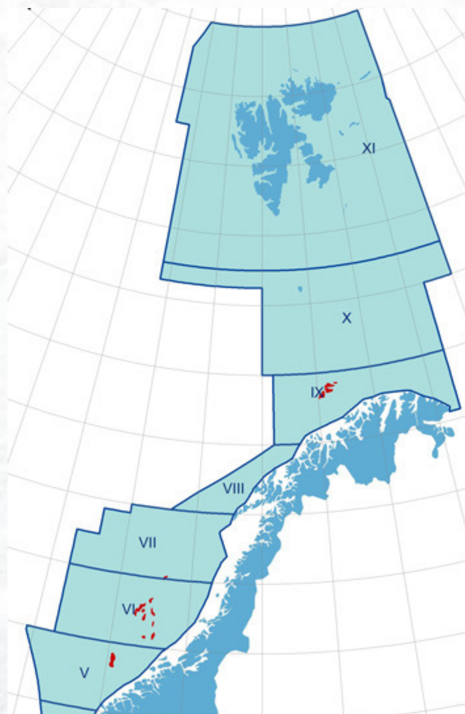
Rapport Report

Offshore sediment monitoring on the Norwegian shelf

A regional approach 1996-2006



Akvaplan-niva AS Report: 3487 - 003

Cover page illustration: Sediment monitoring regions in the Norwegian offshore: Regions housing petroleum activities are monitored every third year. Red areas indicate active oil and gas fields. Source: www.sft.no.

Akvaplan-niva AS
Rådgivning og forskning innen miljø og akvakultur
Org.nr: NO 937 375 158 MVA
Polarmiljøsenteret
9296 Tromsø
Tlf: 77 75 03 00, Fax: 77 75 03 01
www.akvaplan.niva.no

Report title

Offshore sediment monitoring on the Norwegian shelf

A regional approach 1996 - 2006

Authors	**Akvaplan-niva report no**
Paul E. Renaud (Akvaplan-niva) Tor Jensen (Det Norske Veritas) Ingar Wassbotten (Unilab Analyse) Hans Petter Mannvik (Akvaplan-niva) Helge Botnen (Unifob)	3487 - 003
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Report description
In 1996, the Offshore Monitoring of petroleum activities on the Norwegian continental shelf changed from an individual field –by –field approach, to a regional approach in which larger areas were surveyed and results evaluated for multiple fields in each region. An initial report from the first three years of regional monitoring entitled 'Environmental status of the Norwegian offshore sector based on the petroleum regional monitoring programme' was published in 2000 by Akvaplan-niva, Det Norske Veritas, and Unilab Analyse.

The current project is an update of the 2000 report, and addresses longer-term trends of impact, including an investigation of the consequences of changes in industry practices. The following analysis is based on regional-based sampling conducted between 1996 and 2006, with several fields examined in finer detail to the early 1990s. Results and recommendations presented here provide a knowledge base to help design future monitoring strategies.

Project manager	**Quality controller**
Paul E. Renaud	Lars-Henrik Larson

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1 Preface

The Offshore Regional Monitoring Programme for petroleum activities on the Norwegian continental shelf began in 1996 with the goal of assessing potential impacts and providing information to the industry and management authorities so procedures and policies could be evaluated. A report from this program titled ‘Environmental status of the Norwegian offshore sector based on the petroleum regional monitoring programme 1996-1998’ was published in 2000 by Akvaplan-niva, Det Norske Veritas, and Unilab Analyse. The regional monitoring approach replaced the single field approach which was applied in the early 1980s.

This project is an update of the 2000 report, and addresses longer-term trends of impact, including an investigation of the consequences of changes in industry practices. The following analyses are based on regional-based sampling conducted between 1996 and 2006, with several fields examined in finer detail to the early 1990s.

The analyses documented here represent a collaborative work by Akvaplan-niva, Det Norske Veritas, Unilab Analyse, and Unifob, and was funded by the Oil Industry Association (OLF). The data represent the collected efforts of these and other organizations that have been contracted over the past 11 years for sampling, analysis, and data management. The Norwegian Pollution Control Authority and its expert group have advised this program since its inception. Expert-group coordinator Torgeir Bakke, along with Einar Lystad (OLF), Ingunn Nilssen (StatoilHydro), Nina Jørgensen (APN), Helge Botnen (Unifob), Lars-Henrik Larsen (APN), Kristin Nåvik (DNV), Knut Forberg (APN), and Karl Henrik Bryne (Norwegian Clean Seas Association for Operating Companies) have improved the report through their comments during planning of the project and on early drafts of the report. Thomas Moskeland and Sam Nøland (both of DNV) provided assistance with the database and analyses. We are grateful to all for their contributions.

The authors would also like to acknowledge the contributions of the late Prof. John S. Gray, who worked tirelessly to further the development of environmentally sound industry practices and monitoring strategies as a scientist and member of the expert group. His efforts continue to impact environmental management policies in Norway and beyond.

Tromsø, 17 March 2008

Paul Renaud

2 Executive Summary

The Norwegian continental shelf is a dynamic and productive system reaching depths over 300 m, with associated petroleum fields at depths of over 1000 m, and encompasses a variety of sediment types and faunal communities. Petroleum activities have increased over the past 40 years, and with it the concern for evaluation of its impacts to seafloor communities. Since 1996, environmental monitoring of the seafloor areas around petroleum installations on the Norwegian continental shelf has been conducted using a regional-based approach. Instead of annual monitoring of each field, fields and reference stations within larger regions are sampled every 3 years using standardized methodologies. A report published in 2000 summarized the results from the first sampling cycle in 5 of the regions, and this report expands on those findings, and incorporates data from the following 2-3 monitoring cycles in each of those regions.

Contamination and impacts near installations are unavoidable and continue to be measured. In some cases these can be severe, with metal and hydrocarbon concentrations reaching very high levels, and faunal communities being heavily disturbed. Levels of many contaminants and areas of impact, however, have decreased sharply in the past 10 years in some regions. Evidence from regional surveys, and especially from case studies at three fields, suggests this is most likely due to changes in industry practices. Evidence for recovery, as measured by surface-sediment concentrations of metals and organic contaminants, has been observed in as little as 3-6 years following the transition from oil-based drilling fluids to water-based fluids.

In some regions, however, no change in impact or contamination, or even some increase, was observed for some indicators (Sediment Total Hydrocarbon Content (THC), barium (Ba), fauna). Some of these effects may be due to changes in field activity (drilling, pipeline construction, etc.), but there was little evidence for recent discharges influencing contamination area on a region-wide scale. Higher levels of fine sediments in field versus reference sites suggest that petroleum activities, for example the release of drilling muds and resuspension during anchoring or pipeline construction may be responsible. Although evidence of recovery is seen in surface sediments, the presence of elevated concentrations of THC in subsurface sediments suggests the potential for these 'legacy' hydrocarbons to diffuse slowly into surface layers and overlying water, or to be remobilized by physical (storms) or biological (fauna) processes.

Strong interannual differences in faunal community structure continue to be observed, and are likely due to changes in industry practices, but also to natural variability in recruitment, mortality, etc. In fact, natural gradients (depth, sediment grain size, total organic matter) within a region appear to be more important in determining community structure in most regions than are effects of petroleum installations.

The initial report on regional monitoring published in 2000 noted that only a small portion of the Norwegian shelf has been influenced by petroleum exploration and extraction. The percentage of the shelf that shows evidence of metal or chemical contamination, or ecological impact, remains low, and has decreased in most regions since the first cycle of regional monitoring. Presently, well below 0.10 % of the total area is contaminated or impacted in regions where petroleum activities are taking place.

The results presented in this report suggest that the regional monitoring approach is appropriate and useful. Habitat heterogeneity within some regions requires careful selection of suitable reference sites. Additionally adequate replication of both reference and field stations during each monitoring period is necessary to assure that statistical techniques can be employed to identify impact or recovery. There is currently sufficient data to make these decisions regarding reference-site placement. The policy of changing sampling schemes from one monitoring cycle to the next may be cost efficient, but it also may hinder analyses where identification of change between or among years is of interest.

New techniques that combine ecological knowledge and multi-species data sets have been used to evaluate impacts of the petroleum industry in other areas of the world ocean, and offer a powerful, sensitive, and complementary approach to current practices. The use of a polychaete/amphipod ratio, or perhaps the development of other metrics, needs to be further explored for Norwegian shelf sites.

Finally, the future of the petroleum industry in Norway promises new opportunities and new challenges. Expansion into regions such as the deep-sea and the Arctic will necessitate new technologies and responses to new regulatory policies. Environmental monitoring policy and practice will need to keep pace with these developments to assure responsible environmental stewardship accompanies new economic opportunities.

3 Acronyms

Below is a list of acronyms or other abbreviations used in this report and the terms to which they refer.

APN	Akvaplan-niva
Ba	Barium
DNV	Det norske Veritas
LSC	Level of significant contamination
MDS	Multidimensional Scaling
MOD	Miljøovervåkningsdatabase (Environmental Monitoring Database)
MPC	Maximum permissible concentration
NAC	North Atlantic Current
NCC	Norwegian Coastal Current
OBM	Oil-Based Muds
OLF	Oljeindustriens Landsforening (Norwegian Oil Industry Association)
PNEC	Probable No-Effect Concentration
SBM	Synthetic-Based Muds
SFT	Statens forurensningstilsyn (Norwegian Pollution Control Authority)
THC	Total hydrocarbons
TOM	Total Organic Matter
WBM	Water-Based Muds

4 Introduction

The Norwegian continental shelf holds some of the largest known petroleum reserves in Europe. Since the discovery of oil here in 1969, Norway has become the 5th largest exporter of oil and the 3rd largest producer of natural gas (Norwegian Ministry of Petroleum and Energy 2007). Oil and natural gas account for approximately 25% of Norway's GDP, over 50% of its exports, and nearly three-quarters of its trade revenues.

The increasing importance of natural gas production, which has seen its share rise from 15% of production in 1996 to nearly 35% in 2006 and to an expected 50% by 2013, has presented additional regulatory and technological challenges (Figure 1).

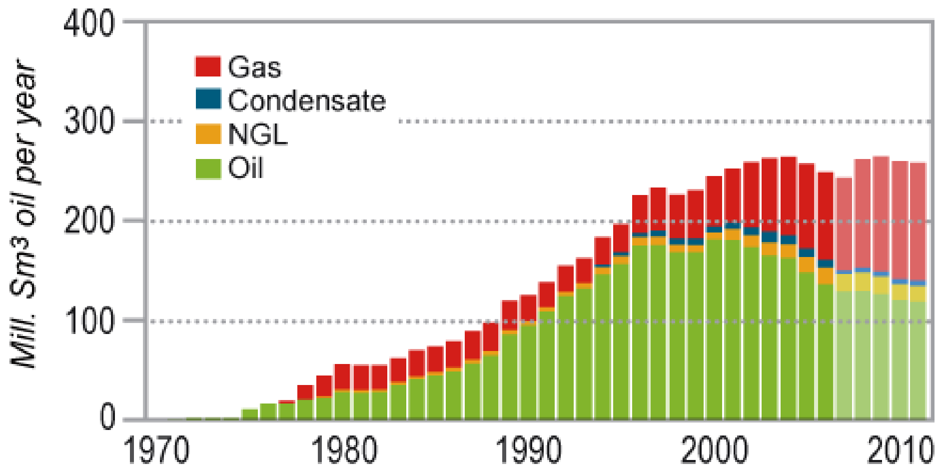

Figure 1 Historical and projected petroleum production from Norwegian waters. Data are from 2006.

NGL= Liquefied natural gas. Source: Norwegian Petroleum Directorate; www.npd.no

Norwegian waters span temperate, boreal, and Arctic bio-provinces and result in a rich diversity of marine animals, plants, and microbes. Finally, these organisms are also being explored for their unidentified wealth: value as new food resources, safer pesticides and antifouling compounds, and natural products for the biomedical industry. Clearly then, Norway has a special interest as well as a special responsibility to manage and preserve the marine environment as it exploits its petroleum resources. A combination of technology, regulation, and environmental monitoring highlight these efforts.

One of the challenges in evaluating potential impacts of petroleum activities is that there may be both short-term and long-term effects on the environment (Peterson et al. 2003). This makes continued commitment a necessity. New forms of technology may have unforeseen impacts, and risk-assessment models developed for one region may not be applicable to another region where fauna or environmental conditions are different. The Norwegian government and the oil industry have devoted considerable effort and financial resources to support an ambitious environmental monitoring program evaluating impacts of oil and gas development on the marine environment. The current system has been in place since 1996.

The report "Environmental Status of the Norwegian Continental Shelf" (Carroll et al. 2000) summarized the results of historical sediment monitoring, and the first round of regional monitoring of petroleum activities in the Norwegian part of the North Sea, adopted in 1996-98. This report, "Offshore sediment monitoring on the Norwegian shelf, a regional approach 1996-2006," will allow for analysis of longer term trends in impacts of exploration and production activities, including fields where OBM and SBM has been used versus fields drilled with WBM, as well as recovery from earlier practices in the North Sea – all based on the regional concept. The previous report showed a reduction in concentration of oil contaminants in the sediment surface layer, and thus in the total area of the sea floor impacted. In this study we will also evaluate if the hydrocarbon pollution is still in the sediments, but at deeper layers. Furthermore, we produce an overview of the findings of these annual reports that addresses both short- and long- term effects with this perspective of more than a decade of data and interpretation. We aim to link levels and types of industry activity with environmental parameters and impacts on sediment chemistry and faunal communities. Finally, we will address methodological and analytical issues that have arisen over the first 10 years of regional-based monitoring.

4.1 Historical perspectives and environmental setting

4.1.1 Developing a monitoring strategy

Oil and gas development on the Norwegian continental shelf is less than 40 years old. Government ministries have managed the development of Norway's reserves through lease management, regulatory activities, and requirements for environmental monitoring. Since the early 1970s, oil companies have been required to submit reports outlining the environmental status of their production areas. Gradually, the relationship among the oil industry, regulators, and the scientific community has become more cooperative (for a more complete history see Gray et al. 1999). A scientific 'expert group' has been instrumental in developing scientifically sound monitoring guidelines.

The primary goal of the Offshore Regional Monitoring Programme is to identify effects/impacts of petroleum activities on the marine environment surrounding the installations as well as gradual changes on a regional scale that could be associated with discharges from the installations. "The monitoring shall be adapted to the existing pollution risk, and shall be able to discover and map pollution of the external environment. The monitoring shall furthermore identify development trends and provide basis for prognoses of anticipated development." (from Section 49 of the 2002 Regulations Relating To Conduct Of Activities In The Petroleum Activities: http://www.npd.no/regelverk/R2002/Aktivitetsforskriften_e.htm)

Initial strategies relied on chemical and biological studies around each field. In 1996, this system was changed to the current Regional Monitoring Programme whereby the Norwegian shelf, including Svalbard and the Barents Sea, is divided into 11 regions (Figure 2, Appendix 7) and the physical features, chemistry and biology of seafloor sediments in each region under development or production are monitored every 3 years. Regional stations reflecting background levels and conditions are included in the monitoring.

Seven of the 11 regions along the Norwegian continental shelf currently have oil or gas fields in production. The petroleum companies (the operators) having fields in the respective regions jointly fund the monitoring, which is performed by independent nationally-accredited consulting companies, applying standardized methods. This makes data comparable from region to region and from survey to survey, and long-term studies thus be used to detect environmental changes due to both industry operations and external factors (e.g. fishing activity, climate variability). Baseline surveys and monitoring after decommissioning are also required, but those surveys are not discussed here with the exception of baseline surveys for Region IX.

Figure 2 The Norwegian Offshore with regional boundaries delineated. Active regions (development, production, or decommissioned fields) covered in this report are: Region I- Ekofisk, Region II- Sleipner, Region III- Oseberg, Region IV- Tampen, Region VI- Haltenbanken, and Region IX- Southern Barents Sea. Region V- Møre is under development but not discussed here. Source: www.sft.no

4.2 Norwegian continental shelf habitats

The Norwegian continental shelf spans the depth range from the tidal line to depths of 300 m or more. In some areas of the coast, the shelf is a broad, relatively flat platform, but other zones are characterized by steep trenches or deep holes. Water depth generally affects the strength of bottom currents (shallower waters 'feel' the strength of the ocean waves to a greater extent than deeper areas), sediment grain size (shallower sites are often dominated by coarser sands rather than silt or clay), and even parameters like temperature (shallower waters may experience more variability over the year). These factors may independently affect seafloor communities, or may interact with effects of petroleum activities to determine habitat characteristics.

The Norwegian shelf is primarily under the influence of two northward flowing ocean currents: The North Atlantic Current (NAC), with origins in the western tropical Atlantic, and the Norwegian Coastal Current (NCC), which originates as transformed water from the North Sea and mixes with nearshore waters as it continues northward along the Norwegian coast (Figure 3). The current has a transport of 1 Sv (1 Sverdrup = 1 million $m^3 s^{-1}$) out of the North Sea (Ottersen & Auran 2007).These currents are important as they carry with them the chemical and biological signatures from other seas and coasts, such as larvae and contaminants. Larvae of benthic (seafloor) species characteristic of the North Sea and southern Norwegian coast are available to colonize areas further north. Finally, chemical constituents of seawater, including human-derived pollutants, are also brought into the Norwegian shelf region from the North Sea and North Atlantic. All of these factors can affect the benthic ecosystem being monitored and must be considered when interpreting data from the Regional Monitoring Programme.

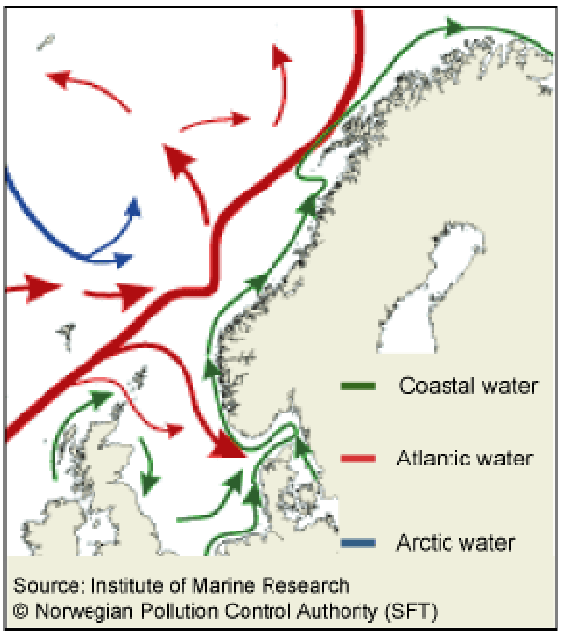

Figure 3 Major surface currents in the North Sea and southeastern Norwegian Sea. Colors of the arrows indicate the prevailing water mass type: Arctic, Atlantic, or coastal waters. Source: SFT: www.sft.no.

5 Assessing impacts of petroleum activities

5.1 Scope of report

This report will update the findings of the 2000 report, "Environmental Status of the Norwegian Continental Shelf", and summarize trends over the first 3-4 monitoring cycles at each region studied in 1996-2006. Although regional monitoring in Region IX began only in 2007 (results not included here), some baseline data are provided for comparative purposes.

We will focus on estimating the area of sea floor with hydrocarbon and heavy metal concentrations above level of significant contamination (LSC) levels calculated from reference stations. Biological impacts of petroleum activities will be determined through community analysis of the infauna at the same stations evaluated for total organic matter and metal impacts. The area of impact to the biological community, then, represents an aggregate effect of discharge, disturbance, and biological tolerances of the organisms present. Impact on benthic communities can result in shifts in abundance, biomass, and taxonomic composition.

Produced water, released in high volumes and containing low concentrations of oil, chemicals, and other organic compounds, is another potential risk factor. As it is not directly assessed by benthic monitoring, it will not be considered in this report.

After summarizing regional results, we will look more closely at three fields: Ekofisk, Statfjord A and Snorre TLP. These fields have been chosen as they differ in age, development and production history, and abiotic environmental factors such as depth (Table 1). Over time, standard practices have changed from use of slowly-degrading oil- and synthetic- based drilling muds (OBM, SBM) to use of water-based muds (WBM) today. In order to obtain insights about specific practices, the case studies also include data from the early 1990s (i.e. a period before discontinuation of OBM use).

Based on these findings, we will identify any weaknesses in the current monitoring programme and make recommendations for futures monitoring, both in terms of sampling strategy and analysis.

Table 1 The case studies, Ekofisk, Statfjord A and Snorre TLP.

	Ekofisk	Statfjord A	Snorre TLP
Location (Lat.; long.)	56º 33'N; 03º 27'E	61º 15'N; 01º51'E	61º 27' N; 02º 09'E
Start of production	1972	1979	1992
Water Depth	70-75 m	150 m	300-350 m

5.2 Data sources and sampling methodology

Field discharge data for this report were compiled from several sources, including OLF's Environmental Web database (2003-2006), SFT's annual reports on discharge to the

Norwegian Offshore, and regional monitoring reports submitted to SFT. All operational and accidental discharges (metals, oils, chemicals, cuttings) are reported annually by the operating companies. Data from the individual regions and years are presented in Appendix 3 . Since both disturbance and discharges are expected as a consequence of normal field activity, we also present data on the number of wells drilled during each year as a metric of activity level (Appendix 2).

Field sampling and laboratory analyses are standardized according to SFT regulations to assure comparable data among regions and years. Reports on each regional monitoring should be consulted for methodological details. Only a very brief description will be given here.

The monitoring summarized in this report was conducted within each active region every three years. Fieldwork was carried out between mid-May and 01 July.. Samples were collected using replicate 0.1 m^2 Van Veen grabs (Figure 4) from predetermined sites at different distances (250 – 4000 m) from field installations; and undisturbed regional stations (including in some cases reference stations 5000 m or more from the installation) are sampled as well. Biological parameters (diversity indices and species lists) are presented per station and included in the monitoring reports provided to SFT.

Samples for sediment chemistry (metals, THC, PAHs) and geological parameters (granulometry, total organic matter) were also sampled with the Van Veen grab and analysed by standard methods in accredited laboratories.

The monitoring reports are evaluated by the SFT-appointed Expert Group of scientists for compliance with established guidelines and to assure that interpretations are scientifically sound.

5.3 Data analysis

Monitoring data from 1990 to 2006 are contained within the Norwegian Oil Industry Association (OLF) MOD (environmental monitoring) database. Analyses of faunal, chemical, and sediment data for this report were taken directly from this database. Faunal data used do not include juvenile animals since they may dominate the fauna abundance, and as newly settled juveniles may be just a transitory part of the community.

Reference samples are used to determine background levels and faunal composition for comparison with areas of potential impact. Field-based impact/contamination areas have been summed by region for the purposes of this report.

Faunal community structure was analysed using multivariate statistical techniques that consider both the number of individuals per station and the distribution of those individuals across the various taxa found. The PRIMER software package (Clarke and Gorley 2006) was used to determine station similarity, and to perform multidimensional scaling (MDS) analysis. In addition, station groupings were compared using the ANOSIM routine.

Figure 4 Sampling on the Norwegian shelf showing the Van Veen grab being rinsed. Photo: Hans-Petter Mannvik

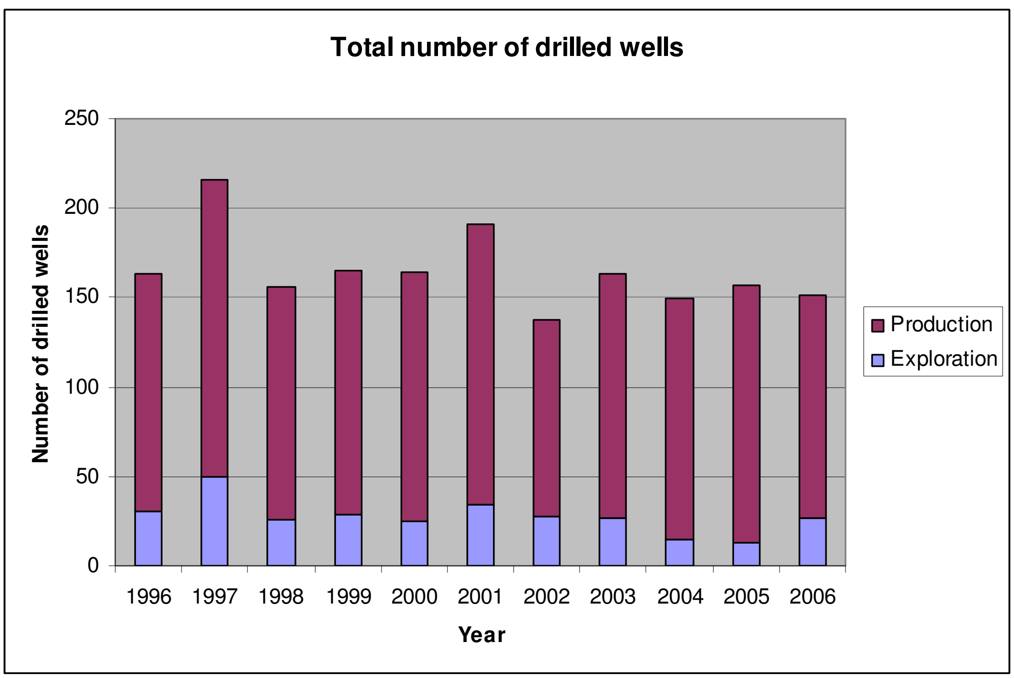

Figure 5 Total number of exploratory and production wells drilled on the Norwegian offshore from 1996-2006. All regions are combined. See Appendix 2 for sources of data and distribution among regions.

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Table 2 Ranges of values for environmental and chemical data collected during the Offshore Regional Monitoring Programme for reference and field stations. Treshold concentrations (MPC) in field station table indicate the concentrations which call for extended risk assessment according to SFT (2005). See text for more information on these values. A more detailed presentation of these data for each sampling year is provided in Appendix 1.

