Environmental Status of the Norwegian Offshore Sector Based on the Petroleum Regional Monitoring Programme, 1996-1998

Prepared for the Norwegian Oil Industry Association (OLF)

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Preface

Substantial oil and gas exploration and production activity has taken place on Norway's marine continental shelf area over the past 25 years. Environmental monitoring programs have been conducted over this period in order to determine the magnitude and spatial extent of environmental effects of such activities and serve as an informational basis for modifying activities and discharges to the marine environment that will minimise future effects. The content and procedures of these surveys have been strictly regulated by the Norwegian Pollution Control Authority (SFT).

In 1996, a substantial revision in the way monitoring surveys are carried out in Norway was implemented. This new strategy is based on an assessment of regional impacts rather than solely those at the individual field level, as was done previously. In the period 1996 -1998, all of the regions containing petroleum activity have been surveyed. The Norwegian Petroleum Operators Association (OLF) and SFT wish to review the environmental status of Norway's offshore sector based on the information collected through these regional surveys.

The project encompasses three main products, with the present document representing the first of these:

1. A Popular Report. This report is intended to summarise the major features of the monitoring regions, the development of the monitoring programme to its present form, and the main results of the regional environmental survey activities. It is intended for a wider audience and focuses on summary information without citations to original literature or source information.
2. A Conference Paper. The scientific results on which this summary was based have been presented at the 14th International Senckenberg Conference ("Burning Issues of North Sea Ecology") in Wilhelmshaven, Germany, from May 8-12th 2000.
3. A Technical Scientific Manuscript. Derived from the conference paper, this fully cited manuscript will be submitted for publication to a peer-reviewed international scientific journal of marine science. Publication of the manuscript is anticipated for late 2001.

Together, these three products are intended to disseminate to a wider audience than would ordinarily view the basic monitoring results, a synthesis view of the state of the Norwegian offshore environment and to demonstrate the value and utility of the large amount of environmental data collected through the Norwegian offshore monitoring programme.

This project has been a co-operative effort by three Norwegian organisations. The project group has been led by Akvaplan-niva AS, with substantial participation from Det Norske Veritas AS and Unilab Analyse AS. These three organisations are all fully accredited, and each has more than a decade of experience in carrying out environmental surveys.

In addition, the contributors wish to acknowledge the project sponsor OLF and SFT for their input. Data for this report were collected from a number of sources, both published and unpublished. We would particularly like to also acknowledge OLF for their database containing biological information from the regional monitoring surveys, Novatech AS for compiling the chemical discharge information, and members of the SFT Expert Group for their constructive criticisms and suggestions. There are a number of other individuals and organisations on which we have relied on at one point or another during the course of this project, to all we are grateful.

Table of Contents

Summary

In 1996, environmental monitoring surveys of the marine sea bottom around petroleum installations were modified to focus on regional effects, rather than solely on field effects. Of the 11 geographic regions defined by SFT, five currently support petroleum production: Region I = Ekofisk, Region II = Sleipner, Region III = Oseberg, Region IV = Statfjord, Region VI = Trøndelag, and one additional region, Region IX = Finnmark, has been opened for exploration. During the period from 1996 to 1998, all of the regions were surveyed: Regions I and IV in 1996, Regions II and VI in 1997, and Region III and IX in 1998.

The overall physical environment in the offshore regions is controlled primarily by the depth, currents, and sediment type. As a result of the two main continental shelf bathymetric features, the North Sea Plateau in the southern portion and the Norwegian Trench in the northern regions, Region I is uniformly shallow (about 100 m), Region VI is predominantly deep (>250 m), whereas Regions II and III and IV have a large range in depths. Large scale movement of water is under the overall influence of two main current systems, the offshore North Atlantic Drift and the nearshore Norwegian Coastal Current. Local flows and seawater characteristics are also influenced by a variety of small-scale currents and factors such as bottom topography. Sediment distributions correlate with depth, with fine-grained material generally occurring at depths over 120 m. In shallow areas, sediments are frequently remobilized and transported by episodic storm events.

Fields in Region I were the first to be developed in Norway and therefore have the longest production history, mostly from surface installations. Region II also is predominantly developed via surface installations, while regions III – VI support progressively greater proportions of subsurface installations. The greatest oil reserves are found in Region IV, gas is dominant in Region III, condensate reserves are highest in regions II and VI, while natural gas liquids are proportionally split between regions I, III, and VI. Overall drilling activity increased significantly over the period from 1990-1998. The increasing trend in drilling activity is due to increases in the annual number of production wells, and not to exploration or appraisal well drilling which exhibits no distinct temporal trends.

The main contributor to seafloor disturbance around oil- and gas-installations on the Norwegian sector has been the deposition of cuttings and mud containing slowly degradable oil, heavy metals and other compounds. Cuttings from wells drilled with synthetic and oil-based drilling fluids tend to settle to the bottom close to the discharge point, while chemical compounds from wells drilled with water-based muds are highly water soluble and therefore disperse widely from the discharge point. Discharges of both water-based and synthetic-based cuttings and drilling fluids exhibited a decreasing trend over the period from 1996-98, as did barite present in both water- and synthetic-based muds. The main discharge from producing wells is oil-contaminated produced waters. Discharges of produced water increased over the period due to an increase in the number of production wells, as well as maturing of existing wells. The average concentration of oil in produced water in 1998 for the entire region was 23 mg/l, well below the maximum permitted concentration of 40 mg/l for single sources.

Monitoring surveys in 1996-1998 encompassed a total of 87 regional and reference stations for the determination of background values, and 687 field stations for the assessment of petroleum-related effects. The regions with the highest number of stations with disturbed fauna were I, III, and IV (i.e. the areas with the longest history of industrial activity), whereas the more recently exploited regions II and VI had the fewest disturbed stations.

The background range of barium values in the five regions was 6 – 550 mg/kg, with the highest background levels recorded in Region IV. At the field stations, the range of barium was 11 – 9100 mg/kg, with the highest values also occurring in Region IV. Barium values of

>2000 mg/kg were recorded at field stations in all regions. For total hydrocarbons (THC), the background range over all regions was 1 – 14 mg/kg, while the field range was 1 – 5200 mg/kg. The highest THC levels were found in Region IV, and Region III also had maximum levels >2000 mg/kg. In all other regions, maximum recorded levels were <500 mg/kg. For lead, the background range was 1 – 47 mg/kg, the field range was 1 – 172 mg/kg, with Region IV showing the highest field levels. For biological diversity (measured by the Shannon-Wiener index), the background range was 3.2 – 6.2, and the field range was 1.6 – 6.4. The lowest levels occurred in Region I.

An integrated analysis was conducted on all data from 1996 to 1998 together with data from field-specific surveys from 1990 to 1995 to determine the relative influence of industrial activities and of natural variability on benthic communities. It was found that 92% of the total variability was attributable to either natural or unrecorded factors. Of the natural factors, water depth and grain size were the most influential, with inter-annual variations also being important. Of the 8% of community variation attributable to chemical effects, the most important factors were the levels of THC and cadmium. A region-specific analysis indicates that the effects of chemical variables increased between 1993 and 1998 in Region III at two recently developed fields, while chemical effects declined in Region IV in the vicinity of two older installations. The overall effects in all such areas were found to be far smaller that those recorded from fields in Region I in 1990-91 when OBM was being discharged.

SFT uses three indicators to estimate the spatial extent around installations with identifiable effects of petroleum-related activities: bottom area contaminated with barium, the area contaminated with hydrocarbons (THC), and the area with disturbed sea-bottom fauna. The barium indicator traces dispersion of drilling components in general. THC indicates contamination from drilling with oil-based muds (OBM). The biological fauna indicator traces overall disturbance to the sediment community. Region I, the oldest and most extensively developed region, contains the greatest extent of affected area based on all three indicators. All the regions have essentially the same temporal trends of effects. Barium and THC indicators rise through the early 1990's, then THC decreases after 1992, presumably due to prohibition of OBM. Barium also peaks and then decreases after 1994, but the reasons for this pattern are more complex. The biological indicator similarly shows the greatest extent of disturbed fauna in the 1993-94 time period, however it is much less variable from year-to-year than the other indicators. This is presumably due to the fact that biological communities integrate external environmental effects over several years.

In order to determine the relative extent of impacts to the Norwegian offshore sector as a whole, the estimates of total affected area based on the biological and THC indicators are expressed as a proportion of the total area of Norwegian offshore area. This approach indicates that petroleum activities impact far less than 1% of the total bottom area in the different regions. Proportional values for the biological indicator range from a low of 0.004% in Region II to a maximum of 0.3% in Region I, and values for the THC indicator ranged from 0.01% in Region VI to 0.3% in Region IV.

Two case studies demonstrate the changes in the extent of contamination through time under different scenarios. Gyda field (Region I) was developed based on drilling with OBM, while wells in the Tordis field (Region IV) were drilled predominantly with synthetic-based muds (SBM). Monitoring surveys at Gyda trace an almost undisturbed area before production drilling changing to one extensively affected by THC due to the use of OBM during drilling. Since then, conditions have gradually improved due to the slow degradation of hydrocarbons. In contrast, the use of SBM during drilling at Tordis resulted in an initially smaller affected area as well as a faster recovery of the environment from the effects of drilling.

1 Introduction

Petroleum production plays a central role in Norwegian industry. The production of oil and gas in the Norwegian sector of the North Sea has increased 6-fold since the early 1980's (Figure 1). Norway is among the world's ten largest producers of oil and gas, and Norwegian exports of oil and gas rank second and fourth largest, respectively, in the world. Internationally, Norwegian oil and gas supplies the demands particularly of European countries, but also other regions of the world. Domestically, a significant proportion of the country's economic base derives from the petroleum industry, both from the royalties paid by operators to the state and from the economic infrastructure supporting and servicing the exploration and production of petroleum.

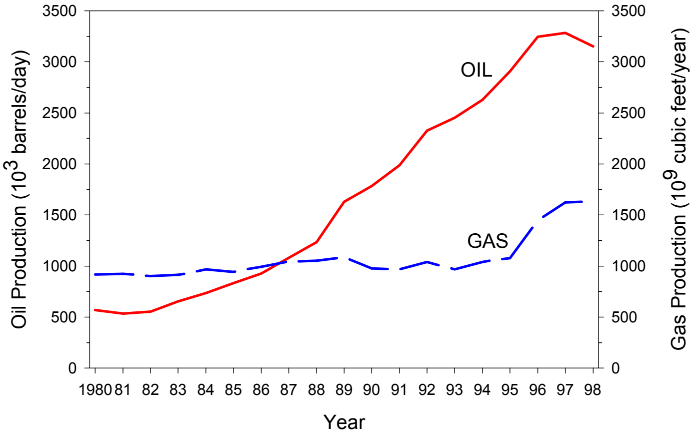


Figure 1: Norway Petroleum Production 1980-1998.

All of Norway's known petroleum reserves are located offshore, so this account focuses on the major effects of the industry on the marine environment[1]. The extent and magnitude of any environmental effects depend upon the types of chemical compounds released to the environment, the amounts discharged, and the time-course over which discharges take place. Of the two general categories of discharges: accidental and operational, we shall concentrate on the operational discharges, which are defined as the known and expected releases of compounds from normal petroleum operations.

The discharges from the exploration and production phases of an installation are bound nationally by the provisions of the Pollution Control Act and internationally by the Oslo-Paris Convention (OSPAR), which regulates discharges of polluting compounds into the North Atlantic. As a consequence, an operator must carry out an environmental monitoring programme on a field according to guidelines established by the Norwegian Pollution Control Authority (SFT) in order to measure the impact of the drilling and consequent chemical discharges on the marine environment.

Norwegian authorities have instructed the operators to carry out monitoring surveys around petroleum installations in Norwegian waters since oil first began flowing in the early 1970's. The surveys have been conducted in order to gain information about the discharges from the installations and the effects on the marine environment and marine life. However, the foci of these surveys, as well as the methods, protocols, and analytical techniques used in carrying them out, have developed over time as more information has been gained about the environment and as more sophisticated analytical techniques have become available. In 1988, the Paris Commission released guidelines developed by SFT for environmental monitoring around offshore petroleum installations, and in 1990 these guidelines were adopted as the standard for monitoring in Norway. A particularly important milestone was reached in 1996, when the Norwegian authorities radically changed the strategy of the monitoring.

Prior to 1996, a *field-specific approach* was employed, whereby each oil field was surveyed and considered completely independently of other fields in the area. The new *regional*

[1] The effects of emissions to air are not covered in this report.

approach adopted in 1996 still conducts sediment sampling around each installation, but places far more emphasis on an assessment of regional characteristics in determining the level and extent of any effects on the environment of discharges from petroleum activities. Also, since 1998, regional monitoring includes biological effects and water column monitoring. The new approach was a response to a number of considerations. These included the increasing levels of produced water being discharged from production installations as fields matured and their potential effects on biota in the water column, the wide dispersal of discharged contaminants and the potential for far-field effects, and cost effectiveness. Thus it was deemed necessary to broaden the scope of the surveys over a wider area. Such surveys were also intended to facilitate greater understanding of the natural environmental variation inherent in the region and thus provide better baseline information for determining possible anthropogenic effects.

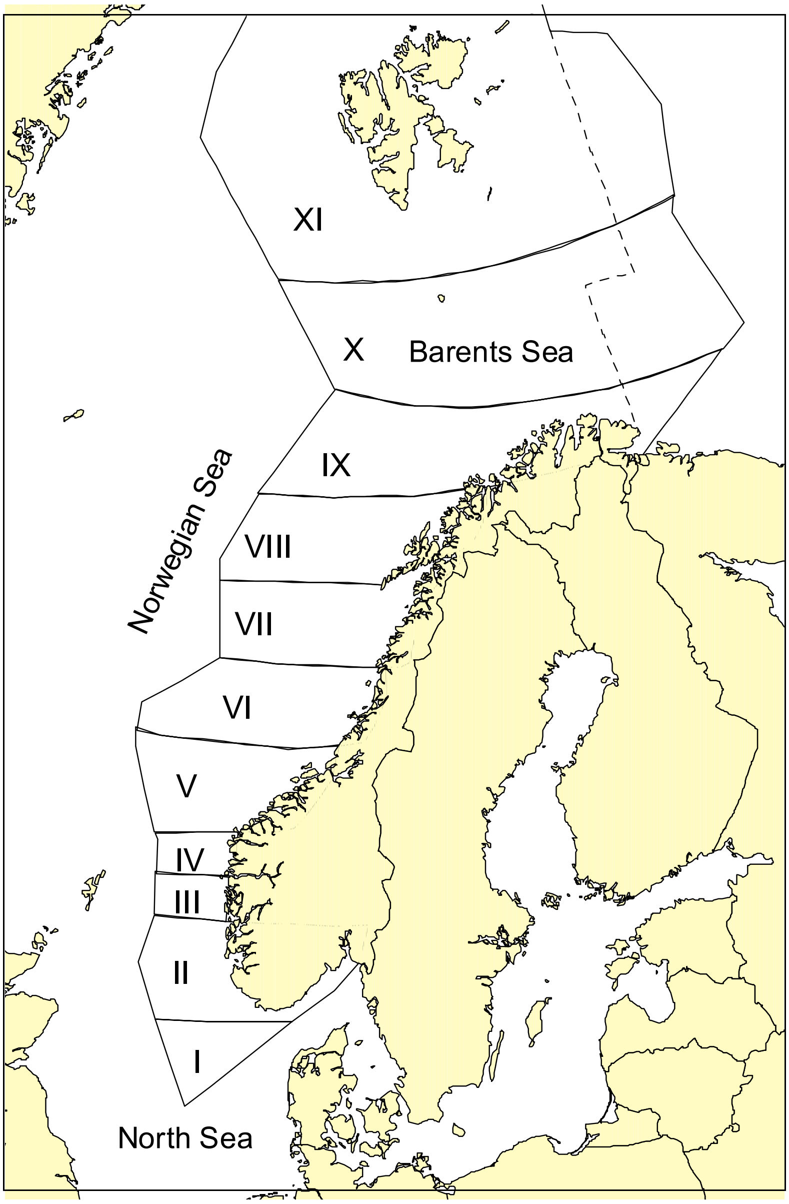


Figure 2: Map of Scandinavia and the Norwegian offshore sector showing the 11 offshore regions as defined by the Norwegian Pollution Control Authority.

Norwegian waters have been divided into 11 regions for sediment monitoring distributed across the North Sea, the Norwegian Sea, and the Barents Sea (Figure 2). Six of the regions support production of oil and gas or are open for exploration. Under the regional monitoring programme, all the fields within a specific region are sampled in a single survey, as well as a number of regional and reference stations, which are used as controls. During the three-year period from 1996 to 1998, all of the six "active" regions have been surveyed using the regional approach. Although the regional surveys will continue, OLF, with the co-operation of the Norwegian Pollution Control Authority, has felt it timely to use the information from the regional monitoring surveys in 1996, 1997, and 1998 to review and summarise the status of the marine environment of Norwegian waters in the regions where petroleum activities are taking place.

2 Descriptive Account of Each Survey Region

Of the 11 monitoring regions in Norway defined by SFT, five support active exploration and production, while one additional region (Finnmark, Region IX) will experience an increase in exploration activities from 2000 onward. This report shall review only those five regions in which there is a history containing both environmental baseline and monitoring studies (Table 1). This chapter reviews environmental characteristics that are important for benthic communities used in the monitoring studies.

