Environmental monitoring survey of oil and gas fields in Region II in 2009

Summary report

Contract: 4501751349

UNI RESEARCH AS
Section of Applied Environmental Research
Thormøhlensgate 49
5006 Bergen
Phone: 55 58 44 05 Fax: 55 58 45 25

Bergen, March 2010

Content

1. Summary 3
2. Introduction 4
3. Materials and methods 7
4. Results 8
   Regional sampling sites 8
   Field specific sampling sites 9
   The region 13
5. Conclusions and recommendations 18

1. Summary

The oil companies Statoil ASA, ExxonMobil Exploration and Production Norway AS, Total E&P Norge AS, Talisman Energy Norge AS and Marathon Petroleum Norge AS commissioned Section of Applied Environmental Research at UNI RESEARCH AS to undertake the monitoring survey of Region II in 2009. Similar monitoring surveys in Region II have been carried out in 1996, 2000, 2003 and 2006.

The survey in 2009 included in total 18 fields: Rev, Varg, Sigyn, Sleipner Vest, Sleipner Øst, Sleipner Alfa Nord, Glitne, Grane, Balder, Ringhorne, Jotun, Vale, Skirne, Byggve, Heimdal, Volve, Vilje og Alvheim. Sampling was conducted from the vessel *MV Libas* between May 18 and May 27. Samples were collected from in totally 137 sampling sites, of which 15 were regional sampling sites. Samples for chemical analysis were collected at all sites, whereas samples for benthos analysis were collected at 12 fields.

As in previous surveys, Region II is divided into natural sub-regions. One sub-region is shallow (77-96 m) sub-region, a central sub-region (107-130 m) and a northern subregion (115-119 m).
The sediments of the shallow sub-region had relatively lower content of TOM and pelite and higher content of fine sand than the central and northern sub-regions. Calculated areas of contamination are shown for the sub-regions in Table 1.1.

The fields Sigyn, Sleipner Alfa Nord, Glitne, Grane, Balder, Ringhorne, Jotun, Skirne, Byggve, Vilje og Alvheim showed no contamination of THC. At the other fields there were minor changes from 2006.

The concentrations of barium increased in the central sub-region from 2006 to 2009, also at fields where no drilling had been undertaken during the last years. The same laboratory and methods are used during the three last regional investigations. The changes in barium concentrations may be due to high variability of barium concentrations in the sediments. This is supported by relatively large variations in average barium concentrations at the regional sampling sites in the central sub-region between the monitoring surveys. No contamination of other metals were observed at the fields Rev, Glitne, Grane, Balder, Jotun, Skirne and Byggve and at the other fields the concentrations were lower or stayed at the same levels as in 2006. In some cases, the sampling sites did not reach clean sediments and as a result the estimation of contaminated areas became uncertain.

The composition of the benthic fauna was examined at Rev, Varg, Sigyn, Sleipner Øst, Glitne, Grane, Balder, Ringhorne, Jotun, Volve, Vilje og Alvheim. The high numbers of individuals that were observed at several regional and field specific stations in 2006, decreased in 2009 as a result of natural oscillations in the fauna. Diversity was generally high and no disturbance was observed at any of the examined fields in 2009.

An extra sampling site was examined at Ringhorne in 2009, in connection to previous oil leakage from the sea-bottom. The THC-level was high at this sampling site as in 2006 and the bottom fauna was poor in 2009. However, the conditions at this site did not affect the areas that were covered by the grid of monitoring sites.

Radioactive isotopes were examined at Jotun and Varg in addition to two regional sampling sites RII06 and RII09. The radioactivity levels were generally low, with the exception of lead in one grab sample from RII09.

Table 1. The table presents estimated contamination of THC, barium and other metals and disturbance of benthic fauna in Region II from 1997 to 2009. When the areas are evaluated, it should be considered that some of the numbers from 2009 are calculated as minimum-areas.

Area	Year	THC	Ba	Other metals	Fauna
Northern sub-region (Vale)	**2001**	0,00	0,00	0,00	0,00
	2003	0,00	1,77	0,39	0,00
	2006	0,00	0,05	0,10	0,00
	2009	0,05	0,59	0,25	-
Shallow sub-region	**1997**	1,32	15,13	0,14	0,43
	2000	1,91	4,42	0,25	0,15
	2003	0,58	1,67	0,29	0,15
	2006	0,21	1,25	0,84	0,00
	2009	0,89	7,67	0,40	0,00
Central sub-region	**1997**	2,40	6,69	3,76	0,59
	2000	3,17	13,08	1,25	0,62
	2003	8,08	10,37	5,22	0,12
	2006	0,33	1,48	1,14	0,00
	2009	0,08	3,47	1,12	0,00

2. Introduction

The operators in Region II, Statoil ASA, ExxonMobil Exploration and Production Norway AS, Total E&P Norge AS, Talisman Energy Norge AS and Marathon Petroleum Norge AS commissioned in 2009 an environmental monitoring survey of Region II from UNI Research AS, Section of applied environmental research-marine (SAM-marin). Region II is situated on the Norwegian sector of the North Sea (Figure 1). The investigation in 2009 covered a total of 18 fields and the region as an entity. This was the fifth regional environmental monitoring survey in this region. Similar investigations in Region II have previously been carried out in 1997, 2000, 2003 and 2006.

The objective of this investigation was to collect sediment samples and analyze the samples with regard to content of oil hydrocarbons, heavy metals and benthic fauna, in order to determine the environmental status and seabed conditions at each installation and for the entire region. In addition, some sediment samples were collected to examine the occurrence of radioactive isotopes of lead, radium and thorium. The results of this investigation are compared to earlier investigations to illuminate changes of importance. The collected material from this investigation is available as reference for coming surveys and for future assessments of environmental status and possible changes of status.