REFERENCE STATIONS	Region I	Region II	Region III Deep	Region III Shallow	Region IV Deep	Region IV Shallow	Region VI	Region IX
Number of stations in latest survey	14	22	4	7	5	8	16	0*
Depth (m)	65 -120	71 -127	274 - 354	93 - 183	275 - 377	131 - 270	212 - 434	160 - 365
Pelite (%)	0.3 - 5.8	0.8 - 21.8	95.2 - 99.1	1.2 - 5.7	18.1 - 64.1	1.2 - 10.1	24.8 - 98.9	60.5 - 73.4
TOM (%)	0.5 - 1.5	0.5 - 2.6	2.2 - 12.4	0.4 - 1.4	1.9 - 6.5	0.9 - 3.6	2.1 - 10.4	8.2 - 8.7
Barium (ppm)	4 - 102	4 - 215	229 - 462	9 - 217	107 - 479	19 - 452	47 - 228	98 - 125
Cadmium (ppm)	0.003 - 0.160	0.004 - 0.050	0.027 - 0.130	0.003 - 0.040	0.048 - 0.100	0.016 - 0.138	0.015 - 0.117	0.107 - 0.178
Copper (ppm)	0.3 - 1.3	0.3 - 2.1	1.8 - 19.3	0.3 - 1.9	1.6 - 6.6	0.4 - 3.0	3.1 - 14.7	11.8 - 16.1
Mercury (ppm)	0.005 - 0.048	0.003 - 0.014	0.005 - 0.049	0.003 - 0.027	0.005 - 0.128	0.003 - 0.036	0.010 - 0.062	0.020 - 0.081
Lead (ppm)	3.7 - 9.9	2.1 - 6.9	4.6 - 46.5	1.9 - 5.9	4.4 - 15.6	2.7 - 9.1	9.2 - 28.1	22.8 - 25.2
Zinc (ppm)	2.6 - 8.9	0.9 - 12.0	9.6 - 83.7	1.8 - 6.7	11.4 - 34.3	1.0 - 12.9	22.5 - 71.6	46.3 - 60
THC (ppm)	1.3 - 6.8	1.5 - 15.4	1.2 - 29.9	0.7 - 10.4	1.5 - 5.1	0.5 - 8.0	1.1 - 7.1	1.4 - 4.4

* Regional monitoring in Region IX began in 2007, with only baseline and single-field monitoring before that date. Some of these data are included in this report.

FIELD STATIONS	Region I	Region II	Region III Deep	Region III Shallow	Region IV Deep	Region IV Shallow	Region VI	Region IX	MPC
Number of stations in latest survey	154	172	39	124	45	106	205	35	
Depth (m)	63-124	80-131	303 - 375	96 - 176	278 - 382	122 - 223	232 - 403	160-365	
Pelite (%)	0.2 - 99.5	0.4 - 25.2	82.4 - 99.5	0.3 - 51.4	11.0 - 87.6	1.3 - 39.7	20.3 - 98.9	5.9 - 96.9	
TOM (%)	0.4 - 6.6	0.4 - 4.5	5.9 - 13.7	0.4 - 5.0	1.7 - 6.8	0.6 - 6.3	1.7 - 12.9	1.3 - 11.3	
Barium (ppm)	3 - 7412	8 - 3942	317 - 6948	11 - 7190	3 - 10750	23 - 8959	83 - 8476	19 - 945	
Cadmium (ppm)	0.003 – 0.527	.003 - 0.095	0.046 - 0.293	0.003 - 0.399	0.025 - 0.243	0.006 - 0.458	0.015 - 0.123	0.025 - 0.339	**29**
Copper (ppm)	0.2 - 78.3	0.3 - 18.5	10.4 - 22.8	0.3 - 71.3	1.6 - 50.9	0.3 - 297	3.0 - 154	1.9 - 19.1	**72**
Mercury (ppm)	0.005 - 0.25	0.002 - 0.033	0.02 – 0.062	0.002 - 0.092	0.005 - 0.247	0.003 - 0.163	0.007 - 0.297	0.003 - 0.062	**1**
Lead (ppm)	3.1 - 98.9	2.0 - 43.7	20.7 - 48.2	2 - 105	3.1 - 73.9	1.1 - 172	7.0 - 66.1	3.2 - 45.3	**4723**
Zinc (ppm)	2 - 204	0.5 - 230	37 - 193	2 - 185	2 - 207	0.5 - 726	23 - 149	10 - 70	**685**
THC (ppm)	0.5 - 6489	0.5 - 418	0.5 - 707	0.5 - 18936	0.4 - 2501	0.5 - 1149	1.2 - 5897	0.7 - 9.0	

6 Regional trends from field and reference stations

Graphics presented here will be used to highlight the general results. In the interest of space and clarity, we have selected specific graphs or tables that are representative of the results from the large number of analyses that we have performed. Therefore, most graphs and tables are included in appendices for those interested in further details.

6.1 Chemical and sediment values

6.1.1 Discharges from drilling, special focus on barium

Drilling fluids are used to stabilize the formation with respect to pressure and reactivity, transport drill cuttings and lubricate/cool the operation. Weight material is used to apply counter-pressure. Common weight materials include barite, ilmenite, hematite and brines. Barium (Ba) is a metal that is found in high concentrations in barite. Ba does not degrade, and is useful as a tracer of dispersion and transport of discharges related to drilling activities, such as drilling muds and drill cuttings. Heavy metals contained in drill cuttings (mainly from impurities in the barite) are likely to be distributed in a similar manner as Ba, and drill cuttings have been shown to impact faunal communities (e.g. Olsen et al. 2007). Since Ba does not degrade, contaminated area reflects several factors, including historical levels of drilling activity, fluctuations in background levels, and redistribution by ocean currents. For this reason, large parts of the Norwegian continental shelf show elevated Ba levels. It is important to note that the use of the term 'contaminated' in the sense discussed here for Ba (and later for THC) is not equivalent to significant ecological consequences, but only indicates that values are elevated compared to LSC (background concentrations as evaluated from reference stations).

The area contaminated by Ba shows no clear trend that is consistent across the different regions. It varies widely among region and year, from nearly 140 km^2 in Region I during 1996 sampling to under 5 km^2 in Region II (2006) (Figure 6). Regions I, II, and III show a decline in contaminated area defined by Ba concentrations between 1996 and 2006, while there is no trend in either Region IV or VI (Figure 6).

Ba-contaminated area also may be expected to reflect recent trends in drilling activity and discharge, but our data do not support this. Discharge varies by more than a factor of 10 both within a region and among regions, while contaminated area does not vary nearly as much. Further, the highest discharges of Ba during the time period of this study are in Regions IV and VI, but the highest contaminated area is in Region I (Figure 6, Figure 7). Finally, the number of wells drilled fluctuates throughout the study period (Figure 5, Appendix 2), with little correlation to calculated contaminated area (Figure 7). Drilling, however, may not result in discharges if material is brought to shore or reinjected into the well. These results seem to suggest the importance of historical effects in some regions (Region I has the longest history in Norway), and also suggest that long-range transport of Ba (within and across regional and, potentially, national boundaries) by ocean currents may redistribute Ba and associated heavy metals, leading to this lack of correlation with discharge and drilling effort.

Due to different history of field activity, the characteristic ranges in barium within the regions are different, but only in Region IV (deeper fields) does there seem to be a trend (increase) in Ba. Reference stations have consistently low concentrations, generally well below 400 ppm. As expected, the region with the shortest history of field activity and tightest discharge regulations (Region IX) has little Ba in the sediments, and values are not above background (Figure 8, Table 2).

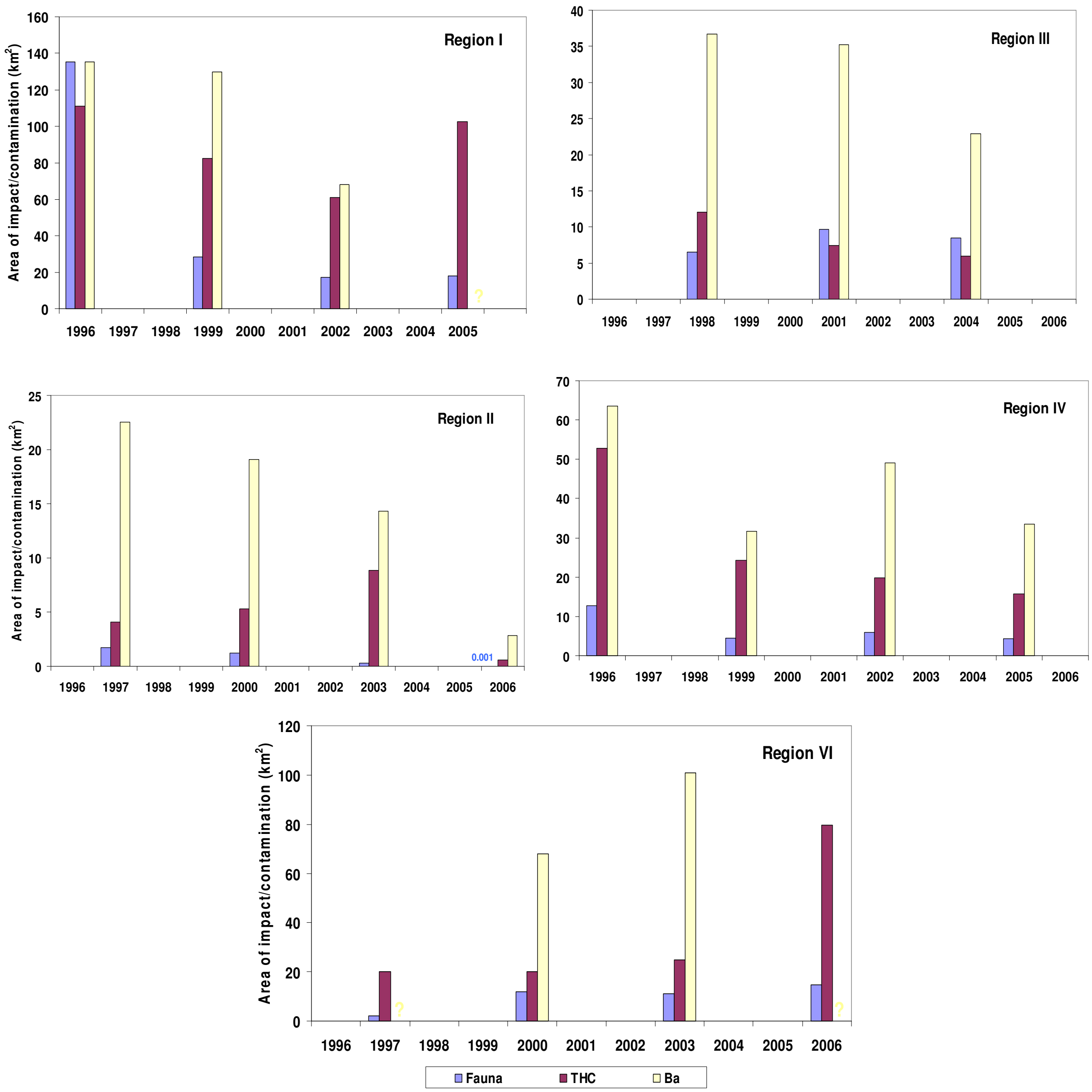


Figure 6 Area of impact (km^2) estimated for fauna and area of contamination (km^2) estimated for barium and THC, for the different sampling years for Regions I, II, III, IV, and VI. Note the difference in scale of the axes.

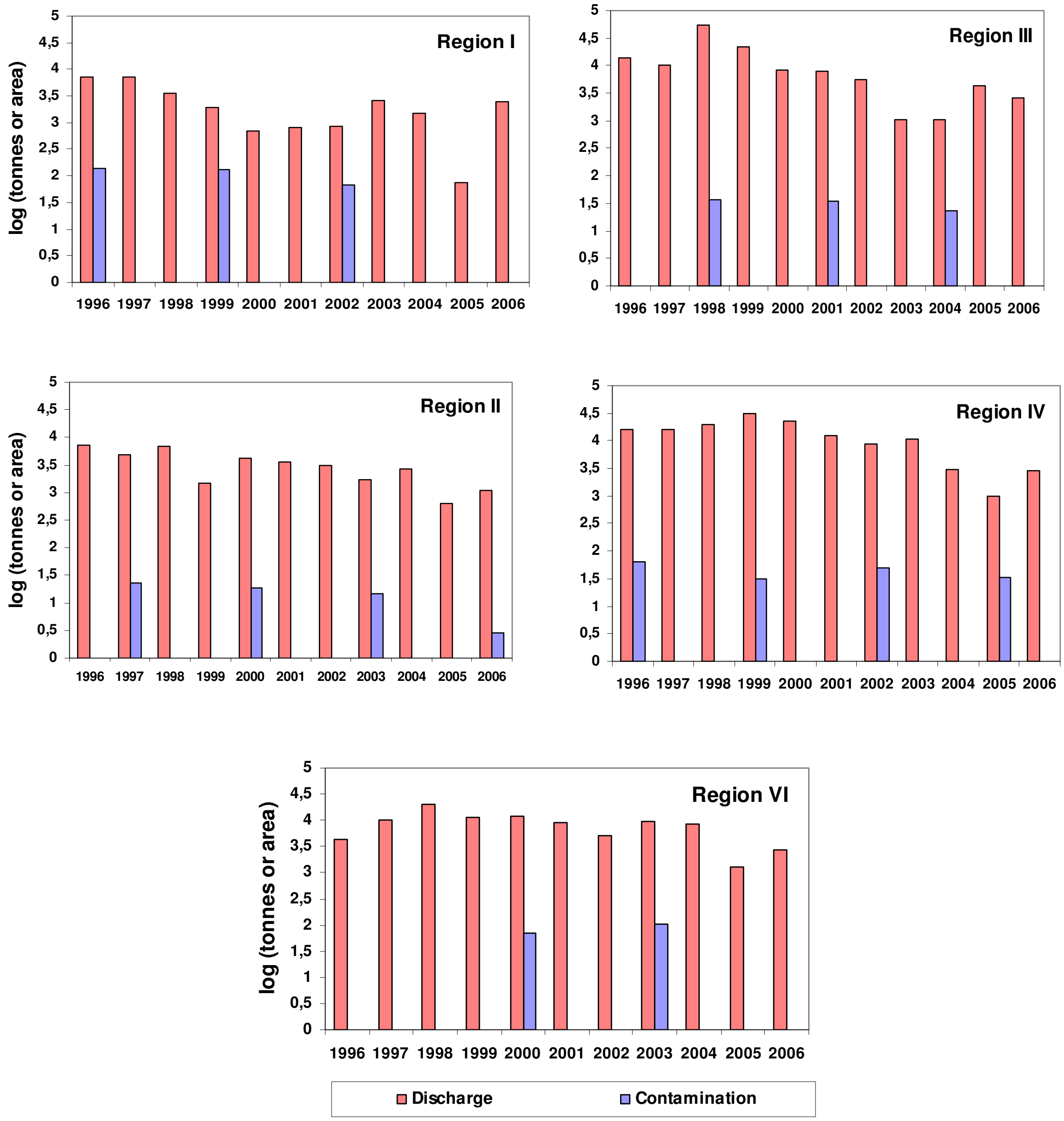


Figure 7 Annual barium discharge and Ba contamination area for all Regions and years. Note the log scale of the y-axis referring to the log of either discharge (in tonnes) or contamination (in km^2).For example, in Region VI, many of the annual discharges are around 10,000 tonnes, while area contaminated by barium is around 100 km^2.

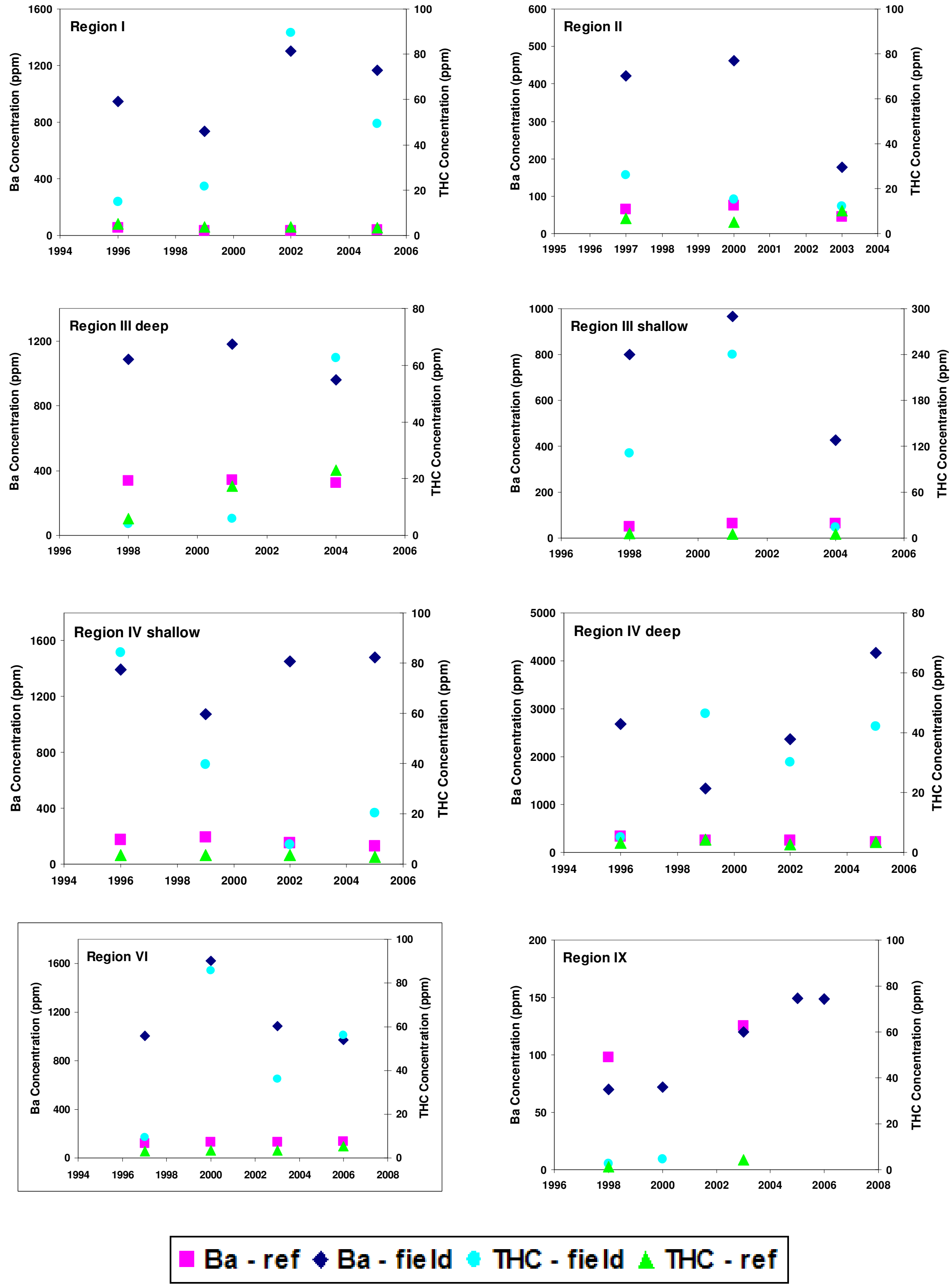


Figure 8 Annual mean values for barium concentrations (left-axis scale) and THC concentration (right axis scale) for reference and field stations in all regions. Regions III and IV are separated into their deeper and shallower areas. Note difference in the axis scales.

6.1.2 Heavy metals

Within the field sites, heavy metals with known detrimental biological effects (e.g. copper, zinc, cadmium) exhibit maximum values up to 100 times the background (regional reference station) levels (Table 2). Norway lacks any specific legal guidelines for metal concentrations in offshore sediments. We, therefore, present threshold concentrations (MPC) developed for Norwegian inshore regions (Table 2) to indicate when an expanded risk assessment has to be implemented and remediation considered. Maximum values for zinc and copper measured during the offshore regional monitoring programme are above these MPC levels (Table 2). There is generally, however, a wide range in field values, likely representing the broad differences in sampling distances (250 – 4000 m) from the installations within the fields, and variability among fields within a region. Minor to moderate contamination (above reference-station levels) by several heavy metals is observed at field sites within most regions.

6.1.3 Sediment grain size and total organic matter (TOM)

Sediment grain size generally reflects depth and prevailing current velocity, and has significant impact on faunal community composition as current velocity will not only affect the particle size of the sediment, but also the level of sediment disturbance and resuspension. Not surprisingly, areas with finer sediment have higher organic content. This is expected because organic matter is generally transported and deposited in a manner similar to that of the finest sediment particles. Reference and field stations are quite similar in both % pelite (fine sediment: silt+clay fraction) and total organic matter (TOM) for a given region (and depth zone for Regions III and IV) (Figure 9).

Maximum TOM values for field stations are always higher than those for reference sites (Table 2), however, suggesting local enrichment at some fields. Separation of Regions III and IV into depth-defined zones is necessary as these regions are heterogeneous in terms of depth, which affects grain size and organics. Relatively high variability for a region (standard error bars fairly large relative to mean) suggests high variability among fields within a region, effects of varying distance from discharge point (installations), or both.

There is very little evidence of any trend in these two variables among years (Figure 9). The exception is perhaps pelite in Region IX, but this region is not sampled very intensively, and this may represent station-to-station differences instead of an overall regional trend.

6.2 Sediment hydrocarbons

Impacts of industry activities on total hydrocarbon (THC) concentration are presented in two manners. The first (contamination) is similar to that for Ba in that it represents the area with concentrations above background levels (which change somewhat from one sampling to the next). This is the technique that has been used in the standard monitoring reports. The second technique uses the Surfer software package to estimate the area of the shelf contaminated at a level of at least 50 ppm. In a Drill Cuttings Initiative prepared by the United Kingdom Offshore Operators Association in 2002, THC was determined to be “the key parameter regarding biological effects”. A value of 50 mg THC/kg in sediments was considered to be the (lower) limit for a biological effect (UKOOA 2002). In Surfer, station data were entered into the regional grid and values were interpolated using a kriging algorithm.

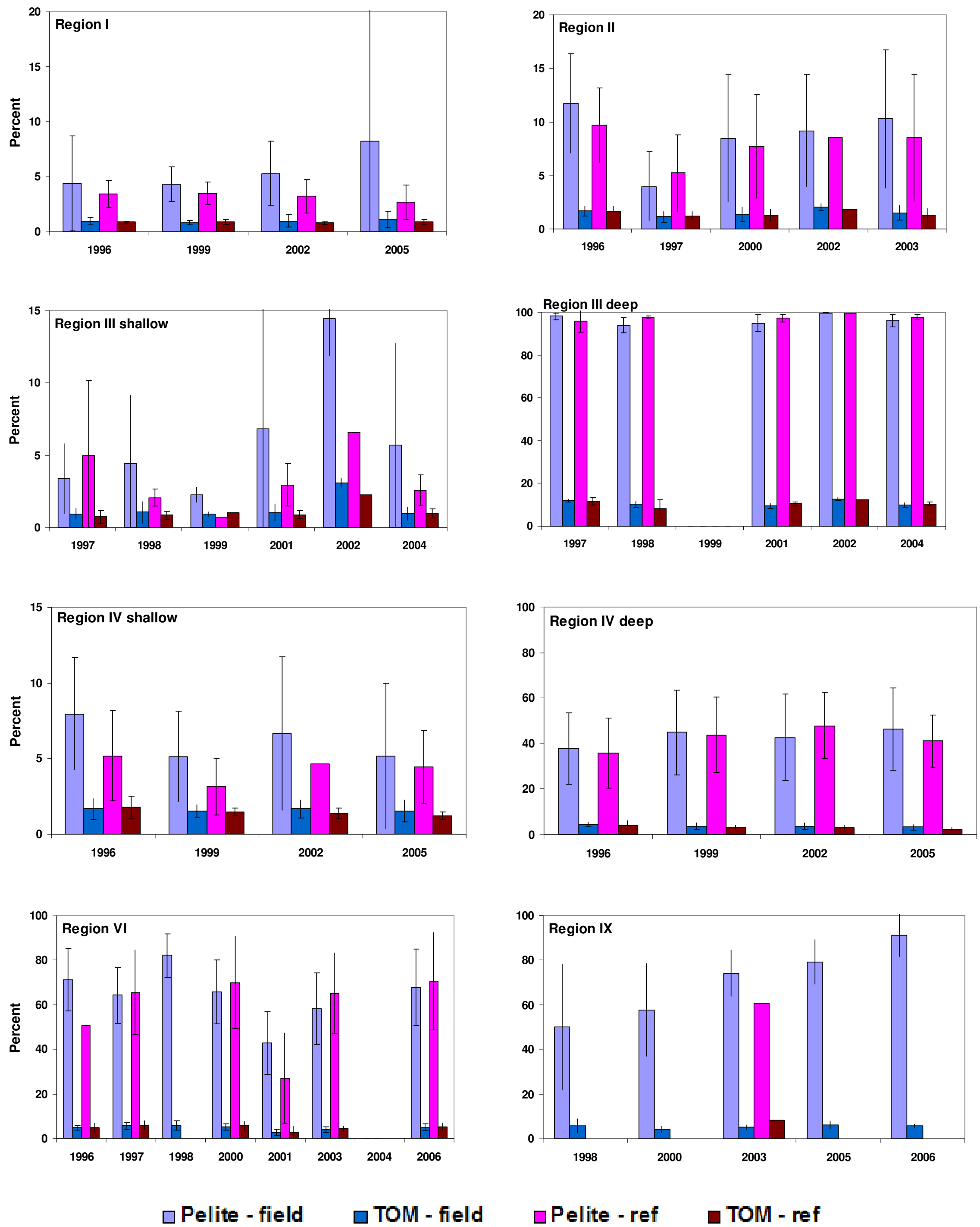


Figure 9 Mean sediment % pelite and total organic matter (TOM) for different sampling years for reference and field stations in all regions. Regions III and IV are separated into the deep and shallow areas. Region IX data are from baseline and field-specific surveys. Note the difference in scale of the axes. Error bars represent 1 standard deviation.

No clear trends were observed in the area of THC contamination determined as values above background (Figure 6). The contaminated area in Region IV decreased from 50 to 20 km^2 between 1996 and 2005, while it increased from 20 to approximately 85 km^2 over the same period in Region VI. Contaminated area ranged from over 110 km^2 in Region I during 1996 to a low of less than 1 km^2 in Region II in 2006. The observed year-to-year variability represents a combination of real changes in contamination, perhaps due to activity levels, and the effect of changing background levels. Background levels, however, have only changed appreciably in Region III (deeper area) where THC concentrations have gone from 6 ppm in 1998 (9 stations sampled) to 23 ppm in 2004 (4 stations sampled) (Appendix 1C).

The second technique for determining area of THC contamination (the SURFER-method) was also inconclusive for most regions, although the final sampling date had a lower area of impact than the earliest for Regions I, II, and III (Table 3). This technique allows for selection of a fixed value (in this case the PNEC level of 50 ppm), instead of assessing contamination against a variable baseline (LSC). The total area for the five regions presented in Table 3 is approximately 142,000 km^2, indicating that for each sampling year, impact-area estimates are less than 0.10% of the total area of the regions. Since it estimates contaminated area for the entire region, it is strongly affected by the sampling density, both around an installation and within the region as a whole. At some fields in Regions IV and VI, significant contamination at the threshold level was found at the outermost station, leading to artificially high contaminated-area estimates. Restricting analyses to those stations sampled in at least 3 of the 4 sampling periods led to different area estimates (both higher and lower area, depending on year and sampling period), but the overall pattern at each region was the same. These results suggest that, if the SURFER method is to be continued, better sampling is needed within these regions, both sampling further from the installation and resampling more stations on a regular basis.

