Short- and long-term effects of accidental oil pollution in waters of the Nordic countries

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Preface

Commissioned by the Nordic Council of Ministers, the short- and long-term effects of accidental oil pollution in waters of the Nordic countries have been evaluated. The main objective of this study is to assemble experiences of short- and long term effects relevant for the Nordic Countries and to identify knowledge gaps. The project is mainly based on studies in the Northeast Atlantic; the waters surrounding Greenland and the Faroes, the North Sea and the Baltic Sea. But to cover insufficient knowledge of oil effects, international experiences are also taken in to account with consideration taken for the conditions in the Nordic areas (temperature, salinity, arctic conditions etc).

The results will be disseminated to the Environmental Ministers and the Official Environmental Committee. The results will also be disseminated to the Nordic Countries, Nordic authorities working with oil matters, HELCOM, OSPAR, EU, and arctic programmes; AMAP and PAME.

Jonas Fejes
August 2007

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 waters have specific environment habitats with specialised key-species which have different sensitivities to oil spills. This report studies the short- and long-term effects of accidental oil spills in these habitats. Accidents are usually caused by collisions of tankers, groundings or technical failures. Another important source of marine oil spills is illegal oil releases like bilge water releases, tank washing, etc. The project does neither specifically include this illegal spills, nor continuous oil spills from e.g. land sources.

This study shows that the major part of the waters of Nordic Countries differ from other regions in the world, with lower temperature, lower salinity, lower exchange rates and icing. The Nordic waters are therefore in some context more vulnerable to oil spills than other waters in the world.

In the foreseeable future the number of minor oil spills is likely to increase, as will the risk for major accidents. Thus there is a strong need for mapping and identifying important and sensitive areas. There are regional and national efforts to develop environmental oil spill sensitivity atlases, which is most welcome. However, above sensitivity maps made by some Nordic countries and by HELCOM there is as yet no common Nordic Sensitivity Atlas.

There are considerable differences between short-term and long-term effects of oil spills. As presented in this report, birds and questionably marine mammals are under greatest threat from both short- and long-term effects. The plankton community will also be affected, but is quickly re-established. The impact on pelagic fish is negligible in short term but not in a long time perspective, and benthic fauna will be practically unaffected by short-term effects. They can however in a long-term suffer significantly from settled oil slicks.

1. Introduction

1.1 Justification

International marine pollution is of great concern for the Nordic Countries. The effects of oil spill are environmental problems and have long been known as threats to the Nordic environment. Nordic environmental co-operation concerning oil spills and associated environmental effects at sea is therefore required, to increase understanding of common environmental issues, 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 indicators for sustainable management to prevent the impacts of chemicals at sea.

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

The studied seas have different characteristics compared both to other oceans and to each other. The Nordic waters have colder temperatures compared to most other marine areas and seasonal or permanent ice-covered environments. Compared to each other, the waters 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 affected by oil spills.

1.2 Objective

The objective of this report is to study the short- and long-term effects of accidental oil spills in Nordic marine and coastal habitats. Accidents are usually caused by collisions of tankers, groundings or technical failures, e.g. during bunkering of oil. Another important source of marine oil spills is illegal oil releases like bilge water releases, tank washing, etc. The project does neither include deliberate spills, nor continuous oil spills from e.g. land sources.

Figure 1 Map over the seas around the Nordic countries (Source: Wikimedia Commons, 2007)

2. Background

2.1 Properties of oil

Oil is a general term that includes a wide variety of natural substances of plant, 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. The most important properties are viscosity and density. 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 it contains. Density is the mass (weight) of a given volume of oil. Density is important because it indicates whether 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. These processes are discriminated into two types. The first is weathering, 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. Another weathering process is *natural dispersion*, which occurs when fine droplets of oil are transferred into the water column. The opposite process is *emulsification*, when water is dispersed into oil in the form of small water droplets. *Biodegradation* is when microorganisms degrade 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 set of processes whereby the physical and chemical properties of the oil change after an oil spill. (Source: ITOPF 2002)

The second type 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 types of transformation processes depend on a combination of 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 destruction of a particular biological community. A coastal area which can trap oil (e.g. shel-

tered 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 effects 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 is usually related to changes in metabolism, growth, reproduction, or ability to survive.

2.4 Factors influencing impact and recovery

2.4.1 Oil type

Different types of oils vary significantly over a wide range of physical and chemical parameters, giving each oil type its specific characteristics. These characteristics will change, however, when the oil weathers. Usually the viscosity increases and toxicity decreases as volatile compounds evaporate. 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 and 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. This is fortunately quite rare, since lighter oils also have higher evaporation rates. For example, gasoline is highly toxic but evaporates within hours under normal weather conditions. 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 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 bays and inlets, where oil in the water may reach higher concentrations than in the open sea.

On the shore there is a range of possibilities for the fate and effects of oil. These are related to two important variables: the energy level of the shore (degree of exposure to wave energy), and substratum type. With increasing degree of shelter, 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 1, 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 1 Biological recovery depends on exposure to wave energy – but other variables, such as oil type, are also involved. (Modified from Baker J., 2000)

If oil penetrates into substratum, residence times are likely to be increased. Shores over a range of wave 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. Warmth 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 near-shore 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 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 affected by short- and long-term exposure to oil spills.