18 fields were examined in 2009, of which three (Volve, Vilje and Alvheim) were included in the regional investigation of Region II for the first time (Figure 2). In total, samples were collected from 137 field specific sampling sites and 15 regional sampling sites (Table 2 and Figure 1). At Ringhorne samples were collected from one sampling site where a leakage of oil from the sea floor had previously occurred.

The collected samples were examined with regard to physical properties, chemical contents and benthic fauna. The collection and examination of the samples were performed in accordance to ”Activity regulations, Technical appendix 2: Sediment monitoring” and the quality assurance and accreditation procedures at SAM-marin in Bergen and Eurofins Norsk Miljøanalyse as in Moss.

Table 2. The table gives an overview of the fields and the regional sampling sites with and without connection to a field. The regional sampling sites RII07 and RII08 are assigned Sleipner Vest and Glitne, respectively.

Operator	Field	Number of sampling sites	Regional sampling sites assigned to field	Regional sampling sites not assigned to field
Talisman	Varg	11	VAR-14R	
	Rev (Varg sør)	10		
Statoil	Heimdal	6	HEM-22R	
	Vale	6		
	Grane	8	GRA-14R	
	Sleipner Øst and Loke	13	SLE-41R	
	Sleipner Vest	3		RII07
	Sleipner Alfa Nord	6	ALF-15- ref	
	Glitne	5		RII08
	Volve	13		
	Vilje	14		
ExxonMobil	Balder	5	BAL-27R	
	Jotun	8	JOT-30R	
	Ringhorne	10		
	Sigyn	5	SIG-17R	
Total	Skirne	5		
	Byggve	6		
Marathon	Alvheim	11		
All	Regional sampling sites			RII03
				RII04
				RII06
				RII09
				RII10

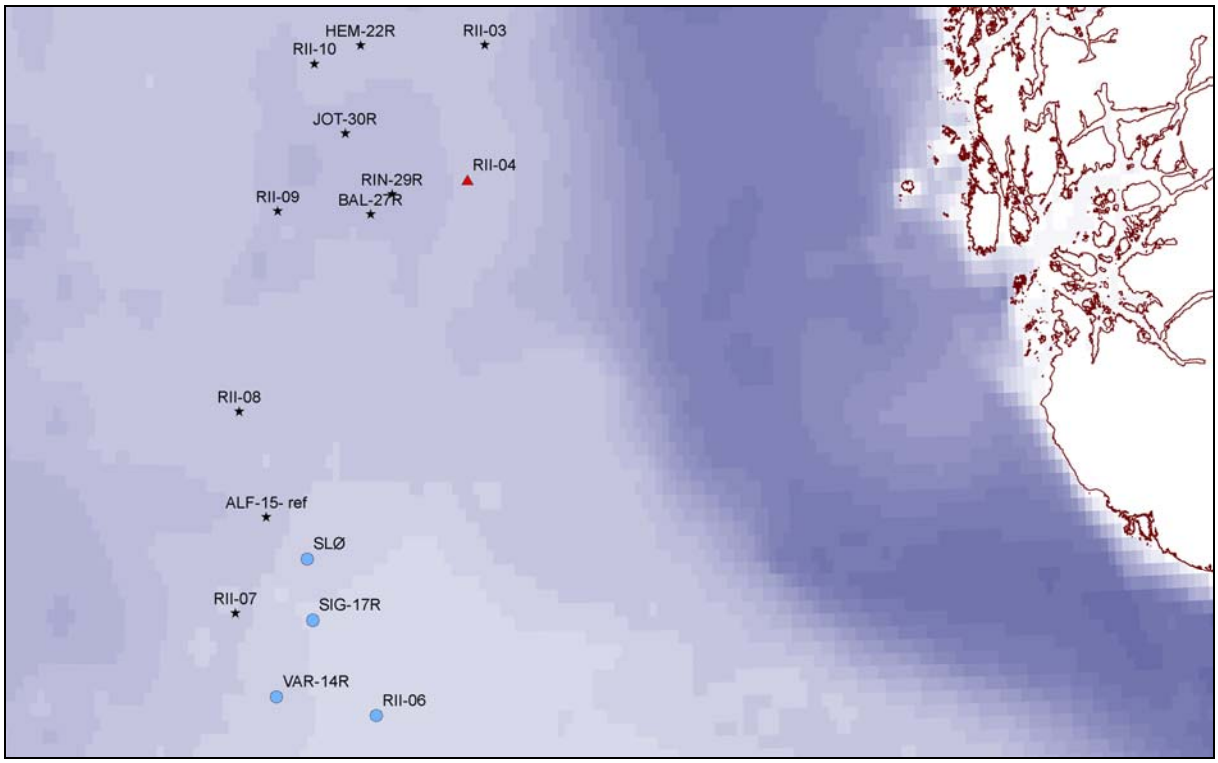

Figure 1. An overview of regional sampling sites, seen in relation to the coastline of southwest Norway. The sampling sites in the shallow sub-region are marked with blue circles, in the central sub-region with black stars and the northern sub-region with red triangle. Mapsource ArcGis.

