8.7.4.

Heidrun Field

Environmental Impact Assessment

Petter Wang, mNGD

HEIDRUN

conoco

HEIDRUN FIELD

ENVIRONMENTAL IMPACT ASSESSMENT

Heiþrún heitir geit es stendr höllu á (Herjaföþrs)
ok bítr at Læráþs limum;
skapker fylla hón skal ens skíra mjaþar,
knáat sú veig vanask.

Hethrún, the goat on the hall that stands,
eateth off Læráth's limbs;
the crocks she fills with clearest mead,
will that drink not e'er be drained.

THE POETIC EDDA
Grimnismàl, verse 25

PREPARED BY:
CONOCO NORWAY INC.
DECEMBER 1989

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ABBREVIATIONS

API	American Petroleum Institute (Standard)
BPD	Barrels Per Day
BOP	Blowout Preventer
BOPD	Barrels of Oil Per Day
CFCs	Chlorofluorocarbons
CMS	Cooperating Marine Scientists
CNI	Conoco Norway Inc.
CO_2	Carbon Dioxide
dB	Decibel
DNMI	Det Norske Meteorologiske Institutt (Norwegian Meteorological Institute)
DST	Drill Stem Test
DWT	Dead Weight Tons
EIA	Environmental Impact Assessment
EOM	Extractable Organic Material
ESD	Emergency Shut Down
ES100	Expected Number of Species per 100 Individuals Based on Hurlbert (1971) Rarefaction Curves
E&P Forum	Exploration and Production Forum
FLP	Floating Loading Platform
FSO	Floating Storage and Offloading Vessel
GBS	Gravity Based Structure
GBT	Gravity Based Template
HCl	Hydrochloric Acid
HP	High Pressure
Hs	Significant Wave Height
Hs	Shannon-Wiener Diversity Index
HVAC	Heating, Ventilation and Air Conditioning
Hz	Hertz
IKU	Institutt for Kontinentalsokkelundersøkelser og Petroleumsteknologi A/S
IR	Infra-red Spectrophotometry
KCl	Potassium Chloride
LP	Low Pressure
MD	Measured Depth
MDS	Multidimensional Scaling
MLWS	Mean Low Water Springs
MMSCFD	Million Standard Cubic Feet per Day
MWt	Molecular Weight
NIVA	Norwegian Institute for Water Research
NINA	Norwegian Institute for Nature Management
NOFO	Norsk Oljevernforening for Operatørselskaper
NPD	Norwegian Petroleum Directorate
NPD	Naphthalene, Phenanthrene, Dibenzothiophene
NO_X	Nitrogen Oxides
OBM	Oil Based Mud
OD	Outside Diameter
ODAP	Oceanographic Data Acquisition Project
ODP	Ozone Depletion Potential
PARCOM	Paris Commission
PHPA	Partially Hydrolysed Polyacrylamide
ROV	Remote Operated Vehicle
R&D	Research and Development
SFT	Statens Forurensningstilsyn (State Pollution Control Authority)
SIFSH	Statens Institutt for Strålehygiene
SO_2	Sulphur Dioxide
THC	Total Hydrocarbons
TLP	Tension Leg Platform
TOC	Total Organic Carbon
TVD	Total Vertical Depth
WBM	Water Based Mud
WSF	Water Soluble Fraction
Btu/hr-ft^2	British Thermal Units per Hour per Square Foot
Barrel	42 US Gallons (1 m^3 = 6.2898 barrels)
Sm^3	Standard Cubic Metre

A. SUMMARY

1. INTRODUCTION

In pursuance of the requirements of the Pollution Control Act of 13 March 1981, and of the Petroleum Act of 22 March 1985, an Environmental Impact Assessment (EIA) of the proposed Heidrun field development has been carried out.

Conoco Norway Inc. (CNI) has received specialist input to the EIA, on the description of the existing environment, on oil spill recovery and drift modelling, possible impacts on plankton and fisheries, seabirds, marine mammals, coastal resources (including recreation and amenities) and aquaculture. Contact has also been made with the municipalities and relevant authorities in the process of compiling these reports.

Thanks is due to the Norwegian Institute for Water Research (NIVA), Cooperating Marine Scientists A/S (CMS), Asplan A/S, the Norwegian Institute for Nature Management (NINA), the Norwegian Meteorological Institute (DNMI) and A/S Spesialavfall.

Most of the data are adequate for the purposes of the EIA, but it is recognised that in some areas further information is needed (e.g. seabirds at sea).

2. CONCLUSIONS

2.1 General

Studies which have been carried out indicate that the Heidrun development should under normal operating conditions have minimal environmental impact.

The main environmental impacts associated with the Heidrun development are similar in nature to those arising from other offshore developments in the North Sea. Increasingly restrictive legislation is being introduced to minimise the risk of pollution from offshore operations, and new developments such as Heidrun are thus likely to exhibit reduced environmental impact when compared to many existing fields.

The risk of potential problems leading to major environmental impacts is extremely low, and the use of best available technology and sound procedures, along with regular environmental monitoring and auditing, will ensure that operations are conducted in an acceptable environmental manner.

There will be physical disturbance of the seabed as a result of the installation and abandonment of field facilities and the discharge of materials such as drill cuttings. These impacts will be localised and recovery of seabed communities will take place following cessation of activities. Minimal environmental impact will arise from water based mud (WBM) and cuttings discharges. During the period 1993-2000, water based cuttings disposal in the field could amount to approximately 68,500 tons.

Unless highly effective WBM systems become available prior to development drilling commencing, oil based drilling muds (OBM) would have to be used in the Heidrun field for technical, safety and economic reasons. A total of approximately 26,000 tons of OBM cuttings could be generated. New restrictions on the discharge of oily cuttings will, however, severely limit the offshore disposal of this waste or ban it altogether. This will reduce the volumes of oil entering the marine environment from drilling operations. The nature and extent of seabed impacts observed at Heidrun will be less than those for existing fields discharging cuttings under the present 100 g/kg oil on cuttings limit.

Transshipment of cuttings to shore for disposal will pose logistical, technical, safety and environmental problems. Satisfactory reception and treatment facilities do not presently exist for this material, although they could be developed by the time OBM has to be used in the Heidrun field.

Aqueous discharges will be treated to ensure that oil-in-water levels do not exceed the legal limit. Dispersion and dilution in the deep offshore environment at Heidrun is expected to be good and such discharges should not cause any unacceptable impact. The maximum produced water discharge envisaged is 20,000 m^3/day. Pipeline test water discharges will be of small volume because of the small diameter and length of Heidrun in-field flowlines. All discharges from field facilities will be carried out under permit from Statens Forurensningstilsyn (SFT).

Flaring will be very limited (emergency or essential equipment maintenance) as gas will be recovered for export or reinjection to the reservoir(s). Other sources of atmospheric emissions will be small by comparison (exhaust gas, vents, fugitive emissions etc.) and Heidrun's contribution to local or global pollution problems will not be significant.

The Operator recognises increasing concerns about the offshore use and discharge of chemicals, and the fate and effect of these chemicals in the marine environment. A major R&D study addressing all of these issues has been funded by the Operator and should be completed in 1994. The findings will be used in the Heidrun field to minimise possible impacts from this source.

The most serious potential impact from the Heidrun field is that of a major oil spill. The coastal area within the impact zone (as defined by drift modelling) has been examined in the EIA, and vulnerable habitats, economic resources and natural communities identified. The area is topographically extremely complex with numerous skerries, islands and bays, and is densely scattered with areas where oil may accumulate and remain for long periods.

The coastline does contain many important locations, particularly for seabirds, otters, and the aquaculture industry and these could be severely impacted by a large spill.

Offshore recovery operations will significantly reduce the amount of oil drifting ashore, and facilities design and operation will incorporate the necessary safeguards to minimise the occurrence of oil spills. A thorough evaluation of risks and possible spill sources has been carried out and the probability of a major spill from any source is low. Contingency planning and the use of a comprehensive computerised environmental database will allow the greatest possible protection to be afforded to sensitive locations.

The mosaic distribution along the coast, of a range of resources considered of importance for different reasons, makes it difficult to categorise sites or geographical regions according to value. The coastlines which are given the highest priority on the basis of several of the resources being present, are Trondheimsfjord and areas around Hitra, Frøya and the Froan archipelago, the coast from Vega to Meløy, and from Røst to Andøya. Of these regions, the coast from Vikna to Leka and from Vega to Meløy is likely to be the most susceptible to oil spill impact, according to drift modelling.

2.2 Fisheries and Aquaculture

The impact of routine aqueous discharges from field facilities on plankton, fisheries and aquaculture is expected to be minimal, and indistinguishable from natural variation in populations.

Hydrocarbon tainting of fish populations as a result of routine discharges from Heidrun facilities is unlikely. As a result of new restrictive legislation on oily drill cuttings discharges, tainting of fish near the Heidrun platform will be less likely than than for platforms presently discharging 100 g/kg oil on cuttings.

The Operator will apply for permission to establish safety zones around Heidrun field installations and this will impose restrictions on vessel access and fishing activities. The effective area of restriction could be approximately 20 km^2. Heidrun is not a heavily fished area and the fishing gear most commonly used is long-line. Disruption to fishing activity and income, through loss of access is thus expected to be minimal.

The effects of a major oil spill incident on fishing activities could include oiling of gear and vessel hulls (avoidable in certain instances); temporary loss of access to some fishing areas; impacts on eggs and larvae of certain species (dependant on presence, development stage and length of exposure); and possible oiling of inshore spawning and nursery areas.

The effects of a spill on inshore fisheries will probably be of limited importance. Aquaculture systems could, however, be severely affected in the event of a spill, with tainting, and injury or mortality in some species being the most likely impacts. Oiling of gear could also be significant in such a situation. Early notification to owners, and where possible, protection of aquaculture sites from oiling, would be an important element in contingency planning.

3. FOLLOW-UP PROGRAMMES

The Operator will continue to participate in oil spill exercises and training programmes, and to provide an adequate level of staffing to ensure that response to an oil spill will be as efficient as possible.

Oil spill contingency plans will be kept updated and improved where necessary, as indicated by changing events, legislation or lessons learned from exercises. In this regard, the Operator will investigate with the authorities and the other Haltenbanken operators, the possibility of developing a coastline classification scheme with priority protection zones for oil spill response purposes.

Funding continues to be made available for the development and updating of a comprehensive computerised coastal and offshore environmental database, which will be immediately accessible within the Heidrun Operator's offices on a 24 hour basis as from 1990. Its primary uses are in EIA updating, contingency planning, spill response strategy planning and notifications.

The Heidrun baseline environmental survey was completed in 1988, and regular monitoring according to SFT guideline requirements will commence in the field in 1994. Provision has also been made for a partial resurvey in 1992, should this be required.

The Operator will conduct dispersion and dilution studies for aqueous and atmospheric emissions to ensure discharge acceptability, and will further investigate the dispersion characteristics for oil from a subsea blowout.

Areas where there is an acknowledged lack of environmental information will be addressed either within the Haltenbanken operators group, or by the Heidrun Operator, and where appropriate, steps will be taken to gather such data. Extensive R&D programmes into offshore environmental issues are being undertaken in Norway or within the wider european oil industry. More specifically, Conoco projects include:

- A major four year R&D study in Norway (with support from international specialists) into the offshore use and discharge of chemicals. Including improving knowledge on chemical characteristics, mode of action, fate and effects in the marine environment, chemical substitution, alternative plant design and construction materials, alternative operating practices, improved chemicals tracking and other possible means of minimising chemical use, and impacts from constituents in discharges. Ongoing.

- Funding or part-funding the development of improved cuttings cleaning systems for OBM cuttings (to achieve an oil content of less than 2%). Two mechanical systems (SCS and RMD) and one solvent extraction system (Solvtec) are involved. Ongoing.

- Development of hydroclyclone technology for improved oily water treatment. Ongoing.

- An R&D project on the analysis, identification and quantification of dissolved organics and hydrocarbons in produced water, and fate and effects (UK Sector). 1990.

- Continuing studies into the identification of alternatives to halons and chlorofluorocarbons (CFCs) for offshore use. Conoco's parent company Du Pont have since 1975, spent $110 million on the development of alternatives to fully halogenated CFCs. Ongoing.

In addition, there has during 1989, been direct participation in the joint operator funded studies listed below. Work in these areas is ongoing.

- Fish taint studies (Statoil, Shell, Hydro, Phillips, CNI)

- Oil and chemical massbalance studies, designed to identify and minimise losses of these materials to the marine environment (SFT, Statoil, Shell, Hydro, BP, Saga, Amoco, CNI)

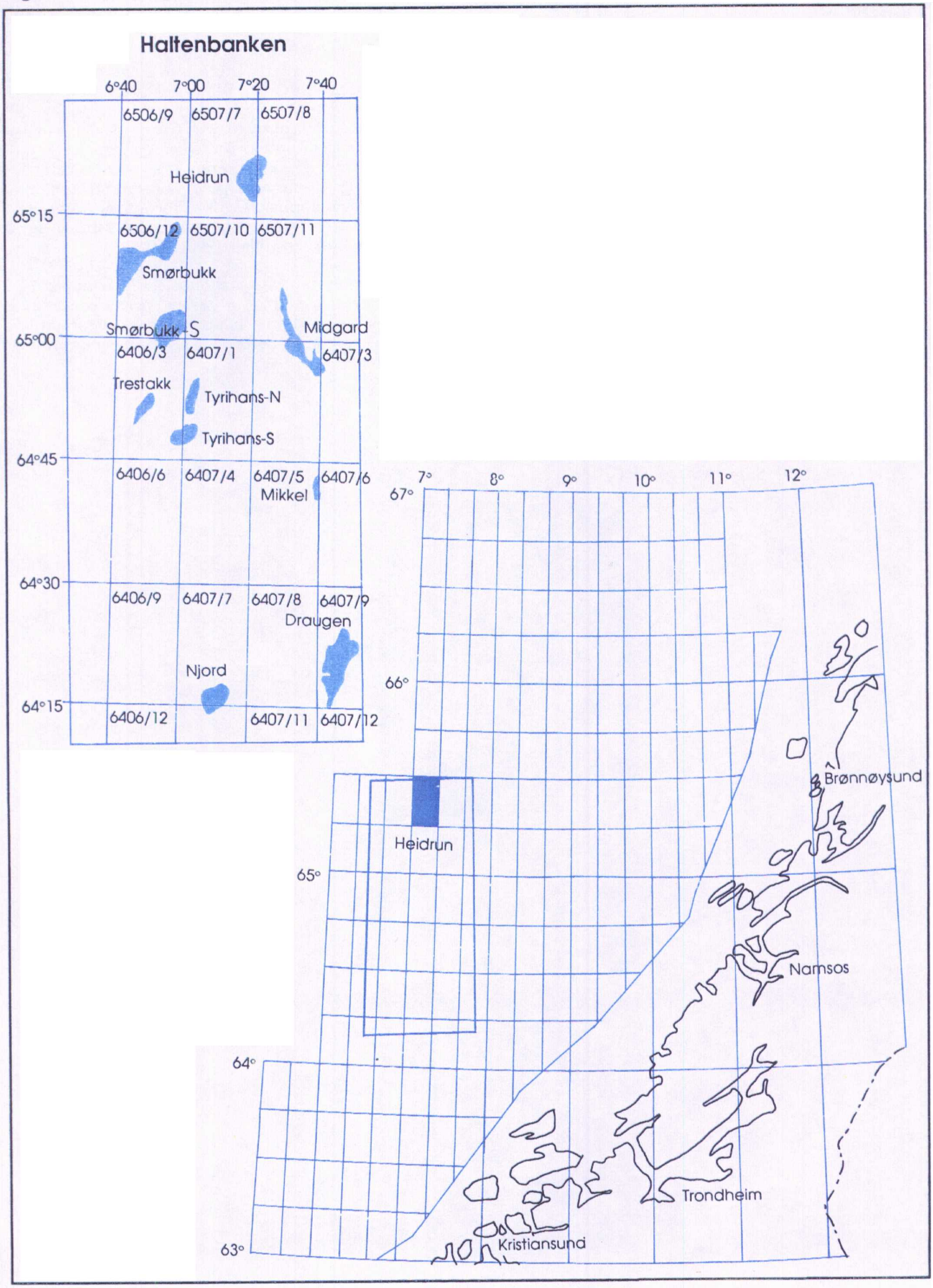
- OLF funded study on the identification of atmospheric emissions and areas for improvement (1990)

- Development of a computerised environmental database for coastal and offshore areas (CMS, SFT, Statoil, Shell, Hydro, BP, Saga, CNI)

The results of the programmes will be available to the Heidrun Operator and will wherever possible be incorporated in the engineering design and operating procedures to improve performance and minimise environmental impacts. All of the above R&D programmes are very much in accordance with the aims of SFT's Longterm Plan 1990-1993.

The Operator will throughout field life conduct environmental auditing to review performance and compliance, and to identify areas where improvements need to be made to equipment or operating practices.

Figure B.1.1 Location of the Heidrun Field



B. GENERAL DESCRIPTION OF THE PROJECT

1. INTRODUCTION

The Heidrun field is situated in Norwegian Offshore Continental Shelf Production Licences 095 and 124. The field lies predominantly within Block 6507/7, with an eastern extension into Block 6507/8 (Figure B.1.1).

Production Licence 095, in Block 6507/7, was allocated in 1984 to a group comprising Conoco (30%) (appointed Operator), Statoil (50%), Arco (10%) and Tenneco (10%). Production Licence 124, in Block 6507/8, was allocated to Statoil (50%) (Operator), Conoco (15%), Arco (10%), Tenneco (10%), Norsk Hydro (10%) and Det Norske Oljeselskap (5%).

In 1988, Conoco purchased 100% of the stock in Tenneco in Norway. The present interests in the unitised Heidrun field are:

Conoco Norway Inc. (CNI)	25.80%
Statoil	50.75%
Arco Norway Inc.	9.85%
Conoco Petroleum Norge AS	9.85%
Norsk Hydro Produksjon a.s	2.50%
Det Norske Oljeselskap A/S	1.25%

CNI will serve as Operator during the development phase, and following commissioning of the Heidrun facilities, Statoil will assume Operatorship.

2. FIELD GEOLOGY

2.1 General Description

The field is located in an area generally designated as the Mid-Norwegian Shelf, which includes Haltenbanken. The predominant structural features are the Trøndelag Platform, the Nordland Ridge, the Halten Terrace and the Vøring Basin.

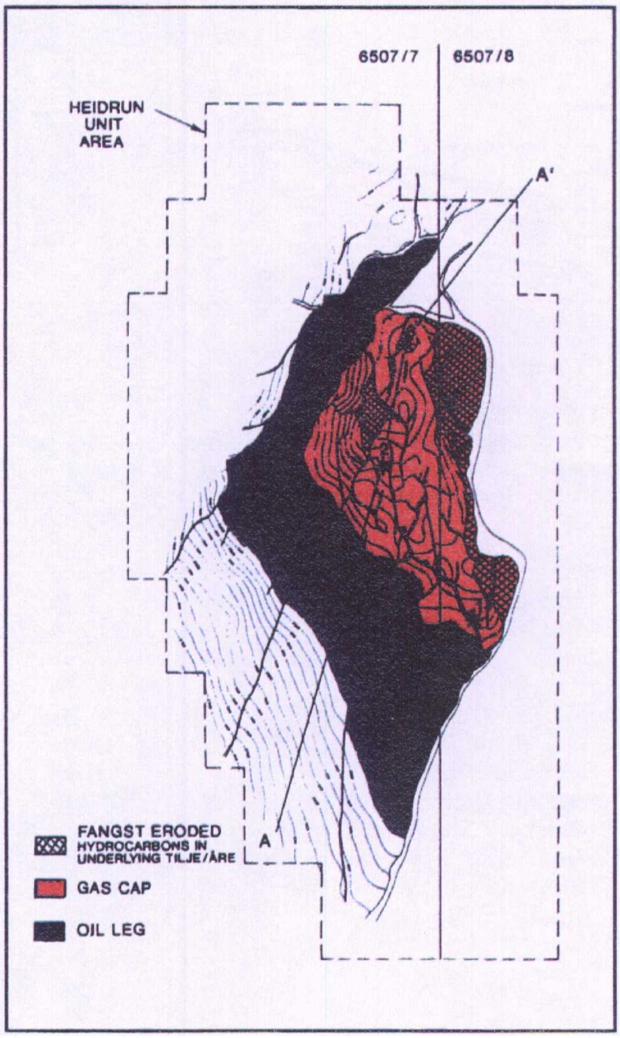
The Heidrun field is located on the southernmost extension of the predominantly southwest-northeast trending Nordland Ridge, which is an intensely faulted high that separates the Helgeland Basin from the more westerly Vøring Basin. South of the Nordland Ridge, the area plunges into the less intensely faulted Halten Terrace, which is close to numerous oil and gas fields. These include Draugen, Smørbukk, Smørbukk South, Tyrihans, North and South Midgard, Trestakk and Njord.

Heidrun lies within a tilted horst block with closure at the top of the Middle Jurassic Fangst Group. The field is 10.5 km long and 5.5 km wide at its widest point (Figure B.2.1). Depth to the crest of the structure at the top Fangst Group is 2478 m. A gas cap is present above the oil. Reservoir temperature of the oil is approximately 85°C.

The major reservoirs in the Heidrun field are the Fangst Group, the Upper and Lower Tilje Formation and the Åre Formation, all of Jurassic age. Additional potential zones also exist.

All reservoirs are sandstones. Depositional environments range from marginal marine to tidal-flat in the Tilje and Åre Formations, and shallow marine to fluvial in the Fangst Group. Hydrocarbons were sourced from the Upper Jurassic Spekk Formation and the accumulation is sealed by Upper Cretaceous shales.

Figure B.2.1 Structure of the Heidrun Reservoir



2.2 Exploration and Appraisal History

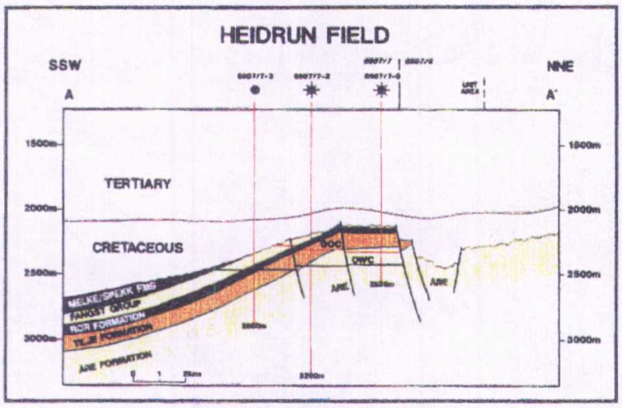
The first well in PL 095, 6507/7-1, was spudded in August 1984 and recorded only traces of gas. Well 6507/7-2 was completed in June 1985 on the Heidrun structure and encountered 137 m of oil column in the Lower Tilje Formation (Figure B.2.2). In addition, the upper part of the Tilje Formation and the Middle Fangst Formation were found to be gas bearing.

Details of the drilling history to date are given in Section E.2.

In addition to the wells drilled by CNI, Statoil completed the 6507/8-1 well in December 1986, which tested and confirmed the prognosed oil column.

Flow rates from drill stem testing (DST) on wells 6507/7-2 to 6707/7-8 ranged up to 6,000 barrels of oil per day (BOPD), with oil gravities between 21° and 30° API.

Figure B.2.2 Heidrun Reservoir Geological Cross-Section



2.3 Crude Oil Properties

Analysis indicates that four distinct oil types are present in the Heidrun field. As the Fangst Group is potentially the largest producer in terms of volume, its characteristics are presented in Table B.2.1.

Gravity °API	29.6
Gravity, Specific, 60/60°F	0.8783
Viscosity, Kinematic, cSt	
at 15°F	66.30
at 50°F	21.20
at 80°F	10.86
Sulphur, Total, Wt.%	0.47
Sulphur, Mercaptans, Wt.%	< 0.001
Hydrogen Sulphide, Wt.%	< 0.001
Pour Point, °F	< -85
Heavy metals by AA, ppm	
Vanadium	8.5
Nickel	1.5
Iron	1.0
Copper	< 0.5
Gas-Oil Ratio	
(multistage flash, Sm^3/Sm^3)	112.0

Table B.2.1 Oil Composition and Physical Properties

3. DEVELOPMENT PLAN

3.1 Field Facilities

A number of platform design options have been considered for the field. Due to the problems of deep water and piling in an area with boulders in the subsurface sediments, the use of a traditional steel piled platform was dismissed. During 1989, the Heidrun Unit Owners jointly considered several alternative concepts suitable for the deep water environment in the Heidrun field, including:

- Gravity based structure (GBS): One, two and three shafts.
- Deep concrete floater: New design based on the semi-submersible, but with a draft of 150 m and integral oil storage.
- Fixed platform/catenary anchored floater (Veslefrikk concept): A facility comprising a fixed wellhead platform with storage, and a concrete semi-submersible production vessel with life support and auxiliary systems, linked by a bridge.
- Tension leg platform (TLP) with a concrete hull: As selected and further described in Sections D and F of this report.

The key features of the proposed development are summarised in Table B.3.1.

An overview of the field layout is given in Section D.1, and details of the design, installation and operation of the various facilities are provided in Sections D to G.

It should be noted that the main body of the EIA deals with a floating storage and offloading vessel (FSO) and tanker export. Other subsea crude oil storage tank options with export via a loading buoy, are, however, also under consideration, and these are dealt with separately in Appendix A.

3.2 Onshore Support Services

The offshore facilities will be served by a warehouse/supply base in Kristiansund and an onshore operations organisation in Stjørdal. Travel times to the field from Kristiansund are approximately 15 hours by supply vessel (distance of approximately 144 nautical miles), and 1 hour 15 minutes by helicopter. Further details of the onshore facilities, their operation and the socio-environmental and economic consequences of the development are provided in the Heidrun Consequence Analysis.

For the purposes of this EIA, it is assumed that the satisfactory development and operation of such onshore facilities as are listed above will be the subject of planning control and hence all environmental issues would be dealt with to satisfy local requirements.

3.3 Development Schedule

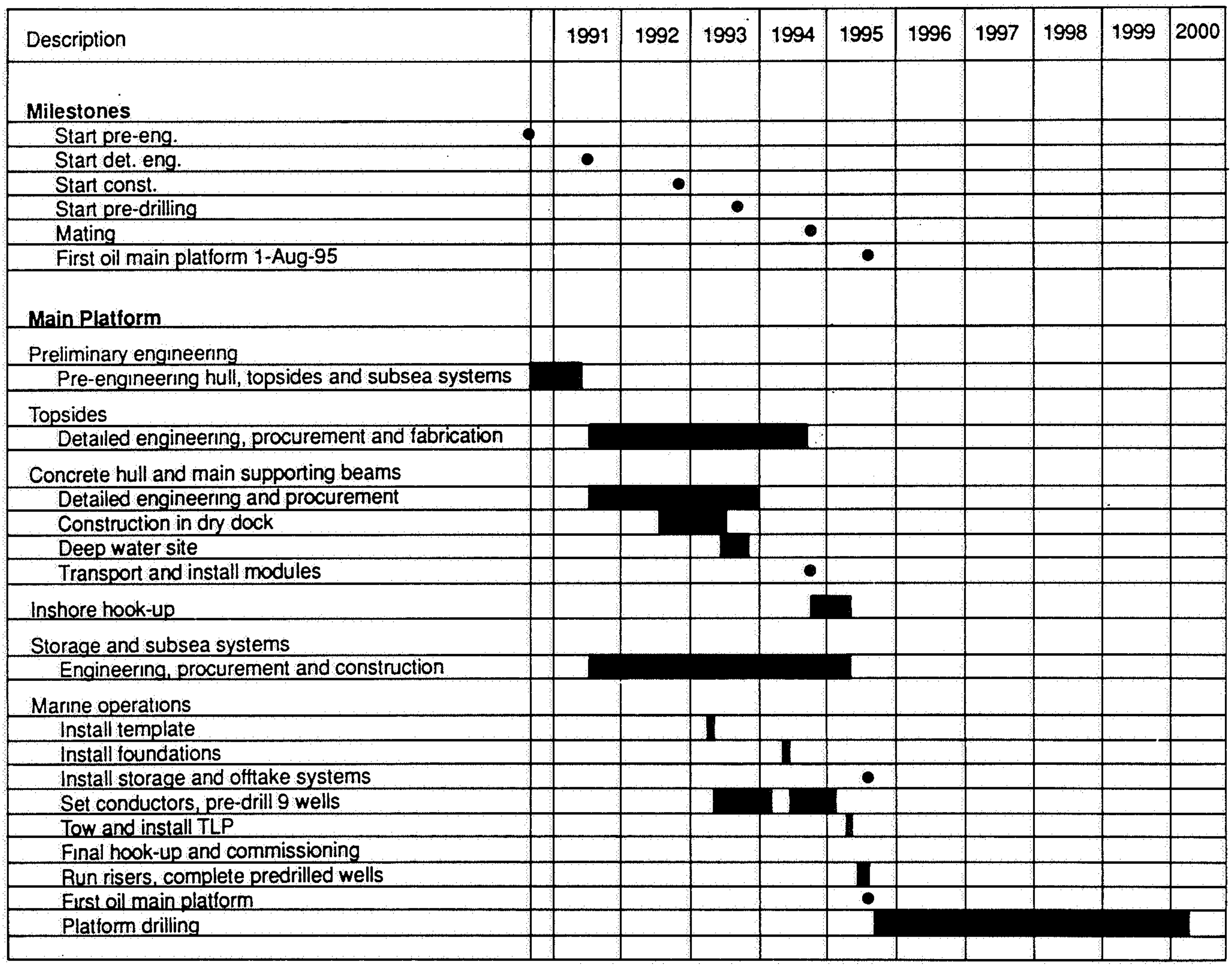
An outline field development schedule is presented in Figure B.3.1.

Field Installations
1) Concrete TLP and 48 Slot Steel Template (Platform Location 65°19'32.82"N, 07°19'04.95"E) 2) Southern Area Subsea Wells 3) Northern Area Subsea Wells 4) Floating Storage and Offloading Vessel (FSO), or Subsea Concrete Storage Tank 5) Pipelines/Flowlines and Riser System Linking the Above Features

Design Features	
Average Plateau Oil Production Rate	31,800 Sm^3/day (200,000 barrels/day)
Number of Wells	49 (36 platform, 4 southern, 9 northern, possible Theta gas injection well)
Recoverable Reserves	119.3 million Sm^3 of oil (750 million barrels)
Expected Field Life	1995-2016
Oil Storage Capacity	240,000 m^3 (1.5 million barrels of oil)
Oil Export Tanker Capacity	140,000 m^3 (880,000 barrels of oil)
Gas Disposal	Gas export/reinjection
Regional Development	Provision made on the TLP

Table B.3.1 Key Features of the Heidrun Development

Figure B.3.1 Heidrun Field Development Schedule (Simplified)



C. THE PHYSICAL ENVIRONMENT

1. SURFACE GEOLOGY, BOTTOM CONDITIONS AND WATER DEPTH

1.1 Surface Geological History and Water Depth

The Heidrun field lies about 100 km northwest of the shallowest part of Haltenbanken, in the northern section of a submarine plain which has fairly gentle topography and water depths for the most part varying between 200 and 300 m. As one approaches the shelf edge to the west and northwest of Haltenbanken, water depths increase (SINTEF, 1985).

Across the Heidrun field, water depths range from 320-348 m, with deeper water being encountered in the northeast quadrant. Water depth at the proposed platform location is approximately 345 m.

The field lies on the southern slope of a wide trough which reaches depths of more than 400 m, some 5.5 km to the north. This has sheltered the area from the most severe reworking of surface sediments by icebergs during the later stages of the last glaciation. Iceberg calving within the area has, however, led to grounding and ploughing of the sea floor.

Along the shelf edge to the west of Heidrun lies the southern end of a major terminal moraine system called Skjoldryggen. The existence of such a system suggests that the entire continental shelf was glaciated at least once, and the submarine topography of ridges and troughs is the result of the capacity of the ice sheets to erode, retransport and deposit large volumes of sediments, regardless of grain size and without a gravity-controlled tendency to in-fill depressions.

Geological investigations of the Norwegian continental margin have been undertaken by IKU as part of a regional mapping programme. The results of this survey for the latitudes 63°N to 65°N have been summarised by Bugge (1980) and a series of geological maps published (IKU, 1984).

Although these reports describe the marine geology somewhat to the south of the Heidrun field, there is no evidence to suggest that the origin, the depositional environment or the post-depositional history of the sediments at Heidrun differs significantly from the sediments described in the Haltenbanken region.

The Haltenbanken region has been inundated by several major glaciations during the last 1.5 to 2 million years, and the majority of the deposits in the Quaternary sedimentary column in Haltenbanken were thus transported and deposited by glacial processes. Late-glacial and post-glacial modification, reworking and retransport in the deep water areas, including Heidrun, has been minimal. The thickness of the upper sediments is variable and ranges from 150-250 m on Haltenbanken.

The shallower parts of Haltenbanken were exposed to severe wave energy during the later part of the last glaciation, during a period of lower sea level. The wave erosion resulted in a cover over the bank of an erosional remnant (lag deposit). The lag deposit is made up of rounded cobbles, stones and boulders.

1.2 Near-Surface Geology

A coring survey conducted during June 1988 (Fugro-McClelland, 1988) indicates that the near-surface geological sequence is as outlined below in Table C.1.1.

Layer	Description	Range of Layer (m)	
		Top	Base
I	VERY SOFT olive grey slightly sandy very silty CLAY with fine to medium gravel	0.0	0.5-2.0
II	SOFT dark grey slightly sandy CLAY with fine to medium gravel	0.5-2.0	2.0-2.5
III	FIRM to STIFF dark grey slightly sandy CLAY with fine to medium gravel	2.0-2.5	6.0-7.0
IV	HARD to VERY HARD dark grey slightly sandy CLAY with fine to medium gravel, occasional coarse gravel and cobbles	6.0-7.0	29.5-30.0
V	VERY HARD very dark grey slightly sandy CLAY with fine to medium gravel, occasional coarse gravel and cobbles	29.5-30.0	61.0-61.4

Table C.1.1 Heidrun Near-Surface Geology

1.3 Seabed Surface Characteristics

Results from field surveys employing remote operated vehicles (ROVs) equipped with side-scan sonar and video, and also coring studies for geotechnical purposes, all confirm the glaciomarine nature of the sediments (Fugro-McClelland, 1988; Stolt-Nielsen, 1988; Geoteam, 1987).

The seabed in the Heidrun field area is generally featureless, with soft smooth clay, cobbles and boulders (occasionally up to 1.0 m in height) present. There are several small depressions or pockmarks (<2 m deep), evidence of partially infilled iceberg plough marks and indications of a moraine ridge.

Anchor impact hollows, scour and chain marks from drilling operations have also been recorded.

Detailed information on shallow surface sediments (<10 cm) is available from benthic sampling undertaken during the Heidrun Baseline Environmental Survey in 1988 (NIVA, 1989) and is described in Section H.2.2.

2. METOCEAN CONDITIONS

2.1 General

Data on the meteorological and oceanographic conditions prevalent at the Heidrun site and their variations on a seasonal basis have been reviewed for this study. The conditions would play a major role in the transport and dispersion of effluent discharges and any accidental oil spill from the facilities.

In this connection, transport of effluents is typically driven by regional wind and current conditions, while dispersion would be most affected by wave action, sea temperature and salinity variations.

CNI has undertaken a major effort over the past five years to define the mean and extreme metocean conditions in the area (Peters, 1988a; 1988b). This has included both in-house and contract engineering work using existing measurements and hindcast data, as well as a one year current data gathering programme (Soras, 1988). It should be noted that these studies include data from the entire central Norwegian offshore and coastal area, not just stations local to the Heidrun field.

2.2 Background Wave and Meteorological Data

Figures for annual average wind, wave and temperature conditions for Heidrun are based on eight years of data recorded near the Heidrun site (Halten-I1), as part of the Oceanographic Data Acquisition Project (ODAP). They include wind speed versus direction, significant wave height versus spectral peak period and direction, and bivariate distribution for air temperature versus sea temperature.

The frequent and intense storms that affect the area can produce high winds and currents from any direction. Little, if any, effect on wave energy is produced by the complex bathymetry at Heidrun, due to the presence of very deep water. Extreme storm-driven waves can occur over the entire western exposure from 180°true (T) to 030°T. Additionally, even when the site is not directly affected by a storm, it is often exposed to moderately high and persistent swell waves generated over the wide expanse of the North Atlantic and propagating through the gap between Iceland and the UK.

Due to the proximity of the coastline, much of the eastern exposure (040°T to 170°T) has greatly reduced wave criteria. The design level (100-year return period) values for significant wave height and 10-minute wind speed for the Heidrun location have been estimated at 15.5 m and 38 metres per second (m/sec), respectively.

The prevailing wind and wave direction is from the southwest.

Direction, deg°	Annual Frequency,%	Mean Value, m/sec
0°	6.6	8.4
30°	6.8	7.8
60°	7.5	7.6
90°	6.5	8.0
120°	6.4	8.2
150°	7.1	8.2
180°	10.7	9.2
210°	12.9	10.1
240°	11.4	9.6
270°	8.9	9.6
300°	7.9	9.0
330°	7.4	8.8
All directions	8.3	8.9

Data Source: Peters, 1986.

Table C.2.1 Wind Characteristics as a Function of Direction

2.3 Background Current Conditions

Again, the ODAP programme is the single largest source of current data for the Heidrun area. Site-specific data have been gathered over a four year period at the Halten-I1 site, and intensive surveys covering the entire central Norwegian shelf area, including Haltenbanken and the Norwegian trench, have been undertaken during four 3-month seasonal periods. In addition, CNI has conducted a one year current survey for each of four depth locations (Station H1).

The Heidrun site lies on a plateau between two relatively energetic current regimes, neither of which affect the location. These are the near-shore Norwegian Coastal Current, and the circulation around Haltenbanken to the southeast. Additionally, the energetic internal wave activity on the shelf slope to the west of Heidrun does not seem to influence the site to any great degree.

There is a relatively weak background circulation at all depths at the Heidrun location, with the peak tidal component being less than 0.15 m/sec.

These oceanographic features will influence the transportation and dispersion of effluents discharged from the facilities, and specific modelling studies will be carried out to elucidate further the dilution and dispersion characteristics for the area.

Extreme near-surface storm-driven currents (100-year return period) have been estimated at 1.0 m/sec.

2.4 Tidal Levels

The extreme water level variations due to storm surge and tides (referenced to mean low water springs, MLWS) are 0.5, 0.7 and 0.8 m for 1, 10 and 100-year return periods, respectively.

2.5 Air and Sea Temperatures

Air and sea temperature distributions are relatively moderate, although there are occurrences of large air-sea temperature differences (approximately 10°C) during cold air outbreaks from the east. Extreme minimum and maximum air temperatures for the location (referenced to 10 m above MLWS) are -12°C and 23°C, respectively (Peters, 1988b). Sea temperature variation with season, and with depth is shown in Figures C.2.1, and C.2.2, respectively.

As might be expected in this sea area, there is evidence of considerable stratification in the summer and early autumn, with the entire water column being very well mixed during the winter and spring (Peters, 1988a).

Location	Depth(m)	Min.	Mean	Max. (°C Ranges)
H1	25	7.2-8.5	7.7-10.3	8.2-11.9
	150	6.8-8.2	7.2- 8.9	7.9- 9.3
	250	6.5-7.2	6.7- 7.9	7.1- 8.5
	330/345	6.0-6.9	6.3- 7.5	6.5- 8.0

Data collected over the period 22/5/87 - 25/5/88. (Peters, 1988a)

Table C.2.2 Sea Temperature Data - Buoyed Meters

Figure C.2.1 Variation in Mean Sea Temperature with Season

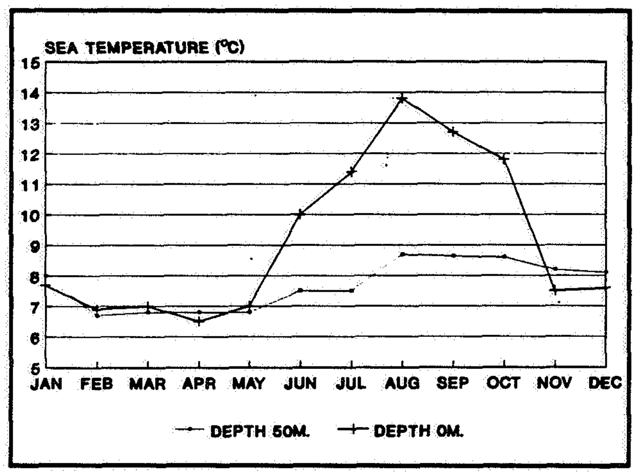
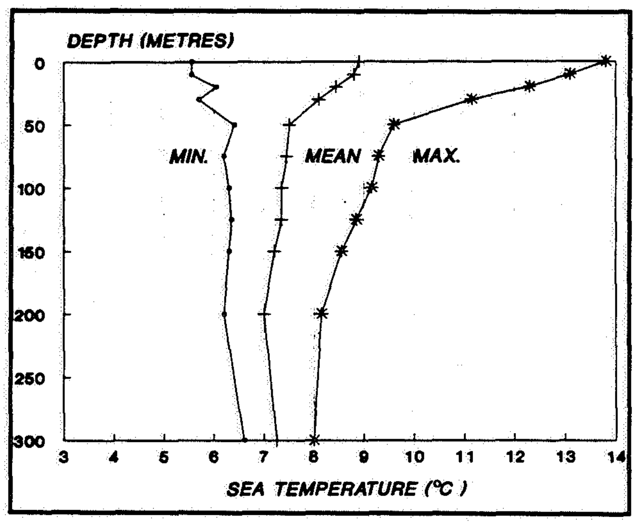


Figure C.2.2 Annual Sea Temperature versus Depth (Different Data Set to Table C.2.2)



2.6 Seawater Characteristics

Outlined below in Tables C.2.3 and C.2.4 are available data on seawater density and salinity.

Water Depth	Density (g/cm³)
Surface	1.0267
35m	1.0268
50m	1.0274
90m	1.0275
Bottom	1.0276

Data Source: Peters, 1988b.

Table C.2.3. Summer Water Density Profile (May-August)

Location	Depth(m)	Temp.(°C)	Salinity(°/oo)
65°17.14'N	1.50	8.44	36.65
07°15.87'E	330.50	7.02	35.16
(24/11/87)			
65°18.73'N	2.00	8.04	35.15
07°14.89'E	331.00	7.67	35.20
(15/01/87)			

Data Source: Peters, 1988a.

Table C.2.4. Temperature and Salinity Data - Cruise Recorded Data

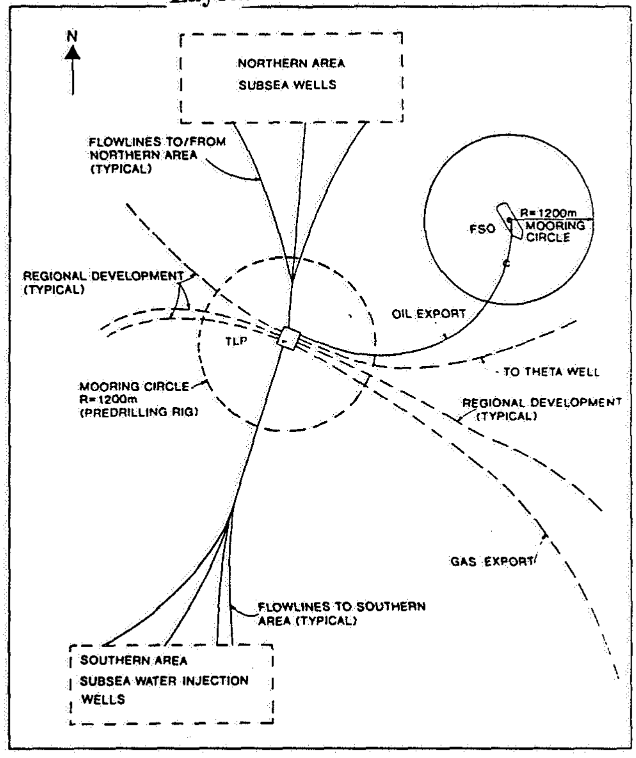
D. CONSTRUCTION/INSTALLATION PHASE

1. GENERAL

An overview of the project schedule, which includes construction and installation, is given in Figure B.3.1. Details of the platform area predrilling plans and programme are given in Section E.3.

A simplified view of the field facilities layout is given in Figure D.1.1.

Figure D.1.1 Overview of the Heidrun Field Facilities Layout



2. WELL TEMPLATE INSTALLATION

The cathodically protected steel platform well template will be installed using a semi-submersible crane vessel in 1993, in order that predrilling may commence in that year. The template, measuring 41 x 60 x 9 m, would be piled to the seabed.

During 1994, the location would be surveyed for dispersion of cuttings from predrilling activities, to ascertain whether levelling would be required prior to installation of the platform foundations.

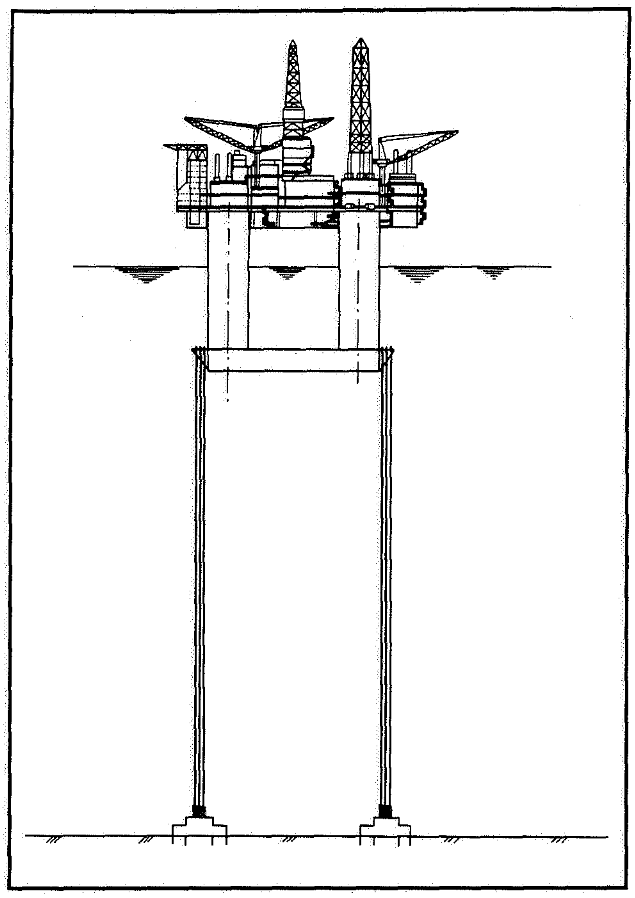
3. PLATFORM INSTALLATION

The TLP is a design which comprises:

- foundations
- a vertical anchoring system
- a concrete hull to support topsides and auxiliary systems
- multiple risers

Figure D.3.1 gives an impression of the platform and its mooring system.

Figure D.3.1 Outline Impression of Heidrun TLP



3.1 Foundations

The well template would be used to position the foundations accurately and can be considered an integral part of the installation.

Four concrete tether anchor pods would be aligned with the template and lowered individually to the seabed. The initial penetration due to the weight of the pods would be increased by adding ballast to dedicated slots in the structures and applying suction.

The octagonal concrete foundations (x4) would have sufficient weight in water to compensate for the tension in the platform tether system. They also have skirts which penetrate the soil to approximately 6 m and resist any horizontal movement of the structure. Each anchor would be approximately 14.5 m in height and 31.6 m in diameter, with a base area of 825 m^2.

3.2 Anchoring System

The hull is anchored to its foundations by three vertical, steel tubular tethers at each of the four corners. The tethers are welded, near-neutrally buoyant and aluminium coated. Flex joints allow rotation of the hull with respect to the tether body.

The platform is maintained in position by a combination of tether tension and hull buoyancy.

3.3 Hull

The concrete hull consists of four square lower pontoons, supporting at the corners, four circular cylindrical columns which emerge from the water and in turn support beams which carry the various platform modules.

The pontoons are subdivided internally into various watertight compartments and service compartments, and the columns are partially subdivided. Access is provided into the hull via watertight hatches and a service column into the pontoon section.

The column annuli will house separate steel tanks for potable water, drilling water and diesel fuel.

The platform would have a draft of 64 m, a deck elevation of 31 m above MLWS and a displacement of 175,400 tons. Ballast would total approximately 11,000 tons.

3.4 Installation

TLP installation is scheduled to take place in 1995.

After fabrication onshore, the tethers would be launched and towed at mid-depth to mating with the platform hull. The towing tugs and a ROV would be used to assist in upending the tethers and manoeuvering them into position using guidelines.

When all the tethers are in place in the respective anchor pods, and in the hull connectors, the platform would be deballasted into position. The tensioning operation could then take place to anchor the free-floating platform hull on location.

The FSO would be installed next. The 8 anchor lines would be precisely located over the preinstalled oil export line, and the 50 ton anchors, each with 500 m of chain, would be set. The flexible loading hose would then be installed and marked by buoy, as would the anchors.

The FSO would on arrival, pick up and tension the anchor lines and connect the flexible loading hose.

3.5 Riser System

The riser system comprises production/injection well risers (36 x 9 5/8" OD) and export/import risers (8 x 14" to 28" OD). A high pressure drilling riser (1 x 21" OD) and surface blowout preventer would be used for drilling and completion. Risers will be either rigid or flexible (subsea well risers and umbilicals). All risers will be supported by tensioners to compensate for TLP movement.

The 48 well-slot template allows certain rows to be used for either well risers or import/export risers.