Mainly references from the Nordic Countries, excluding Iceland, i.e. Greenland, the Faroes, 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), Food, Veterinary and Environmental Agency of the Faroe Islands (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, and Fu Shan Hai.

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

4.1 Statistics for the last decades

In the last decades maritime transportation has been growing steadily, reflecting the intensified co-operation and trade in the Nordic region and a prospering economy. The oil pollution load to the Baltic Sea is 20,000–70,000 tonnes per year. 10 percent of this load is from shipping. It is more common that oil is discharged into the sea on purpose than is released accidentally. Deliberate illegal oil discharges from ships are regularly observed within the Nordic waters since 1988. Numbers of oil spills per year are shown in Figure 4. As from 1999 the number of observed oil discharges has slightly decreased. This trend is reflected also in a decrease in the number of observed oil discharges per flight hour surveillance.

Figure 4 Number of oil spills in Baltic Sea, the North Sea and waters surrounding the Faroes.

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) 1987–2003 and the Norwegian Pollution Control Authority 2004–2006. The oil spills in the North Sea mainly come from offshore and ship activities.

The numbers of oil discharges observed during continuous surveillance of confined areas in the Baltic Sea does not support the general conclusion that the overall number of 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 1988–2006, resulting in an out-flow of more than 100 tonnes of oil, are shown in Table 1. The most common oil types in Baltic Sea area are diesel, crude oil and heavy fuel (Table 2) (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-activities. 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-activities and maritime traffic (50 %). Offshore-activities also represent a higher volume of oil spill than maritime traffic.

The volume of oil spilled from offshore in 2003 was one of the largest registered in Norway during the last 10 years (Figure 5). Oil spills from offshore-activities, from 2002 to 2003, increased from 212 m³ to 897 m³ and this was mainly due to one large oil spill at the Draugen field. 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 1 Major oil incidents in the Baltic Sea 1988 – 2003 (Source: HELCOM, 2004)

Year	Name of ship	Amount 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 2 Most common types of oil in waters of the Nordic Countries

Baltic Sea Area	North Sea	Waters surrounding the Faroes	Waters surrounding Greenland
Diesel	Diesel	Gas/Diesel	Kerosine (paraffin)
Crude oil	Crude oil	Hydraulic oil	Gasoline
Heavy fuel oil	Heavy fuel		Gasoline/Diesel
Light oil	oil		Jet fuel

Figure 2 Quantity of oil spills in Baltic Sea, the North Sea and waters surrounding the Faroes.

There is no data from waters surrounding Greenland. Baltic Sea data from HELCOM, Norwegian data from Norwegian Pollution Control Authority and data about Faroe 2000–2006 from Food, Veterinary and Environmental Agency of the Faroe Island.

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). For many recorded accidents, the spill volume is not known and can therefore not be included.

There is no official oil spill statistics in waters surrounding Greenland. Approximately 5–10 small oil spills ($0.2\text{--}0.5\text{ m}^3$) 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 are however plans for this kind of activities in the future.

The Faroes has a similar situation to Greenland with no historical statistics of oil spill in the surrounding waters.. Since 2002, MRCC on the Faroes (Maritime Rescue and Co-ordination Centre) has the responsibility of preparedness for oil spill. Number and quantity of registered oil spills in 2001–2006 are shown in Figure 4 and Figure 2. The Figure 4 shows an increasing trend for 2001–2004 and one reason for that is more efficient

and systematic reporting system during the last years. Oil spills in waters surrounding the Faroes are usually diesel spills. It also occur spills of hydraulic oil. There has not been any large oil spill accident in waters surrounding the Faroes. The largest oil spills during 2001–2006 was from a foreign fishing ship, 27 m³ gasoline.

4.2 Prognosis for the next decade

Maritime traffic in the Baltic Sea is very dense and it accounts for approximately 15 % of the total maritime traffic in the 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 %), slight 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.

Figure 6 Projected petroleum production in Norway 2004–2014. (Norwegian Pollution Control Authority, 2005)

Projections for Norwegian oil and gas production indicate that it will remain at about the current level for the next 10 years. Oil production is expected to drop, whereas gas production will rise. Future expansion of offshore-activities in Barents Sea includes both gas and oil fields. 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).

Because of lack of historical statistics it is not possible to make a forecast of oil spills in waters surrounding Greenland and the Faroes for the next ten years. The future expansion of oil drilling operations will increase the risk of oil accidents, but not necessarily mean an increasing number of oil spills. Number of registered oil spills on the Faroes may increase due to more environmental aware civilian population, i.e. more reports that oil spills have 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 higher consciousness by local oil suppliers.

5. Coastal and marine habitats of Nordic Countries

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 and in the Faroes, only oil 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 Barents Sea is a part of the Arctic Ocean located north of Norway and Russia. It is a rather deep shelf sea (average depth 230 m), bordered by the shelf edge towards the Norwegian Sea in the west, the island of Svalbard (Norway) in the northwest, and the islands of Franz Josef Land and Novaya Zemlya (Russia) in the northeast and east. The southern half of the Barents Sea, including the ports of Murmansk (Russia) and Vardø (Norway) remain ice-free year round due to the warm North Atlantic drift. In September, the entire Barents Sea is more or less completely ice-free. Until the Winter War, Finland's territory also reached to the Barents Sea, with the harbour at Petsamo being Finland's only ice-free winter harbour.