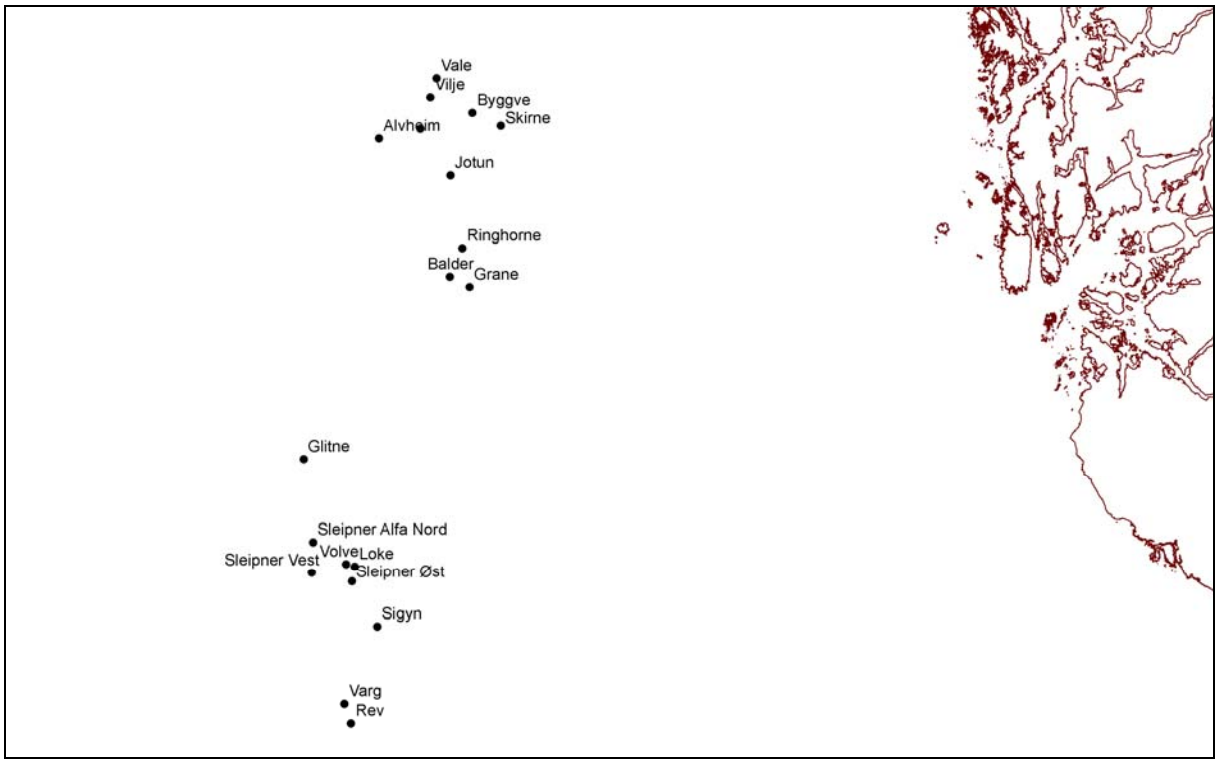

Figure 2. Location of the examined fields in Region II in 2009. Mapsource ArcGis.

3. Materials and methods

Region II is located from 58° N to 60° N at the Norwegian sector of the North Sea. Figure 1 presents the positions of the examined regional sampling sites and Figure 2 presents the field positions in relation to the coastline. The water depth of the collection sites varied between 77 m and 130 m.

The collection of samples was conducted from M/V *Libas* that was hired from the Lie-group AS by StatoilHydro ASA. The cruise started from Liaskjæret in Fjell County on May 18th and ended May 27th. Sampling crew from UNI Research AS and Eurofins Norsk Miljøanalyse AS participated. The survey cruise started at the regional sampling site RII-03 and ended at Rev.

Positioning of the vessel was performed as informed in the programme for the survey (ED 50 UTM zone 31 N). By the help of DGPS and DP class 1 the vessel was held in position (± 3 m). Because of conflicts between installations at the seabed, or large quantities of stones in the samples, the original positions were moved at 5 sampling sites (see cruise report). The surveyor from Fugro Survey AS looked after the positioning of the vessel and calculated new directions and distances for the changed positions. The positions of each sampling site are given in the appendix of the cruise report. The water depth was measured by help of the echo sounder of the vessel.

Sampling was conducted at 137 field specific sampling sites and 15 regional sampling sites. An extra sampling site at Ringhorne was included in the survey of 2009. A full set of samples from one sampling site included 5 samples for biological analyses, 3 samples for chemical analyses and 1 mixed sample for geological analysis (collected from the 3 samples used for chemical analyses). Totally, 545 samples were collected for biological analyses, 494 samples for THC-analyses, 467 samples for heavy metals (Cu, Cr, Zn, Ba, Pb and Cd), 155 samples for Hg-analyse, 155 samples for NPD/PAH-analyses and 109 samples for geological analyses. 18 samples were also collected for radioactive isotope analyses. In total, 1943 samples were collected.

The sediment samples were collected using 0.1 m^2 van Veen grabs with volumes of 23 litres (grab with long arms) and 22 litres (grab with short arms). Some of the samples were collected using a dual-purpose grab with two chambers, of which one was 0.1 m^2 for biological sampling. The top of the van Veen grab can be opened to give access to the surface of the sample. Samples were accepted when the grab arrived to the surface, in a closed condition with free space above the sample.

The samples examined for chemical analyses (THC, PAH/NPD and heavy metals, mercury included), were collected from the top layer (0-1 cm) of the sample. The samples for radioactivity measurements were collected from the upper 2 cm. After enclosing and labelling, the samples were frozen at ÷20 °C. The samples were kept frozen until further processing in the laboratory.

The samples for geological analyses and TOM were taken with a spoon from the top of the upper 5 cm of the sediments. These samples were also kept frozen until further processing in the laboratory.

Grab samples for biological analysis were emptied on a working table, where the content was washed through sieves of 5 and 1mm, both with circular holes. After each sampling the sieves were thoroughly cleaned. Material caught by the sieves, was collected with a spoon and kept in a plastic container. Borax and 4 percent formalin were added to the samples. The plastic containers were kept in transport boxes until the possessing started in the laboratory on shore.

