Short term effects of accidental oil pollution in waters of the Nordic Countries

IVL Swedish Environmental Research Institute

in

collaboration with SYKE, SFT, HFS and DMU

Nordic Council of Ministers

June 2004

U964

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IVL

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Report Summary

Project title

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Client

Nordic Council of Ministers

Expert Group

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Bibliografiska uppgifter/Bibliographic data

Arkivnr U964

Foreword

Commissioned by the Nordic Council of Ministers short-term effects of accidental oil pollution in waters of the Nordic countries has been evaluated. The main objective of this study is to assemble oil effects experiences of the Nordic Countries and furthermore identify knowledge gap. The project is mainly based on studies in Northeast Atlantic; the waters surrounding Greenland and Faroese, the North Sea and the Baltic Sea. To cover insufficient knowledge of oil effects, international experiences are turn to account in the Nordic areas applied with its typical conditions (temperature, salinity, arctic conditions etc).

The aim with the project is to describe the effect situation of oil spills, but also to give opportunities to compare the threat of oil with other environmental problems at sea as eutrophication, outfishing and supply of heavy metals to the marine systems. The results for decision-making will be disseminated to Environmental Ministers and the Official Environmental Committee. The results will as well be disseminated to the Nordic Countries, Nordic authorities working with oil matters, HELCOM, OSPAR, EU, and arctic programmes; AMAP and PAME.

Summary

The main objective of the present report is to support Nordic Countries with environmental impact assessments of accidental oil spills in Nordic areas, in the work to control and reduce the cause of these effects. The Nordic Seas have due to its typical environment specific habitats with specialised key-species, which have different sensitivities of oil spills. The objective of this report is to study the acute toxic effects of accidental oil spills in these habitats. The accident is usually caused by collisions of tankers, groundings or technical failures. Another important source of marine oil spills is also illegal oil releases like bilge water releases, tank washing, etc. The project does not include continuous oil spill from e.g. land sources.

This study shows that the waters of the Nordic Countries differs from other regions in the world, with lower temperature and icing, but also from each other with varying salinity, exchange rates et cetera. In all Nordic waters are more vulnerable to oil spills.

In the foreseeable future the minor oil spills will likely increase, as will the risk for major accidents. Thus there is a strong need for mapping and identification of important and sensitive areas. There are national efforts to develop environmental oil spill sensitivity atlases, which is most welcome. So far there is no common Nordic atlas however.

There are considerable differences in short-term, acute, effects of oil spills and long-term effects. As presented in this report, avifauna and questionably marine mammals are under greatest threat from acute effects. The plankton community will also be affected, but is quickly re-established. The impact on pelagic fish is negligible, and also benthic fauna will be practically unaffected by acute toxic effects. They can however suffer significantly from suffocation by thick settled oil slicks.

Content

1 Introduction

1.1 Justification

International marine pollution problems are of large concern for the Nordic Countries. Effects of oil spill are environmental problems and have since long been known as threats to the Nordic environment. Nordic environmental co-operation concerning oil spills and its environmental effects at sea is therefore required, to increase understanding of common environmental issues to develop Nordic strategies and protect sensitive areas. The Nordic Action Plan 2001-2004 (*Det nordiske miljøhandlingsprogram 2001-2004*) pointed out the importance of environmental protection issues and oil combating co-operation within the Nordic countries. The Nordic Environmental Strategy (*Bæredygtig udvikling – En ny kurs for Norden 2001*) also set off indicators for sustainable management to prevent impacts of chemicals at sea.

Commissioned by the Nordic Council of Ministers the short-term effects of accidental oil pollution in waters of the Nordic countries have been evaluated. Waters of the Nordic countries that has been evaluated in the present report include North East Atlantic; the waters surrounding Greenland and Faroese, the North Sea and the Baltic Sea. The region is illustrated in Figure 1.

These studied seas have different characteristics compared both to other oceans and when compared amongst each other. The Nordic Seas have colder temperature and temporary or constant ice-covered environment, compared to most other marine areas. Compared to each other, the waters in this study have variations relating to salinity, wave exposure, arctic conditions etc. These differences are important for the behaviour of oil and thus justify an evaluation of how Nordic coastal and marine habitats are effected by oil spills.

1.2 Objective

The objective of this report is to study the acute toxic effects of accidental oil spills in Nordic marine and coastal habitats. The accident is usually caused by collisions of tankers, groundings or technical failures. Another important source of marine oil spills is also illegal oil releases like bilge water releases, tank washing, etc. The project does not include continuous oil spill from e.g. land sources.

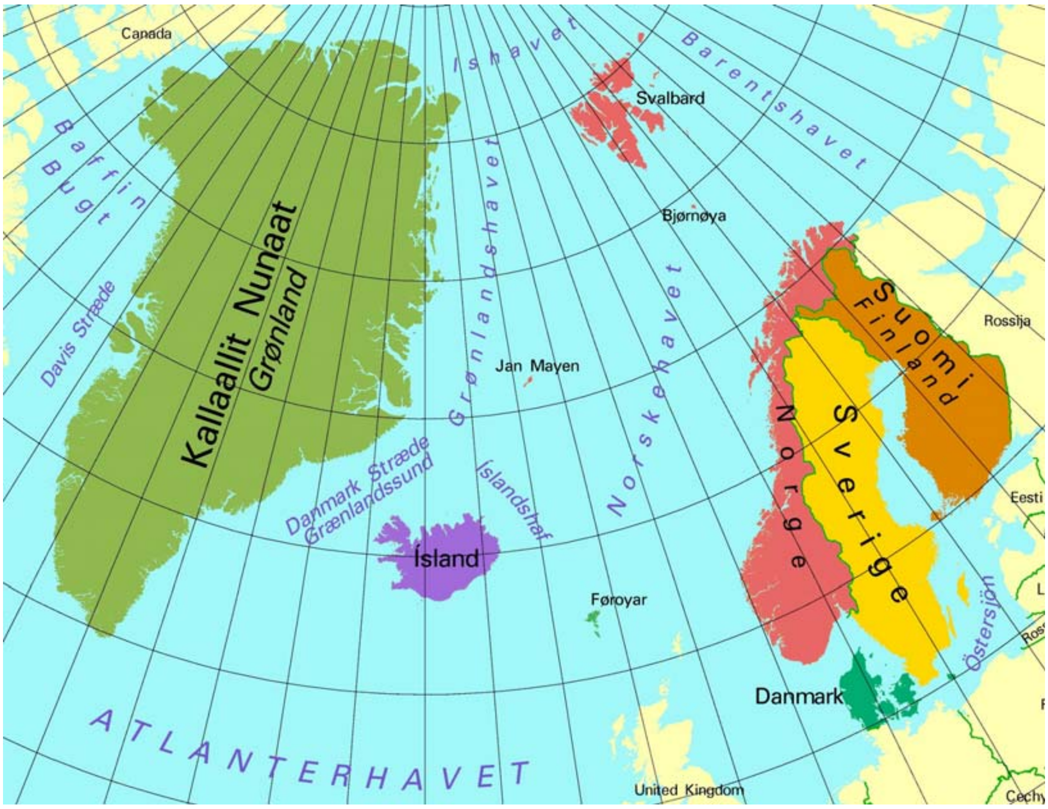

Figure 1. *Map over the Nordic Seas (Source: the Nordic Council of Ministers, 2004)*

2 Background

2.1 Properties of oil

Oil is a general term that describes a wide variety of natural substances of plants, animal, or mineral origin as well as a range of synthetic compounds. The many different types of oil are made up of hundreds of major compounds and thousands of minor ones. As their composition varies, each type of oil or petroleum product has certain unique characteristics or properties. These properties influence how the oil behaves when it is spilled and determine the effects of the oil on living organisms in the environment.

The physical properties of oil are viscosity, density (or specific gravity), solubility, flash point, pour point, distillation fractions, interfacial tension and vapour pressure. Viscosity is the resistance to flow in a liquid. The lower the viscosity, the more readily the liquid flows. The viscosity of the oil is largely determined by the amount of lighter and heavier fractions that contains. Density is the mass (weight) of a given volume of oil. Density is important because it indicates whether a particular oil will float or sink in water. Water has the density of (approximately) 1 kg/L.

2.2 Transformation processes

When oil is spilled on water, a number of transformation processes occur that are referred to as the "behaviour" of the oil. Two types of transformation processes occurred. The first is weathering, a series of processes whereby the physical and chemical properties of the oil change after spill. *Evaporation* is usually the most important weathering process. It has the greatest effect on the amount of oil remaining on water or land after a spill. The rate at which oil evaporates depends primarily on the oil's composition. The more volatile components an oil contains, the greater the extent and rate of its evaporation. Other weathering processes are; *natural dispersion*, which occurs when fine droplets of oil are transferred into the water. The opposite process is *emulsification*, when water is dispersed into oil in the form of small water droplets. *Biodegradation* also occurs when a large number of micro-organisms are capable of degrading petroleum hydrocarbons. *Sedimentation* is the process by which oil is deposited on the bottom of the sea. *Photooxidation* can change the composition of oil, when the sun's action on an oil slick causes oxygen and carbons to combine and form new products. (Figure 2)