The Norwegian Sea, the Greenland Sea and the Icelandic Sea are sometimes collectively referred to as the Nordic Seas. In the Norwegian Sea and Greenland Sea, surface water descends two to three kilometres down to the bottom of the ocean, forming cold, oxygen-rich groundwater. As a result, there is a warm surface current and a cold depth current running along the west coast of Norway. The so-called East Iceland Current transports cold water south from the Norwegian Sea towards Iceland and then east, along the Arctic Circle. The Norwegian Current, a branch of the Gulf Stream carries warm water masses northward and contributes to the mild and moist climate in Norway. The Gulf Stream is also responsible for the relative mild climate in the Faroes. The Norwegian Sea is the source of much of the North Atlantic Deep Water. The region remains ice-free due to the warm and saline Norwegian Atlantic Current.

The exchange of salt water between the North Sea and Atlantic occurs through the English Channel, as well as in the northern North Sea along the Scottish coast and through the Norwegian Sea. The North Sea receives fresh water not only from its influent rivers but also from the Baltic rivers, whose water must be exchanged through the Baltic Sea via the Skagerrak.

The water temperature varies a great deal depending on the influence of the Atlantic currents, Arctic currents, water depth, and time of year, reaching 25 °C (77 °F) in summer and 10 °C (50 °F) in winter. In the deeper northern North Sea the water remains a nearly constant 10 °C (50 °F) year round because of water exchange with the Atlantic. The greatest temperature variations are found on the very shallow Wadden Sea coast, where ice can form in very cold winters.

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 the Faroes 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, 85 million inhabitants, 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 Ocean and has small water volume compared to seas and hence relatively smaller dilution of hazardous substances. The shallow and smaller water volume in the Baltic Sea results in higher concentration of chemicals in the water and the sediments.

The Baltic Sea and the North Atlantic are characterised by cold waters. The Baltic Sea has an average water temperature of 10 degrees, and during winter water temperature can be even below 0°. Natural decomposition processes of oil are very slow in low temperature water. During winter the seas are more or less covered with ice and snow (Furman et al. 1998), which partly inhibits photodegradation and volatilisation activities.

The Baltic Sea has a permanent stratification of water because of its halocline, with denser bottom 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

There are three main types of water masses in the Barents Sea: Warm, salty Atlantic water (temperature $>3^{\circ}\text{C}$, salinity $>35\text{‰}$) from the North Atlantic drift, cold Arctic water (temperature $<0^{\circ}\text{C}$, salinity $<35\text{‰}$) from the north and warm, but not very salty coastal water (temperature $>3^{\circ}\text{C}$, salinity $<35\text{‰}$).

The Nordic Seas has a salinity of about 35 ‰. The salinity of the North Sea is dependent on place and time of year but is generally in the range of 15 to 25 ‰ around river mouths and up to 32 to 35 ‰ in the northern North Sea.

The Baltic Sea has compared to The Atlantic Sea brackish water with a low salinity, ranging 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 than in normal saline seawater.

5.1.3 Biological features

Due to the North Atlantic drift, the Barents Sea has a high biological production compared to other oceans of similar latitude. The spring bloom of phytoplankton can start quite early close to the ice edge, because the fresh water from the melting ice makes up a stable water layer on top of the sea water. The phytoplankton bloom feeds zooplankton and krill. The zooplankton feeders include young cod, capelin, polar cod, whales and little auk. The capelin is a key food for top predators such as the north-east arctic cod, harp seals, and seabirds such as common guillemot and brunnich's guillemot. The fisheries of the Barents Sea, in particular the cod fisheries, are of great importance for both Norway and Russia.

The Wadden Sea National Parks in Germany, Denmark and the Netherlands are also home to a variety of wildlife including millions of birds, both common seals and grey seals, as well as hundreds of plant and animal species unique to the region.

The Baltic Sea has a short history compared to the Atlantic Ocean. 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 with 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 recurring 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 affected 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 waters. 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 (1998).

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 a prioritised marine habitat represented in Sweden (SNV 1997). The endangered biotopes according to HELCOM are listed in Table 3.

HELCOM has developed a GIS-system called MARIS (Marine Accident Response System for the Baltic Sea). It uses 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).

Regional oil spill response plans have been established in Norway in order to address the responsibilities of the industry in the case of events of significant unplanned releases of oil on the Norwegian continental shelf. These plans cover all aspects of oil spill combat, including databases and datasets - providing on-line access to databases on combat resources, oil properties, environmental sensitivity and priority sites. See maps below.

Figure 7 Sensitive areas for oil pollution on the Norwegian coast, summer (top) and winter (bottom). National areas: red, local areas: yellow (NOFO, 2007)

In April 2006, the Norwegian government launched a White Paper on a new holistic management plan for the Norwegian part of the Barents Sea, including the fishery protection zone around Svalbard. Following international guidelines for ecosystem-based management, the plan provides an overall framework for managing all human activities (oil and gas industry, fishing, and shipping) in the area to ensure the continued health, production, and function of the Barents Sea ecosystem. The primary function of area-based management is the identification of areas of special importance from either ecological or human perspectives. In each area, access for different human activities is to be carefully managed. The plan is based on an assessment of the current and anticipated impact of human activities and of the interactions between them, taking into account deficits in current knowledge of ecosystem state and dynamics. To monitor the overall development of the Barents Sea's state of health, a set of indicators with associated environmental quality objectives has been developed (Olsen et al, 2007).