Relevant information of each sample was noted in the cruise journal (see the cruise report).

4. Results

Regional sampling sites

The regional sampling sites are included to the survey in order to provide a measure of the environmental condition in the region and utilizing this knowledge to separate contaminated and uncontaminated sediment. This information is also used when partitioning a larger region into sub-regions, in order to adjust the marginal values to fit the natural conditions at each installation. This assumes that the regional sampling sites are unaffected by spills from oil- and gas activity in the area.

The results from the survey divided Region II into three sub-regions; a relatively shallow southern sub-region (77-96 m); a deeper central sub-region (107-130m) and a north eastern sub-region with depths from 115 m to 119 m. Sediments of the shallow region contained more fine sand and less TOM and pelite than in the central and northern sub-regions (Table 3).

The average THC content at the regional sampling sites varied between 0.1 and 9.8 mg/kg (Table 3). The average THC concentration for all the regional sampling sites was 4.0 ± 3.2 mg THC/kg dry sediment. The average THC contents were 1.6 ± 2.1 mg/kg, 5.1 ± 3.1 mg/kg and 2.8 ± 0.2 mg/kg, at the shallow, central and northern sub-regions respectively. There were small changes compared to the results from 2006.

The metals copper, chrome, zinc, barium, lead, cadmium and mercury occurred in the following minimum maximum intervals at the regional sampling sites in 2009 (table 3): Copper from 0.5 to 3.8 mg/kg, chrome from 3.7 to 10.9 mg/kg, zinc between 8.3 and 18.5 mg/kg, barium between 6.2 and 113.0 mg/kg, lead from 2.6 to 6.5 mg/kg, cadmium from 0.005 to 0.049 mg/kg and mercury between 0.002 and 0.013 mg/kg dry sediment. Compared to 2006 concentrations of cadmium were lower, copper, chrome and lead were the same or lower and zinc, mercury and barium were on the same level or higher.

The bottom fauna at the regional sampling sites contained 12 881 individuals divided on 317 taxa. As in 2006, there were averagely more taxa in the central (123 taxa), than in the shallow (65 taxa) and northern (84 taxa) sub-regions (Table 3). The average number of individuals was also largest at the central (1 106 individuals), while the shallow and the northern contained 348 and 431 individuals, respectively. The diversity at most sampling sites was at the same high level as before. Compared to 2006 there was an increased diversity in all sub-regions, with the greatest increase in the shallow sub-region. This is mainly due to a reduction in number of individuals and is probably a result of natural temporal variations among individual species. According to results from the multivariate analyses, the presence of

bottom fauna follows the same partition into sub-regions as the chemical parameters. This division is partly correlated to water depth and type of sediment and there are still variations in the material that can not be explained by distribution of the investigated chemical parameters.

Field specific sampling sites

Since 2006 six wells have been drilled and there are no reports on accidental spills at **Rev**. Two sampling sites were moved in the 2009 survey. As before, there was a large content of fine sand in the sediments, while the level of TOM was lower in 2009. The concentrations of barium were above LSC to 1000 m north, west and south and the THC levels were higher than LSC to 1000 m north and 500 m south. The remaining metals analysed were below LSC. No fauna disturbance was detected in 2009. The northernmost sampling site was contaminated by THC and barium, hence the size of the contaminated area is most likely underestimated.

From 2006 to 2008 four new wells have been drilled at **Varg**. The sediments contain fine sand, with pelite and TOM concentrations at the same levels as before. The content of THC was lower, but still above LSC 250 m northwards. Concentrations of barium were above LSC to 1000 m north and 250 m south. The rest of the analyzed metals were in concentrations above LSC to 500 m north and south. Only low values of radioactive isotopes were detected at Varg. There was a considerable reduction in number of individuals from 2006 to 2009 and an increase in diversity. This is due to natural variations in the presence of certain polychaet species and is not a result of petroleum activity at Varg. The bottom fauna was generally similar throughout the area, as seen in 2006. The fauna composition indicates good environmental conditions at Varg in 2009. The area contaminated with barium was larger in 2009 compared to 2006, while the areas contaminated with THC and other metals were smaller.

At **Sigyn** there has been no drilling activity since 2002 and only minor spills. After the previous survey in 2006, the installations have been relocated and the axis of sampling sites rotated. New sampling sites (SIGNY) are therefore not directly comparable to the former (SIG). This may explain some of the detected alterations. The content of fine sand, pelite and TOM in the bottom sediments of the new sampling sites, were approximately at the same level as at the previous ones. The content of THC and metals in the sediment were lower or still at the same low level as earlier, with the exception of zinc which was higher at 250 m south in 2009. Barium levels were above LSC at all the inspected sampling sites. The number of individuals was averagely lower in 2009 compared to 2006. This is due to natural variations in the presence of polychaet species and is not a result of the activity at Sigyn. The bottom fauna was generally more similar throughout the area in 2009, and together with the species composition in the samples, this indicates a good environmental conditions at Sigyn. The areas contaminated by THC at the SIGNY sampling sites in 2009 were smaller than what was measured at the SIG sampling sites in 2006. A small increase in area was detected for barium and other metals. As in 2006, the bottom fauna was not disturbed.

Since 2000 there has not been drilling activity or major spills from **Sleipner Vest**. During the survey in 2009, samples from three sampling sites in the northern transect from the field centre were collected. Geological and biological analyses were not included in the program of

2009. Concentration of THC was above LSC to 500 m northwards. The content of barium had increased since 2006, and was above LSC to 1000 m towards north. The area contaminated by THC and barium was greater in 2009 than 2006, but lower than estimated area in 2003.

