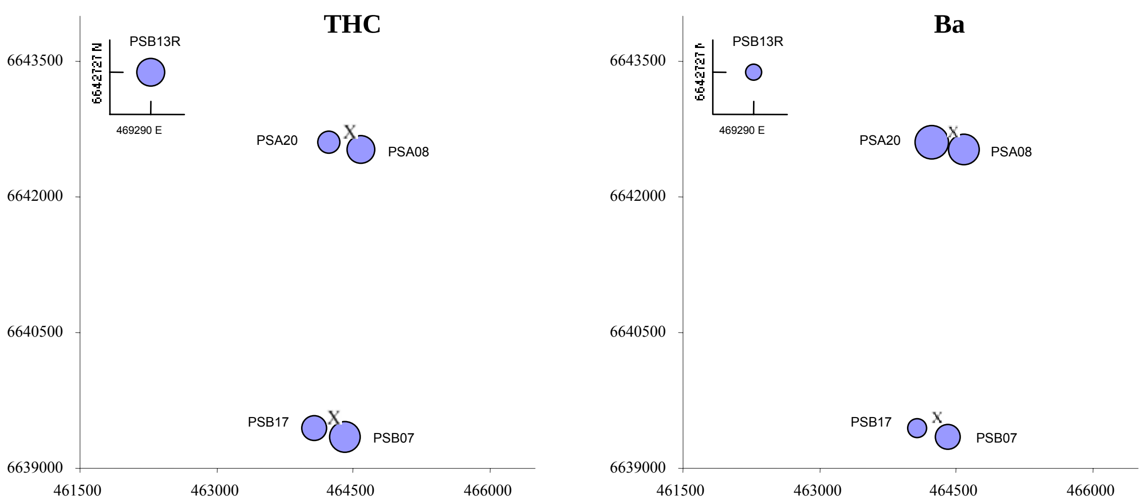


Figure 18.5. Distribution of THC and barium in sediments at the sampling sites at Øst Frigg in 2003. The sizes of the circle indicate the amount of THC and Ba. The field centre is marked with an X.

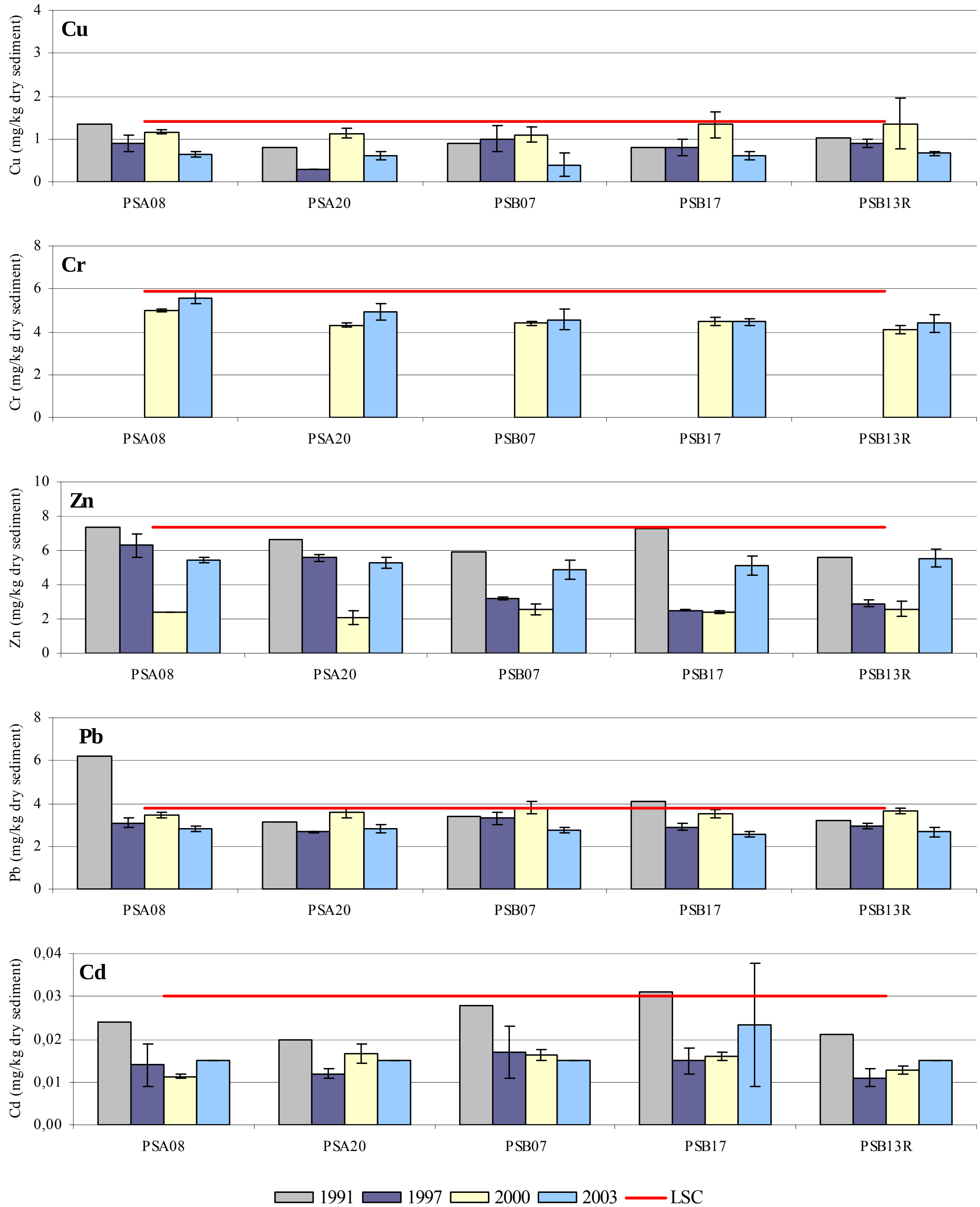


Figure 18.6. The content of metals in sediment from Øst Frigg in 2003 and previous surveys. Red line is $LSC_{north\ 97\text{-}03}$.

The field sites at Øst Frigg were compared to nearby regional (RII01 and RII02) and field specific reference (LFR01R and FRI10R) sites based on sediment characteristics (TOM and pelite) and chemical content in the sediments (Figure 18.7). The sites at Øst Frigg were grouped together when compared to the other regional and field specific reference sites, indicating homogeneity within the field specific sites, except for PSB07 which are separated from the other sites due to small nuances in the natural conditions within the field.

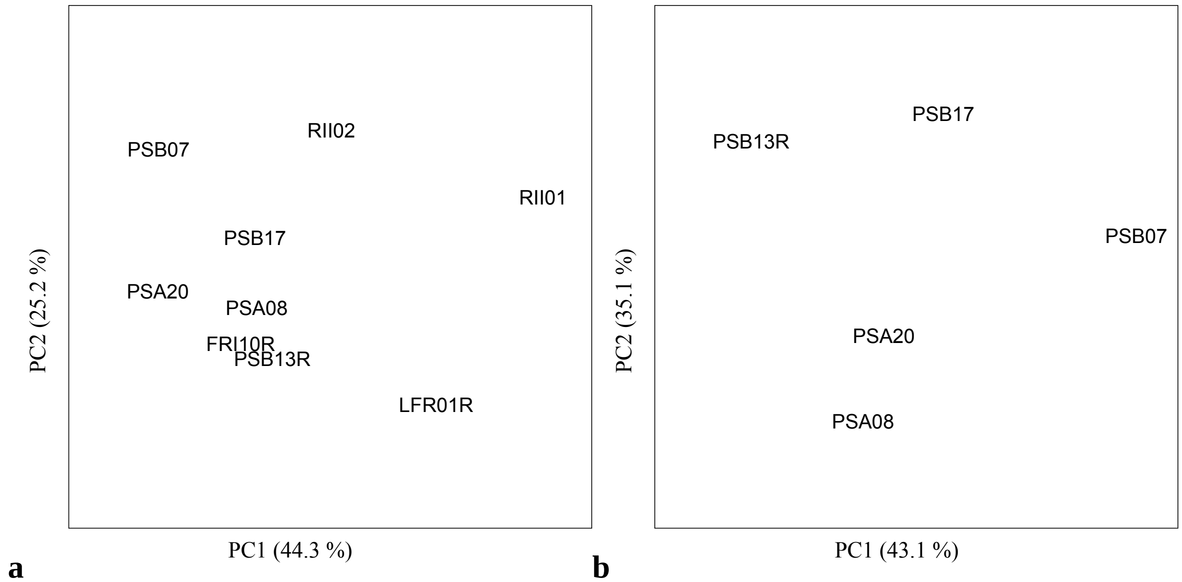


Figure 18.7. 2-D plot from the PCA analysis of environmental variables (% pelite, % sand, % gravel, median Φ, % TOM, Cu, Ba, Zn, Cr, Pb and THC) carried out on:

e) Øst Frigg field sites compared to the reference sites at Frigg and Lille Frigg and the regional sites RII01 and RII02. Explained variation in the data 69.4 %.
f) Øst Frigg field sites. Explained variation in the data 78.2 %.

18.1.2.3 Bottom fauna

A summary of the distribution of individuals and taxa within the main taxonomic groups are given in Table 18.8. Unidentified juveniles of the sea urchins Spatangoids (8478 individuals) and Echinoides (428 individuals), juveniles of the polychaete *Owenia fusiformis* (356 individuals), and juveniles of the two brittle stars *Amphiura filiformis* (265 individuals) and *Ophiura affinis* (483 individuals) are omitted from the analyses, as they occurred in extremely high numbers. In total, 4693 individuals within 165 taxa were collected at Øst Frigg in 2003. The fauna was numerically dominated by annelida with 54 % the individuals and 52 % of the taxa (Table 18.8). A complete species list is available in the Appendix.

Table 18.8. Distribution of individuals and taxa within the main taxonomic groups at Øst Frigg in 2003 including data from PSB13R (unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis*, *Ophiura affinis* and *Owenia fusiformis* are not included).

Main taxonomic groups	Number of individuals	%	Number of taxa	%
Annelida	2527	54	86	52
Arthropoda	248	5	27	16
Mollusca	1043	22	31	19
Echidermata	487	10	11	7
Diverse groups	388	8	10	6
Total	4693	100	165	100

The species/area curve for PSB13R indicates that five replicate samples give a representative impression of the bottom fauna in the area (Figure 18.8). However, as more area is sampled, more taxa are collected, indicating that not even 10 replicate samples give the full species assemblage of the area.

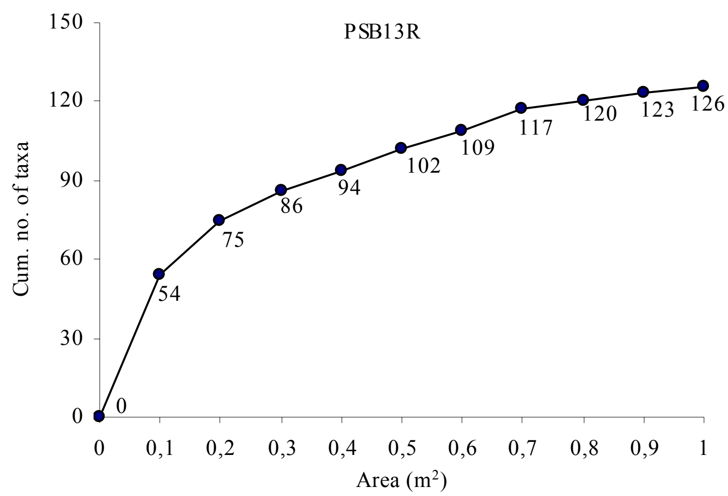


Figure 18.8. Species/area curve for the reference site at the Øst Frigg field. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis*, *Ophiura affinis* and *Owenia fusiformis.*

The distribution of individuals and taxa are shown in Figure 18.9. Number of individuals and taxa at each site, and the calculated diversity indexes (H' and ES_{100}) are given in Table 18.9 and Figure 18.10. The number of individuals varied from 591 (PSA08) to 937 (PSB07), and the number of taxa varied from 81 (PSA08) to 99 (PSA20). The Shannon-Wiener diversity index (H') varied from 4.55 (PSB07) to 5.13 (PSA20), whereas the ES_{100} index varied from 31.3 (PSB07) to 38.4 (PSA20). The evenness index J varied from 0.71 (PSB07) to 0.79 (PSA08). The corresponding values at PSB13R are within or near the variation at the field sites. The number of taxa, diversity and evenness indicate good environmental conditions at all sites.

Table 18.9. Number of individuals, species/taxa and selected community indices for each site (0.5 m^2) at the Øst Frigg field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis*, *Ophiura affinis* and *Owenia fusiformis*.

Site number	Number of individuals	Number of taxa	Diversity H'	Evenness J	H'-max	ES_{100}
PSA08	591	81	4.98	0.79	6.34	35.8
PSA20	642	99	5.13	0.77	6.63	38.4
PSB07	937	83	4.55	0.71	6.38	31.3
PSB17	784	85	4.70	0.73	6.41	31.8
PSB13R (6-10)	884	102	5.14	0.77	6.67	37.4
PSB13R (11-15)	855	91	4.89	0.75	6.51	34.4
PSB13R (6-15)	1739	126	5.10	0.73	6.98	36.1
Sum[1]	2954	140				
Average[1]	739	87	4.84	0.75	6.44	34.3
SD[1]	156	8	0.26	0.03	0.13	3.4
Min[1]	591	81	4.55	0.71	6.34	31.3
Max[1]	937	99	5.13	0.79	6.63	38.4
Average[2]	919	95	4.78	0.73	6.57	34.5
SD[2]	428	12	0.65	0.11	0.19	5.3
Min[2]	574	80	3.51	0.52	6.32	24.6
Max[2]	1749	109	5.31	0.82	6.77	39.6

[1]Øst Frigg field, exclusive PSB13R
[2]Reg + Ref $_{north\ 03}$

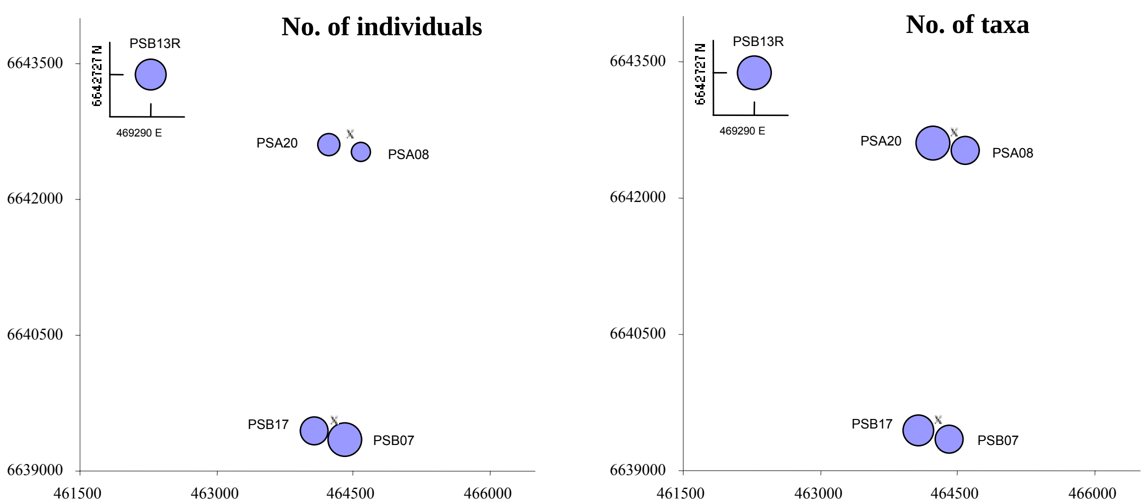


Figure 18.9. Distribution of bottom fauna (individuals and taxa) among the sampling sites in 2003. The size of the circle indicates the number of individuals and taxa. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis*, *Ophiura affinis* and *Owenia fusiformis.* Values for PSB13R are average of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2). The field centre is marked with an X.

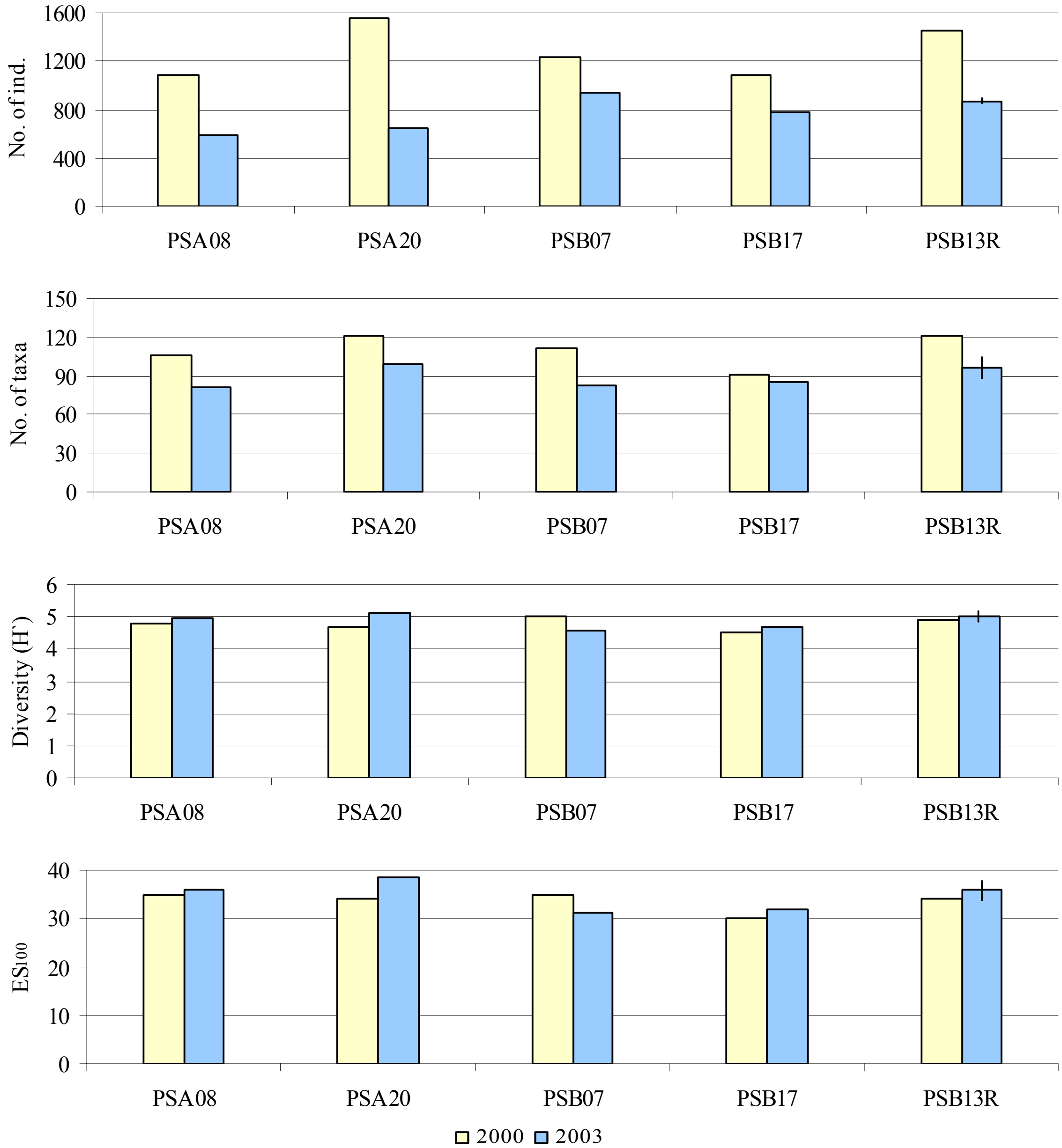


Figure 18.10. Number of individuals, taxa and selected community indices for each site (0.5 m^2) at the Øst Frigg field for 2000 and 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis*, *Ophiura affinis* and *Owenia fusiformis*. Values for PSB13R are average ± standard deviation of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2).

Distribution of taxa in geometrical classes is presented in Figure 18.11. The smooth graphs are representing undisturbed bottom fauna.

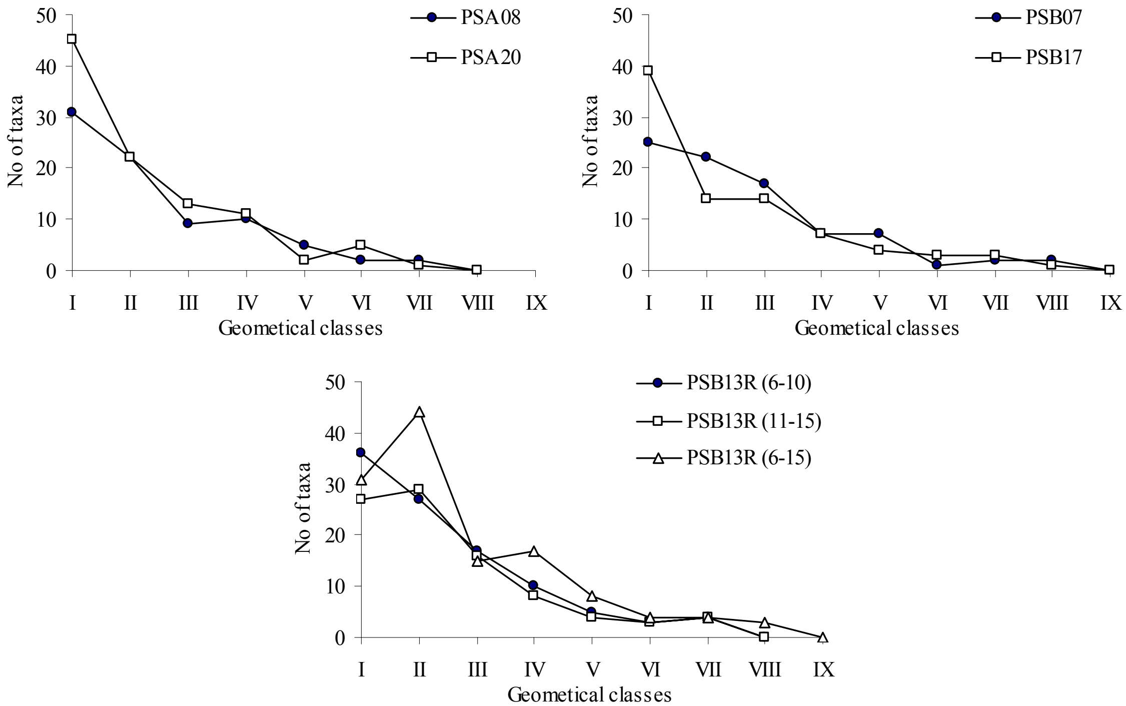


Figure 18.11. Distribution of taxa in geometrical classes for the sites at Øst Frigg in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis*, *Ophiura affinis* and *Owenia fusiformis.*

The ten most numerous taxa are listed in Table 18.12 at the end of this chapter. The list comprise 16 taxa and 3437 individuals, which was 9.7 % of all (165) taxa and 73.2 % of all (4693) individuals. The most abundant species were the polychaetes *Owenia fusiformis, Myriochele oculata* and *Spiophanes bombyx*, the brittle star *Amphiura filiformis*, the bivalve *Thyasira flexuosa* and the phoronoid *Phoronis* sp. All of these species were among the ten most abundant species at all sites at Øst Frigg in 2003. *Spiophanes bombyx* and *Amphiura filifomis* were among the most abundant species in 2000 too. The low number of species among the ten most numerous taxa indicate uniform distribution of the fauna in the sampling area. *Thyasira flexuosa* are commonly found in high numbers in sediments where the fauna is disturbed. However, the presence of the *Amphiura filiformis* is mitigating this impression and species assemblage indicates good environmental conditions at all sites.

The results of the multivariate analyses are given in the dendrogramme (Figure 18.12) and the MDS plott (Figure 18.13).

In the cluster analysis, all sites are grouped together within 67 % similarity, indicating relatively high similarity in the species assemblages within the sampling area. Although the species assemblage at PSB17 were somewhat different compared to the fauna at the other sites.

The results of the MDS analysis support the findings in the cluster analysis. The stress test of the MDS analysis was 0.02, indicating an excellent fit of the data.

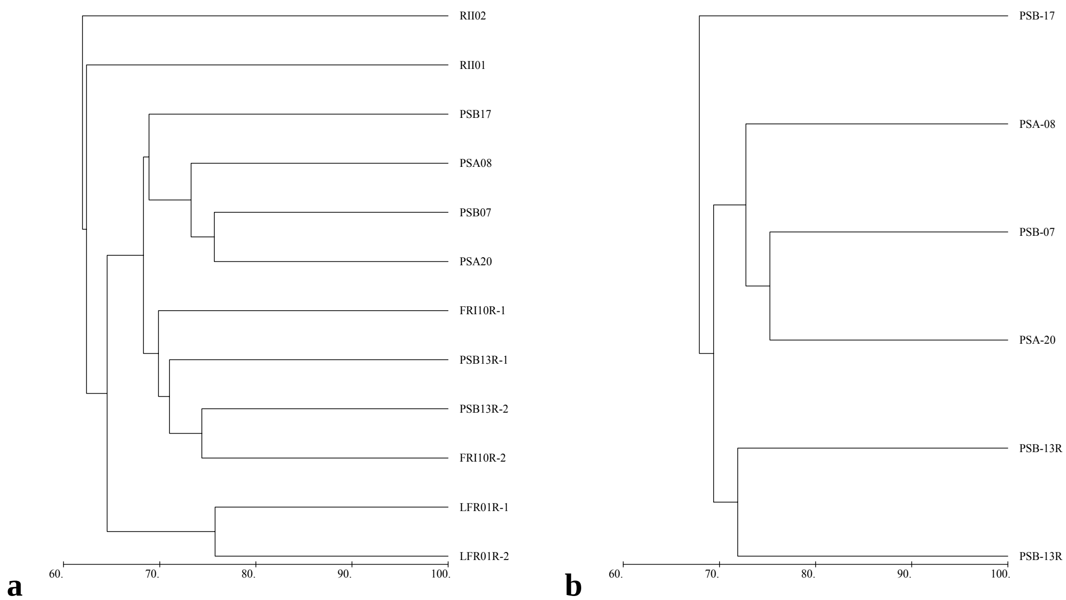


Figure 18.12. Dendrogram showing the similarity between fauna from sampling sites at:

a) Øst Frigg field compared to regional sites (RII01 and RII02) and reference sites (LFR01R and FRI10R) in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.
b) Øst Frigg field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis*, *Ophiura affinis* and *Owenia fusiformis.*

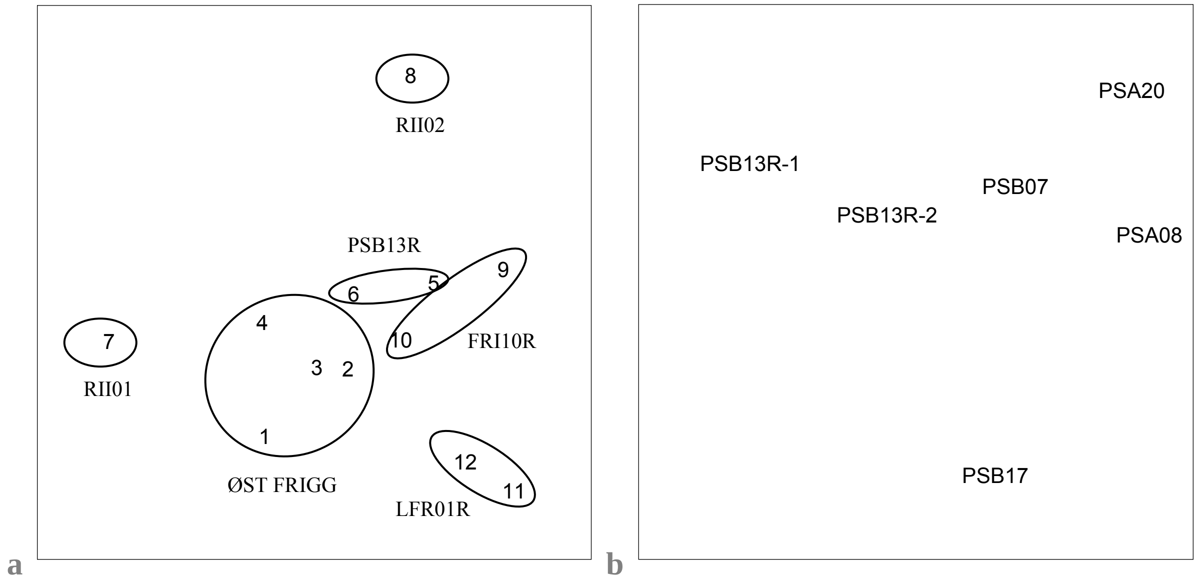


Figure 18.13. A 2-dimetional plott of the MDS analysis of the fauna data from:

a) Øst Frigg field compared to regional sites (RII01 and RII02) and reference sites (LFR01R and FRI10R) in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea. Stress = 0.14. Codes in table below.

b) Øst Frigg field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis*, *Ophiura affinis* and *Owenia fusiformis.*Stress = 0.02.