Table 1: Environmental regions in the North and Norwegian Seas covered in this report.

No.	Region Name	Delimitation (ºN)
I	**Ekofisk**	56 - 58
II	Sleipner	58 - 60
III	Oseberg	60 - 61
IV	Statfjord	61 - 62
VI	Trøndelag	64 - 66

2.1 Bathymetry

The bottom topography of the environmental monitoring regions is shown in Figure 3. The Norwegian sector in the North Sea is dominated by the relatively shallow North Sea Plateau (ca. 100 m) and the deeper Norwegian Trench (300-400 m). The Norwegian Trench runs along the Norwegian coast through the Ekofisk, Sleipner, Oseberg and Statfjord area. To the west and south of the trench there is a graded slope up to the North Sea Plateau. In the north the Trøndelag area is dominated by a wide and relatively deep shelf area to the east, and deeper areas outside the continental shelf to the west (down to 3000 m).

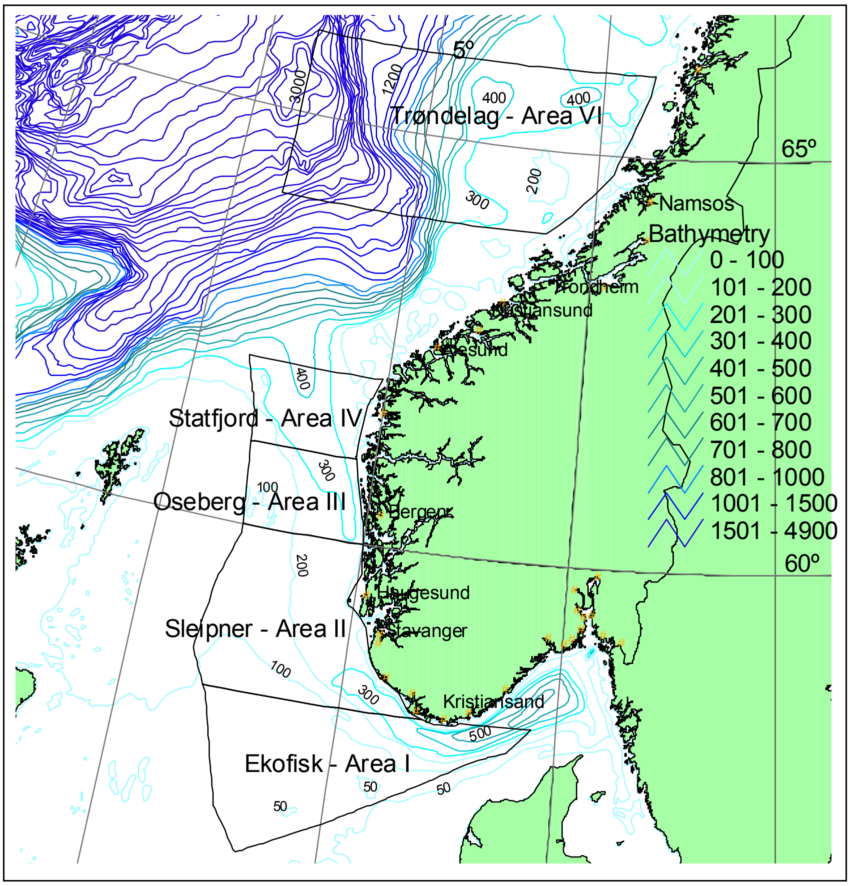


Figure 3: Bathymetry in the environmental monitoring regions.

The Ekofisk and Sleipner areas are dominated by the shallow North Sea Plateau, with the Ekofisk area being the shallowest area. As the Norwegian sector narrows in the northern parts of the North Sea, the Norwegian Trench and its western slope become the dominant features in the Oseberg area and especially the Statfjord area. The western parts of the Oseberg area and the southwestern parts of the Statfjord area have depths under 200 m, and are thus the shallowest areas in these two regions.

2.2 Currents and Water Bodies

The water masses of the North Sea originate from North Atlantic water and fresh water run-off from adjacent landmasses (Figure 4). Bottom topography is important in relation to circulation and vertical mixing. Flows tend to concentrate in areas with the steepest slopes, with the currents flowing along the contours. The major inflow of water to the North Sea consists of Atlantic water that follows the 200 m depth contour to the north of the Shetland Islands before passing southward along the western edge of the Norwegian Trench. A flow of somewhat smaller volume, the Dooley current, enters the northern North Sea between the Shetland and Orkney Islands. In the southern North Sea, Atlantic water enters through the English Channel and moves towards the Skagerrak together with low salinity coastal water.

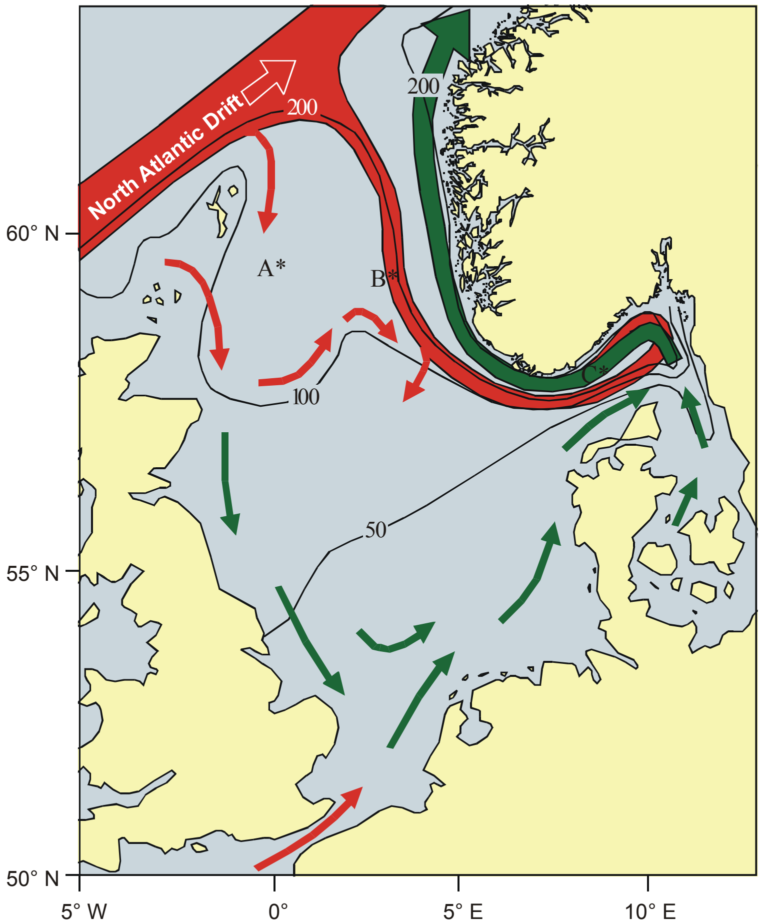


Figure 4: Major sea currents in the North Sea. (Redrawn with permission from Institute of Marine Research, Bergen).

The North Sea has one dominating outflow. It starts in the Skagerrak and is formed from all the above inflows, from water originating in the Baltic Sea and from Norwegian coastal run-off. This current, known as the Norwegian Coastal Current, has a volume of approximately 10^6 m^3/s as it leaves the North Sea. This circulation is normally stronger in winter than in summer because it is enhanced by southwesterly winds. The Atlantic Current crosses the entrance to the North Sea and flows northward along the continental slope of Norway with a lower boundary at a depth of 500-600 m on the coastal slope of Trøndelag. Coastal water forms a wedge overlying the heavier Atlantic water. The position of the coastal water's outer boundary shows a seasonal variation, usually being at its most extensive during summer. At greater depths outside the continental shelf of Møre and Trøndelag, slope water, a mixture of Atlantic water and the upper part of deep water in the Norwegian Sea, dominates.

Bottom water currents can deviate from the dominant surface water currents and show seasonal variations. In the eastern parts of the Norwegian Trench, heterogeneity in the bottom topography causes deviation from the dominant northern flow. In the central part of the trench there are great variations in the bottom flow, but with a dominance of current flow towards north and east. On the western slope of the Norwegian Trench, waters below 100 m have a fairly stable current flow towards south-southwest and southeast. In large areas of the central and northern North Sea, the bottom water becomes almost motionless during summer particularly at depths greater than 70 m, except in areas adjacent to bottom slopes.

Region II, III and IV are dominated by the inflow of Atlantic water along the western edge of the Norwegian Trench and the Norwegian Coastal Current, whereas Region I is influenced more by Dooley Current water, i.e. central North Sea water. Region VI is dominated by northward-flowing Atlantic water following the continental slope.

2.3 Sediments

The sediments on the North Sea Plateau consist mainly of sand and become generally finer with depth down to approximately 120 m (Figure 5). It is assumed that the sediment distribution is caused mainly by storm-induced events, rather than permanent currents, which lead to the resuspension and transport of finer particles in the shallow areas. Fine and silty sands occur on the plateau at depths over 120 m, and on the western slope of the Norwegian Trench at depths between 120 and 300 m.

The sediments in the shallow Ekofisk and Sleipner regions consist mainly of sand that becomes generally finer to approximately 120 m depth. Below 120 m fine sands and silty sands dominate.

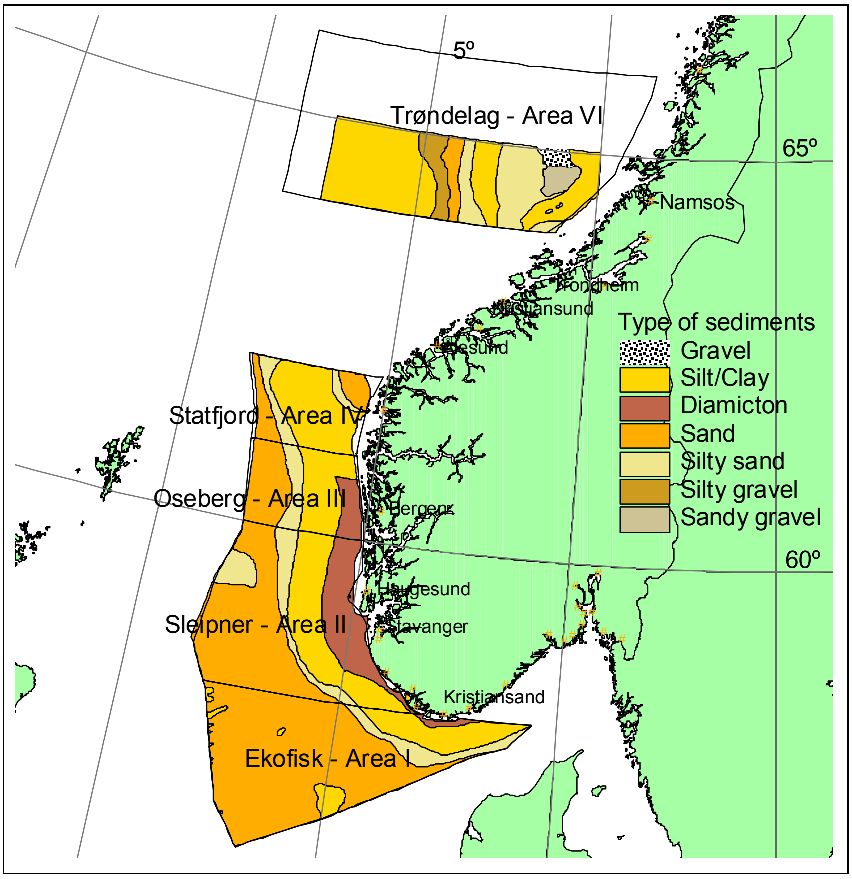


Figure 5: Sediment distributions in the environmental monitoring regions.

Sediments with silt and clay in the deeper parts e.g. in the Norwegian Trench, are assumed to partly originate from particles in the water column. The centre of the Norwegian Trench is characterised by sediment deposition.

The sediments outside the continental shelf are generally fine silt or clay. In the Oseberg and Statfjord areas, there are sandy sediments in the western parts while the sediments in the central and western parts of the Norwegian Trench and the deeper parts of the slope are composed of silt and clay.

3 Field Development Review

In this chapter, the history of petroleum development and the present development situation is presented for each of the regions. Recoverable reserves of oil and gas in each region are presented in Figure 6. The greatest reserves of oil are found in Region IV, while gas is dominant in Region III. Condensate and natural gas liquids are also present at much lower volumes in each of the regions. Regions II and VI hold the greatest proportion of the known condensate reserves totalling approximately 100 x 10^6 Standard Cubic Metres (Scm), while the total reserves of natural gas liquids (150 x 10^9 tonnes) are proportionally split between regions I, III, and VI.

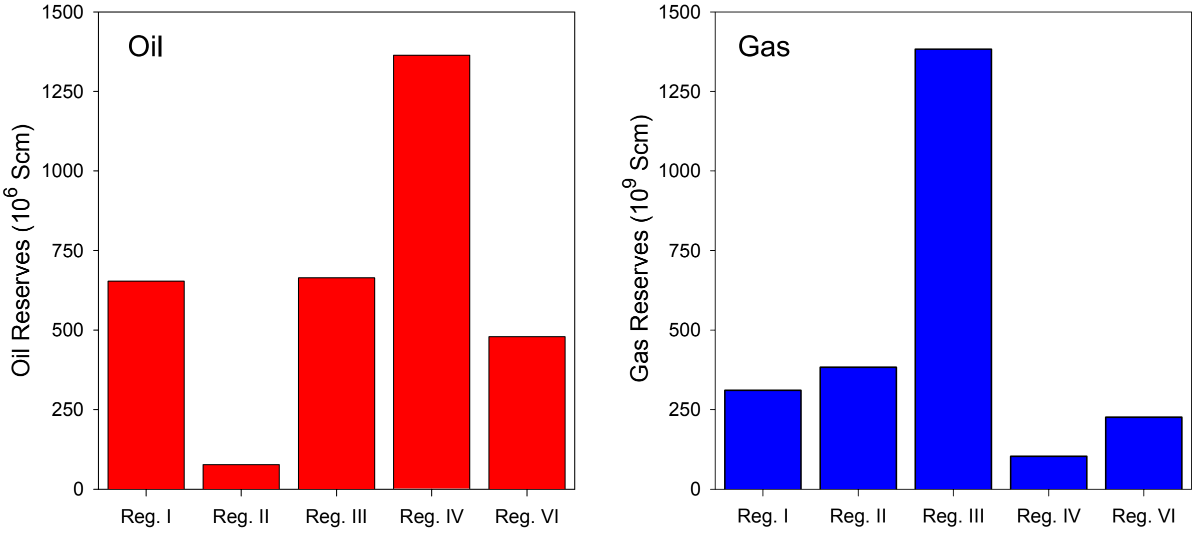


Figure 6: Recoverable reserves of the oil and gas in the different regions (1000 m^3 gas = 1 m^3 oil = 1 Scm).

The current number of installations include 48 fixed and floating installations and 140 subsea installations (Figure 7). Fields in Region I were the first to be developed in Norway and therefore have the longest production history, mostly from surface installations. Region II also is predominantly developed via surface installations, while regions III – VI support progressively greater proportions of subsurface installations.

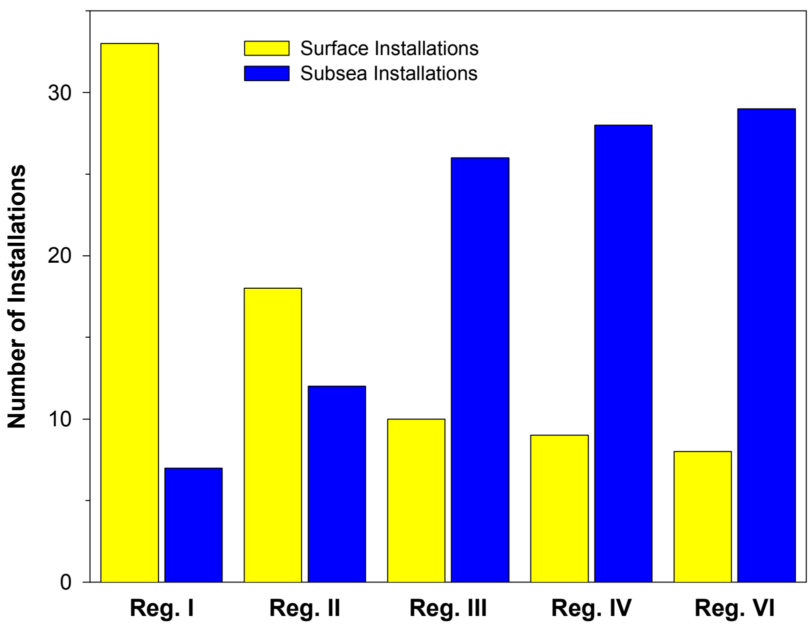


Figure 7: Number of surface and subsea installations in the different regions in 1998.