1, 1 and 4 wells were drilled at **Sleipner A** in 2007, 2008 and first half of 2009, respectively. The sediments still contain mostly fine sand with some pelite and TOM. The content of THC in the sediment was especially high 250 m to the south in 2009 compared to earlier. The barium content had increased at all sampling sites at Loke and Sleipner A. The concentration of other metals was mostly as before. An exception is the content of copper that was above LSC on certain sampling sites. In 2009 the number of animals in the bottom samples was lower than in 2006. This is due to natural variations and is not correlated with the petroleum activity in the area. The number of taxa increased at most sampling sites from 2006 to 2009. Area contaminated with THC and barium was larger in 2009 than in 2006, while the area contaminated with other metals was smaller. No disturbance of the bottom fauna was detected in 2009. In 2006 it was impossible to determine the size of the contaminated area at Loke. The area contaminated with THC and barium at Loke was smaller in 2009 than 2003, while area contaminated with other metals increased.

No drilling activity was conducted between 2006 and 2008 at **Alfa Nord**. According to the program, sediments for geological and biological studies were not sampled. No THC contamination was detected in any directions in 2009. Barium contamination was proven to 250 m north, west and south, in addition to contamination of other metals to 250 m west, north and east. This differs from 2006, when no contamination of metals was detected.

One well was drilled at **Glitne** in 2007. The bottom sediment still contains mostly fine sand with some pelite. The content of TOM was lower at the field specific sampling sites in 2009 compared to 2006. The barium content of the sediment increased from 2006 to 2009 and was higher than LSC at the sampling sites towards northeast, southeast and southwest. No contamination of THC or other metals was detected. Generally high numbers of taxa and diversity was detected in 2009, as in 2006. The environmental conditions at Glitne were good and the bottomfauna is still undisturbed.

From 2007 to May 2009 19 wells have been drilled at **Grane.** The bottom sediments contain mostly fine sand with some pelite. The TOM content was slightly lower than in 2006. The concentration of THC was low and at approximately the same level as in 2006. The levels of barium had increased from 2006 and were above LSC at all sampling sites. The remaining metals were only slightly different between the two survey years. Generally the number of individuals was lower and the number of taxa was higher in 2009. The results indicate good environmental conditions at Grane and the bottomfauna was still undisturbed. The sampling grid did not reach uncontaminated area. Therefore the size of the contaminated area is most likely underestimated.

There has not been any drilling activity at **Balder** since 2001, and no major spills during the recent years. The sediments contained mostly fine sand with some pelite. There was a slight increase in TOM content compared to 2006. Contamination of barium was detected at three sampling sites. A generally lower concentration of other metals and THC was found in 2009 compared to 2006 and no contamination was proven. The bottomfauna was generally more alike over the whole area, and no fauna disturbance was detected in 2009, as in 2006. Outermost sampling sites were contaminated; hence the size of the contaminated area is most likely underestimated.

Since the previous survey, 2 wells have been drilled at **Ringhorne**. The bottom sediments consisted of 84.9 % fine sand and 1.6 % TOM. At sampling sites close to an oil leakage at RH-Ekstra, the sediments contained 9.9 % fine sand and 6.7 % TOM. At these sampling sites levels of THC were above LSC. The area contaminated with barium and other metals increased from 2006 to 2009 and some transects did not reach uncontaminated area. The number of individuals decreased from 2006 to 2009, while number of taxa and the diversity had a slight increase. The sampling sites were dominated by the polychaet *Paramphinome jeffreysii* as in 2003 and 2006. Generally the bottom fauna was quite similar all over the area, except at RH-Ekstra where the diversity was low and the number of individuals high. At this sampling site the polychaet *Capitella capitata* dominated with 82 % of total number of individuals. Except from this sampling site, the environmental conditions at Ringhorne were good and the bottomfauna was still undisturbed.

Since 2006 three wells have been drilled at **Jotun**. The sediments had a high content of pelite and TOM as before. No contamination of THC or other metals was detected in 2009. The area with contaminated sediment increased for barium and decreased for the remaining metals from 2006 to 2009. Transects towards northwest, southwest and southeast did not reach sediments uncontaminated by barium. Only low values of radioactive isotopes were measured. The polychaet *Paramphinome jeffreysii* was the most common species, as in 2003 and 2006, and the bottom fauna was generally similar all over the area and the regional sampling site. As in 2006, the bottom fauna was still undisturbed.

In 2005 one well was drilled at **Vale** and since then no drilling activity has been conducted. The program for Vale in 2009 did not include geological or biological surveys. The concentration of THC 500 m south was lower than in 2006, however due to a decreased LSC, the two sampling sites were characterized as contaminated. In contrast, the concentrations of barium increased at most sampling sites and transects did not reach uncontaminated sediments. The levels of other metals were above the LSC towards northeast, southwest and southeast. It was not possible to determine an accurate size of the area contaminated as many of the outermost sampling sites were polluted.

There has not been any drilling activity at **Skirne** since 2003. A baseline survey was conducted in 2002 and the production started in 2004. The program for Skirne in 2009 did not include geological or biological surveys. Levels of THC were below LSC in all directions and there were only minor changes compared to 2006. Barium concentrations increased from 2006 to 2009 and were above LSC to 500 m north and 250 m west and south. No contamination by other metals was detected.

Since 2003, no drilling activity has been conducted at **Byggve**. The program for Byggve in 2009 did not include geological or biological surveys. No contamination of THC was detected in any direction. There was an increase in barium concentrations compared to 2006, and contamination was detected in areas to 500 m north and 250 m south and west. Concentrations of other metals were lower than in 2006 and no contamination was proven in 2009.