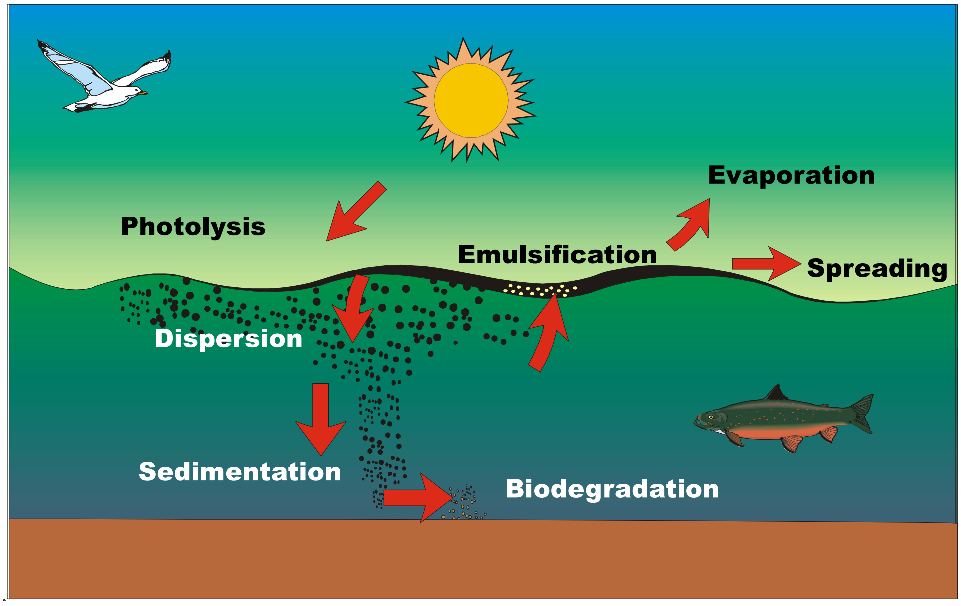

Figure 2. *The weathering processes a series of processes whereby the physical and chemical properties of the oil change after spill. (Source: IVL Swedish Environmental Research Institute Ltd)*

The second is a group of processes related to the movement of oil in the environment. *Spreading* of oil spilled on water is one movement. *Sinking* is another, if oil is denser than the surface water.

These two main transformation processes depend very much on the type of oil spilled and the weather conditions during and after the spill.

2.3 Effects of oil spills on the environment

The initial impact of oil in coastal and marine systems can vary from minimal (e.g. following some open ocean spills) to the death of everything in a particular biological community. A coastal area which can trap oil (e.g. sheltered wetlands), leading to death of the vegetation and associated fauna, can present a particularly bleak picture.

Oil spills have many adverse effects on the environment. Oiled birds are one frequent and highly publicised outcome of oil spills, but there are many other less obvious effect such as the loss of phytoplankton and other microscopic forms of life. These effects are varied and influenced by a number of factors. Toxic effects are classified as *acute* and *chronic*, which refers to the rate of effect of toxin on an organism. Acute toxic effects occur within a short period of exposure in relation to the life span of the organism, while chronic effects occur during a relatively long period, usually 10 % or more of the life span of the organism. Chronic toxicity refers to long-term effects that are usually related to changes in such things as metabolism, growth, reproduction, or ability to survive.

2.4 Factors influencing impact and recovery

2.4.1 Oil type

Different oils vary significantly over a wide range of physical and chemical parameters, giving each oil its specific characteristics. These characteristics will change, however, when the oil weathers. Usually the viscosity increases and toxicity decreases as volatile compounds evaporates. On the other hand, oil can start to "bleed" again, releasing lighter and more viscous volumes, e.g. when warmed by sunlight.

One environmentally very important parameter is toxicity. Crude oils as well as refined products differ widely in toxicity. Experiments on plants and animals have shown that severe toxic effects are associated with compounds with low boiling points, particularly aromatics. The greatest toxic damage has been caused by spills of lighter oil, particularly when confined in a small area. Lighter oils also have higher evaporation rates. This means that e.g. gasoline is highly toxic but evaporates within hours under normal weather conditions. Thus a crude oil spill which reaches a shore quickly will be more toxic to the shore life than if the slick has been weathering at sea for several days before stranding.

Spills of heavy oils, such as some crude and Bunker fuel oils, may blanket areas of shore and kill organisms mainly through smothering (which is a physical effect) rather than through acute toxic effects.

2.4.2 Oil loading

If oil loading is high, penetration into some sediments may be enhanced, and there is a greater likelihood of oil masses incorporating stone and gravel and hardening to form relatively persistent asphalt pavements. They persist longest on the upper shore where they can constitute a physical barrier, which restricts recolonisation, e.g. plants such as grasses and shrubs.

2.4.3 Geographical factors

In the open sea there is scope for oil slicks to disperse, and some large spills have caused minimal ecological damage for this reason. Close to shore, damage is likely to be more pronounced in sheltered shallow water bays and inlets, where oil in the water may reach higher concentrations than in the open sea.

On the shore itself there is a range of possibilities concerning the fate and effects of oil. These are bound up with two important variables: the energy level of the shore (degree of exposure to wave energy), and substratum type. On exposed rocky shores, effects on shore life tend to be minimal and recovery rates rapid because oil does not stick easily to such shores. Even if some does, it is likely to be quickly cleaned off by vigorous wave action. With increasing shelter of rocky shores, the likelihood of oil persisting increases, as does the algae biomass with its capacity to trap oil. The most sheltered shores tend to be sedimentary, with mud flats and marshes. Such vegetated areas have a high biological productivity but are also the worst oil traps, and are therefore of particular concern following spills.

The general relationship between shore energy levels and biological recovery times is shown in Figure 3, which draws upon a number of reports in the international scientific literature. Recovery times tend to be longer for more sheltered areas because of oil persistence, but the correlation is not always straightforward because other variables (such as oil type) are also involved.

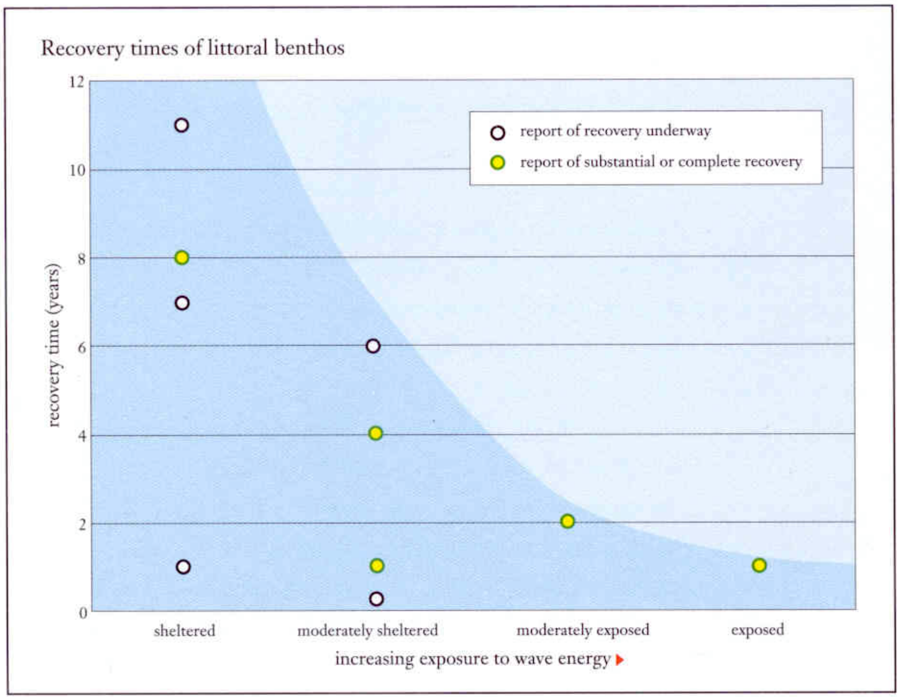

Figure 3. *Biological recovery depends on exposure to wave energy – but other variables, such as oil type, are also involved. (Baker J., 2000)*

If oil penetrates into substratum, residence times are likely to be increased. Shores over a range of energy levels with freely draining sand, gravel or stone are porous, and oil penetrates relatively easily. If it then becomes adsorbed onto the large surface area of the sub-surface grains, and weathers *in situ* to become more viscous, it may remain in the sediment for many years. In contrast, oil does not readily penetrate into firm waterlogged fine sand or mud.

The picture may be very different on sheltered sand and mud shores with high biological productivity. Burrows of worms, molluscs and crustaceans, and the stem and root systems of plants provide oil pathways. Under normal conditions, these pathways allow the penetration of oxygen into sediments that would otherwise be anaerobic. A possible problem following oiling is that there is sub-surface penetration of the oil, followed by death of the organisms that normally maintain the pathways. Thus oil can be trapped in anaerobic sediment, where its degradation rate will be very low, and organisms trying to recolonise may encounter toxic hydrocarbons.

2.4.4 Climate, weather and season

High temperatures and wind speeds increase the weathering of oil. Temperature facilitates evaporation and affects the viscosity of the oil (and so the ease with which it can be dispersed, and with which it can penetrate into sediments). Temperature, together with oxygen and nutrients supply, also determines the rate of microbial degradation, which is the ultimate fate of oil in the environment. Wind, or rather waves, is an important factor for increasing the dispersion rate.

According to season, vulnerable groups of birds or mammals may be congregated at breeding colonies, and fish may be spawning in shallow nearshore waters. Winter months may see large groups of migratory waders feeding in estuaries. Marked reduction of flowering can occur if plants are oiled when the flower buds are developing, even though there may be good vegetative recovery, there is loss of seed production for that year.

2.4.5 Biological factors

Different coastal and marine habitats have different sensitivities to oil spills, just as organisms do. Since habitats and the organisms living in them are closely interacting, the sensitivity – or tolerance – to oil spills is usually a combination of factors. For example, many algae (seaweed) are quite tolerant, possibly because of their mucilage coatings and the frequency of tidal washings. In contrast, eelgrass habitats are very sensitive. Comments on the main groups of plants and animals are given in chapter 6.6 Overview of sensitivity of different fauna groups.