3.1 Region I: Ekofisk

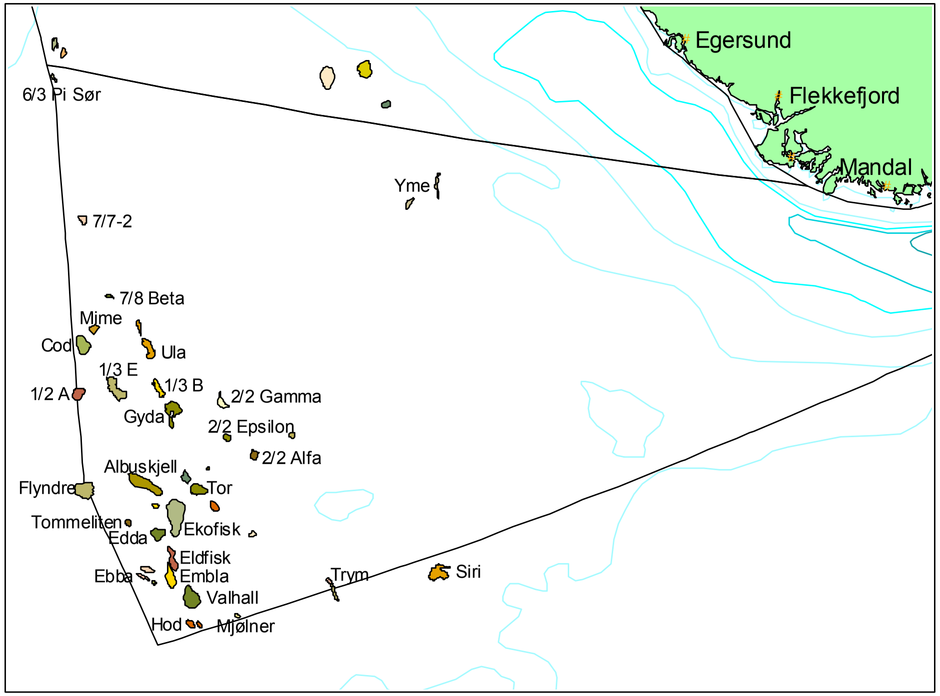


Figure 8: Overview of fields in Region I (56-58°N).

Table 2: Fields in production in Region I.

Fields	Planned Period of Production	Surface Installations	Subsea Installations
Ekofisk	1971-	12	1
West-Ekofisk	1977-1998	1	
Albuskjell	1978-1998	2	
Cod	1977-1998	1	
Edda	1979-1998	1	
Eldfisk	1979-2013	3	
Embla	1993-	1	1
Gyda	1990-	1	
Hod	1990-	1	1
Mime	1990-1993		1
Tommeliten Gamma	1988-1998		1
Tor	1978-2005	1	
Ula	1986-	3	
Valhall	1982-	4	
Yme	1996-	2	2
SUM		**33**	**7**

3.2 Region II: Sleipner

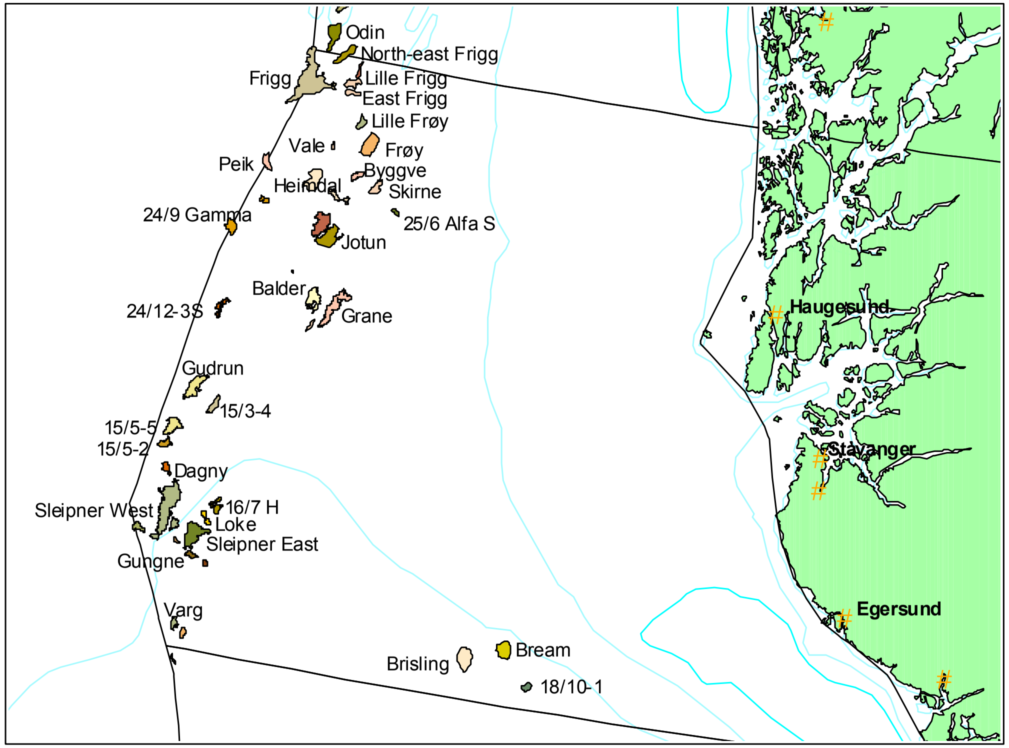


Figure 9: Overview of fields in Region II (58-60°N).

Table 3: Fields in production in Region II.

Fields	Planned Period of Production	Surface Installations	Subsea Installations
Balder	1999-2013	1	
Frigg	1977-2001	5 (1)	
East Frigg	1988-1997		3
Frøy	1995-2001	1	
Heimdal	1985-2011	2	
Jotun	1999-2015	1	3
Lille Frigg	1994-1999		2
North-East Frigg	1984-1994	1	
Odin	1996-2014	2	
Sleipner West	1996-2014	1	2
Sleipner East	1993-2014	2	2
Varg	1998-2002	2	
SUM		**18**	**12**

(1) Three of the installations are located in the British sector.

3.3 Region III: Oseberg

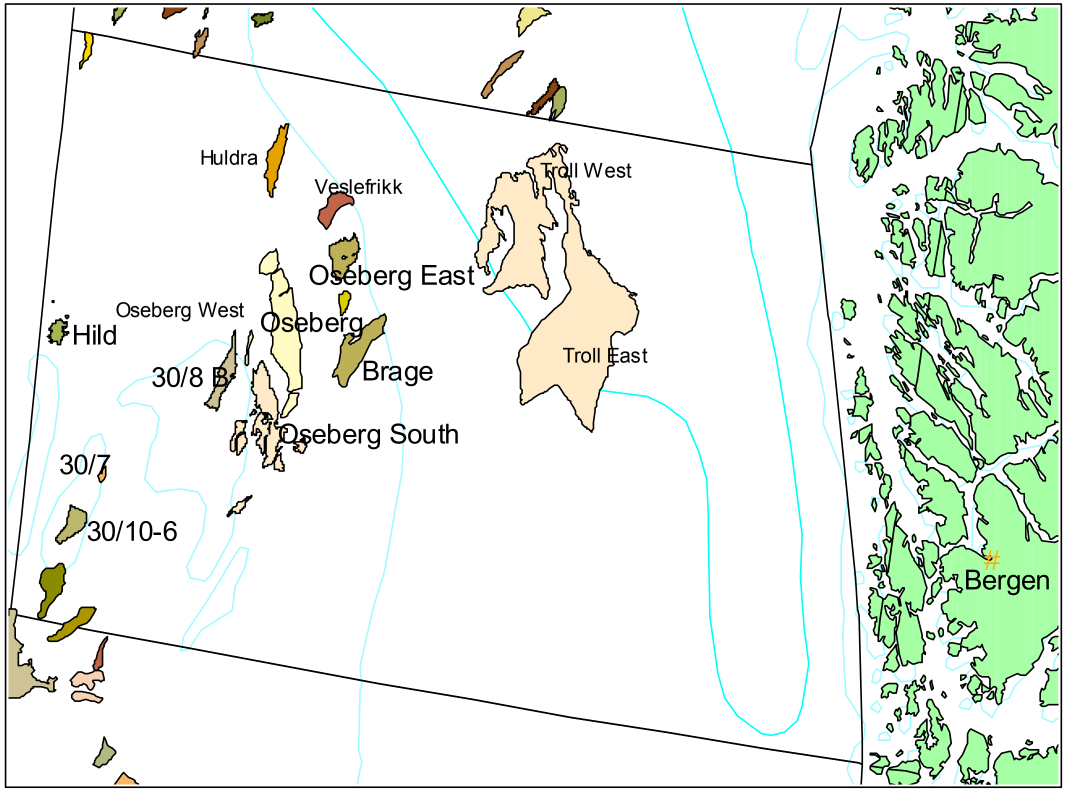


Figure 10: Overview of fields in Region III (60-61 °N).

Table 4: Fields in production in Region III.

Fields	Planned Period of Production	Surface Installations	Subsea Installations
Brage	1993-2012	1	
Oseberg	1988-2020	3	2
Oseberg East	1999-2026	1	
Oseberg West	1991-2028		2
Troll West	1995-2020	2	21
Troll East	1996-2050	1	
Troll East	1991-2002		1
Veslefrikk	1989-2009	2	
SUM		**10**	**26**

3.4 Region IV: Statfjord

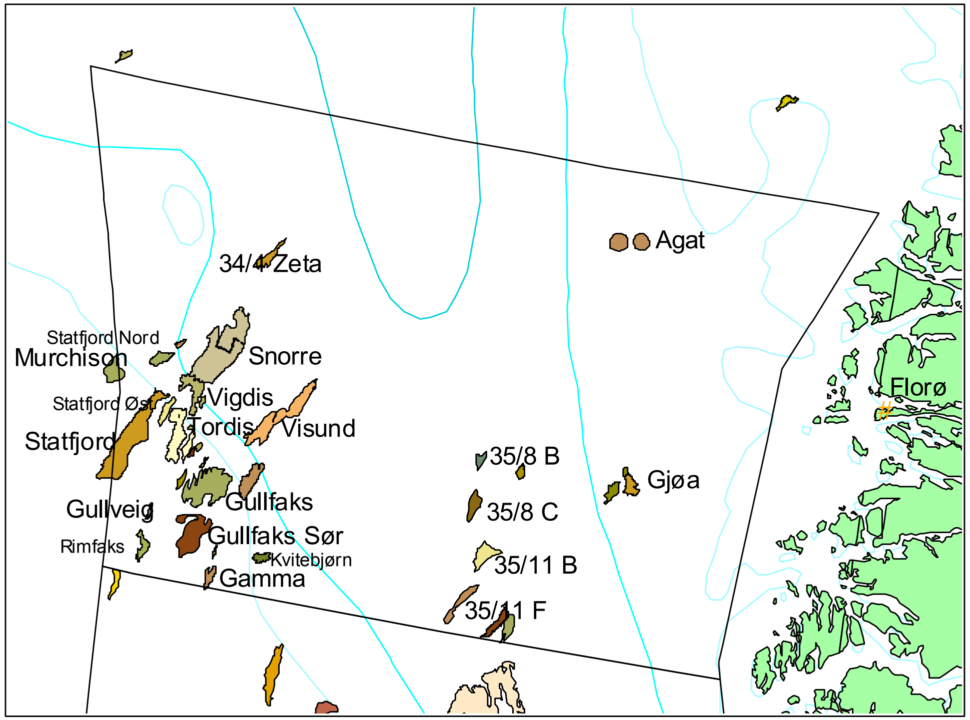


Figure 11: Overview of fields in Region IV (61-62°N) .

Table 5: Fields in production in Region IV.

Fields	**Planned Period of Production**	**Surface Installations**	**Subsea Installations**
Gullfaks	1986-2017	3	
Gullfaks South (1)	1998-2013		4
Gullveig (1)	1998-2012		1
Murchison	1980	1 (2)	
Rimfaks (1)	1998-2013		3
Snorre	1992-2020	1	1
Statfjord	1979-2014	3	1
Statfjord North	1995-2019		3
Statfjord East	1994-2019		3
Tordis	1994-2014		8
Tordis East	1998-2014		1
Vigdis	1997-2014		3
Visund	1998-2028	1	
SUM		**9**	**28**

(1) Considered together as Gullfaks Satellites

(2) Installation located in the British sector.

3.5 Region VI: Trøndelag

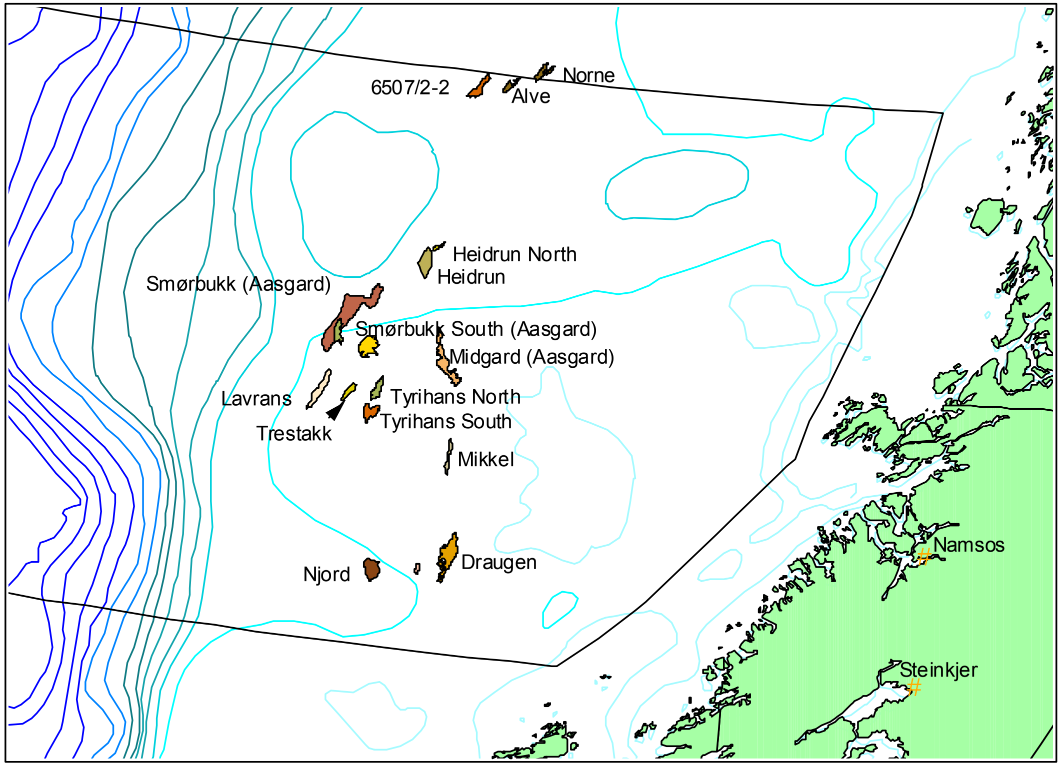


Figure 12: Overview of the fields in Region VI (64-66°N).

Table 6: Fields in production in Region VI.

Fields	Planned Period of Production	Surface Installations	Subsea Installations
Draugen	1993-2018	1	5
Heidrun	1995-2016	1	3
Njord	1997-	2	
Norne	1997-2017	1	5
Åsgard	2000-	3	16
SUM		**8**	**29**

4 Environment and Environmental Surveys

4.1 Introduction to Environmental Impacts

Environmental impacts from offshore petroleum activities arise from several causes. Emissions to air and discharges to sea directly associated with activities are the most obvious. Operational discharges from an offshore petroleum development project are known and expected under normal operation activities. Such discharges, as opposed releases from accidental events, are regulated under a discharge permit issued from SFT. Both accidental and operational discharges are given attention in the monitoring programme. A specific field-survey, if not included in the regular regional monitoring survey in May/June, may be demanded by SFT at fields were accidental spills have occurred.

Organisms living on the sea bottom usually have a sedentary or, at most, semi-mobile lifestyle. These organisms are therefore sensitive to contamination and sedimentary disturbance. Successional changes in marine benthic communities in relation to increasing levels of pollution and disturbance have been well documented. Thus the comparative levels of disturbance to benthic communities can be related to distance from a discharge centre and to the concentration of sedimentary contaminants.

Disturbance or pollution progressively reduces the diversity and complexity of pristine communities and restricts the range of functions they can perform. Disturbance may take many forms. In the context of oil production in the North Sea the discharge of drill cuttings and production water introduces a variety of potential environmental disturbances which need to be considered. Discharges from drilling can affect the benthic environment in several ways, described below.

Physical effects on the benthic fauna

The degree of physical disturbance depends on the sedimentation rate. Releases of cuttings with synthetic and oil-based drilling fluids (or accidental discharges of cuttings with OBM) will lead to aggregations of the small cuttings and barite particles that settle to the bottom close to the discharge point, causing elevated concentrations of drilling fluid components in the vicinity of the discharge. In contrast, the inorganic chemical compounds in WBM are highly water soluble and therefore disperse more easily. The small particles of barite in this solution will not attach to the cuttings, but will disperse with the water and settle over a large area. Thus, the release of cuttings and associated water-based mud will therefore affect a larger area of the seabed, but with a lower degree of impact compared to release of cuttings drilled with oil based or synthetic based drilling fluid.

An important tracer for the spread of particles is barium (Ba) which is one of the constituents of barite ($BaSO_4$). Elevated levels of barium in the marine environment is almost totally derived from discharges from drilling operations. Barium is thus a tracer for the distribution of drilling-related compounds and has been found in North Sea sediments at a great distance (100 km) from known discharge points. Studies that have focused solely on physical effects of inorganic particulate discharges show that lower abundances and diversity occurred in the benthic fauna when large amounts of inorganic materials were discharged. The observed effects were ascribed to both physical burial and a reduction in the organic content (i.e. exploitable food) in the sediment. Overall, the physical disturbance of the benthic fauna from sedimenting drill cuttings occurs over short time scales and is generally limited to 50-100 m from the discharge at the depth and current conditions prevailing in the North Sea.