No drilling activity has been conducted at **Heimdal** for several years, and only minor spills are reported. The program for Heimdal in 2009 did not include geological or biological surveys. THC contamination was detected 300 m south of the centre. Contamination of barium and other metals was detected 320 m northeast and 300 m south. From 2006 to 2009

the area contaminated with THC and barium increased in size, while area contaminated with other metals decreased.

Since 2007 seventeen new wells have been drilled at **Volve.** The sediment contained approximately the same share of fine sand as found in the baseline survey in 2002, while the content of TOM was higher in 2009. The sampling site grid was relocated a little compared to the baseline survey. 1000 m north and 250 m west, the concentrations of THC were above LSC. The concentrations of barium were above LSC within 1000 m in all directions, with the highest concentrations 500 m north and 250 m west. Contamination of copper and zinc was also found at some sampling sites. The bottomfauna was still undisturbed. As not all transects reached unpolluted sediment, the calculated contaminated area is most likely an underestimation.

Since 2006 eight wells have been drilled at **Vilje**. The sediments have a high content of fine sand and a low content of TOM. Low concentrations of THC were found on all sampling sites, and none were above LSC. Contamination of barium was detected to 215 m southeast, 250 m northeast and southwest and 500 m northwest. Sediments were contaminated with copper and zinc to 250 m southwest and 500 m northeast. Compared to the baseline survey in 2005, the concentrations of lead, cadmium and chrome were generally lower. The number of individuals and species decreased in the same time period, while the diversity increased slightly. This difference is within the range of natural variation. Generally the bottomfauna was similar throughout the area in 2009, as in 2005. The results indicate good environmental conditions at Vilje and a still undisturbed bottomfauna. All transects reached uncontaminated sediment.

19 wells have been drilled at **Alvheim** since 2006. The sediments contain mostly fine sand with a small level of TOM. Two sampling sites have been relocated since the basline survey. THC concentrations were below LSC at all sampling sites, while concentrations of barium were above LSC to 500 m north, southwest and southeast and 250 m northeast. Sediments contaminated by other metals (copper, chrome and zinc) were found to 500 m southwest and 250 northeast. There was a general decrease in number of individuals and an increase in diversity and number of taxa from 2004 to 2009. However, the differences are not greater than what is expected of natural variation. The bottomfauna was similar throughout the area in 2009 and the species composition indicated good environmental conditions and an undisturbed bottomfauna. All transects did not reach uncontaminated sediments, hence the size of estimated area contaminated is most likely underestimated.

The region

Table 3 indicates average values, standard deviation and span of the investigated parameters (grain size distribution, chemistry and biology) within the three sub-regions in 2009. The average concentrations of metals were generally lower at the regional sampling sites than the field specific sampling sites). When this was not the case, the differences were mostly within the standard deviations of the mean value.

The survey of 2009 included fewer sampling sites than before (Table 4). The span (minimum to maximum) of some of the investigated parameters at the regional and the field specific sampling sites from 1997 to 2009 is presented in Table 4. Regional and field specific sampling sites had a larger span of barium in 2009 compared to 2006. The diversity was proven to be lower in 2006 than 2009 both at regional and field specific sampling sites, which can be linked to a natural variation in number of individuals. The upper limit of the span of THC was lower in 2009 compared to former surveys.

Estimated area contaminated by THC, barium and other metals is presented in Table 5. At several installations, all sampling sites included in the sampling programme were contaminated, hence the limit between contaminated and uncontaminated sea floor is uncertain. In these circumstances, the area presented is a minimum area, and the comparison with earlier estimated areas is therefore correspondingly uncertain. Summarized contaminated area is presented in Figure 3. The increase of barium in 2009 is most likely due to high variability of barium concentrations in the sediments.

Table 3. Summary presenting average (**av**) with standard deviation (**sd**) and span (**max-min**) of the investigated parameters (grain size distribution, chemistry and biology) in 2009 for regional and field specific sampling sites in the three sub-regions. In the northern region (Vale), samples for biology and grain size distribution were not collected in 2009.

REGIONAL		**THC**	**Ba**	**Pb**	**Cd**	**Cu**	**Cr**	**Hg**	**Zn**	**Number of individuals**	**Number of taxa**	**Diversity (H')**	**ES(100)**	**TOM %**	**Gravel %**	**Sand %**	**Pelite %**
shallow	**av**	1,6	55,5	3,9	0,017	1,5	6,2	0,007	10,7	348	65	5,0	36,4	0,63	0,07	97,26	2,67
	sd	2,1	38,2	0,9	0,01	0,8	1,7	0,003	2,6	58	4	0,25	3,8	0,17	0,04	1,11	1,12
	min	0,1	6,2	2,6	0,005	0,5	3,7	0,002	8,3	305	61	4,63	31	0,39	0,03	95,92	1,48
	max	4,7	113	6,5	0,049	3,8	10,9	0,013	18,5	429	69	5,17	39,3	0,78	0,12	98,4	4
central	**av**	5,1	78,2	3,9	0,022	1,9	6,4	0,009	11,4	1106	123	5,4	41,9	1,42	0,27	85,93	13,8
	sd	3,1	23,4	1	0,01	0,7	1,8	0,002	2,8	254	14	0,27	3,0	0,34	0,36	4,1	4,29
	min	0,1	35,8	3,1	0,014	1,1	4,1	0,006	8,8	740	103	4,73	34,9	0,92	0,01	78,25	7,13
	max	9,8	113	6,5	0,049	3,8	10,9	0,013	18,5	1677	150	5,6	44,6	1,98	1,16	92,67	21,74
northern (RII04)	**av**	2,8	9,7	2,6	0,007	0,7	3,7	0,003	9,0	431	84	5,45	44,1	0,74	0,97	96,54	2,48
FIELD SPECIFIC																	
shallow	**av**	6,0	109	4,5	0,006	0,9	6,5	0,004	9,0	614	83	5,04	37,68	0,69	0,20	97,37	2,43
	sd	4,2	181	1,0	0,002	0,5	0,9	0,001	2,5	194	9	0,39	3,53	0,16	0,39	0,94	0,92
	max	23,1	1024	7,0	0,010	4,1	8,1	0,004	17,7	1241	102	5,62	44,63	1,03	1,75	98,88	4,31
	min	<1	7	3,1	0,003	0,4	5,2	0,000	5,9	332	67	3,93	28,53	0,01	0,00	95,65	0,79
central	**av**	6,0	259	4,0	0,020	2,6	6	0,009	13,6	1287	133	5,46	42,25	1,66	0,23	81,72	15,03
	sd	3,8	173	1,5	0,009	2,7	1,4	0,002	7,9	187	10	0,21	2,14	0,33	0,47	8,53	3,67
	max	26,0	1013	11,6	0,072	23	12,1	0,013	60,3	1588	154	5,79	46,96	2,41	2,58	93,38	24,00
	min	<1	31	2,3	0,009	<1	3,1	0,000	7,2	822	105	4,90	37,69	0,85	0,00	55,45	6,58
northern (RII04)	**av**	4,7	157	3,3	0,012	1,5	4,1	-	7,9	-	-	-	-	-	-	-	-
	sd	0,6	84	1,1	0,004	0,6	0,6	-	2,3	-	-	-	-	-	-	-	-
	max	5,1	311	5,4	0,020	2,6	4,8	-	12,4	-	-	-	-	-	-	-	-
	min	4,2	74	2,4	0,010	<1	3,3	-	6,2	-	-	-	-	-	-	-	-

