DNV CONSULTING

Environmental Baseline Survey Vilje 2005:

Report for NORSK HYDRO ASA
Report no.: 2006-0345
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MANAGING RISK

Environmental Baseline Survey Vilje 2005	DET NORSKE VERITAS AS Veritasveien 1 1322 Høvik Tel: +47 67 57 99 00 Fax: +47 67 57 99 11 Registered in Norway NO 945 748 931 MVA
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Prepared by:	*Name and position* Bakke, S. M., Rustad, I., Brinchmann, K. M., Nøland, S. A.	*Signature*	
Verified by:	*Name and position* Tor Jensen, Group Manager	*Signature*	
Approved by:	*Name and position* Magne Tørhaug, Director	*Signature*	
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Contents:

Preface

The environmental baseline survey at Vilje in 2005 has been carried out jointly by Det Norske Veritas and Molab, on behalf of Hydro. Hydros representative has been Bjørge Fredheim.

Personnel

Field work: Tor Jensen (survey leader), Sam-Arne Nøland, Thomas Møskeland, Amund Ulfsnes and Øyvind Fjukmoen (all DNV) and Håkon E. Larsen and Andreas Parslow (both Molab).

Sediment analyses:

Grain size distribution:	Stein-Tore Bogen, Terje Kolberg, Eli Ellingsen
TOM analyses:	Gaute Botten, Håkon E. Larsen
Metal analyses:	Andreas Parslow, Karina E. Ødegård, Håkon E. Larsen
THC analyses:	Mariam Bouzga, Gaute Botten, Frøydis Oreld, Tove Kristin Dokka Torstensen
Selected hydrocarbon analyses:	Tove Kristin Dokka Torstensen

The chemical analyses are performed at Molab AS, section Oslo. The grain size distribution is analysed at Molab AS, section Glomfjord.

Biological analyses:

Species identification:	Siri Mordal Bakke, DNV (Polychaeta, varia) Thomas Møskeland, DNV (Crustacea) Amund Ulfsnes, DNV (Echinodermata) Mikkel Petersen, DNV (Polychaeta, varia) Per Bie Wikander, Molltax (Mollusca) Øystein Stokland, Marine Bunndyr (Polychaeta, varia)

Sorting has taken place at DNV's Biology Laboratory. Karen Marie Brinchmann and Mikkel Petersen has been in charge of the sorting.

Univariate analyses:	Thomas Møskeland, Siri Mordal Bakke
Multivariate analyses:	Siri M. Bakke

Report preparation:

Chemistry:	Helle Malerød
Biology:	Siri M. Bakke, Karen Marie Brinchmann, Sam-Arne Nøland
Main Report:	Sam-Arne Nøland
Verification:	Tor Jensen

Project Manager: Sam-Arne Nøland

Molab AS is accredited by Norwegian Accreditation to perform chemical analyses, accreditation number Test 032. The accreditation is according to NS-EN ISO/IEC 17025. The accreditation includes methods for determination of total hydrocarbon content (THC), polycyclic aromatic hydrocarbons (PAH), selected hydrocarbons (NPD), metals and total organic matter (TOM).

DNV's Biology laboratory (DNV Consulting) is accredited by Norsk Akkreditering for sampling of marine sediments for chemical and biological analyses, and to perform out biological analyses, accreditation number TEST 083. Accreditation is according to NS-EN ISO/IEC 17025.

1.0 Resumé

This report presents the results from the environmental baseline study of Vilje in 2005. A total of 15 stations were investigated including a reference station.

The sediments are characterized by grain size distribution and by content of total organic matter (TOM). The sediments are analysed for the content of total amount of hydrocarbons (THC) and metals. Additionally, NPD, PAH and decalins are analysed for three stations where samples from different layers were investigated.

The investigation at Vilje has revealed the following:

- Sediments consist mainly of fine sand. The sediment shows a uniform grain size distribution. The average median particle diameter is 3.33. The sand content varies from 78 to 94 %. The content of gravel is generally low.
- The content of total organic matter is relative low (1.05 – 2.10 %), and the average content is 1.75 %.
- No contamination of hydrocarbons, barium or heavy metals (Cd, Cr, Cu, Hg, Pb and Zn) is found in the sediments.
- The average concentration of Ba ranges from 21 to 254 mg/kg, and the average concentration is 112 mg/kg.
- The average THC concentration varies from 2.0 mg/kg to 6.5 mg/kg.
- The concentration of NPD and PAH is low, the highest detected concentrations are 0.05 mg/kg and 0.18 mg/kg.
- Decalins are not detected.
- The levels of NPD, PAH, THC and metals are characterized as the natural background level for the area.
- The fauna community at Vilje reveals high diversity indices and is characterised as undisturbed.

2.0 Sammendrag / Summary

2.1 Summary

Chemical analyses and physical characterization of the sediments

This summary presents the main results of the environmental baseline survey at Vilje in 2005. The sediments have been analysed as described in Table 2.1.1.

Table 2.1.1. *Methods for chemical analysis and physical characterization.*

Analytical method	Parameter
Sediment characterization	
• Grain size distribution	- Distribution of pelite (< 63 µm) and sand (>63 µm) - Cumulative weight % distribution 63-2000 µm - Median particle diameter (Mdϕ), deviation (SDϕ), skewness (Skϕ) and kurtosis (Kϕ)
• Total organic matter	- % TOM in the sediment
Chemical analyses	
• Hydrocarbons	- THC, sum C_{12}-C_{35} - NPD, sum of naphtalene, phenanthrene/anthracene and dibenzothiophene and their C_{1-3} alkylated derivatives. Sum and single compounds - PAH, 16 EPA compounds Sum and single compounds - Decalins, sum of C_5-C_8 alkyl Decalins
• Metals	- Ba, Cd, Cr, Cu, Hg, Pb, Zn

Samples were taken from 14 stations and one reference station. The sediments consist mainly of fine sand. The sand content varies from 78 % to 94 %. The silt and clay content ranges from 5.8 % to 21 %, and the content of gravel is very low (0 – 1.6 %). The median particle diameter ranges from 2.35 to 3.59, and the average median particle diameter is 3.33.

The content of total organic matter (TOM) ranges from 1.05 % to 2.10 %, and the average content is 1.75 %.

The sediments are not contaminated by THC. The content of hydrocarbons varies from 2.0 to 6.5 mg/kg. NPD and PAH are only analysed at 2 stations downstream, in addition to the reference station. The concentrations of NPD and PAH are low, the highest concentrations detected are 0.05 mg/kg and 0.18 mg/kg, respectively. Decalins have not been detected.

The mean concentrations of Ba range between 21 mg/kg and 254 mg/kg. Additionally, the concentrations of the heavy metals (Cd, Cr, Cu, Hg, Pb and Zn) are low.

The concentration of hydrocarbons, Ba and heavy metals are within what can be characterized as the natural background level for the area. The baseline survey at Vilje has revealed that the sediments are not polluted.

A summary of the variations is given in Table 2.1.2.

Biology

The fauna community at Vilje reveals high diversity indices and is characterised as undisturbed.

Station VILJE-01 (150º/250m) and VILJE-07 (60º/2000m) differ from the other stations with a slightly different fauna.

Average and variations within both chemical and biological parameters:

Table 2.1.2. *The variations within the chemical and biological parameters at Vilje 2005.*

Analytical method	Parameter	Average and variations (in parenthesis) at Vilje 2005
• Depth	m	122 (116 – 124)
Sediment characterization		
• Grain size distribution (%)	Silt & clay:	17.1 (5.8 – 21)
	Sand:	4.0 (78 – 94)
	Gravel:	0.5 (0 – 1.6)
• Median particle diameter (ϕ)	Mdϕ:	3.33 (2.35 – 3.59)
• Total organic matter (%)	TOM:	1.75 (1.05 – 2.10)
Chemical analyses		
• Hydrocarbons (mg/kg)	THC:	4.2 (2.0 – 6.5)
	NPD:	0.03 (0.01 – 0.05)
	PAH:	0.12 (0.06 – 0.18)
	Decalins:	Not detected
• Metals (mg/kg)	Ba:	111 (21 – 254)
	Cr:	7.6 (5 – 16)
	Cu:	1.75 (<1.0 – 5.1)
	Pb:	5 (3 – 13)
	Zn:	11 (6 – 25)
	Cd:	0.034 (<0.001 – 0.74)
	Hg:	0.01 (<0.01 – 0.03)
Biological analyses (0.5 m^2 samples)		
• Number of species	S	149 (127 – 165)
• Number of individuals	N	1731 (1245 – 2117)
• Shannon-Wiener diversity index	H’	5.5 (5.1 – 5.8)
• Expected numbers of species per 100 individuals	ES_{100}	43.9 (39 – 47)

2.2 Sammendrag

Kjemiske analyser og fysisk karakterisering av sedimentet

Dette sammendraget presenterer hovedresultatene fra grunnlagsundersøkelsen på Vilje i 2005. Metodene som er blitt benyttet er angitt i Tabell 2.2.1.

Tabell 2.2.1. *Oversikt over metoder for kjemisk og fysisk karakterisering.*

Analyse	Parameter
Sedimentkarakterisering	
• Kornstørrelsefordeling	- Fordeling av pelit (< 63 µm) og sand (>63 µm) - Kumulativ vekt% fordeling fra 63-2000 µm - Median partikkel diameter (Mdϕ), standard avvik (SDϕ), skjevhet (Skϕ) og kurtosis (Kϕ)
• Totalt organisk materiale	- % TOM i sedimentet
Kjemiske analyser	
• Hydrokarboner	- THC, sum C_{12} – C_{35} - NPD, sum naftalen, fenantren/antracen og dibenzotiofen og deres C_{1-3} alkylhomologe. Sum og enkeltforbindelser - PAH, 16 EPA forbindelser. Sum og enkeltforbindelser - Dekaliner, sum av C_5-C_8 alkyldekaliner
• Metaller	- Ba, Cd, Cr, Cu, Hg, Pb, Zn

Det ble tatt prøver fra 14 stasjoner og en referansestasjon. Sedimentene består hovedsakelig av finkornet sand. Innholdet av sand varierer fra 78 til 94 %. Innholdet av silt og leire varierer mellom 5,8 – 21 %, mens innholdet av grus og grovere sediment er meget lavt (0 – 1,6 %). Gjennomsnittlig median partikkeldiameter er 3,33.

Innholdet av totalt organisk materiale (TOM) er tilnærmet lik for alle stasjonene, og konsentrasjonen varierer mellom 1,05 og 2,10 %. Gjennomsnittlige konsentrasjon er 1,75 %.

Totalt innhold av hydrokarboner (THC) er lavt og varierer mellom 2,0 – 6,5 mg/kg. Det er analysert for NPD og PAH på to stasjoner i tillegg til referansestasjonen. Konsentrasjonene av NPD og PAH er også lave, de høyeste konsentrasjonene som er detektert er henholdsvis 0,05 mg/kg og 0,18 mg/kg. Dekaliner er ikke detektert.

Gjennomsnittlige konsentrasjoner av barium (Ba) varierte mellom 21 og 254 mg/kg. Konsentrasjonen av tungmetaller (Cd, Cr, Cu, Hg, Pb and Zn) var lav og ingen kontamineringer ble funnet.

Konsentrasjonene av hydrokarboner, barium (Ba) og tungmetaller (Cd, Cr, Cu, Hg, Pb and Zn) kan karakteriseres som naturlig bakgrunnsnivå for området. Grunnlagsundersøkelsen viser at sedimentene på Vilje ikke er forurenset.

Sammendrag av variasjonene er gitt i Tabell 2.2.2.

Biologi

Faunasamfunnet ved Vilje viser høye diversitetsindekser og karakteriseres som uforstyrret.

Stasjonene VILJE-01 (150º/250m) og VILJE-07 (60º/2000m) skiller seg fra de andre stasjonene med en noe annerledes fauna.