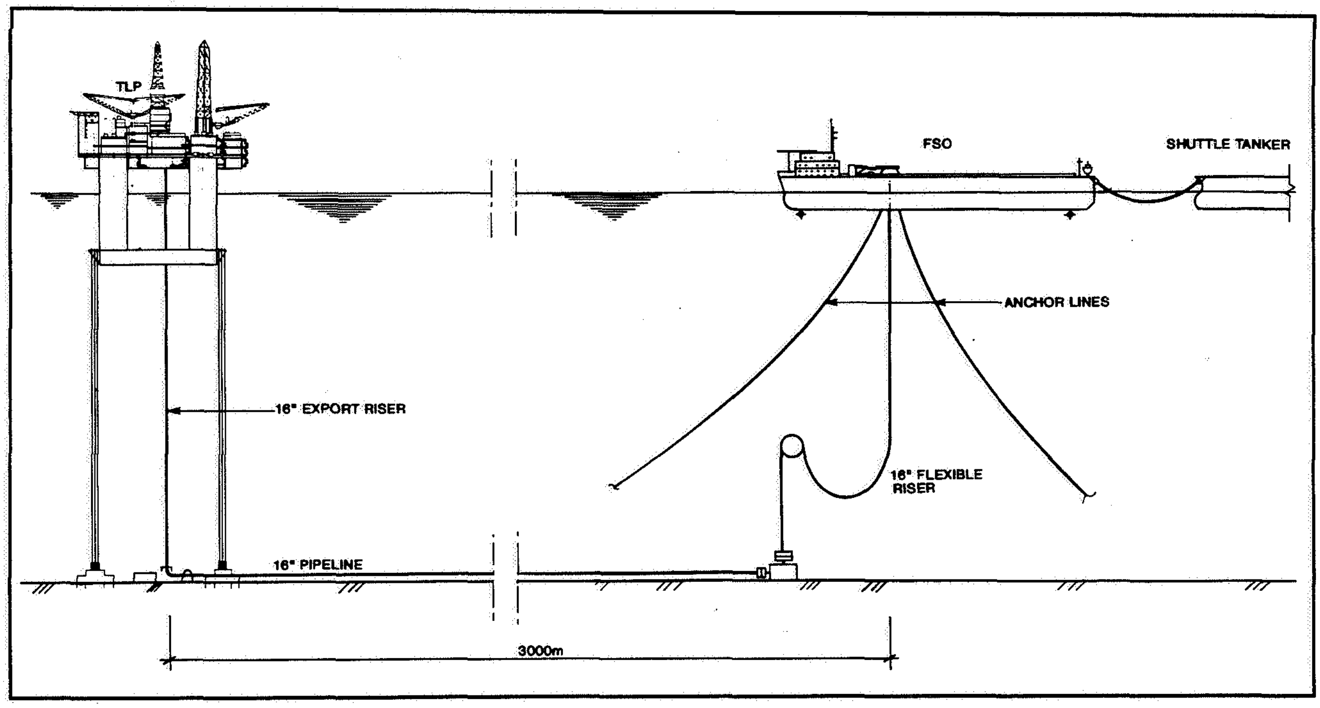
4. OIL STORAGE/EXPORT ARRANGEMENTS

The oil storage facility being considered for use with the TLP, is the FSO. Use of a subsea storage tank and export buoy is, however, also being investigated and this option is discussed in Appendix A.

4.1 Floating Storage and Offloading Vessel (FSO)

In this design, crude oil would be pumped continuously at field production rate, through a steel seabed pipeline, to the FSO located approximately 3.0 km from the platform. A flexible 400 mm (16") riser would connect the seabed pipeline with the vessel (see Figure D.4.1).

Figure D.4.1 Diagram Showing the Arrangement of the FSO and Export Tanker



The vessel would be specially designed to provide storage for approximately 240,000 m^3 (1.5 million barrels) of oil, with a segregated ballast capacity of 80,000 tons. The FSO's dimensions (length 310 m, breadth 52 m and depth 26 m) would make it equivalent to a 230,000 DWT (dead weight tons) tanker. An outline of the FSO layout is shown in Figure D.4.2.

All manned areas including living quarters, helideck, machinery space and pumproom would be located forward i.e. upwind. An internal mooring turret and the connections for the anchoring lines would be located about one-third the FSO length from the bow. Offloading equipment would be situated at the stern, for the transfer of crude oil to a tandem-moored, dynamically positioned tanker.

The vessel would not have a propulsion system. It would be held on location by a mooring system comprising an internal turret supporting 8 catenary mooring lines at 45° to each other. Two thrusters would, however, be installed to maintain heading control, to facilitate station-keeping while off-loading, and for personnel comfort. Thruster power would also be sufficient for emergency purposes.

The oil transfer system, as presently envisaged, is a central pumproom with each of several pumps capable of taking suction from any oil storage tank. Oil and ballast systems are not connected. Ballast would be stored in wing tanks down each side of the vessel, and crude oil in the centre tanks.

The export hose would normally be submerged and hanging vertically from the stern.

5. PIPELINES

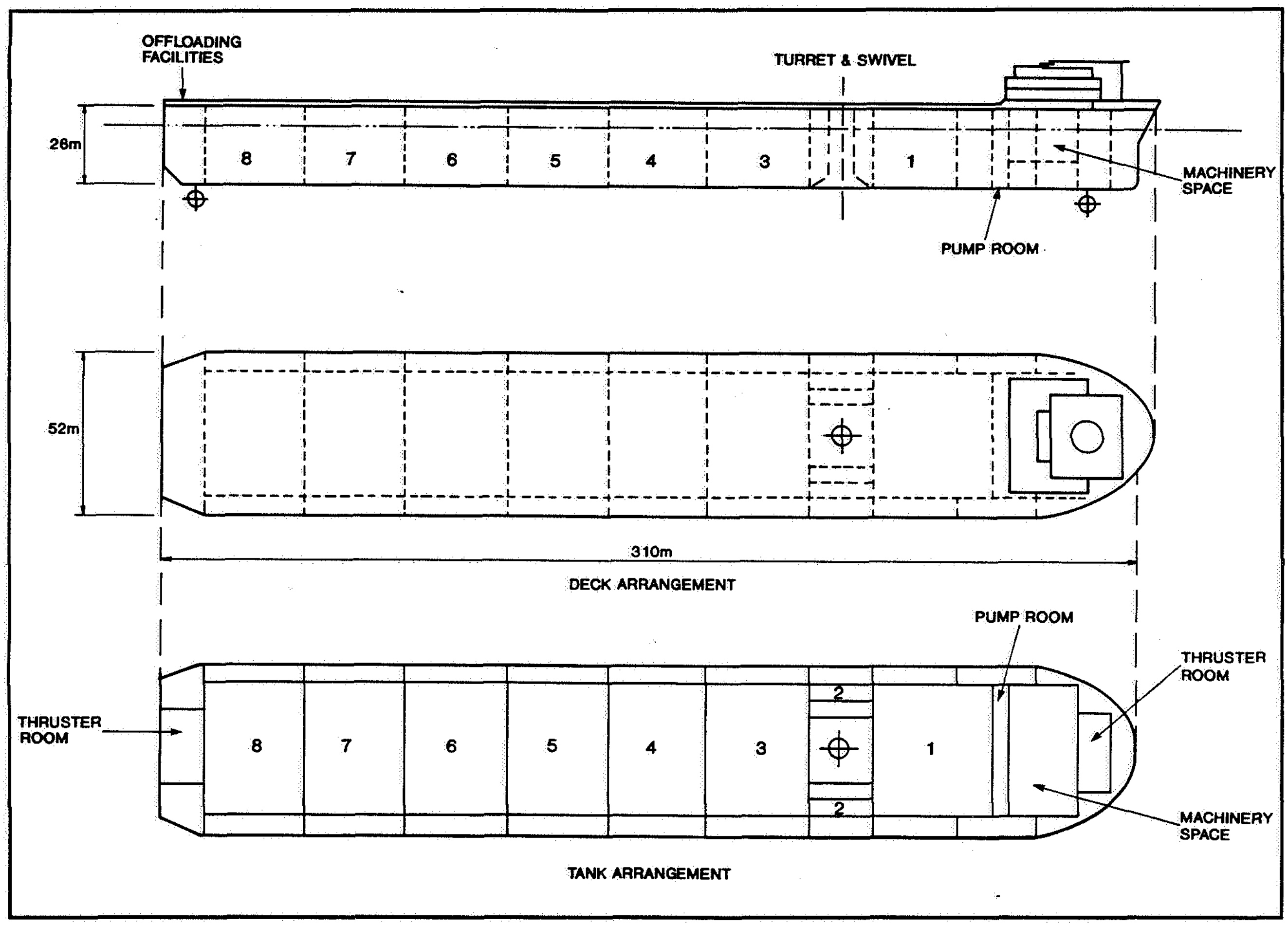
5.1 General

The number and dimensions of pipelines/flowlines and the method of installation have yet to be finalised. The description provided below is illustrative and based on the present understanding of requirements.

Because of the uncertainties/unknowns at this time, no attempt has been made to review the impact of pipelines which might be routed to Heidrun during regional development in the Haltenbanken area. Any such future development work would, however, be covered by a separate or updated EIA, and its preparation would be the responsibility of Statoil (possibly in conjunction with other operators).

A seabed survey or surveys of the proposed pipeline/flowline routes would be carried out. Lines would in most probability be trenched or ploughed in, hydro-

Figure D.4.2 Proposed FSO Configuration



tested to ensure structural integrity and the area re-surveyed to obtain information on the "as installed" status.

5.2 Oil Export Line

The oil export line connecting the platform location with that of the export facilities, would be the first to be installed, during 1994. In the case of the FSO, it would have a diameter of 400 mm (16"), length of approximately 3.0 km and a design pressure of 15 bars. It is currently assumed that the line would be of steel construction, corrosion wrapped, cathodically protected and possibly concrete weight coated.

Installation could be achieved by using the predrilling semi-submersible drilling rig to pull the line into position (east north easterly direction from the platform location) whilst it is being deployed by a pipe lay-barge. The line would be pin piled into position.

5.3 Gas Injection Flowline

Should gas reinjection be required, a flowline to a Theta injection well might be needed. Provisionally, this could be a 200 mm (8") line of approximate length 8 km. Design and installation would be similar to 5.2 above.

5.4 Flowlines to Southern Area Subsea Wells

The final configuration of injection wells at this location has not been decided. It is assumed that flowlines would be flexible, with a diameter of 150 mm (6") and lengths of approximately 4-6 km. Flexible flowlines and accompanying control umbilicals are typically deployed from a purpose built dynamically positioned vessel, which can simultaneously lay and trench lines.

5.5 Flowlines to Northern Area Subsea Wells

Plans for development of the Northern Area are very uncertain at this time. Assuming 9 subsea wells are drilled, there could be 9 individual flexible flowlines, with diameters between 150 mm (6") and 250 mm (10"), with average length 3.5 km. Installation would be similar to 5.4 above. Options may be available to reduce the number of flowlines (e.g. manifolding, bundling, template drilling etc.) and these will be considered.

5.6 Gas Export Line

A gas disposal line, possibly 700 mm (28") in diameter, would be required from Heidrun. The responsibility for installation and operation of the gas export line would rest with the operating body for the gas transportation system on Haltenbanken, and further information is not available at this stage.

5.7 Gas Import Line

If Haltenbanken was chosen to supply a gas market in excess of the capabilities of Heidrun gas production, the scenario might include the import of gas from the Midgard field or other fields in the region. This activity would be the subject of a separate Consequence Analysis and EIA, and is not considered further here.

5.8 Hydrotest Discharges

Until such time as further information is available on the specific pipeline/flowline requirements in the Heidrun field, it would be unrealistic to calculate discharge volumes, discharge depths, rates, timing and hence environmental impact.

However, certain general assumptions can be made. Lines are normally filled with water containing oxygen scavenger and biocide, to protect against corrosion and microbial growth, until such time as pipeline/flowline commissioning takes place.

All pipeline discharges must receive a permit from SFT. The discharge application in effect serves as a mini-EIA in that sufficient detail on the chemicals, the receiving environment and the discharge process must be presented to ensure that the operations are performed in an environmentally acceptable manner.

Pipelines/flowlines in the Heidrun field, for which the operator has responsibility, are very small in terms of overall volume. Commissioning will also be staggered, because of the nature of the development programme. The dilution and dispersion potential is good and there is no reason to believe that unacceptable environmental impacts will arise from such hydrotest discharges.

6. NORTHERN AREA DEVELOPMENT

Due to the structural complexities of the northern part of the Heidrun reservoir, further appraisal would be required. Engineering work on the subsea installation design has not progressed far enough to enable details to be presented here.

7. ABANDONMENT

Abandonment of the Heidrun facilities and removal of equipment from the field would be undertaken as required by the relevant legislation in force. Outlined here are details of how facilities removal might physically be achieved in a safe and environmentally acceptable manner.

Removal of the TLP would essentially be a reversal of the installation process. Equipment would be decommissioned, all wells would be safely plugged and abandoned, pipelines purged, and the platform hull and tether system removed from the anchoring points. Investigations will be carried out into how pipeline/flowline purging and cleaning can be undertaken with minimal environmental impact.

It would be feasible to safely bury the template and anchor elements in-situ, in such a way as to restore the seabed profile to one which should not cause an obstruction to the fishing industry.

The FSO would be disconnected and the loading system and anchors retrieved. Further studies of the subsea concrete storage tank options would include removal considerations.

E. DRILLING OPERATIONS

1. GENERAL

All drilling operations will be conducted in accordance with the legal requirements laid down in the "Regelverksamling for petroleumsvirksomheten". In this connection, a set of comprehensive drilling procedures is being developed by the Heidrun Operator, to ensure that all drilling activities are carried out in a safe and environmentally conscious manner.

Waste disposal from drilling operations is discussed in Section F.1.7 of this report, and issues associated with the risk of oil spills in Sections G.1.1 and G.1.6.

2. DRILLING HISTORY

During the period 1984-1987, a total of nine wells were drilled in the Heidrun field. Details of the drilling history are given below in Table E.2.1. In all cases WBM was used.

All wells have been abandoned and surface wellhead equipment removed.

3. FUTURE DRILLING REQUIREMENTS

Drilling in the field will comprise platform wells and Northern and Southern Area subsea wells. Details of well plans, casing designs, mud programmes, completion, workover and test requirements for the field, as outlined here, are preliminary and may be subject to change. In particular, the final number of subsea wells, their locations and the timing of drilling activities may require re-evaluation.

The platform template design provides for 48 well-slots, and it is anticipated that 36 of these would be used for drilling purposes. This allocation may be changed later in the development, according to infill drilling requirements.

3.1. Drilling Facilities

Semi-submersible rigs employed to predrill platform wells, and Northern and Southern Area subsea wells, would be designed and equipped to the standard required by the Operator, and by Norwegian law.

Design of platform drilling facilities has not yet been finalised. Drilling modules would, however, lie in a central platform position between the utility module and the Heidrun process module (Figure E.3.1).

The drillers module, which is approximately 48 m x 15 m x 26 m, would include mud pumps and tanks, solids control and cuttings cleaning equipment, and chemical/bulk storage. The module would also contain drillers offices, stores and electrical areas and would have a controlled environment with heating, ventilation and air conditioning (HVAC) installed. This would prevent unacceptable build-up of gas and hydrocarbon vapours from mud and cuttings handling areas.

The wellbay module would support the drilling substructure (housing the blowout preventer (BOP) deck, the drill floor, and the drilling rig), and would include Xmas trees, flowlines, manifolds and riser tensioners.

The drilling rig has been designed to be skidded over any of the 48 well/riser slots.

3.2 Drilling Programme

Nine of the platform wells would be drilled from a semi-submersible drilling rig prior to platform installation. Predrilling of wells allows early oil production following platform commissioning. Drilling of these wells is scheduled to commence in 1993, with completion in mid 1995.

The rig could then be moved to drill two Southern Area water injection wells in 1995, and a further two wells in 1995/6. All of these could be completed as individual subsea wells and tied back to the main platform by pipeline.

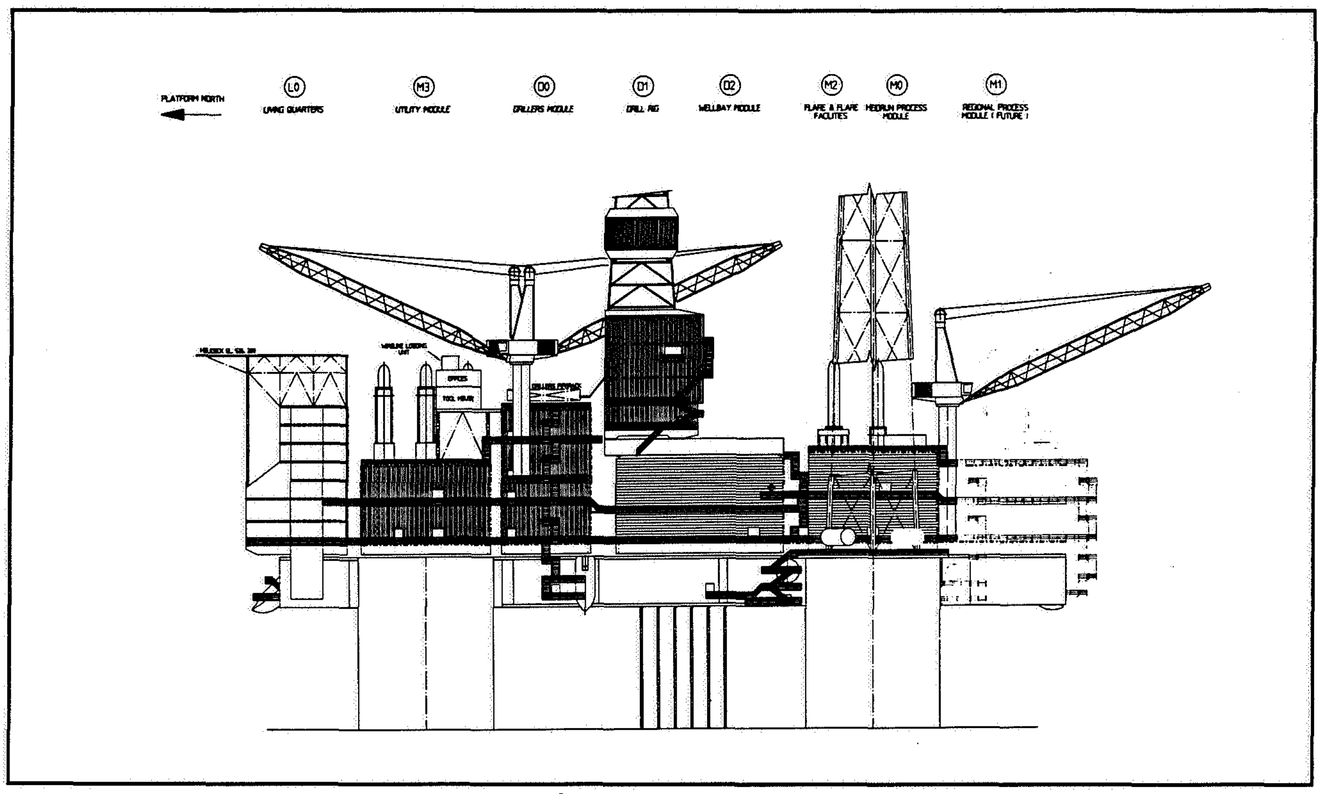
The remaining platform wells, would be drilled during the period 1995-2000, giving a total of 36 platform wells.

Well	Location	Mud System	Date
6507/7-1	65°27'16"N, 07°12'52"E	Gyp lignite	1984
6507/7-2	65°20'12"N, 07°18'34"E	Gyp polymer	1985
6507/7-3	65°19'01"N, 07°17'44"E	Gyp polymer	1986
6507/7-4	65°19'11"N, 07°15'44"E	Gyp polymer	1986
6507/7-5	65°21'30"N, 07°17'35"E	KCl polymer	1986
6507/7-6	65°21'30"N, 07°19'10"E	KCl polymer	1986
6507/7-7	65°17'52"N, 07°18'50"E	Seawater	1987
6507/7-8	65°17'56"N, 07°18'49"E	KCl polymer	1987
6507/7-9	65°19'31"N, 07°19'03"E	Seawater*	1987

* shallow gas detection well, to augment existing high resolution shallow seismic data.

Table E.2.1 Heidrun Drilling History

Figure E.3.1 Platform Topsides Diagram (West Elevation)



Plans for the Northern Area subsea development are still preliminary, but it is anticipated that seven production and two injection wells would be drilled at this location (approximately 3.5 km north of the platform). Northern Area drilling is unlikely to be initiated before late 1996.

3.3. Casing Designs

Heidrun well designs are divided into two broad categories:

A. Low angle wells, subsea wells and high rate production wells.

B. Injection wells and high angle low rate production wells.

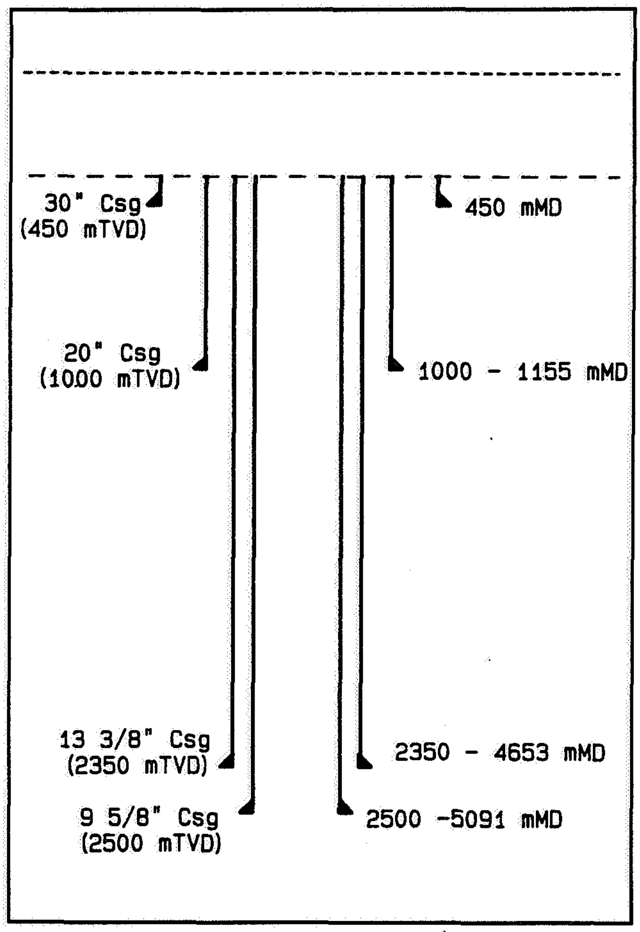
A typical casing design for category "A" wells is shown in Figure E.3.2. These wells could account for 37 out of the total of 49 wells planned for the Heidrun field.

3.4 Drilling Muds

A combination of reactive shales (Lower Tertiary and Cretaceous), long open-hole sections through these shales, and high angle deviation wells, dictates that OBM would be required to ensure safe and economic drilling operations. Mineral oil with a low aromatic hydrocarbon content would be selected as the base oil, unless an effective alternative is identified prior to 1993.

Based on existing knowledge of the formations, the requirement to set 9 5/8" casing through difficult

Figure E.3.2 Heidrun Casing Design for Category "A" Wells



shale sections, and the limitations of present WBM systems, the Operator has for the purposes of this study assumed that wells with a deviation of greater than 45° from the vertical would be drilled with OBM. This would require OBM to be used in 23 platform wells, from the 17 1/2" section down to total depth. Of these, six wells have a deviation in excess of 60°. Mud system change-out during drilling, i.e. WBM-OBM-WBM, is avoided where possible.

Use of OBM in subsea wells is not envisaged at this time.

WBM systems which might be considered, would include potassium chloride (KCl) polymer, partially hydrolysed polyacrylamide (PHPA), and muds employing specialist new additives to improve shale inhibition, such as the Du Pont Duponol WBS-100 system.

Only mud systems which have passed the SFT toxicity test regime and received approval for use on the Norwegian continental shelf would be employed.

Chemical constituents of the proposed drilling mud systems (see Section I.2.2) will be reviewed and where feasible, chemical substitution will be undertaken to replace chemicals for which there are less toxic/persistent but equally effective alternatives available. In this context, comments in Section F.1.5.8 also apply.

Chemical use and discharge from drilling operations would, as required by legislation, be reported on an annual basis to SFT.

3.5. Drilling Mud and Cuttings Disposal

Under Norwegian legislation, permits must be obtained for all discharges associated with production drilling operations. Further discharge conditions may be imposed by SFT where they consider that the receiving environment warrants additional protection. SFT have also notified operators of their intention to update and make more stringent the existing guidelines issued in 1986, particularly as these relate to cuttings disposal from OBM drilling.

Disposal of drilling waste from the Heidrun operation shall be undertaken strictly in accordance with the requirements of the relevant legislation in force at the time.

Drilling mud and cuttings discharge from the platform could be undertaken by means of a chute located in one of the TLP columns. This would give a discharge depth of approximately -64 m (MLWS). The need for good dispersion and dilution and minimal risk of carry-over of material to any service water abstraction point is recognised.

3.5.1 Water Based Mud and Cuttings

Under existing guidelines, discharges of WBM and cuttings to the marine environment are allowed, and for the purposes of this EIA, it is assumed that this practice will continue to be acceptable. Acceptability of used mud in terms of its toxicological properties is ensured by carrying out testing on mud samples during drilling of the deepest well section.

Theoretical volumes of cuttings which could be generated during Heidrun drilling operations have been calculated. The figures assume that all 36" and 26" holes would be drilled with WBM, and that in wells with a deviation of less than 45° from vertical, all remaining hole sections (17.5", 12.25" and 8.5") would in the vast majority of cases, also be drilled with WBM.

The relatively large volume of WBM cuttings which would be generated in 1993 (see Figure E.3.3) at the platform location, is a result of batch drilling all 36" hole sections from the semi-submersible drilling rig. Wells drilled entirely with WBM would typically produce 1,396-2,031 tons of cuttings per well. The actual volume of cuttings is calculated from the theoretical volume using a conversion factor of 1.3. A density conversion factor of 2.6 is applied to convert cubic metres to tons.

Approximate WBM cuttings discharges would be 47,500 tons (platform), 14,000 tons (Northern Area subsea wells) and 6,500 tons (Southern Area subsea wells).

3.5.2 Oil Based Mud and Cuttings

Th Operator recognises increasing concerns about loss of oil to the marine environment from OBM drilling operations. Discharge of OBM is prohibited, and further theoretical work and field studies are being undertaken by SFT and a number of operators (including CNI), to improve our ability to carry out accurate massbalance of base oil use/losses. SFT's aim is for users to be able to account for 95% of this material.

SFT have also notified operators of their intention to introduce a ban on the discharge of oily cuttings from drilling operations from 1991. Until the Industry receives further guidance and information on the implementation and detail of the new legislation, and on alternative disposal methods which SFT consider acceptable, specific details of the disposal of such material from the Heidrun field cannot be elucidated here. This would be the subject of a separate specific study, prior to submission of the Discharge Permit application for the Heidrun field.

As legislative requirements have not been finalised, provision for cuttings cleaning equipment and cuttings holding tanks has been made in the current platform engineering design. By 1995, when installation and full production drilling commences, advanced cuttings cleaning equipment may be capable of reaching oil on cuttings limits of less than 2%. Alternative offshore disposal options may also have been identified.

If operators are, however, instructed to transship all oily cuttings to shore for treatment and disposal, it is possible that offshore pretreatment may be limited. Further work will be required in the area of cuttings handling, movement and storage on, and offloading from, the rig/platform. The implications of onshore disposal of such wastes are reviewed in Section F.1.7.

Theoretical figures have been calculated for oily cuttings generation based on the limitation of present day WBM systems. Reductions in cuttings volumes may be achieved as technology advances and increased geological knowledge and drilling experience in the Heidrun formations is gained. Re-evaluation of casing and completion designs, and bit size (for example, the feasibility of drilling 16" hole rather than 17.5" for 13.375" casing) may also reduce the figures below those given here.

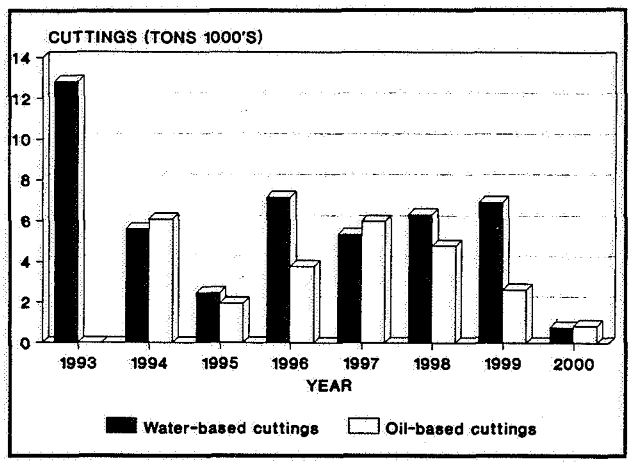
Assuming for the present, a high angle cut-off of 45° deviation, OBM may be used in the 17.5", 12.25" and 8.5" hole sections of 23 of the 36 platform wells. Typically, 731-1,947 tons of oily cuttings could be expected per well, giving a total oily cuttings production for the field (platform wells, 1993-2000) of approximately 26,000 tons.

To minimise losses of oil from drilling operations:

- WBM would be used as far as possible
- drainage, handling and storage arrangements, and procedures for the platform would be designed to ensure a lower risk of operational losses/spillages of mud and base oil
- improved solids control equipment would be used in platform drilling operations
- detailed drilling massbalance calculations would be performed and comprehensive records maintained
- routine re-evaluation of the systems/procedures in place and advances in WBM formulation and performance, would be carried out to ensure as far as possible, use of best available technology

A summary of the approximate cuttings volumes (WBM and OBM) generated throughout field life is given in Figure E.3.3.

Figure E.3.3 Heidrun Field Drill Cuttings Generation (1993-2000)



3.6 Well Testing

The requirement to carry out limited short-term DST on predrilled platform wells or Northern Area subsea wells has not yet been established. Platform well testing would be undertaken using the test separation facilities (Figure F.1.2).

3.7 Completion and Workover

After the well has been drilled to total depth, the production tubing cemented in place and the casing cleaned up, completion fluid will be introduced and circulated/filtered until the desired standard has been reached. Workover and completion fluids used in Heidrun drilling operations will be relatively simple, comprising seawater and calcium chloride. In addition, a range of chemical additives similar in composition to those used in drilling mud formulations would be required. A "typical" workover and completion fluid composition which could be considered for Heidrun is given in Table E.3.1.

Main Constituents	Associated Chemicals
Seawater	Hydroxyethel cellulose
Calcium chloride brine	Ammonia chloride
(Specific gravity	Corrosion inhibitor
1.0-1.36)	Non-ionic surfactant
	Caustic soda
	Calcium carbonate
	Sodium calcium borate salt
	Naptha
	Diatomaceous earth
	Biocide
	Oxygen scavanger

Table E.3.1 "Typical" Workover/Completion Fluid Composition

Volumes, frequency of discharge and nature of these materials would be included in the Heidrun Discharge Permit application.

Also, there will be a more limited requirement for acid treatment of wells. This may be performed in the drilling phase following completion of a gravel pack (to control sand production), and to clean up the near wellbore formation, or during the production phase, to stimulate flow by removing solids, scale or corrosion deposits. As these deposits are soluble in acid, the most typical treatment is hydrochloric (HCl) and in some cases HCl/hydrofluoric acid, with a number of specialist chemicals.

3.8 Incineration

Incineration of OBM or oily wastes on the platform will not be performed.

3.9 Other Materials

In addition to mud and cuttings, cements containing additives may also be discharged during drilling operations. These materials are used to set casing strings in place or in the case of "squeeze cementing", to target a cement plug to an area requiring corrective sealing or isolation.

F. PRODUCTION PHASE

1. PLATFORM

1.1 Process Systems

The Heidrun process facilities will be designed to include all systems and equipment necessary to permit the following operations:

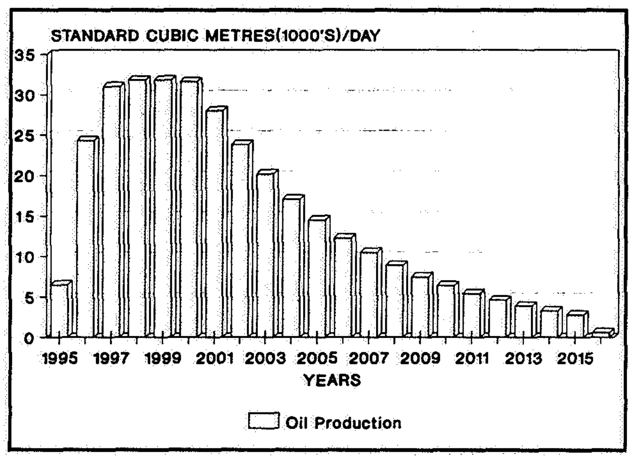
- Separation of produced oil, gas and water.
- Transportation of stabilised crude oil to storage.
- Clean-up of all effluent/drainage water for disposal to sea.
- Dehydration and compression of associated gas.
- Seawater lifting, treatment and distribution.
- Platform life support (350 persons).

The platform systems will have the following maximum design rates:-

Oil production:	1,457 Sm^3/hour (220,000 BOPD)
Gas production:	4.7 million Sm^3/day (165 MMSCFD)
Produced water:	1,027 m^3/hour (155,000 BPD)
Seawater inj.:	2,186 m^3/hour (330,000 BPD)

Estimated annual oil production through field life (1995-2016) is presented in Figure F.1.1.

Figure F.1.1 Heidrun Estimated Annual Oil Production



The oil production system will consist of a single train of three-stage separation, which would be designed to produce low vapour pressure crude oil with a base, sediment and water content of less than 0.5%. Following this treatment, crude oil would be cooled, metered and then sent to storage. Oil would at this stage be expected to have a mean stock tank gravity of 29° API.

Associated gas recovered from the separators would be dehydrated and then compressed. Gas would be dried using glycol. A recovery/regeneration unit will be provided which will allow continued reuse of glycol with minimal losses. Any condensate produced during the process would be returned to the separators. All gas not required for fuel would be either injected into the reservoir(s) via gas injection wells, or exported.

A simplified process diagram showing the key elements of oil, water and gas handling and treatment is shown in Figure F.1.2.

Produced water is a term applied to a combination of formation water which originates with oil in the reservoir, and injection water which is pumped into the reservoir to maintain pressure. Over time, the percentage of water produced (the water cut) will increase. In the Norwegian sector in 1988, daily produced water discharges from platforms totalled approximately 28,500 m^3 (SFT, 1989).

Operators are presently required to install separation facilities to reduce the oil-in-water content to a level of 40 mg/l measured as a monthly average (dispersed oil), although there are indications that stricter limits may be enforced in due course (see Appendix C).

It is presently envisaged that produced water from Heidrun would be cleaned to the required legal limit using hydrocyclone units. These have been found to be more effective than gas flotation cells, particularly on a moving TLP. Oil recovered from hydrocyclones would be returned to the process stream. Any gas evolved during water treatment would be directed to the low pressure flare. Water would then be metered and discharged overboard.

In addition, the Operator will be considering means to further reduce the oil content of produced water, including the technical and economic feasibility of measures such as produced water reinjection.

The seawater lift system provides water for a range of process and utilities purposes, as discussed in Section F.1.4.2.

A listing of typical major utility and process support systems is provided in Table F.1.1.

1.2 Shutdown Systems

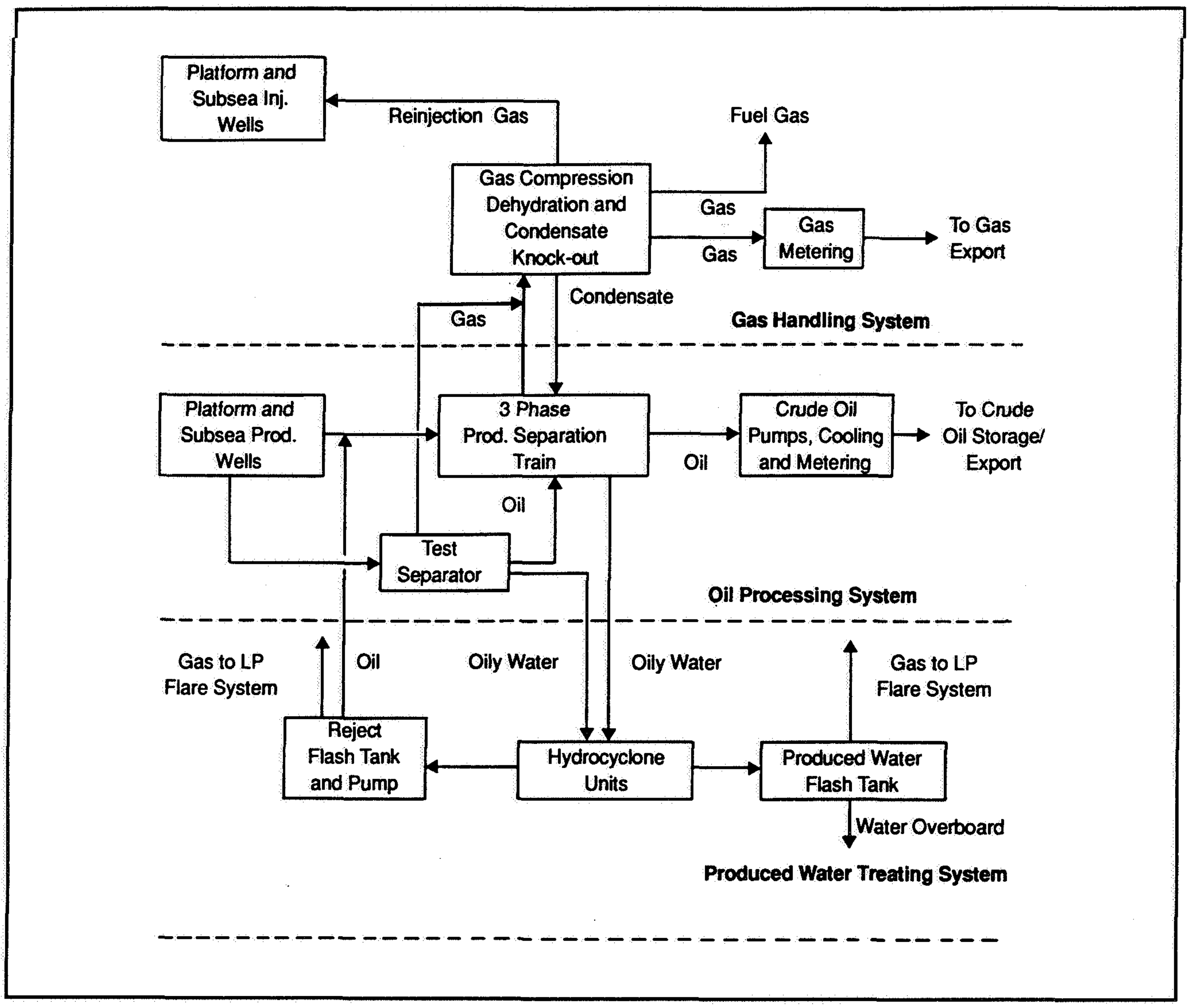
The platform shutdown system will be designed to provide safe and orderly shutdown and, where appropriate, depressurisation of the process plant. The system would be fail-safe in operation, and would receive input from the fire and gas detection and process systems, in addition to manual input from the operator.

As final protection against over-pressure, a relief system would operate to relieve any build-up of pressure due to failure or malfunction of the process, utilities or shutdown systems. This would provide safe over-pressure protection to all pressurised equipment by means of the flare, vent and drain systems.

1.3 Flaring Systems

The gas processing facilities will be designed to minimise the requirement to flare gas. This would be achieved by maximising the amount of gas recovered

Figure F.1.2. Simplified Heidrun Process Flow Diagram



for reinjection or export. Flaring of excess gas, under normal operating conditions, would therefore be expected to be minimal. In order to handle potential flaring situations, a dual-pressure flare system would be provided. Hydrocarbon gas and liquids which must be flared under emergency pressure relief, equipment blowdown, or normal platform operating conditions, would be directed to a flare tower on the platform (see also Section F.1.6.1).

The basic design assumptions and criteria for the flare system are as follows:

- The high pressure (HP) flare system will be designed to handle the maximum instantaneous produced flow rate.

- The low pressure (LP) flare system will be designed to handle relief from equipment which cannot with-

Heating ventilation and air conditioning (HVAC)	Potable water systems
Flare and vent systems	Power generation and distribution
Diesel fuel storage	Instrument and plant air systems
Fire and gas detection and suppression	Service water
Chemical injection systems	Drain systems
Heating and cooling medium systems	Glycol regeneration
Nitrogen gas generation	Refrigeration systems
Drilling rig	Sewage systems
	Helicopter refuelling
	Safety and loss control

Table F.1.1 Major Utility and Process Systems

stand the back-pressure of the HP flare header, such as in the event of a compression blowdown. The system is sized to handle the blowdown from the entire Heidrun processing facility during an emergency shut down (ESD) situation.

- The HP and LP flare scrubbers will be sized so as to limit liquid carryover with the gas (droplets smaller than 600 microns).
- The height of the flare tower will be based on limiting the thermal radiation to 2000 Btu/hr-ft^2 under conditions of maximum flaring.
- The flare system will be designed such that smokeless flaring can normally be achieved. However, some generation of smoke may occur, particularly under abnormal operating conditions. The effects of radiation, noise and gas dispersion from the flare will be studied in detail during the engineering phase of the development.
- Vapour from vessels or headers which are normally purged with nitrogen will be routed to a vent located on or near the flare tower.

1.4 Utilities

1.4.1 Power Generation

The main power generation system would consist of three 50% turbine generators located on the platform and designed to operate in parallel. These would be capable of burning either gas or liquid as fuel. The possible use of a steam power system for supplying electrical and mechanical demand is also under consideration. The gas consumption of such a system would be greater than that indicated in the overall gas usage figures presented in Figure F.1.5.

There would also be a requirement for diesel-driven emergency power generation.

1.4.2 Seawater Services and Injection System

The seawater lift system will be designed to meet the demand for water for a range of uses. The system would have a design rate of 2,186 m^3/hour for seawater injection purposes, and a total design capacity of 3,745 m^3/hour.

The seawater injection system would provide filtered, deoxygenated seawater to the water injection wells for reservoir pressure maintenance. Avoidance of reservoir plugging by entrained solids, and corrosion control are key objectives.

Water used for cooling and secondary services would eventually be discharged to the sea. This water (up to 1,559 m^3/hour) could contain chlorine at 0.5 ppm and would be at a temperature of approximately 32°C. Process arrangements will be designed to eliminate the possibility of contamination of this water with oil.

Chemical injection facilities will be provided to treat the seawater. This would include the use of antifoaming agents, oxygen scavengers, biocides and sodium hypochlorite for biological control, as well as scale inhibitors.

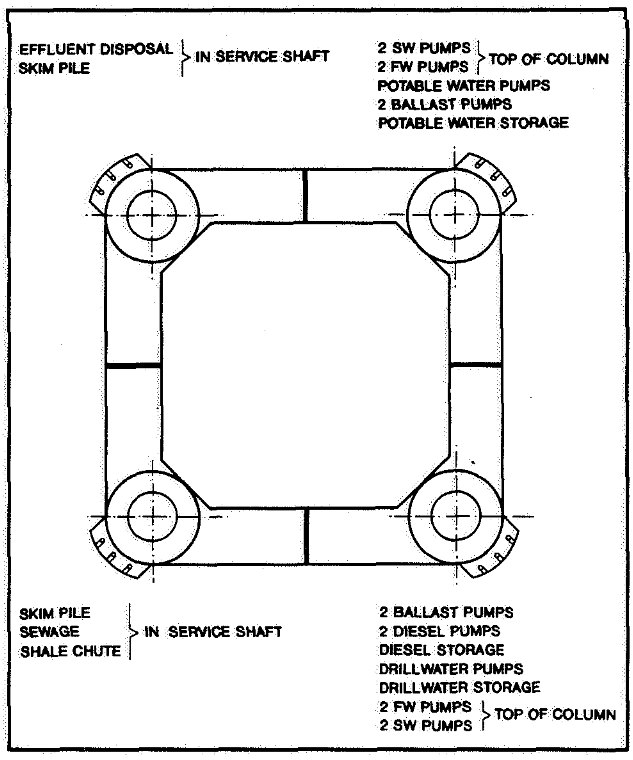
Deoxygenated water from the deaeration tower would also feed the service water system, and the service water header in turn supplies utility service stations. The water would be used for several purposes, including deck washdown.

Seawater will be abstracted at a depth of approximately -64m through stainless steel intakes located at pontoon corners. A choice of intake points would be available, which should avoid any possible cross-contamination from platform effluents, including drill cuttings. Water would be pumped to the ballast manifolds (x2) and then distributed to seawater lift and firewater systems (x2).

The configuration of Heidrun discharge and intake points has not yet been finalised but Figure F.1.3 is illustrative of one possible option.

Potable water requirements would be met by the use of either reverse osmosis or distillation units. The seawater supplied to these units would be taken from the seawater lift system, after addition of chlorine, and prior to the addition of any other chemicals. The platform would also be capable of receiving potable water from supply vessels. Potable water would be stored in platform column tanks (Figure F.1.3) and pumped to users via header tanks.

Figure F.1.3 Possible Configuration of Intake/Discharge Points on a TLP Platform



1.4.3 Fuel Systems

Aviation fuel would be delivered to the platform in tote tanks, and would be offloaded using the platform cranes.

Diesel fuel would be used for emergency power generation, diesel engine drivers for fire pumps and cranes, the cementation unit, well logging unit, and as a substitute fuel for the turbine drivers of the main generators when fuel gas is not available.

Diesel fuel would be delivered by supply vessel and transferred to the platform via flexible reinforced hoses. Regular inspection and replacement of these hoses would be carried out, and strict operational procedures would be enforced in order to minimise spillage. Diesel fuel would be stored in platform column tanks prior to transfer to individual day tanks.

1.5 Operational Discharges (Aqueous)

1.5.1 General

Effluent collection and treatment systems would be installed to facilitate separate treatment of produced water and platform drainage water. Such an arrangement is necessary in order to avoid any possible chemical interaction or scaling.

1.5.2 Composition

Produced water from North Sea operations contains a wide range of material, including some 1 g/l of non-hydrocarbon organic matter, largely comprising salts of acetic, propionic and butyric acids, and 20-40 mg/l of dissolved hydrocarbons. The non-hydrocarbon components originate in formation water. Water has also been found to contain some 20-30 mg/l of ammoniacal nitrogen and a number of inorganic components (Somerville, 1987).

Concentrations of soluble nonvolatile organic compounds (not removed by conventional treatment methods) in produced water may range from 500-600 mg/l (Neff et al., 1987). Somerville (1987) found a similar level for 4 North Sea platforms (500-700 mg/l total organic carbon).

A range of elevated heavy metals may be present in the form of either metal ion complexes or colloidal suspensions.

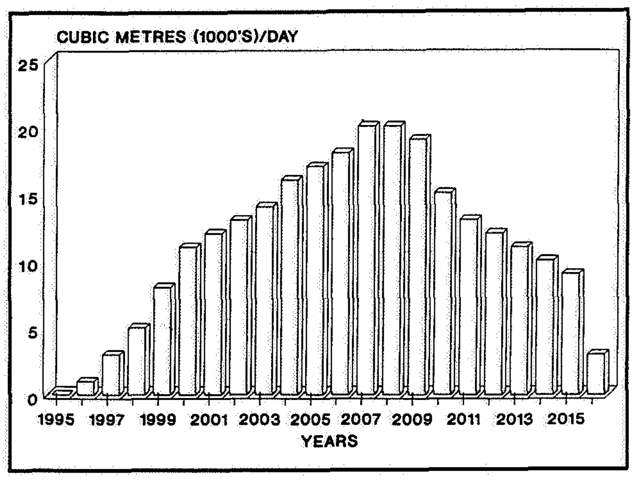
1.5.3 Produced Water Discharges

Produced water from all separators would be treated in a system designed for a rate of 1,027 m^3/hr, and oil-in-water levels would be monitored to ensure compliance with the legal limit prior to discharge. Monitoring for the purposes of legislative reporting is undertaken according to defined extraction procedures, and with determination of hydrocarbons by infra-red spectrophotometry (such a process measures dispersed rather than dissolved oil).

Reservoir modelling has generated estimated annual produced water discharges over the field life. These are presented graphically in Figure F.1.4.

At the present time, only a limited number of formation water samples have been recovered during well testing and analysed. Results for the Fangst reservoir are presented in Table F.1.2.

Figure F.1.4 Heidrun Estimated Annual Produced Water Discharges



The results obtained from these samples indicate that the Heidrun formation water may have a lower total dissolved solids content than seen in many North Sea fields, and with a specific gravity more similar to seawater (seawater 1.027; Heidrun 1.033-1.038; Gyda 1.18; Auk 1.085; Brent 1.014). Such characteristics may result in less marked plume formation on discharge and more rapid integration into the marine environment.

In order for produced water released into the environment to have any direct toxicological effect, it must be present in sufficient concentrations for an adequate period of time to elicit a response.

Produced water dispersion and dilution modelling is accurate, can be validated and will be carried out for the Heidrun field to ascertain optimum discharge depth and design for the TLP.

Constituents	Levels (mg/l)
Sodium	16,810
Potassium	345
Calcium	880
Magnesium	185
Barium	25
Strontium	88
Total Iron	145
Dissolved Iron	0.2
Chloride	28,010
Sulphate	20
Bicarbonate	660
Carbonate	-
Hydroxide	-
Total Dissolved Solids	47,010
Specific Gravity	1,033
Resistivity (at 15.5°C) (ohm.m)	0.185
pH	6.9

Table F.1.2 Heidrun Produced Water Analysis

1.5.4 Ballast Water

The platform would require in excess of 11,000 tons of ballast. Some 4,000 tons of this would be offloaded should a regional development module be installed on the TLP. Should seawater be used as ballast, there could be a non-oily water discharge from this source.

1.5.5 Cooling Water

See Section F.1.4.2. for details of composition.

1.5.6 Drainage Water

Surface water drainage from areas containing machinery or equipment, and where oil contamination is possible, would be collected in an open drain system. Drainage from equipment under hydrocarbon pressure would be collected in closed drains, with oil being returned to the process system.

Overflows and drains from fuel tanks and other non-volatile, oil-containing vessels would also be connected to the open drain system. All oily water from open drains would be routed to the deck drainage collection system. Effluent flow from this drainage system would normally be low.

Consideration is presently being given to the use of a slops tank and centrifuges or hydrocyclones for separation and recovery of oil from drainage water. In addition, the TLP design provides for "skim piles" within the hull columns. These would function as open-ended gravity separation columns, from which further oil recovery could take place if necessary. They could also serve as an emergency holding facility in the event of a major oil spill on the platform.