3 Methods and material

3.1 Literature study of Nordic coastal and marine habitats

The first and major part of this report is a literature study. It attempts to describe what characterises the coastal and marine habitats of the Nordic countries' waters and how they will be effected of short-term exposure to oil spills.

Mainly references from the Nordic Countries, excluding Iceland, i.e. Greenland, Faroese, Denmark, Norway, Sweden and Finland are used. The material has been collected in co-operation between IVL Swedish Environmental Research Institute Ltd, Finnish Environment Institute (SYKE), Norwegian Pollution Control Authority (SFT), Miljø- och Levnedsmiddelstyrelsen (HFS) and Denmark's National Environmental Research Institute (DMU) and includes both published and internal material. Among the major oil spills in Nordic waters used as examples in this report are Tsesis, Baltic Carrier, Fu Shan Hai etc.

3.2 Screening of potentially sensitive areas

In order to estimate the area of potentially sensitive habitats in Nordic waters in comparison to today protected areas a simple screening is conducted. The applied method is very straightforward, defining potentially sensitive areas as the coastal zone, enclosed by the shore line and a parallel line at a constant distance from the shore. The potentially sensitive habitats can be found within the entire littoral zone, but shallow accumulation bottoms, such as reefs and banks, outside the coastal zone are also of ecological importance. The criteria for potentially sensitive areas are listed in Table 1.

The accumulated area from these different groups will probably differ from the coastal zone area, approximated using the method described above. In lack of bathymetry data over the area of interest the used method will give an idea on order of magnitude for area sought.

Table 1. *Classification of sensitivity areas in water of the Nordic Countries.*

Group 1	Open sea (>20 m depth)	
Group 2	Open sea (<20 m depth)	
Group 3	Coastal waters (0-X m depth)	a) Sheltered bay, archipelago
		b) Lobate coastal area
		c) Exposed coastal area

To get an indication of how much of this area that is already identified as sensitive, the ratio between the total area of Swedish marine Natura 2000 sites and the Swedish coastal zone is calculated. Note that Natura 2000 sites are not actually protected, but rather exploitation and enterprises are restricted.

Calculation of coastal length was performed in GIS environment using ArcInfo workstation. Data from *ESRI data & Maps* Arc World, was used as base maps complemented with data for the Natura 2000 areas from Swedish National land survey.

4 Oil spills in the past and future in waters of the Nordic Countries

4.1 Historical statistics for the last decade

In the last decade maritime transportation has been growing steadily, reflecting the intensified co-operation and trade in the Baltic Sea region and a prospering economy. 20,000 – 70,000 tonnes of oil enter the Baltic Sea every year. 10 percent of this total comes from shipping. Most years more oil is discharged into the Baltic Sea on purpose than is released accidentally. Deliberate illegal oil discharges from ships are regularly observed within the Baltic Sea since 1988. Numbers of oil spills per year are shown in Figure 4. As from 1999 the number of observed illegal oil discharges has slightly decreased. This trend is reflected also in a decrease in the number of observed oil discharges per flight hour.

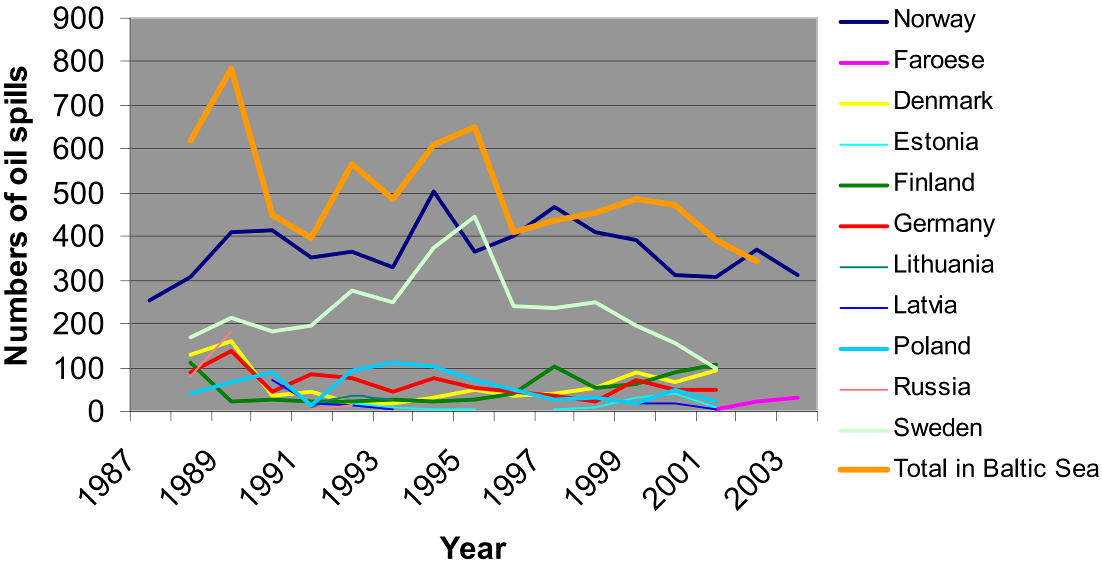

Figure 4. *Numbers of oil spills in Baltic Sea, the North Sea and waters surrounding Faroese. There is no data from waters surroundings Greenland. The data of Baltic Sea area is gathered on the basis of national reports from the nine countries bordering on the Baltic Sea area and Contracting States to the 1992 Helsinki Convention. The data of the North Sea is from Norwegian Coastal Administration (Kystverket). The oil spills in the North Sea mainly come from offshore-activities.*

The numbers of illegal oil discharges observed during continuous surveillance of confined areas in the Baltic Sea, for 24 or more hours, does not support the general conclusion that the overall number of illegal oil discharges is decreasing. This might imply that the decrease is related to specific areas in the Baltic Sea with intense aerial surveillance and efficient law enforcement. Groundings and collisions are the main reasons causing ship accidents. Most accidents are confined to narrow and port areas.

Major oil incidents in the Baltic Sea 1988 – 2003, resulting in an outflow of more than 100 tonnes of oil, are shown in Table 2. The most common oil types in Baltic Sea area are diesel, crude oil and heavy fuel (Table 3). (HELCOM, 2004)

The number of observed oil discharges in the North Sea has slightly decreased during the last 20 years. The oil spills in the North Sea mainly come from offshore. Only 3 % of crude oil spill were derived from maritime traffic during 2003. Spill of "waste oil" on the other hand mostly came from maritime traffic (92 %). Source of diesel spill is divided equal between offshore and maritime traffic (50 %). Offshore-activities also represent a higher quantity of oil spill (m^3) than maritime traffic.

Volume of oil spills from offshore during 2003 was the largest registered since 1987, when registration of oil spill started (Figure 5). Oil spills of offshore, from 2002 to 2003, increased from 520 m^3 to 1,788 m^3 and this is an increase of 244 %. The major identified cause to large spills from offshore is problem with safety valve, and trouble with tubes. Ship accidents are mainly caused by groundings, only a small part of the accidents is due to collisions and fire/explosions. (Kystverket, 2004)

Table 2. *Major oil incidents in the Baltic Sea 1988 – 2003 (Source: HELCOM, 2004)*

Year	Name of ship	Tonnes of oil spilled	Location
2003	Fu Shan Hai	1,200 tonnes	Bornholm, Denmark/Sweden
2001	Baltic Carrier	2,700 tonnes	Kadetrenden, Denmark
1998	Nunki	100 m^3	Kalundborg Fjord, Denmark
1995	Hual Trooper	180 tonnes	The Sounds, Sweden
1990	Volgoneft	1,000 tonnes	Karlskrona, Sweden

Table 3. *Most common types of oil in waters of the Nordic Countries*

Baltic Sea Area	North Sea	Waters surrounding Faroese	Waters surrounding Greenland
Diesel	Diesel	Gas/Diesel	Kerosine (paraffin)
Crude oil	Crude oil	Hydraulic oil	Gasoline
Heavy fuel	Heavy fuel oil	Refinery "waste oil"/ semiproducts	Gas/Diesel
Light oil			Jet fuel

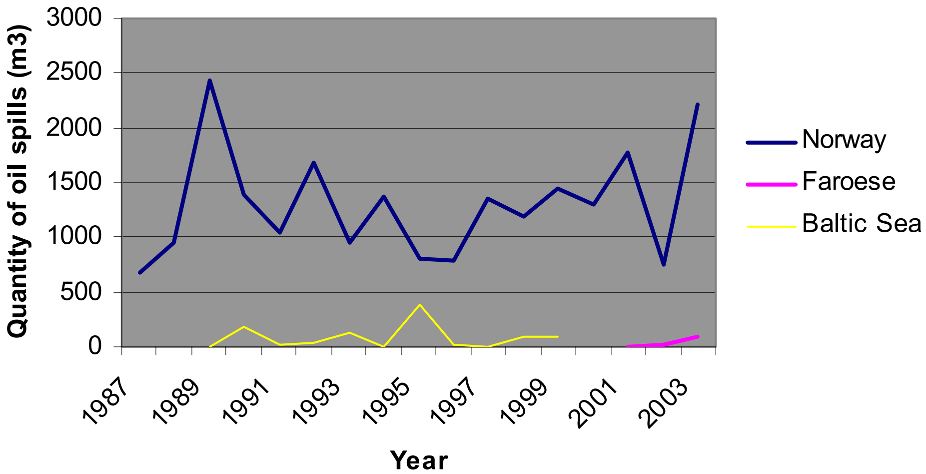

Figure 5. *Quantity of oil spills in Baltic Sea, the North Sea and waters surrounding Faroese. There is no data from waters surroundings Greenland.*

Volume of spilled oil in the Baltic Sea has been compiled by the Ministry of Environment Protection and Regional Development of the Republic of Latvia (HELCOM 2001).