Gjennomsnitt og variasjoner i de kjemiske og biologiske parametrene:

Tabell 2.2.2. *Gjennomsnitt og variasjoner i de kjemiske og biologiske parametrene på Vilje 2005.*

Analytisk metode	Parameter	Gjennomsnitt og variasjoner (i parentes) på Vilje 2005
• Dyp	m	122 (116 – 124)
Sediment karakterisering		
• Kornstørrelsesfordeling (%)	Silt & leire:	17,1 (5,8 – 21)
	Sand:	4,0 (78 – 94)
	Grus:	0,5 (0 – 1,6)
• Median partikkel diameter (ϕ)	Mdϕ:	3,33 (2,35 – 3,59)
• Totalt organisk materiale (%)	TOM:	1,75 (1,05 – 2,10)
Kjemiske analyser		
• Hydrokarboner (mg/kg)	THC:	4,2 (2,0 – 6,5)
	NPD:	0,03 (0,01 – 0,05)
	PAH:	0,12 (0,06 – 0,18)
	Dekaliner:	Ikke detektert
• Metaller (mg/kg)	Ba:	111 (21 – 254)
	Cr:	7,6 (5 – 16)
	Cu:	1,75 (<1,0 – 5,1)
	Pb:	5 (3 – 13)
	Zn:	11 (6 – 25)
	Cd:	0,034 (<0,001 – 0,74)
	Hg:	0,01 (<0,01 – 0,03)
Biologiske analyser		
• Antall arter	S	149 (127 – 165)
• Antall individer	N	1731 (1245 – 2117)
• Shannon-Wiener diversitetsindeks	H'	5,5 (5,1 – 5,8)
• Forventet antall arter per 100 individer	ES_{100}	43,9 (39 – 47)

3.0 Introduction

Hydro is planning development of the oil field Vilje with two subsea installations connected to Alvheim.

3.1 Development of Vilje

Information about the field technical installations, positions and drilling program is taken from the Environmental Impact Assessment (Roald, 2004). Vilje is located in PL 036 ca. 11 km north of Heimdal. Vilje will be developed with two subsea wells connected to Alvheim production vessel located ca. 19 km south east of Vilje (Figure 3.1.1). Production is planned to commence in February 2007.

The connection to Alvheim will consist of:

- subsea installations at Vilje
- a well stream pipeline (12") from Vilje to Alvheim
- a gas pipeline (5,5") from Alvheim to Vilje for gas lift
- a gathering pipeline for service pipeline and control cable from Vilje to Alvheim (approximately 19 km).

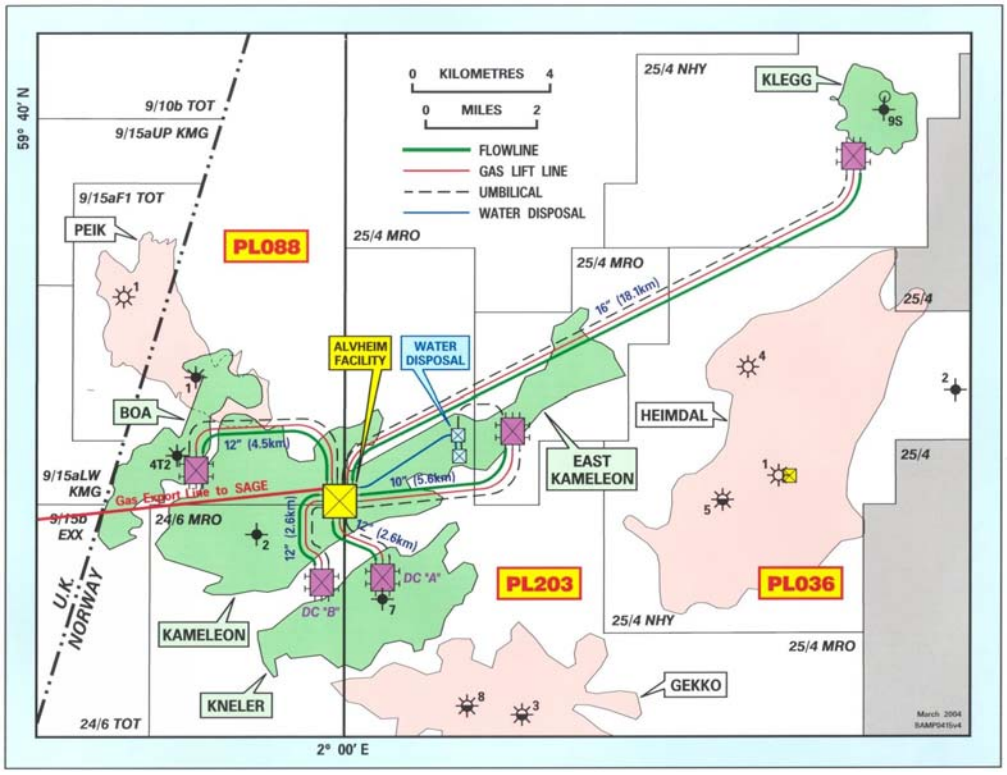


Figure 3.1.1. *Sketch of the Vilje concept (formerly Klegg ((Haldorsen & Denley 2004)) to Alvheim.*

The distance between the templates will be 50m. The wells will possibly be drilled with branches to improve the exploitation of the resources. The subsea installations will carry protection against trawling (Figure 3.1.2) and the pipelines will be buried and covered with sand. In the case that the pipelines have to cross areas with marine clay it will be covered

with pebbles to isolate and protect the pipeline. The project will seek to avoid this when deciding on route.

The pipelines will cross the Vesterled pipeline. To protect the pipelines against damage it will be necessary to carry out rock dumping.

East of the planned production wells three pipelines and a service line are located at the sea bed.

- In 230 m distance Vale 8" flow line & umbilical/2" service line
- In 510 m distance 36" Oseberg gas transport line
- Between these 22" Huldra gas export line

The subsea development will be connected to Alvheim via a new well stream pipeline with a diameter of 12" and a new pipeline for gas to gas lift of 5.5". An umbilical for supplies of hydraulic oil, auxiliary chemicals and control cable will also be installed. It will be prepared to connect possible other findings in the area to the same well stream pipeline.

Figure 3.1.2. *Well frame at Vilje.*

Drilling of pilot holes is planned in 1rst quarter of 2006. Commencement of oil production from Vilje is planned in 1st quarter of 2007.

3.2 Planned Drilling activities

Two wells will be drilled at Vilje in 2006, using water based drilling mud in upper sections of the wells. Cuttings and drilling mud will be discharged. Discharges of cutting with drilling mud are estimated to 1600 m^3 in the EIA. Environmentally sound chemicals are used in the drilling mud and the consequences of discharges from drilling will primarily be related to covering the sea bed with sludge.

In the lower sections of the wells oil base drilling mud will be utilised. Mud and cuttings from these sections will be collected and transported ashore for further treatment/disposal.

3.3 Meteorology, oceanography and sea bed conditions

The wells at Vilje will be located 11 km north of Heimdal, west of the pipelines from Oseberg, Huldra and Vale. The water depth around Vilje, Heimdal and Alvheim is approx. 120 m. The area is flat – sea bed gradient under <1° - consisting of fine sand with elements of silt and clay.

The currents in the North Sea and along the Norwegian coast are illustrated in Figure 3.3.1. Water from the Atlantic Ocean forms a south east directed current in the deeper water masses in the Vilje area. Prevailing wind direction in the area is from south/south west, causing the wind driven surface current from south to north.

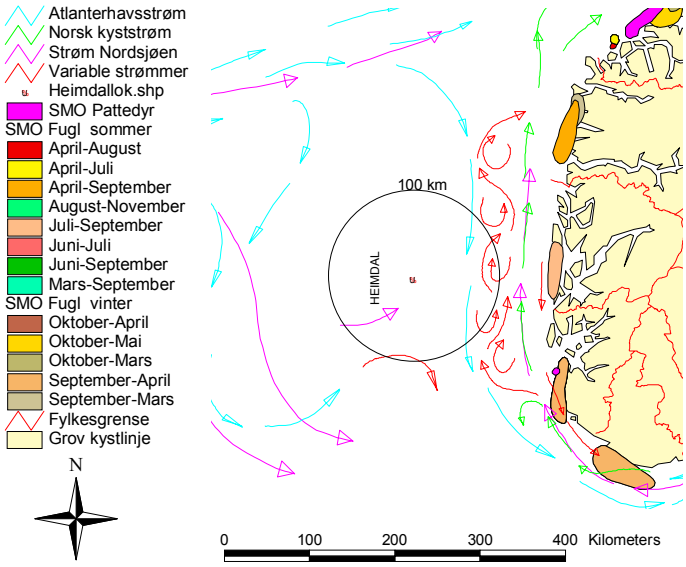


Figure 3.3.1. *Currents in the North Sea and along the Norwegian coast.*

3.4 Previous surveys of the sea bed in the area

According to Aktivitetsforskriften (Activities regulations) § 52 (Dtil, SFT and SHdir 2001), technical appendix 2 in appendix 1 (updated 2003), environmental monitoring of pollution from operational discharges shall be carried out in defined regions every third year. Regional monitoring has taken place in Region II since 1997, last survey in 2003.

4.0 Materials and Methods

4.1 Field work

4.1.1 Sampling strategy

The location of Vilje and the sampling stations are shown in the figures below.

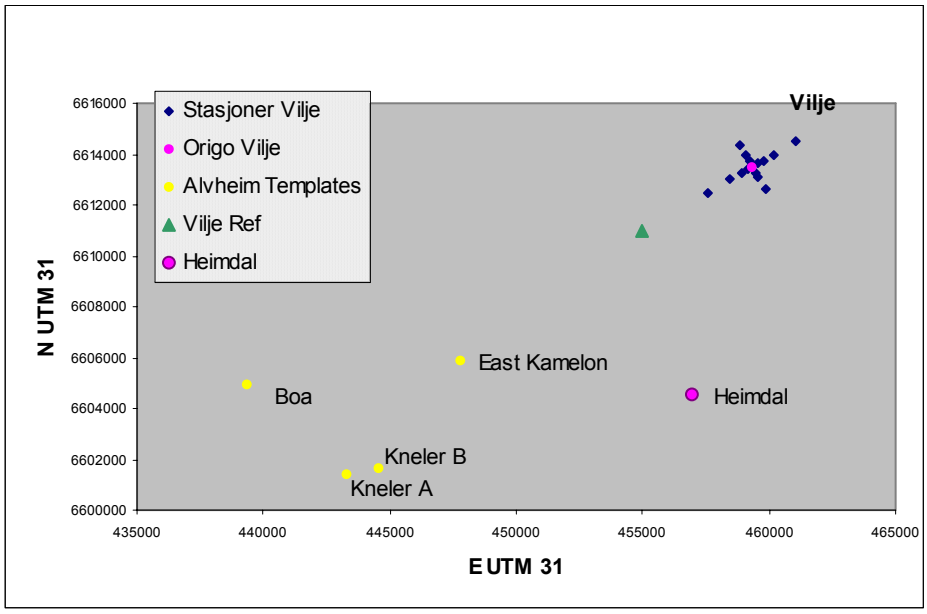


Figure 4.1.1. *Vilje, including existing and planned installations in the vicinity.*

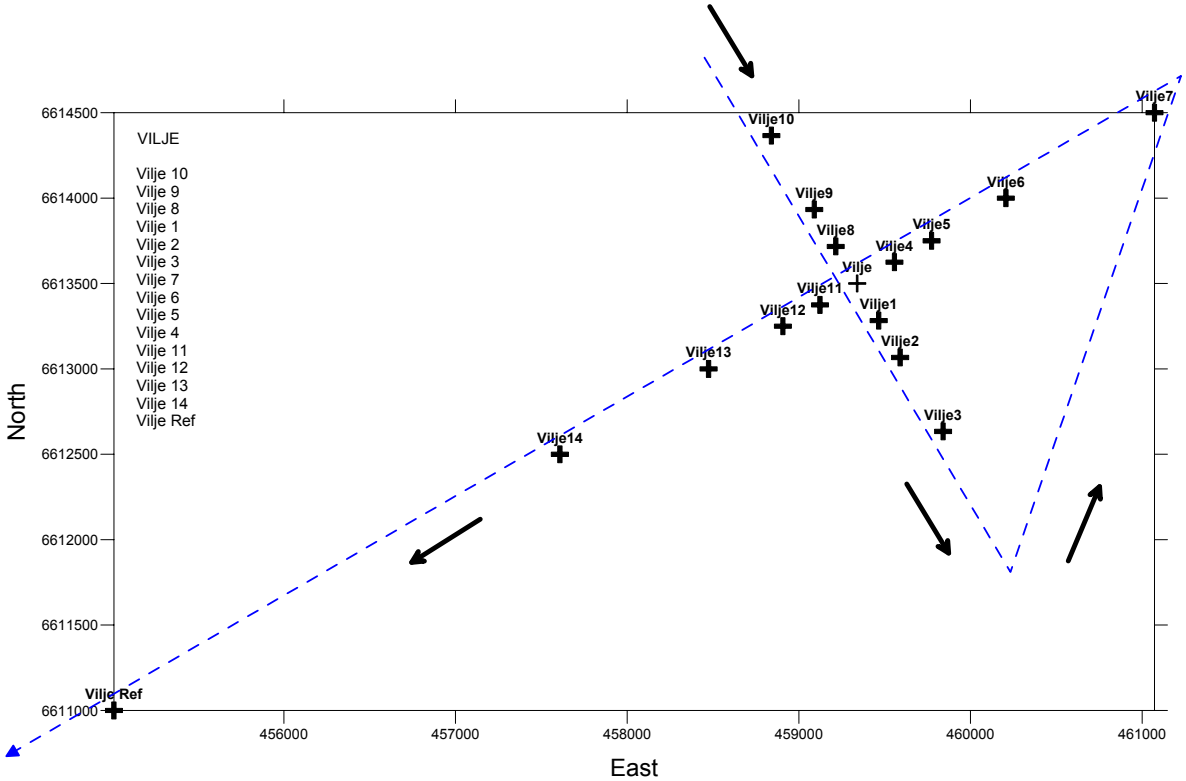


Figure 4.1.2. *Baseline stations, Vilje 2005.*

The sampling programme is based on the requirements to environmental baseline surveys in the Aktivitetsforskriftene (Activities regulations) § 52 (Dtil, SFT and SHdir 2001), technical appendix 2 in appendix 1 (updated 2003). The programme is enclosed in Appendix E.