1	PSA08	5	PSB13R-1	9	FRI10R-1
2	PSA20	6	PSB13R-2	10	FRI10R-2
3	PSB07	7	RII01	11	LFR01R-1
4	PSB17	8	RII02	12	LFR01R-2

Linking of biotic and environmental variables by BIOENV revealed that the content of barium, gravel and lead were correlated to the biota at $\rho_w = 0.76$ (Table 18.10).

Table 18.10. Combinations of the 10 environmental variables, taken *k* at a time, yielding the best matches of biotic and abiotic similarity matrices for each *k*, as measured by weighted Spearman rank correlation ρ_w. Bold type indicates overall optimum. All possible combinations of variables and associated correlation to the biotic are given in the Appendix.

Number of Variables (*k*)	Correlation coefficient (ρ_w)	Environmental variables									
1	0.680	Pb									
1	0.449	Ba									
1	0.238	Gravel									
1	0.074	Sand									
1	0.051	Cr									
1	0.007	Pelite									
1	-0.100	TOM									
1	-0.102	THC									
1	-0.125	Zn									
1	-0.264	Cu									
2	0.725	Ba	Gravel								
3	**0.761**	**Ba**	**Gravel**	**Pb**							
4	0.693	Ba	Gravel	Pb	Cr						
5	0.635	Ba	Gravel	Pb	Cr	Sand					
6	0.597	Ba	Gravel	Pb	Cr	Sand	Pelite				
7	0.509	Ba	Gravel	Pb	Cr	Sand	Pelite	TOM			
8	0.459	Ba	Gravel	Pb	Cr	Sand	Pelite	TOM	Zn		
9	0.234	Ba	Gravel	Pb	Cr	Sand	Pelite	TOM	Zn	THC	
10	0.090	Ba	Gravel	Pb	Cr	Sand	Pelite	TOM	Zn	THC	Cu

18.2.4 Estimation of influenced area

The extension of contamination along sampling transects and the minimum area of contaminated sediments for THC, barium and other metals as well as for faunal disturbance is given in Figure 18.15 and Table 18.11. Only one site (PSA20) was contaminated by barium and only one site (PSB07) was contaminated by other metals (mercury). Faunal disturbance was not detected at any site. The total area contaminated by THC and barium decreased from 2000 to 2003, whereas a negligible increase in the total area (0.02 km²) contaminated by other metals was found.

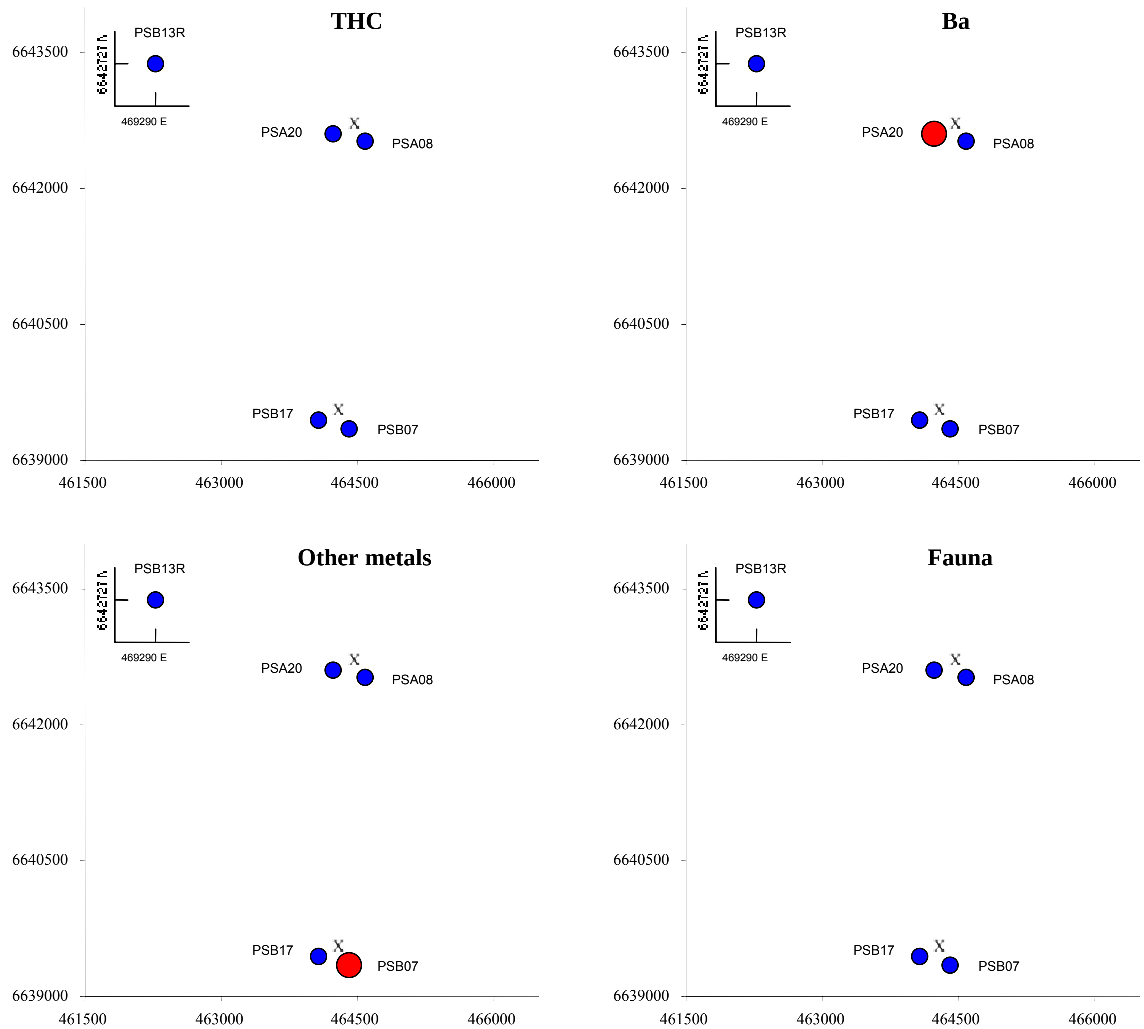


Figure 18.15. Faunal disturbance and chemical contamination of the sediments at Øst Frigg in 2003. Uncontaminated sites and sites with no faunal disturbance are marked with small blue circles. The field centre is marked with an X.

Table 18.11. Estimated distance of contamination and faunal disturbance from the installation, and estimated area of contamination and faunal disturbance around the field centre.

Øst Frigg PSA	NE m	SE m	SW m	NW m	2003 km²	2000 km²	1997 km²
THC	0	0	0	0	0.00	0.07	0.00
Ba	0	0	250	0	0.02	0.07	0.22
Other metals	0	0	0	0	0.00	0.00	0.00
Fauna	0	0	0	0	0.00	0.00	0.00

Øst Frigg PSB	NE m	SE m	SW m	NW m	2003 km²	2000 km²	1997 km²
THC	0	0	0	0	0.00	0.00	0.11
Ba	0	0	0	0	0.00	0.11	0.11
Other metals	0	250	0	0	0.02	0.00	0.00
Fauna	0	0	0	0	0.00	0.00	0.00

Øst Frigg SUM	NE m	SE m	SW m	NW m	2003 km²	2000 km²	1997 km²
THC					0.00	0.07	0.11
Ba					0.02	0.18	0.33
Other metals					0.02	0.00	0.00
Fauna					0.00	0.00	0.00

18.3 Summary and conclusions

Production ceased at Øst Frigg in December 1997 and the wells were permanently plugged and abandoned in 1999. The sub-sea structures were removed in 2002. The sediments at Øst Frigg are characterized as fine sand. The THC content was low and relatively evenly distributed across the sampling sites. No THC contamination was revealed. Also the metals occurred in low and relatively even concentrations across the field. Contamination by metals was only found at two sites PSA20 (barium) and PSB07 (mercury). Despite lower number of individuals and taxa in the samples in 2003 than in 2000 the species diversity was approximately the same. And despite correlation between the fauna and some of the environmental variables (barium, gravel and lead) no faunal disturbances were found, as in 1997 and 2000. The area contaminated with barium was smaller in 2003 than in 2000, whereas the area contaminated by other metals had increased from 0 to 0.2 km^2.

Table 18.12. Number of individuals and relative abundance for the ten predominant taxa at each site at the Øst Frigg field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis*, *Ophiura affinis* and *Owenia fusiformis*.

PSA08	No. of ind.	%	Cum %
Amphiura filiformis	82	13,9	13,9
Spiophanes bombyx	72	12,2	26,1
Thyasira flexuosa	48	8,1	34,2
Myriochele oculata	37	6,3	40,4
Mysella bidentata	27	4,6	45,0
Owenia fusiformis	22	3,7	48,7
Phoronis sp.	22	3,7	52,5
Abra prismatica	22	3,7	56,2
Chaetozone sp.	18	3,0	59,2
Cylichna cylindracea	15	2,5	61,8

PSA20	No. of ind.	%	Cum %
Owenia fusiformis	88	13,7	13,7
Spiophanes bombyx	60	9,3	23,1
Amphiura filiformis	60	9,3	32,4
Myriochele oculata	47	7,3	39,7
Thyasira flexuosa	43	6,7	46,4
Phoronis sp.	34	5,3	51,7
Chaetozone sp.	21	3,3	55,0
Cylichna cylindracea	16	2,5	57,5
Cerianthus lloydii	14	2,2	59,7
Scoloplos armiger	12	1,9	61,5
Myriochele fragilis	12	1,9	63,4

PSB07	No. of ind.	%	Cum %
Montacuta substriata	195	20,8	20,8
Owenia fusiformis	140	14,9	35,8
Spiophanes bombyx	86	9,2	44,9
Myriochele oculata	64	6,8	51,8
Amphiura filiformis	53	5,7	57,4
Phoronis sp.	31	3,3	60,7
Thyasira flexuosa	29	3,1	63,8
Harpinia antennaria	25	2,7	66,5
Scoloplos armiger	22	2,3	68,8
Goniada maculata	19	2,0	70,9
Mysella bidentata	19	2,0	72,9

PSB17	No. of ind.	%	Cum %
Owenia fusiformis	134	17,1	17,1
Spiophanes bombyx	79	10,1	27,2
Myriochele oculata	72	9,2	36,4
Amphiura filiformis	68	8,7	45,0
Thyasira flexuosa	60	7,7	52,7
Phoronis sp.	42	5,4	58,0
Mysella bidentata	32	4,1	62,1
Chaetozone sp.	19	2,4	64,5
Harpinia antennaria	19	2,4	67,0
Cerianthus lloydii	18	2,3	69,3

PSB13R	No. of ind.	%	Cum %
Owenia fusiformis	217	12,5	12,5
Myriochele oculata	193	11,1	23,6
Amphiura filiformis	166	9,5	33,1
Phoronis sp.	120	6,9	40,0
Spiophanes bombyx	114	6,6	46,6
Thyasira flexuosa	97	5,6	52,2
Chaetozone sp.	87	5,0	57,2
Myriochele fragilis	45	2,6	59,7
Cylichna cylindracea	42	2,4	62,2
Harpinia antennaria	42	2,4	64,6

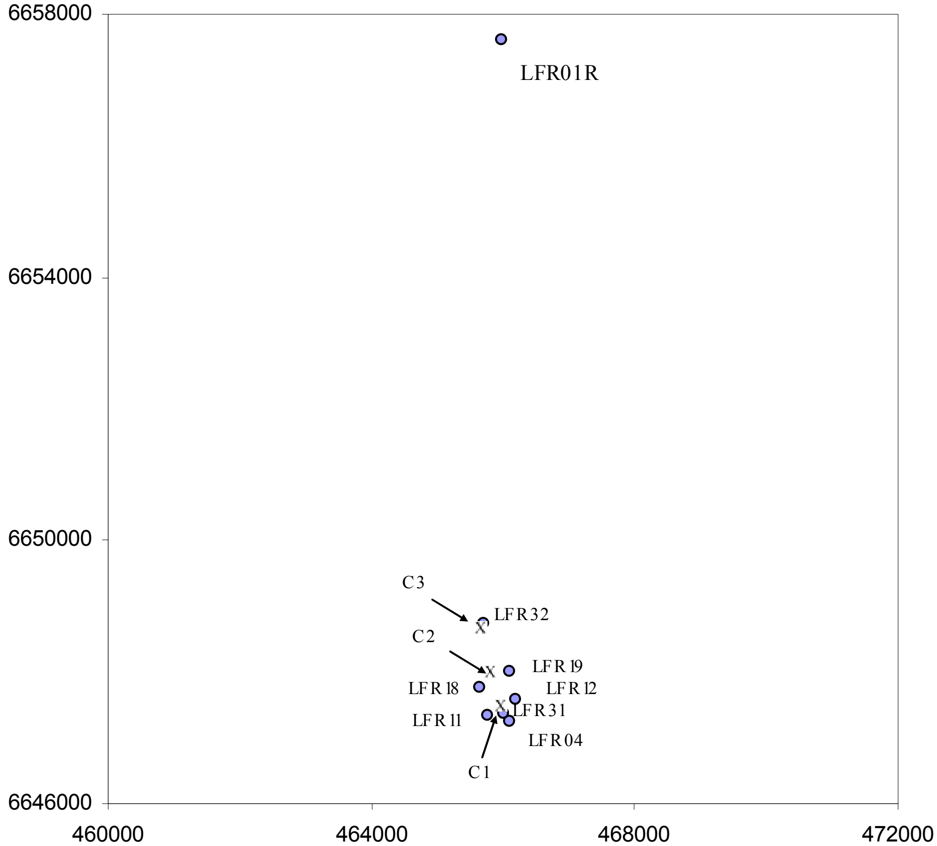
19 Lille-Frigg

19.1. Introduction

The Lille-Frigg field is situated in block 25/2, north east of Øst Frigg. Production at Lille-Frigg started in 1994 and ceased in 1999. There have been no drilling activities at Lille-Frigg since 1993/94 and all wells were permanently plugged and abandoned in 2000/2001. This monitoring survey is the last mandatory survey after production shut down. Recent discharges are all, except one, related to the plugging of the wells (Table 19.1). Monitoring of the field was undertaken both in 1997 and 2000, and a separate survey of the cutting piles was undertaken in 2000. In 2000 no faunal disturbances were found and only low levels of THC were detected at some sampling sites, and some of the piles of cuttings were covered by natural sediments. Thus in an attempt to better define the borderline between contaminated and uncontaminated sediments sampling only 100 m off the field centre was carried out at two sites in 2003. The locations of sampling sites are shown in Figure 19.1.

Table 19.1. Recent discharges, in tonnes, from operations and accidental spills at Lille-Frigg.

	1997	1998	1999	2000	2001	2002	Comments
No of wells drilled	0	0	0	0	0	0	
Barite	0	0	0	140	0	0	
Cuttings	0	0	0	0	0	0	
Water-based drilling mud	0	0	0	775	957	0	Plugging of wells
Cementing chemicals	0	0	0	13	0	0	
Accidental discharges	0	0	0	1.1	0	0	Hydraulic oil



Site	ED50 UTM Zone 31		Distance (m) / direction (º)	Depth (m)
	E	N		
LFR-04	466101	6647233	250/150	114
LFR-11	465760	6647324	250/240	112
LFR-12	466193	6647574	250/60	116
LFR-18	465659	6647750	250/240	114
LFR-19	466092	6648000	250/60	117
LFR-31	466026	6647363	100/150	115
LFR-32	465724	6648738	100/60	115
LFR-01R	465976	6657599	10150/0	116

Figure 19.1. Map showing the internal distribution of sampling sites in Lille-Frigg in 2003. Positioning according to UTM ED50 zone 31. The field centre is marked with an X.

19.2. Results and discussion

19.2.1 Sediments characteristics

TOM, the amount (%) of gravel, sand and pelite, median (Φ), sorting, skewness and kurtosis in the sediment from the present survey is presented in Table 19.2. Additional information on colour and smell can be found in the Appendix. Median (Φ), pelite, sand and TOM are compared with data from 2000 in Figure 19.2.

The sediments at Lille-Frigg are classified as fine sand with median (Φ) values ranging from 2.54 (LFR11) to 2.67 (LFR12). The amount of pelite varied from 5.3 % (LFR11) to 9.9 % (LFR31), the sand varied from 89.9 % (LFR31) to 94.7 % (LFR11), and the TOM varied from 0,97 % (LFR04) to 1.59 % (LFR32). The conditions at the reference site (LFR01R) were close to or within the variation found at the field sites.

Compared to the results of 2000 only minor differences were seen (Figure 19.2).

Table 19.2. Total organic matter and sediment grain size at all sites at Lille-Frigg in 2003. For comparison averages, standard deviations, max and min values for the regional and reference sites are included.

Site	TOM %	Gravel %	Sand %	Pelite %	Median (Φ)	Sorting	Skewness	Kurtosis
LFR04	0.97	0.00	93.47	6.53	2.59	0.71	0.38	1.85
LFR11	1.04	0.01	94.68	5.32	2.54	0.61	0.15	1.67
LFR12	1.46	0.18	89.96	9.86	2.67	0.97	0.49	1.93
LFR18	1.20	0.01	93.94	6.06	2.58	0.65	0.33	1.73
LFR19	1.15	0.19	93.33	6.48	2.62	0.73	0.41	1.80
LFR31	1.28	0.21	89.92	9.87	2.60	0.97	0.45	2.50
LFR32	1.59	0.39	91.71	7.91	2.61	0.87	0.42	2.17
LFR01R	1.17	0.03	93.99	5.98	2.46	0.94	0.08	1.72
Average[1]	1.24	0.14	92.43	7.43	2.60	0.79	0.38	1.95
SD[1]	0.22	0.14	1.92	1.83	0.04	0.15	0.11	0.29
Min[1]	0.97	0.00	89.92	5.32	2.54	0.61	0.15	1.67
Max[1]	1.59	0.39	94.68	9.87	2.67	0.97	0.49	2.50
Average[2]	0.99	0.02	95.16	4.83	2.73	0.75	0.12	1.58
SD[2]	0.19	0.02	1.27	1.28	0.48	0.15	0.10	0.19
Min[2]	0.68	0.00	93.99	2.85	2.45	0.54	-0.06	1.37
Max[2]	1.19	0.03	97.12	5.98	3.69	0.94	0.23	1.87

[1] Field sites, exclusive LFR01R
[2] Reg + Ref $_{\text{north 03}}$

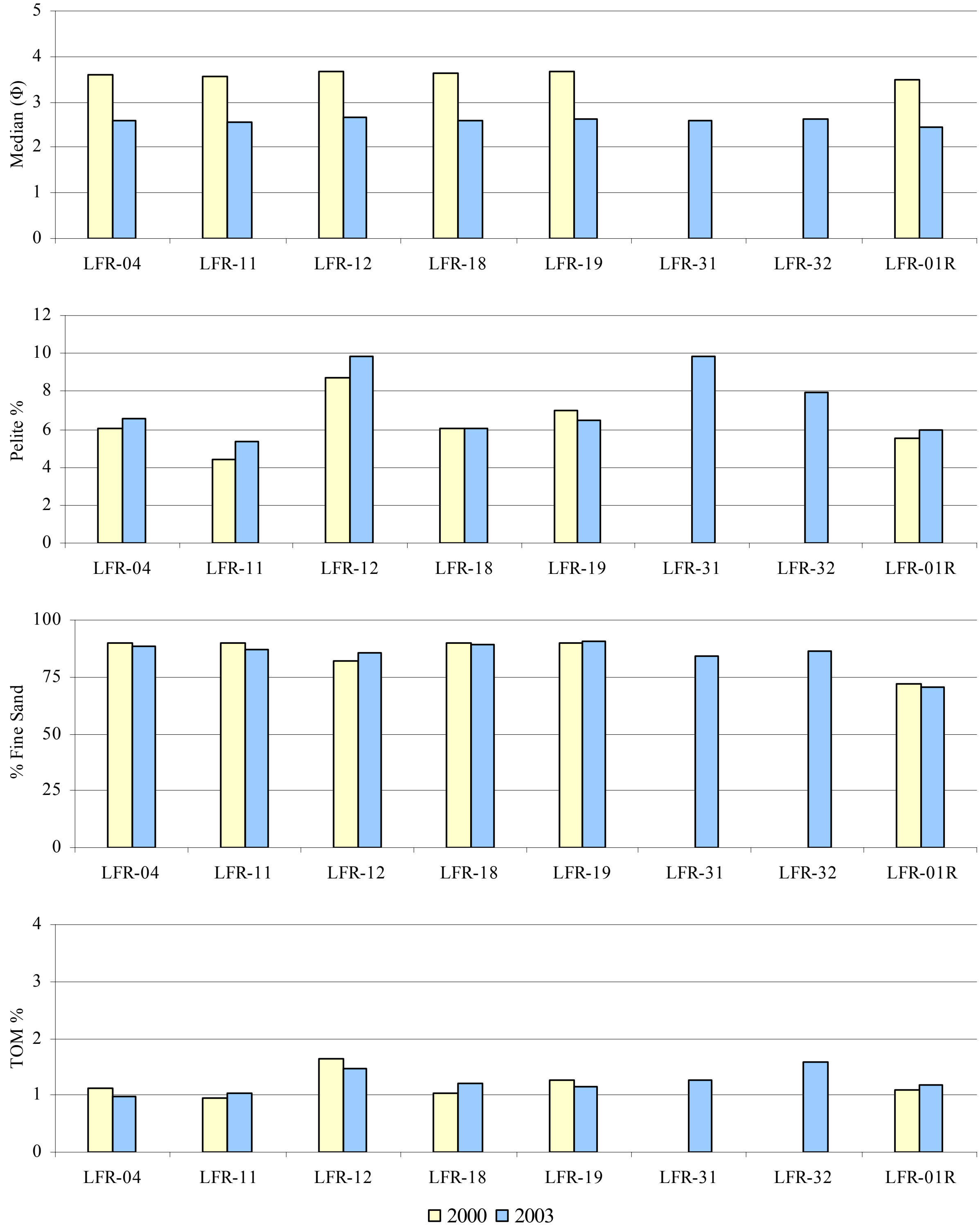


Figure 19.2. Sediment characteristics at Lille-Frigg in 2000 and 2003. Fine sand is the relative amount of sand with grain size 63-250 µm.

19.2.2 Chemical compounds

19.2.2.1 LSC

The results of the LSC (limits of significant contamination) calculations of hydrocarbons and metals are presented in the chapter concerning the regional and reference sites. Both the $LSC_{north\ 97\text{-}03}$ and the field specific LSC value ($LSC_{LFR01R\ 03}$) are presented in Table 19.3. Fine sediments are more likely to have higher affinity for pollutants than coarse sediments. LSC in the text relates to $LSC_{north\ 97\text{-}03}$.

Table 19.3. Limits of Significant Contamination (LSC) for the Lille-Frigg field in 2003, and for the north part of Region II based on data from 1997 to 2003 ($LSC_{north\ 97\text{-}03}$) and the whole of Region II based on data from 1997 to 2003 ($LSC_{regII\ 97\text{-}03}$). For comparison, LSC-values from 2000 are included. All values in mg/kg dry sediment.

	THC	PAH (16)	NPD's	Decalins	Cu	Cr	Zn	Ba	Pb	Cd	Hg
$LSC_{LFR01R\ 03}$	14.7	0.040	0.016	0.054	0.9	8.9	7.7	58	3.2	0.03[1]	0.011
$LSC_{north\ 97\text{-}03}$	13.3	*	*	*	1.4	5.9	7.4	76	3.8	0.03[1]	0.008
$LSC_{regII\ 97\text{-}03}$	13.3	*	*	*	2.0	9.4	11.1	136	6.6	0.03[1]	0.011
$LSC_{LFR01R\ 00}$**	9.7	*	0.03	0.079	1.1	5.3	5.3	132	3.8	0.02	0.006
$LSC_{regII\ 97\text{-}00}$**	9.8	*	*	*	2.0	9.6	8.9	146	7.0	0.03	0.008

* NPD's, PAH's and decalins are not analysed at regional sites in 1997 and 2000
** Data from Mannvik & al. 2001
[1] LSC = detection limit

19.2.2.2 Hydrocarbons

Summarised results of the hydrocarbon analyses, along with the content of selected hydrocarbon compounds in the different layers (0-1, 1-3 and 3-6) are given in Table 19.4 and Table 19.5. The complete data set including replicates is given in the Appendix. Comparison of the THC content in 2003 with previous surveys is presented in Figure 19.3.

Table 19.4. The content of oil hydrocarbons in sediments from Lille-Frigg in 2003. All values in mg/kg dry sediment. THC values above $LSC_{north\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{LFR01R\ 03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data for the regional and field reference sites in the north part of region II are included.

Site	THC		PAH(16)		NPD		Decalins	
	a.v.	sd.	a.v.	sd.	a.v.	sd.	a.v.	sd.
LFR04	12.9	1.8	0.034	0.005	0.049	0.027	0.068	0.038
LFR11	7.6	5.8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
LFR12	8.5	6.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
LFR18	7.5	2.3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
LFR19	6.6	3.3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
LFR31	15.9	1.1	0.038	0.001	0.069	0.011	0.098	0.006
LFR32	12.3	3.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
LFR01R	11.2	1.5	0.033	0.003	0.012	0.002	0.042	0.005
av. ± sd.[1]	10.2±3.5							
min – max[1]	6.6-15.9							
av. ± sd.[2]	10.6 ± 2.0		0.028 ± 0.008		0.013 ± 0.002		0.157 ± 0.081	
min – max[2]	7.4-13.2		0.016-0.037		0.011-0.016		0.042-0.287	

n.a. = not analysed.
[1] Field sites, exclusive LFR01R
[2] Reg + $Ref_{north\ 03}$

THC was found in the range from 6.6 to 15.9 mg/kg, and THC concentrations above LSC were only found at LFR31, 100 m to the southeast of C1. In general the THC content was lower or at the same level as in 2000 except at LFR04 and LFR01R where the THC content increased.