Table 3. Area of impact (km^2) for THC for each region and sampling period. Impact was determined by kriging in the Surfer software package for a threshold concentration of 50 ppm, and included all stations sampled during the monitoring period.

Region	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
I	<8.3			<0.06			<7.2			<4.9	
II		<23.3			<41			>1			
III			<14			<49			<2.3		
IV	37			138			10			132	
VI		84.2			24.9			0			>100

A variety of patterns are observed in the mean annual THC concentrations from field stations at the different regions (Figure 8). Regions II and IX have consistently low concentrations, while the other regions (Regions III and IV with shallow and deep areas considered separately) vary irregularly between low and high (up to 240 ppm) values. THC in the shallow area of Region IV seems to have declined since 1996 (Figure 8). It is unclear how to interpret these results as the distribution of sampling with distance from the installation has changed over time. Another way of considering these data is to examine trends in THC concentrations in field stations through time at different distances from installations. These data show that, as expected, the highest values are found at the closest stations (0-250 m). In addition, values decrease both over time, and with distance from the installation (Figure 10). In all regions and for all distances, the median THC values for the latest sampling are similar to or below those when the regional monitoring began (Figure 10).

The most important sources for sediment THC in different regions may vary, and include both local discharges and discharges in other areas followed by transport and deposition. In addition, 'legacy' OBM contained in deeper sediment layers probably represents a significant source of THC to both surface sediments (through remobilization and diffusion), and to the water column, but volume of that contribution is unknown. THC has been measured at different depths within the sediment, and several patterns emerge. Consistently low THC values are found in reference stations at all depths (Figure 11 A), while within a region, field values vary considerably and are 3 - 20x higher than at reference stations (Figure 11 A-C). In many fields, there are trends toward higher THC values at sediment layers below 1 cm, especially after 1999. Finally, some stations showed extremely high values in surface sediments at the beginning of regional-based monitoring, but these values decreased dramatically within 3 years and patterns here more resemble those at other fields in later monitoring periods (Figure 11D). A clear decline in THC concentrations in the surface layer of sediment can also be observed over time at the field level (this is discussed in more detail in Section 5), and is probably due to discontinuation of OBM use in 1993. THC may be eroded or degraded over time at the sediment surface, but higher concentrations at depth indicate the possibility for remobilization of THC due to sediment disturbance due to storms, bioturbation, or petroleum-related activities. A low THC concentration in surface sediments, therefore, does not provide a complete picture of potential ecological impacts over a longer time period.

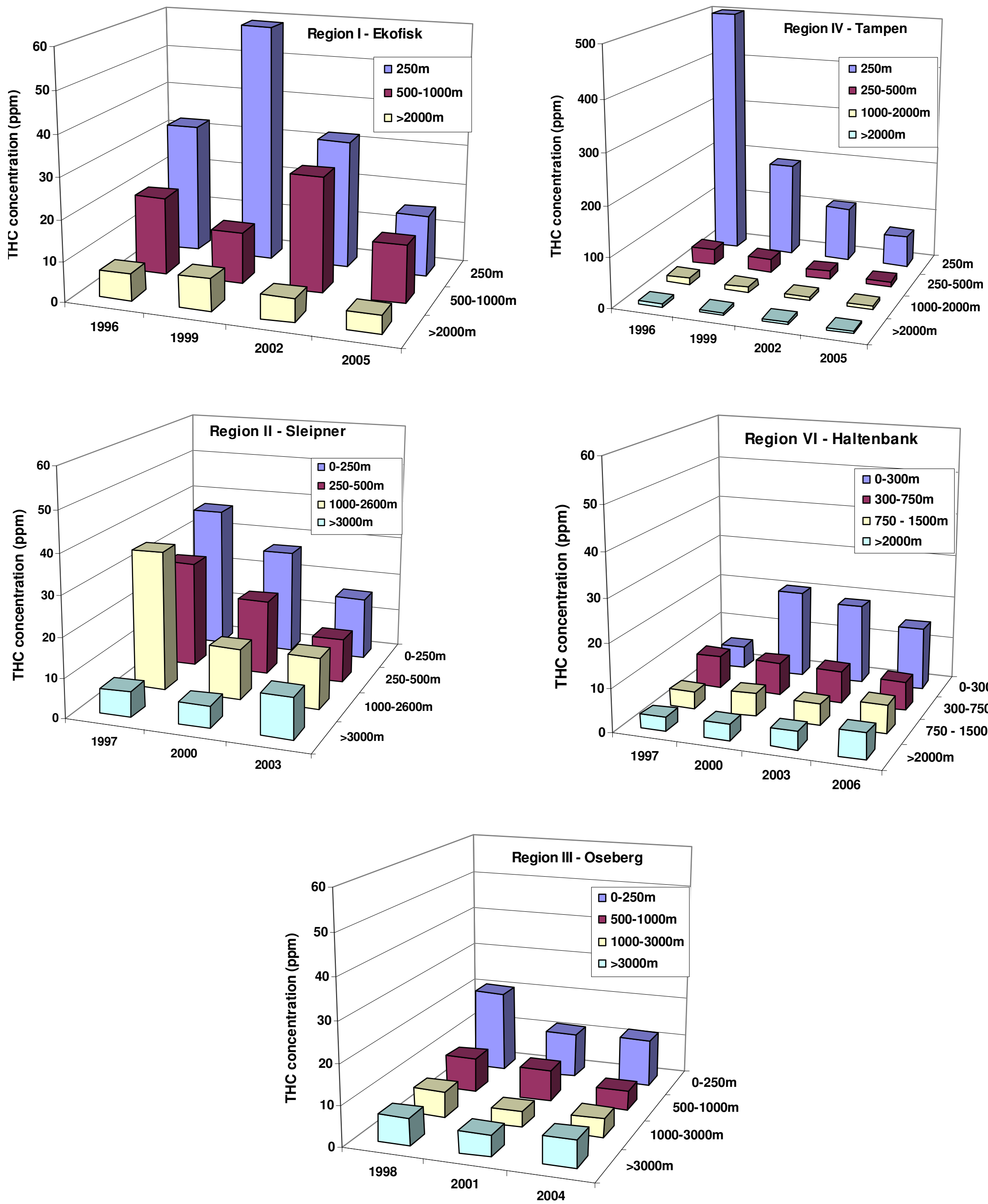


Figure 10 Graphs of median THC concentration (ppm) by distance from the nearest installation for each region and sampling period. Only stations that were sampled during all sampling periods are included. Note the different axis scale for Region IV.

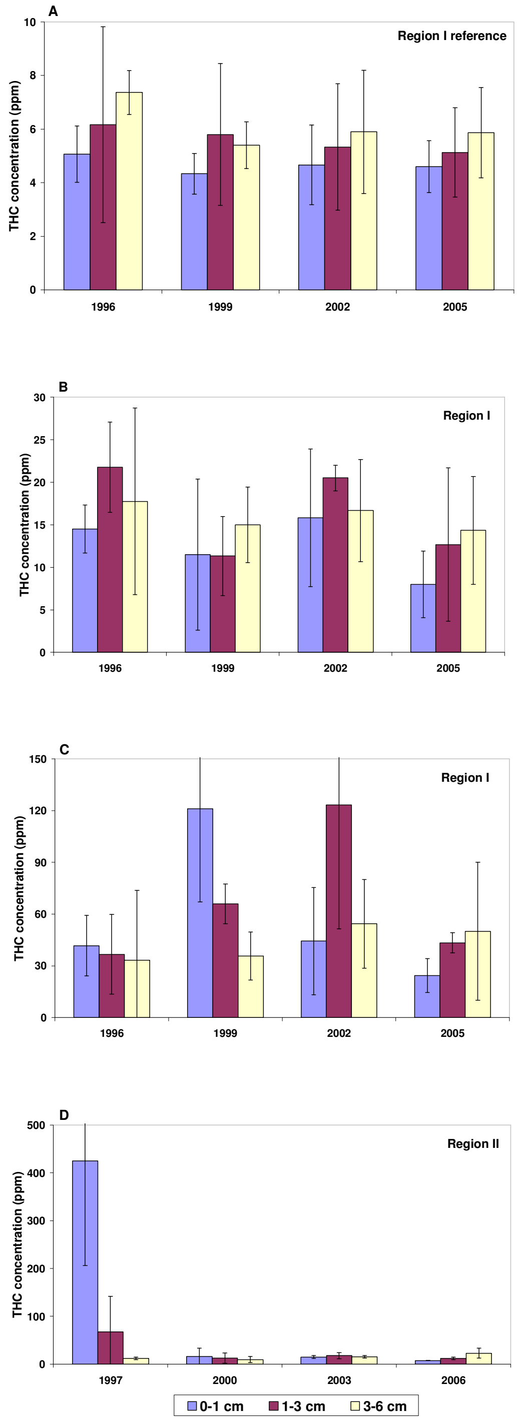


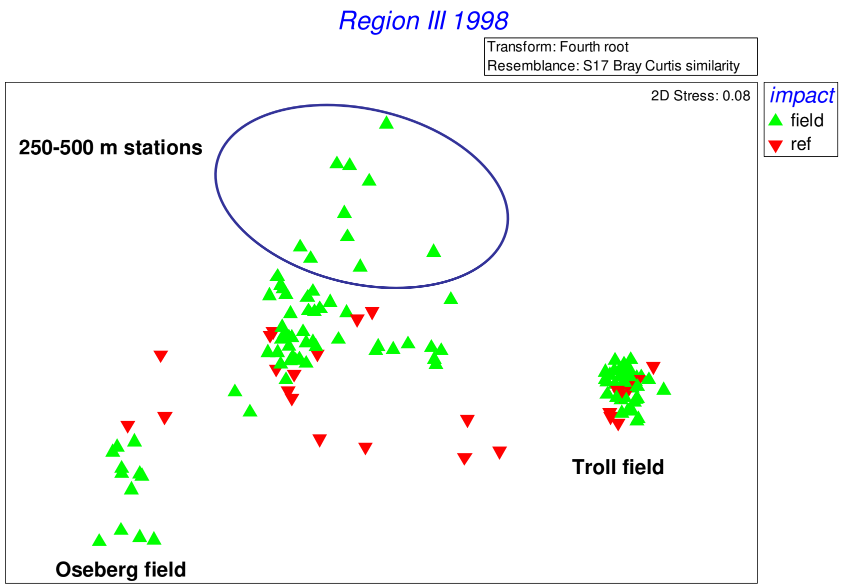
Figure 11 THC concentration (ppm) at 3 sediment depths sampled between 1996 and 2006. (A) means of 3 reference stations from Region I; (B) means of values from Region I stations with low concentrations: Eldfisk B (500 m from installation), Gyda (500 m), and Ula (500 m); (C) means of values from Region I stations with high concentrations: Ekofisk B (500 m), Yme Gamma (500 m), and Valhall (1000 m); (D) means of values from Region II Balder (250 m) and Varg (250 m). Note different axis scales. Error bars represent 1 standard deviation.

6.3 Faunal community data

Soft-sediment infaunal communities have been shown to respond to a wide variety of physical and chemical stressors (including dredging, high sedimentation, organic loading, and oxygen depletion) in similar ways. Faunal community disturbance, whether estimated in the monitoring reports by diversity statistics or species dominance, was therefore used to quantify the area of ecological impact surrounding the oil and gas installations. These impact area estimates are generally lower than the contaminated areas estimated for Ba or THC and suggest a sharp decrease in impact in Region I (from nearly 140 km^2 to under 20 km^2), and more moderate decreases in Regions II and IV (approximately a 50% decline in each region) (Figure 6). There is no trend in Region II and an increase in Region VI between the first monitoring in 1997 and all subsequent surveys. Summing from the latest samplings in each region resulted in a total impacted area of less than 50 km^2 over the entire Norwegian shelf (Figure 6).

MDS plots suggest communities are structured in part by grain-size related factors (organic content, depth), but there is some indication that disturbance makes up a large part of the secondary axis for most regions. In the figure from Region III below (Figure 12), the Troll field is deeper and characterized by silt/clay sediments, while Oseberg is shallower and has coarser sediments. Often, stations group by field regardless of distance from the installation (Figure 12, Appendix 4). This suggests that field-specific conditions (e.g. sediment grain size), and not impacts on a regional scale, are mostly responsible for structuring communities. In quite a few cases, the 250m (and occasionally 500m) stations are plotted with extreme values on the second axis (e.g. Figure 12). This indicates a disturbance due to the installation.

It is possible that these MDS plots could be useful in evaluating recovery in faunal communities following discontinuation of the discharge of OBM. If field stations were becoming more like reference locations, then they should be plotted more closely to reference stations in successive monitoring periods. This is not evident from many of the MDS plots (Figure 12, Appendix 4). At least three factors may be responsible for this. First, there may not be any appreciable recovery. Second, patterns suggesting recovery within a region may be obscured by field-specific results, or by the plotting together of all stations between 250-4000 m from the installation. Finally, regional reference stations may not represent reasonable endpoints for recovery, i.e. unimpacted stations from a field or across the region may *never* be similar to the relatively few reference stations sampled. Our results cannot discount the first possibility, but suggest that both of the other two possibilities are likely (see especially Region III 1998 in Figure 12). As mentioned above, 250 and 500 m stations from many fields show clear impact, but stations further than 500 m from each other show no strong pattern.



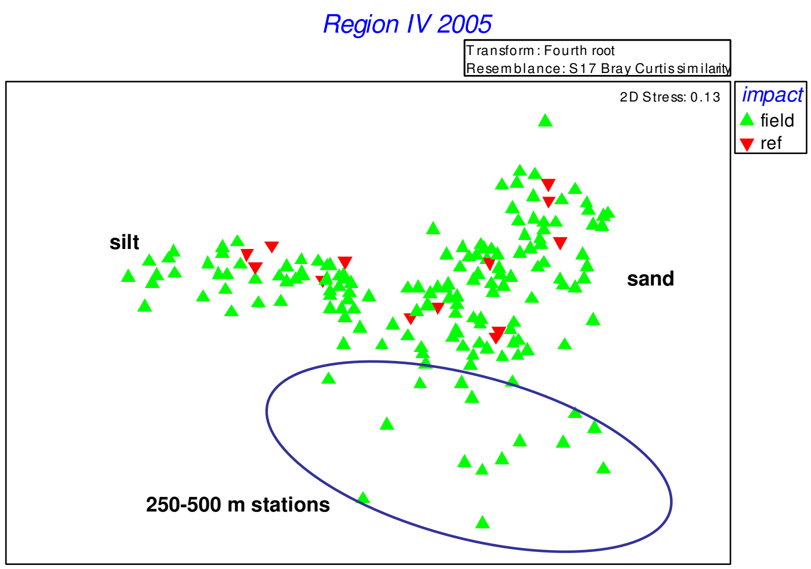


Figure 12 Multidimensional scaling (MDS) plot of station similarity in faunal community structure at field and reference sites in Region III (1998) and Region IV (2005). The station position along the horizontal axis generally reflects a gradient in sediment parameters, while the vertical axis includes some element of faunal impact. Plots for other regions and years are in the appendices.

Reference stations often fall outside the clusters that often represent the specific fields (Figure 12, Appendix 4), implying that other environmental characteristics (e.g. sediment grain size) than those due to petroleum activities may be responsible for the majority of the differences between field and reference stations. This is an even greater issue in regions that are themselves highly variable (Regions III, IV), and has implications for selection of the number and location of reference stations in future monitoring strategies.

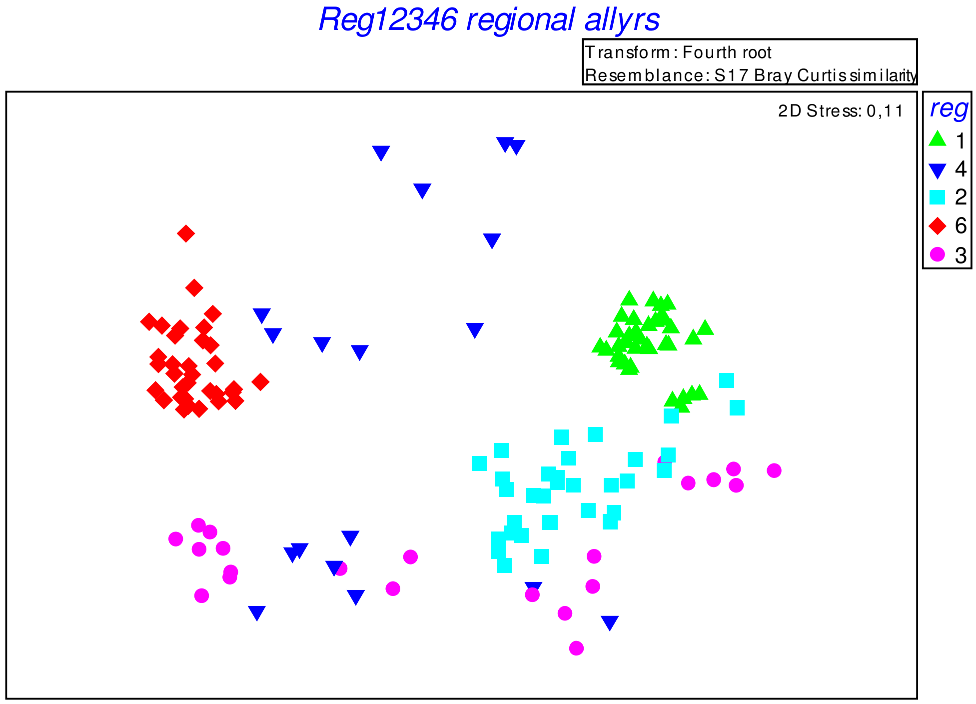


Figure 13 MDS plot of faunal communities at all regional reference stations during all years. Regions are coded by color and shape. Interannual variability is seen only within each region cluster, and these plots are available in the appendices.

When all faunal communities from regional reference stations are analyzed together, the stations from each region cluster tightly, except for Regions III and IV (Figure 13). These two regions are heterogeneous in terms of depth and sediment grain size, and the faunal communities of the regional reference stations reflect this heterogeneity. For example, the Region III stations are generally increasing in depth from right (under 120 m) to left (over 300 m). In addition, Region IV stations are similarly ordered with increasing depth from right to left, but reference stations sampled in 1996 are plotted as the uppermost 10 points, while other years are plotted in the lower section of Figure 13 (see also Appendix 5). While significant interannual changes in faunal composition of the reference stations in each region was observed (Appendix 5), the data plotted in Figure 13 show no consistent pattern of interannual changes within each region (i.e. change is not in the same direction for each region).

6.4 Summary of trends in field and reference station data

There were no overall trends in impact area across all regions for Ba, THC, or fauna. In some regions there were suggestions of an increase in impact or contamination, while others showed no trend or a decline (Figure 6). It was expected that THC might show a general decline as the regions recover from OBM use, but unquantified sources must be providing additional THC in some regions (Regions I, II, and VI).

It seems reasonable that sedimentary Ba concentrations and faunal impacts may increase or decrease depending on operational activity and discharge. While we do not assess all types of activity (especially related to physical disturbance), there is little evidence that Ba discharge is directly related to impact area, at least within the time scales investigated here (Figure 7). Finally, as mentioned above, area-estimation methodologies are imprecise, and changes in concentrations may result in disproportionate changes in impact or contaminated area values. Despite the relative inability to track mechanisms behind changes in impact or contaminated area, the total area affected by petroleum activities is very low based on these measurements. No indicator suggests impacts of even close to 1% of the total area of the regions sampled (Table 3).

Both the chemical and faunal characteristics of the regional reference stations vary interannually within a region (Figure 11, 13). This represents a potential problem if field stations are to be compared, and recovery assessed relative to a 'moving target.' Closer evaluation of the data, however, indicates that the interannual variability in Ba and THC at reference stations is very low compared to that in field stations, and the concentrations themselves are well below MPC levels (Table 1, Figure 11). Despite some analytical methodologies that may suggest unusually large areas of the shelf are contaminated by Ba or THC (see above), mean values even within our sampling areas are very low.

Regional differences among faunal communities at reference stations are far greater than interannual differences (Figure 13). Our data also suggest that environmental differences unrelated to petroleum activities, e.g. sediment grain size, have an overriding influence on community structure at reference stations (see comments about distribution of points for Regions III and IV in Figure 13 above). These results support the idea that it may be appropriate to continue to compare regional stations to field stations when assessing community change, despite the interannual variability observed within each region, but care must be taken to assure that field stations are being compared to appropriate, in terms of depth and sediment type, reference stations.

While the regional reference station approach may be good in theory, current reference stations do not seem to be adequate. The indication that environmental differences based on depth or other characteristics may not be representative of the region as a whole suggests that current monitoring practices should be modified. More than 10 years of a regional approach to monitoring has highlighted fundamental differences among regions, and that heterogeneity on some scales (e.g. depth gradient from Region I to Region VI) is captured by regional nature of monitoring. But some regions are, themselves, heterogeneous (depth, grain size, other factors), and the regional approach for field and reference monitoring needs to address this. MDS plots showing clear groupings of field and reference stations can be used to identify how many faunal/environmental sub-regions exist within a region, and how regional reference stations should be distributed so as to act as reasonable comparison sites. For example, Region I may have more randomly distributed reference sites as this region is relatively homogeneous, while Regions III and IV would have 3 or 4 clusters of reference stations. Our results suggest, therefore, that if the regional approach to monitoring petroleum activities is reasonable, the data accumulated over the past decade must be used to inform a flexible monitoring strategy to assure an adequate number and distribution of regional reference stations. This may entail increasing the number of reference stations sampled in regions that are particularly heterogeneous.

Finally, it has been suggested that, despite a common accreditation process, identification and analysis performed by different consulting companies may vary, thus impacting some of the conclusions. While it is true that two individuals (perhaps even at the same consulting company) may identify some taxa differently, this is most likely to be the case for the most uncommon species. While this may represent a large fraction of the number of species in a region, these taxa are not so important numerically. It is likely that major trends in faunal communities will be observed similarly, regardless of consultant, but this can be tested by running multivariate statistical analyses on both transformed (+/-) and untransformed data, as the former values each species equally, and the latter downgrades the importance of rare species.

7 Case studies

7.1 Ekofisk

Ekofisk was the first production field on the Norwegian shelf, and thus, has a long history that spans a variety of standard practices. The duration and nature of activity at Ekofisk suggest that it may represent a field on the Norwegian shelf that has been considerably affected by the petroleum industry. In this way, it may also be one of the sites where long-term faunal response, including possible trends in recovery following the switch from OBM to WBM discharge, may be observed. The data presented here are from the Center and 2/4 B&K installations at Ekofisk.

There has been little evidence of significant change in either pelite or TOM at Ekofisk from 1990 to present (Figure 14). Ekofisk is characterized by shallow (under 100 m) water and sandy sediment with low pelite values. Pelite values were less than 8% for all but one sampling, and were higher at field stations compared to reference stations at nearly all sampling dates. TOM values were virtually identical between the two types of station at all sampling dates.

THC was high at Ekofisk during the early 1990s (mean values up to 234 ppm, with a maximum value of over 3000 ppm at one station 100 m from the installation in 1992), but declined rapidly after the ban on discharges of OBM effective from 1993 (Figure 14). From 1994 to present, the average concentration has been above 50 ppm (the accepted Predicted No-Effects Concentration, PNEC; UKOOA 2002, DNV 2004) only once (2002). Ba showed no obvious trend at Ekofisk during the time period, with an average concentration between 1000 and 3500 ppm at all field sites (Figure 14). It is important to consider that all of these values are means and include stations as close as 250 m and as far away as 4000 m. See Appendix 1G for maxima and minima for these values, as well as values for heavy metals.

MDS plots indicate a strong annual signal in the faunal community data, i.e. the stations from each sampling year is more similar to each other than they are to stations from any other year, regardless of the distance from the installation. In addition, there is a sharp division between stations sampled from 1990-1993 and those from 1996 to present (Figure 14, Appendix 6). This suggests that the effect of switching to synthetic- and water-based drilling muds in 1993 was seen already in 1996. This may represent a short lag period, but since no faunal samples were taken in 1994 or 1995, this cannot be ascertained. Finally, most reference stations appear to be more similar to each other than to most of the field stations (Figure 14).

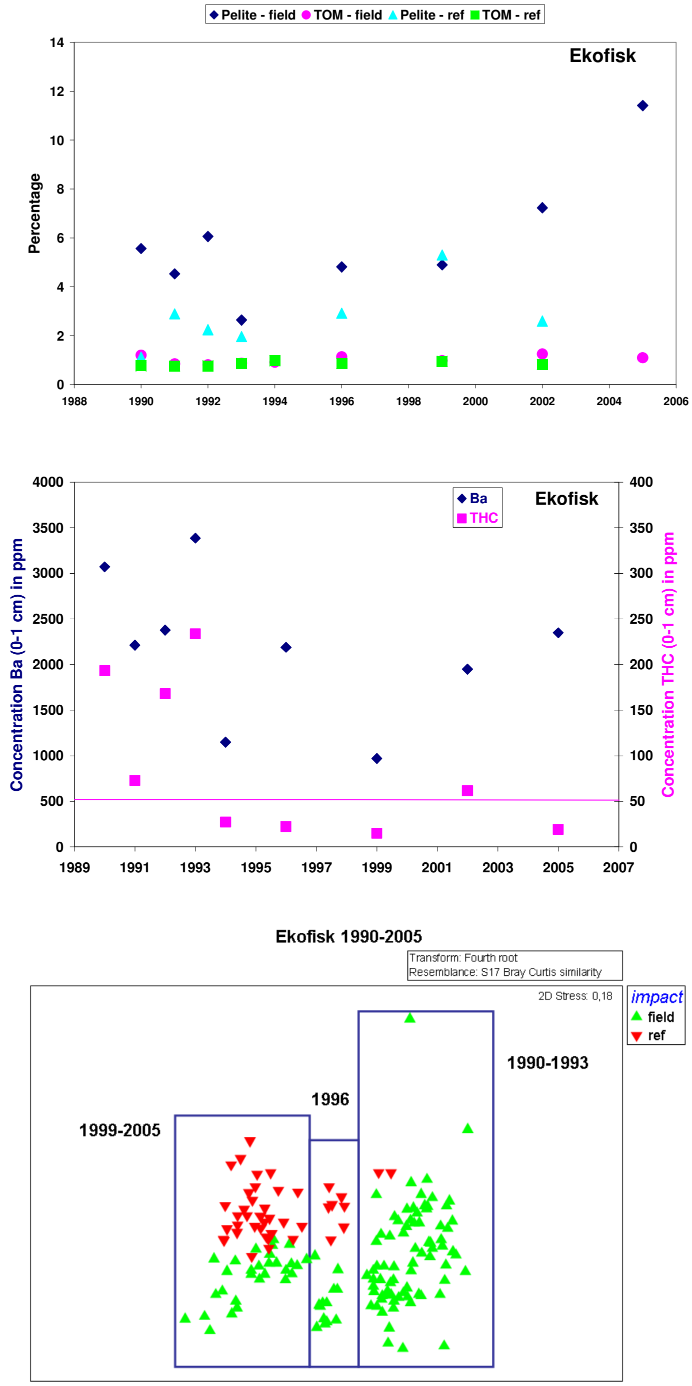


Figure 14. Geology, chemistry, and biological data for the Ekofisk field from 1990 to 2005. (top) Annual mean grain size (% pelite) and total organic matter (% TOM). (middle) Annual mean values for barium concentrations (left-axis scale) and THC concentration (right-axis scale). Red line indicates the PNEC level of 50 ppm for THC. (bottom) MDS plots faunal communities from field and reference stations. Boxes and circles indicate sample year.