There is no official oil spill statistics in waters surrounding Greenland. Approximately 5 – 10 small oil spills (0.2 – 0.5 m^3) occur every year, mostly spills of diesel. The largest one in the latest ten-year period was 42 m^3 Arctic Grade fuel oil (2001). This accident was primarily on land. There is no crude oil drilling operations today in waters surrounding Greenland. There is however plans of this kind of activities in future.

Faroese has a similar situation to Greenland with no historical statistics of oil spill in the surrounding waters. The responsibility of reporting oil spills has earlier been the Danish defence staff. Since 2002, MRCC on Faroese (Maritime Rescue and Co-ordination Centre) has the responsibility of preparedness for oil spill. Number and quantity of registered oil spills in 2001 – 2003 are shown in Figure 4. The Figure 4 shows an increasing trend and one reason of that is more efficient and systematic reporting system during the last year. The oil spills in waters surrounding Faroese are for the most part of diesel spills. It also occur spills of hydraulic oil and refinery “waste oil”/semiproducts. There has not been any large oil spill accident in waters surrounding Faroese. The largest oil spills during 2001 – 2003 was from a foreign fishing ship, 27 m^3 gasoline.

4.2 The prognosis for the following next decade

Maritime traffic in the Baltic Sea is very dense and it counts approximately 15 % of the marine traffic in the whole world. It is estimated that the expanding oil transport increases the risk for a large spill (between 10,000 and 100,000 tonnes of oil) by 35 % for the whole Baltic Sea and by 100 % for the Gulf of Finland. Oil transportation is estimated to double by 2017, compared to 1995 if all existing plans to expand existing oil terminals and build new ones are carried out. Of 251 accidents over a period of eleven years (1989 – 1999), every fifth resulted in oil pollution (HELCOM, 2004). The Baltic Sea has recently been nominated as a Particularly Sensitive Sea Area, PSSA. How this will affect the future situation is too early to say.

The total maritime traffic in the North Sea is estimated to increase. The prognosis for 2010 – 2015 is reduction of fishing boats (- 10 %), weak increase of passenger traffic and other kinds of traffic (5 %), existing terminal traffic will be constant, but the largest increases will be caused by increased Russian oil export, and expansion in Norwegian oil sector (Barents Sea). Future expansion of offshore in Barents Sea includes both fields of gas and oil. Offshore expansion in Barents Sea will represent 0.4 % of the total forecasted traffic in the North Sea and 7 % of petroleum ship traffic. The traffic from Russia will be 2.5 larger than the traffic from the Norwegian expansion in Barents Sea. (DNV, 2003).

The forecast for the next ten years of oil spills in waters surrounding Greenland and Faroese is not possible because of lack of historical statistics. A future expansion of oil drilling operations may increase the risk of oil accidents, but not necessarily mean an increasing numbers of oil spills. Number registered oil spills on Faroese may increase caused by more environmental aware civilian population, i.e. more reports that oil spills has happened, and facilitated processes of internal reporting by the local authorities. More efficient registration of oil spills may also reduce number and quantity of them, because of more consciousness by local oil suppliers. Suppliers from Faroese have recently introduced new praxis concerning oil bunkering of tankers to reduce number of oil spills.

5 Coastal and marine habitats of Nordic Seas

5.1 Similarities and differences

Significant oil and gas exploration activities in the Arctic marine areas of the Nordic countries occur along the Norwegian continental shelf and in the Barents Sea. Sweden and Finland have no Arctic coastline and do not carry out any oil or gas activities in the Arctic. Iceland has not conducted any exploration and does not produce any oil or gas. It imports all its oil via tankers. In Greenland, only exploration activities have been carried out.

For petroleum activity purposes, the Norwegian continental shelf is divided into three sectors: the North Sea, the Norwegian Sea (area between 62°N and 69°30'N), and the Barents Sea (area north of 69°30'N and west of 30°30'E), of which the two latter are within the Arctic

The area of interest for this study, the waters of the Nordic Countries, can be described as generally more vulnerable than temperate waters, due to low temperature slowing down weathering and decomposition processes. Also, the Baltic Sea is a brackish water system, making it even more sensitive. These aspects are further elaborated below.

5.1.1 Physical features

The Baltic Sea is in contrast to the Atlantic Ocean semi-enclosed with slow exchange of water, minimal tides and low sediment circulation. The physical features in the Baltic Sea cause trapping of chemicals in the form of stocking up of chemicals in anoxic, deep sediments, which bring occurrence of stable hot spot areas (sedimentation areas). The North Sea and waters surrounding Faroese and Greenland has instead typical tidal flows (ebb and flood) close to land, with high exchange of water (FOIG, 2001).

The catchment area of the Baltic Sea is large and densely populated, with high inflow of freshwater. The area is also affected by high atmospheric deposition of anthropogenic contaminants. These circumstances lead to high input of hazardous substances. The Baltic Sea is shallow compared to the Atlantic Sea and has small water volume compared to seas and hence smaller dilution of hazardous substances compared to seas. This cause higher concentration of chemicals in the water and the sediments.

The Baltic Sea and the North Atlantic are characterised by cold waters. The natural decomposition processes of oil are very slow in low temperature water, like the Baltic Sea with an average water temperature of 10 degrees, and during winter water temperature can be even below 0°. During winter the seas are ice and snow covered (Furman et al. 1998), which inhibits photodegradation and volatilisation. In the Baltic Sea higher concentrations of slowly degradable chemicals, photodegradable and volatile chemicals are measured.

The Baltic Sea has a permanent stratification of water because of halocline, with denser shallow water than the surface water, caused by higher salinity. Temporary stratification of water also occurs because of a thermocline (Furman et al.1998). These physical features in the Baltic Sea inhibit the exchange of water and dissolution of substances as well as particulate matter across halocline or thermocline.

5.1.2 Chemical features

The Baltic Sea has compared to The Atlantic Sea brackish water with a low salinity range from 0 to 20 ‰ (Kautsky and Andersson 1997). Salinity affects the biodegradation processes e.g. dispersion of oil. Dispersion is less effective in low saline water compared to the seawater.

5.1.3 Biological features

The Baltic Sea has a short history compared to the Atlantic Sea. The current salinity has existed about 3,000 years. Organisms are not fully adapted to live in the Baltic Sea, which cause low biodiversity. One consequence of low biodiversity is that the Baltic Sea has only few key species, i.e. species that have an important ecological role in the ecosystem. If these species would decline, there are no other species taking over their functions. Bladder wrack (*Fucus vesiculosus*) and blue mussel (*Mytilus edulis*) can be regarded as key species in the Baltic Sea (Kautsky and Andersson 1997).

Species living in the Baltic Sea are originally marine or freshwater species and thus live close to their physiological tolerance limits regarding the ambient salinity. Species living in the Baltic Sea are more vulnerable to chemicals compared to marine or freshwater species (Tedengren and Kautsky 1987, Tedengren et al. 1988).

5.2 Sensitive habitats

When compared to most other habitats in the world, the Nordic waters are strongly influenced by low temperatures, with reoccurring partial or total icing. The coasts and shorelines are shaped by the ice age and the land elevation is still significant in e.g. Gulf of Bothnia. The Baltic Sea is the world’s largest brackish-water system.

The areas that are effected by oil spills are primarily the littoral between highest and lowest water level (the part effected by tides and waves), living accumulation bottoms and the water surface. The littoral zone and accumulation bottoms are home to a vast number of benthic organisms, plants, and algae and juvenile and larvae stadiums of fish as well as predators, such as waders. Avifauna and marine mammals must stay in close contact with the air-water interface and are thus easily contaminated by surface oil slicks.

In order to protect especially sensitive habitats, both national and international inventories and classifications of biotopes are made in the Nordic Seas. The two most important ones are the Habitats Directive (EEC-Directive 92/43) and HELCOM's Red List of Marine and Coastal Biotopes and Biotope Complexes of the Baltic Sea, Belt Sea and Kattegat (1997).

HELCOM classifies one out of eleven biotope complexes (Lagoons including Bodden, barrier lagoons and Fladas) and twenty out of 131 biotopes as "heavily endangered" (HELCOM 1998). The biotope complex of Lagoons corresponds well with the Habitat Directive identifying Coastal lagoons and Boreal Baltic coastal meadows as prioritised marine habitats represented in Sweden (SNV 1997). The endangered biotopes according to HELCOM are listed in Table 4 below.

HELCOM has developed a GIS-system called MARIS (Marine Accident Response System for the Baltic Sea). It uses for four categories of data – Vulnerable areas, Maritime traffic and risks, Response capacity and Geographical background information – to describe the situation in the Baltic Sea. The system includes parameters such as protected areas, nesting areas for birds, traffic volumes, high risk areas, accident history, response vessels, surveillance aircrafts, and sea charts. (HELCOM 2003)

For Greenland's West Coast, the Danish Ministry of Environment and Energy together with the Danish Energy Agency has published an environmental oil spill sensitivity atlas (Mosbech et al 2000). Differing significantly from the enclosed brackish Baltic Sea the Greenland coast is evaluated with another approach than just looking at habitats. The atlas covers the coast from 62^{o} N to 68^{o} N, dividing the area into 279 shoreline areas and 12 offshore areas. Each area is assigned an index-value, based on its individual characteristics. Being an atlas focusing especially on oil spill sensitivity four criteria are used for calculating the index:

- The abundance and sensitivity of selected species or species groups,
- Resource use (human use), mainly fishing or hunting,
- The potential oil residency on the shoreline based mainly on wave exposure, substrate and slope of coast,
- The presence of towns, settlements and archaeological sites (for shorelines).