4.1.2 Execution of field work

The field work was performed by DNV in cooperation with MOLAB using the vessel Northern River in the period May 31st to June 5th 2005. The survey was carried out as a part of the regional survey in the Ekofisk region. An extract from the survey report (DNV rep. 2005-0966) is enclosed in Appendix A.

Sampling and analysis were carried out with reference to the Activity Regulations (OD, SFT, Hi, 2001), appendix 1, *Requirement to Environmental Monitoring of the Petroleum Activity on the Norwegian Continental Shelf* – technical appendix 2*, Sediment* (updated in 2003) and DNV procedures for this kind of work.

Samples for chemical and biological analysis were collected with a van Veen grab (surface area 0.1 m^2). For chemical analysis, the surface sediments (0-1 cm) from three replicate grab samples were collected on each location. On selected stations additional samples were collected from the 1-3 and 3-6 cm layers. Five grab samples were collected for fauna analyses on each location.

Figure 4.1.3. *Typical sediments from baseline survey at Vilje.*

The main equipment used was:

- van Veen grab
- Reception table for grab in stainless steel
- Washing table for biological samples
- Sieves for washing of biological samples
- Munsels colour chart

Sampling was carried out in accordance with accredited procedures described in *Handbook for the Biology laboratory; sampling of marine sediment and soft bottom analyses* (DNV Operating Procedures – Production; CONNO652-5-1-2). It was emphasized that the sediment surface in the samples should be undisturbed and that the washing/sieving of the fauna samples was carried out gently. Animals were fixed in formalin (4 %, neutralized with hexamine). Rose Bengal was added and the samples were stored in 3.7 l plastic buckets. All samples were doubly marked and packed in solid boxes to avoid damage to the sample packing.

The field work was carried out in accordance to the survey program. Details are given in the Survey report, Appendix A.

The vessel was provided with dynamic positioning equipment. This means very precise positioning, and that the vessel can be kept in the exact same position over time. The variance in positioning was better than ±1 m.

4.2 Macro benthic analyses

4.2.1 An introduction to macro benthos

The macro benthic fauna considered in this survey is found living either in, or on sand, silt or clay sediments. This fauna comprises the following main taxonomic groups: Polychaeta, Crustacea, Mollusca, Echinodermata and Varia (remaining groups). Only animals more than 1 mm (macro benthos) are included in the analysis.

Macro benthic fauna are traditionally included in offshore environmental monitoring. The reason for this is that the study of benthic communities can give an indication of the effects of pollution from offshore activities, while chemical monitoring of sediments is aimed at assessing the dispersion and concentration levels of pollutants in the vicinity of offshore installations. The benthic fauna is a suitable biological parameter for monitoring the effects of pollution since most of the species have limited mobility and changes in species composition and densities of individuals can therefore easily be identified. The distribution of the fauna can be related to natural variations in environmental parameters such as depth and type of sediment, but also anthropogenic factors such as discharges of drilling fluids, cuttings and others, including accidental releases of oil and physical disturbances.

4.2.2 Sorting and species identification

In the laboratory the samples were washed on 1 mm sieves with (circular holes) to remove formaldehyde and remaining fine sediment, and then sorted by hand under a magnifying glass. The animals were split into the major taxonomic groups; Echinodermata, Polychaeta, Crustacean, Mollusca and Varia and transferred to 70% ethanol before further identification was undertaken.

The literature used for species identification is recommended in the Aktivitetsforskriftene (Activities regulations) § 52 (Dtil, SFT and SHdir 2001), technical appendix 2 in appendix 1 (updated 2003). Apart from the exceptions detailed below, all animals were identified to the lowest possible taxonomic level (i.e. generally to species level) and the number of individuals per taxon in each sample was recorded. In accordance with the Aktivitetsforskriftene, Nematoda, Foraminifera and colonial organisms (i.e. Porifera and Bryozoa), were excluded from any data analyses. Some taxa (i.e. Platyhelminthes, Nemertini, Tunicata and Tanaidacea) were quantified but were not identified further. A number of representative specimens of each of the species/taxa identified were included in our reference collection.

4.2.3 Analytical methods

The statistical and mathematical methods utilised to aid interpretation of the benthic fauna data are summarised below.

- Abundance ratio
- Shannon-Wiener's diversity index, H' (Shannon & Weaver 1963)
- Evenness calculated by Pielou's "evenness" J' (Pielou 1969)
- Expected number of species in a sample of 100 individuals (ES_{100})
- Fauna similarity between stations by Bray-Curtis dissimilarity index d (Bray & Curtis 1957). The resulting similarity matrix was utilised in multivariate analyses in order to group stations and assess gradients in the benthic communities. These methods were: hierarchical agglomerative classification with group-average sorting (Lance & Williams

1966), ordination with non-metric Multi-Dimensional Scaling (MDS) (Shepard 1962, Kruskal & Wish 1978).

Classification and MDS ordination were carried out using the programme-package PRIMER (**P**lymouth **R**outines **I**n **M**ultivariate **E**cological **R**esearch). Formulas and further explanations are given in Appendix D.

The raw data is stored in MOD; *MiljøOvervåkingsDatabasen* (Environmental Monitoring Database).

4.3 Chemical analyses and physical characterization of the sediments

Analytical parameters

Analysis	Parameter
Sediment characterization	
• Grain size distribution	- Distribution of pelite (< 63 µm) and sand (>63 µm) - Cumulative weight% distribution from 63-2000 µm - Median particle diameter (Mdϕ), standard deviation (SDϕ), skewness (Skϕ) and kurtosis (Kϕ)
• Total organic matter	- % TOM in the sediment
Chemical analyses	
• Hydrocarbons	- THC, sum C_{12}-C_{35} - NPD, naphthalenes, phenanthrenes and dibenzothiophenessum. Sum and single compounds - PAH, 16 EPA compounds. Sum and single compounds - Decalins, sum of C_5-C_8 alkyl Decalins
• Metals	- Ba, Cd, Cr, Cu, Hg, Pb and Zn

4.3.1 Sediment characterization

Grain size distribution

The method for grain size distribution analysis is described in Buchanan (1984). The analysis includes a fast mechanical separation of the sand fraction (>63 µm) from the silt and clay fraction. The sand fraction is then dried and sieved over a series of graded sieves.

From each station three sub samples (0-5 cm) from separate grabs were mixed and homogenized, and one homogenized sample from each station was analysed. Approximately 10 g of the sample was weighed to the nearest 0.01 g before wet sieving on a 63 µm sieve. The fraction passing this sieve was transferred to a plastic bottle. A separate sample was weighed and dried for dry weight determination. The percentage silt and clay (<63 µm) of total dry weight in the sample was then calculated.

The fraction >63 µm was dried at 100 °C for 12 hrs and sieved over a series of Wenthworth graded sieves (Endecott Test Sieves, London) with mesh sizes ranging from 2000 to 63 µm. The sample was shaken on a Retsch KG testing sieve shaker for ten minutes. The weight retained upon each sieve was determined to the nearest 0.01 g. The weight of all size

fractions was used to prepare cumulative % weight distribution tables for each sampling site. This table was then used in calculating the median particle diameter and deviation, skewness and kurtosis of the particle size distribution. As the grain size distribution was not determined for the fraction <63 µm, the ϕ-value for this fraction was given the value 8. The values for Mdϕ, SDϕ, SKϕ, and Kϕ should therefore be considered as extrapolated results.

The mathematical expressions are given below.

Mdϕ (median particle diameter):

Mdϕ= the ϕ-value of the midpoint (i.e. 50 %) of the cumulative % weight curve. This measures the central tendency of the size frequency distribution.

SDϕ (standard deviation):

SDϕ estimated as:

$$SD\phi = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

SDϕ gives a measure of the spread in particle size around the Mdϕ, and thus is a measure of the degree of sorting of the particles.

Skϕ (skewness):

Skϕ estimated as:

$$Sk\phi = \frac{\phi 16 + \phi 84 - 2Md\phi}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2Md\phi}{2(\phi 95 - \phi 5)}$$

Skϕ describes the symmetry of the spread in distribution around the Mdϕ. A completely symmetrical distribution will have Skϕ = 0, negative values indicate displacement of the distribution curve towards coarser sediment, and positive Skϕ indicates displacement towards finer sediment.

Kurtosis, Kϕ:

Kϕ estimated as:

$$K\phi = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$$

Kϕ describes the toppedness of the distribution, i.e. how heavy the tails are (expressed by the ϕ5 and ϕ95 fractions) compared to the central portion of the distribution. For a normal distribution the expression above will give a Kϕ value of 1.00. Interpretation tables are enclosed in Table 4.3.1 and Table 4.3.2.

Table 4.3.1. *Grain size distribution. Interpretation of descriptive indices (Buchanan,1984).*

Parameter	Index value	Verbal classification
Standard deviation (SDϕ)	<0.35	Very well sorted
	0.25-0.50	Well sorted
	0.50-0.70	Moderately well sorted
	0.70-1.00	Moderately sorted
	1.00-2.00	Poorly sorted
	2.00-4.00	Very poorly sorted
	>4.00	Extremely poorly sorted

Cont.

Table 4.3.1. *cont.*

Skewness (Skϕ)	+1.00 to +0.30	Strongly fine skewed
	+0.30 to +0.10	Fine skewed
	+0.10 to -0.10	Symmetrical
	-0.10 to -0.30	Coarse skewed
	-0.30 to -1.00	Strongly coarse skewed
Kurtosis (Kϕ)	<0.67	Very platykurtic
	0.67-0.90	Platykurtic
	0.90-1.11	Mesokurtic (nearly normal)
	1.11-1.50	Leptokurtic
	1.50-3.00	Very leptokurtic

Table 4.3.2. Grain size distribution. Mesh sizes used and Wentworth grade classification (Buchanan, 1984).

Mesh diameter (μm)	ϕ	Description
4000	-2	Gravel
2000	-1	Very coarse sand
1000	0	Coarse sand
500	+1.0	
355	+1.5	Medium sand
250	+2.0	
180	+2.5	Fine sand
125	+3.0	
90	+3.5	Very fine sand
63	+4.0	
<63	>+4.5	Silt and clay (pelite)

The silt and clay fraction was given the ϕ-value of 8.

Total organic matter

30-40 g of wet sediment was weighed into a porcelain dish. The sample was heated at 105 °C for minimum 20 hours, cooled and weighed, and then heated to 480 °C for minimum 16 hours. The percent weight loss after the combustion was then calculated, and this value represents the total organic matter content (TOM) in the sediment. Two sediment standards with known TOM and calcium carbonate were heated together with the sediment samples. The calcium carbonate was used as a cross check on potential weight loss due to the conversion of carbonate to oxide.