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). The atlas covers the coast from 62° N to 68° N, dividing the area into 279 shoreline areas and 12 offshore areas. Differing significantly from the enclosed brackish Baltic Sea the Greenland coast is evaluated with another approach. 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 sensi-

tive 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 water current-affected sites have been listed. The Faroes have also made an oil spill sensitivity map, where the coasts are prioritised.

Table 3 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
		Natural or almost natural coniferous forest on dunes
	Brown dunes covered with trees	Natural or almost natural deciduous forest on dunes (beech, oak, birch forest)
		Wet dune slacks
	Wet dune slacks	Wet dune slacks, incl. coastal fens dominated by shrubs or trees
		Salt pioneer swards
		Lower meadows
		Upper meadows
		Dry meadows (incl. alvars)
	Meadows and pastures	Tall herb stands
		Coastal bogs
		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
		Oligotrophic freshwater coastal lakes
	Permanent freshwater pools	Permanent eutrophic freshwater pools (incl. rock pools etc)
		Permanent mesotrophic freshwater pools (incl. rock pools etc)

6. Short-term effects of accidental oil spills in Nordic waters

Recovery times following oil spills can vary from a few days to more than ten years. This chapter 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. See 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 (GESAMP 1993), 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 m³ 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 Seabirds

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 show 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 predatory birds and 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 (*Ardeidae*) was halved from 100 to 50 pairs and on a nearby island 600 birds, including 96 pairs of cormorants (*Phalacrocoracidae*) 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. (Storstrøms amt, 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 (*Cephus grylle*), which population consequently needed a few years to recover (Pahtamaa et al 1987).

6.3 Fish

Field studies, even after 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 (Storstrøms amt 2001). Also after 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 benthic 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. Especially on low energy beaches, 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. Primary production may be divided into three seasons (Thingstad 1990):

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

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.

Summer/autumn, when nutrient levels are very low and production is modest and based on nutrients re-mineralised 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 oil/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. 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 its vulnerability to oil spills. The example of species given below are either particularly vulnerable to oil spill (eelgrass), or of considerable ecological (whales), or commercial (cod) importance, or a combination thereof (FOIG 2001).

Table 4 Fauna and flora groups with different sensitivities to oil (Baker, 1991.

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 (<i>Uria aalge</i>) Puffin (<i>Fratercula arctica</i>) Razorbill (<i>Alca torda</i>)	Birds using the water-air interface are at risk, particularly auks and divers. 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 (<i>Micromesistius poutassou</i>) Capelin (<i>Mallotus villosus</i>) Cod (<i>Gadus morhua</i>) Eelpout (<i>Zoarces viviparus</i>) Haddock (<i>Melanogrammus aeglefinus</i>) Sprat (<i>Sprattus sprattus</i>) Plaice (<i>Pleuronectes platessa</i>)	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 (<i>Balanus balanoides</i>) Burrowing polychaetes (<i>Nereis diversicolor</i>) Common mussel (<i>Mytilus edulis</i>)	Invertebrates include shellfish (both molluscs and crustaceans), worms of various kinds, sea urchins, 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) Eelgrass habitat	Bladder wreck (<i>Fucus vesiculosus</i>)	Oil does not always stick to the larger algae because of their mucilaginous coating. When oil does stick to plants on the shore, they can become overweight and subject to breakage by the waves. Intertidal areas denuded of algae are usually readily re-populated once the oil has been substantially removed. 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 the habitat 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 Nordic studies found are presented. The classification is based on the viscosity of the oil, since viscosity decides the oils' characteristics in water. Each class is represented by 3–5 different types of oil, common in the Nordic Countries.

Both the properties of oil and the behaviour of different fauna groups have been discussed above. Generally it can be said that lighter petroleum oils are more toxic compared with heavier petroleum oils (van den Heuvel Greve and Koopmans, 2007). 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.

For gasoline, kerosine, diesel and light/medium crude oil 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 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 from the Baltic Carrier oil spill was overlaid with uncontaminated 15 ‰ seawater. Mortality was generally observed first after long exposure times (Storstrøms amt, 2001).

Table 5 Oil types have been divided in three groups, based on viscosity with similar effects on biota.