In total 40 areas are identified as having extreme sensitivity and 72 as high (the two highest index values on a scale of four). Using this approach the calculated sensitivity can differ between two sites of the same biotope. Hence this a more precise method of identifying especially sensitive habitats than just looking at a model habitat classification, which is as it should be considering the different purposes of an environmental oil spill sensitivity atlas and biotope classification.

In Norway 36 areas are prioritised in the protection plan, twelve of them in the northernmost part (Brude et al 2003). In most cases the benthic flora and fauna has been the main reason for giving an area special status. Especially shallow areas, open coastlines, shelf areas and current-affected sites have been listed. The Faeroes have also prioritised their coasts as a part of the emergency preparedness plans.

Table 4. *Heavily endangered biotopes according to HELCOM's Red List (1998)*

Class	Category	Type
Pelagic marine biotopes	Offshore (deep) waters	Offshore (deep) waters below the halocline
Benthic marine biotope	Sublittoral photic zone	Sublittoral level sandy bottoms dominated by macrophyte vegetation
Terrestrial biotopes	White dunes	Grey dunes Brown dunes with dwarf shrubs Brown dunes with dune shrubbery
	Brown dunes covered with trees	Natural or almost natural coniferous forest on dunes Natural or almost natural deciduous forest on dunes (beech, oak, birch forest)
	Wet dune slacks	Wet dune slacks, incl. coastal fens dominated by shrubs or trees
	Meadows and pastures	Salt pioneer swards Lower meadows Upper meadows Dry meadows (incl. alvars) Tall herb stands
	Swamps	Coastal bogs
	Coastal fens	Calcareous fens ("rich" fens)
Coastal lakes, pools and "Glo-lakes"	Brackish coastal lakes	Eutrophic brackish coastal lakes Mesotrophic brackish coastal lakes
	Freshwater coastal lakes	Mesotrophic freshwater coastal lakes Oligtrophic freshwater coastal lakes
	Permanent freshwater pools	Permanent eutrophic freshwater pools (incl. rock pools etc) Permanent mesotrophic freshwater pools (incl. rock pools etc)

6 Effects of short-term exposure on Nordic coastal and marine fauna groups

Recovery times following spills can vary from a few days to more than ten years. This report focuses on the short-term effects. There is no clear-cut correlation between size of spill and extent of damage. As accounted for above a number of factors are important in influencing degree of damage and recovery times.

In the following paragraphs the potential short-term effects on marine mammals, avifauna, fish and plankton communities are described. Sea also chapter 6.6 Overview of sensitivity of different fauna groups.

6.1 Marine mammals

The effects of petroleum on marine mammals have received a great deal of attention, particularly due to the high public interest in these animals. The polar seas, and especially the Arctic, are the habitat for a large proportion of the marine mammals of the world (GESAMP1993), primarily seals and whales, but also sea otters and polar bears. Being dependent on air breathing, all marine mammals must stay in close contact with the air-water interface and hence easily come in contact with a surface oil slick. This is particularly the case in ice-filled areas where the restricted open surfaces are crucial for the animals and are also the areas where the oil becomes concentrated. Still the documented cases of oil pollution incidents affecting marine mammals are few and questionable.

The risks are not negligible however. In 1997 a 5,000 m^3 crude oil spill killed 5,000 South American fur seal pups, a sixth of the colony's pups, outside Uruguay's coast (Mearns et al 1999). Much like otters, the fur seal is depending on its fur for insulation.

6.2 Avifauna

Effects of oil on seabirds have attracted strong attention and public concern during most oil spills. Clear individual damage has been manifested by loss of thermal insulation capabilities due to fouling of plumage, by toxic effects caused by ingestion of oil with food or during preening of plumage, and by fouling of eggs causing embryonic mortality. Seabirds are particularly at risk from damage from oil because of their social behaviour. Arctic regions have specific times and places with very large aggregations of seabirds in connection with breeding, molting, overwintering, and preparation for migration. A single Arctic breeding colony may contain a large proportion of the total standing stock of a certain bird species and an oil spill in the vicinity of such a colony may, therefore, cause a disproportional large amount of damage. For example, approximately one fourth of the European long-tailed duck (*Clangula hyemalis*) population, or 500,000 – 1,000,000 birds, is wintering on Hoburgsbank, south of Gotland.

It is usually hard to present good estimations on the total number of oil-killed birds. Studies in the North Sea shows that only 7 – 40 % of the struck birds are found ashore (SOU 1998). In the case of wintering long-tailed ducks monitoring since 1997 of ornithologists and hunters suggests that as many as 10 % of the Hoburgsbank population is killed each winter of oil spills (Larsson 2004). The public will not observe the overwhelming part of these birds, since they easily fall prey to gulls or foxes. This remarkably high mortality is due only to “normal” small spills from the 50,000 yearly ship-passages at Hoburgsbank. A larger incident would threaten the entire population. There are numerous examples of similar bird concentrations and colonies, both in the Baltic Sea and outside.

Experiences from the oil spill in Grønsund, Denmark, March 2001 suggests that the short-term effects on seabirds can be considerable, even though bird populations will recover. For instance a colony of herons was halved from 100 to 50 pairs and on a nearby island 600 birds, including 96 pairs of cormorants disappeared, presumably dead. In both cases only a few dead birds were found. The total number of killed birds was estimated to be as high as 20,000. 1,750 dead birds were actually collected. (Storstrøm 2001)

Similar experiences were made after the MS Eira oil-spill outside Kvarken 1984. 1,914 dead birds were found out of totally 3,000 – 3,600 estimated. 75 % of the found birds were Black Guillemots, which consequently needed a few years to recover (Pahtamaa et al 1987).

6.3 Fish

Field studies, even after one of the very large oil spills, have generally failed to document any widespread effects on fish. Presumably this is due to a combination of several factors including avoidance reactions to oil, the relatively low content of toxic hydrocarbons beneath oil slicks, and the highly dynamic nature of fish stocks reducing the possibilities of identifying changes caused by the oil. However, adverse effects have been recorded during chronic exposure of winter flounder (*Pseudopleuronectes americanus*) to sediments contaminated with petroleum at concentrations commonly found to occur under oil spill conditions (GESAMP 1993).

Pelagic fish have been affected due to oil spills both outside Norway and Denmark. After the grounding of Green Ålesund west of Haugesund in Norway increased levels of PAH metabolites were found in cod (Aas and Bjørnstad 2001). Shrimps, eel and flounders showed elevated levels of both PAHs and B(a)P-toxic equivalents after the Baltic Carrier oil spill in Denmark (Storstrøm 2001). Also from the well-known Amoco Cadiz oil spill especially flounders were affected (SNV 1986).

Fish eggs and larvae are, in general, more vulnerable to oil spills than adult fish, partly due to their intrinsically higher sensitivity to oil toxicity, and partly to their higher probability of exposure. The eggs and larvae of many species, such as cod eggs and larvae and herring larvae, develop near the water surface where the concentrations of toxic components from an oil slick are highest. It is also during these stages that their ability to avoid oil by active swimming is low.

In larval cod and capelin, Føyn and Serigstad (1989) found very low tolerance, which was manifested as irreversibly reduced oxygen uptake, even to short (2 – 24 hour) exposures to 50 µg/L of the water soluble fraction of crude oil.

6.4 Benthic fauna

Shoreline and shallow subtidal communities are prime targets of concern during most coastal oil spills. As opposed to open waters, where the concentrations of hydrocarbons are rapidly reduced, massive stranding and contamination may occur. On low energy beaches especially, the loss of harmful components may be very slow. Oil with little weathering may be trapped for decades and slowly released to the ecosystem.

Polar intertidal areas are often biologically barren due to frequent ice scouring, which means that the communities that do occur in such areas are, by nature, transitory. Any effects of stranded oil may, therefore, be regarded as just another instance in the recurring pattern of community destruction. The persistent presence of oil may, however, further reduce the community by preventing colonisation between the scouring periods. (AMAP, 1998)

In more subarctic regions, such as along the northern Norwegian coast, ice scouring is infrequent and the intertidal communities are of a boreal type with more or less dense cover of barnacles, mussels, and several other organisms on hard substrates. In these communities, the impact of stranded oil will be similar to more temperate regions. (AMAP, 1998)

A thorough investigation of the immediate impact and recovery of the intertidal communities after the *Exxon Valdez* crude oil spill in Alaska (Stoker *et al.* 1992) showed that, even on the most heavily impacted shores, survivors of the main groups of organisms, barnacles, mussels, and periwinkles, were present just after the spill. This demonstrated a very strong recovery potential of the shoreline community through recruitment from nearby unaffected sites.

The impact of oil on cold-water, rocky-shore communities may be regarded as one of several factors of disturbance, which can destabilise the ecosystem and drive the community in the direction of monoculture (Southward 1982). The effects normally vary greatly among different species. Many organisms resist desiccation during low tide by closing up their shell or outer protection, e.g., mussels and barnacles, and they may survive short-term oil smothering in the same way. Still, thick layers of oil will suffocate them (Wikander 1982). Mobile organisms such as crustaceans may escape by seeking deeper water, but escape responses can also cause animals to get stuck in the oil (Bonsdorff and Nelson 1981). In general, crustaceans, and in particular amphipods, have been found to be sensitive to oil spills (den Hartog and Jacobs 1980, Sanders *et al.* 1980, Elmgren *et al.* 1983, Teal and Howarth 1984, Cross *et al.* 1987, Kingston *et al.* 1995, and others).

Experience with cold-water oil spills confirms that the recovery potential of hard-bottom intertidal organisms is high, but that the recovery time is also dependent on other factors, such as wave exposure and substrate topography and texture, which mainly influence retention time of the oil in the system. Oil may become stranded on backshores by storms or spring tide. The residence time of this oil may be extremely long due to gradual asphalt formation (Sergy 1985).