4.3.2 Chemical analyses

Hydrocarbons

The chemical analysis comprises determination of the total hydrocarbon content from n-C_{12} to n-C_{35} (THC) and selected hydrocarbons (NPD, PAH and decalins). The analytical steps are shown in Table 4.3.3. The sediment samples were worked up by saponification, followed by extraction with dichloromethan. The extract was then separated in a non-polar and a polar fraction using a silica column. The non-polar fractions were analysed for hydrocarbons by use of gas chromatography (GC).

Preparation procedure:

The sediment samples were taken in Rilsan bags. Homogenization was performed by stirring in the Rilsan bag, and small portions of the wet sample was taken randomly giving a total weight of about 50 g. Benthic animals were avoided if possible. Internal standards were added, 5 µg each of naphthalene-d_8, biphenyl-d_{10}, phenanthrene-d_{10}, pyrene-d_{10}, chrysene-d_{12} and perylene-d_{12}. The sample was refluxed with 50 mL 0.5 N KOH in methanol for 2 hours. The mixture was then extracted by 80 mL dichloromethane. The extract was evaporated to approximately 1 mL, re-dissolved in hexane and fractionated (clean up) on Bond-Elut silica columns (Isolute, International Sorbent Technology). The hexane fraction was concentrated and analysed for hydrocarbons.

An aliquot of the wet and homogenized sediment was weighed out and dried for 48 hours at 105 °C, for determination of the dry weight,

Quantification:

THC (total hydrocarbon content) was determined by gas chromatography-flame ionization detector (GC-FID), in the boiling range of n-C_{12} alkane to n-C_{35} alkane. The quantification was carried out according to an external standard of the reference oil, HDF 200, a drilling mud base oil. The reported values were corrected for background levels from procedural blanks.

NPD, PAH and decalins were determined by gas chromatography/mass spectrometry (GC/MS) operated in the selected ion recording mode (SIR). The quantification was carried out according to the added internal standards and integration of the molecular ions. The following compounds were determined: Naphthalene, phenanthrene/anthracene, dibenzothiophene and their C_1-, C_2- and C_3-alkylated derivatives, acenaphtene, acenaphthylene, fluorene, pyrene/fluoranthene, chrysene/ triphenylene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene/benzo(j)fluoranthene/ benzo(k)fluoranthene, benzo(g,h,i)perylene, indeno(1,2,3-cd)pyrene and dibenzo(a,h)anthracene. In addition the sum of selected bicyclic alkanes, C_5 - C_8 alkyl decalins, was determined.

Reference compounds were available for all the aromatic compounds. For each of the C_1 - C_3 alkyl homologue groups one of the isomers was used as reference in the quantification. For the bicyclic alkanes, C_5 - C_8 alkyl decalins, reference compounds were missing, and a response factor was calculated from n-octylcyclohexane with the assumption that the response of the molecular ions are similar. The reported values were corrected for background levels from procedural blanks.

GC – FID conditions:

Gas chromatograph:		Perkin Elmer Autosystem XL
Column:		12 m x 0.20 mm i.d., fused silica, crosslinked with dimethyl silicone
Temperatures:	Column:	50 °C (2 min) – 20 °C/min – 350 °C (8 min)
	Injector:	320 °C
	Detector:	350 °C
Carrier gas:		Helium
Injection volume:		1 µL
Data system:		TotalChrom 6.2
HDF 200:		0.1 – 10 mg/mL hexane

GC/MS conditions:

Mass spectrometer	: Clarus 500 Mass Spectrometer. Perkin Elmer
Data system	: TurboMass
Gas chromatograph	: Clarus 500 Gas Chromatograph. Perkin Elmer
Column:	: 30 m fused silica, 0.25 µm DB-5ms
Temperatures: Column	: 40 °C (2 min)-20 °C/min -120 °C -10 °C/min-300 °C- (15 min)
Injector	: 300 °C
Ion source	: 180 °C
Carrier gas	: Helium
Ionization	: Electron impact, 70 eV
Masses (m/z)	
C_0-C_3 naphthalene	: 128, 141, 156, 170
C_0-C_3 phenanthrene	: 178, 192, 206, 220
C_0-C_3 dibenzothiophene	: 184, 198, 212, 226
PAH	: 152, 153, 166, 202, 228, 252, 276, 278
C_5-C_8 decalins	: 208, 222, 236, 250
n-octyl cyclohexane	: 196
Deuterated standards	: 136, 164, 188, 212, 240, 264
Injection volume	: 1 µL

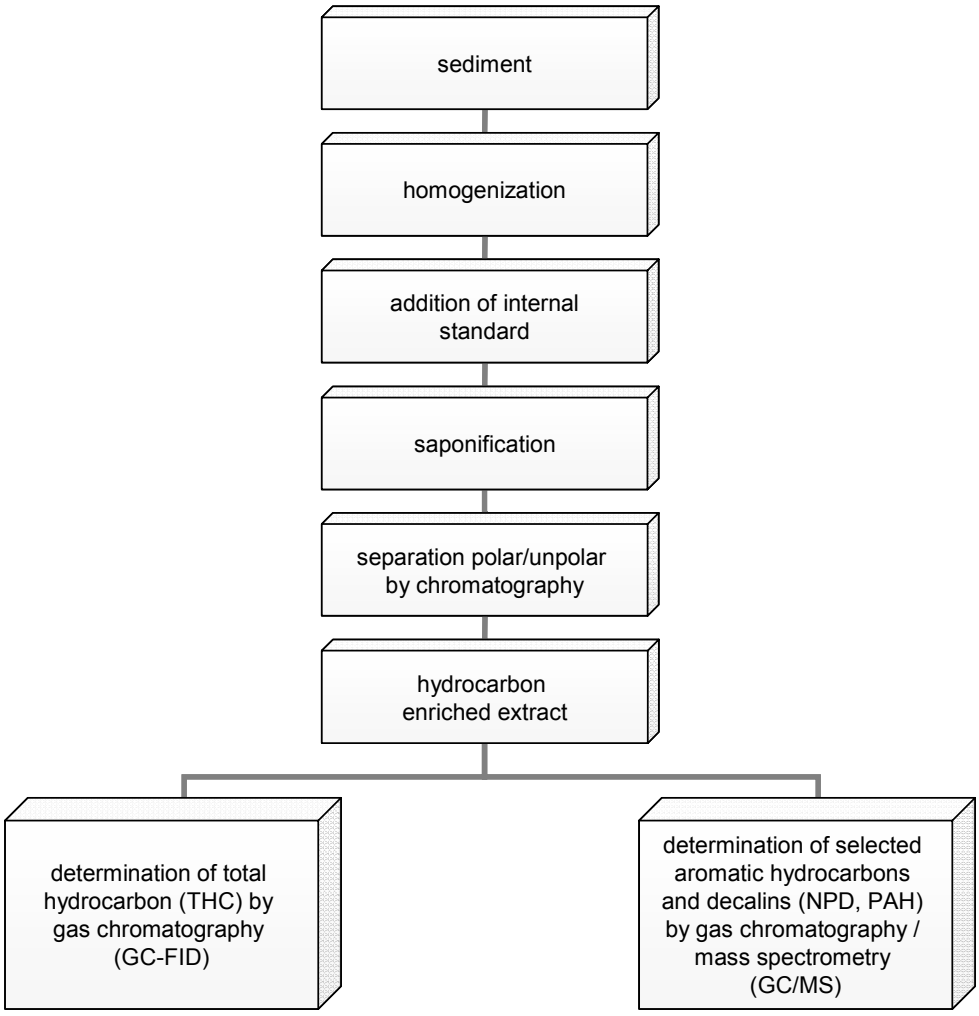


Table 4.3.3. *Flow scheme of essential steps in the hydrocarbon analyses of sediments.*

Metals

The metal analyses included determination of Ba, Cd, Cr, Cu, Hg, Pb and Zn after digestion with nitric acid (NS 4770).

The wet sediment sample was dried at 40°C for two days, homogenized and sieved through a 500 µm nylon sieve. The fractions larger and less than 0.5 mm were weighed. 1 g of the fraction less than 0.5 mm was extracted with 20 mL 7 M nitric acid in a Pyrex decomposition bottle in an autoclave at 120°C for 30 min. After cooling, 80 mL of distilled water was added to the Pyrex bottle. The clear solution was decanted into a polyethylene bottle until analysis.

Ba, Cr, Cu, Pb and Zn were determined by inductively coupled plasma atomic emission spectrometry (ICP-AES). Cd was determined by atomic absorption, graphite furnace technique (GF-AAS). Hg was determined by atomic adsorption cold vapour technique (CV-AAS) based on NS 4768.

ICP-AES:
Instrument: Thermo Jarrel Ash Iris Advantage
Analytical lines:
Ba: 493.409 nm Cr: 267.716 nm Cu: 324.754 nm Pb: 220.353 nm Zn: 213.856 nm

GFAAS:
Instrument: Perkin Elmer Analyst 600.
Analytical line: Cd: 228.8 nm
The element was measured with a hollow cathode lamp. Ammonium phosphate was used as a modifier.

CVAAS:
Instrument: Perkin Elmer 3100.
Hg was determined at 253.7 nm by use of stannous chloride in hydrochloric acid.

Detection and quantification limits

The limit of detection (LOD) and limit of quantification (LOQ) are calculated as 3 SD (standard deviation) and 10 SD above the measured average blank values respectively. This is according to "Guidelines for Data Acquisition and Data Quality Evaluation in Environmental Chemistry", Anal.Chem. 52 (1980) p. 2242-2249).The limit of detection (LOD) and limit of quantification (LOQ) for NPD, PAH and decalins are based upon the lowest standard that gives sufficient concentration recovery. The limit of detection (LOD) and limit of quantification for hydrocarbons and metals are given in Table 4.3.4 and Table 4.3.5.

Table 4.3.4. *Limit of detection (LOD) and limit of quantification (LOQ), hydrocarbons.*

Analytical parameter	LOD Mg/kg	LOQ mg/kg	Blank samples Number
THC	1	5	23
Sum NPD	0.01	0.03	-
Sum PAH	0.005	0.02	-
Sum decalins	0.1	0.3	-

Table 4.3.5. *Limit of detection (LOD) and limit of quantification (LOQ), metals.*

	Ba	Cd	Cr	Cu	Hg	Pb	Zn
	ICP	GFAAS	ICP	ICP	CVAAS	ICP	ICP
LOD mg/kg	1	0.01	0.2	0.5	0.01	0.5	1
LOQ mg/kg	3	0.04	0.7	2	0.03	2	3

4.4 Quality assurance

Accreditation

DNV's Biology Laboratory is accredited by Norsk Akkreditering to perform sampling of marine sediments for sediment characterisation and chemical/biological analyses, as well as laboratory analyses of macro benthic fauna under accreditation number Test 083. The accreditation is according to NS-EN ISO/IEC 17025.

Molab AS is accredited by Norsk Akkreditering to perform chemical analyses, accreditation number Test 032. The accreditation is according to NS-EN ISO/IEC 17025.

Quality assurance for macro fauna analyses

Procedures including routines for quality assurance related to sorting, species identification and recording of macro benthos samples are given in DNV's *Biolaboratoriets Kvalitetssystem, Prøvetaking av marint sediment og bløtbunnsanalyser.* A brief summary is given here:

All samples are recorded and doubly labelled during fieldwork, and transported in wooden boxes in a steel container. During sorting in the laboratory all relevant information about each sample is recorded (who sorted what and when, time spent, number of bottles etc.). After sorting, each sediment sample is examined for remaining organisms by approved personnel. Each identifier establishes a separate reference collection of species for comparison purpose. To maintain traceability each identifier signs a log to keep track over which grab samples and animal group(s) he or she has been working on. The project reference collection is kept at DNV, Høvik.

Quality assurance for grain size distribution

Six different laboratory reference sediments (from the 2003 survey) were chosen as a control for the grain size distribution.

Quality assurance for total organic matter

Together with the samples, calcium carbonate and two in house standards were heated to 480 °C. The calcium carbonate was used as a control of loss of carbonate from the sediment samples. The in house standards have known TOM (0.88 % and 8.31 %). If the results of one or both in house standards were outside the accepted range of variation, the samples were reanalyzed. The results of the analyses are given in Appendix C.