At LFR31 concentrations of THC, NPD and decalins were found above LSC down to 6 cm in the sediments, and concentrations of PAH was above LSC in the 1-3 and 3-6 cm layers. At LFR04, 250 m to the southeast of C1, concentrations of NPD was found above LSC down to 6 cm, whereas concentrations of decalins was found above LSC in the 1-3 and 3-6 cm layers and concentrations of THC and PAH occurred above LSC in the 3-6 cm layer. Concentrations of PAH, NPD and decalins occurred above LSC in the 3-6 cm layer at LFR01R. The hydrocarbons were more uniformly distributed in the sediments at LFR31 than at LFR04 and LFR01R, where concentrations were increasing with increasing depth in the sediments (Table 19.5). This indicates no recent supply of these compounds to the sediments, but might be a result of covering by natural sediments as found in the survey of the pile of cuttings in 2000. LFR31 was also located closer (100 m) to the field centre than the original sampling site which was located at 250 m.

Table 19.5. The content of oil hydrocarbons in vertical sections of sediment from 3 sampling sites at Lille-Frigg in 2003. All values in mg/kg dry sediment. THC values above $LSC_{north\ 97\text{-}03}$ and PAH, NPD and decalin values above $LSC_{LFR01R\ 03}$ are dark shaded.

Site	Layer (cm)	THC	PAH(16)	NPD	Decalins
LFR04	0-1	13.0	0.039	0.032	0.053
	1-3	12.7	0.037	0.089	0.076
	3-6	17.4	0.053	0.033	0.059
LFR31	0-1	16.3	0.037	0.082	0.103
	1-3	24.5	0.063	0.204	0.188
	3-6	25.6	0.108	0.410	0.160
LFR01R	0-1	10.6	0.037	0.015	0.049
	1-3	11.7	0.032	0.014	0.051
	3-6	11.1	0.047	0.017	0.074

19.2.2.3 Metals

Table 19.6 summarises the results of the metal analyses of the Lille-Frigg field in 2003. Concentrations of selected metals in the different layers (0-1, 1-3 and 3-6) of sediment are given in Table 19.7, whereas the complete data set including replicates is given in the Appendix. Comparisons of the metal contents in 2003 with the metal contents in 1997 and in 2000 are presented in Figure 19.6.

Table 19.6 Content of metals in sediments from Lille-Frigg in 2003. All values in mg/kg dry sediment. Metal values above $LSC_{north\ 97\text{-}03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data in the regional and field reference sites in the north part of the region II are included.

Site	Cu		Cr		Zn		Ba		Pb		Cd		Hg	
	a.v.	sd.	a.v.	sd.	a.v.	sd.	a.v.	sd.	a.v.	sd.	a.v.	sd.	a.v.	sd.
LFR04	0.9	0.1	4.9	0.6	7.5	0.2	369	18	5.4	0.1	<0.03	-	0.008	0.001
LFR11	1.0	0.1	4.7	0.1	7.0	0.4	340	69	5.3	0.3	<0.03	-	n.a.	n.a.
LFR12	1.9	0.4	5.7	0.3	8.6	0.7	404	99	7.4	0.4	<0.03	-	n.a.	n.a.
LFR18	0.7	0.1	4.6	0.3	7.0	0.5	207	56	3.7	0.4	<0.03	-	n.a.	n.a.
LFR19	0.8	0.1	5.0	0.2	7.3	0.2	319	32	4.6	0.3	<0.03	-	n.a.	n.a.
LFR31	2.8	0.3	5.5	0.2	10.8	0.8	709	84	20.1	1.5	<0.03	-	0.017	0.008
LFR32	1.4	0.2	5.0	0.2	8.8	1.2	395	100	6.4	0.4	<0.03	-	n.a.	n.a.
LFR01R	0.8	0.1	5.6	1.4	6.0	0.7	34	10	2.5	0.3	<0.03	-	0.008	0.001
av. ± sd.[1]	1.4 ± 0.8		5.1 ± 0.43		8.1 ± 1.38		391.9 ± 154		7.6 ± 5.7		<0.03			
min – max[1]	0.7 - 2.8		4.6 - 5.7		7.0 - 10.8		207 - 708		3.7 - 20.1		<0.03			
av. ± sd.[2]	<0.6		4.6 ± 0.8		5.9 ± 0.3		29 ± 10		2.5 ± 0.3		<0.03		0.007 ± 0.001	
min – max[2]	<0.6-0.8		3.7-5.6		5.5-6.3		18-41		2.1-2.8		<0.03		0.004 -0.014	

n.a. = not analysed.
[1] Field sites, exclusive LFR01R
[2] Reg + $ref_{north\ 03}$

Table 19.7. The content of metals in vertical sections of sediment from 3 sampling sites at Lille-Frigg in 2003. All values in mg/kg dry sediment. Metal values above $LSC_{north\ 97\text{-}03}$ are dark shaded.

Site	Layer (cm)	Cu	Cr	Zn	Ba	Pb	Cd	Hg
LFR04	0-1	0.9	4.6	7.6	389	5.4	<0.03	0.008
	1-3	1.1	4.7	8.4	428	5.8	<0.03	0.008
	3-6	1.3	4.8	8.8	666	6.5	0.04	0.009
LFR31	0-1	3.0	5.3	11.6	623	20.0	<0.03	0.013
	1-3	3.8	6.1	12.6	641	21.0	<0.03	0.020
	3-6	3.5	6.5	17.4	987	19.0	0.07	0.020
LFR01R	0-1	0.8	5.1	7.3	50	2.4	<0.03	0.007
	1-3	0.9	5.0	6.6	62	2.4	<0.03	0.007
	3-6	0.9	4.9	6.3	48	2.6	<0.03	0.008

Barium was found in a range from 207 to 708 mg/kg, lead from 3.7 to 20.1 mg/kg, cadmium was <0.03 mg/kg in all samples, chromium from 4.6 to 5.7 mg/kg, copper from 0.7 to 2.8 mg/kg, mercury from 0.008 to 0.017 mg/kg and zinc from 7.0 to 10.8 mg/kg (Table 19.6). Sediments from all sites but the reference site had barium content above LSC. Copper occurred above LSC at LFR12 and LFR31, zinc at LFR04, LFR12, LFR31 and LFR32, lead at LFR04, LFR11, LFR12, LFR31 and LFR32, and mercury at LFR31.

Vertical sediment samples (0-1, 1-3 and 3-6 cm) from LFR04 had zinc and barium and lead content above LSC in all depth intervals, and cadmium and mercury were found above LSC in the 3-6 cm interval. At LFR31 copper, zinc, barium, lead and mercury occurred above LSC in all depth intervals. Chrome was above LSC in the 1-3 and 3-6 cm intervals and cadmium was above LSC in the 3-6 cm interval (Table 19.7). Most metals had a uniform vertical distribution in the sediments, except for barium which occurred in increasing concentrations with increasing depth in the sediments, indicating former supply of barium to the sediments.

Generally the barium content was lower in 2003 than in previous years.

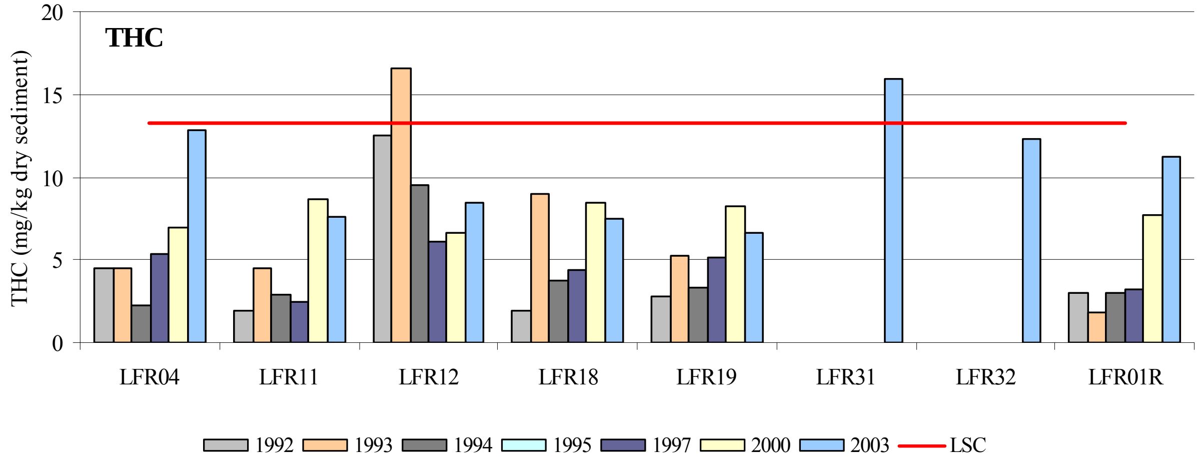


Figure 19.3. Average THC concentrations and standard deviations in sediments from Lille-Frigg in 2003 and previous years. Red line is $LSC_{north\ 97\text{-}03}$.

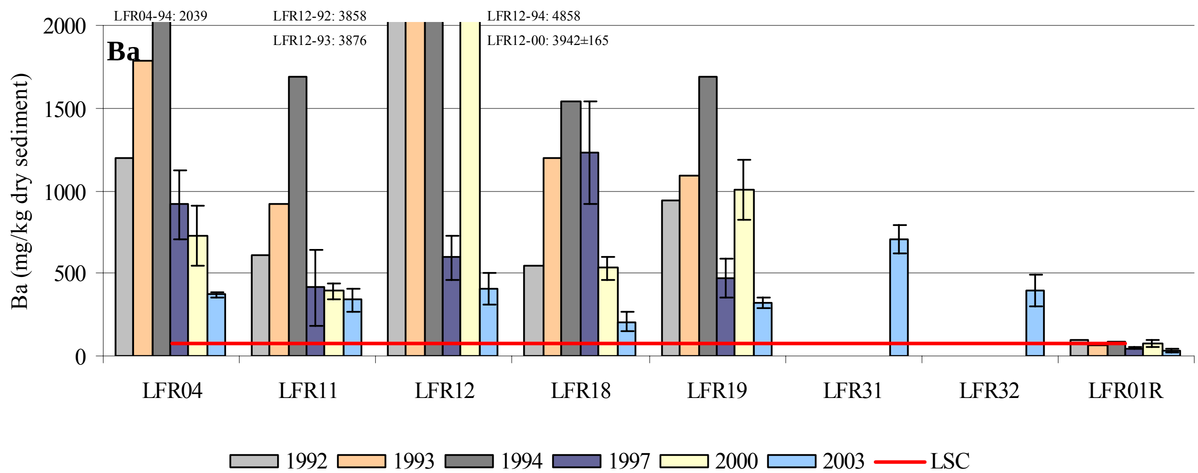


Figure 19.4. Average barium concentrations and standard deviations in sediments from Lille-Frigg in 2003 and previous years. Red line is $LSC_{north\ 97\text{-}03}$.

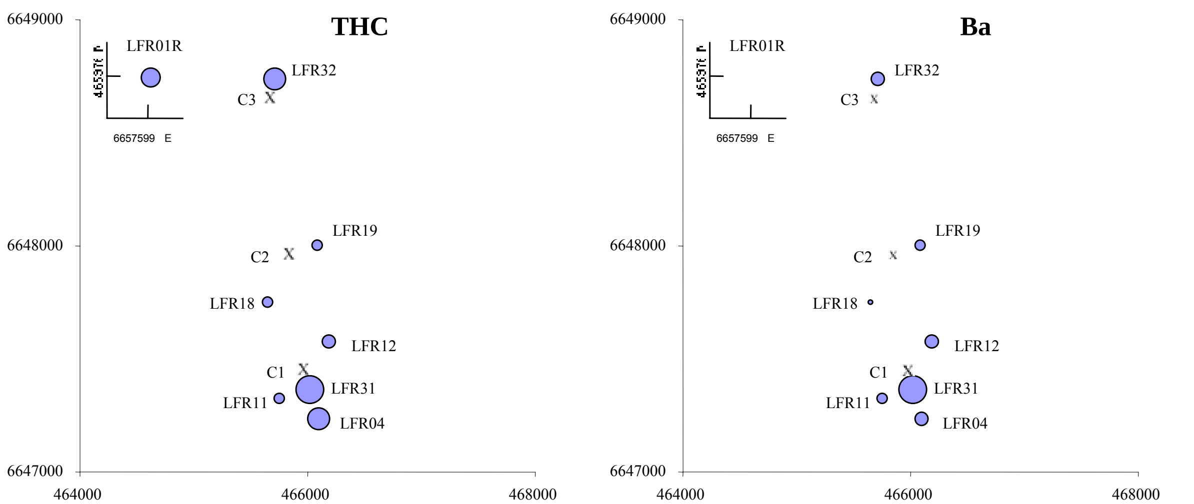


Figure 19.5. Distribution of THC and barium in sediments at the sampling sites at Lille-Frigg in 2003. The size of the circle indicate the amount of THC and Ba. LFR01R is not visible in the figure due to low relative barium content. The field centre is marked with an X.

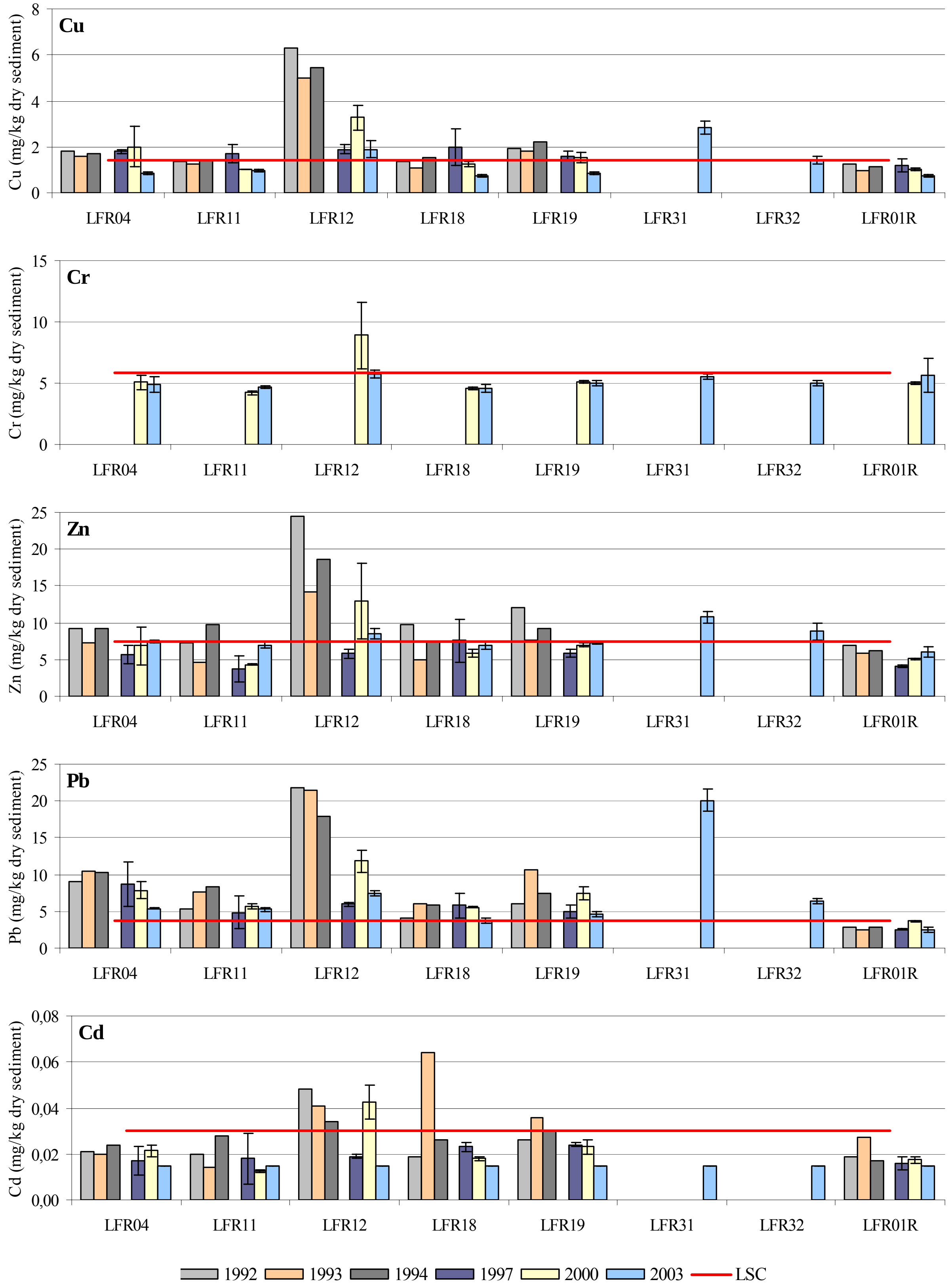


Figure 19.6. Average content and standard deviations of metals in sediment from Lille-Frigg in 2003 and previous surveys. Red line is Red line is $LSC_{north\ 97\text{-}03}$.

The field sites at Lille-Frigg were compared to nearby regional (RII01 and RII02) and field specific reference sites (PSB13R and FRI10R) based on sediment characteristics (TOM and pelite) and chemical content in the sediments (Figure 19.7). LFR31, 100 m to the southeast of C1, LFR12, 250 m to the northeast of CI, and LFR32, 100 m to the northeast of C3 did not group together with the other sites due to higher content of chemical compound s in the sediments at these sites.

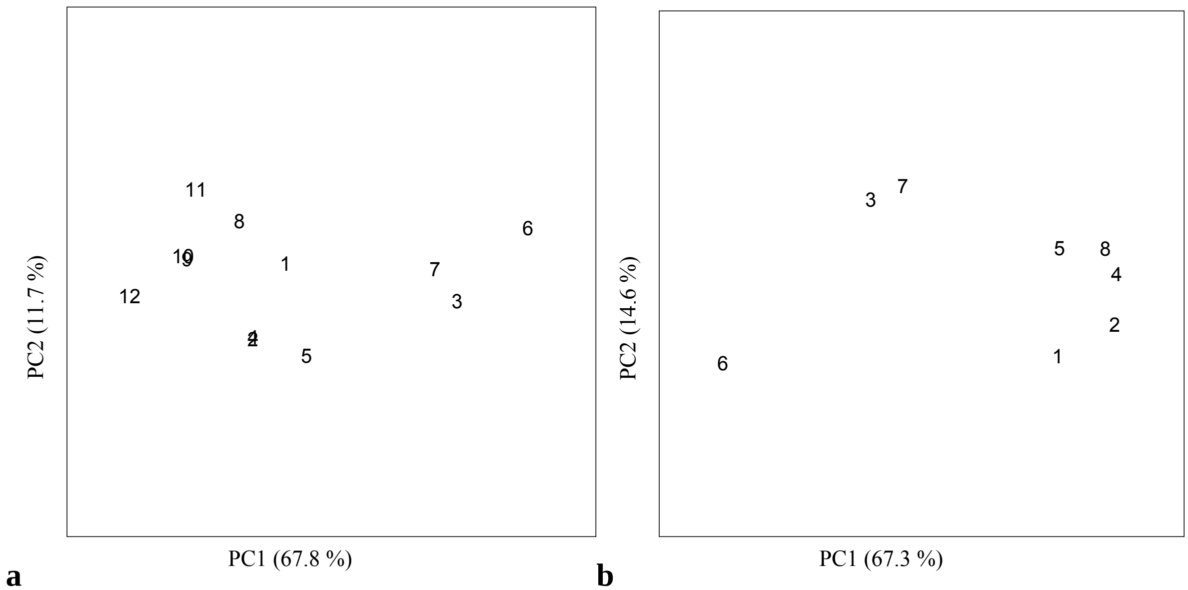


Figure 19.7. 2-D plot from the PCA analysis of environmental variables (% pelite, % sand, % gravel, median Φ, TOM, Cu, Ba, Zn, Cr, Pb and THC) carried out on:
a) Lille-Frigg field sites compared to the reference sites at Frigg and Øst Frigg and the regional site RII01 and RII02. Explained variation in the data 79.5 %.
b) Lille-Frigg field sites. Explained variation in the data 81.9 %.
Numbers in the plot identify the sampling sites. See table below.

1	LFR-04	5	LFR-19	9	PSB13R
2	LFR-11	6	LFR-31	10	FRI-10R
3	LFR-12	7	LFR-32	11	RII-01
4	LFR-18	8	LFR-01R	12	RII-02

19.2.3 Bottom fauna

A summary of the distribution of individuals and taxa within the main taxonomic groups are given in Table 19.8. Unidentified juveniles of the sea urchins Spatangoids (7104 individuals) and Echinoides (756 individuals), the polychaete *Owenia fusiformis* (1126 individuals) and the brittle star *Ophiura affinis* (445 individuals) are omitted from the analyses, as they occurred in high numbers. In total, 9734 individuals within 232 taxa were collected at Lille-Frigg in 2003. The fauna was numerically dominated by annelida with 55 % the individuals and 48 % of the taxa (Table 19.8).

Table 19.8. Distribution of individuals and taxa within the main taxonomic groups at Lille-Frigg in 2003 including data from LFR01R (unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Owenia fusiformis* and *Ophiura affinis* are not included).

Main taxonomic groups	Number of individuals	%	Number of taxa	%
Annelida	5306	55	112	48
Arthropoda	519	5	54	23
Mollusca	1352	14	40	17
Echidermata	1350	14	14	6
Diverse groups	1207	12	12	5
Total	9734	100	232	100

The species/area curve for LFR01R indicates that five replicate samples give a representative impression of the bottom fauna in the area (Figure 19.8). However, as more area is sampled, more taxa are collected, indicating that not even 10 replicate samples give the full species assemblage of the area.

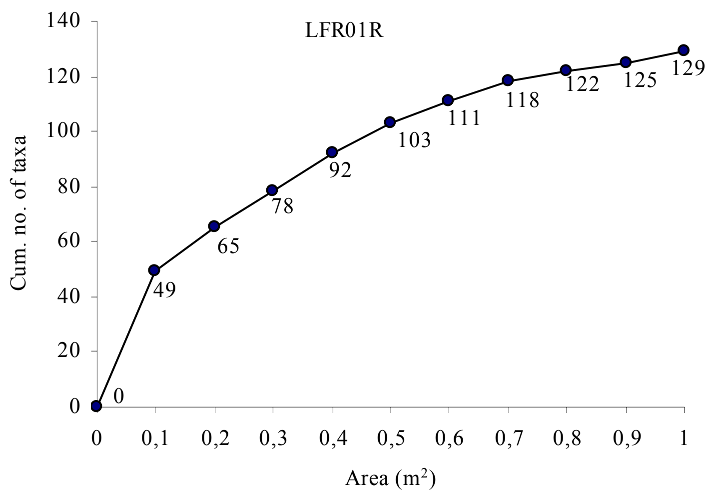


Figure 19.8. Species/area curve for the reference site at the Lille-Frigg field. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Owenia fusiformis* and *Ophiura affinis*.

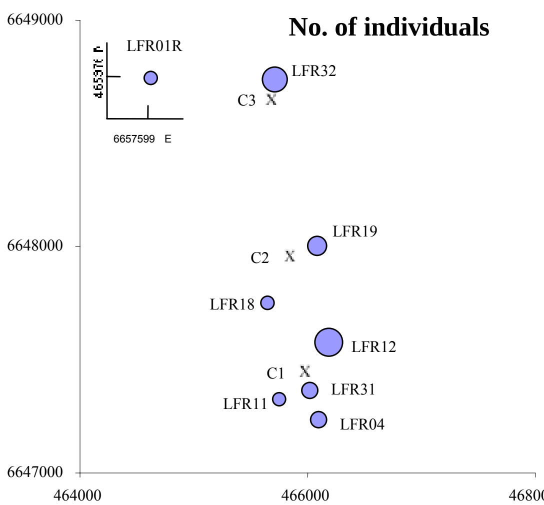
The distribution of individuals and taxa are shown in Figure 19.9. Number of individuals and taxa at each site, and the calculated diversity indexes (H' and ES_{100}) are given in Table 19.9 and Figure 19.10. The number of individuals varied from 701 (LFR11) to 1349 (LFR12), and the number of taxa varied from 82 (LFR11) to 124 (LFR32). The Shannon-Wiener diversity index (H') varied from 4.72 (LFR19) to 5.32 (LFR32), whereas the ES_{100} index varied from 32.2 (LFR19) to 39.4 (LFR32). The evenness index J varied from 0.72 (LFR19) to 0.79 (LFR31). The corresponding values at LFR01R were within or near the variation at the field sites. The number of taxa, diversity and evenness indicate good environmental conditions at all sites.

Compared to the results of 2000 there was fewer individuals and taxa in 2003 but higher species diversity. This is due to higher evenness among the taxa as seen as an increase in average evenness from 0.65 ± 0.05 in 2000 to 0.75 ± 0.02 in 2003. High evenness is considered as an indicator of good environmental conditions.

Table 19.9. Number of individuals, species/taxa and selected community indices for each site ($0.5\ m^2$) at the Lille-Frigg field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Owenia fusiformis* and *Ophiura affinis*.

Site number	Number of individuals	Number of taxa	Diversity H'	Evenness J	H'-max	ES_{100}
LFR04	808	87	4.87	0.76	6.44	34.9
LFR11	701	82	4.87	0.77	6.36	34.4
LFR12	1349	113	5.00	0.73	6.82	34.9
LFR18	765	89	4.91	0.76	6.48	34.2
LFR19	1003	97	4.72	0.72	6.60	32.2
LFR31	877	98	5.20	0.79	6.61	38.2
LFR32	1233	124	5.32	0.76	6.95	39.4
LFR01R (6-10)	843	103	5.31	0.79	6.69	39.1
LFR01R (11-15)	656	100	5.31	0.80	6.64	40.0
LFR01R (6-15)	1499	129	5.39	0.77	7.01	39.5
Sum[1]	6736	215				
Average[1]	962	99	4.99	0.75	6.61	35.4
SD[1]	246	15	0.21	0.02	0.21	2.5
Min[1]	701	82	4.72	0.72	6.36	32.2
Max[1]	1349	124	5.32	0.79	6.95	39.4
Average[2]	919	95	4.78	0.73	6.57	34.5
SD[2]	428	12	0.65	0.11	0.19	5.3
Min[2]	574	80	3.51	0.52	6.32	24.6
Max[2]	1749	109	5.31	0.82	6.77	39.6

[1]Lille-Frigg field, exclusive LFR01R
[2]Reg + Ref $_{north\ 03}$



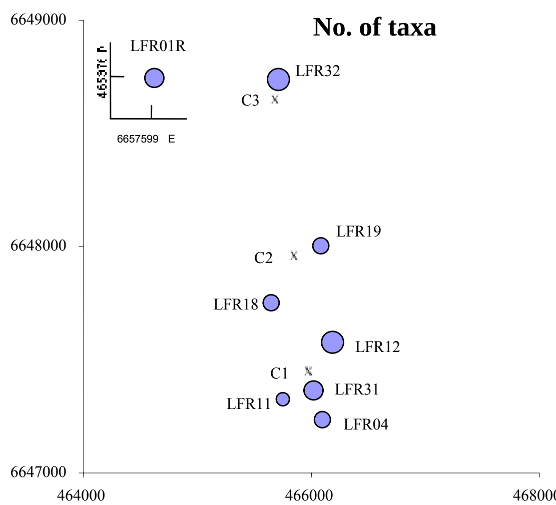


Figure 19.9. Distribution of bottom fauna (individuals and taxa) among the sampling sites in 2003. The size of the circle indicates the number of individuals and taxa. Exclusive unidentified juveniles of Spatangoida and Echinoidae and juveniles of *Owenia fusiformis* and *Offiura affinis*. Values for LFR01R are average of samples 6-10 ($0.5\ m^2$) and 11-15 ($0.5\ m^2$). The field centre is marked with an X.