On sheltered sandy and muddy shores, the effects can be more pronounced. In addition to initial mortality, delayed mortality related directly or indirectly to the oil being buried in place has been demonstrated (Kuiper *et al.* 1983).

6.5 Plankton communities and productivity

Seasonal variations in light conditions and ice cover are the main factors governing the primary production of the arctic pelagic ecosystem. The primary production may be divided into three seasons (Thingstad, 1990):

1) Winter, with very little light due to low sun as well as ice cover, and almost no production.

2) Spring/summer, when light conditions and surface water stratification combine with high nutrient levels to form the basis for very intense primary production, which provides the basis for intensive zooplankton growth, which in its turn supports intensive grazing by fish.

3) Summer/autumn, when nutrient levels are very low and production is modest and based on nutrients remineralised in the photic zone itself.

The Arctic pelagic food chain is characterised by few species, with very high individual densities and biomasses. Earlier studies concluded that the damage of oil spills to primary producers is likely to be rather modest and of short duration. Major negative effects on primary production have been reported from experimental work, but have not been verified from *in situ* studies. Reduction in primary production has been documented at total concentrations of 200-300 mg/L (from plastic bag experiments) (Anon, 1984), but mainly as an indirect effect of reduced nutrient excretion and shading by the oil slick. The relative low concentrations of oil found in the productive surface layers of water after a spill have in some cases stimulated rather than hampered primary production. The above findings may be relevant for Arctic phytoplankton growth, but also signs of stimulated growth, during several days' exposure to 10 ppm of a range of crude oils. Plankton studies are generally not given priority after oil spills because the oil content of the water is usually so low that effects are unlikely (Moe et al, 1993).

Large moving populations of scavenging amphipods and mysids are often present in Arctic waters (Wells and Percy 1985, Sakshaug 1992) and may possibly play a similar important trophic role as the krill in the Antarctic (Sakshaug 1992). Oil damage to amphipods may, therefore, have more severe ecological consequences in the Arctic than in warmer regions. For zooplankton the vulnerability to oil differs among different species. Krill (*euphausiids*), for example, is found to be more vulnerable than *daphnia* (Johansen et al 2003).

Field observations on zooplankton have also been made at numerous accidental and experimental spills (Wells and Percy 1985), including some few from Arctic regions. Collectively these studies show that negative biological effects and changes can occur after a spill, but they appear to be short-lived. Zooplankton populations and communities in open temperate waters appear to recover rapidly, largely because of their wide distributions and rapid regeneration rates. Hence if any negative effects occur, regeneration must be expected to be slower in the Arctic than in temperate waters.

6.6 Overview of sensitivity of different fauna groups

Below is an overview given of important species for each fauna group, together with short comments on the groups vulnerability to oil spills. The example species given below are either particularly vulnerable to oil spill (eelgrass) or of considerable ecological (whales) or commercial (cod) importance or a combination thereof (Fejes 2004, FOIG 2001).

Table 5. Fauna groups with different sensitivities of oil. Examples of important and/or vulnerable species are given for each group.

Group	Example of species	Comments
Mammals	Fin whale, pilot whale, grey seal	It has been rare for seals, whales and dolphins to be affected following a spill. Sea otters are more vulnerable both because of their way of life and their fur structure.
Birds	Guillemot (*Uria aalge*) Puffin (*Fratercula arctica*) Razorbill (*Alca torda*)	Birds using the water-air interface are at risk, particularly auks and divers. Badly oiled birds usually die. Treatment requires specialist expertise. Recovery of populations depends either on the existence of reservoir of young non-breeding adults from which breeding colonies can be replenished (e.g. guillemots) or a high reproductive rate (e.g. ducks). There is no evidence so far that any oil spill has permanently damaged a seabird population, but the populations of species with very local distributions could be at risk in exceptional circumstances.
Fish	Blue whiting (*Micromesistius poutassou*) Capelin (*Mallotus villosus*) Cod (*Gadus morhua*) Eelpout (*Zoarces viviparus*) Haddock (*Melanogrammus aeglefinus*) Sprat (*Sprattus sprattus*) Plaice (*Pleuronectes platessa*)	Eggs and larvae in shallow bays may suffer from heavy mortality under slicks, particularly if dispersants are used. Adult fish tend to swim away from oil. There is no evidence so far that any oil spill has significantly affected adult fish populations in the open sea. Even when many larvae have been killed, this has not been subsequently detected in adult populations, possibly because the survivors had a competitive advantage (more food, and less vulnerable to predators). Adult fish in fish farm pens may be killed, or at least made unmarketable because of tainting.
Benthic fauna – invertebrates	Barnacle (*Balanus*	Invertebrates include shellfish (both molluscs and crustaceans), worms of various kinds, sea

	balonoides) Burrowing polychaetes (*Nereis diversicolor*), Common mussel (M*ytilus edulis*)	urchins (e.g. starfish) and corals. All these groups may suffer heavy casualties if coated with fresh crude oil. In contrast, it is quite common to see barnacles, winkles and limpets living on rocks in the presence of residual weathered oil.
Planktonic organisms		Serious effects on plankton have not been observed in the open sea. This is probably because high reproductive rates and immigration from outside the affected area counteracts short-term reductions in numbers caused by the oil.
Larger algae (Macrophytes, e.g. seaweed)	Bladder wrack (*Fucus vesiculosus*)	Oil does not always stick to the larger algae because of their mucilaginous coating. When oil does stick plants on the shore, they can become overweight and subject to breakage by the waves. Intertidals areas denuded of algae are usually readily re-populated once the oil has been substantially removed.
Eelgrass habitat	Eelgrass	Eelgrass is perennial and lives in shallow coastal areas. Eelgrass provides food, breeding areas, and protective nurseries for fish, shellfish, crustaceans and many other animals and is therefore very sensitive to oil.

6.7 Toxicity-tests

It is not easy to find Nordic toxicity-tests of oil. Environmental Technology Centre in Canada probably has the largest database on toxicity for different oils currently available (ETC 2004). In the table below the found Nordic studies are presented. The classification is based on the viscosity of the oil, since viscosity decides the oils' characteristics in water. 3 – 5 different types of oil, common in the Nordic Countries' waters represent each class.

Both properties of oil and the behaviour of different fauna groups have been discussed above. Generally it can be said that lighter petroleum oils are generally more toxic than heavier. As for the sensitivity of exposed organisms pelagic organisms are obviously less likely to be affected than benthic. Egg and larvae are more vulnerable than adult examples.

Table 6. *Oil types have been divided in three groups, based on viscosity with similar effects on biota. The parameters used in the studies above are EC_X (effect concentration, for which X % of the organisms are effected), IC_{50} (inhibit concentration, for which the growth is inhibited by 50 %), LC_{50} (lethal concentration, for which 50 % of the organisms die) and LC_m (the median LC_{50}-concentration). OWD is an abbreviation for Oil-water dispersion, while WAF stands for Water-accommodated fractions.*

Groups of oil	Oil type	Test species	Method	Parameter	Result	Unit
Light oil Viscosity at 20 °C: 0 –100 cSt	Gasoline	Fish (herring)	WAF	LC_{50} 96 h	10 – 18	mg/L
		Fish	OWD	LC_{50} 96 h	82, 119	mg/L
		Fish	OWD	LC_{50} 48 h	91	mg/L
		Fish	OWD	LC_{50} 24 h	47, 58	mg/L
		Fish	WAF	LC_{50} 96 h	8.3, 27	mg/L
		Invertebrate	WAF	EC_{50} 96 h	2.0 – 32	mg/L
		Invertebrate	OWD	EC_{50} 96 h	201	mg/L
		Invertebrate	WAF	EC_{50} 48 h	5,9	mg/L
		Algae	WAF	IC_{50} 72 h	3.1 – 30,000	mg/L
	Kerosine (jet fuel)	Fish	OWD	LC_{50} 96 h	45	mg/L
		Fish	WAF	LC_{50} 96 h	7.3 – 25	mg/L
		Invertebrate	WAF	LC_{50} 96 h	0.9	mg/L
		Invertebrate	WAF	LC_{50} 48 h	1.4 – 21	mg/L
		Algae	WAF	IC_{50} 72 h	3.7 – 8.3	mg/L
	Diesel	Fish	OWD	LC_{50} 96 h	31, 54	mg/L
		Fish	OWD	$LC_{m\ 96\ h}$	33 – 125	mg/L
		Fish	WAF	LC_{50} 96 h	21 – 230	mg/L
		Invertebrate	OWD	LC_m 48 h	1.6 – 9.4	mg/L
		Invertebrate	WAF	LC_m 48 h	6.2 – 210	mg/L
		Algae	WAF	IC_{50} 72 h	>10 – 78	mg/L
	Light/medium crude	Fish (Salmon)	OWD	LC_{50} 96 h	258, 291	mg/L
		Fish	OWD	LC_{50} 96 h	3,700 – 80,000	mg/L
		Invertebrate	OWD	LC_{50} 96 h	27 – 119	mg/L
		Invertebrate	OWD	LC_m 96 h	200 – 6,000	mg/L
		Invertebrate	OWD	LC_m 48 h	37.5, 63	mg/L
		Invertebrate	WAF	LC_{50} 96 h	39.5, 618	mg/L
		Algae	OWD	IC_{50} 15 d	5,7	mg/L
	Volgoneft		Microtox	EC_{20} 5 min	3.6	
			Microtox	EC_{20} 15 min	3.0	
			Microtox	EC_{50} 5 min	13	
			Microtox	EC_{50} 15 min	11	
	EO 1		Microtox	EC_{20} 5 min	2.3	
			Microtox	EC_{20} 15 min	2.2	
			Microtox	EC_{50} 5 min	7.7	
			Microtox	EC_{50} 15 min	7.5	
Medium heavy oil	Lubricating oil					
Viscosity at 20 °C: 100 – 1000 cSt	EO 3-4	Mollusc (*Lumnaea peregra*)	WAF	EC_{23} 96 h	10	%

		Mollusc (*Lumnaea peregra*)	WAF	EC_7 48 h	10	%
		Mollusc (*Lumnaea peregra*)	WAF	EC_7 24 h	10	%
	Bunker B					
Heavy oil Viscosity at 20 ^{o}C: > 1000 cSt	Heavy crude					
	Bunker C	*Arenicola marina*		LC_{50} 8 d	>> 8,640	ppm
		Nereis diversicolor		LC_{50} 10 d	>> 8,640	ppm
		Cerastoderma sp.		LC_{50} 8 d	> 2,800	ppm
		Mytilus edulus		LC_{50} 8 d	>> 8,640	ppm
	Asphalt					

For gasoline, kerosine, diesel and light/medium crude the data comes from CONCAWE (2001). The fish tests are conducted on juvenile or adult individuals, not eggs or larvae, which are more sensitive to hydrocarbons in water. The CONCAWE-data consists of 93 studies in total.