Quality assurance for hydrocarbons

The instruments are regularly calibrated by use of appropriate standards, and instrument performance is checked regularly. The analytical procedures are regularly controlled by analysis of standards, blank samples and quality assurance samples. Standards of mineral

oil are analyzed together with the THC samples. For NPD, PAH and decalins reference samples containing known amounts of the different compounds are analyzed to establish response factors due to differences in extraction, volatility and GC-MS response compared to the internal standards.

In house standards are analyzed regularly, and the results are plotted on control charts.

The accuracy of the THC analysis is documented by participation in the international intercalibration exercise SETOC. The accuracy is also controlled by analysis of sediments containing certified amount of THC.

The accuracy of the NPD and PAH analysis is controlled by analysis of in house standards.

Quality assurance for metals

All reagents are of pro analysis grade. In house reference and blank samples are included in the analyses. Accuracy and reproducibility are controlled by the results obtained for the in house reference materials.

4.5 Deviation from Aktivitetsforskriften (Activities regulations)

The survey was performed according to the Aktivitetsforskriftene (Activities regulations) § 52 (Dtil, SFT and SHdir 2001), technical appendix 2 in appendix 1 (updated 2003).

5.0 Results and discussion

See Appendix F for a fold out map of the location of the sampling stations.

5.1 Chemical analyses and sediment characterization

A summary of the results at Vilje 2005 is described below. Sediments were sampled from 15 stations at Vilje including a reference station. The depths at Vilje vary from 116 m to 124 m. The main results of the physical characterization and chemical analyses from the survey at Vilje in 2005 are shown in Table 5.1.1.

All the values found in this baseline survey at Vilje are considered to be the natural background level for the area. No contamination of hydrocarbons, barium (Ba) and heavy metals (Cr, Cu, Pb, Zn, Cd and Hg) are found in the sediments at Vilje.

The sediment at Vilje is dominated by fine sand. The average median particle diameter is 3.33.

The total organic matter contents are relatively low. The concentrations vary from 1.05 % to 2.10 % and the average value is 1.75 %. Small particles generally have greater affinity for binding organic matter than coarse particles.

The complete set of results for the grain size distribution is given in Appendix C.

Table 5.1.1. *Summary of the chemical analyses and physical characterization.*

Analytical method	**Parameter**	**Variations at Vilje 2005**
Depth (m)		116 - 124
Sediment characterization		
Grain size distribution (%)	Silt & clay: Sand: Gravel:	5.8 – 21 78 – 94 0 – 1.6
Median particle diameter (ϕ)	Mdϕ:	2.35 – 3.59
Total organic matter (%)	TOM:	1.05 – 2.10
Chemical analyses		
Hydrocarbons (mg/kg)	THC: NPD: PAH: Decalins:	2.0 – 6.5 0.01 – 0.05 0.06 – 0.18 Not detected
Metals (mg/kg)	Ba: Cr: Cu: Pb: Zn: Cd: Hg:	21 – 254 4.6 – 16 <1 – 5 2.7 – 13 5.5 – 25 <0.001 – 0.74 <0.01 – 0.03

5.1.1 Sediment characterization

Grain size distribution

The main results of the grain size distribution are shown in Table 5.1.2. The sediments at Vilje are dominated by fine sand. The sand contents vary from 78 % to 94 %. The contents of silt and clay vary from 5.8 % to 21 %, while the content of gravel ranges from 0.0 % to 1.6 %. The average median particle diameter is 3.33. The results from the complete grain size distribution are given in Appendix C.

Table 5.1.2. *Vilje 2005, grain size distribution.*

Station	Median diameter Mdϕ	Classification	Grain size distribution 2005 (%)		
			Silt and clay	Sand	Gravel
Vilje1 150°/250m	3.57	Very fine sand	20.9	78.0	1.1
Vilje2 150°/500m	3.58	Very fine sand	18.9	81.1	0.0
Vilje3 150°/1000m	3.56	Very fine sand	19.4	80.6	0.0
Vilje4 60°/250m	3.54	Very fine sand	19.3	80.6	0.1
Vilje5 60°/500m	3.58	Very fine sand	19.7	80.3	0.0
Vilje6 60°/1000m	2.79	Fine sand	14.2	84.1	1.6
Vilje7 60°/2000m	2.35	Fine sand	5.8	94.0	0.2
Vilje8 330°/250m	3.49	Very fine sand	17.5	82.5	0.0
Vilje9 330°/500m	3.43	Very fine sand	17.2	82.7	0.1
Vilje10 330°/1000m	3.22	Fine sand	16.1	83.7	0.1
Vilje11 240°/250m	3.59	Very fine sand	19.4	80.6	0.0
Vilje12 240°/500m	3.55	Very fine sand	21	78.4	0.7
Vilje13 240°/1000m	3.53	Very fine sand	18.7	81.3	0.0
Vilje14 240°/2000m	3.38	Fine sand	16.9	83.1	0.0
Vilje Ref. 240°/5000m	2.81	Fine sand	11.2	88.4	0.3
Mean	3.33	Fine sand	17.1	82.6	0.3
SD	0.38		4.1	4.0	0.5

Total organic matter (TOM)

The sediments at Vilje consist mainly of fine sand, and the total organic matter in the sediments is therefore low. The contents vary from 1.05 % and 2.10 %, and the average total organic matter is 1.75 %. The results are shown in Table 5.1.3.

Table 5.1.3. *Vilje 2005, % total organic matter (% TOM) of dry sediment.*

Station	% TOM 2005
Vilje1 150°/250m	1.53
Vilje2 150°/500m	1.95
Vilje3 150°/1000m	1.70
Vilje4 60°/250m	2.10
Vilje5 60°/500m	1.70
Vilje6 60°/1000m	1.45
Vilje7 60°/2000m	1.05
Vilje8 330°/250m	1.97

Station	% TOM 2005
Vilje9 330°/500m	1.94
Vilje10 330°/1000m	1.73
Vilje11 240°/250m	2.05
Vilje12 240°/500m	1.95
Vilje13 240°/1000m	1.86
Vilje14 240°/2000m	1.72
Vilje Ref. 240°/5000m	1.52
Mean	1.75

5.1.2 Chemical analyses

The following parameters are analyzed in the sediment samples from Vilje:

- THC
- NPD, PAH, decalins
- Metals (Ba, Cd, Cr, Cu, Hg, Pb and Zn).

Three replicate samples from the top layer, 0-1 cm, are analyzed. Additionally, samples of the 1-3 and 3-6 cm layer are analyzed at three stations.

THC

The THC results are shown in Table 5.1.4.

The average concentrations of THC vary from 2.0 mg/ kg (Vilje7) to 6.5 mg/kg (Vilje12). The concentration level of THC is characterized as the natural background level. There is no significant difference in the contents of total hydrocarbon between the upper 0-1 cm layer and the 1-3 and 3-6 cm layers. A bar diagram of the THC content in the sediments is shown in Figure 5.1.1. Representative gas chromatograms are given in Appendix C.

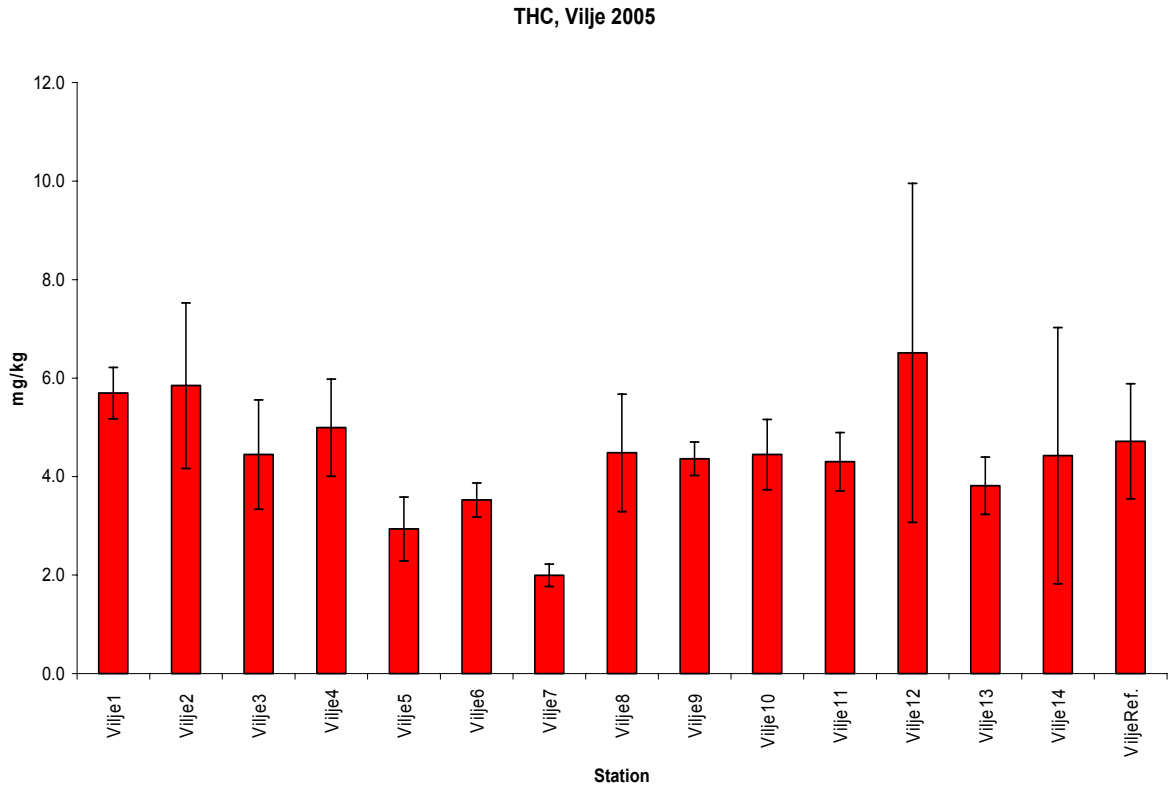


Figure 5.1.1 *Bar diagram of THC at Vilje. The error bars are based on the standard deviation of three sample replicates.*

Table 5.1.4. *Vilje 2005, total hydrocarbon (THC) (mg/kg dry sediment).*

Station	Layer/cm	# 1	# 2	# 3	# 4	# 5	Mean	SD
Vilje1 150°/250m	0-1	6.2	5.2	5.7			5.7	0.5
Vilje2 150°/500m	0-1	6.9	3.9	6.7			5.8	1.7
Vilje3 150°/1000m	0-1	4.1	3.6	5.7			4.4	1.1
Vilje4 60°/250m	0-1	5.7	5.4	3.9			5.0	1.0
Vilje5 60°/500m	0-1	2.5	3.7	2.6			2.9	0.6
Vilje6 60°/1000m	0-1	3.2	3.6	3.9			3.5	0.3
Vilje7 60°/2000m	0-1	1.8	2.2	1.9			2.0	0.2
Vilje8 330°/250m	0-1	4.7	3.2	5.6			4.5	1.2
Vilje9 330°/500m	0-1	4.2	4.8	4.2			4.4	0.3
Vilje10 330°/1000m	0-1	3.6	5.0	4.7			4.4	0.7
Vilje11 240°/250m	0-1	3.6	4.8	4.5			4.3	0.6
	1-3	4.9					4.9	
	3-6	4.7					4.7	
Vilje12 240°/500m	0-1	10.5	4.4	4.7			6.5	3.4
	1-3	3.8					3.8	
	3-6	3.7					3.7	
Vilje13 240°/1000m	0-1	3.2	4.4	3.9			3.8	0.6
Vilje14 240°/2000m	0-1	5.2	1.5	6.5			4.4	2.6
Vilje Ref. 240°/5000m	0-1	5.3	6.0	3.4	3.6	5.3	4.7	1.2
	1-3	2.7					2.7	
	3-6	3.0					3.0	

NPD, PAH and decalins

Sediments from three stations (reference station and two stations downstream) were analysed for NPD, PAH and decalins. Three replicates from the 0-1 cm top layer and one sample from the 1-3 cm and 3-6 cm were analysed. The results for NPD and PAH are shown in Table 5.1.5 and Table 5.1.6. Decalins were not detected.

The average NPD concentrations vary from 0.01 mg/kg (ViljeRef) to 0.05 mg/kg (Vilje11). The average PAH concentrations vary from 0.06 mg/kg (ViljeRef) to 0.18 mg/kg (Vilje12).

The highest concentrations of NPD and PAH are found at Vilje12 in the 0-1 cm layer, NPD 0.05 mg/kg and PAH 0.18 mg/kg respectively. Single compounds are given in Appendix C.