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
	Kerosine (jet fuel)	Algae	WAF	IC ₅₀ 72 h	3.1–30,000	mg/l
		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/me- dium 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
	Vologneft		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 Viscosity at 20 °C: 100 – 1000 cSt	I					
	EO 3-4	Mollusc (<i>Lum- naea peregra</i>)	WAF	EC ₂₃ 96 h	10	%
		Mollusc (<i>Lum- naea peregra</i>)	WAF	EC ₇ 48 h	10	%
Heavy oil Viscosity at 20 °C: > 1000 cSt	Heavy crude Bunker C	Mollusc (<i>Lum- naea peregra</i>)	WAF	EC ₇ 24 h	10	%
		<i>Arenicola marina</i>		LC ₅₀ 8 d	>> 8,640	ppm
		<i>Nereis diversi- color</i>		LC ₅₀ 10 d	>> 8,640	ppm
		<i>Cerastoderma sp.</i>		LC ₅₀ 8 d	> 2,800	ppm
		<i>Mytilus edulus</i>		LC ₅₀ 8 d	>> 8,640	ppm

The parameters used in the studies are EC_x (effect concentration, for which X % of the organisms are effected), IC₅₀ (inhibit concentration, for which the growth is inhibited by 50 %), LC₅₀ (lethal concentration, for which 50 % of the organisms die) and LC_m (the median LC₅₀-concentration). OWD is an abbreviation for Oil-water dispersion, while WAF stands for Water-accommodated fractions (ETC 2004).

7. Long-term effects of accidental oil spill in Nordic waters

7.1 Background

There is more literature about short-term effects of accidental oil spills than of long-term effects. One reason is that the interest in a major oil spill is greatest in the first few weeks and months after the spill. Thereafter the interest diminishes and it might get harder to find funding for studies of long-term impact. Another interpretation, which was stated by Jon Moore (2006), is that the sparseness of publications could reflect a lack of detectable long-term impacts.

Studies of long-term impacts are important and should be carried out after every major oil spill. It is well known that some constituents of oils are carcinogenic and persistent. There are lessons to learn from every spill and knowledge of the long-term effects could simplify the contingency planning. Decisions on how and where to start the combat operations are easier to make if there is sufficient information on the effects of oil spills in sea areas with different environmental characteristics.

7.2 Long-term effects and recovery

There is no world-wide definition of long-term environmental effects of oil in marine waters. Moore (2006) defines long-term impacts as the impacts that still exist after five years. To understand whether there are long-term impacts after an oil spill or not, two things need to be defined; the meaning of “clean” and “recovery” of an ecosystem. One definition of recovery is given by Parker & Maki (2003): “when the injured resource reaches the state it would have been if not been injured in the first place”. Another definition is given by Kingston (2002). Kingston believes that recovery must be judged in terms of the “function” of the ecosystem which means that the ecosystem is recovered when the function is as before the spill. The first definition looks at recovery on ecosystem composition and the other on ecosystem deliverables.

Biological recovery of an ecosystem damaged by an oil spill begins as soon as the toxicity or other damaging properties of the oil have declined to a level that is tolerable to the most robust colonising organisms (Baker et al. 1990). According to Baker (1999) typical recovery times are 1–5 years, with or without clean-up. Sell et al. (1994) claims that ecological recovery of shore biota usually follows natural time scales of up to three years for rocky shores, and five years for salt marshes, regardless of cleanup. Kingston (2002) concludes that environmental recovery is a relatively quick process, and that recovery is complete within 2–10 years. Dicks (1999) claims that a major oil spill rarely will cause permanent effects. One conclusion of all these statements is that ecological recovery can mean different things depending on the expectations of the observer (SEEEC 1998). OLF, The Norwegian Oil Industry Association, defined “full recovery” within the MIRA-guidelines to 99% re-establishment of damaged ecosystem. “Original ecosystem delivery within five years” is the definition recommended by the Swedish Oil Spill Environmental Advisory Service to use for recovery from long-term effects.

A definition of clean is stated by Kingston (2002) “Clean, in the context of an oil spill, may be defined as the return to a level of petroleum hydrocarbons that has no detectable impact on the function of an ecosystem”.

The impact of an oil spill on an intertidal community is summarised and presented in Figure 8 (Sell et al. 1994). Sell et al. (1994) have summarised findings of many monitoring programs in different parts of the world. The figure shows the naturally fluctuating state of the community. Every fluctuation between the dotted lines is normal. The sharp dip in the line indicates that the shore is oiled and the community might be degraded or locally wiped out. The progressive return of recovery can be divided in three stages. “Initial Colonization”, “Recovery” and “Recovered”.

Figure 3 The impact of a spill on an intertidal community (modified from Sell *et al.* 1994)

7.3 Major oil spills with long-term follow-up studies

There have been a number of major spills around the world where follow-up studies has been done. Those of them that are relevant for the Nordic waters (Table 6) are discussed below in this report.

Table 6 Oil spills with documented follow-up studies.

Name	Location	Year	Amount of oil (tonnes)
Arrow	Chedabucto Bay, Nova Scotia	1970	11 000
Tsesis	Södertälje, Sweden	1977	1 100
Amoco Cadiz	Brittany, France	1978	223 000
Exxon Valdez	Prince William Sound, Alaska	1989	37 000
Braer	Shetland, UK	1993	85 000
Sea Empress	Pembrokeshire, UK	1996	72 000
Baltic Carrier	Denmark	2001	2 700

Arrow

The tanker Arrow grounded off Nova Scotia, Canada, in 1970. 11 000 tonnes of Bunker C fuel were released into the sea. Ten percent of the affected shoreline was subjected to cleanup procedures, the rest was left to nature and was evident in 1999 as asphalt pavements, stain on rocks, surface sheen, and liquid reserves trapped within sediments at some low-energy sites. The sediments from the oiled sites had low toxicity in 1999 (Lee *et al.* 1999) (but they were still contaminated!).