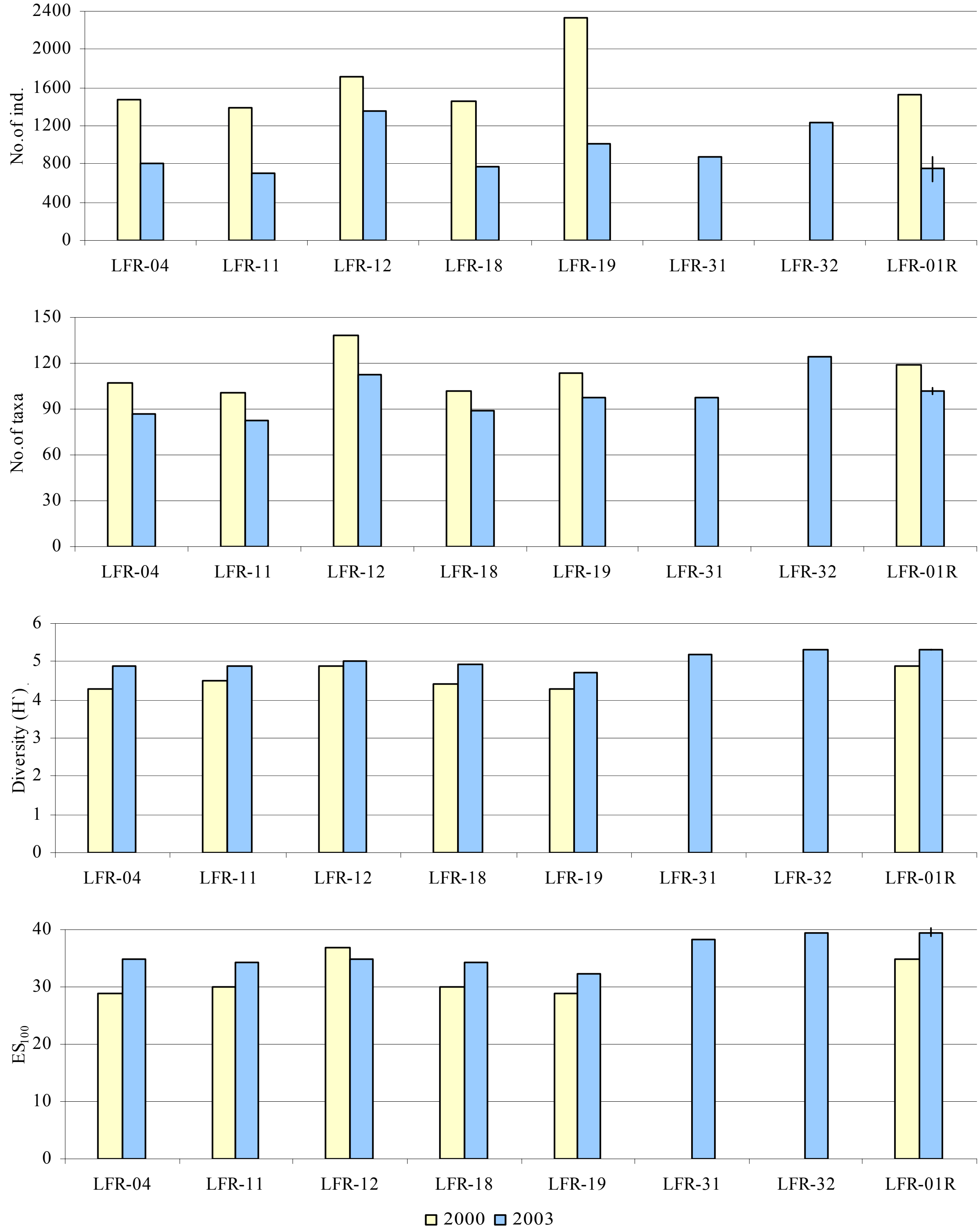


Figure 19.10. Number of individuals, taxa and selected community indices for each site (0.5 m^2) at the Lille-Frigg field in 2000 and 2003. (Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Owenia fusiformis* and *Ophiura affinis* in 2003). Values for LFR01R in 2003 are average ± standard deviation of samples 6-10 (0.5 m^2) and 11-15 (0.5 m^2).

Distribution of taxa in geometrical classes is presented in Figure 19.11. The graphs are indicating undisturbed bottom fauna and good environmental conditions.

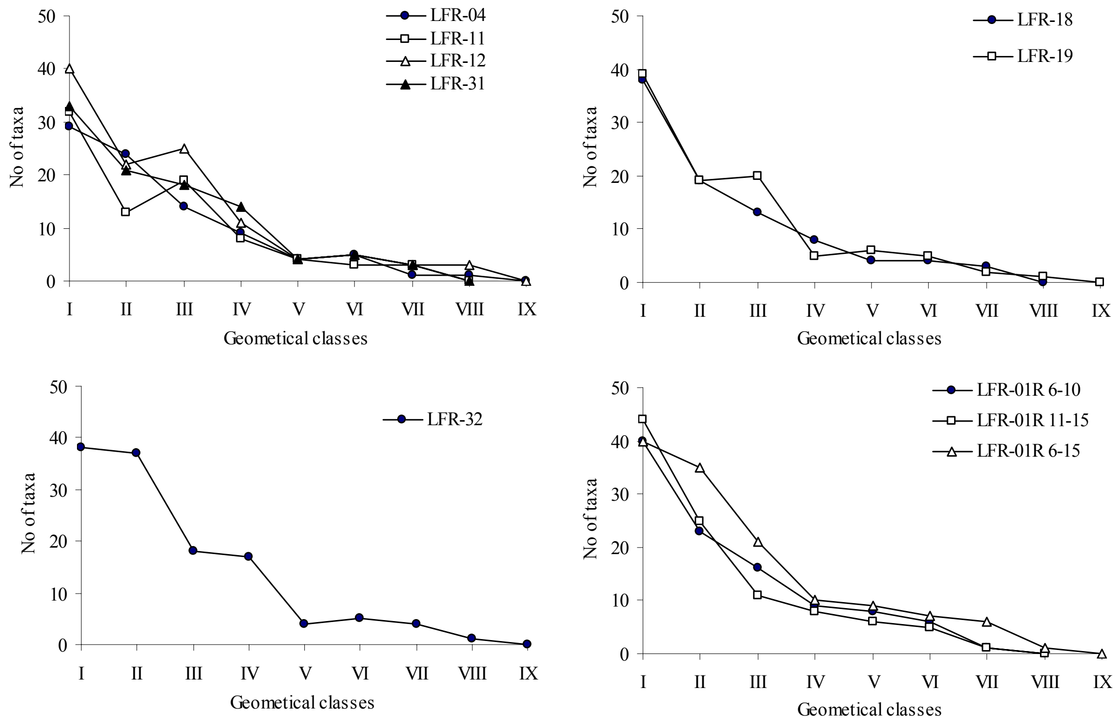


Figure 19.11. Distribution of taxa in geometrical classes for the sites at Lille-Frigg in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Owenia fusiformis* and *Ophiura affinis*..

The ten most numerous taxa are listed in Table 19.12 at the end of this chapter. The list comprise 15 taxa and 5722 individuals, which was 6.5 % of all (232) taxa and 58.8 % of all (9734) individuals. The most abundant and wide spread species were the brittle *star Amphiura filiformis*, the phoronid *Phoronis* sp., the bivalvia *Thyasira flexuosa* and the polychaetes *Myriochele oculata*, *Spiophanes bombyx, Chaetozone setosa* and *Owenia fusiformis*. Among these are species which indicate both good and poor environmental conditions. Due to the presence of species which are known to live only under good conditions, there are good reasons to conclude that the conditions were good at all sites in 2003.

The results of the multivariate analyses are given in the dendrogramme (Figure 19.12) and the MDS plott (Figure 19.13).

In the cluster analysis, all sites are grouped together within 64 % similarity, indicating relatively high similarity in the species assemblages within the field. The species assemblages at LFR04 and LFR11 were the most similar (73 %).

The results of the MDS analysis support the findings in the cluster analysis, confirming the similarity in species assemblage at LFR04 and LFR11, but also showing that the fauna at LFR18 is relatively similar to LFR04 and LFR11. The stress test of the MDS analysis was 0.07, indicating a good fit of the data.

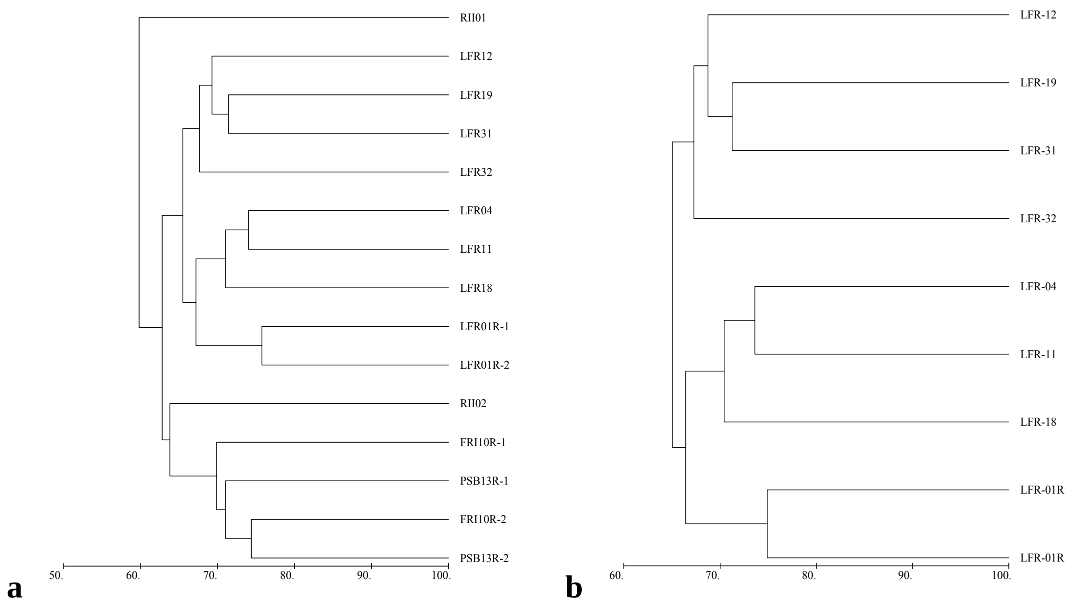
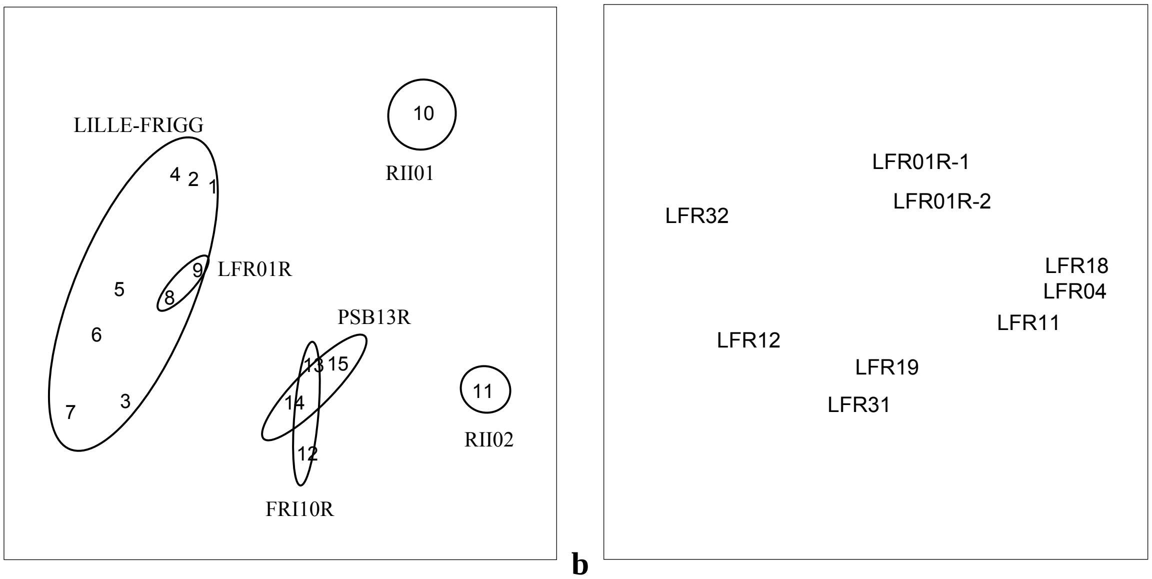


Figure 19.12. Dendrogram showing the similarity between fauna from sampling sites at:

a) Lille-Frigg field compared to regional sites (RII01 and RII02) and reference sites (FRI10R and PSB13R) in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.
b) Lille-Frigg field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Owenia fusiformis* and *Ophiura affinis*.



a **b**

Figure 19.13. A 2-dimetional plott of the MDS analysis of the fauna data from:

a) Lille-Frigg field compared to regional sites (RII01 and RII02) and reference sites (FRI10R and PSB13R) in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea. Stress = 0.13. Codes in table below.
b) Lille-Frigg field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Owenia fusiformis* and *Ophiura affinis*. Stress = 0.07.

1	LFR04	5	LFR19	8	LFR01R-1	12	FRI10R-1
2	LFR11	6	LFR31	9	LFR01R-2	13	FRI10R-2
3	LFR12	7	LFR32	10	RII01	14	PSB13R-1
4	LFR18			11	RII02	15	PSB13R-2

Linking of biotic and environmental variables by BIOENV revealed that the combination of content of gravel, chromium, barium and TOM were best correlated to the biota at $\rho_w = 0.75$ (Table 19.10). This indicates that there was an association between some environmental variables and the bottom fauna.

Table 19.10. Combinations of the 10 environmental variables, taken *k* at a time, yielding the best matches of biotic and abiotic similarity matrices for each *k*, as measured by weighted Spearman rank correlation ρ_w. Bold type indicates overall optimum. All possible combinations of variables and associated correlation to the biotic are given in the Appendix.

Number of variables (*k*)	Correlation coefficient (ρ_w)	Environmental variables									
1	0.652	Gravel									
1	0.351	TOM									
1	0.344	Zn									
1	0.287	Sand									
1	0.241	Pelite									
1	0.233	Cu									
1	0.133	Ba									
1	0.131	Cr									
1	0.125	Pb									
1	-0.111	THC									
2	0.626	Gravel	Cr								
3	0.685	Gravel		Ba	TOM						
4	**0.750**	**Gravel**	**Cr**	**Ba**	**TOM**						
5	0.702	Gravel	Cr	Ba	TOM	Zn					
6	0.622	Gravel	Cr	Ba	TOM	Zn	Cu				
7	0.584	Gravel	Cr	Ba	TOM		Cu	Sand	Pelite		
8	0.550	Gravel	Cr	Ba	TOM	Zn	Cu	Sand	Pelite		
9	0.526	Gravel	Cr	Ba	TOM	Zn	Cu	Sand	Pelite	Pb	
10	0.459	Gravel	Cr	Ba	TOM	Zn	Cu	Sand	Pelite	Pb	THC

19.2.4 Estimation of influenced area

The extension of contamination along sampling transects and the minimum area of contaminated sediments for THC, barium and other metals as well as for faunal disturbance is given in Figure 19.14 and Table 19.11. The total area contaminated by THC was reduced in 2003 compared to the situation in 2000. Only one site at 100 m to the south of C1 was contaminated by THC. Also the total area contaminated by barium was reduced in 2003 compared to 2000. Whereas the total area contaminated by other metals had increased by 0.03 km². As in 1997 and 2000 no faunal disturbance was revealed at Lille-Frigg.

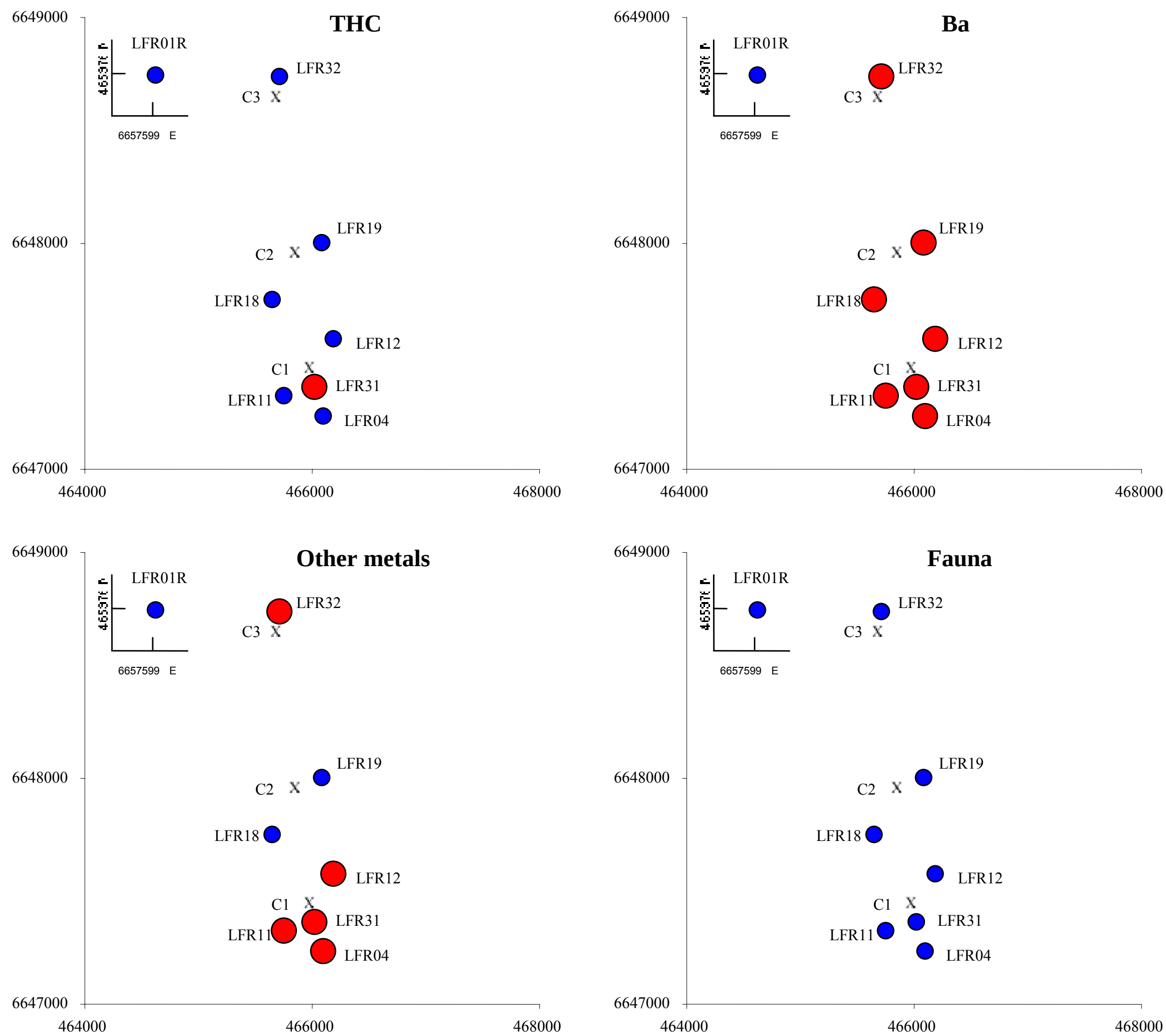


Figure 19.14. Faunal disturbance and chemical contamination of the sediments at Lille-Frigg in 2003. Uncontaminated sites and sites with no faunal disturbance are marked with small blue circles. The field centre is marked with an X.

Table 19.11. Estimated distance of contamination and faunal disturbance from the installation, and estimated area of contamination and faunal disturbance around the field centre.

Lille-Frigg C1	NE m	SE m	SW m	NW m	2003 km^2	2000 km^2	1997 km^2
THC	0	100	0	0	0.00	0.07	0.00
Ba	250	250	250	0	0.10	0.37	0.15
Other metals	250	250	250	0	0.10	0.00	0.00
Fauna	0	0	0	0	0.00	0.00	0.00

Lille-Frigg C2	N m	E m	SW m	W m	2003 km^2	2000 km^2	1997 km^2
THC	0	0	0	0	0.00	0.07	0.00
Ba	0	250	250	0	0.05	0.15	0.10
Other metals	0	0	0	0	0.00	0.07	0.00
Fauna	0	0	0	0	0.00	0.00	0.00

Lille-Frigg C3	NE m	SE m	SW m	NW m	2003 km^2	2000 km^2	1997 km^2
THC	0	0	0	0	0.00	0.00	0.00
Ba	100	0	0	0	0.00	0.07	0.07
Other metals	100	0	0	0	0.00	0.00	0.00
Fauna	0	0	0	0	0.00	0.00	0.00

Lille-Frigg Sum	NE m	SE m	SW m	NW m	2003 km^2	2000 km^2	1997 km^2
THC					0.00	0.15	0.00
Ba					0.15	0.59	0.32
Other metals					0.10	0.07	0.00
Fauna					0.00	0.00	0.00

19.3 Summary and conclusions

Production at Lille-Frigg ceased in 1999. There have been no drilling activities at Lille-Frigg since 1992/93 and all wells were permanently plugged and abandoned in 2000/2001. Thus only the sampling sites within 100 m and 250 m was sampled in 2003. The sediments are still characterized as fine sand. The amounts of THC were highest 100 m to the south of C1 which also was the only place contamination by THC was revealed. Despite generally lower levels of barium and other metals barium contamination was still present at all sites except the reference site and contamination by other metals were found at most sites except two. More taxa and individuals were found in the bottom fauna in 2003 than in 2000, and the species diversity had increased. Despite high correlation between the fauna and some environmental variables (gravel, chromium, barium and TOM) no faunal disturbance was revealed, as in 1997 and 2000. The area contaminated by THC and barium was smaller in 2003 than in 2000, whereas the area contaminated by other metals had increased slightly.

Table 19.12. Number of individuals and relative abundance for the ten predominant taxa at each site at the Lille-Frigg field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Owenia fusiformis* and *Ophiura affinis*.

LFR04	No of ind.	%	Cum %
Owenia fusiformis	138	17,1	17,1
Amphiura filiformis	105	13,0	30,1
Myriochele oculata	55	6,8	36,9
Phoronis sp.	54	6,7	43,6
Chaetozone setosa	42	5,2	48,8
Thyasira flexuosa	42	5,2	54,0
Spiophanes bombyx	40	5,0	58,9
Cerianthus lloydii	24	3,0	61,9
Abra prismatica	18	2,2	64,1
Scoloplos armiger	17	2,1	66,2
Harpinia antennaria	17	2,1	68,3

LFR11	No of ind.	%	Cum %
Amphiura filiformis	105	15,0	15,0
Owenia fusiformis	79	11,3	26,2
Myriochele oculata	64	9,1	35,4
Phoronis sp.	46	6,6	41,9
Spiophanes bombyx	43	6,1	48,1
Thyasira flexuosa	35	5,0	53,1
Chaetozone setosa	29	4,1	57,2
Cerianthus lloydii	25	3,6	60,8
Scoloplos armiger	24	3,4	64,2
Goniada maculata	16	2,3	66,5

LFR12	No of ind.	%	Cum %
Phoronis sp.	178	13,2	13,2
Owenia fusiformis	138	10,2	23,4
Myriochele oculata	129	9,6	33,0
Amphiura filiformis	123	9,1	42,1
Thyasira flexuosa	76	5,6	47,7
Paramphinome jeffreysii	66	4,9	52,6
Spiophanes bombyx	49	3,6	56,3
Chaetozone setosa	47	3,5	59,7
Scoloplos armiger	46	3,4	63,2
Aricidea laubieri	41	3,0	66,2

LFR18	No of ind.	%	Cum %
Amphiura filiformis	117	15,3	15,3
Myriochele oculata	70	9,2	24,4
Owenia fusiformis	65	8,5	32,9
Thyasira flexuosa	54	7,1	40,0
Spiophanes bombyx	49	6,4	46,4
Phoronis sp.	41	5,4	51,8
Chaetozone setosa	33	4,3	56,1
Harpinia antennaria	31	4,1	60,1
Cerianthus lloydii	26	3,4	63,5
Mysella bidentata	20	2,6	66,1

LFR19	No of ind.	%	Cum %
Owenia fusiformis	191	19,0	19,0
Amphiura filiformis	122	12,2	31,2
Myriochele oculata	89	8,9	40,1
Thyasira flexuosa	59	5,9	46,0
Phoronis sp.	58	5,8	51,7
Chaetozone setosa	50	5,0	56,7
Spiophanes bombyx	44	4,4	61,1
Scoloplos armiger	41	4,1	65,2
Paramphinome jeffreysii	24	2,4	67,6
Goniada maculata	23	2,3	69,9

LFR31	No of ind.	%	Cum %
Amphiura filiformis	98	11,2	11,2
Owenia fusiformis	96	10,9	22,1
Phoronis sp.	76	8,7	30,8
Myriochele oculata	62	7,1	37,9
Thyasira flexuosa	39	4,4	42,3
Scoloplos armiger	35	4,0	46,3
Spiophanes bombyx	34	3,9	50,2
Paramphinome jeffreysii	33	3,8	53,9
Chaetozone setosa	29	3,3	57,2
Cerianthus lloydii	23	2,6	59,9

LFR32	No of ind.	%	Cum %
Amphiura filiformis	158	12,8	12,8
Phoronis sp.	117	9,5	22,3
Owenia fusiformis	85	6,9	29,2
Paramphinome jeffreysii	77	6,2	35,4
Myriochele oculata	72	5,8	41,3
Chaetozone setosa	60	4,9	46,1
Thyasira flexuosa	59	4,8	50,9
Spiophanes bombyx	42	3,4	54,3
Scoloplos armiger	36	2,9	57,3
Goniada maculata	35	2,8	60,1

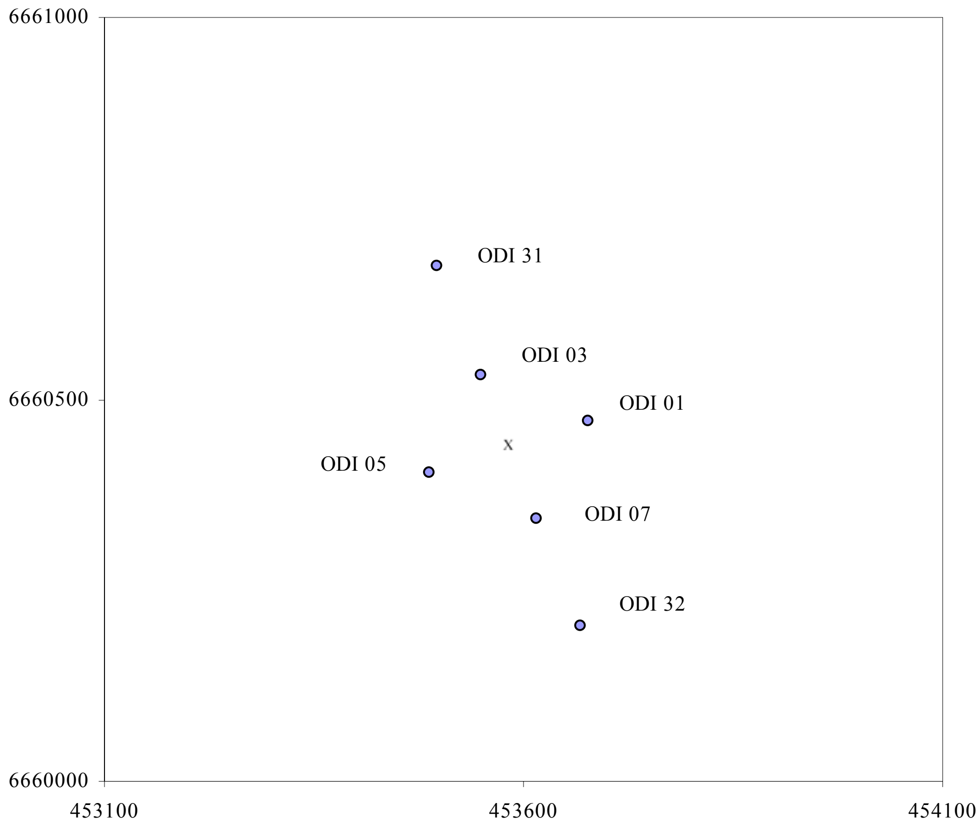
LFR01R (6-15)	No of ind.	%	Cum %
Amphiura filiformis	200	13,3	13,3
Phoronis sp.	90	6,0	19,3
Thyasira flexuosa	86	5,7	25,1
Myriochele oculata	83	5,5	30,6
Cerianthus lloydii	79	5,3	35,9
Spiophanes bombyx	76	5,1	41,0
Mysella bidentata	68	4,5	45,5
Chaetozone setosa	54	3,6	49,1
Goniada maculata	49	3,3	52,4
Scoloplos armiger	44	2,9	55,3

20 Odin

20.1. Introduction

The Odin field is situated in block 30/10, about 22 km north east of the Frigg area. Production at Odin started in 1984 and ceased in 1994. The installation was removed in 1997. Monitoring of the field have been carried out in 1991 (Holte & al. 1992), 1997 (Mannvik & al. 1998) and 2000 (Mannvik & al. 2001).