Table 5.1.5. *Vilje 2005, sum NPD (mg/kg dry sediment).*

Station	Layer/cm	# 1	# 2	# 3	# 4	# 5	Mean	SD
Vilje11 240°/250m	0-1	0.05	0.05	0.06			0.05	0.01
	1-3	0.04						
	3-6	0.06						
Vilje12 240°/500m	0-1	0.09	0.02	0.02			0.04	0.04
	1-3	0.03						
	3-6	0.02						
Vilje Ref. 240°/5000m	0-1	0.01	0.01	0.01	0.01	0.01	0.01	0.00
	1-3	0.02						
	3-6	0.02						

Table 5.1.6. *Vilje 2005, sum PAH (mg/kg dry sediment).*

Station	Layer/cm	# 1	# 2	# 3	# 4	# 5	Mean	SD
Vilje11 240°/250m	0-1	0.14	0.12	0.09			0.12	0.03
	1-3	0.07						
	3-6	0.15						
Vilje12 240°/500m	0-1	0.31	0.10	0.12			0.18	0.11
	1-3	0.13						
	3-6	0.11						
Vilje Ref. 240°/5000m	0-1	0.07	0.05	0.05	0.06	0.06	0.06	0.01
	1-3	0.05						
	3-6	0.07						

Metals

The concentrations of Ba, Cr, Cu, Pb, Zn, Cd and Hg are in general low and are considered natural background level for the area. The Hg concentration were analyzed at three stations and the concentration range is low, between <0.01 and 0.03 mg/kg.

The sediment layers at 1-3 and 3-6 cm were analyzed at three stations. The content of Ba and heavy metals (Cr, Cu, Pb, Zn, Cd and Hg) are the same as found in the 0-1 cm layer.

The concentration ranges of the metals are shown in Table 5.1.7, while the results of the chemical analyses are listed in Table 5.1.8. A bar diagram of the Ba concentrations is shown in Figure 5.1.2.

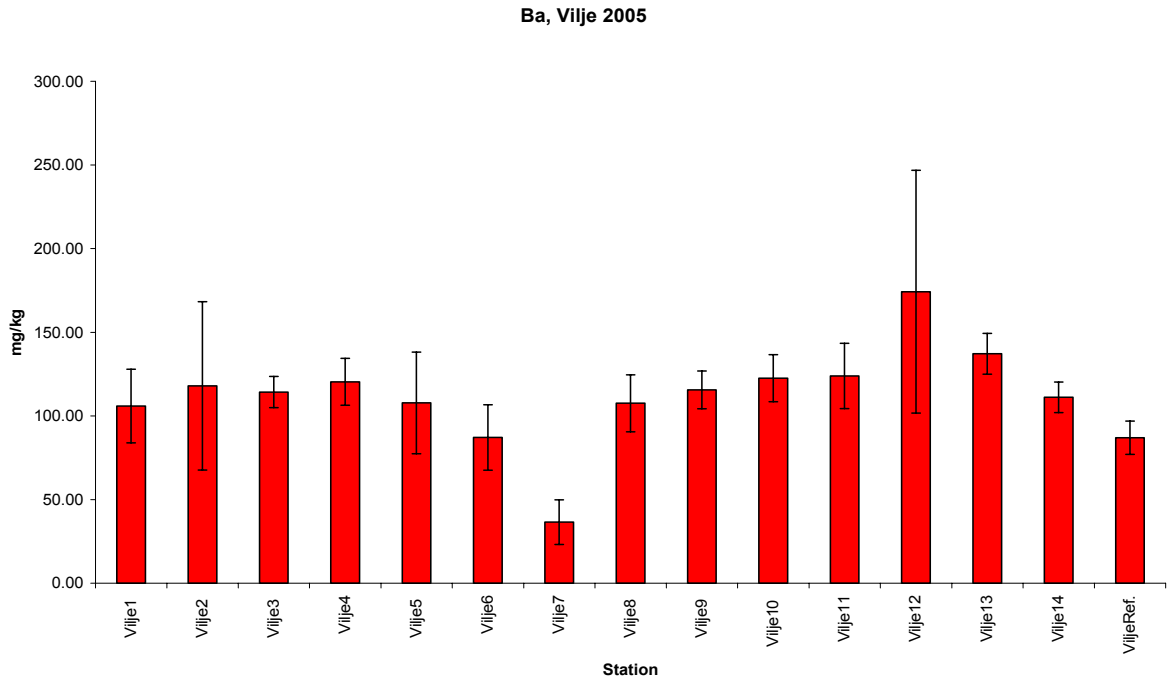


Figure 5.1.2. *Bar diagram of Ba at Vilje. The error bars are based on the standard deviation of three sample replicates.*

Table 5.1.7. *Vilje 2005, concentration range, metals 0-1 cm, mg/kg dry sediment.*

Element	Min		Max
Ba:	21	-	254
Cr:	4.6	-	16.2
Cu:	<1.0	-	5.1
Pb:	2.7	-	13.3
Zn:	5.5	-	25.4
Cd:	<0.001	-	0.74
Hg:	<0.01	-	0.03

Table 5.1.8. *Vilje 2005, metals (mg/kg dry sediment).*

Station	Sample	Ba 2005	Cd 2005	Cr 2005	Cu 2005	Hg 2005	Pb 2005	Zn 2005
VILJE1	1	121	0.02	8.6	1.8		3.7	11.1
150°/250m	2	116	0.02	9.4	2.1		4.4	13.1
	3	81	0.01	7.1	1.3		3.2	9.0
Mean		**106**	**0.02**	**8.3**	**1.7**		**3.8**	**11.1**
SD		22	0.00	1.2	0.4		0.6	2.0
VILJE2	1	148	0.02	8.6	2.3		4.8	11.8
150°/500m	2	60	0.03	7.6	1.6		4.8	12.0
	3	146	0.02	8.8	2.3		5.0	12.1
Mean		**118**	**0.02**	**8.3**	**2.1**		**4.9**	**12.0**
SD		50	<0.01	0.6	0.4		0.1	0.1
VILJE3	1	106	0.09	7.2	1.6		4.9	10.0
150°/1000m	2	112	0.02	7.5	1.8		3.7	11.3
	3	124	0.02	8.2	2.0		4.5	11.7
Mean		**114**	**0.04**	**7.6**	**1.8**		**4.4**	**11.0**
SD		9	0.04	0.5	0.2		0.6	0.9
VILJE4	1	120	0.02	7.7	1.9		4.8	10.1
60°/250m	2	135	0.02	8.7	1.9		5.3	11.3
	3	107	0.01	7.7	1.9		4.7	10.1
Mean		**120**	**0.02**	**8.0**	**1.9**		**4.9**	**10.5**
SD		14	0.00	0.6	0.0		0.3	0.7
VILJE5	1	81	0.02	7.5	1.5		4.7	13.6
60°/500m	2	141	0.02	8.6	1.9		4.3	11.6
	3	102	0.02	8.0	1.7		4.7	10.5
Mean		**108**	**0.02**	**8.0**	**1.7**		**4.5**	**11.9**
SD		30	0.0	0.5	0.2		0.2	1.6
VILJE6	1	94	0.01	6.5	1.4		3.6	8.8
60°/1000m	2	65	<0,01	5.4	<1		4.1	7.8
	3	102	0.01	6.1	1.2		5.0	8.4
Mean		**87**	**0.01**	**6.0**	**1.2**		**4.3**	**8.3**
SD		20	0.0	0.6	0.1		0.7	0.5
VILJE7	1	41	<0,01	5.1	<1		2.9	6.6
60°/2000m	2	47	<0,01	5.4	<1		3.8	6.7
	3	21	<0,01	4.6	<1		2.7	5.5
Mean		**37**	<0,01	**5.1**	**<1**		**3.1**	**6.3**
SD		13	0.0	0.4	0.0		0.6	0.7

Cont.

Table 5.1.8 *cont.*

Station	Sample	Ba 2005	Cd 2005	Cr 2005	Cu 2005	Hg 2005	Pb 2005	Zn 2005
VILJE8	1	110	0.01	7.9	1.7		5.3	10.6
330°/250m	2	90	0.01	7.7	1.5		4.5	9.8
	3	124	0.01	7.8	1.7		5.2	10.4
Mean		**108**	**0.01**	**7.8**	**1.6**		**5.0**	**10.3**
SD		17	0.0	0.1	0.1		0.4	0.4
VILJE9	1	108	0.02	8.0	1.8		5.6	10.8
330°/500m	2	111	0.01	7.6	1.7		5.2	10.2
	3	129	0.01	8.0	1.9		5.0	10.7
Mean		**116**	**0.01**	**7.9**	**1.8**		**5.3**	**10.6**
SD		11	0.006	0.2	0.1		0.3	0.3
VILJE10	1	107	0.01	6.8	1.5		4.5	9.3
330°/1000m	2	135	0.74	7.6	1.9		5.2	11.4
	3	125	0.01	7.1	1.5		5.3	12.0
Mean		**123**	**0.25**	**7.2**	**1.6**		**5.0**	**10.9**
SD		14	0.42	0.4	0.2		0.5	1.4
VILJE11	1	133	0.01	8.4	1.9	0.01	5.4	12.7
240°/250m	2	102	0.02	8.6	1.9	0.01	5.2	15.6
	3	138	0.02	9.2	2.1	0.01	5.8	12.0
Mean		**124**	**0.02**	**8.7**	**2.0**	**0.01**	**5.5**	**13.4**
SD		20	0.06	0.4	0.1	0.00	0.3	1.9
1-3 cm	1	122	0.02	8.8	2.0	0.01	6.0	11.9
3-6 cm	1	151	0.02	8.4	2.0	0.01	5.6	11.1
VILJE12	1	254	0.05	16.2	5.1	0.03	13.3	25.4
240°/500m	2	111	0.01	7.6	1.5	0.01	5.0	9.9
	3	158	0.02	8.0	2.0	0.01	5.9	12.4
Mean		**174**	**0.03**	**10.6**	**2.9**	**0.01**	**8.0**	**15.9**
SD		73	0.02	4.8	2.0	0.02	4.5	8.3
1-3 cm	1	145	0.02	9.8	2.2	0.02	6.5	14.1
3-6 cm	1	120	0.03	8.0	2.0	0.01	5.3	11.1
VILJE13	1	125	0.01	7.4	1.8		5.2	12.7
240°/1000m	2	138	0.02	8.0	2.1		5.1	13.0
	3	149	0.02	7.9	2.1		5.0	11.5
Mean		**137**	**0.02**	**7.8**	**2.0**		**5.1**	**12.4**
SD		12	0.006	0.3	0.2		0.1	0.8
VILJE14	1	116	0.02	7.3	1.8		4.8	11.0
240°/1000m	2	101	0.01	7.0	1.4		4.3	9.6
	3	117	0.02	7.1	1.6		5.2	10.2
Mean		**111**	**0.02**	**7.1**	**1.6**		**4.8**	**10.3**
SD		9	0.006	0.2	0.2		0.5	0.7

Cont.

Table 5.1.8 *cont.*

Station	Sample	Ba 2005	Cd 2005	Cr 2005	Cu 2005	Hg 2005	Pb 2005	Zn 2005
VILJEREF	1	79	0.01	6.3	1.2	0.01	4.5	8.4
240°/5000m	2	90	0.01	6.2	1.4	<0.01	5.0	8.9
	3	80	<0.01	5.8	1.3	<0.01	4.5	10.4
	4	103	0.01	6.2	1.5	<0.01	4.9	8.9
	5	83	<0.01	5.7	1.2	<0.01	3.2	7.8
Mean		**87**	**0.01**	**6.1**	**1.3**	**<0.01**	**4.4**	**8.9**
SD		10	0.0	0.3	0.1	0.0	0.7	1.0
1-3 cm	1	67	0.03	6.2	1.3	<0.01	4.1	8.8
3-6 cm	1	80	0.02	6.0	1.4	<0.01	4.3	13.9

5.2 Biological analyses

The cumulative number of species plotted versus number of grab samples at the reference station is presented in Figure 5.2.1. The shape of the curve indicates that the numbers of species still increase after ten grab samples. This means that even ten grab samples will not sample the total number of species at Vilje.