Toxic effects

All synthetic drilling fluids have to be tested according to standard procedures (e.g. toxicity, bioaccumulation, and biodegradation) before discharge to sea as fluid retention is allowed. Toxicity testing focus on acute effects. However, effects at lower concentrations may also occur through chronic exposure. For example, recent laboratory investigations of chronic effects of used oil- and water-based drilling fluids have shown that growth, reproduction and survival in the scallop *Placopecten magellanicus* is negatively affected, even at concentrations which in tests did not show any acute toxicity effects.

Organic contents in the sediment

The introduction of excess organic carbon to the sediments can result in a process called eutrophication. This can overload the benthic decomposition regime leading to excessive biological oxygen demand (BOD) in the sediments and bottom waters. Eventually such conditions can lead to bottom water anoxia and, under extreme conditions result in the death of all macroscopic organisms in the benthic system. The introduction of toxic contaminants in discharges may accelerate such processes by increasing mortality and decreasing recruitment in benthic communities. The impact of such disturbances on marine benthic communities is progressive rather than instantaneous. Thus disturbance following low levels of carbon enrichment initially brings about increases in both the abundance and biomass of the normal community members. As enrichment increases the larger and longer lived species will be replaced gradually by smaller more rapidly growing types suited to the changing conditions. This results in reductions in biomass and species richness accompanied by a further rise in overall abundance as the incoming “opportunists” take advantage of the increased detrital inputs to rapidly increase their populations. These successional changes in benthic communities following disturbance through eutrophication are illustrated in Figure 13.

Synthetic drilling fluids are generally broken down faster than oil-based fluids, with the overall degradation rate varying between the different types. Rapidly degradable ester-based fluids can result in increased organic matter content in the sediment, with associated oxygen depletion in the sediment and impacts to the benthic communities. Discharge of drill cuttings drilled with water-based drilling fluid will reduce the organic content in the bottom sediment in the platform vicinity. This effect is considered insignificant compared to the physical effects of particle sedimentation, but few studies have addressed this specifically.

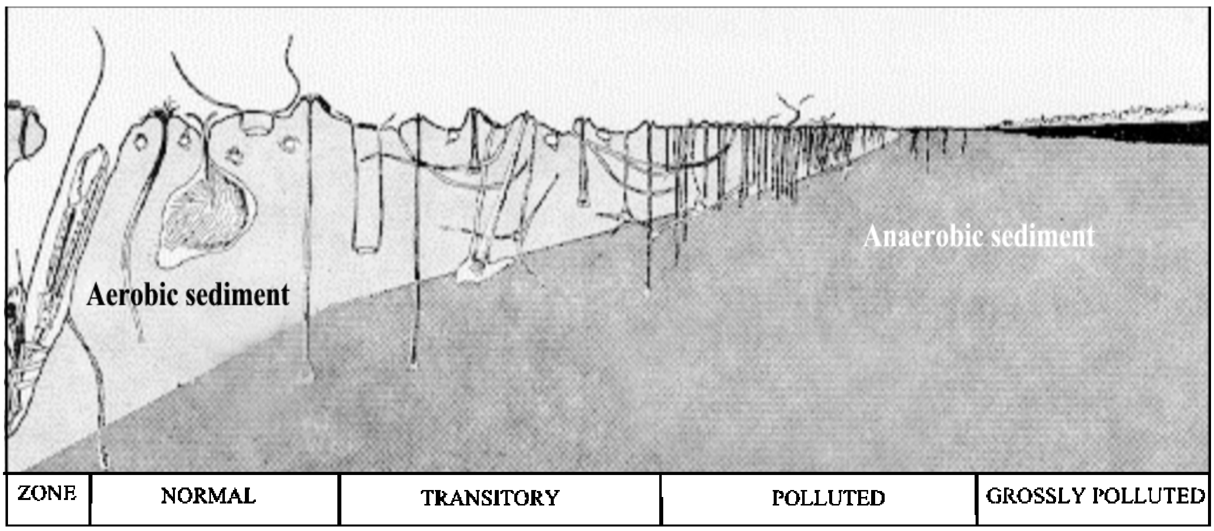


Figure 13: Diagrammatic representation of changes in fauna and sediment structure along a gradient of increasing organic pollution (after Pearson & Rosenberg 1978).

4.2 Environmental Surveys

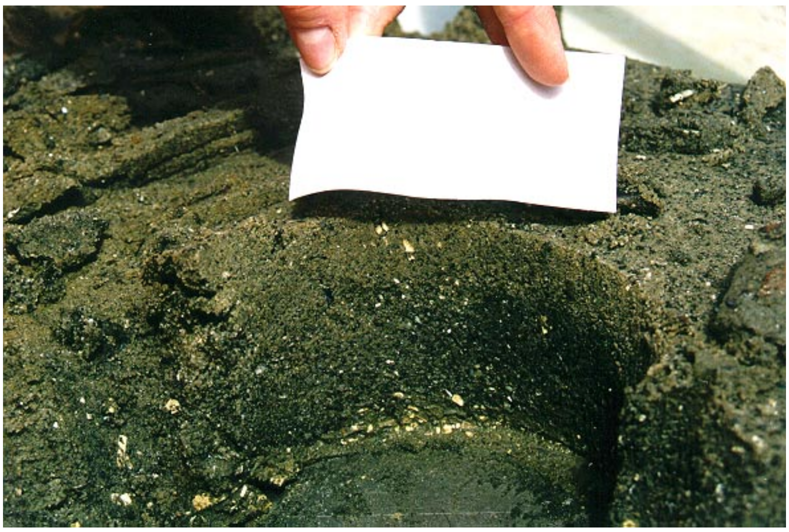
4.2.1 Rationale and Legislative Framework

A sediment sample being brought aboard with the van Veen grab.

Based on regulations in the Pollution Control Act, the discharge permits issued by SFT require operators to carry out environmental monitoring. The monitoring programs should give an overview of the environmental conditions and developmental trends over time as a result of offshore activities, i.e. whether the environmental conditions are stable or whether these are deteriorating or improving over time as a result of the operator's activities. Monitoring surveys have been carried out in the Norwegian sector of the North Sea since the mid-1970's, but a desire to standardise methods, results, and the quality of the surveys resulted in a first set of guidelines being developed by SFT in 1988 for the Paris Commission, and adopted for use in Norway in 1990. The Norwegian guidelines have been updated to reflect the regional approach (see below). Up to 1998, monitoring focussed only on the effects to the sea bottom, but from 1998 onward there is also a provision for monitoring levels and effects in the water column.

4.2.2 Survey Strategy

The impact of industrial activities related to oil extraction on the environment of the Norwegian sector has been assessed by measuring the levels of oil-related contaminants and the distribution of benthic organisms in the sediments around oil field installations. Samples are collected at a number of stations located at various distances and directions from individual structures. Detailed laboratory analyses are undertaken to assess the comparative physical, chemical, and biological characteristics of these samples.



An example of sediment from a sample.

An initial baseline survey is required around each new field installation prior to any production well drilling being undertaken. Baseline survey data is then used to define the natural background levels of the physical, chemical and biological parameters to be measured in subsequent monitoring surveys.

Field-specific surveys were initially commissioned and carried out around single oil field installations. As more and more fields were developed, more produced water was discharged, and oil production areas spread northwards along the Norwegian coast, it became increasingly evident that individual field surveys did not provide sufficient information to assess potentially synergistic inter-field effects and any far-field effects. Thus more recently (1996), a regional strategy was adopted which simultaneously surveys all field installations within a defined geographical region. In addition to a selection of field and reference stations previously sampled in field-specific surveys, these regional surveys include a series of stations sited in areas well away from the influence of any installations. The results from a combination of the regional stations and the field-specific reference stations provide a comprehensive reference data set which can be used to assess regional background levels over time and with which any putative disturbance effects at field stations can be compared.

The sediment is washed carefully before sieving to separate biota from the sediments.

In general, monitoring surveys are conducted every three years. Fieldwork is carried out during the same time of the year, preferably in spring (May to early June) in order to avoid problems related to the settlement of juvenile benthos and to take advantage of favourable weather conditions for sampling. The result of the survey is presented in an integrated report written for the entire region. The report is divided into three main sections: A summary report characterising the main findings of the survey, a main report presenting the data and findings that lead to the overall conclusions, and an appendix containing all of the data and measurements that were conducted throughout the survey.

4.2.3 Analytical parameters

The minimum requirements for analytical parameters are:

- Sediment description (visual description, presence of fauna, colour and smell)
- Physical characterisation of sediments (Total Organic Matter and Grain Size Distribution)
- Hydrocarbons (total hydrocarbon content, aromatic hydrocarbons, naphthalene, phenanthrene/anthracene, dibenzothiophene) and their C_1-C_3 alkyl-homologues (NPD), PAH-compounds on EPA's list, decalines, and the main component(s) of drilling fluid(s).
- Metals (Ba, Cd, Cr, Cu, Pb, Zn, Hg, Al, Li)
- Benthic fauna (taxonomic name and numbers of individuals of all species).

4.2.4 Assessment of Effects

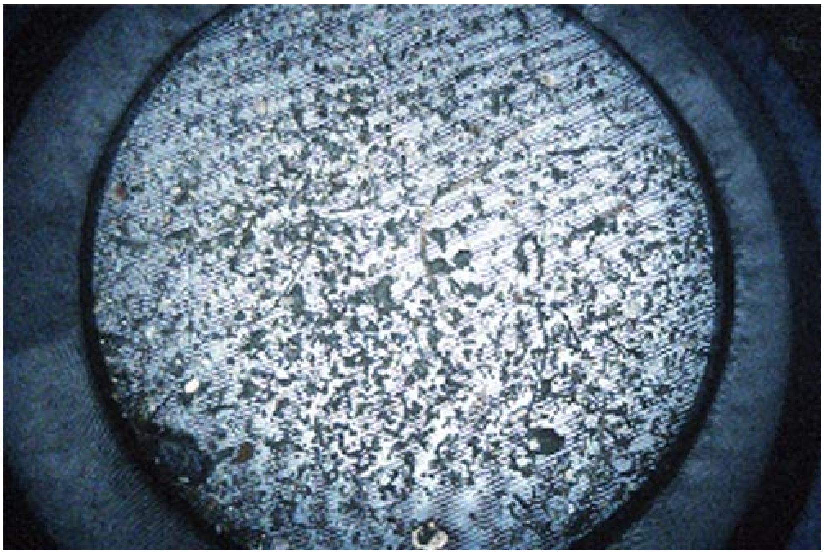
For all parameters and each station, average values and summary statistics (min., max. and SD or SE) are calculated. For the chemical parameters, background values and Limits of Significant Contamination (LSC) are calculated. The fauna is analysed using a variety of techniques (Table 7). Univariate techniques provide summary parameters for initial assessment, and multivariate analyses allow a more in-depth analysis of the faunal characteristics. The correlation between physical, chemical and biological parameters is assessed at present by the application of canonical correspondence analysis (CCA).

Table 7: Parameters assessed during the analysis of the fauna data from the samples..

Univariate Statistics	Multivariate Statistics
Number of taxa and number of individuals	Clustering analysis (Bray-Curtis dissimilarity index)
Ten most dominant taxa at each station ("Top 10")	Multidimensional Scaling (MDS)
Species-area curves	Correspondence analysis (CA)
Diversity index (Shannon-Wiener, H')	Canonical correspondence analysis (CCA)
Evenness (Pielou's measure, J)	
Expected number of species per 100 individuals (Es_{100})	

In the single-field (pre-1996) surveys, patterns of disturbance effects observed with increasing distance from the field centre were assessed by statistical comparison of the variation in a range of sedimentary contaminants with variation in the composition and abundance of the benthic fauna. One approach currently used to summarise the extent of disturbance is to categorise each sampling station as belonging to one of a sequence of disturbance groups based on faunal composition, e.g. Group A = undisturbed; Group B = slightly disturbed; Group C = disturbed; Group D = highly disturbed. Such categorisations are made by subjective comparisons of the results of non-parametric correlation of selected contaminant and faunal variables and the relative distance between station groups defined from multivariate classifications and ordinations of the faunal data. The relative area of the sediments affected by each level of disturbance has then been estimated from plots of the positions of stations falling into each of the disturbance groups.

Since the introduction of regional surveys more complex multivariate statistical analyses have been employed. One such technique is Canonical Correspondence Analysis (CCA) which permits direct comparison of environmental and biological parameters within the same data matrix. The results of CCA are easily interpretable because of the visual (spatial) nature of the analytical result. Stations are plotted in a 2-dimensional space also showing the direction and magnitude of the influence of physical parameters. The station grouping in relation to other stations and to the most influential physical variables indicates the degree of dissimilarity of the stations. Using such tools, the relative influence of different environmental factors on the measured biological variance can be assessed and directly compared.



Biological organisms remaining after washing and sieving the sediment from the sample (see the numerous polychaete worms). In the laboratory, this material will be sorted and identified by experts before statistical analyses are conducted.

5 Drilling and Discharges

5.1 Drilling Activity

There were a total of 1541 wells drilled during the period from 1990-1998 (Figure 14). Of these, 1167 (76%) were production wells, 239 (16%) were exploration wells, and 135 (9%) were appraisal wells. Total drilling activity increased significantly over the period, from a low of 121 in 1990 to a high of 218 in 1997. This was followed by a small decrease in 1998. Neither exploration wells nor appraisal wells varied significantly through time. Therefore the annual variation of total drilling activity is due to increases in production wells drilled over this period.

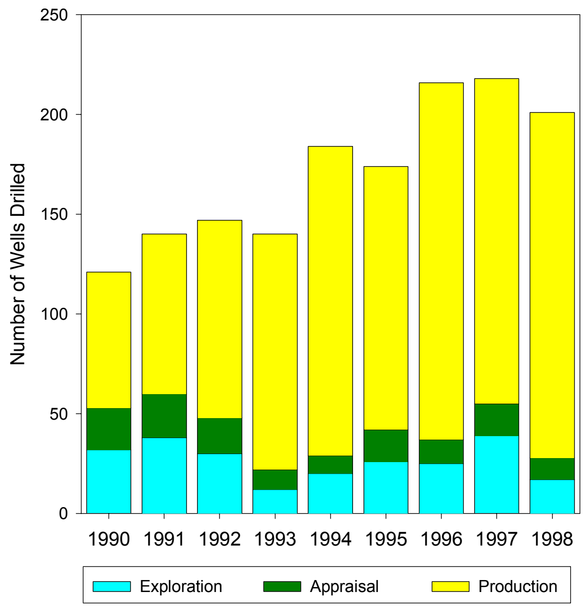


Figure 14: Trends in drilling activity of different types in the Norwegian offshore sector from 1990-1998. Figures include gas injection wells.

5.2 Discharge History

During the lifespan of an offshore oilfield, operational discharges to the sea vary with time. Drill cuttings and fluids dominate discharges during exploration and pre-production phases of development, while produced water and associated constituents are the primary discharges after commencement of production. (Table 8).

Table 8: Major operational discharges to sea from offshore oil and gas platforms.

Category of discharge	Sub-categories	Description
Drilling products	Drill cuttings	Pulverised rock material from the reservoir.
	Used drilling fluid	Three types: water-based (WBM) containing for example KCl/polymers or glycol, oil-based (OBM) comprising clean mineral oils, and synthetic-based (SBM) drilling fluids commonly comprising olefins, ethers or esters. OBM are now forbidden. Cuttings with SBM may only be discharged after permission from SFT. See more information in the chapter.
Oil-contaminated water	Produced water	Represents approximately 80 % of the total discharges of oil to sea. In addition to oil, it contains processing chemicals and a number of dissolved organic and inorganic compounds, including heavy metals. Composition varies from field to field. More information in the chapter. Dissolved organic compounds are dominated by carboxylic acids (95 %), with small amounts of BTX, phenols, PAH and alkyl phenols.
	Displacement water	Originates from crude oil storage cells on some of the installations.
	Drainage water	Includes water from platform decks etc. May contain chemicals.
Chemicals		Dominant source (> 90%) is drilling wastes. Other sources are chemicals in production, water injection and transport of oil and gas. In the OSPAR area, since 1995 all applications for discharge permits must include environmental characteristics of the chemical in a standardised form (HOCNF - Harmonised Offshore Chemical Notification Format).

Drilling fluids and cuttings

The main contributor to seafloor disturbance around oil- and gas-installations on the Norwegian sector has been the deposition of cuttings and mud containing slowly degradable oil, heavy metals and other compounds. Drilling fluids are used to lubricate the drill string, bring up drill cuttings from the well hole, control internal pressure and stabilise the well. Originally, diesel was commonly used as a drilling fluid in the lower sections of the well. After the use of diesel was banned in 1984, refined, low aromatic mineral oils were introduced as drilling fluids. Up to September 1991 the allowed amount of OBM discharged together with cuttings was restricted to 100 mg oil/kg dry cuttings. In 1993 the limit for OBM was set to 10 mg/kg dry cuttings, which in fact resulted in the abandonment of OBM's. Although synthetic and water-based fluids to a large extent have replaced oil-based fluids, OBM's are still used (but not discharged) in technically demanding drilling operations. Cutting with synthetic drilling muds (SBM) may be discharged on permission, but it is forbidden to discharge the synthetic fluid itself.