7.2 Statfjord A

In 1979, production began at Statfjord A in the shallow section (140-180 m) of Region IV. Again, this field is important since it can provide a long time-series of data with which to evaluate management and production practices. In addition, Statfjord A has had a history of some of the most contaminated sediments sampled in conjunction with oil industry activities on the entire Norwegian shelf. In this way, it presents a good opportunity to compare the potential and time-frame for recovery under different contamination regimes.

Again, little obvious trend in grain size was observed from 1990-2005, with pelite ranging from approximately 6-10% in field stations and 3.5-8% in reference sites. As at Ekofisk, reference sites had consistently less fine sediment than field sites. TOM was again similar at field and reference stations, with only a slight trend for decline over the 15 year sampling period (1.8 to 1.55% in field and 2-1.34% at regional reference stations) (Figure 15).

THC concentrations reached 6700 ppm at one station in 1990, with an average across all field stations sampled during that year of over 920 ppm (Appendix 1H). Mean THC dropped dramatically from 1990-1992, with 1992 values under the 50 ppm PNEC. Values were nearly 200 ppm in 1993 and have experienced a gradual decline since then, again dropping below the PNEC in the 2005 (Figure 15). These data suggest, again, a rapid response in the THC concentration of surface (0-1 cm) sediments to discontinuation of use of OBM, and this is more likely due to erosion than degradation (UKOOA 2002). While it took longer at Statfjord than at Ekofisk, perhaps due to greater depth and lower current velocities, levels were near the PNEC 6 years after the shift in practice (see also Larsen et al. 2004). Data presented here do not include the legacy (i.e. THC in sediment layers below 1 cm) of more than 13 years of OBM use. While some of the THC may have degraded or been exported with ocean currents, a significant inventory of THC in deeper sediment layers may still exist (e.g. Figure 11 for Regions I and II). Mean Ba concentrations at Statfjord are relatively constant between 2000 and 3500 ppm (Figure 15).

Faunal data from Statfjord A exist in the MOD database from 1993-2005, and show a similar pattern to those from Ekofisk. Again, there is a sharp delineation between stations sampled from 1993-1996 and those sampled afterward on the horizontal axis (Figure 15, Appendix 6). In addition, stations group largely by year of sampling (Appendix 6). Furthermore the 250 and 500 m stations are plotted furthest from reference stations. Regional reference stations never group closely with any of the field stations, even those more than 2 km from the installation (Figure 15). All reference stations do, however, appear on the opposite side of the MDS plot from the stations closest to the installation, suggesting that there is an underlying impact gradient on the vertical axis of the plot.

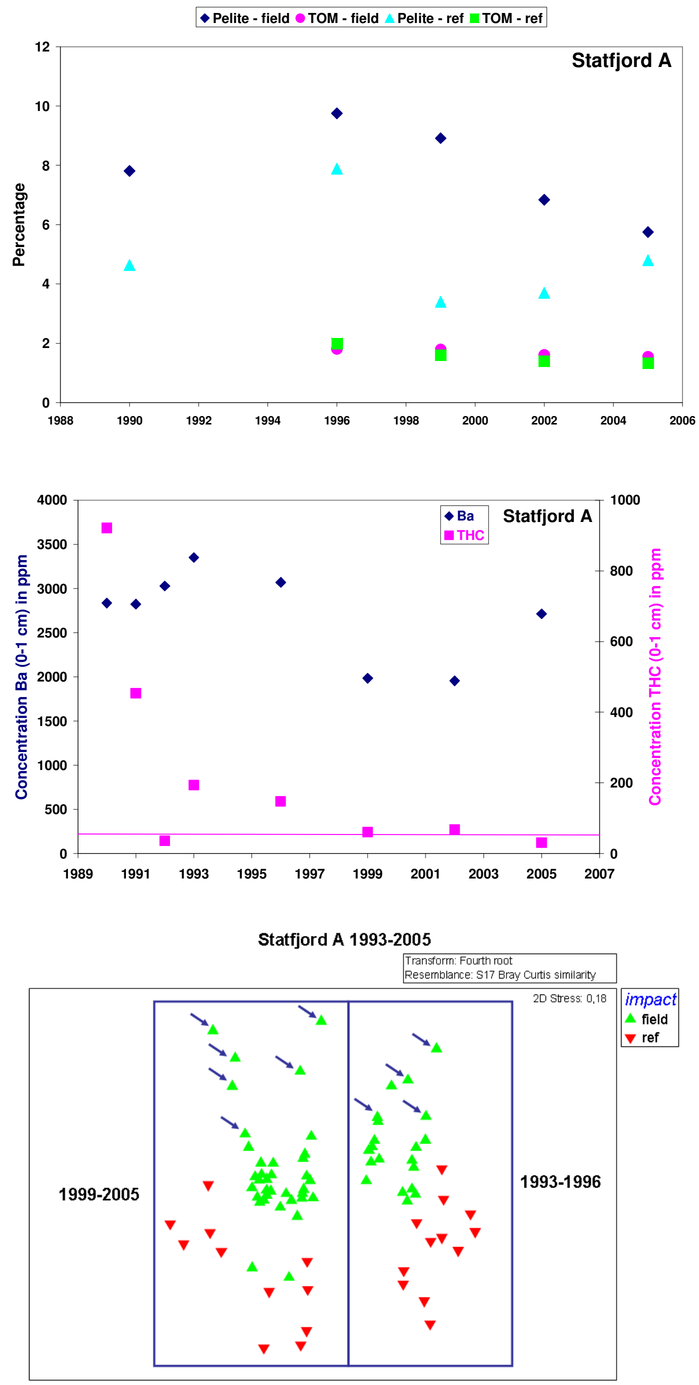


Figure 15 Geology, chemistry, and biological data for the Statfjord A field from 1990 to 2005. Figure orientation and symbols as in Figure 14. Blue arrows in bottom panel indicate stations 250 and 500 m from the installation.

7.3 Snorre TLP

Snorre TLP is also located in Region IV, but within the deeper zone (300-340 m). Production in this field began in 1992 and little OBM has been used during drilling operations here. The much greater depth and low use of OBM at Snorre present a good contrast with the nearby Statfjord field.

Greater depth and, presumably, lower current speed result in a much finer sediment at Snorre, with pelite accounting for approximately 50% of the total sediment (Figure 16). This fraction represented 30% of the sediment in 1991 and has increased gradually to nearly 60% in 2005 at field stations. Reference stations show a similar pattern (31-50%), but, again, there is nearly always less pelite than at field stations. This increase in pelite concentration could be due to an increase in deposition along the shelf in this region (perhaps from shallow water areas), or an artifact of sampling design. TOM is higher than at either of the two other fields, fluctuating inconsistently between 2 and 4.6% at field stations and from 2-2.7% at regional reference sites (Figure 16). The same regional reference sites are resampled each time, but this is not the case for field stations. For example, before 1996, 8 of 21 stations were further than 1000 m from the installation at each sampling, while from 1999-2005, only 2 of 9 stations sampled each year were further than 1000 m. This is unlikely to be the cause for the pattern, however, since a large proportion of the increase in pelite took place between 1991 and 1993 (Figure 16). Deeper areas in Region IV had fairly consistent pelite content between 1996 and 2005 in the range of 36-46% (Figure 9), suggesting undetermined local processes at this field are responsible for the levels approaching 60% pelite between 1999 and 2005.

Since 1991, mean THC concentration has never been above PNEC, and the maximum value measured is under 200 ppm. No clear trend is evident, although mean values are higher during the last three sampling periods (1999-2005) than 5 of the 6 previous samplings ($p > 0.05$, linear regression). Mean Ba concentration has varied widely from just over 2000 ppm to nearly 6000 ppm, with a maximum value in 2005 of over 10,000 ppm (Figure 16, Appendix 1I).

Faunal communities were sampled from 1991-2005. Again, the largest division in the data was between stations sampled from 1991-1996, and those sampled afterward (Figure 16, Appendix 6). As for Ekofisk, stations grouped by year and not by distance from the installation. One strong difference between Snorre and the other two fields was that community structure at regional reference stations was similar to that at most of the field stations sampled during each year (Figure 16). Only the stations nearest the installation deviate from this pattern. This suggests not only that the reference stations are representative of the field and vary interannually as the field stations do, but also that most field stations show little impact in faunal communities.

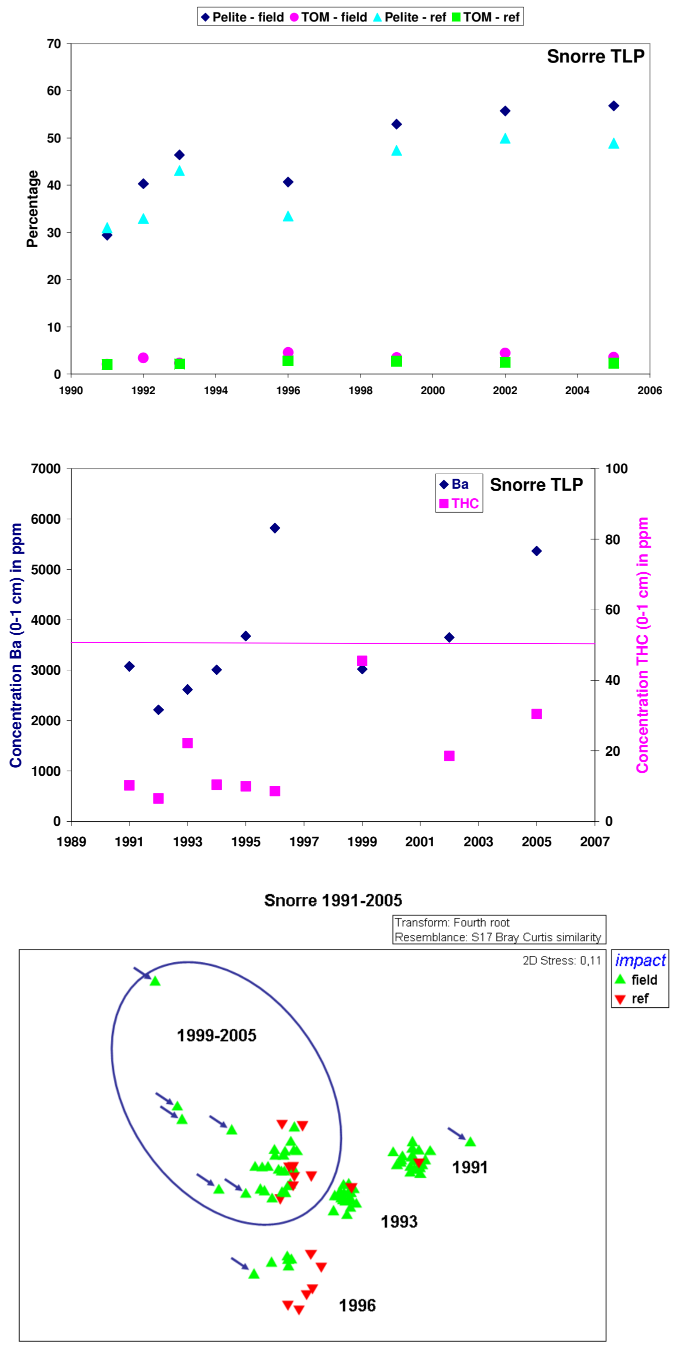


Figure 16 Geology, chemistry, and biological data for the Snorre TLP field from 1991 to 2005. Figure orientation and symbols as in Figure 15.

7.4 Impacts, recovery, and methodology

These temporal case studies have provided several insights into impacts, recovery, and potential methodological issues that were not possible by only having a regional (geographical) perspective. First, the consistently finer sediments in field sites compared with regional reference stations suggest that petroleum activities, including discharge of drilling muds and from resuspension during sediment disturbance, may be responsible. In some cases, higher pelite percentages may be expected to result in higher TOM values, but this was not observed to be a general pattern among these three sites (Figure 14). Faunal community structure may be affected by this increase in pelite, but annual monitoring reports suggest a variety of other factors (e.g. interannual variability, Figure 16) are correlated with faunal disturbance evaluated at the field-scale. There is no single factor that explains a majority of the observed differences between faunal communities in field and reference sites

Ba levels in the sediments varied considerably, but with no general trend over the past 15 years at these three sites (Figure 16). Recent field activity, as well as redistribution of sediments by ocean currents, could be responsible for this. Again, we have no evidence to suggest or rule out any of these possibilities. Conversely, THC concentration in surface sediment shows a clear response to management and subsequent changes in industry practices (Figure 15). Although Ekofisk and Statfjord had high THC levels in the sediments due to 1-2 decades of use of OBM, discontinuation of OBM in 1993 led to disappearance of THC in the surface layer within 3-6 years, a time-frame similar to that observed in the North Sea (Kröncke et al. 1992, Daan and Mulder 1996). This is likely due to degradation/weathering of THC, transport away from the area, and/or burial under new sediments. Snorre, where OBM use was minimal, has never had THC levels above the PNEC value, again indicating the value of this management decision. A report by SFT (Norwegian Pollution Control Authority; SFT 2007) indicated that sediments were the greatest source of polyaromatic hydrocarbons (PAHs) to the marine environment in Region I. Legacy hydrocarbons in deeper sediment strata (Figure 11) may be an important component of this, indicating the importance of considering sediments beneath the surface layer in environmental assessment.

The other question we attempted to address with these case studies was whether patterns and monitoring strategies from shallower areas can be transferred to deeper sites. The petroleum industry will continue to search in deeper waters as need for oil increases and technology is developed. Snorre TLP, at over 300 m, is one of the first deeper sites explored. After 13 years of monitoring, we can conclude that, despite fine sediments and higher organic content, faunal communities have experienced minimal impact of industry activities. Deeper shelf areas are usually homogeneous in terms of sediment grain size, thus making selection of reference stations easier. This statement does not apply to slope areas. The increase in pelite content we observed is puzzling, and is likely not a consequence of oil production since the same trend was observed in reference stations. This may be an artifact of sampling, or may indicate a pattern of sediment transport, but needs further investigation.

These case studies, and the regional data discussed in Section 7, provide some insight into strengths and weaknesses in current monitoring strategies. First, it is clear that the regional approach is useful, both because some regions are rather homogeneous, and also as it can be used to make informed decisions about appropriate sampling strategies. The most important element of experimental design when testing for effects (including recovery) is having adequate reference stations. The switch from a field-based monitoring program to a regional-based system in 1996 was accompanied by the initiation of regional reference stations. This works fairly well in regions that are rather homogeneous (e.g. Region I), but environmental characteristics of these stations must be better matched with field values (e.g. Region III, IV). MDS analyses suggest that too few appropriate reference stations are available to compare with field stations, either on a field or regional basis. Many statistical analyses that could suggest or refute impacts are not possible within the current monitoring scheme. A revised combination of field- and regional-based reference stations selected for each region is suggested as a first improvement for future monitoring strategies.

Faunal community analyses performed here represent an effort to best detect changes in the community that are relevant ecologically. This multivariate approach (i.e. taking into account not only the number of species or density, but how the number of individuals is distributed among the species present) has been determined to be more effective in identifying important trends than an univariate approach based solely on density, diversity or biomass (Olsgard and Gray 1995). It may be possible that these techniques can be combined into a new faunal index to improve the ecological relevance and sensitivity of the faunal indicator. One metric that has been used in petroleum-impact monitoring in the Gulf of Mexico is the polychaete/amphipod ratio, whereby the numbers of individuals in each group are summed and the ratio is taken (Peterson et al. 1996). Amphipods generally live on or near the sediment surface and have life-history and feeding strategies that may be impacted by sedimentation and other sediment disturbance. Further, they are thought to be more sensitive to many pollutants than polychaetes (Green and Montagne 1996, Montagne and Harper 1996). As an example of the potential utility of this analytical tool, we calculated this ratio for infauna collected at Snorre TLP and separated the stations by distance from the installation.

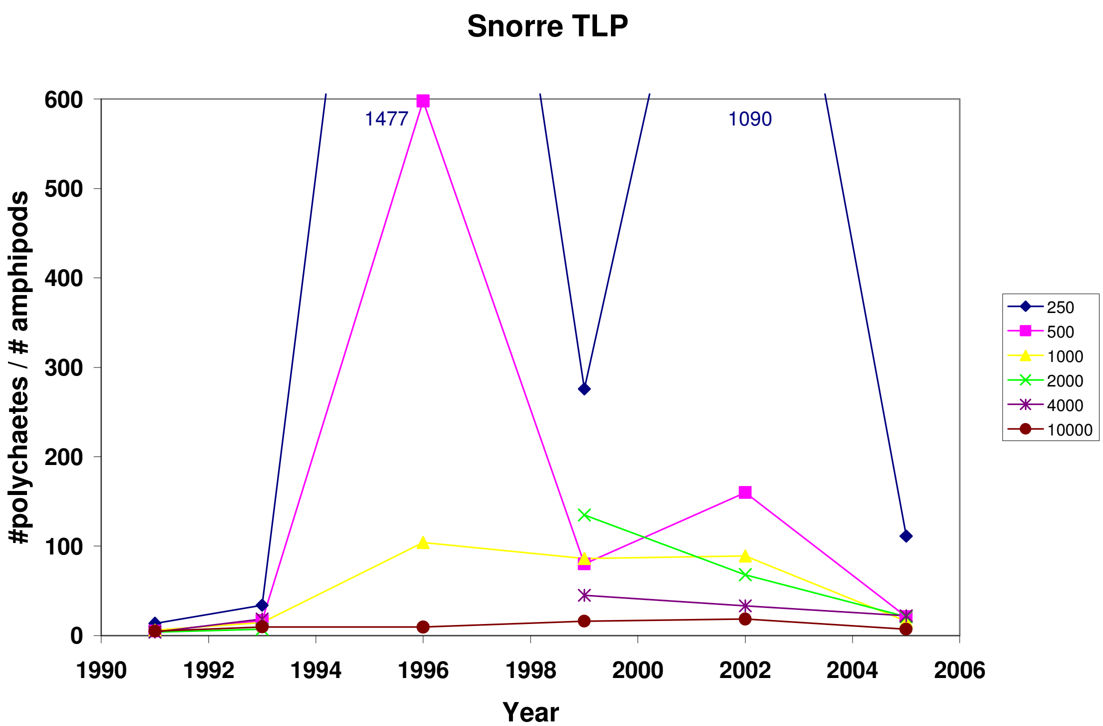


Figure 17 Plot of the ratio in abundance of polychaetes to amphipods at the Snorre TLP field from 1991 to 2005. Different colors indicate different distances from the installation. Reference stations also included and are 10,000 m from the installation.

Shortly following production in 1992, the ratio rises dramatically at the nearest stations, but also as far away as 1000 m (no stations further away than 1000 m were sampled in 1996). The ratio declined at all stations in 1999, then rose again at all but 2000 m in 2002. In 2005, only the 250 m stations appear to be impacted (Figure 17). A few field-specific events may shed more light on these results. The rise in the ratio in 1996 parallels an increase in mean TOM at Snorre from 2.3% to 4.6%. The decline in the ratio also accompanies a decline in TOM to 3.5%. Additionally, the increase in this metric in 2002 follows a deposition of 8000 tonnes of cementing compounds used at the site in 2000. This disturbance, not surprisingly, was only accompanied by an increase in the ratio at the 250 and 500 m stations. Another interesting result is that measurable impacts appear to be visible up to 4000 m from the installation (in 1999). This has not been previously observed using the multivariate method.

With any method, or data set, there are several caveats. Any ratio will respond to changes in either, or both, of the terms (in this case, polychaetes or amphipods). Should there be few amphipods, a small change in their abundance may strongly affect the ratio. Additionally, there is low replication at the different distances sampled to generate this plot. In fact, some distances in some years are represented by only one station. This makes it difficult to analyze the results statistically, but higher sampling in the future could remedy this problem. There are, however, several lines of evidence that suggest that this technique may be valid and sensitive. From 1991 to 2005, reference stations showed a consistently low ratio thus suggesting unimpacted fauna, a finding expected if reference sites are undisturbed and the metric is meaningful. Further, it is encouraging that in nearly every sampling period the rank order of the ratio is identical to the distance from the installation (i.e. 250 m has the highest ratio followed by 500, 1000, etc.). Finally, events at the field coincide reasonably well with large changes in the ratio. Clearly this is worth exploring as a technique for future impact assessment, and should be tested with data from more fields for validation.

8 Future perspectives

The future of the petroleum industry in Norway promises new opportunities and new challenges. Expansion into regions such as the deep-sea and the Arctic will necessitate new technologies and responses to new regulatory policies. Environmental monitoring policy and practice will need to keep pace with these developments to assure responsible environmental stewardship accompanies new economic opportunities.

Production is expanding in deeper regions of the continental shelf and new installations are in operation off-shelf at around 1000 m depth in Region V. Exploration continues as well in the deep Norwegian Sea. Monitoring in these areas must look to other regions in the world where these activities occur (e.g. Gulf of Mexico) and learn from their experience. An obvious challenge that remains is that of a poorly described fauna in the deep Norwegian Sea, and the need for enhanced taxonomic expertise within Norway. It is also likely that Arctic fauna, while better catalogued than that from the deep sea, may also pose taxonomic challenges that can hinder accurate monitoring of petroleum activities there. The Barents Sea is a developing frontier for both oil and gas, and we have limited knowledge of the ecosystems in this area. There is some indication that faunal communities may respond to oil differently in the Arctic than in regions further south (Olsen et al. 2007), and further studies need to be performed to determine whether, in the light of this new knowledge, that impact models developed for the North and Norwegian Seas translate to the Arctic.

9 Conclusions and recommendations

Contamination and impacts near offshore installations have been documented, and therefore Norwegian law require that a monitoring programme must be maintained during the production period and up to ten years after decommissioning.

In some cases (250 m stations near active fields, see maximum values in Table 1), the impacts can be severe. Levels of potential contaminants and areas of impact, however, have decreased sharply in the past 10 years in some regions, continuing the initial pattern noted in the 2000 report on the regional monitoring programme. Evidence from case studies suggests this is most likely due to change from OBM to WBM.

In some regions, however, no change in area of impact or contamination, or even some increase, was observed for some indicators (THC, Ba, fauna). There was little evidence at the regional level that this was due to changes in discharges, however. The presence of elevated concentrations of THC in subsurface sediments suggests the potential for these ‘legacy’ hydrocarbons to diffuse slowly into surface layers and overlying water, or to be remobilized by physical (storms) or biological (fauna) processes.

Strong interannual differences in community structure continue to be observed, and are likely due to changes in industry practices, and to natural variability in recruitment, mortality, etc.

The initial report on regional monitoring published in 2000 noted that only a small portion of the Norwegian shelf has been influenced by petroleum exploration and extraction. The percentage of the shelf that shows evidence of metal or chemical contamination, or ecological impact, remains low, and has decreased in most regions since the first cycle of regional monitoring. Current total impact areas are well below 0.10 % of the total area of the regions where petroleum activities are taking place.

Depth and related parameters (sediment grain size, TOM) seem to have a strong impact on faunal community structure, and often are more important than identified impacts of petroleum activities on the regional scale.

Several methodological issues have been discussed here, including questions of replication, impact assessment metrics, and choice of reference sites. Changing sampling schemes over the years makes some statistical comparisons impossible, as does the uncertainty regarding suitability of reference stations within some regions. While reference station selection and replication seems to be appropriate in more homogenous regions, monitoring in more variable regions would benefit from more reference stations selected to more appropriately reflect the conditions at the active fields. Impact and contamination assessment may be improved by considering alternative metrics (e.g. polychaete/amphipod ratio) if further validation continues to suggest its utility and sensitivity.

The industry, working with SFT and the Expert Group, need to assure that monitoring programs are designed to optimize reliability and scientific defensibility of results. Flexible, adaptive schemes that preserve long-term data sets and can be responsive to new results can, thus, maintain an efficient and effective monitoring strategy for offshore petroleum production in Norway.

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Appendix 1. Metals and some organic compounds measured during regional surveys between 1996 and 2006, and for individual case-study fields from 1990-2006. Ba: Barium, Cd: Cadmium, Cu: Copper, Hg: Mercury, Pb: Lead, Zn: Zinc, PAH: Polyaromatic hydrocarbons, NPD: naphthalene, phenantrene, and dibenzotiophene, THC: Total hydrocarbons. Concentrations are in mg/kg (ppm).