A total of 302 species and 28334 individuals were sampled at 15 stations. Greatest abundance (66.9 %) was found among the polychaetes, see Table 5.2.1. A complete species list is enclosed in the DNV Test Report, Appendix B.

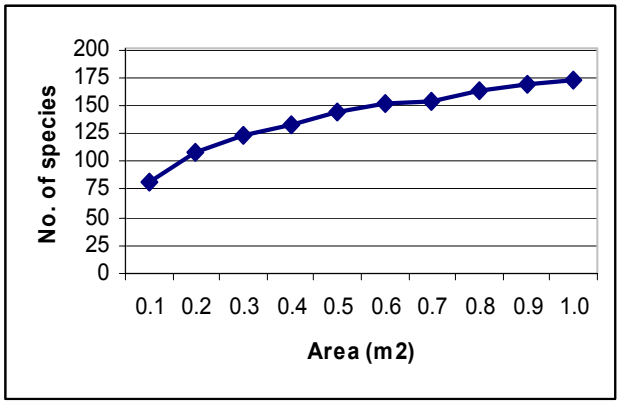
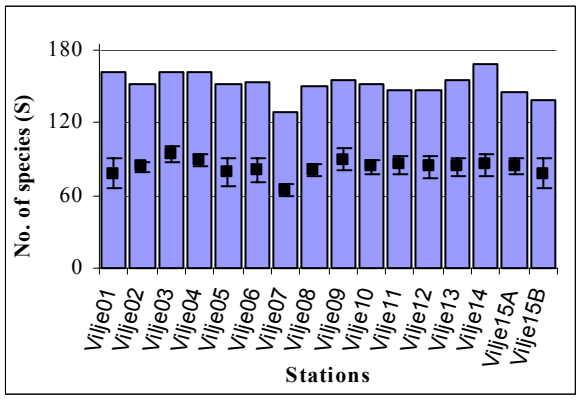


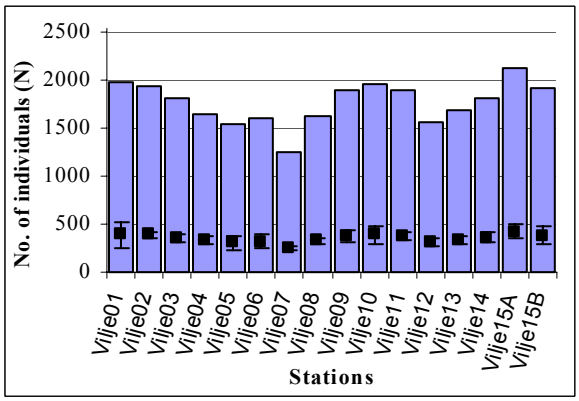
Figure 5.2.1. *The cumulative numbers of species vs. number of grab samples at the reference station, Vilje 2005.*

Figure 5.2.2 shows the numbers of species and individuals sampled at each station and variations between grab samples.

Table 5.2.1. *Number of species and individuals distributed between the main groups, Vilje 2005.*

Main animal groups	Individuals		Species	
	Number	%	Number	%
Varia	1539	5.4	19	6.3
Polychaeta	18965	66.9	150	49.7
Crustacea	1687	6.0	66	21.9
Mollusca	4009	14.1	54	17.9
Echinodermata	2134	7.5	13	4.3
Total	28334	100	302	100





Station	°/m	Station	°/m	Station	°/m	Station	°/m
VILJE01	150/250	VILJE02	150/500	VILJE03	150/1000	VILJE04	60/250
VILJE05	60/500	VILJE06	60/1000	VILJE07	60/2000	VILJE08	330/250
VILJE09	330/500	VILJE10	330/1000	VILJE11	240/250	VILJE12	240/500
VILJE13	240/1000	VILJE14	240/2000	VILJE15 A	240/5000	VILJE15 B	240/5000

Figure 5.2.2 *Numbers of species (S) and individuals (N) per 0.5 m^2, mean values per grab sample and standard deviation, Vilje 2005.*

Diversity and dominant species

The dominant species at each station varied from 14.9 % at VILJE-03 (150°/1000m) and Vilje-14 (240°/2000m) to 21.5 % at VILJE-07 (60°/2000m). The 10 most abundant species made up from 48.3 % at VILJE-13 (240°/1000m) to 60.1 % at VILJE-07, see Table 5.2.2. Frequently found species were the bristle worms *Paramphinome jeffreysii, Myriochele oculata, Prionospio cirrifera, Aricidea catharina, Amythasides macroglossus* and the mussels *Thyasira croulinensis and T. ferruginea.* Most of the above mentioned species are suspension feeders, *A. catharina* is both suspension- and deposit feeder, while *P. jeffreysii* is mainly a carnivore species. The composition of the fauna community (excl. juveniles) reflects an undisturbed environment.

Table 5.2.2. *The 10 most abundant species at each station, Vilje 2005.*

10 most dominating species							
VILJE-01	**No.**	**%**	**Cum. %**	**VILJE-02**	**No.**	**%**	**Cum. %**
Paramphinome jeffreysii	406	20.5	20.5	Paramphinome jeffreysii	402	20.8	20.8
Echinoidea spp.juv.	212	10.7	31.2	Myriochele oculata	140	7.2	28.0
Diplocirrus glaucus	92	4.7	35.9	Thyasira croulinensis	125	6.5	34.4
Myriochele oculata	85	4.3	40.2	Prionospio cirrifera	78	4.0	38.5
Prionospio cirrifera	78	3.9	44.1	Aricidea catherinae	72	3.7	42.2
Amythasides macroglossus	61	3.1	47.2	Nemertea spp.	55	2.8	45.0
Thyasira equalis	55	2.8	50.0	Amphiura chiajei	47	2.4	47.4
Nemertea spp.	53	2.7	52.6	Amythasides macroglossus	45	2.3	49.8
Ophiura affinis	41	2.1	54.7	Thyasira ferruginea	42	2.2	51.9
Amphiura filiformis	37	1.9	56.6	Glycera lapidum	42	2.2	54.1

Cont.

Table 5.2.2. *cont.*

10 most dominating species

VILJE-03	No.	%	Cum. %	VILJE-04	No.	%	Cum. %
Paramphinome jeffreysii	269	14.9	14.9	Paramphinome jeffreysii	306	18.5	18.5
Myriochele oculata	115	6.4	21.2	Thyasira croulinensis	109	6.6	25.0
Thyasira croulinensis	100	5.5	26.7	Prionospio cirrifera	84	5.1	30.1
Prionospio cirrifera	86	4.8	31.5	Aricidea catherinae	63	3.8	33.9
Aricidea catherinae	63	3.5	35.0	Myriochele oculata	55	3.3	37.2
Thyasira ferruginea	62	3.4	38.4	Nemertea spp.	50	3.0	40.2
Nemertea spp.	59	3.3	41.6	Amythasides macroglossus	46	2.8	43.0
Amythasides macroglossus	55	3.0	44.7	Amphiura chiajei	37	2.2	45.2
Glycera lapidum	37	2.0	46.7	Lumbrineris scopa	33	2.0	47.2
Lumbrineris aniara	36	2.0	48.7	Cerianthus lloydii	28	1.7	48.9

VILJE-05	No.	%	Cum. %	VILJE-06	No.	%	Cum. %
Paramphinome jeffreysii	288	18.7	18.7	Paramphinome jeffreysii	274	16.9	16.9
Thyasira croulinensis	109	7.1	25.8	Myriochele oculata	100	6.2	23.1
Aricidea catherinae	75	4.9	30.7	Thyasira croulinensis	80	4.9	28.0
Myriochele oculata	70	4.6	35.2	Amythasides macroglossus	75	4.6	32.7
Prionospio cirrifera	62	4.0	39.2	Prionospio cirrifera	65	4.0	36.7
Amythasides macroglossus	49	3.2	42.4	Aricidea catherinae	64	4.0	40.6
Laonice sarsi	47	3.1	45.5	Amphiura filiformis	47	2.9	43.6
Nemertea spp.	35	2.3	47.7	Thyasira ferruginea	40	2.5	46.0
Amphiura filiformis	34	2.2	49.9	Glycera lapidum	39	2.4	48.4
Thyasira ferruginea	34	2.2	52.1	Spiophanes bombyx	39	2.4	50.8

VILJE-07	No.	%	Cum. %	VILJE-08	No.	%	Cum. %
Myriochele oculata	270	21.5	21.5	Paramphinome jeffreysii	337	20.7	20.7
Paramphinome jeffreysii	151	12.0	33.6	Thyasira croulinensis	128	7.9	28.6
Thyasira croulinensis	62	4.9	38.5	Myriochele oculata	70	4.3	32.9
Amphiura filiformis	52	4.2	42.7	Prionospio cirrifera	68	4.2	37.1
Lanice conchilega	51	4.1	46.7	Aricidea catherinae	56	3.4	40.5
Spiophanes bombyx	44	3.5	50.2	Amythasides macroglossus	55	3.4	43.9
Owenia fusiformis	38	3.0	53.3	Laonice sarsi	39	2.4	46.3
Phoronis muelleri	35	2.8	56.1	Thyasira equalis	36	2.2	48.5
Nemertea spp.	27	2.2	58.2	Amphiura chiajei	34	2.1	50.6
Ophiura affinis	24	1.9	60.1	Amphiura filiformis	31	1.9	52.5

VILJE-09	No.	%	Cum. %	VILJE-10	No.	%	Cum. %
Paramphinome jeffreysii	368	19.3	19.3	Paramphinome jeffreysii	358	18.3	18.3
Thyasira croulinensis	143	7.5	26.8	Myriochele oculata	145	7.4	25.7
Amythasides macroglossus	100	5.3	32.1	Amythasides macroglossus	103	5.3	31.0
Prionospio cirrifera	83	4.4	36.5	Thyasira croulinensis	93	4.8	35.7
Myriochele oculata	65	3.4	39.9	Prionospio cirrifera	70	3.6	39.3
Aricidea catherinae	60	3.2	43.0	Aricidea catherinae	66	3.4	42.7
Amphiura chiajei	53	2.8	45.8	Nemertea spp.	51	2.6	45.3
Thyasira ferruginea	47	2.5	48.3	Ophiura affinis	48	2.5	47.7
Phoronis muelleri	39	2.1	50.3	Thyasira ferruginea	47	2.4	50.1
Laonice sarsi	39	2.1	52.4	Amphiura chiajei	43	2.2	52.3

Cont.

Table 5.2.2. *cont.*

10 most dominating species

VILJE-11	No.	%	Cum. %	VILJE-12	No.	%	Cum. %
Paramphinome jeffreysii	388	20.5	20.5	Paramphinome jeffreysii	312	19.9	19.9
Thyasira croulinensis	132	7.0	27.4	Thyasira croulinensis	76	4.8	24.7
Amythasides macroglossus	80	4.2	31.7	Prionospio cirrifera	70	4.5	29.2
Aricidea catherinae	78	4.1	35.8	Aricidea catherinae	68	4.3	33.5
Myriochele oculata	75	4.0	39.7	Amythasides macroglossus	45	2.9	36.4
Prionospio cirrifera	66	3.5	43.2	Myriochele oculata	45	2.9	39.2
Thyasira ferruginea	62	3.3	46.5	Nemertea spp.	42	2.7	41.9
Amphiura chiajei	45	2.4	48.9	Laonice sarsi	41	2.6	44.5
Lumbrineris aniara	37	2.0	50.8	Glycera lapidum	40	2.6	47.0
Laonice sarsi	36	1.9	52.7	Thyasira ferruginea	36	2.3	49.3

VILJE-13	No.	%	Cum. %	VILJE-14	No.	%	Cum. %
Paramphinome jeffreysii	309	18.2	18.2	Paramphinome jeffreysii	271	14.9	14.9
Thyasira croulinensis	112	6.6	24.8	Thyasira croulinensis	114	6.3	21.2
Myriochele oculata	75	4.4	29.2	Spatangidae spp.juv	90	5.0	26.2
Amythasides macroglossus	63	3.7	32.9	Myriochele oculata	90	5.0	31.1
Prionospio cirrifera	63	3.7	36.6	Prionospio cirrifera	71	3.9	35.0
Thyasira ferruginea	50	2.9	39.6	Amythasides macroglossus	69	3.8	38.8
Aricidea catherinae	45	2.7	42.2	Aricidea catherinae	52	2.9	41.7
Spiophanes bombyx	36	2.1	44.3	Amphiura filiformis	45	2.5	44.2
Laonice sarsi	35	2.1	46.4	Lanice conchilega	41	2.3	46.4
Amphiura chiajei	34	2.0	48.4	Amphiura chiajei	40	2.2	48.6