Rainwater from non-oily areas would be collected in gullies and discharged directly to sea. Helideck drains would be collected in a separate system and discharged to sea. Fire water overflows and open drains from the living quarters would also be routed directly overboard.

1.5.7 Sewage, Galley and Sanitary Waste

Macerated sewage, organic kitchen waste and water from domestic facilities on the TLP would be discharged to sea, as permitted under present legislation. The advisability of the installation of sewage treatment facilities will, however, be investigated further.

1.5.8 Chemicals

The requirement for use of chemicals in the Heidrun field will not be finalized until a later stage of the development. The range of chemicals which could theoretically be used on a production facility is large and a number of the key groups are outlined in Table F.1.3. A comprehensive review of oilfield chemicals is provided by Hudgins (1989).

In applying for a Discharge Permit for the Heidrun field, the Operator will be obliged to provide information to SFT on the proposed discharges, dilution and dispersion potential, the nature and volume of the chemicals in question and their environmental acceptability (in particular toxicity and biodegradation potential). In this connection, international bans/restrictions imposed by the Paris Convention will also apply.

Corrosion inhibitors	Scale inhibitors
Wax inhibitors	Biocides
Pour point depressants	Oxygen scavangers
Demulsifiers	Reverse breakers
Surfactants	Coagulants
Flocculants	Antifoamers
Speciality chemicals	Refined oils
Domestic/utility chemicals	Hydrate inhibitors
Gas drying chemicals	Solvents

Table F.1.3 Typical Groups of Production and Utilities Chemicals Used Offshore

In addition to the need to screen carefully and select more environmentally acceptable chemicals where feasible, the Operator will be obliged to observe the requirements relating to storage, handling, supply of material safety data sheets, and maintenance of records as laid down in Section 11 of the Work Environment Act, 1977. The Operator's MSDS sheets are presently being revised to incorporate the PARCOM approved E&P Forum "minimum data set".

Annual returns on offshore chemical use and discharge (according to specified categories) will also have to be made to SFT.

Recognising European concern about the scale of use and discharge of chemicals to the North Sea by a wide range of industrial operations and also domestic consumers, there is a growing awareness of the need to minimise where possible, use of chemicals, and in particular those which might be considered toxic and persistent.

Furthermore, it is generally recognised that there is a requirement for more comprehensive information on the characteristics, mode of action, solubility, and the ultimate fate and effects of certain of these materials in the receiving environment. In addition to involvement in Joint Operator/SFT massbalance studies to investigate some of the above mentioned elements, CNI has embarked on a 3-4 year R&D study on all aspects of chemicals use and discharge offshore.

The results from these studies and those being undertaken by operators and authorities in Europe and North America should be available by 1995 when Heidrun facilities become operational, and would assist with all aspects of chemical selection/usage.

A listing of "typical" chemicals, applications, and approximate dosage rates which might be appropriate to Heidrun is given in Table F.1.4.

In addition to the use of chemicals on the platform, provision will be made for the inclusion of chemical flowlines within the subsea well umbilicals. This would allow batch methanol injection, as prevention against unacceptable hydrate formation. Wax depo-

Chemical	Application	Injection Point	Typical Dosage (mg/l)	Disposal Route
Antifoam	Foam Reduction	Inlet to Separators	5	Oil and Produced Water
Demulsifier	Assists Oil/Water Separation	Wellhead Manifolds, Inlets to Separators	15	Oil and Produced Water
Scale Inhibitor	Reduces Scale Formation	Wellhead, Flowlines, Separators	20	Produced Water
Corrosion Inhibitor	Reduces Corrosion	Separators, Inlets to Gas Heat Exchangers	30	Oil, Gas and Produced Water
Poly-electrolyte	Assists Oil/Water Separation	Effluent Water Treat-ment System	10	Produced Water
Biocide	Prevents Microbial Growth and Corrosion	Injection System	700 (slug) dose	Injection Water
Hypochlorite	Prevents Marine Growth	Seawater Lift	0.5	Injection Water
Oxygen Scavanger	Assists Water Deoxygenation	Feed to Deoxygenator	2.5-5	Injection Water
Coagulant	Filtration Aid	Inlet to Injection Filter Unit	1-2	Filter Back Wash
Scale Inhibitor	Reduces Scale Formation	Inlet to Water Treatment Residence Drum	10-25	Injection Water

Table F.1.4 Anticipated Heidrun Chemicals Use

sition from Heidrun crude is not considered to be a major problem and methanol would also assist in preventing any wax build-up in subsea lines.

1.6. Operational Discharges (Atmospheric)

1.6.1 Nature and Source of Emissions

Sources of atmospheric emissions from fixed offshore installations include:

- Equipment exhausts, including turbines, diesel fuelled generators, cranes, emergency pumps, cement pumps, wirelining units etc.
- Flares (HP and LP) and vents.
- Fugitive emissions.
- Open tanks and vessels, including mud tanks and slops tanks/skim piles (volatile organics).

In addition, there would be emissions associated with marine shipping located in, or servicing, the field (FSO, export shuttle tankers and supply vessels).

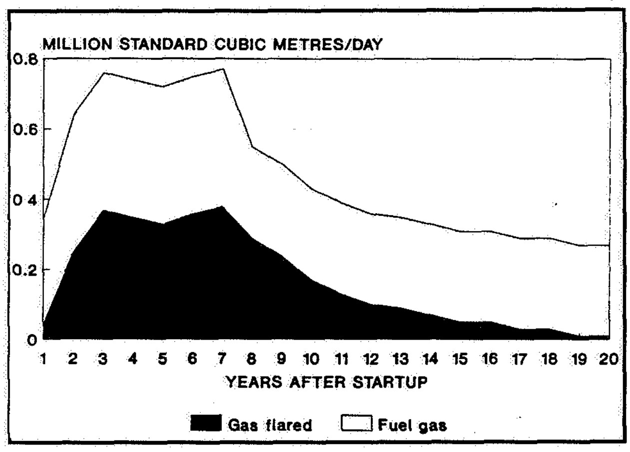
Combustion products would typically include NO_X, SO_2 (negligible when Heidrun low sulphur gas is used as fuel), low level particulates, and carbon monoxide/dioxide.

Further work is planned within the Industry (North Sea) into the nature and scale of offshore discharges, and identification of areas where design improvements or emission control might be considered. Additionally, because of concerns for global warming, there is renewed interest in the question of venting (methane) rather than flaring of hydrocarbon gases, and which option might be considered more environmentally acceptable. Levels of CO_2 in discharges can also be dependant on reservoir CO_2 concentration, which for the Heidrun is approximately 1.1%.

Gas produced and separated from the crude oil would be used for a combination of platform power generation, injection to the reservoir(s), and for export purposes. Consequently, very little gas would be flared on the platform under normal operating conditions. It is only under upset or emergency conditions that more significant amounts of gas might be involved. Dispersion characterisitics for this type of emission will be calculated for the Heidrun platform to assist further engineering design work (see Section F.1.3).

Estimated quantities of gas for flaring and for fuel are given in Figure F.1.5. These quantities have been calcuated assuming that the compression system would be available 90% of the time (on an annualised basis). The annual volume of gas flared has been converted into a mean daily volume. Work will be carried out during project detailed engineering, to confirm these estimates.

Figure F.1.5. Heidrun Gas Usage Estimates (Sm^3x10^6 per day)



Gas volumes used for purging the flare and vent systems, and for the flare pilot, would be minor compared with platform fuel gas usage and flaring rates.

It is anticipated that, from time to time, minor fugitive leaks from installed equipment would occur. Fugitive emissions originating from valves, relief valves, flanges, pump seals, compressor seals etc are very difficult to quantify in terms of volumes (Bolton. P.W. et al., 1980). Based on available data, these are expected to be very small, and would have no significant environmental impact.

1.6.2 Halon and Chlorofluorocarbons (CFCs)

Halon has been essential for offshore safety and firefighting purposes. However, due to the Ozone Depletion Potential (ODP) of halogenated hydrocarbons, international measures have been agreed to reduce their use and discharge.

Three halons (1211, 1301 and 2402) are identified in Group II of the Montreal Protocol. Of these, 1211 and 1301 have been widely used in either total flood systems or in portable fire extinguishers in key offshore locations such as the control room, radio room, electrical equipment banks and accommodation areas.

SFT have notified offshore operators of the Storting decision to phase out the use of all ozone destructive substances as from 1995 (SFT Communication, 28 September 1989), which includes halon 1211 and 1301.

A number of reports on the feasibility/suitability of alternative extinguishants are becoming available (UNEP, 1989; Nordisk Ministerråd, 1989). The Operator has commissioned a study to look at alternative systems for fire protection of Heidrun field facilities.

CFCs, like halons are covered by the Montreal Protocol. Their ODP is lower than that for the halons, and their use offshore is primarily as a coolant in refrigeration systems. Du Pont (Conoco's parent company) is presently a large producer of CFCs and has acknowledged the need for an orderly transition towards the phase-out of environmentally damaging fully halogenated CFCs (Du Pont, 1989). Active research is being conducted into acceptable alternatives, and the Heidrun facilities would be in a good position to make early use of any replacement products which become available.

1.7 Waste Disposal

1.7.1 General

As with any industrial process, there will be waste produced from offshore facilities. Those wastes which can be treated, and disposed of overboard in a safe and environmentally acceptable manner would be discharged in accordance with the conditions laid down in the Discharge Permit issued by SFT. There are, however, a range of materials which the authorities do not consider suitable for offshore disposal, either because of their limited biodegradability or their inherent toxicity.

Table F.1.5 outlines the types of material which might be generated from offshore oil production activities, for which onshore treatment and disposal might be required.

Certain of the above items could, by virtue of their oil content or chemical properties (e.g. heavy metal content, acids/alkalis etc), be classed as "Special Wastes".

Empty drums and chemical sacks
Construction waste
Waste chemicals, oils and solvents
OBM drilling mud and cuttings
Low activity radioactive scale
Domestic refuse
Redundant equipment
Oily waste from drilling and process streams
Specialist items including spent filters, batteries, etc.

Table F.1.5 Examples of Wastes Produced from Offshore Installations

Comprehensive waste storage, classification, labelling, handling, shipment and disposal procedures which recognise the current legislation and the need for safe and environmentally acceptable waste disposal will be developed for the Heidrun field.

In the first instance, waste would be received at the Kristiansund base and would then be routed to an appropriate facility. Evaluation of approved reception facilities in Region 2 (Møre and Romsdal, Sør and Nord Trøndelag) has commenced.

In addition, by 1993 the proposed waste treatment facility at Mo i Rana may be operational. It is understood that Mo i Rana would provide disposal for inorganic material and solid/liquid organics, through use of a high temperature (1200°C) rotary kiln, fixation and controlled landfill.

Restricted waste could include low activity radioactive scale. Scale can develop on certain items of equipment as a result of precipitation of naturally occurring radionuclides in formation water, particularly later in field life when there is co-production of formation and water injection water. The nature and origin of these materials, handling, removal and disposal requirements are well documented (E&P Forum, 1987; UKOOA, 1985).

Heidrun's operating procedures will encompass all the necessary safeguards for acceptable handling and disposal of any such scale, should it arise. SFT and Statens Institutt for Strålehygiene (SIFSH) would be contacted in this connection.

Disposal of waste from Heidrun should not give rise to any unacceptable environmental impact, given that the appropriate procedures are followed and that permitted disposal facilites/operators conduct their business to the required standard.

1.7.2 Oil Based Mud Cuttings and Fines

Should SFT require that oily cuttings and fines from drilling operations on the Norwegian continental shelf be transshipped ashore for disposal, Heidrun could have a disposal requirement amounting to approximately 26,000 tons over the field life. The annual volume for disposal could be in the order of 6,000 tons in 1994 and 1997.

A number of studies have been, and are being, carried out by operators in North America in connection with disposal of oily cuttings from areas where discharge bans already exist (Gulf of Mexico, Beaufort Sea and Californian coastal waters). In addition, Norwegian operators have carried out studies more specific to the problems of transshipping cuttings in high latitude areas with poor weather conditions, to onshore areas where acceptable disposal options and existing facilities are extremely limited (COWIconsult, 1988; References as listed in Petreco, 1989). Details of the results of such studies will not be reiterated here.

It is recognised that acceptable onshore treatment facilities could be commissioned by 1994, when OBM drilling commences on the Heidrun field. Cuttings cleaning technology could be sufficiently far advanced by 1995, to allow a unit to be installed on the Heidrun platform that would be capable of reducing oil on cuttings, to levels which would be perceived as being more environmentally acceptable than the present 100 g/kg limit. To this end, Conoco will continue to sponsor R&D and field trials of promising equipment.

In addition, as discussed in Section E.3.5.2, the Heidrun Operator will continue efforts to minimise the use of OBM, and will continue to work on the development of more effective WBM's such as Duponol WBS-100, which was approved for use in Norway in 1989.

However, there is a need to develop further onshore facilities capable of treating oily solids waste, as there could be material produced that would prove difficult to treat offshore. At the present time, this might include high oil content centrifuge wastes, OBM which cannot be reprocessed, separator waste etc.

2. OIL STORAGE/EXPORT FACILITIES

2.1 Export Shuttle Tankers

Shuttle tankers would be purpose built in accordance with the specification prepared for Statfjord-Gullfaks vessels (1985). These vessels are highly manoeuverable (with dynamic positioning capability and bow thrusters) and have an oil carrying capacity of approximately 140,000m^3 (880,000 barrels). A tanker loading rate of 8,000m^3/hr (50,000 barrels/hr) is planned.

Weather limitations on offshore loading are somewhat system specific but presently the guidelines employed are 4.5 m significant wave height for mooring, and 6.0 m for disconnection. In the North Sea, tandem-moored vessels would normally maintain a 60-80 m separation.

In general terms, the procedure for oil transfer would be similar for all offloading systems. The shuttle tanker would approach, a mooring hawser would be secured, the tranfer hose connected and loading would commence. Transfer would probably be via a 20" hose (offloading system specific), and a dry break coupling would be used on the loading hose to ensure minimal risk of oil spillage during disconnection.

For an oil production rate of 31,800 m^3/day (200,000 BOPD) and turnaround time of 21 hours, a shuttle vessel could be engaged in loading activities in the field 25% of the time (one day in four). A field production efficiency of 99.5% is envisaged.

2.2 Floating Storage and Offloading Vessel

See descriptions of operations given in Sections D.4.1 and G.1.3.1.

Atmospheric discharges will be similar in nature to other marine tanker operations e.g. combustion products from diesel engines and volatile hydrocarbons from crude oil storage (minimised where feasible by loss prevention measures).

Tank bottoms (oily water and sediment/sludge) which cannot be treated to the appropriate discharge limit will be removed to shore for disposal.

Further impact assessment will, however, be carried out as engineering design work progresses.

3. SUBSEA WELLS

Subsea wells would be remotely controlled and would rely on hydraulically operated systems. This may involve the discharge of hydraulic fluids. If open systems are involved, the impact on the marine environment can be reduced by using water based rather than oil based fluids. Further engineering work is required before any details can be given on alternatives, discharge volumes, frequency, chemicals etc. It is anticipated that discharges from this source would, however, be relatively small.

G. OIL SPILL ISSUES

1. POTENTIAL SPILLS

In all offshore activities, strict adherence to operating procedures and the maintenance of a high level of staff training and awareness of pollution issues should help to minimise the occurrence of, and hence risk from, oil spills.

All spills must be reported to the authorities, either to SFT on a monthly basis in the case of volumes of less than 1 ton, or via the Rescue Co-ordination Centre to the relevant authorities in the case of spills greater than 1 ton. In addition, strict pre-notification and report updating requirements exist for well testing operations, which are perceived to be a higher risk activity.

1.1 Drilling Operations

Spill sources associated with drilling operations might include refined oils such as drilling mud base oil and diesel, and crude oil from welltesting. On a rig designed for oil based muds, "closed" drainage arrangements provide an opportunity to recover spilled oil from working areas. Heidrun predrilling from a semi-submersible rig will comprise nine wells. The requirement for, and level/duration of DSTs which might be needed at this stage, or associated with the Northern Area subsea wells, has not yet been determined, but will probably be limited.

The majority of production wells will be drilled from the TLP, and for these wells, platform test separator facilities will be available. The incidence of spills from TLP drilling operations has, from experience on the UK Hutton platform, been no greater than for other facility designs.

Issues associated with loss of well control/blowout are dealt with in Section G. 1.6 and G. 1.6.1.

Issues associated with the use of OBM and reduction of losses of oil to the marine environment are dealt with in Section E. 3.5.2.

1.2 Platform

The Heidrun Concept Safety Evaluation and associated documents have analysed potential causes and sources of hydrocarbon losses (liquid and gases) from platform facilities and pipelines/flowlines (Siktec 1988a, 1989; CNI 1989). Also considered, are possible volumes, duration of spills, and residual accidental events. Such detail will not be reiterated here.

Compared with other process plants, the Heidrun TLP relies on a simple arrangement, with large separation vessels. Although leaks from such sources could be greater in terms of volume, the simplicity of the design would provide for a lower leak occurrence probability. Drainage system design (see Section F.1. 5.6) provides for recovery of spilled oil from all potentially oily areas.

The most frequent causes of small operational spills from offshore facilities are human error and mechanical failure. In the latter category, hose leakage/rupture, tank over-fill and valve failure are the most common causes of spills over 1 m^3 (SFT, 1989). During 1988 in the Norwegian offshore sector (excluding contributions from UK operations), 25 reported spills accounted for 288 tons of oil.

1.3 Storage/Export Arrangements

A number of consultants' reports have been generated on the engineering aspects of the various storage and export options described in Section D.4 and in Appendix A. Only general categories of spill risk will be considered at this stage.

An essential element in the selection of the system to be used, is the ability to include the necessary pollution safeguards in the final engineering design. These include stringent operational controls, procedures and equipment to minimise the risk of tank overfill, dropped object and collision damage, oil carry-over in displacement water from the subsea crude storage tank (in the case of selection of this option, see also Appendix A), hose and riser rupture or damage etc. Environmental input to and review of all the constituent elements of the system, would be an ongoing process, as would discussions with the relevant authorities.

1.3.1 Floating Storage and Offloading Vessel (FSO)

The vessel would be constructed and operated to meet offshore standards laid down by the Norwegian Petroleum Directorate (NPD) and the Norwegian Maritime Directorate, although certain features inherent in international tanker design (as recognised by the International Maritime Organisation) would be incorporated to minimise oil pollution risks.

- There would be complete segregation of crude oil and water ballast systems, and no cross-use of tanks for other purposes.

- Crude oil washing rather than water washing would be used to minimise sediment accumulation in oil tanks.

- Drains from the pumproom, metering station and other crude oil handling areas would be directed to slops tanks and treated to an oil-in-water discharge limit of 40 mg/l or less. Non-oily drains would discharge directly to sea or to a drain tank fitted with pumps.

- Storage of crude oil would be located in centre rather than wing tanks, thus providing a measure of protection against collision damage.

1.3.2 Oil Export

Offshore loading would be carried out following similar procedures and practices to those observed at Statfjord and Gullfaks. These fields have a good record and only one large oil spill incident has been reported, that of a 20m^3 spill in 1983, from a loading system malfunction.

Insignificant losses arise from sources such as disconnection of the dry break couplings.

Weather limitations should not affect oil pollution risk. Operational limits for extreme environmental conditions are well defined and dictate disconnection timing.

Additionally, pollution prevention measures include:

- On the FSO and the shuttle tanker, drip pans are installed under crude oil manifolds, and when oil is transferred between two vessels, scupper plugs would be in place, thus isolating/sealing main decks.

- Watch officers would be on station to observe offloading activities. Television monitoring of the bow manifold and visual inspection (Statoil procedure) would provide additional protection.

- The bow and FSO offloading area would be lit to enable safe round-the-clock operation. Deck pipework would also be lit.

- Tankers are dedicated and crews are familiar with operating procedures and equipment.

1.4 Risers and Pipelines/Flowlines

Exact details of the numbers and types of risers and pipelines/flowlines would be dependent on finalisation of plans on subsea wells, regional development, selection of the appropriate storage and export options etc. As it is too early to specify such detail, the options available have been listed in Table G.1.1 (see also Section D.5).

Of the risers and pipelines, only those carrying oil are considered. Risk of damage or leakage from such sources has historically tended to arise from material failure, and dropped object or collision damage.

The small diameter and short line lengths associated with the Heidrun facilities, give rise to relatively small line volumes. In addition, trenching (and coating where appropriate) of lines will provide protection against possible vessel damage. Corrosion protection and inspection programmes will help to protect against material failure.

Risers are fitted with tensioners to compensate for TLP movement, and design parameters thus allow for extreme environmental conditions. Experience from the Hutton TLP does not suggest that this design feature will give rise to a significantly increased spill risk.

Additional safeguards such as the provision of ESD valves are under review.

1.5 Collision Risk

Collision risks and consequences have been considered in the Heidrun TLP Concept Safety Evaluation and associated studies. Included in the various analyses are collision risks for the TLP and FSO, involving merchant and fishing vessels (very limited traffic), supply vessels and oil export shuttle tankers. Additionally, consideration has been given to events such as FSO anchor failure and subsequent collision with the TLP, and also TLP tether failure.

The probability of a collision resulting in a spill risk is low.

1.6 Loss of Well Control/Blowout

Safety evaluations of platform simultaneous drilling and production operations have been carried out and blowout risk/rates calculated. The causes of blowout and means of dealing with them are well documented and will not be reiterated here.

Possible sources of blowout would be the same for any offshore production operation, namely: platform development drilling, subsea development drilling, and platform and subsea production. Hazard evaluations for Heidrun have considered drilling, completion, production, workover, wirelining, subsea wells and various combinations of simultaneous activities, carried out on an annual basis throughout field life.

Unacceptable blowout risks have not been identified and there appears to be no significant additional risk from simultaneous drilling and production operations. Environmental spill risk is considered to be comparable with other North Sea installations.

Platform	Gas Export Riser, Oil Export Riser, Flexible Subsea Well Risers, Platform Well Risers
	Possible Risers Associated With Regional Development (Including Oil and Gas Import Risers)
Others	Northern and Southern Subsea Flowlines (Including a Possible Theta Remote Gas Storage Injection Line), Gas Export Line (not dealt with here), Regional Development Pipelines (not dealt with here), Oil Pipeline and Flexible Risers to the FSO

Table G.1.1 Heidrun Riser and Pipeline/ Flowline Options

Shallow gas zones pose a threat in the North Sea/ Norwegian Sea, and high resolution seismic survey and shallow drilling (Well 6507/7-9) operations have been carried out in the Heidrun field to improve existing knowledge of the TLP area.

Minimisation of the risk of blowout and its consequences are of extreme importance, and safety/ prevention equipment, training and the enforcement of well established and tested procedures form the basis of all drilling and operations plans. Blowout with oil spill is a rare occurrence in the North Sea, which is testimony to the success of the strict preventative measures which are enforced.

1.6.1 Blowout rate

Westergaard (1987) gives possible oil spill volumes of 2,000-7,000 tons/day for blowouts from North Sea wells with production tubing in place (4.5"-7"). He also notes that blowouts usually come from the payzone, in which there is no casing during drilling. The hole size is thus larger than for a completed well, and flow-rate is only limited by friction in the well bore.

However, this scenario assumes that a substantial part of the reservoir pay zone has been penetrated, that the reservoir has a high productivity before stimulation, and that the high flow-rate can be maintained. Such high flow-rates of long duration have a low probability. Reservoir bridging, choking, depletion, well capping and killing with mud are all activities that might be achievable within 10 days (Westergaard, 1987).

1.7 Oil Spill Modelling

Heidrun high rate oil producing wells have been designed for completion with 9 5/8" casing. Thus a "worst case" modelling scenario involving an open hole blowout during drilling has been selected (cased well, with 0.5" reservoir perforations). Modelling has provided an oil production rate of approximately 11,000 tons/day.

Two studies have been carried out for Heidrun in connection with oil movement during a major spill. These are: 1) an analysis of the oil recovery efficiency of Norsk Oljevernforening for Operatørselskaper (NOFO) equipment deployed offshore to combat such a spill (Langfeldt, 1989), and 2) oil spill drift modelling (DNMI, 1989).

The scenario selected is based on a surface blowout. The dispersion characteristics for oil from a subsea blowout in deep water, could be different from those of a surface blowout, as could the range and severity of environmental impacts. Further investigations into subsea blowout will be undertaken to more clearly define such characteristics.

1.7.1 Oil Spill Contingency Planning and Preparedness

In Norway, oil spill response capability is provided jointly by the operators through NOFO. NOFO's responsibilities in the event of a spill include provision of equipment, co-ordination of recovery vessels and personnel, and adoption of an appropriate spill response strategy. The NOFO emergency response system is intended for major oil spills, although other categories of spill can be dealt with. Mechanical recovery is the SFT preferred method for Norwegian waters.

It is the responsibility of the Operator (Act of 22 March 1985 no.11 pertaining to Petroleum Activities) to ensure an adequate response capability. This is primarily achieved through NOFO. Additionally, the Operator must prepare inhouse contingency plans, provide trained company personnel and take part in emergency preparedness exercises.

NOFO has prepared a general plan for operators' oil spill preparedness on the Norwegian continental shelf (Totalplan, Contingency Area 1, 1989), which outlines all the key elements of the response capability. Within this, realistic response times for Haltenbanken are listed as 16-24 hours for 2 systems (system is defined as an oil recovery vessel, towing vessel, boom unit and skimmer) and 24-48 hours for 4 systems. Two additional standby systems (making 6 in total) could also be available within 36-72 hours of the spill.

The Operator will prepare both an overall Emergency Preparedness Plan and an Oil Spill Contingency Plan, for use in the event of any oil spill incident.

In view of the sensitivity of the coast within the impact area of the Haltenbanken fields, it would be appropriate for Haltenbanken operators to jointly enter into discussions with the appropriate authorities, to more clearly define areas for priority protection in an oil spill response strategy.

1.7.2 Oil Recovery Efficiency

Recovery efficiency has been calculated (Langfeldt, 1989) based on the following parameters:

Blowout rate :	11,000 tons/day (460 tons/hour, 522 m^3/hour)
Density :	0.8783 tons/m^3
Duration of spill :	10 days
Total volume spilled :	125,242 m^3

Crude oil characteristics as described in Section B.2.3, would give 22% evaporation and 55% emulsification of oil prior to any skimming taking place. Oil volume available for recovery would thus be 97,690 m^3. Time to availability of the necessary recovery equipment is as described in Section G.1.7.1.

Calculations have been based on an analysis of wave height frequency data for Heidrun, using 0-1, 1-2, and 2-3 m significant wave heights (Hs). Recovery beyond an Hs of 3 m is considered to be zero. The duration of sea states above and below 3 m for all months of the year has also been calculated (Table G.1.2).

Acknowledging the possible difficulties of night-time recovery, efficiencies of both 50% and 100% have been calculated. NOFO actually consider that a night-time efficiency of better than 70% might be achievable. The number of hours of daylight (including half-light) have been calculated from the Norwegian Almanac.

Thus, recovery efficiency calculations are based on Hs, duration of sea state, % equipment efficiency in the given sea states, number of daylight hours and arrival time of recovery equipment.

Hs (metres)	0-1	1-2	2-3
January	0.27	15.95	25.78
February	0.00	16.60	27.71
March	2.28	21.63	26.96
April	2.75	28.91	28.65
May	11.79	56.71	24.27
June	16.45	54.69	23.46
July	19.91	58.34	16.43
August	20.86	49.91	22.54
September	1.89	39.70	34.47
October	1.20	12.95	27.10
November	1.24	15.89	25.58
December	0.09	10.21	28.51
Mechanical Efficiency (%)	80	75	60

Table G.1.2 Frequency of Significant Wave Heights (Hs) for Mechanical Oil Recovery (Heidrun Field)

By way of example, outlined below in Table G.1.3 are calculations of the efficiency of recovery assuming 100% efficency for night-time recovery.

Recovery efficiency is low in winter due to wave height and action. However, when oil recovery becomes impossible at Hs 3 m, dispersion by breaking waves will be increased. The rate of natural dispersion for an 11,000 tons/day spill will be in the order of 5, 15 and 20% for Hs values of 1, 2 and 3 m respectively (NOFO, 1989). This process would not give any significant loss of oil before recovery, and has been omitted from the calculations made here. The dispersion process would, however, have an effect on the volume of oil reaching coastal areas, and has been included in oil spill drift modelling (DNMI, 1989).

	Average	Minimum	Maximum
January	24.0	2.6	55.0
February	25.2	10.0	42.2
March	29.7	27.5	58.4
April	35.6	39.2	59.1
May	57.7	52.6	62.2
June	59.2	54.8	62.6
July	60.4	47.3	63.7
August	58.7	45.6	62.9
September	45.1	39.8	59.3
October	23.4	12.3	33.8
November	24.5	23.9	54.8
December	21.6	19.2	47.4

Table G.1.3 Average, Minimum and Maximum Efficiency. Blowout Lasting 10 Days, 100% Night Efficiency

The amount of oil emulsion available for collection, assuming 22% evaporation and 55% emulsification (55% water in oil) is 217,084m^3.

Each Transrec system is deployed from a supply vessel with a tank capacity of at least 1000 m^3. Approximately 70% efficiency in oil-water separation (with an emulsion breaker), and a 12 hour fill/empty cycle for vessel tanks is assumed. With oil transfer downtime taken into consideration, a vessel will have recovered approximately 1,540 m^3 of emulsion during one 12 hour cycle (3080 m^3 of emulsion/day), giving an average recovery capacity of 128 m^3 of emulsion/hour.

The target recovery rate based on the Heidrun blowout scenario presented, is 900 m^3 of emulsion/hour (217,084 m^3/(10 (days) x 24 (hours)). Thus at any time of the year, seven units would need to operate continuously to recover the oil being produced. This is provided for by present NOFO stocks.

1.7.3 Oil Spill Drift Modelling

The oil drift model at the Norwegian Meteorological Institute has been used to prepare statistical oil drift data for the Heidrun field (DNMI, 1989).

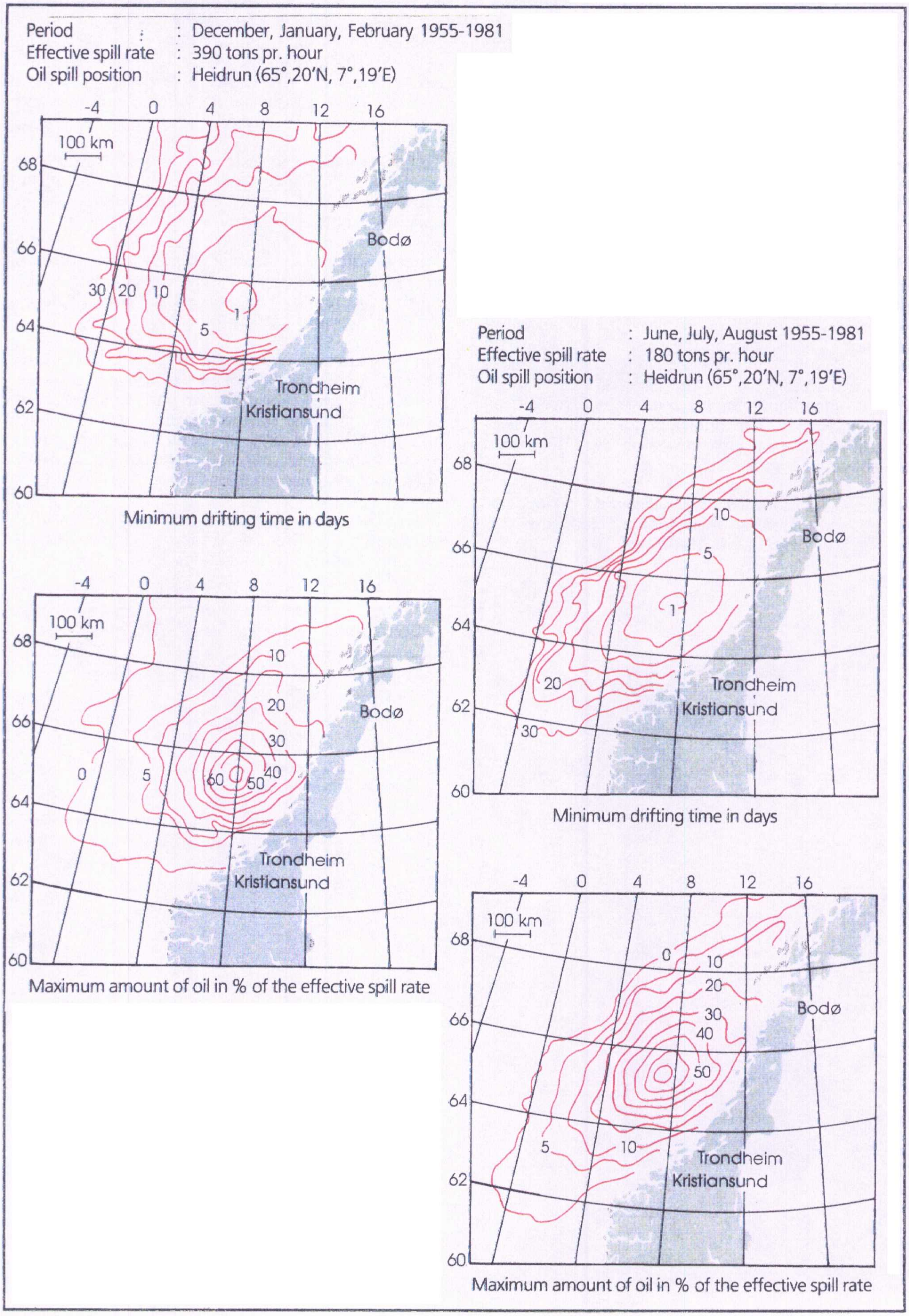
The basic data are historical wind fields (on a six hourly basis from 1955 to 1981) from the upgraded hindcast database at DNMI. In addition, a background current field is incorporated into the model. For every six hour period from 1955, the trajectories of oil patches together with the amount of oil remaining on the sea surface have been calculated (every oil patch is simulated during a 30 day period). The statistical information on the oil drift is obtained by analysing all the simulated oil trajectories and amounts for the whole period from 1955-1981.

DNMI have used the mean recovery efficiencies for the different seasons (calculated in Section G.1.7.2 above), to calculate the "effective" spill rates, assuming a 50% night recovery and the conditions given in the NOFO Operational Plan (NOFO, 1989). Results are given in Table G.1.4 below.

Season	Mean Recovery Efficiency (%)	Effective Spill Rates (Tons/Hour)
Mar/Apr/May	36.5	290
Jun/Jul/Aug	60.9	180
Sep/Oct/Nov	25.3	340
Dec/Jan/Feb	15.6	390

Table G.1.4 Mean Equipment Recovery Efficiency and Effective Spill Rates at Heidrun.

Figure G.1.1. Selected Results From Heidrun Oil Spill Drift Modelling

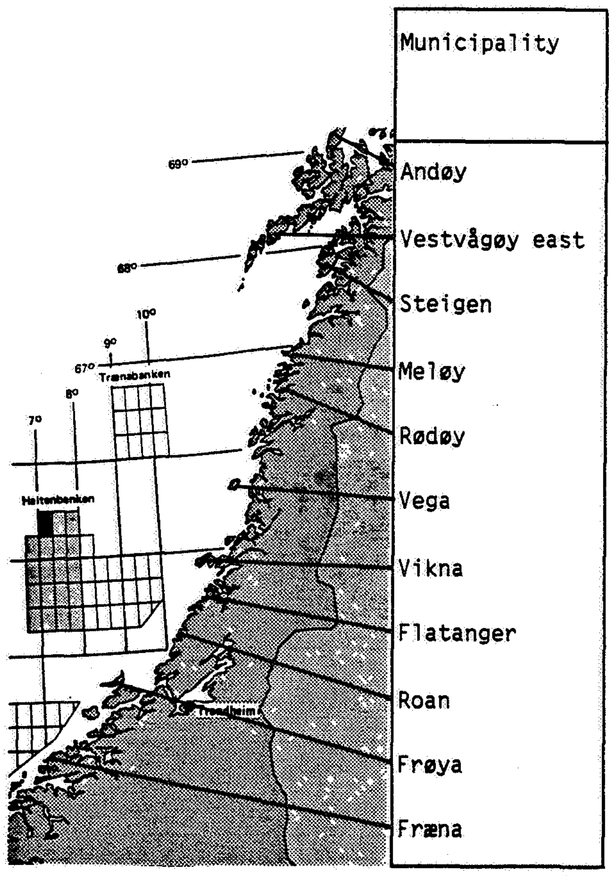


Results from the statistical analyses present the geographical distribution of five statistical parameters; minimum drift time, mean drift time, maximum amount of oil, mean amount of oil and arrival frequency. The statistics are given by season (Dec/Jan/Feb; Mar/Apr/May; Jun/Jul/Aug; Sep/Oct/Nov) and selected results are presented in Figure G.1.1.

The statistics calculated from these simulations, show that the *maximum extent* of the coastline which might be contaminated with oil from a spill in the Heidrun field, is from Fræna in Møre and Romsdal to north of the island of Senja in Troms.

Within this coastline, the impact zone has been defined, on the basis of modelling, as the region which is likely to receive oil at a rate of 5% or more of the effective rate of oil discharge at any season of the year. This would be the region from Frøya to Andøy. Within this area, one might also define a "high impact region" on the basis of a 10% mean rate of oiling figure. Such a zone would extend from Vikna to Rødøy. The municipalities within the Heidrun oil spill impact area (based on the 5% criteria) are shown in Figure G.1.2.

Figure G.1.2 Location of Municipalities Within the Heidrun Impact Area Identified by Oil Spill Drift Modelling



The fastest drift time from the Heidrun field to the coast depends on the season. For the spring, summer, autumn and winter, this would be 6-8 days, 10-12 days, 5-7 days and 4-6 days, respectively. The mean drift time from the Heidrun field to the same coastal areas is 14-15 days, 19-20 days, 15-17 days and 10-15 days for the spring, summer, autumn and winter seasons, respectively.

To further indicate the extent of the area which might be affected by a major spill from the Heidrun field, and the difference which oil combat activities could make, two additional scenarios were simulated.

The oil drift model used in these simulations is an upgraded version (not yet fully operational) of the existing (operational) model. In this version, spreading of oil has also been considered.

Both scenarios were simulated for 20 days in September (the results should not be extrapolated to other times of the year). The duration of the spill was taken as 10 days and the spill rate selected was 460 tons/hour (11,000 tons/day). In the first scenario, no oil recovery was carried out, and in the second, recovery operations commenced after 25 hours.

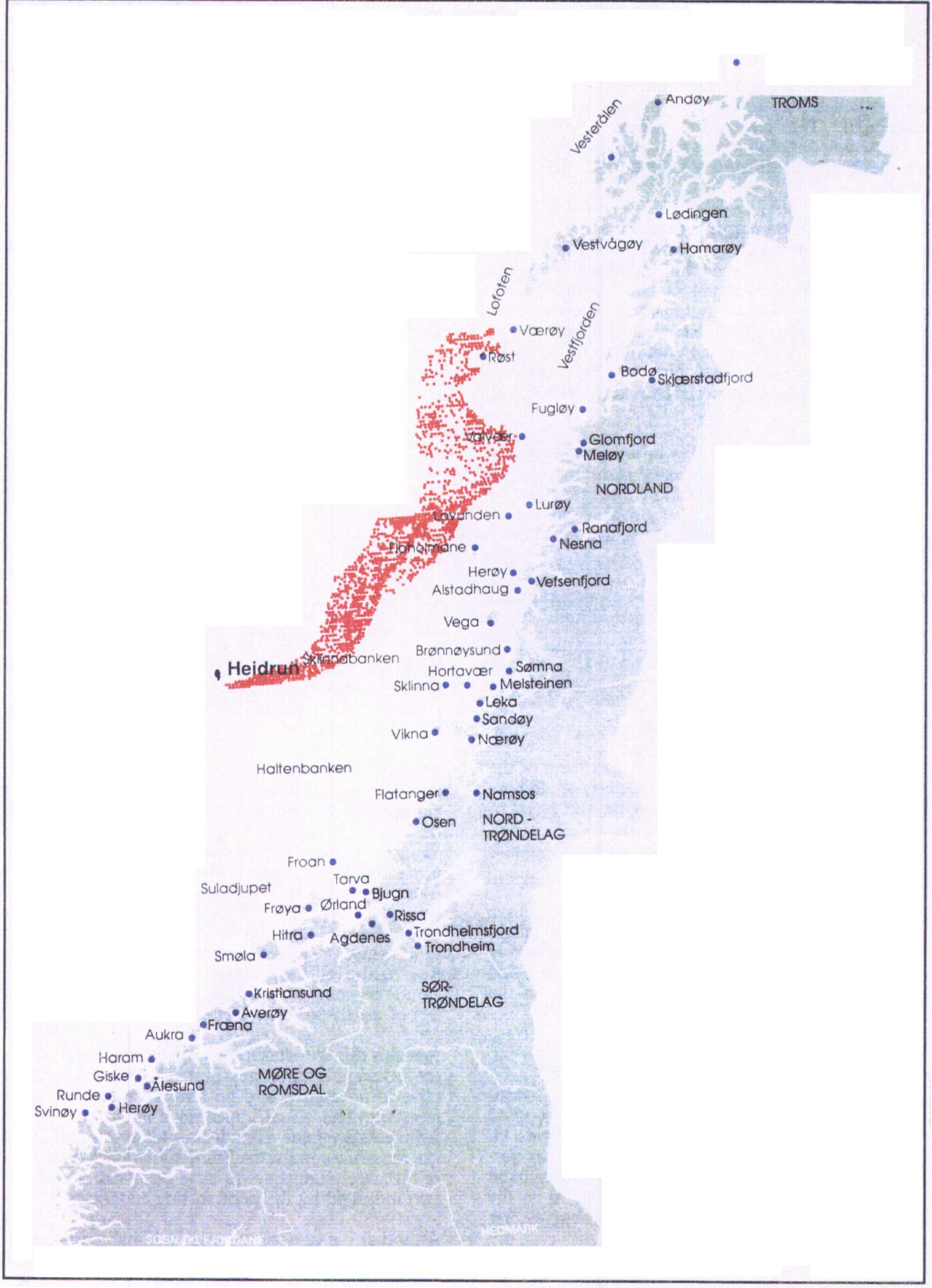
Figure G.1.3 shows the area which would be covered by oil after 10 days, and Table G.1.5 gives the remaining amount of oil for the two scenarios described above.

Scenario	5 days	10 days	15 days	20 days
Without Combat	36	48	34	21
With Combat	22	31	22	13

Source: DNMI, 1989.

Table G.1.5 The Remaining Amount of Oil on the Sea (10^3 Tons) After 5, 10, 15 and 20 Days for Two Spill Scenarios in September.

Figure G.1.3 The Area Covered by Oil in a Simulated Spill from Heidrun during September (After 10 Days)



H. EXISTING ENVIRONMENT

1. INTRODUCTION

This chapter presents information on the natural resources which may be influenced by the Heidrun development. The assessment describes the main characteristics of each of the resources and their temporal and spatial distribution offshore or along the coast.

Information has been drawn from local and regional environmental research performed by consultants or institutions, general scientific literature, previous EIAs and supporting documentation, regional plans, and interviews with the authorities. Much of this material was prepared in connection with the opening to petroleum activity, of the area north of 62°N. In addition, certain specialist reports were commissioned specifically for the Heidrun EIAs (1987 and 1989).

Continuous updating of the key information required for EIA revision and contingency planning/oil spill response, and priority protection planning will be provided through the joint operator/SFT computerised environmental database, which will be operational from 1990 (see Appendix B).

Figure G.1.3 shows the location of all geographical sites of interest referred to in sections H and I.

2. BENTHIC CONDITIONS AT HEIDRUN

2.1 General

The objective of an environmental assessment of the bottom sediments and biota in the vicinity of offshore facilities, is to obtain information on the physico-chemical properties of the sediments and the structure of the macrofaunal communities which inhabit them.

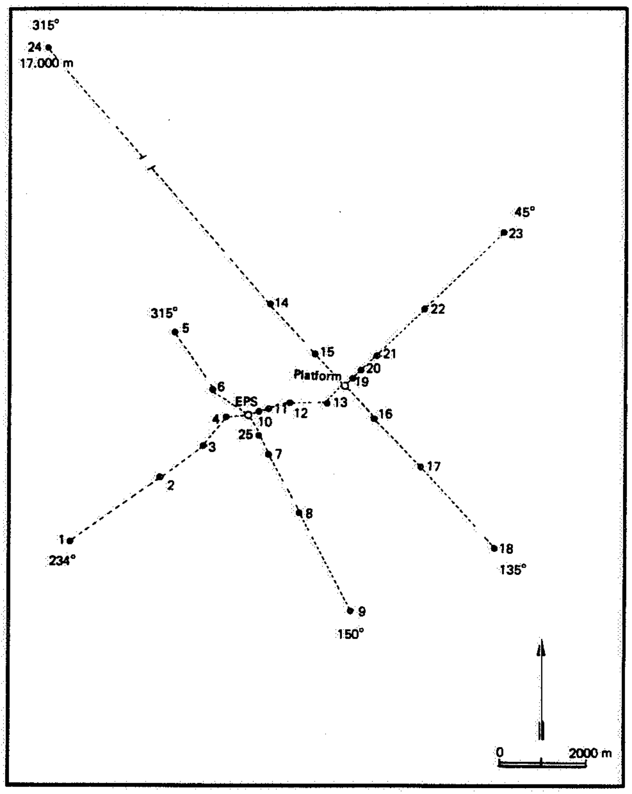
Subsequent monitoring studies allow a quantative and qualitative assessment to be made of the changes which can occur in the vicinity of installations during the life of the field. Such monitoring will be carried out in the Heidrun field and will be based on the Guidelines prepared by SFT (SFT, 1988).

2.2 Physical Characteristics of the Sediments

The main source of information is a baseline investigation performed at 25 stations around the proposed location of facilities in the Heidrun field (Figure H. 2.1) (Bakke et al., 1989), and a baseline survey performed in 1985 at 38 stations across Haltenbanken (Bowler et al., 1986). These are referred to as the Heidrun survey and the Haltenbanken survey, respectively.

Characterisation of the surface sediments has involved measurement of a large number of parameters. In addition to those listed in Table H.2.1., the visual appearance of the bottom material (texture, colour, and odour), as well as content of polyaromatic hydrocarbons, isoprenoids and bicyclanes have been reported.

Figure H.2.1 Map of the Heidrun Field with the Positions of the Baseline Survey Sampling Stations. Platform and Early Production System (Cancelled) are Indicated.



The impression gained from the Heidrun survey is that the seabed area is uniform, with no strong gradient in characteristics. This is also indicated by the water depth, which ranged from 320-348 m across the sample area. The reference station, lying 17 km northwest of the platfrom site, was the exception and water depth here was 380 m.

The sediments consist of sandy silt or silty sand, with sand, gravel, pebbles, and stones interspersed. The fine nature of the sediment is also reflected in a "mud" content (particles less than 0.06 mm in diameter) of nearly 50% on average (Table H.2.1).

Beneath this soft surface layer of thickness 3-10 cm, the sediment is stiffer and more clayey. The colour is olive to olive-grey, and no unusual odour has been reported. The visual appearance indicates that the sediments originate from drift or till deposition under glaciomarine conditions. Some subsequent reworking of till material appears to have occurred, and this is also indicated by the poor sorting co-efficients.

Although the bottom material is homogeneous over the field, a tendency towards more fine-grained sediments towards the north is reported (Bakke et al., 1989), probably reflecting the gentle slope towards a bottom depression north of Heidrun. The Heidrun

Element	Total Average 1988 *	Range 1988 *	Station 4 1985 **
Organic Compounds:			
TOC %	0.52	0.44 - 0.63	0.38
EOM mg/kg	-	-	12.6
THC mg/kg (IR)	4.9	1.0 - 10.0	-
THC mg/kg (GC)	2.92	0.80 - 8.99	2.58
NPD mg/kg	0.018	0.004 - 0.030	0.018
Metals:			
Cd mg/kg	0.081	0.056 - 0.130	-
Cr mg/kg	24	16 - 33	<20
Cu mg/kg	8.8	6.3 - 12.0	<20
Pb mg/kg	17	10 - 29	-
Ni mg/kg	20	15 - 29	<20
V mg/kg	35	27 - 53	60
Zn mg/kg	43	30 - 56	110
Fe g/kg	16.8	12.2 - 22.2	24.8
Ba mg/kg	160	65 - 543 (1200	340
Sr mg/kg	270	210 - 370	-
Hg mg/kg	<0.1	<0.1 - <0.1	-
Other Factors:			
Mud %	44.1	25.6 - 64.0	79.5
Eh mV	+ 456	+363 - +529	+353
pH	-	-	6.9

* from Bakke et al., 1989 ** from Bowler et al., 1986

Table H.2.1. Average Levels of Chemical Components in the Surface Sediments at Heidrun.

area does not stand out from other areas of Haltenbanken with respect to grain size composition (Bowler et al., 1986).

The fineness of the sediment suggests that the Heidrun field is a low energy area where deposition predominates (see Section C.2.3).

Redox conditions at 2 cm sediment depth showed no gradients across the Heidrun field and were typical for well oxygenated sediments (Table H.2.1). The Haltenbanken survey indicated that the bottom is oxygenated at least down to 8 cm below the sediment surface. The sedimentary pH is only known from one site at Heidrun (pH 6.9), but in general, the pH values in the north of Haltenbanken were reported to be somewhat lower than in the south (Bowler et al., 1986). The low pH may reflect an intensive mineralisation of organic matter in the sediments.

2.3 Chemical Characteristics of the Sediments

The average total organic carbon content (TOC) of the sediment at Heidrun (0.52%, Table H.2.1) is slightly higher than the average found for the whole of Haltenbanken (0.40%). There was no apparent gradient in TOC levels across the field.

The content of "extractable organic matter" (extracted with dichloromethane: hydrocarbons, esters, alcohols, glycerides, ketones, resins, and pigments) is known from one site at Heidrun (Bowler et al., 1986). The level was within the range for the rest of Haltenbanken and is considered normal for unpolluted sediments.

The fairly homogeneous total hydrocarbon levels measured by IR at Heidrun (Table H.2.1) are typical for unpolluted sediments with similar physical characteristics, and were comparable with earlier data from Haltenbanken.