Appendix 1A: Region I - Ekofisk

Field Stations:		1996	1999	2002	2005
Ba	Average	943,4	733,55	1301,444	1168,33
	St.dev.	917,6	1155,65	1576,285	1538,98
	Max	3996,7	5676,67	7411,667	5941,67
	Min	31,7	7,00	6,667	3,00
	Number of stations	121	113	144	129
	Median	577,7	253,00	559,33	468,00
Cd	Average	0,009	0,02	0,030	0,03
	St.dev.	0,007	0,04	0,052	0,08
	Max	0,045	0,33	0,290	0,53
	Min	0,003	0,01	0,005	0,01
	Number of stations	121	113	144	129
	Median	0,01	0,01	0,010	0,01
Cu	Average	1,186	1,33	3,710	3,81
	St.dev.	1,264594	2,50	7,360	10,38
	Max	12,333333	19,40	70,067	78,33
	Min	0,300	0,15	0,367	0,25
	Number of stations	121	113	144	129
	Median	0,90	0,73	1,65	1,10
Hg	Average	0,010	0,02	0,039	0,04
	St.dev.	0,005107	0,01	0,045	0,05
	Max	0,0233333	0,05	0,250	0,19
	Min	0,005	0,01	0,008	0,01
	Number of stations	24	24	40	35
	Median	0,01	0,02	0,02	0,02
Pb	Average	9,797	10,90	13,282	12,25
	St.dev.	4,1128734	10,00	11,393	13,08
	Max	32,066667	74,70	71,000	98,90
	Min	3,853	4,97	4,367	3,13
	Number of stations	121	113	144	129
	Median	8,85	8,17	9,28	8,19
THC	Average	14,95	21,51	89,69	49,23
	St.dev.	19,98	52,99	553,57	367,92
	Max	162,37	384,43	6489,67	4510,81
	Min	0,60	0,52	0,12	0,34
	Number of stations	124	113	144	129
	Median	8,66	8,24	10,63	5,85
Zn	Average	7,752	11,06	17,769	17,80
	St.dev.	5,159703	17,43	24,346	29,07
	Max	33,366666	131,60	150,000	204,20

	Min	1,933	3,97	3,967	4,43
	Number of stations	121	113	144	129
	Median	6,60	6,73	9,05	8,92

Regional/Reference Stations:					
		1996	**1999**	**2002**	**2005**
Ba	Average	53,124	29,82	33,71	35,36
	St.dev.	22,975	18,626	21,05	23,79
	Max	102,000	67,000	71,60	87,00
	Min	5,800	4,667	6,40	4,33
	Number of stations	14	13	13	14
	Median	59,37	31,33	35,00	33,40
Cd	Average	0,007	0,02	0,01	0,02
	St.dev.	0,003	0,012	0,00	0,04
	Max	0,014	0,052	0,01	0,16
	Min	0,003	0,010	0,01	0,01
	Number of stations	14	13	13	14
	Median	0,01	0,01	0,01	0,01
Cu	Average	0,597	0,49	1,05	0,35
	St.dev.	0,179	0,146	0,16	0,28
	Max	0,880	0,80	1,28	1,32
	Min	0,300	0,25	0,80	0,25
	Number of stations	14	13	13	14
	Median	0,62	0,47	1,03	0,25
Hg	Average	No Hg data available in MOD	0,016	0,01	0,01
	St.dev.		0,011	0,00	0,00
	Max		0,048	0,01	0,01
	Min		0,005	0,01	0,01
	Number of stations	14	13	13	14
	Median		0,01	0,01	0,01
NPD	Average	0,020	0,012	0,02	0,01
	St.dev.	0,006	0,006	0,01	0,01
	Max	0,028	0,022	0,03	0,04
	Min	0,012	0,004	0,01	0,00
	Number of stations	9	13	13	14
	Median	0,02	0,01	0,02	0,01
PAH	Average	0,054	0,034	0,04	0,04
	St.dev.	0,013	0,013	0,02	0,02
	Max	0,085	0,052	0,06	0,06
	Min	0,043	0,015	0,01	0,01
	Number of stations	9	13	13	14
	Median	0,05	0,04	0,04	0,04
Pb	Average	6,820	6,69	6,12	5,96
	St.dev.	1,286	1,50	1,00	1,05
	Max	9,104	9,90	7,48	7,74
	Min	4,523	3,87	3,73	4,00

	Number of stations	14	13	13	14
	Median	6,90	6,80	6,14	6,10
THC	Average	5,232	3,64	3,69	3,51
	St.dev.	1,187	1,33	1,37	1,31
	Max	6,843	5,45	5,78	5,82
	Min	3,582	1,40	1,60	1,27
	Number of stations	14	13	13	14
	Median	5,46	3,88	3,70	3,67
Zn	Average	4,608	5,45	5,95	5,89
	St.dev.	1,418	1,28	1,13	1,28
	Max	6,660	7,40	8,23	8,88
	Min	2,600	2,67	3,50	3,17
	Number of stations	14	13	13	14
	Median	4,27	5,50	5,98	5,83

Appendix 1B: Region II – Sleipner

Field Stations:		1996	1997	2000	2003	2006
Ba	Average	103	420	461	177	
	St.dev.	82	585	632	144	
	Max	324	2480	3942	709	
	Min	20	17	19	8	
	Number of stations	81	140	159	172	
	Median	67	199	226	142	
Cd	Average	0,016	0,016	0,020	0,019	**No data**
	St.dev.	0,004	0,011	0,012	0,009	**in MOD**
	Max	0,030	0,085	0,095	0,060	**for 2006**
	Min	0,015	0,003	0,003	0,015	
	Number of stations	81	140	159	172	
	Median	0,015	0,016	0,019	0,015	
Cu	Average	1,5	1,8	2,1	1,7	
	St.dev.	0,6	2,0	2,2	1,8	
	Max	2,6	18,5	14,7	17,0	
	Min	1,0	0,3	0,4	0,3	
	Number of stations	77	140	159	172	
	Median	1,0	1,6	1,6	1,4	
Hg	Average	0,045	0,006	0,005	0,010	
	St.dev.	0,000	0,003	0,004	0,005	
	Max	0,045	0,012	0,019	0,033	
	Min	0,045	0,002	0,003	0,004	
	Number of stations	81	20	27	39	
	Median	0,045	0,005	0,005	0,009	
Pb	Average	5,8	5,5	7,1	5,6	
	St.dev.	0,9	2,9	3,9	4,2	
	Max	7,8	26,3	31,0	43,7	
	Min	3,9	2,0	2,6	2,6	
	Number of stations	81	140	159	172	
	Median	5,6	5,2	6,5	4,8	
THC	Average		25,97	15,28	12,11	
	St.dev.		67,49	38,61	13,29621	
	Max		417,84	411,53	154,33	
	Min		0,50	2,50	1,50	
	Number of stations		140	159	172	
	Median		7,80	8,40	10,57	
Zn	Average	10,4	11,4	11,2	13,9	
	St.dev.	3,0	12,7	18,0	20,3	
	Max	16,6	124,6	132,7	230,3	
	Min	6,8	1,6	0,5	4,9	
	Number of stations	81	140	159	172	
	Median	9,7	8,3	7,9	10,6	

Regional/Reference Stations:						
		1996	1997	2000	2003	2006
Ba	Average	97,5	65,4	75,6	45,6	
	St.dev.	75,8	42,9	48,6	33,0	
	Max	196,0	176,3	214,8	145,8	
	Min	33,0	6,3	8,0	4,5	
	Number of stations	4	20	19	22	
	Median	80,5	50,2	74,2	40,9	
Cd	Average	0,019	0,014	0,017	0,020	
	St.dev.	0,007	0,006	0,009	0,010	
	Max	0,030	0,023	0,035	0,050	
	Min	0,015	0,004	0,004	0,015	
	Number of stations	4	22	21	22	
	Median	0,015	0,012	0,017	0,015	
Cu	Average	1,3	1,3	1,2	0,9	
	St.dev.	0,6	0,5	0,5	0,5	
	Max	2,0	2,0	2,1	1,7	
	Min	1,0	0,3	0,3	0,3	
	Number of stations	3	22	21	22	
	Median	1,0	1,2	1,1	0,8	
Hg	Average	0,045	0,004	0,005	0,008	
	St.dev.	0,000	0,002	0,002	0,003	
	Max	0,045	0,009	0,008	0,014	
	Min	0,045	0,003	0,003	0,004	
	Number of stations	4	22	21	22	
	Median	0,045	0,004	0,005	0,008	
NPD	Average	0,252	0,023	0,019	0,017	
	St.dev.	0,407	0,009	0,011	0,005	
	Max	0,863	0,039	0,039	0,028	
	Min	0,042	0,004	0,003	0,011	
	Number of stations	4	12	14	22	
	Median	0,051	0,023	0,017	0,017	
PAH	Average	**No data**	**No data**	0,063	0,045	
	St.dev.	**in MOD**	**in MOD**	0,043	0,028	
	Max			0,153	0,102	
	Min			0,006	0,007	
	Number of stations			14	22	
	Median			0,052	0,038	
Pb	Average	5,8	3,9	5,2	3,8	
	St.dev.	0,6	1,3	1,3	1,1	
	Max	6,7	6,1	6,9	5,7	
	Min	5,2	2,4	3,1	2,1	
	Number of stations	4	22	21	22	
	Median	5,7	3,6	5,0	3,8	
THC	Average	5,4	6,6	5,2	10,2	
	St.dev.	1,7	2,3	2,0	3,6	
	Max	6,9	11,3	8,9	15,4	
	Min	4,0	2,0	2,2	1,5	

	Number of stations	4	22	21	22
	Median	5,4	7,0	5,3	10,6
Zn	Average	10,2	4,9	5,2	7,9
	St.dev.	3,8	2,2	2,4	2,0
	Max	15,4	9,4	9,3	12,0
	Min	7,4	1,3	0,9	5,5
	Number of stations	4	22	21	22
	Median	9,1	5,3	5,2	7,7

Appendix 1C: Region III – Oseberg

Shallow stations (depth: < 190 m):

Field Stations:				
		1998	2001	2004
Ba	Average	801	966	477
	St.dev	1152	1370	864
	Max	4362	7190	5373
	Min	11	44	16
	Number of stations	66	96	124
	Median	286	390	149
Cd	Average	0,018	0,023	0,016
	St.dev	0,038	0,040	0,038
	Max	0,289	0,370	0,399
	Min	0,003	0,003	0,003
	Number of stations	66	96	124
	Median	0,008	0,013	0,010
Cu	Average	3,1	2,8	2,41
	St.dev	8,1	5,2	6,61
	Max	60,8	44,8	71,27
	Min	0,3	0,6	0,75
	Number of stations	66	96	124
	Median	1,1	1,5	1,43
Hg	Average	0,009	0,016	0,018
	St.dev	0,009	0,019	0,027
	Max	0,049	0,080	0,092
	Min	0,003	0,003	0,002
	Number of stations	66	15	10
	Median	0,005	0,012	0,008
Pb	Average	7,3	7,3	4,55
	St.dev	11,0	11,4	5,50
	Max	78,6	105,0	60,07
	Min	2,4	2,6	2,00
	Number of stations	66	96	124
	Median	4,2	4,6	3,67
THC	Average	110,7	240,3	14,0
	St.dev	351,8	1922,6	36,8
	Max	2100,0	18 936,0	319,4
	Min	0,71	0,5	0,5
	Number of stations	66	97	124
	Median	9,9	9,2	4,7
Zn	Average	10,6	9,4	8,22
	St.dev	21,1	18,4	17,01
	Max	151,3	163,0	184,67
	Min	2,6	2,2	3,30
	Number of stations	66	96	124
	Median	4,7	5,0	5,52

Regional/Reference Stations:		1998	2001	2004
Ba	Average	49,6	62,6	63,2
	St.dev	43,1	61,8	49,8
	Max	146,4	217,3	138,9
	Min	13,8	9,0	16,0
	Number of stations	9	11	7
	Median	29,7	46,0	36,6
Cd	Average	0,008	0,017	0,012
	St.dev	0,006	0,011	0,006
	Max	0,021	0,040	0,021
	Min	0,003	0,003	0,003
	Number of stations	9	11	7
	Median	0,006	0,015	0,011
Cu	Average	0,7	1,1	1,2
	St.dev	0,3	0,4	0,3
	Max	1,1	1,9	1,6
	Min	0,3	0,5	0,6
	Number of stations	9	11	7
	Median	0,7	1,1	1,2
Hg	Average	0,007	0,006	0,003
	St.dev	0,008	0,005	0,000
	Max	0,027	0,016	0,003
	Min	0,003	0,003	0,003
	Number of stations	9	11	5
	Median	0,003	0,005	0,003
NPD	Average	0,011	0,011	0,041
	St.dev	0,005	0,006	0,087
	Max	0,017	0,020	0,238
	Min	0,005	0,002	0,003
	Number of stations	5	11	7
	Median	0,011	0,010	0,008
PAH	Average	0,019	0,019	0,020
	St.dev	0,008	0,010	0,010
	Max	0,029	0,034	0,033
	Min	0,007	0,005	0,006
	Number of stations	5	11	7
	Median	0,019	0,017	0,019
Pb	Average	3,3	3,8	3,2
	St.dev	0,7	1,0	0,9
	Max	4,0	5,9	4,5
	Min	1,9	2,6	2,0
	Number of stations	9	11	7
	Median	3,3	3,8	3,0
THC	Average	5,7	4,6	5,2
	St.dev	2,9	2,1	2,1
	Max	10,4	8,5	7,6
	Min	1,4	0,7	2,0

	Number of stations	9	11	7
	Median	5,4	4,6	4,8
Zn	Average	3,8	3,6	4,8
	St.dev	1,4	1,5	0,9
	Max	6,5	6,7	6,1
	Min	2,1	1,8	3,3
	Number of stations	9	11	7
	Median	4,0	3,5	4,9

Deep Stations (depth > 270 m):

Field stations:		1998	2001	2004	2005
Ba	Average	1088	1178	962	347
	St.dev	845	1373	545	75
	Max	3612	6948	2797	569
	Min	327	317	326	213
	Number of stations	42	45	39	20
	Median	795	689	869	350
Cd	Average	0,092	0,110	0,090	0,109
	St.dev	0,009	0,030	0,013	0,008
	Max	0,112	0,293	0,111	0,123
	Min	0,071	0,089	0,046	0,090
	Number of stations	42	45	39	20
	Median	0,094	0,106	0,090	0,110
Cu	Average	14,1	14,3	17,3	17,6
	St.dev	1,7	1,5	2,2	1,4
	Max	18,4	17,9	22,8	20,4
	Min	10,7	10,4	14,1	15,7
	Number of stations	42	45	39	20
	Median	14,0	14,3	17,6	18,0
Hg	Average	0,035	0,036	0,029	0,062
	St.dev	0,007	0,007	0,006	0,012
	Max	18,400	0,050	0,036	0,070
	Min	0,021	0,027	0,020	0,053
	Number of stations	42	9	9	2
	Median	0,033	0,033	0,030	0,062
Pb	Average	35,8	33,3	36,0	50,8
	St.dev	6,0	5,3	6,6	5,1
	Max	48,2	42,7	47,7	57,1
	Min	21,5	20,7	24,6	32,7
	Number of stations	42	45	39	20
	Median	36,4	33,6	36,4	51,5
THC	Average	4,0	6,0	62,5	
	St.dev	2,7	5,7	149,4	
	Max	15,8	21,3	707,4	
	Min	0,7	0,5	15,1	
	Number of stations	42	45	38	
	Median	3,4	3,6	26,1	
Zn	Average	68,3	58,5	70,5	96,4
	St.dev	8,9	23,0	9,1	8,0
	Max	86,3	193,3	85,4	128,0
	Min	48,3	36,8	54,5	89,4
	Number of stations	42	45	39	20
	Median	67,5	53,3	72,6	95,2

Regional/Reference Stations:					
		1998	2001	2004	2005
Ba	Average	335	341	321	**No data**
	St.dev	77	30	80	**In MOD**
	Max	462	387	407	
	Min	231	308	229	
	Number of stations	9	6	4	
	Median	328	334	324	
Cd	Average	0,075	0,107	0,092	
	St.dev	0,035	0,015	0,008	
	Max	0,113	0,13	0,10	
	Min	0,027	0,091	0,083	
	Number of stations	9	6	4	
	Median	0,085	0,105	0,092	
Cu	Average	10,2	15,2	17,1	
	St.dev	6,2	1,4	1,6	
	Max	16,4	17,2	19,3	
	Min	1,8	13,3	15,9	
	Number of stations	9	6	4	
	Median	13,1	15,0	16,6	
Hg	Average	0,026	0,041	0,033	
	St.dev	0,016	0,006	0,010	
	Max	0,045	0,049	0,043	
	Min	0,005	0,033	0,021	
	Number of stations	9	6	4	
	Median	0,031	0,041	0,035	
NPD	Average	0,182	0,245	0,226	
	St.dev	0,042	0,067	0,211	
	Max	0,229	0,330	0,493	
	Min	0,148	0,164	0,013	
	Number of stations	9	6	4	
	Median	0,169	0,248	0,200	
PAH	Average	0,339	0,531	0,474	
	St.dev	0,050	0,141	0,164	
	Max	0,389	0,749	0,581	
	Min	0,289	0,357	0,234	
	Number of stations	9	6	4	
	Median	0,340	0,531	0,540	
Pb	Average	27,8	38,5	37,9	
	St.dev	17,5	5,1	6,0	
	Max	46,5	46,0	46,3	
	Min	4,6	32,2	32,7	
	Number of stations	9	6	4	
	Median	35,1	36,6	36,2	
THC	Average	5,8	17,4	23,1	
	St.dev	4,8	11,4	4,8	
	Max	13,6	29,9	28,8	
	Min	1,2	3,4	17,7	

	Number of stations	9	6	4	
	Median	4,5	19,8	22,9	
Zn	Average	53,0	61,5	71,0	
	St.dev	31,8	7,5	6,7	
	Max	83,7	71,7	80,8	
	Min	9,6	52,4	65,3	
	Number of stations	9	6	4	
	Median	66,0	61,5	68,9	

Appendix 1D: Region IV – Tampen

Shallow stations (depth < 270 m):

Field Stations:		1996	1999	2002	2005
Ba	Average	1393	1077	1450	1484
	St.dev	1930	970	1609	1732
	Max	8959	4327	7620	7407
	Min	23	39	25	26
	Number of stations	153	141	203	106
	Median	450	725	727	679
Cd	Average	0,053	0,053	0,064	0,062
	St.dev	0,056	0,033	0,053	0,045
	Max	0,373	0,262	0,458	0,270
	Min	0,010	0,013	0,006	0,013
	Number of stations	153	141	203	106
	Median	0,037	0,042	0,057	0,047
Cu	Average	11,0	7,8	9,4	12,2
	St.dev	28,7	20,6	26,3	35,2
	Max	225,4	189,0	297,0	261,7
	Min	0,5	0,3	0,8	0,9
	Number of stations	153	141	203	106
	Median	2,4	2,0	3,0	2,6
Hg	Average	0,021	0,014	0,019	0,027
	St.dev	0,027	0,027	0,023	0,029
	Max	0,100	0,163	0,106	0,120
	Min	0,005	0,003	0,003	0,010
	Number of stations	29	35	49	18
	Median	0,010	0,008	0,009	0,014
Pb	Average	12,9	9,3	10,2	11,9
	St.dev	24,3	12,3	15,8	16,1
	Max	172,3	111,5	137,3	104,6
	Min	1,1	2,1	2,3	2,8
	Number of stations	153	141	203	106
	Median	6,1	6,5	6,3	8,4
THC	Average	84,3	39,7	7,8	20,3
	St.dev	472,9	118,1	9,9	48,2
	Max	5517,3	1148,7	43,4	387,2
	Min	0,5	0,5	0,5	0,5
	Number of stations	149	141	56	106
	Median	5,9	8,6	4,0	6,8
Zn	Average	34,7	26,7	27,5	41,9
	St.dev	82,8	67,3	67,0	100,4
	Max	650,5	629,3	686,7	726,0
	Min	1,0	0,5	4,4	5,7
	Number of stations	153	141	203	106
	Median	9,6	9,0	10,5	13,7

Regional/Reference Stations:		1996	1999	2002	2005
Ba	Average	177	191	152	126
	St.dev	139	126	92	91
	Max	452	365	248	289
	Min	31	26	19	32
	Number of stations	8	8	8	8
	Median	169	190	165	118
Cd	Average	0,067	0,060	0,051	0,061
	St.dev	0,039	0,040	0,027	0,041
	Max	0,114	0,138	0,100	0,127
	Min	0,016	0,022	0,024	0,027
	Number of stations	8	8	8	8
	Median	0,06	0,05	0,041	0,05
Cu	Average	1,8	1,3	1,9	1,5
	St.dev	0,7	0,7	0,5	0,3
	Max	3,0	2,2	2,5	2,0
	Min	1,1	0,4	1,2	1,0
	Number of stations	8	8	8	8
	Median	1,6	1,2	1,9	1,6
Hg	Average	0,012	0,005	0,004	0,003
	St.dev	0,011	0,003	0,002	0,000
	Max	0,036	0,010	0,008	0,003
	Min	0,005	0,003	0,003	0,003
	Number of stations	7	7	8	8
	Median	0,008	0,004	0,004	0,003
NPD	Average	0,847	0,017	0,031	0,018
	St.dev	2,214	0,016	0,019	0,015
	Max	5,867	0,053	0,069	0,046
	Min	0,003	0,006	0,009	0,006
	Number of stations	7	7	8	8
	Median	0,011	0,011	0,033	0,010
PAH	Average	0,017	0,021	0,050	0,023
	St.dev	0,008	0,010	0,024	0,013
	Max	0,031	0,039	0,086	0,049
	Min	0,012	0,010	0,015	0,008
	Number of stations	6	7	8	8
	Median	0,013	0,019	0,054	0,019
Pb	Average	6,0	5,4	5,2	5,9
	St.dev	1,6	2,1	1,3	1,9
	Max	8,4	8,3	7,0	9,1
	Min	4,0	2,7	2,9	3,1
	Number of stations	7	8	8	8
	Median	6,0	5,2	5,4	5,8
THC	Average	3,5	3,5	3,5	2,9
	St.dev	2,1	2,1	2,3	1,7
	Max	6,0	6,9	8,0	5,80
	Min	1,0	1,1	0,5	0,9

	Number of stations	8	8	8	8
	Median	3,2	3,2	3,7	2,6
Zn	Average	6,9	6,9	8,0	9,6
	St.dev	3,7	3,3	2,1	2,5
	Max	12,6	11,0	11,2	12,9
	Min	1,0	2,4	5,5	6,0
	Number of stations	8	8	8	8
	Median	6,6	6,6	7,9	9,4

Deep Stations (depth > 274 m):

Field Stations:		1996	1999	2002	2005
Ba	Average	2687	1330	2361	4174
	St.dev	2907	1276	2040	3293
	Max	9095	4679	7620	10750
	Min	265	31	141	3
	Number of stations	39	84	76	45
	Median	956	694	1472	3107
Cd	Average	0,076	0,073	0,089	0,083
	St.dev	0,017	0,021867	0,0353	0,039
	Max	0,150	0,139333	0,23	0,243
	Min	0,048	0,025	0,044	0,047
	Number of stations	39	84	76	42
	Median	0,073	0,074	0,081	0,075
Cu	Average	7,71	6,636	9,955	10,20
	St.dev	5,85	7,187143	9,312304	10,40
	Max	30,90	38,13333	47,00	50,87
	Min	1,83	1,633	2,967	2,71
	Number of stations	39	84	76	42
	Median	6,00	4,63	7,56	6,96
Hg	Average	0,056	0,020	0,045	0,038
	St.dev	0,080	0,012809	0,036818	0,030
	Max	0,247	0,054333	0,16	0,107
	Min	0,005	0,007	0,017	0,010
	Number of stations	8	16	14	13
	Median	0,021	0,018	0,032	0,030
Pb	Average	14,1	10,8	12,2	12,9
	St.dev	13,1	9,0	10,0	11,0
	Max	73,9	52,7	62,1	59,9
	Min	3,1	3,7	3,4	4,6
	Number of stations	39	84	76	42
	Median	11,4	9,1	10,5	9,7
THC	Average	5,07	46,5	29,8	42,1
	St.dev	4,7	272,7	66,6	220,5
	Max	18,0	2500,7	363,0	1790,8
	Min	1,0	0,4	0,5	0,8
	Number of stations	31	85	68	42
	Median	3,3	3,5	7,4	6,3
Zn	Average	27,6	27,2	30,3	42,3
	St.dev	14,2	21,5	25,8	42,7
	Max	93,0	166,4	140,2	207,0
	Min	12,3	2,0	10,3	12,6
	Number of stations	39	84	76	42
	Median	26,6	22,9	25,2	27,0

Regional/Reference Stations:		1996	1999	2002	2005
Ba	Average	332	248	249	220
	St.dev	149	144	120	90
	Max	479	430	378	311
	Min	129	109	107	118
	Number of stations	6	7	6	5
	Median	377	196	264	225
Cd	Average	0,075	0,069	0,076	0,067
	St.dev	0,018	0,018	0,014	0,013
	Max	0,100	0,100	0,096	0,09
	Min	0,048	0,052	0,062	0,053
	Number of stations	6	7	6	5
	Median	0,071	0,064	0,070	0,060
Cu	Average	4,7	3,4	4,8	4,0
	St.dev	1,4	1,3	1,4	1,0
	Max	6,5	5,0	6,6	5,7
	Min	3,4	1,6	3,5	3,3
	Number of stations	6	7	6	5
	Median	4,0	3,0	4,2	3,6
Hg	Average	0,042	0,013	0,012	0,007
	St.dev	0,058	0,002	0,003	0,004
	Max	0,128	0,018	0,018	0,013
	Min	0,006	0,012	0,010	0,005
	Number of stations	4	5	5	5
	Median	0,017	0,012	0,010	0,005
NPD	Average	0,067	0,036	0,039	0,039
	St.dev	0,031	0,019	0,004	0,008
	Max	0,105	0,061	0,043	0,051
	Min	0,035	0,008	0,032	0,031
	Number of stations	4	5	5	5
	Median	0,063	0,037	0,039	0,038
PAH	Average	0,116	0,054	0,089	0,056
	St.dev	0,037	0,026	0,032	0,012
	Max	0,168	0,081	0,139	0,076
	Min	0,078	0,012	0,066	0,044
	Number of stations	4	5	5	5
	Median	0,110	0,064	0,073	0,054
Pb	Average	8,5	6,5	6,9	6,5
	St.dev	3,9	2,2	1,7	1,8
	Max	15,6	9,9	8,8	9,6
	Min	6,0	4,4	4,7	5,1
	Number of stations	6	7	6	5
	Median	6,4	5,8	6,8	6,1
THC	Average	3,3	4,2	2,6	3,5
	St.dev	0,8	0,5	1,0	1,2
	Max	4,4	5,10	3,90	5,07
	Min	2,4	3,6	1,5	1,7

	Number of stations	6	7	6	5
	Median	3,2	4,3	2,3	3,4
Zn	Average	20,4	17,6	18,5	17,8
	St.dev	7,0	5,4	4,3	3,4
	Max	34,3	26,5	24,7	23,7
	Min	15,7	11,4	13,0	15,5
	Number of stations	6	7	6	5
	Median	18,2	16,1	17,7	16,9