VILJE-15A	No.	%	Cum. %	VILJE-15B	No.	%	Cum. %
Paramphinome jeffreysii	336	15.8	15.8	Myriochele oculata	330	17.1	17.1
Myriochele oculata	215	10.1	25.8	Paramphinome jeffreysii	249	12.9	30.0
Thyasira croulinensis	155	7.3	33.1	Thyasira croulinensis	144	7.5	37.4
Prionospio cirrifera	94	4.4	37.5	Spiophanes bombyx	91	4.7	42.1
Amythasides macroglossus	90	4.2	41.7	Prionospio cirrifera	72	3.7	45.9
Spiophanes bombyx	90	4.2	45.9	Amythasides macroglossus	68	3.5	49.4
Aricidea catherinae	55	2.6	48.5	Nemertea spp.	56	2.9	52.3
Laonice sarsi	55	2.6	51.1	Aricidea catherinae	54	2.8	55.1
Nemertea spp.	47	2.2	53.3	Phoronis muelleri	41	2.1	57.2
Phoronis muelleri	42	2.0	55.3	Laonice sarsi	41	2.1	59.3

The numbers of species were high and varied from 127 at station VILJE-07 (60°/2000m) to 65 at VILJE-14 (240°/200m), see Table 5.2.3. The numbers of individuals were also relatively high ranging from 1245 at VILJE-07 to 2117 at VILJE-15A (240°/5000m). The Shannon Wiener diversity index was >5 at all stations, ranging from 5.1 at VILJE-07 to 5.7 at VILJE-14. The Hurlberts indices (ES_{100}) ranged from 39 at VILJE-07 to 47 at VILJE-03 (150°/1000m). The indices reveal an undisturbed fauna community.

Table 5.2.3. *Numbers of individuals (N) and species (S), depth, Shannon-Wiener diversity index (H'), Pielou's evenness index (J), and expected number of species per 100 individuals (ES_{100}) for each station at Vilje 2005 (excl. juv.).*

Station	Direction °	Distance m	Depth	S	N	H'	J	ES_{100}
VILJE-01	150	250	122	159	1757	5.4	0.7	44
VILJE-02	150	500	123	149	1908	5.4	0.7	42
VILJE-03	150	1000	123	158	1780	5.8	0.8	47
VILJE-04	60	250	124	159	1628	5.7	0.8	46
VILJE-05	60	500	123	150	1528	5.5	0.8	44
VILJE-06	60	1000	120	150	1604	5.6	0.8	44
VILJE-07	60	2000	116	127	1245	5.1	0.7	39
VILJE-08	330	250	123	147	1613	5.5	0.8	44
VILJE-09	330	500	123	153	1879	5.6	0.8	45
VILJE-10	330	1000	121	148	1929	5.5	0.8	43
VILJE-11	240	250	123	144	1877	5.5	0.8	44
VILJE-12	240	500	122	144	1540	5.6	0.8	46
VILJE-13	240	1000	121	153	1673	5.6	0.8	46
VILJE-14	240	2000	124	165	1694	5.7	0.8	46
VILJE-15A	240	5000	120	143	2117	5.4	0.8	42
VILJE-15B	240	5000	120	137	1920	5.2	0.7	40

Classification and ordination

The dendrogram from the cluster analysis and the MDS plot from the ordination analysis at station level are presented in Figure 5.2.3 and Figure 5.2.4. The similarity between most of the stations is >70 %. However, stations VILJE-01 (150°/250m) and VILJE-07 (60°/2000m) deviate somewhat from the other stations at a similarity of about 65 – 70 %.

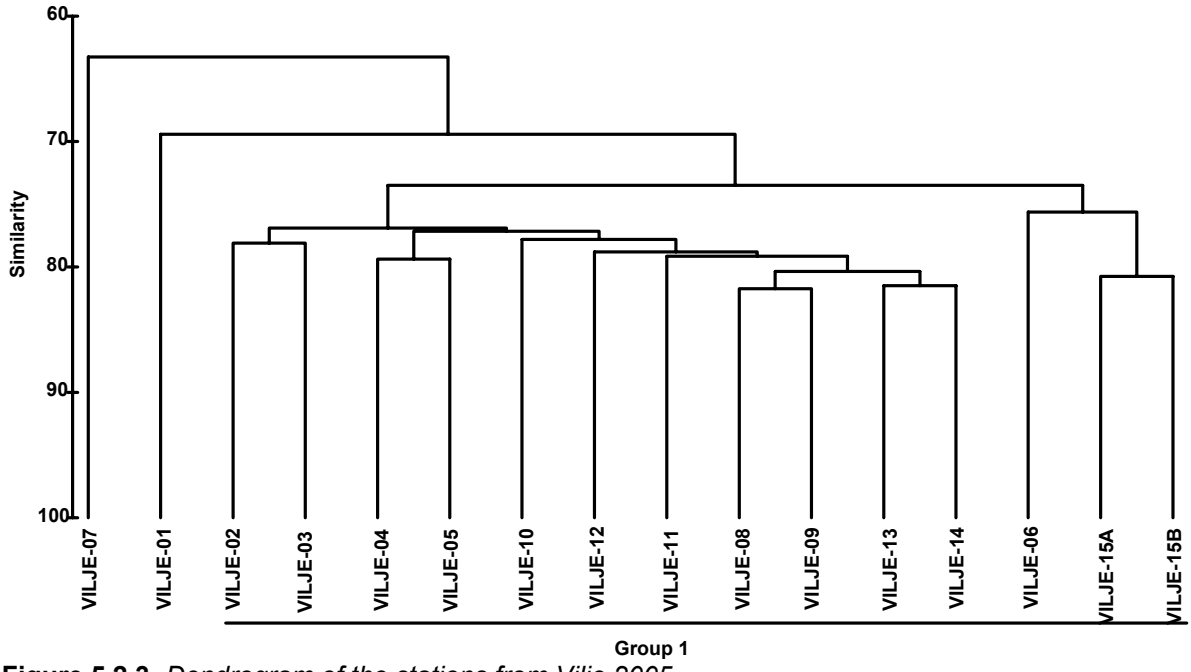


Figure 5.2.3. *Dendrogram of the stations from Vilje 2005.*

The species which contribute the most to the differences between the main group and VILJE-01 and VILJE-07 are somewhat higher numbers of the bristle worms *M. oculata* and *Owenia fusiformis* at station VILJE-07, higher numbers of the bristle worm *P. jeffreysii* at station VILJE-01 and higher numbers of the bristle worm *Amythasides macroglossus* and the mussel *Thyasira croulinensis* at the stations in the main group.

Almost all of the above mentioned species and many of the dominating species are suspension feeders, and they are typically found in undisturbed environments.

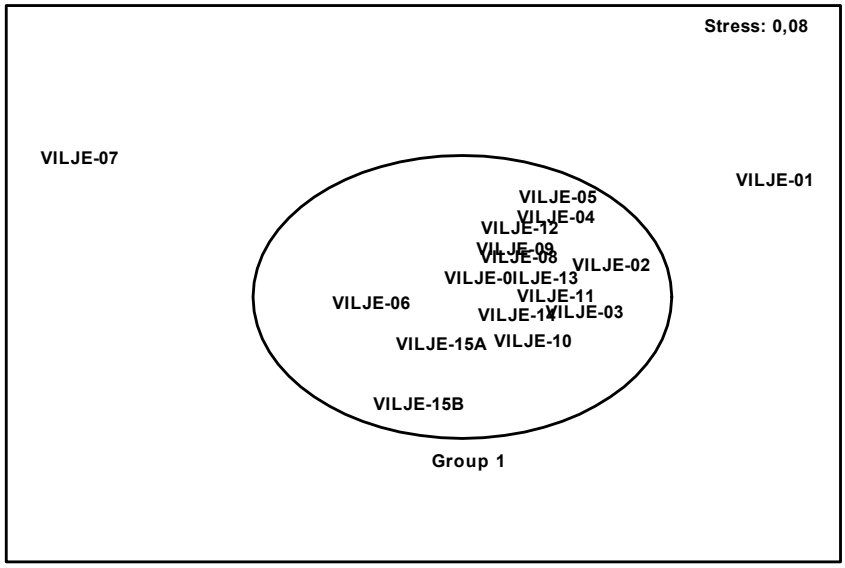


Figure 5.2.4. *MDS plot of the stations from Vilje 2005.*

5.3 Conclusions

The sediments at Vilje are dominated by fine sand and the gravel contents are low. The average median particle diameter is 3.33.

The content of organic matter is generally low. The contents vary from 1.05 % to 2.10 % and the average content of organic matter is 1.75 %.

The concentrations of hydrocarbons (THC) vary from 2.0 to 6.5 mg/kg. The concentrations of NPD and PAH are low, the highest values detected are 0.06 and 0.18 mg/kg, respectively. Decalins have not been detected.

The mean concentrations of barium (Ba) range from 21 to 254 mg/kg and the average concentration for all the stations is 112 mg/kg.

The results from this environmental baseline survey show that the sediment is not influenced by pollution of hydrocarbons, barium (Ba) or heavy metals (Cd, Cr, Cu, Hg, Pb and Zn).

The fauna community at Vilje is characterised as undisturbed with high diversity indices.

6.0 References

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APPENDIX

A
EXTRACT FROM THE SURVEY REPORT

O:\635upstream\projects\2005\66110757 Ekofisk\Rapportering\Vilje\Appendices\Appendix A - Utdrag av toktrapport

- Toktrapport Ekofisk 2005, rev.2
- App. 1 toktrapport

APPENDIX

B
DNV TEST REPORT (BIOLOGY)

O:\635upstream\projects\2005\66110757 Ekofisk\Rapportering\Vilje\Appendices\Appendix B - DNV Prøvingsrapport (biologi)

- Appendix B Prøvingsrapport Vilje og Fram øst 2005
- Appendix A artslister prøvingsrapport vilje og Fram Øst

APPENDIX

C
ANALYSES REPORT (CHEMISTRY)

O:\635upstream\projects\2005\66110757 Ekofisk\Rapportering\Vilje\Appendices\Appendix C - Analyserapport – Kjemi\Analyserapport.doc

APPENDIX

D
STATISTICAL ANALYSES

O:\635upstream\projects\2005\66110757 Ekofisk\Rapportering\Vilje\Appendices\Appendix D - Statistical analyses – Biology\Statistiske metoder 2005.doc

APPENDIX

E
SAMPLING AND ANALYSING PROGRAMME

O:\635upstream\projects\2005\66110757 Ekofisk\Rapportering\Vilje\Appendices\Appendix E - Sampling and analysing programme\Program grunnlagsundersøkelse Vilje final.doc

APPENDIX

F
MAP OF THE STATIONS AT VILJE

O:\635upstream\projects\2005\66110757 Ekofisk\Rapportering\Vilje\Appendices\Appendix F – Stasjonskart\Kart.doc

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N-1322 Hovik
Norway
Phone: +47 67 57 99 00

DNV CONSULTING
Johan Berentsenvei
109-111
N-5020 Bergen
Norway
Phone: +47 55 94 36 00

DNV CONSULTING
Bjergstedveien 1
N-4002 Stavanger
Norway
Phone: +47 51 50 60 00

DNV CONSULTING
Ingvald Ystgaardsvei 15
N-7496 Trondheim
Norway
Phone: +47 73 90 3500

DNV CONSULTING
Businesspark
Essen - Nord
Schnieringshof 14
45329 Essen
Germany
Phone: +49 201 7296 412

DNV CONSULTING
Duboisstraat 39 – Bus 1
B-2060 Antwerp
Belgium
Phone: +32 (0) 3 206 65 40

DNV CONSULTING
Palace House
3 Cathedral Street
London SE1 9DE
United Kingdom
Phone: +44 20 7357 6080

DNV CONSULTING
Highbank House
Exchange Street
Stockport
Cheshire SK3 0ET
United Kingdom
Phone: +44 161 477 3818

DNV CONSULTING
Cromarty House
67-72 Regent Quay
Aberdeen AB11 5AR
United Kingdom
Phone: +44 1224 335000

DNV CONSULTING
16340 Park Ten Place
Suite 100
Houston, TX 77084
USA
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