Corresponding concentrations of total hydrocarbons from analysis by gas chromatography, including both aromatic and aliphatic compounds, are similar to background levels found in the North Sea. The gas chromatograms verified the chemically homogeneous nature of the sediments.

Concentrations of normal alkanes in the range C12-C35, are comparable to, although in the lower range of, previous background levels for the North Sea (Bakke et al., 1989). The composition of normal alkanes suggests a predominantly biogenic input.

Bicyclanes, being indicative of oil based drilling fluids, have not been detected at Heidrun.

The naphthalene, phenanthrene, dibenzothiophene (NPD) concentrations (Table H.2.1) are within the range found elsewhere for uncontaminated sediments, and the composition of total polyaromatic hydrocarbons indicates no particular influence from petrogenic sources.

Some of the trace metals analysed in the Heidrun sediments are priority pollutants in most monitoring studies (cadmium, zinc, vanadium, chromium, copper and mercury). Some elements are constituents in produced water, whereas the source for elements like barium, chromium, lead and nickel is to a large extent drilling fluids.

The analytical procedure in the Heidrun survey applied a slightly milder extraction than in the Haltenbanken survey, but still the results from the two surveys are reasonably comparable. Mercury was not detected in any of the samples. The content of barium (65 to 543 mg/kg) is also within background concentrations. One sample falling outside of this range (1,200 mg/kg), was recovered from a station in the vicinity of an exploratory well, and indicated slight contamination from drilling activity. No indication of contamination at this site was observed for any other element or chemical parameter analysed. Except for this observation, no evidence of metal zonation within the Heidrun area has been found.

The conclusion drawn from the Heidrun survey is that the sediment samples collected represent an homogeneous, undisturbed seabed.

2.4 Benthic Macrofaunal Communities

A thorough assessment of the benthic fauna from the Heidrun baseline survey was reported by Bakke et al., 1989. The Heidrun faunal characteristics were also set in a wider geographical context in the Haltenbanken baseline survey (Bowler et al., 1986). The purpose of these surveys has been to characterise the existing macrofaunal communities, such that changes due to the Heidrun field activities, and those of the wider Haltenbanken developments could be monitored.

The conclusion from the Heidrun survey is that the seabed sediments contain an homogeneous and highly diverse macrofaunal community, with a slight gradient in composition from southwest to northeast, primarily due to changes in sediment grain size composition.

Diversity index values were among the highest recorded for an offshore locality, and no signs of environmental disturbance were detected.

The number of individuals larger than 0.5 mm recovered from five 0.1 m^2 grab samples at each of 25 stations in the Heidrun field, ranged from 285 to 814 (Figure H.2.2b), representing between 71 and 109 taxa (i.e. species or higher systematic groups) (Figure H.2.2a). Evidence suggested that the sampling had recovered somewhat less than 80% of the real number of taxa present in the surface sediment.

The correlation between number of taxa and number of individuals in the samples was strongly positive, which resulted in small variations in evenness and dominance values across the field. Evenness was in general high (Pielou (1966), index values 0.86-0.90) and dominance low (Simpson (1949), index values 0.022-0.035).

Diversity expressed by the Shannon-Wiener information index Hs (Shannon and Weaver, 1963) was also very high and stable, and within the range 5.47-5.93 (Figure H.2.2c). Correlation analysis suggested that diversity was more a function of species richness than of the evenness in distribution of the individuals among the species.

Another index of diversity, the expected number of species per 100 individuals (ES100), based on Hurlbert (1971) rarefaction curves, attained values between 43.3 and 49.1, which is very high. In theory, a value of 50 implies that every second individual encountered in a sample of 100 individuals can be expected to represent a new species. The ES100 values were higher than has been found in clean coastal and fjord communities along the coast of Norway (Rygg, 1984). None of the diversity indices showed any systematic change across the Heidrun area.

The numerically dominant animal group in the sediment was the polychaetes (bristle worms). At 18 of the 25 stations analysed by Bakke et al. (1989), the most abundant species was a polychaete, with *Spiophanes kroeyeri* being the most abundant. Other numerically important animal groups were sipunculids, ascidians, bivalves and crustaceans. The presence of sponges, bryozoans and ascidians indicated that the scattered pebbles and stones in the sediments supported a hard bottom fauna.

The most abundant species represented both pollutant sensitive and tolerant forms. Some (e.g. *Chaetozone setosa*) are classified as opportunistic. They have high reproductive ability, short generation time, and prosper under disturbance and medium pollutant stress. The densities of *C. setosa* recorded in the Heidrun field were far below those found at polluted sites, and similar to North Sea baseline densities (Hobb, 1987). The stations having the highest densities of this polychaete were not linked to earlier drilling or other exploration activity.

Although slight gradients in densities were recorded for several of the species, the gradients were not systematic. Figure H.2.3 shows the distribution of four of the important species.

The distribution of the individuals upon the species conformed reasonably with the log-normal pattern characteristic for undisturbed communities (Pearson et al., 1983).

The similarity between the stations on the basis of macrofauna was analysed to see if any particular grouping of stations, according to similarity, was apparent. Grouping of the stations by two different multivariate analysis methods, cluster analysis and ordination (multidimensional scaling, MDS), gave no consistent result when comparing the same similarity analyses, although some stations were always grouped together (Figure H.2.4). Lack of correspondence in grouping is to be expected if highly similar units are grouped by different computational procedures.

Figure H.2.2 Macrofaunal Characteristics at Heidrun, June 1988. a: Number of Species. b: Individual Densities. c: Shannon-Wiener Diversity.

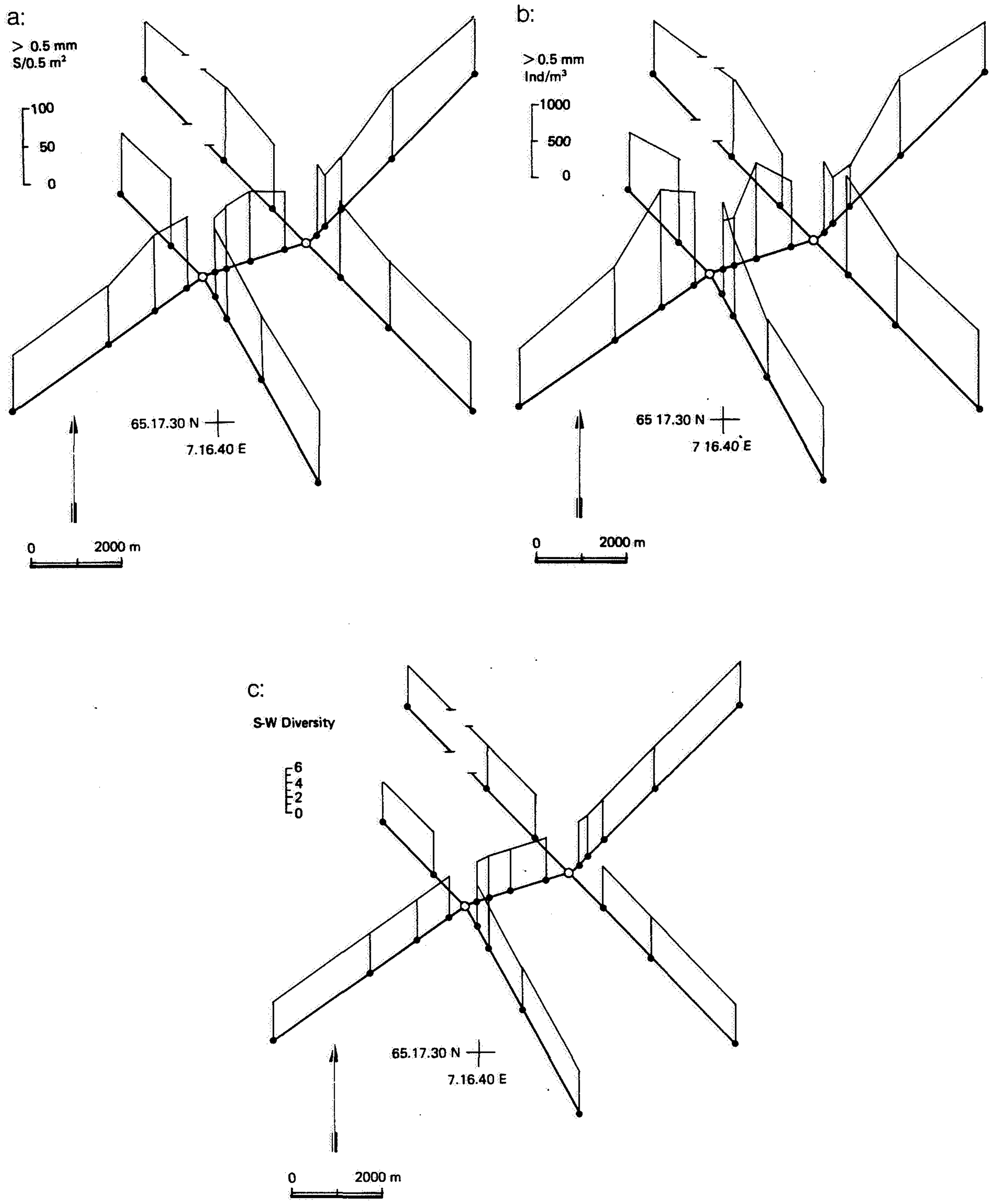
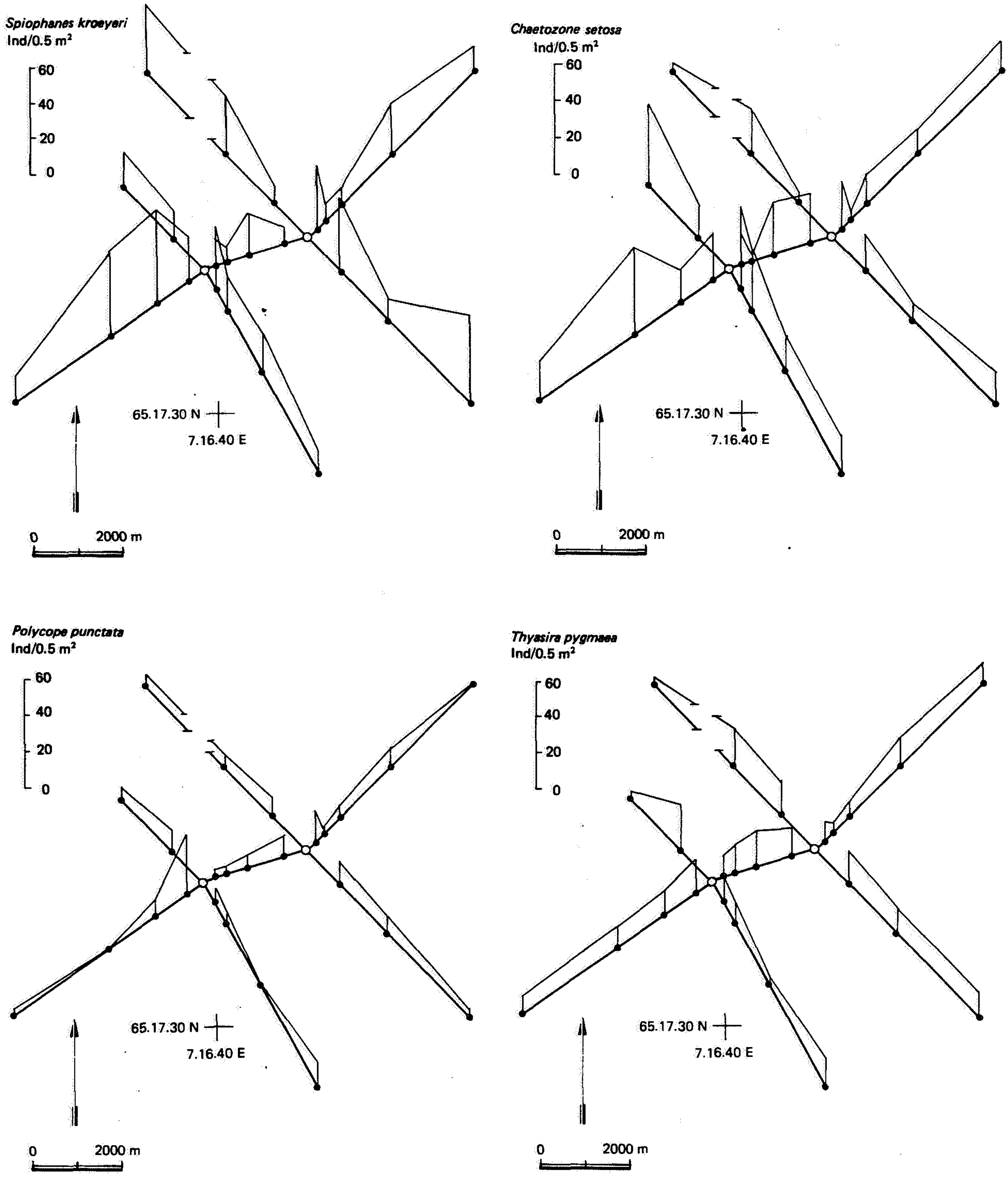


Figure H.2.3 Density Distribution of Four Dominant Macrofaunal Species at Heidrun, June 1988.
a: *Spiophanes kroeyeri.*
b: *Chaetozone setosa*
c: *Polycope punctata.*
d: *Thyasira pygmaea*



The only clear trends reported from this analysis were that, a) the reference station 17 km to the northwest of the field centre was separated from the other stations, and b) that the groups of stations defined by the MDS analysis were arranged largely in a southwesterly to northeasterly pattern across Heidrun (Figure H.2.4). Furthermore, these groups differed slightly, but significantly, in terms of the percentage silt/clay in the sediments. It was also shown that the percentage silt/clay correlated negatively with diversity, i.e. highest diversity was linked to the lowest percentage silt/clay.

Bowler et al. (1986) concluded that there were no clear gradients in macrofaunal structure across Haltenbanken, and that the single station investigated in the Heidrun area, conformed with those in the regions further south.

The mean number of taxa per station found at Heidrun (Bakke et al., 1989) conforms with the 1985 Haltenbanken survey results (Bowler et al. 1986). However, the range across the stations was larger in the latter, which is expected, since the geographical region covered was greater and differences in parameters such as depth and grain size were more marked.

Similarly, the Shannon-Wiener diversity index range was larger across the whole of Haltenbanken than at Heidrun, but the mean diversity was highest at Heidrun.

At comparable stations in the Heidrun area, the number of individuals larger than 1 mm found in 1988 was 3-4 times as high as in 1985, and the number of taxa twice as high. Such a change in species richness and abundance would be remarkable over 3 years, in an area which gives an overall impression of faunal homogeneity. Although a natural shift in the fauna may have occurred, there is reason to believe that the differences observed between 1985 and 1988, could relate at least to some extent to procedural differences between the two surveys.

Eleftheriou and Basford (1989), found 25-79 taxa per grab haul at 76 stations over a large area in the northern North Sea. The corresponding range at Heidrun was only 19-63, despite the fact that Eleftheriou and Basford (1989) had a slightly lower resolution in their species identification scheme.

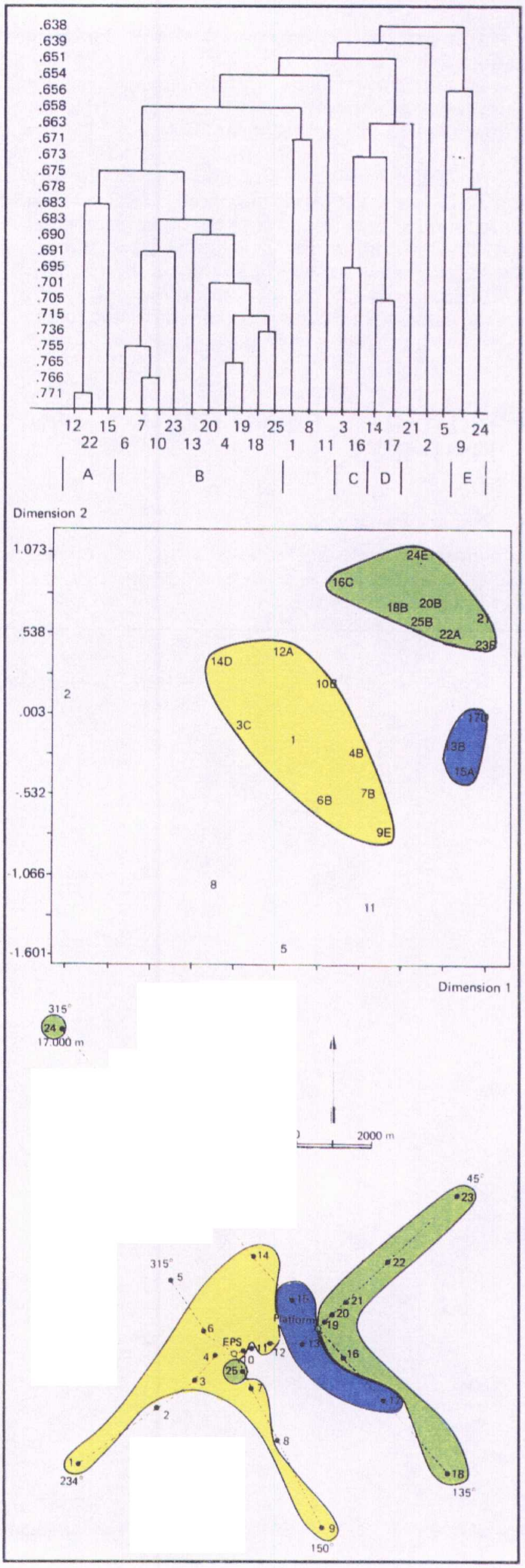


Figure H.2.4 Station Faunal Similarity at Heidrun, June 1988.
a: Station Groups A-E According to Cluster Analysis. b: Station Groups According to MDS Analysis (Defined Groups are Colour Shaded. Position of the Cluster Analysis Groups are Indicated by Their Letters A-E Next to the Station Number) c: Distribution of the MDS Groups of Stations in the Heidrun Area.

Furthermore, the Institute of Offshore Engineering (1985) found 136-177 taxa per station at the outer stations of the Statfjord field. This suggests that the species richness at Heidrun (71-109 taxa) is slightly lower than further south, which could be linked to the greater depth and finer sediment.

On the other hand, the Shannon-Wiener diversity and ES100 values at Heidrun appear to be similar to those found at Statfjord, due to the higher individual densities in the latter. ES100 values at Heidrun were also higher than corresponding values in the northern North Sea in general (Eleftheriou and Basford, 1989), but the values are not directly comparable due to different levels of species identification.

3. PRIMARY PRODUCTION AND FISHERIES

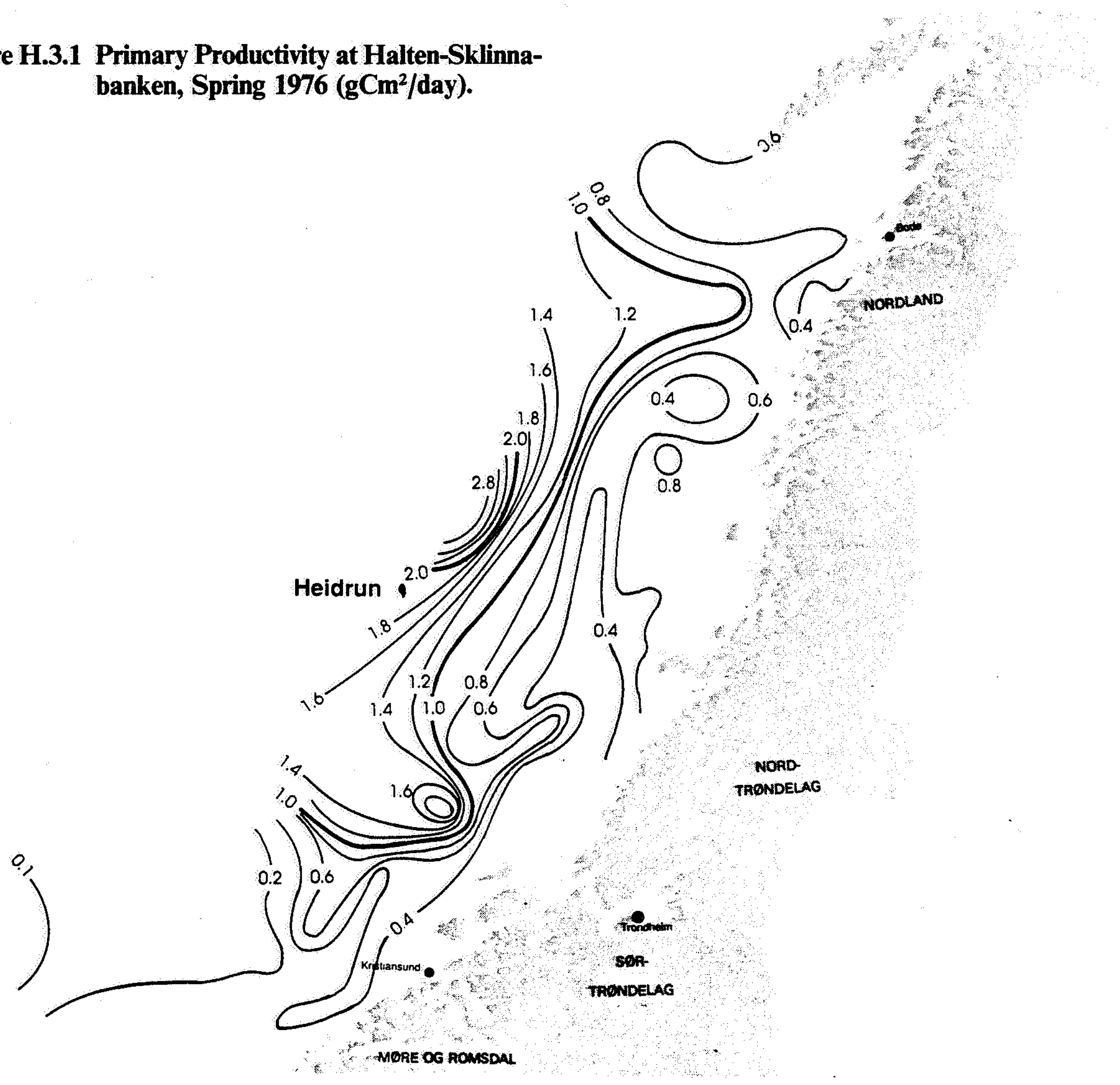
3.1 Primary Production

In connection with the proposed expansion of petroleum activities to the north of 62°N, the Institute of Marine Research has since 1975, carried out a series of environmental investigations in the Haltenbanken area (Rey, 1981a). Primary productivity studies have been performed as part of this programme.

It has been shown that the vertical stability of the water column is decisive for initiation of the spring bloom in coastal areas north of 62°N (Rey, 1981b). Three main regulating factors are involved: the interaction between Atlantic and coastal waters, wind conditions during the spring season and some local hydrographic conditions.

A typical set of primary production data for the spring situation on Halten-Sklinnabanken is presented in Figure H.3.1. It reveals a considerable variation in daily production rates. Maximum primary production values are usually found during spring, with decreasing values during summer (Rey, 1981a). In offshore regions, the values continue to decrease through the autumn, whereas near the coast, a small production maximum can be observed. These factors give rise to a relative percentage distribution of primary production during spring, summer and autumn for offshore and coastal regions in the order of 60, 20 and 20% and 40, 40 and 20%, respectively.

Figure H.3.1 Primary Productivity at Halten-Sklinnabanken, Spring 1976 (gCm²/day).



An extremely high primary production value of 7.8 g Carbon m^2/day was measured in May 1978 on Haltenbanken (Rey, 1981a). Primary production values throughout the year at Haltenbanken, would, however, typically be expected to range from 5 mg C m^2/day in winter, to 1200 mg C m^2/day in May, which leads to a yearly integral of 100 g C m^2.

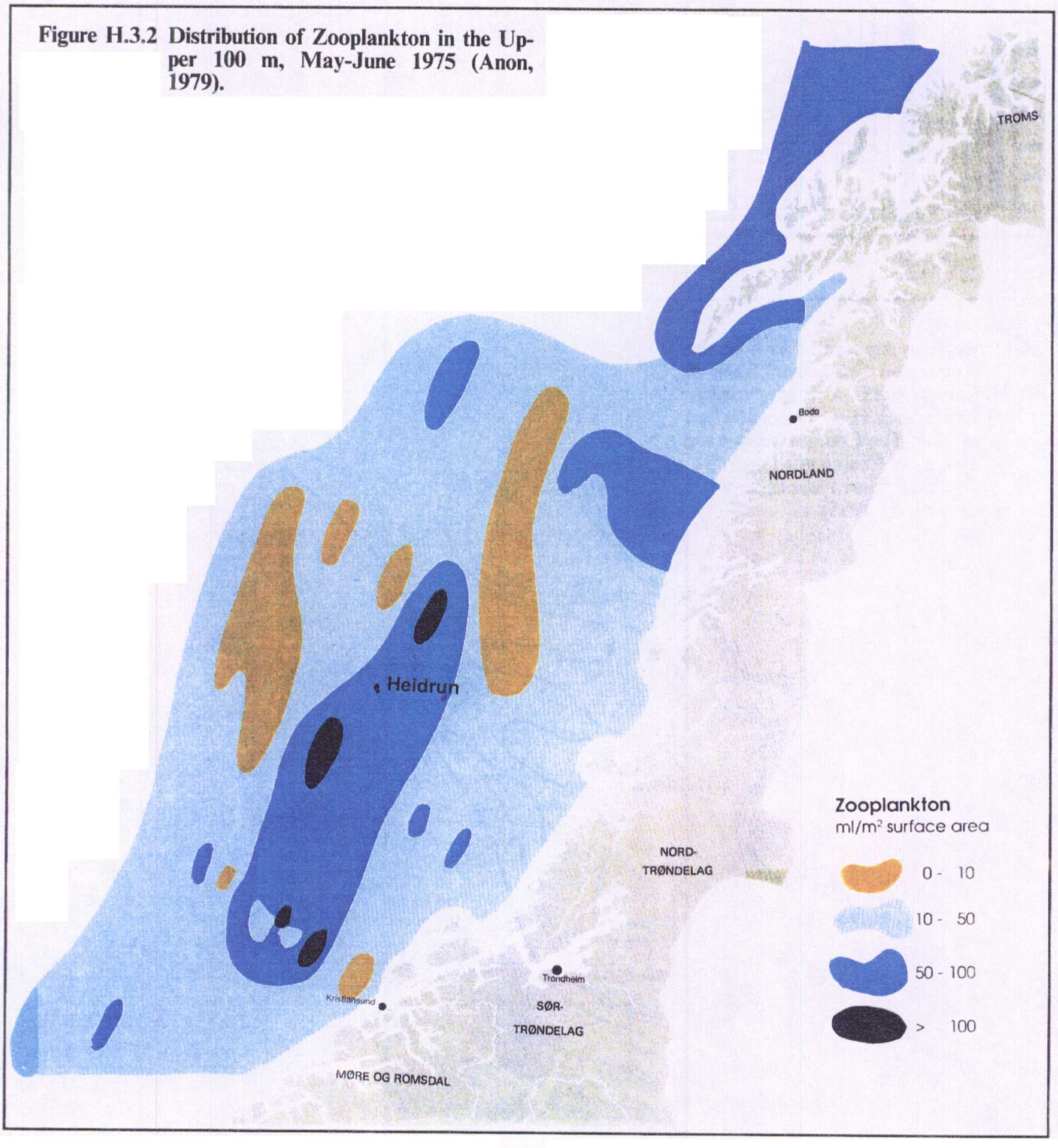
3.2 Zooplankton

The distribution pattern of zooplankton in the upper 100 m along the coast during May-June 1975 is shown in Figure H.3.2. It reveals large but patchy stocks of zooplankton, often exceeding volumes of 100 ml m^2 in the Haltenbanken area. As the zooplankton consists mainly of primary consumers, successful growth depends on a sufficiently good supply of phytoplankton.

3.3 Fish Stocks

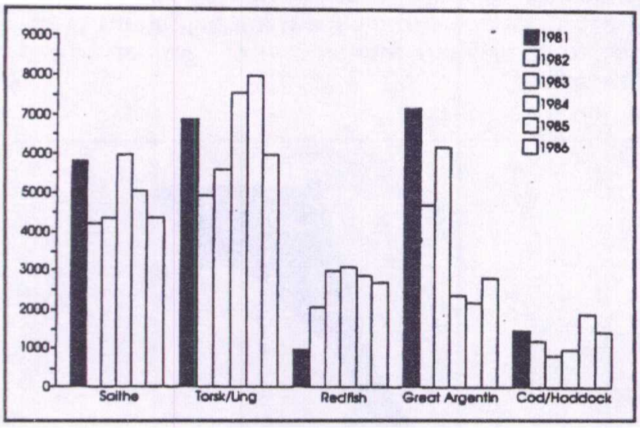
The Norwegian continental shelf is an area with large fishery resources (Figure H.3.3), and Haltenbanken is particularly valuable as it contains spawning and nursery grounds for several commercially important species. A prominent feature of note with regard to the general area, is the Norwegian Coastal Current, which forces species with pelagic eggs and larvae to perform countercurrent spawning migrations in order to compensate for the drift of eggs, larvae and juveniles.

Figure H.3.2 Distribution of Zooplankton in the Upper 100 m, May-June 1975 (Anon, 1979).



Landings of fish from the Haltenbanken area are sizable, with saithe, ling, torsk, redfish, cod and great argentin being the most important. Figure H.3.4 shows the total landings of the key species in area 06, which includes Haltenbanken.

Figure H.3.4 Norwegian Catches of the Most Important Fish Species in Metric Tons/Year, from the Haltenbanken Area (Stat. Area 06) in the Period 1981-1986 (NT Consult A/S, 1988).



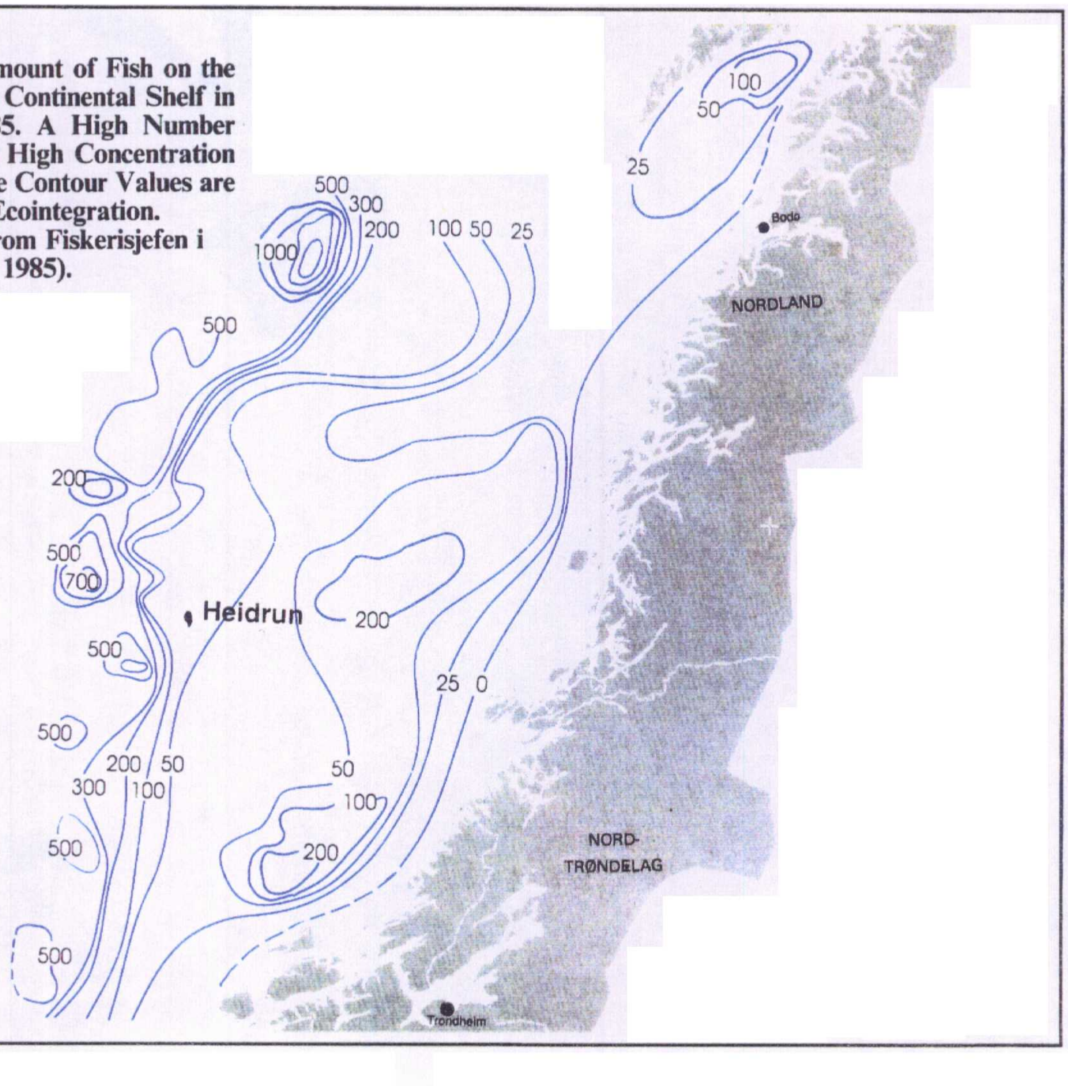
Species which spawn and have nursery grounds in the Haltenbanken area are cod, saithe, haddock, herring, plaice, redfish, ling, torsk, great argentin and crab (see Table H.3.1). Some of these species are for the time-being not important for the fisheries in the Haltenbanken area, but may be of importance for other areas. Other species, such as herring, were considered of commercial value until the end of the 1960's, when stocks became severely depleted through overfishing.

Information on the spatial and temporal distribution of fish eggs and larvae on the Norwegian continental shelf, including Haltenbanken, has improved since the introduction of the HELP programme in 1986. Regular reports are issued by the Institute of Marine Research in Bergen, and these have been accessed to provide the latest information revelant to the Heidrun field. Use of such information in predicting the effects of any oil spill on fisheries stocks is discussed

3.3.1 Commercially Important Species

The most commercially important fish species in the Haltenbanken area are discussed below (see also Table H.3.2). These include saithe and arcto-Norwegian cod which spawn within or to the south of Haltenbanken. Furthermore, a component of the

Figure H.3.3 Relative Amount of Fish on the Norwegian Continental Shelf in Spring 1985. A High Number Indicates a High Concentration of Fish. The Contour Values are Based on Ecointegration. Modified from Fiskerisjefen i Trøndelag, 1985).



Species	Period	Spawning Depth (m)	Site	Eggs Depth (m)	Larvae Depth (m)
Cod	Mar-May	50-200	Møre to Lofoten Haltenbanken	<50	<50
Saithe	Jan-Apr	100-200	Lofoten and South	<30	Pelagic
Herring	Feb-Apr	Bottom	Stadt to Lofoten	Bottom	130
Great Argentin	May-Sep	300-500	Shelf Area	Deep Pelagic	Deep Pelagic
Haddock	Mar-Jun	100-500	Møre to Lofoten	Pelagic	10-40

Table H.3.1 Spawning Characteristics of Some Major Species Within the Heidrun Influence Area

spring spawning herring stock also spawns outside Møre.

a) Cod

Cod spawning takes place from the end of March to the beginning of May. The most important spawning grounds are in the Lofoten area, outside Møre and Romsdal and in the Haltenbanken area. Cod spawns pelagically at depths between 50 and 200 m, depending on the depth at which the required temperature range of 4° - 6° C is found. Eggs are distributed in the upper 50 m of the water column, with an increasing concentration near the surface. During periods of low wind speed, some 80% of the cod eggs may be concentrated in the upper 20 m. This figure can be expected to decrease to 50% in a fresh breeze.

Eggs hatch after about three weeks. Most of the larvae can then be found in the upper 30 m of the water column, with a maximum concentration between 10 and 20 m. The wind speed will once again influence the vertical distribution. The cod stock is presently at a very low level (Fisken og havet, 1989) and restrictive quotas can be expected in coming years if the fishery is to be rebuilt.

b) Saithe

The saithe stock spawn in the period from January to April, at a depth of 100-200 m, and at temperatures between 6° and 10° C, from Lofoten and southward along the Norwegian coast. The main spawning grounds lie outside Møre and within the Haltenbanken area, and Lofoten. On Haltenbanken, the main spawning appears to start in the first half of March (HELP report no. 16).

The results from the HELP programme indicate a low concentration of saithe eggs in the upper 30 m, but the data are poor. However, saithe eggs are buoyant and may be concentrated near the surface in calm weather conditions. The distribution of saithe eggs in the period from February to April 1987 is shown in Figure H.3.5.

Little is known of the vertical distribution of newly hatched saithe larvae. (HELP report no. 19).

Saithe are usually confined to coastal areas, and are seldom found at depths exceeding 200 m. The stock has been at a low level during the last few years, but appears to be increasing slowly (Fisken og havet, 1989).

c) Herring

The main spawning areas for the spring spawning herring are along the coast from Stad to Lofoten, where the substrate consists of rock, gravel or shell sand. An important spawning area is also located in Haltenbanken, southeast of the Heidrun field.

Herring spawn in the period from February to April, with a maximum intensity in the first part of March. After spawning, the eggs sink to the bottom and adhere to the substrate, where they remain for approximately three weeks until hatching.

Institute of Marine Research data indicates that about 50% of the herring larvae are distributed in the upper 30 m (HELP report no. 19). Following a massive reduction in the stock through overfishing, a system of strict fishing quotas and control has led to slow improvements in stock status over the last decade.

d) Great Argentin

The stock of great argentin is distributed along the Norwegian coast from Skagerrak to East Finnmark. The species is pelagic and can be found at depths of 100-900 m, but more commonly from 300-600 m. The mature population is found in the deeper part of the depth range, and the younger individuals mainly above 300 m.

Significant stocks are found on the continental edge west of the Heidrun field. This population of great argentin is one of the most important for the local fisheries in the Haltenbanken area. The eggs are pelagic, but little is known about the vertical distribution of either eggs or larvae.

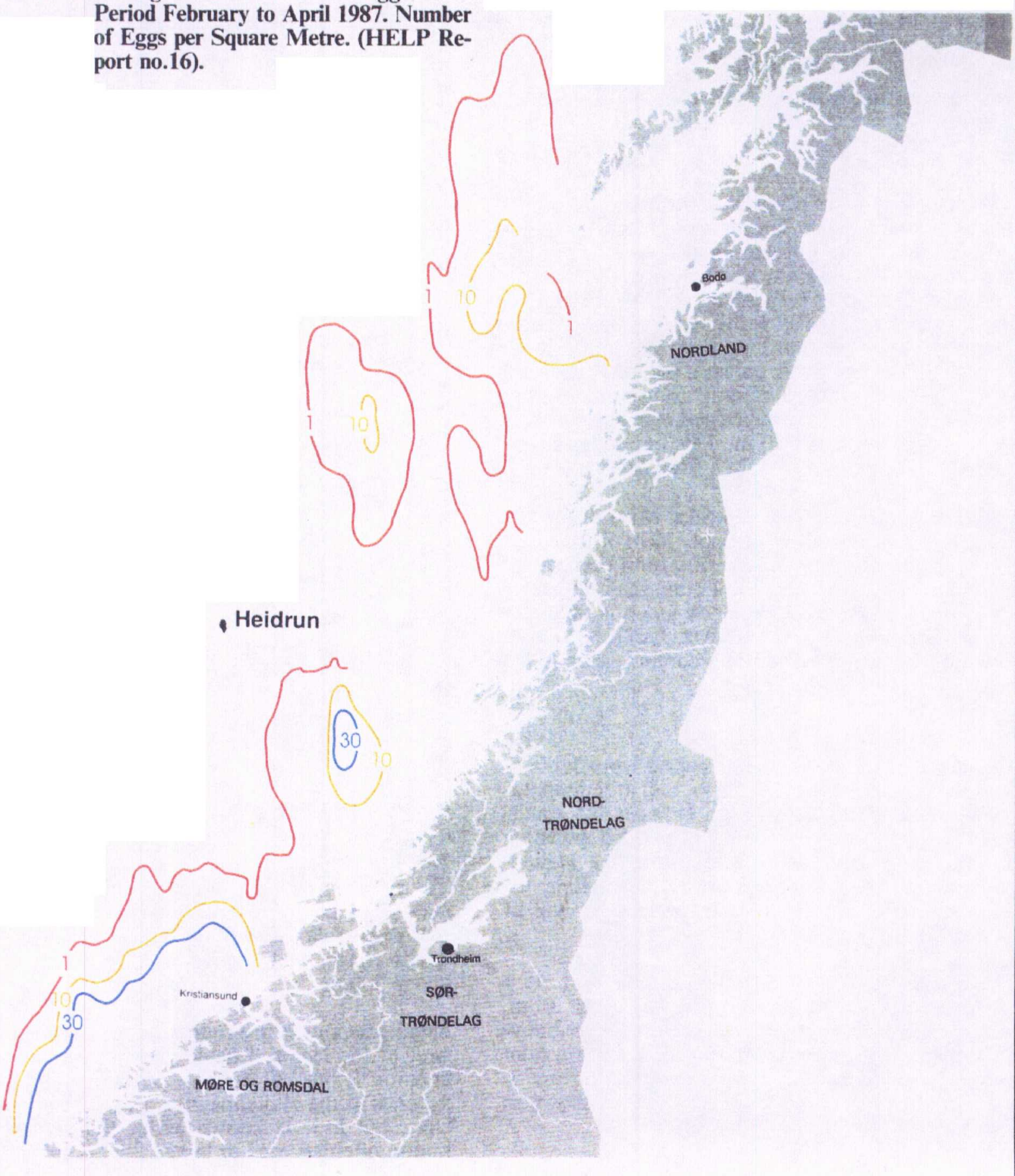
During the past few years there has been increasing interest in the great argentin fishery north of 62°N. This fishery takes place throughout the year, but is most active in April and May. Traditionally it has been a bottom trawl fishery, concentrated on Sklinnadjupet in spring, and Suladjupet in autumn. More recently, experimental mid-water trawling has been undertaken (flytetrål). The most important area has been the edge of the continental shelf outside Helgeland, and further development of the fishery can be expected (Fisken og havet, 1989).

e) Other Species

Haddock spawn in the period March-June at a depth of 100-150 m. The spawning grounds are more diffusely located than are those of the migratory cod, and larvae are transported with the Coastal Current in the depth range 10-40 m.

Ling is most abundant along the Norwegian coast between Stad and Vesterålen at a depth of 300-400 m. This species spawns along the coast as far north as Vesterålen.

Figure H.3.5 Average Number of Saithe Eggs in the Period February to April 1987. Number of Eggs per Square Metre. (HELP Report no.16).



Redfish is distributed all along the Norwegian coast. It is found both on the continental shelf at 100-500 m depth, and mesopelagically. Important spawning grounds are located in the Vesterålen and Lofoten areas. Mature redfish are distributed in deep water and the eggs and larvae in shallower water.

3.3.2 Offshore Fisheries

Haltenbanken is located within area 06 of the Norwegian fisheries statistics, and landings of the most important species from this area for the period 1981-1986 are shown in Figure H.3.4. The Heidrun field is, however, also located close to area 07, and fisheries in both statistical areas have been considered here.

During 1981-1986, the total Norwegian catch outside the base line ("grunnlinjen") in area 06, ranged from 17,000 tons (1982) to 29,000 tons (1984). The landings from 06 represented on average approximately 1% of the quantity and 3% of the value of the total Norwegian fisheries. Within the same period, the landings from area 07 represented on average, approximately 2% of the quantity and 3.4% of the value (NT Consult, 1988).

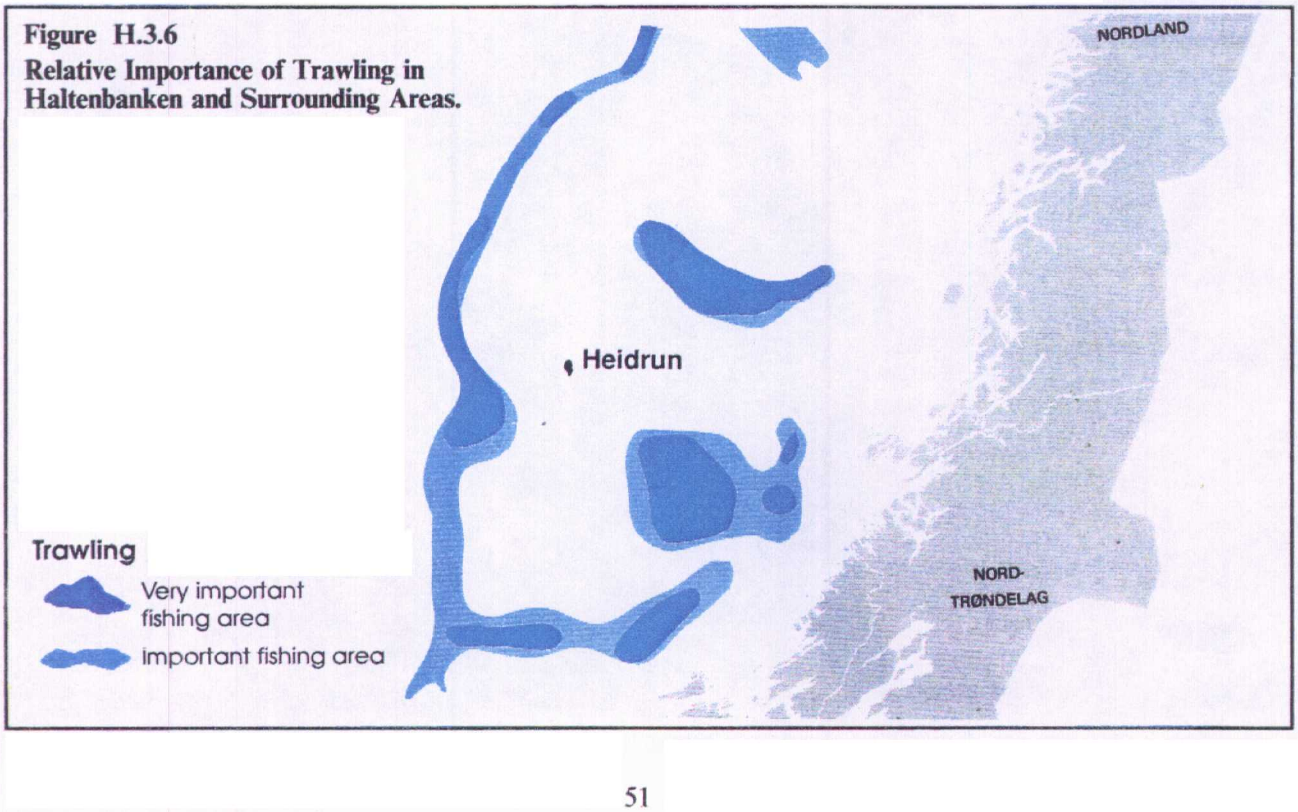
Fishing activity in the Haltenbanken area, especially the long-line fishery, is dominated by vessels with an overall length of 20 m or more. Vessels come mostly from the municipalities of Averøy, Giske, Haram and Fræna in Møre and Romsdal. Participating vessels from Sør-Trøndelag, Nord-Trøndelag and Nordland tend to be smaller in size. The trawl fishery in this area is also important for vessels from Nordland.

Most of the catch from the area is landed in Møre and Romsdal (approximately 60% of the total catch in 1983). The municipalities of Ålesund, Fræna, Giske and Haram are the most important for landings from this area. In Nordland, most of the catches are delivered in Vestvågøy and Herøy. In Nord-Trøndelag , the municipalities of Vikna and Flatanger are most heavily involved, and in Sør-Trøndelag, catches are delivered mostly to the fish processing industry in Hitra, Frøya and Osen.

Location	Block	Species	Fishing Gear
0608	6406/1,2	Torsk/ling	Long line
	6406/1,4	Redfish	Trawl
0610	6408/1,2	Torsk/ling	Long line
	6408/1,2,3,5,6	Saithe	Trawl
	6408/1-6	Saithe	Gill nets
0613	6506/7,8	Torsk/ling	Long line
	6506/11,12	Redf./G.argent	Trawl
0614	6507/7,8,11,12	Torsk/ling	Long line
0615	6508/10	Torsk/ling	Long line

Table H.3.2 Major Fishing Areas Around the Heidrun Field (NT Consult, 1987 and 1988).

Figure H.3.6
Relative Importance of Trawling in Haltenbanken and Surrounding Areas.



The Heidrun field is situated in statistical area 0614, corresponding to blocks 6507/7 to 6507/12. The major fisheries at this location and key surrounding locations, or parts of them, are listed in Table H.3.2. The importance of the different parts of Haltenbanken and its surroundings are also presented in the form of fishing activity maps (Figures H.3.6, H.3.7 and H.3.8, NT Consult, 1988).

From the table, it can be seen that in the Heidrun area (location 0614), the long line fishery has been of particular importance, with torsk and ling being the target species. Basking shark has also been taken. It appears that nine long-liners are regularly fishing this location, but it must be underlined that the level of activity may differ from one year to another. Only minor trawl activity has been reported, and there appears to be no gill net fishery.

Figure H.3.7
Relative Importance of Netting in Haltenbanken and Surrounding Areas.