Since the removal of the platform in 1997 a gradual improvement of the environmental conditions at Odin have been registered, thus the 2003 survey included only sampling sites out to 250 m to the north west and south east and out to 100 m to the east north east and west south west (Figure 20.1). There are no known recent discharges at Odin.



Site	ED50 UTM Zone 31		Distance (m) / direction (°)	Depth
	E	N		(m)
ODI-01	453677	6660472	100/70	104
ODI-03	453549	6660532	100/340	104
ODI-05	453489	6660404	100/250	106
ODI-07	453617	6660344	100/160	105
ODI-31	453497	6660673	250/340	104
ODI-32	453669	6660203	250/160	106

Figure 20.1. Map showing the internal distribution of sampling sites in Odin 2003. Positioning according to UTM ED50 zone 31. The field centre is marked with an X.

20.2. Results and discussion

20.2.1 Sediments characteristics

TOM, the amount (%) of gravel, sand and pelite, median (Φ), sorting, skewness and kurtosis in the sediment from the present survey is presented in Table 20.1. Additional information on colour and smell can be found in the Appendix. Median (Φ), pelite, sand and TOM are compared with data from 2000 in Figure 20.2.

The sediments at Odin are classified as fine sand with median (Φ) values ranging from 2.41 (ODI05) to 2.47 (ODI31). The amount of pelite varied from 2.56 % (ODI31) to 3.05 % (ODI03), the sand varied from 96.7 % (ODI03) to 97.4 % (ODI31), and the TOM varied from 0.68 % (ODI32) to 0.84 % (ODI05). The sediments were uniform in the sampling area.

There were only minor changes in the sediment characteristics between the sampling 2000 and 2003.

Table 20.1. Total organic matter and sediment grain size at all sites at Odin in 2003. For comparisons average, standard deviation, max and min values for the regional and reference sites are included.

	TOM	Gravel %	Sand %	Pelite %	Median (Φ)	Sorting	Skewness	Kurtosis
ODI01	0.75	0.06	97.12	2.82	2.46	0.56	-0.05	1.46
ODI03	0.79	0.25	96.71	3.05	2.45	0.59	-0.05	1.56
ODI05	0.84	0.21	96.93	2.86	2.41	0.64	-0.15	1.43
ODI07	0.74	0.15	97.11	2.73	2.43	0.62	-0.13	1.47
ODI31	0.71	0.03	97.40	2.56	2.47	0.52	-0.06	1.38
ODI32	0.68	0.01	96.97	3.02	2.46	0.56	0.00	1.46
Average[1]	0.75	0.12	97.04	2.84	2.45	0.58	-0.07	1.46
SD[1]	0.06	0.10	0.23	0.18	0.02	0.04	0.05	0.06
Min[1]	0.68	0.01	96.71	2.56	2.41	0.52	-0.15	1.38
Max[1]	0.84	0.25	97.40	3.05	2.47	0.64	0.00	1.56
Average[2]	0.99	0.02	95.16	4.83	2.73	0.75	0.12	1.58
SD[2]	0.19	0.02	1.27	1.28	0.48	0.15	0.10	0.19
Min[2]	0.68	0.00	93.99	2.85	2.45	0.54	-0.06	1.37
Max[2]	1.19	0.03	97.12	5.98	3.69	0.94	0.23	1.87

[1] Odin field sites
[2] Reg + Ref $_{north\ 03}$

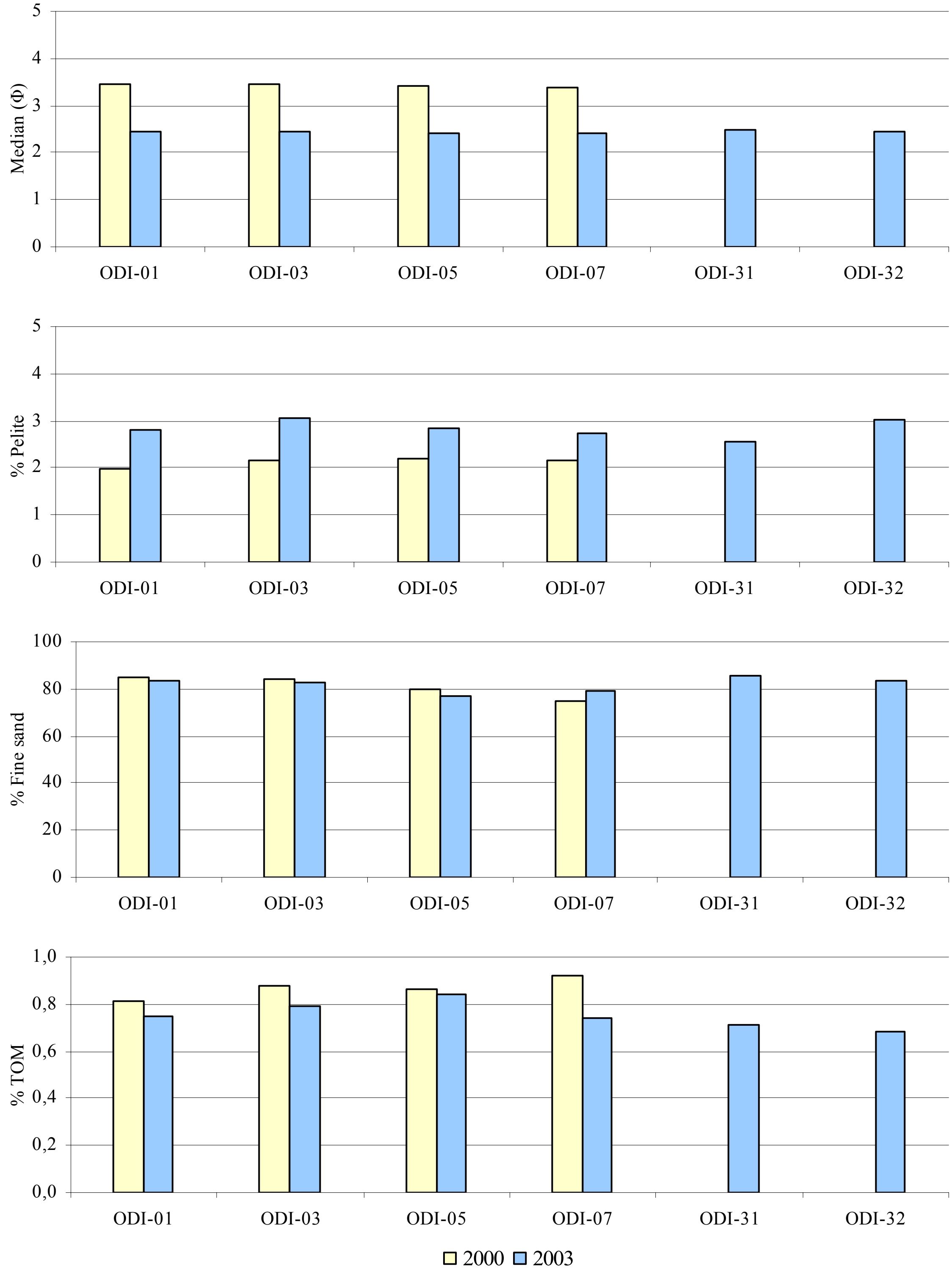


Figure 20.2. Sediment characteristics at Odin in 2000 and 2003. Fine sand is the relative amount of sand with grain size 63-250 µm.

20.2.2 Chemical compounds

20.2.2.1 LSC

The results of the LSC (limits of significant contamination) calculations of hydrocarbons and metals are presented in the chapter concerning the regional and reference sites. Since there was no reference site (ODI14R) at Odin in 2003, $LSC_{north\ 03}$ are presented in Table 20.2 instead of the field specific LSC value. LSC for the north fields in Region II ($LSC_{north\ 97\text{-}03}$) is also presented in Table 20.2, and LSC in the text relates to that.

Table 20.2. Limits of Significant Contamination (LSC) for the Odin field in 2003. The LSC value is calculated for the north part of Region II based on data from 1997 to 2003 ($LSC_{north\ 97\text{-}03}$) and 2003 alone ($LSC_{north\ 03}$), and the whole of Region II based on data from 1997 to 2003 ($LSC_{regII\ 97\text{-}03}$). For comparison, LSC-values from 2000 are included. All values in mg/kg dry sediment.

	THC	PAH (16)	NPD's	Decalins	Cu	Cr	Zn	Ba	Pb	Cd[1]	Hg
$LSC_{north\ 03}$	14.9	0.045	0.018	0.334	0.9	6.3	6.6	50	3.1	0.03[1]	0.010
$LSC_{north\ 97\text{-}03}$	13.3	*	*	*	1.4	5.9	7.4	76	3.8	0.03[1]	0.008
$LSC_{regII\ 97\text{-}03}$	13.3	*	*	*	2.0	9.4	11.1	136	6.6	0.03[1]	0.011
$LSC_{00\ ODI14R}$**	3.2	*	0.005	0.008	1.3	6.8	5.2	82	5.5	0.03	0.016
$LSC_{97\text{-}00\ regII}$**	9.8	*	*	*	2.0	9.6	8.9	146	7.0	0.03	0.008

* NPD's, PAH's and decalins are not analysed at regional sites in 1997 and 2000
** Data from Mannvik & al. 2001
[1] LSC = detection limit

20.2.2.2 Hydrocarbons

Summarised results of the hydrocarbon analyses, along with the content of selected hydrocarbon compounds in the different layers (0-1, 1-3 and 3-6 cm) are given in Table 20.3 and Table 20.4. The complete data set including replicates is given in the Appendix. Comparison of the THC content in 2003 with previous surveys is presented in Figure 20.3.

THC was found in the range from <3.0 (detection limit) to 13.8 mg/kg. Highest concentrations were found at 100 m to the north of the field centre at ODI03. In general there was lower THC content in the sediments in 2003 than in 1997 and 2000.

THC occurred above LSC in the sediments at ODI03, and in the 3-6 cm layer NPD was above $LSC_{north\ 03}$ at ODI07.

Table 20.3. The content of oil hydrocarbons in sediment from Odin in 2003. All values in mg/kg dry sediment. THC values above $LSC_{north\ 97-03}$ and PAH, NPD and decalin values above $LSC_{north\ 03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data for the regional and field reference sites in the north part of region II are included.

Stasjon	THC		PAH(16)		NPD		Decalins	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.
ODI 01	4.8	3.8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
ODI 03	13.8	9.4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
ODI 05	8.1	1.9	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
ODI 07	9.3	1.1	0.014	0.001	0.018	0.005	0.158	0.019
ODI 31	<3.0	-	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
ODI 32	7.6	0.6	0.014	0.005	0.013	0.001	0.132	0.012
av. ± sd.[1]	7.5 ± 4.2							
min – max[1]	<3.0 - 13.8							
av. ± sd.[2]	10.6 ± 2.0		0.028 ± 0.008		0.013 ± 0.002		0.157 ± 0.081	
min – max[2]	7.4-13.2		0.016-0.037		0.011-0.016		0.042-0.287	

n.a. = not analysed.
[1] Odin field sites
[2] Reg + $Ref_{north\ 03}$

Table 20.4. The content of oil hydrocarbons in vertical sections of sediment from 3 sampling sites at Odin in 2003. All values in mg/kg dry sediment. THC values above $LSC_{north\ 97-03}$ and PAH, NPD and decalin values above $LSC_{north\ 03}$ are dark shaded.

Stasjon	Layer (cm)	THC	PAH(16)	NPD	Decalins
ODI 07	0-1	8.7	0.012	0.013	0.150
	1-3	8.5	0.011	0.013	0.170
	3-6	10.0	0.014	0.028	0.215
ODI 32	0-1	8.2	0.019	0.013	0.125
	1-3	8.0	0.020	0.014	0.135
	3-6	7.5	0.023	0.013	0.135

20.2.2.3 Metals

Table 20.5 summarises the results of the metal analyses of the Odin field in 2003. Concentrations of selected metals in the different layers (0-1, 1-3 and 3-6 cm) of sediment are given in Table 20.6, whereas the complete data set including replicates is given in the Appendix. Comparisons of the metal contents in 2003 with the metal contents in 1997 and in 2000 are presented in Figure 20.4 and 20.6.

Table 20.5. Content of metals in sediments from Odin in 2003. All values in mg/kg dry sediment. Metal values above $LSC_{north\ 97\text{-}03}$ are dark shaded. For comparison, average ± standard deviations for 2003 data in the regional and field reference sites in the north part of the region II are included.

Site	Cu		Cr		Zn		Ba		Pb		Cd		Hg	
	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.	av.	sd.
ODI 01	2.2	0.4	5.4	0.4	13.5	1.4	30	10	6.9	0.7	<0.03	-	n.a.	n.a.
ODI 03	3.5	0.6	6.2	0.9	30.2	1.9	23	6	8.9	0.4	<0.03	-	n.a.	n.a.
ODI 05	2.2	0.7	5.4	0.4	12.5	2.7	28	10	5.7	1.0	<0.03	-	n.a.	n.a.
ODI 07	1.7	0.4	4.6	1.1	12.5	3.3	25	15	6.5	1.3	<0.03	-	0.009	0.004
ODI 31	1.0	0.2	5.1	0.1	7.0	1.3	34	16	2.9	0.1	<0.03	-	n.a.	n.a.
ODI 32	1.0	0.4	4.8	0.5	5.2	0.4	19	7	3.0	1.2	<0.03	-	0.007	0.001
av. ± sd.[1]	1.9 ± 1.0		5.3 ± 0.6		13.5 ± 8.8		27 ± 5		5.7 ± 2.3		<0.03			
min - max[1]	1.0 -3.5		4.6 - 6.2		5.2 - 30.2		19 - 34		2.9 - 8.9		<0.03			
av. ± sd.[2]	<0.6		4.6 ± 0.8		5.9 ± 0.3		29 ± 10		2.5 ± 0.3		<0.03		0.007 ± 0.001	
min - max[2]	<0.6-0.8		3.7-5.6		5.5-6.3		18-41		2.1-2.8		<0.03		0.004 -0.014	

n.a. = not analysed.
[1] Odin field sites
[2] Reg + Ref $_{north\ 03}$

Table 20.6. The content of metals in vertical sections of sediments from two sampling sites at Odin in 2003. All values in mg/kg dry sediment. Metal values above $LSC_{north\ 97\text{-}03}$ are dark shaded.

Site	Layer	Cu	Cr	Zn	Ba	Pb	Cd	Hg
ODI 07	0-1	2.0	5.3	12.5	41.8	5.3	<0.03	0.007
	1-3	2.0	6.0	12.3	19.3	8.0	<0.03	0.007
	3-6	4.1	5.7	24.6	71.2	5.6	0.04	0.006
ODI 32	0-1	1.3	5.4	5.7	26.7	4.4	<0.03	0.007
	1-3	0.9	4.8	6.2	38.8	2.9	<0.03	0.008
	3-6	1.1	5.4	6.9	107	2.5	0.05	0.009

Barium was found in a range from 19 to 34 mg/kg, lead from 2.9 to 8.9 mg/kg, cadmium <0.03 mg/kg, copper from 1.0 to 3.5 mg/kg, mercury from 0.007 to 0.009 mg/kg and zinc from 5.2 to 30.2 mg/kg (Table 20.5). The occurrence of copper, zinc and lead were above LSC at all sites, except ODI31 and ODI32. The chrome content was above LSC at ODI03 and the mercury content was above LSC at ODI07. The barium content in the sediments has decreased at all sampling sites since 1991 and 1997, whereas barium was at same level in 2003 as in 2000. A decrease in concentrations or occurrence in concentrations at the same level as before was also seen for the other metals.

Vertical sediment samples (0-1, 1-3 and 3-6 cm) from ODI07 had copper, zinc and lead content above LSC in all depth intervals, chromium was found above LSC in the 1-3 cm interval, and cadmium were above LSC in the 3-6 cm interval. At ODI32 barium, cadmium and mercury were present above LSC in the 3-6 cm interval and lead in the 0-1 cm interval, whereas the other metals were below LSC in the sectioned samples (Table 20.6).

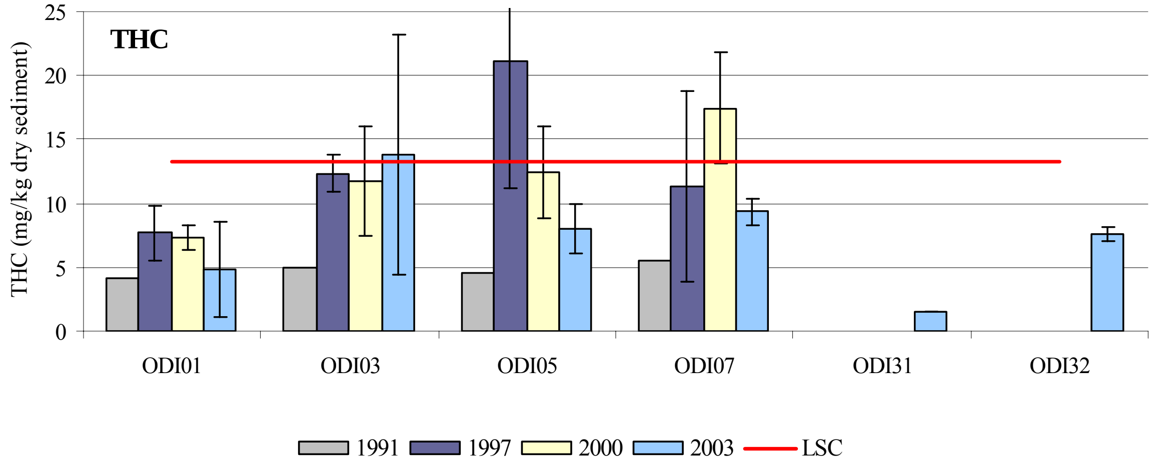


Figure 20.3. Average THC concentrations and standard deviations in sediments from Odin in 2003 and previous years. Red line is $LSC_{north\ 97\text{-}03}$.

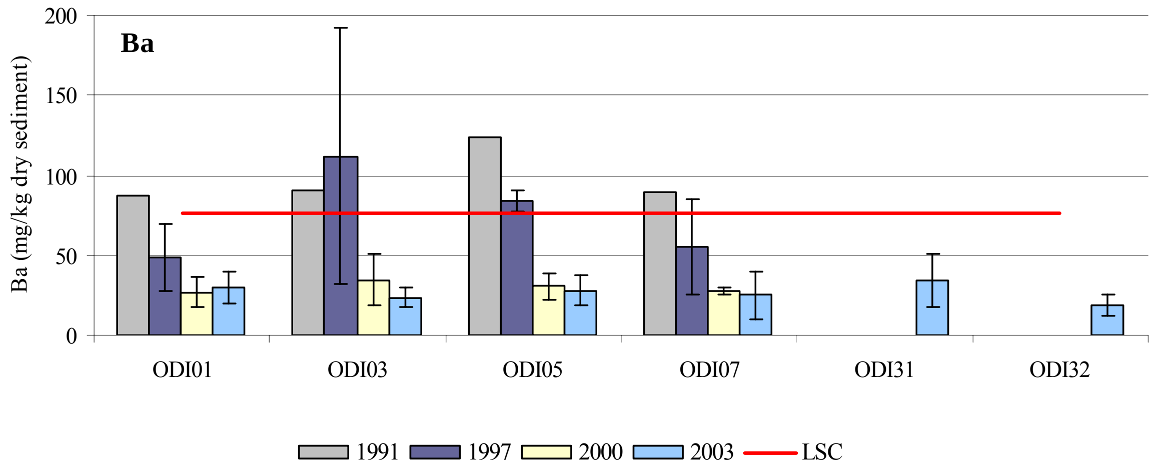


Figure 20.4. Average barium concentrations and standard deviations in sediments from Odin in 2003 and previous years. Red line is $LSC_{north\ 97\text{-}03}$.

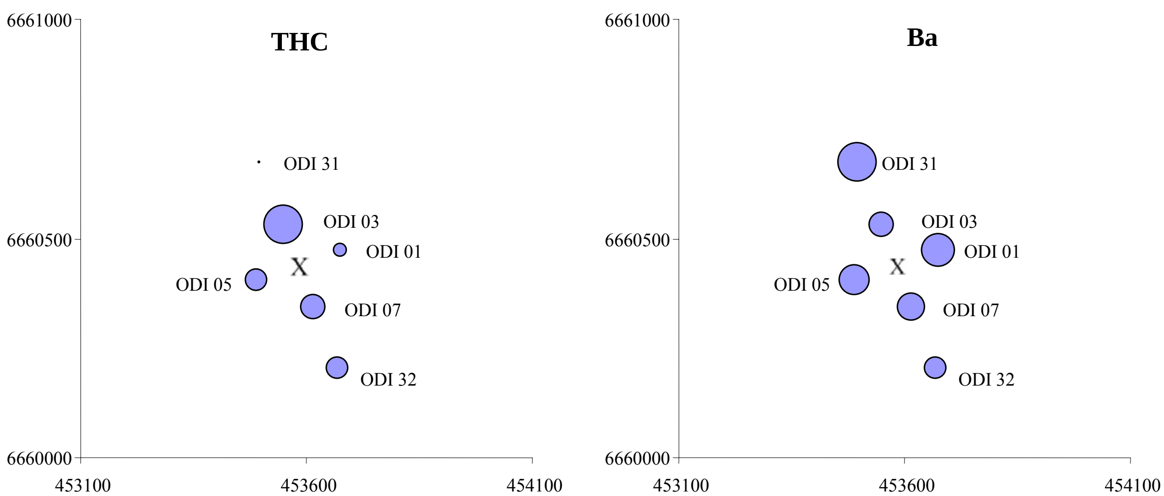


Figure 20.5. Distribution of THC and barium in sediments at the sampling sites at Odin in 2003. The size of the circle indicate the amount of THC and Ba. The field centre is marked with an X.

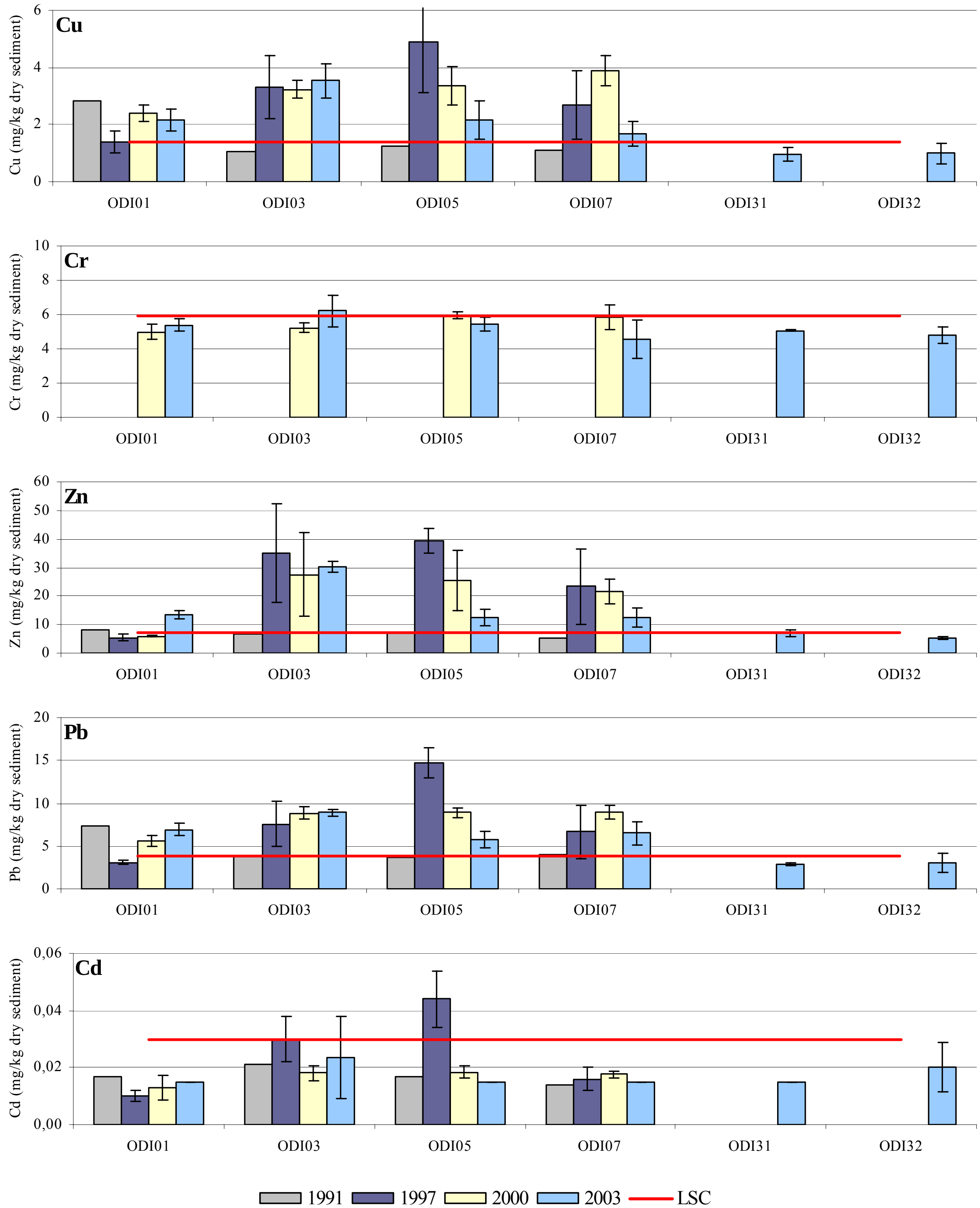
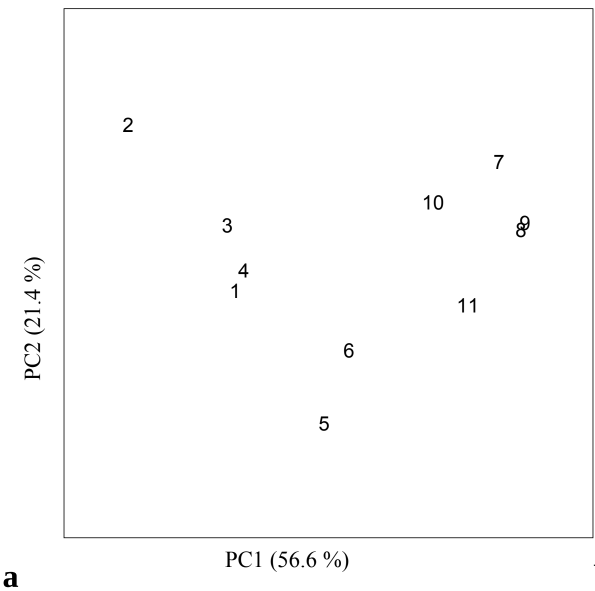


Figure 20.6. The content of metals in sediment from Odin in 2003 and previous surveys. Red line is Red line is $LSC_{north\ 97\text{-}03}$.