When testing the Volgoneft-spill, Enell et al (1990) compared it with EO 1 using a Microtox-test. In a Finnish mortality study found Lax and Vainio (1988) tested heavy burning oil (EO 3 – 4). The heavy fuel oil (Bunker C) spilled from Baltic Carrier was tested on six species of benthic macro fauna. Sediment homogeneously contaminated with oil (collected directly from Baltic Carrier) was overlaid with uncontaminated 15 $^{o}/_{oo}$ seawater. Mortality was generally observed first after long exposure times. (Storstrøm 2001)

7 Screening of potentially sensitive coastal and marine areas in Nordic Seas

Figure 6 is a relief map over eastern part of the studied area. It clearly indicates the complexity of the bottoms. For instance is the Faeroes Shelf considerably larger than the Faeroes Islands, visible above the surface. Baltic Sea is also comparatively shallow.

In Table 7 are the Nordic Countries' calculated coastlines presented. A few geographically important islands are presented separately (in column Coastline islands), but included in the total coastline. The surprisingly short coastline of Greenland is most likely due to different resolution of the maps. With infinitely high resolution, any coastline will be infinitely long. All geographical information, except for Greenland, is acquired from the same map, thus having the same resolution.

Maximum depth to be acutely effected by oil spill is assumed to be 20 metres. This area is negligible outside the coastal zone.

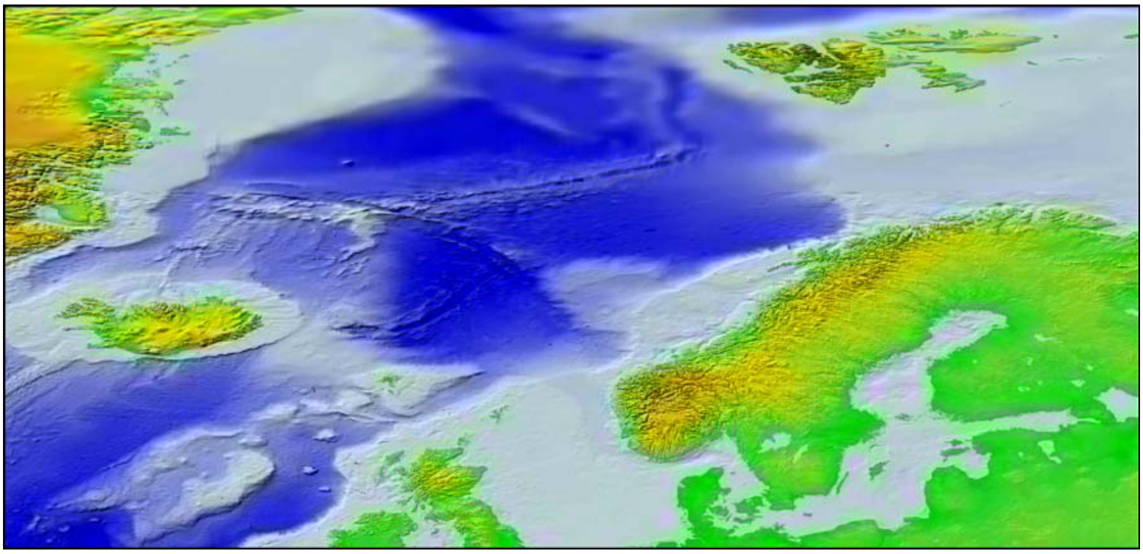

Figure 6. *Relief map of the Nordic Countries and corresponding waters (note that just the eastern part of Greenland is visible). The map clearly shows the complexity of the sea floor, with large shelf areas surrounding the Faeroes and Greenland. The scale is distorted due to the projection.*

***Table** 7. Length of the Nordic Countries' coast line, in kilometres*

Country	Major island	Coastline [km]	Coastline islands [km]	Total [km]
Sweden		31,000		32,000
	Gotland		900	
	Öland		500	
Denmark		5,500		5,500
Finland		23,000		23,000
Norway		47,000		55,000
	Jan Mayen		150	
	Björnöya		83	
	Spitsbergen		8,300	
Faeroes		1,100		1,100
Greenland		33,000		33,000
Total				**149,000**

The total area of coastal and marine Natura 2000 areas in Sweden is 5,800 km^2.

Depending on the width of the coastal zone the percentage of Natura 2000 areas will vary. In table Table 8, four alternatives are given. The relationship is liner, since the percentage is calculated as

$$\%Area = \frac{5{,}800}{33{,}000 \cdot Width} \cdot 100$$

***Table 8**. Area of the Swedish coastal zone, in kilometres and percentage appointed as Natura 2000*

Width [km]	Swedish coastal zone [km^2]	Area appointed as Natura 2000
0,5	16,000	36 %
1	33,000	18 %
2	65,000	9 %
5	160,000	4 %

8 Discussion

8.1 Risk for future spills and possibilities to reduce them

Obviously the best way to decrease the effects of oil in the environment is to decrease the volume of spilled oil. As presented in 4.1 Historical statistics for the last decade it seems that intense aerial surveillance and efficient law enforcement will reduce the number of illegal spills. Since accidents will continue to happen, regardless of safety-precautions, the illegal spills must be a priority. They are deliberate and can thus be prevented.

Today it is virtually impossible to maintain constant surveillance. Therefor responsible authorities must prioritise. This report is focusing on identifying environmentally oil sensitive habitats, which is an important aspect when making such a decision. However, other considerations must also be done, e.g. ship traffic patterns, cross-border co-ordination of surveillance resources and readiness to respond to observed incidents.

The Baltic Sea has been nominated as a Particularly Sensitive Sea Area (PSSA), excluding the Russian part of the Gulf of Finland. Discussions are currently underhand on what regulations this will result in. This is a political process with many considerations. It is likely that double-hulled vessels will be required for oil tankers, but many other aspects can be included. Designated refuge areas or safe havens, where ships in distress can be tugged for minimised environmental consequences of a spill is one possible aspect, and changed ship routes another.

There is also an on-going discussion of classifying the west coast of Europe as PSSA, from Gibraltar in the south to Shetland in the north (Marine Environmental Protection Committee, IMO). This may e.g. affect the maritime traffic routes and benefit advantageous restrictions for Faroese. Or the opposite, maritime traffic from Scandinavia and Russia risk ending up in a worse position than before, with traffic routes closer to Faroese.

8.2 Influence on oil spill effects due to time of year

The time of year has a major influence on the oil's behaviour as well as the sensitivity of species and habitats. This is an important aspect that is easily overlooked. It is not possible to make a general statement on how the sensitivity depends on time of year. For instance during winter lower temperature and presence of snow and ice will slower the weathering and complicate clean-up operations. Large congregations of birds will gather in specific areas, being extremely vulnerable to oil spills. On the other hand winter storms and ice scouring will efficiently disperse oil slick on exposed shores. Many habitats will also be less vulnerable due to the fact that there is significantly lower biological activity that can be effected.

8.3 Classification and mapping of sensitive habitats

It would be valuable to identify key species and habitats for Nordic waters, to facilitate prioritising areas for protection and intensified surveillance. It is currently difficult to conduct this ranking. Such definitions and classifications are being developed at both national and international level. The most important ones for the region studied are the European Council's directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora, also known as Natura 2000-areas, and HELCOM's red list of marine and coastal biotopes and biotope complexes of the Baltic Sea, Belt Sea and Kattegat. The European Environment Agency (EEA) is also developing an extensive database of species, habitats and sites in Europe. It is used for environmental reporting and assisting the Natura 2000-process.

In addition to these two separate systems, there are national regulations defining different habitat and biotope types. The conclusion is that there is no single, general accepted list of coastal and marine key-biotopes.

It is important to remember that these classifications are quite general and do not address the effects of oil spills specifically, but rather identifies ecologically and environmentally important areas. A better-suited approach is to develop a specific oil sensitivity environmental atlas, such as the one describing Greenland's West Coast. This requires additional work, but can probably be based on the work of the Habitats Directive and HELCOM. At least Sweden is currently preparing to develop an atlas of its own.

After identifying protect-worthy areas there is still one aspect not discussed in this study; the transportation of oil in water. It is well known that currents and wind rapidly can transport oil on the surface. This can be fairly well predicted by oceanographical models, such as SMHI's (Swedish Meteorological and Hydrological Institute) Sea Track Web for the Baltic Sea. If the oil sinks, the situation gets considerably more complicated and it is not unlikely that it actually transports horizontally by underwater currents before it settles. Thus it is not necessarily the surface immediately above a sensitive bottom that requires protection.