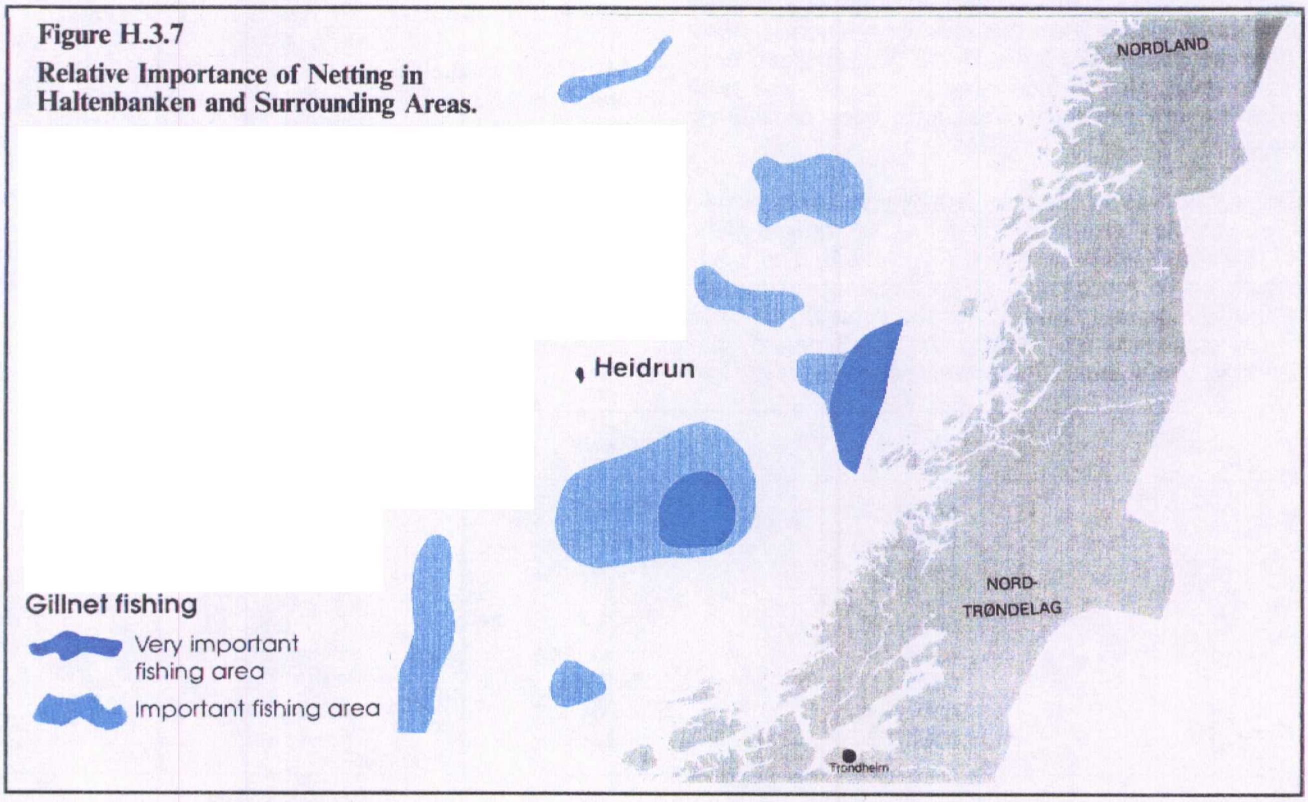
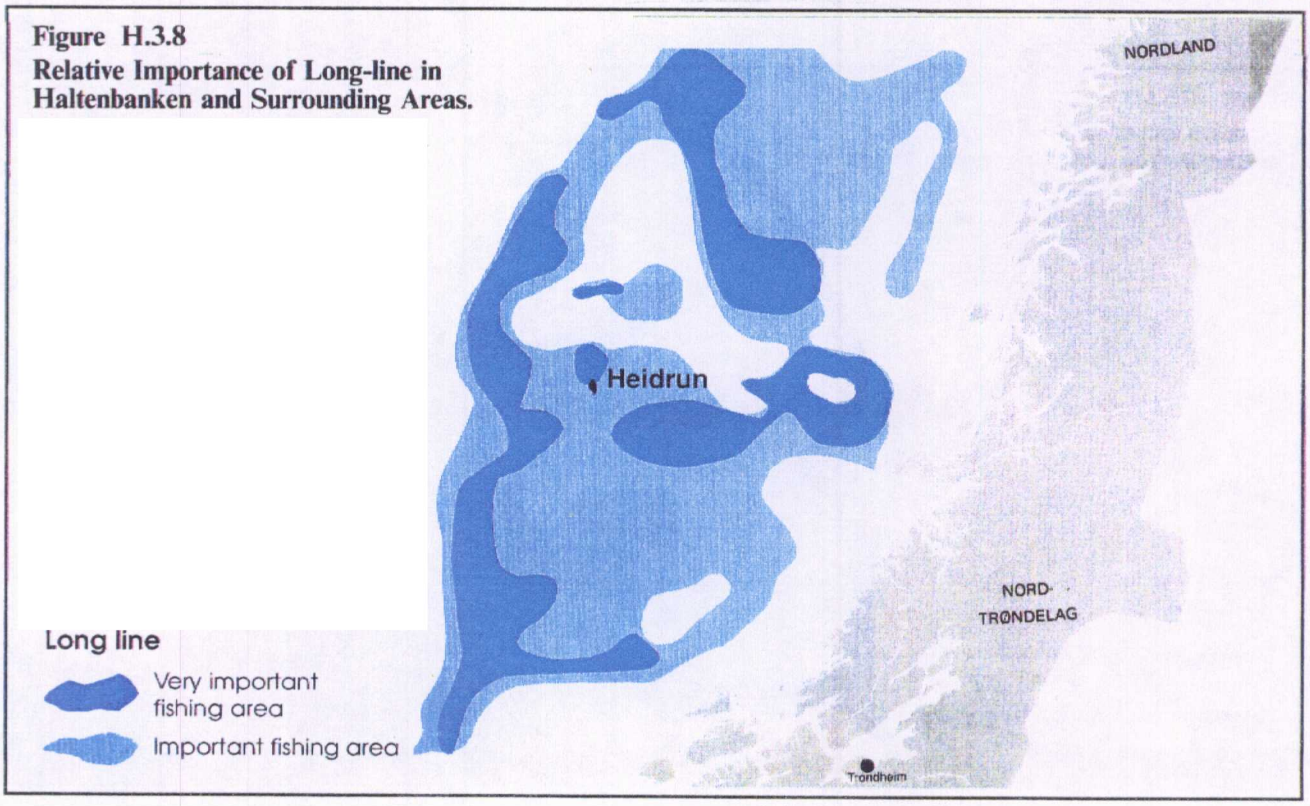


Figure H.3.8
Relative Importance of Long-line in Haltenbanken and Surrounding Areas.



Consequently, one can conclude that the long-line fishery is the most important in the vicinity of the Heidrun field, and that the area to the north of the platform is the most heavily fished. Activity is at its highest during February-March and October-November. Fishing for basking shark takes place mainly in blocks 6507/7,8,9 (NT Consult, 1987).

Fishing for great argentin has, up to now, been carried out in areas not expected to be influenced by Heidrun field activities or installations.

3.3.3 Inshore Fisheries

See also Section H.7 on aquaculture.

The inshore fisheries, i.e. the fisheries inside 12 nautical miles from the base lines, are especially important in Nordland. Approximately one third of the catches from the inshore fisheries are traditionally landed in the county, and this represents more than half of the total monetary value of fish landings in Nordland (Fishery Statistics, Central Bureau of Statistics for Norway). The emphasis on inshore fishing activity is also reflected in the composition of the fishing fleet, where small fishing boats predominate. The cod fishery is the most important both in terms of quantity and value.

4. SEABIRDS

4.1 Species and Geographical Area Covered

The category seabirds includes species which depend on the sea for the bulk of their nutrient resources. Greatest emphasis is placed here on species which are vulnerable to oil contamination according to a number of criteria; such as individual vulnerability to oil contamination, population size of vulnerable species, congregations of birds during critical periods, and localities which are more likely to be exposed to a major offshore oil spill drifting ashore, e.g. outlying coastal archipelagos and skerries.

The geographical area reported comprises the coastline between Ålesund (62°30'N) and Bodø (67°20'N), but some data from Runde in Møre and Romsdal county and Røst/Værøy in Nordland county, is included. The distribution maps cover a somewhat larger area, as they include data from between Stadt (62°N) and Lofoten/Vesterålen (68°30'N). This is a more extensive area than that covered by the maximum geographical extent of the Heidrun impact zone defined by oil spill drift modelling.

4.2 Annual Life of Seabirds

Abundance and distribution of seabirds vary seasonally. Some species, which breed in large conentrations, later spread out over larger geographical areas. Other species with a scattered breeding pattern, congregate in large flocks during migration, while moulting, and/or throughout the winter.

The most typical seabirds are restricted to marine areas on a year-round basis, and this is the largest and most important group of seabirds in Norway. Seasonal seabirds usually breed near freshwater, but rely on the sea during the remainder of the year.

The most important periods in the annual life-cycle of seabirds include:

Breeding
Post breeding movements by auks
Moulting waterfowl
Migration
Wintering
Open sea

A complicating factor in a description of the breeding season, is a period of colony attendance prior to egg-laying. This is a regular feature of the breeding biology of many species, but its length varies both within and between species. For example, in some auk populations, the first adult birds return to their breeding sites about 3-4 months before egglaying. At this time, large congregations of birds may be found on the sea close to their breeding sites.

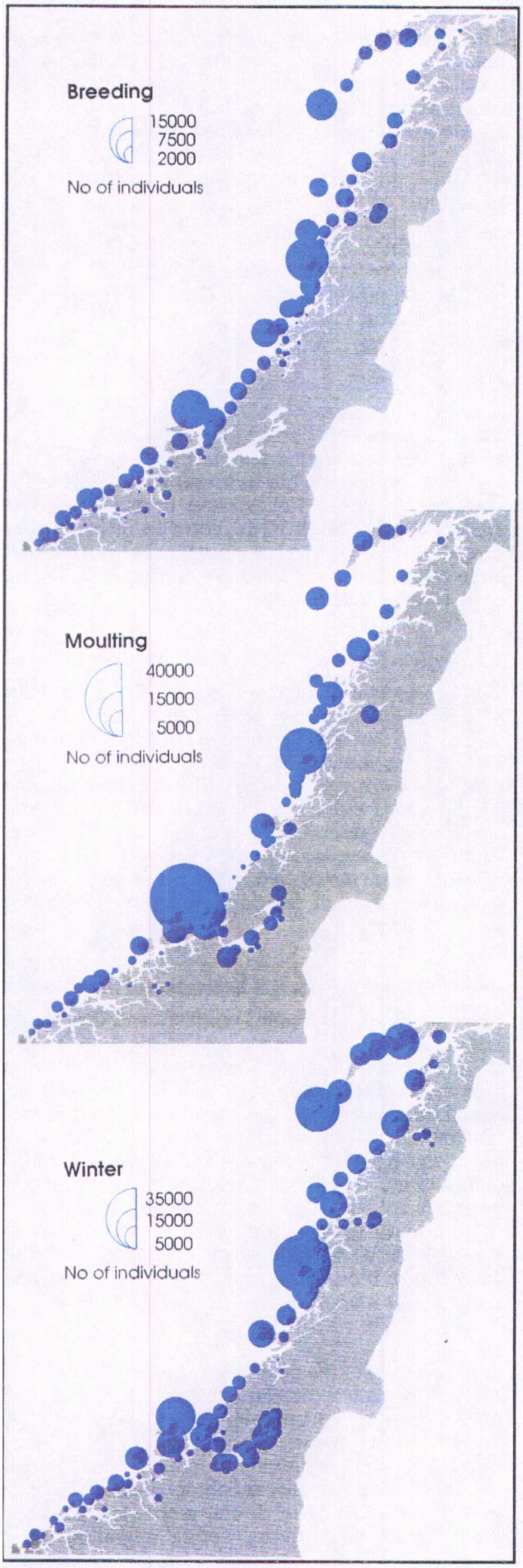
4.3 Seabird Ecology

A characteristic of typical seabirds is their low rate of reproductive capacity. They become sexually mature at 3 to 7 years (up to 10 years for the Fulmar), and in some species (e.g. most auks) the female produces only one egg per year. This low reproductive rate coincides with a low natural mortality for adults, which are in general longlived. In such a situation, even a slight increase in mortality of adult birds, may result in severe consequences for the population, due to their low rate of reproductive capacity and long recovery period.

4.4 Material/Methods and Evaluation of the Database

Information about seabird numbers and their distribution within the influence area of Heidrun is compiled from data stored by the Norwegian Institute for Nature Research (NINA). The data have been obtained from several sources, including projects carried out for the Royal Norwegian Ministry of Environment, the Royal Norwegian Ministry of Petroleum and Energy, the Directorate for Nature Management, several oil companies through Operatør komite Nord, as well as data from the Norwegian Ornithological Society and various private individuals. Most counts have been carried out according to standard methods for mapping seabirds (see review in Anker-Nilssen, 1987).

An evaluation of the data base shows that little if any of the information can clarify some critical situations in the event of an oil spill, such as post breeding movements of auks, the distribution of seabirds at sea (few data), and spring migration and roosting areas (no data). Even if occasional observations do indicate large concentrations of divers, grebes and ducks in some coastal areas during spring migration, these



observations are not indicated on maps as they may present a disorted picture of the actual situation.

The weaknesses and limitations of the data must be borne in mind when considering any evaluation of impacts. In many areas, only one count has been made and results presented here should be regarded as minimum numbers (Follestad et al., 1986; Anker-Nilssen, 1987).

4.5 Inshore Seabird Populations Within the Influence Area

4.5.1 Breeding Season

Between 2 and 3 million pairs of seabirds annually breed along the coast of Norway, representing breeding populations comparable in size with those of Great Britain, Ireland and Iceland (Røv et al., 1984). The cliff-breeding species are most numerous, but the main part of the population is outside the influence area of Heidrun. The influence area of Heidrun is, however, the main breeding area in Norway for several other species, which may be scattered along the coast or concentrated in a number of colonies.

The most important breeding areas for the Cormorant lie in the outer archipelago in Trøndelag and on the coast of Helgeland. About 70% of the Norwegian population of approximately 21,000 pairs breed in the influence area. Individuals are easily disturbed during the breeding season, and would quickly abandon the nesting area if humans approached. Cormorants spend parts of the day on resting or roosting sites. They may therefore be less affected by an oil spill, unless they are driven by disturbance away from the skerries into a slick.

Coastal areas of Trøndelag and Helgeland are the most important breeding grounds for the Common Eider in Norway (Figure H.4.3a). Eiders are associated with the sea throughout the year, and are among those seabird species which are highly vulnerable to oil contamination.

The auks are one of the most specialized groups of seabirds, but are also the seabirds most vulnerable to man's activities, especially oil pollution and fishing nets. Rough estimates (from Røv et al., 1984) of the number of individuals of auk species in colonies of cliffbreeding seabirds within the coastal area under study, are given below in Table H.4.1.

Heavy population declines in northern Norway during recent years, particularly for the Guillemot, imply that these populations must at present be regarded as extremely vulnerable to additional losses of adult birds.

4.5.2 Post Breeding Movements by Auks

Consideration of the post breeding movements of auks away from their colonies, is critical to an evalu-

Figure H.4.3 Distribution of Common Eider.
a: At Breeding b: At Moulting c: At Wintering

Colony	Razorbill	Guillemot	Puffin
Runde	3,200	10,000	75,000
Lovunden			60,000
Fugløy			10,000
Røst	4,000	< 1,000	700,000
Værøy	800	2,000	70,000

Table H.4.1. Cliffbreeding Auk Species at Selected Sites.

ation of the impact of oil spills from offshore installations. These data are therefore treated separately, although data from Norwegian coastal and offshore areas are scarce.

Following a period of twenty days confined to the breeding ledge, young Razorbills and Guillemots, which are as yet incapable of flying, take to the sea accompanied by one of their parents, usually the male. Together they embark on a swimming migration to wintering areas. They may take to the sea early in July at Runde, and somewhat later, in August, in northern Norway.

Adult birds start moulting abruptly and lose all of their remiges (large feathers in the wing) simultaneously. This temporary loss of flight ability is compensated by complete renewal of feathers later. The entire moulting process usually lasts about 40-50 days. Young birds are able to fly at about the same time as the adults.

Studies on the postbreeding movements of auks were performed at Runde in 1985 and 1988 (Follestad, 1988). A majority of the young Razorbills moved to the south in both years, and the present data therefore indicate that they would not normally be affected by an oil spill from Heidrun. The young Guillemots moved northwards in 1985, which has probably been the normal pattern for the 80's. In 1988, however, they moved southwards or into the fjords.

Haltenbanken appeared to be a very important area for Guillemots in 1985, and densities between 2 and 5 young Guillemots per km^2 were observed in August. In 1988, however, Haltenbanken was apparently of no importance for young Guillemots in July and August. This change in migration pattern is hard to explain, and results from earlier ringing of Guillemots would need to be analysed to ascertain whether such a migration pattern has occurred before. In 1988, the migration pattern may possibly have been connected to rich food supplies (high concentrations of herring fry) in the areas south and southwest of Runde.

4.5.3 Moulting Season

Like auks, waterfowl renew all large wing feathers simultaneously, during the course of a 3-4 week period between June and September. The actual point in time varies from species to species, and with the sex and age of individual birds. Waterfowl are incapable of flying during moult, and form large flocks, often in exposed areas off the skerries of the outer archipelago. Such flocks are extremely vulnerable to oil spills.

Divers and grebes also moult their remiges simultaneously, but little is known about their distribution during the moulting periods (autumn, Red-throated Diver and grebes: spring, other divers). Like other seabirds temporarily incapable of flying, divers and grebes must be regarded as highly vulnerable to oiling.

The four main waterfowl species within the influence area of Heidrun moult at different times, and it has been difficult to cover the actual moulting period for each species throughout the entire survey area.

The most important moulting areas for the Greylag Goose are Froan Nature Reserve and the Helgeland coast, including the island of Vega.

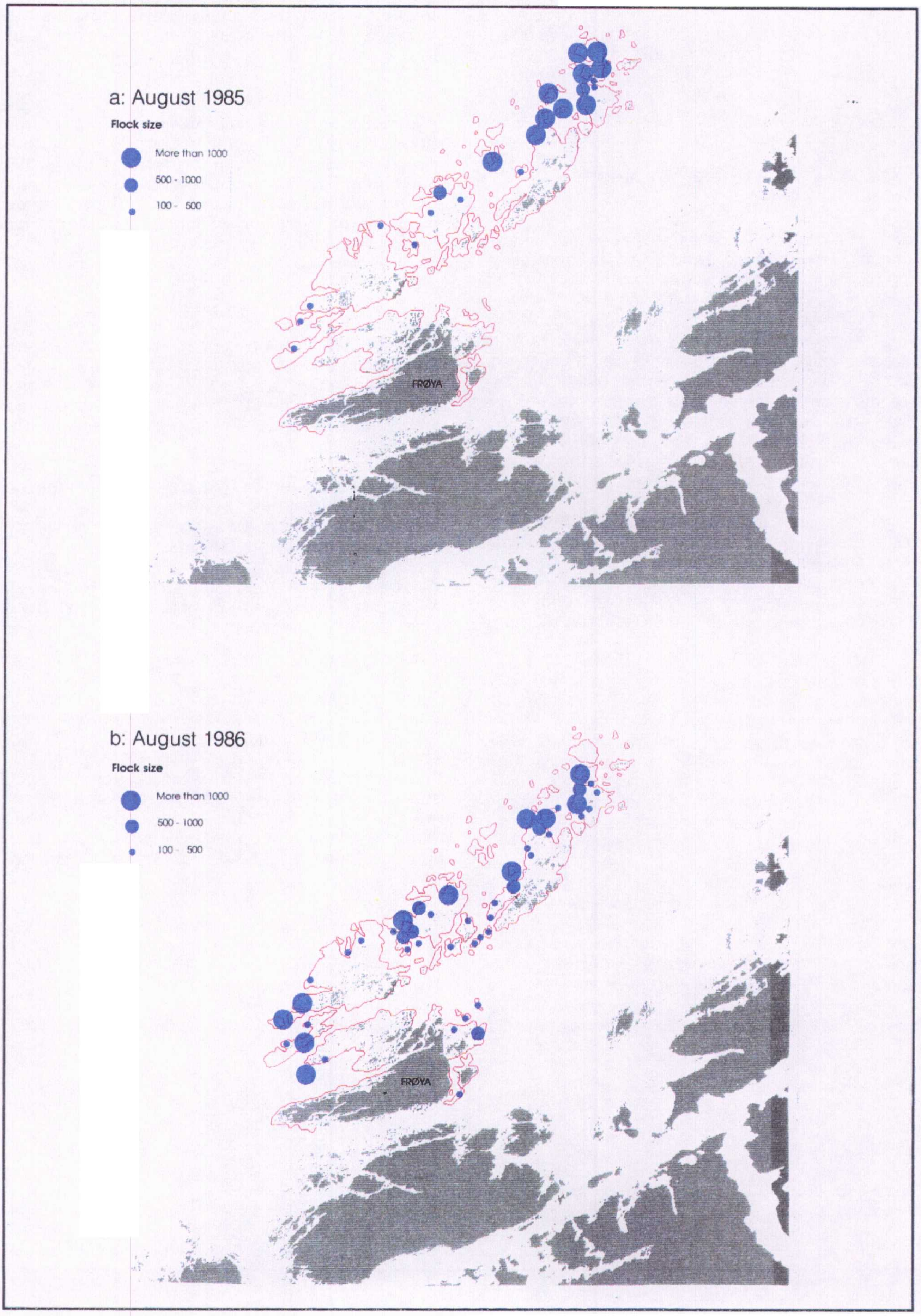
Froan Nature Reserve is without doubt the most important moulting area for the Common Eider in Norway. Totals of 36,000 and 29,000 Eiders, mostly adult males, were recorded in Frøya municipality in 1985 and 1986, respectively (Figures H.4.1 and H.4.3b). This number is considerably higher than that potentially recruited from the local breeding population. The extent of birds (Norwegian or otherwise) originating from other countries is unknown. Also, the island of Vega is an important moulting area for Eiders, as 12,000 were registered here in 1985.

Velvet Scoter is a marine species outside the breeding season, and is one of the least abundant of the sea ducks. During moult and in the winter, it exhibits flocking behaviour and has a very localised distribution. The moulting population of Velvet Scoter in the influence area is outstanding in Europe, and com-

County	Greylag Goose	Eider	Velvet Scoter	Red-breasted Merganser
Møre and Romsdal	900	13,000	550	1,300
Sør-Trøndelag	6,700	52,500	8,700	4,750
Nord-Trøndelag	1,900	7,500	260	750
Nordland (south)	8,800	24,000	1,600	2,800
Total	18,300	97,000	11,000	9,600

Table H.4.2. Moulting Waterfowl Species within the Heidrun Influence Area.

Figure H.4.1 Flocks of Moulting Eiders. (See also Figure H.4.3b).



prises a minimum of 11,000 individuals. Ørlandet is the most significant moulting area in Norway, and numbers increased to 7,000 individuals in 1985. Vega is the most important site in Nordland, and Smøla is another important site in Møre and Romsdal.

Mapping of moulting Red-breasted Mergansers has only been given priority in Frøya municipality. The total number presented is therefore an absolute minimum. Another important moulting area is located south of Vega on the Helgeland coast. The documented numbers are among the highest in Europe, with a moulting population of approximately 10,000 individuals. Birds congregating within the influence area of Heidrun, probably originate from a substantial part of their breeding range in Fennoscandia.

4.5.4 Migration

The extent to which different seabird species wander in search of food outside the breeding season is variable. It depends among other factors on the predictability of the food. This will vary between species, from those feeding on benthic organisms (e.g. mussels), with a reasonably good predictability, to those feeding on pelagic zooplankton or fish, with a very low predictability.

Present knowledge is largely confined to ringed birds, but recent research based on biometrics of dead birds may add new information on the origin of the wintering populations. Knowledge of the migrational movements of seabirds may be critical for evaluation of which seabird populations may be affected by an oil spill in a given area.

A better understanding of the winter and spring distribution of seabirds off central Norway, will require detailed studies of their diet in different areas at different times of the year. NINA has recommended that future studies on seabirds at sea, as well as inshore, give priority to oceanographic and biological factors that may influence the distribution of the birds at sea.

A rough comparison of recoveries of ringed seabirds indicates that birds from several populations winter within the influence area. Existing material is not, however, adequate for evaluating the composition of these seabird populations, or the extent to which certain populations may be affected in the event of an oil spill.

4.5.5 Winter

The Norwegian coast is an important wintering area for many seabirds, and for several species, it holds a significant part of the European population (for waterfowl, see Nygård et al., 1988).

Counting seabirds in Norway during the winter, with rough sea conditions, low temperature and short daylight hours is difficult. Thus existing information on wintering seabirds is mainly based on single counts, and variations from year to year may bias conclusions (Follestad et al., 1986).

Current knowledge of the status of some wintering seabird populations in the influence area of Heidrun, is given in Table H.4.3 (Seabird project, NINA, unpubl. data). This does not include those species for which a considerable part of the population remains offshore during winter.

Divers and grebes are, compared with most other seabird species, present in low numbers, but the wintering populations of some species in Norway are nevertheless outstanding in Europe. The influence area of Heidrun holds about 90% and 80% of the Norwegian winter populations of the Red-necked Grebe and Slavonian Grebe, respectively.

The principal wintering area for Shags, and in smaller numbers, Cormorants, are the archipelagos of Smøla, Hitra and Frøya. These species also winter in large numbers at several other localities. Of the total winter population of the two cormorant species, Shags make up about 70%. Ringing recoveries indicate: a) that the influence area is an important wintering area for

Species or Systematic group	Møre og Romsdal	Sør-Trøndelag	Nord-Trøndelag	Nord-land	% of Total Population in Norway
Divers	600	575	300	600	69
Grebes	1,650	650	180	300	79
Cormorants	19,000	18,000	6,000	13,000	62
Eider	25,000	50,000	33,000	160,000	65
King Eider	100	700	1,000	25,000	38
Velvet Scoter	4,500	8,000	3,200	5,000	69
Long-tailed Duck	8,000	11,000	4,500	20,000	51
Red-breasted Merg.	6,000	3,500	1,500	3,500	52
Black Guillemot	2,000	6,000	2,000	10,000	77

Table H.4.3. Current Status of Some Wintering Seabirds within the Heidrun Influence Area.

some of the north Norwegian Cormorant populations, and b) that Shags from Sunnmøre winter in large numbers north as far as Froan. Cormorant prefer shallow inshore water, and are rarely found far out at sea. This may to a greater extent be the case for the Shag.

The Common Eider is the most abundant coastal seabird species in Norway during winter, and its large year-round population is in many ways characteristic for the area under discussion. Counts within the influence area revealed approximately 160,000 individuals. The Eider is distributed along the whole coastline, but is especially numerous at the island of Vega (winter population about 25,000), and at Froan, Ørlandet, outer Vikna, Røst and Værøy. Annual mid-winter counts indicate a recent decline in the Eider population ((Seabird project, unpubl. data) Figure H.4.3c).

The King Eider is a high arctic species which does not breed in Norway. However, high numbers winter in northern Norway, often on very exposed localities. Røst and Værøy are important winter sites.

The Velvet Scoter has a very localised winter distribution. The most important wintering areas are Ørlandet, Smøla, inner parts of Frøya, Sandøy, Tarva in Bjugn, outer Vikna and Vega.

The Long-tailed Duck is distributed throughout the whole influence area, but has only occasionally been found in large concentrations. Long-tailed Ducks are often found far out to sea, and even large concentrations may have been overlooked during counts.

The winter population of Red-breasted Mergansers constitutes a sizable part of the European population. The origins of this population are unknown.

The influence area of Heidrun is the main wintering area for Sea Eagles in Norway. This species is entirely dependent on the sea for food, and fish and seabirds make up most of its diet. Consumption of oiled seabird carcasses by Sea Eagles may result in internal damage and poisoning.

Waders include several species for which wetlands are important habitats (e.g. the wetland system at Ørlandet). The winter population of Purple Sandpipers is of international importance.

The Black Guillemot is, unlike other auk species, associated with coastal areas during winter. Several locations within the influence area of Heidrun are among the most important wintering grounds for the species, particularly Froan and Vega. The other auk species, in particular Razorbill, Guillemot and Little Auk, may occasionally be found in large numbers close to the coast, often associated with a locally abundant food resource. They are, however, usually found in great numbers well offshore, and are more fully considered in Section H.4.6 below.

4.6 Offshore Seabird Populations within the Influence Area

Observations of seabirds at sea off the coast of central Norway have occasionally been made over the last few years, but the coverage is poor. A brief summary of the current state of knowledge is presented here. Emphasis is placed on the distribution of seabirds related to the frontal system along the Norwegian coast between the warm and saline Atlantic water, and the cold and less saline Norwegian Coastal Current.

Available information is inadequate for evaluating the species distribution throughout the year. Some data from spring and from the post breeding movements of auks (see above), are, however, commented on to illustrate differences in the distribution patterns of some species.

Generally, seabirds at sea are not distributed at random. They usually concentrate where food resources are abundant, and this may sometimes be related to oceanographic factors like salinity and temperature. Fronts between different currents often coincide with regions of increased primary production, and the effects of fronts on seabird distribution are well known from several areas.

4.6.1 Spring Distribution

The following comments are based on presently available data, which includes information on the most common seabird species at sea within the influence area in spring.

Gannets seem to be spread in a belt along the coast, and have not been observed at Haltenbanken. They dive after relatively large prey, and may occur in high numbers in areas with concentrated access to fish.

Fulmar appear to be abundant throughout all of the areas investigated. Particularly high concentrations are often related to commercial fishing activity, where the Fulmar will feed on offal. They wander extensively over large open-sea areas, mainly feeding on plankton, smaller fish and crustaceans. Some distributional patterns may thus be related to frontal systems.

Kittiwake distribution is similar to that of the Fulmar, but their numbers are in general smaller. High densities may occur near the breeding colonies, from the time when the Kittiwake take up occupation.

Razorbills occur in smaller numbers than other species, and most individuals have been observed near the bird cliffs at Runde. Some feeding areas north of Runde may, however, be important to both the local population at Runde and immature birds from other breeding populations.

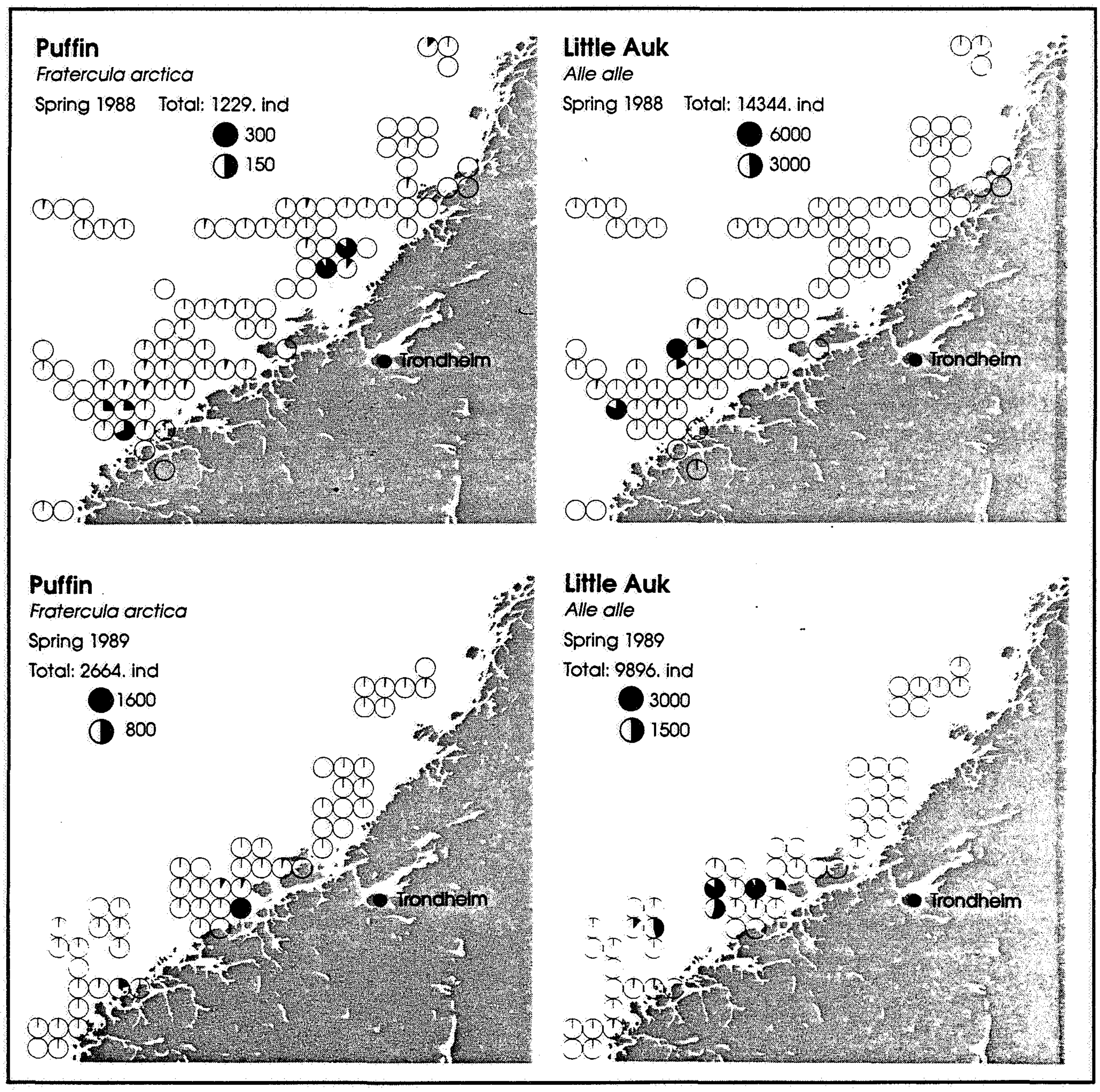
Guillemots appear to have the same distribution pattern as Razorbills, but they occur in larger numbers, possibly reflecting the larger numbers of Guillemots at the breeding colony at Runde. One can expect that most of the larger auks near Runde in springtime originate from the breeding populations there. The majority of auks from Great Britain and the Faroe Islands will already have returned to their respective colonies by this time. Guillemots visit the cliffs at 3 to 5-day intervals, and between visits they remain at sea.

Guillemots have been observed far out at sea in spring, and some birds appear to concentrate at the frontal system on the continental shelf.

Puffins also congregate near the breeding colonies. Large concentrations may, however, be found north of Runde in late winter and spring. Densities of up to approximately 1,200 birds per km² have been recorded (Buagrunnen, 63°05'N 6°30'E, 27 February 1989). Large numbers are also found close to the coast in several areas, north to Froan (data are lacking farther north). Data also indicate that Puffins may concentrate in the eddy at Haltenbanken, but further data are needed on this phenomenon.

Little Auks breed in arctic areas, but regularly winter at the Norwegian coast. Sometimes they are observed in immense numbers, even inshore, for example on 26 January 1986, 5,000 to 15,000 Little Auks were recorded between the islands of Hitra and Frøya. They migrate northwards to breeding grounds in March/April, and recent data indicate that they may

Figure H.4.2 Distribution of Little Auk and Puffin at Sea off Central Norway in March 1988 and 1989. Data are Aggregated within Plots of Size 20x20 km, with Shading of the Circles Showing the Number of Birds Observed within Each Square. Note Different Scaling of the Symbols Between Maps.



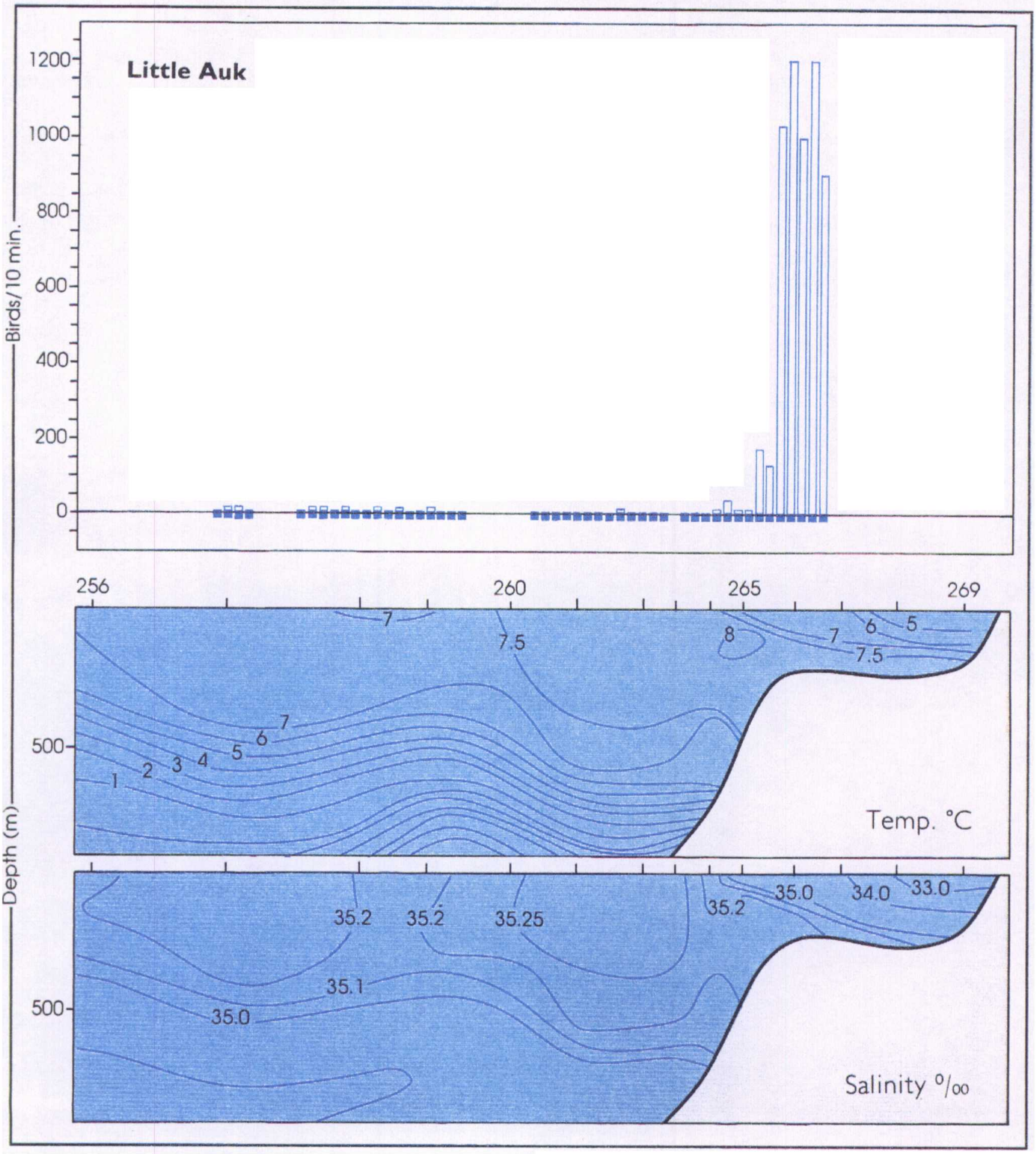
occur in very high numbers off central Norway at this time (see below). Little Auks are seldom observed off the coast of central Norway during the last half of April.

4.6.2 The Frontal System off Central Norway

Seabirds associated with fronts or upwelling areas are often plankton feeders such as the Little Auk. Results from a survey of seabirds at sea in March and April 1988, show that some of the pelagic distributional patterns of the Little Auk, as well as other seabirds, may in spring be related to the frontal system between Atlantic water and the Coastal Current off central Norway (Follestad in print).

Little Auks were present in a non-randon pattern of distribution mainly south of 64°N (Figure H.4.2). Most Little Auks were recorded on the continental shelf, but were also found more or less evenly distributed in smaller numbers all the way out to the Greenwich meridian.

Figure H.4.4 Densities (Counts/10 Minutes) of Little Auk Alongside a Transect from the Greenwich Meridian to Svinøy (23 March 1988) in Relation to Temperature and Salinity



In the Coastal Current, large concentrations of up to 300-400 Little Auks per km² were found near shore on 4-6 March 1988. When areas north to 69°N were surveyed in the middle of March, only a few Little Auks were observed, and no particular concentrations were evident. At the end of March and in early April, however, very high densities of Little Auk, between 900 and 1,500 birds per km², were recorded in two areas on the continental shelf between 62°30'N and 63°30'N.

On 23 March 1988, on a transect from the Greenwich meridian to the coastal areas near Svinøy (62°20'N 05°16'E), salinity and temperature were measured at certain intervals. Close to the edge of the continental shelf there was a front between the Atlantic and coastal water, and a rapid change in temperature and salinity was recorded (Figure H.4.4). The numbers of Little Auks observed in each 10-minute period along this transect increased very rapidly at the frontal area, from almost zero to 900-1,200 birds (Figure H.4.4). At ship speeds of 11-12 knots and a transect width of 300 m, these numbers are almost equal to densities given as birds per km².

High densities were also recorded in March 1989. About 2,300 Little Auks per km² were recorded close to the coast on 22 March (63°20'N), but at the same time more than 1,000 Little Auks per km² were recorded in some areas on the continental shelf or over the continental slope.

The normal winter range of Little Auks in the eastern Atlantic extends south to the North Sea and Skagerrak areas, as shown by surveys of seabirds at sea and by their presence among seabirds found dead after an oil spill in Skagerrak (1980/81) (Anker-Nilssen et al., 1988). Little Auks are commonly found in the North Sea, but according to recent research, only in small numbers (Tasker et al., 1987).

Densities of 1,000-1,500 Little Auks per km² (observed in two areas in 1988), are exceptionally high compared to those found in the western part of the North Sea, where mean densities above 2 birds per km² rarely occur (Tasker et al., 1987). With a density of about 1,000 birds per km², there will be in the order of 400,000 Little Auks in just one square of 20x20 km, used for aggregating data in the maps (Figure H.4.2). At such densities, even a small oil spill may damage a very large number of birds. It is not known whether these concentrations of Little Auks stay on Haltenbanken and at feeding grounds farther north, on their migration northwards to their breeding sites, or if their distribution patterns are related to fronts or other oceanographic factors.

NINA consider that improved coverage of the seas off central Norway will be essential to complete an accurate description of the distribution of seabirds normally occurring in larger numbers offshore in the influence area of Heidrun.

5. MARINE MAMMALS

A review entitled "Marine Mammals and Oil Pollution" has been prepared for this EIA (CMS, 1989). The document draws on previous work by Moe (1987a), Griffiths and Øritsland (1986), as well as information prepared for a previous Heidrun EIA (1987) by Øritsland, and information drawn from other scientific publications and interviews with marine scientists. A summary of the key findings of relevance to the Heidrun field is presented here.

5.1 General

Marine mammals present along the coast of Norway are given protection by law, according to the area and the time of year. Coastal seals have all-year protection from the Swedish border to Sogn and Fjordane; from Møre and Romsdal to Værøy they are protected from 1 May to 31 October (all-year within reserve areas); and from Værøy north to the Russian border they are protected from 1 May to 30 November.

Outlined below in Table H.5.1 are those species which might directly or indirectly be affected by activities associated with the Heidrun development, including those species found within the area which might be influenced by a major oil spill.

Seals	Baleen whales	Toothed whales
Grey seal	Fin whale	Sperm whale
Harbour seal	Sei whale	Harbour porpoise
Harp seal	Minke whale	Killer whale
(Ringed seal)	Blue whale	(Pilot whale)
(Hooded seal)		(Dolphins)
Otter*		

* The otter does not systematically belong among the marine mammals but is included in the assessment because of its habitat requirements.

Table H.5.1 Marine Mammals in the Area of Influence

Underlined species are those permanently in the area of influence, those without underlining are considered to occur periodically in the area, and species in parenthesis are classed as sporadic visitors.

5.2 Species of Interest

5.2.1 Seals

Three main groups of seals are recognised; the true seals, the eared seals, and the walruses (Bonner, 1981). Only true seals are regularly present at the Heidrun field. They have no external ears, but can nevertheless hear perfectly well above and below water (Stonehouse, 1985). They typically also have a thick layer of subcutaneous blubber which serves as a means of energy storage and insulation. They give birth on land or on ice, and the pups enter the water only days after being born, depending on the species (Bjørge, 1981).

All seal species normally found in Norwegian coastal waters are true seals. These include the grey seal (*Halichoerus grypus*), harbour seal (*Phoca vitulina*) harp seal (*Phoca groenlandica*), hooded seal (*Cystophora cristata*), bearded seal (*Erignathus barbatus*), and the ringed seal (*Phoca hispida*).

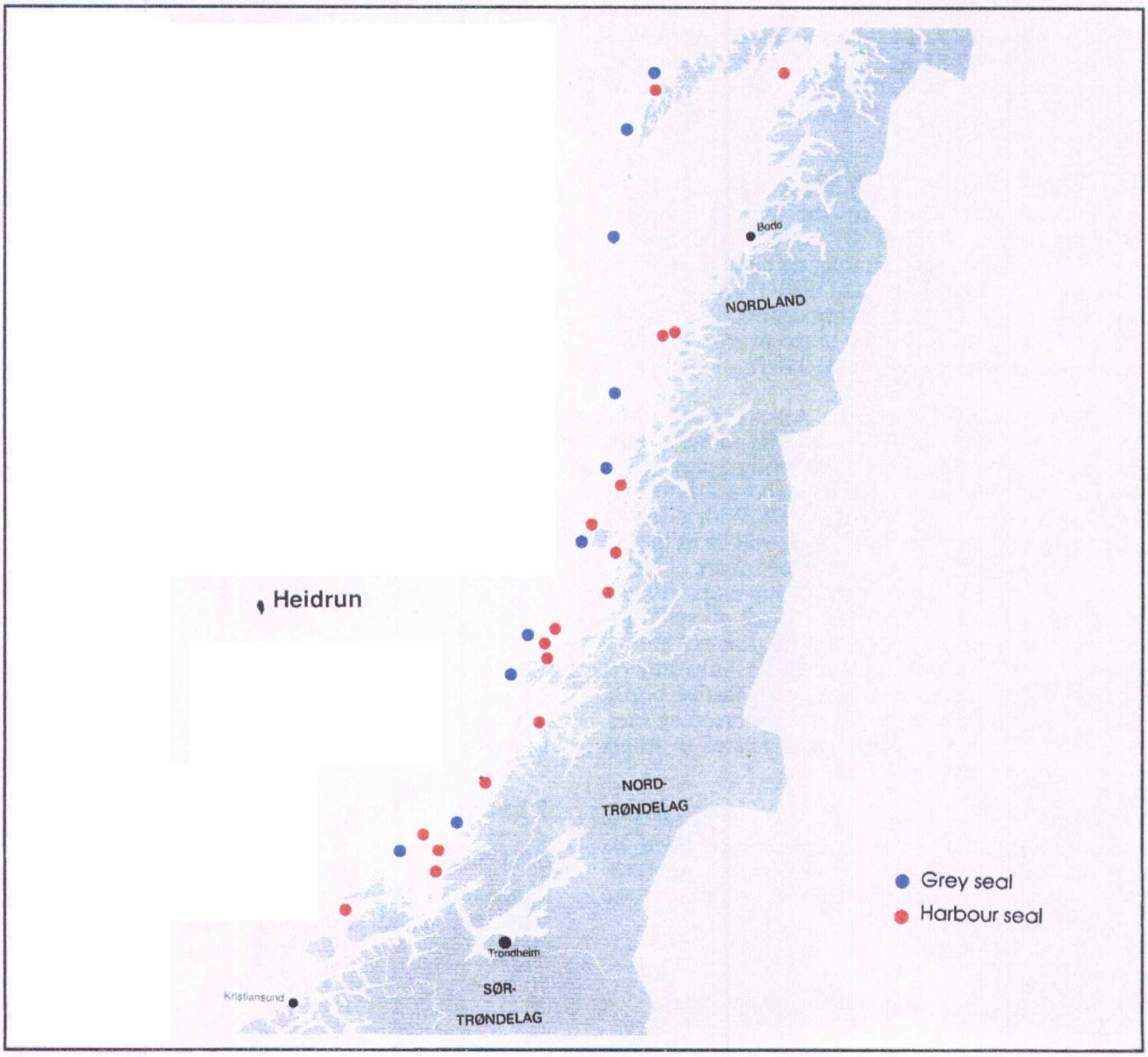
Among these, the coastal seals such as the harbour and grey seals are most important because they are permanent residents within the area of influence (Figure H.5.1). The other species including harp seals, ringed seals, and hooded seals are less frequent visitors whose breeding areas lie far to the north.

a) Grey seal (Halichoerus grypus)

Breeding populations of this species are found along the coasts of the UK, Ireland, Faroe Islands, Kola Peninsula, eastern Canada and Norway. Popülations which reproduce on ice are present in the Baltic Sea and in the Gulf of St. Lawrence (Bonner, 1981). The world population is estimated to be 180,000 individuals (Wiig, 1986).

Local grey seals differ in distribution and behaviour from the harbour seals, preferring more exposed skerries and rocky islets along the outer coastline. Discrete populations or individual wanderers can be found on almost all of the coast, although the bulk of the population and the major breeding groups occur in Sør-Trøndelag, and in the area from 63°N to 68°N. Estimated population size for seals within the coastal area of interest is given in Table H.5.2.

Figure H.5.1 Distribution of Grey and Harbour Seals According to Wiig (1986) and Bjørge (1987)



Sør-Trøndelag

The largest population of grey seals in Norway is present in the Froan nature reserve. Some of the colonies within this area have had an annual growth of 13%, while the total population has on average increased annually by 3%. Next after Froan in terms of importance as a weaning site is Melsteinen. Most of the births take place in the first half of October at this location.

Nord-Trøndelag

The main areas are Vikna and Hortavær islands. In 1979, the total population was estimated to be approximately 230 individuals.

Nordland

The largest concentrations are found in the vicinity of Vega, Floholmene, Valvær, and between Røst and Lofoten. In 1986, an estimated 860 individuals were distributed along this long coastal stretch, giving only a low average density of individuals. The pups are born from mid-October to mid-December.

b) Harbour Seal (Phoca vitulina vitulina)

This subspecies is distributed from France, the Irish coast and Great Britain in the south, to the western coast of Prins Karls Land and Western Spitsbergen in the north. A group of several hundred have recently established themselves in the latter location. Distribution of harbour seals within the coastal area of interest is given in Table H.5.3.

Localised breeding colonies are found among the skerries and smaller rocky islands, along the coastline, and in some of the deep fjords, throughout the entire area of possible oil impact.