The field sites at Odin were compared to nearby regional (RII01 and RII02) and field specific reference sites (PSB13R, FRI10R and LFR01R) based on sediment characteristics (TOM and pelite) and chemical content in the sediments (Figure 20.7). ODI03, 100 m to the north of the field centre did not group with the other sites due to higher content of chemical compounds in the sediments. ODI01 (100 m to the east), ODI05 (100 m to the west) and ODI07 (100 m to the south) formed a separate group due to the middle high content of chemical compounds in the sediments. The grouping of the sites indicates a decrease in concentrations of chemical compounds with increasing distance to the field centre.



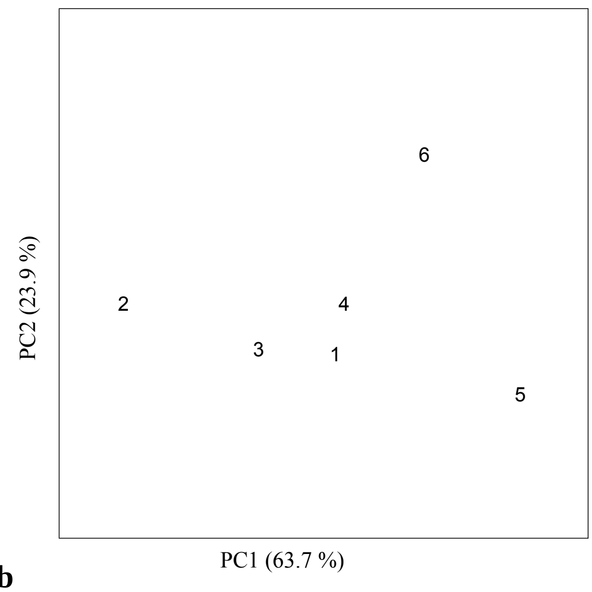


Figure 20.7. 2-D plot from the PCA analysis of environmental variables (% pelite, % sand, % gravel, median Φ, % TOM, Cu, Ba, Zn, Cr, Pb and THC) carried out on:
a) Odin field sites compared to the reference sites at Frigg, Lille-Frigg and Øst Frigg and the regional sites RII01 and RII02. Explained variation in the data 78.0 %.
b) Odin field sites. Explained variation in the data 87.6 %.
Numbers in the plot identify the sampling sites. See table below.

1	ODI01	5	ODI31	9	FRI10R
2	ODI03	6	ODI32	10	RII01
3	ODI05	7	LFR01R	11	RII02
4	ODI07	8	PSB13R		

20.2.3 Bottom fauna

A summary of the distribution of individuals and taxa within the main taxonomic groups are given in Table 20.7. Unidentified juveniles of the sea urchins Spatangoids (10411 individuals) and Echinoides (1735 individuals), and juveniles of the brittle stars *Ampiura filiformis* (359 individuals) and *Ophiura affinis* (1074 individuals) are omitted from the analyses, as they occurred in extremely high numbers. In total, 3697 individuals within 179 taxa were collected at Odin in 2003. The fauna was numerically dominated by annelida with 49 % the individuals and 47 % of the taxa (Table 20.7). A complete species list is available in the Appendix.

Table 20.7. Distribution of individuals and taxa within the main taxonomic groups at Odin in 2003 (unidentified juveniles of Spatangonida and Echinoidea and juveniles of *Amphiura filiformis* and *Ophiura affinis* are not included).

Main taxonomic groups	Individuals number	%	Taxa number	%
Annelida	1823	49	84	47
Arthropoda	271	7	40	22
Mollusca	732	20	32	18
Echinodermata	511	14	13	7
Diverse groups	360	10	10	6
Total	3697	100	179	100

No species/area is presented for Odin in 2003 as there was no sampling at the reference site ODI14R.

The distribution of individuals and taxa are shown in Figure 20.8. Number of individuals and taxa at each site, and the calculated diversity indexes (H' and ES_{100}) are given in Table 20.8 and Figure 20.9. The number of individuals varied from 436 (ODI32) to 745 (ODI07), and the number of taxa varied from 76 (ODI32) to 97 (ODI007). The Shannon-Wiener diversity index (H') varied from 4.75 (ODI05) to 5.01 (ODI07), whereas the ES_{100} index varied from 33.4 (ODI05) to 37.1 (ODI07). The evenness index J varied from 0.75 (ODI05) to 0.78 (ODI32). The number of taxa, diversity and evenness indicate good environmental conditions at all sites.

Table 20.8. Number of individuals, species/taxa and selected community indices for each site (0.5 m^2) at the Odin field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis* and *Ophiura affinis*.

Site number	Number of individuals	Number of taxa	Diversity H'	Evenness J	H'-max	ES_{100}
ODI01	698	89	5.01	0.77	6.48	36.4
ODI03	643	90	4.92	0.76	6.49	34.7
ODI05	634	79	4.75	0.75	6.30	33.4
ODI07	745	97	5.01	0.76	6.60	37.1
ODI31	541	81	4.79	0.75	6.34	36.2
ODI32	436	76	4.87	0.78	6.25	36.5
Sum[1]	3697	179				
Average[1]	616	85	4.89	0.76	6.41	35.7
SD[1]	112	8	0.11	0.01	0.13	1.4
Min[1]	436	76	4.75	0.75	6.25	33.4
Max[1]	745	97	5.01	0.78	6.60	37.1
Average[2]	919	95	4.78	0.73	6.57	34.5
SD[2]	428	12	0.65	0.11	0.19	5.3
Min[2]	574	80	3.51	0.52	6.32	24.6
Max[2]	1749	109	5.31	0.82	6.77	39.6

[1] Odin field sites
[2] Reg + $Ref_{north\ 03}$

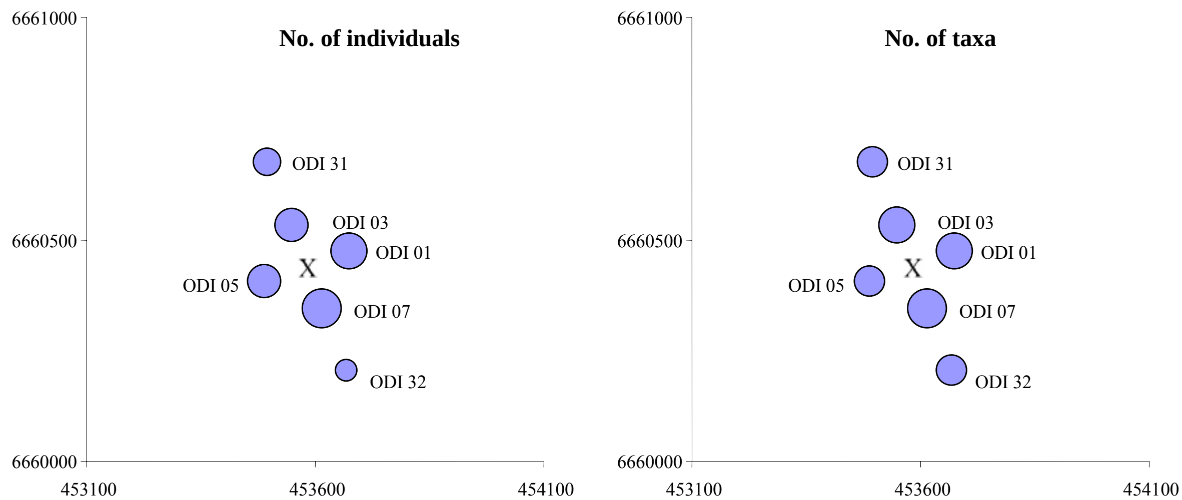


Figure 20.8. Distribution of bottom fauna (individuals and taxa) among the sampling sites in 2003. The size of the circle indicates the number of individuals and taxa. Exclusive unidentified juveniles of Spatangoida and Echinoidae and juveniles of *Amphiura filiformis* and *Ophiura affinis*. The field centre is marked with an X.

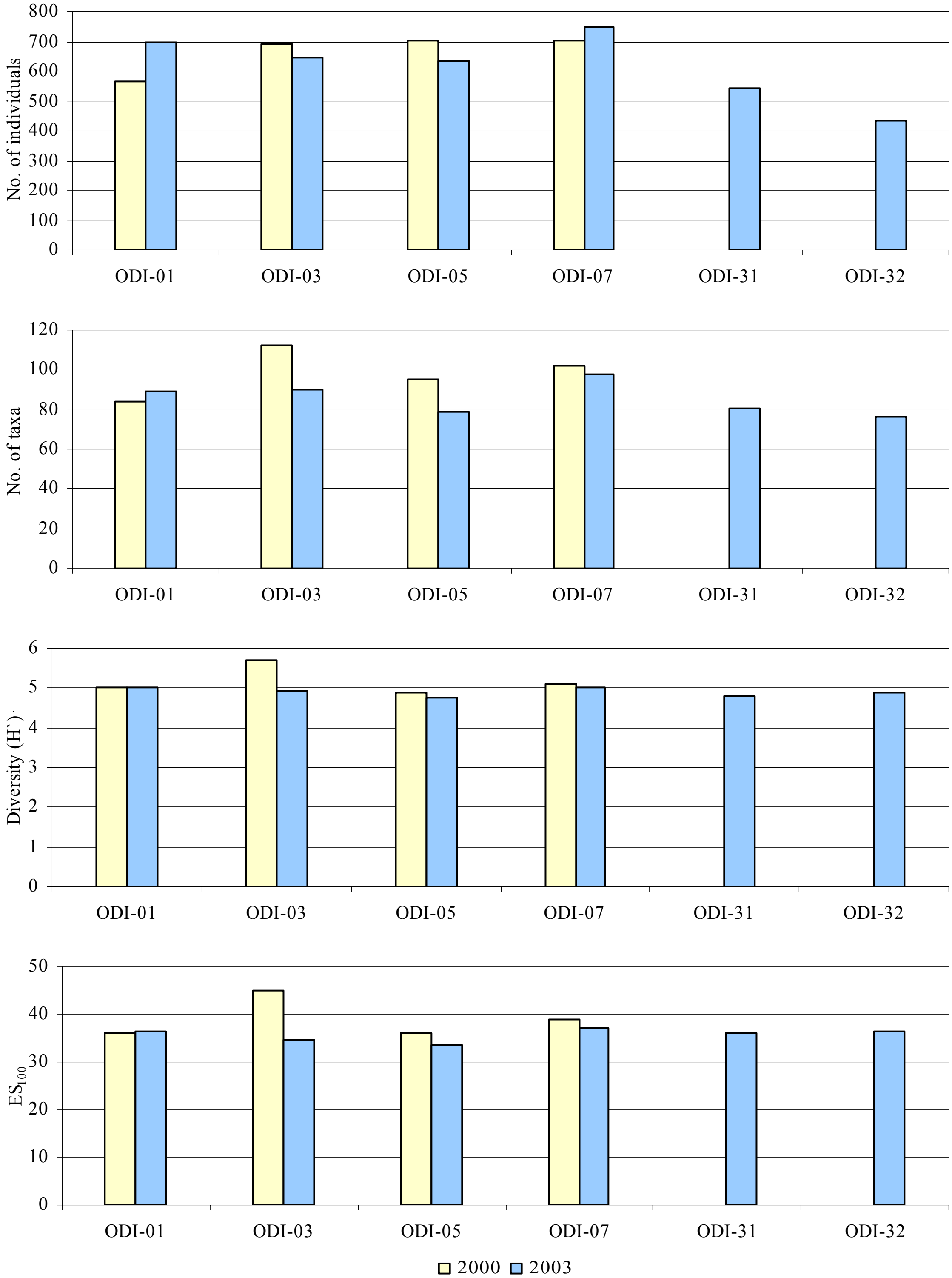


Figure 20.9. Number of individuals, taxa and selected community indices for each site (0.5 m^2) at the Odin field for 2000 and 2003. (Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis* and *Ophiura affinis* in 2003).

Distribution of taxa in geometrical classes is presented in Figure 20.10. The smooth graphs representing ODI07 and ODI32 indicate undisturbed bottom fauna, whereas the graphs representing ODI01 and ODI05 indicate some fauna disturbance.

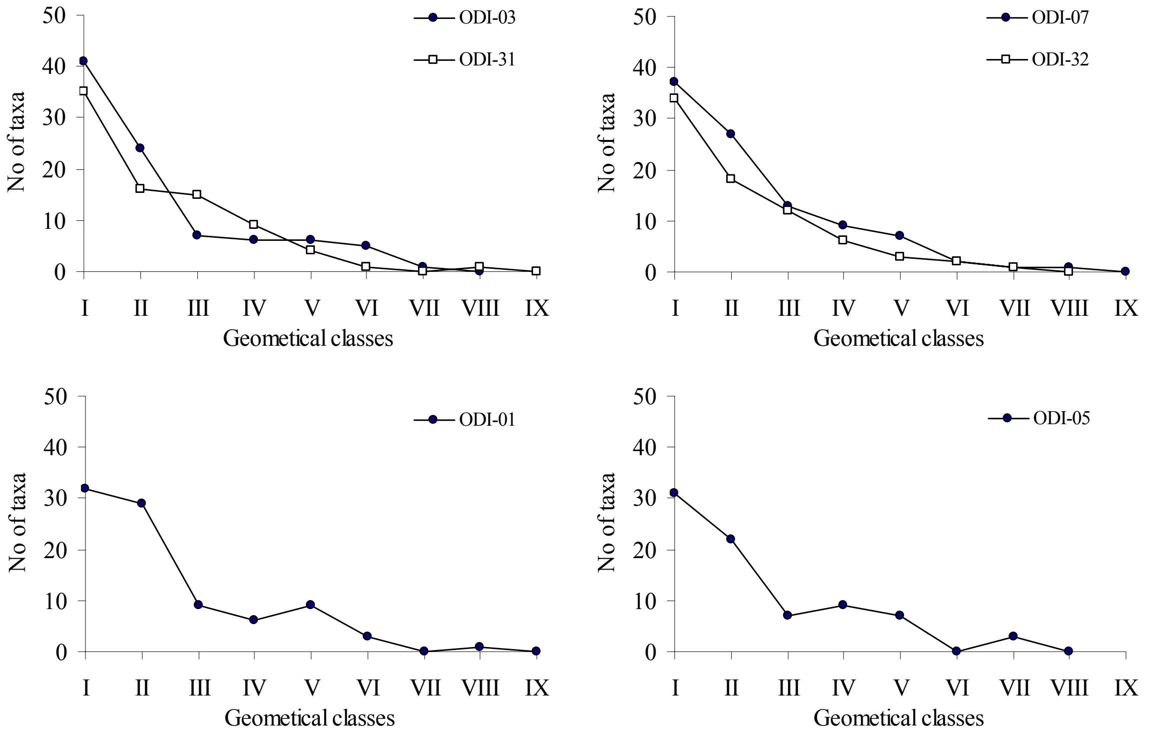


Figure 20.10. Distribution of taxa in geometrical classes for the sites at Odin in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis* and *Ophiura affinis*.

The ten most numerous taxa are listed in Table 20.11 at the end of this chapter. The list comprise 17 taxa and 2655 individuals, which was 9.5 % of all (179) taxa and 71.8 % of all (3697) individuals.

The most abundant and well distributed species were the polychaetes *Spiophanes bombyx*, *Owenia fusiformis* and *Chaetozone setosa*, the brittle star *Amphiura filiformis*, the bivalves *Mysella bidentata*, *Thyasira flexuosa* and *Lucinoma borealis*, the anthozoa *Cerianthus lloydii* and the phoronid *Phoronis* sp. Among these are species which indicate both good and poor environmental conditions. Due to the presence of species which are known to live only under good conditions, there are good reasons to conclude that the conditions were good in 2003.

The results of the multivariate analyses are given in the dendrogramme (Figure 20.11) and the MDS plott (Figure 20.12).

In the cluster analysis, all sites are grouped together within 63 % similarity, indicating relatively high similarity in the species assemblages within the field. The species assemblages were not particularly more similar at any pair of sites.

The results of the MDS analysis indicate high similarity in the fauna at ODI01 and ODI07 and that the fauna at ODI31 and ODI32 are somewhat different from the fauna at the other sites. The appearance of faunal differences in the MDS-plot might be a function of the few sites in the analysis. This gives more space for showing relative similarity than in a plot presenting many sites. Further this means that the MDS-plot of the Odin data is reflecting only marginal relative differences in the fauna composition. The overall impression of the fauna assemblage was good environmental conditions at Odin in 2003.

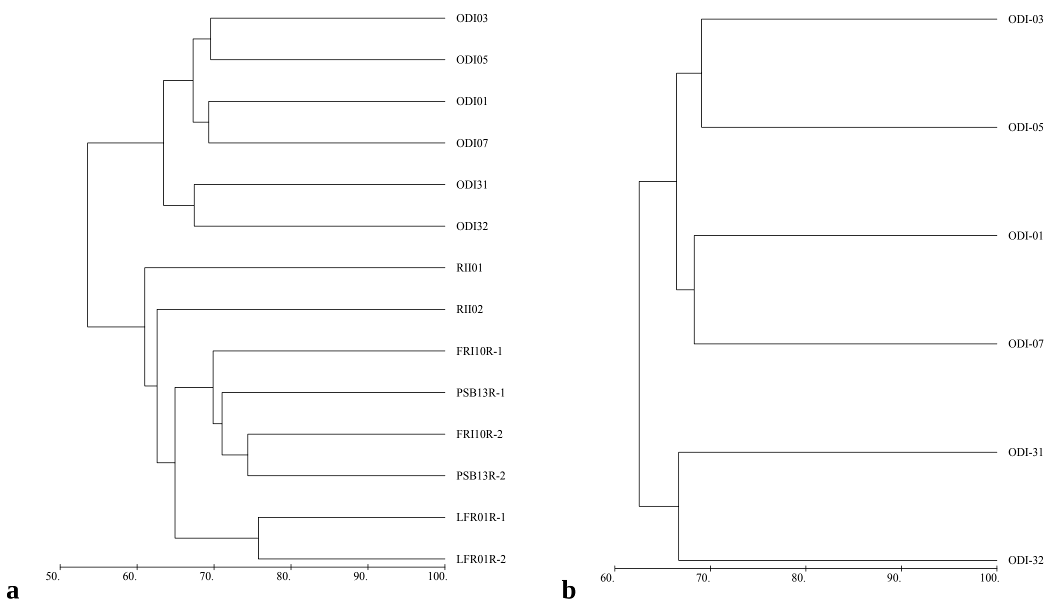
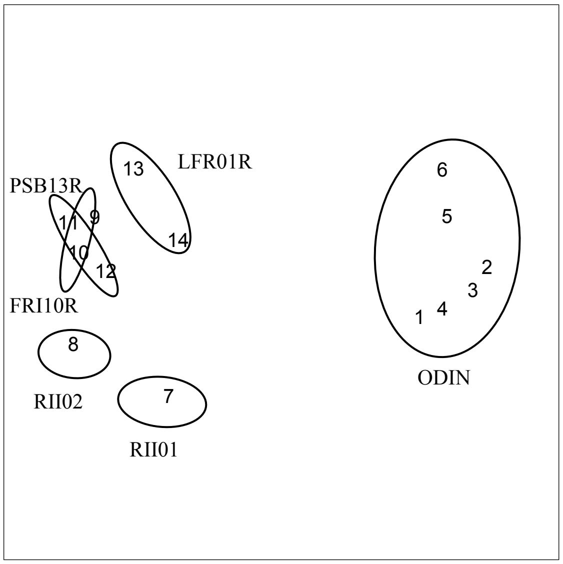


Figure 20.11. Dendrogram showing the similarity between fauna from sampling sites at:

a) Odin field compared to regional sites (RII01 and RII02) and reference sites (FRI10R, PSB13R and LFR01R) in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea.
b) Odin field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis* and *Ophiura affinis*.



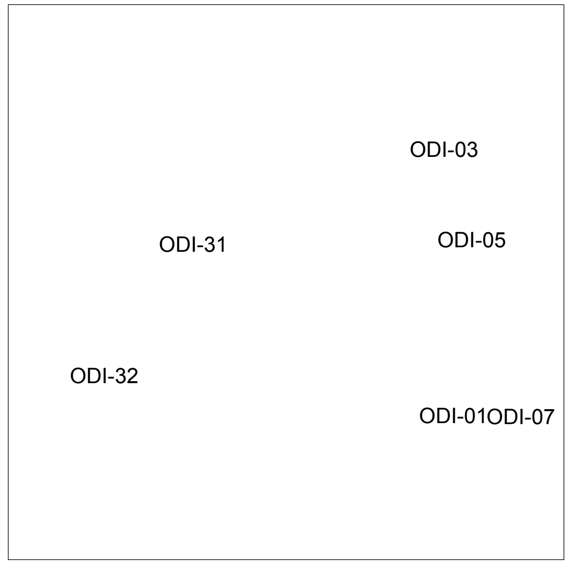


Figure 20.12. A 2-dimetional plott of the MDS analysis of the fauna data from:

a) Odin field compared to regional sites (RII01 and RII02) and reference sites (FRI10R, PSB13R and LFR01R) in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea. Stress = 0.07. Codes in table below.
b) Odin field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis* and *Ophiura affinis*. Stress = 0.06.

1	ODI01	4	ODI07	7	RII01	11	PSB13R-1
2	ODI03	5	ODI31	8	RII02	12	PSB13R-2
3	ODI05	6	ODI32	9	FRI10R-1	13	LFR01R-1
				10	FRI10R-2	14	LFR01R-2

Linking of biotic and environmental variables by BIOENV revealed that the combination of the content of lead, TOM, gravel chromium, barium and copper THC and copper in the sediments were best correlated to the biota at $\rho_w = 0.78$ (Table 20.9). This indicates that there was an association between some environmental variables and the bottom fauna.

Table 20.9. Combinations of the 10 environmental variables, taken *k* at a time, yielding the best matches of biotic and abiotic similarity matrices for each *k*, as measured by weighted Spearman rank correlation ρ_w. Bold type indicates overall optimum. All possible combinations of variables and associated correlation to the biotic are given in the Appendix.

Number of Variables (*k*)	Correlation coefficient (ρ_w)	Environmental variables									
1	0.578	Pb									
1	0.541	Zn									
1	0.441	Ba									
1	0.422	Cu									
1	0.396	Gravel									
1	0.179	TOM									
1	0.070	Pelite									
1	0.014	Sand									
1	-0.034	Cr									
1	-0.139	THC									
2	0.646	Pb	Zn								
3	0.722	Pb		TOM	Sand						
4	0.737	Pb				Gravel	Cr	Ba			
5	0.771	Pb		TOM		Gravel	Cr		THC		
6	**0.782**	**Pb**		**TOM**		**Gravel**	**Cr**	**Ba**		**Cu**	
7	0.780	Pb	Zn	TOM		Gravel	Cr	Ba		Cu	
8	0.722	Pb	Zn	TOM		Gravel	Cr	Ba	THC	Cu	
9	0.645	Pb	Zn	TOM	Sand	Gravel	Cr	Ba	THC	Cu	
10	0.622	Pb	Zn	TOM	Sand	Gravel	Cr	Ba	THC	Cu	Pelite

20.2.4 Estimation of influenced area

The extension of contamination along sampling transects and the minimum area of contaminated sediments for THC and barium and other metals as well as for faunal disturbance is given in Figure 20.13 and Table 20.10. Contamination by THC was only found at one site, whereas contamination by barium was not revealed. Faunal disturbance was not found in 2003. Contamination by other metals was found at all sites within 100 m distance to the field centre. The area contaminated by other metals had increased slightly since 2000, whereas the area contaminated by THC was reduced to 0.0 km².

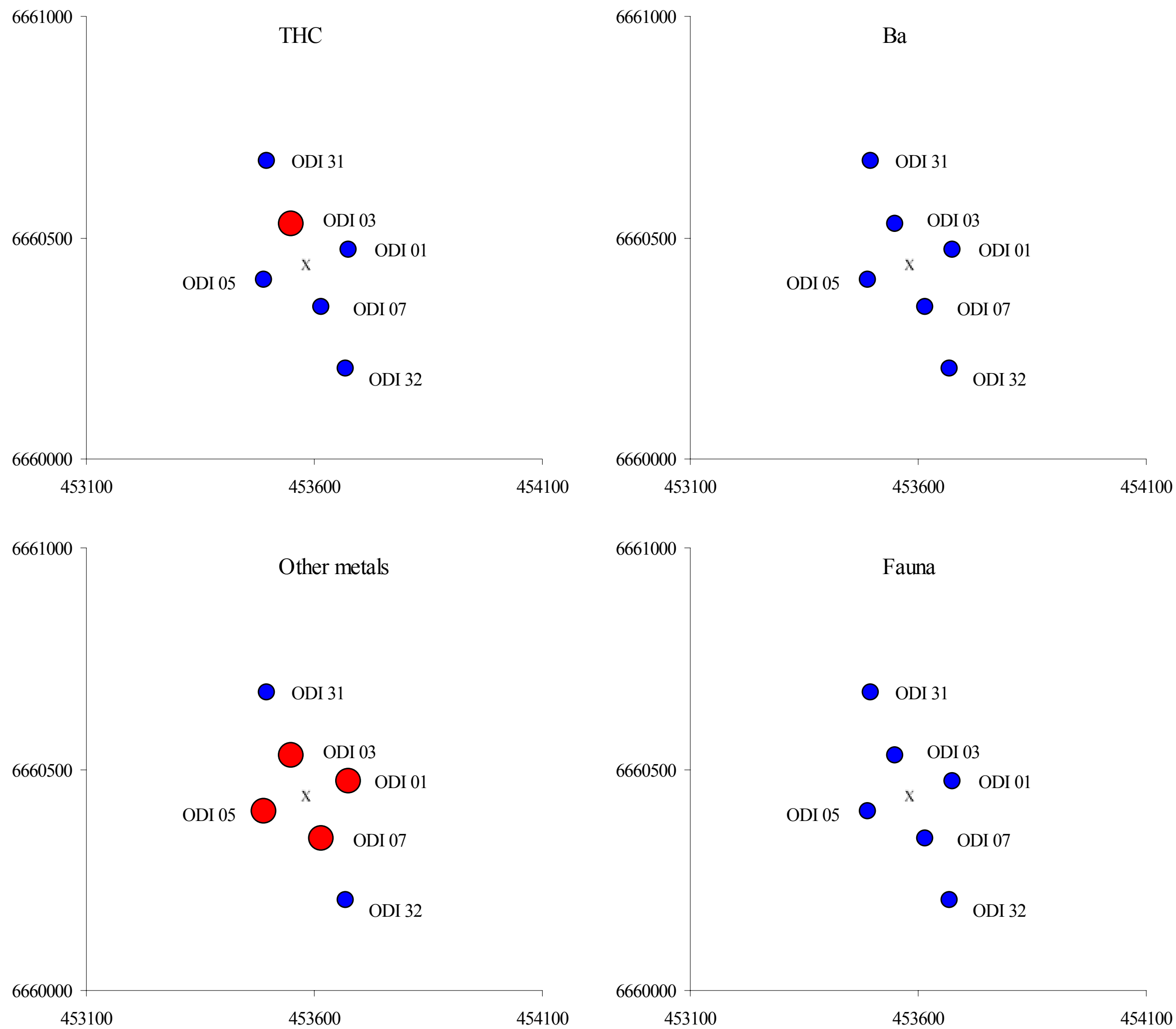


Figure 20.13. Faunal disturbance and chemical contamination of the sediments at Odin in 2003. The field centre is marked with an X. Uncontaminated sites and sites with no faunal disturbance are marked with small blue circles.