In general SBM has lower toxicity and higher degradation rates compared to OBM. Results from experimental studies have shown that the half-life of OBM to be approximately 6 months compared to 2 months for different types of SBM (olefins, esters). The SBM poly-alfa-olefins were found to have degradation rates comparable to OBM, in contrast to a saturated-ester (SBM) which had a half-life of around 2-3 weeks. Degradation of saturated esters, however, leads to anoxic conditions in the sediment and generally gives the most severe effects in macrobenthic communities used in experiments.

The water-based drilling fluids mainly consist of inorganic components and the chemicals in use are generally regarded as less harmful to the marine environment than chemicals in oil- or synthetic-based fluids. In contrast, the amount of chemicals involved in drilling activities is larger when water-based drilling fluids are used than when oil-based or synthetic drilling fluids are used (Table 9).

Table 9: Environmental characterisation of oil-based, synthetic-based and water-based drilling fluids.

Oil-based drilling fluids The main constituents are a refined mineral oil, calcium chloride and emulsifiers. Oil-based drilling fluids have optimal lubrication capabilities and are stable at temperatures up to 200ºC. Investigations have shown that a threshold of about 1000 ppm base-oil in the sediments was needed to trigger major impacts on benthic fauna. The concentrations of heavy metals (Ba, Cd, Pb, Zn) in the different drilling fluids did not generally affect the benthic fauna, as metals associated with drilling fluids can generally be considered only slightly to non bioavailable for marine organisms which encounter drilling waste.
Synthetic-drilling fluids These can be divided in three groups: ester-based, olefin-based and ether-based. Synthetic-based drilling fluids have approximately the same drilling capabilities as the oil-based drilling fluids, but the manufacturing cost is far higher. Ester-based drilling fluids are rapidly degraded by micro-organisms. Laboratory investigations on the effects of cuttings drilled with different types of synthetic drilling fluids (olefins, ethers, esters) on benthos determined that the effects of the ester-based cuttings on the redox potential and macro zoobenthos communities were stronger than the effects of olefin-based cuttings. Degradation of ester-based fluid caused accumulation of hydrogen sulphide (H_2S) in the interstitial water of the sediment. However, results from in situ monitoring at oil fields where only synthetic and water based drilling fluids have been used show that the drilling fluid has little or no effect on the bottom fauna outside a radius of 250 - 500 m.
Water-based drilling fluids Water based drilling fluids can be discharged without treatment. The two main ingredients in water-based drilling fluids are bentonite clay and barite, both of which are non-toxic. However, these compounds have a burying (smothering) effect on sessile benthic animals, and can render the bottom substrate unsuitable for some species. Investigations have found that discharge of water-based drilling fluid generally lead to only minor effects on the benthic fauna and only within a very small radius (25m) around the platform, with even the minor effects disappearing after 12 months.

The discharges of drill cuttings and drilling fluid to the environment as a result of drilling operations using both water-based and synthetic-based muds are shown in Figure 15 and Figure 16, respectively. The discharge of water-based materials peaked in 1995 (for fluids) to 1996 (for cuttings) (Figure 15), and has since decreased at in all regions except Region VI, where the discharge is comparatively low and has remained relatively constant. The total discharges of synthetic-based materials (cuttings and fluids) across all regions have remained relatively constant from 1995 to 1998 (Figure 16), with the exception of 1997, when the discharge was lower. In 1998, decreases in discharges of synthetic-based drilling material to the environment in Region I was offset by increases in Regions III and IV. Discharges of weighing materials in drilling muds (mostly barium sulphate), show a decreasing trend from 1995-1997, before rising again in 1998.

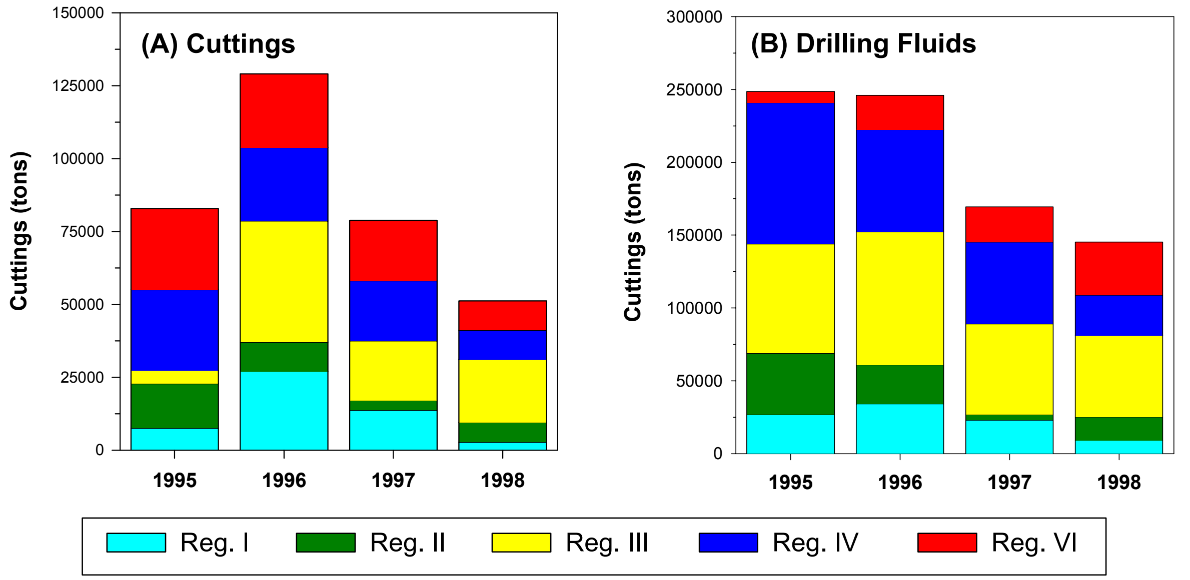


Figure 15: Water-based cuttings (A) and drilling fluids(B) from water-based drilling operations in the regions during 1995-1998.

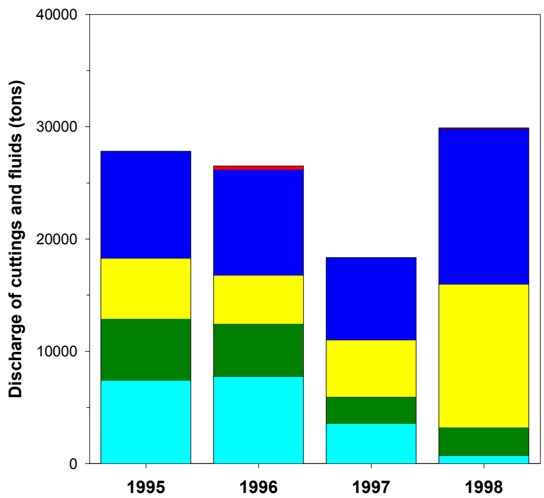


Figure 16: Annual discharges of cuttings and drilling fluids combined from synthetic-based fluid drilling operation in the regions during 1995-1998[2]. Regions as shown in legend of Fig. 15.

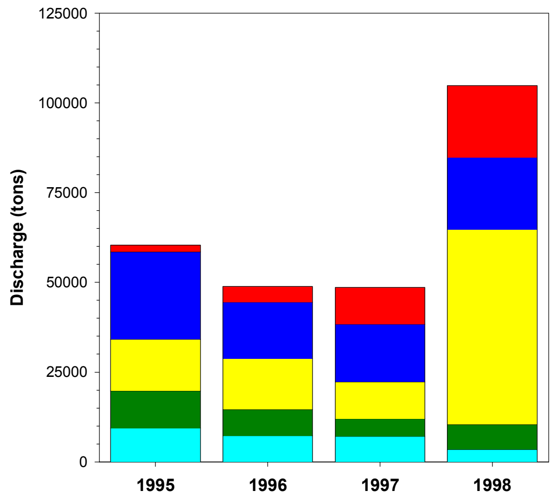


Figure 17: Weighting materials (mostly barite) from both synthetic-based and water-based fluid drilling operations (figures from 1998 include discharges of inorganic chemicals). Regions as shown in legend of Fig. 15.

[2] Synthetic drilling materials (A) in Reg. VI were used only in 1994 and 1996.

Discharges with barite are generally the dominant source of metals to the environment (Figure 18). Arsenic, lead, copper, mercury and zinc all showed far higher discharges through barite than produced water (see next section), while the opposite trend was seen only in nickel. But to a large extent, metals in barite occur as virtually insoluble salts. The biological availability of these heavy metals is therefore very small.

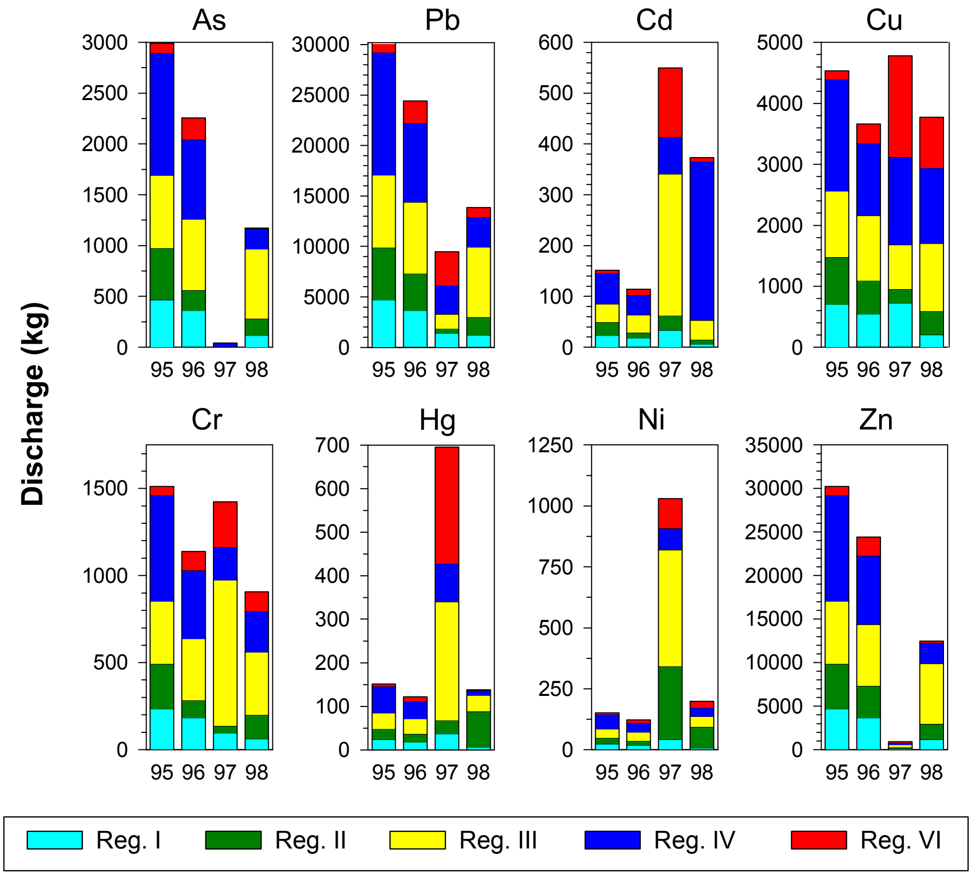


Figure 18: Estimated discharges of eight different heavy metals in barite by region from 1995 - 1998.

Produced Water

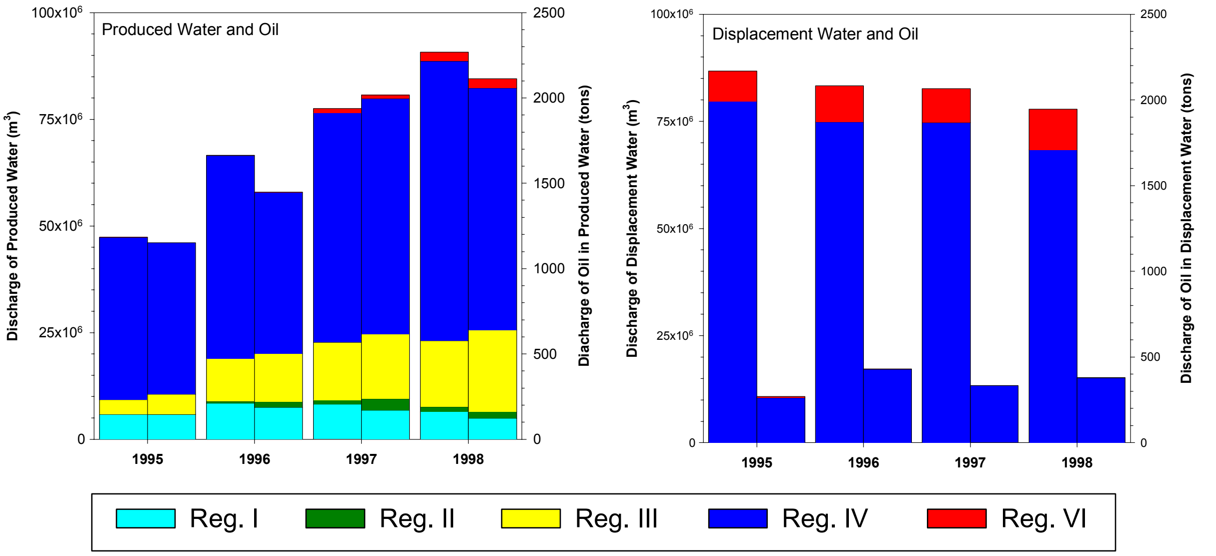
By far the dominant discharge from regular oil and gas production offshore is produced water. Produced water varies from field to field in amount and composition, but it is generally a mixture of: a) formation water contained naturally in a reservoir, b) injected water used for secondary oil recovery, and c) treatment chemicals added during production, in the oil-water separation process, and in preparation for re-injection of produced water. In general, produced water contains dissolved inorganic salts, minerals and heavy metals together with dissolved and dispersed oil components and other organic compounds such as carboxylic acids and phenols from the formation water (Table 10). The specific chemical composition will vary between reservoirs, and within a reservoir as production proceeds.

Table 10: Major chemical components in produced water.

Chemical Group			
Organics	**Inorganics**	**Injection- and production chemicals**	
Hydrocarbons	Major cations	Corrosion inhibitors	Coagulants
Non-hydrocarbons	Heavy metal ions	Scaling inhibitors	Flocculants
Acidic compounds	Elementary mercury	Biocides	Antifoams
N-compounds	Hydrogen sulphide	Emulsion breakers	Asphaltene/wax agents
N-, S-, and O-compounds	Radioactive elements	Reverse emulsion breakers	

The proportion of produced water to other fluids depends on the geochemical characteristics of the reservoir and the processing techniques. The amount of produced water can vary between 2 and 98% of the gross fluid production. The relative proportions change through time as production proceeds, with the general trend of an increasing ratio of water to hydrocarbons as the field ages. Before discharge, the produced water must be treated in order to separate oil from water. The maximum permitted concentration of oil in discharged produced water is 40 mg/l. Most fields manage to stay well below this limit; and produced water is also increasingly re-injected into the reservoir. In 1998, the average concentration of oil discharged with produced water was 23 mg/l. In addition to the physical dilution of the produced water once discharged into the sea, the distribution of discharged chemical compounds is governed by a series of transport and transformation processes including evaporation, chemical transformation (hydrolysis, oxidation and complex formation), sedimentation, and biotransformation.

The discharges of produced water, displacement water, and drainage water, along with the oil-in-water discharges for each, are shown in Figure 19. The volume of displacement water is the greatest of the three types of discharged waters, while the oil released in water was due predominantly to produced water, with slightly more than 2000 tonnes released in 1998. The overall discharge of displacement water was stable from 1995-1998, while produced water had a clearly increasing trend, with all regions exhibiting greater discharges of both produced water and oil in produced water through the period from 1995 to 1998 except for Region I. About 70 and 75% percent of all produced water and oil-in-produced water, respectively, is discharged in Region IV, with Region III occupying the second position by 1998.



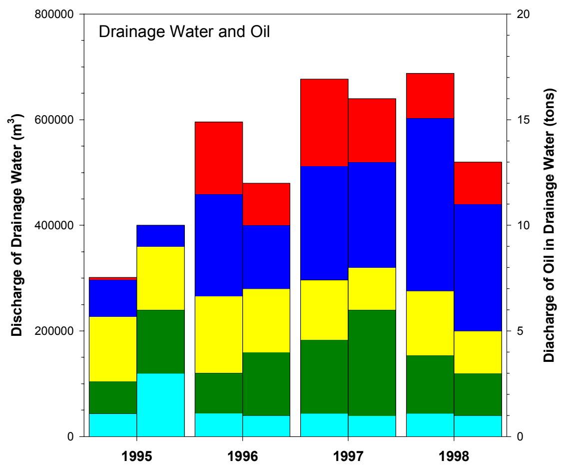


Figure 19: Discharges of water (left axis and bar) and oil-in-water (right axis and bar) by region from produced water, displacement water, and drainage water from 1995-1998. Displacement water is used and discharged only in Regions IV and VI. Note different axis scale for figures of drainage water.