The species is considered non-migratory, although seasonal movements do take place in some areas and

County	Year	Number of Pups Counted	Estimated Numbers
Sør-Trøndelag	1979	228	1400
Nord-Trøndelag	1979	47	230
Nordland	1979	140	860

Table H.5.2 Estimated Population Size of Grey Seals by County (Wiig, 1986)

County	Locality		Population Estimate
Sør-Trøndelag	Frøya		45
	Froan		200
	Tarva		170
	Tristeinen		20
	Buholmsråsa		15
		Total	450
Nord-Trøndelag	Namsenfjorden		30
	Vika		165
	Hortavær		45
		Total	240
Nordland	Horsvær		65
	Lyngvær		10
	Torgøyane		10
	Vega		10
	Kilværfjorden		20
	Kalholmane		25
	Valvær		25
	Vestfjorden		30
	Outer Lofoten		200
	Outer Vesterålen		70
		Total	465

Table H.5.3 Distribution of Harbour Seals. Estimates by Bjørge (1987)

population shifts such as those observed across the English Channel have been noted (Bonner and Whitthames, 1974).

c) Other Seal Species

Harp, hooded and ringed seals are observed in variable numbers every year along the Norwegian coast. These species do not normally reproduce here, but may at times be numerous.

5.2.2 Baleen Whales

Because of their presence within and near to the area of influence, the large fin whales including blue whale, fin whale, sei whale, and minke whale have been included in this review. Some of these species have been significantly reduced by whaling and are still uncommon. An example of such a species is the blue whale which used to be numerous along the Norwegian coast, but which has not been observed with any regularity since 1955 (Arnesen, 1982). The black right whale is another which was heavily hunted, although its population in the North Atlantic now seems to be increasing (Haug and Reymert, 1982).

5.2.3 Toothed Whales

Many of the toothed whale species make feeding migrations from breeding areas in the south, to the rich feeding areas along the Norwegian coast. Killer whales and harbour porpoises are present along the coast throughout the entire year (Christensen et al., 1982; Gulliksen, 1982).

Most toothed whale species form herds that may consist of anything from 2-4 individuals (bottlenose dolphins and porpoises), to as many as a hundred (pilot whales and killer whales).

5.2.4 Otter (Lutra lutra)

The otter is widely distributed across Europe, Asia and northwest Africa, from Scotland to Kamsjtka, and south to Java (Eldøy, 1987). Its populations have rapidly declined throughout Europe, and in countries where population estimates are available, they range from a few individuals to a few hundred (Eldøy, 1987). In the European Council, it is listed as an endangered species (1976, 1981), and is presently on list 2 of the Bern Convention.

The European otter (*Lutra lutra*) is in Norway not exclusively tied to the marine habitat, but is also present at inland freshwater sites. The highest densities are, however, found on the coast. As otters are frequently present in the intertidal zone, they are susceptible to oil spills (Griffiths and Øritsland, 1986).

Eldøy (1987) reported that the species had basically disappeared from southern Norway, but that solitary individuals had been observed in Aust-Agder, Opland, Hedmark and Østfold. In Rogaland and Hordaland there were only scattered occurrences, but in the outer parts of Sogn and Fjordane and Møre and Romsdal, there were permanent populations present. Eldøy does not specify population sizes or areas.

Most municipalities north of Trondheimsfjord have permanent populations of otters, and the coastal areas in north Norway (Nordland, Troms and Finnmark) probably have the highest densities.

6. NATURE RESERVES, PROTECTED AREAS AND AREAS OF PARTICULAR SCIENTIFIC INTEREST

6.1 Introduction

A review has been undertaken of the distribution of areas which have been defined as nature reserves by the Ministry of Environment, areas which are protected or proposed for protection by national and regional official plans, and areas of scientific value for university or regional high school authorities. The assessment has been limited to the three main counties which might fall within the Heidrun influence area.

The basis for defining areas as protected or proposed for protection, is their value due to the occurrence of particularly vulnerable or valued ecological communities, or species of plants and animals. In general, these two considerations are tightly bound.

Among protected areas and areas proposed for protection, only those that could be affected by a major spill from the Heidrun field have been considered. Most of the areas would thus be tidal flats, areas with supralittoral vegetation or sites important to birds. The first two shoreline types may also be important to birds.

The registration of areas which are of interest to nature conservation but which do not at present have formal protected status, is based mainly on official government documents and plans.

6.2 Protected and Proposed Protected Areas

The assessment of protected areas is based for the most part on work carried out by NIVA (Bakke et al., 1987) for the 1987 Heidrun EIA. Other reports which have been incorporated are the CMS report (Moe, 1987) and Økoforsk reports (Kristiansen, 1988; Elven at al., 1988 a, 1988b). The Økoforsk reports cover Nordland county to Hamarøy municipality. Reports dealing with the northern part of the county are in preparation.

All protected areas and areas proposed for protection in Nordland, Nord-Trøndelag and Sør-Trøndelag, are shown in Figure H.6.1. Other coastal sites of great importance are also indicated on the figure.

6.3 Areas of Special Marine Ecological Scientific Interest

Five areas in Sør-Trøndelag, three in Nord-Trøndelag and six in Nordland county are considered to be of special scientific interest or are valued for educational purposes (Figure H.6.1).

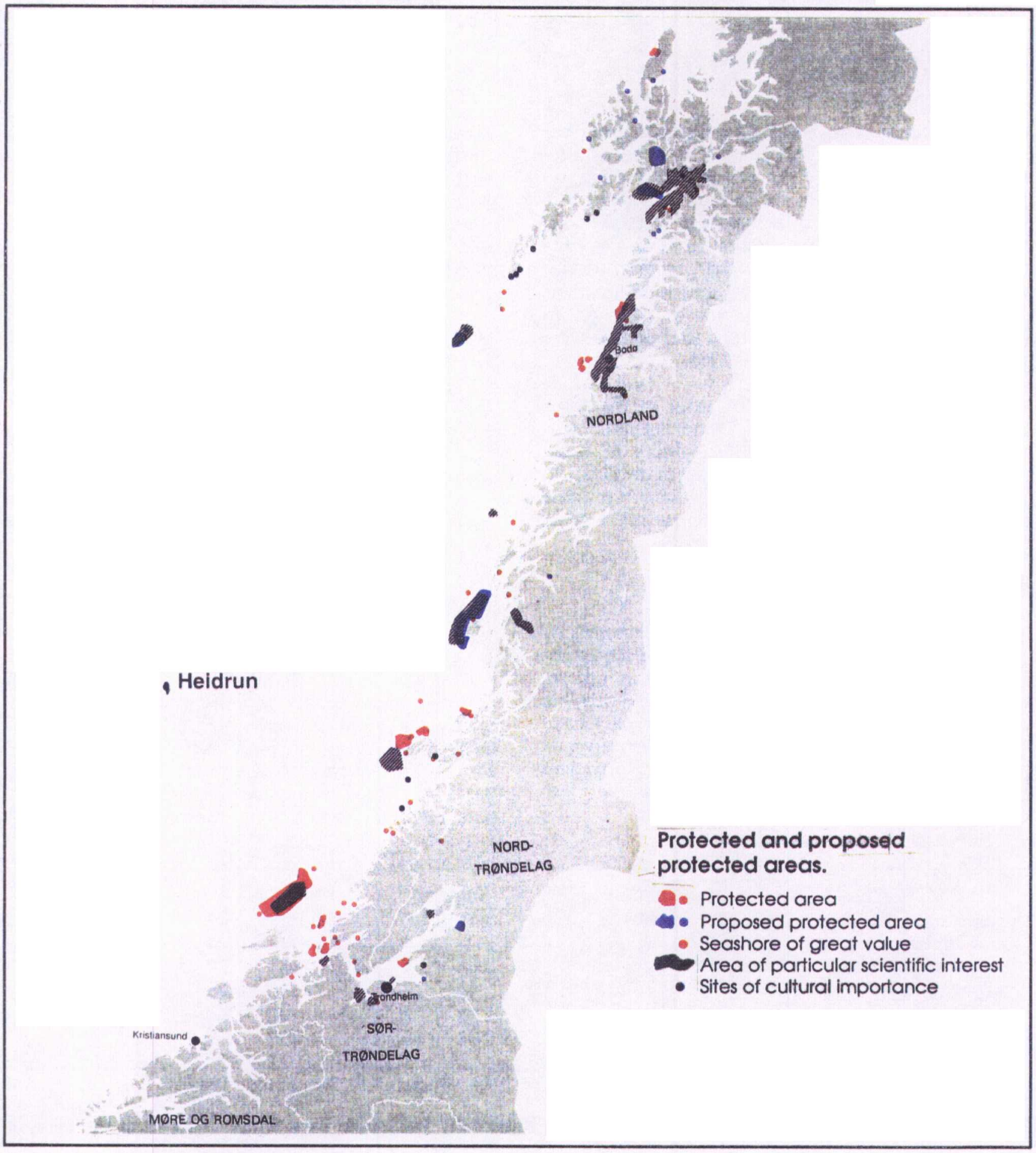
6.4 Sites of Cultural Preservation

The Preservation of Culture Act of 9 June 1978 states that "No one must - unless it is permitted under paragr. 8 - start work that will damage, destroy, dig out, move, change, cover, hide or in any other way unduly harm preserved memorials of the past, or cause a risk of this happening".

Because of the rise in land levels, most of the cultural memorials lie above today's shoreline, and are therefore not so exposed to the weather. There are, however, quite a number of fishing stations, docks and piers which, in addition to their cultural value, are attractive to and of value for, the tourist trade.

The data presented here are based on information collected from the county conservation officers in the counties of Sør-Trøndelag (Hannhus), Nord-Trøndelag (Dahle) and Nordland (Forselv). In assigning priority, areas and structures which are particulary exposed and should be protected in the event of an incident, are highlighted. The degree of consistency in rating by the counties is not considered here.

Figure H.6.1 Distribution of Protected Areas, Areas of Particular Scientific Interest and Sites of Cultural Preservation within the



In Sør-Trøndelag, the fishing station on Halten has been given clear priority. It is the farthest outpost on the 5 mile long group of islands in Frohavet, and comprises seahouses, docks and piers. It is also a new tourist attraction.

In Nord-Trøndelag, priority has been given to the remnants of the bridge to Steinvikholmene in Trondheimsfjord. A special mention is given to the fishing station Sørgjæslingan, Berggårdspollen in Rørvik, and the docks by Folla lighthouse. In addition, there are some floating vessels worthy of preservation.

In Nordland, there are six harbours in Vesterålen and one in Kjerringøy which are of special interest.

7. AQUACULTURE

The importance of inshore and nearshore areas has increased dramatically over the last 10 years as a result of the expansion of the aquaculture industry in Norway. The production of salmon and trout was 90,000 tons in 1988 and is expected to be 125,000 tons in 1990, whereas production in 1979 was only 6,833 tons. Other species (cod, char, halibut, turbot, eel and mussels) are expected to constitute less than 1% of the total farmed production in 1989. As an example, only 15 tons of cod and 6 tons of char were farmed in Norwegian waters in 1988.

The production of salmon and trout in the three counties (Sør-Trøndelag, Nord-Trøndelag and Nordland) which have the highest probability of being affected by a major oil spill originating in the Heidrun field, comprised 28% of the total production of these species in Norway in 1988. This represents a value of 985 million NOK.

7.1 Licensing System

The aquaculture industry in Norway is governed by the authorities through legislation. Before the establishment of an aquaculture plant, certain criteria relating to spread of diseases, pollution and possible conflicts with other activities (navigation etc.) have to be satisified. For approval to rear post-juvenile salmon and trout (matfiskanlegg), total Norwegian production, market size, and export possibilities are considered before a concession is awarded.

The number of concessions and the local distribution of these among the different counties are decided annually by the central authorities. The county fisheries authorities (fiskerisjefen) on the other hand, are responsible for distribution of the concessions among the applicants. A concession usually contains permission to use a seawater volume of 12,000 m^3 for production.

For hatcheries, mussel farms and for the production of fish other than trout and salmon, no special concession is required. The plants do, however, have to be registered by the county fisheries authorities and the necessary criteria relating to disease, pollution and similar concerns have to be satisfied.

The number of aquaculture concessions in the counties which might potentially be affected by a major spill from the Heidrun field is given in Table H.7.1. It is important to note that the number of concessions for mussel production gives a biased impression of the importance of this particular species to the industry, since only a fraction of these concessions actually contain a functional unit. In 1988, the total Norwegian production of blue mussel was only 87 tons. The importance of the mussel industry is, however, expected to increase in the future. The production of oysters amounted to 84,000 individuals, representing a total value of 450,000 NOK.

7.2 Aquaculture Techniques - Finfish

7.2.1 Intensive Sea-based Production

Fish are reared in cages which typically comprise a floating framework from which the enclosing net is suspended. This form of production dominates the present aquaculture industry. The salmonids are hatched and reared in freshwater during the juvenile stages, and at a weight of approximately 50-100 g., they are transferred to seawater pens, where they are kept for 1 to 3 years before being harvested.

7.2.2 Extensive Sea-based Production

In this method, larger sections of an estuary, fjord or bay are closed or partially closed to form a catchment and rearing area, and additional fish stocks are added. This method of farming is insignificant in terms of overall commercial production at the present time, but may become more important in the future.

Area	Salmon/ Trout	Salmon/ Trout Juv.	Other Fish	Mussels
Møre and Romsdal	99	90	63	110
Sør-Trøndelag	76	39	40	59
Nord-Trøndelag	60	32	40	29
Nordland	132	103	127	77

Source: Fiskeridirektoratet, Bergen. Fish data: May 1989, mussel data: September 1989.

Table H.7.1 Number of Aquaculture Units in Areas Potentially Influenced by a Major Spill from the Heidrun Development

7.2.3 Land-based Systems/Hatcheries

Such systems include basins, tanks or similar structures supplied with either freshwater or seawater. Also included, are existing freshwater ponds which have been drained and refilled with seawater for the production of marine species. Land-based systems are used for producing juvenile salmonids (hatcheries) and cod, and for the rearing of turbot, eels, and some other marine species (on an experimental scale).

7.3 Aquaculture Techniques - Shellfish

Shellfish species cultivated in Norway include the blue mussel (*Mytilus edulis*), oyster (*Ostrea edulis, Crossaster gigas*), Iceland scallop (*Chlamys islandica*), queen scallop (*Chlamys opercularis*) and bay scallop (*Pecten maximus*). Of these 5 species, the blue mussel is the most important. Plants for the production of mussels are usually located in more sheltered areas than are fish production units. The mussel industry has in recent years had some delivery problems as a result of the effects of toxic algal blooms.

The production of the blue mussel is based on cultivation of larvae recruited from natural populations, onto vertical or horizontal ropes or plastic bands suspended near the surface. Typically, these larval collectors would then be suspended vertically from a raft, where they would remain for the remainder of the production period.

Production of oysters in Norway is dependant on cultivated larvae. Cultivation beyond the juvenile stage is usually performed in baskets suspended from a raft or on horizontal ropes in the sea.

When compared with production volumes and income derived from other forms of aquaculture, scallop farming in Norway is still of minor importance. Cultivation beyond the juvenile stages relies on a modification of the methods used for oysters, with baskets or trays of scallops suspended vertically in surface waters.

7.4 Location of Aquaculture Systems and Production Sites

The distribution of aquaculture sites along the coastline which might be influenced by a major spill from the Heidrun field is shown in Figures I.7.1 and I.7.2. It should be noted that no part of the coastline can be excluded as a possible future location for aquaculture.

7.5 Market Value

Table H.7.2 outlines the annual production rates and market value of the main two finfish species farmed in Norway.

8. SHORELINE BIOTOPES

8.1 Introduction

The coastline within the Heidrun impact area has an extremely complex topography with about 6,700 km of shoreline on the mainland and another 16,000 km around islands and skerries. A classification of the main types of shoreline biotopes and a ranking of their vulnerability with respect to oil spills is summarised below.

Immersion separates the biotopes into three broad categories:

- the biotopes above high tide level (supralittoral zone)
- the proper shore biotopes between the high and low tide levels (littoral zone), and
- the constantly submerged shallow water communities below the low tide level down to about 20 metres (sublittoral zone).

The depth limit has been set to include bottoms where one might expect significant amounts of oily material to be deposited in the event of a major oil spill drifting ashore. Normally this would be regarded as the upper 20 metres, although remobilised aggregates of stranded oil and sediment particles could be expected to be transported to greater depths.

Classification of substrate types according to particle fate (Håkanson, 1981) is relevant in this context:

- *Depositional substrates.* Areas which act as a sink for particles with diameter down to less than 0.06 mm.

County	Salmon Production (1000 Tons)	Trout Production (1000 Tons)	Total Production (1000 Tons)	Total Value (1000 NOK)
Møre and Romsdal	14,418	2,030	16,465	615,868
Sør-Trøndelag	6,283	1,361	7,644	280,993
Nord-Trøndelag	4,475	150	4,627	170,984
Nordland	11,582	880	12,477	479,664
Norway Total	80,303	9,352	89,796	3,293,358

Table H.7.2 Tonnage and Value of Salmon and Trout Produced in 1988 (Fiskeoppdretternes salgslag A-1).

- *Transport substrates.* Areas where fine particles will be deposited and resuspended intermittently.
- *Erosion substrates.* Sites where fine sediment particles will not be deposited.

The first category will include substrates covered with soil on land, and muddy, clayey and silty substrates in the sea, where the main processes are sedimentation and deposition. Sandy bottoms should be considered as transport substrates characterised by both deposition and erosion, depending on the predominant currents and waves. Pure erosion substrates include rocky headlands, and bottoms consisting of boulders, stones and coarse gravel.

8.2 Supralittoral Biotopes

Spill incidents may bring oil above the high tide level (e.g. for Norway: Wikander, 1982; Falk-Petersen et al., 1983). Hence the vegetational zone, especially above wind and wave exposed shores, is likely to be impacted. These communities are found scattered along the whole coast. The main types are:

Gravel and boulder areas. These generally occur in wave exposed areas and/or where the substrate slopes more steeply towards the sea. Vegetation and associated fauna are confined to rock crevices and other sheltered patches, where plant debris may accumulate to produce soil.

Sandy shores and dune areas. Coarse sand areas are most frequent in the inner parts of wave exposed bays. Fine sand areas and dunes occur in open parts of the coast. They are in general exposed to waves and wind.

Seaweed banks. Found in smaller areas on exposed coasts, where detached seaweed collects above the surf zone.

Saltmarshes. Mainly found at the inner end of the fjords associated with larger river outlets, and areas where post-glacial landrising has turned silty and muddy tidal flats into marshland.

Several supralittoral communities have been defined on the Norwegian coast, based on the dominant species of vegetation (Holten et al., 1986). The plants of these communities can tolerate higher levels of salt in soil (halophytes). Some are obligate halophytes, e.g. glasswort and species of *Atriplex*. Some are facultative halophytes e.g. marram grass and scurvy grass.

Other members of these communities are indifferent as to location. Several species have their northern limit of occurrence in Trøndelag and Nordland, but the most important gradient in species composition within the impact zone runs from the outer coastline to the inner end of the fjords (Holten et al., 1986). Seasonality is typical for land vegetation with a summer growth and flowering season, and a winter resting season. The soil fauna of the supralittoral communities is not very diverse and is dominated by small forms such as the collembolans (closely related to insects), nematodes (roundworms) and insects.

8.3 Littoral Hard Bottom Biotopes

This is the dominant type of tidal zone community along the coast. Typical rocky shore communities are found on solid bedrock, as well as shores with a stable substrate of boulders and large stones.

The communities are structured by two physical gradients of overwhelming importance: horizontally by wave exposure and shelter, and vertically by tide levels. Their structure is characterised by a relatively few ground-cover species such as algae, barnacles, mussels, etc., grazers and predators such as limpets, periwinkles, and dog-whelks, and a wide range of subordinate or opportunistic species.

The dominant organisms on most rocky shores when wave exposure is less severe, are the fucoid algae, in particular knotted wrack and bladder wrack. These algae are long-lived and a knotted wrack association is in general extremely stable, as long as no external force removes the wrack (e.g. ice scouring). With increasing wave action, the fucoid cover declines and is partly replaced by a dense cover of barnacles, mussels and tufts of short cushion-formed algae.

Biological cycles are strongly seasonal, with dense spring/summer settlement and growth of larvae, and epiflora and epifauna. A typical winter feature of the northern part of the coast is local destruction of the tidal zone biota by ice scouring, especially in fjords influenced by freshwater run-off from rivers.

The change in community structure from the outer skerries to the inner part of the fjords is more conspicuous than the latitudinal change, and is a response to change in water movement and fresh water input.

8.4 Littoral Sediment Biotopes

These communities are found on shores with transport and depositional substrates. In general, they form a much wider band between high and low tide levels than do rocky shore communities.

Soft bottom shores can be classified into:

gravel and coarse sand	(exposed)
fine sand	(exposed, sheltered)
mudflats	(sheltered)
eelgrass	(sheltered)
salt marsh	(sheltered)

The salt marshes constitute a transitional community between the supralittoral and the littoral zones. Similarly, the eelgrass communities are transitional between the littoral and the sublittoral zones.

With the exception of eelgrass areas, the sedimentary shores appear to have little animal and plant life. The vegetation is mostly microscopic, consisting of unicellular or small filamentous algae. The fauna is mainly found either in interstitial spaces (meiofauna), or burrowing through the sediment (macrofauna).

The major macrofaunal groups are the molluscs, bristle worms and crustaceans (McLachlan, 1983).

An important element of the fauna is the mobile forms such as shrimps and fish (gobiids) moving in over the sediment at high tide to prey on other organisms, or birds moving in at low tide for the same purpose.

The fauna and flora of sedimentary shores do not normally encounter the desiccation and extremes in temperature and salinity which rocky shore communities must endure, and are therefore considered to be less hardy. Lack of oxygen in finegrained sheltered sediments, and the abrasive effects of sand grains during wave exposure can, however, be additional forms of stress.

The only types of sedimentary shores where the macrovegetation is conspicuous are the eelgrass beds and salt marshes. The eelgrass beds of Northern Europe are now confined to small sheltered estuarine areas with low salinity. The dominant structuring species are the sea grasses *Zostera marina* and *Z.nana*, of which only the former extends into the tidal zone. Among their leaves and in the sediment below, a rich and diverse community of snails, bristle worms, crustaceans, and fish is found. Silt tends to be deposited amongst the leaves and stems of the grass so that the bottom level rises, and as the tidal influence decreases, the eelgrass beds are turned into salt marsh areas.

8.5 Sublittoral Hard Bottom Biotopes

These communities are found as continuations of rocky headlands and shores, generally down to a depth of 10-40 m, and even deeper, where they meet with level sedimentary bottoms. Within water depths with net productivity, i.e. about 0-30 m in the coastal region in question, the communities are dominated by sessile macroalgae. The most conspicuous and canopy forming species are the large kelps *Laminaria hyperborea*, *L. digitata* and *L. saccharina*, frequently down to about 20 m, and the serrated wrack closer to the surface. Sessile understorey species include numerous red, brown, and green algae.

Typical sessile animals include various species of sponges, sea anemones, hydroids, tube-worms, bryozoans and tunicates (sea squirts). Mobile fauna on the substrate include winkles, dogwhelks, sea urchins and starfish. Among the fronds of seaweeds are crustaceans (isopods and amphipods) and several species of fish, many being juvenile stages of fish normally found in deeper water or offshore.

Predation and competition for space are the main structuring factors. Seasonal changes are mainly characterised by strong growth of shortlived algae during the summer months. The horizontal change in community structure is far less conspicuous when going from north to south along the coast, than going from the outer exposed shores to the sheltered shores, fjords and landlocked bays. Under similar hydrophysical conditions, the subtidal hard bottom communities are roughly the same along the coastline in question.

8.6 Sublittoral Soft Bottom Biotopes

Several types of sedimentary bottoms are found in shallow water along the coast. They range from coarse gravel and sand along the outer islands and in sounds with rapid water movement, to bottoms dominated by silt and clay in sheltered bays and fjords. The soft bottom communities host a range of organisms, mainly animals on or in the sediment. The seasonal fluctuation is characterised by input of juvenile stages of the fauna, after settling of larvae in spring to autumn and stabilisation during winter.

Settling intensity varies from one year to another, and this can cause dramatic changes in population densities (cf. Mileikovsky, 1971, with references). As with subtidal hard bottoms, the latitudinal change in community structure is much smaller than the change from exposed to sheltered areas (change in sediment features), and from shallow to deep bottoms.

9. RECREATIONAL/AMENITY USE OF THE MARINE ENVIRONMENT

9.1 Introduction

In this connection, recreation/amenity and tourism includes outdoor life, water sports, sport-fishing, excursions by private boats, etc. The assessment has been limited to the counties of Sør-Trøndelag, Nord-Trøndelag and Nordland.

It is important to note that there are limitations to the quality and in some cases accuracy of certain of the existing data. For some of the municipalities, the data gives little information on the relative value of the area in terms of recreation or amenity use. In most cases the value is, with few distinctions, said to be local or regional.

The use/value of the inner parts of some of the deep fjords has not been assessed, as these areas are considered to be less at risk from oiling (either because of the drift characteristics or the effect of oil spill recovery/combat activities).

Data on the recreational areas are based on work prepared for the 1987 Heidrun EIA (Bakke et al., 1987).

9.2 Sites of Importance

All recorded areas of interest in Nordland, Nord-Trøndelag and Sør-Trøndelag counties are indicated in Figure H.9.1. The sites are given priority according to the level of use and degree of vulnerability. A highly valuable area with high vulnerability (low self-cleaning ability) would be given priority in oil spill protection planning.

Each site is given priority according to the matrix given in Table H.9.1.

The assessment shows in general, that the high priority areas for recreation are mostly situated near high densities of population. The outer part of Andøya - Vesterålen, an area around Nesna municipality on the Helgeland coast, the Nærøy - Vikna coastline and in particular the outer and inner parts of Trondheimsfjord are the most important areas. Key recreational areas are also given priority as tourist attractions.

Some of the outdoor recreational areas are only in use during summertime and for a great many of the other areas, activity is higher in summer than for other times of the year.

For a complete listing of recreational areas, reference should be made to Bakke et al., (1987) or Moe (1987).

	Vulnerability				
Value of Usage	L	L/M	M	M/H	H
L	L	L	L	L	L
L/M	L	L	L	L	M
M	L	L	M	M	M
M/H	M	M	M	H	H
H	M	M	H	H	H

Table H.9.1 Vulnerability of Recreational/Amenity Sites to Oil Spill Impact

Figure H.9.1 Registered Sites of Value for Recreation and Amenity, Classified according to Vulnerability and Usage Value, into High, Medium and Low Priority.

I. ENVIRONMENTAL EFFECTS

1. SUMMARY OF IMPACTS

The potential impacts arising from the Heidrun development and the primary habitats or activities which might be affected have been summarised in Table I.1.1. Because of the variable nature and duration of the possible impacts, and the ability of elements of the receiving environment to assimilate the discharges or recover from the impact, no attempt has been made to rank severity or the relative importance of impacts. The list serves merely as a general guide.

A comprehensive description of the technical aspects of oil and gas E&P activities and their environmental impacts is provided by UNEP (In Print).

2. BENTHIC CONDITIONS

Impact on the benthos arises from physical disturbance caused by installation and abandonment of field facilities and the input of particulate matter to the seabed from drilling, production and domestic waste discharges.

With the great water depth at Heidrun, surface spills of oil and discharges of produced water and other aqueous effluents are not considered to be a significant threat to the benthos.

In the event of a subsea blowout, the vertical rise of oil and gas should be too rapid to directly impact the surrounding seabed, except for physical disturbance caused by increased bottom water turbulence. Further studies into subsea blowout dispersion characteristics are, however, planned.

Future legislation is likely to either prohibit the discharge of OBM cuttings or severely limit the residual oil content on cuttings discharged to the marine environment (Appendix C). The nature and extent of benthic impacts resulting from OBM cuttings discharges at a level of up to 100 g/kg oil on cuttings (or more), are well known and documented, and will not be reiterated here.

Further research is, however, required to be able to assess the level of oil on cuttings which would give rise to only limited impacts, such as those presently seen with WBM and cuttings discharges. A full assessment of the impacts of very low levels of oil on cuttings has thus not been considered separately from the impact of WBM cuttings.

Discharges of WBM and cuttings are expected to continue. The empirical basis for assessing the effect of water based cuttings alone is very limited, since almost all platforms in the North Sea have had discharges of OBM cuttings. However, most fields around the US coast have discharged only WBM and cuttings, and the assessment below is thus based on US experience, and that from a small number of North Sea fields and wells.

2.1 Physical Impact

Physical disturbance during installation and abandonment of field facilities (TLP, FSO and mooring system), rig and vessel anchoring and pipeline laying will cause local disturbance.

In the close vicinity of operations, surface sediments would be buried or resuspended. Because of the silty character of the surface sediment and the relatively low bottom current activity at Heidrun, large plumes of fines could be generated. Hypersedimentation of settled material will be observed in the residual current direction, with some alteration in sediment grain size.

Discharge of drilling mud and cuttings will also increase sedimentation. Coarse cuttings will settle rapidly to the bottom in the vicinity of the platform and can create mounds of material several metres thick.

The large water depth and potential for dilution at Heidrun, will tend to increase the distribution of fines. The seabed surface is already naturally dominated by fines and a significant change in grain size composition is not anticipated. On the microhabitat scale, however, one could expect the introduction of particles different in shape and mineral composition from those occurring naturally at site.

Results of offshore monitoring programmes consistently demonstrate a rapid dispersion of drilling related discharges. Discharge plumes are typically diluted to background levels within a period of several hours and/or within several hundred metres of the discharge source (Payne et al., 1987).

Evidence indicates that the key grain-size factor influencing bottom fauna is the content of silt and clay. Monitoring around sites in the North Sea, during the period of production drilling, has not in general revealed any major changes in the content of silt and clay in surface sediments beyond the inner impacted zone (IOE, 1989). The small cohesive forces associated with WBM and cuttings will cause the lighter and finer clay size particles to be distributed over a much wider area than experienced around platforms using OBM (Boehm et al., 1989).

2.2 Chemical Impact

Sources of chemical impact derive mainly from constituents of drilling mud and cuttings discharges, with a possible contribution from domestic waste and production effluents.

To ensure technically sound, safe and economic drilling operations, certain properties of the mud need to be adjusted as drilling progresses, including density, viscosity, filtration and chemistry. Some of the more commonly used WBM additives are listed below in Table I.2.1 (some materials perform more than one

Table I.1.1 Heidrun Field Impact Summary

Nature of Possible Impact	Primary Area(s) Affected
1. Installation	
a) Physical disturbance	Seabed
Template emplacement	
TLP foundation emplacement	Seabed
TLP hook-up	Seabed
Pipeline trenching and laying	Seabed
FSO anchoring	Seabed
b) Loss of access	
TLP location	Shipping/fishing
FSO/export facilities	Shipping/fishing
c) Aqueous discharges	
Pipeline hydrotest water	Water column
Sewage, galley and sanitary waste	Water column
Drainage water	Water column
d) Atmospheric emissions	
Marine and other diesel engines	Atmosphere
e) Oil spills	
Refined oils (minor)	Water column
f) Waste disposal	
Various	Existing onshore sites
g) Transport	
Shipping and helicopters	Social/coastal
2. Abandonment	
a) Physical disturbance	
TLP and FSO and subsea wellhead removal	Seabed
Template burial	Seabed*
b) Other general categories as described under "Installation"	
3. Predrilling (and drilling of Southern and Northern subsea wells)	
a) Physical disturbance	
Rig anchors	Seabed
Drill cuttings discharges	Seabed/water column
b) Loss of access	Shipping/fishing
c) Aqueous discharges	
Drilling mud (WBM), completion fluid etc.	Water column/seabed
Sewage, galley and sanitary waste	Water column
Drainage water	Water column
d) Atmospheric discharges	
Flaring during well testing	Atmosphere
Marine and other diesel engines	Atmosphere
e) Oil spills	
Crude oil, refined oils	Water column/coast** Seabirds at sea
f) Waste disposal	
Various	Existing onshore sites
OBM, oily cuttings***	New onshore disposal facility
g) Transport	
Shipping/helicopters	Social/coastal
4. Production	
a) Loss of access	
TLP, FSO and shuttle tanker	Shipping/fishing
b) Seabed obstruction/loss of access	
Southern and Northern Area subsea wells	Fishing
c) Aqueous discharges	
Produced water	Water column
Drainage water, cooling water	Water column
Sewage, galley and sanitary waste	Water column
(Displacement water, subsea storage	Water column
option only)	Water column
Non-oily ballast water (TLP)	
Drilling waste (including cuttings)	Water column/seabed
d) Atmospheric emissions	
Restricted flaring (HP/LP flares)	Atmosphere
Vents, fugitive emissions	Atmosphere
Volatile hydrocarbons	Atmosphere
Marine and other diesel engines	Atmosphere
e) Oil spills	
Crude oil, refined oils (TLP, risers, pipelines/ flowlines, storage and export facilities)	Water column/coast** Seabirds at sea
f) Waste disposal	
Various free, restricted and special wastes	Existing onshore sites
OBM, oily cuttings***	New onshore disposal facility
5. Onshore Facilities	
a) General	
Base at Kristiansund	Social
Offices at Stjørdal	Social

* Dependant on legislative requirements
** Only in the event of a major spillage
*** Assuming a requirement for transshipment of oily cuttings

Deflocculants	Ferrochrome lignosulphonates, chrome lignosulphonates, modified tannins, ferro lignosulphonate, chrome lignite
Clays	Montmorillonite e.g. sodium or calcium montmorillonite (bentonite)
Weight Materials	Barium sulphate (barite), calcium carbonate, dolomite, haematite
Polymers	Function as viscosifiers, deflocculants, fluid loss control agents, inhibitors (by encapsulation), flocculants, and dispersants, and include sodium carboxy methyl cellulose, pregelatinised starch, organic resins, xanthan gum (polysaccharide), guar gum, sodium polyacrylates, polyacrylamides
Precipitation Agents	Lime, gypsum, sodium bicarbonate, soda ash, barium carbonate, potassium carbonate
Salts	Calcium chloride, potassium chloride, sodium chloride
pH Adjustment Material	Sodium hydroxide and potassium hydroxide
Lost Circulation Materials	Mica, walnut shells, calcium carbonate, diatomaceous earth, natural fibres

Plus a range of chemicals (typically proprietary products) acting as surfactants, defoamers, lubricants, shale stabilisers, biocides, emulsifiers, corrosion inhibitors, H_2S scavangers etc.

Table I.2.1 Summary of Some of the Key WBM Drilling Additives

function). OBM is formulated from similar basic ingredients, but using a low aromatic mineral oil as a base.

The most typical seabed impact observed is the elevation of barium and other heavy metals. Trace metals such as mercury, zinc, lead, copper, chromium and cadmium occur as impurities in barite and other additives. There may also be a contribution from the formation rocks through which drilling is taking place.

Insoluble metal salts or metals tightly adsorbed to sediments tend not to be remobilised into the water column and have a very limited bioavailablity (Neff et al., 1989). Barium may accumulate and be transferred along the food chain, but without any increase in tissue concentration (biomagnification) at higher trophic levels.

Several metals in the forms in which they occur in used drilling fluids have low toxicities to marine organisms (Neff, 1987 and 1989). The US National Research Council supports this view and state that the accumulation of toxic trace metals and hydrocarbons in exposed shelf waters, due to periodic releases of water based generic mud and cuttings, is unlikely, and cumulative impacts or long-term degradation of the water column from operational discharges are not major concerns (National Research Council, 1983).

Spud muds are very simple (typically water and bentonite) and have a toxicity not markedly different from suspended clay (Neff, 1987).

The distribution of other drilling fluid organics such as polymers is assumed to follow a different and wider route of dispersion than the heavier barite particles (Sauer et al., 1989), and their impact might be similar to other organic inputs to the benthos, causing slight eutrophication. Such effects have not been reported around shallow water platforms, and would be unlikely at Heidrun.

2.3 Biological Impact

Adverse effects of WBM have been found in laboratory and microcosm experiments (e.g., Menzie, 1982; Duke and Parrish, 1984; Parrish et al, 1989; Neff et al., 1989; Tagatz et al., 1982), but not convincingly in the field (e.g. Hartley pers. inf.)

This could be due to the fact that most experimental work uses fresh mud and cuttings diluted to the desired concentrations, whereas in the field many of the potentially toxic components would be solubilised before the particles settled to the seabed. Another reason could be the general difficulty in detecting subtle effects in the natural environment, compared to a controlled experiment.

The bioavailability of sediment adsorbed metals (see also Section I.2.2) and non-polar organics, such as petroleum hydrocarbons, has been observed to be inversely related to the sediment organic content and directly related to sediment grain size and pollutant concentration (Breteler and Neff, 1983).

In general, toxicity of drilling fluids is due to a combination of the chemical toxicity of water-accommodated mud ingredients and chemicals associated with the particulate phase, and physical irritation and damage to delicate gill and body structures from mud particles (Neff, 1987).

Addy et al. (1984) detected faunal changes in the UK Beatrice field out to a distance of 250 m, but not to 750 m, after drilling 13 wells with WBM. It is uncertain whether the effects observed resulted primarily from smothering or toxicity. Hartley and Ferbrache (1983) found localised reduction beneath the platforms, but no significant cuttings related gradients in macrofaunal populations (80 wells drilled with WBM from four platforms in the UK Forties field). Mulder et al. (1988) came to the same conclusion for a one well site in the Dutch sector. After several years of monitoring, Hartley (pers inf.) has made the same observation for the UK Buchan field.

The slight physical and chemical changes in the surface sediments may cause long-term faunal shifts. During settlement, the freeswimming larvae of several seabed organisms have been shown to be quite selective about bottom substrates.

The input of drilling mud fines may alter the signalling effects of the sediments, and thereby alter recruitment. In a field experiment over two years, the recolonisation pattern in cuttings from a lignosulphonate drilling system was different from control sediments, and this was believed to be due to differences in grain size (Bakke et al., 1985). The overall community characteristics (diversity, dominance etc.) developed normally.

Slight long-term shifts in the fauna around the Heidrun field might be expected, although the bioturbative mixing of drilling mud particles with natural sediment by the rich benthic community at Heidrun should make any such signal alterations less likely.

Neff (1987) considers that serious damage to the benthos from the accumulation of WBM and cuttings, through chemical toxicity, change in sediment texture or burial is likely to be small. The rate of recovery will depend on the extent of the impact and the mud and cuttings removal rate through resuspension and bed transport.

3. PRIMARY PRODUCTIVITY AND FISHERIES

Offshore oil and gas development may have an impact on fisheries through: the effect of an oil spill coincident with a critical period of concentration of eggs and larvae near the water's surface; the chronic effects of toxic components of petroleum or chemical additives released with routine discharges; alteration of habitats or restricted access for fishing activities.

The area which might theoretically be affected by a major spill from the Heidrun field development encompasses an immense body of water.

Most predictions of impact are based on certain assumptions concerning physical phenomena, and the confidence in such predictions generally decreases with longer time scale and distance from the source of impact. The variability of most marine biological populations is also so great that one cannot expect to distinguish man-induced, low level effects from background variability.

3.1 Seismic Operations

Seismic operators are encouraged wherever possible to use airguns rather than explosive seismic sources, as data available to date indicate that this form of energy source poses little hazard to fish or larvae (Wright, 1982; Engelhardt and Paterson, 1985). See also Section I.5.1.

3.2 Offshore Discharges

3.2.1 Dilution and Dispersion

Information on the nature of routine drilling and production discharges is given in Sections E, F and I.2.

Extensive monitoring has been carried out around offshore fields in the North Sea. In the US, there have in addition, been 3 major multiyear, multidisciplinary investigations into long-term (10-25 year) offshore oil and gas developments in the northwestern Gulf of Mexico (Offshore Ecology Investigation, the Central Gulf Platform Study and the Buccaneer Gas and Oil Field Study). Major reviews of published literature have also been carried out (Middleditch, 1981, 1984).

These studies have indicated that where there is adequate dispersion into a receiving water of sufficient capacity, effluents from oil production activities cause no significant environmental damage. Factors such as the density, composition, volume, discharge depth, discharge rate, water depth, currents, surface energy, receiving volume etc., must of course be considered.

Discharges above the thermocline have been found to promote dispersion into the wave zone, and discharges above or just beneath the water will tend to be subject to maximum dilution and aeration, permitting volatilization of light compounds such as aromatic hydrocarbons.

Deep water areas with relatively dynamic hydrological patterns are less likely to demonstrate measurable impacts from production water discharges than are shallow quiescent environments.

3.2.2 Environmental Impact of Produced Water Discharges

Chemical properties which could theoretically cause harmful effects in marine organisms and ecosystems include elevated salinity, altered ion ratios, low dissolved oxygen, petroleum hydrocarbons, chemical additives and other organics, and heavy metals. See also Section I.2.2.

Salinity, total suspended particulates, net sedimentation and biodegradation are all important in determining fate and effects.

Salts of acetic, propionic and butyric acids present in produced water are not of ecotoxicological concern in the context of offshore discharges, nor are the inorganic components (ammonia should promote biodegradation). The readily biodegradable nature of the organic constituents and the low toxicity of produced water have been confirmed by direct measurement. Acute toxicity is unlikely at dilutions of greater than 1:100 (Somerville, 1987).

Cox (1986) confirms the low toxicity of produced water in his report on 45 bioassays conducted on samples from the Gulf of Mexico and offshore California. The classification was practically non-toxic (LC_{50} > 10,000ppm). The low toxicity of aqueous discharges and their rapid dispersal is also reflected in the extent of marine growth on platforms.

The toxicity of a crude oil water soluble fraction (WSF) to marine organisms is related to the concentration of light aromatic hydrocarbons (benzene, naphthalene and phenanthrene). Aromatic hydrocarbons in the range from benzene (Mwt 78.1) to fluoranthene and pyrene (Mwt 202) are acutely toxic. Higher molecular weight aromatics are not acutely toxic because of their lower solubility. However, they may still exhibit chronic effects.

Marine species bioaccumulate both organic and inorganic compounds. However, most species can rapidly metabolise and/or depurate these materials. Biomagnification has not been demonstrated for petroleum hydrocarbons (Abbott, 1988).

It is highly unlikely that significant oxygen depletion (as a result of oxygen demand during microbial oxidation of organic material) would be observed in the effluent plume. Unless the volume and turnover rate of the receiving environment are very small, mixing and dilution of discharged produced water with the receiving water is so rapid that significant elevations of ambient salinity are unlikely. The same applies for altered ion ratios.

Inorganic constituents tend to be rapidly diluted to background levels or incorporated into the sediments.

Organic constituents will undergo one or more of several processes following release into the marine environment, including, dilution, volatilization, biodegradation in the water column, and entrainment in the sediments, followed by biodegradation (Abbott, 1988).

The toxicity and chemistry of some of the components, in particular the small amounts of phenols, amino acids, fatty acids, alcohols, and naphthenic and humic substances is not sufficiently well known, and there is insufficient information on the chronic and/or sublethal responses of marine organisms to produced water.

In recognition of the gaps in data, Conoco has initiated an extensive programme of research into chemicals (see Section. F.1.5.8), and produced water characterisation. Similar work is also being carried out by other operators in Norway and the Netherlands.

From laboratory bioassay testing, modelling and hazard assessment, there appears to be no unacceptable toxicological hazard to plankton drifting through an offshore produced water discharge plume (Rose and Ward, 1981). Long-term artificial ecosystem (big-bag) experiments with produced water from the UK Forties and Auk fields also show no direct effect on phytoplankton or cod and herring larvae, although there was some depression of zooplankton populations (work by Davies et al. 1987, reported by Somerville (1987)).

A review of US data on oilfield production, gas processing and stimulation/workover chemicals, their composition, mode of action, use and toxicity has been carried out by Hudgins (1989). He states that only low concentrations of production treating chemicals will normally be discharged, as many of the chemicals are oil soluble and thus remain in the oil phase. It is estimated that only 25% of the total amount of chemicals used is actually discharged with aqueous effluents.

Also, it appears from comparison of aquatic toxicity data (96 hour LC_{50}) and use concentrations, that most of the production treating chemicals in the effluent stream will be at or below the LC_{50} value prior to discharge.

In summary, based on extensive North American and European experience of produced water bioassay testing, dispersion modelling, field observations and monitoring studies, there is no evidence to suggest that there should be any significant detrimental environmental impact associated with the discharge of produced water from the Heidrun field.

3.3 Oil Spills

3.3.1 Plankton

A considerable body of field and experimental data exists on the impact of oil on phytoplankton and zooplankton. Results indicate that spilled oil can have transitory effects on plankton at the site of contamination, that may last up to several weeks, but are generally measurable for only a matter of days (Spies, 1987).

There was no significant effect on primary producers detected from the Ekofisk Bravo blowout, although a slight tendancy towards increased production was observed. Lännergren (1978) found no differences in impact among different size fractions of producers. Similarly, the results of an experimental oil spill at Haltenbanken during the period 25 July-1 August 1982, concluded that no major effects could be seen on the primary productivity rates (Rey, 1983).

3.3.2 Fish Eggs and Larvae

The results from the HELP research programme may enable us to make rather more realistic predictions of the effects of an oil spill on fishery resources, than could previously be made.

Fish eggs and larvae are transported in a predominantly northerly direction by the Coastal Current. The predominant currents off the Norwegian coast are shown in Figure I.3.1. On the continental shelf, more or less permanent eddies may occur, as is the case at Heidrun. Restrictions in the northward drift of fish eggs and larvae caused by such features could increase the probability of overlap between an oil spill and water masses containing eggs and larvae. To illustrate this feature, spawning grounds for herring and the larval drift route are shown in Figure I.3.2.

Since the highest concentrations of hydrocarbons are found near the surface during a spill, those species with eggs and larvae which remain at or near the surface, like cod, haddock and saithe, are more susceptible than species whose younger stages are found in deeper water.

The effects of hydrocarbons on eggs and larvae have been studied mainly through laboratory experiments using individual hydrocarbon components and crude oil WSF.

Of the species found in the Haltenbanken area, cod and herring larvae have been extensively tested for toxic effects of crude oil (Føyn and Serigstad, 1988). In 1989, a few experiments were also carried out with saithe eggs and larvae (Føyn and Serigstad, 1989). The main results of these experiments are given below.

a) Cod

Exposure of cod eggs to oil (50 ± 20 ppb WSF) for only a few hours resulted in reduced oxygen uptake during the development stage, when the larvae changed from endogenous to exogenous food uptake. Reduced oxygen uptake was also recorded when larvae less than 20 mm in size were exposed to oil (50 ± 20 ppb WSF). Cod larvae larger than 20 mm were not affected. There were no differences observed between exposure to low concentrations (50 ± 20 ppb WSF), and high concentrations (230 ± 110 ppb WSF). Cod eggs and larvae showed no recovery when placed in clean water.

b) Herring

There were no observable effects from egg and larval exposure to 85 - 200 ppb WSF. Even when fertilization took place in seawater mixed with cuttings from wells drilled with OBM, development was not affected.

c) Saithe

The oxygen uptake of saithe eggs exposed to oil (30 ppb WSF) and unexposed control groups was the same. After hatching, the oxygen uptake of the oil-exposed larvae was reduced, and the larvae died within a few days. These experiments indicate that saithe is more sensitive to oil exposure than cod.

The reduction in larval oxygen uptake, reflects the level of activity. Affected larvae do not exhibit as much activity as unaffected ones, and are therefore at a disadvantage when competing for food. The effect on cod eggs of the low concentrations of oil likely to be found in the marine environment during an oil spill, is not an acute one. Rather, it represents a more long-term effect leading to starvation of the cod larvae. When the cod is about 20 mm long, i.e. 3-4 weeks after hatching, it has developed the ability to move away from oil.

The highest concentrations of vulnerable eggs and larvae from cod and saithe are found in the Haltenbanken area in the period from March to June (see also Figure H.3.5).

Except for cod, saithe, herring and capelin, similar experiments with eggs and larvae have not been carried out for other species.

The mean drift time for an oil spill in the Heidrun field to the spawning grounds for cod in Lofoten, and outside Møre and Romsdal, during the spawning season, is approximately 20 days. To the most important grounds in the Haltenbanken area, the drift time varies from 5 to 10-15 days. Details of estimated drift times to coastal areas are given in Section G.1. 7.3. Minimum drift time to Lofoten is estimated to be approximately 10 days.

This implies that eggs and larvae originating from spawning in the Lofoten area would not normally be affected by an oil spill in the Heidrun field, because oil would not give rise to significant concentrations of toxic components in the water column. In the case of the Arcto-Norwegian cod spawning outside Møre and Romsdal and in the Haltenbanken area, eggs and larvae may be transported by the Coastal Current into areas with toxic concentrations of hydrocarbons.

The mean drift time for an oil spill to enter areas with high concentrations of saithe eggs and larvae in Haltenbanken is from 5 to 15 days. The minimum drift time is, however, less than 5 days. This implies that eggs and larvae from saithe spawning in the Haltenbanken area could be affected by an oil spill from the Heidrun field. In addition, eggs and larvae from saithe spawning outside Møre and Romsdal may be transported by coastal currents through areas with potentially toxic concentrations of hydrocarbons.

Calculation of the damage an oil spill might cause to the different stocks would be based on the areal extent of the oil slick, its vertical distribution in the water column, and the horizontal and vertical distribution of fish eggs and larvae. In Figure I.3.3, the vertical distribution of cod larvae has been constructed, based on visual observations of the surface layer, and water column sampling. The vertical distribution of oil in the figure has been calculated by using the model for vertical distribution of eggs, described in HELP report no. 18.

Figure I.1.2. Observed Spawning Grounds for Herring (Circles) and the Larval Drift Route. (HELP report no. 8).