Table 20.10. Estimated distance of contamination and faunal disturbance from the installation, and estimated area of contamination and faunal disturbance around the field centre.

Odin	NE m	SE m	SW m	NW m	2003 km²	2000 km²	1997 km²
THC	0	0	0	100	0.00	0.02	0.02
Ba	0	0	0	0	0.00	0.00	0.01
Other metals	100	100	100	100	0.03	0.02	0.02
Fauna	0	0	0	0	0.00	0.03	0.02

20.3 Summary and conclusions

Production at Odin ceased in 1994 and the installation was removed in 1997.The sediments are still characterized as fine sand, although there has been a slight increase in the pelite and slight decrease in TOM content since 2000. Generally the content of THC, barium and other metals were approximately at the same level in 2003 as in 2000, or slightly lower.
The species diversity in the bottom fauna was high and approximately at the same level as in 2000. The fauna assemblage was well correlated to the distribution of most of the measured environmental variables (lead, TOM, gravel, chromium, barium and copper). Despite this no faunal disturbance was revealed. The contaminated area at Odin was negligible.

Table 20.11. Number of individuals and relative abundance for the ten predominant taxa at each site at the Odin field in 2003. Exclusive unidentified juveniles of Spatangoida and Echinoidea and juveniles of *Amphiura filiformis* and *Ophiura affinis*.

ODI01	No of ind.	%	Cum %
Spiophanes bombyx	132	18.9	18.9
Amphiura filiformis	57	8.2	27.1
Mysella bidentata	42	6.0	33.1
Phoronis sp.	38	5.4	38.5
Cerianthus lloydii	30	4.3	42.8
Owenia fusiformis	30	4.3	47.1
Lucinoma borealis	30	4.3	51.4
Montacuta substriata	22	3.2	54.6
Chaetozone setosa	21	3.0	57.6
Goniada maculata	20	2.9	60.5
Thyasira flexuosa	20	2.9	63.3

ODI03	No of ind.	%	Cum %
Spiophanes bombyx	103	16.0	16.0
Lucinoma borealis	58	9.0	25.0
Amphiura filiformis	50	7.8	32.8
Chaetozone setosa	50	7.8	40.6
Cerianthus lloydii	44	6.8	47.4
Myriochele oculata	35	5.4	52.9
Parapleustes latipes	22	3.4	56.3
Mysella bidentata	18	2.8	59.1
Thyasira flexuosa	18	2.8	61.9
Lanice conchilega	18	2.8	64.7

ODI05	No of ind.	%	Cum %
Spiophanes bombyx	123	19.4	19.4
Lucinoma borealis	67	10.6	30.0
Amphiura filiformis	65	10.3	40.2
Mysella bidentata	30	4.7	45.0
Phoronis sp.	27	4.3	49.2
Thyasira flexuosa	24	3.8	53.0
Owenia fusiformis	23	3.6	56.6
Cerianthus lloydii	22	3.5	60.1
Chaetozone setosa	20	3.2	63.2
Myriochele oculata	16	2.5	65.8

ODI07	No of ind.	%	Cum %
Spiophanes bombyx	138	18.5	18.5
Amphiura filiformis	74	9.9	28.5
Lucinoma borealis	62	8.3	36.8
Owenia fusiformis	47	6.3	43.1
Phoronis sp.	30	4.0	47.1
Chaetozone setosa	29	3.9	51.0
Myriochele oculata	29	3.9	54.9
Cerianthus lloydii	25	3.4	58.3
Mysella bidentata	19	2.6	60.8
Thyasira flexuosa	18	2.4	63.2

ODI31	No of ind.	%	Cum %
Spiophanes bombyx	133	24.6	24.6
Amphiura filiformis	58	10.7	35.3
Cerianthus lloydii	31	5.7	41.0
Mysella bidentata	26	4.8	45.8
Scoloplos armiger	19	3.5	49.4
Owenia fusiformis	17	3.1	52.5
Goniada maculata	15	2.8	55.3
Thyasira flexuosa	14	2.6	57.9
Lucinoma borealis	13	2.4	60.3
Chaetozone setosa	13	2.4	62.7
Nephtys hombergi	13	2.4	65.1

ODI32	No of ind.	%	Cum %
Amphiura filiformis	75	17.2	17.2
Spiophanes bombyx	59	13.5	30.7
Mysella bidentata	35	8.0	38.8
Goniada maculata	22	5.0	43.8
Thyasira flexuosa	22	5.0	48.9
Scoloplos armiger	16	3.7	52.5
Cerianthus lloydii	15	3.4	56.0
Owenia fusiformis	12	2.8	58.7
Phoronis sp.	12	2.8	61.5
Dentalium entale	10	2.3	63.8

21 Status for Region II

21.1 Introduction

Until the mid 1990's, the focus of baseline and monitoring surveys was on specific petroleum fields. The focus is still on specific fields, but the perspective has widened to regions including several fields. Norwegian waters are currently divided into 11 such regions. Of these, Region II is the next most southerly region and is situated between 58 and 60 °N. In 2003, 16 separate fields in Region II were surveyed. In this chapter, they are compared to each other, and the current status of the region is summarised.

Detailed information about the data from 2003 is available in the Appendix and in each chapter dealing with specific fields. Since the first regional survey in 1996, analytical methods have improved and more than one laboratory has been involved in the surveys. Over time, evaluations of results have been carried out by several scientists who, in addition to their scientific tools, have used their experience and common sense when evaluating the results of a specific survey. Some sampling sites have been relocated or omitted, and some new ones have been included in the surveys. In some cases, this has had consequences for the estimation of the area contaminated by chemical compounds or the area suffering faunal disturbance. These changes must be taken into consideration when comparing results from the different surveys and when reporting the environmental status of a region.

Among the fields surveyed in 2003, Frigg was the oldest where production started in 1977, whereas Grane was still under construction. Some of the fields in the northern part of the region were abandoned (Frøy, Øst-Frigg and Lille-Frigg), while other fields in the central part of the region were still under operational planning or construction.

Well drilling and discharges were not evenly distributed throughout the region (Table 21.1 and Figure 21.1). Since 1997, most wells have been drilled in the central part of the region, and the largest amounts of discharges occurred in this area. In the southern part, fewer wells are drilled and the amounts of discharges are also smaller. In the northern part, there has been little drilling during the last years and some of the discharges in this area are connected to plugging and abandonment of old wells.

Based on the chemical data from 2003 and the combined chemical data from 1997, 2000 and 2003, there were good reasons to divide Region II into 3 sub-regions. These sub-regions are: the southern shallow part of Region II (comprising Varg, Sigyn, Sleipner Øst and the regional sampling site RII06); the central part of Region II (comprising Sleipner Vest, Glitne, Balder, Grane, Ringhorne, Jotun, Heimdal, Frøy and the regional sampling sites RII03, RII04, RII07, RII08 and RII09); and the northern part (comprising Vale, Frigg, Øst-Frigg, Lille-Frigg, Odin and the regional sampling sites RII01 and RII02). The subdivision of Region II was also supported by the faunal data. The water depth in the shallow southern sub-region was in the range of 77-87 m with a mean water depth of 82 m ± 3 m. In the deeper northern sub-region, the depth range was 100-120 m with a mean depth of 112 m ± 6 m. The deepest waters were found in the central sub-region where the depth range was 101-130 m with a mean depth of 123 m ± 7 m.

Table 21.1. Productions start up year and ending year for the fields surveyed in Region II. Number of wells drilled in specific fields from 2000 to 2002 and the amount of discharged barite, cuttings, and water-based mud.

Field	Production	Number of wells	Drilling	Discharges 2000 – 2002 (tonnes)		
	Start-finish	2000-2002	2000-2002	Barite	Cuttings	Water-based mud
Varg	1998-	None	No	0	0	0
Sigyn	2002-	3 wells	Yes	691	1476	2524 m^3
Sleipner Øst	1993-	5 wells*	Yes*	3226	8121	6854 m^3
Sleipner Vest	1996-	3 wells	Yes	579	1968	3192
Glitne	2001-	5 wells	Yes	1050	3863	6267
Grane	2003-	15 wells	Yes	1946	26475	4774
Balder	1999-	4 wells	Yes	490	2533	615
Ringhorne	?-	5 wells	Yes	907	909	4837
Jotun	1999-	16 wells	Yes	162	4720	15825
Heimdal	1985-	None	No	0	0	0
Vale	2002-	2 wells	Yes	52499	388	2038
Frøy	1995-2001	None***	Yes	0	0	1180
Frigg	1977-	None**	Yes	0	0	0
Øst-Frigg	1988-1997	None	No	0	0	0
Lille-Frigg	1994-1999	None***	Yes	140	0	1732
Odin	1984-1994	None	No	0	0	0

* Drilling only at Sleipner A, no drilling at Loke. No discharges at Loke.
** 14 wells were permanently plugged and abandoned during January to April 2003
*** All wells were permanently plugged and abandoned in 2000/2001

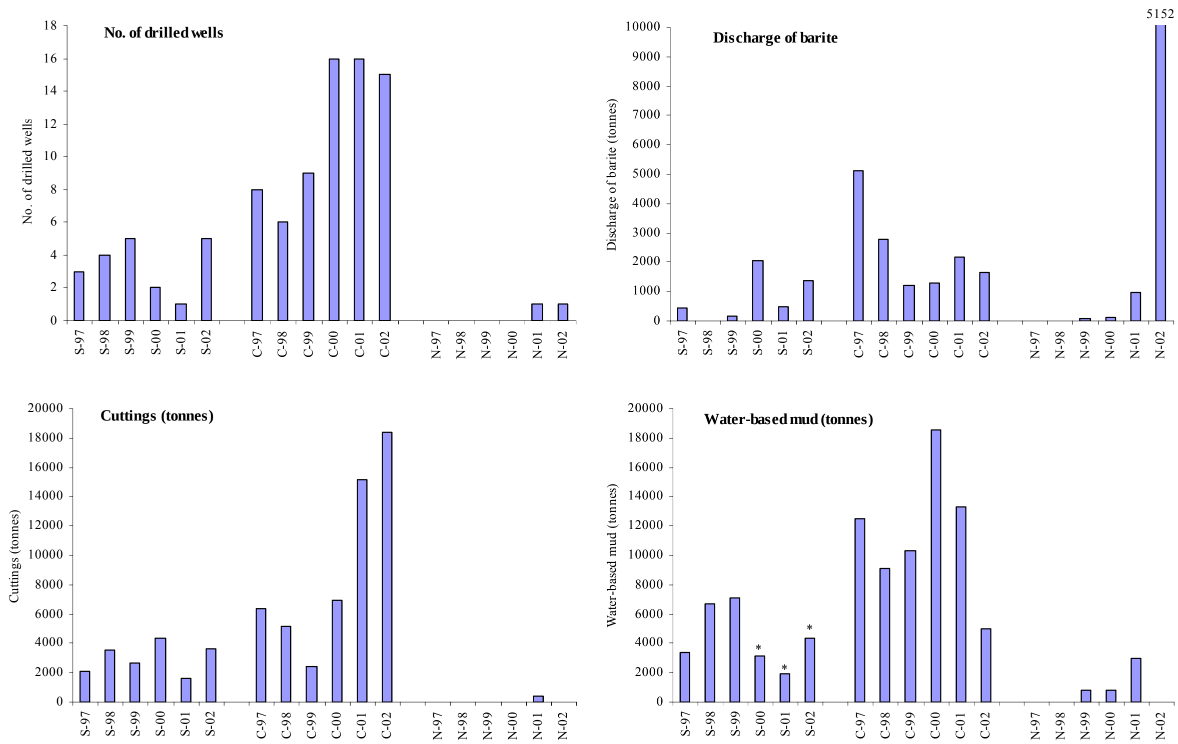


Figure 21.1. Drilling and discharge history of barite, cuttings, and water-based mud in the shallow (S), central (C) and northern (N) sub-region in Region II. * = m^3.

21.2 Sediment characteristics

The southern part of Region II (RII06, Varg, Sigyn and Sleipner Øst) had slightly more sandy sediments with less pelite and TOM content than found in the deeper northern and central sub-regions. In the northern part of Region II (Frigg, Øst-Frigg, Lille-Figg and Odin), the sediments contained more pelite and TOM than in the southern part, but not as much as found in the central part. Compared to the results of the survey in 2000, only minor changes have taken place, and they are probably due to natural variation in the sediments over time (Figure 21.2 and Table 21.2).

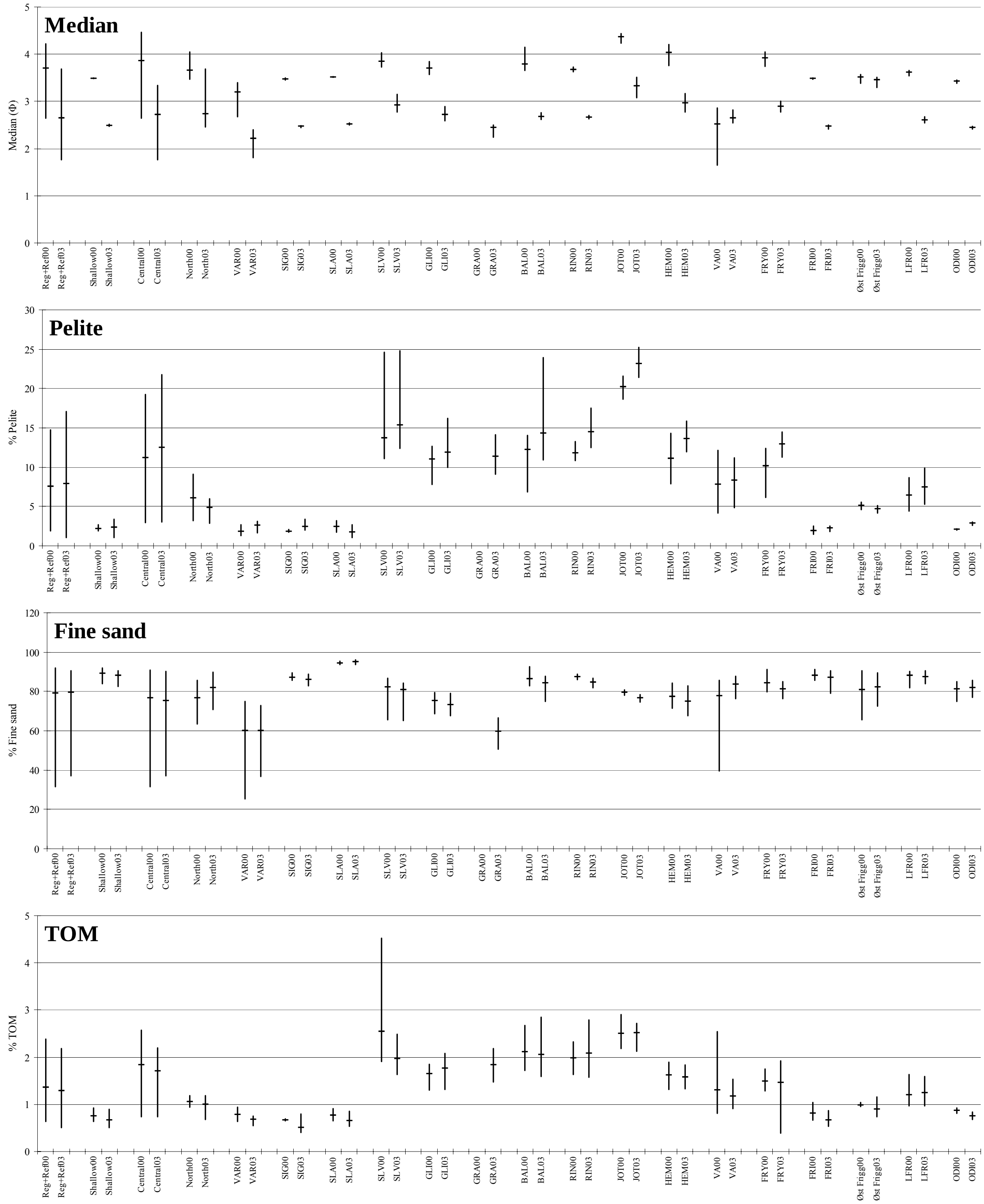


Figure 21.2. The average and range of the median (Φ), pelite, fine sand and TOM at each field in Region II in 2000 and 2003.

21.3 Chemical compounds

The content of THC and metals were generally low at the regional and reference sites, although there has been a tendency toward increased THC and zinc content since 2000. There has been a slight decrease in barium content, however (Figure 21.3 and Figure 21.5). The other metals remain at approximately the same levels as before (Table 21.2). The levels and the variations in concentrations at the regional and reference sites are considered to represent the natural background levels and the natural variations within the region.

At most field specific sampling sites, the highest concentrations of chemical compounds were found in the immediate vicinity of the field centers.

Since 2000, the average THC content has increased at Sigyn, Glitne, Balder, Ringhorne, Vale, Frøy and Frigg. The average THC content has decreased at Varg, Sleipner Vest, Heimdal and Odin. At Sleipner Øst, Jotun, Øst-Frigg and Lille-Frigg the THC content was approximately the same in 2000 and 2003. The most significant changes were the reduced THC content in the sediments at Varg and Sleipner Vest, and the increased THC content in the sediments at Glitne.

The barium content in the sediments decreased at all fields except Glitne and Vale. At Varg, Sigyn, Frigg, Øst-Frigg and Odin, barium concentrations were similar to natural background levels.

Copper concentrations were close to natural background levels at most fields except Heimdal and Frigg. Chromium concentrations were similar to natural background levels at all fields except Sigyn. Zinc occurred above natural background levels at Sleipner Vest, Glitne, Balder, Heimdal, Frigg and Odin. At Frigg and Odin, some samples were collected at 200 m and 100 m distances from the field center, which might explain why higher concentrations of some metals were found at these fields. The concentration of zinc was high in these samples. Lead occurred at natural background levels at all fields except Frigg, and cadmium was only occasionally detected above the limit of detection (0.03 mg Cd/kg).

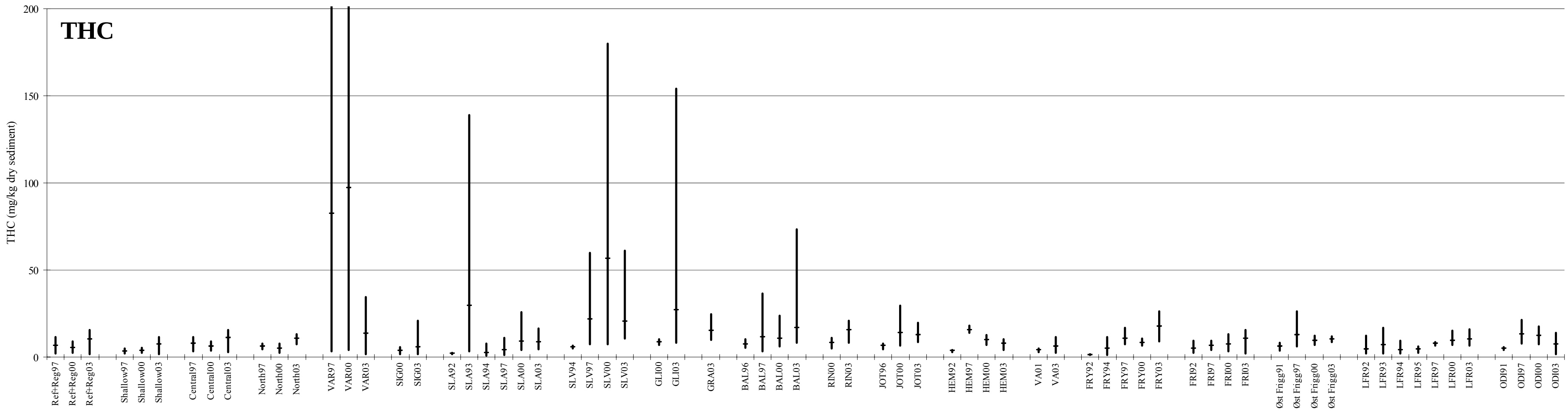


Figure 21.3. The average and range of THC at each field in Region II 2003 compared to previous surveys and the THC content at the regional and reference sites. Some values outside ordinate range.

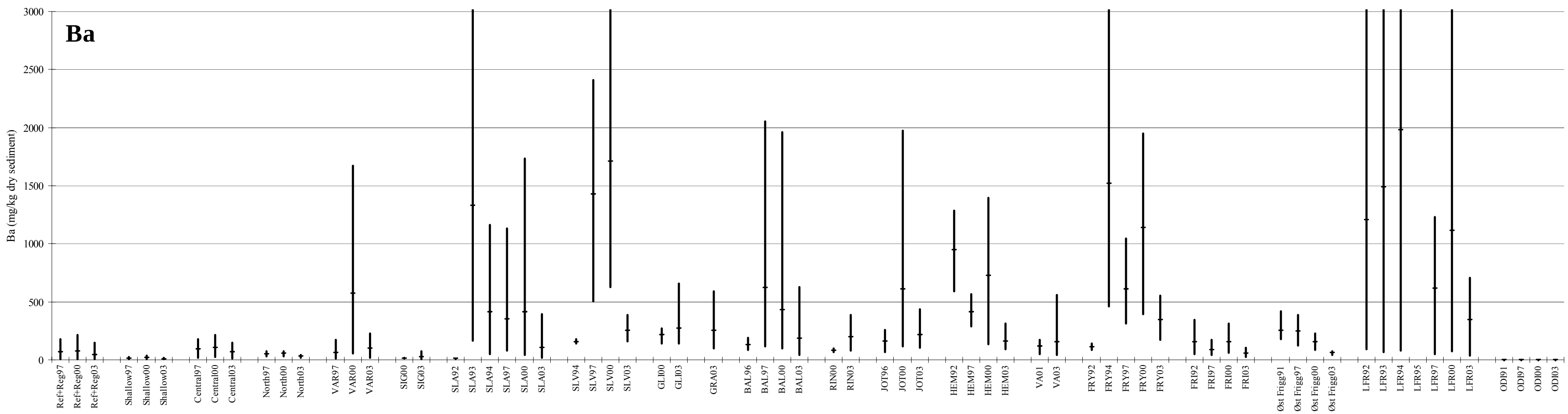


Figure 21.4. The average and range of barium at each field in Region II 2003 compared to previous surveys and the barium content at the regional and reference sites. Some values outside ordinate range.

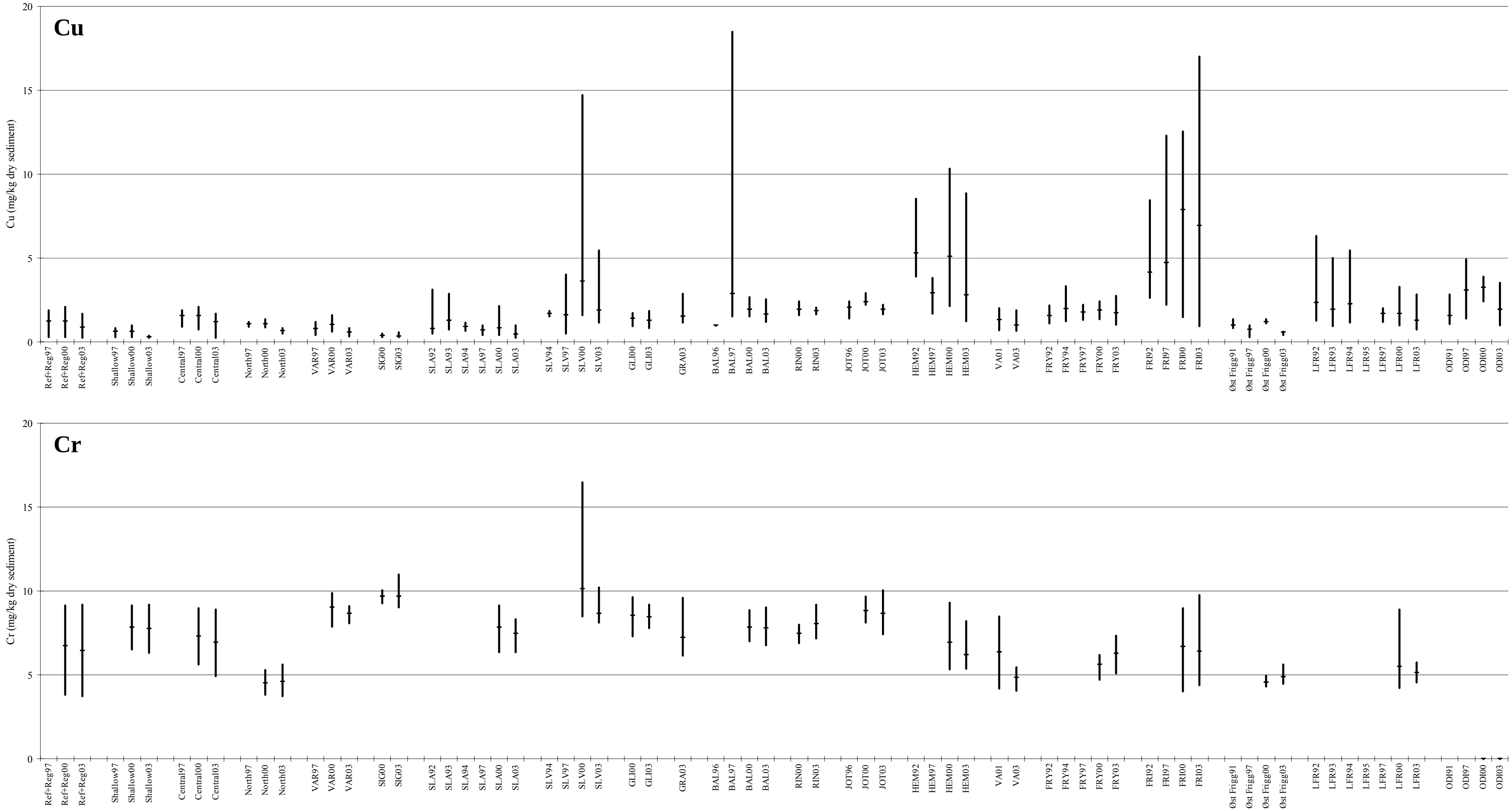


Figure 21.5. The average and range of copper, chromium, zinc, lead and cadmium at each field in Region II 2003 compared to previous surveys and the regional and reference sites.