Appendix 1E: Region VI – Haltenbanken

Field Stations:		1997	2000	2003	2006
Ba	Average	1006	1626	1088	970
	St.dev.	1392	1649	1388	1492
	Max	7802	7587	8139	8476
	Min	111	199	89	83
	Number of stations	96	114	186	205
	Median	515	1055	528	465
Cd	Average	0,054	0,066	0,067	0,076
	St.dev.	0,018	0,017	0,016	0,019
	Max	0,097	0,113	0,120	0,123
	Min	0,015	0,033	0,033	0,033
	Number of stations	96	114	186	205
	Median	0,057	0,063	0,067	0,073
Cu	Average	10,9	9,0	8,5	10,1
	St.dev.	4,9	4,5	11,4	3,2
	Max	29,9	43,1	154,0	34,1
	Min	6,1	5,0	3,0	4,6
	Number of stations	96	114	186	205
	Median	9,3	8,2	7,0	9,5
Hg	Average	0,017	0,023	0,053	0,024
	St.dev.	0,007	0,007	0,045	0,042
	Max	0,030	0,033	0,297	0,260
	Min	0,007	0,010	0,017	0,010
	Number of stations	15	17	35	35
	Median	0,017	0,023	0,047	0,013
Pb	Average	20,7	18,2	17,2	16,4
	St.dev.	5,2	3,8	5,1	3,5
	Max	50,2	46,0	66,1	38,8
	Min	12,4	8,8	7,0	7,4
	Number of stations	96	114	186	205
	Median	20,4	17,7	17,2	16,5
THC	Average	9,5	85,8	36,3	56,0
	St.dev.	16,3	563,4	277,3	387,9
	Max	105,8	5897,0	3663,3	5250,4
	Min	1,2	1,4	1,6	2,8
	Number of stations	96	114	187	259
	Median	4,0	5,6	4,3	6,0
Zn	Average	46,5	48,6	47,0	48,3
	St.dev.	8,6	13,1	16,5	14,2
	Max	74,8	113,5	149,3	104,3
	Min	31,6	32,8	23,7	23,4
	Number of stations	96	114	186	205
	Median	44,2	43,9	43,5	44,2

Regional/reference Stations:					
		1997	2000	2003	2006
Ba	Average	120	131	134	139
	St.dev.	44	49	29	50
	Max	220	225	182	228
	Min	47	49	88	85
	Number of stations	17	12	13	16
	Median	113	123	125	116
Cd	Average	0,042	0,065	0,073	0,069
	St.dev.	0,016	0,022	0,026	0,015
	Max	0,082	0,098	0,117	0,100
	Min	0,015	0,032	0,034	0,050
	Number of stations	17	12	13	15
	Median	0,043	0,067	0,077	0,073
Cu	Average	8,7	7,7	7,6	9,1
	St.dev.	2,7	2,3	2,7	1,8
	Max	14,7	11,2	12,3	13,3
	Min	3,1	3,1	3,4	6,3
	Number of stations	17	12	13	15
	Median	8,43	7,83	7,90	9,07
Hg	Average	0,020	0,020	0,034	0,018
	St.dev.	0,007	0,004718	0,013	0,007
	Max	0,030	0,028	0,062	0,033
	Min	0,010	0,010	0,020	0,010
	Number of stations	6	12	13	15
	Median	0,02	0,02	0,03	0,02
NPD	Average	0,069	0,058	0,069	0,091
	St.dev.	0,017	0,019	0,019	0,020
	Max	0,085	0,078	0,103	0,115
	Min	0,042	0,020	0,035	0,048
	Number of stations	6	12	13	15
	Median	0,073	0,063	0,071	0,096
PAH	Average	0,123	0,102	0,106	0,095
	St.dev.	0,022	0,028	0,022	0,020
	Max	0,144	0,154	0,149	0,133
	Min	0,086	0,051	0,069	0,069
	Number of stations	6	12	13	15
	Median	0,129	0,100	0,101	0,097
Pb	Average	17,5	17,1	18,1	16,0
	St.dev.	4,7	3,6	3,1	2,8
	Max	28,1	21,4	24,3	20,3
	Min	9,2	10,8	12,2	12,2
	Number of stations	17	12	13	15
	Median	17,1	16,7	18,5	15,5
THC	Average	3,1	3,5	3,5	5,4
	St.dev.	0,9	1,4	0,9	0,9
	Max	4,9	5,9	4,7	7,1
	Min	1,1	1,2	1,8	4,1

	Number of stations	17	12	13	15
	Median	3,0	3,3	3,5	5,3
Zn	Average	45,7	44,8	41,9	44,4
	St.dev.	11,2	13,2	10,0	9,9
	Max	71,6	70,3	64,6	70,4
	Min	22,5	23,3	25,6	31,8
	Number of stations	17	12	13	15
	Median	45,3	41,9	41,3	43,8

Appendix 1F: Region IX – Southern Barents Sea

(Data presented here are from baseline and field-specific monitoring performed before regional monitoring was begun in 2007).

Field Stations:					
		1998	2000	2003	2006
Ba	Average	70,0	72,0	120,2	148,6
	St.dev	31,4	13,8	127,4	137,3
	Max	120,3	97,3	945,3	732,0
	Min	19,3	42,7	67,7	25,7
	Number of stations	29	25	45	35
	Median	67,3	72,0	98,5	113,7
Cd	Average	0,089	0,070	0,105	0,078
	St.dev	0,048	0,040	0,043	0,030
	Max	0,227	0,183	0,269	0,145
	Min	0,027	0,030	0,057	0,025
	Number of stations	29	25	45	35
	Median	0,083	0,050	0,094	0,078
Cu	Average	10,5	8,4	11,3	11,6
	St.dev	4,9	2,2	2,3	5,2
	Max	19,1	13,1	17,3	18,7
	Min	1,9	5,4	6,7	2,5
	Number of stations	29	25	45	35
	Median	9,9	7,9	11,1	13,9
Hg	Average	0,020	0,026	0,038	0,019
	St.dev	0,009	0,007	0,015	0,010
	Max	0,043	0,033	0,062	0,029
	Min	0,003	0,020	0,020	0,005
	Number of stations	29	3	13	8
	Median	0,020	0,023	0,044	0,023
Pb	Average	17,1	14,7	16,5	14,6
	St.dev	8,6	5,7	4,2	5,6
	Max	37,9	30,5	32,3	25,1
	Min	3,2	6,3	11,1	5,3
	Number of stations	29	25	45	35
	Median	16,5	13,9	15,6	16,5
THC	Average	2,5	4,7	**NO DATA**	**NO DATA**
	St.dev	1,2	1,5		
	Max	5,4	9,0		
	Min	0,7	2,5		
	Number of stations	30	25		
	Median	2,0	4,7		
Zn	Average	38,6	44,8	46,3	48,3
	St.dev	17,0	11,4	7,0	20,2
	Max	69,6	65,1	61,9	69,7
	Min	9,8	30,9	35,8	14,3
	Number of stations	29	25	45	35
	Median	35,2	44,6	44,3	59,9

Regional/Reference Stations:					
		1998	2000	2003	2006
Ba	Average	98,0		125	
	St.dev				
	Max	98,0		125,2	
	Min	98,0		125,2	
	Number of stations	1		1	
	Median				
Cd	Average	0,107		0,178	
	Max	0,107		0,178	
	Min	0,107		0,178	
	Number of stations			1	
Cu	Average	11,8		16,1	
	Max	11,8		16,1	
	Min	11,8		16,1	
	Number of stations	1		1	
Hg	Average	0,02		0,081	
	Max	0,020		0,081	
	Min	0,020		0,081	
	Number of stations	1		1	
Pb	Average	22,8		25,2	
	Max	22,8		25,2	
	Min	22,8		25,2	
	Number of stations	1		1	
Zn	Average	46,3		60,0	
	Max	46,3		60	
	Min	46,3		60	
	Number of stations	1		1	
THC	Average	1,39		4,36	
	Max	1,39		4,36	
	Min	1,39		4,36	
	Number of stations	1		1	
PAH	Average	no data		0,124	
	Max	in MOD			
	Min				
	Number of stations			1	
NPD	Average	no data		0,099	
	Max	in MOD			
	Min				
	Number of stations			1	

Appendix 1G: Ekofisk field

Field Stations:		1990	1991	1992	1993	1994	1996	1999	2002	2005
Ba	Average	2030,4	2211,7	2377,7	2372,5	1149,0	2188,7	969,8	1949,1	2347,8
	St.dev	1935,2	2114,8	2089,6	2008,3	1089,6	985,9	502,4	1320,8	1270,0
	Max	7710,0	7600	6665	6937	4129	3996,7	1920,0	4676	3861,0
	Min	274,7	148	94,3	611	131,7	737,7	168,0	277	669,3
	Number of stations	24	23	27	9	23	18	17	17	7
Cd	Average	0,04	0,06	0,10,10	0,04	0,01	0,02	0,01	0,04	0,04
	St.dev	0,05	0,06	0,19	0,04	0,01	0,01	0,00	0,04	0,04
	Max	0,25	0,26	0,87	0,13	0,06	0,05	0,02	0,16	0,09
	Min	0,01	0,01	0,00	0,01	0,00	0,01	0,01	0,01	0,01
	Number of stations	24	23	27	9	23	18	16	17	7
Cu	Average	1,8	2,1	3,3	1,8	1,2	2,0	1,2	7,11	2,3
	St.dev	2,7	2,9	5,3	1,6	1,0	1,2	,04	16,5	1,7
	Max	13,5	13,1	24,9	5,9	4,6	6,1	2,0	70,1	5,3
	Min	0,3	0,5	0	0,6	0,3	0,8	0,6	1,0	,06
	Number of stations	24	23	27	9	23	18	17	17	7
Hg	Average	16,5	0,06	0,05	16,3	0,05	0,01	0,02	0,03	0,03
	St.dev	2,7	0,02	0,02	10,3	0	0,01	0,00	0,01	0,03
	Max	58,9	0,12	0,17	41,5	0,05	0,02	0,02	0,05	0,07
	Min	7,6	0,05	0,05	8,6	0,05	0,01	0,02	0,02	0,01
	Number of stations	24	23	27	9	23	3	3	4	3
Pb	Average	0,1	24,5	37,7	0,1	14,0	16,0	11,5	15,3	14,7
	St.dev	0,01	20,0	47,4	0,02	6,4	5,8	2,9	5,7	5,3
	Max	0,17	86,4	219,4	0,17	36,3	32,1	16,3	30,5	22,2
	Min	0,1	6,2	7,12	0,1	6,5	7,6	7,2	8,6	6,7
	Number of stations	24	23	27	9	23	18	17	17	7

THC	Average	36,7	72,9	167,9	44,1	27,2	22,1	15,1	61,7	19,3
	St.dev	100,3	135,5	564,9	111,8	43,8	11,3	10,0	141,0	40,4
	Max	380,8	602,9	3022,0	342,1	174,1	50,9	51,6	601,0	188,4
	Min	1,8	4,7	3,92	2,0	3,1	8,3	6,9	9,7	3,5
	Number of stations	24	38	29	9	27	18	17	17	20
Zn	Average	19,1	22,4	39,7	18,2	11,5	11,8	9,3	21,6	22,7
	St.dev	22,0	24,3	84,1	14,4	9,3	72	3,3	21,0	15,0
	Max	110,9	111,3	433,0	54,7	48,5	33,0	17,6	82,0	47,6
	Min	7,1	5,9	5,35	8,4	4,4	3,0	3,4	7,4	7,6
	Number of stations	24	23	27	9	23	18	17	17	7

Appendix 1H: Statfjord A field

Field Stations:									
		1990	1991	1992	1993	1996	1999	2002	2005
Ba	Average	2835,3	2824,2	3027,9	3351,8	3070,7	1984,2	1954,9	2714,0
	St.dev	2062,3	2062,6	1962,0	1918,1	1860,3	928,4	1225,3	2181,2
	Max	7205	7000	6600	7330	6503,3	3075	4073,3	6740
	Min	460	443	537	1040	631,7	669,7	244,7	524,3
	Number of stations	11	11	11	11	11	13	13	8
Cd	Average	0,15	0,19	0,18	0,11	0,07	0,07	0,09	0,05
	St.dev	0,13	0,05	0,12	0,13	0,10	0,06	0,10	0,04
	Max	0,49	0,2	0,51	0,49	0,37	0,26	0,41	0,14
	Min	0,05	0,04	0,09	0,03	0,03	0,04	0,04	0,03
	Number of stations	11	11	11	11	11	13	13	8
Cu	Average	138,1	55,1	65,9	41,1	47,0	32,1	42,7	49,6
	St.dev	285,1	91,5	131,0	57,8	67,6	50,6	81,3	87,3
	Max	901,0	306,0	445,0	193,0	225,4	189,0	297,0	261,7
	Min	2,1	2,2	2,8	3,4	4,4	2,0	3,0	3,6
	Number of stations	11	11	11	11	11	13	13	8
Hg	Average	**NO DATA**	0,04	0,04	0,04	0,03	0,03	0,05	0,03
	St.dev	**IN MOD**	0,07	0,03	0,05	0,03	0,02	0,03	0,01
	Max		0,27	0,13	0,15	0,05	0,04	0,07	0,03
	Min		0,02	0,02	0,01	0,01	0,01	0,03	0,02
	Number of stations		11	11	11	2	2	2	2
Pb	Average	23,4	24,4	38,2	51,1	36,0	22,8	22,2	25,5
	St.dev	37,5	30,4	71,8	88,7	46,3	28,0	27,1	29,4
	Max	133,0	103,0	247,0	311,0	163,9	111,5	104,6	95,3
	Min	5,5	5,8	6,0	7,9	9,5	6,5	6,2	8,3
	Number of stations	11	10	11	11	11	13	13	8

THC	Average	921,4	453,6	36,7	194,0	147,5	60,5	68,2	31,4
	St.dev	2014,2	962,3	35,3	240,9	256,3	68,2	151,0	49,0
	Max	6700,0	3110,0	108,0	736,0	802,7	232,3	554,2	170,7
	Min	6,4	7,2	7,9	19,5	9,3	12,3	7,3	5,6
	Number of stations	11	11	11	11	11	13	13	11
Zn	Average	187,1	181,9	245,4	148,5	149,0	108,5	112,9	153,6
	St.dev	416,8	308,6	518,8	201,8	190,0	166,7	188,5	236,8
	Max	1430,0	1041,0	1770,0	701,0	650,5	629,3	686,7	726,0
	Min	15,9	17,5	17,0	17,0	21,6	13,9	12,3	21,6
	Number of stations	11	11	11	11	11	13	13	8

Appendix 1I: Snorre TLP field

Field Stations:		1991	1992	1993	1994	1995	1996	1999	2002	2005
Ba	Average	3076,8	2217,5	2616,6	3008,5	3678,2	5818,7	3023,9	3651,5	5366,3
	St.dev	3126,9	2464,1	2155,8	2079,1	2716,8	2470,5	1229,0	1719,6	3346,4
	Max	9343	9367	7000	6920	8510	8797,3	4652,3	6186,7	10 160
	Min	274	218	231	372	307	2578,3	1124,7	1093,3	1021,7
	Number of stations	21	21	21	21	21	8	9	9	9
Cd	Average	0,10	0,09	0,08	0,02	**No Data**	0,09	0,09	0,10	0,09
	St.dev	0,06	0,03	0,02	0,02	**In MOD**	0,02	0,02	0,05	0,05
	Max	0,33	0,19	0,15	0,05		0,15	0,14	0,23	0,23
	Min	0,06	0,06	0,05	0,01		0,07	0,07	0,07	0,06
	Number of stations	21	21	21	21		8	9	9	9
Cu	Average	7,5	7,6	**No Data**	5,4	10,8	13,1	12,0	15,3	13,4
	St.dev	10,6	8,0	**In MOD**	1,8	10,1	9,5	11,0	14,8	15,1
	Max	48,6	31,4		11,0	45,7	30,9	37,8	47,0	48,6
	Min	2,7	3,1		3,7	3,9	5,4	4,3	4,9	4,5
	Number of stations	21	21		21	21	8	9	9	9
Hg	Average	0,07	0,06	0,09	0,02	**No Data**	0,13	0,04	0,12	0,09
	St.dev	0,08	0,03	0,10	0,01	**In MOD**	0,16	0,02	0,06	0,03
	Max	0,37	0,14	0,44	0,03		0,25	0,05	0,16	0,11
	Min	0,05	0,05	0,05	0,01		0,02	0,02	0,08	0,07
	Number of stations	21	21	21	21		2	2	2	2
Pb	Average	20,4	16,6	21,3	8,0	21,2	25,3	17,6	20,2	18,3
	St.dev	34,9	22,4	27,4	4,9	24,7	21,9	14,1	19,2	18,4
	Max	146,7	82,5	102,4	23,0	110,0	73,9	51,2	62,1	59,9
	Min	6,1	5,5	6,2	2,6	6,6	9,1	7,0	3,6	6,3
	Number of stations	21	21	21	21	21	8	9	9	9

THC	Average	10,3	6,5	22,2	10,4	9,9	8,6	45,5	18,5	30,5
	St.dev	13,1	7,1	32,8	5,8	7,1	5,9	55,8	19,3	58,1
	Max	47,9	29,0	97,7	28,3	31,1	16,1	174,0	61,9	194,4
	Min	1,0	1,3	3,3	5,1	2,6	1,8	4,2	3,6	2,4
	Number of stations	21	21	8	21	19	6	9	9	11
Zn	Average	29,5	26,9	28,2	26,6	47,4	41,0	46,5	42,3	50,7
	St.dev	25,4	16,5	23,0	6,1	28,8	24,3	47,0	39,7	55,0
	Max	130,0	76,1	114,2	38,1	147,0	93,0	166,4	140,2	168,0
	Min	17,5	16,1	12,3	18,8	22,2	22,2	19,0	18,0	18,9
	Number of stations	21	21	21	21	21	8	9	9	9

Appendix 2. Number of wells drilled in each region during the 1996-2006 monitoring period.

Sources of data are indicated by color in the legend at the top of the Table.

SFT's årlige rapporter "Utslipp på norsk kontinentalsokkel" 1996-2002
OLF - Environmental Web
Akvaplan-Niva, Unilab, DNV (2000). Environmental Status of the Norwegian Offshore Sector based on the Petroleum Regional Monitoring Programme, 1996-1998.
OLF’s Miljørapport 2006. Olje- og gassindustriens miljøarbeid. Fakta og utviklingstrekk
Miljøundersøkelse APN: www.sft.no
No data available or not relevant

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Region 1	21	24	22	10	14	20	21	19	35	53	45
Region 2	13	18	11	14	13	18	20	23	16	13	14
Region 3	49	43	32	31	31	50	41	25	15	17	14
Region 4	40	65	37	52	60	53	16	50	40	26	17
Region 5										7	12
Region 6	10	16	28	29	21	16	11	19	27	21	20
Region 9									1	7	2
All Regions	133	166	130	136	139	157	109	136	134	144	124
Sum All	**1 508**										

Appendix 3. Summary of discharges by type of discharge, region, and year for the period 1996-2006. Sources of data are indicated by color in the legend at the top of Appendix 2.

Cuttings from Water-based Drilling Operations (tons)

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Region 1	26 944,7	13 632,0	2 630,7	2 133,0	6 605,9	465,0	1 350,8	7 716,8	5 931,0	492,0	9 224,0
Region 2	10 273,0	9 026,0	6 841,0	6 309,0	20 663,0	4 996,0	16 495,0	15 458,0	13 957,0	10 180,0	11 915,0
Region 3	41 610,3	20 392,0	21 559,3	31 670,0	43 512,4	4 722,6	11 997,2	35 603,0	17 794,3	25 036,0	19 272,0
Region 4	15 242,0	21 606,0	12 663,0	15 468,0	90 151,0	17 567,0	17 685,0	10 687,0	14 488,6	2 869,0	8 293,0
Region 5										3 592,2	5 322,0
Region 6	14 209,0	10 592,0	14 865,0	33 603,0	13 292,0	9 712,0	675,0	14 852,0	23 700,0	8 765,0	9 944,0
Region 9									614,0	6 887,0	0,0

Cuttings from Synthetic-based Drilling Operations (tons)

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Region 1	966,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Region 2	3 992,0	2 352,0	4 553,0	0,0	2 672,0	6 244,0	695,0	0,0	0,0	0,0	0,0
Region 3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Region 4	8 315,0	7 956,0	17 318,0	28 023,0	14 168,0	9 147,0	6 670,0	5 042,0	2 451,0	0,0	0,0
Region 5										0,0	0,0
Region 6	0,0	0,0	0,0	0,0	0,0	2 225,0	1 351,2	0,0	0,0	0,0	0,0
Region 9									0,0	0,0	0,0

Drilling Fluids from Water-based Drilling Operations (tons)

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Region 1	9 090,0	25 918,0	10 176,4	9 665,5	5 107,7	7 791,0	5 209,2	2 746,0	28 520,0	1 337,0	38 659,5
Region 2	26 969,5	3 645,0	16 211,0	17 193,3	21 478,6	17 516,2	32 749,6	41 372,0	34 244,8	21 516,0	42 828,0
Region 3	91 323,5	62 525,3	55 815,3	43 301,3	86 622,6	98 068,1	84 260,8	104 012,0	40 335,0	50 802,0	39 985,0
Region 4	35 044,4	56 249,0	26 867,2	36 968,1	91 661,7	43 221,1	39 629,2	40 522,0	19 136,0	8 057,0	24 203,0
Region 5										3 697,4	9 846,0
Region 6	23 519,7	24 224,4	36 414,5	65 009,8	57 681,0	40 957,8	24 715,6	49 372,0	49 935,0	17 173,0	35 860,0
Region 9									1 432,0	18 287,0	5 298,0

Drilling Fluids from Synthetic-based Drilling Operations (tons)

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Region 1	1 732,7	697,4	36,9	1 557,0	3 848,0	0,0	0,0	0,0	0,0	0,0	0,0
Region 2	1 266,4	251,2	662,0	0,0	0,0	251,0	0,0	0,0	0,0	0,0	0,0
Region 3	1 101,5	1 398,0	1 938,8	8 877,0	1 195,0	1 342,0	4 254,0	0,0	0,0	0,0	0,0
Region 4	2 105,0	9 173,0	19 261,0	10 439,0	0,0	0,0	1 420,0	4 395,3	826,0	0,0	0,0
Region 5										0,0	0,0
Region 6	183,0	0,0	39,1	0,0	0,0	5 267,0	5 259,0	0,0	0,0	0,0	0,0
Region 9									0,0	0,0	0,0

Discharge of Drilling- and Well fluids (tons)

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
All Regions	152 859	180 906	139 826	156 042	179 804	152 077	143 237	103 226	74 379	63 116	72 641

Number of Acute Spills Discharged to Sea from installations in the respective regions

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Region 1	53	63	53	193	49	51	91	73	49	21	32
Region 2	31	28	64	66	55	38	51	36	26	43	30
Region 3	110	79	80	89	78	112	77	62	40	59	47
Region 4	62	86	79	71	99	62	60	62	31	50	39
Region 5										7	12
Region 6	22	51	64	53	51	59	55	66	52	64	58
Region 9									0	1	2
All Regions	278	307	340	472	332	322	334	299	198	245	220
SUM	3347										

Chemicals incl. Water-based Drilling Fluids Discharged to Sea (tons)

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Region 1	243,6	3,5	2,1	39,0	58,0	22,0	9,2	48,7	1,8	35,0	11,6
Region 2	20,7	28,4	85,4	39,0	9,0	9,0	15,1	18,2	2,5	3,4	0,5
Region 3	60,9	105,2	85,9	118,0	29,0	35,7	168,4	185,8	36,1	14,5	77,1
Region 4	71,8	173,8	41,6	113,0	270,0	95,9	36,5	217,2	72,4	217,2	97,2
Region 5										0,0	17,0
Region 6	30,0	40,1	245,1	307,0	288,0	134,3	68,1	296,5	67,0	66,4	144,9
Region 9									0,0	0,2	0,0
All Regions	30,0	40,1	245,1	307,0	288,0	134,3	68,1	296,5	67,0	66,6	144,9
SUM	4 733,6										

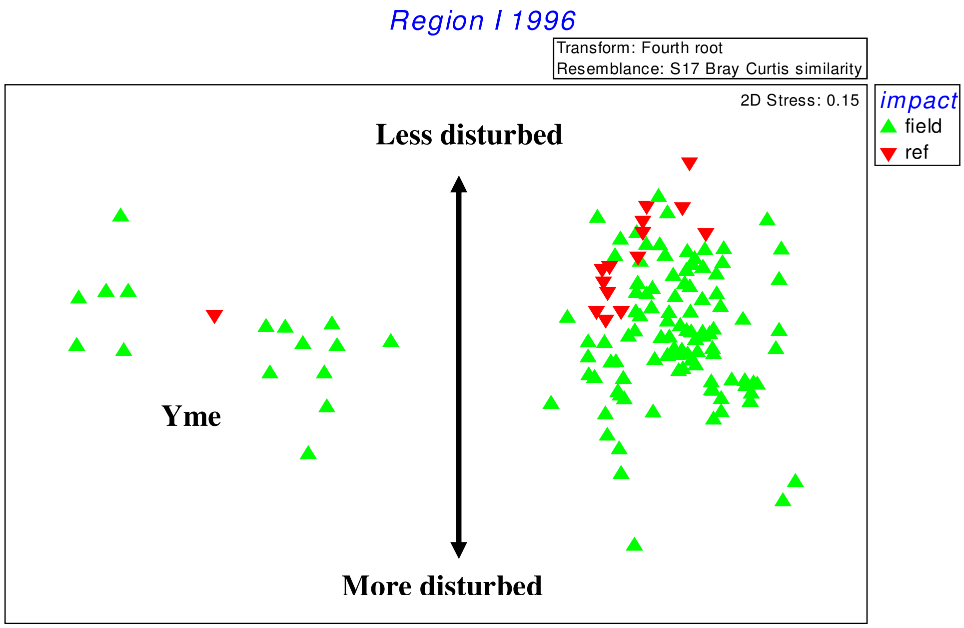
Oils incl. Oil-based Drilling Fluids Discharged to Sea (tons)