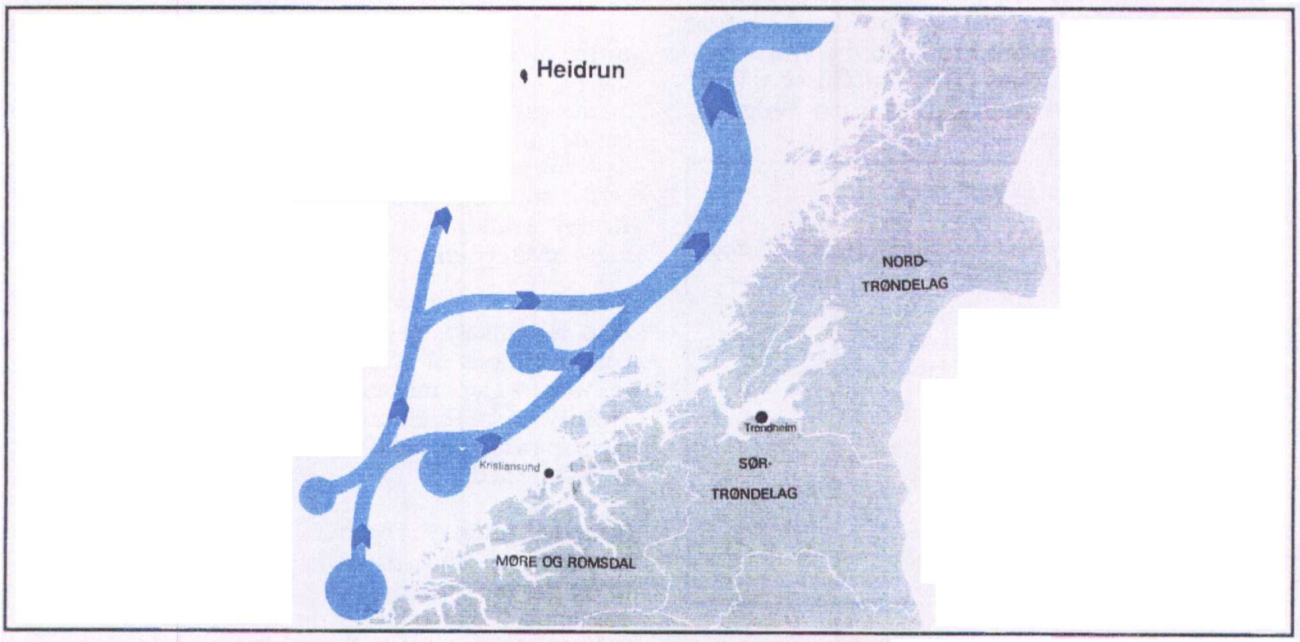


Figure I. 1. 3. The Predominant Currents off the Norwegian Coast (Sætre, 1983)

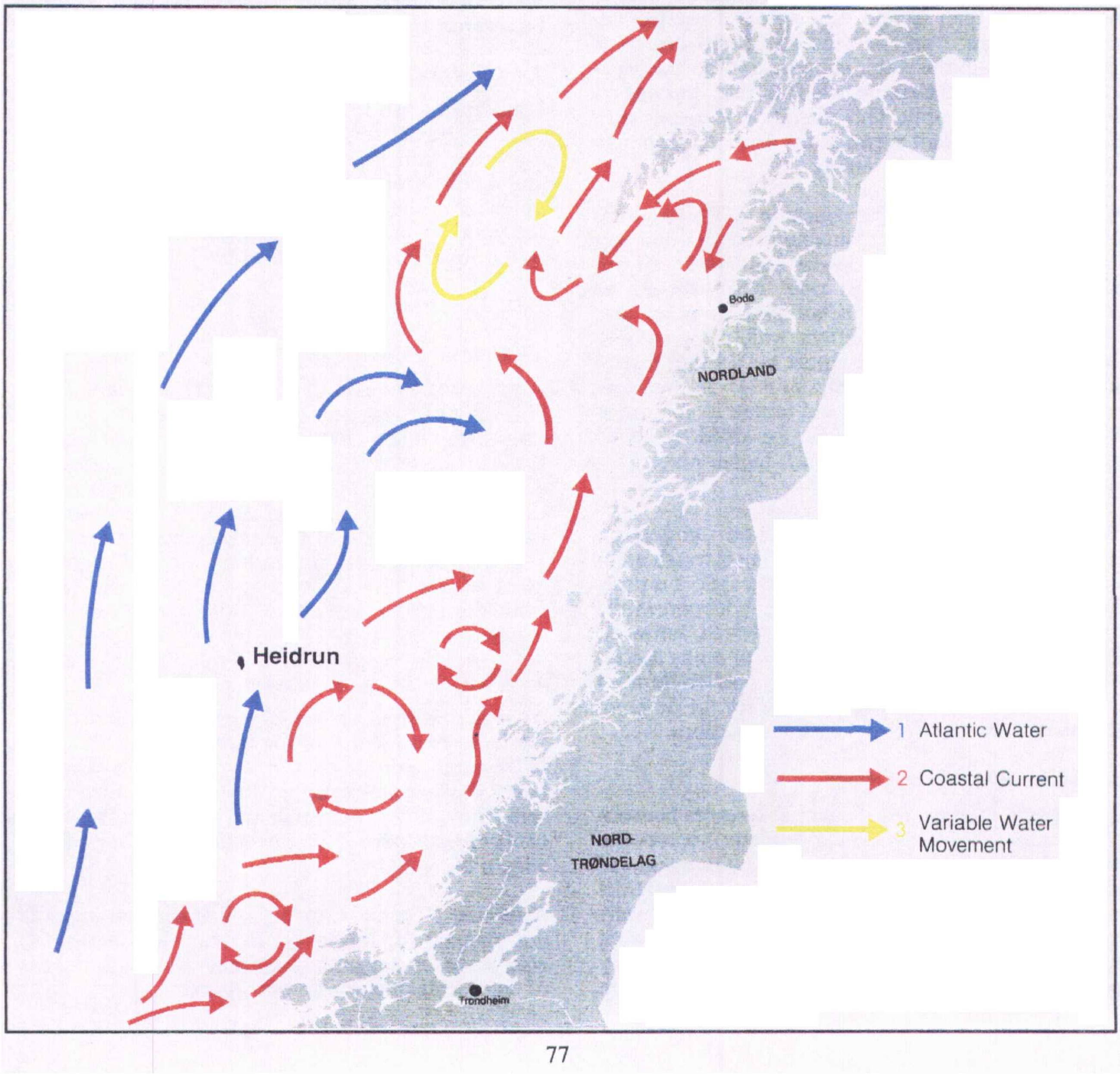
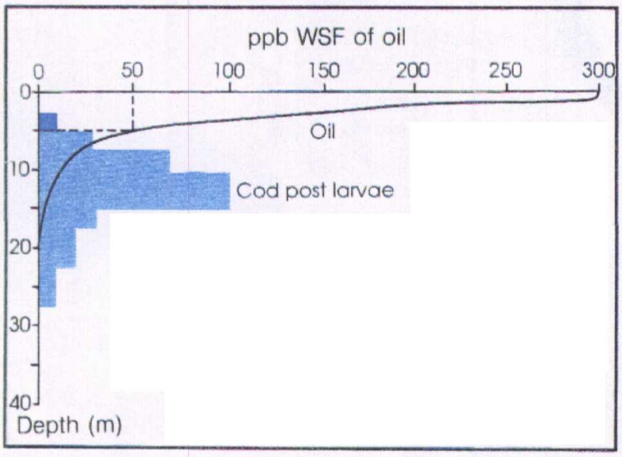


Figure I.3.3 The Constructed Mean Vertical Distribution of Cod Post Larvae at Tromsøflaket in July, and the Calculated Vertical Concentration Profile of the Water Soluble Fractions (WSF) of Oil at a Wind Speed of 5m/sec. (Føyn and Serigstad, 1989).



The figure gives a static picture, showing that 2.5% of larvae are found within any given water depth containing more than 50 ppb WSF of oil. The effect depends very much on the wind speed and degree of oil dispersion in the water column, and on the vertical migration of the larvae, which in turn depends on light and food supply. This migration increases with larval age. Turbulent events in the water column may also add to the vertical mixing.

Føyn and Serigstad (1989) conclude that, as a consequence of the two vertical mixing processes, the percentage of larvae that may be contained daily in water with more than 50 ppb WSF, should be doubled to 5%. This is a contentious point and opinion on its validity differs widely. Sætre and Bjørke conclude in HELP-report no. 19 that due to intermixing of oil and fish eggs and larvae, by wind, waves and migration, eggs and larvae in the upper 30 m of the water column may be killed by an oil spill. This opinion reflects a much higher percentage than that presented above.

With the appropriate information on the concentrations of cod eggs and larvae drifting through areas with toxic concentrations of oil from a spill, it is possible to calculate the possible future reduction in the affected stocks. These calculations should, however, be performed in the wake of a spill. For many species affected by an oil spill in this area, one would need to know more about the toxic levels for the different species, before carrying out such calculations.

3.3.3 Coastal Spawning Areas

To attempt to draw any distinct differences between offshore and inshore spawning grounds is somewhat artificial, since several of the species and populations, like cod, may spawn both inshore and offshore depending on environmental conditions. Systematically collected information on the location of inshore spawning grounds along the coast has traditionally been scarce, but is now rapidly improving through the LENKA-work, carried out by the Ministry of Environment.

In the event of a major oil spill in the Heidrun field, the probability of oil reaching inshore areas is high in the period from December to February. In this period, an oil spill may reach the coast in less than 5 days (mean drift time is approximately 10 days). Generally speaking, the inshore areas from Vikna to Rødøy would, from drift modelling studies, be the most severely impacted (see Section G.1.7.3.)

Stranded oil originating from a spill in the Heidrun field is unlikely to result in ecologically significant concentrations of soluble petroleum components in inshore water masses, except in the immediate vicinity of large amounts of oil. Consequently, pelagic spawning grounds in inshore areas are less likely to be affected.

Stranded oil may, however, smother intertidial nursery grounds and spawning areas, and this is likely to be the most pronounced effect related to inshore spawning. These areas are most vulnerable during the summer season, since their inhabitants usually migrate to deeper water during the winter. This is also the period when nearshore areas are least likely to be severely impacted by a spill (see Section G.1.7.3).

3.3.4 Inshore Fisheries

Landings of fish from the inshore fisheries in Nordland for the different months are arranged in decreasing order from March (highest), through February and April/October/November. This indicates that the important fishery for cod is partly carried out during the period when the area is more vulnerable to oil spill impact from the Heidrun field.

3.3.5 Effects on Fish/Fisheries

a) Mortality

Adult mortality caused by offshore activities is less likely than for egg and larval stages, since adult fish can move out of suboptimal offshore water masses. Experimental studies have shown that cod possess the ability to avoid hydrocarbon concentrations higher than 50 ppb WSF (Bøhle, 1983) and have sensory mechanisms capable of detecting concentrations near 1 ppb WSF (Hellstrøm and Døvig, 1983). In the event of a spill, such behavioural responses would stimulate fish to move into more favourable water masses.

b) Hydrocarbon Accumulation and Taint

After the blowout on the Ekofisk Bravo platform in the Norwegian sector of the North Sea in 1977, fish in the vicinity of the oil slick, analysed for hydrocarbons, showed no evidence of contribution from the spill (Law, 1978). Tidmarsh and Ackman (1986) also confirm that there is little evidence of tainting following a blowout.

After the "Torrey Canyon" oil spill, tainting was documented for mackerel, sea trout and flatfish. It was, however, suggested that this was due to the use of detergents in clean-up operations.

Hydrocarbon and taint studies have been carried out at several North Sea oil installations (DAFS, unpublished; McGill et al., 1987; Randløv and Poulsen, 1986; Palmork and Westrheim, 1988; UKOOA/Univ. of Aberdeen, 1989, unpublished). Results suggest that limited tainting may take place at sites where oily cuttings from drilling operations have been discharged. Flatfish in the immediate vicinity of the platforms are, because of their bottom feeding habits, more susceptible than roundfish. There are no consumer reports of taint.

Bottom feeding fish in inshore areas impacted by an oil spill may be similarly affected.

Haddock caught within 100 m of the Odin platform had elevated levels of aromatic hydrocarbons compared to fish caught in a pristine location (Vogt et al., 1985). Tainting effects, were, however, not tested.

In view of concerns expressed by SFT about the possible scale and nature of such occurrences, the offshore operators initiated 2 further hydrocarbon and taint studies during 1989. Samples have been taken from Statfjord, Oseberg and control areas in Egersundbanken and Haltenbanken. CNI are participants and results are expected in 1990.

Experimental research with rainbow trout indicates that tainting compounds will be eliminated within approximately one month for bony fish, if the source of contamination is removed. Tainting caused by petroleum hydrocarbons is probably, in most cases, reversible and is not likely to affect a significant part of fish stocks offshore for an extensive time period.

When production drilling with OBM commences in the Heidrun field in 1994, oil discharge levels for cuttings will either be extremely low or there will be a complete ban in force. This being the case, hydrocarbon tainting of "local" fish populations as a result of routine discharges from Heidrun facilities is extremely unlikely.

There is also no field evidence to suggest that offshore activities interfere with major migratory routes for fish.

3.4 Reef Effect and Restrictions Imposed by Safety Zones

The presence of an offshore installation can attract an extensive coating of invertebrate species (fouling) and large populations of fish, including saithe, cod and conger eel. The "reef effect" is well documented for production activities in all sea areas. Fish populations within the safety zone(s) will be protected and such "reefs" may therefore have a positive effect on the fish stock as refuge sites, although their significance in this respect has not yet been documented for the North Sea.

The presence of such stocks naturally attracts fishing vessels, which for safety reasons are not permitted in the immediate vicinity of the installation. Safety zones typically have a radius of 500 m. In practice, fishermen also have to take into consideration operational conditions such as currents, wind and the bebehaviour of the different types of fishing gear during setting and hauling, in order to estimate the actual size of safety zone to be observed.

In addition, certain physical obstacles like anchors and anchor chains from rigs, specialist vessels and oil export facilities, and subsea developments/wellheads can further complicate the situation.

Platforms on the Norwegian continental shelf which have offshore loading facilities and subsea developments have been granted additional safety zone protection. Such regulations exist for Ekofisk, Statfjord, Gullfaks and East Frigg.

The size of the Heidrun safety zone has been calculated assuming that fishing activities would effectively be restricted in the vicinity of the TLP, the FSO and its mooring arrangement, and the area between the two installations. An allowance has also been made for access restrictions which might apply to the Northern and Southern Area subsea wells. With increasing numbers of development wells of this type, it is, however, probable that operators will have to design wellheads/templates which do not limit fishing activity.

The area of restricted access for fishing could be in the order of 20 km^2.

For long-liners the most important factors to take into consideration are the depth, the speed of the currents in the area and how fast the gear is sinking. As described in Section H.3, long-line is the most commonly used fishing gear in the Heidrun area. The drift of ordinary long-line (bottom line) during setting in different depths and currents has been estimated, assuming a long-line sinking speed of about 0.2 m/sec (Albatross, 1988). The results indicate that when the currents have a speed of 2 knots (1 m/sec), and depths are similar to those found in the Heidrun field, the expected drift would be about 1750 m.

Operational floating long-line differs from bottom line. The floating line has no link to the bottom, but drifts with the currents. From setting to hauling normally takes 6 to 13 hours. Drift would typically be at approximately the same speed as the current. If the currents flowing towards an installation have a speed of 1 knot (0.5 m/sec), this represents a drift of 11 to 20 km within the above-mentioned time period. (Albatross, 1988). Bottom line is still, however, the most important gear in the Heidrun area.

Taking the drift of the long-line into consideration, the actual safety zones in the Heidrun field, in the countercurrent direction, will represent a greater obstacle to the traditional long-line fishery than indicated by the 500 m radius stipulated.

4. EFFECTS ON SEABIRDS

4.1 Construction Activities

In the North Sea, auks tend to avoid platform construction activities. Their numbers will be greater during the spring and likely response behaviour at this time is unknown. Certain offshore construction work tends, however, to favour the calmer "weather window" involving the period from late spring through to early autumn, and thus major disturbance may be avoided.

4.2 Aqueous Effluents

Oil-in-water limits of 40 mg/l or less for effluents discharged from the Heidrun facilities will not produce surface slicks, but may in calm conditions give rise to a slight rainbow sheen. This would be intermittent and should not harm seabirds on the water surface.

4.3 Helicopter Routes

Normal helicopter and supply base activities appear to have no major impact on seabirds. Helicopter flights at low altitudes should for the most part be into and out of Kristiansund. Helicopter flights at low altitudes would be avoided in the vicinity of Cormorant colonies in the breeding season.

4.4 Vulnerability of Seabirds to Oil Pollution

When the plumage of seabirds is oiled, it no longer serves an insulating function and birds may die of hypothermia. They may also suffer internal damage through ingestion of oil during feeding, or while preening oiled plumage.

The vulnerability of seabirds to oil pollution depends on a variety of factors. These factors include several aspects of their behaviour, season, diet, population status and recovery periods. The species are often divided into three categories of vulnerability, very high, high and moderate. Divers, grebes, marine ducks and auks are considered to be the seabird groups most vulnerable to oil pollution (for a more detailed index of vulnerability, see Anker-Nilssen, 1987).

In general, seabird vulnerability to oil spills is high during winter, and their early appearance at colonies, together with their behaviour and age composition (adult and sexually mature birds), makes them highly vulnerable. Great losses of reproductive birds can result in an instant drop in the population size.

Critical periods for seabirds, where the consequences of an oil spill can be much more serious than at other times of the year, vary between species. Folkestad (1983) summarised the following critical situations in the event of an oil spill:

- concentrations of flightless birds
  - moulting grounds/moulting flocks
  - post breeding movements of auks
  - areas with large numbers of young birds
- concentrations at roosting areas
- periods with poor light conditions at night, particularly during winter in northern areas

Post breeding movement of auks is added to the list, as this is a combination of moulting adult birds and assemblages of young birds. Moreover only one sex of the adults (the male) will be affected, and this will increase the effects of an oil spill. In addition, in the event of a spill, vulnerability will be increased where birds are concentrated at feeding areas, breeding grounds, and during migration.

Changes in both feeding areas, and post-breeding movements, make an evaluation of the environmental impact of oil spills much more complicated. It will also be more difficult to point out the best strategy for oil spill contingency planning and response.

4.5 Minor Oil Spills Offshore

Minor spills may impact seabirds at sea in the immediate vicinity of the field installations, particularly the auk species. A recommendation has been received from NINA that the effects of small oil spills should be monitored in periods where the Haltenbanken area is likely to hold a substantial number of seabirds vulnerable to oil contamination.

4.6 Major Oil Spills

Oil constitutes a serious and well documented danger for seabirds, and many millions have been killed after large and small oil spills. Of the three main factors contributing to the risk for local seabird populations, i.e. the probability of an oil spill event, the dispersal of oil over the area, and the numbers, distribution and vulnerability of seabirds in the area, only the last is amenable to analysis by ornithologists.

An analysis of the impact of oil spills on seabird populations, should, ideally, provide information on the short and long-term effects at population levels of all vulnerable seabirds within a given area. An impact analysis thus involves evaluations of vulnerable seabird populations in inshore and offshore areas during the year, degree of vulnerability, population stability, potential risk, criteria for evaluating the importance of conservation effects concerning a particular population, effects of different types of oil and components, and measures for restricting damage from oil contamination.

A new oil vulnerability index for seabirds, which differentiates between individual vulnerability and population vulnerability, and between different seasons, recognises 17 criteria, 9 at the individual level and 8 at population level (see Anker-Nilssen 1987). However, without a link to digitalized oil drift simulations, this analysis system can not be entirely carried through.

Only a qualitative evaluation, based on descriptions of assumed vulnerable seabird populations relative to statistics on direction and drift obtained through simulation of oil spills, is therefore presented here. It should be emphasized that the data base for seabirds in the open sea is poor. Several simulation experiments demonstrate that these populations would be jeoparidized in the event of a major oil spill at Heidrun. This summary only discusses species which are assumed to be highly vulnerable to oil contamination.

4.6.1 Inshore Seabird Populations

a) Summer

Oil drift simulation experiments (Section G.1.7.3) indicate that the coast of Trøndelag and Helgeland are most exposed to potential stranding of oil from the Heidrun field. Several seabird colonies, some with very large breeding populations of vulnerable species, may be exposed to oil spills. Potential damage to auks in particular may be considerable, but the extent of damage may vary according to time of the year, stages in the breeding cycle, weather conditions etc.

Prior to the start of the breeding season, large and dense flocks of auks often congregate on the sea just outside of the colony. Most of these birds are reproductively active adults. If these individuals were to be hit by an oil spill, the long term effects for the population would be serious. Although actual figures are not available, it is roughly estimated that if half of the breeding population of Guillemot is lost, 50 years might elapse before the population approaches normal levels.

Later in the breeding season, young or non-reproductive individuals may reside near the colony, while breeding birds occupy the cliffs, or are away in search of food. The extent to which breeding birds may be affected by oil contamination depends on the size of the area in the vicinity of a colony through which an oil spill may pass.

Population developments have been negative for all of the auk species in Norway, but particularly for Puffins at Røst and for Guillemots in Troms and Finnmark. Røst/Verøy support by far the largest seabird colonies in Norway. The Puffin population here has been reduced by a half from 1979 to 1989, due to failed reproduction. The Puffin colony at Lovunden also appears to have declined radically. In such a situation, it is of prime importance that oil contamination of these populations is prevented in the future.

Black Guillemots breed in a more widely dispersed manner than other auk species. They are often preyed upon by mink, and therefore mainly nest in out-lying coastal areas, where they could be exposed to stranded oil. The greatest numbers of this species within the influence area for Heidrun, are found at Froan and Vega. Oil which strands in these areas could damage a large proportion of the total population of Black Guillemots in Norway.

At Sklinna, a breakwater between two islands may act as an oil trap, and lead to extensive damage to birds on the water in the vicinity of the colonies.

b) Moulting Period

Moulting seabirds often congregate in dense concentrations in particular locations. Greylag Geese, Eiders and Mergansers assemble in exposed areas of the archipelago. They are unable to fly and are therefore highly vulnerable to contamination from oil spills. Velvet Scoter usually flock in less exposed areas, but are nevertheless a species which is highly vulnerable to oil.

A significant part of the Greylag population would be threatened if an oil spill struck the coast near Froan or Vega during the moulting period, particularly if they were driven away by disturbance from the feeding areas or roosting sites ashore, into an oil slick.

Damage to moulting duck populations may be considerable if oil stranded in areas such as Froan, Ørlandet and Vega. Today, these regions are internationally important for moulting waterfowl.

The composition of moulting flocks along the coast is unknown. Damage to moulting waterfowl populations (local as well as foreign populations, possibly including Fennoscandian breeding populations) may have serious long-term consequences for breeding populations.

c) Winter

Computer simulation of oil drift and stranding reveals that potential for stranding in wide areas of Sør-Trøndelag, Nord-Trøndelag and Helgeland is highest during the winter. The risk of birds being killed by oil contamination during the winter is higher because of the lower number of daylight hours and reduced visibility, and decreased survival due to hypothermia, even after minor oil damage.

The influence area of the Heidrun field is the most important wintering area in all Norway, for most of the seabird species which are considered vulnerable to oil contamination. A significant weakness in the available material on these species, is the lack of information concerning which populations winter in the area. Evaluation of the impact of damage related to oil spills, is largely limited to the number of birds which may be affected, and to a lesser degree the long-term consequences for different populations.

Divers and grebes are highly vulnerable to oil contamination. These species breed in small numbers throughout their entire distributional range. Therefore, a relatively significant number of birds winter in coastal regions in the influence area. Oil stranding may lead to high losses of certain species and significant reductions in the breeding population.

Experience from England demonstrates that species like the Great Northern Diver are exceptionally vulnerable. During one oil spill, the number of carcasses of Great Northern Divers found dead as a result of oil contamination exceeded the total number of individuals previously thought to be living in the area. The above illustrates the extreme difficulties in properly surveying these species. Information on the size of the breeding population of several of these species is limited, and it is difficult to make conclusions concerning populations in different areas.

Cormorants winter along the coast in the entire area, with the largest concentrations at Froan. Damage to cormorants here would probably affect birds originating from several areas along the coast, thereby reducing the total extent of damage to a single population.

Shag are more often found in outlying coastal areas, and are therefore more vulnerable to oil contamination than the Cormorant. Reduction in the number of adult Shag at the colony at Runde, which has undergone serious decline, and poor reproductive success in recent years, would have particularly serious consequences.

Common Eiders are found in both inner and outer coastal areas, with the largest concentrations in areas highly exposed to oil contamination. Oil stranding in Froan, Vikna, Vega or at Røst could injure large wintering populations. There is no information on which populations would experience greatest losses. Serious losses may intensify negative development already seen in wintering populations of Eiders in recent years.

Waders are considered less vulnerable to oil pollution, although conflicts may arise if oil is washed ashore in zones where waders search for food. The Purple Sandpiper population may directly be influenced by a spill if feeding areas in the tidal zone of exposed skerries are contaminated.

Velvet Scoter are highly vulnerable to oil contamination, as documented during several oil spills abroad. Heavy losses of Velvet Scoter may be expected in the event of oil spill stranding at Frøya/Ørlandet, Vikna or Vega. There is no information on which populations might be involved.

Long-tailed Ducks are often found in areas which are exposed to oil spills. The species is relatively abundant and evenly distributed throughout the influence area of the Heidrun field. The consequences for breeding populations, and potential losses resulting from oil contamination, are unknown.

Mergansers are highly vulnerable to oil contamination, but often occur in areas which are less exposed, such as between islets and skerries. They are highly mobile, and may follow shoals of fish. At present there is no information on which populations might be affected in the event of an oil spill.

Auks are highly vulnerable to oil contamination. Although they may occur in varying numbers along the coast, all species but the Black Guillemot, are most abundant at open sea. Experience from earlier oil spills has shown that the Black Guillemot is highly vulnerable to oil, but even if long-term effects on local populations were expected as a result of mortality, there is insufficient reliable data on population development of this species in Norway to be able to predict the impacts.

4.6.2 Offshore Seabird Populations

Although the data base on the distribution and abundance of seabirds at sea is poor, there is sufficient to indicate that an oil spill might injure a very high number of seabirds, particularly the auk species, even within a relatively restricted area.

The majority of open sea data are from areas between 62°N and 64°N. The effects of small oil spills on seabirds present in the vicinity of the Heidrun field therefore cannot be properly evaluated.

Little Auks feed where prey is most concentrated, and a better understanding of the winter and spring distribution of Little Auks off central Norway is necessary.

Concentrations of Little Auks and Puffins as high as 1,000 birds per km^2, or more, have been found off the coast of Møre and Romsdal and Sør-Trøndelag in spring. Such concentrations appear to be highly unpredictable in time and location, but are most probably related to food resources.

It is not known whether the birds winter in this area, but if they do, the short-term effects of even a small oil spill could be great, with a large number of birds killed. The long-term effects at population level, however, cannot be evaluated properly with the present knowledge of their origin, and how their distribution and abundance is related to food resources.

4.7. Important Seabird Localities

Particularly important seabird localities are shown in Figure I.4.1, and are described here only briefly. Emphasis is placed on the species most vulnerable to oil spills.

Runde, Lovunden and Røst/Værøy are the three largest bird-cliffs which may directly or indirectly be affected by oil spills from Heidrun. Directly by an oil spill present in the vicinity of the colonies during the breeding season, and indirectly by oil spills that may threaten auks on their post breeding movements, for example Guillemot from Runde moving north towards Haltenbanken.

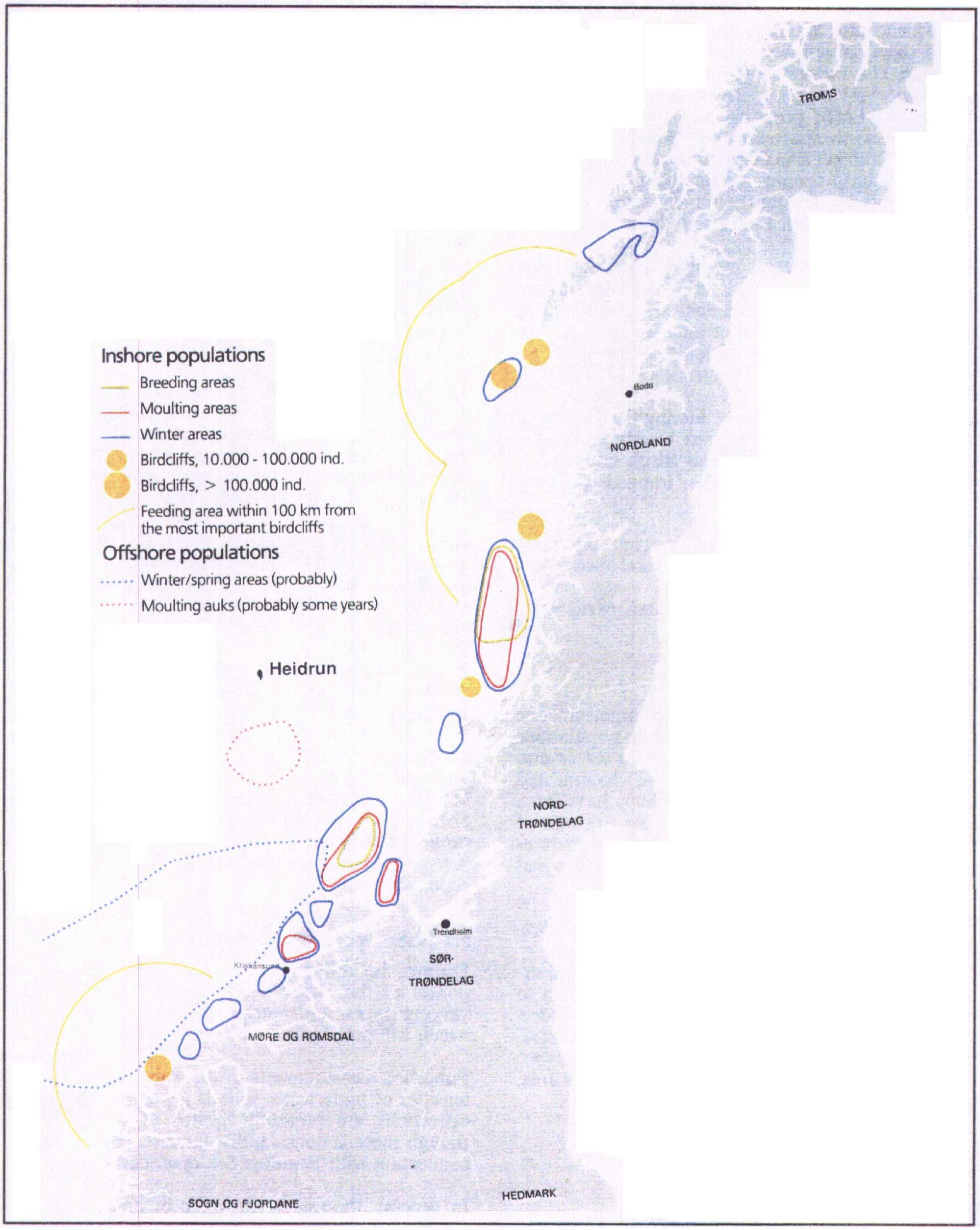
Giske and Haram support significant populations of divers, grebes and cormorants. Relatively large numbers of Red-breasted Merganser have been observed at Giske, and good populations of other marine ducks have been found in both municipalities.

Outer coastal areas of Romsdal are important for several species. Large numbers of divers, grebes, cormorants and Red-breasted Merganser have been observed in the municipalities of Midsund, Sandøy, Aukra and Fræna, as well as significant populations of Common Eider, Long-tailed Duck and Velvet Scoter. A large population of Whooper Swans is also found in the Fræna/Eide area.

High numbers of cormorants and Red-breasted Mergansers have been observed in the vicinity of Averøya.

Smøla is clearly the most important wintering area on the coast of Møre and Romsdal county. Signifi-

Figure I.4.1 Distribution of the Important Seabird Localities on the Impact Coast.



cant numbers of several species have been observed here, especially populations of divers and grebes, which are among the largest in the country. The populations of the Red-throated Diver and the Great Northern Diver, which are predominant among divers, and the Red-necked Grebe are of European importance. Smøla is also an important moulting area for Greylag Geese, Common Eiders and Velvet Scoter.

Froan and Vega are two of the most important seabird areas on a year-round basis. They are the most important breeding localities for the Black Guillemot in Norway, and an oil spill here may have significant consequences for the entire population of this species. The breeding populations of the Cormorant and the Eider are also outstanding. Froan and Vega are the most important moulting sites in Norway for Greylag Goose and Eider, probably also for Red-breasted Merganser, with approximately 35,000 male Eiders in Froan. Both are also the most important wintering areas for several species. An oil spill at any time of the year may kill several thousands or tens of thousands seabirds in both Froan and Vega.

Ørlandet is an important moulting area for Velvet Scoter and Eider, and a wintering area for several species. The wetlands of Ørlandet are unique in this region, and are an important area for several dabbling ducks and waders. Some localities are protected according to the Ramsar Convention.

Outer Vikna is an important wintering site for several species. Sklinna is an important breeding area for Cormorants, Shags, Puffins and Black Guillemots. Due to a breakwater, oil may be "trapped" just outside the breeding sites.

The coast of Helgeland south of Vega has important moulting and wintering areas for several species.

Røst is also an important wintering area, particularly for Common and King Eiders.

4.8 Conclusions

The influence area of Heidrun is an important one for a large number of seabirds, holding populations of national or international importance for several species. Oil constitutes a serious and well documented danger for seabirds, and many millions have been killed after large and small oil spills. At any time of the year, oil spills may possibly threaten a large number of vulnerable seabird species both inshore and offshore.

NINA has recommended that special care of seabirds should be taken in contingency planning connected with oil spill combatting and protection. Further mapping and studies of seabirds in relation to field resources is needed to achieve a better understanding of distribution of seabirds at sea off central Norway, and particularly to evaluate the importance of the offshore section of the Heidrun influence area, including the Haltenbanken area.

5. MARINE MAMMALS

5.1 Seismic Operations

At the present time, a requirement for further seismic survey in the Heidrun field is not foreseen. However, should it be necessary, the most likely survey technique used would be air gun.

The shock wave produced by an air gun differs from that of a chemical explosive shock wave in that its peak pressure is relatively low and both the rise time and the time constant of pressure decay are comparatively long. It is thus considered extremely unlikely that any gross damage would occur to marine mammals in the vicinity of seismic operations (Wright, 1981). This general statement is confirmed by a number of more recent US studies which found no physical damage to, and only minor behavioural changes in, whales exposed to seismic operations using airguns.

Observations of the effects of airgun seismic vessel activity on migrating bowhead whales (*Balaena mysticetus*) in the Alaskan Beaufort Sea were carried out through a co-operative programme between the US Minerals Management Service and the US National Marine Fisheries Service. Behavioural observations were recorded using 15 well-defined categories.

The response of all whales was to move away from the approaching seismic vessel. Results suggested that behavioural changes were evident at distances of 3.5 km to 6.7 km, but that whales resumed pre-experimental behaviour following termination of the seismic activity (Ljungblad et al, 1985).

Similar findings were reported by Richardson (1985), who also noted that the overt reactions of bowheads to full-scale seismic operations were similar to those expected when any boat approached within a few kilometres.

A behavioural response study of grey whales *(Eschrichtius robustus)* to airgun seismic operations (single 100 cu.in. and 4,000 cu.in. 20-gun array) was undertaken off the coast of California. Malme and Miles (1985) report that the threshold of avoidance behaviour was 164 dB (average pulse pressure). Levels of 180 dB were found to produce nearly complete avoidance of the area. Within the test area, the effective range for 50% probability of avoidance was 400 m for the 100 cu.in. airgun and 2.5 km for the 4,000 cu.in. seismic array.

5.2 Noise from Offshore Activities

During the drilling, construction and operational phases of the Heidrun development, there will be varying types and intensities of noise produced, which will propagate in the marine environment.

Published measurements of the wavelengths and intensities of underwater sounds generated by drilling operations are presently limited (Turl, 1982), although there is considerable interest, particularly in connection with Beaufort Sea operations.

In general, the frequency range of noise from offshore drilling activities is from 10 Hz to 10 kHz, with peak source levels between 130 dB and 180 dB (Turl, 1982). Greene, quoted by Fraker (1984) measured levels of noise originating from ships, aircraft and drilling operations in the Beaufort Sea and found a frequency range of up to 2 kHz, and an intensity at 100 m distance of 100 dB to 180 dB. After consideration of peak noise output level from platforms and ambient ocean background noise levels, Turl (1982) calculated that detection ranges for marine mammals were 38 km at 0.2 kHz and 174 km at 1 kHz.

Hearing in marine mammals is good and most species can detect sounds in the 10 Hz to 50 kHz range. Observations of mammals in the vicinity of operations in Californian waters and in the Beaufort Sea suggest that minor behavioural changes and avoidance of the noise source were the main responses displayed (Fraker, 1984; Tyack et al, 1983).

Gales (1982) reports that noise from offshore activities can be heard by marine mammals at distances of 185 km, and that within 800 m of a platform, noise levels may be sufficient to partially mask lower frequency communication signals of toothed whales.

Evidence of an animal's ability to habituate to low levels of noise can also be observed, and may be seen in those species which coexist well with human activities (Geraci and St. Aubin, 1987). On the basis of existing knowledge, the effects of noise from the Heidrun field activities are not expected to have any acute detrimental effect on marine mammals in the vicinity.

5.3 Offshore Discharges

Indirect effects of oil and gas production activities on marine mammal populations (such as those associated with routine effluent and drilling discharges), are difficult to detect and cannot be tested experimentally.

Discharges of these materials are approved by SFT subject to their acceptability in terms of toxicity, persistence, dispersion and dilution. The offshore receiving waters in the Heidrun area will provide rapid concentration reductions within a small and well defined mixing zone. No detrimental effects on marine mammals are expected from routine discharges from the facilities.

5.4 Boat and Helicopter Traffic

Supply vessels will be using existing marine shipping routes from the offshore base at Kristiansund. Referring to the discussions on the effects of noise on marine mammals in Section I.5.2 above, unacceptable impacts on coastal and offshore mammals are not envisaged.

Seal populations might be expected to be able to habituate to low level background noise from helicopter traffic. Helicopters will not be flying low over colonies, and coastal populations near to the flight paths are not expected to be detrimentally affected.

5.5 Oil Spills

Responses to acute oil spillage may be considered in connection with detection and avoidance, behavioural effects, surface contact (thermal effects and tissue damage), ingestion (oral obstruction, toxicity and bioaccumulation). These effects are group or species specific and dependent on the presence of animals in the impact area, the degree of oiling and the nature of the oil involved.

5.5.1 Seals

Short-term exposure to high concentrations of oil has not caused observable negative effects on heat balance in seals with a subcutaneous fat layer (Kooyman et al., 1977), but it has caused minor eye damage (Geraci and Smith, 1976). It is uncertain whether a longer exposure to oil will cause skin injury.

Death caused by the highly soluble components of oil, as well as damage to inner organs as a result of ingesting oil, has been demonstrated in experiments where the animals could not avoid the oil (Gerachi and Smith, 1976; Engelhardt et al., 1977). Stranded seals were observed to have similar internal damage and this was assumed to have caused their death (Babin and Duguy, 1985). Oil fouled mothers interacted normally with their pups, but measurements showed that grey seal pups of oiled mothers had significantly lower weight at weaning than those of clean mothers (Davis and Anderson, 1976). This may have had consequences for post-weaned pups.

Based on observations from oil spills, one can conclude that small amounts of partly degraded oil will have a minor influence on the survival of adult and juvenile grey seals. Because adult harbour seals are smaller than grey seals, and juveniles enter the water almost immediately and do not shed their coat (Bigg, 1981), some authors believe that harbour seals may be more prone than grey seals to higher mortality from an oil spill.

5.5.2 Whales

Whales are entirely adapted for aquatic life and they even give birth in the sea. The largest whales are enormous, measuring 30 m in length and weighing 120 tons. Two main groups of whales exist; the toothed whales and the baleen whales (Stonehouse, 1985).

Observations of whales in oil spills are rare, and the ones that are reported indicate that the whales do not recognise oil or are unaffected by it (Griffiths and Øritsland, 1986). Several laboratory experiments also confirm this view (Gerachi and St. Aubin, 1980).

Engelhardt (1983) refers to a report by Goodale, Hyman, and Winn (1981) where several species of whales were observed swimming and feeding at both an oil-covered surface and at a nearby clean surface after the "Regal Sword Accident".

Whether whales are at all affected by oil spills is according to Griffiths and Øritsland (1986) uncertain. Reports from actual spills are few and necropsies of dead animals are rarely performed. It may also be difficult to tell whether oiled animals became so prior to or after death.

Griffiths and Øritsland (1986) conclude that whales in Norwegian coastal waters will not be damaged by a passing contact with floating oil. These authors are reserved with respect to judging the internal effects of ingested oil.

While actively feeding, fin whales and minke whales could conceivably ingest some oil. As in the case of seals stranded on the French coast (Babin and Duguy, 1985), this could cause internal injuries. Gerachi and St. Aubin (1987) note that fouling of baleen has short-term effects on water flow and feeding efficiency, and that the consequences may not be as great as previously predicted.

5.5.3 Otters

Otters are a group of terrestrial carnivores that have adapted to a life in very close contact with water. They spend much of their time swimming and foraging for fish and crustaceans in nearshore waters and in the intertidal zone. Unlike seals and whales, they do not have a layer of blubber, and instead depend entirely on their pelage for insulation. They do have a well developed arterial blood system which regulates the amount of blood flowing to the skin and the heat loss from this source (Costa and Kooyman, 1982).

Oiled fur loses its insulating effect because it cannot maintain the necessary air layer in the underfur. A loss of insulating ability can to a certain degree be compensated for by increased metabolism and restriction of blood flow to the skin, but even slight oiling can still prove fatal.

Cleansing the pelt with oil solvents or detergents decreases the insulating ability of the fur by destroying its water repellent properties, which can also prove fatal (Costa and Kooyman, 1982). Experiments suggest that otters try to avoid a fresh layer of surface oil, but it is uncertain if they will avoid partly degraded oil with a patchy distribution (Siniff et al., 1982).

Otters may ingest oil through grooming or by eating contaminated birds. Field studies have shown that otter populations may be severely impacted by oil spills (H. Christie, pers. comm. Sept. 1989; Skinner and Reilly, 1989; Baker et al., 1981).

5.5.4 Summary

Substantial populations of marine mammals are present within the area which might be influenced by a major spill from the Heidrun field. A large part of the Norwegian otter population also resides in this area.

Because grey seals and harbour seals give birth between June and November, and several migrating whale species pass through the area at this time, it is considered potentially the highest risk period for impacts from major spills originating in the Heidrun field. However, oil spill modelling from the Heidrun field has shown that the breeding season in autumn also coincides with the period of lower risk for contact with oil.

The internal and external effects of oil are group or species specific. Seals and whales have subcutaneous blubber which enables them to maintain their heat in an oiled state and externally oiled individuals from these groups do not show increased mortality over the short-term. Long-term effects are unknown. Otters are particularly at risk of pelage oiling and mortality from hypothermia.

Ingested oil has been shown to cause internal bleeding and necrosis in seals, and is expected to have similar effects on other marine mammals. The amount of oil which might be ingested by resident or transient populations in the event of a spill is unknown, but may be sufficiently high to cause mortality amongst seals, otters and possibly some species of baleen whale.

Terrestrial Mammals

A number of species including deer, reindeer, sheep and mink are frequent visitors in the coastal zone. Grazing of oiled seaweed and vegetation by herbivores may give rise to gastrointestinal disorders and individuals would if possible be removed from impact areas.

6. NATURE RESERVES, PROTECTED AREAS, AND AREAS OF PARTICULAR SCIENTIFIC INTEREST

The main sources of impact on these resources would be smothering by oil drifting ashore and damage due to clean-up operations. The potential impacts on areas of ecological value, primarily those of importance for seabirds, have been considered elsewhere. Damage to shoreline cultural memorials and areas of cultural preservation would be primarily aesthetic, but old wooden structures such as piers, quays and seahouses could be detrimentally affected by oil.

Floating vessels of importance could be removed from a potential impact area into a refuge site and such provisions would be included in contingency plans.

Oiling prior to the main summer tourist season would clearly be disadvantageous.

The areas which are important to nature conservation are grouped in three major regions.

The Froan archipelago and outer parts of Trondheimsfjord.

Froan and the outer part of Bjugn, Ørland and Agdenes municipalities are of particularly high value. Here there are two areas important to scientific research and a large number of nature reserves and protected areas of both national and international value. The Froan region will be particularly vulnerable to an accidental oil spill because the archipelago is on the open coast. The region of Trondheimsfjord and the entrance to the fjord are considered somewhat less threatened, because the possibility that oil from Heidrun would enter these regions is less than for Froan, and because the probability of successful oil spill combat operations and clean-up is greater.

The Vikna - Leka coastline.

In the Vikna - Leka region, there are two areas important for scientific research, two sites with nearshore cultural memorials, three nature reserves and four protected areas. All the protected areas are of great importance because of their bird populations. Most of the areas lie on open coastline.

Outer parts of Bodø municipality.

In Bodø municipality, there are two nature reserves (important for birds), one cultural memorial and an area of importance to scientific research. The areas lie mostly on open coastline.

Helgelandsøyene in Vega municipality, has been proposed for protected status and is important to scientific research. The consequences of an oil spill affecting this region are considered to be similar to those for Froan further south. In the Vega - Lurøy region there are important sites for nature conservation, although these are not protected. The Værøy - Røst region is also of importance to nature conservation and scientific research, and has several valuable harbour sites.

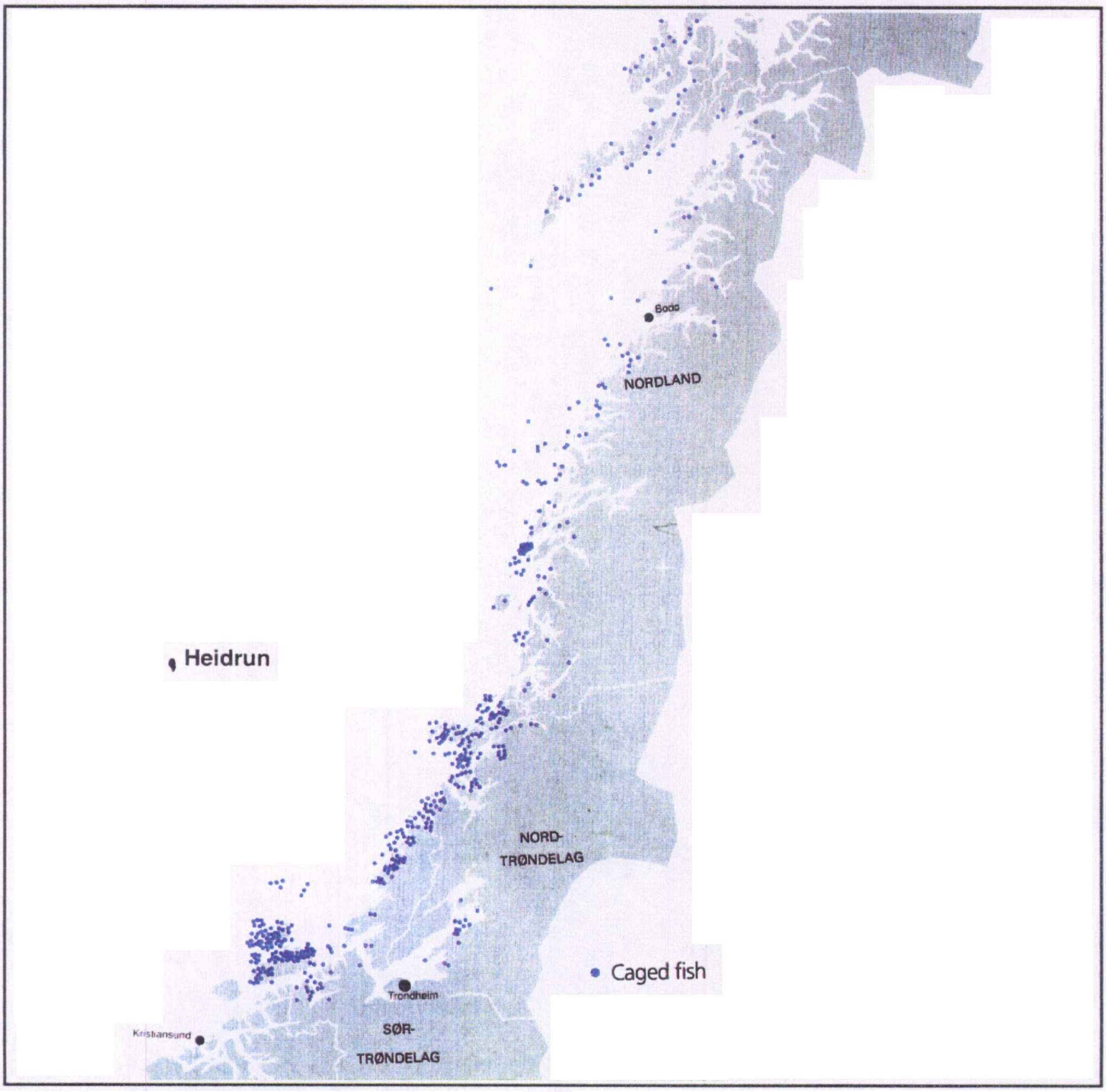
7. EFFECTS OF OIL SPILLS ON AQUACULTURE

7.1 Intensive Production of Fish in Cages

In the event of a major oil spill in the Heidrun field, aquaculture sites in coastal areas in Møre and Romsdal, Sør-Trøndelag, Nord-Trøndelag and Nordland could be affected. The location of aquaculture units within the area of interest is shown in Figure I.7.1.

The effect of oil on aquaculture units was observed following the "Claymore" pipeline spill in the British sector of the North Sea in 1986 (Anon, 1987). Approximately 3,000 tons of crude was released subsurface, and after 10 days some of this material drifted onto the Norwegian coastline. No effects of

Figure I.7.1 Aquaculture Sites in Nordland, Nord-Trøndelag, Sør-Trøndelag and Møre and Romsdal.



the spill were reported, other than those on aquaculture. In Sogn and Fjordane, 100 to 1,000 fish were reported to have died as a consequence of damage to the gills and integument, resulting from oil ingress to the cages.

It has been suggested that the damage may have arisen because the oil elicited an avoidance or fright response. Because the fish were confined within a cage, the increased swimming activity resulted in increased oxygen consumption, oxygen deficiency in the water and increased physical damage.

Such changes in swimming activity have been reported to be triggered by petroleum hydrocarbons. Reiersen and Berge (1985) found increased activity in a littoral fish, at concentrations of crude oil WSF in the range 25-100 ppb, and reduced activity at concentrations above 200 ppb.