Tsesis

The tanker *Tsesis* grounded in the archipelago of Södertälje, Sweden. During the days after the accident, 1100 tonnes of oil was released (Kineman et al. 1980). Considerable oil quantities reached the benthos by sedimentation (Elmgren et al. 1983).

Oil analyses of mussels (*Mytilus edulis*) were carried out after the spill and they showed that oil had reached a larger area than visibly impacted. Oil was still found in mussels one year after the spill. (Kineman et al. 1980).

The impact after “*Tsesis*” in the pelagic ecosystem disappeared within one month; the littoral ecosystems showed obvious but moderate effects after one year, the benthic ecosystem showed effects of a long-term nature. Deeper soft bottoms are more vulnerable to oil pollution than the other systems studied (Lindén et al. 1979).

Amoco Cadiz

The *Amoco Cadiz* almost lost its entire cargo of 223 000 tonnes (Laubier 1980) of Arabian light and Iranian crude oil when it grounded on the Brittany coastline in France (SEEEC 1998). It was a very large spill and it affected a wide variety of coastal resources. According to Moore (2006) its ecological impact is best known for the erosion and slow re-growth of trampled salt marsh areas. The physical alteration of the marsh was the primary cause of long-term effects in this case (Moore 2006).

A small sand hopper, *Ampelisca*, is sensitive to oil pollution and an initial impact of the “*Amoco Cadiz*” oil spill was the kill off of the sand hopper population. The sediment was recovered from contaminating oil but it took ten years before the sand hopper, *Ampelisca*, was back to its prespill population density (Dauvin 1998).

Exxon Valdez

The *Exxon Valdez* released 37 000 tonnes of Prudhoe Bay crude oil into the subarctic environment of Prince William Sound, Alaska, in 1989 (SEEEC 1998). There is a lack of consensus between researchers with different perspectives on the impact of the *Exxon Valdez* crude oil spill (Moore 2006), but Peterson et. al. 2003 showed a number of studies indicating long-term effects on wildlife.

Braer

The tanker Braer was carrying about 85 000 tonnes of Gullfaks crude oil. The Gullfaks crude oil is light and almost all of the oil was dispersed into the water column and significant quantities became incorporated into the sediments offshore (Kingston et al. 1995). Follow-up studies did not go beyond one year (Moore 2006).

Sea Empress

The tanker Sea Empress was bringing crude oil to a refinery in Milford Haven when it ran aground and released 72 000 tonnes of crude oil (SEEEC 1998). There were few visible signs of the oil 18 months after the spill (SEEEC 1998). Almost all known impacts to wildlife and marine and coastal habitats from the Sea Empress oil spill disappeared within five years (Moore J. 2006b).

Baltic Carrier

The oil tanker, Baltic Carrier, collided with another vessel and 2700 tonnes of bunker oil leaked from the cargo. The weather was bad and combat operations could not be initiated at sea. (Storstrøms Amt 2002).

The “Baltic Carrier” oil spill happened in 2001 and according to Jakob Lysholdt Sørensen (personal communication 2006) there seem to be no long-term effects. Samples were taken in: September 2002 (sediment and biota), May-June 2003 (sediment and biota) and November–December 2004 (sediment and biota). A final examination was carried out 2006.

- Sediment: The oil content in the sediment was back to normal in 2003.
- Biota (Blue mussel): the oil content was slightly higher than normal in 2002, but back to normal (background) in 2003 and 2004.

7.4 Long-term effects on Nordic coastal and marine fauna groups

7.4.1 *r/K selected species*

The time-frame for recovery of oil spills on the marine ecosystem depends to a great extent on the reproduction strategies of the organisms inhabiting the impacted ecosystem. Organisms that are r-selected are poor

competitors but have high per-capita population growth rate (r). Such species are often highly dispersive species that colonize new habitats before being out-competed by K-selected species. K-selected organisms are good competitors and often exist in mature habitats, close to the carry capacity (K), where they can out-compete most species (Stiling 1999). Ecosystems denser with K-selected species will therefore take longer time to recover from a major oil spill than ecosystems with less K-selected species. Some differences in characteristics of r - and K-selected species are found in Table 7.

Table 7 Differences in characteristics between r - and K-selected species (table from Stiling, 1999, modified to suit this study).

	r-selected species	K-selected species
Selection favours	Rapid development High reproductive rate Early reproduction Small body size Single reproduction	Slower development Great competitive ability Delayed reproduction Larger body size Repeated reproduction
Length of life	Short, usually less than one year	Longer, usually more than one year
Examples of groups of organisms	Most fish species, benthic fauna, plankton, green algae	Mammals, birds

7.5 Marine mammals

A physical effect of oil spills are when mammals get oiled furs. When mammals become stained with oil, the water repellent structure of the fur disappears and the animal might freeze to death (Lindgren & Fejes 2003), e.g. the sea otter that rely on a dense fur to provide thermal insulation (Baker et al. 1990). The problem is greatest during winter (Härkönen, 2006).