Table 4. The summary presents the highest and lowest values of some of the investigated parameters of grain size distribution, chemistry and biology at the regional and field specific sampling site from 1997 to 2009.

REGIONAL

Parameters	1997	2000	2003	2006	2009
Total number of sampling sites	23	22	22	23	15
Depth (m)	71-123	71-123	77-129	77-129	77-123
Median grain size	1,6-3,9	1,6-4,5	1,8-3,7	2,0-3,7	1,64-3,42
Lead (mg/kg)	2,5-6,1	3,1-6,9	2,1-5,7	1,7-5,1	2,6-6,5
Cadmium (mg/kg)	0,003-0,023	0,004-0,035	<0,03	<0,03-0,04	0,005-0,049
Barium (mg/kg)	6-176	8-215	5-146	5-75	6,2-113,0
THC (mg/kg)	2,0-11,3	2,2-8,9	<3-15,5	2,3-6,4	<0,1-9,8
Diversity H'	3,2-6,1	3,4-5,6	3,5-5,9	2,2-5,9	4,63 - 5,60
Number of taxa per sampling site	67-158	46-149	47-141	50-146	61 - 150
Number of individuals per sampling site	402-2744	236-2994	181-1749	451-2299	305 - 1677

FIELD SPECIFIC

Parameters	1997	2000	2003	2006	2009
Total number of sampling sites	168	217	172	212	137
Depth (m)	78-126	78-126	79-130	75-130	80-130
Median grain size	2,3-4,1	2,7-4,5	2,1-3,5	1,9-3,7	1,66-3,44
Lead (mg/kg)	2,0-26,3	3,2-31,0	2,6-43,7	2,6-13,9	2,3-11,6
Cadmium (mg/kg)	0,005-0,085	0,003-0,095	<0,03-0,045	<0,03-0,05	0,003-0,072
Barium (mg/kg)	11-2480	9-3942	8-709	5,9-286	6,6-1024
THC (mg/kg)	1,1-418	1,6-412	<3-154	1,0-45	<1-26
Diversity H'	3,9-5,9	3,1-5,9	4,1-5,9	2,8-5,9	3,93-5,79
Number of taxa per sampling site	54-173	37-154	45-146	55-157	67-154
Number of individuals per sampling site	235-3748	165-2635	162-1549	373-2669	332-1588

Table 5. Summary presenting contaminated area (km²) for THC, barium and other metals, as well as area (km²) with disturbed bottomfauna. The sums of the columns are not directly comparable, as some years lack data and all sums are based on minimum values.

Field	Sub-region	Year	THC	Ba	Other metals	Fauna
Balder	Central	1997	1,09	2,93	0,37	0,48
		2000	0,54	4,21	0,15	0,37
		2003	2,38	0,43	4,13	0,04
		2006	0,25	0,25	0,25	0
		2009	0	0,08	0	0
Ringhorne	Central	1997				
		2000	0	0	0	0
		2003	3,93	0,74	0	0
		2006	0,03	0,3	0,03	0
		2009	0	0,49	0,79	0
Jotun	Central	1997	0	0	0	0
		2000	1,77	5,3	0,07	0
		2003	ib	1,47	ib	0
		2006	0	0,2	0,1	0
		2009	0	0,59	0	0
Heimdal	Central	1997	0,25	0,25	0,25	0,11
		2000	0,12	0,43	0,29	0,18
		2003	0	0,08	0,15	0,05
		2006	0	0,06	0,63	0
		2009	0,035	0,075	0,075	-
Skirne	Central	2006	0	0	0,02	0
		2009	0	0,15	0	-
Byggve	Central	2006	0	0,02	0,02	0
		2009	0	0,15	0	-
Vilje	Central	2009	0	0,28	0,04	0
Alvheim	Central	2009	0	0,59	0,07	0
Sleipner Vest	Central	1997	0,88	3,14	3,14	0
		2000	0,74	3,14	0,74	0,07
		2003	0,79	3,53	0,1	0,03
		2006	0,02	0,02	0,05	0
		2009	0,049	0,098	0,049	-
Alfa nord	Central	2006	0,03	0	0	0
		2009	0	0,1	0,1	-
Glitne	Central	1997				
		2000	0	0	0	0
		2003	0,88	3,14	0,79	0
		2006	0	0,04	0,04	0
		2009	0	0,28	0	0
Grane	Central	1997	0,18	0,37	0	0
		2003	0,1	0,98	0,05	0
		2006	0	0,59	0	0
		2009	0	0,59	0	0

Table 5. continues. Summary presenting contaminated area (km²) for THC, barium and other metals, as well as area (km²) with disturbed bottomfauna.