For fish exposed to crude oil WSF's, 96 hour LC_{50} values of between 1.2 and 65 ppm were reported (Connell and Miller, 1981). These values are far greater than can be expected under a 10-day old oil slick. Increased swimming activity and the resulting physical damage to fish are thus the most likely immediate consequences of weathered oil impacting fish farms. These effects, in conjunction with the stress resulting from clean-up operations, may increase fish mortality (Aabel et al., 1989).

The area from Vikna to Rødøy is the most likely to receive oil from a major spill at Heidrun (see Section G.1.7.3). The Lofoten area is classed as medium to low impact, as is the important aquaculture area around the islands Frøya and Hitra. The northern section of the coastline of Møre and Romsdal is also in the less impacted zone.

Figure I.7.2 Aquaculture Sites in Nordland, Nord-Trøndelag, Sør-Trøndelag and More and Romsdal

The classification of the different impact zones is based on the mean amount and age of any oil that is likely to reach the coast. This does not imply that a fish farm hit by oil in a low impact area will be any less severely affected than a farm in a high impact zone.

Tainting is a potential problem associated with intensive fish production and oil. This stems not only from the unpalatable taste of tainted flesh, but also from marketing problems arising out of the public's perception of the quality of fish taken from areas affected by an oil spill.

7.2 Hatcheries and Other Land-based Systems

The possibility of oil or other contaminants from the Heidrun field reaching seawater intakes feeding land-based systems is small.

The oil which potentially could reach such areas is likely to be at least 5-10 days old, and capable of leaching only small amounts of soluble components to the water column. Furthermore, the seawater used to supply land-based systems is in most cases pumped from depths of 30-100 m. Even in rough weather, it is unlikely that significant volumes of oil would be transported to this depth.

If soluble petroleum hydrocarbons were introduced to land-based systems used for rearing juveniles, however unlikely, the threshold for direct mortality would be high compared with the concentrations which might be expected. Moles et al. (1987) found in experiments with exposure of pink salmon alevins *(Oncorhynchus gorbuscha)* to crude oil WSFs, that direct mortality did not occur at a concentration of 0.7 and 1.5 mg/l, but did occur at 2.4 mg/l. These concentrations are 1 order of magnitude higher than might be expected even under a fresh oil slick, and are not likely in inshore areas as a result of an offshore oil spill.

It is thus concluded that land-based systems, including hatcheries, are unlikely to be affected by the activities related to the Heidrun field development.

7.3 Extensive Sea-based Production

Extensive sea-based production systems are not presently of commercial importance in Norway. The avoidance reaction and consequences resulting from oiling would not be as marked as those described for the "Claymore" incident in Section I.7.1 above. The lower density of fish in extensive production systems provides greater space and manoeuverability, which results in fewer contacts with cage/enclosure walls or other fish, and hence less physical damage.

Oil entering bays used for extensive production purposes will probably have a limited effect on captive fish. The possible exceptions are shallow water areas and areas with high densities of juveniles near the surface (shallow intertidal zones). An oil spill could, however, cause considerable problems as a result of smothering and oiling of cages, nets and other surface structures.

The probability of concentrations of petroleum hydrocarbons above the threshold for effects occurring in inshore free water masses is small, and the pathological effects on adult pelagic fish stocks is likely to be limited.

Such effects have, however, been documented after oil spills on the French coast ("Amoco Cadiz" and "Gino"), but mainly for flatfish (Maurin, 1984). Ulceration of the skin has been observed by Chasse (1978). Gradual redistribution of sediment hydrocarbons and subsequent availability to fish in or near the intertidal zone was believed to be the cause.

7.4 Mussel Production

Bivalves reared in aquaculture units are filter feeders and select material from the water column on the basis of particle size. This means that oil dispersed as droplets, adsorbed on particles, and oil soluble components will be available to the organisms. Filtering is an active process, which under unfavourable conditions may be stopped for a limited period of time. During such a period (days), species such as mussels are able to survive through anaerobic metabolism and can therefore avoid the effects of short-term high level exposure to oil.

Relatively high concentrations (5-1000 mg/l) are needed to trigger acute mortality from hydrocarbons in *Mytilus* (Craddock, 1977). Long-term exposure of *Mytilus edulis* to low concentrations of petroleum hydrocarbons results in several physiological changes related to energy balance (Axiah and George, 1987), and may give rise to increased mortality.

Widdows et al. (1982) conclude that petroleum hydrocarbons (30 ppb) have significant adverse effects on the physiological and cellular conditions of *Mytilus*. However, if hydrocarbons are incorporated into mussel tissue following a spill, release (depuration) is possible. Farrington et al. (1982) have reported biological half-lives for selected petroleum hydrocarbon compounds (n-alkanes, pristane, naphthalenes and methyl phenanthrenes) in the range 0.2 to 1.7 days, after a brief exposure (2 days) to an oil spill. Widdows et al. (1985) report complete recovery of both physiological performance and tissue hydrocarbon levels in mussels after approximately 55 days in clean water following long-term exposure to diesel oil.

This indicates that contaminated mussels may recover after exposure to hydrocarbons but growth may be reduced. This could in turn result in reduced production figures for the farm, and loss of income.

Another problem is shellfish tainting, which probably is the most tangible effect after a major incident. After the "Amoco Cadiz" oil spill, oyster cultures were badly affected by taint and some mortality was also noted (Chasse, 1978).

If oil from the Heidrun field is introduced to a mussel farm in the high impact zone, direct mortality is likely to be limited. It could be more extensive in cases of physical smothering by oil. Where immediate removal of oil is possible (within 1 week), it is probable that no significant effect on growth would be observed. Tainting is, however, likely.

7.5 Traditional Inshore Fisheries

Tainting is a potential hazard to inshore fisheries. After the "Amoco Cadiz" oil spill, several species of wild fish (including pollack and mackerel) and crab *(Cancer)* caught at a depth of 30 m were occasionally reported as tainted. However, 7 weeks after the oiling, fish and crustaceans from offshore waters were mainly free of taint, and after 2.5 months, this was also the case for all inshore areas except the innermost bays (Chasse, 1978).

Herring, sprat and saithe caught in traditional inshore fisheries are occasionally kept alive in net cages in sheltered bays before delivery. Such shoals of fish may react in a similar manner to the salmonids exposed to oil from the "Claymore" incident. The integument of both herring and sprat is extremely sensitive to physical contact, and lost scales and infection are risk factors. If oil elicits an avoidance or fright reaction simultaneously in all of the fish, such behaviour may result in fish breaking out of the net cage.

The effect of an offshore spill on inshore fish and fisheries will probably be of limited importance, with the possible exception of shallow water areas and nursery grounds in the intertidal zone. There may be impacts associated with oiling of the cages used for storing fish, and any other nets, surface structures or gear deployed in the spill drift path. Impeded fishing activity can also be expected in the vicinity of any oil spill.

The coast of Flatanger to Brønnøysund and the inner part of Trondheimsfjord contain areas with an especially high density of locations used for storing herring. The area from Flatanger to Brønnøysund is thus particularly vulnerable since it also contains a high density of aquaculture systems.

7.6 Harvesting of Seaweed and Kelp

The coast south of Senja is one of the most intensively harvested areas for large subtidal kelp. Due to extensive overgrazing by sea urchins, the kelp has been wiped out over large areas of the bottom north of Senja, and harvesting in these areas has stopped. Harvesting of tidal seaweed, primarily knotted wrack *(Ascophyllum nodosum),* is performed along the whole coast of western and northern Norway, and in some areas this activity has significant economic importance.

Oil pollution can result in reduced growth of seaweed and kelp (Bokn, 1985), possibly due to the inherent chemical toxicity of fresh oil. Reduced growth of algae due to the presence of weathered oil from a spill is not considered significant. Oiling of knotted wrack in the tidal zone would, however, make the wrack unfit for harvesting. Recruitment of new wrack plants is in general very slow, and since the annual growth is also small, a recovery period of at least 10 years might be expected before an area has recovered sufficiently to allow new harvesting to commence.

7.7 Preventing Oil Damage to Aquaculture

Prevention of damage to an aquaculture plant threatened by an oil spill is best performed by avoiding direct contamination of fish nets and other structures. Strategically located collection, deflection and absorbent booms can and have been usefully employed as a first line of defence in such incidents.

Prior warning/notification to installation owners and where appropriate, rapid identification and mobilisation of the necessary oil combat equipment, and possibly towing of cage arrays to predetermined refuge sites, are important first steps. In this connection, the joint industry environmental database (see Appendix B) will give instant and detailed information on all aquaculture units in the coastline area of interest.

Other options may be to lower the cages into deeper water, or to harvest the fish.

Where oiling is unavoidable, care will be taken to minimise stress during clean-up operations as this may cause additional mortality.

7.8 Conclusions

Intensive fish production systems are extremely vulnerable to oiling, more so than extensive systems. This is not primarily a function of the toxicity of the oil, but rather the effect it has on fish behaviour in densely populated cages.

Pathological effects of oil cannot be excluded, but they will probably be transient, mainly affecting species from shallow sheltered water areas where oil may accumulate and persist.

The effect of oil on traditional inshore fisheries is difficult to assess qualitatively, but is expected to be mainly limited to disturbance of fishing activity.

Harvesting of kelp is not considered to be in jeopardy from an oil spill since it is taken from the subtidal zone. Harvesting of seaweed from the littoral zone may, however, be severely restricted for several years. This is primarily due to the mortality of plants, their unsuitability for the market, and the period of time before full recolonisation and harvesting can take place.

In extensive fish production units, traditional inshore fisheries and in mussel farms, tainting is probable.

Tainting is reversible and no effect should be seen after 1 week for salmon kept in clean water, and up to 2.5 months for wild fish, crustaceans and mussels. Tainting of organisms in sheltered bays, where oil may persist for years, will probably continue for longer periods (years) if oil is not removed.

Oiling of fish and aquaculture equipment can also be expected during a large oil spill. Clean-up operations may be necessary to avoid long-term tainting, but may unintentionally result in increased stress in captive fish, in redistribution of oil locally and in increased availability of oil to the biota.

The aquaculture industry is located along almost the whole coastline in the counties which might be affected by a major oil spill from the Heidrun field. For inshore fisheries, and especially for aquaculture, the most vulnerable part of the coastline is from Flatanger to Brønnøysund.

8. SHORELINE ECOLOGICAL COMMUNITIES

8.1 Sources of Impact

The only real threat to these resources from the Heidrun development is that of an oil spill drifting ashore. Apart from local temporary disturbance during construction, base activities, ship and helicopter traffic are not expected to have any impact on shoreline ecological communities.

Because of the potential for dispersion and dilution, operational discharges at Heidrun are not likely to affect the shoreline.

The intial effect of an oil spill on the coastal ecosystem is expected to be smothering, but longer-term impacts may also occur. High molecular weight toxic compounds still contained in the weathered oil could cause long-term sublethal effects, either by gradual leakage or through their photo- and biochemical degradation products. This phase might resemble a chronic oil spill or petrochemical discharge.

Oil can cause physical and chemical alteration of the shoreline sediments. Hardened aggregates of oil and sediment grains may form stable asphalt "pavements" on shores (Gundlach et al., 1982) and thus change the substrate completely. Oil may cause a shift to more reducing conditions in the sediments through a combination of: a) reduced gas exchange at the sediment/water/air interface, b) depletion of oxygen in the pore water resulting from biodegradation of the oil and c) reduced bioturbation leading to stabilisation of the sediment (Kuiper et al., 1983). Sediments can become anoxic and temporarily uninhabitable for most biota.

8.2 Fate of Stranded Oil

Several factors determine the fate of stranded oil. The horizontal and vertical distribution on the coast is determined by oil type and age, but primarily by currents and waves. Wind will generate waves which may transport oil into the supralittoral zone and facilitate redistribution on the shore. On high energy shores, oil will be removed or redistributed in a matter of days or weeks, whereas wave-sheltered shores may act as sinks for recently deposited or redistributed oil. In sheltered areas, the supralittoral zone is less likely to receive oil.

Tides determine the vertical range of shoreline oiling, and influence the redistribution along the shore. Tidal pulsing of interstitial water may cause oil to be transported into the sediment by percolation at falling tide. The degree of burial depends also on sediment porosity. On fine-grained sand beaches, only low viscosity oils will penetrate to a significant extent, whereas on boulder shores, even heavy, tarry oils can rapidly penetrate down to the ground water table (Owens, 1978). Oil buried in sediment or between rocks will not easily be eroded and may persist for many years (e.g., Gundlach et al., 1982).

Temperature mainly determines the viscosity of the oil, which in turn determines the degree of emulsification and dispersion, and the ability of the oil to penetrate into sediments. Sea ice formation will dampen the abrasive effects of waves on oiled shores, and if oil is trapped in or under the ice, the weathering processes may be slowed or stopped. During cold periods, the oil may harden and be less accessible to erosion and degradation. When temperature increases, the oil may become less viscous again and leak out into areas which have been cleaned (Thomas, 1973; Wikander, 1982).

Oily material may finally accumulate in subtidal depositional sediments (Beslier et al., 1980), where the removal is slower than on beaches. Still, the amount of oil reaching subtidal bottoms will never be as high as on the shore. Significant accumulation of oily material on subtidal hard bottoms has not been reported.

8.3 Vulnerability of Shoreline Biotopes

Vulnerability is a combination of the amount of oil likely to impact a biotope, the self-cleaning ability and the biological sensitivity. Effects may be direct or mediated through changes in competition or predation. As sensitivity is also a function of exposure time, it is tightly bound to the rate of oil disappearance. The major types of biotope in the region are briefly reviewed, in order to derive a ranking of overall vulnerability.

8.3.1 Terrestrial Communities

Any oil that impacts above the surf zone will be very persistent due to lack of wave action. Removal processes here will be photochemical and biological degradation, which will be slow when the oil cover is more than a few millimetres thick. Unless removed mechanically, oil can remain in the supralittoral zone for several decades, either hardening to an asphalt "pavement" or gradually being buried under new plant material (Gundlach et al., 1982).

Oil can cause damage to terrestrial plants through toxicity, smothering and by changing soil properties. In general, oiled plants recover only by new growth (Baker, 1971; Wikander, 1982; Klokk, 1986). Individuals of annual plants will normally die after being smothered (Baker, 1971) and the population will not recover unless colonised by new seeds. Furthermore, germination of seeds may be retarded (Danielsen et al., 1985).

Perennials recover by regrowth from the root system or from budding, and may show normal new growth even if large amounts of oil are still present (Wikander, 1982; Falk-Petersen et al., 1983). Oiling during summer impairs flowering and seed production (Baker, 1971), but this has limited effect on perennials as the dominant growth is vegetative. The most severe effect is found when the root system or overwintering organ of the plant has been exposed (Baker, 1971).

Effects of oil on soil microfauna have been recorded in experimental spills of weathered oil (Danielsen et al., 1985, and references therein). These investigations showed clear differences in oil sensitivity of major animal groups due to differences in microhabitat preference, e.g., terrestrial forms were more vulnerable than aquatic.

Scientific ranking of supralittoral communities as to oil sensitivity has not been found, but one can infer from the literature available, that the most likely communities to be impacted are those of the outer coast (Holten et al., 1986). Here, wind and waves are stronger and therefore more likely to transport oil onto land.

In dune areas, the vegetation is normally separated from the sea by a relatively wide buffer zone of sand, which may reduce the amount of oil hitting the dunes. Furthermore, it is apparent that oiling during the summer months will cause most damage, because of severe effects on annual plants. Still, in the spill incidents along the coast of western and northern Norway, where the effects on vegetation have been recorded (Wikander, 1982; Falk-Petersen et al., 1983; Danielsen et al., 1985), the recovery was rapid (communities on gravel and boulder substrates). Similar experience from oil pollution of supralittoral vegetation on exposed sandy shores along the coast does not exist.

Shore Type	Percent Removed in 1 day	Percent Removed in 5 days
Rocky shores		
exposed	60-63	99-99.3
sheltered	5-10	5-22
Sand beaches		
Low wave activity		
beach face	18-26	63-78
backshore	10-18	40-53
High wave activity	40-45	92-95
Gravel beaches		
Low wave activity		
beach face	10-18	40-53
backshore	5-10	22-40
High wave activity	33-40	86-92
Tidal flats (wet)	60-63	99-99.3
Marshes	0.1-1	0.5.5

Table I.8.1. Generalized Daily Oil Removal Rates as a Function of Shoreline Type and Wave Energy (From Gundlach and Reed, 1986).

8.3.2 Littoral Biotopes

Rates of oil removal will vary according to wave exposure and substrate. Gundlach and Reed (1986) have on the basis of a series of major spills, as well as field experiments, computed simplified oil removal coefficients for a range of cold water littoral zone biotopes (Table I.8.1). The removal rates range from 99% lost within 5 days on exposed rocky shores and water saturated tidal flats, to a 0.5%-5% loss in the same period in marsh areas.

The self-cleaning ability on a physical basis, and the expected residence times are summarised below in Table I.8.2. During heavy oil spills (e.g. "Exxon Valdez", Prince William Sound, 1989) resmothering is expected to last for some considerable time.

The coastal area which might be impacted as a result of a major offshore spill, has already experienced one large oil spill, the "Dei Fovos" grounding off the coast at Nesna in 1981. The oil struck supralittorally and in the upper part of the littoral zone. The shores in question are a mixture of erosion and transport substrates.

One year after the grounding, the oil cover was apparently not much reduced and gave a blue sheen on the water (Wikander, 1982). During a visit after 2.5 years (Danielsen et al., 1985) the appearance was much the same. After 3.5 years, the oil in open areas had become more asphalt-like, but was still soft and sticky between rocks and boulders, and produced a blue sheen. As far as is known, the "Dei Fovos" site has not been reinvestigated since, but local authorities (Nesna kommune, teknisk rådmann) stated in 1987, that no apparent contamination existed in the area. One must therefore expect that most of the oil had either been eroded away, degraded, solidified, or had

Substrate Type	Self Cleaning Ability	Estimated Residence Time
Depositional	Small	10-100 Years
Transport	Small-Medium	1-10+ Years
Erosion	Medium-Great	Dependant on Substrate
Boulder and Gravel		1-10 Years
Smooth Rocky Headlands and Subtidal Hard Bottoms		Hours-Months

Table I.8.2 Outline Summary of the Estimated Residence Time for Various Substrate Types

been buried during the 6 years since the stranding, sufficiently so not to cause continued public concern.

The impact of Heidrun oil on rocky shore communities would be regarded as an additional source of disturbance. The effect is normally species selective. Many organisms in the tidal zone may survive short-term oiling by closing their shells or outer protection, e.g. mussels and barnacles. Still, they can be suffocated by thick layers of oil, as seen after "Dei Fovos" (Wikander, 1982 and others). Crustaceans are sensitive to oil (Hartog et Jacobs, 1980; Teal et Howarth, 1984), possibly because it adheres easily to the hydrophobic surface of the exoskeleton.

Macroalgae are considered relatively resistant to smothering since oil does not adhere easily to the mucoid surface, but significant mortality has been reported (e.g., Teal and Howarth, 1984; Wikander, 1982). In areas of heavy smothering by weathered oil from "Dei Fovos" at Helgeland, all algal vegetation died and an initial recovery by green and brown algae was recorded after 2.5 years (Wikander, 1982; Danielsen et al., 1985). In the lightly contaminated areas, the smothered parts of the algae showed strongly retarded growth in the subsequent spring, but new sprouts on the same plants were apparently healthy.

A large recruitment potential exists in water column larvae and spores, and following disappearance of oil, one would expect good recovery of rocky intertidal communities along the coast. Areas with light oiling and good self cleaning ability are likely to begin the recovery process in a matter of weeks or months, depending on season. Even before the oil is gone, the contaminated areas may be invaded by grazers such as winkles and limpets, which are even capable of grazing remaining oil (Wikander, 1982), thus improving the substrate for more vulnerable settlers.

Based on rates of oil removal, rocky shores with boulders are considered somewhat more vulnerable than solid bedrock shores. Based on experience from the "Torrey Canyon" accident (Southward and Southward, 1978), one may assume that cold-temperate rocky shore communities will recover in less than 10 years after the shore has become sufficiently clean for normal regrowth.

Effects of oil on sedimentary shores have been reported from a range of accidental and experimental spills (Sergy, 1985; Sanders et al., 1980; Farke et al., 1985; Kuiper et al., 1983 and many others). On exposed shores with gravel or sand, oil may penetrate to considerable depths during low tide. Impacts on the fauna and flora appear small due to their inconspicuous nature. Mobile fauna moving onto shores at high tide (e.g. crustaceans, flatfish and gobiids) are not expected to be seriously affected by oil attached to sediment, but may be smothered by oil lifted off the bottom by water movement.

On sheltered sandy and muddy (i.e. depositional) shores, severe delayed mortality resulting from buried oil has been demonstrated (Kuiper et al., 1983). Where burial does not occur, the residence time of smaller spills may be short, i.e. a few months (Farke et al., 1985). Little direct penetration occurs when the sediments are saturated with water (Farke et al., 1985), but even then, the bioturbative activity of animals such as lugworms *(Arenicola marina)* may cause burial of oil (Kuiper et al., 1983). In such cases, one must expect the impact of an oil spill on the communities to be long lasting, i.e. several years.

In eelgrass and marsh areas, disappearance of the structuring grass species would cause complete collapse of the community. After "Amoco Cadiz" which occurred in April, the eelgrass itself *(Zostera marina)* remained almost unaffected by the spill (Hartog and Jacobs, 1980). Leaf damage was recorded, but this effect was short-term. The penetration of oil into the sediment was small, because the flatlying eelgrass leaves formed an almost impermeable mat between the slick and the bottom during low tide. This had a selective effect on the fauna, some forms showing no effects, others needing more than a year to recover.

As with eelgrass, salt marsh vegetation seems to survive single small spills with similar selective effects on the rest of the community (Baker et al., 1977). Marsh grass may show deterioration above the ground, but in most cases the root system seems to survive, giving rapid regrowth. During larger oil spills, however, salt marsh vegetation has suffered heavy mortality and very slow recovery (Gundlach et al., 1982).

In the vulnerability ranking used here, sedimentary shores are considered to be more vulnerable than rocky shores, and among the former, mudflats and marsh areas are regarded as the most sensitive.

A summary of the vulnerability ranking for the main shoreline types is given in Table I.8.3.

8.3.3 Sublittoral Biotopes

Oil removal in sublittoral areas is dependent on the rate of sediment deposition and resuspension. On hard substrates, resuspension is the dominant force, and oily material is not likely to remain for any period of time. On silty and muddy substrates, oiled material will accumulate (Beslier et al., 1980), and loss is a function of slow dissolution and biological degradation, much the same as on sheltered soft sediment beaches (Berge et al., 1987).

Bioturbation can cause significant burial to depths of 10-50 cm and alteration of the oiled material (e.g., Gordon et al., 1978). How this affects the residence time is, however, uncertain since bioturbation can cause both burial and increased mineralisation of the oil.

Little attention has been paid to the impact of oil spills on the biota of subtidal rocky bottoms. Oil droplets in the water may be ingested by filter feeders, such as sponges, sea anemones, sea squirts, etc., but adverse effects of such ingestion during oil spills have not, as far as is known, been reported.

Chronic oil exposure may under certain conditions reduce tissue growth of seaweeds and kelp (Bokn, 1985). In a worst case, this might influence the harvesting of kelp for industrial purposes (see Section I.7.6).

Type of Community		Vulnerability
Supralittoral	sand dunes	medium
	mixed sand/gravel	medium
	hard bottoms	low
Littoral	bedrock shores	low
	boulder/stone shores	medium
	gravelly shores	medium/high
	sandy shores	high
	mudflats	very high
	marshes	very high
Sublittoral	hard bottoms	very low
	soft bottoms	low/medium
	eelgrass	low/medium

Table I.8.3 Shoreline Vulnerability Ranking

Evidence has shown that oil which accumulates in subtidal sediments, can affect sediment communities, e.g. through species selective mortality, subnormal recruitment, reduced diversity, increased dominance, and prospering of opportunistic species. (e.g. Sergy, 1985; Sanders et al., 1980; Boucher, 1980; Hartog et Jacobs, 1980; Grassle et al., 1981; FoH, 1984). Massive immediate mortalities have not been reported.

In the nearshore spill from "Amoco Cadiz", crustaceans, molluscs and burrowing sea urchins were affected, some of them seriously, but most other organisms recorded showed little or no immediate reduction (Cabioch et al., 1980; Hartog and Jacobs, 1980). The effects show many similarities to organic enrichment.

Knowledge of the effects of weathered oil is scarce. Oil from the grounding of "Antonio Gramschi", which hit the archipelago of Åland in the Baltic Sea after 2 months adrift, showed no effects on macrofauna, and only small effects on meiofauna (Bonsdorff, 1981), but it is hard to extrapolate to the western and northern Norwegian coasts, since the benthic fauna of the Baltic is already stressed.

There is evidence to show that stressed soft bottom communities are more tolerant to modest oil pollution than unstressed communities, because the sensitive species are already lacking (FoH, 1984). Sediment bound hydrocarbons seem in general to be only moderately available to infauna (Anderson et al., 1979). The oily material may be ingested by sediment feeders, but it will not necessarily affect them. Several years after the "Arrow" spill in Nova Scotia, the lugworms, a typical detritus feeder, were more abundant in the oil contaminated sediments than elsewhere (Gordon et al., 1978).

One cannot rule out subtle, long lasting oil stress on sediment communities. The soft shell clam, a filter feeder, still showed subnormal growth and energy assimilation 6 years after the "Arrow" spill (Gilfillan and Vandermeulen, 1978).

It can also be postulated that even small amounts of oil in sediment may act as a negative signal to settling larvae, and thereby cause gradual diminishment of the community. It is therefore expected that recovery will be delayed as a function of the persistence of oil in the sediment.

8.4 Distribution of Vulnerable Shoreline Biotopes

The assessment is mainly based on the sensitivity maps produced by SINTEF for the counties of Nordland (Klokk et al., 1984), Nord-Trøndelag (Hoddø et al., 1984), and Sør-Trøndelag (Tømmerås et al., 1985). These maps cover most of the coastline. They are comprehensive as to physical characteristics (substrate and wave exposure), but information on biotope types is sparse. Furthermore, they do not contain information on the middle and inner parts of some of the fjords.

Additional information on shore conditions in Glomfjord, Vefsenfjord and Ranafjord has been sought from NIVA reports (Haugen et al., 1981; Knutzen, 1984; Molvær et al., 1984). Information on the inner part of Skjærstadfjorden has been obtained from the official navigation maps produced by Norges Sjøkartverk. The basis for producing distribution maps for subtidal communities does not exist.

The SINTEF maps do not distinguish clearly between the types of soft bottom biotopes, and these are in general marked as tidal flats, important for example as feeding grounds for birds. In general, the areas on the outer coast are typical sand/gravel flats interspersed among islands and skerries. Those of the fjords are more of mixed sandy, muddy and marshland type.

8.4.1 County of Nordland

Sedimentary communities are found scattered along the whole of the coast, especially in the Lofoten-Vesterålen area (Figure I.8.1). On the coast of Helgeland and east of Vestfjorden they are more scarce, but several locations occur between Nesna and Brønnøy. Many of the areas, which are important feeding grounds for birds (see Sections H.4 and I.4) lie on the open coast, but are somewhat sheltered among numerous skerries.

Although the sediment of the littoral zone on the open coast is in general sand or gravel, it is particularly vulnerable. These are the first areas to be hit by oil, and it is unlikely that one could protect these areas with any degree of success.

The communities in the inner part of Vestfjorden (Hamarøy and Lødingen), are according to the oil drift model less likely to be impacted. It should also be feasible to protect the relatively small soft bottom shores recorded in the narrow fjords and land locked bays in the county.

Supralittoral vegetation of any significance is sparse in the county, with the highest occurrence in the Vesterålen region and around Herøy-Alstadhaug. A few of the valuable locations, especially on the coast of Helgeland, are exposed and are more likely to be contaminated by oil in heavy weather.

The most important stretches of sandy shore communities are found at Andøya and Sømna, but examples are scattered along the whole of the outer coast of the county.

8.4.2 Counties of Nord-Trøndelag and Sør-Trøndelag

There are few sedimentary shores on the open coast of Nord-Trøndelag county. The main areas are found

Figure I.8.1 Distribution of Vulnerable Shoreline Biotopes within the Coastal Impact Area

at Leka and Vikna (Figure I.8.1). In contrast, the open coast of Sør-Trøndelag has vast stretches of littoral and shallow sublittoral communities with gravel and sand. The most extensive occurrence on the impact coast from Heidrun is found outside Trondheimsfjord, particularly among the skerries at Froan. This section of open coast is therefore considered to be particularly sensitive to an oil spill.

Sedimentary shores also dominate in Ørland and Rissa municipalities, and are frequent along the inner part of Trondheimsfjord. In addition to their ecological significance, several of these are valued for research and education. The most extensive areas of sandy shore are found in the middle and outer Trondsheimsfjord, in Bjugn municipality, and around Namsos. Muddy shores are distributed along most of the east side of Trondheimsfjord.

The most frequent occurrence of supralittoral vegetation in the counties is also in Trondheimsfjord, especially the middle and outer parts. However, the reduced wave action in this region renders these communities less vulnerable to an oil spill, than the supralittoral communities on the open coast around and to the north of the entrance to the fjord. Some important areas of supralittoral vegetation are localised around Namsos, but these are also sheltered and hence less likely to be smothered by oil.

9. RECREATIONAL/AMENITY USE OF THE MARINE ENVIRONMENT

Contamination of the coastline by an oil spill can seriously reduce the value for human usage. Depending on the extent of the contamination and the self-cleaning ability, the recreational value of an area can be lost for a shorter or longer period. Besides the practical clean-up problems with contamination of beaches, marinas, moorings and yachts, the oil spill may cause harm to the coating on the surface of hulls.

Some of the outdoor recreational areas are only in use during summertime and for a great many of the areas the activity is higher in summer than during other seasons. For some shore types, the self-cleaning ability is so high that oil spilt in autumn may be eroded away before the next summer season. An oil spill on these types of shore will therefore be less harmful to recreational interests, if the pollution occurs during late autumn or winter. For the most sensitive sites, the timing of a spill is of little importance since oil erosion will take many years.

Trondheimsfjord in particular, is regarded as sensitive to oil contamination of tourist and recreational sites. The probability that this may happen after an accident at the Heidrun field, is present, but is considered small.

It is unlikely that significant quantities of oil would enter the inner part of the fjord. However, if oil should get into the fjord, it could cause considerable damage since the shores are mostly sheltered and consist of large stretches of depositional bottoms. These would act as sinks for accumulated oil and would be a source for long-term secondary contamination of nearby regions as well. In the outer part of the fjord, important sites in Bjugn, Ørlandet, Rissa, and Agdenes municipalities would be given attention for much the same reason.

The Vikan-Nærøy area and the Helgeland coast around Nesna warrants special attention. The outer part of the coastline here is without shelter and would therefore be vulnerable to oil spill impact. It would also be exposed to waves, and heavy wave action will quickly erode oil deposits on bedrock. This could, however, transport the oil onto land above the shore, and thereby reduce the recreational value of the areas given priority. Other important sites for human use are situated in the inner parts of the coastline and are more sheltered from waves.

The outer coastline of Andøya - Vesterålen is, as the Helgeland coast, strongly exposed to waves. The area has a great number of sandy beaches which have high sensitivity to oil spill. Heavy waves may, as we have said, assist rapid clean-up, but may also transport oil onto land above shore, which would be a disadvantage in terms of impact on areas in recreational/amenity use.

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APPENDIX A

1. SUBSEA STORAGE TANK

Crude oil storage could be provided for in a concrete subsea storage tank (resting on the seabed). Two main alternative layout configurations are being investigated.

1.1 Remote Subsea Storage Tank

The concrete structure would consist of seven cylindrical cells in a Condeep type arrangement with capacity to store approximately 240,000 m^3 (1.5 million barrels) of oil, in addition to a water buffer of approximately 32,000 m^3 (200,000 barrels). Figure 1.1 gives a general overview of the facility and export arrangements. All seven cells are used for oil storage and are interconnected to form one common storage reservoir. The centre cell provides buoyancy during towing and installation.

Wall and dome thicknesses are approximately 2.2 m, and a layer of shock absorbing concrete is used to protect the upper domes of the storage tank from dropped objects, as is the case for Condeep platforms.

The tank would be located approximately 2.4 km from the TLP and would be connected to it by a 400 mm (16") riser and pipeline. The oil storage principle is similar to that employed in existing GBSs, where oil is stored over a water buffer. Oil flow from the tank to the export facility would be gravity driven due to the density difference between oil and seawater, but would be aided by booster pumps on the loading buoy. Two 500 mm (20") flexible risers would be run between the storage tank and a floating loading buoy above. See Appendix A 1.1.4 for a description of the operation of the loading facilities.

1.1.1 Remote Subsea Storage Tank Operation

Crude oil from the TLP would enter the tank through a pipeline connected near the mudline. It would then be routed through an oil ringmain, located in the top of the structure, for distribution to the storage cells. When offloading, the oil would enter the ringmain and travel down a large diameter pipe to the base of the tank, where the connection to the export risers would be located.

Oil would be stored on a water buffer that freely communicates with the sea through an outlet at the base of the tank. As oil fills the storage tank, water would be displaced from the bottom of the structure. Conversely, during export, water would be drawn in to replace the oil. In principle, this is similar to the method being employed for oil storage on the Draugen platform. The Draugen and Heidrun subsea storage concepts do not in the preliminary engineering phase make any provision for return of discharge water to a surface treatment facility.

An umbilical would contain lines for effluent water sampling, oil level monitoring in the tank, chemical injection and control of the ESD valves.

1.1.2 Monitoring

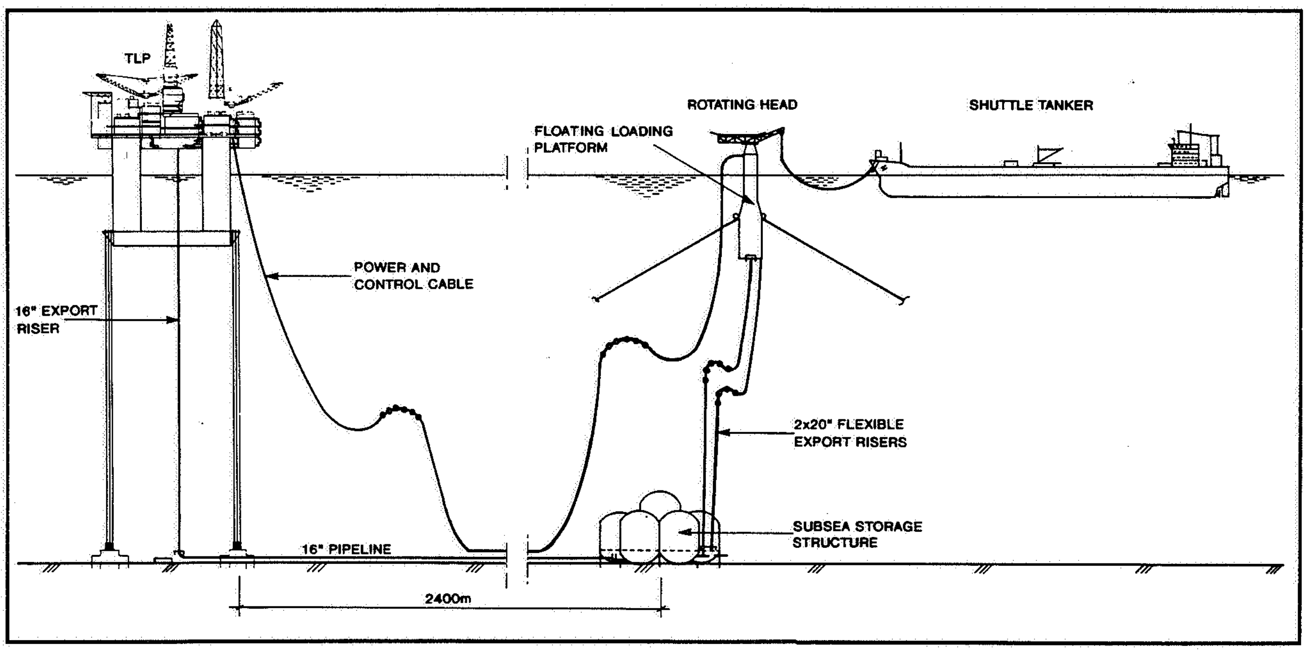
a) Oil Level Measurement

Three methods are currently under consideration for oil level monitoring in the storage tank. These include differential pressure measurement, acoustic level measurement (echo sounder) and nucleonic level measurement (low activity radioactive source and detector).

b) Displacement Water

A number of platforms on the Norwegian continental shelf already successfully use a displacement storage system for crude oil. Condeep platforms Statfjord

Figure 1.1 Remote Subsea storage Tank and Export Facilities



A, B, C and Gullfaks A discharged approximately 135,600 m³ of water per day during 1988 (SFT, 1989). The daily discharge of displacement water from a Heidrun subsea storage tank would be up to 32,000 m³ (200,000 barrels).

Monitoring of the discharge from the Heidrun storage tank would be accomplished by providing two sampling tubes connected to the sea water outlet and routed back to the buoy, via the umbilical. Because of the depth of the facility and the small bore of the sampling tubes, there would be a delay in returning discharge water samples to the surface.

The oil-in-water sampling unit being considered is a type originally developed for monitoring of ballast water from tankers and has a resolution of better than 1 ppm, and an accuracy of approximately 5 ppm. The monitor consists of a sampling system, analyser, discharge and control unit. Signals from the monitor would be sent to the control room in the buoy for logging and interpretation.

The oil content of displacement water measured on existing GBS platforms with oil stored over a sea water buffer, typically ranges from 6 to 8 ppm. The subsea oil storage tank would introduce very little energy for mixing and it is expected that a similar water quality could be achieved.

Further studies into displacement water quality, in terms of dispersed and dissolved oil and chemical content (see Appendix A 1.1.3) will be required before a decision can be made on the suitability of a displacement system for the Heidrun field.

1.1.3 Chemical Injection

A system for injection of biocides to inhibit bacterial growth in the tank would be required. Chemicals would be fed through a small bore tube from the loading buoy and would be injected into the sea water at the storage tank inlet/outlet. Chemical dosage concentrations could be similar to those used in existing GBS platforms.

Water soluble chemicals added on the platform as part of the crude oil treatment process may diffuse in small quantities from stored oil into the sea water buffer. It is expected that this would be similar to existing GBS platforms, although further work will be required on this topic.

1.1.4 Offloading Buoy Operation

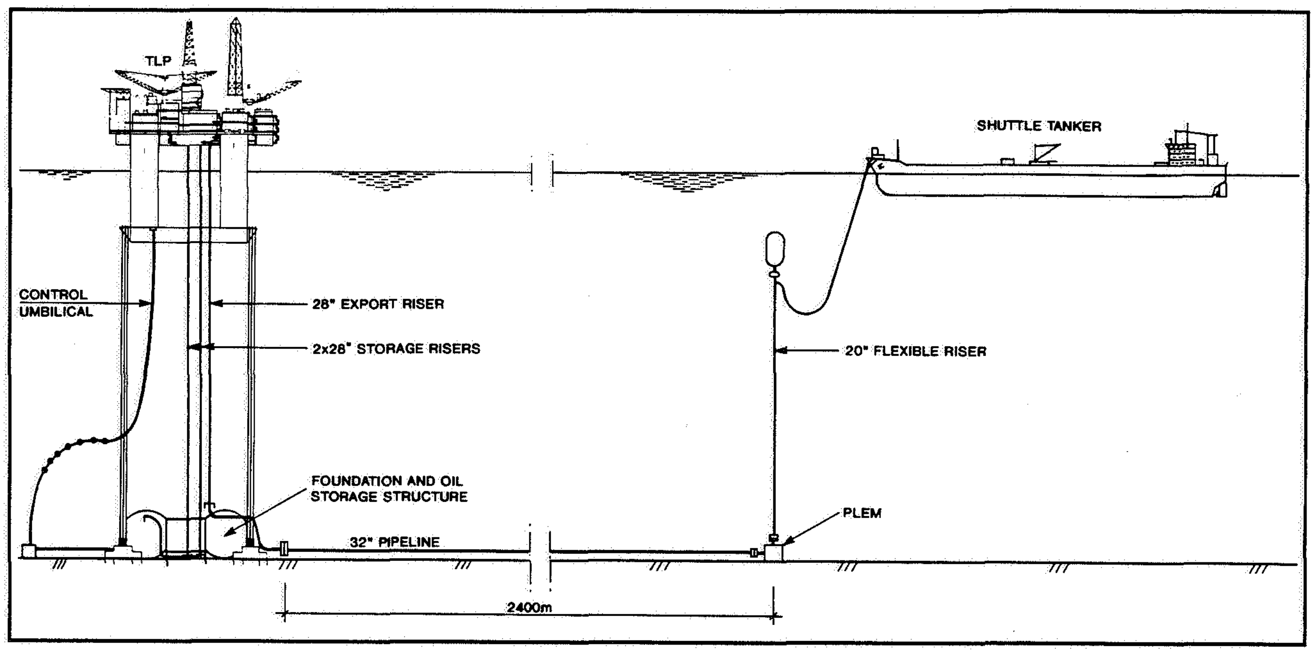
One version of the offloading buoy under consideration for use with the remote subsea storage tank is a catenary moored bottle shaped concrete cylinder 92 m in height and with a body 19 m in diameter, tapering to 11 m at the water line. The buoy would be fitted with a rotating head for offloading operations through 360°.

Equipment contained in the buoy would include booster pumps, a crude oil metering skid, and effluent water sampling station. Flexible risers from the subsea storage tank would be attached to the buoy near its base and would be piped to the equipment room.

The equipment room would be located in the buoy, approximately 20 m below the water line and would house booster pumps, primer pumps, valving and the pig launcher/receivers for the flexible risers. Oily water recovered from the risers would be stored in a separate compartment below the equipment room and would occasionally be pumped to the shuttle tanker for disposal.

Oil would be pumped from the equipment room to the rotating head where it would be metered before entering the flexible offloading hose for discharge to the shuttle tanker. Vessels would maintain position through dynamic positioning, although a mooring hawser would also be provided.

Figure 1.2 Platform GBT and Export Facilities



Power would be supplied to the buoy via a subsea power cable from the TLP. Emergency power would, however, be provided on the buoy and would supply the essential services, such as life support systems, communications and navigational aids.

A control room, helideck, metering, and emergency accommodation would be located on the rotating head. The control room would monitor all critical functions on the buoy as well as communicate with the TLP and the shuttle. Normally the buoy would be unmanned with occasional manning for maintenance.

1.2 Gravity Based Template (GBT) Platform Location

The remote storage tank described in Appendix A 1.1 above can also be located under the TLP where it would form part of the platform foundations and the tether anchoring system, and would incorporate at its centre, the well template (see Figure 1.2). Collectively, this arrangement would be known as a gravity based template (GBT).

Storage cells (one at each corner of the square structure) would have walls 2 m thick, and concrete protection would be provided against dropped objects. The height of the structure would be approximately 45 m and the width approximately 110 m.

1.2.1 GBT Operation

During filling, oil produced from the TLP would be pumped down the two 70 mm (28") rigid risers, which enter the structure below the oil/water interface. As with the remote subsea storage tank, oil would be stored on a water buffer which communicates freely with the sea. As oil is produced into the GBT, water would be displaced and discharged through the sea water inlet/outlet. The entire structure acts as one common oil storage reservoir and an internal piping system would connect the various compartments.

During offloading, oil would flow up to the TLP through the same 2 risers used for filling, and replacement water would flow in through the sea water inlet/outlet. The density difference between oil and water would provide the driving force to push the oil back to the TLP deck. There booster pumps would be used to drive the oil through the metering system, down the export riser and through the 80 mm (32") seabed pipeline to the offloading/export system, located approximately 2.4 km from the TLP.

As with the remote subsea oil storage system, all connections to the storage structure would be made below the oil/water interface, thereby ensuring that oil is not accidentally leaked from connections.

1.2.2 Monitoring and Chemical Injection

Systems for monitoring oil level and chemical injection would be as described for the remote oil storage system, except that the systems previously located in the offloading buoy, would instead be located on the TLP.

1.2.3 Offloading Buoy Operation

Two offloading options for use with the GBT are being investigated.

The UKOLS type loading system is a design which consists of a gravity base, a 500 mm (20") flexible riser, a buoyancy tank which supports the riser, and a swivel and catenary hose. The hose attaches to a shuttle tanker with a hose connection at the bow or midships. The dynamically positioned tanker must remain within a specified radius around the axis of the riser. A UKOLS-type system has been installed at Statfjord A, and another (OLS-8000) has been approved for Statfjord B as a replacement for the present system.

The floating loading platform (FLP) is a smaller version of the loading buoy described for use with the remote subsea storage tank, and consists of a 130 m tall steel column with a rotating head, moored with a catenary system. The FLP is simpler because it does not contain systems for pumping, metering, or control of the subsea oil storage structure.

1.3 Pollution Control

The basic requirement against pollution has been formulated as follows:

"The prevention of environmental pollution shall be of main concern in the design of the system and its operation. To achieve an adequate level of safety against pollution the oil system shall have at least two barriers preventing major pollution during normal loading and offloading."

Although not explicitly stated, it is assumed that a similar level of protection would be achieved during shut-down, maintenance operations or in an emergency situation.

To fulfil these requirements, the following design philosophy has been laid down in the leak prevention design:

- The tank, being open to sea, shall have no penetrations, perforations or exposed piping above the oil/water interface, thus almost eliminating the risk of leakage in the part of the system which has internal overpressure.

- The offloading riser shall be waterfilled when not in use, to ensure external overpressure in all exposed piping.

- An ESD valve which opens to sea shall be placed at the lower riser connector, to allow water to enter and kill the flow of oil escaping from the tank, in case of riser rupture during offloading. The valve shall open upon loss of communication with the TLP (fail open).

- A flood valve which opens to sea shall be placed at the import flowline connector, for similar protection of this seabottom line, which may partly lie above the oil/water interface in the tank. This shall have no spring action, and must be actively opened and subsequently closed.

Risk analyses of the possible source and scale of oil spills under all operating modes, and all aspects of safety, have been prepared (Siktec, 1988b), as has a review of the leak detection, prevention and spill response requirements.

The major spill risks identified relate to incidents such as riser rupture, rupture of the oil export line from the TLP or accidental over-filling of the subsea tank. The probability of the first two is low and would most likely be due to either material failure or vessel collision (including anchor dragging). Regular maintenance and the provision of adequate safety zones for vessel activity in the area are important elements.

In this connection, the risers between the remote storage tank and the offloading and control buoy will be water filled during periods between offloadings. This is achieved by inserting a "pig" into the riser and pumping it down to the tank using water. Pig traps and pumping facilities are contained in the buoy for this operation. Also, an ESD valve is connected to all import and export lines on the tank to avoid accidental loss of oil from the storage tank following damage to a riser or pipeline.

The risk of over-filling the tank is considered very low and would require simultaneous break-down of several level measurement systems and inadequate observation of operating procedures. In order to avoid accidental loss of oil through the seawater outlet, a water buffer equivalent to approximately 32,000 m^3 (200,000 barrels) would remain below the oil in the bottom of the tank, even when full. With such a large buffer, oil loss is unlikely, even with inaccuracies in the measurement systems. In the event that the storage should ever become full, the buffer provides sufficient time for an orderly shut down of production.

Although the layout of the GBT is somewhat different to that of the remote subsea storage tank, the principles of operation are similar. Differences which do exist, include:

- Import and export of oil is via two rigid tensioned risers, equipped with ESD valves. This arrangement carries a smaller leak risk than that of a flexible riser and loading buoy. A twin riser system also provides additional redundancy, and there is the option of by-passing the storage tank and producing directly to the export system.

- The storage tank is located below the TLP which implies increased risk of dropped object damage. This is, however, allowed for in the structural design. A major leak would also present a fire hazard for the TLP, but visual leak detection would be easier from the TLP.

APPENDIX B

1. ENVIRONMENTAL DATABASE

1.1 General

Coastal and offshore environmental data required for EIA and oil spill contingency planning purposes have traditionally been available in a form which is not amenable to immediate access. In addition, the data have not been held centrally and in a easily comparable/understandable format.

In 1987, Norsk Hydro initiated the development of a computerised environmental database, and during 1988/89 A/S Norsk Hydro, Saga Petroleum a.s, Statoil, A/S Norske Shell, BP Petroleum Development (Norway) Limited, and Conoco Norway Inc. became co-funding partners. SFT has endorsed the project and is represented on the steering group.

1.2 Geographical Coverage

The geographical area of principle interest encompasses Haltenbanken and all of the coastline within the possible influence area of the oil and gas developments (Møre and Romsdal to Nordland (inclusive)). During 1990, the coverage will be extended to include Vest-Agder, Rogaland, Hordaland and Sogn and Fjordane.

1.3 Data

Environmental data is in this context defined as information on vulnerable natural resources in coastal/near-shore and open sea areas. The material is drawn primarily from publically available sources, and includes but is not restricted to the following:

- seabirds (nesting areas, moulting areas, wintering areas etc)
- sites of botanical interest
- aquaculture (fish and shellfish farming)
- fish stocks (spawning areas, egg and larval drift etc)
- fishing activities
- nature reserves and sites of scientific interest
- areas of importance to recreation and amenity
- sites of importance for marine mammals

The above information will be held in the Operator's office on a module based relational database. As well as providing a technical/scientific description of the above features, their geographical location and seasonal variability, all source references will be quoted. The data will be continuously updated as new information becomes available.

Classification of coastal areas for priority protection in the event of a major spill, along with location of response equipment, contact points, notes on appropriate action, potential problems areas etc can be input as it is agreed with the relevant bodies/authorities.

APPENDIX C

1. SFT DRAFT LONGTERM PLAN (1990-1993)

The key aims and objectives for the offshore industry outlined in the Plan are as follows:

- To reduce oil discharges to the marine environment by 35%
- To reduce discharges of OBM cuttings by 95% (by 1993)
- To stabilise volumes of oil being discharged with produced water and ballast (displacement) water (by 1992)
- To achieve a 35% reduction in chemical discharges, and a 50% reduction in environmental toxicants (by 1995)
- To improve the reception facilities for oil and chemicals (by 1992)
- To prevent the dumping of waste from offshore installations
- To achieve reductions in the emissions of ozone destructive materials (by 1991)
- To achieve reductions in nitrogen oxides (by 1992)