Whales and adult seals are on the other hand physically not particularly vulnerable to oiling as they do not rely on their fur for insulation (Mosbech (ed.) 2002). Some animals, e.g. most seals are colonial breeders and very large numbers may be exposed to a single oil slick (Baker 1990).

Long-term effects from chronic exposure to residual oil on foraging sea otter has been recorded up to 10 years after the Exxon Valdez oil spill (Peterson et. al., 2003)

7.6 Birds

Kingston (2002) claims that there is little relation between the number of seabird casualties and the size of the oil spill. He has compared the number of dead seabirds from “Exxon Valdez” with those from the “Braer”, where “Braer” was the largest oil spill, almost two and a half times as large. The result from the comparison is that the number of dead seabirds in the “Exxon Valdez” oil spill was almost 23 times that of the “Braer”. Kingston (2002) states further that there is little evidence that individual oil spills cause long-term effect on seabirds, and at the same time he claims that natural variation and other factors that influence bird populations make it hard to estimate the impact from a single event such as an oil spill (Kingston 2002).

The Sea Empress oil spill occurred before the breeding season and 7000 oiled birds were recovered either dead or alive (Parr et al. 1997).

An examination of post-spill trends (1989 – 1998) of marine bird populations in Prince William Sound following the Exxon Valdez oil spill was carried out to evaluate recovery of injured taxa. Most taxa were not recovering and some taxa showed increased effects nine years after the spill (Lance et al. 2001).

An evaluation of pre- and post-spill abundances of birds in Prince William Sound indicated that three of eleven taxa evaluated had declined significantly from numbers recorded four-five years before the spill (Murphy et al. 1997)

7.7 Fish

Oil spills that occur during fish spawning or when larval concentrations are high can cause egg and larval mortality, as those are both sensitive and immobile. Most species of fish produce large amounts of eggs and only a relatively small number reach adulthood due to natural mortality (Mosbech (ed.) 2002). Pink salmon (*Oncorhynchus gorbuscha*) were studied after the Exxon Valdez oil spill and the studies demonstrated unprecedented and controversial long-term impacts. One impact was high mortality of embryos in oiled streams and another was findings of long-term persistence of oil in spawning habitats. The spill in Prince William

Sound was rather unique as the pink salmon numbers and biology were well understood before the spill (Rice et al. 2001).

Long-term exposure of fish embryos to weathered oil (3- to 5-ringed PAHs) at ppb concentrations has population consequences through indirect effects on growth, deformities and behaviour with long-term consequences on mortality and reproduction (Peterson et al. 2003).

7.8 Benthic fauna

Dauvin (2000) has studied a community of benthic fauna during a time period of 20 years. The community was strongly polluted by hydrocarbons from the Amoco Cadiz oil spill in 1978. Long-term changes of the community (1977–1996) showed that it was weakly affected by the spill.

Many animals in the marine environment reproduce with pelagic larvae which are free-floating in the water and areas that have lost flora and fauna can be restored by nearby populations (Kingston 2002).

8. Discussion

8.1 Short- and long term effects

There are at least four parameters that affect the existence of short- and long-term effects in the coastal zone and on the shore; the sensitivity of the area, the amount of oil, the viscosity and type of oil, and finally the time of year the spill occur.

The sensitivity usually correlates with levels of wave energy. In general, exposed shores tend to recover faster than sheltered ones (Kingston 2002). In reality, it is not as simple as that; several things affect the process of recovery, which several follow-up studies from major oil spills have shown. For example a synthesis of 14 years of Exxon Valdez oil spill studies documented the contribution of delayed chronic and indirect effects of petroleum contamination in the marine environment (Peterson et. al., 2003), and the authors suggest a change of paradigm from acute toxicity based on single species towards and ecosystem-based synthesis of short-term direct impacts plus long-term chronic delayed and indirect impacts

Another aspect is the issue of shoreline clean-up and the question of how clean, clean really is. Clean-up attempts can be more damaging than the oil itself, with impacts recurring as long as clean-up (including both chemical and physical methods) continues. Because of the pervasiveness of strong biological interactions, cascades of delayed, indirect impacts (especially of trophic cascades and biogenic habitat loss) expand the scope of injury well beyond the initial direct losses and thereby also delay recovery (Peterson et. al., 2003). For example the IVL Oil Spill Environmental Advisory Service recommends that reasonable (non-sticky, non-smearing, non-bleeding, and non-acute toxic) amounts of oil can be left in most environments. By experience it is clear that in most cases the environment has a capability to degrade the remaining oil and recover on its own.

8.2 Seasonal influences on the effects of oil spills

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 temperatures and the presence of snow and ice will slow the weathering and complicate clean-up operations. Large congregations of birds that gather in specific areas are extremely vulnerable to oil spills. On the other hand winter storms and ice scouring will efficiently disperse oil slicks on exposed shores. Many habitats will also be less vulnerable due to the fact that there is significantly lower biological activity that can be affected.

8.3 Classification and mapping of sensitive habitats

It would be valuable to identify key species and habitats for each sea area within the Nordic waters, to facilitate prioritising areas for protection and intensified surveillance. But it is currently difficult to conduct this ranking. Such definitions and classifications are being developed at both national and international levels. Beside Natura 2000-areas, HELCOM's red list, and each Nordic countries national red list, 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 systems, there are national regulations defining different habitat and biotope types. The conclusion is that there is no single, generally 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 identify ecologically and environmentally important areas. A better-suited approach is to develop a specific oil sensitivity environmental atlas, such as MARIS for the Baltic Sea or the system 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 and Norway is currently developing atlases of its own national purpose.