In addition to oil, a number of compounds are released with the discharge of produced water. The five most common organic discharges are polyaromatic hydrocarbons (PAH), BTX (Benzene, Toulene and Xylene), phenols, alkyl phenols, and carboxylic acids (Figure 20). The most common heavy metals released during drilling are impurities from barite: Arsenic (As), Lead (Pb), Cadmium, (Cd), Copper (Cu), Chromium (Cr), Mercury (Hg), Nickel (Ni) and Zinc (Zn) (Figure 21).

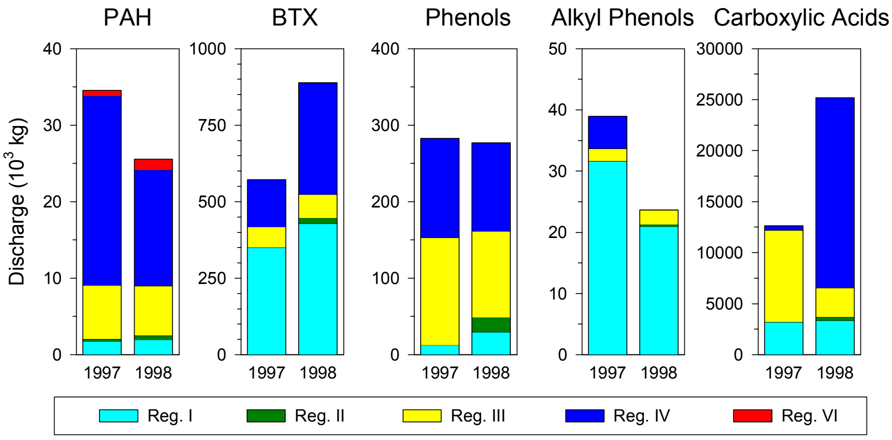


Figure 20: Estimated discharges of dissolved organic components in production water in 1997 and 1998.

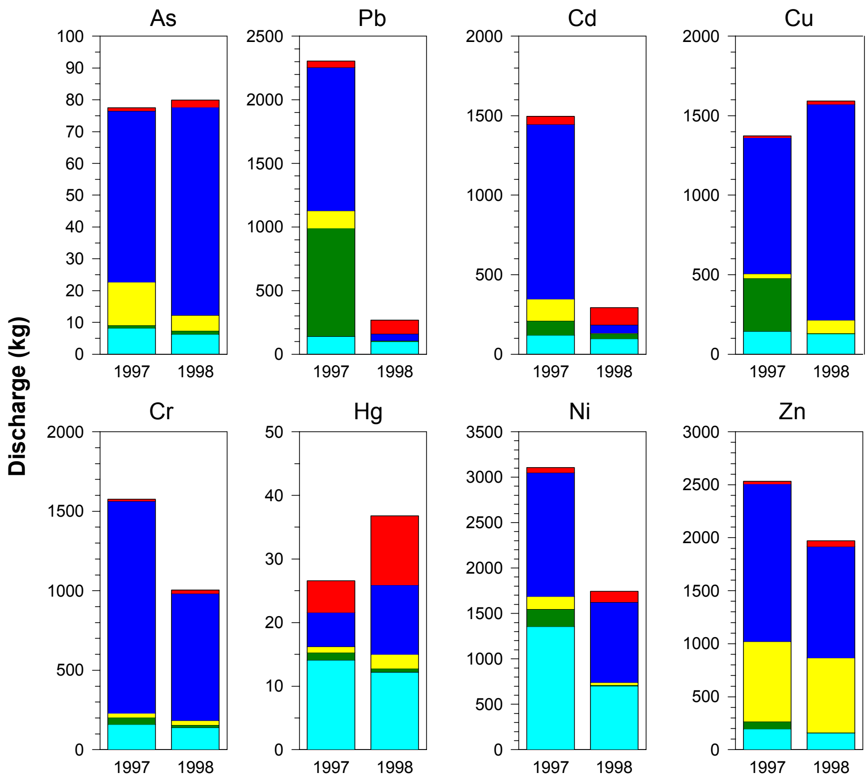


Figure 21: Estimated discharges of heavy metals in production water. Regions as shown in Fig. 20.

It is important to realise that discharges of organic constituents and heavy metals occur against a backdrop of large natural variations of these compounds within a well through time and between fields. Reported discharges through time may also be affected by changes in analytical methods and detection capability. Therefore, only gross differences in the reported discharges may actually signal significant trends.

6 Environmental Status

6.1 Range of Background and Field Values

During the period from 1996 to 1998, all of the regions were surveyed: Regions I and IV in 1996, Regions II and VI in 1997, and Region III in 1998. These surveys included a total of 87 regional and reference stations for the determination of background values, and 687 field stations for assessment of effects petroleum-related activities. Additional surveys during this period included baselines studies of Regional IX (Finnmark) in 1997 and the Vøring plateau (Nordland) in 1998.

The range of natural background levels and field-related levels of different physical, chemical and biological parameters for each of the regions is summarised in Table 11. These data form the basis for determination of the existence and extent of anthropogenic impacts from petroleum-related activities. Not only the levels, but the *range* of background values are essential for determining whether impacts occur. Since levels of chemical constituents and natural communities do vary under normal environmental conditions, it is important to understand the extent of natural variability in order to assess whether additional variability is imparted by petroleum activities.

Table 11: Range of values in each region of several physical, chemical, and biological parameters that are most often used in determining the level of effect on the marine environment, 1996-1998.

Parameter	Background Range*				
	Region I	Region II	Region III	Region IV	Region VI
Total number of background stations	12	23	18	17	17
Depth (m)	65 - 87	71 – 123	93 – 356	115 – 330	212 – 434
Average grain size (Md)	2.5 – 3.6	1.6 – 3.9	2.6 – 9.8	1.1 – 6.1	3.0 – 6.4
Lead (mg/kg)	6.0 – 9.7	2.4 – 6.1	1.9 – 46.5	4.0 – 15.6	9.2 – 26.2
Cadmium (mg/kg)	0.003 – 0.020	0.003 – 0.023	0.004 – 0.113	0.030 – 1.8	0.030 – 0.080
Barium (mg/kg)	6 - 118	6 – 176	14 – 462	30 – 554	48 – 220
THC (mg/kg)	3.6 – 6.8	2.0 – 11.3	1.2 – 13.6	1.0 – 12.8	1.1 – 4.9
Diversity	3.7 – 5.2	3.2 – 6.1	3.6 – 5.7	4.8 – 5.8	4.6 – 6.2
Number of species per station	65 – 87	67 – 158	52 – 139	80 – 135	41 – 133
No. of individuals per stn (0.5 m^2)	462 – 931	402 – 2744	293 – 1704	98 – 2280	127 – 631
	Range of Field Stations				
Total number of field stations	139	168	108	186	86
Depth (m)	64 – 90	78 – 126	99 – 350	112 – 340	235 – 403
Average grain size (Md)	2.5 – 3.8	2.3 – 4.1	1.0 – 10.8	0.5 – 6.3	3.1 – 5.9
Lead (mg/kg)	3.9 – 32.1	2.0 – 26.3	1.9 – 78.6	1.1 –172	12.4 – 50.3
Cadmium (mg/kg)	0.005 – 0.045	0.005 – 0.085	0.004 – 0.289	<0.02 – 0.37	<0.03 – 0.09
Barium (mg/kg)	32 – 3997	11 – 2480	11 – 4362	63 – 9100	111 – 7800
THC (mg/kg)	1.2 – 137	1.1 – 418	0.7 – 2100	1 – 5520	1.1 – 106
Diversity	1.6 – 5.6	3.9 – 5.9	2.3 – 5.8	2.0 – 5.9	4.4 – 6.5
Number of species per station	62 – 111	54 – 173	36 – 148	38 – 147	53 – 139
No. of individuals per stn (0.5 m^2)	362 – 2488	235 – 3748	113 – 5424	59 – 4480	127 - 1024

** Background Range is the range of values at the regional stations and the reference stations of the fields.*

6.2 Regional Analyses

A series of new statistical analyses have been carried out on a database containing the results of all the regional surveys undertaken between 1996 and 1998 together with data from the field specific surveys carried out between 1990 and 1995. This analysis was done in order to assess the impact of industrial activities on the Norwegian offshore area as a whole and to compare the relative level of impact between the different regions. In order to do this, the level of natural variability in the benthic communities throughout the area must be quantified, and then compared to the level of variability induced by the industrial activities.

The overall result of these analyses suggests that the year-to-year differences were much less important over the period than the influence of other environmental factors. Just over 10% of the total variability in the faunal data was explained by the significant natural environmental variables measured, of which water depth accounted for 4.5%, sediment grain size for 4%, and year-to-year changes for 2%. On the other hand, 8% of the variability was attributable to the chemical variables; the most important of which were Cadmium and THC, which contributed 3% each. Conversely, 92% of the variability in the benthic communities sampled could be attributed either to the significant natural variables or to unrecorded factors. Some of the details of the results are discussed below.

6.2.1 Natural Variation

All animal communities and populations vary in both time and space in response to natural changes in their habitat and environment. Some of the chemicals discharged during offshore activities also occur naturally at a background level that can vary in space and time. To assess the extent of the natural variability in the normal benthic communities of the Norwegian offshore area, a data-set comprised of all the information from the regional reference stations and the field-specific reference stations (i.e. all those stations sampled in areas remote from industrial activity), was analysed using CCA (see Section 4.2.4). This type of analysis allows a direct comparison between the relative influence of different environmental factors on the measured biological variance. Five environmental variables were found to have a significant influence on the biological variance in this analysis. These were water depth, sediment grain size, year of sampling and the levels of lead and THC in the sediments. The correlation with lead stems from the close association of metals with the clay content of sediments. The deeper sediments have considerably higher levels of clay than in the coarser shallow areas. There is also a s a weak negative correlation with year of sampling.

Of the five identified variables, the two most important natural variables which influence the benthic faunal communities of the Norwegian offshore area are depth and sediment grain size. The communities of the deeper areas where the sediments are of fine silts and clays differ from those of the shallow coarser areas. The species which contributed most strongly to the variance at stations in deeper areas with fine silt/clay sediments (i.e. were characteristic of these areas), were small burrowing bivalve molluscs and tube dwelling polychaete worms. In the shallower fine sand sediments the species which contributed most to the variance were surface deposit feeding polychaetes and crustaceans, together with burrowing brittle stars. In the coarser sand sediments found in the shallower areas of the Statfjord region the most strongly contributing characteristic species were the filter feeding bivalves and deposit feeding and carnivorous worms.

6.2.2 Regional variation

The regions differ with respect to depth-regimes. Regions IV and VI are predominantly deep in contrast to Region I which is uniformly shallow, whereas Regions II and III have a variable depth range. Analysis of the depth-related differences showed that they were statistically insignificant with the exception of the Region I, which was significantly separated from all other regions. Thus depth was an important factor in distinguishing the fauna in Region I from that in other areas. Reference to Table 11 shows that the depth range in Region I was 65-87 m and overlapped only with the depths in Region II, whereas the depths in the other three regions covered a much greater range (93 – 434 m). Comparison of sedimentary grain size variation showed Region III to have significantly finer sediments than Region IV, although both regions include both shallow and deep areas. No significant differences could be shown in comparisons between the other areas. Table 11 shows the mean and range of grain size values across each region. These demonstrate that Region I had the coarsest sediments with uniformly fine sands throughout, whereas Region VI had the finest sediments. However both there and in Region IV there was a wide range of grain sizes. Both these regions include areas of the slope and bottom of the Norwegian Trench where fine sediments dominate and shallower plateau areas covered by coarser sandy sediments.

The analysis showed that depth and grain size had equal influence on the faunal distributions over the area as a whole. Other measured variables were all associated with much lower levels of biological variance. It suggests, however, that natural levels of THC in the offshore sediments are slightly higher in the shallower areas, background levels of lead are higher in the silt/clay sediments of the deeper areas.

6.2.3 Variation through time

The regional and reference station data set includes samples taken over the ten year period from 1990-1999. The influence of the year of sampling on the faunal distributions was shown to be small in the CCA. This was confirmed by further analysis, which showed that there were no significant differences in the faunal distributions between years. This result should be treated cautiously, however, since with one exception no region has yet been sampled twice. A much longer time series of regional surveys will be needed before a reliable estimate of temporal changes can be made.

6.3 Regional Overview and Anthropogenic Effects

The information contained in Table 11 and the aforementioned multivariate analysis, forms the basis for an overview of the background environmental conditions and petroleum-related changes in each of the regions.

To examine the effects of industrial disturbance over the entire offshore area surveyed an analysis was made of a data-set comprising all the undisturbed regional and reference stations together with a selection of field stations representative of all areas in all of the regions surveyed. The inclusion of data from all regions in this analysis permits a direct comparison of the levels of industrially related disturbance from region to region. The analysis included data from 606 stations of which 122 were undisturbed. The regions with the highest number of disturbed stations were I, III, and IV (i.e. the areas with the longest history of industrial activity), whereas the more recently exploited regions II and VI had the fewest. The most disturbed stations were from Region I in 1990.

Region I

The region is located on the North Sea plateau and represents the shallowest area of all the regions. The sediments consist mainly of fine sand with a quite homogeneous background level of hydrocarbons and heavy metals in the sediments. Sediments from the Yme reference station, located in the deeper parts of the region towards north east, are much coarser than in other parts of the region. The sediment from this location has a very low content of barium and the fauna is poorer in both species overall densities than that found in the other regions.

Stations from the Region I used in the multivariate analysis included data from the surveys of 1990, 1991 and 1996 carried out on the Ekofisk and Embla fields. The ten most disturbed stations in the entire analysis were all from the Ekofisk field in 1990 when an intensive survey was carried out which included many stations in close proximity to the Ekofisk Centre and Ekofisk 2/4 B&K installations. These disturbed stations were all sited within 500 m of these installations and the four stations with the highest levels of disturbance were all less than 200 m from an installation. The species that contributed most to the biological variability at these stations were small burrowing worms and surface deposit feeding gastropod molluscs characteristic of highly enriched and disturbed areas. This group of stations, then, represents a benchmark for disturbed conditions and it is noteworthy that no other stations from any of the regions approach this level of disturbance. In most surveys undertaken after 1990 stations were rarely sited in the highly disturbed areas immediately adjacent to field installations. Instead they were placed in transitional areas between 250 and 1000 m from the installations in order to monitor any increase or decrease in the areas of disturbance. Thus this group of highly disturbed stations in Region I is useful for comparison of the upper limits of disturbance likely to be encountered in offshore sediments. The remaining stations sampled in the region in 1990 and 1991 have intermediate to low levels of disturbance and fall between the 1996 stations and the highly disturbed 1990 stations. This suggests that these stations, sited at increasing distances from the installations represent a cline of decreasing disturbance effects.

The regional survey in 1996 covered the fields at Ekofisk, Eldfisk, Embla, Tor, Valhall, Hod, Ula, Gyda, Tommeliten and Yme, the single well 2/7 - 29, and 5 regional stations. At the field stations, levels of total petroleum hydrocarbons in the surface layer of the sediments were in the range 1 - 137 mg/kg. In most areas the levels were below 50 mg/kg. Synthetic drilling fluids had been discharged with cuttings at several fields, and in general the results showed clear reductions in sediment concentrations of these compounds since surveys done 1-2 years before. The majority of the stations sampled in 1996 in Region I showed low levels of disturbance indicating that they are not influenced by the contaminant variables. Little distinction was found between the stations in respect to the shallow depth and fine sediments emphasising the relative uniformity of this region. The most characteristic species found at all these relatively undisturbed stations were the polychaete worms and brittle stars typical of the fine sand areas in the analysis of the undisturbed station data.

Region II

The region is located on the shallow North Sea plateau. Sediments from the southern part of the region close to Sleipner East and Varg differ somewhat from the other background stations in the region where the fauna is both rich and diverse. These sediments have a lower content of pelite and fewer taxa and individuals compared to what was found at the other stations.

Station data from Region II were taken from surveys carried out in the Frigg field in 1994 and 1997 and the Lille Frigg field in 1992 and 1993 together with regional stations from the 1997 survey. Nearly all these stations were shown to be undisturbed and have similar relatively shallow depths and fine sand sediments. The most characteristic species found were the same as those indicated in Region I.

The survey in 1997 covered the fields Varg, Sleipner, Hermod, Balder, Odin, Heimdal, Frøy, and Frigg, as well as 10 regional stations. At the field stations, levels of total petroleum hydrocarbons in the surface layer of the sediments were in the range from less than 10 - 418 mg/kg. All except three of the fields had hydrocarbon levels below 25 mg/kg at the innermost stations. Levels of synthetic drilling fluids in the sediments were in general low. Only a few stations exceeded 100 mg/kg. The fauna in the region was with few exceptions highly diverse and undisturbed. Only 4 out of 191 stations sampled had disturbed fauna.

Region III

This region, and the fields it contains, vary considerably in water depth from 100 - 350 m. The physical, chemical and biological parameters indicate that the region can be divided into three different sub-regions: the shallow Oseberg area on the plateau, Veslefrikk and the other regional stations on the slope, and the Troll area in the Norwegian Trench. Sediment from the shallow area consists of fine sand with low background levels of heavy metals compared to the concentrations in the more silty sediments in the deepest part of the region. The stations located on the slope separating the Oseberg and Troll fields have the highest numbers of species and individuals. The highest background concentrations of hydrocarbons and barium are also found in the slope.