8.4 Possibility to use specific indicators species for oil spills

One idea that has been discussed during the progress of this work is to identify indicator species for oil spill, relevant to Nordic waters. This has not proved feasible. In order to indicate a specific state, in this case oil spill, the indicator should either never or always be present under the desired state. Since the unaffected state of most coastal and marine habitats is unknown it will not be possible to conclude if any indicator has disappeared recently, or if its absence is the natural state. The other variant, a species only present after oil spill does not seem realistic to find.

Hans Blanck and Lars Förlin (2004) argue for the possibility to observe changes in an entire ecosystem. If species A, B and C are missing for the benefit of D, E and F, it could indicate the effects of a spill. This requires extensive knowledge, since the species at hand will be limited to a specific region. Probably a simple chemical analysis is still the fastest short cut, even though it will not identify historical effects. There are however biochemical indicators. For example can PAH-exposure (a toxic component of especially lighter oils) be identified in blue mussels or as PAH-metabolites in fish bile. In the future toxicogenetic tests might be a possibility.

8.5 Importance of and challenges with toxicity-tests

It is important to have a good understanding of the toxicity of different oils in order to accurately describe the potential environmental effects. Unfortunately, that is difficult. The fact that different species react differently to a specific oil is obvious, and the toxicity-altering effect of weathering are also mentioned. Birds and marine mammals are often affected by smearing, rather than actually poisoned. Oil reduces the insulation of fur and plumage and can also reduce the animal's buoyancy by weighing it down. Toxic effects can however occur as burning of eyes when the animal passes the surface, or when it tries to clean its fur/plumage. For these reasons, there are very few toxicity-tests conducted on birds or marine mammals.

Many of the conducted toxicity-tests have studied organisms not relevant for Nordic waters. This is related to the previously mentioned problem to correctly identify relevant key-species; until it is decided what species are important to study, it is hard to do it. Other reasons are that test-organisms are partly chosen for their ability to live and function in laboratories and that many studies are conducted in countries with different natural conditions than the Nordic Countries.

8.6 The need for a more comprehensive screening approach

The screening presented in this report is deliberately simple. It is solely based on the two geographical conditions of closeness to shore and depth, in order to identify littoral zones and other photic areas. Nevertheless, this approach underlines the need for further studies. Compared to the area potentially requiring protection, the Natura 2000-area is small. It should also be stressed that Natura 2000 sites are not generally protected, but rather associated with restrictions for exploitation and enterprises. They are areas containing important or endangered species, not necessarily sensitive to oil.

The calculated coastal zone willoverlap – more so with increasing width, overestimating the coastal zone area. On the other hand, many sensitive areas are substantially larger, covering an area with the extent more then 5 km from the shore. These effects are counteracting each other.

It is unknown how representative the Swedish situation (ratio of Natura 2000 areas) are for the entire studied region.

Even though no shallow areas are included it does not mean that allexcluded areas are equally (un)important. They are however not acutely sensitive to oil spills, since dispersion will prevent toxic concentrations and thick oil covers deeper than 20 metres during normal conditions.

A screening like this can be much more comprehensive, including possibly commercial, social, historical and public health aspects. This is also convincingly demonstrated in MARIS and the environmental atlas of Greenland. In order to develop a feasible environmental atlas, relevant key-species and habitats must have been defined for the region at hand. Not until that is done can environmental values be weighted against possible other aspects.

8.7 Knowledge gaps

This report has identified a number of topics in need of further examination. The knowledge acquired will not only benefit the understanding of short-term effects, but of the behaviour and consequences of oil in the nature at large.

- **Surveillance and law enforcement:** Where, when and how should surveillance be conducted to generate as efficient environmental protection as possible? How can the illegal spills be prevented, and accidental spills be discovered? This must be a trade-off between the habitat's degree of sensitivity, number of passing ships and possibly the condition of the ships as well as other aspects.

- **Changing physical conditions:** How will time of year, and maybe also weather, influence the sensitivity and priority of the habitats? Specific sites, such as bird colonies, will for sure require different levels of protection depending on time of year.

- **Environmental atlases:** Large parts of the Nordic coastal and maritime regions are not sufficiently described today.

- **Toxicity-tests:** Many species important to the Nordic ecosystems are currently not tested for oil toxicity.

- **Impact of underwater currents:** How important are underwater currents for sinking and settling oil spills?

Conducting more follow-ups on actual accidents will partly cover the latter four. Today the effects of the Tsesis and Exxon Valdez spills are still the most closely monitored. By well-planned monitoring not only the immediate effects of a spill, but also the natural recovery the knowledge-base of how different habitats react will increase significantly, and provide information on interaction between the parameters discussed above; oil type, load, weathering, time of year and habitat characteristics. Just as importantly, studies on Nordic waters will generate information directly relevant to Nordic conditions.

9 Conclusions

The Nordic efforts to increase the understanding of environmental effects of oil spills are required to meet the imminent and future threats. Even though oil and the effects of it are thoroughly researched internationally, the specific Nordic conditions raises a number of questions yet to be answered.

This study has showed that the Nordic coastal and maritime areas differ significantly from most of the rest of the world, but also among each other. The characteristics specific for the Nordic waters are primarily low temperature, complete or partial icing and brackish water (in the Baltic Sea). Unfortunately, this makes Nordic habitats particularly sensitive to oil spills.

Oil exploitation in the North Sea will continue and the already intense shipping in the Baltic and Belt Seas will increase further. This will not only increase the background load of minor deliberate and accidental spills, but also the risk for major accidents.

Large areas are potentially in need of protective status. The current extent is inadequate and the situation requires a continued mapping and identification of most important and sensitive areas. This must be combined with regulatory work and negotiations to increase naval safety and possibly agreement on better shipping routes.

Existing environmental atlases shows how habitat inventories can be conducted. They also point to the conclusion that handling and effects of oil are a complicated topic, where many considerations are necessary.

There are considerable differences in short-term, acute, effects of oil spills and long-term effects. As presented in this report, avifauna and questionably marine mammals are under greatest threat from acute effects. The plankton community will also be affected, but is quickly re-established. The impact on pelagic fish is negligible, and also benthic fauna will be practically unaffected by acute toxic effects. They can however suffer significantly from suffocation by thick settled oil slicks.

This report only regards short-term environmental effects, but even with such strict a limitation the remaining issues are too inter-related to address independently from each other. Geographical, physiological and chemical in conditions governs the weathering and hence influences the behaviour of the oil; where it ends up and its toxicity. This is obviously of importance when identifying areas requiring protection, as is information about the varying intensity of shipping and capacity for correct and efficient clean-up operations. At the same time key-species must be identified by knowing their ecological importance as well as their sensitivity different types and weathered stages of oil.

10 Glossary

Accumulation bottoms: A sub-surface area where settling particles are accumulated. Usually biologically very active sites.

Acute toxic effects: Effects that occur within a short period of exposure in relation to the organisms life span. See also *chronic toxic effects*.

Benthic: Living on the bottom under a body of water. See also *pelagic*.

Biodegradation: The natural process when microbes degrades (consumes) a substance, e.g. oil.

Bunker oil: Heavy oil, used as boat and tanker fuel.

Chronic toxic effects: Effects that occur during a relatively long period, usually more than 10 % or more of the life span of the organism. See also *acute toxic effects*.

Crude oil: The primary state of oil. Crude oil has not yet been refined into different petroleum products.

Density: The mass (weight) of a unit volume of a substance. Water, for instance, has the density of (approximately) 1 kg/L.

Distillation fractions: The different (usually commercially interesting) petroleum fractions in a heavy oil. At atmospheric pressure gasoline is distillable at around 100 ^{o}C, jet fuel 200 ^{o}C and diesel 300 ^{o}C.

Dispersion: Fine droplets of oil is transferred into the water. Usually occurs when the surface oil slick is disrupted by breaking waves. The opposite of *emuslification*.

Emulsification: The process of water getting mixed with oil, in severe cases creating a very viscous “mousse”. The opposite of *dispersion*.

Flash point: Flash point is the lowest temperature at which a liquid can form an ignitable mixture in air near the surface of the liquid. The lower the flash point, the easier it is to ignite the material. A closely related and less common term is fire point, the temperature at which the flame becomes self-sustained so as to continue burning the liquid (at the flash point, the flame does not need to be sustained). The fire point is usually a few degrees above the flash point.

Interfacial tension: An intermolecular force between two surfaces. For instance the interfacial tension governs the shape of a liquid droplet (how spherical it is).

Littoral zone: The marine ecologic realm situated roughly between high tide level and the limit of the continental shelf. It is characterised by intricate inter-relationships between floral and faunal populations, high wave energies and, in the intertidal sub-zone, by alternating submergence and exposure.

Pelagic: Living in or frequenting the open ocean. Applied especially to animals that live at the surface of the ocean, away from the coast. See also *benthic*.

Photooxidation: A chemical process where the energy of sun light (or artificial light) causes chemical reactions..

Pour point: The lowest temperature at which oil will pour.

Sedimentation: The physical process of solid particles sinking, or settling, in a fluid.

Solubility: Solubility is a measurement of the mass of a solute (solid, liquid or gas) that will dissolve in a given volume or mass of solvent. When dissolving one liquid in another it is also called *miscibility*.

Specific gravity: See *density*.

Vapour pressure: Vapour pressure is a measure of the tendency of a material to change into the gaseous or vapour state, and it increases with temperature.

Viscosity: The resistance to flow in a liquid, i.e. how easily the substance flows. Viscosity is usually given in Centistokes (cSt). For most substances the viscosity decreases with increasing temperature. Water has a viscosity of (approximately) 1 cSt at 20 ^{o}C.

Weathering: A number of physical, biological and chemical processes degrading oil. In time natural weathering will obliterate all oil.

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