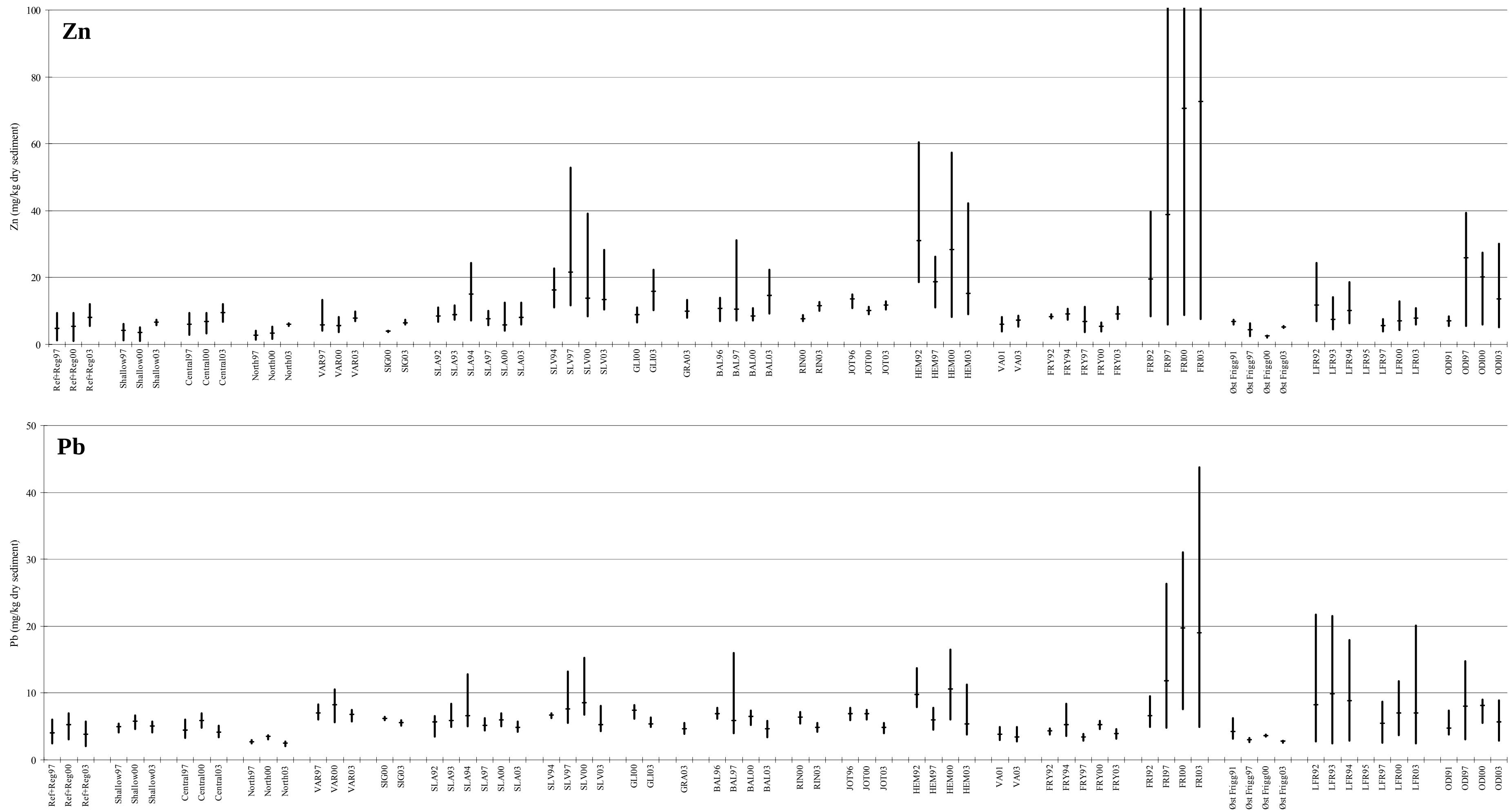


Figure 21.5. continue. The average and range of copper, chromium, zinc, lead and cadmium at each field in Region II 2003 compared to previous surveys and the regional and reference sites. Some values outside ordinate range.

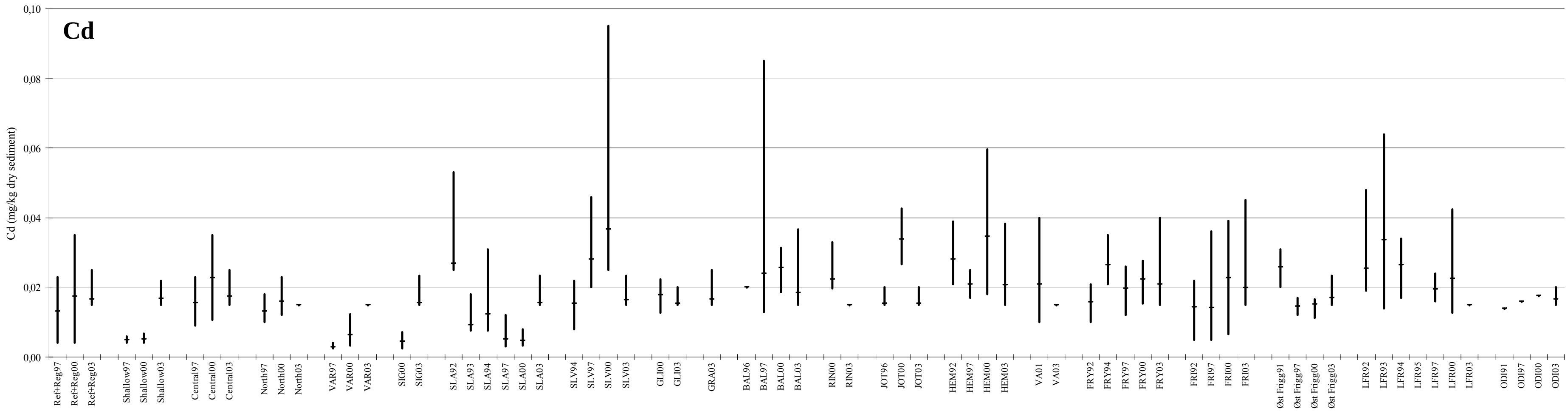


Figure 21.5. continue. The average and range of copper, chromium, zinc, lead and cadmium at each field in Region II 2003 compared to previous surveys and the regional and reference sites.

Table 21.2. Range of values for physical, chemical and biological parameters in Region II, 1997 – 2003.

Parameters	**Background range***			**Range at field sites**		
	1997	**2000**	**2003**	**1997**	**2000**	**2003**
Total number of sampling sites	23	22	22	168	217	172
Depth (m)	71-123	71-123	77-129	78-126	78-126	79-130
Average grain size (Md)	1.6-3.9	1.6-4.5	1.8-3.7	2.3-4.1	2.7-4.5	2.1-3.5
Lead (mg/kg)	2.4-6.1	3.1-6.9	2.1-5.7	2.0-26.3	3.2-31.0	2.6-43.7
Cadmium (mg/kg)	0.003-0.023	0.004-0.035	<0.03	0.005-0.085	0.003-0.095	<0.03-0.045
Barium (mg/kg)	6-176	8-215	5-146	11-2480	9-3942	8-709
THC (mg/kg)	2.0-11.3	2.2-8.9	<3-15.5	1.1-418	1.6-412	<3-154
Diversity H'	3.2-6.1	3.4-5.6	3.5-5.9	3.9-5.9	3.1-5.9	4.1-6.0
Number of taxa per site	67-158	46-149	47-141	54-173	37-154	45-146
Number of individuals per site	402-2744	236-2994	181-1749	235-3748	165-2635	162-1549

* Based on data from the regional and reference sites in Region II

21.4 Bottom fauna

A summary of the distribution of individuals and taxa within the main taxonomic groups is given in Table 21.3. In total, 157294 individuals within 598 taxa were collected and used for evaluation of the environmental conditions in Region II in 2003. In addition to these, approximately 272000 unidentified juveniles of the Spatangoid sea urchin and approximately 17000 unidentified individuals of the Echinoid sea urchin were caught in the samples but not used in the analyses. The fauna was numerically dominated by annelida with 55 % of the individuals and 43 % of the taxa.

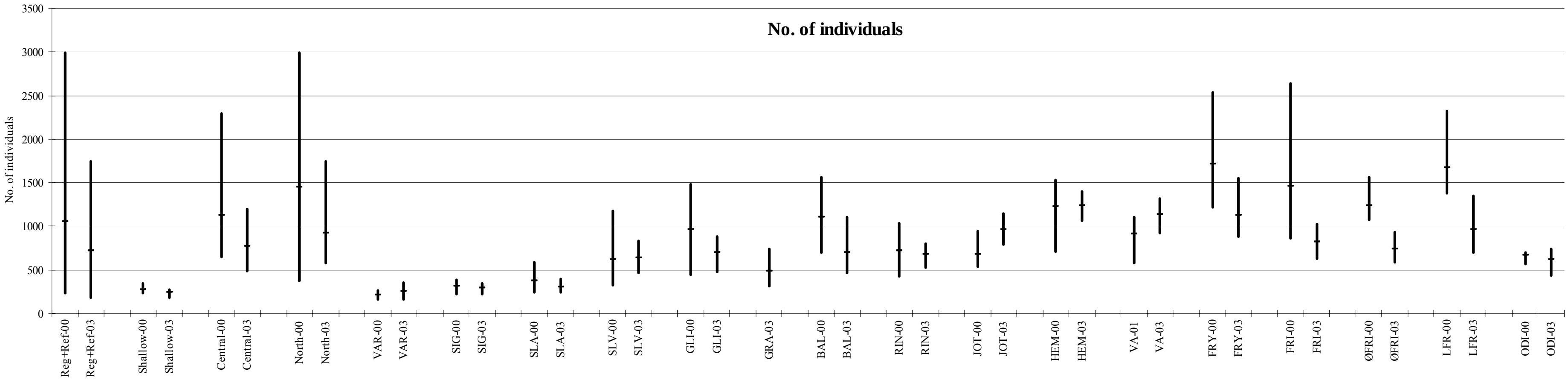
Table 21.3. Distribution of individuals and taxa within the main taxonomic groups in Region II in 2003 (unidentified juveniles of Spatangonida and Echinoidea are not included).

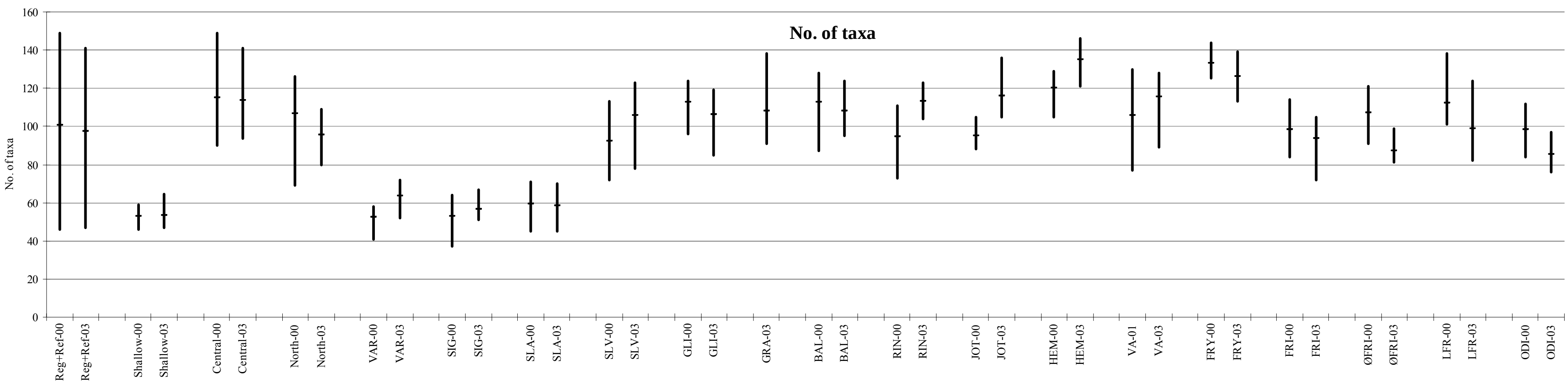
Main taxonomic groups	Individuals number	%	Taxa number	%
Annelida	86749	55	258	43
Arthropoda	13225	8	151	25
Mollusca	23111	15	122	20
Echinodermata	20962	13	31	5
Diverse groups	13247	8	36	6
Total	157294	100	598	100

The fauna samples from the regional and reference sites are considered to be representative of the natural variation in the region. The distribution of the fauna at the regional and reference sampling sites was correlated to the water depth, TOM, barium and lead content in the sediments.

There were fewer taxa and individuals in the samples from the southern sub-region than in samples from the northern and central sub-regions (Figure 21.6). This was also the case in 2000.

The variations in numbers of individuals, numbers of taxa and species diversity at the field specific sampling sites were within the natural variations at all fields (Figure 21.6) This was also true in 2000, and indicates stability over time and that eventual faunal disturbance from the petroleum activity were too weak to impair the species diversity. Only by using sensitive multivariate techniques was it possible to detect some faunal disturbance in the immediate vicinity of Varg, Sleipner Øst, Sleipner Vest, Balder, Heimdal, Frøy and Frigg. The fauna was considered undisturbed at the other fields surveyed.


No. of individuals
No. of individuals
3500
3000
2500
2000
1500
1000
500
0
Reg+Ref-00
Reg+Ref-03
Shallow-00
Shallow-03
Central-00
Central-03
North-00
North-03
VAR-00
VAR-03
SIG-00
SIG-03
SLA-00
SLA-03
SLV-00
SLV-03
GLI-00
GLI-03
GRA-03
BAL-00
BAL-03
RIN-00
RIN-03
JOT-00
JOT-03
HEM-00
HEM-03
VA-01
VA-03
FRY-00
FRY-03
FRI-00
FRI-03
ØFRI-00
ØFRI-03
LFR-00
LFR-03
ODI-00
ODI-03


No. of taxa
No. of taxa
160
140
120
100
80
60
40
20
0
Reg+Ref-00
Reg+Ref-03
Shallow-00
Shallow-03
Central-00
Central-03
North-00
North-03
VAR-00
VAR-03
SIG-00
SIG-03
SLA-00
SLA-03
SLV-00
SLV-03
GLI-00
GLI-03
GRA-03
BAL-00
BAL-03
RIN-00
RIN-03
JOT-00
JOT-03
HEM-00
HEM-03
VA-01
VA-03
FRY-00
FRY-03
FRI-00
FRI-03
ØFRI-00
ØFRI-03
LFR-00
LFR-03
ODI-00
ODI-03

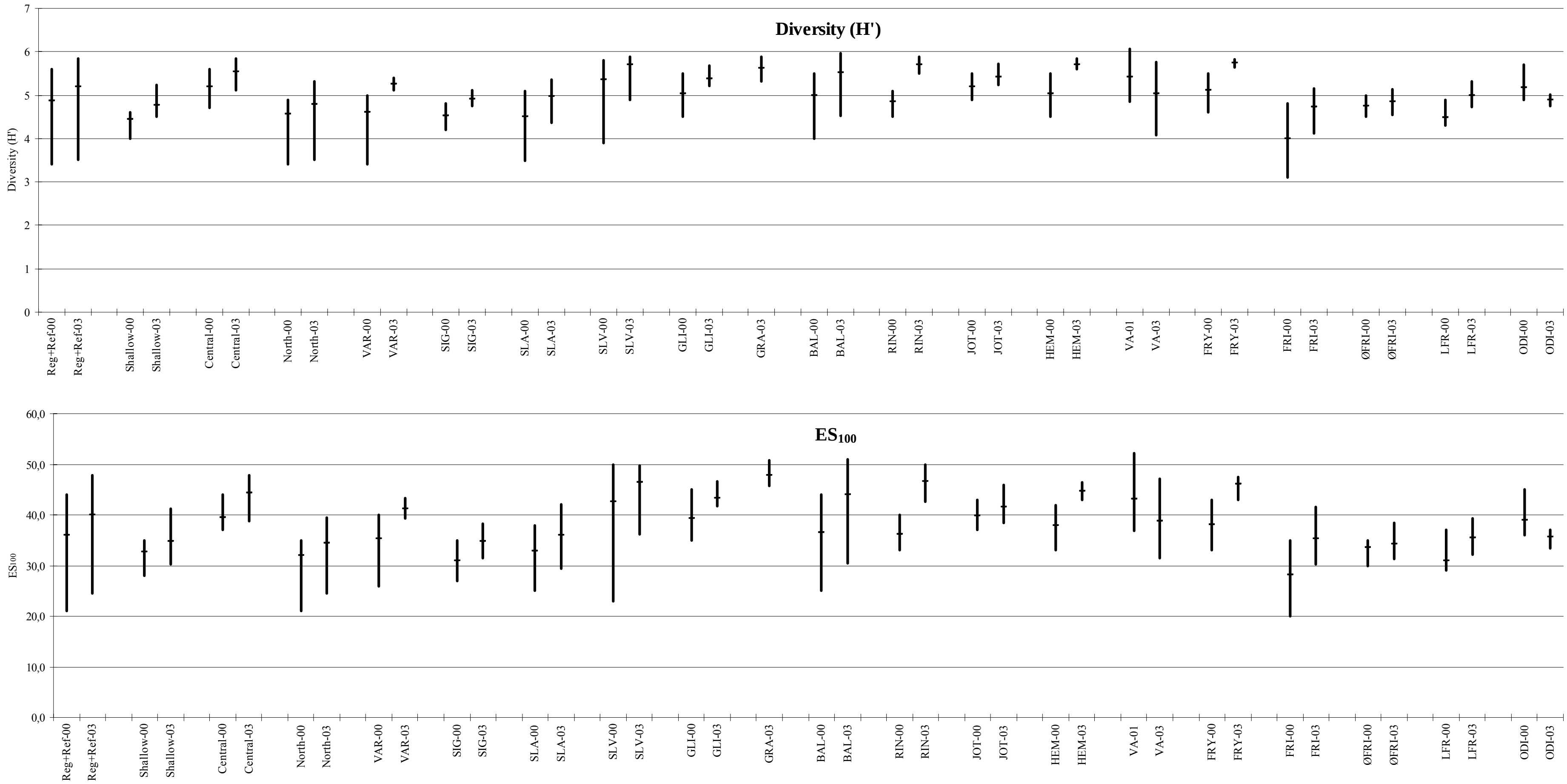


Figure 21.6. Average and range of numbers of individuals, taxa and diversity (H’ and $ES_{n=100}$) at the reference and regional sampling sites and at the petroleum fields in Region II in 2000 and 2003.

21.5 Contaminated area and area with faunal disturbance

The sizes of the areas contaminated by chemical compounds and the sizes of areas with faunal disturbance are listed in Table 21.4.

Estimated total area contamination by THC has increased by 3.60 km^2 (from 5.27 km^2 in 2000 to 8.87 km^2 in 2003) in Region II. The estimated area contaminated by THC increased at Sigyn, Sleipner Øst, Sleipner Vest, Glitne, Balder, Ringhorne, and Frøy. The estimated area contaminated by THC decreased at Varg, Grane (compared to 1997), Heimdal, Øst-Frigg, Lille-Frigg and Odin, whereas the contaminated area was the same at Vale (no contamination) and Frigg (0.06 km^2). At Jotun, the area was not estimated. The main contribution to the increase came from Ringhorne where the area increased to 3.93 km^2 from 0.0 km^2. The main contribution to the decrease came from Varg where the area decreased from 1.33 km^2 to 0.07 km^2.

Estimated total area contamination by barium has decreased by 4.77 km^2 (from 19.09 km^2 in 2000 to 14.32 km^2 in 2003) in Region II. The estimated area contaminated by barium increased at Sigyn, Sleipner Vest, Glitne, Grane (compared to 1997), Ringhorne, and Vale (not estimated before). The estimated area contaminated by barium decreased at Varg, Sleipner Øst, Balder, Jotun, Heimdal, Frøy, Frigg, Øst-Frigg and Lille-Frigg, whereas the contaminated area was still the same at Odin (0.0 km^2). The main contribution to the increase came from Glitne where the area increased to 3.14 km^2 from 0.0 km^2. The main contribution to the decrease came from Jotun where the area decreased by 3.83 km^2 from 5.30 km^2 to 1.47 km^2 and Balder where the area decreased by 3.78 (from 4.21 km^2 to 0.43 km^2).

Estimated total area contamination by other metals, mainly zinc, has increased by 4.40 km^2 (from 2.10 km^2 in 2000 to 6.50 km^2 in 2003) in Region II. The estimated area contaminated by other metals increased at Sigyn, Sleipner Øst, Glitne, Grane (compared to 1997), Balder, Vale (not estimated before), Øst-Frigg, Lille-Frigg and Odin. The estimated area contaminated by other metals decreased at Varg, Sleipner Vest, Heimdal and Frøy, whereas the contaminated area was the same in 2003 as in 2000 at Ringhorne (0 km^2) and Frigg (0.36 km^2). At Jotun, the area was not estimated. The main contribution to the increase came from Balder where the area increased by 3.98 km^2 (from 0.15 km^2 to 4.13 km^2). The main contribution to the decrease came from Sleipner Vest where the area decreased by 0.64 km^2 (from 0.74 km^2 to 0.10 km^2).

Estimated total area with faunal disturbance has decreased by 0.92 km^2 (from 1.21 km^2 in 2000 to 0.29 km^2 in 2003) in Region II. Increase in estimated area with faunal disturbance was not found at any field. The estimated area with faunal disturbance increased at Sleipner Øst and decreased at Varg, Sleipner Vest, Balder, Heimdal, Frøy, Frigg and Odin whereas area with faunal disturbance was the same at Sigyn, Glitne, Grane (compared to 1997), Ringhorne, Jotun, Vale (not estimated before), Øst-Frigg and Lille-Frigg. The main contribution to the decrease came from Balder where the area decreased by 0.33 km^2 (from 0.37 km^2 to 0.04 km^2).

Roughly estimated the total area of Region II is 44 700 km^2. Approximately 23 000 km^2 are located to the west of the Norwegian trench, where also the surveyed fields are located. Based on these estimates approximately 0.04 % of the area west of the trench was contaminated by THC, 0.06 % was contaminated by Ba and 0.03 % was contaminated by other metals, whereas 0.001 % of the area had some faunal disturbance.

Table 21.4. Estimated minimum area (km²) of contaminated sediments and disturbed fauna in Region II 1997 – 2003.

Sub-region	Field	Year	THC	Ba	Other metals	Fauna
Shallow	Varg	1997	1.18	0.10	0.00	0.00
	Varg	2000	1.33	1.77	0.25	0.15
	Varg	2003	0.07	0.20	0.20	0.05
Shallow	Sigyn	1997	n.a.	n.a.	n.a.	n.a.
	Sigyn	2000	0.00	0.00	0.00	0.00
	Sigyn	2003	0.02	0.20	0.02	0.00
Shallow	Sleipner Øst	1997	0.07	13.80	0.07	0.36
	Sleipner Øst	2000	0.40	2.21	0.00	0.00
	Sleipner Øst. Lok and Sla	2003	0.44	0.83	0.07	0.05
Central	Sleipner Vest	1997	0.88	3.14	3.14	0.00
	Sleipner Vest	2000	0.74	3.14	0.74	0.07
	Sleipner Vest	2003	0.79	3.53	0.10	0.03
Central	Glitne	1997	n.a.	n.a.	n.a.	n.a.
	Glitne	2000	0.00	0.00	0.00	0.00
	Glitne	2003	0.88	3.14	0.79	0.00
Central	Hermod (Grane)	1997	0.18	0.37	0.00	0.00
	Grane	2000	n.a.	n.a.	n.a.	n.a.
	Grane	2003	0.10	0.98	0.05	0.00
Central	Balder	1997	1.09	2.93	0.37	0.48
	Balder	2000	0.54	4.21	0.15	0.37
	Balder	2003	2.38	0.43	4.13	0.04
Central	Ringhorne	1997	n.a.	n.a.	n.a.	n.a.
	Ringhorne	2000	0.00	0.00	0.00	0.00
	Ringhorne	2003	3.93	0.74	0.00	0.00
Central	Jotun	1997	0.00	0.00	0.00	0.00
	Jotun	2000	1.77	5.30	0.07	0.00
	Jotun	2003	n.a	1.47	n.a	0.00
Central	Heimdal	1997	0.25	0.25	0.25	0.11
	Heimdal	2000	0.12	0.43	0.29	0.18
	Heimdal	2003	0.00	0.08	0.15	0.05
North	Vale	1997	n.a.	n.a.	n.a.	n.a.
	Vale	2000	n.a.	n.a.	n.a.	n.a.
	Vale	2003	0.00	1.77	0.39	0.00
Central	Frøy	1997	0.29	1.18	0.00	0.29
	Frøy	2000	0.07	1.18	0.15	0.29
	Frøy	2003	0.20	0.74	0.10	0.02
North	Frigg	1997	0.00	0.08	0.36	0.13
	Frigg	2000	0.06	0.08	0.36	0.12
	Frigg	2003	0.06	0.05	0.36	0.05
North	Øst Frigg	1997	0.11	0.33	0.00	0.07
	Øst Frigg	2000	0.07	0.18	0.00	0.00
	Øst Frigg	2003	0.00	0.02	0.02	0.00
North	Lille Frigg	1997	0.00	0.32	0.00	0.00
	Lille Frigg	2000	0.15	0.59	0.07	0.00
	Lille Frigg	2003	0.00	0.20	0.10	0.00
North	Odin	1997	0.02	0.01	0.02	0.02
	Odin	2000	0.02	0.00	0.02	0.03
	Odin	2003	0.00	0.00	0.03	0.00
Total area		1997	4.07	22.51	4.21	1.39
Total area		2000	5.27	19.09	2.10	1.21
Total area		2003	8.87	14.32	6.50	0.29

n.a. = not analyzed

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23 List of abbreviations

Al	Aluminium
Ba	Barium
Cd	Cadmium
Cu	Copper
DP	Dynamic Positioning
ES_{100}	Expected number of species in a 100 specimens sample
Fe	Iron
FPU	Floating Production Unit
GC/FID	Gas chromatography with flame ionization detector
GC/MS	Gas chromatography with mass selective detector
GPS	Global Positioning System
H’	Shannon-Wiener diversity
Hg	Mercury
J	Pielou’s measure of evenness
LSC	Limit of Significant Contamination
MDS	Multidimensional scaling
NPD	Naphthalene, Phenathrene/Anthracene, Dibenzothiophene and their C_1-C_3 homologues
NS	Norwegian Standard
PAH	Polycyclic Aromatic Hydrocarbons, including NPDs and 3-6 ring aromatics
PCA	Principal Components Analysis
Pb	Lead
Sd	Standard deviation
THC	Total Hydrocarbon Content
TOM	Total Organic Material
Zn	Zinc