The data for the muiltivariate analysis from Region III were taken from surveys of the Veslefrikk field in 1993 and 1998 and the Troll field in 1994, 1995 and 1998. The regional survey in 1998 covered the fields Troll, TOGI, Oseberg, Brage and Veslefrikk, as well as 10 regional stations.

The analysis showed that both the Veslefrikk and Troll areas were much more strongly influenced by the contaminant variables in 1998 than was the case in the previous surveys. At 3 of the fields, relatively high sediment levels of hydrocarbons (maximum 2100 mg/kg) or synthetic based fluids and metals were recorded. Five of the 1998 Veslefrikk stations were disturbed, implying a strong influence of contamination in that area. The dominant species at these stations included deposit feeding worms and small bivalve molluscs associated with organically enriched sediments. A further three Veslefrikk stations together with seven stations from the 1998 Troll field survey were dominated by species of small molluscs and worms indicative of moderately enriched conditions. The differences between the Troll and Veslefrikk fields in the dominant species recorded from disturbed areas are attributable to the depth and sedimentary differences. The Troll field lies in the bottom of the Norwegian Trench at 330 m depth in soft silt sediments whereas Veslefrikk is on the upper slope at 170 m where the sediments are of fine sand. The majority of the stations from the Oseberg region were undisturbed. The shallower Veslefrikk stations were dominated by some of the same species found to be characteristic of fine sand areas in Regions I and II but in the deeper areas small bivalves were more predominant. In the undisturbed deep silty sediments of the Troll area tube worms and small bivalve molluscs were equally important.

Region IV

The Norwegian Trench and its western slope are the dominant features in the region. The deepest part of the region has sediments with a high content of pelite (i.e. fine grained sediments). There is a correlation between high background concentrations of heavy metals and high amounts of pelite in the sediments. In these areas communities are richer and more diverse than those found on the shallower areas where the sediments are coarser.

The station data from Region IV used were from the 1993 and 1996 surveys in the Tordis and Statfjord fields. The analysis showed that a group of Statfjord stations in 1993 were disturbed by the contaminants. The dominant species in these areas were all small polychaete worms frequently recorded from disturbed areas. Some of the 1993 stations at the Tordis field showed slight disturbance, but at nearly all the Tordis 1994 and 1996 and the Statfjord 1994 and 1996 stations there was a decrease in contaminant related disturbance after 1993. In the undisturbed areas small differences in depth and sediment type appeared to influence the species. The undisturbed Statfjord stations at 275 m depth with fine sand were characterised by deposit feeding bivalves and large tube worms. The Tordis sediments were of fine silt at a depth of 200 m and were dominated by filter-feeding bivalves and small tubeworms.

The regional survey in 1996 covered the fields Snorre, Tordis, Vigdis, Statfjord, Gullfaks, Rimfaks, and Visund, as well as 10 regional stations. Levels of total hydrocarbons in surface sediments varied from less than 4 - 5520 mg/kg, with the highest levels found at the innermost stations around the older multi-well platforms. Eight out of 15 fields had levels below 25 mg/kg at all stations. The remaining 7 fields had levels above 100 mg/kg at some stations. The fauna at the regional stations was undisturbed and highly diverse. The older fields had a clearly disturbed fauna close to the platforms, although some indications of improvement since earlier surveys were detected. At 5 of the 15 fields, the fauna was undisturbed, while at the remainder a slight to moderate disturbance was detected at some stations, generally those closest to the platforms.

Region VI

A wide and relatively deep shelf area to the east and the deeper areas to the west dominate the region. The sediment in the region consists of fine sand to silt with emphasis on the silt fraction. There is some variation in the background chemical and biological results related to depth and grain size distribution in the sediments. The shallowest regional station exhibited somewhat lower background concentrations of heavy metals in the sediments and a higher number of taxa.

As yet only a limited number of surveys have been undertaken in Region VI. Data from surveys in 1996 and 1997 in the Åsgard field entered into the analysis suggested that there was little contaminant disturbance in the area. A small group of stations with fine sand sediments differed from the majority of the stations, which had fine silt sediments. The depth was uniformly about 300 m through out the area and thus had little influence on station distributions in the analysis. In all stations the characteristic species contributing most to the biological variance included surface feeding tubeworms but burrowing worms were more numerous in the siltier areas.

The 1997 regional survey covered the fields Norne, Åsgard, Heidrun, Draugen and Njord, as well as 10 regional stations. In general the region was only slightly contaminated, and the bottom fauna appeared healthy all over. Slightly elevated levels of oil hydrocarbons were found in the surface sediments at three fields (106 mg/kg, 85 mg/kg, and 29 mg/kg), and here the faunal diversity was also slightly reduced. Apart from this, the fauna diversity was high all over the region.

7 Environmental Impacts

7.1 Extent of Contamination and Impacts

SFT has engaged a group of external experts (the "SFT Expert group") that evaluate the reports from each environmental survey. The SFT expert group has determined the outer limits (maximum distance from the field centre) for chemical contamination and biological effects based on the chemical and the biological results (faunal parameters) for each field and region surveyed. From these outer-limit distances, a calculation is made of the area affected in each field. The barium indicator traces dispersion of drilling components in general. THC indicates contamination from drilling with oil-based muds (OBM) and other discharges. The biological fauna indicator traces overall disturbance to the sediment community.

For sediment chemistry, the contaminated area is defined based on the level of indicator chemicals above the Level of Significant Contamination (LSC)[3]. Prior to the introduction of regional surveys in 1996 the LSC for each field was calculated solely from the levels measured at the field-specific reference station. At present the LSC is determined from the levels measured at selected regional and reference stations giving a better indication of the natural background values in the area.

Assessment of the faunal disturbance at a given station is based on a number of ecological variables covering both the number of species and individuals present, their comparative abundance, and also the presence or absence of specific species known to be indicators of anthropogenic disturbance.

It is useful to examine the overall patterns of affected area over a number of years in order to get an idea of the long-term trends in the affected area, and therefore the environmental quality of the Norwegian offshore region related to the petroleum industry. These calculations were therefore revised this year (2000) to make them more comparable from one survey to the next.

Because not every field or region is surveyed each year, there arises some question as to how to handle the "in-between" years when the surveys are not conducted. There has been a recent suggestion that some type of interpolation may be more realistic of actual temporal trends in the environment. In Figure 22, we have used such a linear interpolation for years ("in-between years") that a region has not been surveyed. We use the latest available data from the SFT expert group on the extent of detection for three different indicators of effects (THC, Barium, and fauna), and interpolate in order to arrive at estimates for years in which no surveys were conducted. For the period from the last survey to the present, where there is no second boundary to establish an interpolation estimate, the value for the last survey is simply adopted until such time as a new survey becomes available, then figures can be revised accordingly. Using this method, long-term trends of the affected area from 1990 to 1998 is presented in Figure 22 for each region and for the Norwegian sector as a whole.

There are clear trends over time in the affected areas, both in the contaminated area and the biologically disturbed area. The area contaminated with THC peaks in 1992 at over 500km^2

[3] Limit of Significant Contamination (LSC)**:** the value of a certain monitoring parameter which signifies the borderline between contaminated and uncontaminated sediments. The LSC value for an area is based on the levels of the parameter at the reference stations and regional stations, and usually set as the average value plus the required confidence interval (i.e. two times standard deviation if 97.5% confidence is required). Some scientific judgement is allowed, and values from impacted reference and regional stations may be omitted.

and then begins a steady decline to 1996, then levels off to 1998. It is suggested that this pattern results from the prohibition of the discharge of OBM from 1993 onward.

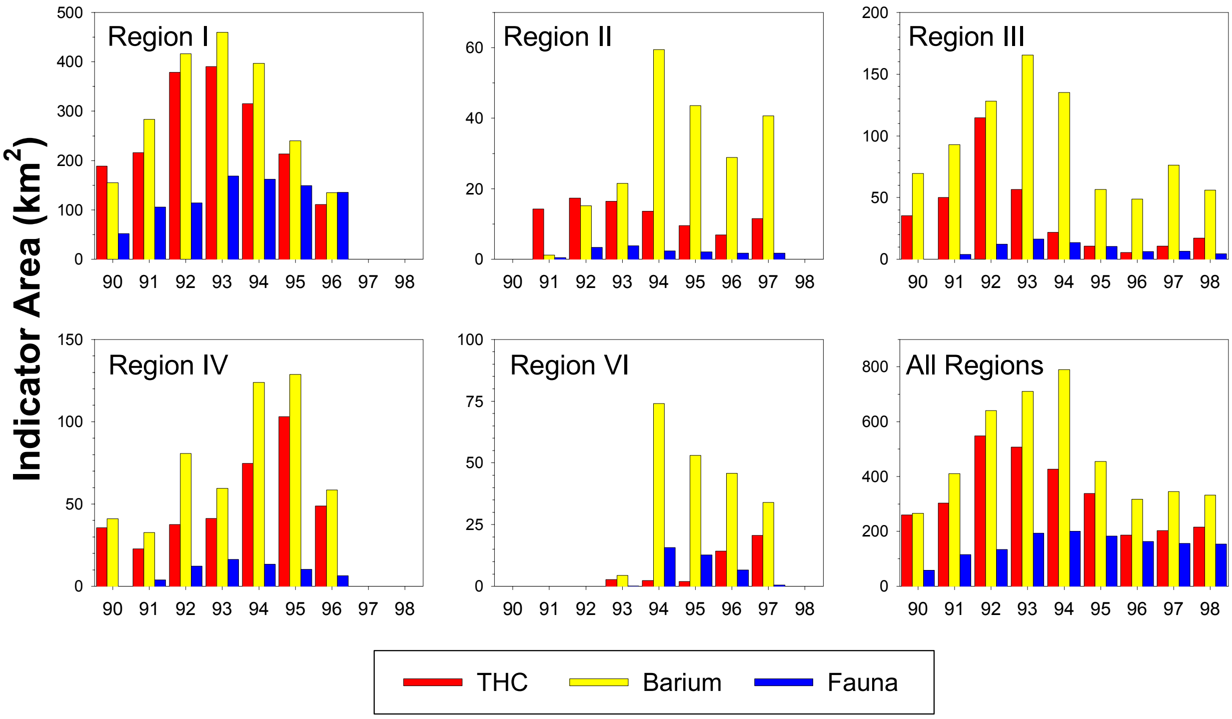


Figure 22: The area in each region estimated as affected from 1990-1998 based on THC, barium, or fauna as indicators of effects. The calculation is made by the SFT expert group based on the distances of the stations around each field that effects are observable. Data for the pre-regional era (1995 and earlier) are summed for all the fields existing at the time in the area within the regional boundary.

Effects on fauna are far more limited than for chemical contaminants, with a peak in 1994 at about 200km^2, followed by an extremely small and gradual decline to 1998. The reasons for this pattern can be explained through several mechanisms. First, the significantly smaller area of faunal disturbance compared to the area of contaminated sediment is probably due to the fact that certain specific levels of hydrocarbons and heavy metals are needed to trigger major impacts on the benthic fauna. In other words, benthic species often exhibit a threshold effect rather than a gradual reaction to chemical contaminants. Second, the gradual pattern of the overall community response to the change in discharges as is likely to be caused by time lags in faunal recovery (due to reproduction, recruitment, growth of juveniles, etc.) that are a fundamental part of the natural system.

The area affected by barium, which itself is not toxic but serves as a tracer of the extent of discharges of WBM, rises from 1990 through 1994, then drops precipitously in 1996 and 1997, before levelling off in 1998. However, discharged quantities of barium may even have increased in recent years as a result of increased use of WBM. The reasons for these seemingly paradoxical results are not straightforward. However, below we explore two possible explanations.

First, with the introduction of regional surveys in 1996, the total number of field stations on the transects from the field centre were reduced. Stations were selected to focus on the zone of transition from impacts to no impacts for the biological and THC indicators. Therefore, outermost stations from the previous field surveys often fell out of the sampling plan. Since barium tends to spread further from the source than THC, there is the possibility that areas contaminated with barium exist beyond the furthest station along sampling transects around individual fields. This explanation however, cannot explain the large drop in the area of the barium indicator between 1994 and 1995.

Second, with the previous methods used for calculation of LSC, contamination of reference stations may lead to higher LSC values. Examples presented in Figure 23 indicate that concentrations of barium and THC have fluctuated dramatically from one year to another, sometimes by more than 100 % at some of the stations (e.g. barium at station Statfjord C-06), or exhibited clear trends (e.g., increasing THC at the Snorre TLP-Reference station, and most of the results from Region II).

A general rise in THC concentrations at the reference and regional stations will lead to higher

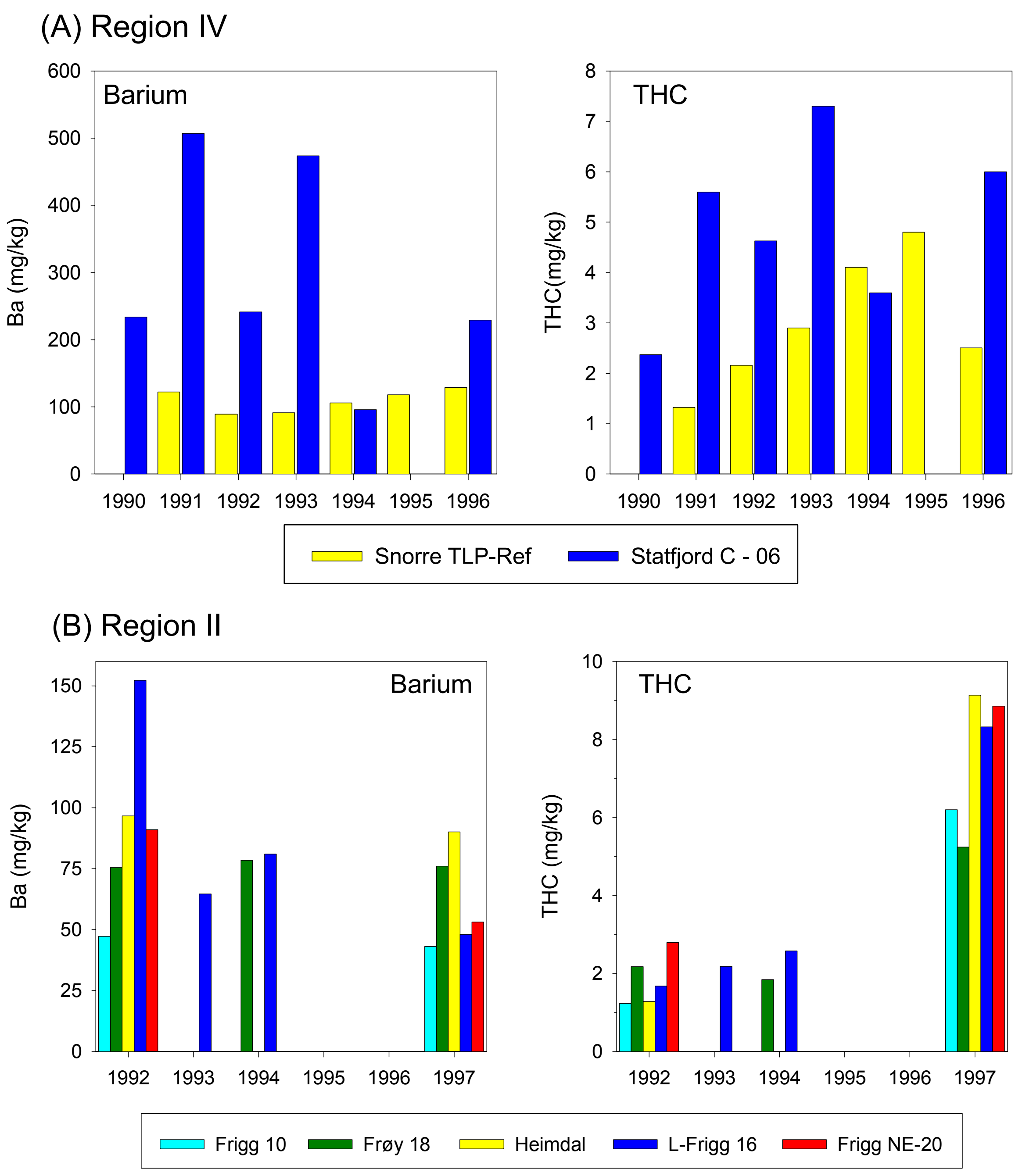


Figure 23: Concentrations of barium and THC from some of the reference stations in Regions IV (A) and II (B). These values have been included in the calculation of LSC values for the individual years.

LSC's. This changes the criteria used for determining contamination at the field stations, and therefore may result in a reduction in the calculated contaminated area, even if concentrations at the field stations remain the same or increase.

The reduction in impacted area over the past several years (Figure 22) occurs against a backdrop of increased petroleum production. In 1998, there were more producing wells than ever before, yet the total area affected by the petroleum industry has been decreasing for several years. In order to put the area measurably disturbed by petroleum activities into some perspective, we have calculated the proportion of disturbed area found in the last regional surveys to the total area of the sea bottom in each of the regions (Table 12).

In all cases, the proportion of area measurably affected by petroleum activities represents far less than 1% of the total offshore area. Proportional values for the biological indicator range from a low of 0.004% in Region II to a maximum of 0.3% in Region I, and values for the THC indicator ranged from 0.01% in Region VI to 0.3% in Region IV. Highest relative effects are thus found in the older regions (I and IV) where oil based muds were discharged before 1993.

Table 12: Disturbed areas compared to total area in each region.