Field	Sub-region	Year	THC	Ba	Other metals	Fauna
Rev	Shallow	2006	0,14	0,95	0,2	0
		2009	0,61	2,36	0	0
Varg	Shallow	1997	1,18	0,1	0	0
		2000	1,33	1,77	0,25	0,15
		2003	0,07	0,2	0,2	0,05
		2006	0,05	0,1	0,49	0
		2009	0,025	0,123	0,098	0
Sigyn	Shallow	2000	0	0	0	0
		2003	0,02	0,2	0,02	0
		2006	0,02	0	0	0
		2009	0	0,1	0,03	0
Sleipner Øst	Shallow	1997	0,07	13,8	0,07	0,36
		2000	0,4	2,21	0	0
		2003	0,44	0,83	0,07	0,05
		2006	0	0,2	0,15	0
		2009	0,025	0,0785	0,025	0
Loke	Shallow	1997	0,07	1,23	0,07	0,07
		2000	0,18	0,44	0	0
		2003	0,05	0,44	0	0,05
		2006	0	?	?	-
		2009	0,025	0,295	0,049	-
Volve	Shallow	2009	0,2	4,71	0,2	
Vale	Northern	2001	0	0	0	0
		2003	0	1,77	0,39	0
		2006	0	0,05	0,1	0
		2009	0,05	0,59	0,25	-

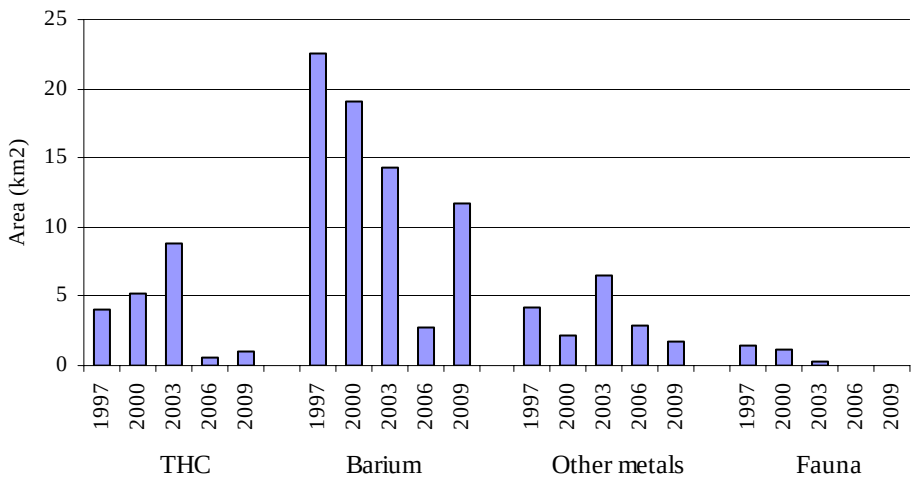

Figure 3. Development of total contaminated area of THC, barium, other metals and fauna in Region II from 1997 to 2009.

5. Conclusions and recommendations

The most important conclusions and recommendations based on the survey of 2009 are listed below.

Conclusions

Natural conditions results in lower average values of number of individuals, number of species and diversity in the shallow compared to the central sub-region. The contents of TOM and pelite in the sediments were averagely lower in the shallow sub-region, and the content of fine sand was lower in the central sub-region. In addition to drilling activity, the high level of pelite may contribute and explain some of the variances between the sub-regions.

The level of THC was generally low in the sub-region and there were only minor alterations compared to the previous survey. The exception was the additional sampling site (RH-Ekstra) at Ringhorne, where oil is leaking through the sea floor. At the fields Sigyn, Sleipner Alfa nord, Glitne, Grane, Balder, Ringhorne, Jotun, Skirne, Byggve, Vilje and Alvheim no THC contamination was detected.

There was a general increase in barium concentration from 2006 to 2009 in all sub-regions. The greatest increase of barium was in the central sub-region, also in areas where no drilling had been conducted throughout the recent years. The same laboratory and methods are used during the three last regional investigations. Since the changes also occurred at the regional stations, the changes in barium concentrations may be due to high variability in the sediments. No contamination of other metals was detected at Rev, Glitne, Grane, Balder, Jotun, Skirne and Byggve. At the remaining fields the values were generally lower or similar to values from 2006.

The fauna distribution was investigated at 12 fields in 2009: Rev, Varg, Sigyn, Sleipner Øst, Glitne, Grane, Balder, Ringhorne, Jotun, Volve, Vilje og Alvheim. No disturbance was proven at any of these sampling sites. The elevated number of individuals detected at most sampling sites in 2006, decreased in 2009 as a result of natural temporal variations in the fauna distribution.

Radioactive isotopes were measured at Jotun and Varg in addition to the two regional sampling sites, RII06 and RII09. Samples from Jotun and Varg were low and did not differ significantly from the regional samples.

Recommendations

1) To ensure an accurate estimation of the area contaminated, the outer sampling limits should reach unpolluted area.

2) When selecting regional sampling sites, one should take in consideration earlier divisions of sub-regions. There should be a selection of permanent sampling sites for the entire region.