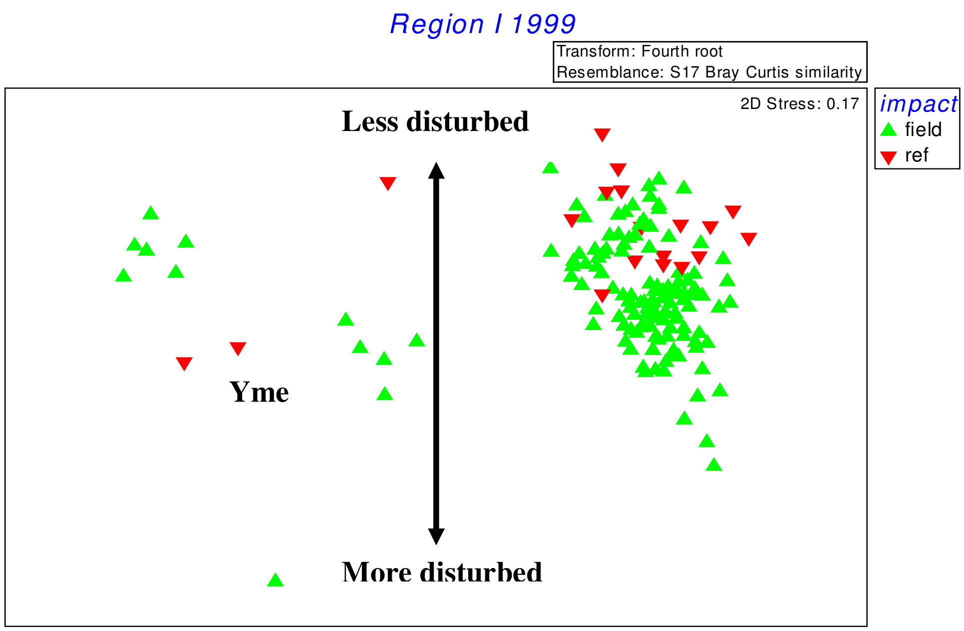
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Region 1	8,0	7,2	82,5	3,0	3,0	3,3	5,1	24,3	14,2	17,7	9,3
Region 2	7,7	35,2	36,2	5,0	3,0	2,0	6,1	78,2	53,2	4,0	0,8
Region 3	18,7	16,8	11,3	96,0	7,0	20,7	11,5	7,9	7,9	7,0	91,5
Region 4	5,8	26,6	32,0	58,0	17,0	5,9	45,4	65,0	221,7	31,1	8,6
Region 5										0,0	0,0
Region 6	2,4	16,2	23,2	6,0	2,0	16,4	40,8	891,7	18,3	355,6	112,2
Region 9									0,0	0,0	0,0
All Regions	2,4	16,2	23,2	6,0	2,0	16,4	40,8	891,7	18,3	355,6	112,2
SUM	2 707,2										

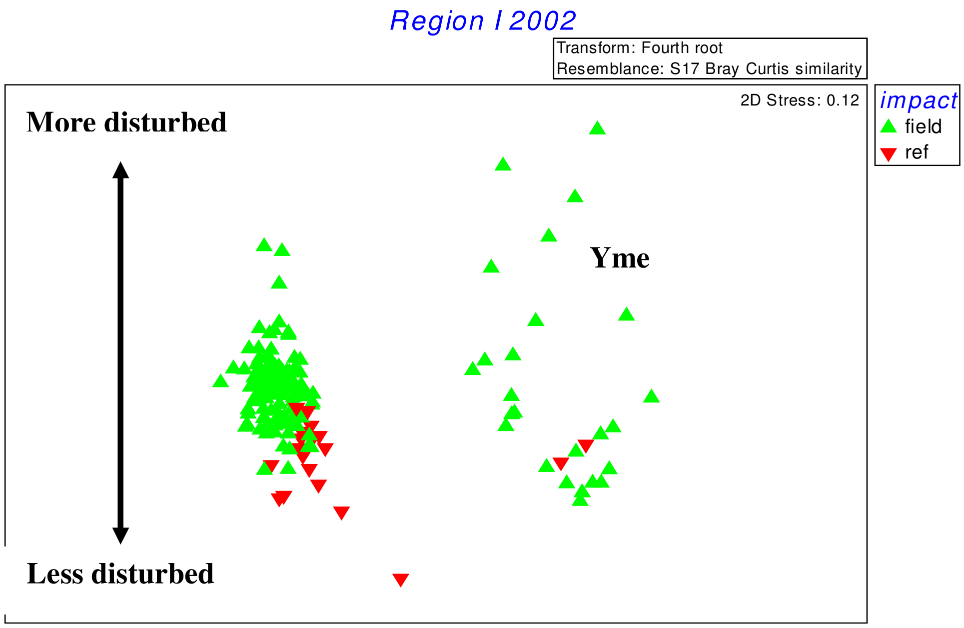
Discharge of Barite (tons)

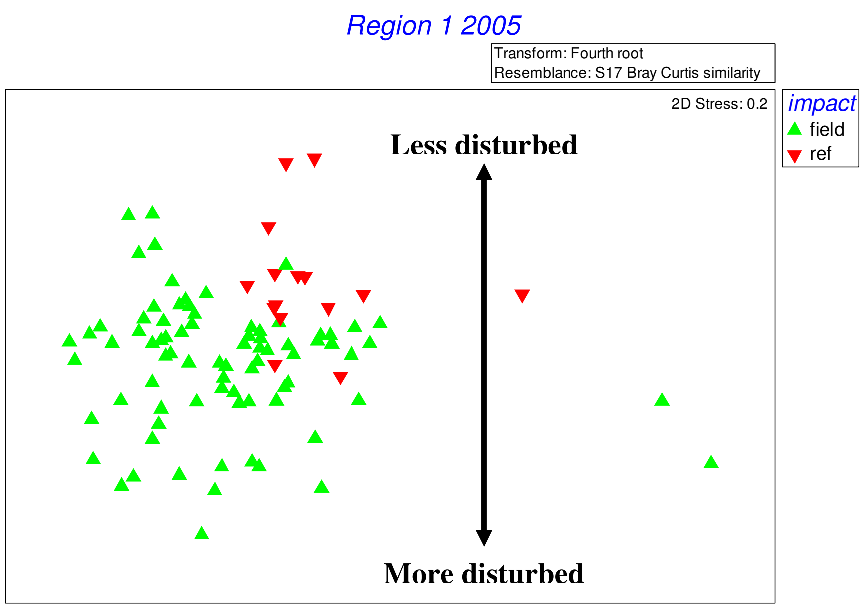
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Region 1	7 321	7 054	3 460	1 936	677	820	845	2 893	1 500	75	3 336
Region 2	7 302	4 915	6 944	1 452	4 268	3 655	3 044	3 683	2 619	642	1 718
Region 3	14 173	10 293	54 305	22 366	8 538	8 057	5 606	1 067	1 040	4 268	2 586
Region 4	15 713	16 098	20 100	30 426	23 165	12 253	8 678	11 040	3 069	982	3 160
Region 5										642	1 474
Region 6	4 339	10 256	20 046	11 608	12 221	9 268	5 007	6 373	8 514	1 278	4 097
Region 9									0	0	0

Appendix 4. Multidimensional scaling plots of community structure by region and year. Red symbols indicate reference stations and green symbols represent field stations. Gradients implied by the point distribution, where present, are indicated in the figures, as are clusters representing a single field.

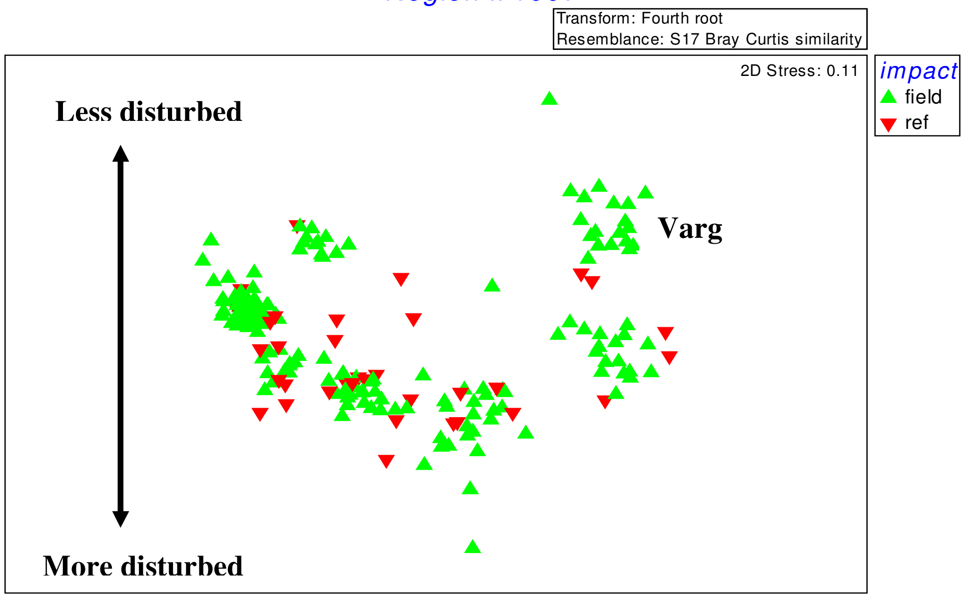




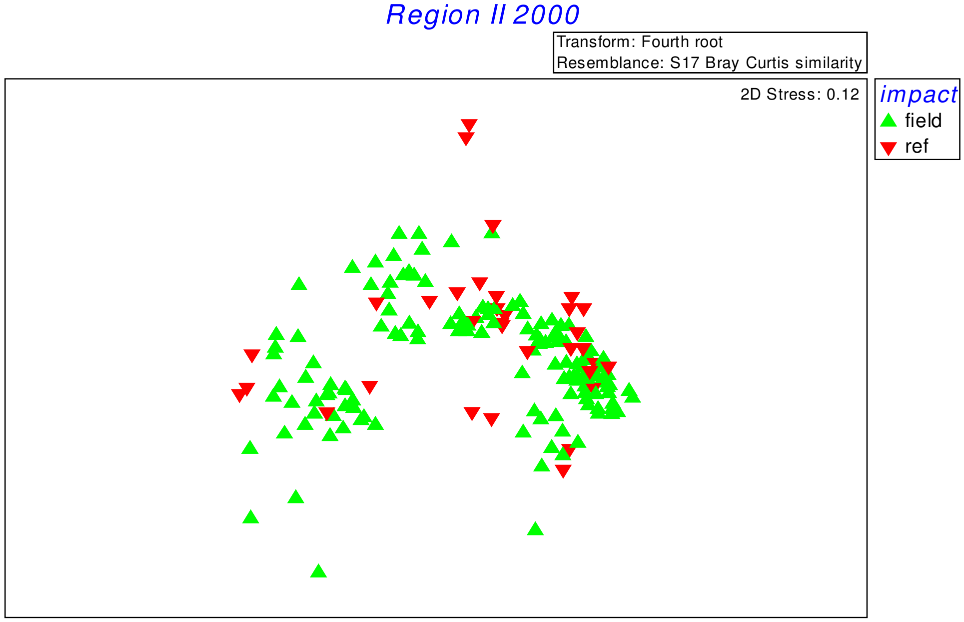

Region I 2002
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity
2D Stress: 0.12
impact
field
ref
More disturbed
Yme
Less disturbed

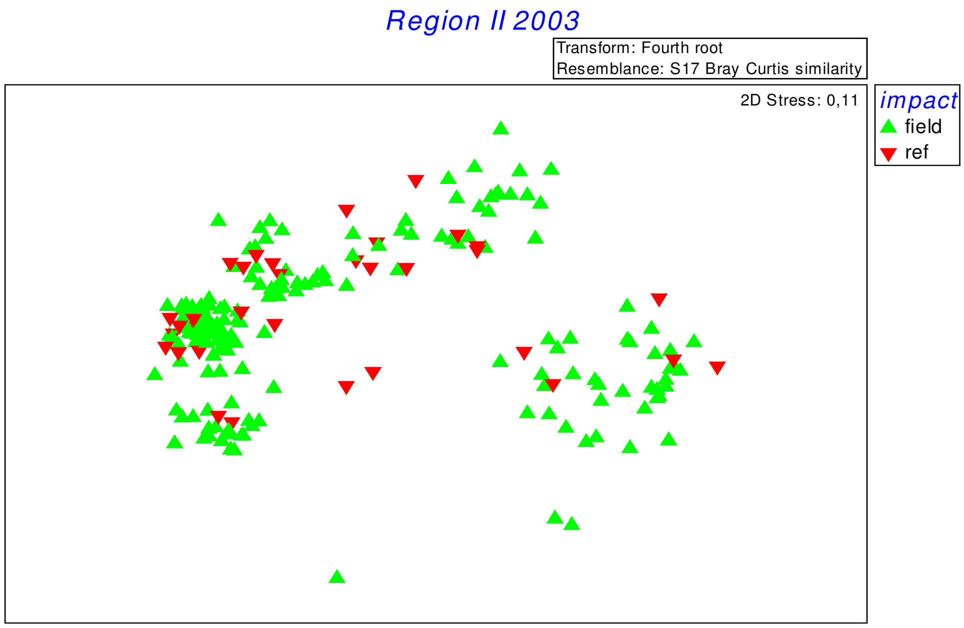

Region 1 2005
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity
2D Stress: 0.2
impact
field
ref
Less disturbed
More disturbed

Region II 1997

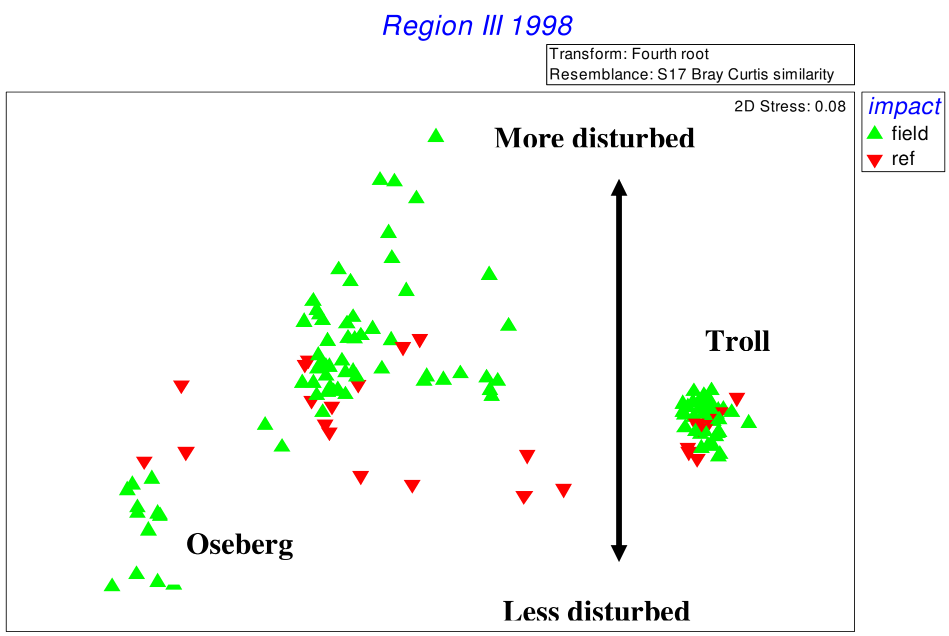


Region II 2000

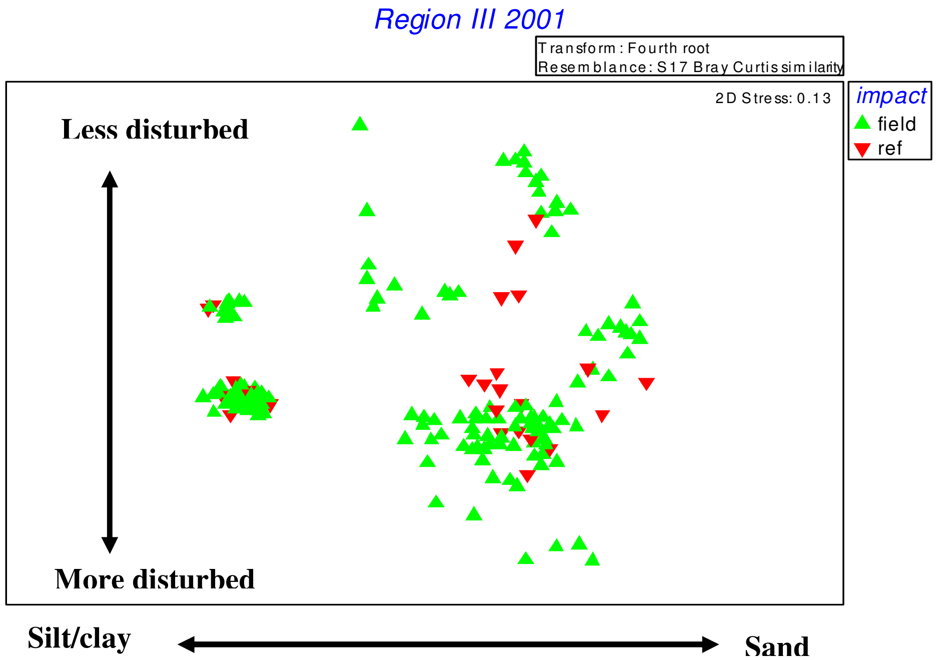


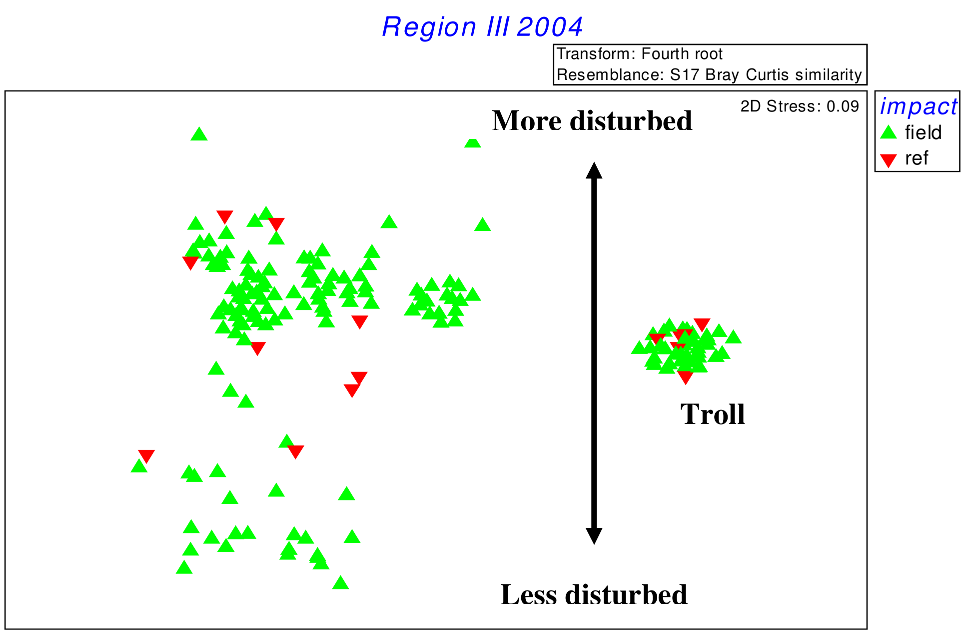


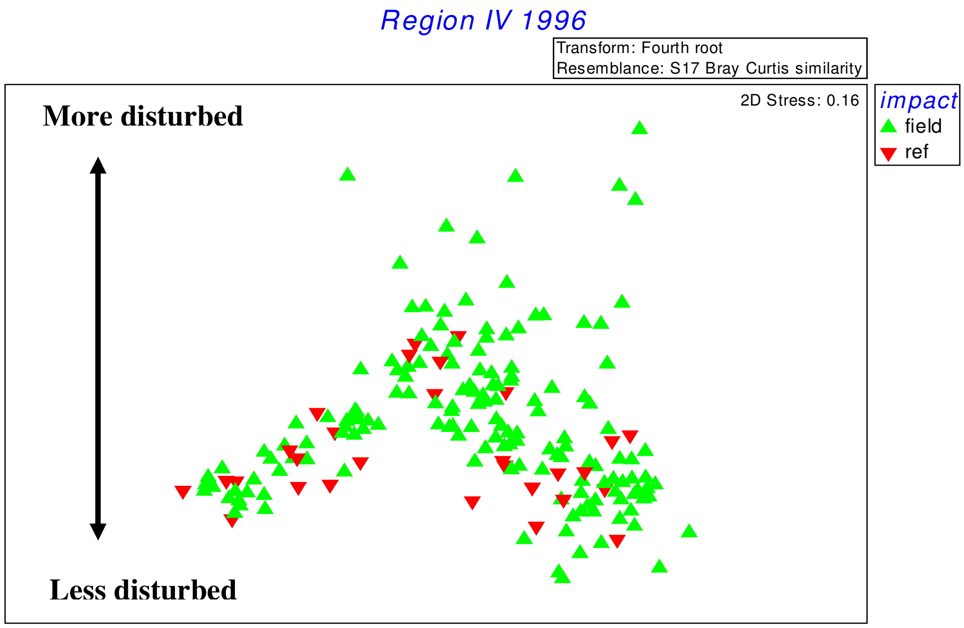
Region II 2003
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity
2D Stress: 0,11
impact
field
ref

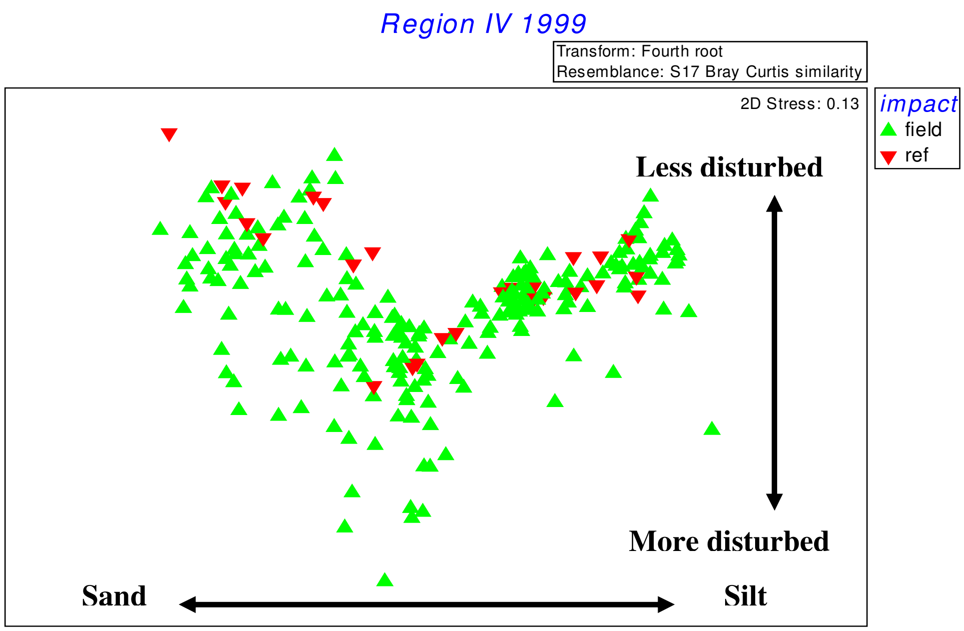


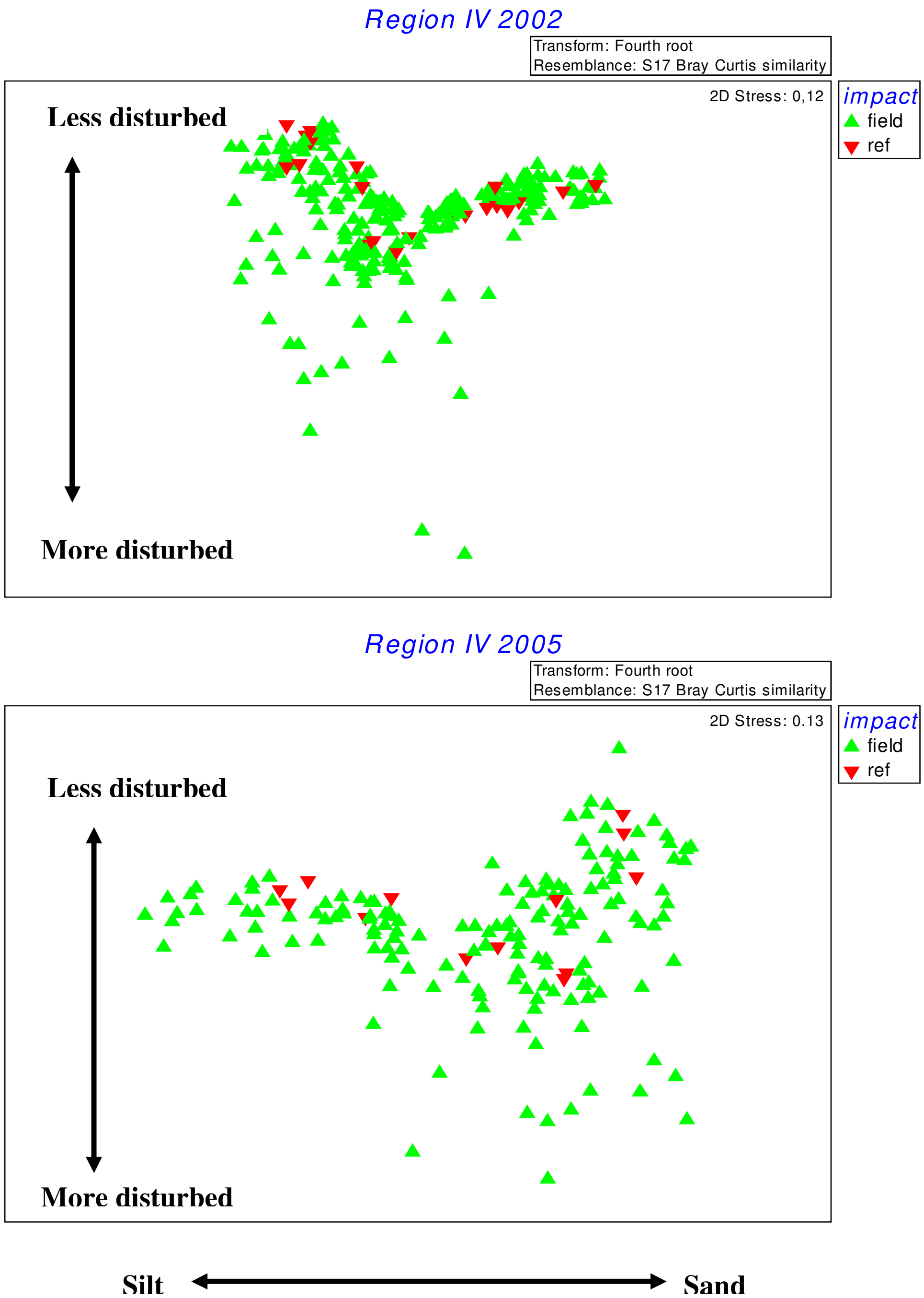
Region III 1998
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity
2D Stress: 0.08
impact
field
ref
More disturbed
Troll
Oseberg
Less disturbed