Region	Total Area in Region (km^2)*	Survey Year	Proportion of Biological Disturbed Area to Total Area (%)	Proportion of THC Contaminated Area to Total Area (%)
Region I Ekofisk	52253	1996	0.03	0.02
Region II Sleipner	48592	1997	0.004	0.02
Region III Oseberg	17465	1998	0.02	0.1
Region IV Statfjord	17527	1996	0.07	0.3
Region VI Trøndelag	96237	1998	0.007	0.01

** Based on a calculation from the inshore basis-line to the offshore extent of the Norwegian Sector, between the latitudinal boundaries set for each region by SFT.*

7.2 Case Studies[4]

A review of the environmental effects of drilling muds based on survey data from fields in Regions I, III, and IV noted that OBM and SBM were mostly adsorbed on cuttings particles and deposited close to the discharge points. In contrast, WBM tended to mix into the seawater and be diluted and dispersed over much wider areas. Surveys could not demonstrate effects of dissolved water-based contaminants.

In this section, some examples are presented of time-trends in the course of contamination and faunal effects, and are discussed in relation to the discharge of OBM and synthetic-based SBM during exploration and production drilling. SBM are engineered to have less harmful effects to the environment than the previously-used mineral oils, thus impacted areas are expected to be smaller in fields/regions where SBM have been used from the start compared to older fields and regions.

The first environmental surveys in the Norwegian sector of the North Sea were conducted at Ekofisk in 1973 and at Statfjord in 1978. Extremely high sediment concentrations of THC

[4] This section summarises the specific research of a number of individuals. References to individuals and citations to published research papers have been excluded in the present document. Those interested should consult the fully-referenced research paper produced as companion to this report.

were observed from this period and persisted to the early 1990's at fields where oil-based drilling muds were been used and discharged (e.g. above 40,000 mg THC/kg dry sediment at the field Statfjord C, 1991). An initial review of the results from the Statfjord field-survey suggested that biological effects could be detected over much larger areas than previously concluded in some of the original survey reports. These results were later supported by other more thorough statistical analyses of survey results from Ekofisk and from other sectors of the North Sea. The impacts were related to discharges of cuttings contaminated with OBM and effects were shown to cover extensive areas, up to 50 km^2 at some fields.

Natural processes degrade hydrocarbons in the sediments over time, and the prohibition on discharging cuttings containing OBM has led to a distinct reduction in the amount of hydrocarbons found in the sediment around the installations. This is particularly evident in the decrease in the extent of the THC indicator presented earlier in Figure 22.

Data has shown that the degradation of OBM is slow and results from offshore monitoring have shown elevated levels of hydrocarbons in the sediment and biological effects on the macrofauna within a radius of several hundred meters several years after discharges of OBM had ceased. High amounts of mineral oils that can be found in sediments around some installations in the present surveys are mostly derived from earlier discharges of OBM or are caused by recent accidental spills at the field. Except for accidental discharges, produced water brought up from the reservoir along with oil and gas is currently considered to be the principal source of operational hydrocarbon-discharges to the sea.

An example of effects from earlier discharges of OBM can be observed in the development around the Gyda oil field located in Region I (Figure 24). In 1987 after only minor drilling waste discharges from exploration drilling, there is essentially no contamination and the fauna exhibits no patterns or gradients around the platform. Production started in 1990 and the area of THC-contaminated sediments peaks in 1993 when it covers close to 30 km^2. In 1996 it declined to less than 5 km^2 and preliminary results from 1999 indicate approximately the same THC-contaminated area as previously.

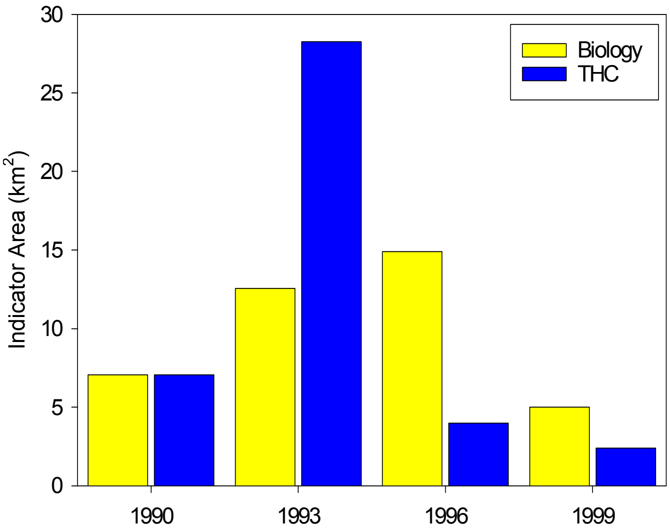


Figure 24: Temporal development of contamination and pollution effects around Gyda oil field. Values for 1990, 1993 and 1996 were calculated by the SFT expert group, and preliminary results for 1999 are based on the survey report.

Disturbance of the benthic community structure was clearly found in 1990 and the area of biological effects continued to rise despite reduced THC levels, until 1996, three years after discharges of OBM had ceased. Preliminary results from the latest survey in 1999, however, indicates improvement to the biological communities, with disturbance of macrofauna at only three stations and a significant decline in the extent of the biological indicator.

Biological effects are a function of toxicity of the compound in the environment and total time of exposure. Most SBM has higher degradation rates compared to OBM and therefore the time-period fauna are exposed to elevated concentrations of SBM is shorter. Effects outside a distance of 250 - 500 m from the discharge point are rarely found in field surveys. Experimental mesocosm studies have shown that internal olefins (IO) and linear olefins (LAO) degrade significantly faster than mineral oil and poly-alfa-olefins (PAO), but not as fast as the esters. Severe biological effects have only been observed in experimental units treated with ester-based mud systems. These effects are largely due to severe oxygen depletion resulting from high biological demand of the bacteria degrading the compound and are temporary.

After a discharge of 96 tonnes of saturated ester over a short period in 1990 at the Ula field (Region I), high concentrations of the ester were detected at a distance of 200 - 500 m from the well, accompanied by a smell of hydrogen sulphide (evidence of anoxic conditions) from sediment samples. In the first year, the macrofauna was disturbed out to a distance of 100 m from the installation. One year later contamination was still detectable, but at lower levels, out to 500 m, with disturbed fauna only found at one station. After 2 years, all stations had background levels and only slightly affected fauna.

Exploration drilling at Tordis field (Region IV) was conducted between 1987 and 1989 using mainly WBM. The baseline study in 1993 detected no contamination and the fauna was described as undisturbed (Figure 25). Production drilling commenced in 1993 and continued at least until 1996 with a mud system including both WBM (>4000 tonnes) and SBM (poly-alfa-olefins ~ 230 tonnes, and ester ~ 220 tonnes). The ester was only used at the end of 1995 and early 1996, and discharges of olefins were highest in 1994. Monitoring surveys in 1994, 1995 and 1996 detected contamination by olefin, with the largest contaminated area in 1996, compared to the THC indicator that peaked in 1995.

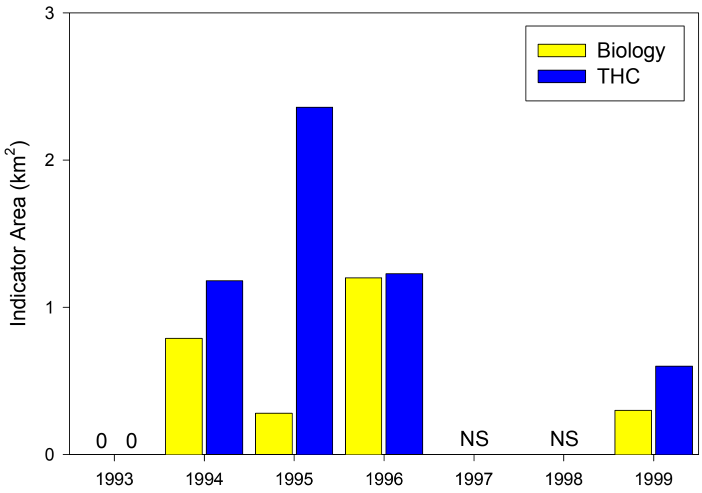


Figure 25: Development of contamination and pollution effects around Tordis oil field in Region IV. Note different y-axis scale compared to Fig. 24. Preliminary results for 1999 are from the survey report. NS = not surveyed.

Ester was detected at 6 stations at Tordis in 1995 after a discharge of 2.6 tonnes. Concentrations of ester in 1996 after discharge of an additional 225 tonnes were not found to be significantly higher, supporting the estimated degradation rates from the experimental studies. The disturbed area was found to be approximately 1 km^2 in 1994 and 1996 and declined to 0.3 km^2 in 1999. Changes in macrofauna were correlated to levels of SBM (mainly olefin) and not to THC.

These case studies support the view that, compared to OBM, the use of SBM has generally resulted in both a smaller total area affected by drilling activities, as well as a shorter time to recovery of disturbed areas. Thus, a given amount of drilling activity and discharges is expected to result in a smaller extent and shorter time-course of environmental effects in fields developed more recently compared to older fields. The continued degradation of contaminants from older fields combined with the smaller area of environmental disturbances in newly developed fields suggests the decrease in the extent of chemically affected or biologically disturbed area in Norwegian Sector observed in the past five years will continue.

8 Conclusions

8.1 The Regional Survey Approach

Experience gained from undertaking regional surveys over the past four years has suggested that the regional approach has brought considerable advantages to the assessment of the effects of the oil industry on the offshore environment at all levels. Thus the local assessment of in-field effects can now be easily compared quantitatively with effects in adjacent fields and the possibility of inter-field synergistic disturbances developing can be monitored. Additionally, inter-regional comparisons can now be carried out with a proper scientific basis. At the regional level it is now possible to contrast the in-field effects with conditions at a suite of undisturbed stations representative of the normal environment in that area and thus improve the statistical accuracy of the comparisons and assessments made. At present, regional surveys still concentrate on assessing sedimentary effects. Urgent consideration is suggested for developing an effective scheme for evaluating any influences on water column biota. Finally comparisons across regions allow the overall effect of the industrialisation of the Norwegian offshore areas to be quantified and compared more easily with the disturbance caused by other industries and activities in offshore waters, such as shore-based waste discharges, trawl fishing, etc.

In addition the groups of undisturbed regional and reference stations that are regularly sampled in each region provide a network of monitoring stations covering a large area of the northern North Sea. This network, together with the coastal monitoring station network, provides one of the most extensive marine monitoring systems in Europe. The data being gathered from these areas will be invaluable not only in the assessment of disturbances caused by pollution but also in the assessment of broad scale climatic change.

8.2 Analysis of the Offshore Survey Data

8.2.1 Trends in the levels of discharged compounds

Over the period 1995-1998 the total discharge of synthetic based cuttings and fluids across the offshore area remained relatively constant whereas discharge of water-based material fell progressively. On the other hand the total discharges of produced water and oil-in-water increased throughout the period. Amongst the heavy metals, releases in barite were the dominant source of most metals to the environment compared to releases with produced water. 1997 appears to be an unusual year for discharges of metals with barite; with some compounds (cadmium, mercury, nickel) showing unusually high discharges, while others (arsenic, lead, zinc) showed exactly the opposite trend. It is unknown whether this results from actual variations in discharges or improved detection limits in monitoring systems.

8.2.2 Natural variation in benthic communities

Water depth and sediment grain size were the two most influential natural variables in structuring the benthic communities. Each was found to explain 6% of the total variability in an analysis of faunal distributions measured amongst the undisturbed stations sampled. Variables associated with metals and hydrocarbons were found to explain 4.5% of the total variability. These values were assumed to represent the natural background levels of these factors.

8.2.3 Anthropogenic effects

In an analysis of data from over six hundred stations spanning both disturbed and undisturbed areas in all regions it was found that contaminant variables explained 8% of the total biological variability measured compared to 10.5% explained by natural variables. This means that the majority of biological variability within the system was due to either natural variation or unrecorded anthropogenic factors. The most influential contaminant variables were THC and Cadmium, each of which explained 3% of the total measured variance. In two regions, there was sufficient survey data available to compare changes over time. In Region III, the influence of contaminant variables was found to have increased between 1993 and 1998 in two recently developed fields, whereas in Region IV, such influence had declined in the vicinity of two older installations. The effects in all such areas were found to be much smaller that those recorded from fields in Region I in 1990-91 when oil-based drilling fluids were being discharged.

Two case studies demonstrate the comparative changes in the extent of contamination through time after drilling with OBM and SBM. The field developed with drilling using OBM (Gyda field, Region I) showed extensive affects of THC that have been measurable for several years due to slow degradation of hydrocarbons. In contrast, the use of SBM during drilling at Tordis field (Region IV) resulted in an initially smaller affected area as well as a faster recovery of the environment from the effects of drilling.

8.2.4 Extent of the total disturbed area

Of the regions, the oldest – Region I (Ekofisk), is the most affected area based on chemical and biological indicators. The temporal trends in the total area of all regions combined deemed to be above the lowest level of significant contamination rose substantially between 1990 and 1992. The area contaminated by THC began to decline in 1993, when use of oil-based drilling fluids was banned, and has stabilised after 1996. The area contaminated by barium continued to increase through 1994 and then also began a steep decline.

The total area of sediment designated as having some level of disturbance in the benthic fauna is considerably smaller then the chemically contaminated area, and has not changed so dramatically over the nine years for which survey data is available. It rose between 1990 and 1994 and has since shown a very slightly decreasing trend. This suggests that the gross community response to the change in discharges was a gradual process that occurred over a three-year period following the change in policy.

It is notable that trends in the area of measurable effects of the offshore industry, both related to chemical contamination and to biological disturbance, have been declining over the past several years despite the fact that exploration continues at a rapid pace and more fields are being brought into production. This overall decrease against a backdrop of increased activity suggests that the environmental effects, normalised to a per-field basis, are declining rather noticeably. However, there is currently no index that normalises effects to some measure offshore activities so it is not possible to make a definitive statement to this effect.

In order to determine the relative extent of impacts to the Norwegian offshore sector as a whole, the estimates of total affected area based on the biological and THC indicators are expressed as a proportion of the total area of Norwegian offshore area. This approach indicates that petroleum activities impact far less than 1% of the total bottom area in the different regions. Proportional values for the biological indicator range from a low of 0.004% in Region II to a maximum of 0.3% in Region I, and values for the for the THC indicator ranged from 0.01% in Region VI to 0.3% in Region IV.

9 Recommended Reading List

For those interested in pursuing the topics covered in this report in more detail, listed here are a number of the most relevant publications.

GESAMP. (1993) Impact of oil and related chemicals and wastes on the marine environment. GESAMP (IMO/FAO/UNESCO/WMO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution) Reports and Studies 50:1-180.

Gray J.S., Bakke T., Beck H.J. & Nilssen, I. (1999) Managing the environmental effects of the Norwegian oil and gas industry: From conflict to consensus. Marine Pollution Bulletin 38:525-530.

Gray, J.S., Clarke, K.R., Warwick, R.M. & Hobbs, G. (1990) Detection of initial effects of pollution on marine benthos: an example from the Ekofisk and Eldfisk oilfields, North Sea. Marine Ecology Progress Series 66:285-299.

Kingston, P.F. (1992) Impact of offshore oil production installations on the benthos of the North Sea. ICES Journal of Marine Science 49: 45-53.

Olsgard, F. & Gray, J.S. (1995) A comprehensive analysis of the effects of offshore oil and gas exploration and production on the benthic communities of the Norwegian continental shelf. Marine Ecology Progress Series 122:207-306.

Pearson, T.H. & Rosenberg, R. (1978) Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanography and Marine Biology Annual Review 16: 229-311.

Royal Ministry of Petroleum and Energy (1999) Norwegian Petroleum Activity: Fact Sheet 1999. The Royal Ministry of Petroleum and Energy; Oslo.

Royal Ministry of Petroleum and Energy (2000) Environment 2000: The Norwegian Petroleum Sector. The Royal Ministry of Petroleum and Energy; Oslo. ISSN 1502-0576.

SFT (1990) Manual for baseline monitoring studies in the vicinity of petroleum installations in Norwegian sea areas. Norwegian Pollution Control Authority Report No. 90:01. 29 pp. (In Norwegian).

SFT (1991) Species list - North Sea Benthos. Version 01-05-91.

SFT (1993) Classification of environmental quality in fjords and coastal sea areas: Effects of environmental contaminants. Norwegian Pollution Control Authority – Guidelines. 20 pp. (In Norwegian)

SFT (1997) Environmental monitoring around petroleum installations on the Norwegian continental shelf: Report from 1995. Norwegian Pollution Control Authority. Report No. 97:13. 60 pp. ISBN 82-7655-045-2. (In Norwegian)

SFT (1999) Guidelines for environmental monitoring of petroleum activities on the Norwegian shelf. Norwegian Pollution Control Authority 99:01. 123 pp. ISBN 82-7655-164-5. (In Norwegian).

10 Acronyms

A number of acronyms are used in this report. For the convenience of the reader, these shall be summarised in on this page.

Acronym Used	Meaning
OLF	Norwegian Oil Industry Association
SFT	Norwegian Pollution Control Authority
OBM	Oil-based drilling muds
SBM	Synthetic-based drilling muds
WBM	Water-based drilling muds
THC	Total Hydrocarbons
LSC	Limit of significant contamination
CCA	Canonical correspondence analysis
OSPAR	Oslo-Paris Commission