After identifying areas worthy of protection there is still one aspect not discussed in this study; the transportation of oil in water. It is well known that currents and wind can rapidly 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 indicator species for oil spills

One idea that has been discussed during the progress of this work is to identify indicator species for oil spills, 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.

Blanck (2004), Förlin (2004), and Peterson (2003), argue for the possibility to observe changes in an entire ecosystem. If species A, B and C are missing to 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 shortcut, even though it will not identify effects on ecosystem level. There are however biochemical indicators. For example PAH-exposure (a toxic component of especially lighter oils) can 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, this is difficult. The fact that different species react differently to a specific oil is obvious, and the toxicity-altering effect of weathering has also been mentioned. Birds and marine mammals are often affected by smearing, rather than actual poisoning. 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 such as burning of eyes when the animal passes through the surface, or as poisoning 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 of correctly identifying 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 Knowledge gaps

This report has identified a number of topics in need of further examination:

- *Surveillance and law enforcement:* Where, when and how should surveillance be conducted to generate as efficient environmental protection as possible? How can illegal spill 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.
- *Oil spill statistics:* Greenland and the Faroes lack relevant statistics, which complicates comparisons and evaluations.
- *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. Even in the presence of atlases, cross-border regions may be described and prioritised differently depending on the atlas.
- *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 points. Today the effects of the Tsesis and Exxon Valdez spills are still the most closely monitored arctic accidents. By well-planned monitoring of not only the immediate effects of a spill, but also of 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

Efforts to increase the understanding of environmental effects of oil spills are required to meet the imminent and future threats to the Nordic countries. Even though oil and its effects are widely researched internationally, the specific Nordic condition raises a number of questions yet to be answered.

The characteristics specific for the Nordic waters are primarily low temperature, complete or partial icing and brackish water (in the Baltic Sea). Unfortunately, those characteristics make Nordic habitats particularly sensitive to oil spills. Therefore combating oil at sea is of great importance. The aim of the oil spill clean up operation shall be to recover as much oil as possible from the surface of the sea.

Oil exploitation in the North Sea, Norwegian Sea and Barents 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 the most important and sensitive areas. This must be combined with regulatory work and negotiations to increase maritime safety and possibly agreement on better shipping routes.

Existing environmental atlases show 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, birds 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 in a long-term suffer significantly from settled oil slicks. Accumulation bottoms and juvenile areas for bottom-living and reproductive organisms such as crayfish, plaice and flounder can be sensitive.

This report deals with both short-term and long-term environmental effects. Geographical, physiological and chemical conditions govern the weathering and hence influence 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 to different types and weathered stages of oil.

10. Glossary

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

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 degrade (consumes) a substance, e.g. oil.

Bunker oil: Heavy oils, 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.

Dispersion: Fine droplets of oil are transferred into the water. Occurs usually when the surface oil slick is disrupted by breaking waves. The opposite of *emulsification*.

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

Emulsification: The process of water getting mixed with oil, in severe cases creating a very vis-

cous "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.

Dissolving one liquid in another 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) 1cSt at 20 °C.

Weathering: A number of physical, biological and chemical processes degrading oil. Weathering will naturally obliterate all oil.

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Sammanfattning

Syftet med denna rapport är att bistå de Nordiska länderna i arbetet med att lindra de miljömässiga effekterna av ett oljeutsläpp. Denna rapport består av en genomgång av kortvariga och långvariga effekter av ett ofrivilligt oljeutsläpp. Olyckor sker och ett utsläpp kan vara ett resultat av en kollision mellan tankfartyg, grundstötningar alternativt tekniska haverier. En annan stor källa till utsläpp av olja är illegala utsläpp som t.ex. i form av tankrengöring. Kroniska utsläpp eller utsläpp som inte härstammar från olyckor ingår inte i denna studie.

Denna studie indikerar att stora delar av de Nordiska vattnen skiljer sig åt från andra regioner i och med att vattentemperaturen är lägre och så även salthalten och vattenomsättningshastigheten. En annan skillnad är att de nordiska vattnen stundom är istäckta. På grund av dessa skillnader är den Nordiska regionen mer känslig för ett oljeutsläpp än många andra delar av vår värld.

Antalet mindre utsläpp kommer mest troligt att öka inom den närmsta tiden och så även risken för stora ofrivilliga utsläpp. Därför finns ett stort behov av verktyg som visar och identifierar skyddsvärda områden. Det finns både regionala och nationella initiativ till att identifiera känsliga områden, dock finns ännu ingen generell atlas för hela Norden

Fåglar och marina däggdjur påverkas kraftigt av både kortvariga och långvariga effekter. Planktonsamhällen påverkas också, men återhämtas snabbt. De kortvariga effekterna på pelagisk fisk är negligerbara, men inte de långvariga effekterna. Bottenfaunan kommer i princip vara helt opåverkad av de kortvariga effekterna, däremot kan de påverkas långvarigt av sjunkande och sedimenterande olja.