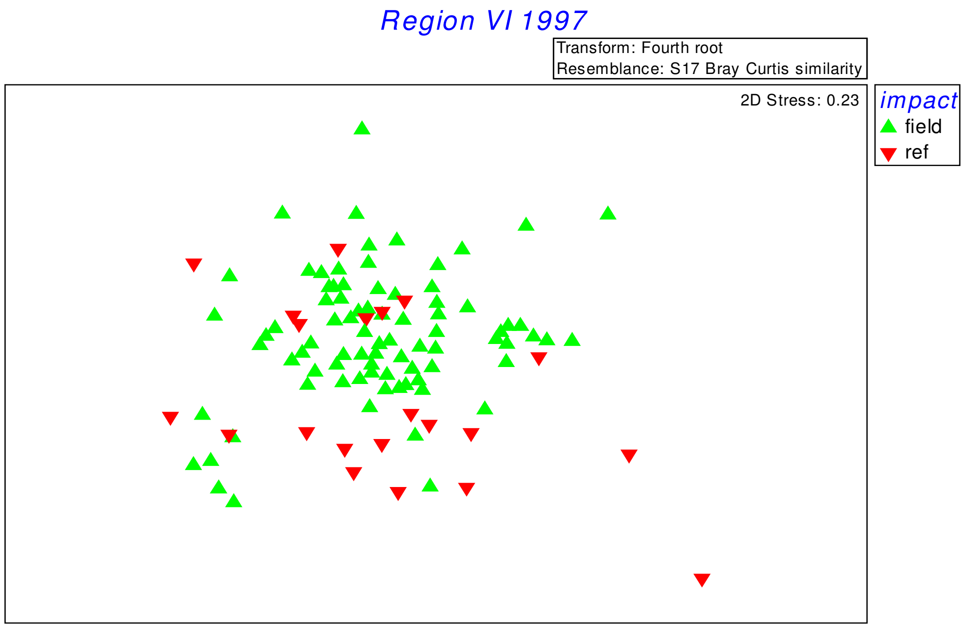

Region III 2001
Transform : Fourth root
Resemblance : S17 Bray Curtis similarity
2D Stress: 0.13
impact
field
ref
Less disturbed
More disturbed
Silt/clay
Sand

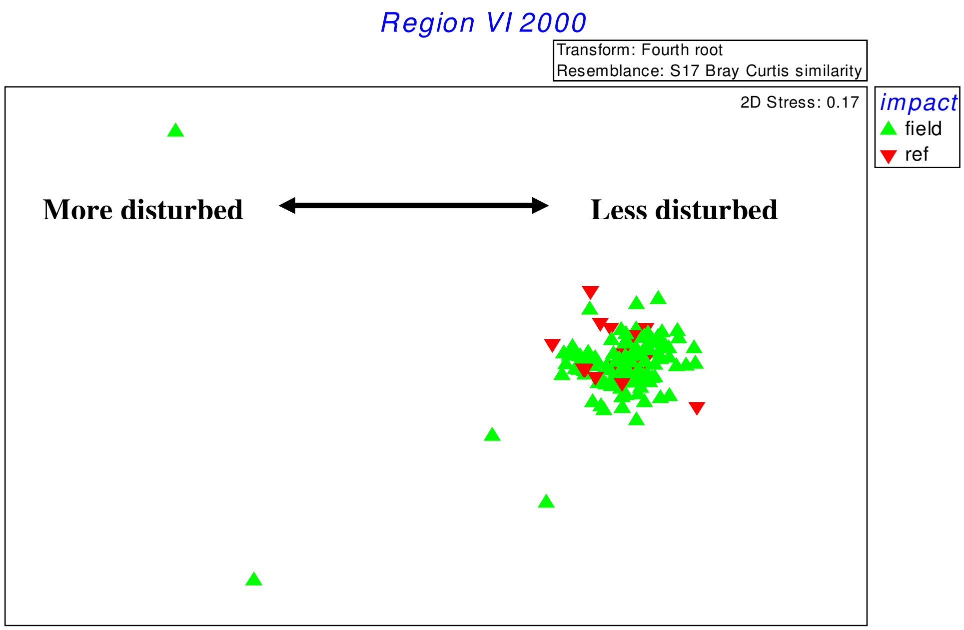

Region III 2004
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity
2D Stress: 0.09
impact
field
ref
More disturbed
Troll
Less disturbed

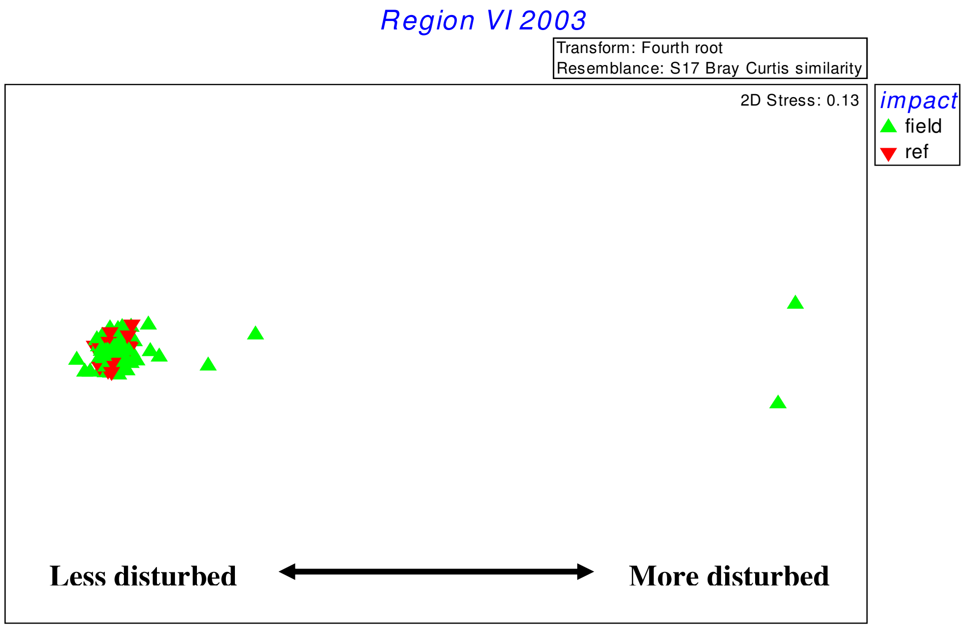

Region IV 1996
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity
2D Stress: 0.16
impact
field
ref
More disturbed
Less disturbed

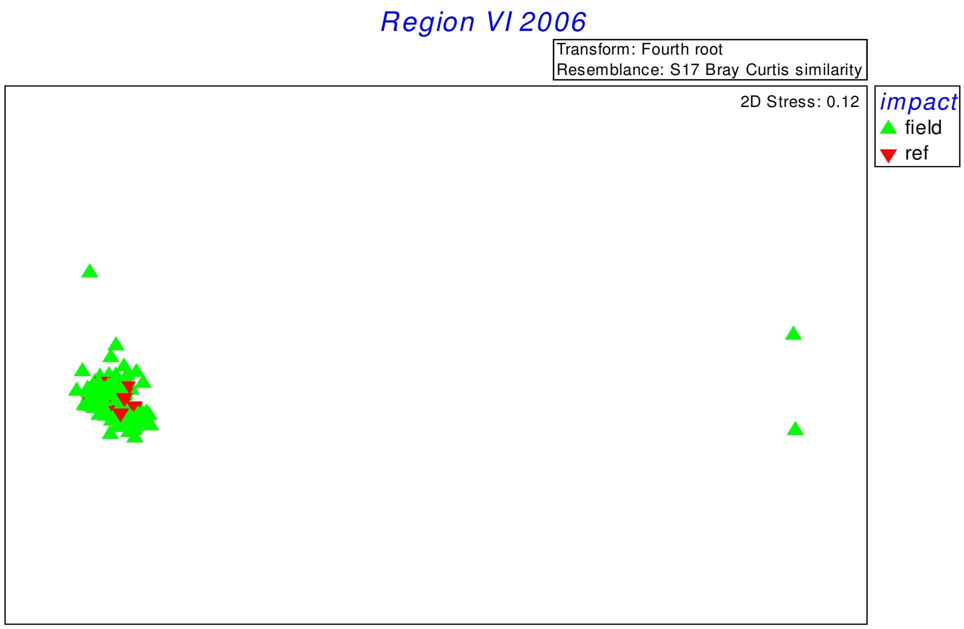

Region IV 1999
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity
2D Stress: 0.13
impact
field
ref
Less disturbed
More disturbed
Sand
Silt


Region IV 2002
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity
2D Stress: 0,12
impact
field
ref
Less disturbed
More disturbed
Region IV 2005
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity
2D Stress: 0.13
impact
field
ref
Less disturbed
More disturbed
Silt
Sand

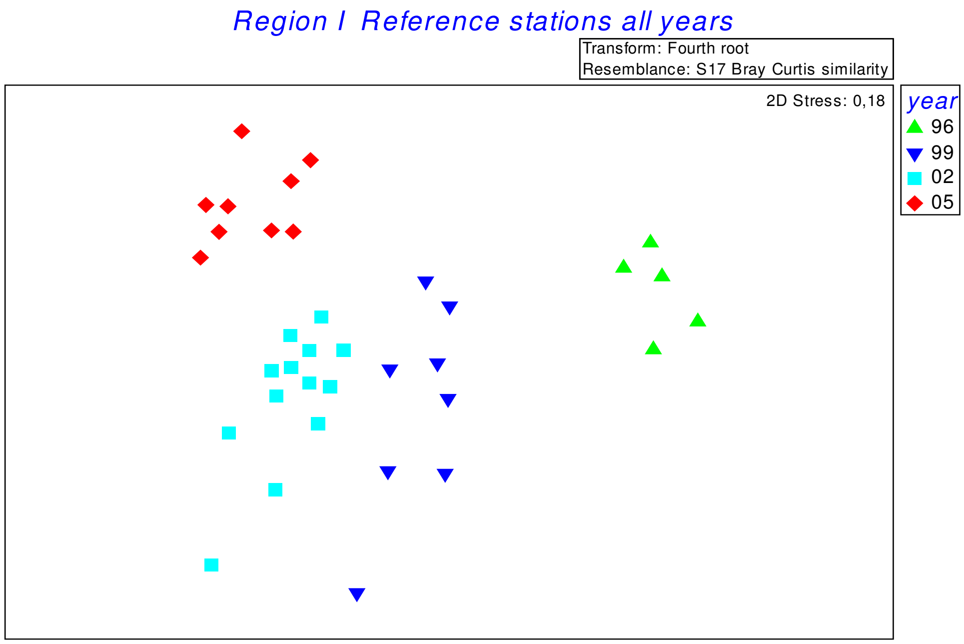

Region VI 1997
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity
2D Stress: 0.23
impact
field
ref

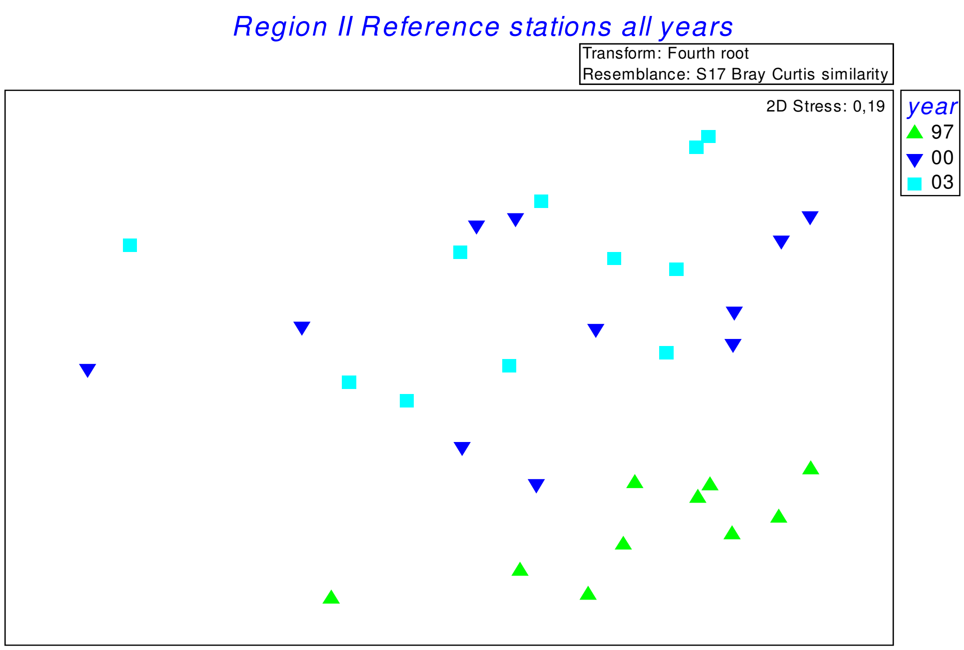

Region VI 2000
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity
2D Stress: 0.17
impact
field
ref
More disturbed
Less disturbed

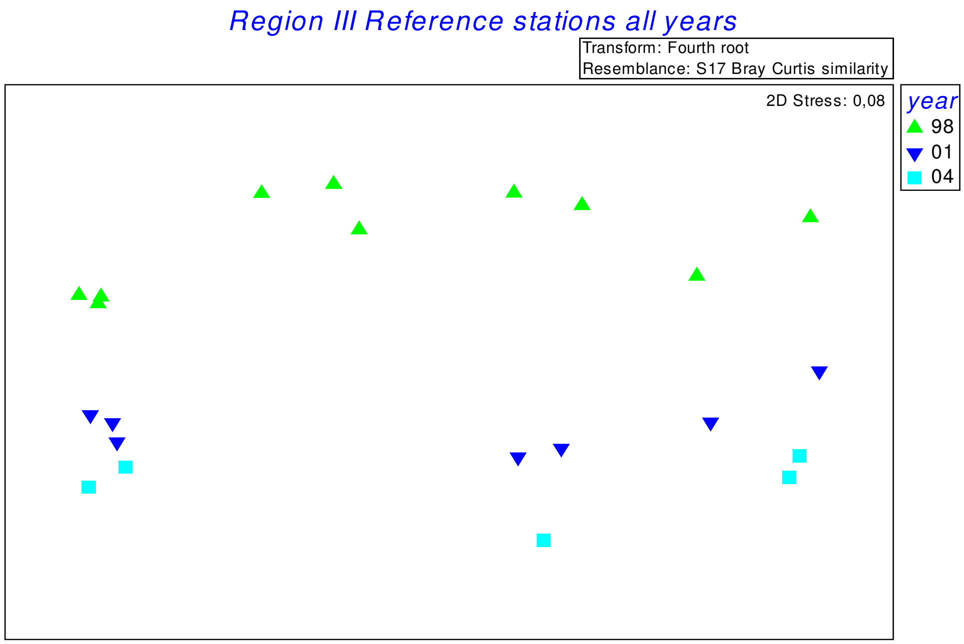

Region VI 2003
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity
2D Stress: 0.13
impact
field
ref
Less disturbed
More disturbed

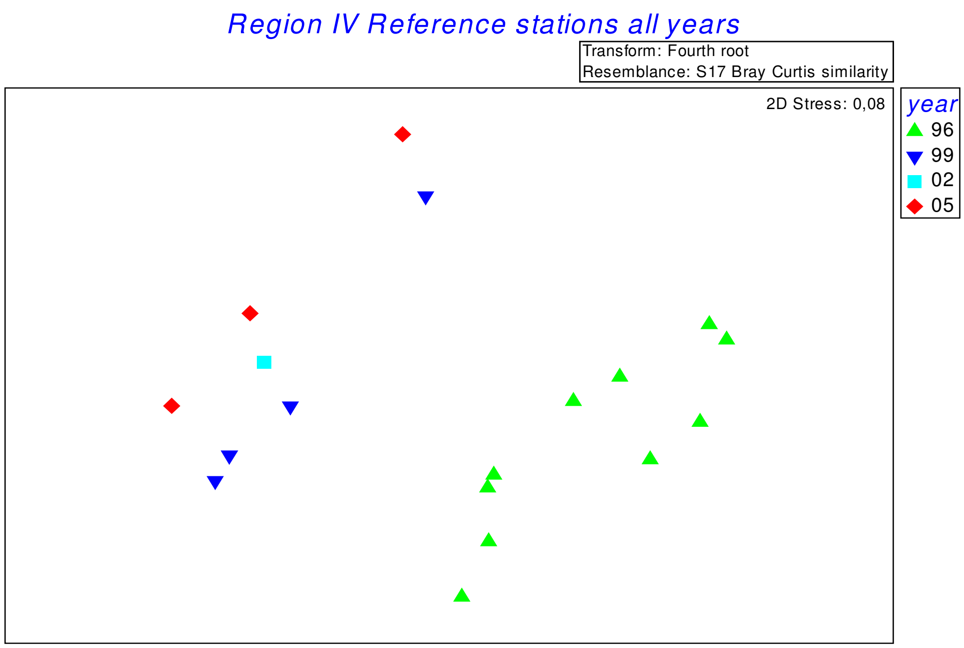

Region VI 2006
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity
2D Stress: 0.12
impact
field
ref

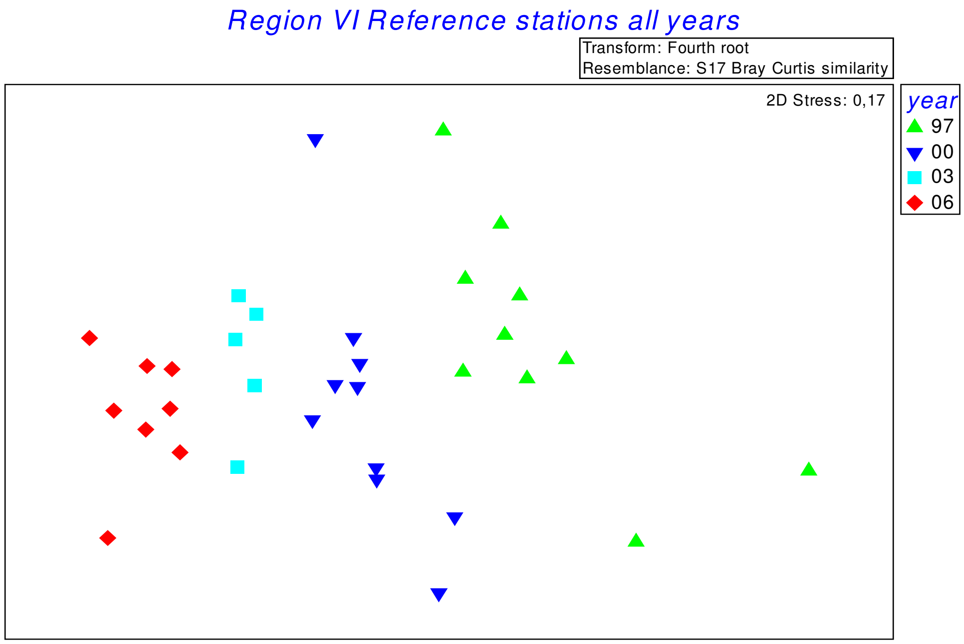
Appendix 5. MDS plots of community structure at reference stations for each region. Symbols indicate different years of sampling. ANOSIM analysis indicated all years significantly different from each other ($p < 0.05$) for Regions I, II, VI. In Region III, 1998 is significantly different from 2001 and 2004. In Region IV 1996 is significantly different from 1999 and 2005. All other pairwise comparisons for Regions III and IV are not statistically significant. Note that the differences among years shown here is far less than differences among regions shown in Figure 13.



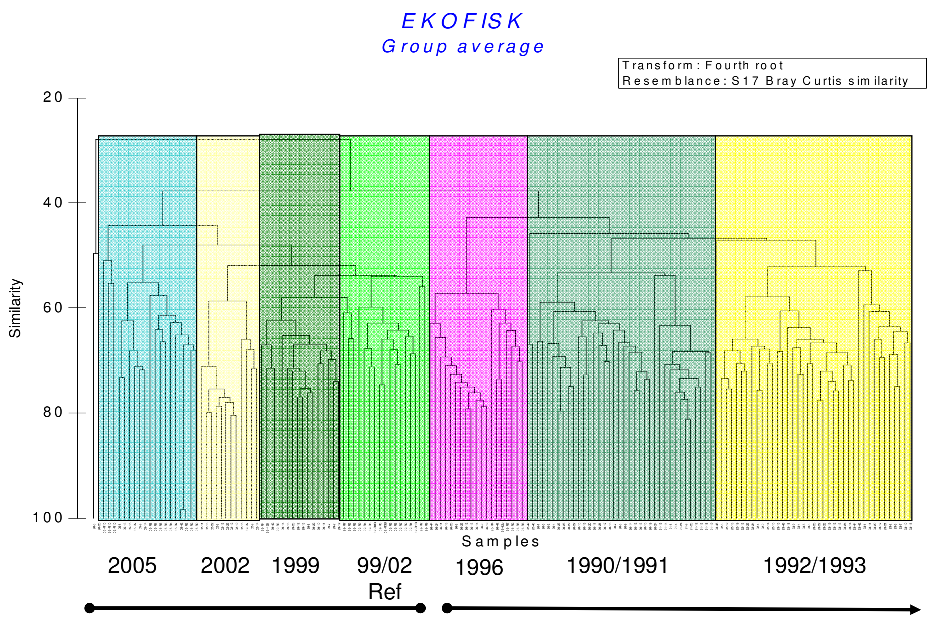


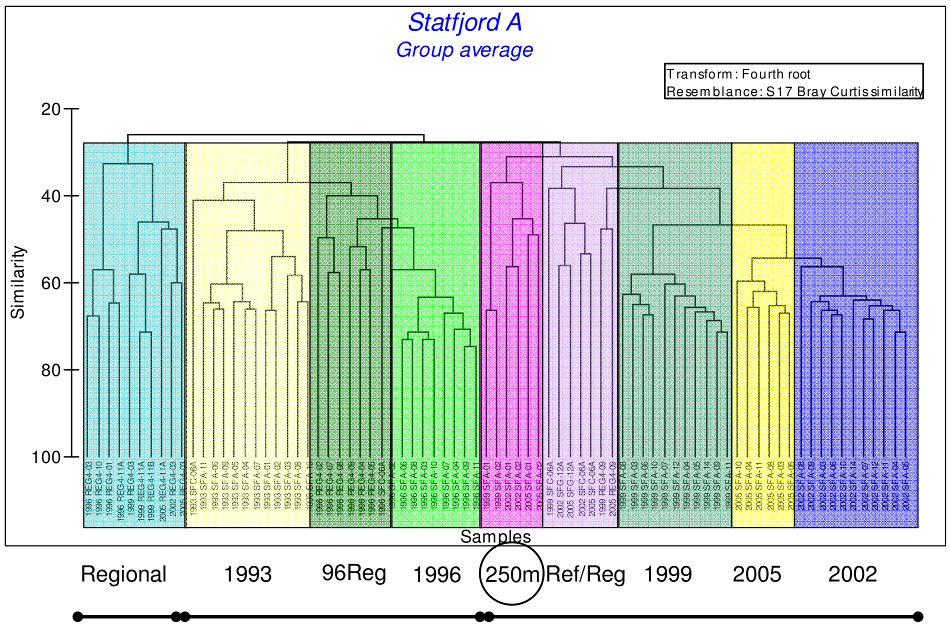

Region III Reference stations all years
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity
2D Stress: 0,08
year
98
01
04

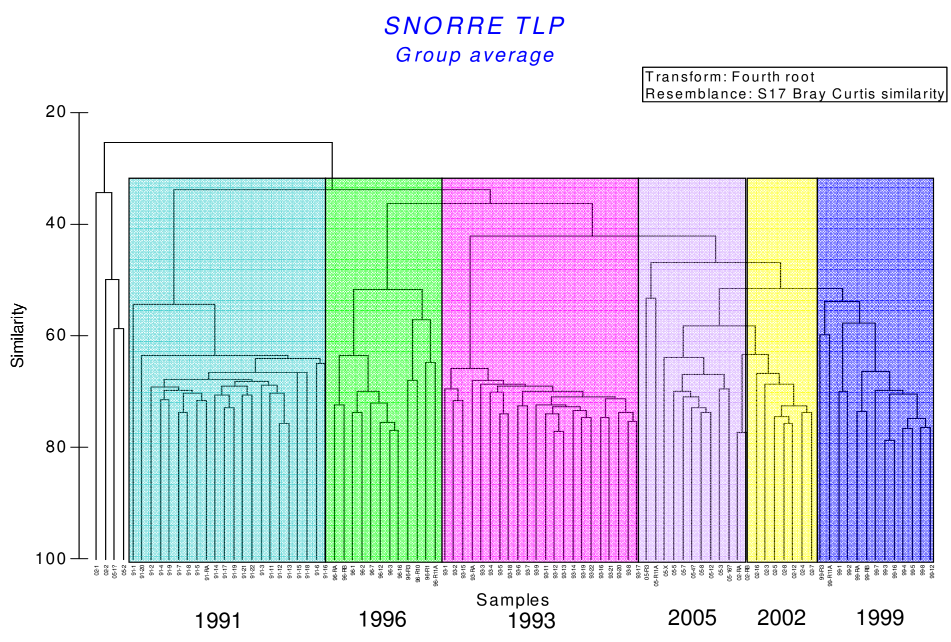

Region IV Reference stations all years
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity
2D Stress: 0,08
year
96
99
02
05


Region VI Reference stations all years
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity
2D Stress: 0,17
year
97
00
03
06

Appendix 6. Cluster diagrams for faunal communities for each sample from case study fields. Color shading indicates samples that correspond to the year (or more specific) label below. Solid lines indicate main groupings delineated by similarity clustering algorithm. 'Ref' and 'Regional' refer to reference stations, '250' indicates stations 250 m from the field installation. In all three fields, samples after 1996 form one major grouping while samples collected from 1990-1996 form a separate group. See text for more details.




Statfjord A
Group average
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity
Similarity
Samples
Regional
1993
96Reg
1996
250m
Ref/Reg
1999
2005
2002


SNORRE TLP
Group average
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity
Similarity
Samples
1991
1996
1993
2005
2002
1999

Appendix 7. List of Regions, their delineation along the coast, and representative fields within each.

Region number	Region name	Latitudinal range (ºN)	Major fields
I	Ekofisk	56 - 58	Ekofisk, Eldfisk, Gyda, Valhall, Yme
II	Sleipner	58 - 60	Balder, Frigg, Sleipner, Varg
III	Oseberg	60 - 61	Brage, Oseberg, Troll, Veslefrikk
IV	Tampen	61 - 62	Gullfaks, Snorre, Statfjord, Tordis, Vigdis
VI	Haltenbanken	64 - 66	Draugen, Heidrun, Åsgard
IX	Southern Barents Sea	70 - 72	Goliat, Nucula, Snøhvit